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Avenida Columbano Bordalo Pinheiro, 87, 3º Andar.
1070-062 Lisboa – Portugal
T. +351 213 220 430 | F. +351 213 220 439
spea@spea.pt | www.spea.com

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Fotografia de grupo dos participantes da WOC 2017. Foto: Assen Ignatov

Fotografia de grupo dos participantes da WOC 2017. Foto: Assen Ignatov





IN MEMORIAM KIMBERLY G. SMITH

This volume is dedicated to the memory of ecologist and educator Dr. Kimberly G. Smith of Arkansas, USA, who passed away in 2018. Kim wrote over 300 scientific publications and positively influenced hundreds of undergraduate and over 67 graduate and postgraduate students. One of these was Mitchell Pruitt and together they studied Saw-whet Owls (*Aegolius acadicus*) migrations and winter ecology in northwestern Arkansas (see their paper published herein).

During his last presentation, on April 5 and just 4 days before his death, Kim entertained a packed room with a summary of his career. He ended his talk with advice to his colleagues: “Be curious, be creative,… learn new things, learn the history of things that interest you, take students on field trips, take students abroad.” and finally, “Have fun doing what you do… I did.”

Thank you, Kim, for all.

EM MEMÓRIA DE KIMBERLY G. SMITH

Esta edição é dedicada à memória do ecólogo e educador Dr. Kimberly G.Smith, natural do Arkansas, EUA, que nos deixou em 2018. Kim escreveu mais de 300 publicações científicas e influenciou centenas de estudantes de licenciatura e mais de 67 estudantes pós-graduados. Um dos seus alunos foi Mitchell Pruitt, com quem estudou as migrações do mocho-amolador (*Aegolius acadicus*) e a sua ecologia nas áreas de invernada no noroeste do Arkansas (o seu artigo em co-autoria está publicado nesta edição especial).

Durante a sua última apresentação, no dia 5 de abril, apenas quatro dias antes da sua morte, Kim falou para uma sala cheia, fazendo uma síntese da sua carreira. Encerrou a palestra com um conselho aos colegas: “Sejam curiosos, sejam criativos, aprendam coisas novas, aprendam a história das coisas que vos interessam, levem os alunos a saídas de campo, levem os alunos ao estrangeiro”. E, finalmente, "Divirtam-se fazendo o que fazem... Eu fi-lo."

Obrigado, Kim, por tudo.

SPECIAL ISSUE
EDITOR'S ACKNOWLEDGEMENTS

This special issue, done in honour of Dr. Kimberly Smith (RIP), would not have been possible without the support of many individuals, including my associate WOC Editorial Board members, who have been involved in all stages of this issue's production. It has been a privilege to work along with James R. Duncan, Dries van Nieuwenhuyse, and my mentor David H. Johnson, who have been very supportive and graciously shared their perspectives on owl research and editorial experience. This issue depended on a significant peer review effort. The reviewers are acknowledged for their careful reading, suggested edits and insightful comments in individual papers herein. I would also like to acknowledge my colleagues Rui Lourenço and Carlos Godinho for reviewing all the Portuguese translations. I would as well like to express my appreciation to Cesaltina Frade (Administrator of University of Évora), Andreia Rosa (Director of the Communication Office), and Susana Rodrigues (Designer) for having authorised, and made possible the support for the pagination of this volume through the University of Évora. A special thanks to the artists who kindly offered illustrations and photos for the papers' layout: Shirley van der Horst (illustrations of *Athene cunicularia* and *Strix davidi*), Brooks Duncan (illustration of *Aegolius acadicus*), Maxime Legare-Vezina (photo of *Aegolius acadicus*), and Jani Witoski (photo of *Bubo scandiacus*). Most of all, I would like to show appreciation to the authors published in this issue, who have given so much of their time and effort to contribute to this valuable collection of papers on world owls research.

Inês Roque
(Guest Editor)

AGRADECIMENTOS DA EDITORA DA EDIÇÃO ESPECIAL

Esta edição especial, em honra do Dr. Kimberly Smith (RIP), não teria sido possível sem o apoio de várias pessoas, incluindo os meus colegas membros da Comissão Editorial da WOC, que estiveram envolvidos em todas as fases desta produção. Foi um privilégio trabalhar ao lado de James R. Duncan, Dries van Nieuwenhuyse e do meu mentor David H. Johnson, que sempre foram solidários e gentilmente partilharam as suas perspetivas da investigação sobre aves de rapina noturnas e a sua experiência editorial. Esta edição contou com um esforço significativo de revisão por pares. Os revisores são reconhecidos nos respetivos artigos pela sua leitura cuidada, pelos seus muitos comentários e sugestões. Gostaria ainda de agradecer aos meus colegas Rui Lourenço e Carlos Godinho pela revisão de todas as traduções para Português. Devo ainda exprimir um profundo agradecimento a Cesaltina Frade (Administradora da Universidade de Évora), Andreia Rosa (Chefe da Divisão de Comunicação) e Susana Rodrigues (Designer) por terem autorizado e possibilitado o apoio para a paginação deste volume do Airo através da Universidade de Évora. Um agradecimento especial aos artistas que gentilmente ofereceram ilustrações e fotos para os artigos: Shirley van der Horst (ilustrações de *Athene cunicularia* e *Strix davidi*), Brooks Duncan (ilustração de *Aegolius acadicus*), Maxime Legare-Vezina (foto de *Aegolius acadicus*) e Jani Witoski (foto de *Bubo scandiacus*). Acima de tudo, gostaria de expressar gratidão aos autores que publicaram nesta edição, pelo seu tempo e empenho em contribuírem para esta relevante coleção de artigos sobre aves de rapina noturnas de todo o mundo.

Inês Roque
(Editora Convidada)

EDITORIAL

The 5th Edition of the World Owl Conference (WOC) - Owls in Science and Society was held in Évora, Portugal, between 26 and 30 September 2017, organized by LabOr – Laboratory of Ornithology (ICAAM – currently MED, University of Évora), with the Global Owl Project and the International Owl Center, in partnership with SPEA (Birdlife Portugal) and STRI (ALDEIA).

This conference brings the opportunity to gather owl researchers from five continents to present and discuss the most significant advances in owl studies in the most diverse scientific fields (ecology, genetics, conservation, among others) but also to debate emerging technologies for owl research, conservation and monitoring. In Évora, this event was attended by approximately 150 participants from 30 countries.

This special issue of AIRO is dedicated to compile original research and achievements presented at the WOC 2017, highlighting the key role that owls play in ecosystems while raising awareness for their conservation. All of these papers were refereed and selected in accordance with the usual editorial standards of the journal.

Teresa Catry
(Editor-in-Chief)

EDITORIAL

A 5ª Edição da World Owl Conference (WOC) - Owls in Science and Society decorreu em Évora, Portugal, entre 26 e 30 de setembro de 2017, organizada pelo LabOr - Laboratório de Ornitologia (ICAAM – atualmente MED, Universidade de Évora), com a Global Owl Project e o International Owl Center, em parceria com a SPEA (Birdlife Portugal) e STRI (ALDEIA).

Esta conferência traz a oportunidade de reunir investigadores dos cinco continentes para apresentar e discutir os avanços mais significativos no estudo de aves de rapina noturnas nas mais diversas áreas científicas (ecologia, genética, conservação, entre outros), mas também para debater tecnologias emergentes para investigação, conservação e monitorização deste grupo de aves. Em Évora, este evento contou com a presença de cerca de 150 participantes de 30 países.

Esta edição especial do AIRO é dedicada a compilar a investigação original apresentada na WOC 2017, destacando o papel fundamental que as aves de rapina noturnas desempenham nos ecossistemas, ao mesmo tempo que promove a necessidade da sua conservação. Todos os artigos incluídos neste volume foram avaliados e selecionados de acordo com os padrões editoriais usuais da revista.

Teresa Catry
(Editora Principal)

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Migration of the Eurasian Scops-owl (*Otus scops*) over the Western Mediterranean

Migração do mocho-d'orelhas no Mediterrâneo ocidental

Carles Barriocanal[1,2]*, David Robson[1], Gabriel Gargallo[1]

1 Catalan Institute of Ornithology, Technical Office, Girona 168, 08037, Barcelona, Catalonia, Spain.

2 Department of Geography, University of Barcelona, Montalegre 6, 08001, Barcelona, Catalonia, Spain.

*** Corresponding author:** carles.barriocanal@ub.edu



ABSTRACT

The Eurasian Scops-owl (*Otus scops*) is the only European Owl that undertakes a long migration south of the Sahara desert. The breeding ecology of the species in southern and eastern Europe is better known but the migration ecology and wintering areas in the Afrotropical region are poorly known. We present data on the passage of Eurasian Scops-owls along the western Mediterranean during spring migration. From the Project Piccole Islands (PPI) we show data about the migration of the species over the Iberian Peninsula and small islands in the western Mediterranean between 1993 and 2011. A total of 537 individual owls were captured and marked during this period. Another project, similar to PPI, started at the north fringe of the Sahara on an oasis located at southern Morocco, and was operated from 2009 to 2013. During these five years a total of 23 individual owls were captured and marked. Data about the phenology and biometry of the captured individuals and inter-annual comparisons are shown. Our results show that there are no differences in arrivals between coastal and island locations suggesting that the Eurasian Scops-owls passing through the western Mediterranean move directly across the sea in spring choosing the shorter, more direct and faster route.

Keywords: Morocco; *Otus scops*; Spain; spring migration; western Mediterranean islands

RESUMO

O mocho-d'orelhas (*Otus scops*) é a única rapina noturna europeia migradora de longa distância, invernando a sul do deserto do Saara. A ecologia reprodutiva desta espécie é bem conhecida no sul e este Europeus, pouco se sabendo sobre a sua migração e localização dos territórios de invernada na região Afrotropical. Neste artigo, apresentamos dados sobre a passagem de mocho-d'orelhas no Mediterrâneo ocidental durante a migração primaveril. Apresentamos ainda dados sobre a migração da espécie na Península Ibérica e em pequenas ilhas no Mediterrâneo ocidental, recolhidos entre 1993 e 2011 no âmbito do Projeto Piccole Islands (PPI). No total foram capturados e marcados 537 mochos-d'orelhas durante este período. Um projeto semelhante ao PPI iniciou-se no extremo norte do Saara, num oásis localizado no sul de Marrocos, tendo decorrido entre 2009 e 2013. Durante estes cinco anos foram capturados e marcados 23 indivíduos. São apresentados dados sobre a fenologia, as biometrias dos indivíduos capturados e comparações interanuais. Os resultados mostram que não existem diferenças nas chegadas entre o continente e as ilhas, o que sugere que a passagem do mocho-d'orelhas através do Mediterrâneo ocidental corresponde a um movimento direto sobre o mar, i.e. à rota mais curta, direta e rápida.

Palavras-chave: Espanha, ilhas Mediterrânicas ocidentais, Marrocos, migração de primavera, *Otus scops*

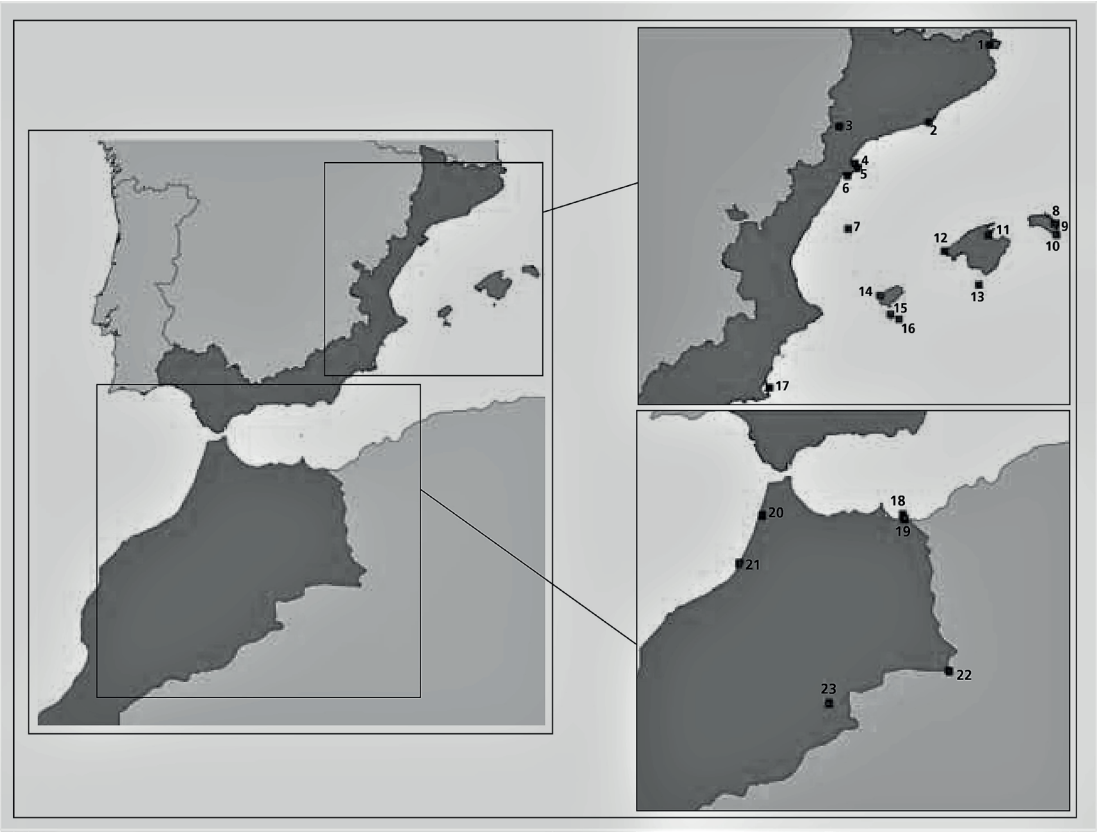
Introduction

The Palearctic-African flyway is a major avian system involving a migratory journey of billions of birds over thousands of kilometers between their breeding and wintering sites. At some point, most of them have to cross several ecological barriers to arrive at their European destinations. Specifically, in the case of the birds migrating through the western Mediterranean flyway, the Sahara desert, the Mediterranean Sea, the Pyrenees and the Alps are major obstacles to overcome. It is known that, when undertaking their migratory flights, landbirds normally avoid crossing such large ecological barriers (Alerstam 1990, Newton 2008). To do so, they often use routes over suitable habitats that allow stopping to rest and refuel, for example by following the edge of continental land masses (Newton 2008). However, in some cases, detours from the shortest route considerably increase travel distance, energy or time, and, therefore, crossing ecological barriers may be beneficial for some species or individuals (Battley et al. 2012). Trans-Sahara migrants arriving at the Mediterranean Sea in spring have two options: either cross the sea near the Gibraltar strait and migrate through the continent, or cross the sea without detour. So far, there are few studies addressing which migratory strategy trans-Saharan migrants use to reach their destination (Pilastro et al. 1998) but studies thus far show that this is a species-specific strategy in which one or both options can be used (Barriocanal & Robson 2007).

The Eurasian Scops-owl (*Otus scops*) is the only European owl that undertakes a long migration, wintering south of the Sahara desert. While the breeding ecology of the species has been studied (e.g. Hagemeijer

Figure 1 - Location of study sites under the Piccole Isle Project, western Mediterranean.

Figura 1 - Localização dos locais de amostragem do Projeto Piccole Islands, Mediterrâneo



& Blair 1997), the migration ecology and winter distribution in the Afrotropical region are poorly known. Here we present data of the northbound spring passage of Eurasian Scops-owl at the northern fringe of the Sahara and the western Mediterranean, to investigate which migration strategy is used by this species to cross the Mediterranean and reach their west-European breeding grounds.

Study Area

The passage time of the Eurasian Scops-owl during their spring migration was studied at 16 ringing sites in the western Mediterranean (Fig. 1) and Morocco. The work was conducted between 1993 and 2011 following standardized protocols within the framework of the Piccole Islands Project (PPI). This project, started in 1988, aimed at understanding the different strategies employed by birds crossing the central Mediterranean during their northbound journeys to Europe (Spina et al. 1993) and was soon expanded to include sites in the western Mediterranean (Gargallo et al. 2011). Eleven of the ringing stations were located on small islands: Columbrets Island 39º 53' N - 00º 40' E, Illa de Colom 39º 57' N - 04º 16' E, Albufera d'Es Grau (Menorca) 39º 57' N - 04º 15' E, Illa de l'Aire 39º 48' N - 04º 17' E, Albufera

d'Alcúdia (Mallorca) 39º 48' N - 03º 06' E, Dragonera 39º 35' N - 02º 20', Cabrera 39º 08' N - 02º 56', Conillera 38º 59' N - 01º 13' E, Formentera (Can Marroig) 38º 44' N - 01º 24' E, Illa Grosa 37º 44' N - 00º 42' W, Chafarines 35º 11' N - 02º 26' W. Four other coastal stations were located in mainland Spain (Aiguamolls 42º 17' N - 03º 07' E, Llobregat 41º 17' N - 02º 04' E, Canal Vell 40º 45' N - 00º 47' E, Alfacada 40º 41' N - 00º 50' E). Further details of the study sites are described elsewhere (Barriocanal & Robson 2006, Gargallo et al. 2011). To the above sites, we also included data from a small station located in the interior of Morocco, along the northern fringe of the Sahara (Yasmina Oasis, 31.21'N - 3.98ºW).

Methods

Data from the PPI is based on continuous and standardized mist-netting (Gargallo et al. 2011). We used data collected from 1993 to 2011 in the western Mediterranean and 2009-2013 at Yasmina. Nets were checked every hr from dawn to dusk, and were closed when meteorological conditions were adverse. For the analysis of arrival data, birds captured on the island stations have been pooled as coming from one group defined as "islands" and in the same way birds captured in the coastal stations have been considered as "continent". We used the mean values of capture date to compare continental and island arrivals. We used the length of the flattened wing (Svensson 1992), measured to the nearest 0.5 mm to analyze if individuals captured in the two areas came from the same breeding population. To compare arrival date between locations, we used non-parametric Mann-Whitney U-tests. To develop analysis of phenology and biometry we have used data of first captures. Date of capture was expressed as Julian date. Capture data was also organized by pentade; a pentade is a 5-day increment of time, reported from the first increment of the calendar year. In order to check for differences in phenology and biometry when comparing islands and continents we used the one-way ANOVA test.

Results

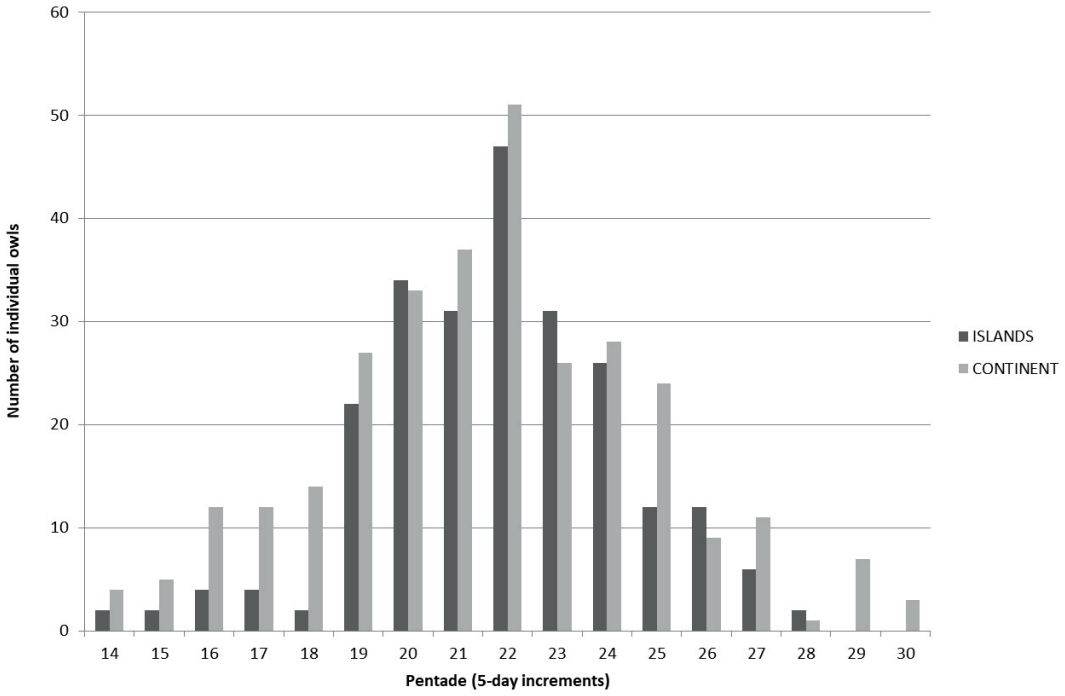
On western Mediterranean sites, during the 19 years of study (1993–2011) a total of 303 Eurasian Scops-owls were captured at the continental stations, ranging from 1 in 1994 to 52 individuals in 2008. On the island stations 234 individuals were captured, from 1 individual in 1993 to 29 individuals in 1997. At the Yasmina Oases (Morocco) we captured a total of 23 individuals between 2009 and 2013.

Phenology

Passage over the western Mediterranean occurred mainly between pentade 20 and 24 (6 -30 April) with a peak during pentade 22 (15-20 April) (Fig. 2). At the continental stations a peak in captures was observed during pentade 22, after which the number of captures diminished, especially after pentade 24. At the island stations the peak in captures also occurred during pentade 22 (Fig. 2). There were no differences in the Julian arrival date of the owls between islands (mean = 83.1, s.d. = 11.4, n = 220) and the mainland (mean = 83.4, s.d.= 8.8, n = 255); ($F = 0.08$, $P = 0.77$), nor when data from Yasmina were compared: Mediterranean (mean = 83.2, s.d.= 10.1, n = 475) and Yasmina (mean = 79.5 , s.d.= 10.9, n = 21); ($F = 2.79$, $P = 0.095$). Arrival dates did not differ significantly between islands (Julian day 107.4) and the mainland (Julian day 106.5) ($P > 0.12$, Mann-Whitney U-test).

Figure 2 - Number of Eurasian Scops-owls captured at island and continental ringing stations by calendar pentade (5-day increment) during northbound migration over the western Mediterranean (1993-2011).

Figura 2 - Número de mochos-d'orelhas capturados nas estações de anilhagem localizadas no continente e ilhas, em intervalos de cinco dias, durante a migração para Norte no Mediterrâneo ocidental (1993-2011).



Wing length

Wing length did not show any increase or decrease during the season (Fig. 3) and there were no differences between the islands (mean = 157.6 mm, s.d. = 5.0, n = 183) and mainland (mean = 157.4 mm, s.d.= 4.6, n = 234); (F = 0.1, P = 0.75), or between the Mediterranean (mean = 157.5 mm, s.d.= 4.8, n = 417) and Yasmina (mean = 156.1 mm, s.d.= 4.8, n = 20; (F = 1.67, P = 0.196) sites.

Body mass

Since there were no differences in wing length between the study sites and along the season we didn't make any effort to correct body mass for body size. No differences in body mass have been found during the season (Fig. 4) or between the islands and continent (islands mean = 83.1 g, s.d. = 11.4, n = 220; mainland mean = 83.4, s.d.= 8.8, n = 255); (F = 0.08, P = 0.77), nor between regions (Mediterranean mean = 83.2 g, s.d. = 10.1, n = 475; Yasmina mean = 79.5 g, s.d.= 10.9, n = 21); (F = 2.79, P = 0.095).

Based on data from 560 Eurasian Scops-owls captured at 16 ringing stations from islands (Balearics) and mainland eastern Spain during 19 years of study, and at the northern fringe of the Sahara desert in southern Morocco during five years of study, our results show slight (but non-significant) differences in the phenology or biometry of northbound-migrating owls.

Figure 3 - Pentade (5-day increment) analysis of flattened wing lengths (mm) of Eurasian Scops-owls during their northbound migration over the western Mediterranean (1993-2011).

Figura 3 - Comprimento da asa com ajuste da curvatura (mm) de mocho-d'orelhas durante a migração para Norte no Mediterrâneo ocidental (1993-2011).

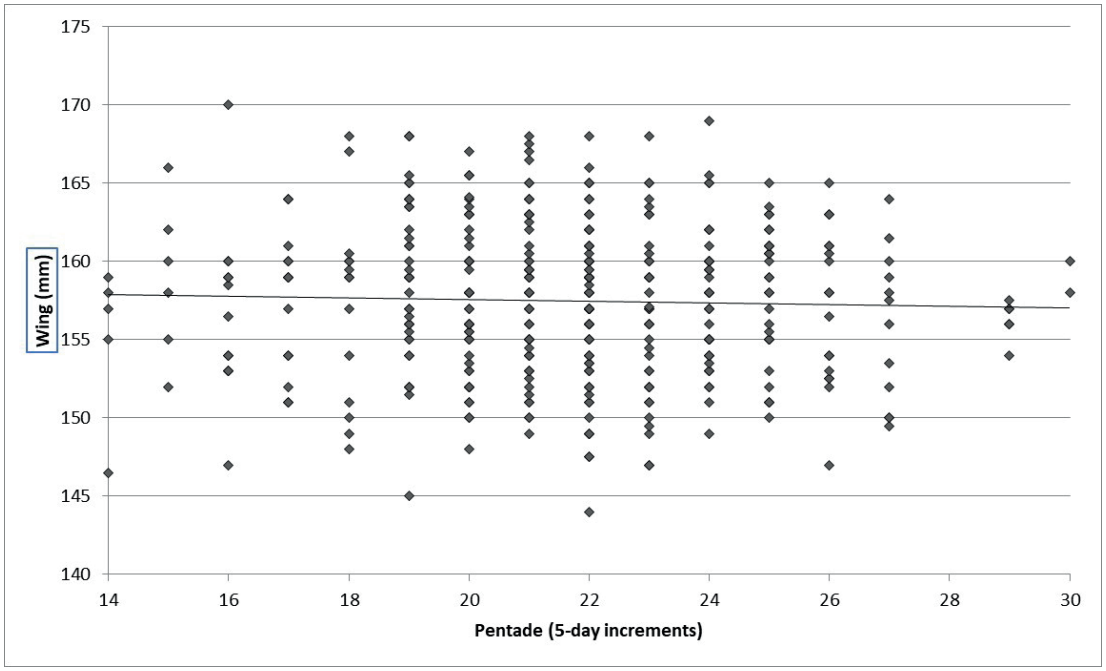
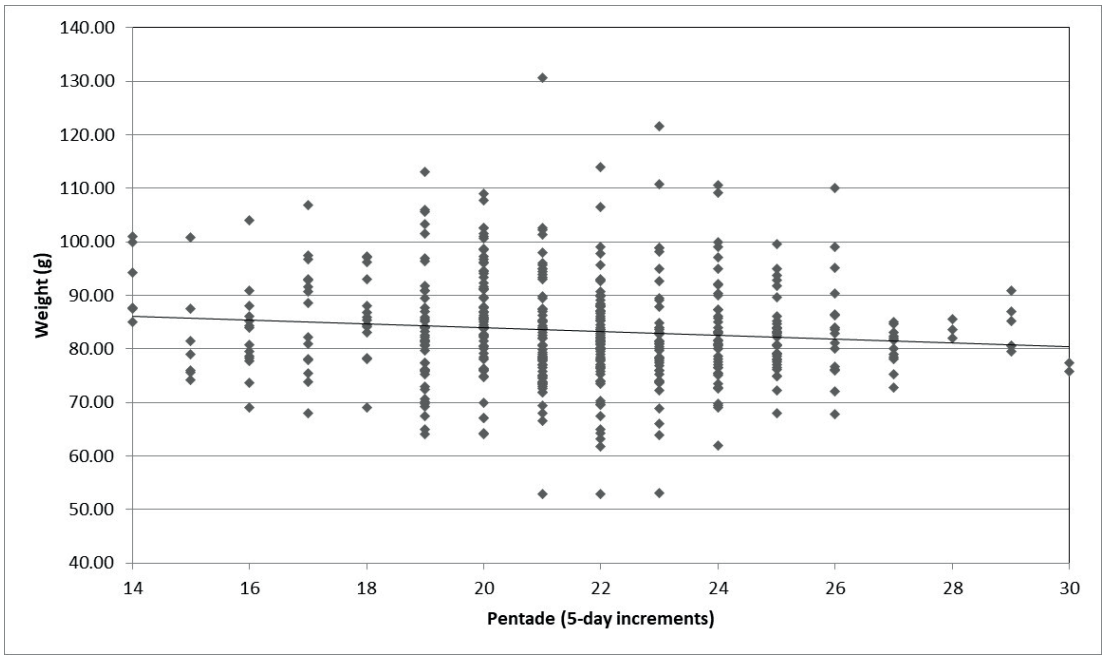


Figure 4 - Pentade (5-day increment) analysis of weight (g) of Eurasian Scops-owls during their northbound migration over the western Mediterranean (1993-2011).

Figura 4 - Peso (g) do mocho-d'orelhas durante a migração para Norte no Mediterrâneo ocidental (1993-2011).



Discussion

During spring migration, an early arrival at the breeding territories presents several selective advantages, especially for males (Møller 1994; Forstmeier 2002; Kokko 1999). Birds migrating through the western Mediterranean are facing one of the last ecological barriers before reaching southern Europe. They have two options to cope with the Mediterranean Sea: follow the coast or cross the sea. Species that select the short route over the sea can arrive earlier on their breeding grounds but may face rapid weather changes and scarcity of landing sites during passage, whereas species that select the continental route (implying a detour) may spend more time in getting at their breeding grounds but have ample opportunities to find adequate stopover sites and face less variable weather (Liechti & Bruderer 1998). This means that birds face a tradeoff between time and safety when choosing the migratory route, which is solved in different, species-specific ways (Spina & Pilastro 1999). We found no evidence of geographic or temporal trends on the timing of passage, suggesting that the migration strategy of this species is passing in a broad front over the Mediterranean without the presence of the sea being an obstacle as seems to happen with other species of birds (Barriocanal & Robson 2006, 2007). While there is a difference in size between sexes - the females and adults being slightly larger - we did not observe differences in the timing of the ages or sexes, which is contrary to the timing found in other species, where male adults have to arrive earlier in order to get the better breeding territories (Morbey & Ydenberg 2001). To conclude, our results show that there are no differences in arrivals between coastal and island locations. Such data supports the position that Eurasian Scops-owls passing through the western Mediterranean in spring move directly across the sea, choosing the shorter, more direct and faster route.

Acknowledgments

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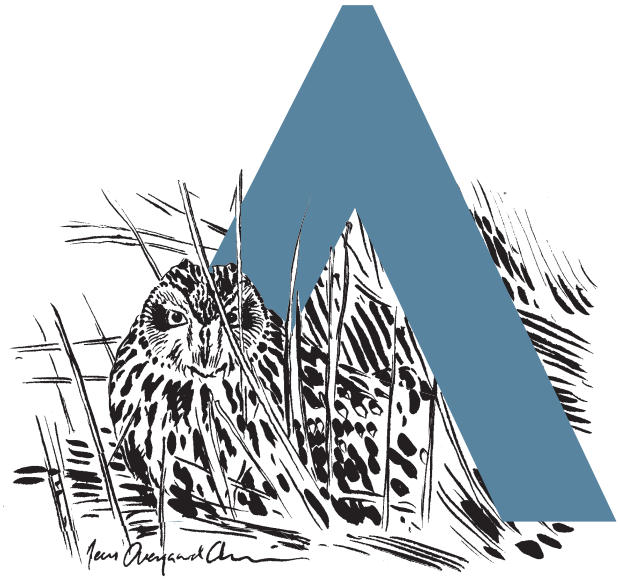
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Distribution and current state of the Short-eared Owl (*Asio flammeus*) in Ukraine

Distribuição e situação atual da coruja-do-nabal (*Asio flammeus*) na Ucrânia



Andriy-Taras Bashta[1]*

1 Institute of Ecology of the Carpathians NAS Ukraine, Koselnytska st. 4 Lviv 79026 Ukraine

*** Corresponding author:** atbashta@gmail.com

ABSTRACT

This paper reviews the literature on the distribution, abundance, and habitat use of the Short-eared Owl (*Asio flammeus*) over time and by nature zones and regions in Ukraine and summarizes its conservation status and threats to its population. Until the early 20th century it was a common breeding species in the current territory of Ukraine whereas today it is generally rare, breeding in small numbers in some areas of the country. In some areas (the Black Sea coast, the Crimea) the Short-eared Owl was observed mainly during migration and winter periods. It was quite numerous during some warm and relatively snow-free winters in the northern part of the country. A significant decline of the Short-eared Owl population was noted since the 1960s in Ukraine caused by degradation of meadow habitats by livestock grazing and burning of vegetation and shooting. Drainage changed the hydrological regime and caused a negative effect on breeding habitat. The species did not recolonize some areas, despite the re-naturalization of wetlands. Today the total population of Short-eared Owls in the Ukraine is estimated at 700-1,400 breeding pairs.

Keywords: *Asio flammeus*, distribution, population decline, Short-eared Owl, Ukraine

RESUMO

Este artigo faz uma revisão da literatura sobre a distribuição, abundância e uso de habitat pela coruja-do-nabal (*Asio flammeus*) ao longo do tempo, nas zonas naturais e regiões da Ucrânia, e resume o seu estado de conservação e as ameaças à população. Até ao início do século XX, a espécie era nidificante comum no território da Ucrânia, sendo atualmente em geral rara, nidificando em pequenos números em algumas áreas do país. Em algumas áreas (costa do Mar Negro, Crimeia) a coruja-do-nabal foi observada principalmente durante a migração e o inverno. A espécie foi numerosa durante alguns invernos amenos e com pouca neve, na parte norte do país. A partir da década de 1960, a coruja-do-nabal registou um declínio significativo na Ucrânia, devido à degradação dos prados pelo pastoreio e pela queima de vegetação, e também devido ao abate. A drenagem alterou o regime hidrológico e causou um efeito negativo no habitat de reprodução. A espécie não recolonizou algumas áreas, apesar da re-naturalização das zonas húmidas. Atualmente, a população total de coruja-do-nabal na Ucrânia é estimada em 700-1.400 casais reprodutores.

Palavras-chave: : *Asio flammeus*, coruja-do-nabal, declínio populacional, distribuição, Ucrânia

Introduction

The Short-eared Owl's (*Asio flammeus*) range includes all continents, except Antarctica and Australia (Olsen et al. 2013). It occurs throughout Ukraine's nature zones (Fig.1), breeding in all areas except the Carpathian and Crimean Mountains. It is migratory, however it may over-winter in some regions. Currently only the nominate subspecies *A. f. flammeus* is believed to occur in Ukraine (Voinstvensky 1960), although in the past Charlemagne (1938) identified *A. f. flammeus* as the widespread common breeding subspecies, and *A. f. leucopsis* being restricted to the area east of the Dnipro river. This paper reviews the literature on the distribution, abundance, and habitat use of the Short-eared Owl over time and by nature zones and regions in Ukraine and summarizes its conservation status and threats to its population.

Methods

A review of studies on the status and distribution of Short-eared Owls in Ukraine was conducted. These covered a variety of landscapes and physiographic zones, including the forest (Polissia), forest-steppe, and steppe zones and the Carpathian region (Fig.1), and many habitats such as deciduous forests (including beech or *Fagus* spp. stands) of Central Europe, forests (including oak or *Quercus* spp. woods) of the forest-steppe areas of eastern Europe, mixed coniferous-deciduous forests of northern Europe and meadow-steppe vegetation of southern areas as well as agricultural areas.

The distribution of breeding territories of Short-eared Owls was depicted on maps (Bibby et al. 1993) with territory boundaries determined by mapping aggressive interactions of neighbouring pairs of owls, as well as of owls with other raptorial birds or corvids, and by locating owl roosting and nest sites. Routine searches throughout known and potential breeding biotopes were also reported. On the Verkhniodnistrovska lowland (Lviv region, western Ukraine) as well as in part of the steppe zone, breeding studies included 1x1 km census plots (Bashta 1997).

Figure 1 - Nature Zones of Ukraine.

Figura 1 - Zonas naturais da Ucrânia.



Results and Discussion

Distribution, population status and trend by zones and regions

While the number of Short-eared Owls fluctuates dramatically from year to year in relation to changes in the availability of small mammal prey, many 19th and early 20th century researchers (Dzieduszycki 1880, Zarudny 1892, Somov 1897, Valh 1900, Averin 1910) described it as being common and widespread in Ukraine. Published estimates of its populations are heterogeneous in Ukraine and based on

limited counts of pairs or individuals on breeding territories within protected nature reserves and anecdotal observations in various zones and regions. Together, these estimates suggest that a significant population decrease has occurred from the middle of the 20th century. I suggest that currently there are 700-1,400 pairs in Ukraine.

Forest zone (Polissia)

Tatarynov (1973) described the Short-eared Owl as common in western Ukraine, in particular in Western Polissia. Since then, its status has changed significantly. In north-western Ukraine's Shatskyi National Nature Park (National Nature Parks are denoted as NNP hereafter) breeding pair density decreased from 5-6 pairs (1.02-1.23 pairs/100 km²) in 1982-87 to 2-4 pairs (0.41-0.82 pairs/100 km²) in 1997-2001 (Gorban 2002). In some parts of Shatskyi NNP, it was not detected despite the re-naturalization of habitats within the park (i.e., stabilization of the water level) (Gorban & Mateychyk 2003).

In the central and eastern part of Polissia, the Short-eared Owl is a rare breeding bird (Lebed et al. 1996, Afanasyev 1998, Polushkevych 2006, Domashevsky 2009). Generally, it is distributed sporadically throughout this region in some years (Khlebeshko & Tsytsiura 1996). It may breed and over-winter in the Chernobyl exclusion zone, in particular in its central part (Domashevsky et al. 2012). Its spring population density in abandoned fields in Eastern Polissia was 0.03 breeding pairs/km² and 0.01 individual owls/km² from spring through autumn (Kuzmenko et al. 2013).

Forest-steppe zone

Plater (1852) reported the Short-eared Owl as common in peat bogs in this part of western Ukraine that then belonged to Poland. Its population decreased significantly during the 20th century (Guziy 1987, Gorban et al. 1998) and today is a rare breeder in the zone's plains and foothills (Bashta 2009).

In the plains of the upper part of the Dnister River basin, it occurs only in wet meadows in the Verkhniodnistrovska Lowland where its breeding density has been estimated at 3 pairs/100 km2 (Bashta 2013) and 1 pairs/km2 (Bokotey et al. 2010). Its population has likely continued to decrease due to shrub and tree encroachment.

In the Bukovyna territory (south-eastern part of the Carpathian region) its status is unknown, and it is rarely detected in the plains, in particular in the central and western districts between the Prut and Dnister rivers (Skilsky & Godovanets 1996).

Khranevych (1925-1926) stated that some Short-eared Owls were resident and that it was a common migrant in Podillia. More recently, it has observed only in the breeding season (Novak 2003, Kapelukh 2008).

At the end of the 19th to the mid-20th centuries it was a frequent breeder and common migrant, and occasionally over-wintered, leading some to suggest it was possibly a year-round resident in the forest-steppe zone of central and north-eastern Ukraine (Somov 1897, Averin 1910, Orlov 1948, Volchanetsky 1954). Significant annual variation in its numbers were noted (Somov 1897). Until the 1960's it bred in meadows, logged areas and in some forest habitats. By the mid-20th century it was not noted every year and then only in small numbers (Matviyenko 2009). Two nests (0.87 pairs/10 km2) were found in 23 km² of flood plain meadows (Sova 1994). Vetrov (2013) estimated up to 100 pairs (0.32 pairs/km²) in the Kharkiv region. This population decline likely occurred concurrently with the degradation of meadow habitat (Sova 1994).

In the forest-steppe part of north-eastern Ukraine, it is rare breeding and migrant species (Lebed et al. 1996, Knysh 2001, Banik et al. 2013).

Steppe zone

At the end of the 19th century the Short-eared Owl was a common nomadic and sedentary species of the steppe part of the Kharkiv province, which included the present Kharkiv region and part of the Lugansk region (Somov 1897). It was a common breeding species of the steppe (in shrub ravines) and island forests adjacent to the Orchyk River (Zarudny 1892).

At the turn of the 19th and 20th centuries in the Katerynoslav province (today - mostly Donetsk and the Dnipro regions) it was a common migrant and bred in some years. Short-eared Owls were as common, and in some places it more numerous, than Long-eared Owls (*Asio otus*), especially in winter (Valh 1900). It was a common breeding throughout the steppe zone (Voinstvensky 1960).

More recently, in northern parts of the Luhansk region, the Short-eared Owl is a common year-round resident and wintering species (Artyushenko 2005). In the southern steppe region it is less common. In this area (southern and eastern Ukraine), its density was estimated at 0.1 (valley of Samara river, Bulakhov et al. 1999) to 0.58-1.93 pairs/km^2 ("Striltsivskyi step" Nature Reserve, Moroz 2011). In the central part of the steppe (biosphere reserve "Askania-Nova") it is common and widespread, including in abandoned fields (Gavrilenko 2011). I observed similar average densities (0.8 individuals/km^2, unpubl. data) in the steppe north of Azov Sea in July 2018. However, the abandoned fields were small, and owls were noted mainly on the ground along narrow forest plantations or on dead tree branches along roads by fields.

Most observations from the Black Sea part of the steppe are from winter; fewer are seen during migration. Here it is considered a rare winter, and probably a breeding species. Recently, an increase in breeding pairs has been noted (Arkhipov 1996). This has only been quantified for parts of the nature reserve: 0.1 pairs/km^2 ("Tarutinsky steppe"; Rusev 2011), 0.15-0.25 pairs/km^2 ("Yelanetsky steppe"; Redinov 2006), and 0.14 pairs/km^2 ("Tuzlovski Limany" NNP; Rusev et al. 2011). It is described as a common breeding species in the reed beds in the Dniester delta (Rusev 2009).

In Crimea in 1959-62, it was common almost throughout the steppe in the breeding season, during migration and in winter (Kostin 1983) but subsequently its numbers fell sharply. Currently the Short-eared Owl is a rare migrant and winter resident in the steppe part of the Crimea, with breeding documented in the plains in the southern part of this peninsula (Beskaravayny 2015) and in the northern part of the Kerch Peninsula (Andryuschenko 1999). Non-breeding individuals were found in other parts of the Crimea, especially in the southeast (Beskaravayny 1999) and southwest (Klestov & Tsvelyh 1999).

Carpathian region

The Short-eared Owl is a rare migrant in this region, appearing during autumn-winter and in spring (Strautman 1954) including in mountains and highlands (Carpathian NNP) where it occurs in open boggy habitats in forest ecosystems (Kyseliuk et al. 2009).

Grabar (1931) noted that it may have bred in the Transcarpathian plain where it remains a common migrant in October-December (Potish 2009) and during the last century its migration peak may have shifted to later in the season. During the breeding season it has been occasionally observed in the flood plain of the Latorytsia River (Potish 2009).

Breeding habitat by zones and regions

Steppe zone

In eastern Ukraine, in particular in the

steppe zone, the typical habitats used by Short-eared Owls include the steppe slopes, the banks of estuaries and seas, flood plains, banks of lakes, and, less often, dry areas of the steppe, but always near reservoirs (Voinstvensky 1960). Other habitats used include steppe bogs, and shrubs and weeds in ravines. In the post-breeding period they rarely enter, buy may remain adjacent to, forests. By day they use thick meadow or marsh grass, sedge, and rarely perch on branches of low bushes near marshes.

Today, breeding occurs in ungrazed protected areas with high grassland and in areas with very low or moderate grazing pressure. Breeding was also noted in watershed and ravine forests and in forest plantations (Volchanetsky 1954); in marshy meadows and swampy sedimentary areas (Zagorodniuk et al. 2012); and in gullies and on steppe slopes (Sirenko & Martynov 1998). Nest sites consists of a small depression in the grass, located on hummocks or directly on the ground under a bush or large grass plants (Somov 1897).

In southern Ukraine (the Dnister Delta area), it commonly breeds in reed complexes or solid thickets of cane with shallow water, sedge thickets, reed beds with interspersed willow bushes (Rusev 2009). Therefore, its breeding status can be impacted the destruction of reed thickets in the upper estuary for fishing channels (Arkhipov 1996).

In Crimea, in years when is abundant, it has colonized most open habitats in the steppe and foothills, including in virgin steppe areas and in crop land. However, when populations are low its distribution becomes sporadic (Kostin 1983).

Forest-steppe zone

In this zone the Short-eared Owl typically breeds in a variety of open meadows and those with tall shrub thickets, as well as in wetlands in Western Ukraine (Bashta 2009). Here nests are either on the ground (Klitin 1959, Tatarynov 1973) or under weeds (Orlov 1948).

In eastern Ukraine its nests in meadows, on logs, and in different types of forests (Sova 1994). More recently nests were recorded in floodplains and meadow habitats around lakes (Banik et al. 2013), damp grassy meadows, banks of lakes and marshes with sparse shrubs and reeds (Afanasyev 1998), and on the slopes of dry ravines (Knysh 2001).

Forest zone

The Short-eared Owl nests in flood plains, dry meadows, lowland swamps, among small forests near abandoned fields, and in logged areas within the forests. Nests are on the ground, often on a tussock, under a willow bush or a low tree (Kuzmenko 2009). In the Chernobyl zone, it has been recorded breeding in abandoned fields, open forests, and in meliorated and marshy meadows in river floodplains (Domashevsky et al. 2012).

Birds are usually active throughout the day, but also perched on dead tree branches, bushes and poles in hayfields. Males often actively protect nest sites, attacking other raptors and corvids that fly over their breeding territories.

Migration by zones and regions

The phenology of Short-eared Owl migration is poorly known but likely depends on variable seasonal climatic conditions across its range. It appears to undergo long-distance seasonal movements and is more visible in northern Ukraine.

Short-eared Owls appear in northeastern Ukraine in mid- to late March (Chernay 1853) whereas in central Ukraine this ranged between mid-March to mid-April (Orlov 1948). In Eastern Polissia, observations ranged from the end of March to early April

(1960s to 1990s; Afanasyev 1998, Knysh 2006). Accounting for the meridional distance from Eastern Polissia to southern Ukraine (about 800 km), these data are consistent with reported departure dates of wintering individuals from Crimea (mid-March, Kostin 1983), as well as with the monitoring of migrants on Zmiiny Island in the Black Sea (mid-March, Korzyukov et al. 2011). In the western part of the Mykolaiv region, recent spring observations occurred at the end of March (Redinov & Korzyukov 2002).

Autumn departure from the Polissia area begins in August. In forest-steppe areas, departures varied by year and spanned from the end of September to the first half of October.

In the Podillia (forest-steppe zone) spring migration was early to mid-March whereas autumn migration occurred in October (Khranevych 1925-1926). In central Ukraine, the period of autumn migration varied from the end of September to early December in the middle of the last century (Orlov 1948). In the outskirts of Lviv (Western Ukraine), autumn migration occurred from September to the first half of November (Miczynski 1962).

In steppe areas, owls were observed mainly in September (Pisarev et al. 2007) and September-October (Arkhipov 2011). In some years, migration was delayed until December (e.g., 1970-1971) but owls did not over-winter (Panchenko 2007). On Zmiiny Island (Black Sea) the number of Short-eared Owl migrants has declined over time (Korzyukov et al. 2011).

Wintering by zones and regions

Short-eared Owl abundance and distribution in winter depends on prey availability and climate conditions. In some warm and less snowy winters in eastern Polissia some were sedentary while others were nomadic (Afanasyev 1998, Knysh 2001). It is known to over-winter in Central Podillia (Novak & Novak 2014), in the central part of Ukraine (Cherkasy region; Gavryliuk & Grishchenko 2001), and in Transcarpathia (Kucherenko 1953). In steppe areas, its winter density fluctuated between 0.97 and 7.50 individuals/km2 (Sirenko & Martynov 1998). In some years, large winter roosts reached 1-1.7 individuals/km² (Upper Dniester lowland, western Ukraine).

In winter in eastern and southern Ukraine (Steppe Zone) it occupied ravine forests and slopes covered with thick bushes. During winters with deep snow and heavy frost, it is found closer to villages and often in threshing locations with abundant prey (Averin 1910).

In winter in the northern banks of the Azov Sea, and generally in the southern part of the Steppe Zone, the Short-eared Owl is rare (Rusev et al. 2003, Redinov 2006, Syzhko 2007) or uncommon (Redinov & Korzyukov 2002, Arkhipov 2012). However, significant numbers have over-wintered in some years due to an abundance of prey (Valh 1990). This was the case in Crimea in prey-rich years with owls remaining in specific locations for long periods and sometimes all winter. Owls were usually observed near large colonies of the Social Vole (*Microtus socialis*) (Kostin 1983).

Negative factors and conservation

There are many natural and anthropogenic factors influencing Short-eared Owl populations. These include threats to it or its habitats caused by human activity. In north-eastern Ukraine, the main limiting factor for this species is livestock grazing in its breeding habitat

(Atemasova 2009). Meliorative drainage in the Verkhniodnistrovska Lowland (western Ukraine) led to changes in the hydrological regime. The resulting negative impacts on breeding habitats have contributed to its decline.

Short-eared Owl numbers, like other microtine or small mammal specialist predators, are influenced by prey availability. It has increased only in the years when its main prey species (mice and other small rodents) increased. Severe climatic conditions during winter often make it disperse in search of prey, regularly resulting in aggregations to form in cities.

The main anthropogenic activities that impact Short-eared Owls includes haying, harvesting, mechanized tillage, excessive grazing, and burning of fields which destroy nests and degrades habitat, and illegal killing (Khlebeshko & Tsytsiura 1996). Vetrov (2013) also reported that humans killing Sort-eared Owls and collisions with vehicles on roads as threats (Patsera 2013).

The Short-eared Owl is noted as a species of conservation concern in the Red Data Book of Ukraine (Kuzmenko 2009). The main conservation measures recommended for this species include the protection of wetland biotopes, ecological education for hunters, stopping overgrazing, and restoring breeding habitat.

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Birds as prey of owls: an intra- and interspecific comparison

Aves como presas de rapinas noturnas: comparação intra e interespecífica

Simon Birrer[1*]

1 Schweizerische Vogelwarte, Seerose 1, CH-6204 Sempach, Switzerland

*** Corresponding author:** simon.birrer@vogelwarte.ch



ABSTRACT

A review on birds as prey of owls is presented based on 3639 prey lists from literature. The percentage of birds varied strongly between prey lists. Differences between owl species were moderate, only Eurasian Pygmy-owl (*Glaucidium passerinum*) and Eurasian Eagle-owl (*Bubo bubo*) showed over all higher percentages of birds in their prey. Differences between seasons were small. The variation within the same owl species (intraspecific variation) across the study regions was larger. In several cases, the percentage of birds as prey tends to have declined over the last decades. Although owls generally prey on mammals, birds are an important alternative prey.

Keywords: Food composition, birds as prey, Strigiformes

RESUMO

Uma revisão sobre as aves como presas de rapinas noturnas é apresentada, com base em 3639 listas de presas da literatura. A percentagem de aves variou muito entre listas de presas. As diferenças entre as espécies de rapinas noturnas foram moderadas, apenas o mocho-anão (*Glaucidium passerinum*) e o bufo-real (*Bubo bubo*) apresentaram no geral as percentagens mais elevadas de aves como presa. As diferenças entre as estações do ano foram pequenas. A variação dentro da mesma espécie de rapina noturna (variação intraespecífica) entre as regiões do estudo foi mais elevada. Em vários casos, a percentagem de aves enquanto presa tende a diminuir nas últimas décadas. Embora as rapinas noturnas geralmente se alimentem de mamíferos, as aves constituem uma presa alternativa importante.

Palavras-chave: aves como presas, composição da dieta, Strigiformes

Introduction

Food composition for many species of owls, regions and seasons is documented by hundreds of publications. Surprisingly, only a few syntheses about this topic have been published in the last three decades. There are some publications dealing with several species (Korpimäki & Marti 1995, Bó et al. 2007) and several on a single species, and most of them cover a restricted geographical range (Schönn et al. 1991, Birrer 2009, Obuch 2010, 2011, Korpimäki & Hakkarainen 2012, Roulin & Dubey 2012, Obuch et al. 2013, 2013, Roulin & Christe 2013, Roulin & Dubey 2013, Roulin 2015, Šotnár et al. 2015, Roulin 2016b, 2016a). The existing quantitative reviews on several species and regions present measures such as prey diversity, prey size or diet similarity but give no information on specific prey groups (Jaksić 1988, Marti et al. 1993).

Food of most owl species is composed primarily of mammals. Birds seem to be of minor importance and are often considered an alternative prey. Because food availability is a basic factor for ecology and conservation, it is important to have quantitative data not only on the main prey but on alternative prey species as well. The aim of this paper is to present data on birds as prey of as much owl species as possible based on a broad literature review.

Methods

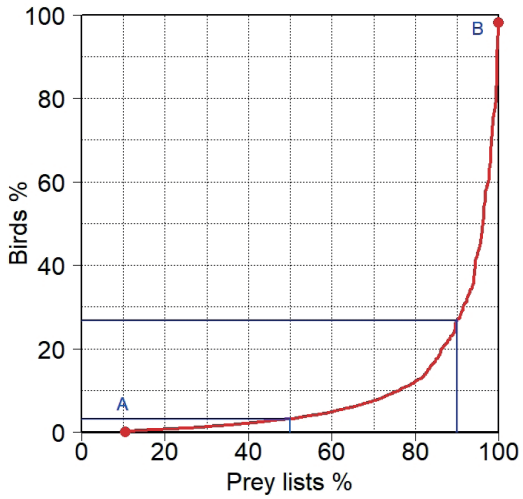
Various bibliographies, databases and entries in the library of the Swiss Ornithological Institute were searched for publications on owl diet. A total of more than 4300 references were found. Of these, 2262 publications were checked and if available, data on owl prey lists was entered into a database. Predator species, prey species or group and minimal number of items per prey species, date, country, place, and longitude and latitude were recorded. Where necessary, absolute numbers of prey items were calculated from published percentages. When a publication contained several sub-lists, i.e. several places, years or seasons, each list was entered separately (Birrer 2009). If the same data set was used several times in different publications, lists were entered only once. The owls' systematics and names follow the IOC World Bird List (Gill & Donsker 2017). Prey biomass was recalculated by multiplying the number of prey items with a mean weight of the prey species derived from literature. Each list was assigned to one major geographical region: North America (Canada, USA, Mexico), South America, Northern Europe (Scandinavia including Denmark, the Baltic States and northern Russia), the British Isles (including Ireland), Central Europe (Germany, Poland, Czech Republic, Slovakia, Austria, northern Switzerland, northern France, Benelux), Southern Europe (Spain, Mediterranean France, Italy, southern Switzerland), Southeast Europe (Slovenia, Hungary, Ukraine and countries south of it), Middle East and North Africa (Africa north of Sahara and Canary Islands), Africa (south of Sahara), Asia (excluding Middle East) and Australia.

For this synthesis, the database was searched for prey lists which fulfilled the following conditions: a) all prey groups were mentioned if present, b) more than 90% of all vertebrates were determined to at least till the order level, c) the list contained more than 100 vertebrate prey items or more than 500 preys items (invertebrates and vertebrates). Furthermore, only owl species with more than 40 prey lists were taken into account for this synthesis.

Results are presented in graphs resembling Lorenz curves (Damgaard & Weiner 2000). Prey lists were first sorted by increasing proportion of birds on vertebrate prey. Then they were plotted along the x-axis. Such a curve allows to accurately visualizing various proportions of the prey list data

Figure 1 - Example of a graph showing the proportion of birds in the prey lists of Northern Long-eared Owl (N=1328) in relation to the proportion of prey lists and some important key metrics: Point A: percentage of prey lists with no birds (exact data point: 10.5 %); Point B: Maximum percentage of birds in a prey list (exact data point: 98.0 %); small rectangle: median (50 % on x-axis; exact data point: 3.2 %); larger rectangle: 90 %-quantile (exact data point: 26.8 %).

Figura 1 - Exemplo de gráfico da proporção de aves nas listas de presas de bufo-pequeno (N = 1328) relativamente à proporção de listas de presas, e algumas métricas importantes. Ponto A: percentagem de listas de presas sem aves (valor exato: 10,5%); ponto B: percentagem máxima de aves numa lista de presas (valor exato: 98,0%); retângulo menor: mediana (50% no eixo horizontal; valor exato: 3,2%); retângulo maior: quantil 90% (ponto exato de dados: 26,8%).



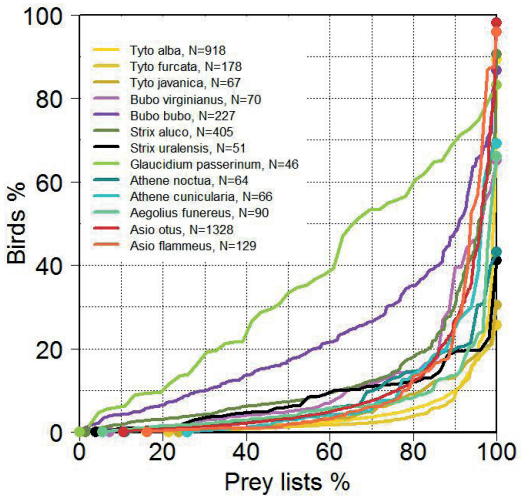
set, e.g. proportion of the median, of the 90%-quantile the maximum and minimum etc. (Fig. 1).

Results

After the selection, 3639 prey lists from 957 references were used for this review. The required 40 prey lists per species were available for 13 owl species. The distribution curves of birds as prey were quite similar for the different owl species: on the left-hand side, a slow increase is visible. At about 80%

Figure 2 - Percentage of birds in prey lists of different owl species.

Figura 2 - Percentagem de aves nas listas de presas de diferences espécies de rapinas noturnas.

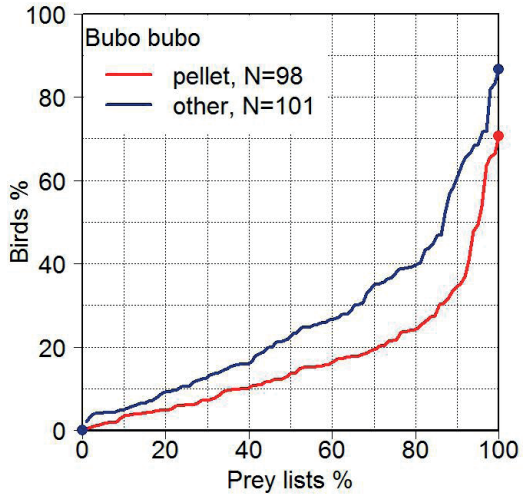


of all prey lists, the curve sharple increases and reaches 90 to 100% of birds at the right end (Fig. 2). In 11.1% of all prey lists no birds were found. The owl species with the most prey lists containing no birds was Burrowing Owl (*Athene cunnicularia*; 25.8%; Fig. 2), followed by Eastern Barn Owl (*Tyto javanica*; 23.9%), American Barn Owl (*Tyto furcata*; 21.3%), Short-eared Owl (*Asio flammeus*; 16.3%) and Common Barn Owl (*Tyto alba*; 16.1%). The fewest prey lists without any birds were found in Ural Owl (*Strix uralensis*; 3.9% of all lists) and Tawny Owl (*Strix aluco*; 1.5%). The prey lists of Eurasian Eagle-owl (*Bubo bubo*) and Eurasian Pygmy-owl (*Glaucidium passerinum*) all contained at least one bird.

Median percentage of birds was lowest in American Barn Owl (1.2%), Common Barn Owl (1.6%) and Short-eared Owl (1.8%). Most other owl species had a median lower than 7.5%, except Eurasian Eagle-owl (17.2%) and Eurasian Pygmy-owl (34.0%). The high proportion of birds in prey lists of Eurasian Eagle-owl and Eurasian Pygmy-owl

Figure 3 - Percentage of birds in prey lists of Eurasian Eagle-owl obtained by pellet analysis and other methods (including combination of pellet analysis and analysis of prey remains).

Figura 3 - Percentagem de aves nas listas de presas de bufo-real obtidas por análise de regurgitações e outros métodos (incluindo análise de regurgitações e restos de presas).



might have some methodological reasons: The vast majority of prey lists of all other species are based on pellet analyses, whereas prey lists of Eurasian Pygmy-owl and Eurasian Eagle-owl not only consider pellets but often prey remains too. It is well known that birds may be overrepresented in prey remains, because in many cases even a single feather of a prey species can be determined. When only pellet-based prey lists of Eurasian Eagle-owl were taken into account, the median proportion of birds dropped to 13.7% (N=98; Fig. 3). For Eurasian Pygmy-owl only 12 prey lists based on pure pellet analysis or on prey caching were available. In those lists, birds accounted for a median of 27.6%.

Intraspecific differences between prey lists of different regions were bigger than interspecific differences in some cases. In the Northern Long-eared Owl (*Asio otus*) there seems to be a latitudinal gradient in proportion of preyed birds across Europe: small proportions in Northern Europe, median proportions in Central Europe and high proportions in Southern Europe and even higher propor-

Figure 4 - Percentage of birds in prey lists of (A) Northern Long-eared Owl (*Asio otus*)and (B) Western Barn Owl (*Tyto alba*) suggesting a regional gradient.

Figura 4 - Percentagem de aves nas listas de presas de bufo-pequeno e coruja-das-torres, sugerindo um gradiente regional.

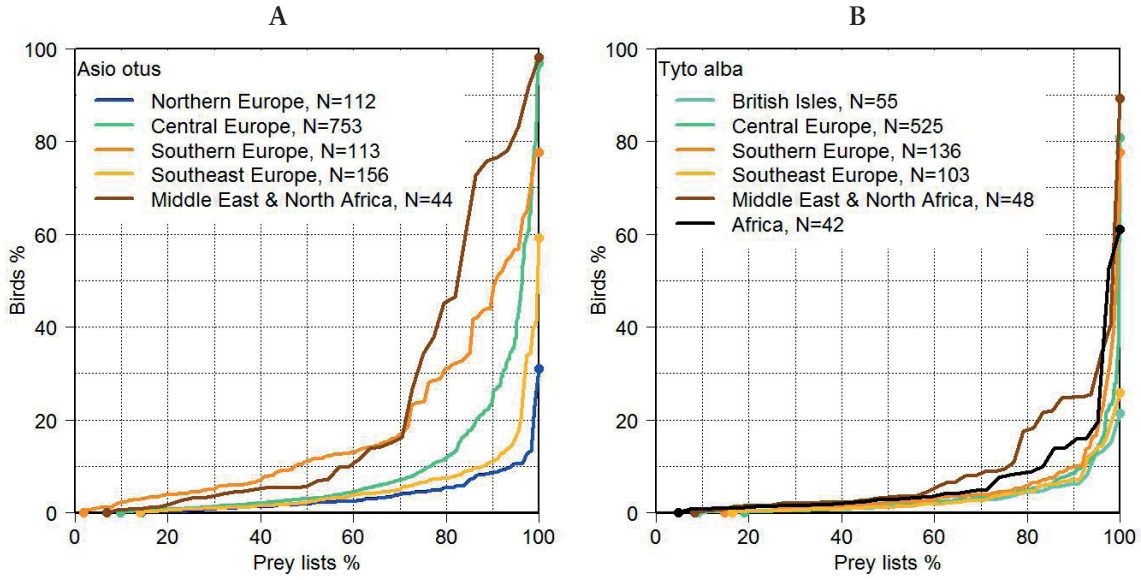
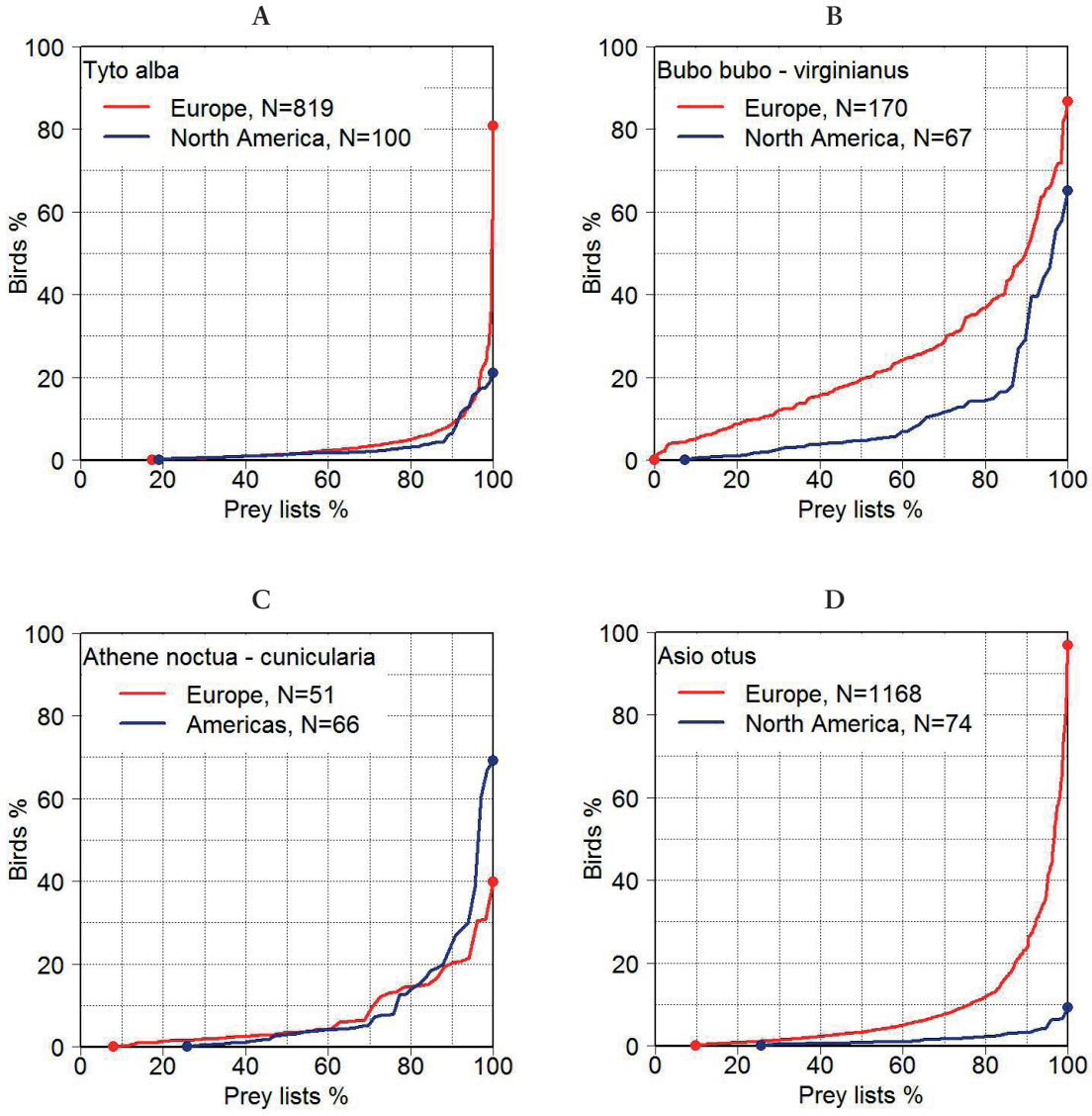


Figure 5 - Comparison of proportions of birds as prey of the same or replacing species in Europe and (North) America: (A) Western Barn Owl versus American Barn Owl (*Tyto alba*), (B) Great Horned Owl versus Eurasian Eagle-owl (*Bubo bubo/virginianus*), (C) Little Owl versus Burrowing Owl (*Athene noctua/cunicularia*) and (D) Northern Long-eared Owl (*Asio otus*).

Figura 5 - Comparação das proporções de aves como presa de uma mesma espécie ou em espécies homólogas na Europa e na América do Norte: bufo-americano versus bufo-real, coruja-das-torres americana versus europeia, mocho-galego versus coruja-buraqueira e bufo-pequeno.



tions in Middle East/North Africa (Fig. 4). In prey lists of Southeast Europe, however, birds were relatively rare. Common Barn Owl prey lists of the region Middle East/North Africa also held higher proportions of birds than those in Europe. Prey lists south of the Sahara desert contained fewer birds. (Fig. 4).

For Northern Long-eared Owl, there were enough data for a comparison between prey lists from Europe and North America (Fig. 5). Such comparisons were also possible for the replacing species Common and American Barn Owl, Great Horned Owl (*Bubo virginianus*) and Eurasian Eagle-owl as well as for

Figure 6 - Comparison of proportions of birds as prey of Tawny Owl in the breeding season and winter.

Figura 6 - Comparação das proporções de aves como presa de coruja-do-mato durante o período reprodutor e o inverno.

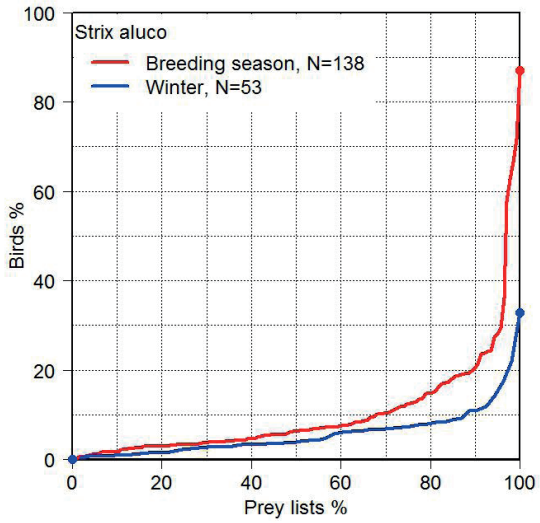
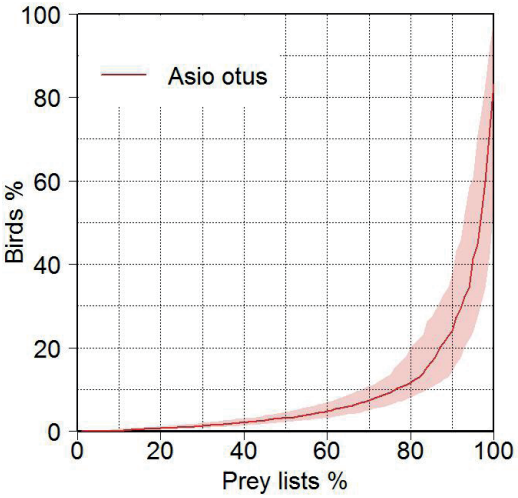


Figure 8 - Repeated sampling of prey lists (including degree of uncertainty): Out of the 1328 prey lists of Northern Long-eared Owls, 200 lists were randomly sampled 5000 times. The solid line shows the mean of all the samples. The shaded area represents the 95% confidence interval.

Figura 8 - Repetição da amostragem das listas de presas (incluindo grau de incerteza). Das 1328 listas de presas de bufo-pequeno, 200 listas foram amostradas aleatoriamente 5000 vezes. A linha sólida representa a média de todas as amostras. A área sombreada representa o intervalo de confiança de 95%.



Little Owl and Burrowing Owl (subsequently compared with combined lists from North and South America). There was no difference in the proportion of birds between prey lists of Common and American Barn Owl and in prey lists of *Athene* species. However, European prey lists contained more birds than North American ones for *Bubo bubo/virginianus* and Northern Long-eared Owl (Fig. 5).

Seasonal differences in food composition are nearly nonexistent in Common Barn Owl and are small in Northern Long-eared Owl. Tawny Owl seemed to feed a bit more on birds during breeding season, but differences were marked only in the 40% of prey lists with the highest proportion of birds (Fig. 6).

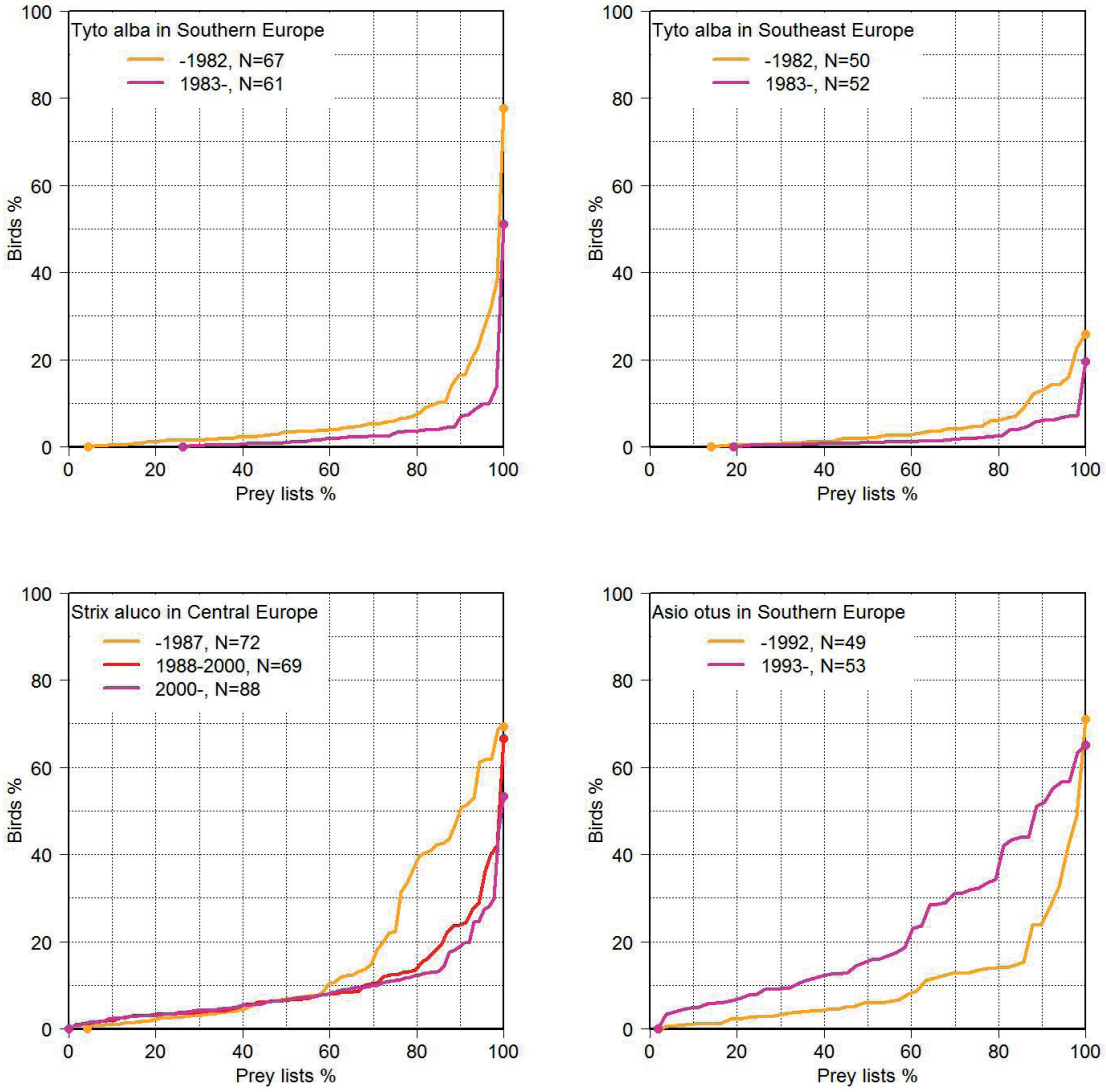
In nine cases, there were enough prey lists to split them into two or more time series. In five of these nine cases, there was a lower proportion of birds in the most recent time series (Common Barn Owl in Southern Europe and Southeast Europe, Tawny Owl in Central Europe and Northern Long-eared Owl in Central Europe and in Southeast Europe, Fig. 7). In three cases there were no obvious differences (Common Barn Owl in Central Europe, American Barn Owl in North America and Northern Long-eared Owl in Northern Europe) and only in Northern Long-eared Owl prey lists from Southern Europe did the most recent prey lists show higher proportions of birds than in older ones.

Instead of the percentage of prey items it is also possible to calculate the percentage of biomass. Differences between percentage of prey items and percentage of biomass were generally small in this data set. They were nearly nonexistent in Common Barn Owl and Northern Long-eared Owl. The most prominent differences were found in Great Horned Owl and Ural Owl.

To get an impression on how precise the graphs are, a random sample of 200 out of the 1327 prey lists of Northern Long-eared Owl was taken. This procedure was repeated 5000 times. The mean and 95% interval of all these

Figure 7 - Some examples of comparisons of proportions of birds as prey in different periods.

Figura 7 - Alguns exemplos de comparações das proporções de aves como presa em diferentes períodos.



lists are shown in Fig. 8. It is obvious that all lists lie close together in the left-hand part, while uncertainty becomes larger in the 20 % of lists with the highest proportions of birds.

Discussion

For this study 2262 publications were checked. This is about half of the known references on prey of owls. The majority (79.3%) of these lists are based on pellet analyses. The rest is based on analysis of prey remains in the nest, analysis of plucking remains, photo or video surveys of nests and on combinations of these methods. The checked publications are not a random sample, and publications in European journals and more recent publications might be overrepresented because of easier access

in the library of the Swiss Ornithological Institute and online respectively. Furthermore papers on Northern Long-eared Owl were clearly overrepresented because of an earlier work by Birrer (2009). After reaching more than one hundred prey lists per region, searching effort on publications on Barn Owl, Eurasian Eagle-owl and Tawny Owls was reduced. Despite a considerable effort to get data for as many owl species as possible, enough data for a quantitative analysis was only retrieved for relatively few combinations of species and regions. Therefore, even if literature on owls' diet is rather extensive, it would be worth publishing further studies, especially for species and/or regions where knowledge has remained poor. Unfortunately there are several publications which could not be used for this review due to methodological problems. For example, some authors publish percentages of each prey but no total number, so that prey items cannot be calculated (e.g. Thal et al. 2014, Wadatkar et al. 2016). Others only present graphs but no tables (e.g. Clulow et al. 2011, Żmihorski et al. 2011), or only the percentage of pellets in which certain prey items were found (e.g. Lavazanian 1996, Zade et al. 2011) or only list prey of some groups but not of all (e.g. Andrade et al. 2016, Lesiński & Beuch 2016).

There is a large body of literature available comparing owl diet between species, regions, seasons, and time. Most papers are based on only a few prey lists and results were contradicting between papers. Some authors found higher percentages of birds in prey lists of Northern Long-eared Owls in winter especially when snow cover was high (Korpimäki & Hakkarainen 2012), whereas others found higher percentages in the breeding season (Manganaro 1997, Bertolino et al. 2001). Our data do not indicate a general difference between seasons in Northern Long-eared Owl and Barn Owl. This is not surprising, because season is a proxy for different factors such as prey abundance or different prey availability (e.g. because of snow cover: Elvers et al. 1979, Canova 1989). Nevertheless, this review shows a somewhat higher proportion of birds in Tawny Owl in the breeding season.

The most pronounced differences were visible between continents and/or regions in one species or related species. Such differences have been described before for birds as food of Barn Owl in Europe (Roulin 2015) and for Northern Long-eared Owl (Birrer 2009).

Roulin (2015) found a decrease of birds as prey of Barn Owl between 1860 and 2012 in Northern and Eastern Europe. Such a decrease is also observed in the presented data for Common Barn Owl in several European regions as well as for Tawny Owl in Central Europe, and Northern Long-eared Owl in Central and Southeast Europe. In Southern Europe, on the other hand, Common Barn Owl prey lists from 1993 and older contained a higher proportion of birds than more recent ones.

An interesting result of this review is the similarity of the Lorenz curves of the different analysed owl species. Only Eurasian Pygmy-owl and Eurasian Eagle-Owl's curves were distinctly higher. For all other species, in more than half of all prey lists birds accounted for less than 10% of prey items. However, for all but Ural Owl, Burrowing Owl, Eastern Barn Owl, and American Barn Owl, birds can be an important prey and can make up more than 50 % of vertebrate prey items.

The distribution of birds in owl prey was very uneven. Such high proportions of birds are often a result of specific situations, e.g. low density of small mammals due to cyclic population changes (Potapov & Sale 2012, Chandler et al. 2016) or unfavourable conditions on islands. Another situation which can lead to high bird proportions in owl prey is low mammal availability, caused e.g. by dense and high ground vegetation in summer or snow cover in winter (Elvers et al. 1979, Ancelet 1987, Canova 1989). Furthermore, an extraordinarily high local bird density can be exploited by owls and can thus also lead to elevated proportions of birds in their prey. Owls are known to hunt

in colonies of waterbirds like terns and gulls (Kayser & Sandoul 1996), or they can exploit concentrations of migrating birds attracted by lighthouses (Moritz & Schonart 1976, Canário & Tomé 2012) or resting places during migration (Reglade 1985, Kiat et al. 2008).

Even though high proportions of birds in owl prey lists are not very common, the flexibility of owls to switch their diet to birds in certain situations might be important for their survival.

Acknowledgments

I am very grateful to many people for helping me to find the literature. Judith Zellweger improved the English. The reviewers gave valuable comments on the manuscript.

Supporting information

Appendix S1 contains additional figures comparing prey numbers with percentage of biomass, per region, in winter and breeding season, and at different time series; Appendix S2 contains the complete list of references included in the analysis; and Appendix S3 contains raw data.

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Owl education methods used around the world

Métodos de educação sobre rapinas noturnas usados no mundo



Karla Bloem[1*]

1 International Owl Center, 126 E Cedar Street, PO Box 536, Houston, MN 55943, USA

*** Corresponding author:** karla@internationalowlcenter.org

ABSTRACT

In this study I provide an overview of different techniques used for educating people about owls around the world and associated laws. I surveyed 17 individuals from 11 countries on 5 continents. Most respondents reached all ages to some extent. Laws varied in different countries, which impacts the methods used. It is not legal to use live owls in some countries, but 86% of educators who live in countries that allow it use live owls. Of them, 27% allow the audience to hold or touch the owls, 27% allow touching only in special circumstances, and no one reported injuries to humans or owls as a result. Dead specimens or feathers were used by 76%. Sixty-five percent dissect owl pellets or give pellets to schools to dissect. Of them, only 45% heat treat pellets to lower the risk of salmonella or other illnesses that can be transmitted to humans through pellet dissection. Eighty-eight percent use real-life stories, 71% use games or activities, and 29% use wild owl experiences. Only 35% have conducted surveys to assess their program impact. Respondents listed a variety of calls to action included in their programs which reflect the prevailing positive or negative cultural attitudes in their area. Time and money were listed as the biggest obstacles for educators. The most important things cited that would help educators are networking, funding, and current research summaries.

Keywords: Conservation, Cultural Beliefs, Education Methods, Laws, Owls

RESUMO

O Neste estudo apresento uma visão geral das diferentes técnicas usadas em educação sobre rapinas noturnas em todo o mundo e das leis associadas. Entrevistei 17 pessoas de 11 países em 5 continentes. A maioria dos entrevistados trabalhou com público de todas as idades. As leis variam consoante o país, o que tem implicações nos métodos utilizados. Não é legal usar aves em alguns países, mas 86% dos educadores que moram em países que o permitem utilizam rapinas noturnas. Destes, 27% permitem que o público agarre ou toque nas aves, 27% permitem tocar apenas em circunstâncias especiais, e ninguém relatou lesões em humanos ou em aves como consequência do manuseio. Espécimes mortos ou penas foram utilizados por 76% dos inquiridos. Sessenta e cinco por cento dissecam regurgitações de rapinas noturnas ou fornecem-nas às escolas. Destes, apenas 45% tratam as regurgitações para diminuir o risco de salmonelas ou outras doenças que podem ser transmitidas aos seres humanos por meio da dissecção de regurgitações. Oitenta e oito por cento utilizam histórias da vida real, 71% utilizam jogos ou atividades e 29% utilizam experiências com aves selvagens. Apenas 35% realizaram inquéritos para avaliar o impacto do programa. Os entrevistados referiram vários apelos à ação incluídos nos seus programas, que refletem atitudes culturais positivas ou negativas predominantes na sua área. O tempo e o financiamento foram referidos como os maiores obstáculos para os educadores. Os contributos mais importantes para ajudar os educadores que foram mais citados foram o trabalho em rede, o financiamento e os resumos de investigação científica atualizados.

Palavras-chave: conservação, crenças culturais, leis, métodos de educação, rapinas noturnas

Introduction

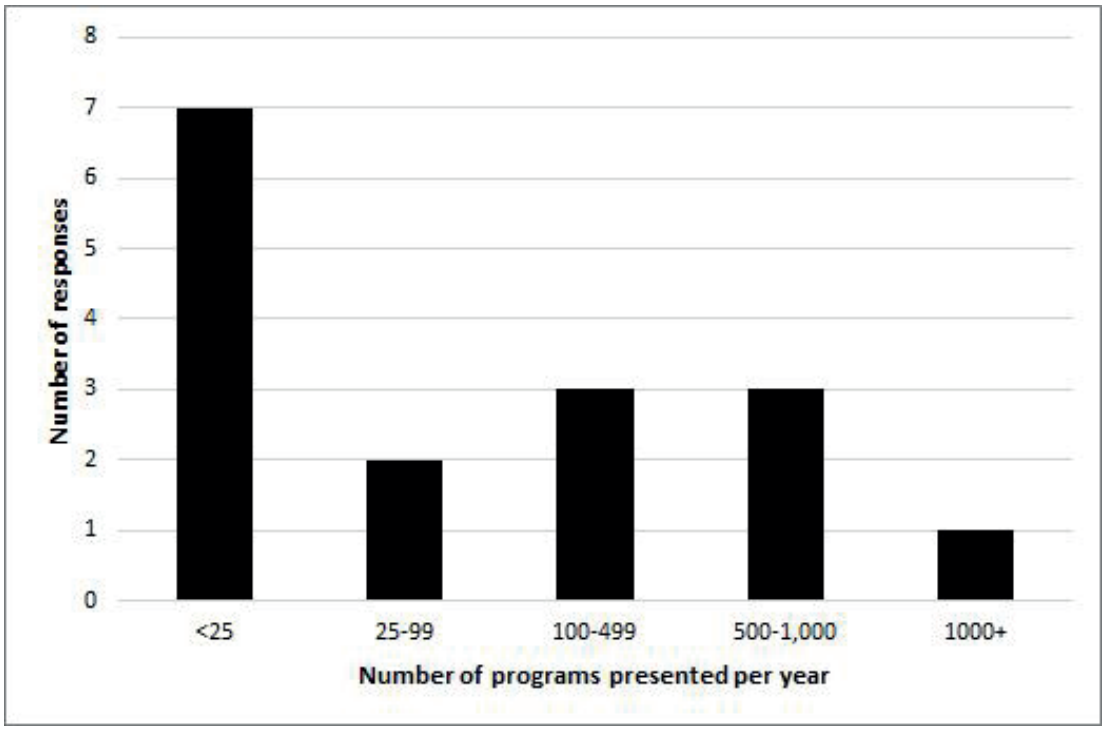
Effective owl educators must connect with their audience. This will necessarily involve different techniques in different countries with different cultures and laws. I have been doing owl education in the United States for 19 years and have met numerous other owl educators from other countries. I noticed different countries had their own biases and laws about how education should be done. My goal was to conduct a survey of owl-focused educators from around the world to compile different education methods to share with other educators in hopes of broadening perspectives and comparing and contrasting techniques so educators can think more openly about which methods may work best in their context.

Methods

I created a survey consisting of 28 main questions (see www.internationalowlcenter.org/workshop-summary) covering the educator's level of experience, facilities, insurance, reach, audience, cultural attitudes, laws, methods, teaching aids, program content, take home message, assessment, and obstacles. I identified educators with a significant focus on owls on all continents in a variety of different countries based on people I knew, recommendations from people I knew and internet searches. Surveys were emailed to 24 people in 14 countries on all 6 continents inhabited by owls.

Figure 1 - The number of programs presented each year by respondents and their associated facilities (n=16).

Figura 1 - Número de programas por ano apresentados pelos inquiridos e instituições a que estão associados (n=16).



Results

I received survey responses from 17 individuals (including myself) from 11 countries on 5 continents, for a 71% response rate. Not every respondent answered every question, and some did not understand the intent of certain questions due to different usages of specific English words.

Respondents had been doing owl education for an average of 22 years (range 7-50 years). Five self-identified as experts, 4 as advanced, 5 as intermediate level educators and 3 did not identify with a specific level of expertise.

Sixty-five percent have facilities where they conduct programs, 88% travel to do programs, and only 53% reported having insurance for their programs. All but one of the 17 respondents reported the number of programs they or their facility conducted and the number of people reached per year. Forty-four percent conduct 25 or fewer programs per year, but 25% conduct 500 or more programs per year (Fig. 1). While two respondents reach over 100,000 people per year (both facilities in large metropolitan areas in the United States), 31% reach 1,000-4,000 people per year and 38% reach 10,000-30,000 per year (Fig. 2).

Twelve respondents provided an age breakdown for their program participants. Most facilities conduct programming for all ages to some extent. Three respondents reported that at least 50% of their audience was adults, while 4 facilities noted at least 50% of their reach was ages 12 and under (Fig. 3).

Live owls are used in owl education in many countries, but this is prohibited by law

Figure 2 - The number of people reached each year by respondents and their associated facilities (n=16).

Figura 2 - Número de pessoas alcançadas por ano pelos inquiridos e pelas instituições a que estão associados (n=16).

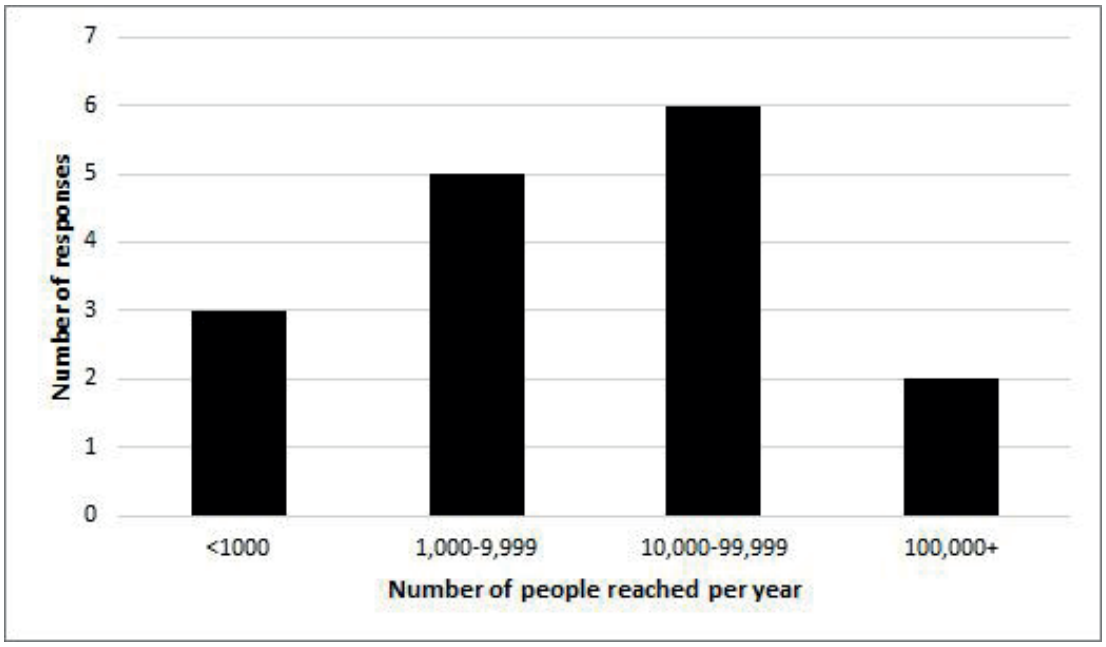


Figure 3 - Age groups reached by each respondent (n=12), by percent. Each column represents one respondent.

Figura 3 - Grupos etários abrangidos pelos inquiridos (n=12; em percentagem). Cada coluna representa um inquirido.

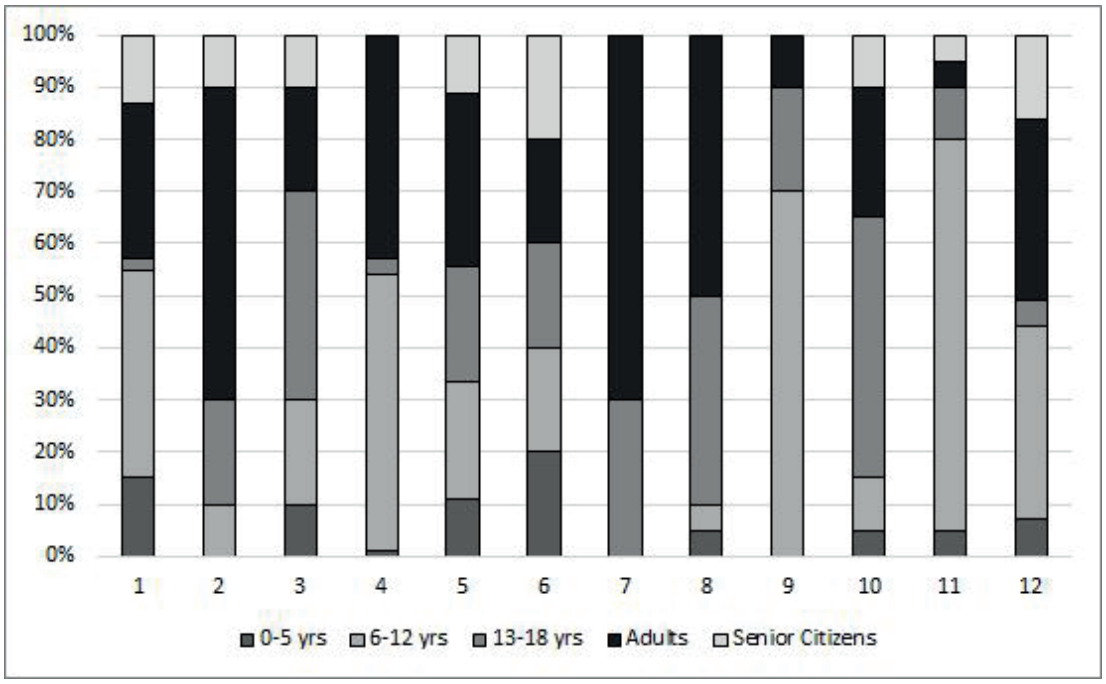
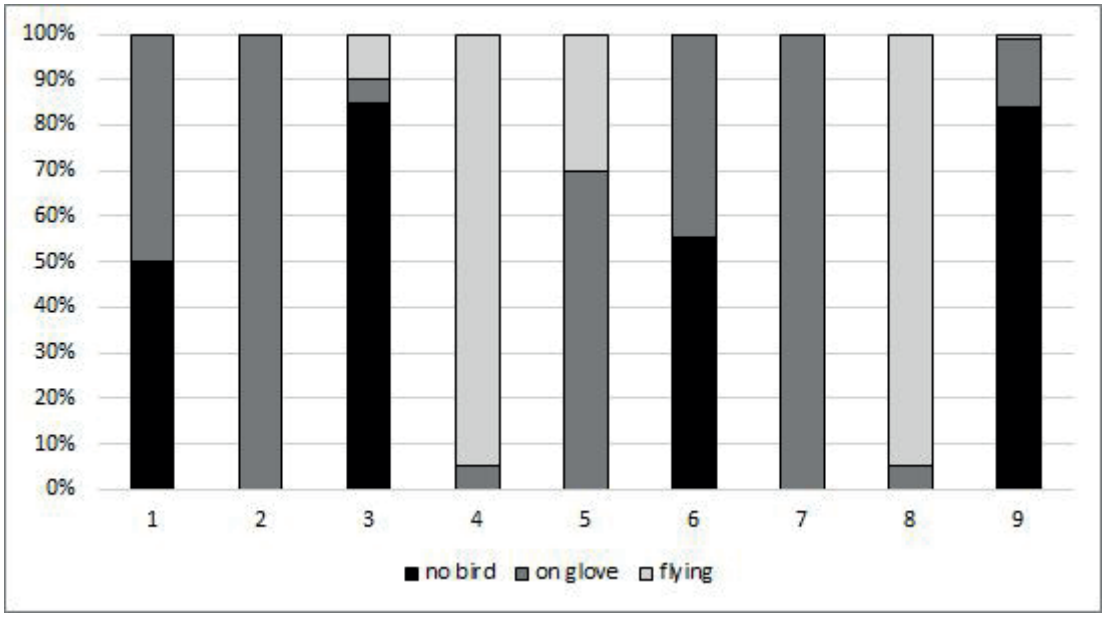


Figure 4 - How live owls are presented by respondents during their programs (n=9). Each column represents one respondent and the percentage of time during the program the bird is not visible, on the glove, or in flight.

Figura 4 - Formas de apresentação das aves de rapina noturnas pelos inquiridos nos seus programas (n=9). Cada coluna representa um inquirido e a percentagem de tempo durante o programa em que a ave está não visível, na luva ou em voo.



in India and Nepal. Permits are required to use live owls in educational programming in most respondent countries that allow it (Argentina, Manitoba and Saskatchewan in Canada, Germany, Portugal, South Africa, and the United States), with Belize not requiring permits and England not requiring permits for most species.

Of the respondents living in countries where it is legal to use live owls in educational programs (n=14), 86% use live owls. Two respondents who do not use live owls but could each conduct 5 or fewer educational programs per year. Of the 12 who use live owls, 50% use birds hatched in captivity and 75% use birds of wild origin that are non-releasable (three facilities, all in North America, use both). The three European respondents all exclusively use captive bred birds. Three-quarters of respondents using live owls give them names for the purpose of creating a connection between the audience and the birds.

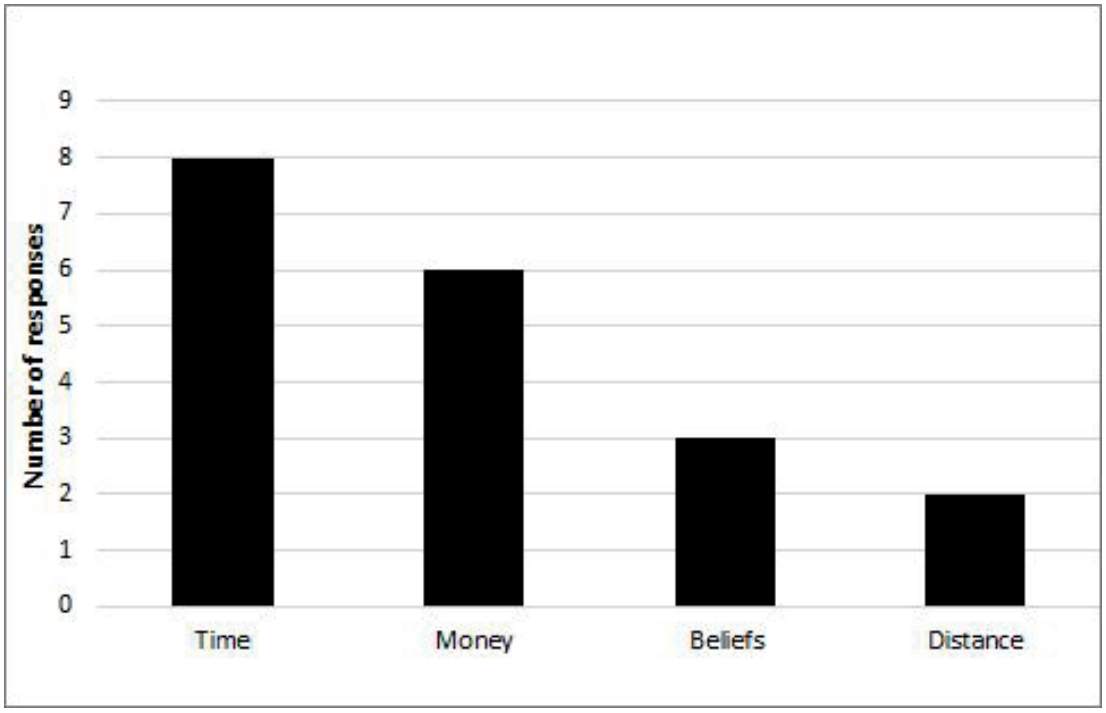
Respondents using live owls (n=9) employed them in different ways during programs. At one extreme, 2 use the live owls for 15% or less of the program, serving as the "grand finale," including a short flight. Five facilities have birds out for the entire duration of the program (Fig. 4.)

Three of 11 respondents allow people to touch or hold live owls to create a more powerful experience, three allow this only under special circumstances, and 5 do not allow it at all. It is not legal in the United States, where 4 facilities are located. Of the respondents that do allow people to come into contact with the owls, none has ever had an injury to a human or an owl as a result. Of the 11 countries represented by respondents, it is legal to have pet owls in only 3 (Japan, Portugal, and the United Kingdom).

Dead specimens or feathers are used by 13 of 17 (76%) of the respondents. Laws vary where respondents use specimens, with no permits required in South Africa, permits required for some species in the United Kingdom, and 6 countries requiring permits (Man-

Figure 5 - Obstacles to conducting owl education programs. Respondents could select more than one option, and 13 individuals provided responses. The vertical axis indicates the total number of respondents who listed each response.

Figura 5 - Obstáculos à realização de programas de educação sobre aves de rapina noturnas. Os inquiridos podiam selecionar mais do que uma opção, e 13 indivíduos responderam. O eixo vertical representa o número total de inquiridos que deram cada resposta.



itoba and Saskatchewan in Canada, United States, Belize, Argentina, Nepal and Japan).

When it comes to dissecting owl pellets, 11 of 17 respondents either dissect pellets with the public or give pellets to schools to dissect. Fifty-five percent use pellets from their own birds and 55% use pellets collected in the wild (one facility uses both). Pellets were heat treated by 45% of respondents employing pellets. No health issues related to pellet dissection were reported.

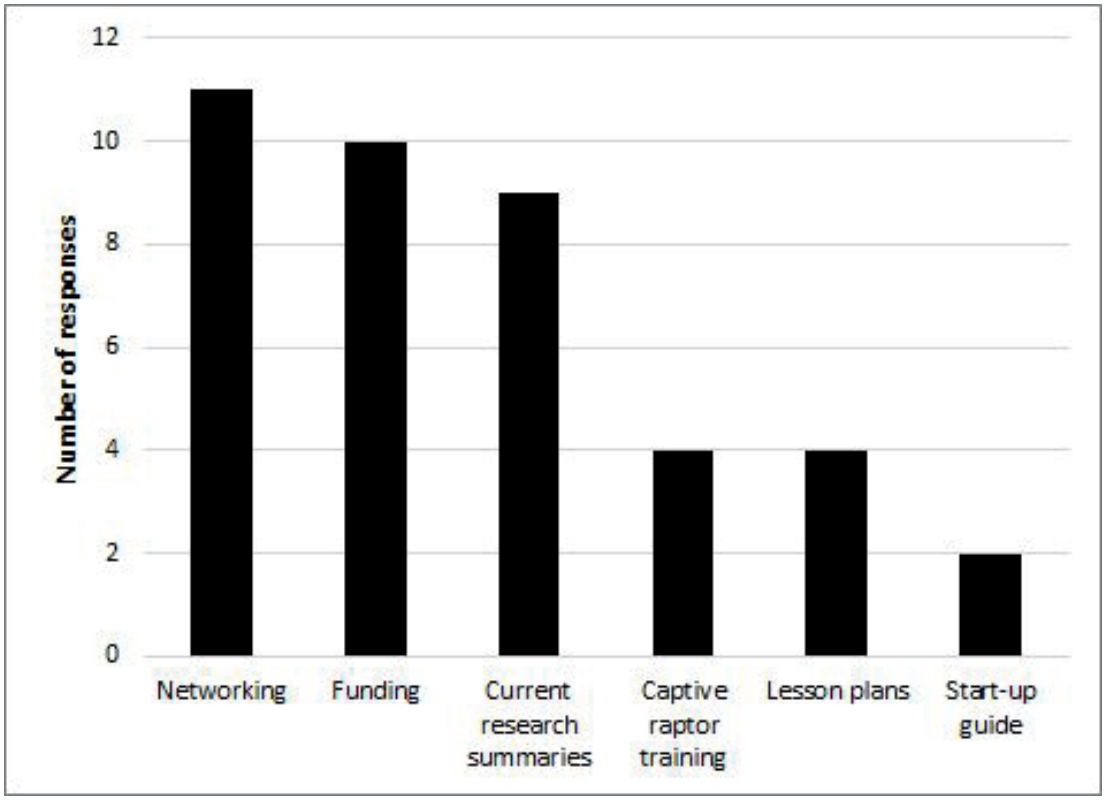
In their educational programs, 88% of all respondents reported using real-life stories, 71% used games or activities, and 29% use experiences with wild owls. Only 35% have conducted some kind of impact survey to assess the effectiveness of their educational programs (n=17).

Respondents listed a variety of key messages and calls to action they convey during their programs: leave dead trees standing, plant native trees, protect habitat, use traps instead of poison to control rodents, take down soccer nets when not in use, take down unused barbed wire, use less paper, keep cats indoors, mow less lawn, put up owl nest boxes, report nesting owls, if young owls are found on the ground observe them to make sure they need help before intervening, owls don't make good pets, get involved in owl research and conservation, donate to owl research and conservation, and be aware of the source of the products you purchase—you "vote" with your money, don't harm owls, and report people who are harming or selling owls.

When listing obstacles to educating the public about owls, 13 people provided

Figure 6 - Respondents (n=14) indicated what would help them be more effective owl educators. Each respondent could report more than one option.

Figura 6 - Inquiridos (n=14) que indicaram o que os ajudaria nos seus programas de educação sobre aves de rapina noturnas. Cada inquirido podia selecionar mais do que uma opção.



responses. Sixty-two percent cited lack of time and 46% cited lack of money. Travel/distance was listed by 15% and beliefs (negative cultural views, bias against conservation, and resistance to owls in urban areas) were cited by 23% (Fig. 5).

Respondents were asked what would help them be more effective educators and a list of potential responses was offered. Three individuals did not provide responses, and most others indicated more than one item. The most cited response (79%) was networking. Next was funding (71%), then current research summaries (64%). Training in captive raptor care was indicated by 29% and lesson plans were also indicated by 29%. Fourteen percent noted that a "how to get started guide" would be helpful (Fig. 6).

Discussion

Laws in each country (and in Canada, each province) have a significant impact on the educational techniques that can be used, such as using live owls and dead specimens in education. In the United States, laws prohibit the public from coming into contact with live birds for the safety of birds and humans, yet none of the respondents in other countries who do allow contact reported any injuries to either. Religious and cultural beliefs may be the reason why using live owls in education is not legal in India or Nepal. Using live owls in education is unregulated in The Netherlands, but the owl working groups there have signed a position statement against the use of live owls in education (pers. obs.)

Many respondents choose to use live owl experiences because they feel they make a significant impression on people. In countries where they can be used, the live owls are often the incentive for people to attend educational programs. In countries with negative cultural attitudes about owls, positive experiences with live owls are a powerful method to help children overcome or avoid developing negative cultural views. Conversely, in countries where owls are allowed to be kept as pets, a person who attends a live owl education program may be so enamored with owls that they then purchase one as a pet, so educators try to discourage keeping owls as pets.

Continental bias is apparent in live owl education. All three Europeans surveyed used captive bred owls exclusively, generally considering it inhumane to use non-releasable birds due to the stress of adjusting to captivity. All other continent use non-releasable wild owls, although some captive bred owls are also used in North America. Educational programs in the United Kingdom include flying owls for nearly the entire program and to a shorter extent in Germany, while owls are held on the glove for all or some of programs elsewhere with little to no flying. This may relate to human-reared owls being easier to train.

None of the respondents reported illness associated with pellet dissection, although pellets have the potential to transmit salmonella (Smith 2005). Proper precautions should be taken when using them for dissection. Carolina Biological Supply Company commercially sells pellets which are heated to 121°C for 4 hours (https://www.carolina.com/teacher-resources/Interactive/owl-pellets-in-the-classroom-safety-guidelines/tr11086.tr). Unpublished student research formerly on the University of Arizona's College of Agriculture and Life Science's website indicated that microwaving pellets did not kill disease-transmitting bacteria in owl pellets but heating to 163°C for 40 minutes in an oven did.

Key messages conveyed in countries where people have a positive attitude about owls focused on what audience members can do to help owls. Messages in countries where negative cultural views prevail focused on not harming owls and reporting people who do. Few people surveyed conducted follow-up surveys to assess the effectiveness of their educational programs. This is an important way to determine if education methods are effective at communicating key messages.

Although funding can be a challenge, it seems feasible to create networking opportunities for educators online and to provide current research summaries to support and improve owl educators.

Acknowledgments

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Sensitivities to land use change by breeding Short-eared Owl (*Asio flammeus*) in Britain

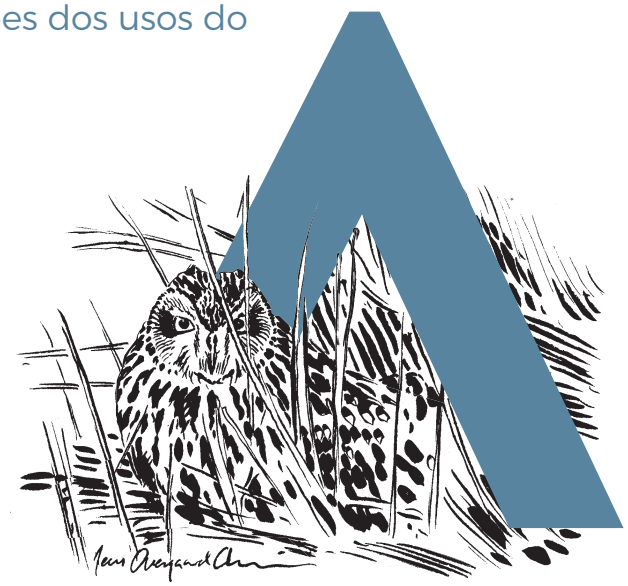
Sensibilidade da coruja-do-nabal (*Asio flammeus*) às alterações dos usos do solo na Grã-Bretanha

Jennifer A. Border[1], John Calladine[2*]

1 British Trust for Ornithology, The Nunnery, Thetford, Norfolk, IP24 2PU, England

2 British Trust for Ornithology, Beta Centre (Unit 15), Stirling University Inovation Park, FK9 4NF, Scotland

*** Corresponding author:** john.calladine@bto.org



ABSTRACT

Although widespread, populations of Short-eared Owls (*Asio flammeus*) are declining in most parts of their range. We present aspects of land use relevant to these owls in Britain. Potential environmental determinants of distribution and change were identified by review of the species' known ecology including published literature and ongoing telemetry studies of habitat use. Generalised Additive Models were then used to assess associations of environmental variables with the recent distribution and change over the preceding two decades. Variables identified for inclusion in the models were: semi-natural habitats, temperature, rainfall, elevation, slope, woodland cover, young growth stage forests, vole occurrence and measures of predator occurrence. Threats to their current status included forest expansion and changes in moorland management. Mechanisms for the negative association with forest expansion will be the replacement of preferred semi-natural open moorland and grassland habitats. Mechanisms associated with moorland management are likely associated with changes in predation risk. The latter also has potential implications for the introduction of predators onto islands. Opportunities for restoring breeding populations include restoring areas where predator densities are naturally low, increasing areas where densities of ground predators are maintained at low levels and adapting forest management plans to include open habitat specialists. Although limitations for breeding Short-eared Owls undoubtedly included the distribution of their favoured prey, voles, detection of their significance in models was limited by data on vole distribution and abundance.

Keywords: *Asio flammeus*, Britain, Conservation framework, Moorland, Predictive models

RESUMO

Apesar da sua distribuição generalizada, as populações de corujas-do-nabal (*Asio flammeus*) estão em declínio na maioria da sua área de ocorrência. Apresentamos aspetos do uso do solo relevantes para a espécie na Grã-Bretanha. Os potenciais determinantes ambientais da distribuição e alterações foram identificados através da revisão da ecologia conhecida da espécie, incluindo literatura publicada e estudos de telemetria em curso sobre uso do habitat. Foram utilizados modelos aditivos generalizados para avaliar associações de variáveis ambientais com a recente distribuição e alterações decorridas nas duas décadas anteriores. As variáveis identificadas para inclusão nos modelos foram: habitats semi-naturais, temperatura, precipitação, elevação, declive, cobertura florestal, florestas jovens em estágio de crescimento, ocorrência de micromamíferos e medidas de ocorrência de predadores. As ameaças ao seu estatuto atual incluíam a expansão da floresta e alterações na gestão das áreas de matos. Os mecanismos para a associação negativa com a expansão da floresta poderão passar pela substituição de habitats preferenciais de matos semi-naturais abertos e prados. Os mecanismos associados à gestão das áreas de matos provavelmente estão ligados a alterações no risco de predação. Este último tem ainda potenciais implicações na introdução de predadores nas ilhas. As oportunidades para restaurar populações reprodutoras incluem restaurar áreas onde as densidades de predadores são naturalmente baixas, aumentar áreas onde as densidades de predadores terrestres são mantidas em níveis baixos e adaptar planos de gestão florestal para incluir especialistas em habitat aberto. Embora as limitações da população reprodutora de coruja-do-nabal incluam, sem dúvida, a distribuição das suas presas preferenciais, micromamíferos da subfamília Arvicolinae, a deteção da sua significância nos modelos foi limitada pela escassez de dados sobre distribuição e abundância das presas.

Palavras-chave: *Asio flammeus*, estratégia de conservação, Grã-Bretanha, matos, modelos preditivos

Introduction

The relationships between a species' distribution and population trends with environmental variables can provide key information to conservation planners. 'Habitat Suitability Models' (e.g. Brambilla et al. 2009, Maleki et al. 2016) can be used to identify areas of suitable habitat for a species and therefore be a useful tool when designating protected areas or reserves (Akcakaya 2000, Tinoco et al. 2009, Yost et al. 2008, Kassara et al. 2014) or to highlight areas where new planning developments would have an adverse effect (e.g. Bright et al. 2008). Such approaches can also provide information on how a species is likely to respond to changes in different aspects of the environment which can then inform conservation and policy and decision makers (e.g. Border et al. 2017).

Although widespread, populations of Short-eared Owls are declining in many parts of their range (Burfield 2008, Booms et al. 2014). For example, their breeding range in Britain contracted from occupancy of 381 ten-km squares with high levels of evidence of breeding in 1990 to 245 by 2010 (Balmer et al. 2013). Bird Atlases are particularly renowned for the depth and extent of their coverage (Eaton et al. 2013). To date, three atlases of breeding birds in Britain and Ireland

have been completed at 20–year intervals with fieldwork for the first centered around 1970 (Sharrock 1976, Gibbons et al. 1993, Balmer et al. 2013). Through identifying associations between the distribution and abundance of breeding Short-eared Owls in Britain with other environmental data sets, we explore the efficacy of developing a tool that predicts their sensitivity to future potential land use and other changes. The aim was to identify:

Limitations – the topographical or other environmental attributes that limit Short-eared Owl distribution and abundance in Britain but which are unlikely to be changed through land management and the areas where these limitations will have the greatest impact;

Threats – features with which the species' current abundance and distribution appear to have an association, and therefore are likely to be a threat to the species if those conditions change within the current distribution, and where changes in these features will have the greatest impact;

Opportunities – spatial examples of where land-use changes could lead to range expansions or increased abundances of target species.

We suggest that this approach should form the basis of a conservation framework for this declining species and for the habitats on which it relies.

Methods

Bird data

Bird data used as dependent variables in predictive models (see below) were sourced from comparable bird atlas fieldwork undertaken in 1988-91 (Gibbons et al. 1993, hereafter *BA1990*) and 2008-11 (Balmer et al. 2013, hereafter *BA2010*). For both atlases, volunteers surveyed a sample of tetrads (2 km 2 km), making two 1-hour visits to each tetrad. In *BA1990* observers simply listed the species encountered, whereas in *BA2010* they counted the number of individuals encountered which has implications for the calculation of abundance change (see below). Any counts or presence information outside the known breeding range (judged from recorded breeding evidence and distribution maps from the respective atlas) were turned to zeroes/absences in order to remove the presence of known (or almost certainly known) migrants from analyses. As counts were not available for *BA1990* we used a 'frequency method' for deriving an index of change in abundance. This is the proportion of surveyed tetrads within each hectad (10 x 10 km) where the species was recorded. It was used in *BA1990* to map spatial variation in relative abundance and relies on the assumption that the frequency index is a valid measure of bird abundance. Simulations and pilot fieldwork confirmed that a positive relationship does exist and is only likely to be unrealistic for the most abundant and widespread of species (Balmer et al. 2013). Accordingly, abundance change for Short-eared Owls in each hectad was calculated by subtracting the *BA1990* frequency index from the *BA2010* frequency index. Hectads where the species was not present in either atlas period were excluded from the change index as it would not be possible to separate stable hectads from ones where the species was never present.

Environmental data

Potential factors to be included in predictive models (see below) included general information on topography and climate and also specific variables identified by a review of literature of the known ecology of Short-eared Owls. These included:

Climate (temperature and precipitation) – Data was sourced from the UK meteorological office at the 5 km resolution (Perry & Hollis 2005). To encompass

conditions when the birds were breeding we used the mean of mean monthly temperatures and the mean of total monthly rainfall from the months April, May, June and July. For winter conditions, the mean of mean winter temperatures and the mean of total rainfall from the months of December, January and February before the breeding season of interest (i.e. December 2007 for 2008 survey) were calculated. The mean of these variables for each 5 km square was then calculated over the relevant years for each period to match the Bird Atlas surveys, 1988–1991 and 2008–2011.

Topography (elevation and slope) - Elevation (in meters above sea level) was extracted from the GGIAR-SRTM 90m raster (Jarvis et al., available at http://srtm.csi.cgiar.org) taking the mean elevation over each hectad (depending on the scale of the analysis). Slope was calculated from elevation in ARCGIS (ESRI 2011). The slope of each elevation raster cell is the maximum rate of change in elevation in one raster cell compared to its eight neighbours. The lower slope values indicate flatter areas, higher values indicate steeper areas. The median slope was taken for each hectad to better represent mostly flat areas.

Habitat - In Britain, the majority of Short-eared Owls breed in upland environments, where they use heather moorland, rough grassland and new plantations (Goddard 1935, Roberts & Bowman 1986, Shaw 1995, Calladine & Morrison 2013), whereas in the lowlands (where they are now very localized) they are mainly found on coastal habitats; salt marshes, dune systems and rough grassland (Taylor et al. 1981, Grainger 2003). Land cover categories from the UK Land Cover Map (Morton et al. 2011) were summarised to create three broad categories of percentage cover within each hectad: (i) semi-natural habitats inclusive of unimproved grasslands, heaths, mires and montane habitats; (ii) coniferous woodlands and (iii) coastal habitats. Additional information on young age-class plantation forests and percent cover of coniferous forest was sourced from the Forestry Commission's National Forest Inventory for 2011 (https://www.forestry.gov.uk/inventory).

Prey abundance - The presence and abundance of small mammals, especially voles, the species' main prey source in Britain and across much of its range, is one key determinant of their distribution (Village 1987, Korpimäki & Norrdahl 1991). Although widespread across mainland Britain, voles are absent from some islands and archipelagos. In the absence of more reliable data on vole distribution and abundance (and because this can vary temporally), simple presence or absence of voles was included in models based on their known distribution across islands.

Predation risk – Short-eared Owls are ground nesting birds and as such can be particularly vulnerable to ground predators. Three sources of data were used as proxies for predation risk: (a) the distribution of the mammalian predators – Red Fox (*Vulpes vulpes*), Badger (*Meles meles*) and Stoat (*Mustela ermina*) from Arnold (1993); (b) indices of abundance of avian predators from Bird Atlases (Balmer et al. 2013); and (c) indices of Willow Grouse (*Lagopus lagopus scotia*) abundance from Bird Atlas data. For mammalian predators, simple presence or absence within each hectad was used as a factor in the models. An index of avian predator abundance was derived from Bird Atlases which combined abundances of Carrion Crow (*Corvus corone*), Hooded Crow (*C. cornix*), Common Raven (*C. corax*) and Eurasian Buzzard (*Buteo buteo*) to provide an index of abundance for generalist avian predators. To accommodate some extremely high values due to large flocks of corvids, counts greater than 50 were set to 50; 99% of count were 50 or below.

Willow Grouse abundance was similarly derived from Bird Atlases and was used as a proxy of management specifically for that species; a combination of management for heather (*Calluna vulgaris*) and active control of predators (Tharme et al. 2001, Fletcher *et al*. 2010). To reduce stochasticity and potential bias specifically associated with the Willow Grouse count data, average counts for all tetrads within a hectad were used as the abundance index; preliminary analysis with the Willow Grouse count data showed that this variable worked best.

Predictive models

Generalised Additive Models (GAMs) were used to assess associations of environmental variables with the change in relative abundance of Short-eared Owls as the dependent variables. The model used a Gaussian distribution (the index was approximately normally distributed) and included a 2D spatial smooth of normalized easting and northing (using thin plate regression splines) to account for spatial autocorrelation and variation in sampling intensity. As the aim was to measure the effect of change, ideally we tried to use environmental variables that reflected change between *BA1990* and *BA2010*. For example change in mean winter temperature or change in Willow Grouse count. However where this was not possible, only the data coinciding with *BA2010* were used in the model. Selection of variables to include in the full models considered variance inflation factors (VIFs; Zuur et al. 2009). Variables with VIFs > 3 and correlations to other variables > 0.7 were removed. Where two or more variables were strongly correlated, variables with a stronger relationship to the dependent variable from single models of the variable against change in relative abundance were preferred over variables with weaker relationships. Uncorrelated variables were then included in one full model. A linear relationship was assumed for all environmental variables apart from elevation, because there is evidence of preference for intermediate elevations for many species (Lomolino 2001). Interactions were not considered because the large number of variables in each model meant that further increases to model complexity caused problems with model convergence and overfitting. The environmental variables were centered and standardized using the Arm package (Gelman 2008, Gelman 2014) to allow direct comparison between them. Models residuals were examined visually to ensure a reasonable fit. A correlation test of predicted relative abundance change from the model against the raw relative abundance change was used to assess the predictive ability of the model.

To assess the impact that future changes in key drivers might have on Short-eared Owls, we used the models to make predictions under different scenarios of change. We identified variables which had a significant effect and reduced this list to variables that would be possible to alter through management. For example forest cover and the level of Willow Grouse management could be altered, whereas slope, elevation and climate would not be possible to alter. Then, individual plots were created for each target variable of the predicted relative abundance change for each increment of the target variable from the minimum value recorded in the dataset to the maximum. Whichever value of the target variable corresponded to the 75th percentile of the predicted relative abundance change was chosen as the new threshold. We used this threshold to alter the environmental dataset. For example if woodland was negatively correlated to abundance and the threshold value was 20% cover of woodland, hectads with woodland cover above 20% cover were reduced to this value. Similarly, Willow Grouse count would only be increased within the range of Willow Grouse (as determined from both *BA1990* and *BA2010*). These scenarios

Table 1- Standardized parameter estimates of a GAM model of change in relative abundance of Short-eared Owl between the 2008-2011 Atlas and the 1988-1991 Atlas, using a Gaussian distribution, deviance explained = 21.6%, n = 328. Change is shown relative to abundance levels in 2008-2011.

Tabela 1 - Estimativas padronizadas dos parâmetros do modelo GAM da variação da abundância relativa de coruja-do-nabal entre o Atlas de 2008-2011 e o Atlas de 1988-1991, usando a distribuição Gaussiana, desvio explicado = 21,6%, n = 328. A alteração é calculada relativamente aos níveis de abundância de 2008-2011.

VARIABLE	MEAN ± SE	P
% Conifer	-0.031 ± 0.010	0.003*
% Young trees	0.001 ± 0.010	0.942
% Coastal	0.003 ± 0.010	0.748
Avian predator change	-0.002 ± 0.009	0.858
Mammal predators	-0.020 ± 0.033	0.543
Voles	0.097 ± 0.135	0.471
Willow Grouse change	0.040 ± 0.008	<0.001*
Mean elevation	-0.039 ± 0.034	0.252
Mean elevation squared	0.025 ± 0.029	0.393
Median slope	0.007 ± 0.012	0.543
Change in mean winter rain	-0.007 ± 0.011	0.497
Change in mean summer temperature	0.002 ± 0.010	0.874
Change in mean summer rain	0.004 ± 0.010	0.698

better replicate what would be possible to change with management action. The difference in Short-eared Owl relative abundance change prediction after altering the environmental data was calculated by subtracting the original predictions from the new predictions. The difference was then plotted as a map to illustrate the areas that would be most affected and the magnitude of this effect.

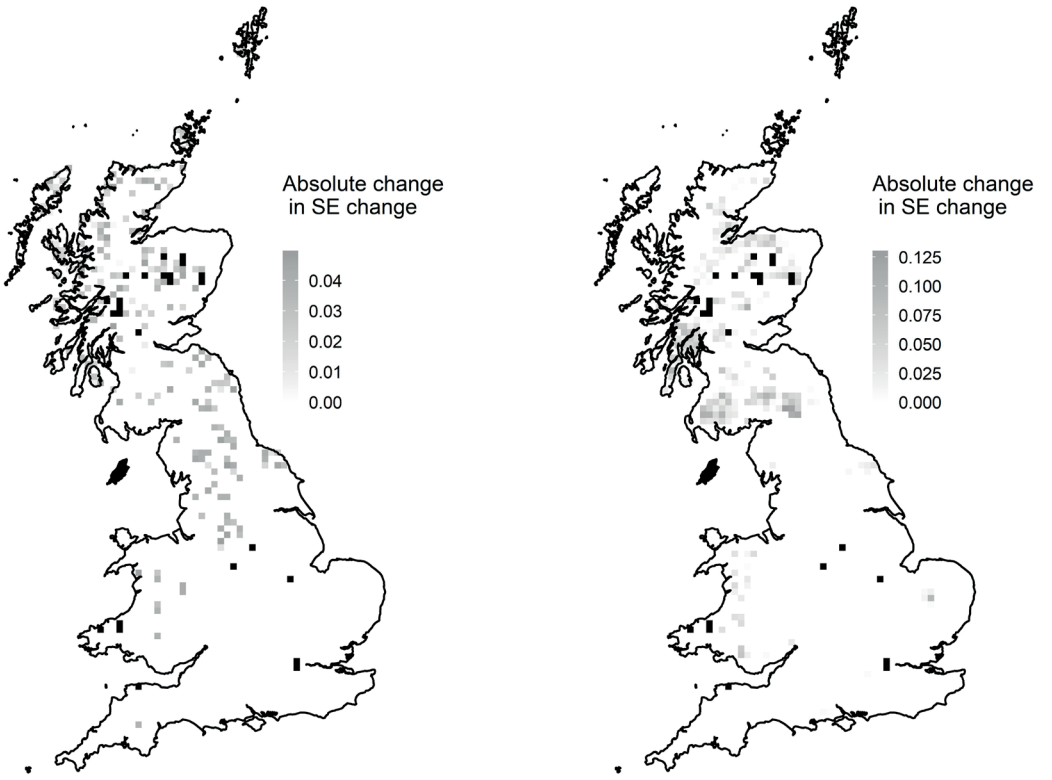
Results

Patterns of predicted change matched well with empirical observations of Short-eared Owl abundance (Pearson's Product Moment Correlation Coefficient (PPMCC) of observed versus predicted values: r = 0.46, $P < 0.001$). Abundance change was negatively associated with cover by coniferous forest (the majority of which are commercially managed plantations; Calladine et al. 2018) and was positively associated with increases in Willow Grouse numbers (Table 1).

Two alternative scenarios were modelled whereby changes in the two significant factors were manipulated to mimic more favourable conditions for breeding Short-eared Owls: (a) increasing the minimum relative density of Willow Grouse to the 75th percentile of that recorded empirically in all hectads within the distribution of breeding Willow Grouse; and (b) decreasing the maximum extent of coniferous forest to 15% (the 25th percentile recorded empirically) in all hectads. Where

Figure 1 - Alternative scenarios to have a positive effect on Short-eared Owl population trends. The maps show the absolute change in the predicted Short-eared Owl trend between *BA1990* and *BA2010* under each scenario for each hectad of Britain, a) promote Willow Grouse, b) decrease coniferous woodland. Note that the black squares show areas with insufficient data (bird and/or environmental) for modelling.

Figura 1 - Cenários alternativos com efeito positivo nas tendências populacionais de coruja-do-nabal. Os mapas representam a variação absoluta na tendência prevista de coruja-do-nabal entre o *BA1990* e o *BA2010* em cada cenário para cada quadrícula de 10x10km da Grã-Bretanha; a) promoção do lagópode-escocês, b) declínio da floresta de coníferas. Note-se que as quadrículas a preto representam áreas com informação insuficiente (sobre aves e/ou o ambiente) para a modelação.



Willow Grouse densities were greater than the 75th percentile or where coniferous forest was less than the 25th percentile, then the original values were retained in the respective predictive model. Management that permitted more extensive high densities of Willow Grouse was predicted to have increased densities of Short-eared Owls through most of their breeding range (Figure 1a) with the exception of the few remaining lowland sites (outside the range of Willow Grouse, where no effect of the modelled changes would be expected) and also some areas which retained high owl densities (e.g. the south-eastern fringe of the Scottish Highlands) (Figure 1a). Interestingly some expansion of range in the south-west of Britain was predicted.

The modelled effect of decreasing the extent conifer forests (predominantly plantations) predicted marked increases in the most forested areas of Britian, the north-east and south-west of Scotland and across the England-Scotland borders. Interestingly, a range expansion was predicted for the now forested areas of the brecklands in south-east England (Figure 1b).

Discussion

Identified threats to and opportunities for breeding Short-eared Owls in Britain were associated with forest cover and with grouse moor management. Both are major land uses in the remaining range of Short-eared Owls in upland Britain and therefore important to consider in Short-eared Owl conservation management actions.

Expansion of coniferous plantations was found to negatively affect Short-eared Owls, presenting a potential threat. New plantations are typically planted on semi-natural open moorland and grassland habitats (Calladine et al. 2018) thereby replacing the habitats preferred by breeding Short-eared Owls. Consequently, reducing forest cover, particularly conifer forest, represents a potential opportunity for population growth and expansion. Young growth stage plantations can offer some nesting opportunities for Short-eared Owls but generally this is restricted to newly planted sites, with plantations generally avoided after canopy closure (Shaw 1995) and second and subsequent rotation plantings are not nearly as attractive to breeding Short-eared Owls as first rotation new plantings (Calladine et al. 2018). Improved modelling of difference in suitability of later rotation plantings from first rotation young growth stages may be achieved where historical data on forest stand age classes and planting histories (through archived forest management plans) are available.

Increases in Willow Grouse were positively associated with Short-eared Owls. Therefore, expansion of the area managed as grouse moor is one potential opportunity to enable increases in range and abundance in Short-eared Owls. Conversely, reductions in the areas and/or intensity of management associated with grouse moors represented a threat to Short-eared Owls. This relationship is unlikely to be driven by Willow Grouse as prey for owls; although young can be taken, they are not known to be important in the diet in Britain (Glue 1977). Management for grouse frequently aims to increase proportional cover with heather and manage it through rotational burning to ensure the availability of young growth as food for grouse (Chapman et al. 2009, Oldfield et al. 2003). Although Short-eared Owls can nest among heather, ongoing studies using GPS-satellite telemetry show distinct preferences for hunting over grassland areas within the mosaic of moorland habitat (pers. obs., see also McGarry 1998, Calladine & Morrison 2013). Such areas will support the most voles but can be targeted by moorland managers for heather expansion to increase resources for grouse. Therefore the most intensively managed grouse moors where management aims to maximise heather cover and thereby decrease suitability for voles could actually be a limitation or threat for Short-eared Owls.

As ground-nesting birds, Short-eared Owls are vulnerable to ground-based predators and it is most likely that they benefit from the active control of such predators that is also part of grouse moor management (Fletcher et al. 2010). Therefore reduced levels of predator control through reduction or abandonment of grouse moor management could be a threat to the status of breeding Short-eared Owls in Britain. A negative association for breeding Short-eared Owls with the abundance of predators is also supported by their presence on islands that have both voles but also an absence of most mammalian ground predators. Further refinement of the modelling approach with more appropriate data on mammal distribution, were it available, would probably tease out these associations. However the introduction of predators on islands should also be recognised as a significant threat to Short-eared Owls (Fraser et al. 2015) as has also been demonstrated for assemblages of other ground-nesting birds (Calladine et al. 2017).

Our analyses failed to identify statistically significant fixed limitations for Short-eared Owls in Britain, but that is arguably a result of lack of statistical power and/or the quality

of environment data sets that were available. For example, the abundance and distribution of voles, their preferred prey is known to influence the spatial and temporal occurrence of Short-eared Owls (Village 1987, Korpimäki & Norrdahl 1991) and despite evidence that suggests an association across the British Isles, their influence was not recognised through the models. For example, among the archipelagos around the north and west of Scotland, some islands support voles while they are absent from others. In the Western Isles, Short-eared Owls breed on the Uists where voles occur but generally not on Barra or Lewis and Harris where voles are absent. Similarly in the northern isles, they breed in Orkney (with voles) but not Shetland (voles absent). Voles are also naturally absent from Ireland (not included in our analyses because of a different availability of environmental data sets), where the owls are also generally absent as breeding species in contrast to the main island of Britain (Balmer et al. 2013). The potential for modelling associations with the presence of voles could be further complicated by the fact that their abundance can vary markedly between years (Petty et al. 2000, Korpimäki et al. 2002) and empirical data on vole abundance and how it varies is not available over the extent of Britain. Exploration of the use of data describing vegetation types and structure (e.g. derived using Lidar) as proxies for vole abundance might prove useful in the further development of a conservation framework for the owls.

Further work to develop an effective conservation framework for Short-eared Owls, as identified by our models, will require: (i) improve monitoring to better understand the nature and distribution of change, though this would be challenging for this species (Calladine et al. 2010); (ii) more refined predictive models to include variables that could act as proxies for vole availability; (iii) a better understanding of the role of habitat interactions at their interface (e.g. forest and moorland); and (iv) better understanding of the role of intra-guild relationships among predators that may affect Short-eared Owls. As a species, Short-eared Owls lie towards the irruptive end of the continuum of migration strategies (Newton 2006, Calladine et al. 2012) and can be remarkably fecund when conditions are suitable. They are able to shift and establish breeding territories to follow temporally variable abundances of appropriate prey within areas of suitable habitat and appropriate conditions (Village 1987, Korpimäki & Norrdahl 1991) with distances between territories held by individuals in sequential years (and potentially even within the same season) of 1000 km being recorded (pers. obs. from ongoing telemetry studies). Improved knowledge of their migrations, year-round habitat requirements and of connectivity between owls breeding in different areas will also be important elements in any conservation strategy for the species.

Acknowledgments

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An evaluation of 25 years of volunteer nocturnal owl surveys in Manitoba, Canada

Avaliação de 25 anos de monitorização voluntária de rapinas noturnas em Manitoba, Canadá



James R. Duncan[1*]

1 Discover Owls, Box 253, Balmoral, Manitoba, Canada R0C 0H0

*** Corresponding author:** jduncan@discoverowls.ca

ABSTRACT

In April 1991, Patricia Duncan (my wife and fellow zoologist) and I initiated a spring volunteer nocturnal owl survey to provide citizens with a personal experience with owls. Our intention was to make wildlife conservation more relevant to them and to address a gap in existing land bird monitoring programs which do not have suitable owl survey methods. Specific survey objectives included to determine owl species distribution, relative abundance, population trends, and habitat associations. Surveyors were provided resources to identify owl calls. From 1991-1999, both passive listening and owl call playback were used to survey owls from point locations spaced 800 m along linear transects. The use of playback ceased in 2000 and owls were surveyed by passive listening only at intervals of 1.6 km. An estimated 6335 owls of 11 species were detected on a total of 32549 km of linear point count surveys over 25 years (1991 to 2015) by at least 900 surveyors. Northern Saw-whet Owls (*Aegolius acadicus*), Great Horned Owls (*Bubo virginianus*), and Boreal Owls (*Aegolius funereus*) were most numerous accounting for 75% of detections. The Burrowing Owl (*Athene cunicularia*) was the only Manitoba owl species not detected. Owl species detection rates varied annually and cumulatively ranged from 0.08 to 0.36 owls/km surveyed. Survey methods, owl species detection rates, and a summary of volunteer participation and retention over the survey period are described. A summary of the use of this project's citizen science data in published papers, graduate theses, species conservation status assessments, and a breeding bird atlas project are presented. Suggestions for new approaches to facilitating and retaining volunteer participation and maximizing data use for this and other citizen science projects are discussed.

Keywords: Citizen science, owl surveys, population monitoring, Manitoba, Canada

RESUMO

Em abril de 1991, Patrícia Duncan (minha esposa e colega zoologista) e eu iniciámos uma monitorização voluntária de rapinas noturnas durante a primavera, para proporcionar aos cidadãos uma experiência pessoal com estas aves. A nossa intenção foi tornar a conservação da biodiversidade mais relevante para o público e colmatar uma lacuna existente nos programas de monitorização de aves terrestres, os quais não dispunham de metodologias adequadas de monitorização de rapinas noturnas. Os objetivos específicos da monitorização incluíam determinar a distribuição, a abundância relativa, as tendências populacionais e as associações com o habitat das espécies de rapinas noturnas. Foram facultados aos participantes recursos para identificação de vocalizações de rapinas noturnas. Em 1991-1999 foram usadas escutas passivas e com emissão de vocalizações para monitorizar rapinas noturnas em pontos espaçados 800 m em percursos lineares. Deixámos de emitir vocalizações em 2000, tendo a monitorização passado a basear-se exclusivamente em escutas passivas e com intervalos de 1,6 km entre pontos. Foram estimados 6335 indivíduos de 11 espécies em 32 549 km de transectos lineares com pontos de escuta, ao longo de 25 anos (de 1991 a 2015) e envolvendo pelo menos 900 participantes. O mocho-amolador (*Aegolius acadicus*),o bufo-real-americano (*Bubo virginianus*), e o mocho-funéreo (*Aegolius funereus*) foram as espécies mais frequentes, perfazendo 75% das deteções. As taxas de deteção das várias espécies variaram anualmente entre 0,08 e 0,36 indivíduos/km. São descritas as metodologias, as taxas de deteção das várias espécies de rapinas noturnas, e um sumário da participação e retenção de voluntários durante a monitorização. É apresentado um sumário da utilização dos dados deste projeto de ciência cidadã em artigos científicos, em teses académicas, em avaliações do estado de conservação das espécies, e em projetos de atlas de aves nidificantes. São discutidas sugestões de novas abordagens para facilitar e reter a participação de voluntários, e maximizar a utilização dos dados deste e de outros projetos de ciência cidadã.

Palavras-chave: ciência cidadã, Canadá, Manitoba, monitorização de populações, monitorização de rapinas noturnas

Introduction

The distribution and status of several owl species have been determined by nocturnal owl surveys conducted by researchers and based on either spontaneous calling or by using playback recordings to elicit calls (Duncan & Duncan 1997, Smith 1987, Takats & Holroyd 1997, Takats et al. 2001). Such surveys have also been used to locate nests (Frith et al. 1997, Whiklo & Duncan 2014), determine habitat use (Duncan & Kearns 1997, Hinam & Duncan 2002), population densities and fluctuations in populations (Francis & Bradstreet 1997), and document migration (Duncan et al. 2009). Although generally secretive, owls are readily detectable by listening for their songs or calls during the breeding season; either spontaneously or in response to broadcast recordings (playback) of their calls. This latter technique is based on territorial behavior; song or call playback, or vocal imitations, within a territory will often elicit a vocal or visual response by an owl attempting to defend its territory against the "intruder." Owl surveys by individual or small teams of researchers have provided local and intensive results but are impractical to cover large geographic areas over multiple decades.

In April 1991, Patricia Duncan (my wife and fellow zoologist) and I initiated a long-term and widespread volunteer-based spring owl survey in Manitoba. In North America, public participation in scientific research has grown in popularity particularly since the Cornell Lab of Ornithology began marketing this practice as "citizen science" in 1995 (Bonney et al. 2009, 2016). Many kinds of citizen science projects exist today (reviewed in Shirk et al. 2012, Bonney et al. 2016). The Manitoba owl survey is a contributory-style project where researchers enroll and teach volunteers to collect the data, which is returned to them for analysis. Such projects are somewhat similar to the traditional collection of observations by naturalists before professional wildlife scientists existed (Bonney et al. 2016, Edwards 2014).

One of the leading causes of species' range contractions and population declines is habitat loss coinciding with an exponentially growing human population of increasingly urbanized citizens that are disconnected from nature. This latter phenomenon, in part, lead Richard Louv (2005) to coin the phrase Nature-Deficit Disorder. Amidst this cultural phenomenon, Livingston (1981) described a scenario in which scientists were conducting sound science on conservation-dependent wild species to identify what actions were needed to conserve them. He argued that the resulting information failed to result in conservation action due to a lack of support from governments since citizens disconnected from nature did not express sufficient concern or support for such action, such as the protection of critical natural habitats from development. Livingston's thesis suggested that citizens needed to be engaged or provided with opportunities to develop a personal connection or relationship with nature so that they would then support or demand conservation actions. It was with this goal in mind that we started the Manitoba nocturnal owl survey.

The Manitoba nocturnal owl survey was also initiated to complement established daytime breeding bird surveys conducted in summer but which fail to effectively detect owl species because owls initiate reproduction in early spring, are mostly nocturnal, and occur at low densities. Populations of owls and their prey fluctuate between years decreasing the ability to detect owl population changes over shorter survey periods. As a result, owl surveys need to be conducted over longer periods in order to obtain reliable or useful data (Saurola 1997).

In summary, the Manitoba nocturnal owl survey objectives were to:

1. Provide an organized opportunity for volunteers to:
   a. learn about owls through pre-survey training,
   b. have a personal experience with wild owls and nature through participation, and
   c. develop or enhance a conservation ethic through participation.

The remaining objectives were to increase our understanding of owl ecology through the collection of data by volunteers, specifically:

2. Determine relative owl species abundance and distribution;
3. Determine owl species habitat associations; and
4. Describe multi-annual fluctuations in the number of owls detected.

This paper summarizes the results of this 25-year owl survey, explores the influence of call playback on owl detections, and reviews survey outcomes relative to its objectives.

Methods

Participants were provided owl territorial or breeding vocalizations (i.e., http://www.naturenorth.com/summer/sound/Owl_Calls.html) to learn to identify the 12 owl species occurring in Manitoba by sound. Owl vocal recordings were obtained from Cornell University (http://www.birds.cornell.edu/AllAboutBirds/owlp) and other sources (e.g., Hardy et al. 1990). Volunteers were provided with owl survey instructions,

cover sheet and summary instructions, and data sheets to record information and observations during the survey (Appendices 1, 2, 3: https://www.researchgate.net/project/Manitoba-Nocturnal-Owl-Survey). Volunteers' abilities to identify owl species or to detect owls were not tested.

Routes along roads were established and assigned in a non-random manner by the survey coordinator, with occasional input from local volunteers. This was necessary because access to roads in late winter and early spring in Manitoba is variable and limited due to thick snow cover and/or spring flooding. Volunteers were encouraged to conduct the same route from year to year and were only required to complete one survey/route per year, however many volunteers surveyed more than one survey/route per year.

Surveys were conducted in the last two weeks of March and the first two weeks of April each year. Surveys started at least 30 min after sunset and finished by midnight. Temperature, cloud cover, wind speed and snow thickness were recorded at the beginning and end of a survey route. At each stop along a route surveyors recorded individual owls detected (heard or seen) and the owl's estimated distance and direction from the stop. Some individual owls could be heard from multiple stops. Therefore, surveyors recorded if an owl detected was also detected at a previous stop or stops. Ancillary information recorded at each stop included time, an odometer reading, noise interference and the number of passing cars.

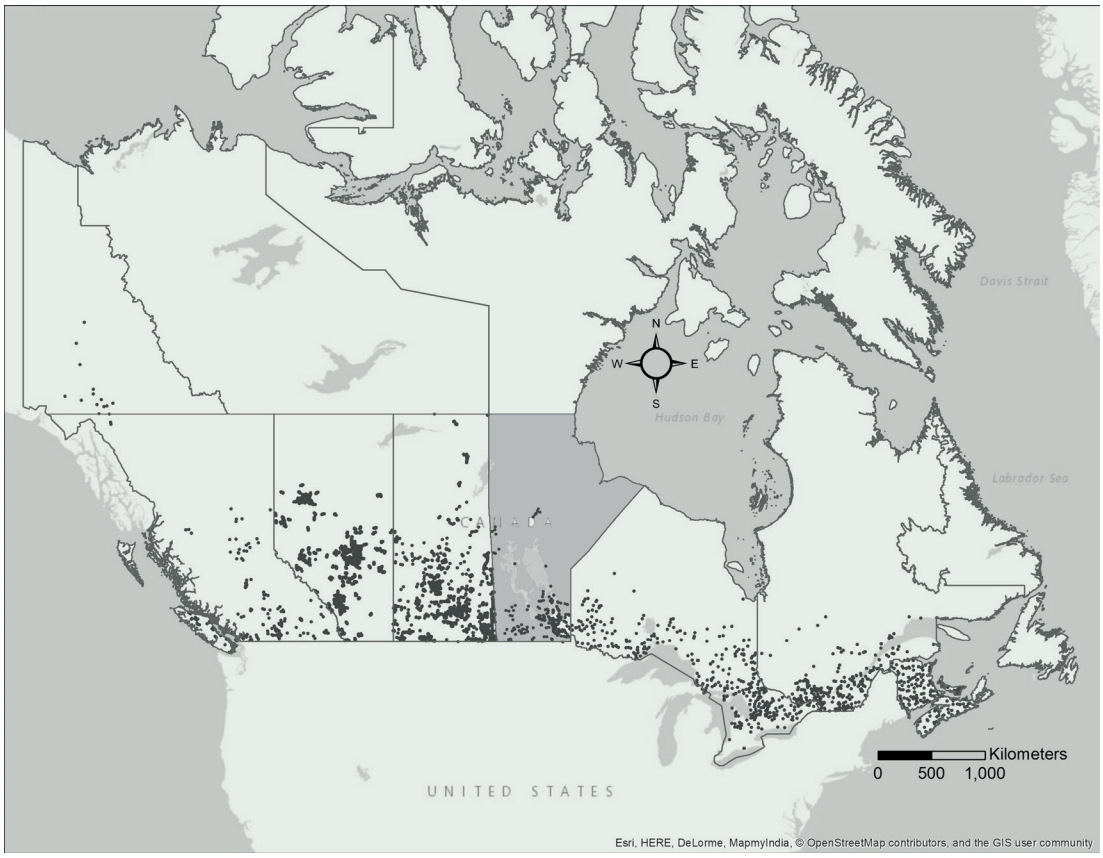
Completed survey sheets were sent to the project coordinator for review. The number of individual owls detected per route was estimated and, along with other information, was entered into a database. Annual owl species indices were calculated as the estimated number of individuals detected/km surveyed to standardize variable annual survey effort. Summary statistics and analyses were prepared using 2016 Microsoft Excel Data Analysis Tool Pack (Winston 2016). Over time, the geographic extent of the owl survey expanded within Manitoba and the survey protocol changed part way through the project as follows.

From 1991 – 1999, both passive listening and owl call playback were used to survey owls. While the primary objective was to survey for all Manitoba owl species, there was an initial emphasis on the Boreal Owl (*Aegolius funereus*) and the Great Grey Owl (*Strix nebulosa*) in boreal forest regions. Consequently, only playback of these species were initially used. Starting in 1995, the survey area expanded to include aspen parkland and grassland regions, and in these regions playback of Northern Saw-whet Owl (*Aegolius acadicus*) and Eastern Screech Owl (*Megascops asio*) territorial calls were used. From 1991 – 1999, survey stops were 0.8 km apart and each survey point took a minimum of 3 min and 40 s to complete: 1 min of listening, 20 s playback of Boreal Owl or Northern Saw-whet Owl, 1 min of listening, 20 s playback of Great Grey Owl or Eastern Screech Owl, 1 min of listening. No standard survey route length was prescribed.

In 1999, Manitoba hosted a workshop of biologists interested in starting volunteer-based owl surveys in other jurisdictions and to explore standardizing survey methods across Canada, and possibly in the United States. The workshop resulted in the adoption and publication of standard owl survey guidelines (Takats et al. 2001). Starting in 2000, the Manitoba owl survey adopted these guidelines and stopped the use of playback. Instead participants surveyed for owls by passive listening for 2 min per stop for 10 stops (spaced 1.6 km apart) per route. Manitoba's volunteer nocturnal owl survey eventually expanded to other Canadian provinces and territories and is now a recognized Canadian citizen science project under the auspices of Bird Studies Canada (Fig. 1).

Figure 1 - Location (dots) of volunteer owl surveys conducted in Canada up to 2017. Owl surveys started in Manitoba (central province shaded in grey) in 1991 and eventually spread across Canada. It became a national citizen science survey program under Bird Studies Canada in 2005.
(Map created by Murray, C. from data from Bird Studies Canada, Beaverhill Bird Observatory, and Nature Saskatchewan)

Figura 1 - Localizações (pontos) do programa voluntário de monitorização de rapinas noturnas no Canadá até 2017. As amostragens tiveram início em Manitoba (província central a cinzento) em 1991 e acabaram por se estender por todo o país. Veio a tornar-se um programa nacional de ciência cidadã da Bird Studies Canada em 2015.
(Mapa criado por Murray, C. a partir de dados de Bird Studies Canada, Observatório de Aves de Beaverhill, e Nature Saskatchewan).



Results

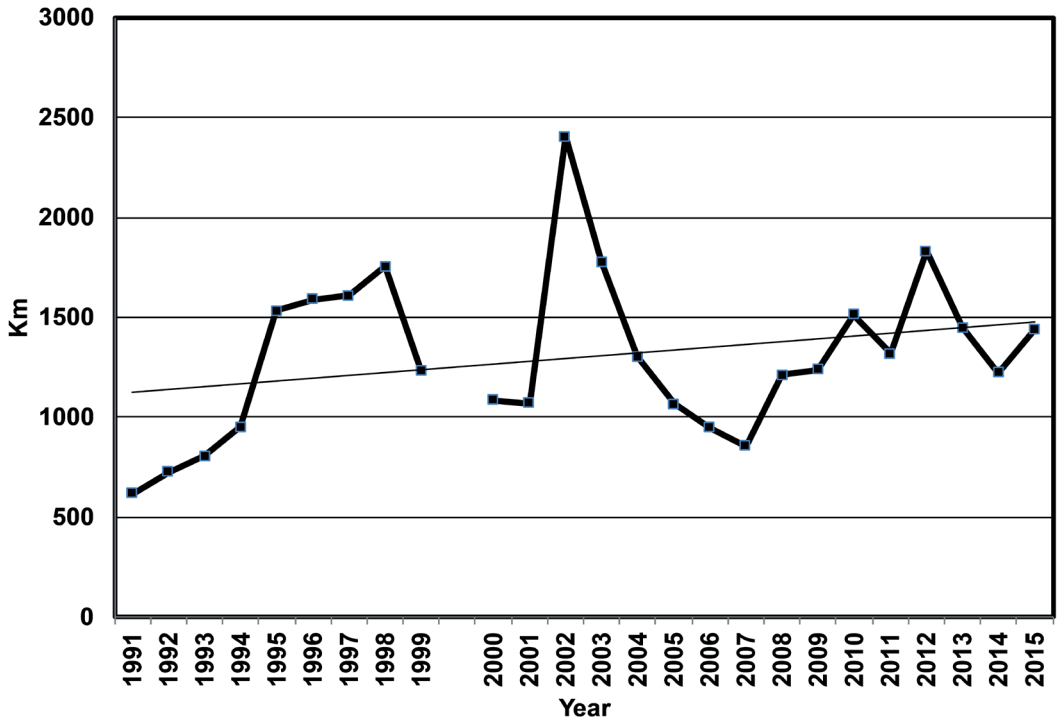
Survey effort

A cumulative total of 3953 owl surveys were conducted in Manitoba by volunteers over the 25-year period, with a mean of 158.1 surveys per year (range 49-308, SD ±57.2). This equaled a cumulative total of 32549 km surveyed for a mean effort of 1302 km per year (SD ±403). The distance surveyed increased annually from 1991 to 1998, and then varied thereafter (Fig. 2). Survey effort increased from a minimum of 618 km in the first year to a maximum of 2403 km in 2002, and generally increased over the course of the project (Fig. 2).

The change in survey methods did not appear to change the annual survey effort per se considering that the total annual distance surveyed grew in the first eight years (1991-1998). Thereafter (1999-2015) it fluctuated around a mean of 1373 km per year (Range 856-1547, SD ±377). Note that survey effort stated herein does not include the distance driven by volunteers to and from their survey routes.

Figure 2 - Number of km surveyed for owls by year in Manitoba, Canada. Straight line is a linear regression. Gap between 1999 and 2000 represents a change in survey methodology (see text).

Figura 2 - Número de km monitorizados por ano em Manitoba, Canadá. A linha representa uma regressão linear. A interrupção entre 1999 e 2000 representa a alteração na metodologia de amostragem (ver texto).



Surveyor recruitment occurred mainly by word of mouth and without an advertising campaign. An anomalous spike in survey effort in 2002 (Fig. 2) followed the wide distribution of a printed promotion inserted within Manitoba Hydro bill mail outs. More people were interested in participating in the owl survey in 2002 than routes available or within a distance they were willing to travel.

Relative owl species abundance

A total of 6335 owls of 11 species were detected during the 25-year survey period (Table 1). The provincially and nationally endangered Burrowing Owl was the only Manitoba owl species that went undetected. Northern Saw-whet Owls, Great Horned Owls (*Bubo virginianus*), and Boreal Owls were most numerous, accounting for 75% of detections (Table1). These three species, along with the Barred Owl (*Strix varia*), Great Grey Owl, and the Northern Long-eared Owl (*Asio otus*), were detected in every year of the survey.

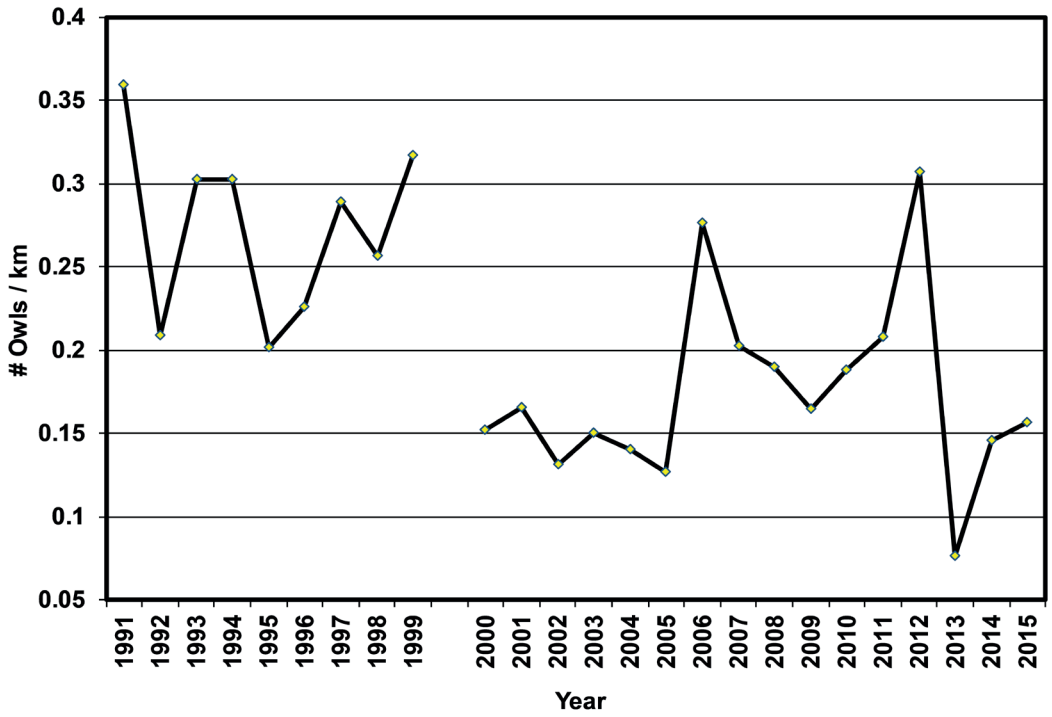
Five of 12 Manitoba owls were detected less frequently than the aforementioned species by an order of magnitude, and were also not detected on at least 6 or more years of the survey period (Table 1). These included the Eastern Screech Owl, Northern Hawk-owl (*Surnia ulula*), Short-eared Owl (*Asio flammeus*), American Barn Owl (*Tyto furcata*), and Snowy Owl (*Bubo scandiacus*).

Multi-annual fluctuations in the number of owls detected

Pooled annual owl detection rates (all owls by year for 25 years) averaged 0.21 owls/km surveyed and cumulatively ranged from 0.08 to 0.36 owls/km surveyed (Table 1, Fig. 3).

Figure 3 - Total owl detections per km surveyed by year in Manitoba, Canada. Gap between 1999 and 2000 represents a change in survey methodology (see text).

Figura 3 - Número total de registos de rapinas noturnas por km e por ano em Manitoba, Canadá. A interrupção entre 1999 e 2000 representa a alteração na metodologia de amostragem (ver texto).



Likewise, the annual detection rates of individual owl species varied over time (Table 1, Fig. 4 & Fig. 5). There was a significant decrease in the pooled owl species detection rate from the first survey period (using playback, etc.) that used a different survey method than the second survey period (no playback, etc., Table 2, Fig. 3). Five of the six more frequently and regularly detected owl species also showed a significant decrease in detection rates after the survey methods changed (Table 2). The detection rates of the five species less frequently and irregularly detected showed either no change or increases after the survey methods changed (Table 2).

The number of owl species pairs that covaried significantly was examined for the six species that were detected more frequently and regularly during the surveys. The covariance was examined in three sets of survey years: the first 9 and last 16 years that used different survey methods, and then the total 25 year-period. The number of owl species pairs that covaried significantly increased from 13% of 15 pairs for the first 9 year-period, to 20% and 60% of 15 pairs for the last 16-year and pooled 25-year periods, respectively (Table 3).

Documenting the distribution of owls and determining owl species habitat associations

The use of data from this survey to document the distribution of owls and to determine owl species habitat associations have been published elsewhere and is reviewed in the discussion.

Providing volunteers with a personal experience with wild owls and nature

At least 900 individual volunteers participated over the 25-year period. A mean of

Table 1- Summary statistics for owl detections and detection abundance indices (#owls detected/km surveyed) of volunteer nocturnal owl surveys in Manitoba, Canada (n = 25 years, 1991-2015).

Tabela 1 - Resumo das estatísticas da deteção de rapinas noturnas e dos índices de abundância (n.º de indivíduos/km) em monitorizações voluntárias de rapinas noturnas em Manitoba, Canadá (n = 25 anos, 1991-2015).

* *T. f. = Tyto furcata, M. a. = Megascops asio, B. v. = Bubo virginianus, B. s. = Bubo scandiacus, S. u. = Surnia ulula, A. c. = Athene cunicularia, S. v. = Strix varia, S. n. = Strix nebulosa, A. o. = Asio otus, A. fl. = Asio flammeus, A. f. = Aegolius funereus, A. a. = Aegolius acadicus.*

	CUMULATIVE 25 YEAR TOTALS AND INDICES		SUMMARY OF ANNUAL INDICES				
Owl Spp.*	Total # Detected	Index: Total #Detected/ Total km Surveyed	Mean Index	Min Index	Max Index	SD Index	#Years no Owls Detected
All Owls	6335	0.195	0.210	0.076	0.359	±0.073	-
A. a.	1927	0.059	0.065	0.014	0.130	±0.031	0
B. v.	1737	0.053	0.055	0.021	0.111	±0.022	0
A. f.	1100	0.034	0.036	0.005	0.085	±0.022	0
S. n.	446	0.014	0.016	0.005	0.071	±0.014	0
A. o.	410	0.013	0.014	0.005	0.030	±0.007	0
S. v.	394	0.012	0.014	0.003	0.040	±0.008	0
S. u.	108	0.003	0.003	0	0.025	±0.005	8
M. a.	91	0.003	0.002	0	0.009	±0.003	9
A. fl.	82	0.003	0.002	0	0.009	0.003	6
T. f.	16	0.000	0.000	0	0.005	±0.001	18
B. s.	9	0.000	0.000	0	0.002	±0.001	19

110.6 people participated each year (range 45-252, SD ±42.5). Over this period, individuals participated from 1 to 23 years (mean 3.1, SD ±3.7) and conducted an average of 4.4 routes each, however participation was skewed (Mode = 1, Median = 2, SD ±7.4) and a large number of volunteers (379 or 42.1%) participated in only one year of the survey (Fig. 6).

Developing or enhancing a conservation ethic in volunteers through participation

This paper does not include an analysis of results for this survey objective but the subject is reviewed in the discussion.

Discussion

The initial success in recruiting and retaining volunteers led to the expansion and growth of this citizen science project largely through word of mouth and without an active communication strategy. While survey effort increased over the 25-year period it appeared to have leveled out after eight years and thereafter fluctuated annually (Fig. 2). The annual fluctuation of effort highlights the need to derive owl detection indices that are standardized to account for variation in effort. Future data analyses can explore the influence of other variables such as wind speed, date, snow cover, noise interference and moon phase on owl detections. The

Figure 4 - Owl detections per km surveyed by year in Manitoba, Canada, for regularly detected owl species*. Gap between 1999 and 2000 represents a change in survey methodology (see text).

Figura 4 - Registos das espécies de rapinas noturnas detetadas com regularidade por km e por ano em Manitoba, Canada. A interrupção entre 1999 e 2000 representa a alteração na metodologia de amostragem (ver texto).

* A. a. = *Aegolius acadicus*, B. v. = *Bubo virginianus*, A. f. = *Aegolius funereus*, S. n. = *Strix nebulosa*, S. v. = *Strix varia*, A. o. = *Asio otus*.

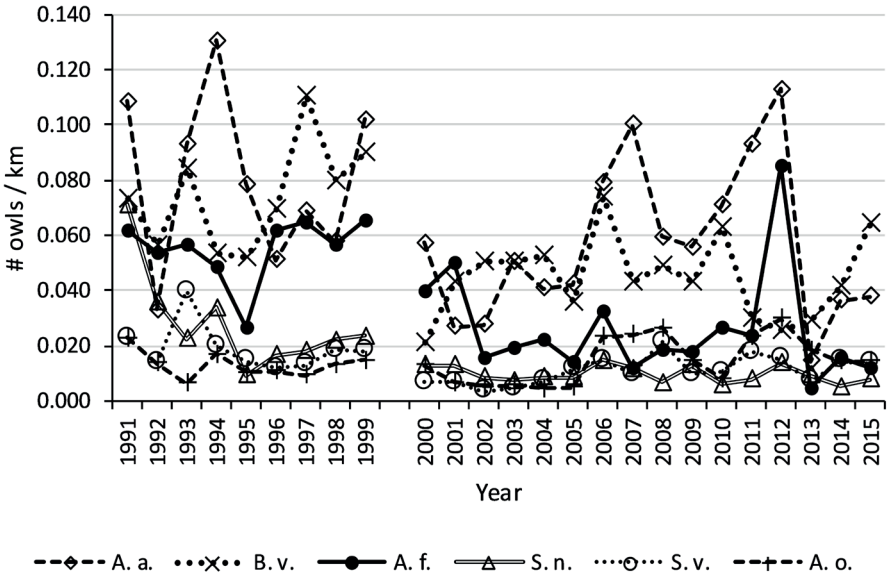


Figure 5 - Owl detections per km surveyed by year in Manitoba, Canada, for irregularly detected owl species*. Gap between 1999 and 2000 represents a change in survey methodology (see text).
Note: A 2006 data point of 0.025 owls / km for the Northern Hawk-owl (Surnia ulula) was removed solely to create this figure.

Figura 5 - Registos das espécies de rapinas noturnas detetadas pontualmente por km e por ano em Manitoba, Canada. A interrupção entre 1999 e 2000 representa a alteração na metodologia de amostragem (ver texto).
Nota: para criar esta figura foi removido um ponto de 2006 com o registo de 0,025 indivíduos/km, referente a Surnia ulula.

* S. u. = *Surnia ulula*, M. a. = *Megascops asio*, A. fl. = *Asio flammeus*, T. f. = *Tyto furcata*, B. s. = *Bubo scandiacus*.

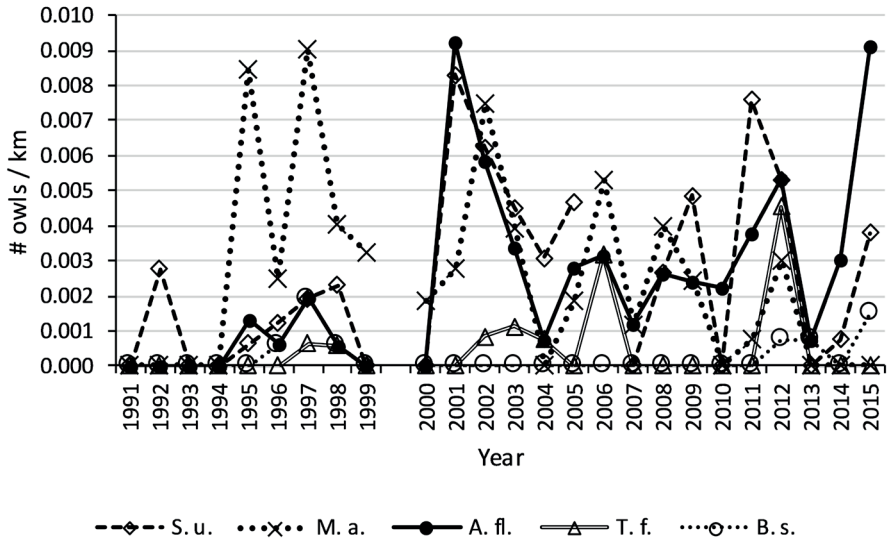


Table 2- Two-sample t-Tests assuming unequal variances for mean owl species detection rates (# owls/km surveyed) for two owl survey periods using different methods (playback used 1991-1999, no playback 2000-2015, see methods) for the volunteer nocturnal owl survey in Manitoba, Canada.

Tabela 2 - Teste de t com duas amostras (assumindo heterogeneidade de variâncias) aplicado à média das taxas de deteção de rapinas noturnas (n.º de indivíduos/km) em dois períodos de amostragem do programa voluntário de monitorização em Manitoba, Canadá. Foram utilizados métodos diferentes (emissão de vocalizações em 1991-1999, escutas passivas em 2000-2015, ver métodos).

** T. f. = Tyto furcata, M. a. = Megascops asio, B. v. = Bubo virginianus, B. s. = Bubo scandiacus, S. u. = Surnia ulula, A. c. = Athene cunicularia, S. v. = Strix varia, S. n. = Strix nebulosa, A. o. = Asio otus, A. fl. = Asio flammeus, A. f. = Aegolius funereus, A. a. = Aegolius acadicus.*

	MEAN OWL DETECTION RATE BY SURVEY PERIOD						
Owl Spp.*	1991-1999	2000-2015	+/-	P(T<=t) one-tail	P(T<=t) two-tail	Significance	Change in Detection Rate
All Owls	0.274	0.174	-0.100	0.000	0.000	S	Decrease
A. a.	0.080	0.057	-0.024	0.039	0.077	NS	
B. v.	0.074	0.045	-0.030	0.001	0.001	S	Decrease
A. f.	0.055	0.026	-0.030	0.000	0.000	S	Decrease
S. n.	0.028	0.010	-0.018	0.008	0.017	S	Decrease
S. v.	0.019	0.011	-0.008	0.011	0.021	S	Decrease
A. o.	0.013	0.015	0.002	0.269	0.538	NS	
M. a.	0.003	0.002	-0.001	0.261	0.522	NS	
S. u.	0.001	0.005	0.004	0.013	0.026	S	Increase
A. fl.	0.000	0.003	0.003	0.000	0.001	S	Increase
B. s.	0.000	0.000	0.000	0.262	0.524	NS	
T. f.	0.000	0.001	0.001	0.076	0.151	NS	

change in survey methods starting in 2000 did not appear to affect the overall survey effort over the long term (Fig. 2). Interest in the Manitoba owl survey grew across Canada to the point where national survey standards were developed and adopted, and the survey became national in scope (Fig. 1).

The ability of the owl survey to meet its objectives is herein assessed using survey outcomes.

Relative owl species abundance

The owl survey was successful at detecting the relative abundance for 11 of the 12 owl species native to Manitoba. However, some owl species were likely under detected, and in one case not detected, due to the survey methods not matching the life history traits of these owl species.

The six most commonly detected species included three species that were targeted using call playback during the initial 9-year survey period (see methods, Table 1). Of these six species, all but the Northern Long-eared Owl and the Northern Saw-whet Owl experienced a significant decrease in their detection rates in the second survey period (2000-2015) during which playback was not used, survey stops were farther apart, and

Figure 6 - Frequency histogram of cumulative number of surveys conducted over 25 years by individual volunteer owl surveyors in Manitoba, Canada (1991-2015). Data labels are the number of volunteers.

Figura 6 - Histograma de frequências do número acumulado de monitorizações de rapinas noturnas realizadas ao longo de 25 anos por voluntários em Manitoba, Canadá (1991-2015). Os valores no topo das barras representam o número de voluntários.

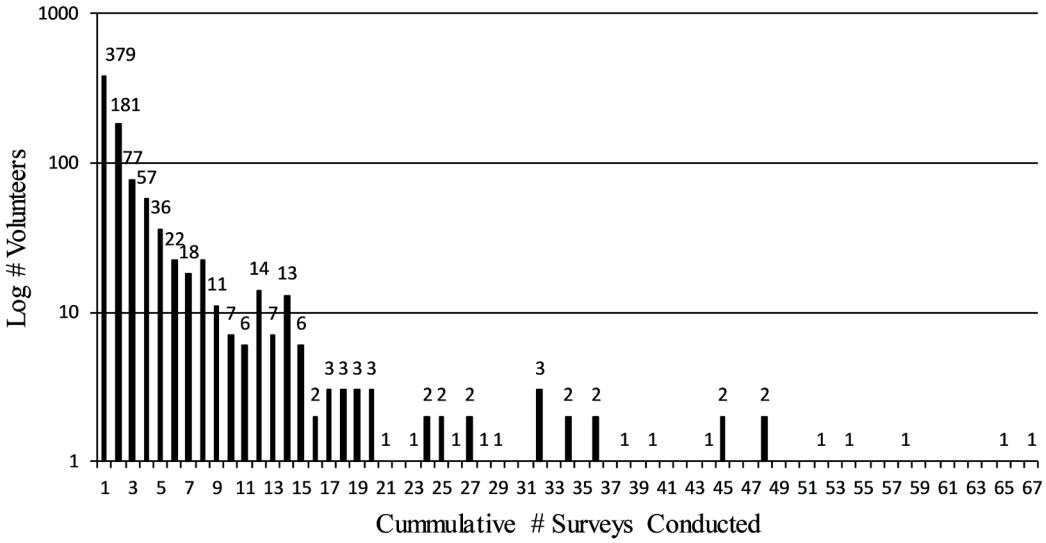


Figure 7 - Relative abundance based on pooled detection rates (#owls/km surveyed) for regularly detected owl species* within each of two survey periods with different survey methodologies** in Manitoba, Canada (1991-2015).

Figura 7 - Abundância relativa baseada nas taxas de deteção (n.º de indivíduos/km) agrupadas para as espécies de rapinas noturnas detetadas frequentemente* em cada um dos dois períodos de amostragem com diferentes metodologias** em Manitoba, Canadá (1991-2015).

* B. v. = *Bubo virginianus*, S. v. = *Strix varia*, S. n. = *Strix nebulosa*, A. o. = *Asio otus*, A. f. = *Aegolius funereus*, A. a. = *Aegolius acadicus*.
** Survey Period 1 = 1991-1999, Survey Period 2 = 2000-2015.
** Período de amostragem 1 = 1991-1999, período de amostragem 2 = 2000-2015.

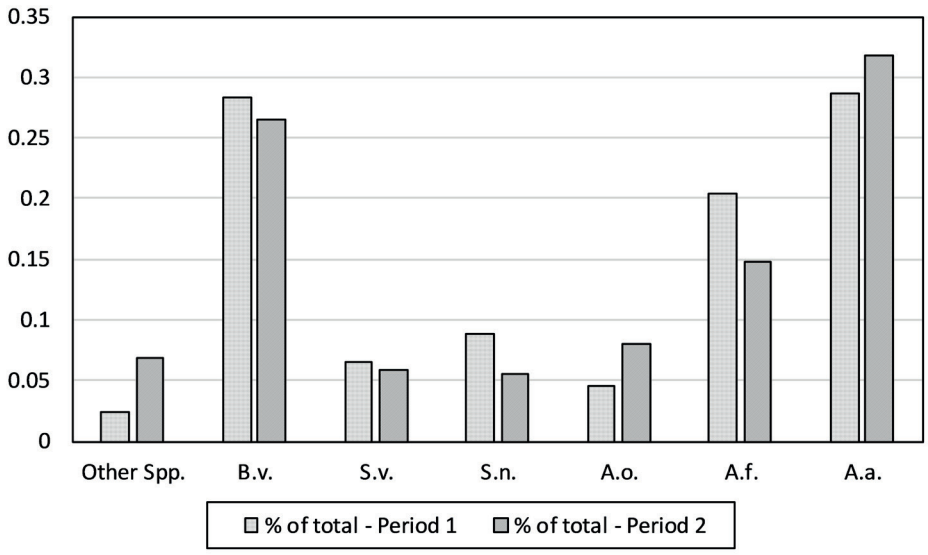


Table 3- Covariance of owl species* detection rates (# owls/km surveyed) for regularly detected owls for two owl survey periods using different methods (playback used 1991-1999, no playback 2000-2015, see methods) and over 25 years (1991-2015) for the volunteer nocturnal owl survey in Manitoba, Canada.

Tabela 3 - Covariância da média das taxas de deteção (n.º de indivíduos/km) das várias espécies* de rapinas noturnas detetadas regularmente em dois períodos de amostragem e ao longo de 25 anos do programa voluntário de monitorização em Manitoba, Canadá. Foram utilizados métodos diferentes (emissão de vocalizações em 1991-1999, escutas passivas em 2000-2015, ver métodos).

** B. v. = Bubo virginianus, S. v. = Strix varia, S. n. = Strix nebulosa, A. o. = Asio otus, A. f. = Aegolius funereus, A. a. = Aegolius acadicus.*

1991-1999 (n = 9 Years)

Owl Species	B. v.		S. v.		S. n.		A. o.		A. f.	
	r	P	r	P	r	P	r	P	r	P
S. v.	0.13	0.74								
S. n.	-0.13	0.74	0.20	0.61						
A. o.	-0.30	0.43	-0.17	0.67	0.84	0.00				
A. f.	0.70	0.04	0.10	0.80	0.30	0.43	0.13	0.74		
A. a.	-0.02	0.95	0.44	0.23	0.35	0.35	0.41	0.27	-0.04	0.92

2000-2015 (n = 16 Years)

Owl Species	B. v.		S. v.		S. n.		A. o.		A. f.	
	r	P	r	P	r	P	r	P	r	P
S. v.	0.07	0.81								
S. n.	-0.15	0.57	-0.13	0.62						
A. o.	-0.19	0.48	**0.72**	**0.00**	0.31	0.25				
A. f.	-0.27	0.32	0.13	0.63	**0.55**	**0.03**	0.29	0.28		
A. a.	-0.09	0.73	0.49	0.06	0.34	0.19	**0.67**	**0.00**	0.49	0.06

1991-2015 (n = 25 Years)

Owl Species	B. v.		S. v.		S. n.		A. o.		A. f.	
	r	P	r	P	r	P	r	P	r	P
S. v.	**0.43**	**0.03**								
S. n.	0.37	0.07	**0.43**	**0.03**						
A. o.	-0.23	0.27	0.25	0.23	0.22	0.30				
A. f.	**0.45**	**0.02**	**0.42**	**0.04**	**0.55**	**0.00**	0.13	0.54		
A. a.	0.21	0.32	**0.56**	**0.00**	**0.44**	**0.03**	**0.50**	**0.01**	**0.48**	0.02

Table 4 - Number of owl survey species records incorporated into the Manitoba Breeding Bird Atlas (2010-2014, http://www.birdatlas.mb.ca).

Tabela 4 - Número de registos das espécies de rapinas noturnas amostradas que integraram o Atlas das Aves Nidificantes de Manitoba (2010-2014, http://www.birdatlas.mb.ca).

OWL SPECIES	NUMBER OF RECORDS
Northern Saw-whet Owl (*Aegolius acadicus)*	120
Great Horned Owl (*Bubo virginianus)*	82
Boreal Owl (*Aegolius funereus)*	54
Northern Long-eared Owl (*Asio otus)*	46
Great Gray Owl (*Strix nebulosa)*	33
Barred Owl (*Strix varia)*	28
Northern Hawk-owl (*Surnia ulula)*	9
Short-eared Owl (*Asio flammeus)*	6

time spent at each stop reduced (see methods, Table 2).

If the chance of detecting four regularly detected common species decreased statistically in the second survey period, then we would expect changes in the proportion of these between the two periods. As expected, Fig. 7 illustrates the change in relative abundance of regularly detected common owl species for the two survey periods within each of the two survey periods that used different survey methods. Hence the influence of the survey methods and survey coverage on the detection rates of owls needs to be studied in more detail. Further factors, such as habitat use and diet, may also account for the relative abundance of these six species.

Five owl species were less frequently and irregularly detected, likely for a variety of reasons. The limited, largely urban distribution of the Eastern Screech Owl in Manitoba (Taylor 2003) and the irruptive dispersal and, predominantly, diurnal calling behavior of the Northern Hawk-owl (Duncan & Duncan 1998) account for their lower and irregular detection rates (Table 1). The low detection rate for the Short-eared Owl reflects its threatened status in Manitoba. It is relatively rare in the province in most years, and likely quickly migrates north each spring past Manitoba's southern prairie region's once lush grasslands to the intact Arctic 'prairies' or tundra to breed (Taylor 2003). The American Barn Owl is both rare and accidental in Manitoba and the majority of Snowy Owls depart southern Manitoba for their Arctic breeding range prior to the survey period (Taylor 2003). Lastly, the provincially and nationally endangered Burrowing Owl was never detected due to its arrival in Manitoba as a late spring migrant (Taylor 2003) after the survey period ended. It also has a small range limited to mixed grass prairies in extreme southwestern Manitoba where few owl surveys took place. These five species require species-specific targeted survey methods to adequately monitor their populations in Manitoba.

Multi-annual fluctuations in the detection rate of owls

This survey documented some dramatic fluctuations in the detection rate (owls/km)

over time (Fig. 3, Fig. 4 & Fig. 5). Data from this survey can be used with other independent lines of evidence (i.e., specimens, banding data) to corroborate these population changes over time, and other data (e.g., mammalian predators and prey monitoring) to explore reasons why such fluctuations exist. In this study, the number of owl species pairs (for frequently and regularly detected owls) that covaried significantly increased with survey period duration (Table 3). This might support the concept that longer-term monitoring of fluctuating or cyclic owl species is required to detect significant results (Saurola 1997) and to explore ecological concepts such as competition, niche overlap among a guild of similar predators, and the influence of climate on populations. However, getting more significant combinations with more years and combining two distinct methodological periods might simply be due to a larger sample size (resp. n = 9, 16, 25 years), (See https://select-statistics.co.uk/blog/importance-effect-sample-size/).

To explore the aforementioned ecological concepts we would need longitudinal data (same observer, same routes, comparable conditions) rather than random samples or a combination of this as we have available in our dataset. Figure 6 illustrates that some volunteers worked constantly yielding such longitudinal data. However, most observers cooperated only once yielding random samples.

Future analysis could split the dataset into longitudinal and randomized data. Bootstrapping techniques would help because they select random samples of the entire dataset and run statistics a few 1000 times to get stability.

Survey data may also yield insight into larger geographic migration or dispersal patterns. An analysis of covariance between Northern Saw-whet Owl survey data from this project with that from another owl survey project over 770 km southeast in Wisconsin, USA provided the first evidence of a spring migration in this species in central North America, and one that is influenced by prey availability (Duncan et al. 2009).

Documenting the distribution of owls

The ability of owl survey data to increase the documented range of owl species in Manitoba (relative to species expected range and/or previously documented range) was assessed for a 5-year period (1991-1995): An 88% increase occurred for the Northern Saw-whet Owl, followed by a 40% and 19% increase for the Boreal and Great Grey Owls, respectively, and smaller increases for the Northern Hawk-owl (10%), Barred Owl (8%) and Great Horned Owl (6%) (Duncan & Duncan 1997). It is interesting to note that the largest increases in distribution occurred for the three species initially targeted by this survey and for which call playback was used. More recently, from 2010-2014, the owl survey contributed almost 400 owl location records for the Manitoba Breeding Bird Atlas (http://www.birdatlas.mb.ca, Table 4). Data on species distributions and how they change over time are essential criteria used to assess the conservation status of species at various geographic scales.

Determine owl species habitat associations

Owl location data from this survey was used to assess the effects of habitat fragmentation and slope on the distribution of Great Horned Owls, Great Grey Owls and Barred Owls in western Manitoba (Hinam & Duncan 2002). Owl survey data was also, in part, used to locate Barred Owl home ranges and nests to assess habitat suitability and describe nest and nest site habitat characteristics (Duncan & Kearns 1997, Whiklo & Duncan 2014). Additional studies of owl habitat use are possible with the data collected by this survey.

Providing volunteers with a personal experience with wild owls and nature

Most volunteers had a repeated or prolonged experience with owls and nature through their participation in this survey (Fig. 6). The value of this survey as an entry level opportunity for the general public to gain such experience lies in its simplicity when compared to other types of bird or species monitoring programs. There are few owl species to identify and they have distinct primary territorial calls or songs that are easy to learn. Volunteers only have to do one survey a year and it occurs at night after most people are finished working a typical daytime shift. Lastly, many people find owls mysterious, attractive and/or interesting.

Developing or enhancing a conservation ethic in volunteers through participation

One intended outcome of this survey project was to awaken or strengthen a conservation ethic or values among volunteers through the experience of participating. While changes in values are known to result in behavioural changes, a review of social science studies concluded that values are quite resistant to change (Manfredo et al. 2017). This paper documents the feasibility of engaging citizens, and the value of the information collected to enhance our knowledge about owls. The effectiveness of participation in this project in developing or enhancing the conservation ethic of volunteers is explored elsewhere (Ng et al. 2018). Ng et al. (2018) also examined other participant variables such as age and gender, in a questionnaire-based study and collected feedback from citizen scientists to assess and describe what motivated volunteers to participate in the owl survey. They concluded that a main motivator of participants surveyed was a chance to have fun with family and friends while also contributing information about owls.

The Future of Owl Monitoring

The Manitoba program manager of Bird Studies Canada assumed coordination of the Manitoba Owl Survey in 2016 and has created opportunities for participants to enter their survey data online through Nature Counts (https://www.birdscanada.org/birdmon) which improves both the management of information and the volunteer's experience. Developing an online self-assessment program would help surveyors improve their ability to identify species or to detect owls, increasing the quality of data collected. Better methods of analysis of owl survey data, including the potential for open data sharing with researchers around the world, will result in learning opportunities for students and ultimately help conserve and manage owls and the habitats they depend on. A recent study of the volunteers and their motivations will help both this owl survey and the design of new participatory citizen science projects (Ng et al. 2018).

The 900 volunteer surveyors gained new personal experiences with wild owls and nature while contributing new data and information on owls. Both these results have fostered better support for the long-term protection and conservation of owls, other wildlife and their habitats. Further statistical analysis is recommended by splitting the data into longitudinal and randomized data sets.

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Breeding ecology of captive-released and wild Western Burrowing Owls (*Athene cunicularia hypugaea*) in southwestern Manitoba, Canada, 2010-2012

Ecologia reprodutiva de coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) em estado selvagem e libertada de cativeiro no sudoeste de Manitoba, Canadá, em 2010-2012

Alexandra L. M. Froese[1], James R. Duncan[2]

1 The Manitoba Burrowing Owl Recovery Program, 47 Nicholas Street, Narol, Manitoba R1C 0A6. mbburrowingowls@gmail.com

2 Discover Owls, P.O. Box 253, Balmoral, Manitoba R0C 0H0. jduncan@discoverowls.ca



ABSTRACT

Western Burrowing Owl (*Athene cunicularia hypugaea*) populations have shown steady and substantial declines across western Canada in the last 50 years. Many inter-related factors are thought responsible for its rapid decline. A breeding ecology study was initiated in Manitoba to identify threats to wild pairs and to assess a modified reintroduction technique using food supplementation to promote nesting success, recruitment, and survival of captive-released first-year owl pairs to augment the numbers of wild owls. Breeding, foraging and behavioural data of captive-released and wild owls were recorded and compared from 2010-2012. During this period, 14 pairs of captive-released owls and six pairs of wild owls were monitored. Average clutch size for six wild first clutches (8.8 eggs) was higher than for 10 captive-released first clutches (6.5 eggs). Likewise, average replacement clutch size for four wild pairs (6.8 eggs) was higher than that of two captive-released pairs (5.0 eggs). Overall, hatching success for wild owls was 69% and captive-released owls was 60%. All hatched young were raised to fledging age for captive-release and monitored wild nests. During this three-year study, nine of 20 young raised to fledging age by wild pairs were removed from nests to become part of the following seasons' captive breeding group. The captive-release effort resulted in the release of 20 adults and 15 young raised to fledging age over three years; 12 young from captive-release pairs were removed from nests to become part of

the following seasons' captive breeding group. This study demonstrated that this captive-release method was at least partially successful. It remains to be seen if young produced survive over the longer term and contribute to the recovery of this endangered species in Canada.

Keywords: *Athene cunicularia hypugaea*, Breeding Ecology, Endangered Species Recovery Program, Reintroduction

RESUMO

As populações de coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) registaram declínios constantes e substanciais no oeste do Canadá nos últimos 50 anos. Muitos fatores inter-relacionados são considerados responsáveis por este rápido declínio. Um estudo de ecologia reprodutiva foi iniciado em Manitoba para identificar ameaças a casais selvagens e avaliar uma técnica de reintrodução modificada com recurso a suplementação alimentar para promover o sucesso da nidificação, recrutamento e sobrevivência dos casais de corujas libertados de cativeiro no primeiro ano, para aumentar o número de corujas selvagens. Entre 2010 e 2012 foram registados e comparados dados de reprodução, alimentação e comportamento de corujas selvagens e libertadas de cativeiro. Durante esse período, foram monitorizados 14 casais de corujas libertadas de cativeiro e seis casais de corujas selvagens. O tamanho médio das seis primeiras posturas de casais selvagens (8,8 ovos) foi superior ao das dez primeiras posturas de casais libertados de cativeiro (6,5 ovos). Da mesma forma, o tamanho médio da postura de reposição em quatro casais selvagens (6,8 ovos) foi superior ao de dois casais libertados de cativeiro (5,0 ovos). No geral, o sucesso de eclosão nas corujas selvagens foi de 69% e nas de cativeiro foi de 60%. Todos os juvenis eclodidos foram criados até à idade de emancipação, quer em cativeiro quer nos ninhos selvagens monitorizados. Durante este estudo de três anos, nove dos 20 juvenis criados por casais selvagens foram removidos dos ninhos para integrarem o grupo de reprodução em cativeiro nas estações seguintes. O esforço de reprodução em cativeiro resultou na libertação de 20 adultos e 15 juvenis criados até a idade de emancipação, durante três anos; 12 juvenis de casais libertados de cativeiro foram removidos dos ninhos para integrarem o grupo de reprodução em cativeiro das estações seguintes. Este estudo demonstrou que o método de reprodução em cativeiro foi pelo menos parcialmente bem-sucedido. Resta ver se os juvenis produzidos sobrevivem a longo prazo e contribuem para a recuperação desta espécie ameaçada no Canadá.

Palavras-chave: *Athene cunicularia hypugaea*, ecologia reprodutiva, programa de recuperação de espécies ameaçadas, reintrodução

Introduction

The Western Burrowing Owl (*Athene cunicularia hypugaea*) is a small (19.5-25.0 cm, 150-180 g), ground dwelling owl and the only owl in North America to nest under the ground. In the migratory portion of their range, they rely upon fossorial mammals, such as Richardson Ground Squirrels (*Urocitellus richardsonii*), Black-tailed Prairie Dogs (*Cynomys ludovicianus*), American Badgers (*Taxidea taxus*), and Red Foxes (*Vulpes vulpes*) to excavate burrows which the owls use for nesting. The Burrowing Owl was

designated as an Endangered species under the Canadian Federal Species at Risk Act (SARA) in 2003, and its status was confirmed as Endangered upon re-assessment in April 2006 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) due to severe and ongoing population declines (Environment Canada 2012).

The furthest eastern extent of the Burrowing Owl range in Canada is in Manitoba. In recent decades, the species range has contracted from southeastern Manitoba near Winnipeg to the southwestern corner of the province (De Smet 1992, 2003). Overall, the Burrowing Owl population in Canada has declined by approximately 63% since the early 1970's and the breeding range has contracted substantially along its northern extremes, but particularly in its western and eastern extent (B.C. and Manitoba) (Environment Canada 2012).

In Manitoba, Burrowing Owls formerly occurred as far north as Dauphin and east of Beausejour. They regularly nested near Winnipeg until the 1980s (De Smet 1997, 2003). In recent years, their range in Manitoba has contracted to the southwestern corner of the province with very few reports outside of this area. No single factor has been identified as causing the decline of the Burrowing Owl in Manitoba or elsewhere in Canada; however, multiple, inter-related factors are thought to be responsible for its major decline. The ultimate cause for Burrowing Owl declines is likely related to habitat loss and degradation. Housing and farming expansion, road development and energy exploration have eliminated much suitable habitat for Burrowing Owls throughout its nesting, migratory, and winter range. Habitat changes and fragmentation have also allowed predators to move into areas where they once were not as common (Environment Canada 2012). Other factors include the decline in fossorial mammals like badgers and prairie dogs, the use of agricultural pesticide which reduce prey availability, migration path and use of wintering grounds. Migration and winter mortality is difficult to assess for long-distance migrants with low nest-site fidelity. As a result, Burrowing Owl migration has not been thoroughly studied at present. In recent years (2013-present), small geolocators and PTT satellite transmitters have been deployed on select owls in western USA states, and Alberta and Saskatchewan in Canada to track migrations. The migration of owls from Manitoba has not been examined.

Reintroductions of Burrowing Owls in Manitoba conducted from 1987-1996 included releases of both young owls (owls born in that season) and one-year old owls (hatched the previous nesting season) obtained from the Owl Research and Rehabilitation Foundation in Ontario, and young transplanted from Saskatchewan, and North Dakota (De Smet 1992, 1997). Owls were held in pens and released after seven days using a soft-release technique. Hard-releases were employed during only one year and were found to be largely unsuccessful. Reintroductions in Manitoba were part of a larger monitoring and recovery effort which examined the factors affecting nesting success and survival, nest and territory re-occupancy, return rates, and movements of banded adults and juveniles (De Smet 1997). Reintroductions were discontinued in 1996 due to poor overall return rates of owls to Manitoba after migration, but limited monitoring and management efforts for the species were continued. From 1997-2006, few Burrowing Owls were observed and it was believed to be on the verge of extirpation from Manitoba until a nesting population inexplicably rebounded in 2006.

Work under this project assessed the feasibility of a modified reintroduction method in Manitoba using recent successful release and food supplementation techniques employed elsewhere in Canada (Wellicome 2000, Poulin et al. 2006, Mitchell 2008, Mitchell et al. 2011) to promote nesting success, recruitment, survival, and return rates of Burrowing Owls in Manitoba.

Figure 1 - Release and nesting sites for captive-released Western Burrowing Owls (*Athene cunicularia hypugaea*) in southwestern Manitoba (2010 to 2012). Broomhill = Reintroduction sites 2010-2012; Pierson and Lyleton = Reintroduction only 2010; Medora and Deloraine = Reintroduction only 2012.

Figura 1 - Locais de libertação e de nidificação de coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) no sudoeste de Manitoba (2010 a 2012). Broomhill (Laranja) = Locais de reintrodução em 2010-2012; Pierson e Lyleton = Reintrodução apenas em 2010; Medora e Deloraine = Reintrodução apenas em 2012.



Figure 2 - Release pens for captive-released Western Burrowing Owls (*Athene cunicularia hypugaea*) in southwestern Manitoba, Canada, 2010-2012.

Figura 2 - Gaiolas de libertação de corujas-buraqueiras-ocidentais (*Athene cunicularia hypugaea*) provenientes de reprodução em cativeiro no sudoeste de Manitoba, Canadá, em 2010-2012.



Methods

We collected data on the current breeding ecology for both captive-released and wild owls in Manitoba. Data collected included nest initiation, clutch size, hatching and fledging success, adult and juvenile mortality rates on the breeding grounds, and natal and post-breeding dispersal timing and rates. In this study, nesting or nest establishment was defined as clutch initiation (one egg observed in the nest). Fledging age of nestlings (35-42 days after hatching) was determined based on their abilities for sustained flight (greater than 30 m). Nesting success was defined as nests fledging at least one young. "Captive-released" Burrowing Owls were either captive-hatched (i.e., from breeding adults in captivity) or wild-hatched juvenile (i.e., from breeding adults in the wild) owls that were then held in captivity for one winter, paired for nesting, and transferred to release pens (Fig. 2) in the study area in mid-May.

Release site selection

Five sites were selected on private land for the reintroduction of Burrowing Owl pairs and individuals in southwestern Manitoba between 2010 and 2012 (Fig. 1). All release sites were pastureland (native and tame) and were grazed by cattle throughout the late spring and summer months. Sites were selected based on proximity to recent Burrowing Owl observations and nests in recent seasons (2006-2009) and availability of suitable habitat for Burrowing Owls (i.e., open pasture, no trees or shrubs and land with ample ground squirrel populations or burrows). Permission for property access, to release owls, and to observe wild owls throughout the nesting season was granted from all landowners.

Artificial Nest Burrow Installation and Soft Release of Owls

In mid-May of each season, 2.4 m x 2.4 m x 2.4 m tall release pens were set up at release sites. Pens were constructed of a wooden frame with chicken wire (outside) and mesh/bird netting (inside) (Fig. 2). Pens were fenced off with a small section of electric fencing so that cattle would not rub against the pens. Anchor ropes were also added in 2011 and 2012 to further secure the pens from extreme winds and storms. Each pen was equipped with an artificial nest burrow (ANB), 60 cm high wooden post for perching, and a Reconyx wildlife camera that recorded activities at the nest entrance 24 hrs per day (Fig. 3). ANBs used at release sites consisted of a 2.5-3 m length of 15 cm dia, corrugated weeping tile leading to a 19-l plastic bucket that served as the nest chamber. A large section of chicken wire was attached below and around the sides of the nest bucket to protect against potential fossorial predators. Two additional buckets were placed above the main nesting bucket to permit easier access to the nest chamber (Fig. 4). A perching post was installed inside the pen at the entrance to the nest burrow, and access to the nesting bucket (nest chamber) was 1 m outside the enclosure. An adaptation to Poulin et al.'s (2006) design was the addition of a 61 cm long section of 50 mm dia PVC piping that extended from the top bucket down into the nesting bucket (Fig. 5), allowing access to the nest chamber for regular observations of egg-laying and hatching through a fiber optic cable and camera (Peeper 2.0, Sandpiper Industries, California).

A soft-release technique was used to house paired owls until a partial clutch was observed (Poulin et al. 2006, Mitchell et al. 2011). To encourage nest success and reduce potential for nest abandonment pairs were held in pens until at least three

Figure 3 - Artificial Western Burrowing Owls (*Athene cunicularia hypugaea*) nest burrow entrance and fence post for roosting inside pen.

Figura 3 - Entrada de ninho artificial para coruja-buraqueira (*Athene cunicularia hypugaea*) e poste para poiso dentro da gaiola.



Figure 4 - Three-bucket artificial nest burrow for Western Burrowing Owls (*Athene cunicularia hypugaea*) allowed for easier access to the nest chamber, via a removable bucket system located outside the enclosure (adapted from Poulin et al. 2006).

Figura 4 - Ninho artificial para coruja-buraqueira (*Athene cunicularia hypugaea*) composto por três baldes, permitindo acesso mais fácil à câmara de nidificação através do sistema de remoção do balde localizado no exterior da gaiola (adaptado de Poulin et al. 2006).

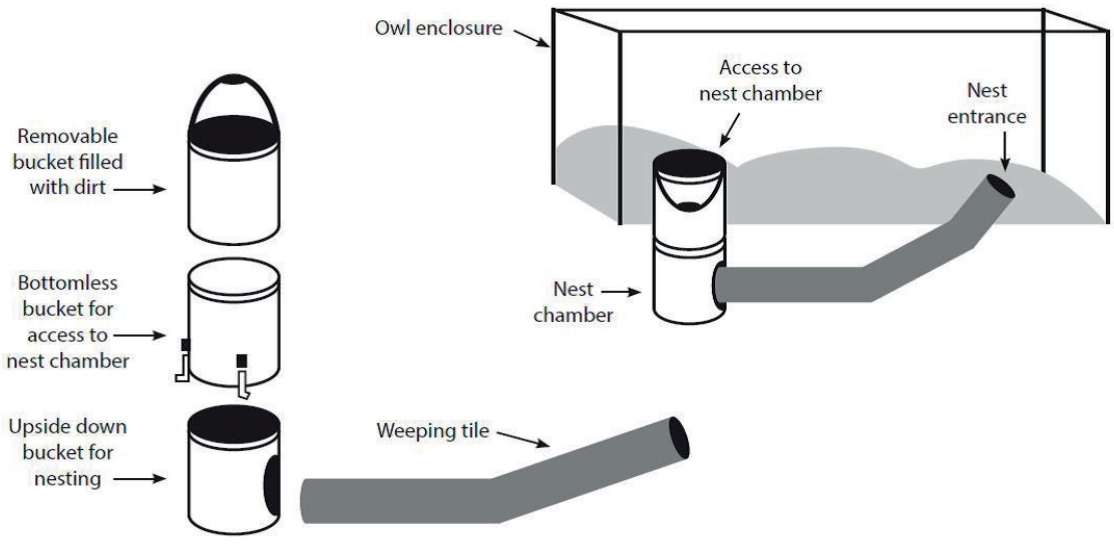


Figure 5 - PVC piping inserted in the top of the third bucket allowed for access to the Western Burrowing Owls (*Athene cunicularia hypugaea*)nest chamber with a fiber optic camera.

Figura 5 - Tubos de PVC inseridos no topo do terceiro balde, permitido acesso à câmara de nidificação da coruja-buraqueira (*Athene cunicularia hypugaea*), através de uma câmara de fibra ótica.



eggs were laid in nests (Poulin et al. 2006). If a nest was not established within six weeks or if a later nest failed (replacement clutches occasionally occurred with early nest failures), owls were recaptured and returned to the Assiniboine Park Zoo for overwintering. A few unpaired owls were also released (2011 & 2012 only) utilizing soft-release techniques (generally released after they had been in the pens for 10 days). Pairs were provided with three frozen-thawed house mice daily. This daily ration was reduced to two mice per pair after the pens were removed to encourage adult owls to forage for food. Adult owl foraging activities were monitored after release daily through personal observations and by reviewing camera images every four days. Once all young emerged from the burrow (generally between 10 and 14 days old) food supplementation was stopped. [Note: from the 2013 season onward, supplemental feeding was continued until the young were seven weeks of age.]

Founding population of Burrowing Owls for Reintroduction

The founding population consisted of hatch-year juveniles from 2009 which included four wild-hatched juvenile owls removed from two larger family groups in southwestern Manitoba (two females and two males); two captive-hatched juvenile owls produced by a non-releasable pair from the Assiniboine Park Zoo (one female and one male); and four captive-hatched juvenile owls from the Alberta Birds of Prey Centre in Coaldale, Alberta (two females and two males). Founding owls were transferred to release sites in mid-May, placed in release pens, and paired for nesting. Owls were intermixed and paired according to where they originated (i.e., Manitoba wild, Birds

Table 1 - Nesting results for captive-released Western Burrowing Owls (*Athene cunicularia hypugaea*) in southwestern Manitoba, Canada, 2010-2012.

Tabela 1 - Resultados da nidificação de casais de coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) provenientes de cativeiro no sudoeste de Manitoba, Canadá, em 2010-2012.

[1]Based on no. of eggs and young observed in successful nests.

	2010	2011	2012
No. of adult pairs	5	5	4
No. of individuals adults released	0	3	3
No. of first clutches	3	3	4
No. of failed first clutches	2	2	1
No. of replacement clutches	0	2	1
No. of failed replacement clutches	0	1	0
Mean clutch size (first clutch, n=10)	6.6 (n=3, 5-8 eggs)	6.6 (n=3, 6-7 eggs)	6.25 (n=4, 4-8 eggs)
Mean clutch size (replacement clutches, n=3)	0	4 (n=2, 4 eggs each)	6 (n=1, 6 eggs)
Total no. of eggs (first and replacement clutches)	20	28	31
A: No. of eggs (only from nests that hatched eggs)	7	11	27
B: Total no. of hatchlings	2	6	19
% Hatching success[1] (B/A x 100)	29%	55%	70%
No. of hatchlings reaching fledging age	2	6	19
No. of fledgling age young removed for overwintering and later captive-release	1	3	8
No. of fledglings released	1	3	11

of Prey Centre (AB), or Assiniboine Park Zoo (MB)) to avoid breeding related owls. All founding owls were released if they fledged at least one young.

Results

Summary of Captive-released Burrowing Owl Reproduction (2010-2012)

Over the three study years, 14 pairs of captive-released owls and six single males were placed in release pens. Ten of 14 pairs successfully initiated a first clutch (71%); seven of ten pairs (70%) successfully fledged young (including two replacement clutches). Of 13 total nests produced by captive-released pairs (10 first and three replacement clutches), six failed. Failures were caused by flooding of the burrow (4 nests), abandonment (1 nest), and a probable predation attempt resulting in the death of the female (1 nest). Excluding one first clutch that was abandoned soon after the release (with only one egg), average clutch size for first clutches during this study averaged 6.5

(n=9, range 5-8 eggs). Replacement clutches were smaller, averaging 5.0 eggs (n=3, range 4-6 eggs). Including all 13 first and replacement clutches, seven clutches were successful (54%) fledging a total of 27 young (3.86 young/successful nest). Overall, 60% (27 of 45) of eggs that were laid hatched. Nestling survival (post-hatching to fledging age; n=27) was 100%. Nests in 2012 were the most successful with 19 hatchlings from 27 eggs (70%), including one particularly successful pair that hatched and raised all 8 of their eggs/young to fledging age. One of 19 young in 2012 was preyed upon six weeks after hatching at the burrow entrance by a Great Horned Owl (*Bubo virginianus*) (the only known instance of predation of a young prior to dispersal at the release site during this study). Young were of fledging age at 5-6 weeks of age so predation after 6 weeks of age did not affect estimates of fledging success. Twenty adults and 15 fledglings were released and dispersed from the release sites during the three-year study period. An additional 12 juveniles were removed from nests to become part of the captive breeding group the following season (Table 1).

Summary of Wild Burrowing Owl Reproduction (2010-2012)

Of eight wild pairs located during 2010-2012, two pairs (six young) were excluded from the monitored pairs as they were located too late in the nesting season to assess breeding ecology (after young had already fledged). For the six monitored pairs, overall clutch size for first and replacement clutches combined was 8.0 eggs/nest, ranging from 8.8 for six first clutches to 6.8 for four replacement clutches. Only two of the six monitored wild pairs were successful with a first clutch, but all four pairs where nests failed produced a replacement clutch and two of these raised young to fledging age. Twenty of 29 eggs in successful wild nests hatched (69%); all 20 young survived to fledging age. Four of 10 monitored nests (40%) and four of six monitored pairs (67%) successfully raised young to fledging age. Nine of these 20 young were removed from nests in 2010 and 2011 to diversify the gene pool of the captive-released breeding population in the next season (Table 2).

Discussion

Clutch Size, Nesting, and Hatching Success (Captive-released and Wild Burrowing Owls)

During this study, the average clutch size for wild first clutches (8.9 eggs) was higher than for captive-released first clutches (6.5 eggs). Part of this difference may be attributed to the fact that wild pairs initiated first clutches much earlier (April 28-May 15) than captive-released owls (May 24- June 10). Wellicome (2000) found that wild Burrowing Owls show a seasonal decline in clutch size as earlier initiated clutches are generally larger than those laid later in the season. The difference in clutch sizes of first clutches (8.9 and 6.5 eggs) versus replacement clutches (6.8 and 5.0 eggs) in the present study also reflects that later clutches are generally smaller.

Hatching success in this study was defined as the number of young that hatched from eggs in either a first clutch or replacement clutch. Hatching success for wild owl nests was higher in 2010 and 2011 (68% and 71%) relative to more variable captive-released nest success (22% in 2010, 55% in 2011, and 70% in 2012). Overall, hatching success for wild owls was 69% (2010 and 2011) and captive-released owls was 60% (2010- 2012). Mitchell (2008) saw a similar hatching success rate of 57% in her 2005 and 2006 study in B.C. when reintroducing captive-bred pairs through a soft-release technique. During the course of this study, conditions in 2012 were the most suitable for breeding Burrowing Owls, with lower rainfall during the nesting period reducing damp or wet conditions in the burrow. All captive-released pairs were

Table 2 - Nesting results for wild Western Burrowing Owls (*Athene cunicularia hypugaea*) in southwestern Manitoba, Canada, 2010-2012.

Tabela 2 - Resultados da nidificação de casais de coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) selvagens no sudoeste de Manitoba, Canadá, em 2010-2012.

[1]Only confirmed eggs in all nests. Cartwright (2010) and Elgin (2011) eggs were not counted as pairs/young were found later in the season.

	2010	2011	2012
No. of adult pairs	5	3	0
No. of individual/additional adults observed	2	4	4
No. of first clutches	5	3	0
No. of monitored first clutches	4	2	0
No. of failed first clutches	2	2	0
No. of replacement clutches	2	2	0
No. of failed replacement clutches	1	1	0
Mean clutch size (first clutches, n=6)*	8.8 (n=4, 8-11 eggs)	9.0 (n=2, 9eggs each)	0
Mean clutch size (replacement clutches, n=4)	6.5 (n=2, 6-7 eggs)	7.0 (n=2, 7eggs each)	0
Total no. of eggs (first & replacement clutches)[1]	48	32	0
A: No. of eggs (only from nests that hatched eggs)	22	7	0
B: Total no. of hatchlings	15	5	0
% Hatching success (B/A x 100)	68%	71%	0
No. hatchlings reaching fledging age	15	5	0
No. of fledgling aged young removed for overwintering and later captive-release.	6	3	0
No. of fledglings released	9	2	0

provided with the same supplemental diet in all three seasons for the same duration (up until all young emerged from the burrow). Male captive-released owls in 2011 and 2012 were observed to be well-adapted hunters bringing back a variety of prey items daily to nest burrows. In 2011, there was an increase in frog and toad populations, which benefited both wild and captive-released pairs (noted in pellet dissection remains). This increased food and more suitable nesting conditions may explain the increase in hatching success for captive-released pairs in 2011 and 2012.

The greatest cause of first clutch failure for both captive-released and wild owls during this study was nest flooding due to heavy rainfall. Seven of nine first clutches failed from flooding (7 of 18 nests, 39%) and two from unknown abandonments (2 of 18 nests, 11%). Seven replacement clutches were established (4 wild and 3 captive-released) and three of these failed from either flooding

(n=1) or predation (n=2). Catlin & Rosenberg (2008) noted that resident Burrowing Owls in California were able to replace a clutch quickly after a nest failure and could have up to three or four replacement clutches in a season, generally with smaller clutch sizes produced after each failure. During this study, most pairs where first clutches failed produced replacement clutches within 10 days. Multiple breeding attempts in a single season are common among many birds, however, replacement clutches had not been observed for Burrowing Owls in Manitoba prior to this study (K. De Smet, pers. comm.).

Overall, 12 of 23 monitored Burrowing Owl nests from 2010-2012 failed (52%); failures were attributed to two main factors, flooding (35%) and predation (9%), with the remainder as unknown caused abandonments (9%). Both captive-released and wild owls responded to nest failures by producing a smaller replacement clutch.

Fledging Success

All hatched young were raised to fledging age for captive-released and monitored wild nests during this study. Nests near Cartwright and Elgin were found later in the season (post-fledging) and hatching and fledging success could not be assessed and they were excluded from the nesting analysis. However, with that said, considerably higher fledging rates were documented in this study for captive-released owls than the 1987-1996 Manitoba reintroduction program and similar efforts in Saskatchewan and B.C (De Smet 1997, Poulin et al. 2006, Mitchell 2008).

One explanation for the high fledging rate in this study may be due to our reducing brood sizes prior to fledging. Removal of young from larger families meant that the remaining hatchlings would likely have greater access to prey resulting in increased body condition and survival prior to migration. It also meant that adults had fewer nestlings to care for, thus their hunting activities would be less taxing, potentially increasing their overall fitness.

Emerging threats

Heavy rainfall combined with elevated groundwater levels resulted in extensive flooding of both natural and artificial nest burrows during 2010 and 2011 and the loss of five captive-released nests and three wild nests. Due to the small number of Burrowing Owl occurrences throughout the last two decades it is not possible to measure significance (statistically) of the impact of rainfall on Burrowing Owl numbers. However, the impact of historical precipitation rates on owl occurrences in Manitoba, personal observations from this study, and the 1987-1996 study, and an important study by Fisher et al. (2015), provide evidence that in times of increased precipitation, Burrowing Owls do not fare as well as during drier periods. De Smet (1997) speculated that increased summer rainfall in the early to mid-1990s was a major factor in the sudden decline in productivity and nesting number of Burrowing Owls in southwestern Manitoba. He believed food shortages, nest abandonments, and other factors may have been the major reasons why Burrowing Owl nests were lost or produced few young during that period. This study documented that prolonged wet periods contributing to a higher than normal water table combined with high event rainfall occurrences can have a significant negative effect on Burrowing Owl nesting success through flooding of a large number of nests. The end result of poor overall nesting success is often reduced return rates of nesting adults to the study area in subsequent years.

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Movements and habitat selection of Short-eared Owls (*Asio flammeus*) in North America

Movimentos e seleção de habitat da coruja-do-nabal (*Asio flammeus*) na América do Norte

Marcel A. Gahbauer[1*], Travis L. Booms[2], Paul G. Novak[3], Mathew D. Schlesinger[4], Lisa Takats-Priestley[5], Kristen L. Keyes[6]

1 Migration Research Foundation, Ottawa, Ontario, Canada

2 Alaska Department of Fish and Game, Fairbanks, Alaska, USA

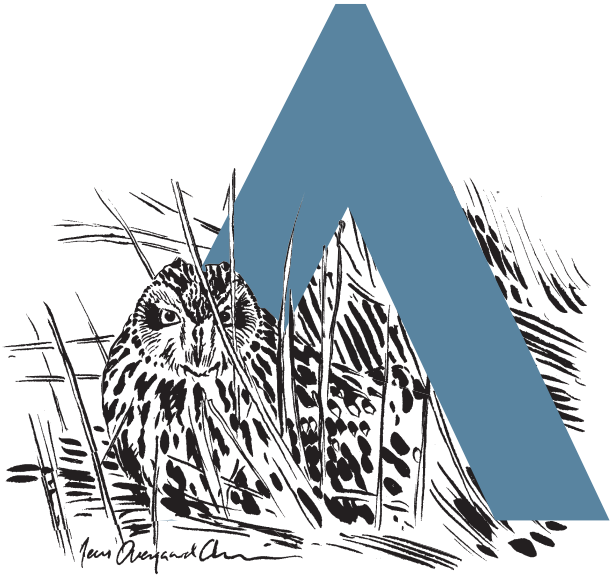
3 New York State Department of Environment Conservation, Schenectady, New York, USA

4 New York Natural Heritage Program, SUNY College of Environmental Science and Forestry, Albany, New York, USA

5 Strix Ecological Consulting, Tofield, Alberta, Canada

6 Migration Research Foundation, Inverness, Scotland

*** Corresponding author:** marcel@migrationresearch.org



ABSTRACT

Effective conservation and management of Short-eared Owls (*Asio flammeus*) requires an understanding of population size, distribution, and linkages, as well as habitat requirements. Research in North America over the past decade has advanced knowledge of these subjects, though many gaps remain. Data on Short-eared Owl movements were historically limited to banding recoveries, with only 54 records since 1923, mostly short- or medium-distance recoveries (mean 308 km; maximum 2,002 km). More recently, satellite telemetry of 26 Short-eared Owls from Alaska revealed long-distance fall migration (ranging from 3,205 to 6,886 km) to a broadly dispersed wintering range, and low site fidelity in owls that returned northward in spring. Our satellite telemetry research on 13 individuals wintering in New York also found long-distance spring migration to breeding grounds (ranging from 1,751 to 1,938 km), but with more consistent population connectivity. While Short-eared Owls are generally considered to use a broad range of open habitat types from tundra to grassland to wetland, very little of this habitat in North America is occupied at any given time, suggesting that more specific preferences exist. A study of wintering Short-eared Owls in New York revealed that ground roosts were associated with significantly greater thatch depth, grass cover, maximum grass and forb height, number of

vertical strata, and vegetation diversity; foraging occurred preferentially in fields with an abundance of vole runways and high forb cover. Similarly, research in Ontario found Short-eared Owls nesting in loose aggregations in areas with taller grasses. Larger concentrations of dozens to hundreds of Short-eared Owls are occasionally reported at various locations across North America. Multiple irruptions have been recorded at Beaverhill Lake in central Alberta, where maximum abundance correlates with vole abundance, in turn triggered by a peak crop of plants such as alfalfa (*Medicago sativa*) and foxtail barley (*Hordeum jubatum*). Expanded documentation of irruptions and satellite tracking of individuals at such locations is considered a research priority.

Keywords: *Asio flammeus*, banding, habitat use, irruptions, telemetry

RESUMO

A conservação e gestão eficazes da coruja-do-nabal (*Asio flammeus*) implicam o conhecimento da sua dimensão populacional, distribuição e ligações, bem como dos seus requisitos de habitat. Ao longo da última década, a investigação na América do Norte produziu conhecimento sobre estes assuntos, embora ainda existam algumas lacunas. Os dados sobre os movimentos de coruja-do-nabal estão historicamente limitados a recapturas de aves anilhadas, havendo apenas 54 registos desde 1923, na sua maioria recapturas de curta ou média distância (média 308 km; máximo 2,002 km). Mais recentemente, 26 corujas-do-nabal do Alasca seguidas através de telemetria de satélite revelaram uma migração outonal de longa distância (variando de 3,205 a 6,886 km) para uma área de invernada amplamente dispersa, e reduzida fidelidade ao local de nidificação em corujas que regressavam ao norte na primavera. O nosso estudo de telemetria de satélite com 13 indivíduos invernantes em Nova Iorque também registou migração de longa distância na primavera para áreas de reprodução (variando de 1,751 a 1,938 km), embora com uma conectividade populacional mais consistente. Apesar de se considerar que a coruja-do-nabal utiliza uma ampla gama de habitats abertos, desde a tundra a pastagens e zonas húmidas, esses não são os habitats mais ocupados na América do Norte, sugerindo a existência de uma preferência de habitat mais específica. Um estudo com corujas-do-nabal invernantes em Nova Iorque revelou que os poisos ao nível do solo estavam associados com maior profundidade de palha, coberto herbáceo, altura máxima do coberto herbáceo e pastagem, número de estratos verticais e diversidade da vegetação. A alimentação ocorreu preferencialmente em campos com abundância de trilhos de micromamíferos e maior altura da pastagem. Da mesma forma, estudos em Ontario revelaram que a coruja-do-nabal nidifica em grupos dispersos em áreas com erva mais alta. Grandes concentrações de dezenas a centenas de corujas-do-nabal são reportadas ocasionalmente em vários locais na América do Norte. Foram registadas várias irrupções no lago Beaverhill, no centro de Alberta, onde a abundância máxima está correlacionada com a abundância de micromamíferos que, por sua vez, é potenciada pelo pico de abundância de culturas como luzerna (*Medicago sativa*) e cevada-marítima (*Hordeum jubatum*). Nesses locais, a documentação das irrupções e o seguimento dos indivíduos por satélite são considerados prioritários para a investigação.

Palavras-chave: anilhagem, *Asio flammeus*, irrupções, telemetria, uso de habitat

Introduction

Knowledge about the movements of Short-eared Owls (*Asio flammeus*) in North America was historically limited to banding data. Of over 3,200 individuals banded since 1923, only 54 (1.7%) have been recovered, at a mean distance of 308 km (range 0 to 2,002 km) from their original location (L. Laurin pers. comm.). Recently, the first published satellite telemetry study of Short-eared Owls in North America documented individuals from Alaska covering much greater distances, ranging from 3,205 to 6,886 km (Johnson et al. 2017).

Occasional large gatherings of Short-eared Owls presumably represent individuals converging from a broader area, but these have mostly been sparsely documented. Habitat preferences are somewhat better described, although much of what is known comes from a few mostly local studies (e.g., Clark 1975, Holt 1992, Dechant et al. 1999, Swengel & Swengel 2014) that may not fully represent the species across its wide range. Although most strongly associated with grasslands, Short-eared Owls can be found in a variety of other open habitats such as tundra, shrublands, and croplands (Wiggins et al. 2006), but the relative importance of these habitat types and the features within them that particularly influence their suitability for Short-eared Owls remain poorly understood (Booms et al. 2014).

Long-term declines in Short-eared Owl populations have been recorded across much of North America over at least the past 50 years, but the species has not yet been the focus of much conservation effort (Holt 1986; Wiggins et al. 2006; National Audubon Society 2010; Pardieck et al. 2017). Part of the challenge is that numbers appear to fluctuate naturally, making it difficult to assess whether changes represent true declines at either a local or regional scale; this is exacerbated by a limited understanding of how populations are linked on a regional or continental scale. Gaps in fine-scale knowledge of habitat preferences also hinder effective conservation management efforts (Booms et al. 2014).

Our objectives were to: 1) document long-distance movements of Short-eared Owls in eastern North America to compare with results from Alaska and identify key locations and regional linkages; 2) summarize and interpret knowledge about irruptions of Short-eared Owls; 3) build on existing knowledge of breeding and wintering habitat, with a focus on fine-scale habitat features used by Short-eared Owls; and 4) provide recommendations for further study in support of conservation and management.

Methods

Satellite telemetry

We deployed 13 Argos satellite platform transmitter terminals (PTTs) on wintering Short-eared Owls at six sites in New York state, from Buffalo (43°13'N, 78°32'W) to Washington (43°14'N, 73°33'W) and Greene (42°22'N, 73°48'W) counties, from 2006 to 2013. The PTTs were 12 g solar powered units (Microwave Telemetry, Columbia, Maryland, USA), equipped with motion, temperature, and battery voltage sensors. All owls outfitted with PTTs were adults. Based on wing chord, they comprised five males, four females, one probable male, one probable female, and two of unknown sex.

Owls were captured with bal-chatri traps, bow-nets, or mist nets near roosts, with either European Starlings (*Sturnus vulgaris*) or House Mice (*Mus musculus*) as bait (Bloom et al. 2007), and sometimes supplemented with MP3 players broadcasting mouse vocalizations. We attached PTTs with a backpack harness of 4 mm wide Teflon-coated nylon ribbon (Bally Ribbon Mills,

Bally, Pennsylvania, USA), as per Steenhof et al. (2006). Known females had a mean mass of 383 g (range 355 to 405 g), whereas males had a mean mass of 335 g (range 311 to 396 g); the PTTs and associated harnesses were on average 3.0% (range 2.4 to 3.5%) of the mass of females and 3.5% (range 3.3 to 3.8%) of males.

We programmed the PTT duty cycle to be 10 hours on and 48 hours off, beginning at time of deployment. We received standard and auxiliary location data via the Argos System (www.argos-system.org) and CLS America (www.clsamerica.com). These were filtered through a systematic hybrid algorithm to remove implausible locations (Douglas et al. 2012). We retained location classes 1, 2, and 3, as well as auxiliary locations (classes 0, A, B, and Z) if they were within 5 km of another location, resultant movement rates were <80 km/h, and changes in direction were not suspiciously acute. We analyzed the best quality location during each duty cycle. We assumed PTT failure when transmission stopped after a period of poor quality data or low battery voltage readings and considered mortality to be probable when a PTT transmitted continuously from a single location, the motion sensor indicated it was stationary, or the temperature sensor reflected ambient conditions.

We defined fall and spring movement periods as beginning when owls were consistently moving away from summer and winter areas and ending when changes in position were reduced to localized multi-directional movements. We considered migratory stopovers to be locations temporarily used by owls in fall or spring, where they moved <35 km within 48 hours. Because PTTs were not transmitting every day, we estimated departure and arrival dates as the midpoint of transmission gaps <= 7 days but did not estimate them for longer gaps. We determined total displacement by measuring the straight-line distance between wintering and presumed breeding locations.

Irruptions

We reviewed all available eBird data to date (as of September 2017) for peaks in occurrence by generating "high count" figures across all years for each state, province, and territory (e.g., eBird 2017). For each jurisdiction, we noted the three highest totals reported, and the corresponding week of the year.

For Alberta, we collected information on winter irruptions of Short-eared Owls from a variety of sources including published literature, volunteer programs (Christmas Bird Counts and dead raptors turned in to Alberta Sustainable Resource Development), Alberta Birds Facebook page, and unpublished data including field notes from naturalists and wildlife biologists. We defined an irruption as more than 10 individuals observed in a small geographic area over a span of at least one month.

During the winter 2005-2006 and 2015-2016 irruptions of Short-eared Owls at Beaverhill Lake, Alberta (53°23' N 112°36' W) we collected data during daylight hours from a viewing blind at Francis Point, looking north over the lake. We also compiled records from others in the local birding community, with requested data including date and time of observations, where observations took place, time spent observing, number of owls observed, and type of optics (Priestley et al. 2008; Priestley and Crosland unpublished data).

We assessed the maximum number of owls observed each day through the two winters, and the number of owls observed versus time to sunset. Because sunset varied considerably throughout the season, we transformed the time that owls were observed into the number of minutes before sunset.

Habitat use

We used coordinated surveys and radio telemetry to study habitat use and home range at 11 primary wintering sites across New York State during the winters of 2007-2008 and 2012-2013. Visual surveys were conducted by trained observers every second week from December through March and took place between one hour before sunset and one half-hour after sunset.

We primarily captured owls using bow nets, but also used bal-chatri traps, noose "carpets", dho-gaza nets, and mist nets (Bloom et al. 2007). Owls (n=76) were fitted with VHF backpack style transmitters (LL Electronics, frequency range 150-152 Hz, 6-7 g; Holohil, frequency range 216-217 Hz, 8-9 g) and banded with standard USFWS leg bands. We obtained locations for these owls while they were present on wintering areas, typically at three-day intervals. We surveyed during daylight hours (30 minutes before sunrise to 30 minutes after sunset) to identify roost locations, and again for several hours during the night when owls were active.

We conducted all home-range data analyses using Biotas Version 2 (2005), and all statistical analyses using MS Excel (2013). Owls observed over a period of less than two weeks, with fewer than 10-15 individual locations, or with very few foraging locations (n=18) were omitted from detailed analysis. Home range calculations were initially performed for 31 owls from eight sites using minimum convex polygons based on both triangulation data and visual observations. However, we considered owls to have home ranges only if the cumulative area of their home ranges, calculated incrementally from three locations to the maximum number of locations collected, appeared to approach an asymptote. Incremental area analyses were conducted by visual inspection. Using this approach, ten owls were eliminated from home range analysis. For the remaining 21 owls analyzed for this report, we collected an average of 45 points per individual owl (range=20-93). We estimated 95% utilization distributions for each individual, omitting occasional sallies to locations outside of the general use area (Hansteen et al. 1997). We calculated spatiotemporal independence of points for each owl using a Mantel's U test, which performs Monte-Carlo simulations to calculate the permutation variance of the frequency of locations near one another across time (Eckley and Curtin 2012). All data on home range sizes were ln-transformed to approximate a normal distribution prior to further analyses.

We assessed habitat selection by using plot-based field measurements and landscape-level GIS data (ArcMap Version 10.2). We evaluated whether sites selected for diurnal roosts differed from those used only (or primarily) for foraging, or from randomly selected sites not used for either foraging or roosting. We collected habitat data from multiple fields in at least one year at eight of the 11 primary study areas and obtained landscape-level measurements for at least one year from two or more fields at seven of the 11 primary study areas. We used visual observation and radio-telemetry to locate owls to identify general roost locations, as well as fields used by owls for foraging. Fields never or only very rarely used by foraging owls were also identified. More precise roost locations were later obtained by walking into roost areas when owls were not present and finding cast pellets or feces.

We defined ground roosts as being centered at the location of cast pellets or whitewash. We randomly selected the center of plots used or not used for foraging from within fields delineated by GIS. Randomly selected plots typically numbered 20 per field, whereas roost plots were generally fewer and equal to the number of pellets/whitewash locations. Field-based plot measurements included % cover in grasses, forbs, and bare ground within

square meter quadrats, and % cover of shrubs or trees within a 5 m radius of the plot center. Maximum vegetation height was measured by recording the presence or absence of vegetation within each of six height intervals (0-10 cm, 10-25 cm, 25-50 cm, 50-75 cm, 75-100 cm, >100 cm) along with a measurement of thatch depth. A vegetation growth diversity measure was developed by multiplying the number of vegetation growth forms by the number of strata with vegetation contacts at each plot. Soil moisture was defined at each plot as inundated (standing water), saturated (wet to touch), or unsaturated (dry). Lastly, the number of distinct small mammal runways within each quadrat was recorded. For conifer roost locations (n=3), data recorded included the height, diameter at breast height, and species of the roost tree, the height where owls roosted (based on whitewash on tree branches, or branch location immediately above pellets on the ground), and azimuth to the center of the conifer.

Landscape-level measurements included a) % cover for a variety of land cover types within both a 0.5 km and 1.6 km radius of the center of a roost, foraging field, or non-use field (defined as being within the home range of an owl, but with no telemetry or visual records), b) nearest distance to a variety of habitat features, and c) a measure of linear habitats not well measured as % cover such as ditches, fence lines, and road edges (Tables 1, 2, & 3). Fields that were used by owls for both roosting and foraging were used twice or treated separately in the analysis. Sample sizes for landscape level measurements are much smaller than for plot measurements as this aspect was developed later during this study. Fewer non-use fields were available for analysis because it was difficult to document that fields were not used. We used one-way ANOVAs to look for significant differences in vegetation for foraging, roosting, and non-use areas. Some tests violated the assumption of homogeneity of variances, but nonparametric tests gave similar results, so we report ANOVA results here. Tukey HSD post-hoc tests are reported as well.

To better understand micro-scale habitat selection by breeding Short-eared Owls, we assessed habitat surrounding active nest sites on Amherst Island (44°08' N 76°43' W) and Wolfe Island (44°10' N 76°22' W), Ontario, in 2009 and 2010, as described in Keyes et al. (2016). We documented the dominant vascular plant species within a 4 m radius of each nest and surveyed 1 m^2 quadrats over the nest and at 5, 10, 15, 25, and 50 m intervals along transects to the east, south, west, and north (Bonham 1989). Keyes et al. (2016) also estimated vegetation composition and average height for each quadrat and recorded the distance from each nest to the nearest waterbody, building, and fence.

Results

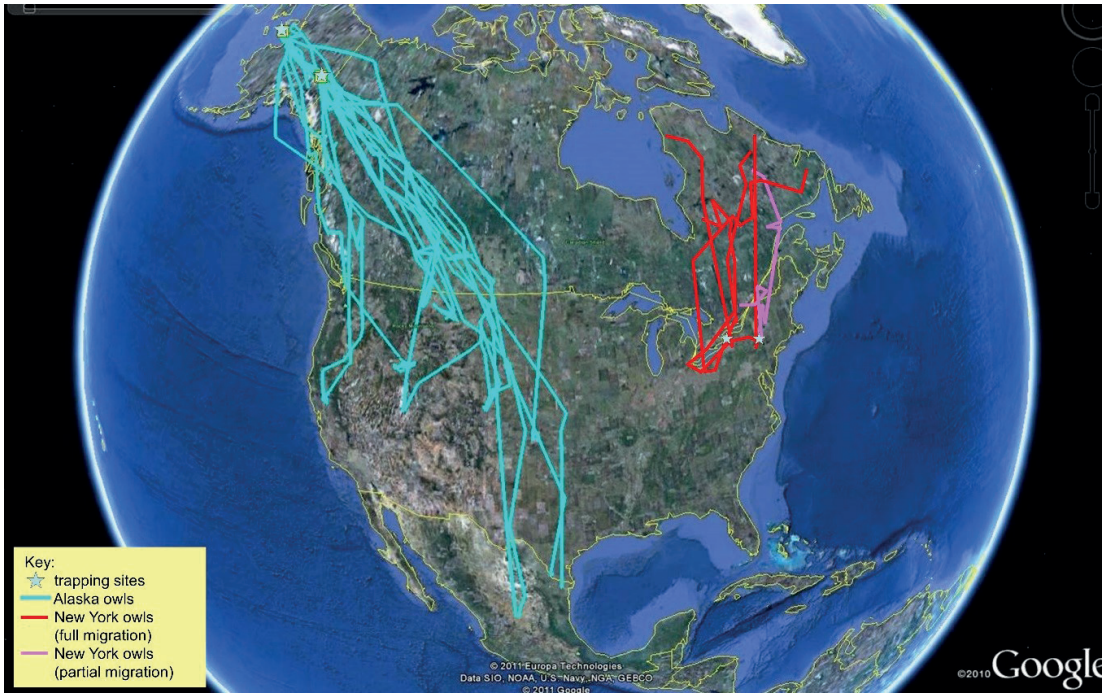
Satellite telemetry

Estimated departure dates of owls carrying PTTs ranged from early to mid-March to late April, similar to data from our study's VHF-tracked owls, which had last detection dates on the wintering area beginning in March (n=8), peaking in April (n=10), and as late as May 7 (n=1). Of the 13 owls satellite-tracked from wintering areas in New York, transmitter failure or mortality occurred for six owls before spring migration was completed. Two other owls were tracked until mid-late May, by which time one was in southern Quebec (326 km from its wintering site) and the other was in western Labrador (1,375 km), but transmissions ended too soon to determine whether these had settled on a breeding home range.

Of the five owls that provided data throughout summer, three departed their wintering sites to the north or northeast, with

Figure 1 - Satellite telemetry tracks from Short-eared Owls (*Asio flammeus*) trapped at wintering grounds in New York, compared with satellite telemetry tracks of Short-eared Owls from breeding grounds in Alaska from Johnson et al. (2017).

Figura 1 - Percursos determinados por telemetria de satélite de corujas-do-nabal (*Asio flammeus*) capturadas em locais de invernada em Nova Iorque, em comparação com os percursos de corujas-do-nabal provenientes de locais de reprodução no Alasca segundo Johnson et al. (2017).

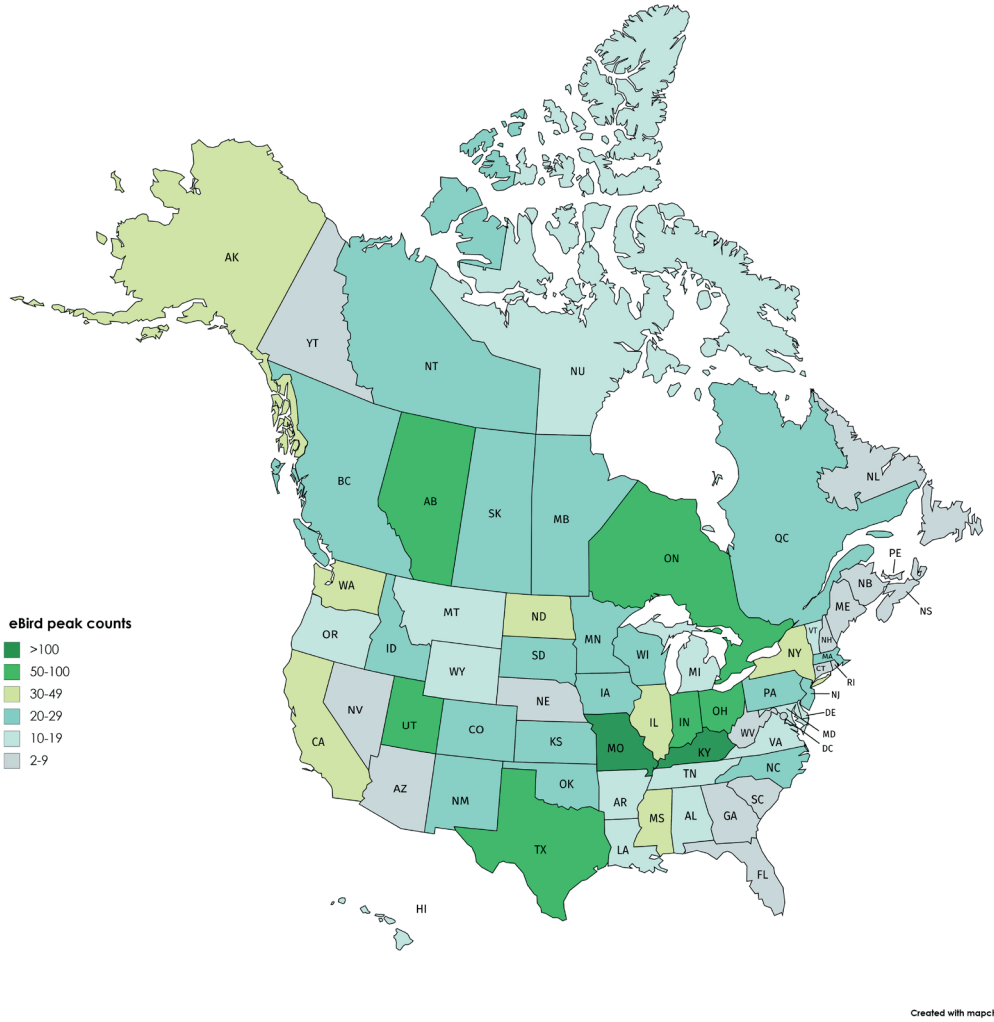


two individuals wintering in Washington County in 2007 and 2010 that migrated north to the Lake Champlain area before continuing into Quebec. Another, captured in Niagara County, moved northeast into southern Ontario and then on to northern Quebec (Fig. 1). The other two owls departed to the west, heading south of Lake Erie and into Ohio prior to crossing north over Ontario and into Quebec. Four of these owls settled on summer territories between mid-May and early July – two of them in western Labrador, another in northern Labrador, and the fourth nearby in northern Quebec, adjacent to Ungava Bay. Their mean straight-line distance from wintering to breeding area was 1,835 km (range 1,751 to 1,938 km). The fifth owl stopped over in southern Ontario between 25 April and 2 May, then continued into central Quebec, where it was detected at numerous locations from mid-June through mid-September.

Transmitters for two owls continued to function longer. One of these, captured in Washington County in 2006, had a single detection on March 12 in Sullivan County, approximately 180 km south of where it had spent the previous winter. Another owl, originally captured in Greene County in 2009, had a single detection on March 12 the following year in Ohio, where it had spent much of April during its spring migration the previous year; it also was detected the following summer in far northern Quebec, approximately 750 km northeast of its location the previous year. In addition, three VHF-tracked owls returned to New York in a subsequent winter. One owl captured in

Figure 2 - All-time peak counts of Short-eared Owls (*Asio flammeus*) in the eBird database for each state, province, and territory in the United States and Canada.

Figura 2 - Contagens de máximos totais de corujas-do-nabal (*Asio flammeus*) na base de dados eBird para cada estado, província e território nos Estados Unidos e Canadá.



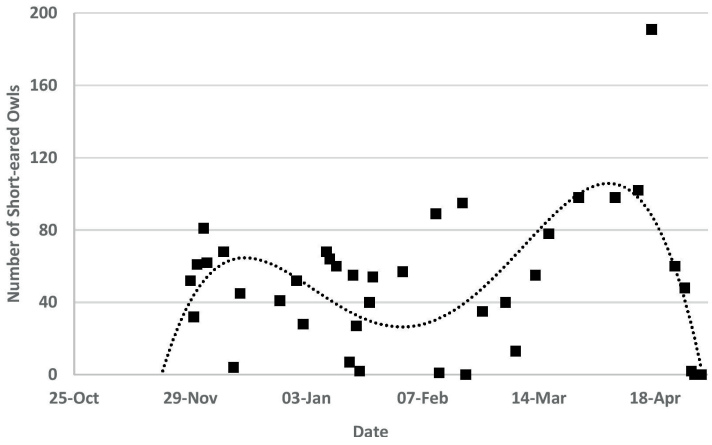
Niagara County on 8 February 2008 was recaptured at the same site on 17 February 2010. Another originally captured at a site south of Rochester on 22 January 2010, returned the following year and spent the winter at another regular wintering site approximately 15 km west of the original capture site. The third returning owl was originally captured 27 December 2009 in wetlands near the Montezuma Wildlife Refuge, Wayne County, and a single radio detection was obtained the following winter on 13 December 2010 at a location on the refuge, approximately 10 km from the original capture location.

Irruptions

Data from eBird up to September 2017 revealed that peak counts of 30 or more Short-eared Owls have been recorded in 13 states and 2 provinces, ranging from Alaska and New York to Texas and Mississippi (Fig. 2). Peak counts mostly occurred in

Figure 3 - The maximum number of Short-eared Owls (*Asio flammeus*) counted on each survey day during winter 2005/06 at Beaverhill Lake, Alberta.

Figura 3 - Número máximo diário de corujas-do-nabal (*Asio flammeus*) durante o inverno de 2005/06 no Lago Beaverhill, Alberta.



winter (December through March), except in North Dakota (1 April), Utah (15 May), and Alaska (8 August). Similarly, 80% of the top three counts for each of these 15 states and provinces were in winter. The aforementioned three states accounted for most of the other exceptions (the other being Alberta, 15 April).

The top two counts were 126 at the Sinclair Unit of Peabody Wildlife Management Area in Kentucky (4 February 1996) and 125 in Dade County, Missouri (31 January 2010). These appear to have been exceptional records, as the second highest counts for Kentucky and Missouri are 20 and 31, respectively.

There is a long history of documented Short-eared Owl irruptions in Alberta. Randall (1925) described a spike in Short-eared Owl abundance and reproductive output in southern Alberta in 1925, associated with a peak in vole numbers. In 1931-32, 'thousands' of Short-eared Owls ate 'mice' that thrived in grain stocks in the central part of the province (Farley in Bent 1938). In winter 1988-89, an invasion occurred in central Alberta, with peak counts of up to 30 owls during December and January. Meadow Voles (*Microtus pennsylvanicus*) were prevalent in uncut alfalfa (*Medicago sativa*) fields at this time, and comprised the only prey remains found in 25 owl pellets that were collected and dissected (E. Wallace & G. Holroyd pers. comm.).

In summer 1997, J. Schmutz & K. Clayton (pers. comm.) reported a Short-eared Owl irruption in southern Alberta. They observed 15 Short-eared Owls in an area where they had observed, on average, less than one owl per year from 1984 to 1996. This corresponded with a rate of 2.6 voles/100 trap nights in 1997, compared to 0.3 in 1996 (J. Schmutz & K. Clayton pers. comm.).

The two largest irruptions documented in Alberta were both at Beaverhill Lake, in the winters of 2005-2006 and 2015-2016. We compiled 46 sightings from Beaverhill Lake in winter 2005-2006, covering 29 days between 29 November and 27 April (Fig. 3). The number of owls counted was variable, peaking at 191 on 17 April and as low as 0 on 20 February; however, the monthly maximum counts were all at least 70. We found the average number of owls observed

Figure 4 - Number of Short-eared Owls (*Asio flammeus*) detected versus time before sunset during winter 2005/06 at Beaverhill Lake, Alberta.

Figura 4 - Número de corujas-do-nabal (*Asio flammeus*) detetadas versus o tempo antes do ocaso durante o inverno de 2005/06 no Lago Beaverhill, Alberta.

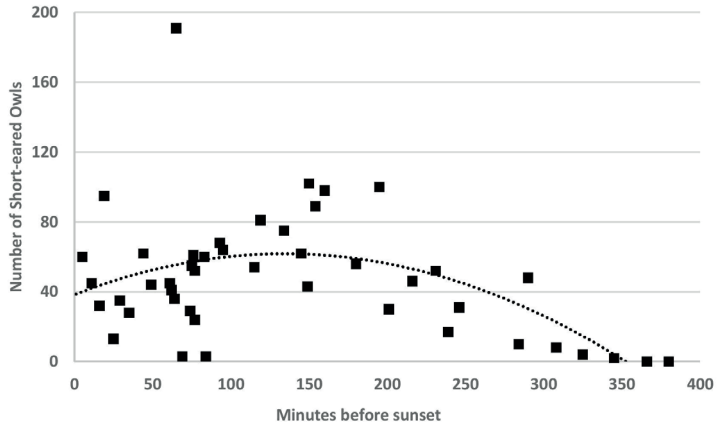
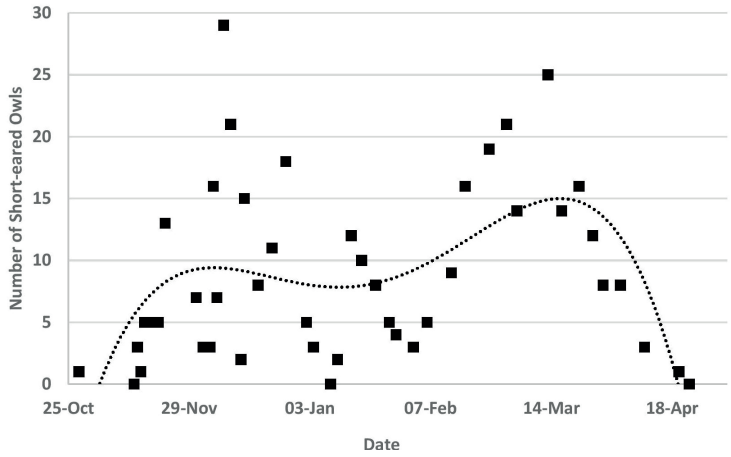


Figure 5 - The maximum number of Short-eared Owls (*Asio flammeus*) counted on each survey day during winter 2015-16 at Beaverhill Lake, Alberta.

Figura 5 - Número máximo diário de corujas-do-nabal (*Asio flammeus*) durante o inverno de 2015/16 no Lago Beaverhill, Alberta.

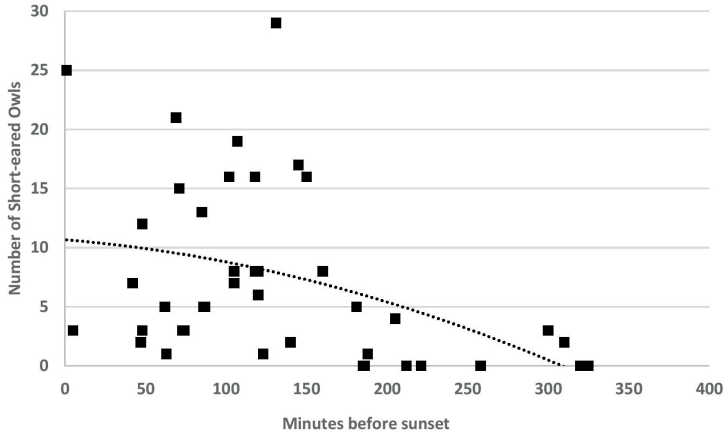


increased through the winter (r=0.39, P<0.01), but tapered off sharply in late April; despite the availability of seemingly suitable nesting habitat, no owls were observed during the subsequent breeding season. We received eight other records of Short-eared Owls from other parts of Alberta during the winter of 2005-2006, but none of them involved large numbers.

Owls were observed foraging at all times of the day but were more frequently observed 50-100 minutes before civil twilight (Fig. 4) (Priestley et al. 2008). There was no linear relationship between number of owls observed and time of day (P=0.94) (Priestley et al. 2008), however the

Figure 6 - Number of Short-eared Owls (*Asio flammeus*) detected versus time before sunset during winter 2015-16 at Beaverhill Lake, Alberta; the line represents the best fit of abundance relative to time before sunset.

Figura 6 - Número de corujas-do-nabal (*Asio flammeus*) detetadas versus o tempo antes do ocaso durante o inverno de 2015/16 no Lago Beaverhill, Alberta.



highest count was made 65 minutes before civil twilight.

During the 2015-2016 irruption at Beaverhill Lake, we compiled 54 owl surveys covering 51 days between 28 October and 3 May (Fig. 5). Owl numbers were lower than in 2005-2006 and were variable but appeared to show two peaks, one in early December (n=29) and the other in the middle of March (n=25). We found the number of owls observed increased as the time of day approached sunset (Fig. 6; r=0.43, P<0.01). On one occasion, two birders went out searching for Short-eared owls at 12:00 and observed none, but 25 individuals were counted beginning at 14:00.

Habitat use

For 21 telemetry-marked owls the average number of days from date of capture to last date detected by telemetry was 53 days (range 26-112). Home ranges for these 21 owls ranged from 49.3 to 1,256.1 ha (mean 217.7 ha, single SE limits 173.6 & 273.0).

Grass cover was most dominant at roosting sites and least abundant at non-use sites, forb cover was more than twice as extensive at foraging sites compared to elsewhere, shrub and tree cover were low throughout all areas, and bare ground was scarce except at non-use sites (Table 1). Vole runways were over 8 times more numerous at foraging sites than roosting sites and 12 times more than at non-use sites (Table 1). The number of vegetation strata and overall vegetation diversity were higher at roosting-only sites than elsewhere (Table 2).

Ground roost locations had significantly greater thatch depth, grass cover, maximum grass height, maximum forb height, number of vertical strata, and vegetation diversity (forms and strata) compared to both foraging fields and non-use fields (Table 3). Fields used for foraging had a significantly greater number of vole runways and significantly greater forb cover than either roost fields or non-use fields. Fields used for foraging also had significantly greater thatch depth, grass cover, maximum height of grass and forbs, and vegetation diversity compared to non-use fields. Non-use fields had a significantly greater amount of bare ground

Table 1 - Vegetation height and cover and vole runways at Short-eared Owl (*Asio flammeus*) field plots in New York.

Tabela 1 - Altura e cobertura da vegetação e trilhos de ratos-cegos nas parcelas ocupadas por coruja-do-nabal (*Asio flammeus*) em Nova Iorque.

	Foraging only (*n*=661)		Roosting only (*n*=183)		Roosting/ Foraging (*n*=58)		Non-use (*n*=181)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Grass cover (%)	78.80	27.79	91.35	15.65	83.64	27.57	44.01	42.74
Grass maximum height (cm)	26.36	26.94	57.27	38.11	31.77	18.47	13.99	12.72
Forb cover (%)	16.07	24.20	6.23	11.18	8.95	19.62	8.05	15.03
Forb maximum height (cm)	41.04	34.79	52.30	37.30	96.25	44.23	8.50	9.32
Shrub cover (%)	1.97	8.70	2.21	8.61	0.03	0.26	0.47	3.05
Shrub maximum height (cm)	60.17	71.23	56.14	68.74	0.00	0.00	0.00	0.00
Tree cover (%)	0.08	0.78	0.01	0.19	0.00	0.00	0.00	0.00
Bare ground cover (%)	3.17	10.89	1.89	10.07	6.64	18.86	44.34	39.47
# Vole runways	2.28	3.40	0.27	1.38	1.32	1.49	0.18	0.76

Table 2 - Vegetation growth forms and strata at Short-eared Owl (*Asio flammeus*) field plots in New York.

Tabela 2 - Formas de crescimento da vegetação e estratos nas parcelas ocupadas pela coruja-do-nabal (*Asio flammeus*) em Nova Iorque.

	Foraging only (n=631)		Roosting only (n=183)		Roosting/ Foraging (n=19)		Non-use (n=125)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number of growth forms	1.95	0.78	1.81	0.68	1.84	0.69	1.12	0.73
Number of strata	1.77	1.15	2.96	1.41	1.37	0.76	1.58	1.11
Diversity (forms x strata)	3.88	3.83	5.25	2.85	2.58	1.39	2.12	1.59
Thatch depth (cm)	4.92	3.87	5.91	5.53	7.16	6.94	1.49	3.03

compared to both fields used for roosting and fields used for foraging. In addition, soil was inundated more frequently at roost sites than at foraging sites, and unsaturated more frequently at foraging sites than at roost sites (Table 4; $X_2^2 = 65.74$, $P<0.0001$).

At some roost locations, pellets were found in pockets between vegetation where taller vegetation provided a backdrop. Plant species observed providing these conditions included: common reed (*Phragmites australis*), reed canary grass (*Phalaris arundinacea*), purple loosestrife (*Lythrum salicaria*), and various species of rushes (*Juncus* spp.), sedges (*Carex* spp.), and cattails (*Typha* spp.). Notably, these are all wetland species, which may correlate with the finding of more frequent soil inundation at roost plots.

At three of the 11 study areas, Short-eared

Table 3 - Statistical comparison of vegetation growth forms and strata at Short-eared Owl (*Asio flammeus*) field plots in New York.

Tabela 3 - Comparação estatística das formas de crescimento e estratos da vegetação em parcelas ocupadas pela coruja-do-nabal (*Asio flammeus*) em Nova Iorque.em Nova Iorque.

VARIABLE	F	df	*P*	NON-USE VS. FORAGING	ROOSTING VS. FORAGING	ROOSTING VS. NON-USE
Grass cover (%)	134.1	1021, 2	<0.0001	<0.0001	<0.0001	<0.0001
Grass maximum height (cm)	121.20	934, 2	<0.0001	<0.0001	<0.0001	<0.0001
Forb cover (%)	21.55	1021, 2	<0.0001	<0.0001	<0.0001	0.9396
Forb maximum height (cm)	43.66	985, 2	<0.0001	<0.0001	0.9572	<0.0001
Shrub cover (%)	2.885	1020, 2	0.0563	0.0643	0.9347	0.0963
Shrub maximum height (cm)	9.623	929, 2	<0.0001	0.0003	0.4748	0.0001
Tree cover (%)	1.44	980, 2	0.2370	0.3597	0.4215	0.9802
Tree maximum height (cm)	1.012	890, 2	0.3640	0.6392	0.4340	1.0000
Bare ground cover (%)	343.6	1011, 2	<0.0001	<0.0001	0.7102	<0.0001
# Vole runways	52.46	933, 2	<0.0001	<0.0001	<0.0001	0.9599
Number of growth forms	63.01	936, 2	<0.0001	<0.0001	0.0653	<0.0001
Number of strata	77.75	936, 2	<0.0001	0.2459	<0.0001	<0.0001
Diversity (forms x strata)	31.03	936, 2	<0.0001	<0.0001	<0.0001	<0.0001
Thatch depth (cm)	52.38	932, 2	<0.0001	<0.0001	<0.0001	<0.0001

Table 4 - Soil moisture counts for Short-eared Owl (Asio flammeus) habitat characterization in New York.

Tabela 4 - Valores de humidade do solo para caracterização do habitat da coruja-do-nabal (Asio flammeus) em Nova Iorque.

	INUNDATED	SATURATED	UNSATURATED	TOTAL
Foraging	25 (4.0%)	368 (58.6%)	235 (37.4%)	628
Roost	37 (20.7%)	109 (60.9%)	33 (18.4%)	179
Total	62	477	268	807

Owls roosted almost exclusively in conifers. These roosts were within one of three roost site types: Christmas tree farms or tree clusters, tree rows, and lone conifers. Roost trees therein included eastern white pine (*Pinus strobus*), Scots pine (*Pinus sylvestris*), white fir (*Abies concolor*), and blue spruce (*Picea pungens*). Individual roost tree height ranged from 0.6 to 8.0 m, with site roost tree height averages as follows: Christmas tree farms or tree clusters = 4.1 m; tree rows = 3.5 m; and lone conifers = 8.0 m. The average diameter at breast height of the roost trees at the three sites were 8.2, 10.3, and 17.5 cm, respectively. Roost heights averaged 1.1, 1.4, and 2.3 m, respectively, and were typically on the leeward (i.e., east/northeast) side of a given tree.

At the landscape level, public roads were not significantly farther from roosting sites

(470.4 ± 319.7 m) than from foraging sites (250.2 ± 184.9 m; $t_{8.13}$=-1.88, P=0.097). Perennial water sources were almost significantly closer to roosting sites (305.4 ± 314.7 m) than to foraging sites (651.4 ± 632.3 m; $t_{22.34}$=2.07, P=0.050). The areal extent of grassland was not significantly greater within 0.5 km of foraging vs. roosting sites (131.2 ± 41.1 ha vs. 76.7 ± 70.0 ha, $t_{8.17}$=2.12, P=0.066) but it was significantly greater within 1.6 km of foraging vs. roosting sites (910.8 ± 492.9 ha vs. 335.8 ± 454.3 ha, $t_{9.48}$=2.98, P=0.015). Analysis of landscape level data for non-use and roosting categories was not conducted due to low sample sizes.

Seven active nests were studied on Amherst and Wolfe Islands in Ontario in 2009 and 2010 (Keyes et al. 2016). In 2009, three of them were clustered within 2 km of each other in the south-central part of Amherst Island, while in 2010, another three were also within 2 km of each other on the eastern part of Amherst Island, ~5 km from the previous year's concentration. Five of the nests were in grazed grassland, with one each in a hayfield and a fallow field. Five of the seven nests were near grid wire fencing with wooden posts. All four nests that survived to nestling stage were within 540 m of a marsh or pond (mean 366 ± 181 m; range 175-540 m) and most were within 1,000 m of an occupied human residence (mean 767 ± 526 m; range 370-1,500 m).

Birdsfoot trefoil (*Lotus corniculatus*) and cow vetch (*Vicia sativa*) were found at five of the seven nests, Canada goldenrod (*Solidago canadensis*) and reed canary grass (*Phalaris arundinacea*) were observed at four nests, and smooth brome (*Bromus inermis*), red clover (*Trifolium pratense*), redtop (*Agrostis gigantea*), timothy (*Phleum pratense*), thistle (*Carduus* spp., *Cirsium* spp., *Silybum* spp.), and sedge species (*Carex* spp.) were each documented at three nests (Keyes et al. 2016). Vegetation was taller and grass cover was greater (70 ± 13%) surrounding nests than at any other survey quadrants, whereas forb cover and bare ground were more frequent away from nests (Keyes et al. 2016).

Discussion

Until recently, Short-eared Owl movement data were largely limited to band recoveries and mostly indicated short to moderate distance displacement (mean 308 km, L. Laurin pers. comm.). Initial satellite telemetry research in the early 2000s documented longer movements (e.g., ~1,500 km from Saskatchewan to Iowa, Migration Research Foundation 2007; ~1,900 km from southern Ontario to northern Quebec, Bird Studies Canada 2011; >2,000 km from central Alberta to Kansas, G. Holroyd & H. Trefry, unpub. data), but sample sizes were small and possibly not representative of populations. Johnson et al. (2017) showed that long-distance movement is typical for Short-eared Owls breeding in Alaska, with seven individuals tracked throughout fall migration traveling between 3,205 and 6,886 km (mean 4,722 ± 1,156 km) over a span of 61 to 147 d (mean 85.2 ± 31.8 d). Although migration routes were concentrated through western Yukon as well as southeastern Alberta and southern Saskatchewan, winter locations of these owls varied widely, spanning 21° of latitude from Montana to Texas, and 24° of longitude from California to Kansas; two other owls were farther south near Zacatecas, Mexico, and still on the move when transmissions ended. In contrast, the mean distance between wintering and breeding areas by New York owls (1,835 km) was more comparable to the previous result from southern Ontario, and there was much tighter migratory connectivity, with all of the owls occupying summer home ranges in Labrador or central-northern Quebec.

The lack of breeding site fidelity shown by western Short-eared Owls is like that observed for PTT-marked Burrowing Owls

(*Athene cunicularia*) (Holroyd & Trefry 2011; Holroyd et al. 2011) and Snowy Owls (*Bubo scandiaca*) (Fuller et al. 2003; Therrien et al. 2012). Like Snowy Owls, Short-eared Owls are rodent specialists, and presumably select their breeding areas annually in response to asynchronous fluctuations in prey populations (Kalela 1962; Korpimäki & Norrdahl 1991; Pitelka & Batzli 2007). Although owls from Alaska ranged widely, all stayed west of 95°W, whereas all of the owls from New York remained east of the upper Great Lakes. This is consistent with band recovery data, in which all Short-eared Owls banded in the Pacific or Atlantic flyways were recovered in the same flyway, whereas those from the Central and Mississippi flyways were occasionally encountered in adjacent flyways. This suggests that although Short-eared Owls are considered nomadic and breeding concentrations appear to shift considerably from year to year, there may be a divide in North America between western and eastern populations.

Satellite telemetry has also revealed the importance of stopover locations to Short-eared Owls. To some extent, pauses in migration that we observed were likely associated with encountering headwinds. However, the extended duration of several stays and the clustering of stopover sites suggests that some regions may be of particular value for this species and warrants further investigation. In particular, western Yukon and southeastern Alberta appear to be particularly important for western Short-eared Owls (Johnson et al. 2017), while corresponding areas in the east include the shorelines of Lake Erie and Lake Ontario, as well as parts of central Quebec.

Insights from our satellite telemetry research were somewhat constrained by using a less frequent transmission duty cycle designed to prolong PTT lifespan. While this had minimal influence on our ability to describe timing and displacement of long-distance movements, it yielded limited data for assessing habitat use at stopover locations and documenting fine-scale migration route details. The recent availability of lightweight GPS transmitters that can be safely worn by Short-eared Owls allows for much more precise documentation of habitat use (e.g., Calladine 2017), and we recommend the use of this technology for future study of Short-eared Owl movements.

Our VHF telemetry research provided the first estimates of winter home range size (mean 218 ha) for Short-eared Owls which were more than triple the mean size of breeding home ranges reported by Wiggins et al. (2006). There was, however, considerable variability in home range size. Many factors could drive winter range size, including small mammal densities, snow cover, and interspecific and intraspecific competition; results can also be influenced by sampling effort. At some sites, there were individuals, possibly subdominant, with much greater home ranges. Winter home range sizes for Short-eared Owls in Taiwan (Tseng et al. 2017) averaged nearly twice as large as in our study. The owls in Taiwan possibly differed in that they moved between different core areas every few days, whereas in our study, most owls that were tracked for longer periods of time remained in the same area throughout the winter months. However, we lost track of some individuals over the course of our study, so it is possible they also moved between different core areas.

Our results highlighted several distinctions between roosting and foraging locations. There was strong selection of foraging habitat with higher forb cover and greater vole activity. Typical ground roost sites in New York had tall, diverse, herbaceous cover and owls roosted at low heights in low to mid-height conifer trees. In his study of wintering Short-eared Owls in New York, Clark (1975) documented roosting in a quarry, a gravel pit, stubble fields, and conifer groves; Bosakowski (1986) also reported the use of conifer roosts. While we found three roost sites with conifers, most

roost sites in our study were on the ground either in old fields that had not been mowed for several years, or in hayfields that had not been mowed in late summer or fall. This supports the conclusion that wintering Short-eared Owls in New York prefer fields with taller, thicker, more diverse vegetation for ground roosting which provides owls with shelter from wind and protection from mammalian predators. During our study, we found the remains of several Northern Harriers (*Circus hudsonius*), which also roost on the ground, and tracks indicated Coyote (*Canis latrans*) as the likely predator in each case. In Taiwan, Tseng et al. (2017) also found owls roosting in tall grasslands and suggested avoidance of predators as one possible factor in roost site selection.

While avoidance of areas with human activity might be a factor in roost selection, two of the three conifer roosts observed in this study were near residences or barns, and others have been noted in New York State since the completion of our study. Similarly, during winter surveys we conducted on Amherst Island, Ontario, in January 2010, we found a roost of 18 Short-eared Owls in a red cedar (*Juniperus virginianus*) 3 m from an occupied residence. Availability of suitably-sized conifers for roosting may be limited in some areas, and the importance of shelter may outweigh the occasional disturbance by people and or pets, especially during extreme weather, when buildings may provide additional shelter from the elements.

The significantly higher number of vole runways in foraging plots is expected, given that voles are a primary prey item, and fluctuations in vole abundance have long been recognized as influencing Short-eared Owl numbers (e.g., Goddard 1935, Elton 1942). Most non-use fields identified were row crop fields or closely cut hayfields, which likely support lower prey densities.

High concentrations of voles are likely also at the basis of periodic concentrations of Short-eared Owls. Beaverhill Lake has been drying out since the late 1990s, with 2005 being the driest year since the early 1950s. In the summer of 2005, foxtail barley (*Hordeum jubatum*) colonized extensive portions of the dry lake bed. The prevailing northwest winds carried seeds to the southern shore of the lake and collected in piles >1 m high. As a result, microtine abundance, particularly Meadow Voles, spiked sharply, presumably in response to the increase in seeds as a source of food. In addition, below-average snowfall resulted in shallow snow cover, allowing Short-eared Owls access to the voles.

Despite the large number of Short-eared Owls present at Beaverhill Lake over a span of several months, there were occasions when very few or even none were observed. Although it is possible that there was some movement of birds within the region, sightings were not reported from surrounding areas. Moreover, same-day differences in counts suggest that variation in numbers was primarily a function of detectability, which in turn was highest within the last 1-2 hours of daylight. Our experience highlights how easy it is to overlook even unusually large concentrations of Short-eared Owls, and the importance of surveying late in the afternoon to optimize detection at wintering sites.

Although large numbers of Short-eared Owls remained at Beaverhill Lake into April in both 2006 and 2016, no local evidence of breeding was observed in either year, despite the availability of apparently suitable nesting habitat. Similarly, habitat across much of Amherst and Wolfe Islands appears suitable for breeding, yet nesting records were largely clustered in different areas in consecutive years of our study. These results suggest that there are important factors in habitat site selection that remain poorly understood and require further research. Our findings that Short-eared Owls preferentially nested adjacent to taller vegetation and near wooden fence posts are likely just site-specific details superimposed

on other criteria considered by the owls.

Our research, as summarized in this report and Gahbauer et al. (2021), has addressed aspects of the three Short-eared Owl conservation research priorities identified by Booms et al. (2014), namely better defining important habitat, improving population monitoring, and describing seasonal and annual movements. Our habitat studies highlight that, both in summer and winter, Short-eared Owls have some very specific microhabitat preferences, although these may well differ across the range of the species and warrant further investigation in other locations. Our telemetry results reinforced the belief that Short-eared Owls are highly mobile and have nomadic tendencies, although we discovered an apparent divide between eastern and western populations, with more consistency in movements in eastern North America.

The potential for ecological and behavioural differences between western and eastern North American Short-eared Owls may have implications for conservation and management and warrants additional study. Satellite telemetry of owls wintering in the US Midwest may be particularly important to target, since this is an area with relatively large wintering numbers, but the linkages to breeding areas remain unclear. Strong consideration should also be given to PTT-tagging owls during irruptions to investigate the area over which individuals from such congregations subsequently disperse. Stable isotope analysis of feathers collected from owls during winter irruptions would provide insights as to where the sampled feathers were grown, clarifying whether individuals from different breeding areas gather at such locations. More detailed and standardized study of the irruptions themselves is needed to better understand how owl numbers and activity levels vary in relation to time of day, season, and weather conditions. We recommend heightened awareness of the importance of irruptions to understanding Short-eared Owl ecology, and coordination of research and communication efforts across North America to track these occurrences over time and space. The use of GPS transmitters for any future satellite telemetry research will provide highly detailed location data that can be used to address questions like those above, as well as helping to continue refining our understanding of key habitat requirements in different parts of the species' range.

Acknowledgments

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Status and monitoring of Short-eared Owls (*Asio flammeus*) in North and South America

Estatuto e monitorização da coruja-do-nabal (*Asio flammeus*) na América do Norte e do Sul

Marcel A. Gahbauer[1*], Robert A. Miller[2], Neil Paprocki[3], Alejandro Morici[4], Adam C. Smith[5], David A. Wiggins[6]

1 Migration Research Foundation, Ottawa, Ontario, Canada

2 Intermountain Bird Observatory, Boise, Idaho, USA

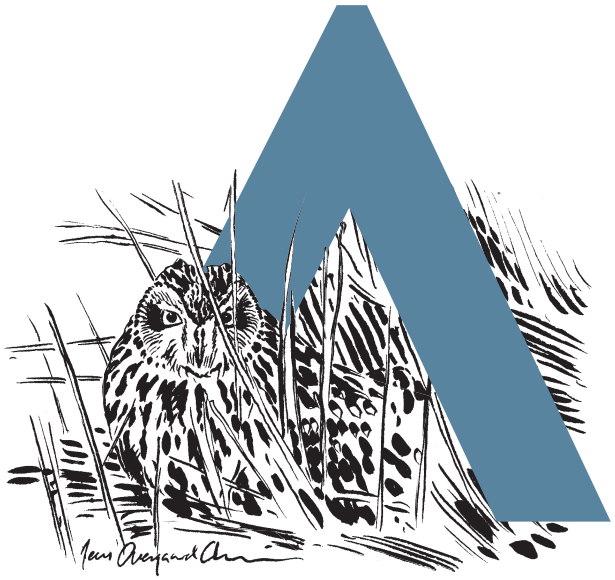
3 HawkWatch International, Salt Lake City, Utah, USA

4 Fundación Azara, Buenos Aires, Argentina

5 Canadian Wildlife Service, Environment and Climate Change Canada, Ottawa, Ontario, Canada

6 Uppsala, Sweden

*** Corresponding author:** marcel@migrationresearch.org



ABSTRACT

The breeding range of the Short-eared Owl (*Asio flammeus*) in North America includes all 13 Canadian provinces and territories, and approximately 25 states in the United States; the wintering range extends south to northern Mexico. It is listed as a species of Special Concern in Canada under the Species at Risk Act and subject to special protection in Mexico, but is not covered under the United States Endangered Species Act, although NatureServe has ranked the species as imperiled or critically imperiled in 21 states. In South America, it is found in eight countries, and is considered vulnerable in Argentina. Its conservation status is highly influenced by assessment of population trends, which are derived from multiple sources, each of which has advantages and limitations. In North America, both the Breeding Bird Survey and Christmas Bird Count reveal a widespread decline over the past half century, especially in the midwest and northeast United States. Several second-generation state and provincial breeding bird atlases have shown a reduction in the occurrence of Short-eared Owls compared to initial results approximately 20 years earlier. Overall though, traditional multi-species monitoring programs have not been effective at assessing Short-eared Owl populations. The Western Asio flammeus Landscape Study (WAfLS) is the first regional monitoring effort specific to this species, using standardized surveys and modeling the results using occupancy analysis. Over its first three years, it has already yielded

valuable data on population fluctuations, and the WAfLS approach can be readily adapted to other regions. In South America, monitoring to date has been more limited and further research is required, but it is thought there have also been widespread declines related to habitat loss.

Keywords: *Asio flammeus*, monitoring, Short-eared Owl, status, trends

RESUMO

A área de reprodução da coruja-do-nabal (*Asio flammeus*) na América do Norte inclui as 13 províncias e territórios Canadianos e 25 estados nos Estados Unidos. A área de invernada estende-se para Sul até ao norte do México. Está listada como espécie de *Special Concern* no Canadá no âmbito da Lei de Espécies em Risco e sujeita a proteção especial no México, mas não está abrangida pela Lei de Espécies Ameaçadas nos Estados Unidos, apesar de a organização *NatureServe* ter classificado a espécie como ameaçada ou criticamente ameaçada em 21 estados. Na América do Sul, está presente em oito países e é considerada vulnerável na Argentina. O seu estatuto de conservação é muito influenciado por estudos de tendências populacionais derivados de várias fontes, cada uma com vantagens e limitações. Na América do Norte, o Censo de Aves Nidificantes e a Contagem de Aves no Natal revelam um declínio generalizado ao longo do último meio século, especialmente no médio-oeste e no nordeste dos Estados Unidos. Vários atlas de aves reprodutoras de segunda geração, ao nível do estado ou da província, revelaram uma diminuição da ocorrência de coruja-do-nabal comparativamente aos resultados obtidos cerca de 20 anos antes. No geral, porém, os programas de monitorização multi-específicos não têm sido eficazes na avaliação das populações de coruja-do-nabal. O *Western Asio flammeus Landscape Study* (WAfLS) é o primeiro esforço de monitorização regional dirigido a esta espécie através de métodos de censo padronizados e modelação de resultados com análise de ocupação. Nos primeiros três anos, o estudo já produziu informação importante sobre flutuações populacionais e a abordagem WAfLS pode ser facilmente adaptada a outras regiões. Até à data, a monitorização na América do Sul tem sido mais limitada, sendo necessária mais investigação, embora se estime que também tenham ocorrido declínios generalizados devido à perda de habitat.

Palavras-chave: *Asio flammeus*, coruja-do-nabal, estatuto, monitorização, tendências

Introduction

The Short-eared Owl (*Asio flammeus*) has the largest global distribution of any owl species; in the western hemisphere, its range extends from the northern edge of Alaska (71.3ºN) to the southern tip of South America (55.7ºS) (Duncan 2003). In North America, it breeds in all 13 Canadian provinces and territories and roughly 25 states in the United States (U.S.), including Alaska and most of the lower 48 states north of approximately 42ºN; its regular wintering range extends from five provinces in southern Canada throughout the lower 48 states and into northern Mexico (Wiggins

et al. 2006). In South America, the Short-eared Owl is a permanent resident of most of Chile, Argentina, Paraguay, and Uruguay, and parts of Brazil, Peru, Colombia, and Venezuela. Although widespread, the species is uncommon to rare in much of its range, and has experienced long-term declines in North America, as well as in parts of Europe (COSEWIC 2008, European Commission 2016). Multiple threats to the species have been recognized, including loss of habitat through intensification of agriculture, urbanization and reforestation; and mortality through rodenticide poisoning, vehicle collisions, and mowing and harvesting (Duncan 2003, Wiggins et al. 2006, BirdLife International 2016, Environment Canada 2016).

Despite these concerns, relatively little conservation action has targeted Short-eared Owls, in part because its population status and trends are poorly documented in much of its range (Booms et al. 2014). In North America, there are several long-term programs to monitor bird populations, such as the Breeding Bird Survey (BBS), Christmas Bird Count (CBC), and breeding bird atlases (BBAs), but all of these have limitations in documenting trends in Short-eared Owls (Booms et al. 2014). Limited conservation funding and efforts tend to focus on other species for which declines are clearly documented and overlook those such as the Short-eared Owl where trends are less clear. In South America, knowledge about the distribution and abundance of the Short-eared Owl is even more limited.

Our objectives were to: 1) Summarize the status of the Short-eared Owl throughout its North and South American range; 2) Evaluate and compare existing sources of long-term bird data for effectiveness at monitoring Short-eared Owl trends; 3) Implement and evaluate a monitoring protocol specific to the Short-eared Owl; and 4) Provide recommendations to improve Short-eared Owl trend and status assessments.

Methods

Status review

We compiled the current legal status for the Short-eared Owl for each country (and in Canada and the U.S., for each province, territory, and state) by consulting the official websites for the relevant department in each jurisdiction (e.g., Ministry of Natural Resources, Division of Wildlife). We accessed the most recent (2016) national (N) and state/provincial/territorial (S) conservation rankings for the Short-eared Owl in North America through NatureServe Explorer (NatureServe 2018).

Trend analysis

The North American BBS is a standardized citizen science roadside survey that was started in 1966 and has become the basis for population and trend estimates for hundreds of species (Hudson et al. 2017). Each BBS route comprises 50 stops, 800 m apart, and is surveyed once annually during the peak of the breeding season. The Canadian Wildlife Service derives population trends for species from BBS data using a hierarchical Bayesian model (Smith et al. 2014). We reviewed long-term (1970-2016) and short-term (2006-2016) BBS trends for the Short-eared Owl at the national scale (U.S. and Canada), for the entire BBS study area (continental-scale), and for individual states and provinces. We did not use the published estimates of population trends from the BBS data (e.g., Sauer et al. 2017, ECCC 2017a) that rely on year-to-year, pairwise comparisons of abundance between the first and last years, because they are designed to be sensitive to annual population fluctuations that are well supported by the data (Smith et al. 2014). Because Short-eared Owl observations in the BBS data show extreme annual fluctuations (annual indices of abundance regularly fluctuate by a factor of two between years)

that most likely reflect movements of owls in and out of the BBS survey-area and not continental population fluctuations, we instead used an alternative estimate of long-term trend that is less sensitive to annual fluctuations. This estimate uses the slope of a log-linear regression through the published indices of annual abundance as a better estimate of the overall average rate of change in the population (hereafter, "slope-trend"). Using the full Markov chain Monte Carlo (MCMC) output from the standard hierarchical Bayesian analysis, we calculated the 95% credible intervals of these slope-trends as a measure of uncertainty. We calculated trends for the full BBS study area ("North America"), Canada, the U.S., and each of the states and provinces, to demonstrate the spatial patterns in population trends.

BBAs have been published for 41 U.S. states and eight Canadian provinces, and are currently underway for the first time in an additional province. They typically are based on field observations from hundreds of volunteer participants over a period of several years, and map the distribution of possible, probable, and confirmed breeding records for each species in a region. In jurisdictions where "second generation" atlases have been completed, maps or text generally illustrate changes in populations since the first atlas. We focused on the 13 states and six provinces where a second atlas has been completed, to describe changes in the occurrence of Short-eared Owls.

The CBC was started at 25 locations in 1900 and has grown to be an annual tradition throughout North America and beyond. Data are collected once annually between 14 December and 5 January at each 24 km radius count circle, maintained in the same place over time. Population trends are derived from the CBC data using a hierarchical Bayesian model (Soykan et al. 2016). We included updated long-term (1970-2016) and short-term (2006-2016) trend estimates at the continental scale, as well as long-term trends for states and provinces (Meehan et al. 2018). As we did for the BBS, we used the full MCMC output to calculate slope-trends for each state and province, Canada, the U.S., and North America (Canada and the U.S. combined).

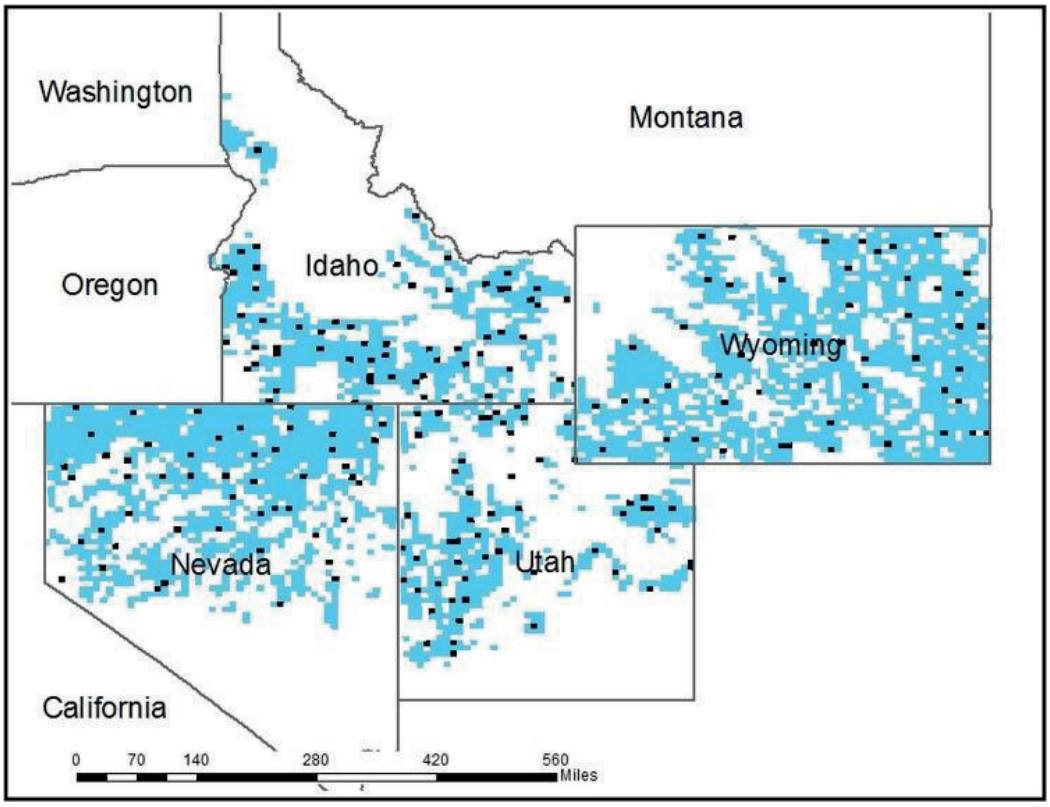
The most recently developed citizen science portal for bird data is eBird, founded by the Cornell Lab of Ornithology and National Audubon Society in 2002 (Sullivan et al. 2009). Unlike the BBS, BBAs, and CBC, which have formal methods, timelines, and analytical frameworks, eBird encourages observations to be reported from anywhere at any time. Although standard approaches to trend estimation from eBird data have yet to be established, existing tools for exploring the database allow for generation of simple summaries. We explored differences in winter (December to February) and summer (June-July) distribution as a complement to BBS and CBC results, using the 'species maps' feature and filtering for the most recent decade (2008 to 2017).

Standardized monitoring - WAfLS

To better understand population changes at a regional scale, we established the Western Asio flammeus Landscape Study (WAfLS) in Idaho and Utah in 2015 (Miller et al. 2016b). Surveys were repeated in 2016 (Miller et al. 2016a) and expanded in 2017 to also include Nevada and Wyoming (Miller et al. 2017). We stratified this region by first laying a 10 x 10 km grid over the four states, and within these grid cells, we quantified presumed Short-eared Owl habitat, i.e., areas of grassland, shrubland, marshland/riparian, and agriculture land cover classes (Wiggins et al. 2006), choosing grids for our stratum with at least 70% land cover consisting of any of these four classes. The result consisted of 9,460,000 ha in Idaho, 10,260,000 ha in Nevada, 7,760,000 ha in Utah, and 13,810,000 ha in Wyoming (Fig. 1).

Figure 1 - Western *Asio flammeus* Landscape Study Project survey strata (blue squares) and spatially-balanced survey transects (black squares) for Short-eared Owl surveys during the 2017 breeding season across the United States of Idaho, Nevada, Utah, and Wyoming.

Figura 1 - Locais de amostragem estratificada (quadrados azuis) e transectos de monitorização espacialmente equilibrados (quadrados pretos) do *Western Asio flammeus Landscape Study Project* para monitorização de corujas-do-nabal durante a época de reprodução de 2017 nos Estados Unidos de Idaho, Nevada, Utah e Wyoming.



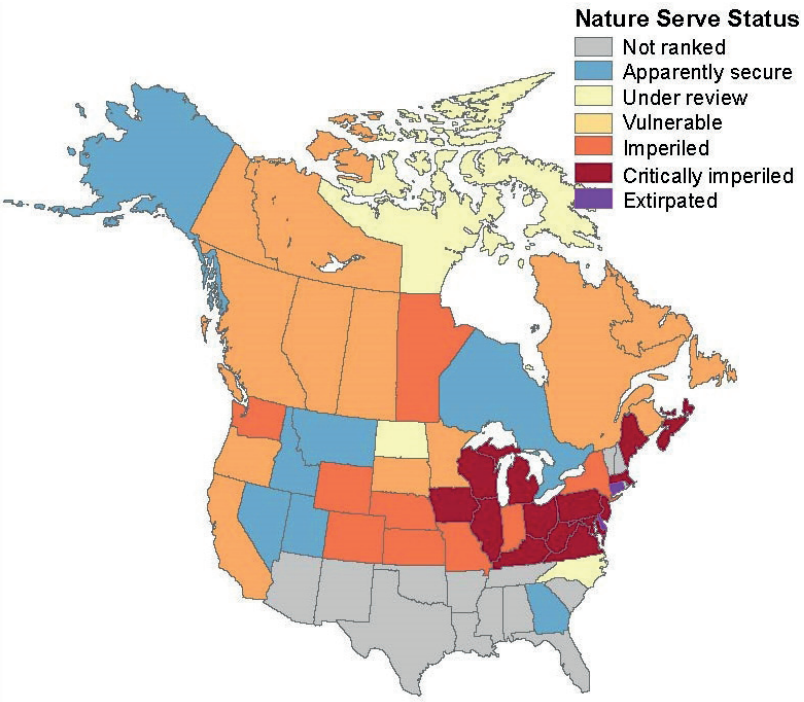
We selected a spatially-balanced sample of 50 survey transects per state within the stratum using a Generalized Random-Tessellation Stratified (GRTS) process (Stevens Jr. & Olsen 2004) (Fig. 1). For each transect, we delineated a ~9 km survey route along secondary or tertiary roads, which was the maximum survey length feasible using the protocol, and our justification for choosing a 10 x 10 km grid (Larson & Holt 2016).

Larson & Holt (2016) report that under favorable conditions Short-eared Owls can be correctly identified up to 1,600 m away, with high detectability up to 800 m. Calladine et al. (2010) had a mean initial detection distance of 500 – 700 m, with a maximum recorded value of 2,500 m. As our analysis method is robust against false negative detections, but less so against false positive detections, we chose to assume a larger average initial detection distance of 1 km. Therefore, we considered all land within 1 km of the surveyed points as sampled habitat.

We recruited volunteers to complete survey routes across the four states (Fig. 1). Approximately two-thirds of our volunteers were non-professional citizen scientists, whereas one-third were professional

Figure 2 - NatureServe status of the Short-eared Owl (*Asio flammeus*) in all states, provinces, and territories in the United States and Canada.

Figura 2 - Estatuto *NatureServe* da coruja-do-nabal (*Asio flammeus*) em todos os estados, províncias e territórios dos Estados Unidos e Canadá.



biologists either volunteering to survey routes or assigned by their agency or company to complete the route (e.g., on restricted lands). We provided reference materials (e.g., owl identification), a procedure manual, a freely accessible YouTube training video (Paprocki 2017), maps, civil twilight schedules, and datasheets to volunteers to promote survey quality. We asked volunteers to submit data via an online portal.

Observers attempted to complete two surveys per transect, one during each of two three-week survey windows, scheduled in relation to elevation. Survey timing was chosen to coincide with courtship, the period of highest detectability when male Short-eared Owls perform elaborate courtship flights. Observers surveyed eight to 11 points, separated by approximately 800 m, during the 90-minute span from 100 to 10 minutes prior to the end of local civil twilight (Larson & Holt 2016). At each point observers performed a 5-minute point count, noting each individual bird minute-by-minute (e.g., for an owl observed only during minutes 2 and 3 of the 5-minute period, we would assign a value of "01100").

We performed multi-scale occupancy modeling for its strength in evaluating fine-scale (point-scale in our case) habitat associations and providing a more refined alternative to abundance

estimation. (Nichols et al. 2008, Pavlacky et al. 2012). We implemented a minute-by-minute replacement design, allowing for simultaneous evaluation of detection, point-scale occupancy, and transect-scale occupancy (Nichols et al. 2008).

We also performed Maximum Entropy (MaxEnt) modeling, which provides study-wide habitat mapping, integrating current and future climate scenarios into the predictions (Phillips et al. 2006, 2017). We produced study-wide raster maps of the proportion of each cover type within 150 m of each 30 × 30 m pixel on the landscape (e.g., shrubs, sage, grass, etc.). Similarly, we created study-wide maps of elevation, slope, roughness, and an ecological relevant sample of the 19 standard climate variables derived from 1960–1990 (worldclim.org, Hijmans et al. 2005). All values were then resampled down to 30-second blocks (~1 km, matching resolution of the climate data) using bilinear interpolation. We used all presence and pseudo-absence (locations that we failed to detect owls but cannot be certain that they were absent) observations from the past three years (2015-2017) in the analysis. The result is that the model best represents Idaho with three years of data, then Utah with two years of data, and lastly Nevada and Wyoming with the most limited data.

We conducted all statistical analyses in Program R and Program Mark (White & Burnham 1999, R Core Team 2017). We used the R package "RMark" to interface between Program R and Program Mark for the multi-scale occupancy modeling (Laake 2014). We used R package "AICcmodavg" to rank all models (calculating AICc), and to perform model averaging (Mazerolle 2015). We used R package "dismo" (Hijmans et al. 2017), interfacing with the MaxEnt software engine (Phillips et al. 2017), for all MaxEnt analyses. We used R package "ENMeval" for ranking and evaluating MaxEnt models (Muscarella et al. 2014).

Regional documentation in South America

In South America, the status and distribution of the Short-eared Owl remains poorly understood in most regions. Proyecto Asio was launched in 2015 in honour of the late Argentinian naturalist Juan Carlos Chebez, who was instrumental in the establishment of several national parks and other protected areas. He was a leading voice for endangered species who had noted concerns over the decline of Short-eared Owl in Argentina due to anthropogenic causes and lamented the limited knowledge about the species.

Taking advantage of the growth of social media networks, and in particular the many nature photographers and bird watchers eager to share their observations, we established a Facebook group for Proyecto Asio (Facebook 2017). Members are invited to share all of their sightings, including photo documentation, location, habitat, and date. The data are compiled annually, summarizing occurrences by locality, province, and habitat, which together provides an overview of Short-eared Owl numbers, including statistics such as mortalities (Morici 2016, 2017).

Results

Status review

The Short-eared Owl is listed as Special Concern in Canada (ECCC 2017b) and Vulnerable in Argentina (MAyDS y AA 2017) and is subject to special protection in Mexico (Semarnat 2010). but has it no official national conservation status in other countries in North or South America. In Canada it is also listed as Threatened in two provinces and Special Concern in four others, while in the U.S. it is Endangered in 12 states, Threatened in two states, and Special Concern in three states (Fig. 2).

Figure 3 - Legal status of the Short-eared Owl (*Asio flammeus*) in all states, provinces, and territories in the United States and Canada.

Figura 3 - Estatuto legal da coruja-do-nabal (*Asio flammeus*) em todos os estados, províncias e territórios dos Estados Unidos e Canadá.

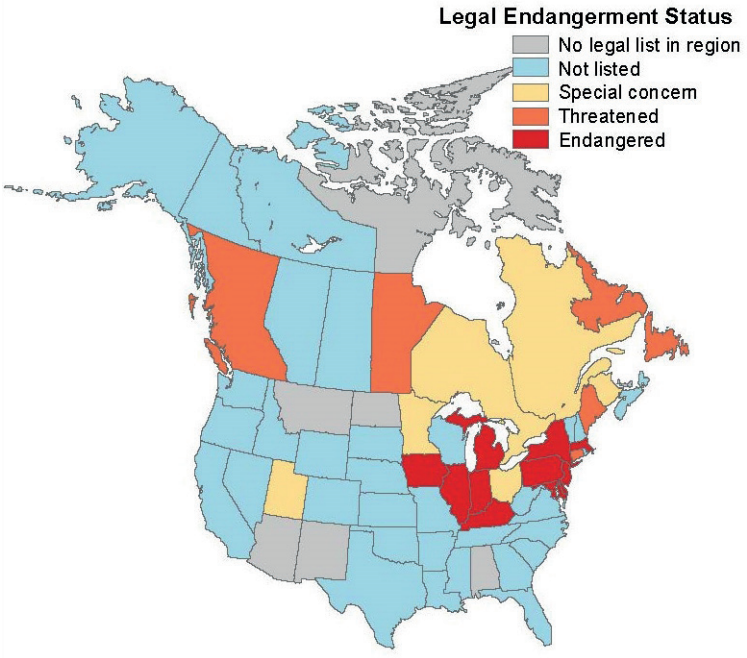
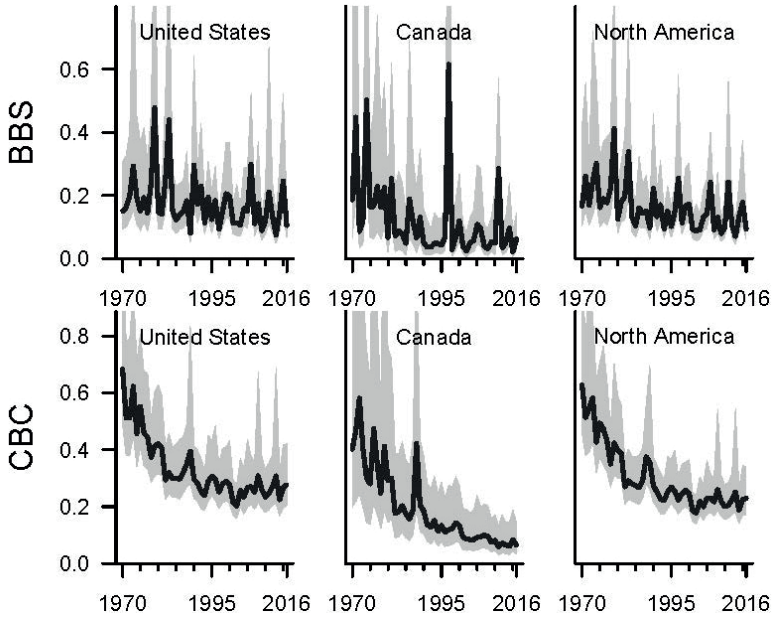


Figure 4 - Short-eared Owl (*Asio flammeus*) population trajectories from 1970 to 2016 based on Breeding Bird Survey (BBS) and Christmas Bird Count (CBC) data for the United States, Canada, and North America. Black lines indicate the estimated mean count of Short-eared Owls on a BBS route or CBC circle within the regions included in each analysis (see maps in Figures 5 and 6). The grey areas around the black lines represent the 95% credible intervals on the estimated means.

Figura 4 - Tendências populacionais de coruja-do-nabal (*Asio flammeus*) de 1970 a 2016 com base em dados do *Breeding Bird Survey* (BBS) e do *Christmas Bird Count* (CBC) para os Estados Unidos, Canadá e América do Norte. As linhas pretas indicam o número médio estimado de corujas-do-nabal no BBS ou no CBC, nas regiões incluídas em cada análise (ver mapas nas Figuras 5 e 6). As áreas a cinzento em torno das linhas pretas representam os intervalos de 95% de confiança das médias estimadas.



NatureServe (2018) has also ranked the status of Short-eared Owl in North America at the state (U.S.) and provincial and territorial (Canada) level. It considers the species critically imperiled (S1) in 12 states and three provinces, imperiled (S2) in nine states and one province, vulnerable (S3) in four states, six provinces, and two territories, and possibly extirpated (SH) in two states and the District of Columbia; the species is only classified as apparently secure (S4) in six states and one province, unranked in three states and one territory, and too scarce to be assessed in the other 13 states (Fig. 3). Status is particularly poor in the U.S. Midwest (S1 or S2 in seven of eight states) and Northeast (S1, S2, or SH in 10 states, and unranked in the other three), while the few apparent strongholds of the species based on assessed status are Ontario, Alaska, and four states in the Intermountain West: Montana, Idaho, Nevada, and Utah. The Short-eared Owl and Long-eared Owl (*Asio otus*) are the only owl species in North America to be considered extirpated from multiple states (NatureServe 2018). Despite the preponderance of S1-S3 ranks throughout North America, NatureServe (2018) lists the Short-eared Owl as secure (N5) in the U.S. and apparently secure (N4) in Canada, although the U.S. rank has not been updated since 1997, whereas Canada's was reviewed in 2012 and 2018.

Trend analysis

Since 1970, Short-eared Owl populations have declined in North America (Canada and the U.S.) by approximately 51% according to the BBS, which surveys during the breeding season, and by approximately 62% according to the CBC, which surveys during the non-breeding season (Fig. 4, and the open circles in Figs. 5 and 6). In Canada, the species' population has decreased by more than 50% since 1970 in all provinces, while in the U.S. state-level populations show a more mixed response and include some states where the species population has changed little or even increased (states near the bottom of the plots in Figs. 5 and 6). Because the Short-eared Owl is recorded infrequently by the BBS, sufficient data exist for long-term trend analysis in only 12 states, four provinces, and one territory. While trends are negative across all jurisdictions, populations that breed in the Great Plains of the U.S. appear to be declining at a slower rate than those elsewhere (Fig. 7). Similarly, there are sufficient long-term CBC data for analysis for 27 states and four provinces; of these, 22 (71%) show a cumulative decline of at least 50%, and there is an increasing trend in only five central states, from Oklahoma northeast to Indiana (Fig. 8). The most recent (2006-2016) BBS trends suggest a continuing widespread decline across North America, whereas CBC data over this period show a more stable pattern in the U.S. but a continuing decline in Canada (Fig. 1 and the open circles in Figs. 5 and 6).

Second-generation BBAs have been completed in six provinces and 13 states (Cadman et al. 2007, Federation of Alberta Naturalists 2007, New York State Breeding Bird Atlas 2007, Ellison 2010, Youngman 2011, Wilson et al. 2012, Renfrew 2013, Stewart et al. 2015, Colorado Bird Atlas Partnership 2016, Mollhoff 2016, Rodewald et al. 2016, Breeding Bird Atlas Explorer 2017a,b, Iowa Department of Natural Resources 2017, Mass Audubon 2017, Quebec Breeding Bird Atlas 2017, South Dakota Game, Fish, and Parks no date). The number of squares with possible, probable, or confirmed breeding evidence declined in 10 atlases (range -17% to -100%; mean -62%), remained unchanged in three atlases, and increased slightly in five atlases (range 5% to 17%; mean 10%) (Fig. 9). Of the 12 atlases reporting the number of squares with confirmed breeding, seven had a decline (range -20% to -100%; mean -58%), three were unchanged (all remaining at zero), and only one increased (from one

Figure 5 - Estimated changes in Short-eared Owl (*Asio flammeus*) populations over the long-term (1970-2016; black lines, solid circles) and short-term (2006-2016; gray lines, open circles), from the Breeding Bird Survey (BBS) for North America, United States, Canada, and individual states and provinces with enough data for analysis. Points represent the mean estimated change in the population (e.g., -50 represents a 50% decrease in population over the associated time-period), and error bars show the 95% credible intervals around the estimated change.

Figura 5 - Variação das estimativas populacionais de coruja-do-nabal (*Asio flammeus*) calculadas a partir do *Breeding Bird Survey* (BBS) no longo prazo (1970-2016; linhas pretas, círculos pretos) e curto prazo (2006-2016; linhas cinzentas, círculos sem preenchimento), na América do Norte, Estados Unidos, Canadá, e estados e províncias com dados suficientes para análise. Os pontos representam a variação média estimada da população (por exemplo, -50 representa uma diminuição de 50% na população ao longo do período de tempo associado) e as barras de erro mostram os intervalos de confiança de 95% da alteração estimada.

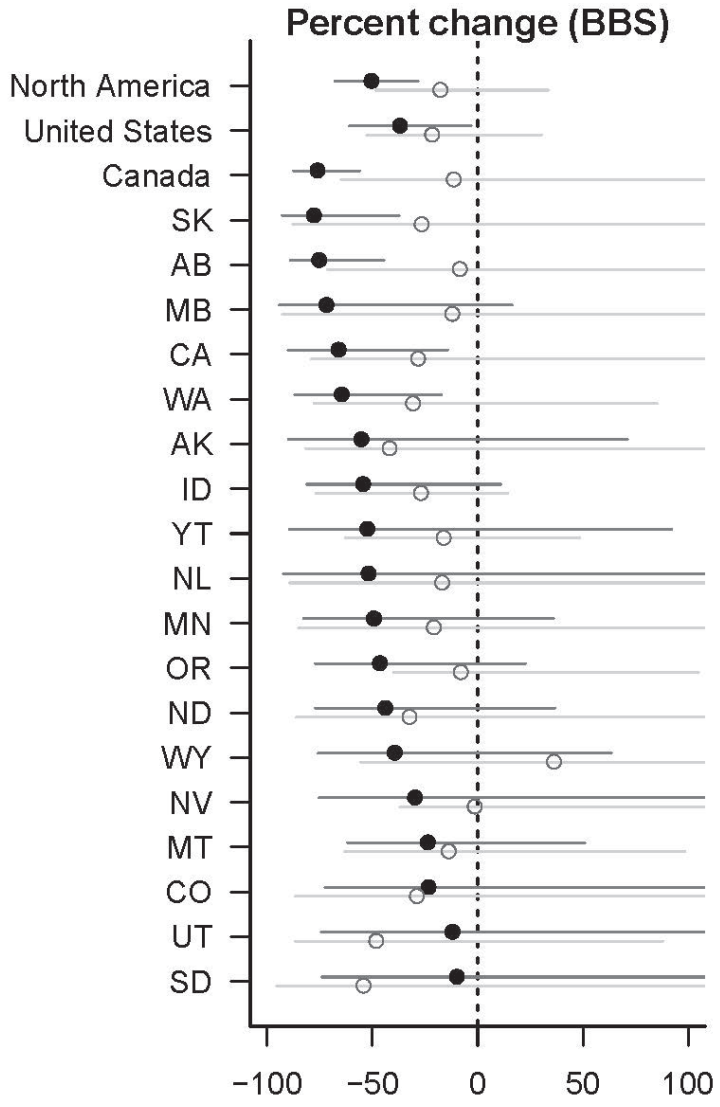


Figure 6 - Estimated changes in Short-eared Owl (*Asio flammeus*) populations over the long-term (1970-2016; black, solid circles) and short-term (2006-2016; gray, open circles), from the Christmas Bird Count (CBC) for North America, United States, Canada, and individual states and provinces with enough data for analysis. Points represent the mean estimated change in the population (e.g., -50 represents a 50% decrease in population over the associated time-period), and error bars show the 95% credible intervals around the estimated change.

Figura 6 - Variação das estimativas populacionais de coruja-do-nabal (*Asio flammeus*) calculadas a partir do *Christmas Bird Count* (CBC) no longo prazo (1970-2016; círculos pretos, sólidos) e a curto prazo (2006-2016; cinza, círculos sem preenchimento), na América do Norte, Estados Unidos, Canadá, e estados e províncias individuais com dados suficientes para análise. Os pontos representam a variação média estimada da população (por exemplo, -50 representa uma diminuição de 50% na população ao longo do período de tempo associado) e as barras de erro mostram os intervalos de confiança de 95% da variação estimada.

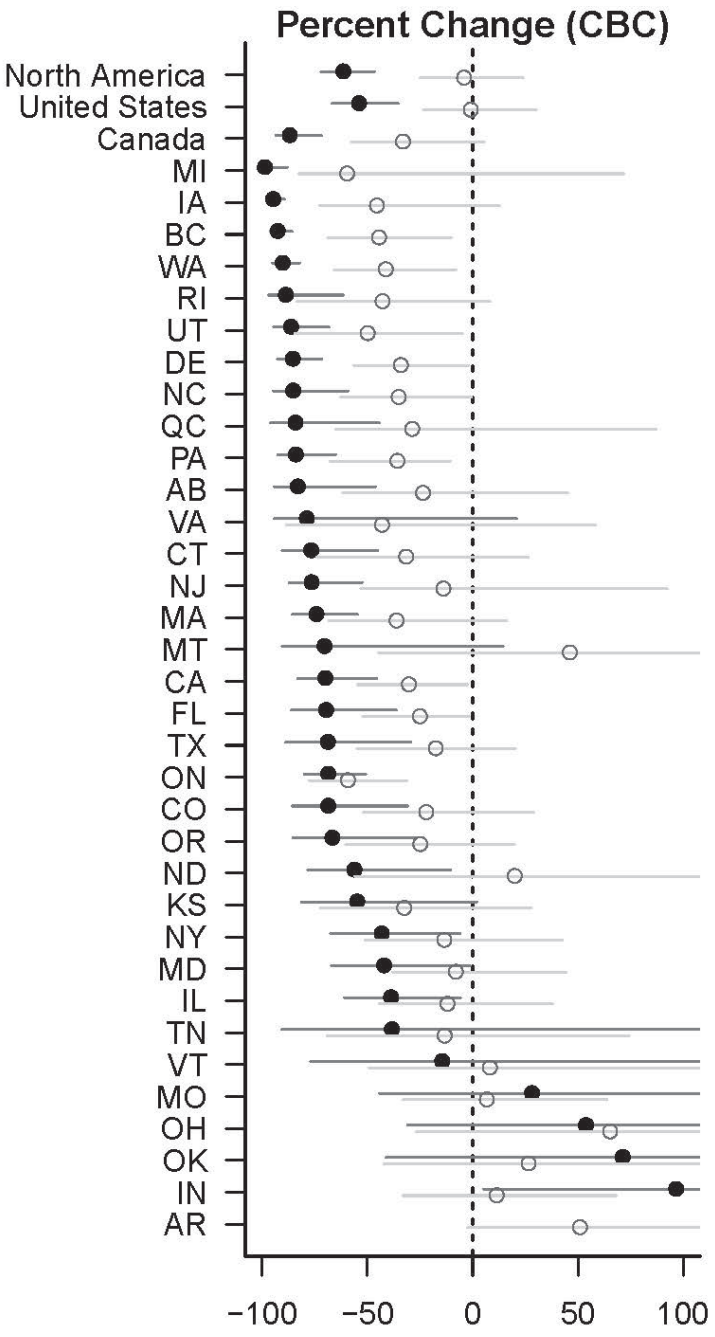


Figure 7 - Cumulative Short-eared Owl (*Asio flammeus*) population change in states, provinces, and territories of United States and Canada from 1970 to 2016, based on Breeding Bird Survey data.

Figura 7 - Variação cumulativa da população da coruja-do-nabal (*Asio flammeus*) em estados, províncias e territórios dos Estados Unidos e Canadá de 1970 a 2016, com base nos dados do *Breeding Bird Survey*.

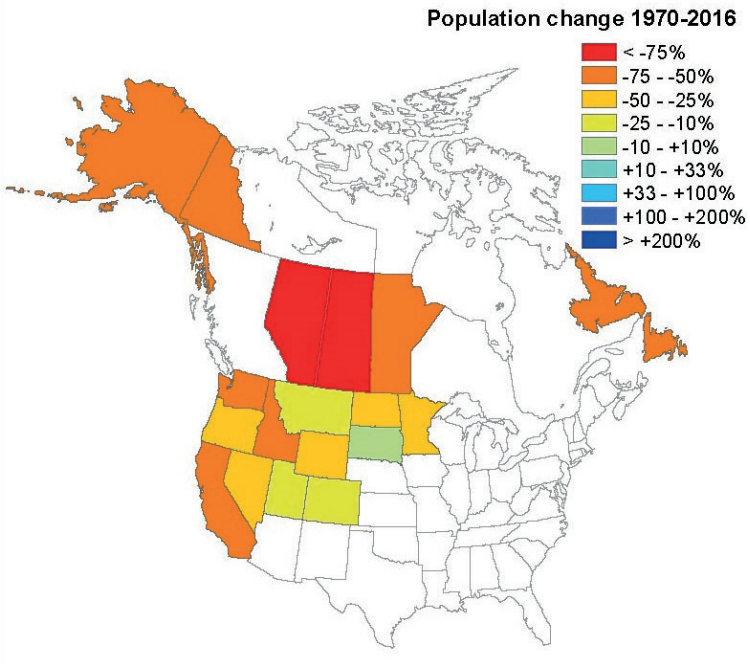


Figure 8 - Cumulative Short-eared Owl (*Asio flammeus*) population change in states, provinces, and territories of United States and Canada from 1970 to 2016, based on Christmas Bird Count data.

Figura 8 - Variação cumulativa da população da coruja-do-nabal (*Asio flammeus*) nos estados, províncias e territórios dos Estados Unidos e Canadá de 1970 a 2016, com base nos dados do *Christmas Bird Count*.

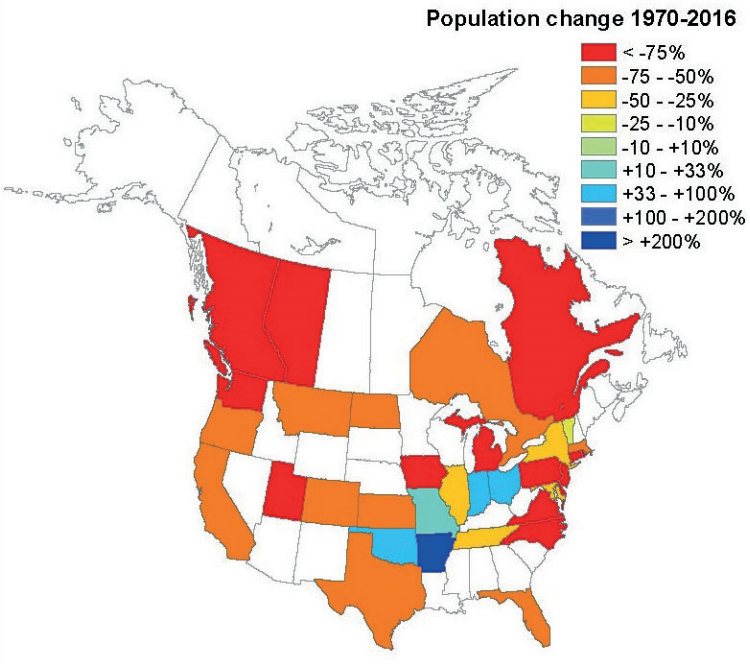
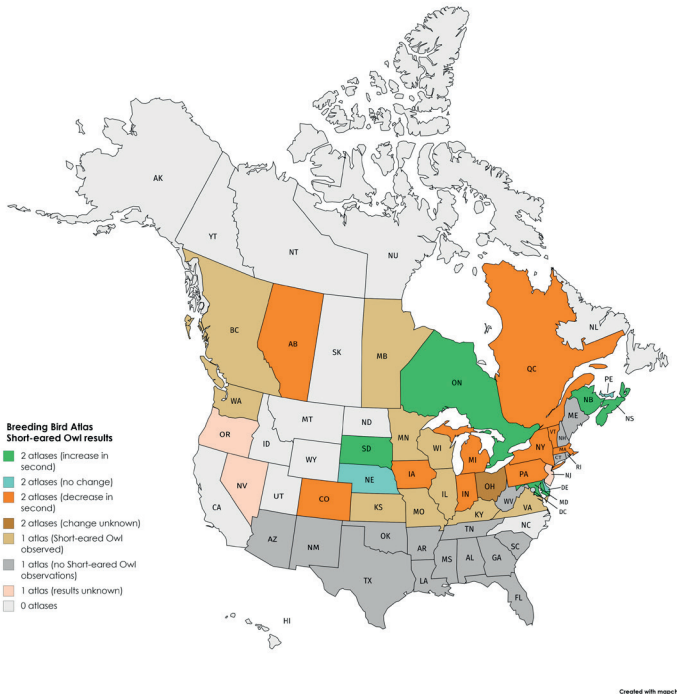


Figure 9 - Breeding Bird Atlas results for the Short-eared Owls (*Asio flammeus*) across the United States and Canada.

Figura 9 - Resultados do *Breeding Bird Atlas* para a coruja-do-nabal (*Asio flammeus*) nos Estados Unidos e Canadá.



to two squares).

Three of five jurisdictions reporting increases between atlases were in Canada. In the Maritime provinces, the number of occupied blocks remained unchanged in Prince Edward Island and increased marginally in New Brunswick and Nova Scotia. Of note, however, the majority (76%) of blocks with detections during the first atlas were no longer occupied during the second, but these local losses were offset by records at other sites where none were documented previously (Lauff 2015). Similarly, in Ontario, only 12 squares were occupied during both Ontario BBA periods, but there were observations in 59 new blocks, whereas there were no new records for 51 blocks with data from the first atlas (Gahbauer 2007). This pattern was also apparent in some jurisdictions showing overall declines. For example, only five survey blocks were occupied during both New York BBAs, compared to 31 just in the first and 19 only in the second (New York State Breeding Bird Atlas 2007).

An additional 30 jurisdictions have completed a first BBA, 27 (90%) of which have readily available results. Of these, 17 (63%) reported no Short-eared Owls (Nicholson 1997, Wiedenfeld & Swan 2000, Benson & Arnold 2001, Florida Fish and Wildlife Conservation Commission 2003, Reinking 2004, Corman & Wise-Gervais 2005, Haggerty 2009, Schneider et al. 2010, South Carolina Breeding Bird Atlas 2015, Breeding Bird Atlas Explorer 2017c,d,e,f,g,h, Arkansas Breeding Bird Atlas no date, Goodman no date). In the other 10 jurisdictions the species was consistently rare, with possible, probable, or confirmed breeding evidence at a mean of 0.4% of squares with survey data (range 0.1% to 1.0%) in eight states specifying coverage (Cutright 2003, Breeding Bird

Figure 10 - All eBird records for the Short-eared Owl (*Asio flammeus*) in North America during a) Summer (June-July) and b) Winter (December-February) for 2008-2017. From lightest to darkest, the five shades of purple represent geographic blocks in which 0-2%, 2-10%, 10-25%, 25-40%, or 40-100% of checklists submitted include Short-eared Owl.

Figura 10 - Registos totais do eBird para a coruja-do-nabal (*Asio flammeus*) na América do Norte durante a) o verão (junho-julho) e b) o inverno (dezembro-fevereiro), em 2008-2017. Do mais claro para o mais escuro, os cinco tons de roxo representam blocos geográficos nos quais 0-2%, 2-10%, 10-25%, 25-40% ou 40-100% das listas de verificação enviadas incluem a coruja-do-nabal.

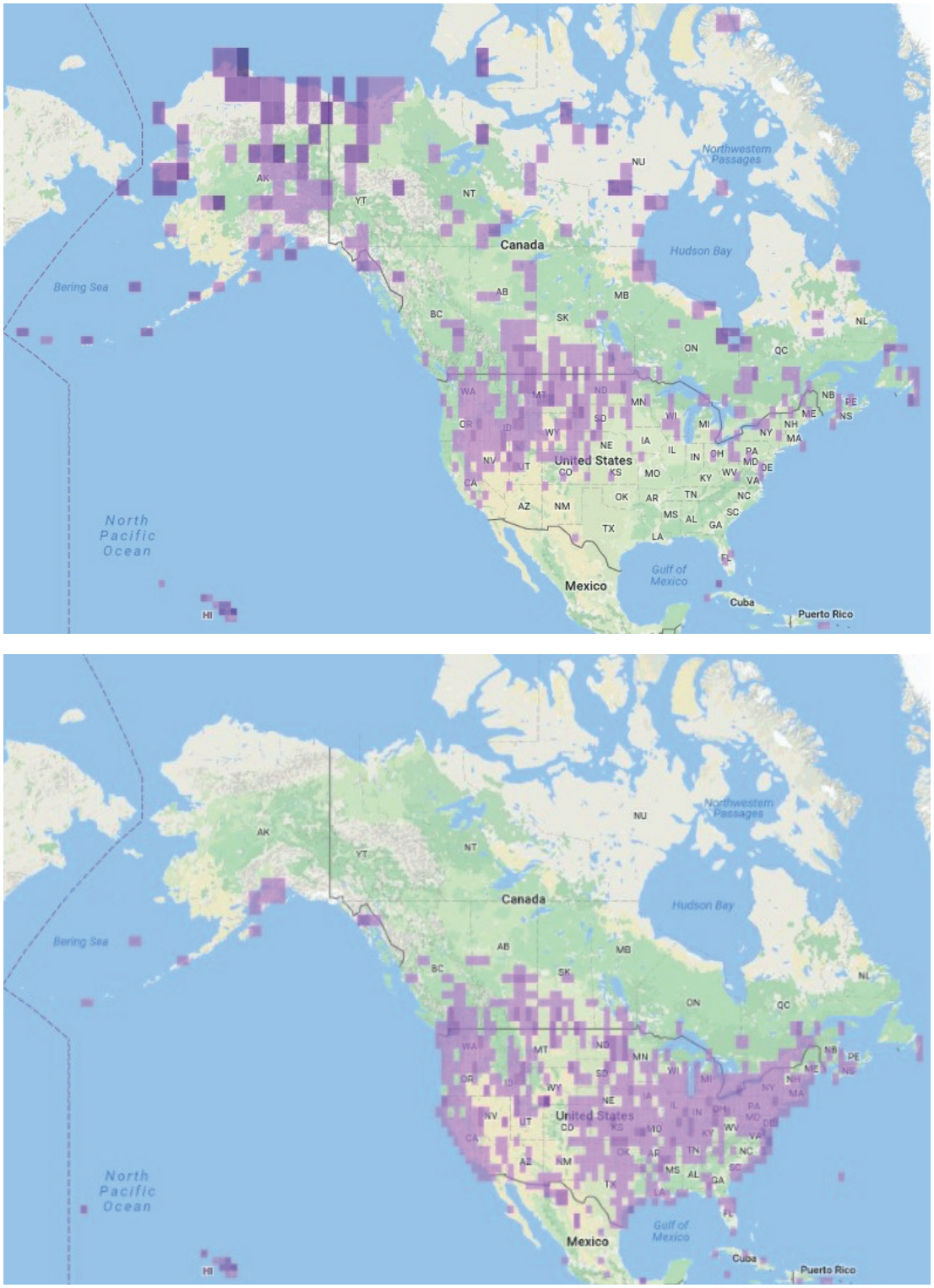
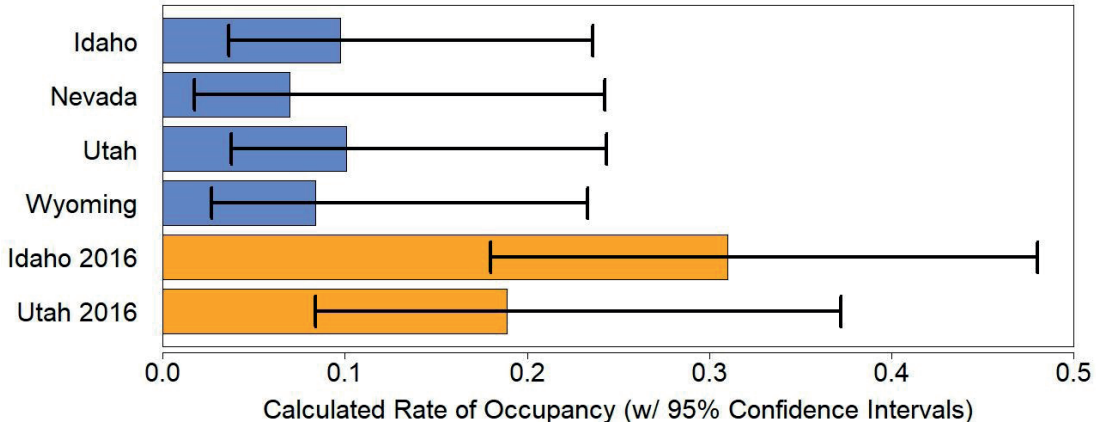


Figure 11 - 2017 Estimated Short-eared Owl (*Asio flammeus*) survey occupancy rates in four United States with 95% confidence intervals (blue) and 2016 results for comparison (orange).

Figura 11 - Taxas de ocupação estimadas da coruja-pequena (*Asio flammeus*) em 2017 em quatro Estados Unidos com intervalos de confiança de 95% (azul) e resultados de 2016 para comparação (laranja).



Atlas Explorer 2017i,j,k,l,m,n, Pfannmuller et al. 2017), and a mean of 1.8% in two provinces (range 1.0% to 2.7%) (Cannings 2015, Artuso 2017).

Reviewing eBird data at the continental scale over the past 10 years provides a snapshot of distribution and relative abundance to complement other survey data. Summer (June to July) observations show breeding season concentrations in the northwest lower 48 U.S. states and adjacent southern Canadian prairies, as well as in parts of Alaska, whereas records in the eastern half of the continent are much more scattered (Fig. 10a). Winter (December to February) records show a somewhat more uniform distribution across most of the lower 48 states and adjacent southern edge of Canada, with the most notable gap in distribution associated with the Rockies and upper Great Plains (Fig. 10b). There appears to be a heavier relative concentration in eastern North America in winter, and overall there is relatively little overlap between the areas with the most observations in summer and winter.

Standardized monitoring - WAfLS

In 2017, 330 people took part in surveys for project WAfLS, contributing 4,315 volunteer hours and traveling 91,077 km to complete the surveys, including preparation, training, and travel to and from survey areas. Short-eared Owls were detected on 13 of the 174 survey grids that were completed.

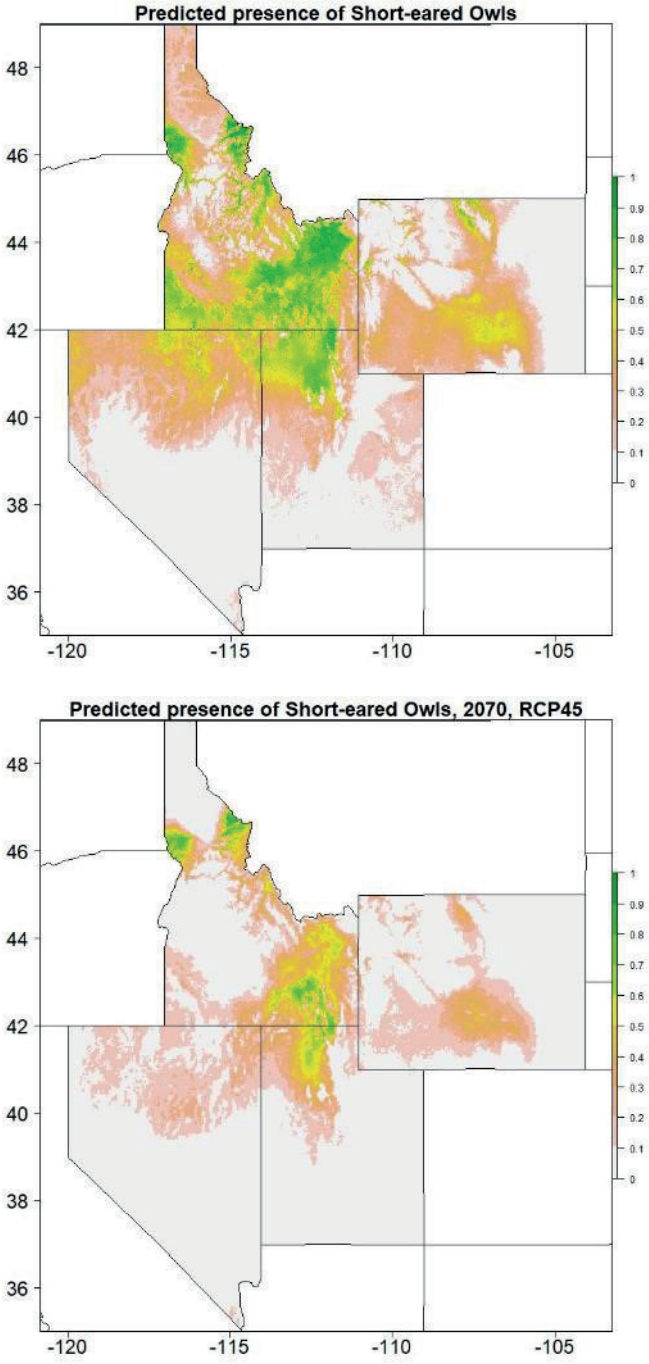
There was a higher probability of detecting Short-eared Owls in low wind speeds and close to the end of civil twilight (dusk). In the 3rd year of the program there were no significant habitat associations at the point scale. However, fewer Short-eared Owls were present at survey points with either high or low amounts of grazing.

In 2017, Short-eared Owl grid occupancy in Idaho declined significantly by about one third from 2016 (no confidence interval overlap, Fig. 11). The decline was less dramatic in Utah.

Short-eared Owls within the WAfLS study area were more likely to be found in locations where it was warmer than average and where temperatures were less variable. They were also more likely to be found in locations with higher precipitation per month throughout the year and at lower, but not the lowest, elevations. Short-eared Owls favored cropland, shrubland, and marshland over monotypic cheatgrass and more complex grasslands.

Figure 12 - Predicted habitat suitability for Short-eared Owl (*Asio flammeus*) presence using current and 2070 climate scenarios, derived from MaxEnt model LQ0.5 using presence and pseudo-absence data (2015-2017) from Western Asio flammeus Landscape Study Project. Green represents areas of high predicted presence (>70%), yellow represents moderate predicted presence (40 - 60%), brown represents low predicted presence (< 30%), and white represents near zero predicted presence. Future climate was projected using the Representative Conservation Pathway 4.5 assumptions generated by Hadley Centre Global Environment Model version 2.

Figura 12 - Adequação de habitat prevista para a presença de coruja-do-nabal (*Asio flammeus*) usando os cenários climáticos atual e previsto para 2070, derivados do modelo MaxEnt LQ0.5, usando dados de presença e pseudo-ausência (2015-2017) do *Western Asio flammeus Landscape Study Project*. A cor verde representa áreas de alta probabilidade de presença (> 70%), o amarelo representa probabilidade de presença moderada (40 - 60%), o castanho representa baixa probabilidade de presença (<30%) e o branco representa probabilidade de presença próxima de zero. O clima futuro foi projetado usando as premissas do *Representative Conservation Pathway* 4.5 geradas pelo *Hadley Center Global Environment Model* versão 2.



Using all variables we plotted the current likelihood of Short-eared Owl land use (Fig. 12a) and then projected future Short-eared Owl land-use by replacing climate variables within the model with future climate variable projections for the year 2070 (Fig. 12b). This assessment of climate-induced change is conservative as it assumes no change in land cover which is expected to change with climate.

Regional documentation in South America

Since the inception of Proyecto Asio in 2015, over 2,380 members have joined the Facebook group, and more than 200 records have been submitted. The rate of data submission doubled in 2017 likely due to an increase in participation rather than a change in abundance. Reports were numerous from the Pampas ecoregion, followed by Mesopotamian Savannas, Chaco, Patagonia, Prepuna, Puna, Monte Desert, and High Andes. Patterns in the data suggest some short- and medium-distance seasonal movements. Of note, there appears to be a high post-reproductive concentration along the central Andes, which is a relatively small area that may have disproportionate importance for Short-eared Owl in Argentina.

Discussion

Although Canada, Mexico, and Argentina are the only countries in the Americas to have recognized Short-eared Owl as a species at risk at a national level, it is evident that the species is also of significant conservation concern in much of the U.S., with nearly one-quarter of states having listed it as endangered. The NatureServe (2018) non-legally binding status assessment of Short-eared Owl status in North America shows a similar overall pattern, though it highlights numerous additional states, provinces, and territories where the species is imperiled or vulnerable, including several that are primarily frequented by the species in winter. Our interpretation is that the species is not considered secure anywhere in North America. It appears to be in greater jeopardy in the eastern half of the continent and its status is particularly tenuous in the southern part of the breeding range. In Canada, the national legal status is scheduled for reassessment in 2021, and recent declines are close to meeting the threshold for being considered Threatened (M.A. Gahbauer, unpubl. data).

BBS results indicate an overall long-term decline of the Short-eared Owl in North America, with a stable or increasing population trend largely limited to the northern Great Plains states where abundance estimates for this species are highest. While the network of BBS routes (>4,100) is extensive, observers are generally highly skilled, and there is a well-established analytical framework for the data, the survey is not optimal for Short-eared Owl because the species has low activity levels during the early morning BBS survey period (Swengel and Swengel 2009, 2013). Additionally, the BBS survey season (late May to early July) occurs after the Short-eared Owl's courtship period and peak of detectability (March to mid-May). With approximately 80 BBS detections across North America in an average year (Pardieck et al. 2017), small differences in observations can have a disproportionate effect on influencing trends, and over much of the continent, data are too sparse to allow for any analysis at all.

CBC data also showed an overall long-term decline of the Short-eared Owl in North America. However, there was a core area, extending from Oklahoma in the southwest and northeast to Ohio, that showed both long-term and short-term increases. It is unclear whether this represents an increase in the populations wintering in this region, or a redistribution of wintering owls that

formerly occurred in surrounding states where moderate to steep declines have been recorded over the same time period. CBC data have been used to show a shift in wintering distribution for other open-country raptors such as the Northern Harrier (*Circus hudsonius*), Rough-legged Hawk (*Buteo lagopus*), and Golden Eagle (*Aquila chrysaetos*) (Paprocki et al. 2014). Given that we know little about population connectivity in Short-eared Owls, it would be valuable to undertake an analysis to determine whether its winter population has redistributed or if there were discrete regional population trends. There are on average just under 700 Short-eared Owls reported on North American CBCs annually (National Audubon Society 2010), far more than by the BBS. However, Short-eared Owls are less active during daylight hours in winter and are likely not well detected away from communal roosts. Additionally, since CBC dates are predetermined, interannual variation in weather conditions can have considerable effects on both observer effort and owl distribution and detectability, and results are therefore most reliable at larger temporal and spatial scales.

In most states and provinces where a second breeding bird atlas has been completed, there were substantial declines in the number of survey blocks where Short-eared Owl were observed and/or confirmed as breeding. Even in areas reporting modest overall increases, such as four Canadian provinces, most of the previously occupied areas no longer reported Short-eared Owls. This may reflect the nomadic tendency of the species but could also be due to limiting factors. In areas with relatively extensive potential breeding habitat remaining, the Short-eared Owl may be able to maintain a stable regional population. Where such habitat is limited, local extirpations may not be offset by new occurrences elsewhere. Breeding Bird Atlas projects typically involve extensive field effort, often including areas that are remote or otherwise difficult to access, and there can be a focus on documentation of regionally rare species. However, BBA survey effort is infrequent (often a 5-year period every 20 years), which for a nomadic species may not accurately reflect fluctuations, especially since adjacent jurisdictions rarely synchronize their atlas efforts.

Despite the limitations of the BBS, BBAs, and CBC with respect to detecting Short-eared Owls, all three data sources agree that there have been widespread and, in many cases, substantial declines throughout much of North America. Only South Dakota shows a modest long-term increase based on BBS data, and just five provinces and states with a second completed BBA reported an increase in the number of Short-eared Owl detections, and most of those were attributed to expanded search effort. The more strongly positive CBC trends from a few central states represent an intriguing exception to the overall pattern and warrant further investigation.

Although existing broad-scale surveys have enough data for trend analysis in at least some states, provinces, and territories, sample sizes are in most cases too small to allow for a high confidence analysis of trends, especially over short time intervals. Moreover, detections are so scarce that they are of minimal value in deriving population estimates. This highlights the need for targeted survey efforts such as WAfLS, which are specifically designed to generate annual population estimates that over time will allow for more rigorous trend determination. Results from the program's first two years already established its viability for estimating regional population trends, identifying important Short-eared Owl habitat associations, and providing insight into which habitats in the region may be most important for conservation and further study (Miller et al. 2016a, 2016b). With a third year of data in 2017 and the

inclusion of two more states, differences among years are becoming apparent, and the understanding of the regional population is increasing. The success of engaging a large group of participants, mostly (82%) non-professional citizen-scientist volunteers, in a statistically-rigorous survey for Short-eared Owls across a broad geographic region suggests that this is a model that can readily be applied to other areas.

In 2017, for the first time, there were insufficient Short-eared Owl detections to produce a quality abundance estimate for any of the states. However, occupancy rates, generally more reliable than abundance estimates, decreased to about one-third of their 2015 and 2016 values in Idaho, and were anecdotally down in Utah as compared to 2016. This sharp decline may signify a continued decline in the population and/or its distribution in relation to prey availability (Clark 1975, Korpimäki & Norrdahl 1991, Johnson et al. 2013). Wiggins et al. (2006) and Johnson et al. (2013) suggested that consistent surveying over a period exceeding multiple prey cycles is required before estimating trends.

Multi-scale occupancy analysis provided key insight into owl detectability relative to weather, timing, and point scale impacts such as grazing. Consistent with Larson & Holt (2016), our results noted an increase in the probability of detection during surveys conducted toward the end of civil twilight. The probability of detection was higher in calmer wind conditions due to strong winds negatively affecting surveyors and male Short-eared Owl courtship flights. In 2016, we started collecting data on grazing activity around survey points. In 2017, Short-eared Owl occupancy was higher in areas with moderate evidence of grazing and was lower in areas of no grazing or high degrees of grazing. This contrasts Larson & Holt (2016) who found no detections in grazed habitats and suggests that the influence of such habitat impacts varies across the species' range and warrants further investigation.

The forecast effects of climate changes on Short-eared Owl population distribution and trends suggests that is a threat to this species. Short-eared Owls were associated with habitats where precipitation occurs throughout the year with only a moderate level of seasonal variation. Climate predictions for our region suggest that annual precipitation may remain constant or slightly increase, but that the seasonality of precipitation is expected to shift with summers continuing to become drier. Climate change associated range contractions suggests a difficult conservation scenario is needed to conserve the species.

In South America, standardized surveys have not yet been implemented, but the growing success of Proyecto Asio in documenting the status of the Short-eared Owl in Argentina has resulted in increased attention on its conservation. Most notably, the compiled results were part of the evidence used to support the recent designation of the Short-eared Owl as Vulnerable in Argentina (MAyDS y AA, 2017). There is growing interest from naturalists in other South American countries to expand the project to a continental scale, which would allow for a much-needed boost to understanding the distribution and status of the species, with potential for conservation status assessments, designations and the implementation of management actions elsewhere.

We conclude that multiple sources of existing data suggest that the Short-eared Owl is experiencing long- and short-term declines across much of North America, and possibly also in South America. However, confidence is limited in some of the trend data due to small sample sizes, and this may impede implementation of necessary conservation and management measures. Therefore, a Short-eared Owl specific population monitoring effort is needed, and we encourage the expansion of standardized

citizen-science programs such as WAfLS. Such programs can generate reliable estimates to serve as the basis for trend analysis, while also yielding new insights into habitat use. We also encourage the expansion of the Proyecto Asio across South America. This is especially needed in parts of the continent where the population warrants special attention. In combination with improved population monitoring, understanding Short-eared Owl demography is critical for long-term conservation of the species. While a long-term population decline is evident, the drivers of the decline remain unknown as there are scant demographic data available. Breeding ecology studies would be particularly useful in assessing the impacts of habitat characteristics (e.g., habitat fragmentation, livestock grazing) on nesting success. Greater understanding of the status, distribution, and demography of Short-eared Owls throughout the Americas will facilitate effective application of conservation efforts.

Acknowledgments

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A 25 year overview of the contaminant exposure and effects in Eurasian Eagle-owl (*Bubo bubo*) from southern Spain

Uma síntese de 25 anos sobre a exposição e efeitos de contaminantes em bufo-real (*Bubo bubo*) no sul de Espanha

Pilar Gómez-Ramírez[1,2], Silvia Espín[1,2,3], Mario León-Ortega[4], Francisco Botella[5], José Francisco Calvo[4], Pedro Javier Jiménez-Montalbán[1,2], Pedro María-Mójica[1,2,6], José Enrique Martínez[4], Isabel Navas[1,2], Juan Manuel Pérez-García[5,7], José Antonio Sánchez-Zapata[5], Alejandra Taliansky-Chamudis[1,2], Nico Van Den Brink[8], Emma Martínez-López[1,2], Antonio Juan García-Fernández[1,2*]

1 Area of Toxicology, Department of Socio-sanitary Sciences, Faculty of Veterinary Medicine, University of Murcia, Campus de Espinardo, 30100 Murcia, Spain

2 Laboratory of Toxicology, Biomedical Research Institute of Murcia (IMIB-Arrixaca), University of Murcia, 30100 Murcia, Spain

3 Section of Ecology, Department of Biology, University of Turku, 20014 Turku, Finland

4 Department of Ecology and Hydrology, Faculty of Biology, University of Murcia, Campus de Espinardo, 30100 Murcia, Spain

5 Ecology Area, Department of Applied Biology, University Miguel Hernández, 03202 Elche, Spain

6 Centro de Recuperación de Fauna Silvestre "Santa Faz" (Alicante), Servicio de Vida Silvestre, Consellería de Infraestructuras, Territorio y Medio Ambiente, Generalitat Valenciana, Spain

7 Department of Animal Sciences, Faculty of Life Sciences and Engineering, University of Lleida, 25198 Lleida, Spain

8 Division of Toxicology, Wageningen University, Helix, Stippeneng 4, Building 124, 6700 EA, Wageningen, The Netherlands

*** Corresponding author:** ajgf@um.es



ABSTRACT

The Eurasian Eagle-owl (*Bubo bubo*) meets the requirements of a suitable sentinel species for biomonitoring environmental contaminants in Southeastern Spain (Murcia Region and Alicante Province). In this area, it is an abundant species, showing the highest breeding density within its distribution range. Since 1992, different sample types from free-living nestlings and adults (blood, feathers, unhatched eggs) or from injured individuals admitted in wildlife rehabilitation centres (blood, feathers, liver, kidney, brain and bones) were analysed for a wide range of pollutants (metals, organochlorine pesticides, anticoagulant rodenticides, neonicotinoid insecticides). Specific biomarkers (antioxidant molecules, lipid peroxidation, δ-ALAD and blood clinical param-

eters) were analysed to perform risk assessment. As main findings, the patterns and concentrations of contaminants in Eurasian Eagle-owl samples reflected the contamination influenced by agriculture, an ancient mining site (AMS) and the use of anticoagulant rodenticides. In general, biomarkers were highly correlated to contaminants (i.e. δ-ALAD inhibition by lead, antioxidant enzymes inhibition by lead and cadmium, lipid peroxidation induction by mercury). Overall, we can confirm the suitability of the Eurasian Eagle-owl to biomonitor contaminants in our study area.

Keywords: anticoagulant rodenticides, *Bubo bubo*, metals, pesticides, flame retardants

RESUMO

O bufo-real (*Bubo bubo*) preenche os requisitos de espécie sentinela para a biomonitorização de contaminantes ambientais no sudoeste de Espanha (região de Múrcia e província de Alicante). Nesta área, é uma espécie abundante, apresentando a maior densidade da sua área de distribuição. Desde 1992, foram recolhidos vários tipos de amostras provenientes de aves juvenis e adultas em liberdade (sangue, penas, ovos não eclodidos), ou admitidas em centros de recuperação (sangue, penas, fígado, rim, cérebro e ossos), tendo sido analisadas para quantificação de uma grande variedade de contaminantes (metais, pesticidas organoclorados, rodenticidas anticoagulantes, inseticidas neonicotinóides). Biomarcadores específicos (moléculas antioxidantes, peroxidação lipídica, δ-ALAD e parâmetros clínicos sanguíneos) foram analisados para avaliação dos riscos. Os padrões e as concentrações de contaminantes em amostras de bufo-real refletem a contaminação influenciada pela agricultura, por uma antiga mina (AMS) e pelo uso de rodenticidas anticoagulantes. Em geral, os biomarcadores apresentaram correlações elevadas com os contaminantes (i.e. inibição de δ-ALAD por chumbo, inibição de enzimas anti-oxidantes por chumbo e cádmio, indução de peroxidação lipídica por mercúrio). De uma forma geral, confirmámos a adequação do bufo-real para biomonitorizar contaminantes na área de estudo.

Palavras-chave: *Bubo bubo*, metais, pesticidas, raticidas anticoagulantes, retardantes de chamas

Introduction

Exposure to environmental pollutants has been linked to detrimental effects on health, both in humans and wildlife (Woodruff, 2011). As a consequence, some European regulations have been set, for instance the REACH directive (European Commission, 2006), or regulations on persistent organic pollutants (European Commission, 2004, 2007), and on pesticides and biocides (European Commission, 2012). To assess the effectiveness of such regulations, as well as spatio-temporal trends and their effects on health, biomonitoring contaminants using birds is considered a suitable tool (Gómez-Ramírez et al., 2014). In fact, several European countries such as Sweden, Norway or United Kingdom have set national biomonitoring programmes using raptors (Gjershaug et al., 2008; Helander et al., 2008; Walker et al., 2008) and a wide range of sample types are

collected and used across Europe for wide scale contaminant monitoring using sentinel raptors (Espín et al., 2016).

Among birds, owls and other raptors are specially suitable to biomonitor persistent contaminants due to their high position in the trophic chain (Gómez-Ramírez et al., 2014). Specifically, the Eurasian Eagle-owl (*Bubo bubo*) in our study area (Southeastern Spain) meets the requirements for a suitable sentinel species for monitoring environmental pollutants (NRC, 1991): it is easy to collect samples from, it is exposed to environmental pollutants, and it is relatively common (Martínez & Calvo, 2006; Pérez-García & Sánchez-Zapata, 2015), with the highest breeding density reported within its distribution range (Pérez-García et al., 2012). In addition, this large owl is a long-lived top predator with a very varied diet (Martínez & Calvo, 2001; Lourenço, 2006) and therefore likely to reflect local pollution (Lourenço et al., 2011). For these reasons, different types of samples (mainly blood) from Eurasian Eagle-owl have been analysed since 1992 by the "Toxicology" research group of the University of Murcia, to obtain as much information as possible to assess the exposure and effects of the most relevant pollutants in this population, looking for spatio-temporal trends and local sources of pollution.

Due to ethical and legal reasons, sampling of free-ranging wildlife is limited. Thus, active monitoring of live birds of prey would only allow the non-destructive sampling of blood, biopsies, plucked feathers and preen oil. Other samples taken without contact with a living bird would be moulted feathers, addled or deserted eggs, regurgitated pellets, excrement, and tissues from carcasses from animals found dead in the field or died in rehabilitation centres (Espín et al., 2016).

For sampling live birds of prey, nestlings are often selected, as they are easier to capture and sample than adults (Andersen, 2007) and are more likely to reflect local pollution, as these are usually fed with prey caught close to the nest (Frank and Lutz, 1999).

Simultaneous and direct measurement of contaminants in fluids and tissues can reflect not only the exposure of this species, but also offer information on absorption and accumulation. However, monitoring the biological responses would give more direct information about their adverse effects (Vanparys et al. 2008). These responses, called biomarkers, comprise any alteration at cellular or biochemical components or processes, structures or functions, which are measurable in a biological system or sample (NRC, 1987). Levels of antioxidant molecules, activities of antioxidant enzymes, blood δ-ALAD activity or eggshell thinning are some of the most common biomarkers studied in birds (Gómez-Ramírez et al., 2011; Helander et al., 2002; Koivula & Eeva, 2010).

The main aim of this work is to provide an overview of the contaminant exposure and related effects in a Eurasian Eagle-owl population from Southeastern Spain after 25 years of research.

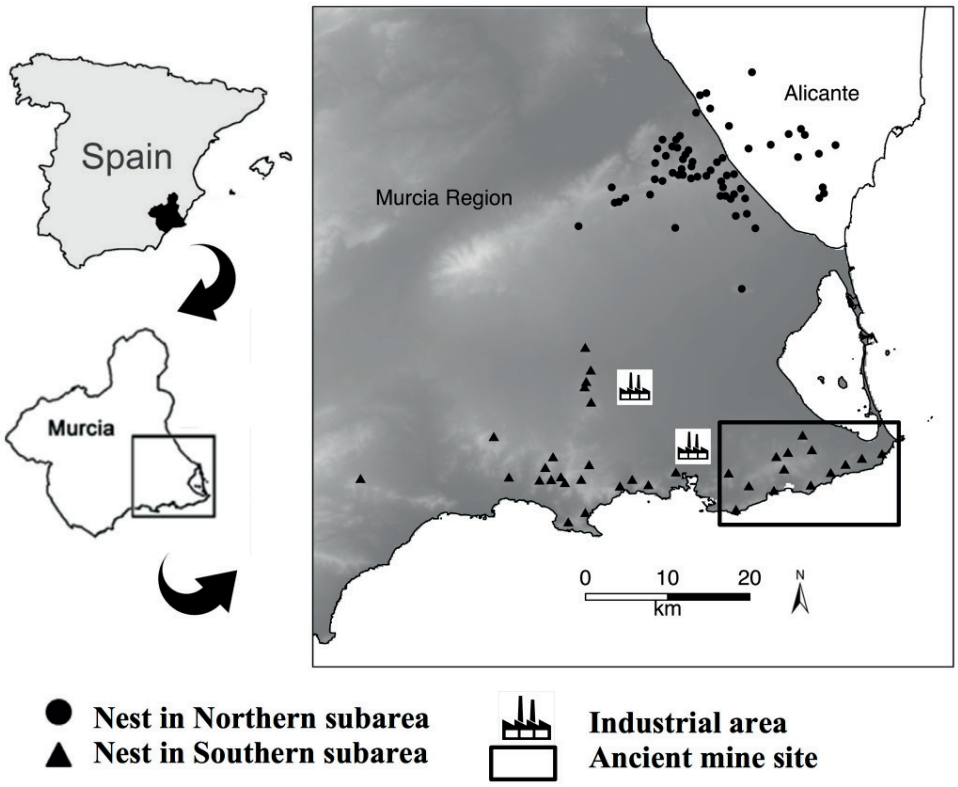
Methods

Study area and species

The study area (Fig. 1) comprises the south of the province of Alicante and Murcia Region, in Southeastern Spain (Escalona, Altaona, Monte el Valle, Columbares, Sierra Minera Cartagena-La Union, La Muela-Cabo Tiñoso and Almenara mountains; 37º 45' N, 0º 57' W). This is a relatively large area, with different land uses and local sources of pollution. Hence, the study area was divided in two subareas: the Northern subarea (Escalona, Altaona, Monte el Valle and Columbares), where main land uses are citrus and dry farming, and the European Rabbit (*Oryctolagus cuniculus*) is very abundant (71% of the prey of Eurasian Eagle-owls; León et al., 2008). In

Figure 1 - Map showing the geographical location of the study area (Province of Alicante and Murcia Region, in Southeastern Spain).

Figura 1 - Localização geográfica da área de estudo (província de Alicante e região de Múrcia, no sudoeste de Espanha).



the Southern subarea, irrigation farming is predominant, with a history of intensive use of pesticides. Some nests were found in an ancient mining site (AMS), in the "Sierra Minera de Cartagena-La Unión" range and most nests are around 16 km from Cartagena, an important industrial city. In addition, in Southern subarea, the European Rabbit is less abundant (35% of the prey of Eurasian Eagle-owls), and the diet is completed with rats (*Rattus rattus* and *R. norvegicus*), pigeons (*Columba* spp.), Red-legged Partridges (*Alectoris rufa*), Hedgehogs (*Erinaceus europaeus* and *Atelerix algirus*) and Yellow-legged Gulls (*Larus michahellis*) (León et al., 2008).

Sampling

Sampling started in 1992. Samples from tissues (liver, kidney, bone, brain) were obtained by necropsy from individuals that died or arrived dead to the Wildlife Rehabilitation Centres in Murcia and Alicante. Samples from free-living individuals were collected by the veterinarians of the "Toxicology" research group in collaboration with the "Mediterranean Ecosystems" research group (University of Murcia, Spain) and the "Area of Ecology" research group (Miguel Hernández University, Spain). Sampling methods for blood, feathers and unhatched eggs coincide with the

EURAPMON sampling and contaminant monitoring protocol for raptors described by Espín et al. (2014a) and further developed by Espín et al. (2021). Except feathers, all the samples were transported in cool conditions and stored frozen at -40º or -80ºC until analysis. The feathers were individually put into sealed plastic bags and they were stored at room temperature in a dark and dry place until analysis. The number of samples analysed for each contaminant is indicated in the corresponding section.

Metal analysis in blood, tissues and feathers

Cadmium and lead were analysed in samples from individuals admitted in "El Valle" Wildlife Rehabilitation Centre between 1993-1994 (whole blood: *n* = 5, kidney: *n* = 26, liver: *n* = 26, brain: *n* = 26 and bone: *n* = 15), using Anodic Stripping Voltammeter (VA-646 processor and VA-647 workstation, Methrohm, Switzerland) after a complete high temperature digestion with a mix of acids to eliminate organic impurities (see García-Fernández et al., 1995, 1997). Following the same digestion method but using a VA-757 Computrace Workstation (Methrohm, Switzerland), cadmium, lead, zinc and copper were analysed in whole blood samples (*n* = 304) from free-living nestlings born between 2004 and 2007 and 2011–2012 (see Gómez-Ramírez et al., 2011; Espín et al., 2014b, 2015).

Total mercury was analysed by atomic absorption spectrophotometry using a Milestone DMA-80 Direct Mercury analyser (Milestone GmbH, Germany) and the method described by Espín et al. (2014c), in whole blood samples from nestlings (*n* = 600) born between 2006-2012 and body feathers (*n* = 229) from nestlings born between 2006-2008. Muscle samples (*n* = 40) from rabbits found in nests as prey in 2009, 2011 and 2012, were also analysed to correlate with levels in nestlings (Espín et al., 2014c).

Organohalogen compounds analysis

Organochlorine insecticides (α-HCH, β-HCH, δ-HCH, lindane, aldrin, dieldrin, endrin, endrin aldehyde, endosulfan I, endosulfan II, endosulfan sulphate, *p,p'*-DDT, *p,p'*-DDD, *p,p'*-DDE, heptachlor and heptachlor-epoxide) were analysed in liver, brain and fat collected after necropsy from 16 Eurasian Eagle-owls registered in "El Valle" Wildlife Rehabilitation Center (Murcia) between 1994-1996. Samples (liver: *n* = 14, fat: *n* = 6 and brain: *n* = 14) were extracted following the method described by María-Mojica et al. (2000), using organic solvents and solid phase extraction. Analysis were conducted by gas chromatography with an electron capture detector (GC-ECD 17 Shimadzu). Whole blood samples collected between 2003–2007 (*n* = 316) from free-living nestlings were analysed following the same method but slightly modified and adapted by Martínez-López et al. (2009).

Analyses of unhatched eggs collected between 2004–2009 (*n* = 58) were performed at Alterra (Wageningen UR) in Wageningen (The Netherlands) under the supervision of Dr. Nico W. van den Brink following the method described by Gómez-Ramírez et al. (2012a). Briefly, homogenised egg contents were extracted with n-hexane and analysed by GC-MSD (Agilent 6890 Series GC System; 5973 Network Mass Selective Detector, Agilent Technologies, Palo Alto, CA, USA) to detect PCBs (8, 31, 44, 52, 70, 101, 149, 151, 28, 105, 138, 195, 118, 170, 77, 128, 126, 156, 153, 169, 180, 194), α-HCH, β-HCH, γ-HCH, δ-HCH, ε-HCH; heptachlor, heptachlor-epoxide, aldrin, isodrin, dieldrin, endrin, endosulfan, cis and trans chlordane, *o,p'*-DDT, *o,p'*-DDD, *o,p'*-DDE, *p,p'*-DDT, *p,p'*-DDD, *p,p'*-DDE; hexachlorobenzene (HCB), metoxychlor, mirex and PBDEs (28, 47, 99, 100, 153, 154 and 183). Egg parameters were measured according to EURAPMON sampling and contaminant monitoring protocol for raptors (Espín et al., 2014a).

Anticoagulant rodenticides analysis in blood and liver

Warfarin, coumatetralyl, brodifacoum, bromadiolone, difenacoum, chlorophacinone and diphacinone were analysed in liver samples (n = 18) from adult Eurasian Eagle-owls that arrived dead or died at the Wildlife Rehabilitation Center "Santa Faz" (Alicante) and in whole blood samples (n = 50: 9 adults caught between 2008 and 2010 and 41 nestlings born between 2008 and 2010). The extraction was performed using a modification of QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe), while detection and quantification was carried out with high performance liquid chromatography coupled to mass spectrometry (Agilent 1100 Series ESI/LC/MSD ion Trap VL), as described by Gómez-Ramírez et al. (2012b).

Neonicotinoids analysis in blood

Whole blood samples from nestlings born in 2016 (n = 30) were analysed to assess the exposure to the neonicotinoids authorised in Spain (acetamiprid, clothianidin, dinotefuran, imidacloprid, thiacloprid, nitenpyram and thiamethoxam). Two extraction techniques based on QuEChERS were adapted and compared: a) using acetate buffer (AB); and b) using citrate buffer (CB). The AB method was chosen based on the best values of repeatability and suitable recoveries. Detection and quantification was carried out with high performance liquid chromatography HPLC (Agilent Series 1200, Agilent Technologies, Santa Clara, CA, USA) coupled to time of flight mass spectrometry (Agilent 6220 accurate mass TOF, Agilent Technologies, Santa Clara, CA) equipped with an electrospray interface operating in the positive ionization mode, as described by Taliansky-Chamudis et al. (2017).

Serum biochemical clinical parameters and haematocrit

Albumin, calcium, inorganic phosphate, aspartate aminotransferase (AST), alkaline phosphatase (AP), cholesterol, triglycerides (TGL), creatine kinase (CK), γ-glutamyltransferase (γ-GT), glucose, lactate dehydrogenase (LDH), total proteins (TP) and uric acid in serum were analysed in 15 adults (6 males and 9 females) and 258 nestlings of free-living Eurasian Eagle-owl using an automated spectrophotometrical analyser (A25, Atom®), as described in Gómez-Ramírez et al. (2016). Haematocrit was studied in 13 adults (2 males and 11 females) and 162 nestlings centrifuging microcapillaries at 2200 g for 5 min and using a microhaematocrit reader.

Determination of blood δ-ALAD activity

Enzymatic activity was determined in 218 blood samples (22 from AMS and 196 from unpolluted areas) obtained from nestlings born between 2003–2007 (Gómez-Ramírez et al., 2011), and both the enzymatic activity and the ratio between the non-activated and the *in vitro* activated enzymes were determined in 139 blood samples collected in 2011 and 2012 from nestlings (n =131) and adult females (n = 8) (71 from Agricultural and Rural Area, 40 from Industrial Area and 28 from AMS; Espín et al., 2015). δ-ALAD activity was determined using the method described by Scheuhammer (1987a) using a UV spectrophotometer (UV-1603, Shimadzu). Quantification was based on measuring the colour of porphobilinogen (PBG). Activity of δ-ALAD was expressed as µmol PBG/h/l red blood cells (RBC). The activity ratio was calculated by dividing the non-activated enzyme absorbance and the reactivated enzyme absorbance.

Table 1 - Levels of lead and cadmium (mean, range) in blood (µg dL-1) and tissues (µg g-1, w.w.) of Eurasian Eagle-owls admitted in the "El Valle" Rehabilitation Centre between 1993-1994 (García-Fernández et al., 1995, 1997).

Tabela 1 - Níveis de chumbo e de cádmio (média, intervalo) no sangue (µg dL-1) e em tecidos (µg g-1, w.w.) de bufos-reais admitidos no Centro de Reabilitação "El Valle" entre 1993 e 1994 (García-Fernández et al., 1995, 1997).

	LEAD (µg dL^{-1} in blood; µg g^{-1} in tissues, w.w.)	CADMIUM (µg dL^{-1} in blood; µg g^{-1} in tissues, w.w.)
Blood	7.71 3–20 (*n* = 12)	0.1 0.04–0.28 (*n* = 5)
Liver	0.48 0.03–0.51 (*n* = 19)	0.14 0.002–0.380 (*n* = 7)
Kidney	0.36 0.03–0.67 (*n* = 19)	0.21 0.01–0.51 (*n* = 7)
Brain	0.14 0.03–0.22 (*n* = 19)	0.012 0.001–0.033 (*n* = 7)
Bone	16.97 0.62–43 (*n* = 12)	0.004 ND–0.047 (*n* = 3)

Oxidative stress biomarkers

141 red blood cell (RBC) samples obtained between 2011–2012 were analysed for oxidative stress biomarkers [total glutathione (tGSH), glutathione peroxidase (GPx), superoxide dismutase (SOD), catalase (CAT), glutathione-S-transferase (GST) and thiobarbituric acid-reactive substances (TBARS)] after RBC homogenization (1:10 w/v) in a stock buffer following the method described by Espín et al. (2014b).

Statistical analyses

Statistical analyses were performed as described in García-Fernández et al. (1995, 1997), Gómez-Ramírez, 2011; Gómez-Ramírez et al. (2011, 2012a, 2012b, 2016), Espín et al. (2013, 2014b, 2014c, 2015) and Taliansky-Chamudis et al. (2017).

Results

Metal levels in blood, tissues and feathers from Eurasian Eagle-owls

Table 1 shows the calculated average levels of lead and cadmium in Eurasian Eagle-owls admitted in the "El Valle" Rehabilitation Centre between 1993–1994 and analysed by García-Fernández et al. (1995, 1997). Bone and blood showed the highest concentrations of lead in tissues while cadmium tends to accumulate in kidney. On the other hand, strong positive correlations were found between tissues for both lead and cadmium ($r > 0.7$, $p < 0.05$). Detailed description of the results can be found in García-Fernández et al. (1995, 1997).

Samples collected between 1993–1994 (Table 1) included juveniles and adults but samples obtained between 2004–2012 from free-ranging birds were taken mostly from

Table 2 - Levels (mean ± SD, median) of lead, mercury, cadmium, zinc and copper (µg dL^{-1}) in blood of Eurasian Eagle-owls born between 2004–2012 (Espín et al., 2013).
*indicates significant differences between subareas ($p < 0.05$).

Tabela 2 - Níveis (média ± SD, mediana) de chumbo, mercúrio, cádmio, zinco e cobre (µg dL^{-1}) em sangue de bufos-reais nascidos entre 2004 e 2012 (Espín et al., 2013).
*indica diferenças significativas entre subáreas ($p < 0.05$).

	NORTHERN SUBAREA	SOUTHERN SUBAREA
Lead*	2.11 ± 2.65 1.19 (n = 191)	5.77 ± 6.40 3.52 (n = 113)
Mercury*	3.38 ± 14.89 1.24 (n = 435)	4.15 ± 12.83 1.84 (n = 188)
Cadmium	0.08 ± 0.20 0.01 (n = 191)	0.07 ± 0.13 0.01 (n = 113)
Zinc	353.24 ± 185.68 323.93 (n = 191)	317.78 ± 107.88 299.20 (n = 113)
Copper	34.30 ± 198.71 11.98 (n = 191)	21.70 ± 66.09 11.69 (n = 113)

nestlings. Only 8 adults were sampled and levels were not statistically different from nestlings, except for copper. However, as shown in table 2, levels of mercury and lead were higher ($p < 0.05$) in birds from the Southern subarea than from the Northern.

As mentioned above, some nests in the Southern subareas are in an AMS, hence about 15% of the individuals sampled were born in that area. When those were compared with the rest of the population, the differences in lead and mercury levels increased (see Gómez-Ramírez et al., 2011; Espín et al., 2014b, 2014c, 2015). Mercury levels in rabbit muscle did not differ significantly between subareas. However, when samples from the AMS were compared with the rest, mean mercury levels in rabbit muscles were significantly higher in rabbits from the AMS (24.98 ± 12.76 vs 12.46 ± 12.38 µg kg^{-1} wet weight (ww); $F = 6.83$; $d.f. = 1,23$; $p = 0.019$; Espín et al., 2014c). In the same study, positive correlations were found between mercury levels in nestlings blood and rabbit muscle ($r > 0.38$, $p < 0.029$). "Year" was the most important factor influencing blood mercury concentrations in Eurasian Eagle-owl (Espín et al., 2014c).

Mercury was significantly higher in feathers than in blood (mean ± SD: 328.88 ± 447.15 µg kg^{-1} vs 36.83 ± 145.58 µg L^{-1} ww; $F = 1590.61$; $d.f. = 1228$; $p < 0.001$). On the other hand, a positive correlation between blood and feather mercury concentrations was found ($r = 0.339$, $p = 0.001$, $n = 229$). A predictive equation was estimated by simple linear regression: log (mercury) in blood (µg L^{-1}, ww) = –0.588 + 0.617 × log (mercury) in feathers (µg kg^{-1}) (Espín et al., 2014c).

Organohalogen compounds

All the organochlorine insecticides except *pp'*- DDD, *pp'*- DDT, aldrin and dieldrin were detected in the tissues sampled between 1993–1994. δ-HCH followed by endrin aldehyde and endosulfan I were the most frequent. Fat showed the highest levels of

total organochlorine, followed by brain and liver. The highest concentrations were found for *p,p'*-DDE in fat (mean = 726.7 ng g^{-1}). Detailed description of results can be found in María-Mojica (1998).

In blood, frequency of detection of the insecticides was in general low (< 20%), being *pp'*-DDE, lindane and Σendosulfan I and II the most frequent. Dieldrin, Σendosulfan I and II, lindane and diphenyl aliphatics were detected at the highest levels. "Year" was considered the most influential variable and linear mixed models showed significant differences among years for all the compounds, except δ-HCH. Like most insecticides, levels of aldrin, dieldrin and Σdiphenylaliphatics in blood tended to decrease along the study period. Detailed description is presented in Gómez-Ramírez (2011).

Regarding levels in unhatched eggs, HCB, *p,p'*-DDE, trans-chlordane and dieldrin were the most common, while dieldrin and *p,p'*-DDE, together with heptachlor-epoxide and endosulfan, were detected in the highest concentrations. On the contrary, cis-chlordane, *o,p'*-DDD, isodrin and its epoxide endrin, were not detected, while *p,p'*-DDE, predominated in all samples. When general linear models were applied, significant interactions between subareas and years were found for *pp'*-DDE, β-HCH, HCB, ∑PCBs and ∑PBDEs. While concentrations in the Southern subarea tended to increase, levels in the Northern tended to decrease, except ∑PCBs and HCB, which remained stable (see Gómez-Ramírez et al., 2012a).

Anticoagulant rodenticides in blood and liver

No traces of anticoagulant rodenticides were detected in blood samples (Gómez-Ramírez et al., 2012b), while about 83% of the liver samples (n = 18) presented residues, being difenacoum and brodifacoum, followed by bromadiolone, the most frequent (82%, 64% and 17%, respectively; Gómez-Ramírez, 2011).

Neonicotinoids in blood of Eurasian Eagle-owl nestlings

Imidacloprid was the only compound detected, in a single blood sample (3.28 ng mL^{-1}). The sample was obtained from a nestling born in a dry land farming area (Taliansky-Chamudis et al., 2017).

Serum clinical biochemical parameters and haematocrit

Most blood clinical parameters were higher in nestlings than in adults, but only significantly for AP, inorganic phosphate and uric acid. On the contrary, γ-GT was significantly lower in nestlings. In adults, sex differences were not significant. Haematocrit levels were significantly higher in adults than in nestlings. Results of this section are described in detail in Gómez-Ramírez et al. (2016).

Blood δ-ALAD activity as biomarker of lead exposure and effect

Significant negative correlations were found between δ-ALAD - Log blood lead levels in Eurasian Eagle-owls studied by Gómez-Ramírez et al. (2011) and Espín et al. (2015). In the first study, the correlation (P = -0.137, p = 0.044) was stronger and more significant when blood lead levels were > 4 µg dL^{-1} (P = -0.341, p = 0.006). This suggested an inhibition of the enzyme activity, which reaches a 55% when blood lead concentrations were > 15 µg dL^{-1}. In the case of birds studied by Espín et al. (2015), the significant negative relationship between δ-ALAD ratio or δ-ALAD activity and Log blood lead levels were r = -0.471 and r = -0.292, respectively, p < 0.001. δALAD activity was inhibited by 50% at blood lead concentrations > 10 µg dL^{-1}, and by 79% when lead levels exceeded 19 µg dL^{-1}.

Oxidative stress biomarkers of metal exposure and effect

SOD activity and TBARS levels were higher in adults than in nestlings. Significant location-related differences were found only for GST activity, with lower activity in Eurasian Eagle-owls from the AMS. However, when adult individuals were excluded, significant higher activity of CAT in the agricultural area than in the AMS was also found ($p = 0.05$, Espín et al., 2014b).

Several oxidative stress biomarkers were inversely correlated with metal concentrations (Espín et al., 2014b). That study provided threshold concentrations at which metals cause effects on the antioxidant system of Eurasian Eagle-owl: Cadmium > 0.3 and 0.02 µg dL^{-1} in blood caused an inhibition of 32% and 8% in GPx activity, respectively, and an inhibition of 26% and 20% in CAT activity, respectively. Lead > 2 µg dL^{-1} in blood also inhibited 8 and 10.5% GPx and CAT activities, respectively, while lead > 15 and 3 µg dL^{-1} caused a depletion of 16% and 4% in tGSH in individuals from the AMS. TBARS were induced by lead (> 2 and 10 µg dL^{-1} produced a TBARS induction of 10% and 28%, respectively) in individuals from both the industrial and mining area. TBARS were especially induced by mercury (> 3 and 10 µg dL^{-1} resulted in a TBARS induction of 102% and 190%, respectively) in Eurasian Eagle-owls from the industrial area.

Positive correlations ($r > 0.21$, $p < 0.01$) were found among oxidative stress biomarkers: GPx-CAT, SOD–CAT, GST-GPx, GST-CAT, and tGSH-TBARS levels. Negative weak correlations ($r = -0.2$, $p < 0.04$) were found between CAT-TBARS, SOD-TBARS and δ-ALAD-Log CAT. Brood size was negatively correlated with GPx and CAT activity while a positive relationship between the brood size and tGSH levels was found. Results of this section are described in detail by Espín et al. (2014b).

Discussion

Metal levels in blood, tissues and feathers from Eurasian Eagle-owls

The results found by García-Fernández et al. (1995, 1997) confirmed that bone was the main organ of lead accumulation, followed by kidney and liver, and finally, by brain and blood. This distribution model agrees with studies in other bird species where bone lead concentrations were considered useful for monitoring chronic exposure (Hutton & Goodman, 1980; Stendell, 1980; Scheuhammer, 1987b; Honda, et al., 1990). In addition, and based on the strong positive correlations also found by García-Fernández et al. (1995, 1997), blood was considered a useful indicator of lead and cadmium exposure in wild birds, raptors included.

Our results show a decreasing trend in blood lead levels in the Eurasian Eagle-owl for the last 25 years in Murcia Region (García-Fernández et al., 1995, 1997; Gómez-Ramírez et al., 2011; Espín et al., 2014b). The end of mining activities in 1991 and the ban on leaded petrol in 2001 could be the cause of this decrease. Particularly, the influence of the latter was demonstrated by García-Fernández et al. (2005a) in tissues of Common Kestrels (*Falco tinnunculus*). Lead exposure was in general similar to birds of prey from non-polluted areas (Henny et al., 1994; Martínez-López et al., 2004). However, some local contamination sources could be the cause for the highest lead concentrations detected in the Southern subarea. There is an important industrial zone near the city of Cartagena (Fig. 1), including electric power plants, and explosives and shipbuilding factories (García-Fernández et al., 1995). In addition, in the AMS, lead, zinc, copper, tin, iron, manganese and silver was extracted for more than 2500 years (Pavetti et al., 2006). As a matter of fact, this was the main source for lead and zinc in Spain during the

nineteenth century (Estevan-Senís, 1967).

Cadmium concentrations were considered low and, based on the lack of differences among areas, no important cadmium emissions were identified. Hence, we can suggest that Eurasian Eagle-owls in Southeastern Spain have been exposed to chronic low doses through the diet in the last 25 years (García-Fernández et al., 1995, 1997; Gómez-Ramírez, 2011; Espín et al., 2014b).

The information about blood mercury levels in Eurasian Eagle-owls is scarce (Espín et al., 2014c). However, concentrations were much lower than those reported for fish-eating raptors (Jagoe et al., 2002; Langner et al., 2012). Although the study area is not considered mercury polluted, spatial differences seem to be mostly related to the AMS. The temporal variations in blood mercury concentrations may be related to rainfalls during the seven years of study (Espín et al., 2014c). In this sense, rainfalls may contribute to a higher mercury removal from the atmosphere and local wet deposition. The positive correlations found between mercury concentrations in blood of nestlings and in muscles of their prey suggest that mercury levels are greatly influenced by mercury ingested through rabbit consumption (Espín et al., 2014c).

In general, zinc and copper concentrations were within the range of physiologic levels in several healthy bird species, including birds of prey (García-Fernández et al., 2005b).

Organohalogen compounds

Compared to other studies in birds collected in the 90's, levels of organochlorines in tissues were considered low (María-Mojica, 1998). However, the high frequency of detection is in agreement with the agricultural use during the study period, since they were still allowed and recommended (Decision 2000/801/EC, Regulation (EC) No 850/2004, Decision 2005/864/EC). Based on the accumulation pattern, fat was considered an ideal tissue for monitoring organochlorine insecticides.

The high frequency of detection of lindane, endosulfan and *p,p'*-DDE in blood of Eurasian Eagle-owl nestlings coincides with previous studies in Booted Eagle (*Aquila pennata*) nestlings from Murcia Region (Martínez-López et al., 2009). Although lindane was banned for agriculture in 2000 (Decision 2000/801/EC), industrial, domestic and forestry use were allowed until 2007 in Europe (Regulation (EC) No 850/2004). Dieldrin levels in some samples were similar to other raptor nestlings born between 1999-2003 in Southeastern Spain (Martínez-López, 2005) and even higher than in Bald Eagles (*Haliaeetus leucocephalus*) caught in 1977 in USA (Henny et al., 1981). Despite its low persistence in the organisms (Wiemeyer, 1996), the detection of endosulfan in our samples was expected, due to the recent ban in the study area (Decision 2005/864/EC). The most abundant and frequent compound was *p,p'*-DDE, similarly to scavenger raptors from Africa (van Wyk et al., 2001) and Spain (Gómara et al., 2004). The concentrations also fell in the range found in blood of Eurasian Buzzard (*Buteo buteo*), Northern Goshawk (*Accipiter gentilis*) and Booted Eagle nestlings born between 1999-2003 in Murcia Region (Martínez-López, 2005; Martínez-López et al., 2009). These concentrations were below the mean described by Donaldson et al. (1999) in plasma of Bald Eagle nestlings without reproductive impairment.

The greater agricultural activity with common use of DDT in the past (Sánchez-Gelabert et al., 2008) was probably the cause of the higher *p,p'*-DDE mean levels in eggs of Eurasian Eagle-owls in our study area compared to eggs of European birds of prey collected during the same decade (Henny et al., 2003; Mañosa et al., 2003; Jaspers et al., 2005; Bustnes et al., 2007; Martínez-López et al., 2007). Dieldrin is very persistent (Martijn et al., 1993). However, unexpectedly, our mean concentrations were as high as in owl eggs collected more than 25 years ago in the

US (Henny et al., 1984). Similarly to blood, the high frequency and concentrations of endosulfan was probably due to its recent restriction (Decision 2005/864/EC). Also coinciding with other raptor eggs (Henny et al., 2003; Mañosa et al., 2003), β-HCH, was the most common and abundant HCHs. Our levels were higher than in owl eggs from other European countries (Jaspers et al., 2005; Bustnes et al., 2007), especially in the eggs from a nest surrounded by intensive agricultural fields in the Northern subarea. Like *p,p'*-DDE, β-HCH has been related to intensive or moderate use of insecticides (Jakszyn et al., 2009). The low frequency and levels of γ-HCH in our samples seem to be related to the total ban of lindane for agricultural use in 2000 (Decision 2000/801/EC) and its rapid metabolism and excretion in birds. Compared to other raptors, exposure to PCBs can be considered intermediate (Wiesmüller et al., 1999; Kubistova et al., 2003; Jaspers et al., 2005; Bustnes et al., 2007). Coinciding with these studies, PCB 138, 153 and 180 were the most abundant. On the contrary, levels of PBDEs were very low compared to other eggs of birds of prey (Jaspers et al., 2005; Chen & Hale, 2010) but similar to Tawny Owl (*Strix aluco*) eggs from Central Norway collected between 2001-2004 (Bustnes et al., 2007). The profile is characteristic of terrestrial birds (Chen & Hale, 2010), and coincides with Little Owl (*Athene noctua*) eggs from Belgium (Jaspers et al., 2005), where BDE 99, 47 and 100 also dominated.

Dietary shifts with a greater ingestion of birds but also the proximity to Cartagena may explain the increasing trend in the Southern subarea. About 36% of the eggs exceeded the No observed adverse effect concentration (NOAEC) of Total toxic equivalents (TEQs) established for Great Horned Owls (*Bubo virginianus*) and 17% of the samples exceeded 400 pg g^{-1} ww, the lowest observed adverse effect concentration (LOAEC) for Total TEQs (Strause et al., 2007). Moreover, the negative correlation between TEQ concentrations and the metabolizable fraction of PCBs (*Fprob* = 0.0018) when TEQs values were above 10 pg g^{-1} ww could indicate hepatic enzymes induction. These females could be suffering from Ah-receptor-related toxic effects, some of which have been related to altered bird reproduction. Finally, a significant negative correlation between *p,p'*-DDE levels and eggshell thickness (r = -0.469, p < 0.001) was observed, with about 17% of eggshell thinning for *p,p'*-DDE levels > 100 μg g^{-1} lipid weight, similarly to previous experimental studies in owls (McLane & Hall, 1972; Newton & Bogan, 1974; Mendenhall et al., 1983). The persistence of this degree of thinning over a period of time has been related to population declines in other birds of prey (Blus, 2011).

Anticoagulant rodenticides in blood and liver

Information regarding the use of rodenticides in the study area is scarce. However, the most frequently detected compounds in our liver samples were also marketed in the highest number of products by the time of sampling in Spain (MARM, 2011), which suggests a higher frequency of use. On the other hand, the lack of detection in blood could be due to the fast transport to the liver, where they can persist up to a year (Erickson & Urban, 2004).

Levels of anticoagulant rodenticides related to toxic effects in owls have been reported between 100–200 ng g^{-1} in liver (Newton et al., 1998, 1999), although concentrations as low as 10 ng g^{-1} of brodifacoum have been related to subcutaneous haemorrhage in Great Horned Owls (Stone et al., 1999). Sublethal haemorrhages may alter locomotion or cause lethargy, predisposing animals to predation, accidental trauma or reduced food intake (Stone et al., 1999). Electrocution and trauma were the main cause of admission of the owls

studied. Because 72% of these individuals presented hepatic levels above 10 ng g^{-1}, we could suggest that these compounds could be involved in the cause of death.

Neonicotinoids in blood of Eurasian Eagle-owl nestlings

In this first assessment of neonicotinoids in blood of free-ranging birds of prey, the very low frequency of detection can be due to several reasons (Taliansky-Chamudis et al., 2017). In order to protect pollinators, there is a European Regulation that restricts the use of imidacloprid, clothianidin and thiamethoxam during blooming in the study area (Commission Implementing Regulation (EU) No 485/2013). Sampling season of Eurasian Eagle-owls coincides with the blooming of most plants and trees grown in the irrigation farming areas (peach, apricot, melon, watermelon, etc.). On the contrary, trees from the dry land farming area usually bloom earlier (almond trees) or later (olive trees). Therefore, the probability of finding residues would be higher in the dry land farming areas. In addition, imidacloprid has longer persistence in the environment than the other neonicotinoids (Miranda et al., 2011). Also, it is the most widely used neonicotinoid in Murcia Region (Sanz-Navarro, 2008) and registered in the highest number of products available on the market in Spain, both for agricultural and veterinary use (AEMPS, 2016; MAGRAMA, 2015).

On the other hand, the apparent lack of exposure could indicate a lower suitability of this species as sentinel in neonicotinoid biomonitoring studies. Thus, further knowledge is needed about the bioavailability of neonicotinoids on birds at the top of the food chain, on the analytical method, including the main metabolites of each compound, and on the use of other matrices and experimental studies of exposure to understand the kinetics in birds.

Serum clinical biochemical parameters and haematocrit

Due to the lack of studies on clinical biochemical parameters and haematocrit on free-ranging Eurasian Eagle-owls, our data have been compared with other species of birds of prey (see Gómez-Ramírez et al., 2016). Most biochemical parameters in our nestlings were in the same range as in the studies mentioned in Gómez-Ramírez et al. (2016). The differences between nestlings and adults had also been found previously in birds of prey: the highest levels of AP in nestlings seem physiological, since this enzyme is synthesised by osteoblasts (Dobado-Berrios & Ferrer, 1997). Phosphorus usually decreases with age, as it is involved in bone and muscle development (Wolf et al., 1985) and was also higher in nestlings than in adults of Spanish Imperial Eagle (*Aquila adalberti*; Dobado-Berrios & Ferrer, 1997), and the same in Red Kites (*Milvus milvus*) and Black Kites (*Milvus migrans*; Viñuela et al., 1991). Another consequence of growing is an increase in protein synthesis, which increases uric acid (Hochleithner, 1994). However, higher levels of uric acid can also be related to the larger daily protein intake of nestlings (Griminger & Scanes, 1986), since it is the main nitrogen waste in birds (e.g. Singer, 2003). γ-GT is a biomarker of liver disease in mammals, but its role in birds is still under discussion. Nevertheless, levels in birds of prey are usually lower in nestlings which coincides with our results (Gómez-Ramírez et al., 2016).

Haematocrits are usually lower in young than in adults in several taxa, including birds of prey (Lanzarot et al., 2001). This could be due to the higher oxygen affinity of foetal haemoglobin, which decreases during development (Bartels et al., 1966). Our haematocrit values, both in adults and nestlings, were in the same range as in other birds of prey, including owls (Ferrer et al., 1987; Jennings, 1996). Thus, we can consider

our values as reference for the Eurasian Eagle-owl.

Blood δ-ALAD activity as biomarker of lead exposure and effect

The inhibition of δ-ALAD, an enzyme for the synthesis of the haeme group of haemoglobine, is considered a biomarker of exposure and effect for lead also in birds (Scheuhammer, 1987a; Finkelstein et al., 2012). In our studies, this inhibition was evidenced, even at lower concentrations than in other species, including birds of prey (Henny et al., 1994; Martínez-López et al., 2004). In general, it is considered that blood lead concentrations > 20 μg dL^{-1} inhibit δ-ALAD activity by 50% in birds. Although concentrations as low as 1 μg dL^{-1} showed a 10% decrease in δ-ALAD activity, 4–5 μg dL^{-1} were established as threshold (Gómez-Ramírez et al., 2011; Espín et al., 2015).

Effects of δ-ALAD inhibition in birds may be more severe than in mammals, due to the higher metabolism of the nucleated red blood cells of birds (Allen, 1971; Brace & Altland, 1956). Laboratory and field studies showed that a 45–59% decrease in δ-ALAD can cause anaemia in American Kestrel (*Falco sparverius*) nestlings (Hoffman et al., 1985; Henny et al., 1994). In our samples, the negative correlation between δ-ALAD activity and haematocrit (r = -0.439, p < 0.001, n = 139) could be related to a compensatory response associated with a decrease in δ-ALAD enzyme (Espín et al., 2015).

Oxidative stress biomarkers of metal exposure and effect

Although, as mentioned above, exposure to metals can be considered in general low, several oxidative stress biomarkers were correlated with metal levels (see Espín et al., 2014b for details). Our findings show that lead may alter oxidative stress biomarkers in Strigiformes at lower concentrations than those typically accepted in birds of prey (8–20 μg dL^{-1} in blood; García-Fernández, 2017). Individuals from the AMS had significant higher lead and mercury concentrations, and significant lower GST and CAT activities. However, the lack of differences in oxidative damage to membrane lipids (TBARS) among areas suggests that the antioxidant capacity of the different populations is able to deal with oxidant species and maintain TBARS levels in the same amount (Espín et al., 2014b).

The positive correlations among the different oxidative stress biomarkers are indicative of their close collaboration as part of the antioxidant system. Given the function of CAT in catalyzing H_2O_2 to H_2O, the negative correlation δ-ALAD-CAT activity in Eurasian Eagle-owls may be related to a protective response against reactive oxygen species (Espín et al., 2015).

Finally, larger broods may have a negative effect on the antioxidant capacity of Eurasian Eagle-owl nestlings, and other ecological parameters should be considered when interpreting metal-related oxidative stress (Espín et al., 2014b).

Conclusions

After 25 years studying Eurasian Eagle-owls in Southeastern Spain, we can confirm the suitability of the Eurasian Eagle-owl as sentinel species to biomonitor contaminants in our study area. In this sense, we can conclude that the overview of the biomonitoring studies shows that patterns and concentrations of contaminants in samples from this species reflected the contamination influenced by the anthropogenic activities, such as agriculture, past mining activities and the use of anticoagulant rodenticides to control pests. With respect to specific contaminants we can conclude:

1. Declining lead levels seem to be related

to the end of mining activities and the ban on leaded petrol.

2. Mercury levels in the Eurasian Eagle-owl may be most influenced by weather conditions.

3. Although most organohalogen compounds had been banned long time ago, the relatively high frequency and levels of some compounds (i.e. *pp'*-DDE and dieldrin) are related to the past intensive agricultural practices in the area.

4. Although further research is needed, our first results of anticoagulant rodenticides analysis are in agreement with its market in Spain.

5. Our preliminary results of the exposure to neonicotinoids in Eurasian Eagle-owls must be confirmed, and further research is needed due to recent UE restrictions in the use of these compounds (Butler, 2018).

6. In general, biomarkers were highly correlated to the exposure to contaminants and they must be taken into account in future biomonitoring studies.

Finally, these studies have contributed to a broad dissemination of science and preparation of researchers, more specifically: 11 research papers, 23 congress contributions, 2 MSc thesis and 4 PhD thesis were generated. The collaboration between volunteers and researchers of different disciplines is especially recognised in this overview. Further studies should be addressed in the Eurasian Eagle-owl from Southeastern Spain to evaluate future spatio-temporal trends of contaminants and possible adverse effects.

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Pre-incubation behaviour of a pair of Eurasian Eagle-owls (*Bubo bubo*) based on IR-video recordings at a nest site in Baden-Württemberg, Germany in 2014-2015

Comportamento pré-incubação de um casal de bufo-real (*Bubo bubo*) com base em gravações de vídeo de infravermelhos num ninho em Baden-Württemberg, Alemanha em 2014-2015

Christian T. Harms[1*]

1 Arbeitsgemeinschaft Wanderfalkenschutz Baden-Württemberg (www.agw-bw.de), Brandensteinstr. 6, D-79110 Freiburg, Germany.

*** Corresponding author:** cth-frbg@go4more.de



ABSTRACT

Pre-incubation behaviours displayed by a pair of Eurasian Eagle-owls (*Bubo bubo*) at a nest site in Southern Germany were captured by infrared (IR) video camera. During courtship, the male exhibited behaviours to guide his mate to the nest site, to gain her acceptance of the site and to strengthen their pair bond in preparation for nesting. Prey presentation and transfer appeared to play a minor role in attracting the female to the nest site compared to male visual and acoustic signals. The duration of male visits varied from a few seconds to over 5 h (total of 47:44 h) but the average visit duration per night increased from 0:29 to 2:51 h and the visit frequency per night increased from 2.5 to 5.1 (N=139) over the pre-incubation period. The female's 29 visits (9:35 h total) also intensified over this period. Copulations were observed 3 weeks before egg laying. Later, the male frequently (n=14) laid down in the nest hollow in an incubation-like posture for >1 h periods. Likewise, in the 3 weeks before egg laying, the female frequently (n=10) spent considerable time (0:28 to 1:25 h) lying in the nest hollow in an incubation-like position. Web cameras have transmitted live footage from various owl nests in recent years but no scientific evaluation of recorded behaviour has been reported. This report provides the first analysis of pre-incubation behaviour of a pair of Eurasian Eagle-owls at their nest site under natural outdoor conditions.

Keywords: *Bubo bubo*, courtship, IR-video recording, nest site behaviour, pre-incubation

RESUMO

Os comportamentos exibidos por um casal de bufo-real (*Bubo bubo*) durante a pré-incubação num local de nidificação localizado no sul da Alemanha foram gravados com uma câmara de vídeo de infravermelhos (IR). Durante a corte, o macho exibiu comportamentos para conduzir a sua parceira ao local de nidificação, para induzir a aceitação do ninho por parte desta, e para reforçar a ligação do casal para preparar a reprodução. A apresentação e transferência de presas pareceu apresentar um papel menos importante na atração da fêmea ao local de nidificação, em comparação com os sinais visuais do macho e com sinais acústicos. A duração das visitas do macho variou entre alguns segundos até mais de 5 h (total de 47h44), mas a duração média das visitas por noite aumentou de 0h29 para 2h51, e a frequência das visitas por noite aumentou de 2,5 para 5,1 (N=139) ao longo do período de pré-incubação. As 29 visitas da fêmea (9h35 no total) também se intensificaram ao longo deste período. As cópulas foram observadas três semanas antes da postura. Mais tarde, o macho assumiu frequentemente (n=14) uma postura deitada, semelhante à de incubação, na cavidade do ninho por períodos superiores a 1 h. Da mesma forma, nas 3 semanas anteriores à postura, a fêmea passou frequentemente (n=10) tempo considerável (0h28 a 1h25) deitada na cavidade do ninho numa postura semelhante à de incubação. Nos últimos anos, têm sido transmitidas imagens em tempo real a partir de vários ninhos de rapinas noturnas através de câmaras online, sem que tenha sido reportada uma avaliação científica dos comportamentos registados. Este relatório apresenta uma primeira análise do comportamento pré-incubação de um casal de bufo-real no seu local de nidificação em condições naturais.

Palavras-chave: *Bubo bubo*, comportamento no ninho, corte, pré-incubação, vídeo de infra-vermelhos

Introduction

Analogue photo-trapping and video recording techniques have been employed in ecological studies for quite some time (Cutler & Swann 1999; Wratten 1994). More recently, digitalization, miniaturization, expanded functionality and reduced cost have stimulated further use of video technology in research (Ribic et al. 2012) and to stimulate public interest in bird watching and conservation. Cameras connected to the internet enable the public to live stream active nests from an increasing range of bird species, including owls. Expert commentary, supportive interpretation and additional information material has contributed to substantially enhance the educational value and impact beyond the visual experience afforded by the camera (see www.uhu.webcam.pixtura.de/tagebuch; www.ageulen.de; and other "livecam" websites). However, detailed and quantified peer-reviewed publications of bird activities and behaviour based on video recordings are rare for diurnal and nocturnal species alike (Bosch 2012, Bosch 2013, Nielsen et al. 2015; Harms 2017a, Harms 2017b; Kniprath 2018). Nocturnal species, such as owls, have been difficult to study (Zuberogoitia & Campos 1998) because of our limited abilities to observe their behaviour at night. Microelectronic devices such as radio-transmitters and infrared (IR) video technology have emerged as powerful new tools to overcome this limitation enabling the unobtrusive observation of nocturnal species at fixed locations such as nest sites.

Figure 1 - Cliff habitat containing an active Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2014-2015.

Figura 1 - Escarpa onde se localizava um ninho de bufo-real (*Bubo bubo*) ativo em 2015-2015, em Baden-Württemberg, Alemanha.



Figure 2 - Equipment employed to monitor a nesting pair of Eurasian Eagle-owls (*Bubo bubo*) in Baden-Württemberg, Germany in 2014-2015. Images are not to scale: (1) IR video camera, (2) wireless receiver, monitor and recording unit, (3) power supply.

Figura 2 - Equipamento usado para monitorar um casal de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, em 2014-2015. As imagens não obedecem a uma escala: (1) câmara de vídeo de infravermelhos, (2) recetor sem fio, monitor e unidade de gravação, (3) fonte de alimentação.



For more than 2 decades, video-based research techniques at bird nest sites have been employed mainly in two areas: to study nest site predation (Bolton et al. 2007, Cutler & Swann 1999, Renfrew & Ribic 2003), and prey delivery by diurnal raptors (see references in Harms 2018a). While owl nest site webcams have been operational for several years (i.e., www.uhu.webcam.pixtura.de) there has been no published scientific evaluation of their behaviour during key stages of their reproductive cycle.

This paper presents a detailed analysis of behaviour of a pair of non-ringed (unbanded) Eurasian Eagle-owls (*Bubo bubo*) during the pre-incubation (courtship) period based on IR video recordings at a nest site in southern Germany in 2014-2015. A resident pair successfully nested in this location for several years in a row and was part of a small local regularly monitored population (Harms et al. 2015; Harms 2016; Harms & Lühl 2017, Harms 2018b).

This research is part of a long-term (since 1965) volunteer program (www.agw-bw.de) to monitor, ring (band), protect and conserve sympatric species inhabiting rock cliff habitats in the federal state of Baden-Württemberg including the Peregrine Falcon (*Falco peregrinus*), Eurasian Eagle-owl and Common Raven (*Corvus corax*). The program has been highly successful and instrumental in re-establishing and protecting the target species in the region from near-extinction to well above 200 occupied territories and breeding pairs in 2015 (Rau 2015).

Methods

Behaviours and activities of a pair of Eurasian Eagle-owls were recorded with a camera at their nest located 25 km West of Freiburg, Baden-Württemberg, Germany (Harms 2017a). The logistics and equipment used is the result of extensive trials as discussed by Harms (2015). To record a full reproductive season, the camera was installed November 2014 and was operated from December 2014 to early June 2015 when the fledglings permanently wandered off the nest. The nest was 20 m high up a calcareous rock cliff in a quarry and was sheltered from uphill vineyards by overhanging rocks and a row of shrubs and trees (*Robinia pseudoacacia*) (Fig. 1). The pole-mounted camera extended beyond the overhang and was positioned 3 m above and 7 m away from the nest. The recorded image took in the nest and the surrounding area (5 m wide and 3 m high).

Equipment (Fig. 2) was locally purchased for under 500 € and included a video camera (Visortech) with 24 infrared (IR) LEDs providing illumination at night to 10 m. The ¼-inch CMOS sensor produced low-quality colour pictures of 512x384 pixel resolution at 25 fps (frames per second) during the day and grey-scale pictures at 3-10 fps, depending on available light, at night. IR illumination was automatically switched on when ambient light was low. The low frame rate under IR-lighting caused fast-moving objects (i.e. owl in flight) to appear blurred on the pictures and made it difficult to observe fine details. The camera and recorder (see below) were powered by 12 V DC lithium-ion adjustable-output rechargeable notebook power banks (ReVolt) of 24,000 mAh capacity. A power cable extended between the camera and the remote battery and recorder locations. The video signal was transmitted wirelessly (2.4 GHz); for technical reasons acoustic signals were not recorded.

A remote receiver-monitor-recorder (Visortech) was used to receive, view and store video signals. Videos were automatically split into 15 min long files and stored on 32 GB SD-storage media using H.264 compression. A monitor was used to view the nest when exchanging batteries but was switched off during recording to extend battery life. The recorder and batteries were protected from the weather by a plastic bag. Due to their limited capacity it was necessary to exchange batteries and storage media once per day. The owls were not disturbed because

Table 1 - Summary information on the IR-video recordings of pre-incubation behaviour of a pair of Eurasian Eagle-owls (*Bubo bubo*) at a nest site in Baden-Württemberg, Germany in 2014-2015.
* time between sunset and sunrise, including dusk & dawn periods

Tabela 1 - Resumo das informações sobre as gravações de vídeo de infra-vermelhos referentes ao comportamento pré-incubação de um casal de bufo-real (*Bubo bubo*) num ninho localizado em Baden-Württemberg, Alemanha, em 2014-2015.

PERIOD	PRE-COURTING	COURTING	ALL PRE-INCUBATION
Date	Dec 8 - Dec 31	Jan 1 - Feb 21	
Calendar days	24	52	76
Recording days	11	37	48
Hours recorded [h:min]	189:40	641:20	831:00
- night time hours recorded* [h:min] (%)	170:47 (90.0)	536:40 (83.7)	707:27 (85.1)
- day time hours recorded [h:min] (%)	18:53 (10.0)	104:40 (16.3)	123:33 (14.9)
avg. recording time per recording day [h:min]	17:15	17:20	17:18

Table 2 - Behaviours of a male Eurasian Eagle-owl (*Bubo bubo*) at a nest site in Baden-Württemberg, Germany. Normal and *courting* behaviours are distinguished by font below, and were captured on IR-video recordings in the pre-courting period (December 2014).

Tabela 2 - Comportamentos de um macho de bufo-real (*Bubo bubo*) num ninho localizado em Baden-Württemberg, Alemanha. Os comportamentos normais (letra normal) e de corte (*em itálico*) foram registados em gravações de vídeo de infravermelhos no período de pré-corte (dezembro de 2014).

DATE	TIME	DURATION [MIN]	ACTIVITY
Dec 12	19:31 - 19:58	27	resting
Dec 14	04:57 - 05:04	7	*repeated excited tail lifting*; maintaining feathers, *calling*
Dec 16	07:36 - 07:45	9	resting, feeding, maintaining feathers, care of plumage
Dec 26	17:44 - 17:48	4	resting, leaves with prey remains taken from deposit
Dec 26	19:57 - 21:00	63	*excited tail lifting, calling*; resting
Dec 27	05:36 - 07:21	105	resting; maintaining feathers, care of plumage
Dec 31	04:50 - 07:29	159	resting, feeding, maintaining feathers; *calling* before take-off
Dec 31	07:35 - 07:44	9	arrives with prey in beak, walks about nest site, takes off
Summary	8 visits in 6 nights	383	mainly 'normal' behaviours; *few behaviours with courting connotation*

the recorder and batteries were placed above the cliff behind vegetation 15 m from the camera. Daily visits enabled a timely response to equipment failures.

Recorded videos were transferred to PC, replayed, and owl behaviour was written down in detail. Behaviours were later transposed into Excel for qualitative and quantitative analysis. As each video frame is time stamped, a precise, second-by-second sequence of behaviours can be described with respect to the duration and temporal intervals. Statistical methods followed McDonald (2014).

Adult Eurasian Eagle-owls are sexually size dimorphic (Marks et al. 1999), and the difference in relative size was used to distinguish the smaller male from the larger female when both owls were present. Previously published sex-specific Eurasian Eagle-owl behaviours (Marks et al. 1999) were also used to identify the male and the female, in addition to a distinct wing plumage pattern on the male. The male also had a habit of frequently closing its left eye.

The pre-incubation period was divided into a pre-courtship period and a courtship period. The pre-courtship period was defined by a concurrent Eurasian Eagle-owl survey program as being prior to 1 January 2015 (Harms 2016). Consequently, the courtship period is defined herein as 1 January to 22 February when the first egg was laid. However, it is acknowledged that this division was somewhat arbitrary in that the male was observed exhibiting a gradual increase in courtship behaviours over the pre-incubation period during visits to the nest site at night.

Results and discussion

Table 1 provides an overview of pre-incubation video recordings. The camera was operated at night intermittently prior to (11 of 24 nights) and during the courtship period (37 of 52 nights). Daytime recording was limited during these periods because the owls were not present at the nest site during the day (Table 1). The results presented and discussed include only data or information obtained from video recordings.

Pre-courtship period behaviour

The male visited the nest site a total of 6:23 h (3.7% of total recorded night hours) during eight visits on six nights during this period. The male exhibited some courtship behaviour during these visits such as excited tail lifting and calling (Table 2). On 26 and 31 December, I inferred that the female was perched nearby based on the male's behaviour. The male's visits appeared to be either short (4-9 min) or long (27-159 min), a pattern also observed during the courtship period. The female was not observed to visit the nest site during this period even though it is likely that she was aware of its presence, either because of the male's presence and/or if she was the same female that successfully reared chicks at this nest site in previous years.

Male courtship period behaviour

Courtship activities at the nest site increased in early January (Table 3). The number of the male's nest site visits per 10-day interval ranged from 15-26 for the first 40 days and then increased to 51 within the last 12 days before egg laying (Table 3). The average number of visits per night increased and the total time at the nest site also steadily increased; 60% of the time the male spent at the nest site was in the last 12 days before egg laying. This is also reflected in the gradual then large increase in the average time per night the male spent on the nest site (Table 3).

The duration and distribution pattern of the male's visits during courtship was highly variable (Table 4). More than half of all visits lasted for 5 min or less and such short visits occurred in all intervals of the courtship period and increased during the last time interval before egg laying. Visits exceeding 60 min also increased dramatically in the final

Table 3 - Quantitative aspects of nest site visitation by a male Eurasian Eagle-owl (*Bubo bubo*) as captured on IR-video recordings in the courting period (January 2015) in Baden-Württemberg, Germany.

Tabela 3 - Aspetos quantitativos das visitas ao ninho por um macho de bufo-real (*Bubo bubo*), conforme gravações de vídeo de infravermelhos no período de corte (janeiro de 2015) em Baden-Württemberg, Alemanha.

MALE ACTIVITY DURING COURTING	JAN 1 - 9	JAN 10 - 19	JAN 20 - 29	JAN 30 - FEB 9	FEB 10 - 21	TOTAL
Calendar days	10	10	10	10	12	52
Recording days	9	5	5	8	10	37
Nights with male presence	6	5	5	8	10	34
Number of visits	15	23	24	26	51	139
Avg. number of visits per night with presence	2.5	4.6	4.8	3.3	5.1	4.1
Duration of all visits [h:min:sec]	2:53:58	3:28:47	4:21:58	8:26:50	28:32:49	47:44:22
Cumulative duration of all visits [h:min:sec]	2:53:58	6:22:45	10:44:43	19:11:33	47:44:22	
Duration of all visits [%]	6.1	7.3	9.1	17.7	59.8	100
Cumulative duration of all visits [%]	6.1	13.4	22.5	40.2	100	
Avg. duration of visits per night with presence	0:29:00	0:41:45	0:52:24	1:03:21	2:51:17	1:24:15
Number of visits <5 min	8	18	15	11	29	81
Number of visits >60 min	1	1	2	4	6	14

Table 4 - Number and duration of nest site visits by a male Eurasian Eagle-owl (*Bubo bubo*) in Baden-Württemberg, Germany as captured on IR-video recordings in the courting period (January 2015).

Tabela 4 - Número e duração das visitas ao ninho por um macho de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, conforme gravações de vídeo de infravermelhos no período de corte (janeiro de 2015).

Duration of visit [min]	<1	>1 - 5	>5 - 15	>15 - 30	>30 - 60	>60	cumulated
Number of visits	12	69	33	6	5	14	139
% of visits	8.6	49.6	23.7	4.33	3.6	10.1	100
% of visits, cumulated	8.6	58.3	82.0	86.3	89.9	100	
Duration of visits [h:min:sec]	0:06:06	2:59:48	4:37:35	2:12:01	3:38:20	34:10:32	47:44:22
% duration	0.2	6.3	9.7	4.6	7.6	71.6	100
% duration, cumulated	0.2	6.5	16.2	20.8	28.4	100	

courtship period interval (Table 3) resulting in a high proportion of the time the male was present at the nest just before egg laying (Table 3, Table 4). Over the entire courtship period more visits occurred during dusk and dawn than close to midnight (unpubl. data).

Male courtship behaviour attracts the female to the nest site and serves to secure the pair bond culminating with the laying of fertile eggs. A total of 275 distinct male behavioural events were summarized by courtship period intervals (Fig. 3); the male's activity level remained steady for the first 40 days of courtship and intensified substantially during the last 12 days prior to egg laying. The male's ear tufts were erect during all courtship behaviours possibly indicating a state of excitement or arousal.

Some behaviours were expressed more frequently during some intervals presumably to assist with pair formation for reproduction. Other behaviours, i.e. calling, were consistent over all intervals to attract the female from a distance, and/or to advertise to other males that the territory was occupied. Behaviours like turning and lying down (an incubation-like posture lasting a maximum of 1 min.) in the nest hollow were recorded more frequently in the later intervals. Dancing displays were confined to the early intervals prior to the female visiting the nest site (see female behaviour below) whereas conversations (i.e. relatively quiet vocalizations uttered when mates are close such as "buh-ju-dugge-dugge", see Mebs & Scherzinger 2008) and ritual copulations (Table 5) were recorded when the female was also at the nest site during the last interval. Some of the male's behaviours at the nest site implied that the female was present nearby but outside the camera's viewing field, i.e., duet vocalizations.

On relatively few occasions the male briefly visited the nest site with prey and then departed with it; a behaviour interpreted as a courtship "display of prey" (Table 5, Fig. 3). The male transferred prey twice before the female appeared to have accepted the nest site (see below) and five times shortly before egg laying. This behaviour is generally associated with the formation and maintenance of pair bonding in birds of prey (Marks et al. 1999). However, the small number of prey transfers and their timing suggested that other male courtship behaviours, such as visual and acoustic signals, may be a more important means to attract females to the nest site. During the last 3 weeks of the pre-laying period the male spent considerable time during longer visits laying down in the nest in a simulated incubation position and often making scratching movements or removing small objects from the nest site (Table 5).

Eurasian Eagle-owl copulations were commonly observed during surveys in the study area in the weeks before egg laying, most often at dusk on the owls' favourite perches (Harms 2016). Several copulations were recorded and captured on HD quality video which revealed that no contact of the birds' cloacae occurred during these early ritual (i.e. incomplete, *pro forma*) copulations. Ritual copulations were also recorded at the nest site in advance of egg laying (Fig. 3) and may function to strengthen pair bonds, synchronize pair behaviour and physiology, and ensure effective fertilization of the eggs.

Concurrent dusk surveys documented that by the end of January the male Eurasian Eagle-owl had moved about 600 m from a daytime forest roost to an ivy-covered oak tree closer to the nest site (Fig. 4) which it used through the courtship, incubation and a major part of the chick rearing periods (unpubl. data).

Female courtship period behaviour

The female was less active than the male, visiting the nest site 29 times on 18 nights of the 52-day courtship period, and one-half of the 9:35 h spent at the nest occurred in the last 12 days before egg laying (Table 6). Visits of different duration were more evenly spaced across the period than the male's but visits exceeding 60 min (n = 5, total duration

Table 5 - Description of courtship behaviours of a male Eurasian Eagle-owl (*Bubo bubo*) as captured on IR-video recordings in the pre-incubation period in 2014-2015, at a nest site in Baden-Württemberg, Germany.

Tabela 5 - Descrição dos comportamentos de corte de um macho de bufo-real (*Bubo bubo*) conforme gravações de vídeo infravermelhos no período de pré-incubação em 2014-2015, num ninho em Baden-Württemberg, Alemanha.

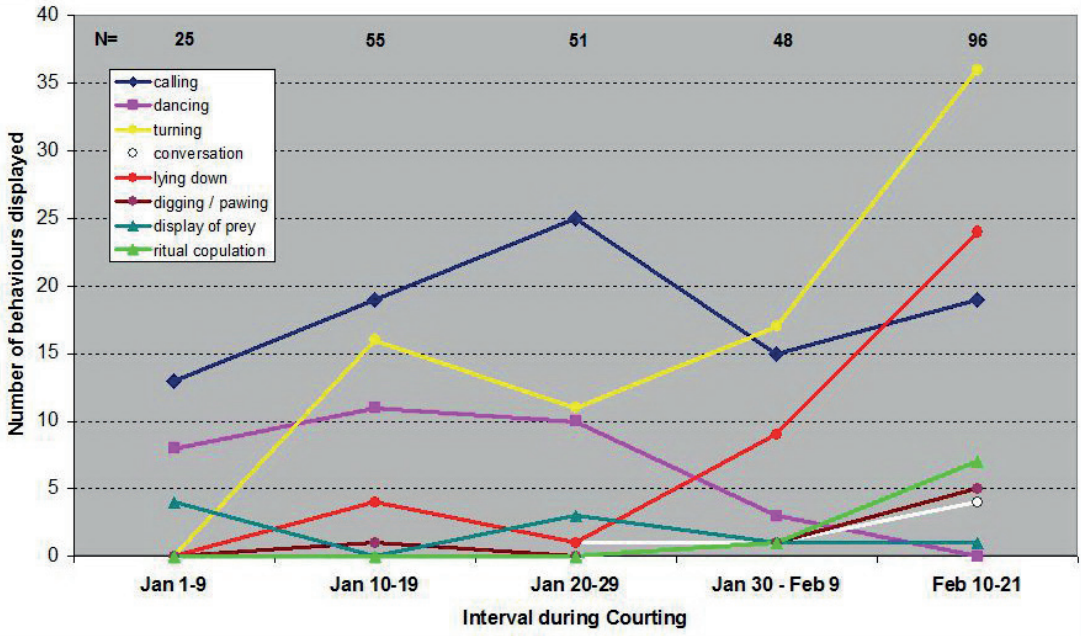
TYPE	DESCRIPTION
calling	repeated calling, inflated white throat clearly displayed, mostly combined with flashing or erect tail
turning	360° turn on the nest site, usually with tripling feet, often in bowed posture and with erect tail
tail whipping/spreading	excited repeated upward flashing of the tail/spreading of tail feathers
dancing	moving about the nest site, often in combination with turns, bows and calls, or shuffling feet
scratching in nest hollow	digging, scratching the surface of the nest site to deepen a shallow hollow for the placement of the eggs, often combined with turns and calls
cleaning nest site or hollow	removing small objects up to the size of eggs from the nest or hollow (particularly pieces of rock with sharp edges which may be harmful to eggs)
conversation	acoustic interaction of male and female when close to and facing each other, often with bowed head or displaying inclined posture
lying down in the nest hollow	lying down in the nest hollow lasting a maximum of 1 min.; may be combined with calls or cleaning activity
simulated incubation	lying down in the nest hollow, often preceded by turning and shuffling; extended duration (10 to >60 min) in an egg incubation-like posture
display of prey	male brings prey item to the nest site, offering or displaying it; may be combined with supportive calls; male departs from nest site with prey
offering & transfer of prey	male landing on nest site with prey item (usually held in beak), immediately followed by the female landing, offering prey to female in bowed posture, transfer of prey beak to beak; may be combined with conversation following transfer; male departs shortly (20-60 sec) after transfer
ritual copulation	copulation attempts without apparent cloacae contact, may occur several weeks before egg laying
copulation	copulations with apparent cloacae contact within the egg laying period leading to fertilization of eggs

6:15 h) accounted for more than 65% of the female's presence at the nest site (Table 7). When and how the female first responded to the advertising behaviour of the male, and when and by which behaviours did the female indicate a decision to accept the nest site were of interest.

The female first appeared at the nest site on 14 January 2015 after the male had been dancing (Table 5) for 2 min and which he continued for another 3 min after the female arrived. Following the male's departure, the female walked about the nest site, inspecting it, and started cleaning it. During the female's 10 min visit she repeatedly called (likely answered by the nearby male). The male returned to the nest 1:30 min after her departure, danced for 2:48 min and also cleaned

Figure 3 - Number and temporal distribution of recorded principal male Eurasian Eagle-owl (*Bubo bubo*) courting behaviours displayed at a nest site in Baden-Württemberg, Germany in 2014-2015.

Figura 3 - Número e distribuição temporal dos principais comportamentos de corte do macho de bufo-real (*Bubo bubo*) exibidos num ninho em Baden-Württemberg, Alemanha, em 2014-2015.



the site and briefly laid down in nest hollow. The male's post female visit behaviour may imply that the female was nearby watching.

The following night (15 January 2015) the female visited the nest for 33 sec and received a prey item from the male, and later again for 18:29 min when she inspected and cleaned the site. Video recordings showed that the female followed the male to the nest site for 18 of 29 female visits, and included the six occasions when the male transferred prey to the female. On 21 of the female's 29 visits, the male departed shortly (avg. 1:31 min) after her arrival which may have provided the female enough room to perform pre-egg laying behaviours at the site: the nest site was approx. 60 cm wide and 25-40 cm deep (see Fig. 1 in Harms 2019a) and there was a solitary stone approx. 50 cm away that was used by either owl as a perch during the courtship period.

The female assumed a simulated incubation posture (Table 5) nine times, initially (18 January; 1, 5 & 9 February 2015) for short duration (3:27 to 26:35 min) and along with other more dominant behaviours. This increased in length to become the dominant behaviour in early evenings between 6-18 February 2015 (n = 5 events, each > 1 h).

For the first time on 18 February 2015 (i.e., less than a week before egg laying), the female spent time at the nest site during daylight: At 17:19 (38 min before sunset) she was in a simulated incubation position in the hollow when I arrived to exchange batteries. The female left the nest site at 18:20:40 after a minimum 70 min simulated incubation session. She returned to the nest at 5:08:20 the next day for 2:15 min to receive prey from the male.

On 18 & 20 January, and twice on 6 February, the female landed at the nest site,

Figure 4 - Male Eurasian Eagle-owl (*Bubo bubo*) perched at a daytime roost close to its nest site in Baden-Württemberg, Germany in May 2015 during the chick rearing period.

Figura 4 - Macho de bufo-real (*Bubo bubo*) num poiso diurno próximo do ninho em Baden-Württemberg, Alemanha, em maio de 2015, durante o período de juvenis no ninho.



Table 6 - Quantitative aspects of nest site visitation by a female Eurasian Eagle-owl (*Bubo bubo*) as captured on IR-video recordings in the courting period (January 2015) in Baden-Württemberg, Germany.

Tabela 6 - Aspetos quantitativos das visitas ao ninho por uma fêmea de bufo-real (*Bubo bubo*) conforme gravações de vídeo de infravermelhos durante o período de corte (janeiro de 2015) em Baden-Württemberg, Alemanha.

FEMALE ACTIVITY DURING COURTING	**JAN 1 - 9**	**JAN 10 - 19**	**JAN 20 - 29**	**JAN 30 - FEB 9**	**FEB 10 - 21**	CUMU-LATED
Calendar days	10	10	10	10	12	52
Recording days	9	5	5	8	10	37
Nights with female presence	1	4	1	5	7	18
Number of visits	1	6	3	9	10	29
avg. number of visits per night with presence	1	1.5	3	1.8	1.4	1.6
Duration of all visits [h:min:sec]	1:20:10	0:43:57	0:13:11	2:34:09	4:43:17	9:34:44
Duration of all visits, cumulated [h:min:sec]	1:20:10	2:04:07	2:17:18	4:51:27	9:34:44	
Duration of all visits [%]	13.9	7.6	2.3	26.8	49.3	100
Duration of all visits, cumulated [%]	13.9	21.6	23.9	50.7	100	
avg. duration of visits per night with presence	1:20:10	0:10:59	0:13:11	0:30:50	0:40:28	0:31:56
Number of visits <5 min	0	3	2	3	3	11
Number of visits >60 min	1	0	0	1	3	5

Table 7 - Number and duration of nest site visits by a female Eurasian Eagle-owl (*Bubo bubo*) in Baden-Württemberg, Germany as captured on IR-video recordings in the courting period (January 2015).

Tabela 7 - Número e duração das visitas ao ninho por uma fêmea de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, conforme gravações de vídeo de infravermelhos durante o período de corte (janeiro de 2015).

Duration of visit [min]	<1	>1 - 5	>5 - 15	>15 - 60	>60	cumulated
Number of visits	4	7	7	6	5	29
% of visits	13.8	24.1	24.1	20.7	17.2	100
% of visits, cumulated	13.8	37.9	62.1	82.8	100	
Duration of visits [h:min:sec]	0:01:35	0:22:13	1:07:22	1:48:09	6:15:25	9:34:44
% duration	0.3	3.9	11.7	18.8	65.3	100
% duration, cumulated	0.3	4.1	15.9	34.7	100	

Figure 5 - Number and distribution of Eurasian Eagle-owl (*Bubo bubo*) nest site visits per night during the courtship period (N=139, male; N=29, female) in Baden-Württemberg, Germany in 2014-2015.

Figura 5 - Número e distribuição de visitas ao ninho pelo bufo-real (*Bubo bubo*) por noite durante o período de corte (N = 139, macho; N = 29, fêmea) em Baden-Württemberg, Alemanha, em 2014-2015.

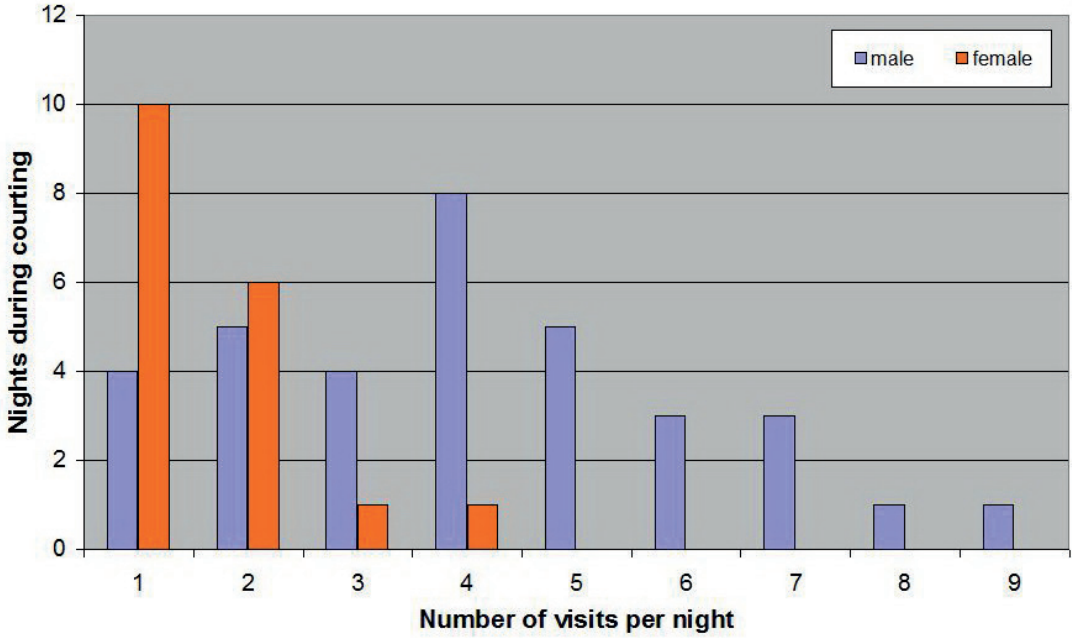


Figure 6 - Number and temporal distribution of Eurasian Eagle-owl (*Bubo bubo*) nest site visits recorded during the courtship period in Baden-Württemberg, Germany in 2014-2015.

Figura 6 - Número e distribuição temporal das visitas ao ninho pelo bufo-real (*Bubo bubo*) registadas durante o período de corte em Baden-Württemberg, Alemanha, em 2014-2015.

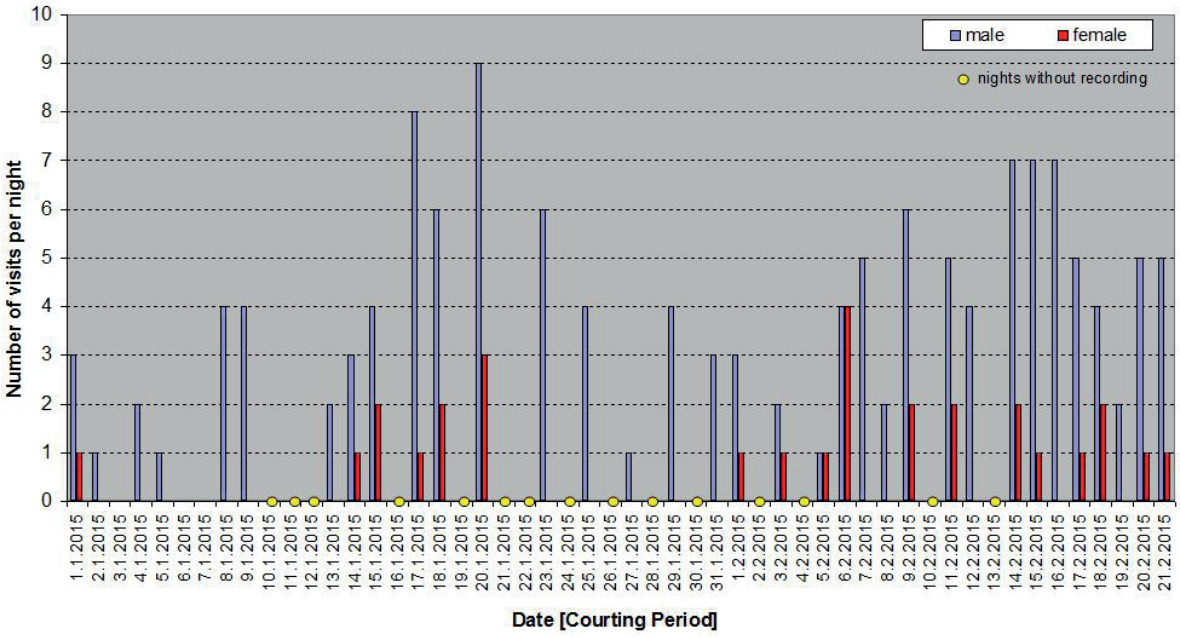


Table 8 - Comparison of male and female Eurasian Eagle-owl (*Bubo bubo*) behaviour as captured on IR-video recordings in the courtship period in 2014-2015 at a nest site in Baden-Württemberg, Germany.

Tabela 8 - Comparação do comportamento do macho e da fêmea de bufo-real (*Bubo bubo*) conforme gravações de vídeo de infravermelhos durante período de corte em 2014-2015 num ninho em Baden-Württemberg, Alemanha.

	MALE	FEMALE
Number of days present	34	18
Total number of visits	139	29
Avg. number of visits per night	4.1	1.6
Total duration of visits [h:min:sec]	47:44:22	9:34:44
Avg. duration per visit [min:sec]	20:36	19:49
Shortest visit [sec]	4	15
Longest visit [h:min:sec]	5:11:19	1:25:35
Date of longest visit	Feb 15	Feb 6
Common time spent at the nest site [min:sec]	31:10	

followed within seconds by the male. Also, for the first time on 6 February, the female landed without being either preceded or followed by the male. However, only 15 seconds after the female left the male landed at the nest site, suggesting he was nearby watching the female's on-site visit.

Comparison of male and female behaviour during the courtship period

The male spent five-fold more time at the nest site and visited it five times more often at nights than the female during the courtship period (Table 8). The male and female spent 31:10 min together at the site, corresponding to approx. 1% of the male's and slightly less than 6% of the female's total time at the nest.

Differences in male and female behaviour distribution patterns include the frequency distribution in the number of visits per night (Fig. 5) and in the phenology of their visits during the courtship period (Fig. 6). The male increased his activities from early January and this peaked on 20 January, which coincided with the female's first cluster of nine visits to the nest site beginning 14 January. Between 21 & 31 January there was a gap of 11 consecutive nights when the female was not present during which time the male made 18 visits and continued to advertise the nest site. Additional, non-recorded, observations suggest an explanation for this gap and are presented below (Conclusions). On 1 February the female started to visit the nest site again after which courtship behaviours increased for both the male and female (Fig. 6). A coordinated increase in nest visits on 6 February suggested a strengthening in the male and female's pair bond and final selection of this nest site which culminated in the laying of the first egg on 22 February.

Both the male and female cleaned the nest site while exhibiting simulated incubation behaviour later in the courtship period. During this behaviour the male indiscriminately, or perhaps symbolically, removed a variety of objects including stones, pieces of wood, and leaves whereas the female appeared to be more selective or practical and removed small rocks with sharp edges from the nest hollow. The latter objects may be more likely to damage eggs and/or to cause discomfort to the incubating female.

The courtship period ended with the laying of the first egg on 22 February when the female remained in the nest during the day.

The female's presence at the nest during daytime hours is a fundamental change of behaviour and a strong signal that egg laying and incubation have begun.

Conclusions

This paper provides the first qualitative and quantitative examination of pre-courtship and courtship behaviour displayed by a pair of Eurasian Eagle-owls in the wild using extensive IR video recordings. A follow-up paper (Harms 2021) focuses on the pair's behaviour during the incubation period; an analysis of the chick rearing period is also available (Harms 2019). During the pre-incubation period more than 70% of the nights were captured providing a near complete chronology of reproductive behaviour for this nocturnal top avian predator. The analysis of the owls' cryptic nocturnal reproductive behaviour has become possible through the use of the IR video camera at a nest site under undisturbed natural outdoor conditions. While some of these results confirm previous observations, often derived from birds kept in captivity, others reveal some new and unexpected behaviours which deserve further comment and discussion.

The male's display and transfer of prey were expected to play a major role to attract the female to the nest site (Lack 1940, Smith 1960). Sharing food may be a strong signal of crucial values such as altruism or commitment in addition to demonstrating the male's fitness, which is indispensable during incubation and chick rearing when female and young are totally dependent upon the male's ability to provide enough food to sustain them (Harms 2018a, 2019). Yet only four food displays and two prey transfers were observed during courtship when the female is presumably choosing a nest site. This suggests that these behaviours play a lesser role in attracting the female to the nest site.

Nest site selection is a complex decision making process involving the exchange of a range of different signals between the male and the female. Male courtship behaviours other than feeding and food display, such as vocal and dancing displays, may be relatively more important to the female in this regard. These aspects of courtship rituals deserve more research, especially given that the acoustic component of the male's behaviour could not be evaluated fully in this study due to a lack of concurrently recorded sound due to technical reasons. Future research should focus on the strategies and mechanisms of mutual (cooperative) decisions in pair formation such as nest site selection, since they play a vital role in the reproductive process (Harms, in preparation) and many aspects of courtship behaviour remain unknown at this time.

Outstanding questions include if it was typical why the female did not visit the nest site until after seemingly excessive courtship behaviour effort by the male intended to guide her to the site. From past monitoring efforts, it was clear that the same female used this site in previous years. She would therefore be familiar with this site and other potential sites in the associated territory, yet the annual ritual courtship display phenomenon still seems to be critical to the selection of the same mate and nest site.

The prominence of the simulated incubation behaviour (Table 5) by the male, and the response by the female, were another unexplained discovery, especially given that egg incubation is not a male role in Eurasian Eagle-owl reproduction. It is possible that it serves as a stimulating signal for the female, as she responded to it with numerous extensive simulated incubation behaviours, especially in the late intervals of the courtship period. Her performance of this behaviour may have simply imitated (mirrored) the male's or it may be a self-stimulatory exercise in preparation for the upcoming nesting period or a signal to her mate indicating progress along the courtship process, or a combination of these purposes. The amount of time invested in this behaviour can be regarded as a measure of

its importance in the courtship process. Such interactions reveal that behaviours associated with courtship and decision making are still poorly understood at this time and deserve further research (Harms, in preparation).

The activity profile during courtship represented in Fig. 6 revealed a striking gap when the female did not appear in the recordings for 11 nights in a row in late January 2015. Observations I made in February and March 2016 help us understand the female's 2015 absence. In 2016, I was again following the activities of this pair of Eurasian Eagle-owls, identified with distinguishable visual features, using the nest-site camera. After a period of 'normal' courtship activities, the owls' activities dwindled and then stopped by the end of February. Again, the recordings offered little in terms of explanation, but their behaviour made it clear that the owls did not intend to nest at this site. Some weeks later, during an exploratory visit, I detected the female lying in a rock cavity about 25 m away from their 'regular' nesting site, and apparently incubating her eggs. Together, these observations in 2016 lead to a new interpretation of the owls' activities: apparently, they were courting at their regular nest site (captured by the camera) but were also exploring alternative sites such as the rock cavity (outside the camera's viewing field) for some time. In 2016, the owls chose to use the alternative rock cavity for their nesting; consequently, congruent with this decision, they stopped courtship at the 'regular' site (as reflected in the camera recordings). Most likely the owls exhibited similar behaviour, exploring alternative nest sites, in 2015 as well. For some time, in January 2015, the owls may have been turning their attention to the exploration of the rock cavity. While the female appeared to focus completely on the alternative site and temporarily discontinued her visits to the original site, the male kept visiting and advertising it - although at a reduced level of activity as shown in Fig. 6. Both sites had been used for raising chicks in previous years. Finally, both the male and female resumed courtship at the regular site once they had selected it for the 2015 nesting season. Based on her presence and absence, the female appeared to make the final nest site location decision while the male advertised possible sites. Consequently, the camera then captured a second peak of courtship activities during February 2015 (Fig. 6). This episode further demonstrates how IR video recordings may be employed in the study of nocturnal species as a tool to elucidate behavioural components associated with essential reproductive decision-making.

Whenever a study, such as this, deals with observations on one or few individuals, the important question arises: how much of observed behaviour is typical of the species versus unique individual variation? Most probably, what was observed was a combination of both, i.e. typical behaviours coloured by a special individual shaping ("Überformung"). The courtship behaviours, both previously known and new, of the pair of Eurasian Eagle-owls in this study culminated in successful reproduction, and therefore generate some forward-looking questions. Which behavioural components are fundamental in the canon of reproductive behaviours? Are courtship rituals simply spooled off like a film? How much variability is possible? How much individual colouring is permitted? Do long-time and reproductively experienced pairs run 'the full program' of behaviours year by year, or do they take short cuts? Do first-time breeding pairs display a more varied repertoire of behaviours than established pairs with years of breeding experience? What courtship behaviours are displayed when an experienced owl mates with an inexperienced or new partner? What are the stripped-down, key behavioural elements of a functional courtship that leads to reproductive success? Similarly, behaviours during the incubation period (Harms 2021) should be scrutinized for a better understanding of what are the essential elements of general validity versus those shaped by coincidence, by individual and situational factors.

Such questions can only be addressed if

more recordings of on-site observations are subject to detailed analyses such as presented in this study. Through the comparison of different versions of complex behaviours we can extract the essentials and begin to understand what constitutes the set of indispensable (*archetypical*) behaviours and collect the full range of individual variability. To this end I have made recordings during courtship, incubation and chick rearing at a different location with another pair of Eurasian Eagle-owls, now awaiting evaluation (Harms, in preparation). It is with these goals in mind that I would like to encourage webcam operators to engage in a comprehensive and systematic analysis of their recorded video materials in order to promote a deeper knowledge of the complexity and diversity of owl reproductive behaviours.

Note: Video clips showing selected scenes extracted from the recordings at the Eurasian Eagle-owl nest site may be viewed on YouTube, channel "cth-ornitho" (https://www.youtube.com/channel/UCikFnM7cQEzDpCkM8gywvmQ). Additional information and published articles are available for viewing or download on www.researchgate.net/profile/Christian_Harms2/

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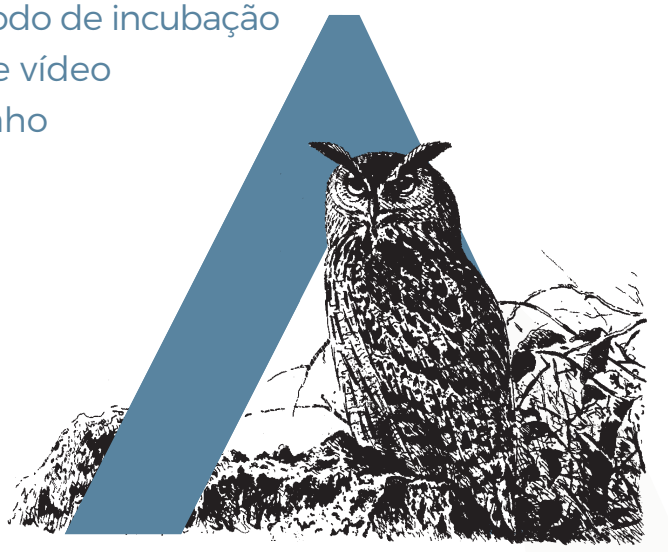
Incubation period behaviour of a pair of Eurasian Eagle-owls (*Bubo bubo*) based on IR-video recordings at a nest site in Baden-Württemberg, Germany in 2015

Comportamento de um casal de bufo-real (*Bubo bubo*) durante o período de incubação com base em gravações de vídeo de infravermelhos num ninho em Baden-Württemberg, Alemanha, em 2015

Christian T. Harms[1*]

1 Deutsche Arbeitsgemeinschaft zum Schutz der Eulen (AG Eulen; www.ageulen.de), Brandensteinstr. 6, D-79110 Freiburg, Germany

*** Corresponding author:** cth-frbg@go4more.de



ABSTRACT

Incubation period behaviours displayed by a pair of Eurasian Eagle-owls (*Bubo bubo*) at a nest site in Southern Germany were captured by infrared (IR) video camera in 2015. During 41 days of incubation, the female left the nest site 169 times for self-maintenance (defecation, feeding, preening, stretching, regurgitation of pellets). Her absences averaged 21 min per night, totalled 14:27 h and were analyzed in detail. The timing and behavioural context of 677 egg turning incidents were evaluated. During incubation the transfer of prey was conspicuous, and their timing and the owl's behaviours were described. Most of the 111 prey items delivered by the male were rodents (66%) including voles (*Arvicolinae* including *Microtus* spp.) and also some birds (10%). Prey delivery was variable and the female experienced temporary food shortages. Thirty-one copulation attempts by the male during the incubation period were rejected by the female and coincided with reduced prey deliveries to the female. This report is the first detailed and comprehensive account of the behaviours displayed by a pair of Eurasian Eagle-owls at their nest during incubation under natural conditions.

Keywords: *Bubo bubo*, Eagle-owl, incubation, IR-video recording, nest site behaviour

RESUMO

O comportamento exibido por um casal de bufo-real (*Bubo bubo*) durante o período de incubação num ninho no sul da Alemanha foi gravado através de uma câmara de vídeo de infravermelhos em 2015. Durante os 41 dias de incubação, a fêmea deixou o ninho 169 vezes para auto-manutenção (defecação, alimentação, *preening*, exercício e regurgitação). As suas ausências demoraram em média 21 minutos por noite, totalizando 14h27 , e foram analisadas em detalhe. O período de ocorrência e contexto de 677 comportamentos de mobilização dos ovos foram avaliados. Durante a incubação, a transferência de presas foi conspícua, e o seu período de ocorrência e comportamento associado foram descritos. A maioria dos 111 itens de presas entregues pelo macho eram roedores (66%), incluindo ratos-cegos (*Arvicolinae* incluindo *Microtus* spp.), e também algumas aves (10%). A entrega de presas foi variável e a fêmea passou por períodos de privação de alimento. Trinta e uma tentativas de cópula pelo macho durante o período de incubação foram rejeitadas pela fêmea e coincidiram com a redução de entrega de presas à fêmea. Este estudo é o primeiro relato detalhado e abrangente dos comportamentos exibidos por um casal de bufo-real em condições naturais, durante a incubação.

Palavras-chave: *Bubo bubo*, bufo-real, comportamento no ninho, incubação, vídeo de infravermelhos

Introduction

The use of photo and video recording techniques to study birds has recently increased with the advancement of associated microelectronic technology (Ribic et al. 2012). Nest-site predation (Bolton et al. 2007; Renfrew & Ribic 2003) and food delivery to raptor chicks (see references listed in Harms 2018a) are the most prominent topics studied using this technology. Quite surprisingly, there are few studies on owls even though affordable infra-red (IR) cameras have been available for several years. IR video recording is best used to study behaviour at fixed locations such as nest sites. Harms (2021a) listed numerous webcams that have used IR-cameras to monitor the nests of various owl species (i.e., www.uhu.webcam.pixtura.de/tagebuch), including Eurasian Eagle-owls (*Bubo bubo*; hereafter Eagle-owl), for public viewing but there are no published studies from these projects.

Nielsen et al. (2015) employed video camera technology to study Eagle-owl prey delivery to chicks at a nest site in Denmark. In 2014, I started an IR video recording project to record and analyse behaviour of breeding Eagle-owls from courtship through chick rearing in Baden-Württemberg, Germany (Harms 2017ab, 2018ab, 2019) including pre-incubation behaviours (Harms 2017a, 2021a) and prey delivery and diet (Harms 2018a). Here I present an analysis of Eagle-owl behaviour during the incubation period.

Table 1 - Summary information on the IR-video recordings of incubation period behaviour of a pair of Eurasian Eagle-owls (*Bubo bubo*) at a nest site in Baden-Württemberg, Germany in 2015.
* time between sunset and sunrise, including dusk & dawn periods

Tabela 1 - Resumo das informações sobre as gravações em vídeo de infravermelhos do comportamento de um casal de bufo-real (*Bubo bubo*) durante o período de incubação, num ninho em Baden-Württemberg, Alemanha, em 2015.

PERIOD	INCUBATION
Date	Feb 22 - Apr 3
Calendar days	41
Recording days	41
Hours recorded [h:min]	699:10
night time hours recorded* [h:min] (% of total)	495:57 (70.9)
daytime hours recorded [h:min] (% of total)	203:13 (29.1)
avg. recording time per recording day [h:min]	17:03

Table 2 - Estimated timing of egg laying and hatching based on IR-video recordings of a pair of Eurasian Eagle-owls (*Bubo bubo*) at a nest site in Baden-Württemberg, Germany in 2015.
Note: switching from CET (Central European Time; UTC+1) to CEST (Central European Summer Time; UTC+2) occurred on March 29, 2015 at 2:00 o'clock
* based on time of first and last sighting

Tabela 2 - Datas estimadas da postura e eclosão dos ovos, referentes a um casal de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, com base em imagens de vídeo de infravermelhos, obtidas em 2015.

	EGG #1	EGG #2	EGG #3
First sighting [date / time]	Feb 22 / 18:20	Feb 25 / 2:05	Feb 28 / 18:18
Last sighting [date / time]	Mar 27 / 22:06	Mar 29 / 20:02	Apr 4 / 8:34
Egg laying interval* [h after previous]	--	55:45	88:13
Hatching interval* [h after previous]	--	44:56	132:32
Duration of incubation [d]	33	32	35

Methods

Behaviours of a pair of Eagle-owls were recorded by means of an IR-video camera directed at their nest site located approx. 25 km West of Freiburg, Baden-Württemberg, Germany (Harms 2017a, 2018b, 2021a). The camera was installed prior to the onset of courting activities in November 2014 and was operated from December 2014 to early June 2015 when the fledglings permanently wandered off the nest. Details of the nest site, the equipment used in this study and the procedures used in the assessment of the videos have been described in Harms (2021a). Some of the technical complications encountered in the selection and operation of surveillance cameras have been discussed in Harms (2015). Prey species were identified from video recordings to genus when possible.

The biomass of prey delivered was estimated according to Plass (2010), Leditznig (2005) and Schweiger & Lipp (2011). Unidentified items were small and eaten by the female at the nest. These were assumed herein to be 25 g mice to calculate estimated prey biomass. Statistical methods followed McDonald (2014).

Results

The nest site location and IR-video recording setup enabled the daily exchange of batteries and storage media without disturbing the owls, particularly the female during incubation (Harms 2017a, 2018b) and rearing of the chicks (Harms 2019). For several years, the resident pair of Eagle-owls (identified from unique plumage markings visible on the recordings) have reared young at this site. They are part of a small local population that are regularly monitored (Harms 2016, 2018b, Harms & Lühl 2017, Harms et al. 2015).

During the incubation period all nighttime and most daytime hours were recorded (Table 1). The onset of incubation brings about a fundamental behavioural change at the nest site. In the pre-incubation (courting) period the nest site remained empty for 96.6% of nighttime and practically 100% of daytime hours (Harms 2021a). By contrast, during incubation, the female spent all daytime and most of the nighttime hours lying in the nest hollow (Fig. 1).

Egg laying started February 22; the first egg was visible when the female left the nest in the evening at 18:20:25. Dates and times of the laying and hatching are summarized in Table 2 together with laying and hatching intervals as revealed by first and last sightings, respectively, in the video recordings. The switch from CET (Central European Time; UTC+1) to CEST (Central European Summer Time; UTC+2) occurred at 2:00 a.m. on March 29 and has been accounted for in the calculation of the hatching intervals. The incubation period ended when the last of three eggs hatched in the early morning hours of April 4 (Table 2).

Female Behaviour

During recorded daytime hours the incubating female never left the nest site. From observations made at other Eagle-owl nest sites, incubating females departed only if threatened (Harms 2018c). Attacks by smaller avian predators such as Common Ravens (*Corvus corax*), Carrion Crows (*Corvus corone*) or Eurasian Buzzards (*Buteo buteo*) may be effectively fended off by the female Eagle-owl by assuming a defensive threatening posture such as fluffed plumage and, under heavier pressure, splayed wings (Harms 2015). If predators force a female off the nest, then the eggs or chicks were usually lost to predation (unpubl. data). Using IR-video recordings, I have documented several unsuccessful attacks by predators including Red Fox (*Vulpes vulpes*), European Badger (*Meles meles*) and domestic cat (*Felis catus*) on a female Eagle-owl during incubation (Harms 2018c).

Absences

Despite the female's broodiness, the eggs were not incubated continuously. Each night the female spent time away from the nest in order to take care of bodily needs such as preening or stretching. For the 41-day incubation period, the female was absent 169 times, averaged 4.1 times per night, averaged 5:08 min./absence and the absences totalled 14:27:40 h (Fig. 2). This averaged 21:10 min per night and representing 2.9% of the nighttime hours in the period.

Female absences fell within four distinct categories according to characteristics such as their timing and purpose (Harms 2017b, Table 3) as follows.

(1) **First evening absence.** This behaviour was consistent for 39 days of the incubation period and was female's first nighttime absence. Sixty percent of these departures

Figure 1 - Incubating female Eagle-owl (*Bubo bubo*) in Baden-Württemberg, Germany in 2015.

Figura 1 - Fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação.



Table 3 - Characteristics of a female Eurasian Eagle-owl 's (*Bubo bubo*) absences from a nest site in Baden-Württemberg, Germany in 2015.

Tabela 3 - Caracterização das ausências de uma fêmea de bufo-real (*Bubo bubo*) do ninho, em Baden-Württemberg, Alemanha, em 2015.

CATEGORY	TYPE A	TYPE B	TYPE C	TYPE D
Label	Evening absence	Feeding absence	Intermittent absence	Morning absence
Definition	First absence after sunset	Departing from nest with prey item received from the male	All other absences without a defined recognizable cause	Last absence before sunrise
Purpose	Defecation, pellet removal, self-maintenance	Consumption of large prey items	Self-maintenance	Defecation, pellet removal, self-maintenance
Number within incubation period	39	20	74	36
Number of nights with this activity	39	16	38	36
Total duration [h:min:sec]	3:17:06	3:21:28	5:45:14	2:03:52
Average duration [min:sec]	5:03	10:04	4:37	3:29
Min. / max. duration [min:sec]	1:59 / 20:15	3:00 / 35:00	0:13 / 16:10	1:04 / 10:04
Median duration [min:sec]	3:29	6:33	3:26	3:01

Figure 2 - Number and temporal distribution of absences of a female Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015.

Figura 2 - Número e distribuição temporal das ausências de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015.

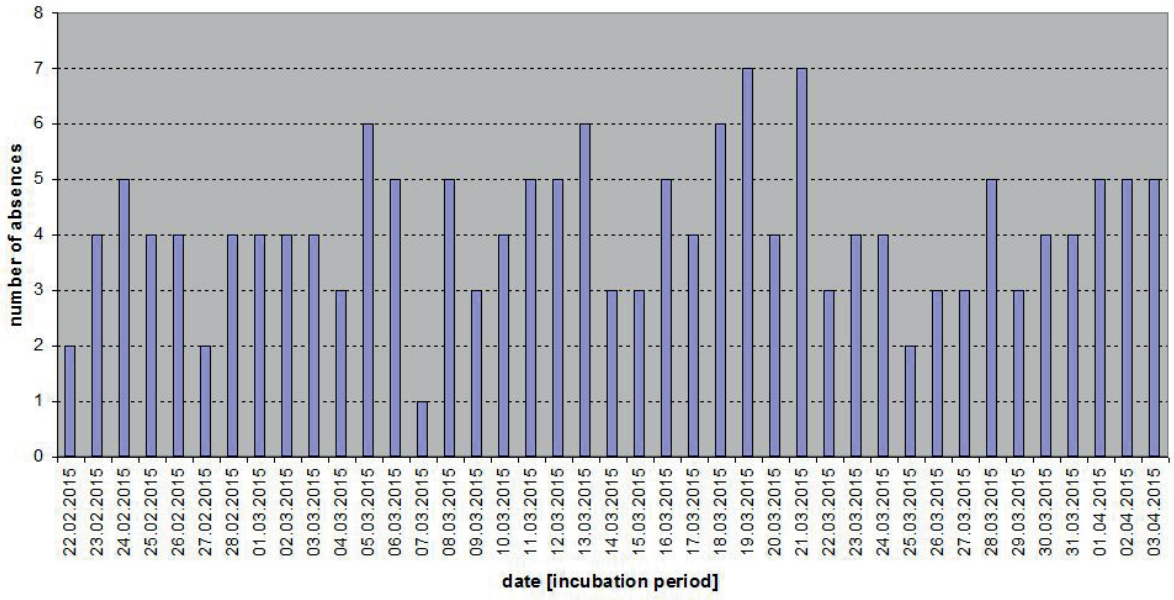


Figure 3 - Duration and temporal distribution of first evening absences of a female Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015.

Figura 3 - Duração e distribuição temporal das primeiras ausências da noite de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015.

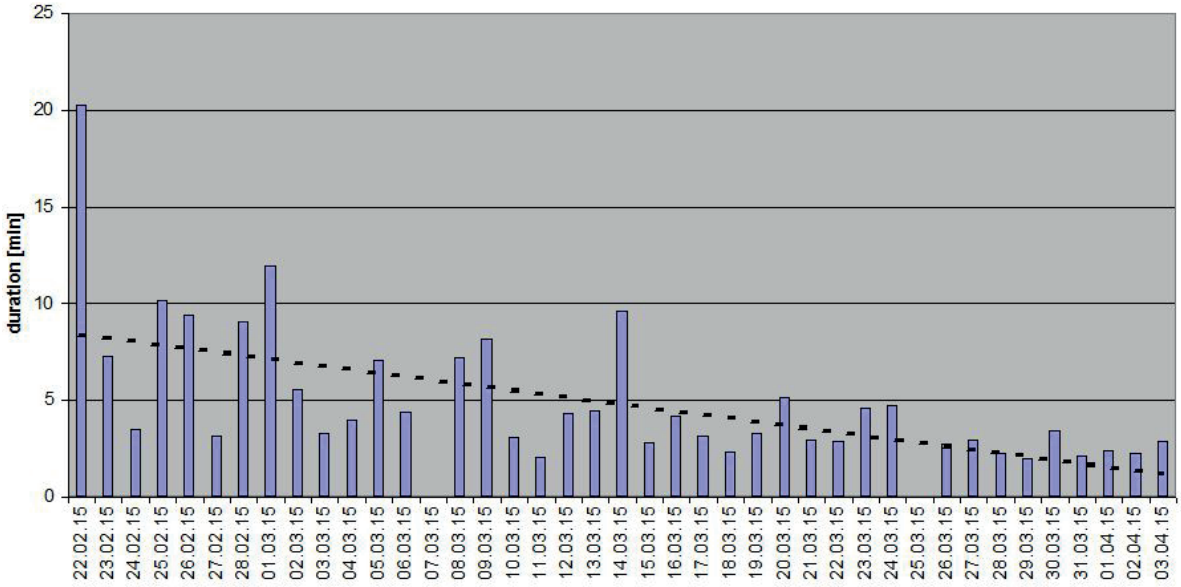


Figure 4 - Duration and temporal distribution of feeding absences of a female Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015.

Figura 4 - Duração e distribuição temporal de ausências para alimentação de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015.

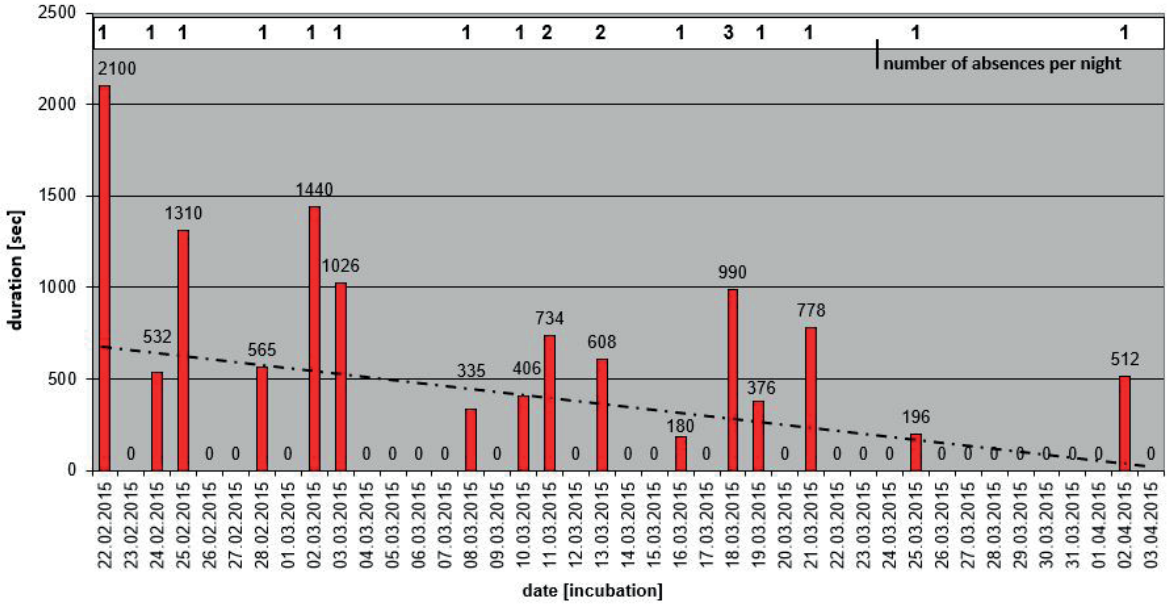
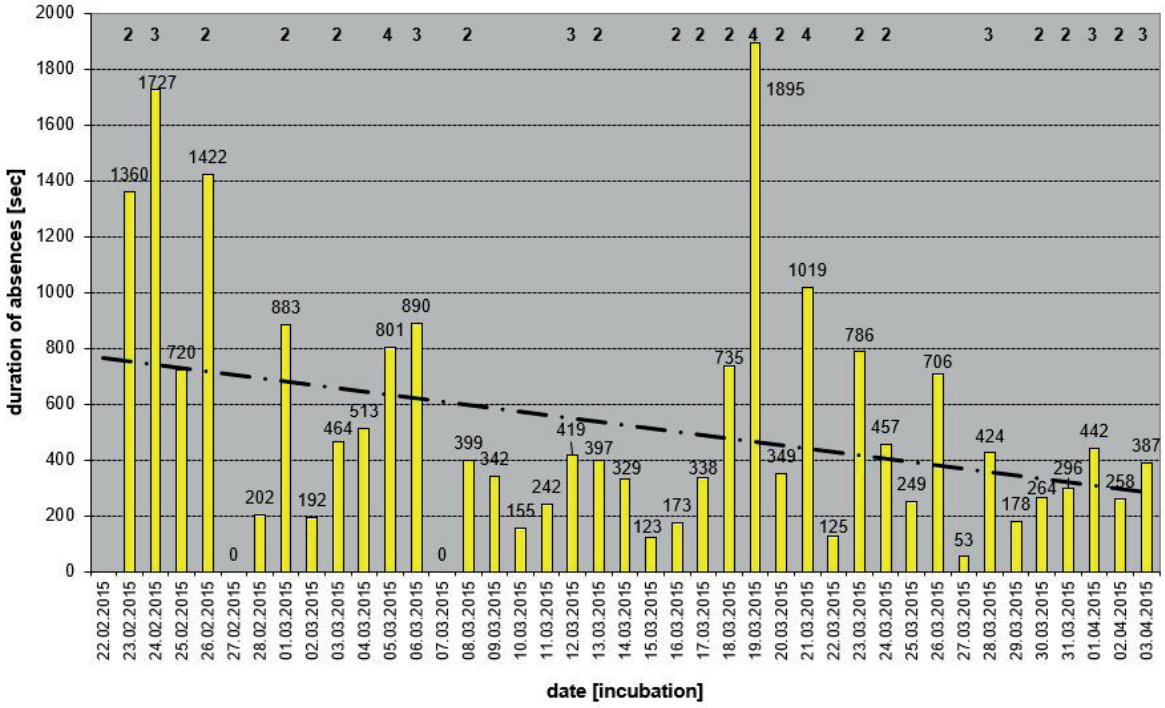


Figure 5 - Duration and temporal distribution of the intermittent absences of a female Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015. The numbers above columns indicate the number of absences represented by the column.

Figura 5 - Duração e distribuição temporal das ausências intermitentes de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015. Os números acima das colunas indicam o número de ausências representado por essa coluna.



occurred within 30 min after sunset, and 90% within 1 hour after sunset. The earliest was 4:31 min after sunset and the primary purpose of these absences was likely defecation. Unlike many diurnal raptors, the female Eagle-owl was never observed to defecate at the nest site. These absences decreased in duration over the incubation period (Fig. 3).

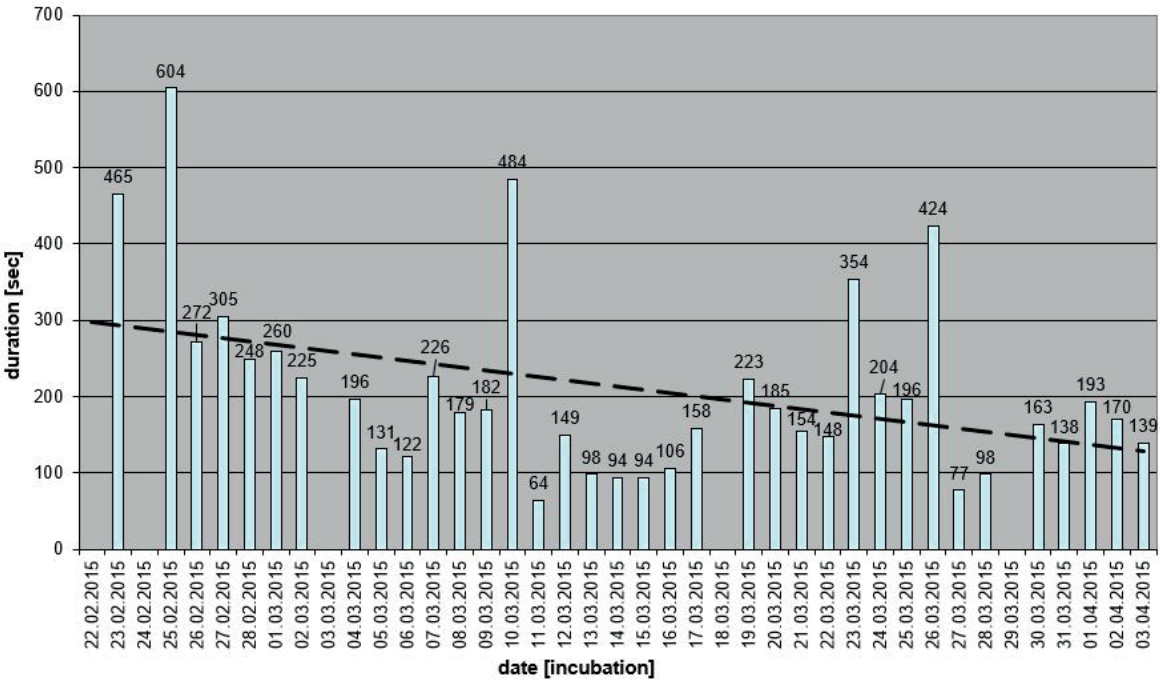
(2) **Feeding absence**. This absence occurred when the female left to eat larger prey delivered by the male that were too large to swallow whole; such prey were never consumed at the nest site during incubation. The number (20 in 16 nights) and timing and duration of these varied (Figs. 4, 11 & 13) and correlated with the size of the prey item (Fig. 4). Like first evening absences, feeding departures lasted longer during the early stages of incubation and tended to become shorter as the incubation progressed.

(3) **Intermittent absence**. This was the most broadly defined, variable and frequent of the female's absences from the nest site (Table 3). Seventy-four departures totalled 5:45:14 h and averaged 4:37 (± 3:29, range 0:13 to 16:10) min. The duration of up to 4 such absences per night decreased over time (Fig. 5) and occurred more often between 3 and 5 o'clock in the morning (unpubl. data).

(4) **Early morning absence**. The last absence of the female before sunrise was likely to defecate; the owls did not defecate at the nest site but did so at specific nearby locations to provide a territorial signal to conspecifics

Figure 6 - Duration and temporal distribution of early morning absences of a female Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015.

Figura 6 - Duração e distribuição temporal das ausências matinais de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015.



(Penteriani & Delgado 2008). The average departure time was 58 (± 37) min before sunrise and absences lasted 3.5 min on average. Five early morning absences were associated with eating large prey delivered by the male (not included in Fig. 6 but shown in Figs. 7 and 8) but the female likely also defecated. The duration of these absences also decreased over the incubation period (Fig. 6.).

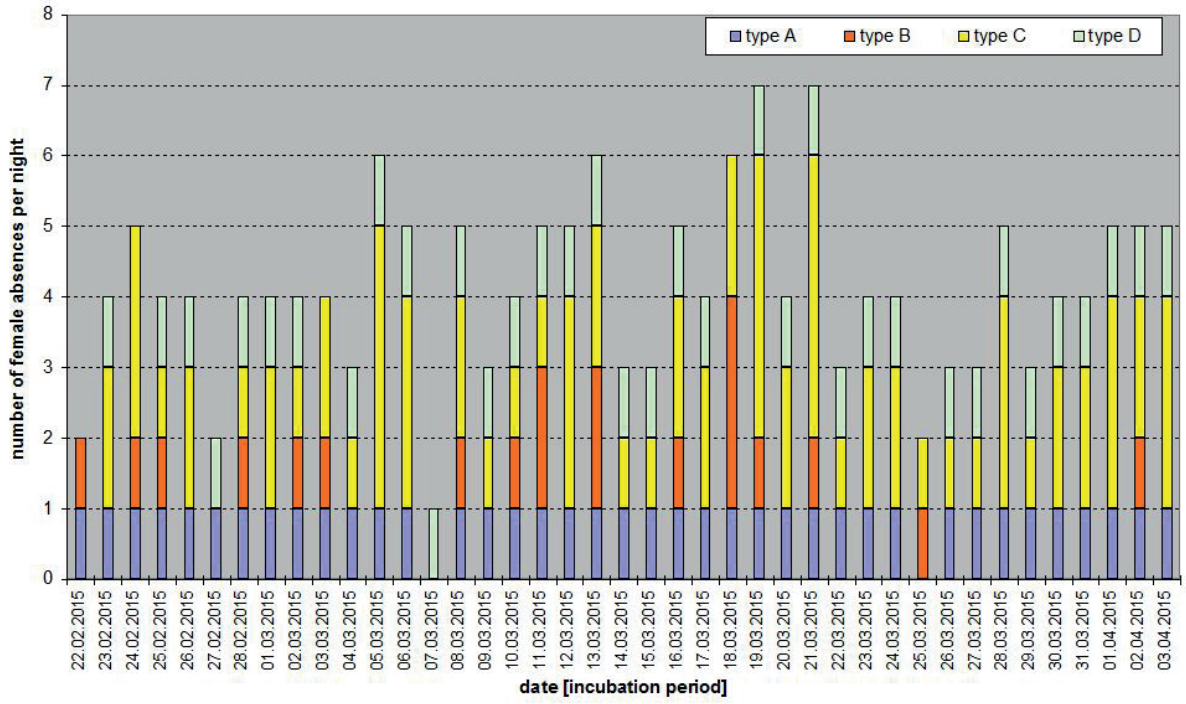
The number and temporal distribution of all female absence types are presented in Fig. 7 and Fig. 8 represents their duration.

Clutch maintenance, egg turning

The female must protect, shelter and warm the eggs containing the developing embryos. Regular and frequent egg turning ensures they receive warmth from all sides and to keep the egg yolk and embryo suspended, by the chalazae, in the centre of the albumen. Eggs were turned on average every 57 min during nighttime and less frequently (once every 1:24 h) during daytime (Table 11) and the daily distribution of 677 observed egg turning actions are depicted in Fig. 9. Extrapolated to include the daytime hours which were not recorded, we may expect 880-900 egg turning incidents during the incubation period. Egg turning activities were significantly reduced (Fig. 9) and intervals between turning increased as hatching progressed. Sixty-five percent of the egg turnings were followed by another turning action within 60 min and 84% of all turnings occurred within 90 min of the previous (Fig. 10, n = 636 egg turning events). Eggs were often turned within 2 min following the female's return to the nest after an absence and after a copulation, the consumption of delivered prey, or plumage maintenance (Harms 2017b, Table 5).

Figure 7 - Number and temporal distribution of all absences of a female Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015. Type A = Evening absence; Type B = Feeding absence; Type C = Intermittent absence; Type D = Morning absence. See Table 3 for more detail on absence type definitions and behavioural context.

Figura 7 - Número e distribuição temporal de todas as ausências de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015. Tipo A = Ausência noturna; Tipo B = Ausência para alimentação; Tipo C = Ausência intermitente; Tipo D = Ausência matinal. Ver Tabela 3 para mais detalhe sobre a definição dos tipos de ausência e contexto comportamental.



Plumage maintenance

Attending to plumage and turning eggs were associated behaviours ('behavioural ensembles') and occurred at least 450 times (Table 5). The number and temporal distribution of feather care by the female was not assessed in detail but there were extended times of low activity as well as times when the female appeared restless or nervous, during which she was engaging in feather care activities much more frequently. On some nights the female was relaxed while on other nights she appeared to be irritated and hyperactive.

Handling of prey

Smaller items (a mouse or vole) were always swallowed on-site and in one piece and usually shortly after received. Larger items (i.e., moles, rats, larger mammals, birds) were consumed outside the nest (see above). The duration of feeding absences (3 to 35 min) were roughly proportionate to the size of prey delivered (unpubl. data). This changed after eggs hatched when all prey, regardless of their size, were torn apart at the nest and small pieces offered to the chicks. The female consumed small bits while feeding her chicks and swallowed bulky pieces once the chicks were fed. In stark contrast with female behaviour during incubation, surplus feed items were always stored at the nest site for future consumption once eggs had hatched (unpubl. data).

Figure 8 - Cumulative duration of all absences of a female Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015. Type A = Evening absence; Type B = Feeding absence; Type C = Intermittent absence; Type D = Morning absence. See Table 3 for more detail on absence type definitions and behavioural context.

Figura 8 - Duração cumulativa de todas as ausências de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015. Tipo A = Ausência noturna; Tipo B = Ausência para alimentação; Tipo C = Ausência intermitente; Tipo D = Ausência matinal. Ver Tabela 3 para mais detalhe sobre a definição dos tipos de ausência e contexto comportamental.

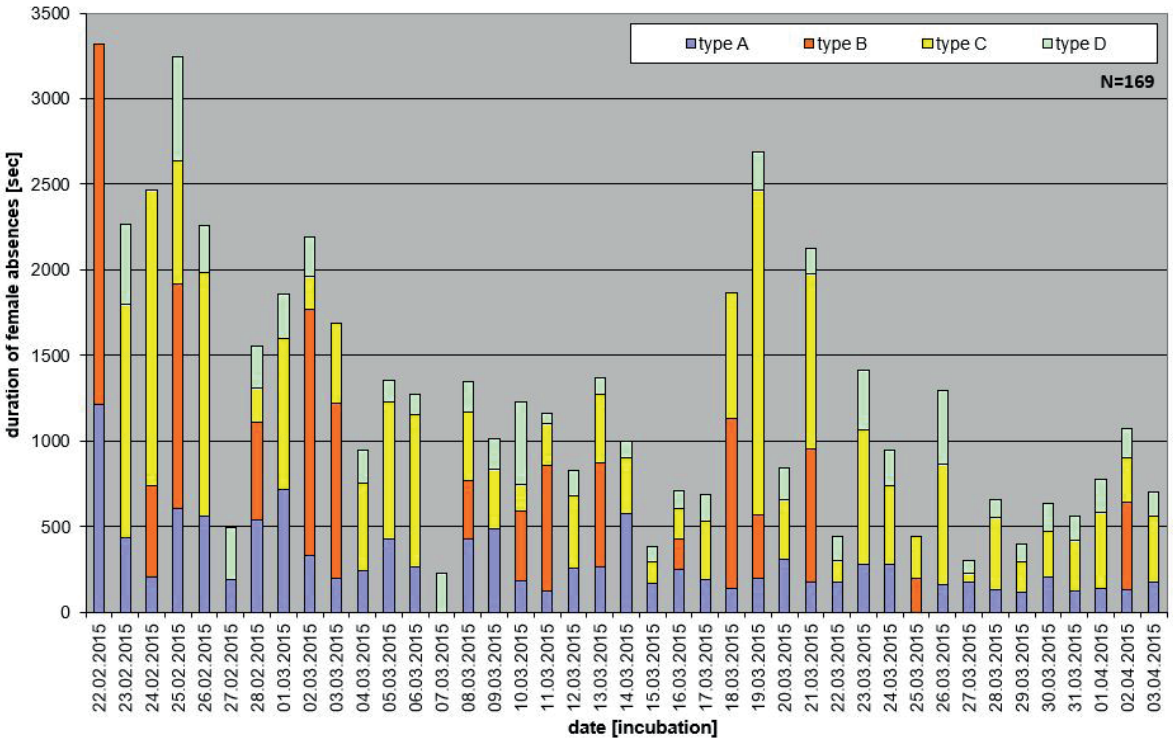


Table 4 - Egg turning behaviour of a female Eurasian Eagle-owl (*Bubo bubo*) at a nest site in Baden-Württemberg, Germany in 2015.
* hours from sunset to sunrise; ** recorded day time hours only

Tabela 4 - Comportamento de viragem dos ovos de uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, em 2015.

RECORDED EGG TURNING (FEB 22 - APR 3)	NIGHT*	DAY**	NIGHT AND DAY
number (%) during incubation period	532 (79)	145 (21)	677
avg. number per day ± SD	13 ± 4.4	3.5 ± 2.9	15.5 ± 5.6
min. / max. number	3 / 22	0 / 13	3 / 26
median number	14	3	16
avg. time between 2 consecutive egg turnings (N=636) [h:min:sec]	0:56:56	1:24:00	1:01:58

Figure 9 - Number and temporal distribution of egg turning during the incubation period at an Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2015.

Figura 9 - Número e distribuição temporal da viragem de ovos durante o período de incubação num ninho de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, em 2015.

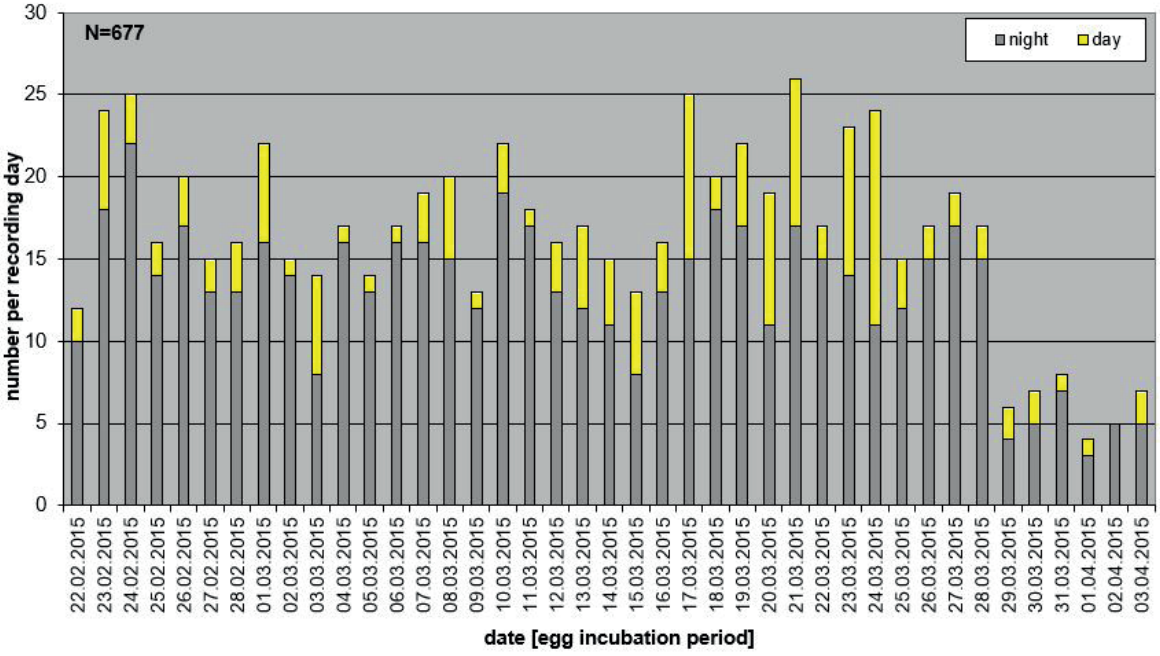


Table 5 - Context of egg turning behaviour of a female Eurasian Eagle-owl (*Bubo bubo*) at a nest site in Baden-Württemberg, Germany in 2015.

Tabela 5 - Contexto do comportamento de viragem dos ovos por uma fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, em 2015

BEHAVIOURAL CONTEXT	RECORDED OCCURRENCE	COMMENTS
Return from absence	160 of 169 absences	Not practiced 4x during incubation & 5x during hatching
Copulations incl. attempted	30 of 37 copulations	
Prey delivered by male and then eaten by female	37 of 80 prey deliveries by male eaten by female	No egg turning in 43 cases (6x during incubation & 37x during hatching)
Preening	450 incidents	

Figure 10 - Time between two egg turning actions within the same night at an Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2015.

Figura 10 - Tempo entre duas ações de viragem de ovos na mesma noite num ninho de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, em 2015.

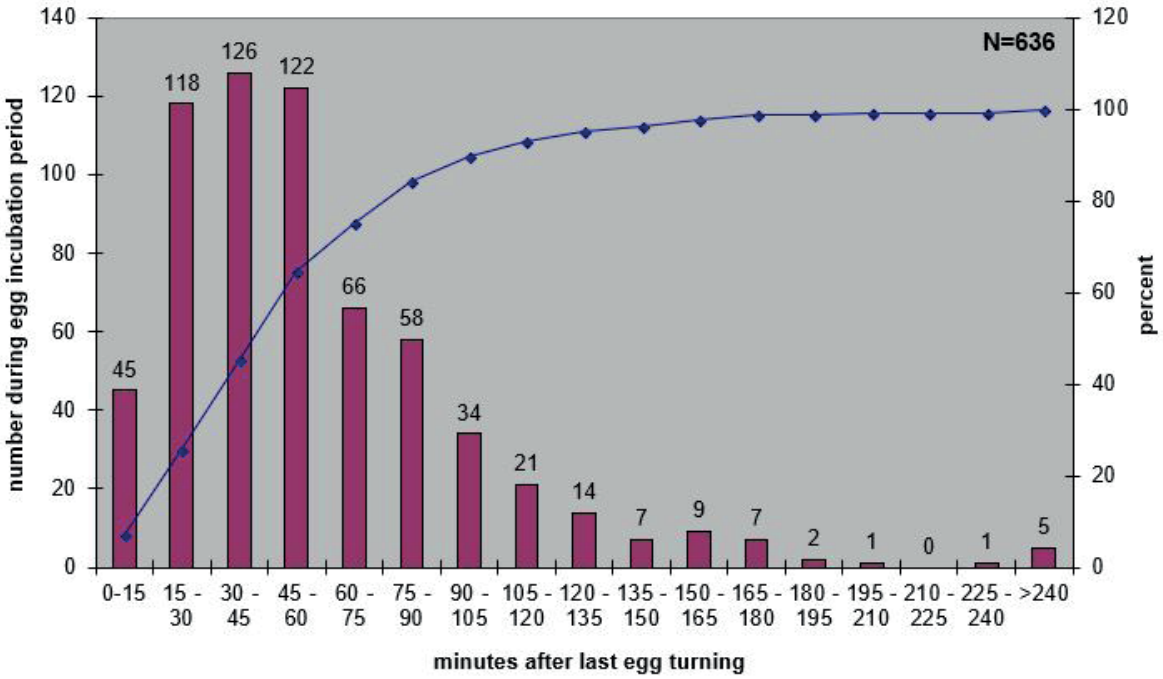


Figure 11 - Number and temporal distribution of prey deliveries by a male Eurasian Eagle-owl (*Bubo bubo*) during the incubation period at a nest site in Baden-Württemberg, Germany in 2015.

Figura 11 - Número e distribuição temporal de entregas de presas pelo macho de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015.

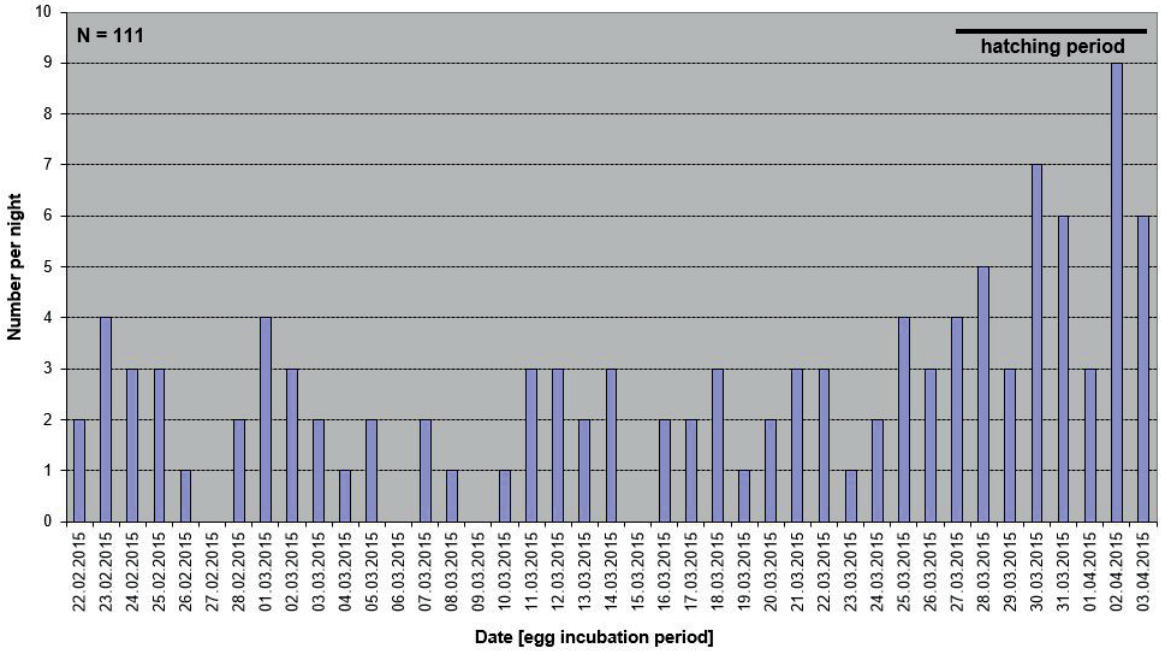


Figure 12 - Timing of the first nocturnal prey delivery during the incubation period at an Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2015.

Figura 12 - Período de ocorrência da primeira entrega de presas da noite durante o período de incubação num ninho de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, em 2015.

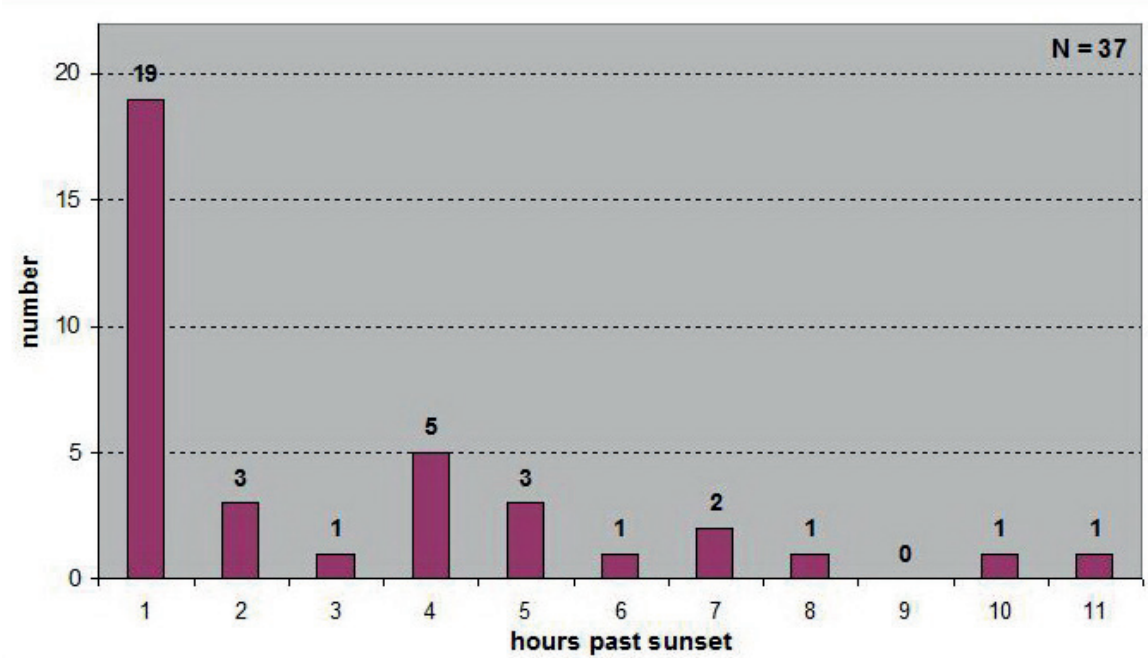


Figure 13 - Time of first prey delivery by date during the incubation period at an Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2015.

Figura 13 - Período de ocorrência da primeira entrega de presas por data durante o período de incubação num ninho de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, em 2015.

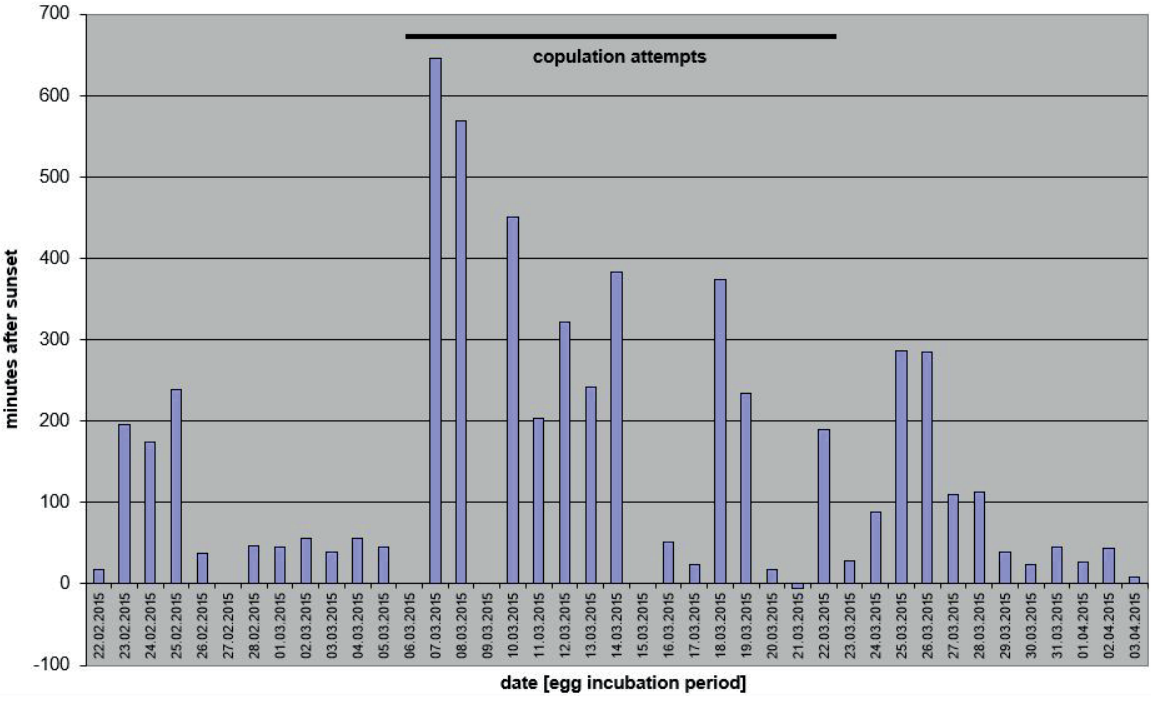


Figure 14 - Time elapsing between two consecutive prey deliveries within the same night during the incubation period at an Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2015.

Figura 14 - Período de tempo entre duas entregas de presas consecutivas na mesma noite durante o período de incubação num ninho de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, em 2015.

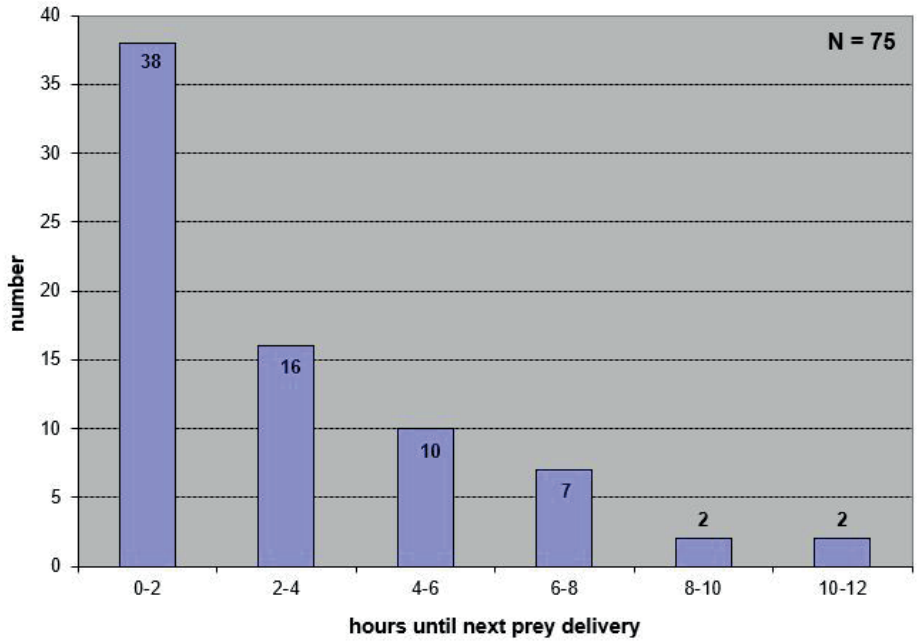


Figure 15 - Time elapsed between two consecutive prey deliveries in the following night (across the day time gap) during the incubation period at an Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2015.

Figura 15 - Período de tempo entre duas entregas de presas consecutivas na noite seguinte durante o período de incubação num ninho de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, em 2015.

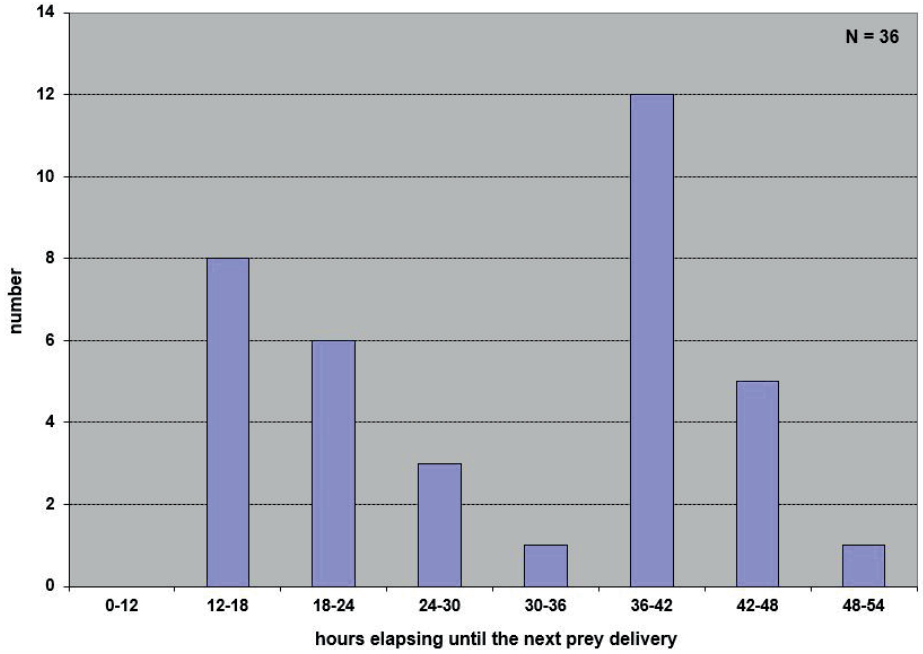


Table 6 - Prey deliveries during incubation and hatching periods at an Eurasian Eagle-owl (*Bubo bubo*) nest site in Baden-Württemberg, Germany in 2015.
* means followed by different letters are significantly different (Tukey-Kramer test, P < 0.05; McDonald 2014)

Tabela 6 - Entrega de presas durante os períodos incubação e eclosão num ninho de bufo-real (*Bubo bubo*) em Baden-Württemberg, Alemanha, em 2015.

	INCUBATION	HATCHING	INCUBATION & HATCHING
Period (date)	Feb. 22 - Mar. 26	Mar. 27 - Apr. 3	Feb. 22 - Apr. 3
Duration (calendar days)	33	8	41
Prey deliveries, number (%)	68 (61%)	43 (39%)	111
Prey deliveries, avg. per night ± SD*	2.06 ± 1.17 **a**	5.38 ± 2.07 **b**	2.63 ± 1.89
Min. / max.	0 / 4	3 / 9	0 / 9
Median	2	5.5	2

Hatching

Hatching and early brooding could not be observed because the female covered them. It was noted that the eggs had hatched after the female left the nest. During hatching the female half sat and half lay on the nest making a small space covered by long breast and belly feathers that both sheltered and hid the chicks. The female also bent her head low to groom, for feeding and cleaning the hidden chicks. Hence it was not possible to detect if the female assisted the hatching process or to quantify nestling care behaviour during the first days after hatching. Although there were no audio recordings it appeared that the female communicated with the chicks about 2 days before they hatched in response to their 'beeping' calls. No shell remains were visible in the hollow when she left the nest site, and she was also not observed to carry the shells in her beak when departing, as is common for many bird species. It is possible that the female crumbled and/or ate the shells for nutrition or to protect the hatchlings (sharp and/or a predator attractant).

Male Behaviour

In contrast to the courting period (Harms 2021a), the presence of the male Eagle-owl at the nest site was brief and totalled only 1:11:30 h for the incubation period. Of the male's 159 documented visits to the nest site, 111 represented prey deliveries to the female, and 37 were copulations or copulation attempts (see below). On average, each visit lasted 27 sec, ranging from 1-2 sec for the copulation attempts to over 2 min for some of the prey deliveries.

Prey deliveries

The male delivered prey 111 times (mean 2.7 per night, Fig. 11) and deliveries increased towards the end of the period and particularly during hatching. This change in behaviour was significant (1-way ANOVA with Tukey-Kramer test: $F_{1, 39} = 37.4$, $P = 3.58 \times 10^{-7}$) with 68 (61%) deliveries occurring in the incubation period and 43 (39%) during the 8 day hatching period (Table 6). Approx. 70% of the prey deliveries lasted < 30 sec, and 90% lasted < 1 min. Prey deliveries occurred throughout the night but more frequently near dusk and dawn (Harms 2017a). The earliest first delivery occurred 6 min before sunset and 19 of 37 first deliveries were < 60 min after sunset (Figs. 12 & 13). Other deliveries occurred 2-11 h after sunset. The time of first prey delivery varied with a cluster of later first deliveries (7-26 March, Fig. 13) discussed below. In 38 of 75 consecutive deliveries (within the same night) the second occurred within 2 h (average time

Table 7 - Description of prey deliveries not accepted/eaten by a female Eurasian Eagle-owl (*Bubo bubo*) at a nest during the incubation period in Baden-Württemberg, Germany in 2015.

Tabela 7 - Descrição das entregas de presas não aceites/consumidas pela fêmea de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015.

DATE	TIME (START - END)	PREY	DESCRIPTION OF INCIDENCE
Feb 22	18:21:05 - 18:22:00	plucked bird; size: jay	Female (F) not present; Male (M) departed with prey
Feb 25	03:03:10 - 03:04:08	vole	M presented prey to F; F refused to accept; M put prey in front of F; vocalizations; M departed with prey
Feb 26	00:17:44 - 00:18:16	rat	F not present; M departed with prey
Feb 26	18:47:05 - 18:49:10	mouse	F not present; M swallowed prey before departing
Mar 12	03:20:37 - 03:22:48	plucked bird; size: blackbird	M repeatedly presented prey to F; F refused to accept prey; M departed with prey
Mar 22	00:46:30 - 00:48:15	not identifiable; size: rat or bigger	M repeatedly presented prey to F; F refused to accept; M put prey in front of F; intense vocalizations; M departed with prey

Figure 16 - Copulations (blue, in February) and copulation attempts (red, in March) during the incubation period at an Eurasian Eagle-owl (Bubo bubo) nest site in Baden-Württemberg, Germany in 2015.

Figura 16 - Cópulas (a azul, em fevereiro) e tentativas de cópula (a vermelho, em março) durante o período de incubação num local de nidificação de bufo-real (Bubo bubo) em Baden-Württemberg, Alemanha, in 2015.

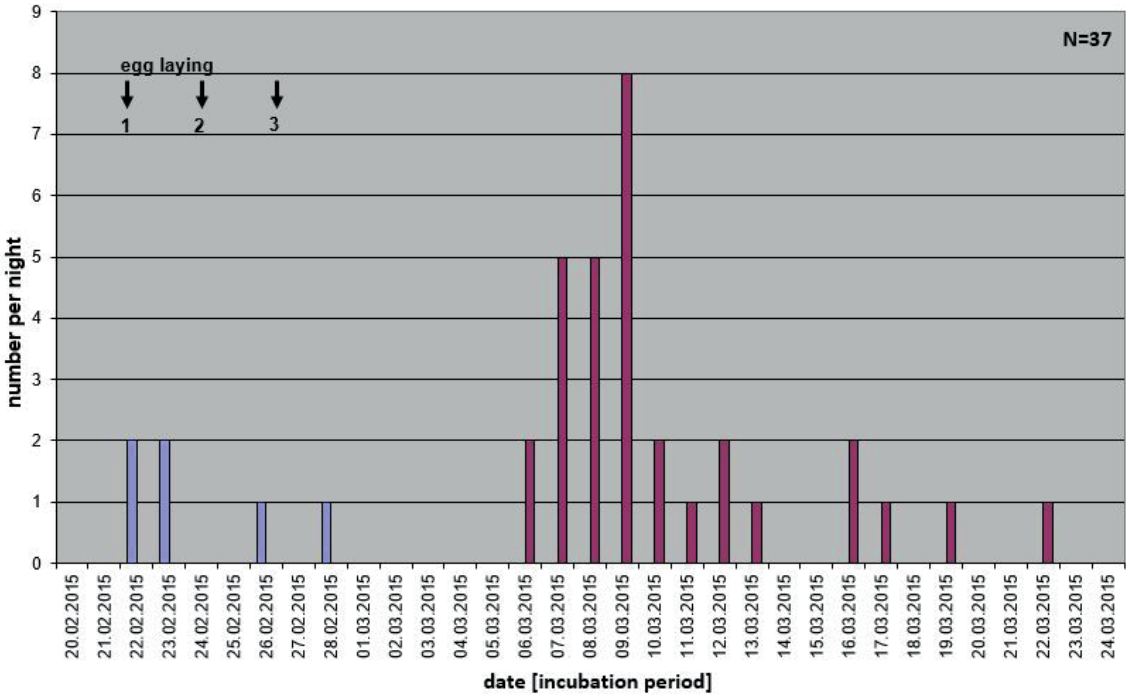


Table 8 - Percent frequency and percent estimated biomass of prey delivered by a male Eurasian Eagle-owl (*Bubo bubo*) during the incubation period to a nest in Baden-Württemberg, Germany in 2015.

Tabela 8 - Frequência e biomassa estimadas (em percentagem) das presas entregues pelo macho de bufo-real (*Bubo bubo*) num ninho em Baden-Württemberg, Alemanha, durante o período de incubação em 2015.

	N	% FREQUENCY	% BIOMASS
Mammals	77	69.4	69.8
mice (Muridae) and *Microtus* spp. voles	55	49.5	20.7
other voles (Arvicolinae)	18	16.2	33.3
rats (*Rattus norvegicus*)	3	2.7	12.0
ermine (*Mustela erminea*)	1	0.9	3.8
Birds (Aves)	11	9.9	21.6
Unidentified	23	20.7	8.7

2:49:46 ± 2:33:59, range 4:43 min to 11:04 h, Fig. 14). There were four nights without prey deliveries (successive deliveries at least 36 h apart, Fig. 13). Eighteen of 36 (50%) successive deliveries spanning two successive nights were < 36 whereas 18 were > 48 hours (Fig. 15). For 44% of this period (18 of 41 d) the female waited > 36 h for a delivery.

Interactive behaviours

Principal male-female interactive behaviours quantified from video recordings during the incubation period were food transfers and copulations. Copulations during the incubation period may serve to maintain the pair bond whereas food exchanges are essential for successful incubation by the female.

Transfer of prey items

When the female became aware of the approaching male with prey, she usually faced him and stood up in a bowed position. The male landed and walked towards her. Prey were transferred immediately from beak to beak, sometimes with some tugging before the male released it. On several occasions, the male carried larger prey in his claws while landing, but immediately picked it up with his beak to offer it to the female. Following transfer, the female crouched, turned her head and prey sideways away from the male and remained motionless for 5 to 20 sec. Her ear tufts were horizontal, and she looked up at the male. The male stood upright at the nest edge with erect ear tufts looking at her, then turned his head and body away before leaving. The male appeared to often utter intimate vocalizations (not recorded) after the transfer. The female usually maintained her bowed motionless posture until the male left. Small prey (mice or voles) were typically swallowed intact immediately soon after the male left. Larger prey was taken apart and consumed after she left the nest (see *feeding absences* above).

Copulations

Unexpectedly, starting on 6 March, 7 days after the last egg was laid, the male attempted to copulate 31 times over 17 days (Fig. 16).

Prey species frequency and biomass

Prey species

Small mammals (70%) were the most common of 111 prey delivered followed by birds (10%); 21% were not identifiable

because they were hidden from view or the video images were blurred (Table 8). Small mammals were mainly mice (Muridae; 66%) including voles (*Microtus* spp., *Arvicolinae* spp.). When unidentified prey was assumed to be small mammals (see methods) then their contribution to the estimated diet increases to 85% (frequency) and 63% (biomass) (Table 8).

Three bird carcasses were delivered within a short period of time; at 0:51:37, 1:08:09, and 5:10:16 on 19 March. In each case the female left immediately after accepting them returning after 4:06, 6:46 and 5:38 min, respectively. Nearly fledged nestlings of Carrion Crow, Rook (*Corvus frugilegus*), Common Kestrel (*Falco tinnunculus*) and Eurasian Buzzard were identified as prey remains from other Eagle-owl nests in this region (unpubl. data). It is possible, based on the timing of the bird prey delivered 19 March, that the male repeatedly returned to a nest to harvest nestling corvids which reproduce early in the area.

Prey mass

The total estimated biomass of 111 prey items delivered to the nest was 6,650 g. Six items were not transferred to the female (Table 7) and the total estimated biomass transferred to the female was 5,850 (average 143 g/night).

Discussion

This analysis of IR video recordings provides the first detailed evaluation of nest-site behaviours of a pair of Eagle-owls during incubation. The results confirm and detail previously reported behaviours, often derived from birds kept in captivity, and describe new behaviours.

Many bird species exhibit a variety of nest sanitation behaviours that reduce the likelihood of predation at the nest site (Van Tyne & Berger 1976). Likewise, the owls in this study were never observed to defecate at the nest site, a behaviour consistent with other owl species (i.e., Mazur & James 2000). Presumably female owls have a strong need to defecate after each uninterrupted daytime incubation session which is required to protect the eggs from diurnal predators. The female Eagle-owl in this study left the nest to defecate at dusk (average absence duration 5:03 ± 3:37 min) when the risk of egg predation was reduced. Defecation outside the nest is also an opportunity for owls to mark their breeding territory using splashes of faeces as a visual signal to conspecifics (Penteriani & Delgado 2008).

Post egg laying copulations may be a common behaviour in some owl species. Video recordings at a Common Barn Owl (*Tyto alba*) nest box showed frequent copulations following prey deliveries through the incubation period and even after some of the chicks had emerged (unpubl. data). Continued copulations after egg-laying may be ritualized, i.e. reproductively non-relevant (Harms 2017b, 2021a) as evident from the tail positioning of the owls which indicated that cloacal contact was decreasing while copulation. Post laying copulations in barn owls have a food-reproduction context and may serve to strengthen the pair bond.

In contrast, the unsuccessful copulation attempts by the male Eagle-owl (Fig. 16) were associated with delayed food delivery (Fig. 13) and unlikely served to strengthen the pair bond. Moreover, new video recordings in 2018 and 2019 at two additional eagle owl nest sites showed no post-egg laying copulations (unpubl. data). The temporal distribution of the male's copulation attempts (Fig. 16) may reflect a decay curve after a surge of testosterone or another effector substance followed by its gradual degradation.

Female raptors, including owls, depend on the male's ability to provide prey during incubation and brooding to breed successfully (Newton 1979, Harms 2018a, 2019). The food requirements of Eagle-owls reported by Thiede (2003) differed from prey delivered in this study; average observed prey biomass transferred was ca. 60% of the afore-

mentioned daily requirements of the female during incubation. While not life-threatening it was unexpected and may have reflected a decreased local prey supply, the male's inability to provide sufficient prey, and/or the camera missing food transfers outside the nest site. The latter was unknown but anecdotally there was no evidence of this occurring during incubation. It was noteworthy that there was ample prey cached at the nest site during the subsequent chick rearing period (Harms 2019). Our knowledge of the food requirements of Eagle-owls and changes in prey availability under natural conditions is still very limited. The Eagle-owl, a diet generalist, is likely able to adapt to local or temporal shortages of preferred prey such as small rodents (Bezzel et al. 1976, Geidel 2014, Görner 2016, Leditznig 2005, Plass 2010, Lourenço 2006).

Thiede (2003) reported a 130 g stomach capacity for the Eagle-owl suggesting that multiple feedings are required to satisfy their daily dietary requirements. The capacity of the oesophagus to hold food may increase the amount of food an owl can ingest in a single feeding event, portions of which then gradually released into the digestive system. Contrasting with Thiede (2003), 14 field mice (with an estimated biomass of 280-340 g) have been found in the stomach of a female Eagle-owl (Görner 2016), and 17 *Microtus* skulls in a single pellet, thus suggesting a substantially greater holding capacity of the stomach than reported by Thiede (2003).

Video recordings of prey delivery and consumption are more accurate than that estimated by examining prey remains at nest sites or from pellets (Marchesi et al. 2002, Penteriani et al. 2005). Nielsen et al. (2015) used video recordings to examine food consumption of Eagle-owl chicks at a nest in Denmark. Numerous web camera recordings have been taken at Eagle-owl nests (i.e., www.uhu.webcam.pixtura.de) which represents a significant potential source of data that has yet to be published.

Avian prey were hard to identify from grey-scale video recordings because of a lack of colour and their carcasses were delivered partially plucked, decapitated, and/or with no wings. Infrequently some diagnostic plumage or body features enabled the bird's identification (i.e., the unique feet of the Common Coot, *Fulica atra*).

A dependency on small rodent prey species has been reported for Eagle-owls in Europe (Bezzel et al. 1976, Geidel 2014, Görner 2016, Schweiger & Lipp 2011, and references in Harms 2018a) while European Rabbits (*Oryctolagus cuniculus*) were the owls' preferred prey in Mediterranean countries, often comprising over 90% of the diet (Donázar & Ceballos 1989, Lourenço 2006, Marchesi et al. 2002, Penteriani et al. 2005). Pellet-based diet studies are biased (Bezzel et al. 1976, Marchesi et al. 2002, Penteriani et al. 2005), often cannot distinguish the male and female's diets, and can be inappropriate or illegal regarding owl disturbance. Since prey remains are not left at the nest site during the incubation period, IR-video methodology appears to be the only approach to estimate details of the female's diet (prey species, mass and phenology).

In Denmark, rats (*Rattus norvegicus*) and hedgehogs (*Erinaceus europaeus*) were prominent prey consumed during the Eagle-owl chick rearing period revealed by video recordings (Nielsen et al. 2015), while mice played a minor role. Based on pellet analyses, Schweiger & Lipp (2011) determined voles (*Arvicolinae* spp.) were preferred prey during the Eagle-owl chick rearing period in Bavaria, Germany. Because of their diverse diet Eagle-owls are considered opportunistic hunters and generalist predators, but their diet is usually not a mirror image of the trophic diversity within their territory. Rather, they tend to exploit the most abundant food source available in their habitat (Bezzel et al. 1976, Donázar & Ceballos 1989, Görner 2016, Leditznig 2005, Plass 2010) and thus may be considered 'facultative specialists', in a regional context.

IR-video methods are valuable to study the

behaviour of difficult to observe nocturnal species such as Eagle-owls (Harms 2021b). Our knowledge of owl behaviour will grow if more studies use IR-cameras (van Harxen & Stroeken 2021, Kniprath 2018ab). Based on the video recordings made herein I was able to analyse the activities and behaviours of an incubating female and her mate during this important phase in their reproductive cycle. Likewise, pre-incubation and chick rearing behaviours at this nest site have also been analysed (Harms 2017a, 2019, 2021a). Analysis of behaviour from other owl nest webcams recordings should also be encouraged.

Note: Video clips showing selected scenes extracted from the recordings at the Eagle-owl nest site can be viewed on YouTube, channel "cth-ornitho" (www.youtube.com/channel/UCikFnM7cQEzDpCkM8gywvmQ). Additional information and published articles are available for viewing or download at www.researchgate.net/profile/Christian_Harms2/.

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Monitoring owl populations in a natural mountainous forest in the Austrian Alps (Dürrenstein Wilderness Area, IUCN Category I)

Monitorização de rapinas noturnas numa floresta natural de montanha nos Alpes Austríacos (Área Selvagem da Dürrenstein, IUCN Categoria I)

Thomas Hochebner[1*], Ingrid Kohl[2], Claudia Schütz[1], Gerard Rotheneder[1]

1 Dürrenstein Wilderness Area Administration, Brandstatt 61, A-3270 Scheibbs, AUSTRIA, Tel./Fax: 0043748243203, web: www.wildnisgebiet.at

2 REWILD Institute - Research on Ecosystems and Wilderness, AUSTRIA, office@rewild.institute, web: https://rewild.institute

*** Corresponding author:** t.hochebner@aon.at



ABSTRACT

Between 2015 and 2019 population densities of Boreal Owl (*Aegolius funereus*), Eurasian Pygmy-owl (*Glaucidium passerinum*), Tawny Owl (*Strix aluco*) and Ural Owl (*Strix uralensis*) are being surveyed in the Dürrenstein Wilderness Area (IUCN Category I) in Lower Austria. The study area is located between 720 and 1,500 m a.s.l. and covers 1,650 ha of mixed stands of spruce (*Picea abies*), fir (*Abies alba*) and beech (*Fagus sylvatica*) within the Dürrenstein Wilderness Area (IUCN Category I), including the Rothwald primeval forest (400 ha). This offers unique opportunities to study owls breeding in natural cavities rather than in nest boxes. Each year three standardised surveys are carried out between March and June, using playbacks at 22 monitoring points. Yearly abundances of small mammals as well as seed production of the main tree species are taken into account to assess effects of their fluctuations on the breeding densities of owls. Data from the first three years reveal Boreal and Tawny Owls to be the most common species in the study area. In 2016 a beech mast increased the density of small rodents and in the subsequent breeding season Boreal Owls showed an impressive increase in breeding densities from 11.5 to 20.0 territories/10 km². Breeding success was rather high with at least twelve broods with fledglings confirmed. The species breeds exclusively in natural tree cavities usually provided by Black Woodpeckers (*Dryocopus martius*) that breed at high densities in the area. Tawny Owls showed

a slight increase from 12.1 to 13.3 territories/10 km². Breeding success was rather low in 2017, probably due to heavy snowfalls in April. Eurasian Pygmy-owls showed relatively low densities of 3.0 territories/10 km²; the high density of Tawny Owls may be the main reason for the scarcity of this species. Ural Owls have been reintroduced to the area and have still a low abundance (1.2 territories/10 km²).

Keywords: *Aegolius funereus, Glaucidium passerinum,* population dynamics, primeval forest, *Strix aluco*

RESUMO

Entre 2015 e 2019, as densidades populacionais de mocho-funéreo (*Aegolius funereus*), de mocho-anão (*Glaucidium passerinum*), de coruja-do-mato (*Strix aluco*) e de coruja dos Urales (*Strix uralensis*) estão a ser monitorizadas na Área Selvagem de Dürrenstein (IUCN Categoria I), na Baixa Áustria. A área de estudo está localizada entre 720 e 1500 m a.s.l. e abrange 1650 ha de povoamentos mistos de abeto-falso *(Picea abies*), abeto-branco (*Abies alba*) e faia-europeia (*Fagus sylvatica*), incluindo a floresta primitiva de Rothwald (400 ha). Em cada ano, três censos padronizados são realizados entre março e junho, usando reproduções de vocalizações em 22 pontos de amostragem. Anualmente estão a ser avaliados a abundância de micromamíferos e a produção de sementes pelas principais espécies arbóreas, para aferir os efeitos das suas variações na densidade de rapinas nocturnas nidificantes. Os dados dos primeiros três anos revelam que o mocho-funéreo e a coruja-do-mato são as espécies mais comuns na área de estudo. Em 2016, um tronco de faia contribuiu para aumentar a densidade de pequenos roedores e, na época de reprodução subsequente, foi registado um grande aumento nas densidades de pares reprodutores de mocho-funéreo, de 12,1 para 20,0 territórios/10 km². O sucesso reprodutivo foi bastante elevado, com juvenis voadores em pelo menos doze ninhadas confirmadas. A espécie reproduz-se exclusivamente em cavidades naturais de árvores, geralmente construídas por pica-pau-preto (*Dryocopus martius*). A coruja-do-mato apresentou um ligeiro aumento de 12,1 para 13,3 territórios/10 km². O sucesso reprodutivo foi bastante baixo em 2017, provavelmente devido a fortes nevões em abril. O mocho-anão apresentou densidades relativamente baixas de 3,0 territórios/10 km²; a elevada densidade de coruja-do-mato pode ser a principal razão para a escassez desta espécie. A coruja dos Urales foi reintroduzida na área e ainda apresenta uma reduzida abundância (1,2 territórios/10 km²).

Palavras-chave: *Aegolius funereus*, dinâmica populacional, floresta primitiva, *Glaucidium passerinum, Strix aluco*

Introduction

The Dürrenstein Wilderness Area in Lower Austria includes the primeval forest Rothwald with an area of 400 ha and surrounding woodlands that also have hardly been used. It is the largest remnant of natural virgin forest in the Alps. The area therefore contains many old growth stands with tall trees and abundant natural cavities. It was supposed that this exceptional woodland provides suitable habitat for different owl species but a population survey of this predator group has not been carried out in the past. It was there-

fore a main goal to fill this gap. The population fluctuations caused by beech mast years and the subsequent response of small rodents should also be taken into account. Although there are already many studies dealing with this topic, they mainly focus on owl populations of boreal forest, especially in Finland and mainly on nest box populations (Korpimäki 1986, Korpimäki & Hakkarainen 2012). So far few studies were carried out in the Eastern Alps and even fewer on owl populations breeding in natural cavities. In our study area no nest boxes were mounted for Boreal Owl (*Aegolius funereus*) and Eurasian Pygmy-owls (*Glaucidium passerinum*). Both species are therefore bound to use natural cavities, often provided by woodpecker species.

Since the year 2008 a reintroduction project for the Ural Owl (*Strix uralensis*) is taking place in the Wilderness Area and its surroundings. For supporting and monitoring these owls seven nest boxes have been mounted in the study area. In 2015 a monitoring project on the owl species of the Dürrenstein Wilderness Area was started and will last until 2019. Results of the first three monitoring seasons are presented.

Methods

Study area

The Wilderness Area covers an area of 3,500 ha and is strongly protected as Strict Nature Reserve (IUCN Category Ia) and Wilderness Area (IUCN Category Ib). Forestry, hunting and public access are not existing in the area. Furthermore, it is part of the UNESCO World Heritage Site "Primeval Beech Forests of the Carpathians and Other Regions of Europe".

The study area is located between 720 and 1,500 m a.s.l. and covers 1,650 ha of mixed stands of spruce (*Picea abies*), fir (*Abies alba*) and beech (*Fagus sylvatica*). Depending on local abiotic factors like duration of snow cover, exposition, steepness and soil depth deciduous or coniferous trees are prevailing. Geologically it is part of the Northern Limestone Alps with an annual precipitation of 1,700 to 2,400 mm. In wintertime the area is covered by a thick layer of snow up to 2 m deep often lasting until early May.

Field surveys and data analysis

The monitoring standards for owl species given by Südbeck et al. 2005 were slightly modified due to remoteness, elevation and climate conditions of the study area. Each year three standardised surveys are carried out in March, April and June, using playbacks at 22 monitoring points. In 2017 the first survey took place early April due to heavy snowfall. Buffers of 500 m radius around the monitoring points define an approximate distance of perceptibility per monitoring point and determine a cohesive study area of 1,650 ha. The recording distance was 500 m, as in spring the streams and rivulets carry masses of melting water producing a remarkable noise – a challenge for acoustic monitoring. Two teams consisting of two investigators carry out the survey simultaneously in different parts of the study area for security reasons and for verifying only short or distant calling individuals. Usually snow shoes have to be used until early May. All surveys have been carried out under favourable weather conditions (no or very calm wind and no precipitation) and started about three hours before sunset to record Eurasian Pygmy-owls and lasted about five hours after dusk. Direction and estimated distance of each calling owl was recorded and daily observation maps were drawn using Google Earth. The observations were summarised to territories with a Geographical Information System (ESRI ArcGIS) according to the guidelines of Bibby et al. 1995.

Yearly abundance of small mammals has continuously been monitored using life traps in different parts of the study area since 2002

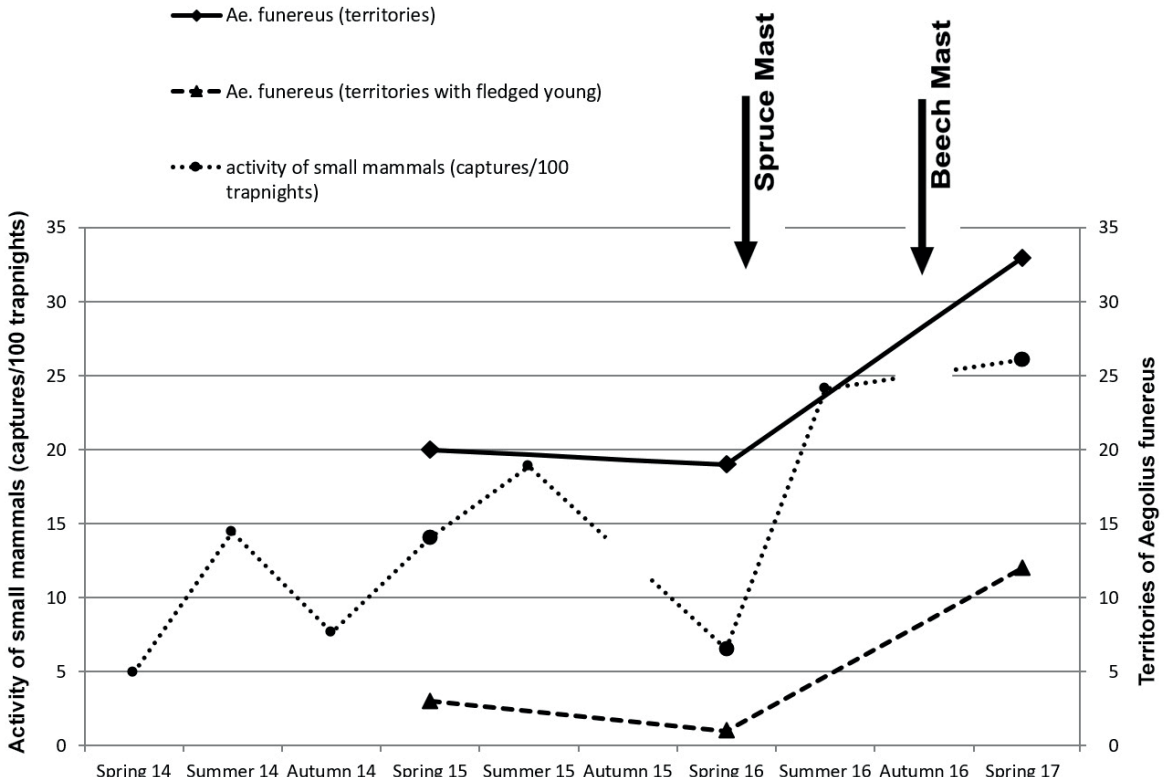
Table 1 - Recorded population densities (territories/10 km²) of the four owl species breeding in the study area (1,650 ha) during the first three years of the monitoring.

Tabela 1 - Densidade populacional (territórios/10 km²) das quatro espécies de rapinas noturnas reprodutoras na área de estudo (1.650 ha) durante os três primeiros anos de monitorização.

POPULATION DENSITY (TERR./10 Km²)	2015	2016	2017
Tawny Owl	11.5	12.1	13.3
Ural Owl	1.8	1.2	1.2
Boreal Owl	12.1	11.5	20.0
Eurasian Pygmy-owl	3.0	1.8	3.0

Figure 1 - Number of territories and breeding success of Boreal Owl in respect to activity of small mammals (captures/100 trap nights) between spring 2014 and spring 2017.

Figura 1 - Número de territórios e sucesso reprodutivo de mocho-funéreo em relação à atividade de micromamíferos (captura/100 noites de armadilhagem) entre as primaveras de 2014 e de 2017.



(Kempter & Nopp-Mayr 2013, F. Sachser unpubl. data). The two most abundant rodent species in the area are the Bank Vole (*Myodes glareolus*) and the Yellow-necked Mouse (*Apodemus flavicollis*). Moreover, the seed production of the main tree species has been surveyed by other research groups for many years. It was found, that in this area beech masts occur every four to five years (Kempter & Nopp-Mayr 2013).

Results

So far six species of owls were observed in the Wilderness Area. The four regularly breeding species Tawny Owl (*Strix aluco*), Ural Owl, Boreal Owl and Eurasian Pygmy-owl are the target species of this study. Data from the first three years reveal Boreal and Tawny Owls to be the most common species in the study area (Tab. 1). Eurasian Eagle Owl (*Bubo bubo*) does not occur regularly and does not breed in the area, Long-eared Owl (*Asio otus*) was first discovered as a breeding bird in 2017 in more open parts of the area (1,450 m a.s.l.) outside the study area.

In 2016 a beech mast increased the density of small rodents and in the following breeding season Boreal Owls showed a significant increase in breeding densities from 11.5 to 20.0 territories/10 km² (Fig. 1). The breeding success showed a steep increase too in 2017, covering twelve broods with fledglings confirmed.

Tawny Owls occurred regularly up to an altitude of 1,380 m a.s.l. and showed a slight increase from 12.1 to 13.3 territories/10 km² during the first three years of the study. With only three pairs recorded breeding successfully in 2017, breeding success was remarkably low despite the high activity of rodents, suggesting other limiting factors.

Eurasian Pygmy-owls showed relatively low densities of 1.8 to 3.0 territories/10 km².

Ural Owls have been reintroduced to the area and occur with a density of 1.2 territories/10 km². Three successful broods within the Wilderness Area have been recorded so far, all three in natural tree cavities.

Discussion

A remarkable feature of the Dürrenstein Wilderness Area with the Primeval forest Rothwald is that Tawny Owls und Boreal Owls occur together with a comparably high density, whereas other studies found avoidance of areas of high Tawny Owl abundance by the smaller species (Pedroli et al. 1975). The diversity of the habitat with old growth forest and a very good supply of natural breeding holes might explain this lower interspecific competition in our area. The Black Woodpecker occurs in an abundance of 0.75 territories/100 ha (Hochebner et al. 2015) and until now 58 cavities have been found in the study area. The density of Black Woodpecker holes in the study area (3.52/100 ha) is much higher than in pristine coniferous woodlands in Finland (Virkkala et al. 1994: 0.5-1.5/100 ha) or in managed coniferous forests in Sweden (Johnsson et al. 1993: 0.3-0.4/100 ha). This is due to the absence of forestry (logging) in the Wilderness Area. Cavities in beech trees can be used as breeding holes for decades, whereas holes in coniferous trees are lost to a much higher extent (Meyer & Meyer 2001).

Tawny Owls were already recorded with several individuals calling in this area back in 1944 (Machura 1944), so it is not a new species. In 2017 a loss of many broods was probably caused by heavy snowfalls on the 19th of April when 2 m of snow fell within 24 hours. At this time, Tawny Owl young already hatched in their nests. Tawny Owls obviously have greater difficulties to cope with high snow cover in early spring compared to Boreal Owls, which breeding period starts later. Despite a large population of

Figure 2 - Number of Boreal Owl territories already occupied during the first survey compared to the number of unique territories initially recorded during the second and third survey for each of the three survey years.

Figura 2 - Número de territórios de mocho-funéreo ocupados durante a primeira amostragem (preto), comparado com o número de territórios inicialmente registado durante a segunda e terceira amostragem (cinzento), em cada um dos três anos de monitorização.

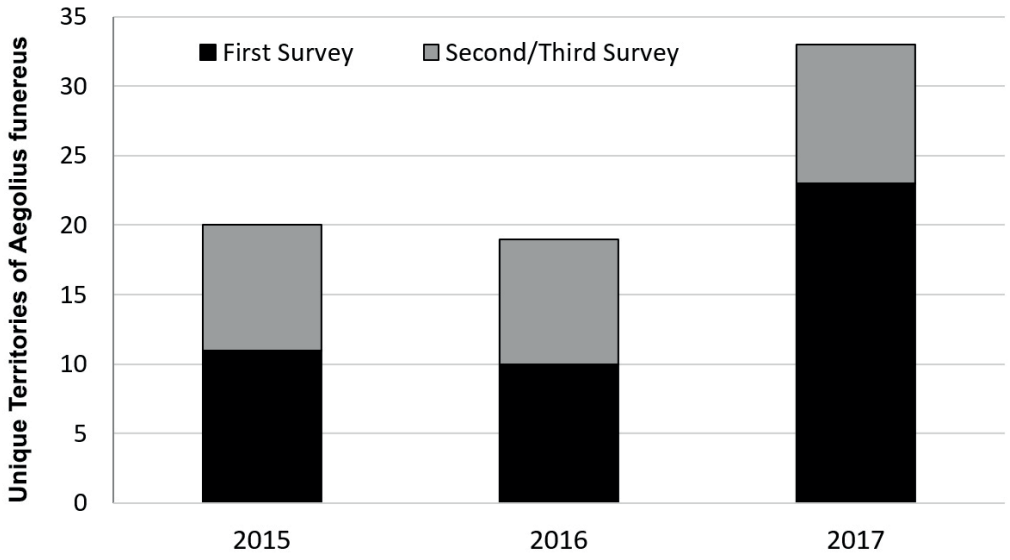


Table 2 - Comparison of the recorded owl population densities between the Wilderness Area and other areas located in the Eastern Austrian Alps.

Tabela 2 - Comparação das densidades populacionais de rapinas noturnas registadas na Área Selvagem e em outras áreas localizadas na região Este dos Alpes Austríacos.

	NP Kalkalpen, Weißmair et al. (2014)	NP Gesäuse, Teufelbauer et al. (2012)	Ennstal, Styria, Scherzinger (1970)	Dürrenstein Wilderness Area
Study area (ha)	3,242	1,522	6,000	1,650
Elevation (m)	620 - 1,670	480 - 1,780	650 - 1,818	720 - 1,500
Tawny Owl (terr./10 km²)	8-9	5.3	-	11.5 - 13.3
Boreal Owl (terr./10 km²)	5	4.9 - 5.6	-	11.5 - 20.0
Eurasian Pygmy-owl (terr./10 km²)	6-7	4.3 - 5.6	1.4	1.8 - 3.0

rodents caused by a preceding beech mast, breeding success of Tawny Owls was very low in 2017.

The Boreal Owl is a species, which shows a quite diverse mating system with polyandry and polygyny occurring quite often. Some males start to display at secondary and even tertial breeding holes after the first brood has been started successfully (Korpimäki & Hakkarainen 2012). Furthermore, a certain percentage of males stay unpaired. Therefore it is difficult to extrapolate from the hooting males to the actual breeding population size. Hence Fig. 2 gives the amount of territories detected in the first survey carried out in March, when males are hooting at their primary hole (Korpimäki & Hakkarainen 2012), combined with the new unique territories as obtained during the second and third survey.

In 2017 more than two thirds of all territories (n = 33) had already been found in the first survey. Hence there may have been at most 30% of the males singing at a second or even tertial breeding cavity. Of these 10 extra territories five have been confirmed with fledglings found in June. That means that for this year with good food supply only five out of 33 claimed territories (15%) might refer to bachelors displaying at secondary or tertial cavities.

Eurasian Pygmy-owls were quite hard to find and rather rare. This may be the result of high population densities of Tawny and Boreal Owls which are not only competing for food, but also bring along some predation risk for the smallest owl species (Mikkola 1983), which is probably increasing when small mammal populations are low. A recently published a remarkably detailed study on the interspecific distribution patterns of Boreal and Eurasian Pygmy-owl in Finland showed that the heterospecific competitor and intraguild predator Boreal Owl did not affect spatial settlement of Eurasian Pygmy-owls, but proximity of the bigger species was associated with low hatching and fledging success of Eurasian Pygmy-owls (Morosinotto et al. 2017). So the dense population of Tawny Owls on the other hand is supposed to be the main reason for the scarcity of Eurasian Pygmy-owls. Further surveys and analyses are necessary to find out more about the interspecific relation of the different owl species in our study area.

Since 2008 a reintroduction project for Ural Owls has been carried out. The species is not very vocal and often does not react well to tape recordings. We found some calling individuals and even fledged young on two occasions. There is a small population establishing in the study area and its surroundings, but the breeding density of the species is still rather low. This also may affect the smaller owl species and probably will bring some change to the intraguild relations.

Compared to surveys in neighbouring areas of the Austrian Eastern Alps, quite high densities of Tawny and Boreal Owl were found in our study area, whereas the population of Eurasian Pygmy-owls was comparably low (Tab. 2). Scherzinger (1970) found a similar value in the Enns valley in Styria (Austria).

Our studies will be continued for at least two more seasons. After finishing field work habitat analyses with respect to the niche selection of different owl species are intended to be made.

Acknowledgements

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Recent and historical distribution of Little Owl (*Athene noctua*) in Bulgaria

Distribuição recente e histórica do mocho-galego (*Athene noctua*) na Bulgária

Assen Ignatov[1,2*], Georgi Popgeorgiev[1,2]

1 National Museum of Natural History, 1 Tsar Osvoboditel Blvd., 1000 Sofia, Bulgaria

2 Bulgarian Society for the Protection of Birds / BirdLife Bulgaria, Yavorov Complex, Bl. 71, Vh. 4, PO Box 50, 1111 Sofia, Bulgaria

*** Corresponding author:** assen.ignatov@gmail.com



ABSTRACT

In this paper we present historical and newly collected distribution data in order to update the distribution map of the Little Owl (*Athene noctua*) with the help of members of the Bulgarian Society for the Protection of Birds (BSPB) – consisting of unpublished field observations covering the whole Bulgarian territory. All previously published data have been reviewed and used, to give an updated view on the presence of the species. The distribution is shown on a map with 10x10 km grid. From all 1240 squares there are 1126 squares found occupied, 398 have been published and reconfirmed, 8 are new records and 720 published ones that were not reconfirmed. The elevation distribution reveals that most Bulgarian Little Owls are breeding up to about 300-400 meters asl. No more than 9% prefer higher altitudes from 400 to 800 m. Just 5% are above 900 m and several localities up to about 2300 m, mainly in mountain huts. This study confirms that most owls prefer to breed and winter in human settlements (90%).

Keywords: *Athene noctua*, Bulgaria, distribution, Little Owl

RESUMO

Neste artigo são apresentados dados de distribuição históricos e recolhidos recentemente, com a ajuda de membros da Sociedade Búlgara para a Proteção das Aves (BSPB), com o objetivo de atualizar o mapa de distribuição do mocho-galego (*Athene noctua*). Os dados consistem em observações não publicadas em todo o território da Bulgária. Todos os dados previamente publicados foram revistos e usados, de forma a obter uma perspetiva atual da presença da espécie. A distribuição foi representada num mapa com uma grelha de 10x10 km. O mocho-galego foi registado em 1126 das 1240 quadrículas amostradas, correspondendo 398 a registos publicados e confirmados, 8 a novos registos e 720 a registos publicados não confirmados. Relativamente à altitude, a maioria da população búlgara de mocho-galego nidifica até aos 300-400 m. Cerca de 9% prefere altitudes entre 400 e 800 m. Apenas 5% da população nidifica acima dos 900 m e em localidades acima dos 2300 m, principalmente em edificações em montanhas. Este estudo confirma que a maioria dos mochos-galegos preferem nidificar e passar o inverno em povoações (90%).

Palavras-chave: *Athene noctua*, Bulgária, distribuição, mocho-galego

Introduction

Little Owl (*Athene noctua*) is one of the best-known owls throughout its distribution (Van Nieuwenhuyse et al. 2008). In Europe, this species is categorized as SPEC 3 – declining. At a national level it is protected by the Law of the Protection of the Nature (Annexes II, III of Biological Diversity Act, 2016), Appendix II of the Convention on the Conservation of European Wildlife and Natural Habitats, BERN and Appendix II of the Washington Convention. The species is widespread everywhere in Bulgaria occurring to about 900 m asl (Patev 1950, Simeonov 1983), about 98% in human settlements (Ignatov 1993), mostly in villages and cities, such as in 1983, in Sofia (capital of Bulgaria), with 140 reported breeding pairs (Iankov 1983). In the following decades, no changes have been reported, including the last previously published data from the Atlas of breeding birds in Bulgaria (Iankov 2007). The population of Little Owl is found to be occupying villages, towns and the city of Sofia (Simeonov 1983, Iankov 1983,). In order to better understand the species requirements it is necessary to update and refine its distribution data. Hence an inventory project was started in 2007, spread across the entire territory of Bulgaria including all types of human settlements.

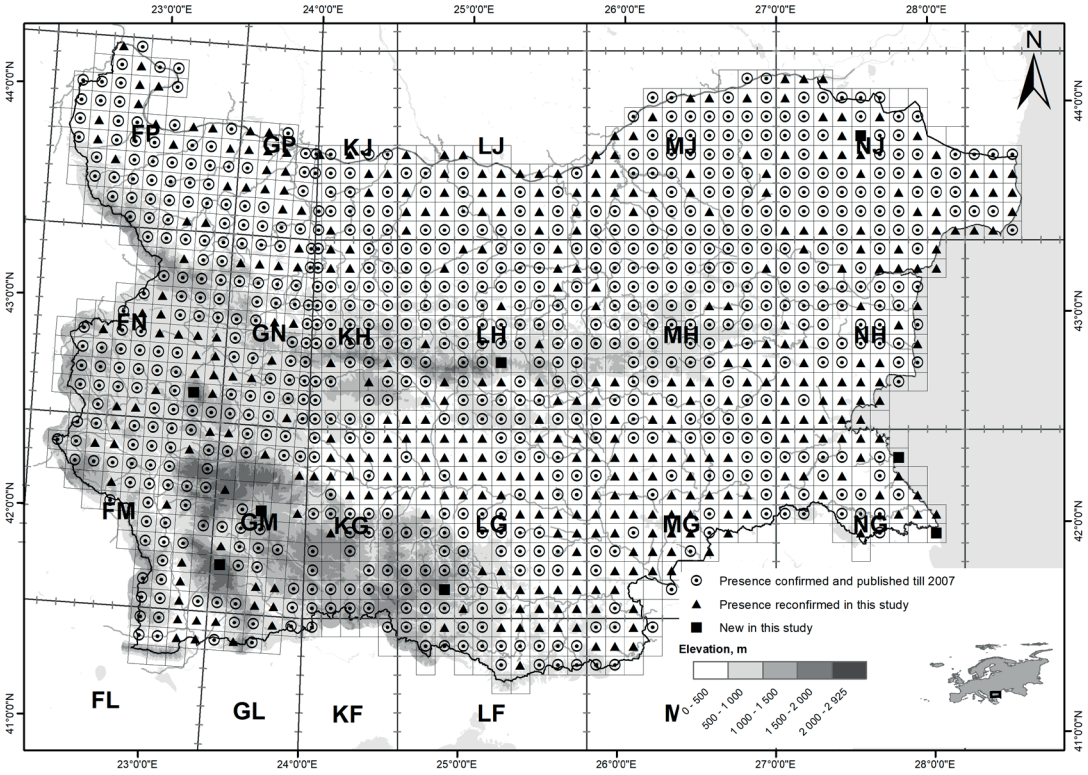
Study area

Bulgaria is a country in the Eastern Balkans – to its North is Romania, to the West is Serbia, to the Southwest is Macedonia, to the South is Greece, and to the Southeast is Turkey. The territory is 111 000 km^2 covering 1240 10x10 km grid cells. It is an area rich in biodiverse habitats. It has high mountains reaching almost 3000 m asl, as well as plains, steppes, Mediterranean habitats, dense forests and to the east is the Black sea coastline.

The present study was carried out in human settlements of different sizes, spread across the whole territory of Bulgaria.

Figure 1 - Distribution of Little Owl (*Athene noctua*) in Bulgaria, showing published data, confirmed data and newly collected data in the standard 10 km UTM grid covering Bulgaria (1240 grid cells).

Figura 1 - Distribuição do mocho-galego (*Athene noctua*) na Bulgária, com base em dados publicados, confirmados e recolhidos recentemente na grelha UTM de 10 km que cobre todo o território nacional (1240 quadrículas).



Methods

This study combines historical data that were already published, more recent unpublished data, the database of the Bulgarian Society of the Protection of Birds and data newly collected during the inventory project. The records are presented in the standard 10 km UTM grid, 1240 squares of 10x10 km, the same grid as used in the Atlas of Breeding Birds in Bulgaria. We study the Bulgarian territory, using published and not published data:

Published data

We assembled all the previously published data starting with the first observations in 1859 (Finch 1859) till 2007. Most of the localities are well explained and it was easy to find them on Google map.

Unpublished data

All data collected from the observers are for two periods: 1969-1993 and 2006-2016 (data collected using GPS). In addition, own data collected from 1984 to 2016, data collected by colleagues from 1969 to 2016 and data obtained through a questionnaire from 1991-1992. Our research aimed to confirm registered records. All records are precisely georeferenced using GPS units (Garmin) or smartphones with GPS application – Smart-Birds Pro (Popgeorgiev et al. 2015), provided by the Bulgarian Society for the Protection of Birds/BirdLife Bulgaria.

Newly collected data

The investigation used playback to stimulate a response from any territorial Little Owls present. This is the most commonly used method for recording Little Owl presence (Van Nieuwenhuyse et al. 2008). Field work was carried out mostly during the breeding season and located in villages.

Results

Combining the data from the records (published and unpublished) gives the most complete representation of the distribution of the Little Owl in Bulgaria. The updated distribution of the Little Owl presence is shown in a 10x10 km UTM grid in Fig. 1. Breeding localities are registered in 1126 squares (90.08%) of 1240 squares for the country. The species is not registered in some of the high mountains and in the border areas (9.92%).

Published data

Much of the first published data were based on feeding studies, counting collected pellets, or observations of the Little Owl as part of the diet of other predators. The first map of the distribution was published in 1993 (Ignatov 1993). Based on this map, and by including data from the Bulgarian Society for the Protection of Birds, an updated distribution map of Little Owl in Atlas of Breeding Birds in Bulgaria (Iankov 2007) was published in 2007.

Unpublished data

We identified 406 localities squares of Little Owl (*Athene noctua)*, 8 of them are new records on the distribution map – in the mountain area - FN81, GM02, GM25, LH53, LG21 and in lowland are NG68, NG84, NJ45.

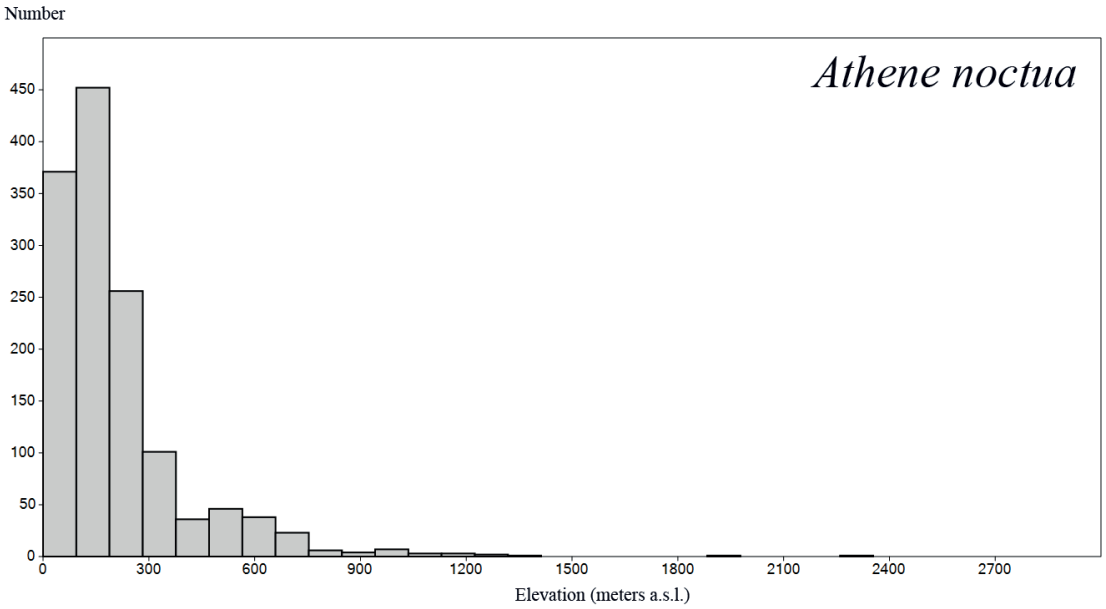
Newly collected data

We reconfirmed the presence of the species in 398 squares of the historical records. All squares that were subjected to playback were reconfirmed during our study.

The horizontal distribution of the species is shown in Fig. 1 and is mainly determined by availability of places for breeding, hiding, resting (Fig. S1) and hunting near to settle-

Figure 2 - Histogram of vertical distribution of Little Owl (*Athene noctua*) in Bulgaria.

Figura 2 - Histograma da distribuição vertical do mocho-galego (*Athene noctua*) na Bulgária.



ments, single buildings, single trees in open areas, quarries, gorges, stony or sandy cliffs or piles of stones. Due to their diversified diet (Van Nieuwenhuyse et al. 2008) it follows that the seasonal status of the species is also widespread in Bulgaria, with only a small percentage wandering (mostly in the winter and autumn, young birds) (Van Nieuwenhuyse et al. 2008). The most important factor for the changes in the seasonal status of the Little Owl is food variation or availability – insects, rodents, birds, amphibians, reptiles (Simeonov 1983).

There are many breeding pairs in the villages and outside as well in the regions of the middle part of Struma valley, valleys of rivers - Russenski Lom, Provadiiska, Rossitca, Suha Reka, Ogosta, Kamchia, Arda and Iskar. For regions like lowland mountains – Eastern Rhodopi Mountain, Strandja Mountain and Southern Dobrudja most breeding pairs are found in villages.

The vertical variation is presented in Fig.2. The Little Owl in Bulgaria is widespread from 0 to 2300 m asl. Most territories are around 400 m asl. 95% of the population is to 800-900 m asl (Simeonov 1983, Ignatov 1993). One confirmed record of breeding at about 2300 m was published (Simeonov 1983). Four new records (Rhodopi Mountain - 2, Vitosha Mountain - 1 and Central Balkan range - 1) in the mountains, one even at an altitude of 2400 m in Pirin Mountain. More than 50% of Bulgarian Little Owls are breeding from 0 to 400 m – villages on the Black Sea coast, low mountains villages and those around river valleys. There are just a few pairs breeding in high mountains, in mountain huts – in Rila Mountain (Partizanska poliana), Pirin Mountain (Banderitca), Rhodopi Mountain (Perelik and Persenk) and Stara Planina Mountain (Sinanitca).

In the autumn-winter period, the highest place where the species was recorded was 1100m asl. Birds inhabiting settlements do not usually displace for winter. Most of the owls leaving their breeding areas are young birds or those breeding outside of the settlements.

Discussion

Comparing the past (published data) and the present situation (unpublished data) we observe that there are changes in the vertical distribution. The Little Owl has started to breed about 100 m higher in Bulgaria and there are more birds that inhabit locations above 2000 m. The main reason is that more and more settlements are becoming uninhabited by people, which is favorable for the owls in finding undisturbed living locations.

Data from the last century clearly shows how many Little Owls are breeding successfully in villages as well as the wider countryside. However, after the changing of the political system in Bulgaria, and the decline of small-scale agricultural farming activities in the 1990's (Ignatov 1993), we observe that more than 90% of Little Owls prefer to breed, hunt and roost in villages. The situation in the following decades is almost identical (Iankov 2007).

Based on the collected observational data we deduce that the specified requirements of the species to exist at a specific habitat (e.g. settlements with abandoned attics with holes (Fig. S2), where humans are not disturbing the nesting birds, availability of farm buildings, barns and stony walls and piles; alternatively natural habitats – limestone area, cliffs (Fig. S3), gorges, abandoned quarries, single trees near to the open areas and forest margins) and the seasonal prey presence determine the probability of encountering the Little Owl. There are many other factors (e.g. mortality, changing climate conditions, presence of bird-protected areas, illegal hunting) which are important as well. To precisely determine the importance of these factors more research is needed in the future.

Acknowledgements

Thanks to Bulgarian Society for the Protection of Birds (BSPB) for the provided data. We are very thankful to those members of BSPB who kindly made their data available: Dimitar Popov, Dimitar Plachiiski, David Horal, Dimitar Demerzhiev, Dimitar Gradinarov, Dobromir Dobrev, Martin Schaefer, Georgi Gerdjikov, Emil Iordanov, Mihail Iliev, Jordan Hristov, Irina Ivanova, Irina Mateeva, Ivailo Tonev, Ivaylo Tonev, Ivailo Dimchev, Kalin Velev, Mladen Gramatikov, Nicky Petkov, Nedko Nedyalkov, Petar Iankov, Svetoslav Mitkov, Ralitsa Georgieva, Stojan Nikolov, Stoycho Stoychev, Svetoslav Stoyanov, Svetoslav Spasov, Svilen Cheshmedjiev, Vasil Genchev, Vladimir Dobrev, Viktor Vasilev, Vladimir Mladenov and Zahari Kerelski. Finally, we would like to thank Richard Bashford and Stefan Patchedjiev to improve English in the manuscript.

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Designs for nest box, owl stopper, and patio trap for Eurasian Scops-owl (*Otus scops*) and other small cavity-nesting owls

Planos de caixa-ninho, dispositivo de captura e armadilha de entrada para mocho-d'orelhas (*Otus scops*) e outras aves de rapina noturnas cavernícolas de pequeno porte

David H. Johnson[1*], Elif Göçer[2], C. Can Bilgin[3]

1 Global Owl Project, 6504 Carriage Drive, Alexandria, Virginia 22310 USA

2 Global Owl Project, 06490, Ankara, Turkey

3 Middle East Technical University, Department of Biology, 06800 Ankara, Turkey

*** Corresponding author:** djowl@aol.com



ABSTRACT

In 2017, we began conducting migration and demographic work on the Eurasian Scops-owl (*Otus scops*) in Turkey. This paper focuses on three practical aspects of conducting Eurasian Scops-owl research using nest boxes and related equipment. Based on the literature and input from other researchers, we developed and built nest boxes, a device (owl stopper) to capture owls by keeping them from exiting the nest boxes upon our approach, and a patio trap for capturing adult owls. We offer specific plans with dimensions, material lists, and construction instructions and techniques to enable researchers to build and use these items for research on Eurasian Scops-owls and other small cavity-nesting owls.

Keywords: nest box, *Otus scops*, research methods, trap design and construction

RESUMO

Em 2017, iniciámos o estudo da migração e da demografia do mocho-d'orelhas (*Otus scops*) na Turquia. Este artigo foca-se em três aspetos práticos relacionados com o uso de caixas-ninho na investigação do mocho-d'orelhas. Com base na literatura e em contributos de outros investigadores, desenvolvemos e construímos caixas-ninho, um dispositivo (*owl stopper*) para capturar os mochos impedindo-os de sair das caixas-ninho durante a aproximação do captor, e uma armadilha de entrada para capturar mochos adultos. Disponibilizamos os planos com dimensões, lista de material, instruções de construção e técnicas para permitir que outros investigadores construam e utilizem estes métodos para estudar o mocho-d'orelhas e outras aves de rapina noturnas cavernícolas de pequeno porte.

Palavras-chave: caixa-ninho, metodologias de investigação, *Otus scops*, planos e construção de armadilhas

Introduction

In 2017, we (and colleagues) began demographic work on the Eurasian Scops-owl (*Otus scops*) in Turkey, Slovenia and Spain. We wanted to be able to capture, band/mark, and in subsequent years recapture, a large number of owls. In order to do this, we established networks of nest boxes, with boxes spaced at about 200 m increments, in landscapes that held few (if any) natural cavities. Our two study sites in Turkey had 30 and 40 nest boxes, respectively. The intention was to provide nesting sites for owls, at a large-enough spatial scale, so that when owls moved from one nest site to another, or new owls moved in, we would have sufficient nesting sites to allow us to routinely capture *all* of the owls involved. To aid us in this work, we designed a nest box, an owl stopper, and a patio trap. This methods paper describes these three research tools.

Nest Box for Eurasian Scops-owl

We made nest boxes from 20 mm-thick wood or plywood (Fig. 1). We centered the 60 mm diameter entrance hole 240 mm from the bottom and 120 mm in from either side. The sides were cut at a 14 degree angle, giving a slope to the top. The back edge of the top was cut at a 15 degree angle, to allow a snug fit between the top and back. The top was attached with two hinges. We drilled four or five 5-mm diameter drain holes through the bottom. A total of four 5 mm diameter holes were drilled - two through the top and two through the bottom of the back plate, 25 mm from the ends of the back and 60 mm in from the sides - to allow a wire for wrapping around the tree trunk. We placed about 75 mm of fine wood chips or sphagnum inside the nest box for the female owl to dig her nest cup into and to support the eggs and young.

Owl Stopper

The intention of the owl stopper is to capture the adult female inside of the nest box. It is used by quietly approaching the nest box (typically during daylight hours), and putting the owl stopper into the entrance hole of the nest box, blocking the owls' escape. This design is for a nest box with a 60

Figure 1 - Eurasian Scops-owl (*Otus scops*) nest box design.

Figura 1 - Esquema de caixa-ninho para mocho-d'orelhas (*Otus scops*).

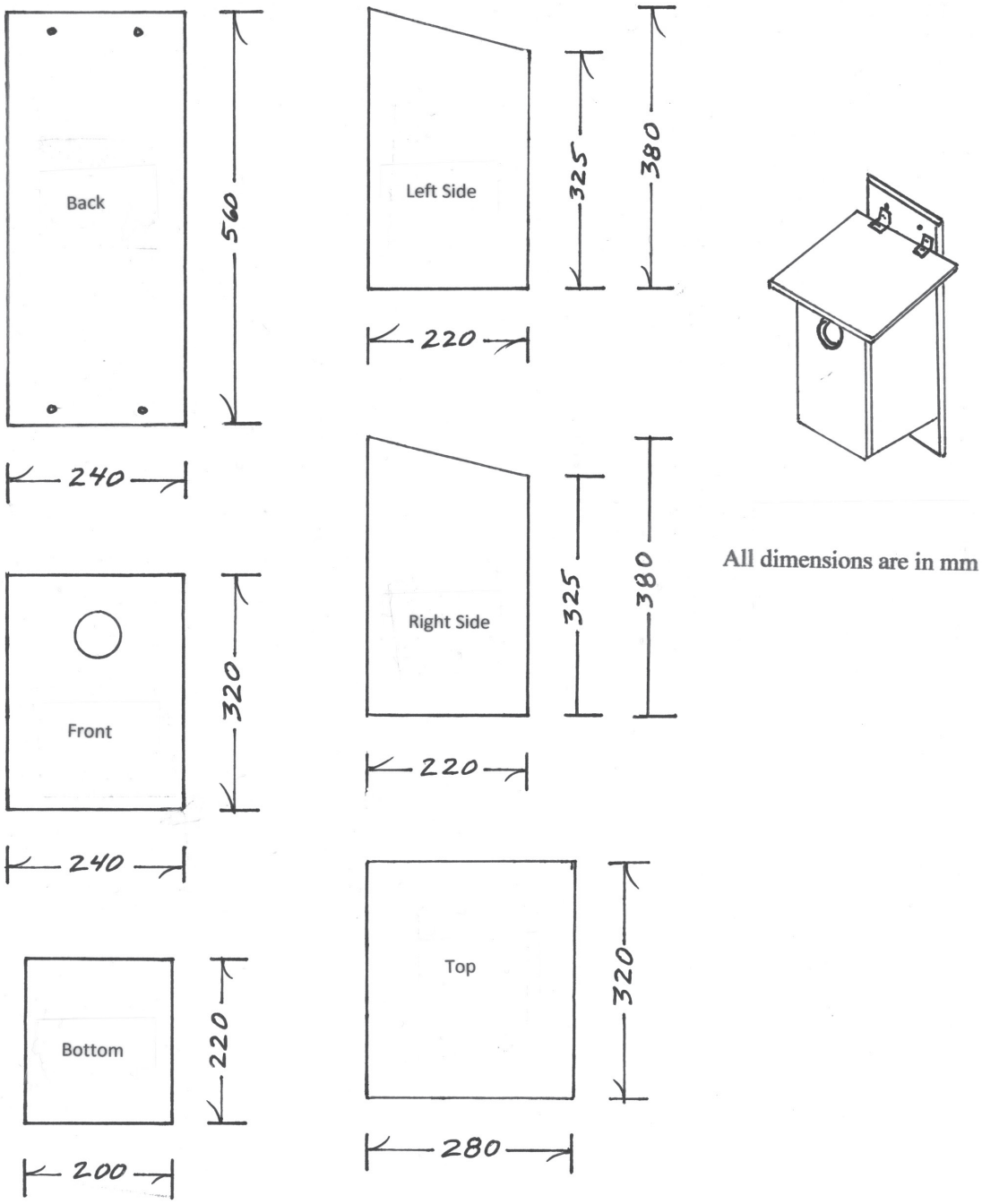


Figure 2 - Schematic design of the owl stopper.

Figura 2 - Esquema do dispositivo de captura.

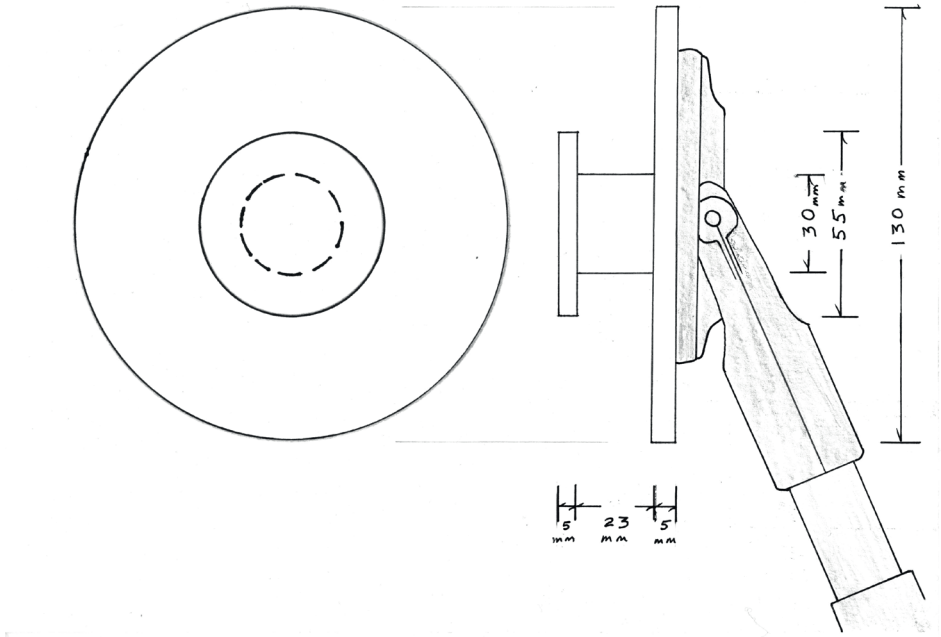


Figure 3 - Photo of owl stopper by nest box opening.

Figura 3 - Foto do dispositivo de captura na entrada da caixa-ninho.



Figure 4 - Patio trap attached to front of nest box on tree.

Figura 4 - Armadilha de entrada fixada em frente à caixa-ninho, numa árvore.



Figure 5 - Front view of patio trap.

Figura 5 - Vista frontal da armadilha de entrada.

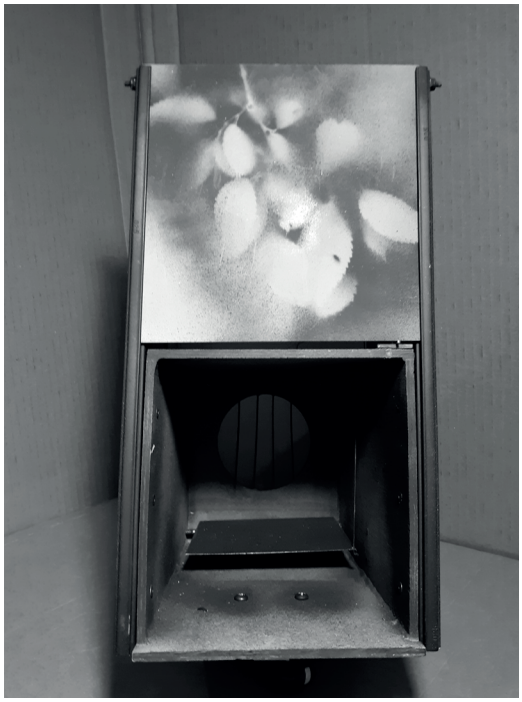
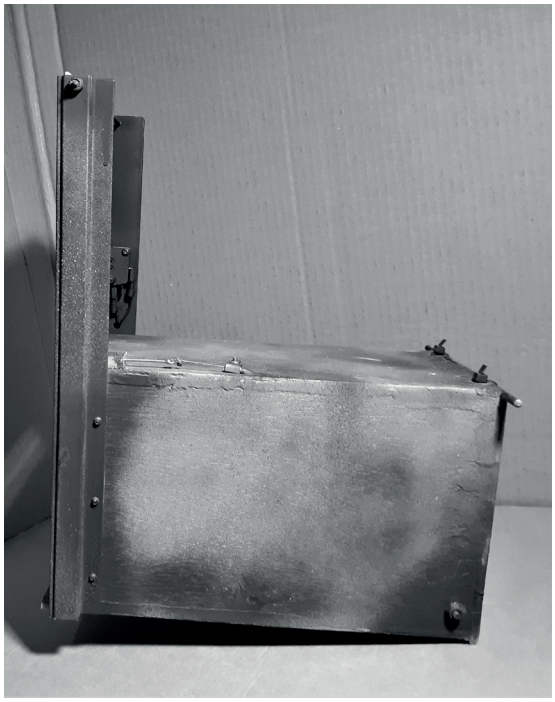


Figure 6 - Side view of patio trap.

Figura 6 - Vista lateral da armadilha de entrada.



mm diameter entrance hole. The headpiece consists of two round discs of 5-mm plywood (55 and 130 mm diameter) and a 30 mm diameter x 23 mm thick spacer dowel epoxied together. This headpiece is attached to a swiveling drywall sanding block, cut to fit the 130 mm plywood disc, and held on with two pop-rivets (Figs. 2, 3). This allowed the headpiece to tilt in two directions (vertically and horizontally). The owl stopper setup is attached to a wooden, plastic, or metal extendable pole handle. After inserting the owl stopper into the entrance hole leave it hanging in the entrance hole while the owl is handled inside the nest box. We captured 30-50% of adult females that remained in the nest box when approached using the owl stopper or similar device (unpubl. data).

Patio Trap

We developed a modified version of a patio trap (Saurola 1987, Kivelä 2001) to capture small owls (80-120 g), particularly males, at their nests at night (Figs. 4, 5, 6). Our goal was to capture every adult owl in the study areas; while up to half of the females were readily captured inside the nest boxes, a patio trap was needed for the other females and all of the males. Thus far, with the design offered here, and an earlier prototype design, we have captured 50 adult Eurasian Scops-owls. The trap captured owls as they tended to young inside the nest box. The patio trap is made from 5 mm plywood, and is 152 mm wide, 160 mm tall, and 277 mm in total length; two-part, quick-cure epoxy was used

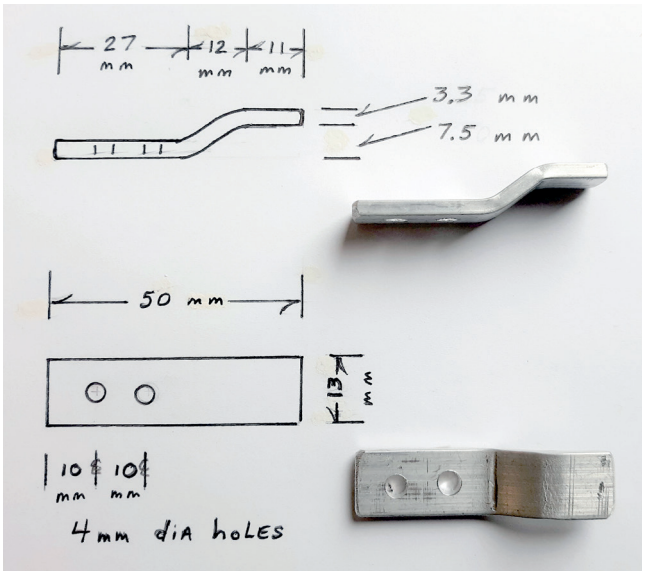
Figure 7 - Patio trap hung on front of nest box with two aluminum hanger clips.

Figura 7 - Armadilha de entrada fixada na frente da caixa-ninho com dois suportes de alumínio.



Figure 8 - Schematic and dimensions of aluminum hanger clips.

Figura 8 - Esquema e dimensões dos suportes de alumínio.



in its construction. To increase acceptance by owls and trap longevity, we camouflaged the trap using flat tan and black spray paint. A painted, finished trap weighed about 910 g. The patio trap is attached to the face of the nest box using a 5 mm metal rod across the rear of the trap and two small aluminum hanger brackets attached to the face of the nest box (Figs. 7, 8). As the aluminum hanger brackets are attached to all nest boxes during the non-breeding season, patio traps can be easily moved, as needed, from box to box. After entering the trap, the owl walks toward the rear hole area of the patio trap, and its weight triggers the treadle, and the plexiglass door drops shut. After setting the trap, we left the area; traps were set around sunset and checked every 50-60 min thereafter. Researchers use a ladder to reach nest boxes and safely attach and remove traps.

Top, Bottom, Left and Right Sides of Patio Trap

The top and both sides of the patio trap are all the same dimension, i.e., 260 mm x 152 mm. The bottom of the trap is 272 x 152 mm. The two sides are mirror images, and each has one 5 mm hole drilled through them in the lower rear corners; the hole is centered 12 mm from the bottom and 12 mm from the rear of the side. These holes hold the 5 mm threaded rod that spans the width of the trap and passes through the holes in the treadle. The bottom is longer than the sides and top, as it extends forward and 'catches' or stops the door when it drops. The bottom of the trap is epoxied to the bottom of the sides, and then the top of the trap is epoxied onto the top of the sides. The top has 2 slots (2 x 5 mm) cut into it for zip ties, located 5 mm from the back and 20 mm in from the sides.

Back of Patio Trap

The back of the Patio Trap (the portion adjacent to nest box entrance) is 160 mm x 152 x 5 mm thick (Fig. 9). Using a hole saw, we cut an 85 mm diameter hole, centered 76 mm from the sides and 62 mm from the top. After cutting the hole, cut a 36 mm strip from the lower part of the back – save this lower strip for later reattachment using epoxy (Fig 10; see below). We used four metal rods (1.5 mm diameter) to create "bars" positioned vertically across the hole, so that the female does not escape from, or the male does not go into, the nest box. Using a 2 mm drill bit, drill the first hole 50 mm from a side of the back, and then drill three subsequent holes at 17 mm increments apart (Fig. 9). Next, flip the back piece (top to bottom) and drill corresponding rod holes. Insert the metal rods (120 mm long each) into the holes, and reattached the lower strip of wood using epoxy. When the lower strip is cut, about 2 mm are lost from the height of the back due to the saw kerf, this is not a concern. When the back was epoxied onto the trap frame, it was only attached to the two sides and bottom of the trap – the 5 mm metal hanger rod was epoxied on the top of the back and against the end of the trap frame (Fig. 11).

Two slots (2 x 5 mm) were drilled into the top of the back piece (5 mm from the top, and 20 mm from the sides). Companion slots were drilled into the top of the patio trap. The 5 mm metal hanger rod, bedded in epoxy, was then held fast by two 5 mm plastic zip ties [these zip ties were required to keep the hanger rod in place, as the epoxy was not sufficient on its own] (Fig. 12).

Treadle for Patio Trap

The treadle was made of 1 mm-thick aluminum sheeting (Figs. 13, 14) and started out being 155 mm wide and 128 mm long in size. Two 5 mm holes were drilled in opposite corners, centered 7 mm from the sides and 8 mm from the ends of the sheet. The corners of the aluminum sheet were rounded slightly with a metal file. The sides (13 mm) of the aluminum sheet were then sharply bent at a 90 degree angle. After this, trim the metal sides at an angle – from 13 mm wide at

Figure 9 - Schematic of back of patio trap.

Figura 9 - Esquema da parte posterior da armadilha de entrada.

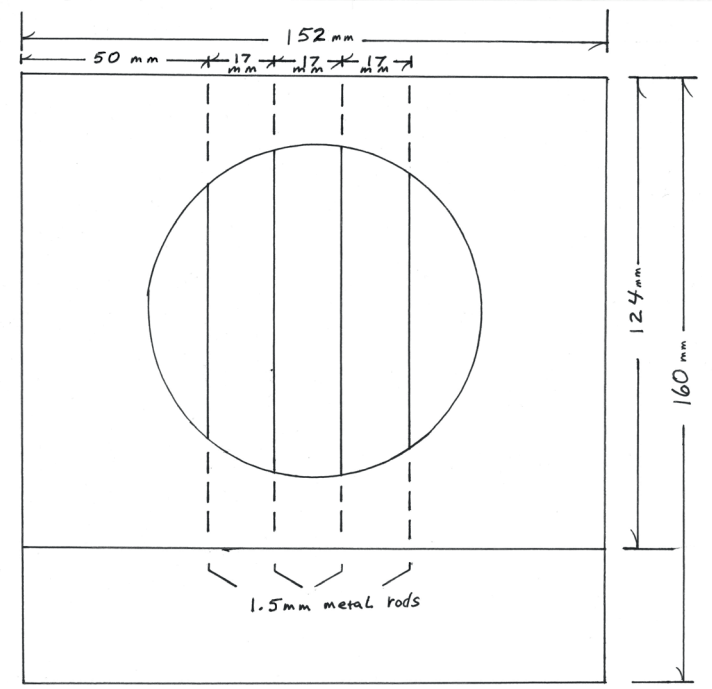


Figure 10 - Photograph of back pieces for two traps under construction. The bottom strip of the back has been cut off, to allow access for drilling holes for vertical 1.5 mm rods. With rods in place, the bottom strip is reattached with epoxy.

Figura 10 - Fotografia das peças posteriores de duas armadilhas em construção. A ripa inferior posterior foi cortada para permitir o acesso para fazer as furações para as varas verticais com 1,5 mm. Após instalação das varas, a ripa inferior é reposicionada e fixada com resina.

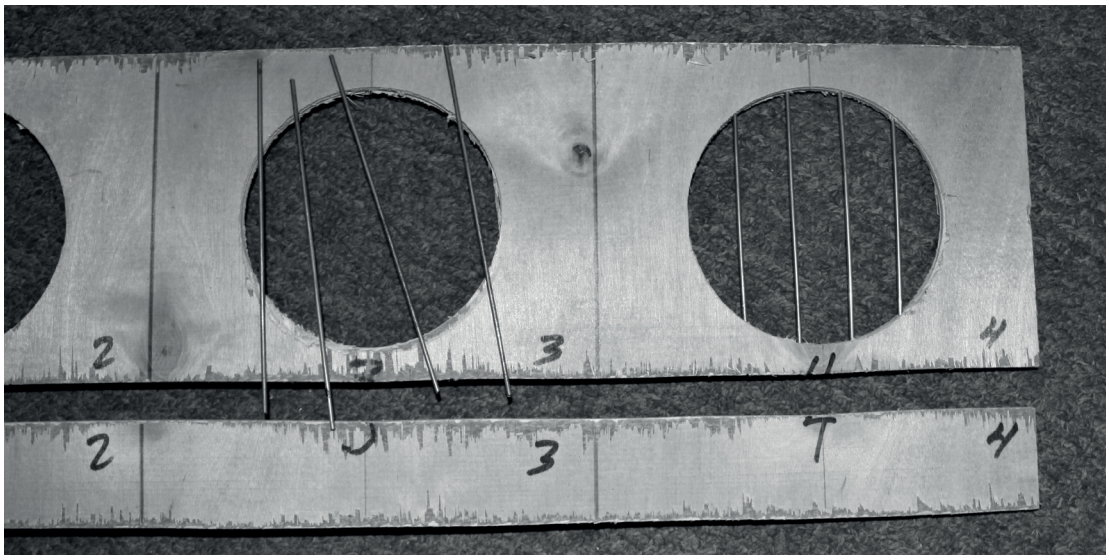


Figure 11 - Schematic of trap, with highlighted area showing hanger rod placement.

Figura 11 - Esquema da armadilha. A área sombreada mostra a posição da vara de encaixe.

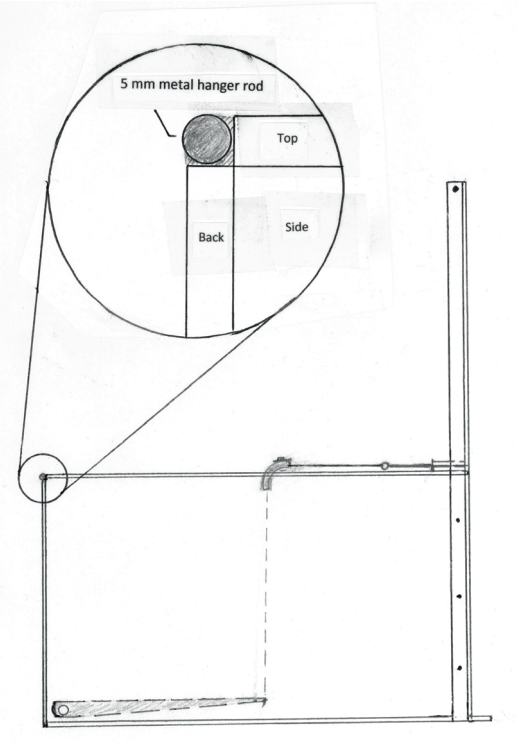


Figure 12 - Photograph of back of patio trap, showing zip ties.

Figura 12 - Fotografia da parte posterior da armadilha de entrada, mostrando as abraçadeiras de plástico.

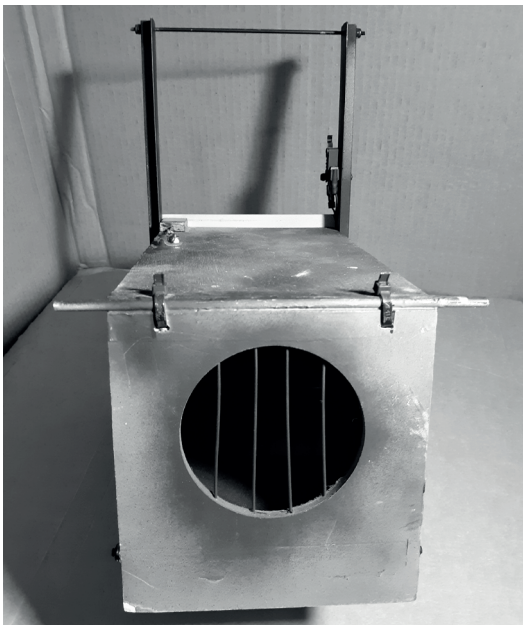


Figure 13 - Schematic of treadle, showing bending and trimming areas.

Figura 13 - Esquema do pedal, mostrando a localização das dobras e dos cortes.

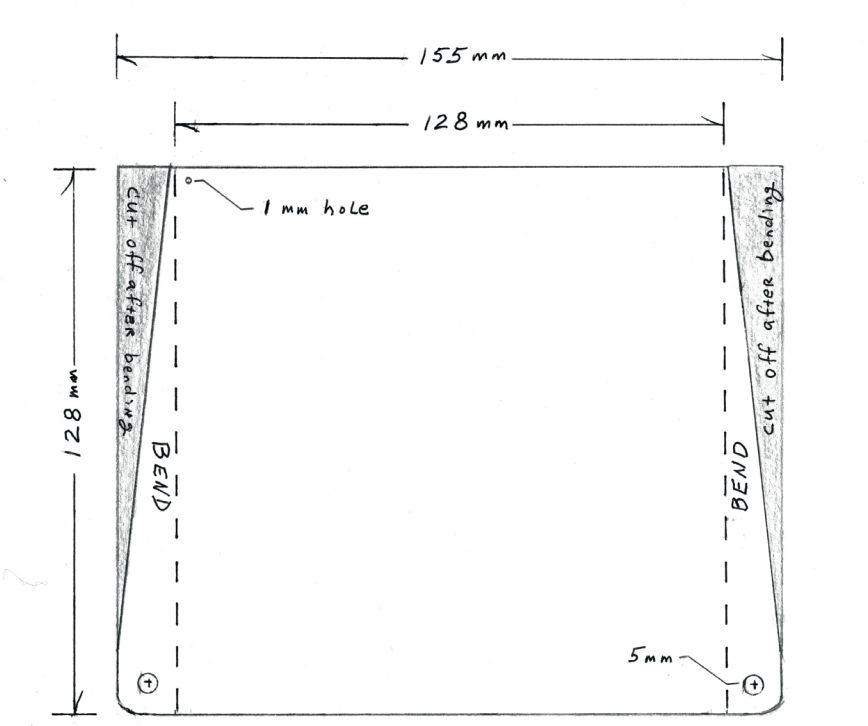
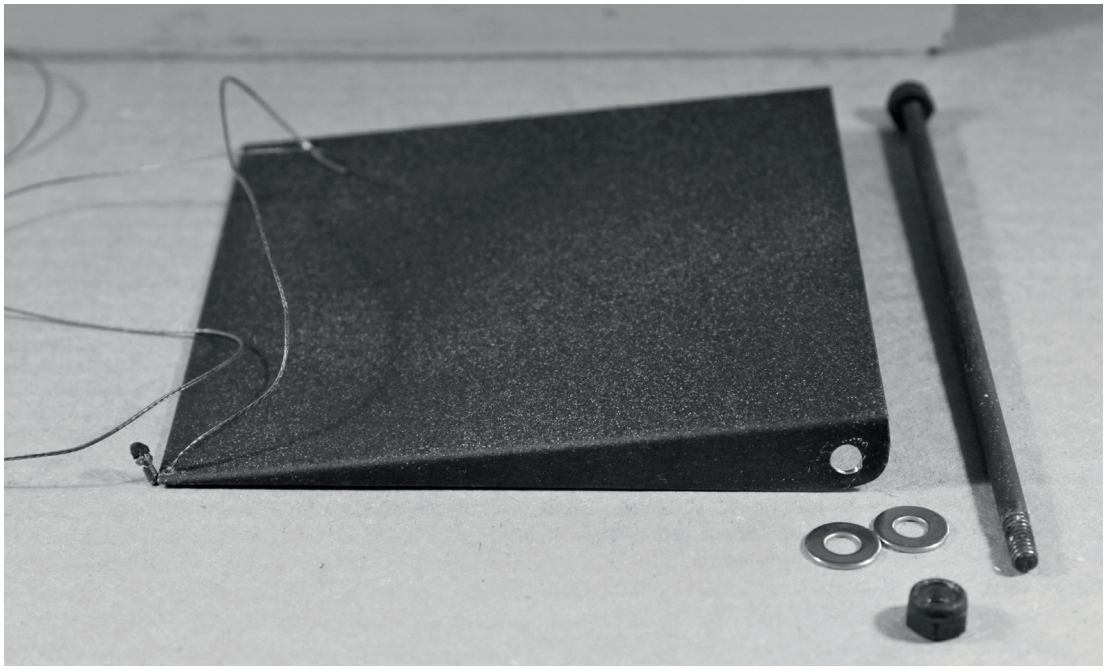


Figure 14 - Photograph of treadle, threaded rod, washers, lock nuts, and Spectra line.

Figura 14 - Fotografia do pedal, vara roscada, porca, anilhas planas e linha de fibra Spectra.



the back to 2 mm wide at the front. This trimming will allow the treadle to fall a few mm more when triggered by the owl. The finished *surface* of the treadle is 128 mm long x 128 mm wide. Drill a 1.0 mm hole 2 mm from the left front corners of the treadle as part of the trigger mechanism. After the corner holes were drilled, sides bent and trimmed, and the small hole drilled for the trigger mechanism, acetone was used to clean the top and bottom of the aluminum treadle. A very thin coat of flat black paint was then applied to the bottom and sides and allowed to dry. Then, the top was painted again, with some fine sawdust quickly sprinkled on the top of the treadle (to soak into the paint) to offer a non-slip walking surface for the owl. Textured paint is an acceptable alternative to the sawdust. A further light coat of spray paint was sometimes needed to hold the sawdust. Very importantly, the treadle must be as lightweight as possible. After the treadle was painted, an 80 cm long piece of 40 kg Spectra braided fishing line was put through the 1 mm hole, and triple knotted on the underside of the treadle; this is the trigger line.

Trigger Mechanism

A 2 mm (inner diameter) copper tube was placed through the top of the trap, 110 mm from the front of the trap and 10 mm from the left side (Fig. 15). This copper tube was 50 mm in length, and critically important, it needed to have a smooth 90 degree bend in it. Such copper tubing is often used for brake fluid lines in vehicles. The tube was placed directly above the corner of the treadle, such that the Spectra line goes directly up from the treadle, through the copper tube, and to the stainless steel trigger pin. The copper tube was held in place with a plastic tie, bolted through the top of the trap. Epoxy was used to seal the copper tube in place and to waterproof the hole. The Spectra line had to run very smoothly through the copper tube. The trigger pin was made of 2.0 mm stainless steel wire, with an 'eye' bent into one end. The initial length of the trigger pin was 76 mm; finished length was 72 mm (Fig. 16). The weight of the owl (~80 g) was enough to drop the treadle, pulling the Spectra line, and thereby pulling the stainless steel pin from beneath the plexiglass door.

Plexiglass Door and Metal Frame for Patio Trap

This patio trap uses a 'guillotine' style plexiglass door that slides freely inside an external metal frame (Figs. 4, 5, 6). The door was 166 x 166 x 2 mm in size; it was painted front and back, with flat tan and black spray paint, in a camouflage-leaf pattern. The metal frame that holds the door in place was an aluminum window frame used for holding insect mesh. Two pieces of this metal frame were used; each were 330 mm long. Each of the two frame pieces were attached to the outer sides of the patio trap with three pop rivets (each about 2.5 mm diameter x 10 mm long in size). Holes for the pop rivets were drilled through the metal uprights first, and thereafter clamped and drilled through the patio trap sides. The metal frame that holds the trap door extended about 2 mm in front of the trap sides and top. Because the bottom of the trap was longer than the top or sides, the trap door was stopped by the trap bottom when it dropped. Note: Attaching the two metal uprights for the door is one of the very last steps in the patio trap assembly process, after the completion of the trap box and treadle efforts.

LED Lighting

We added a light to the bottom of the patio trap which turned on when the trap closed and was easily visible at 40 m. A single, white, LED light was affixed in a white (or clear) plastic frame and was bolted (with 5 mm stainless steel bolts) to the bottom of the trap (Fig 17). The light was powered with 2 AAA batteries. A microswitch (OMRON

Figure 15 - Copper tube fastened and extending through top of patio trap. The Spectra line runs smoothly through this, between treadle and trigger pin.

Figura 15 - Tubo de cobre fixado e a trespassar a face superior da armadilha de entrada. A linha de fibra Spectra passa no interior do tubo, ligando o pedal ao pino do gatilho.

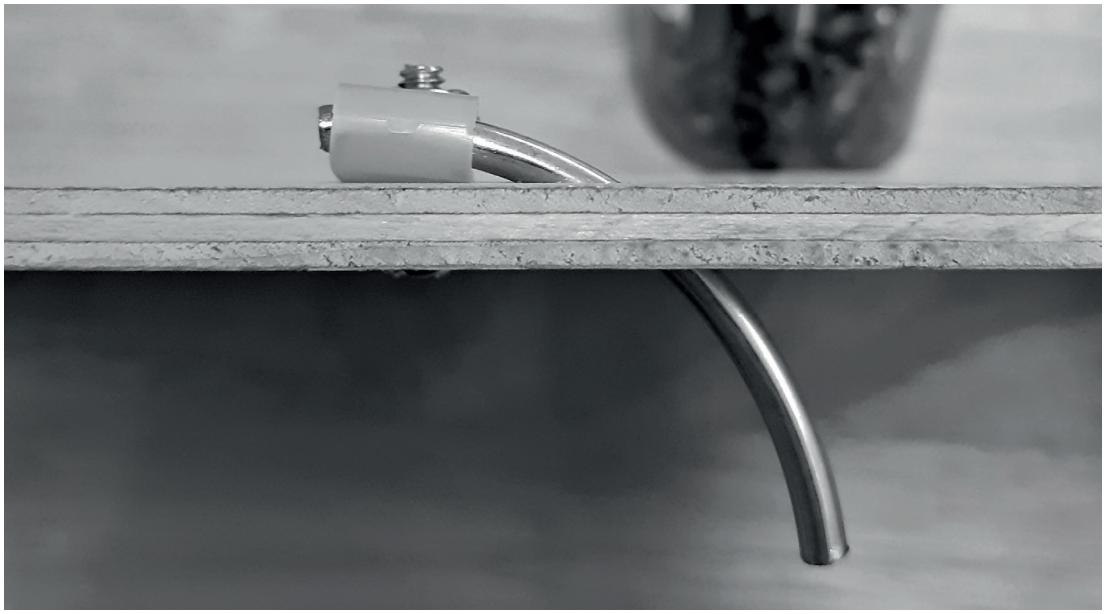


Figure 16 - Trigger mechanism for patio trap door.

Figura 16 - Mecanismo do gatilho da porta da armadilha de entrada.

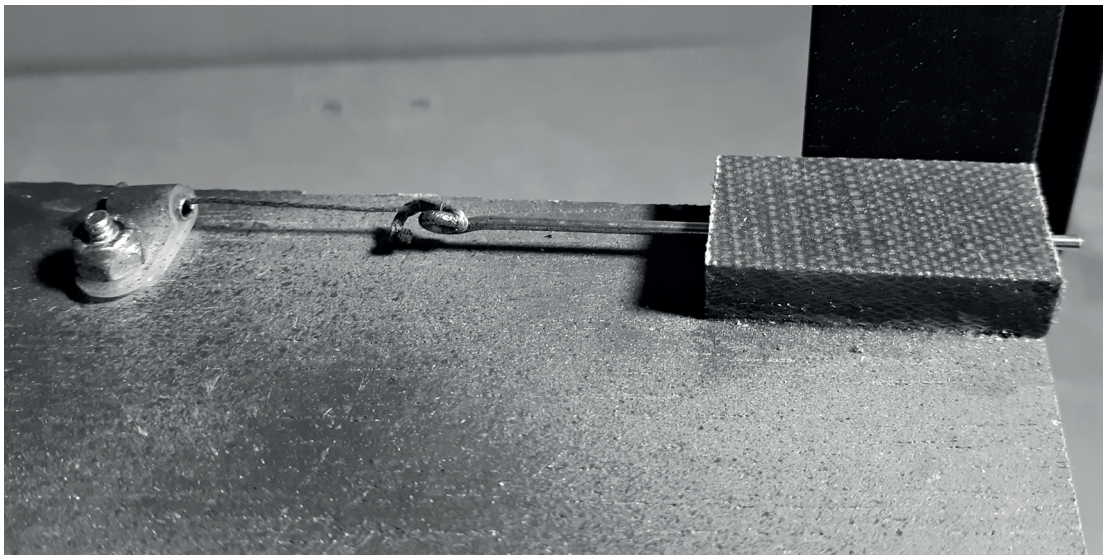


Figure 17 - An LED light fixture bolted to the bottom of the patio trap.

Figura 17 - Luminária LED aparafusada à base da armadilha de entrada.

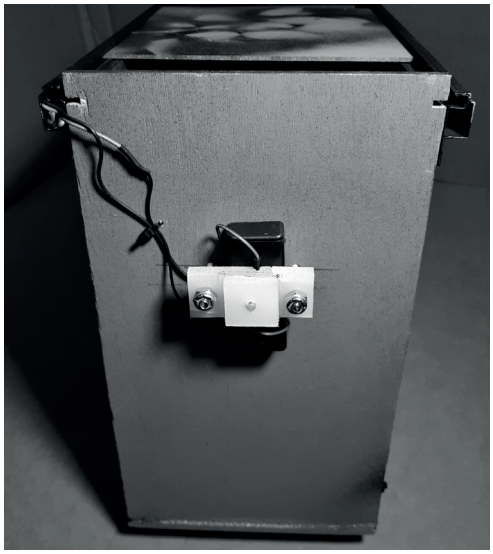
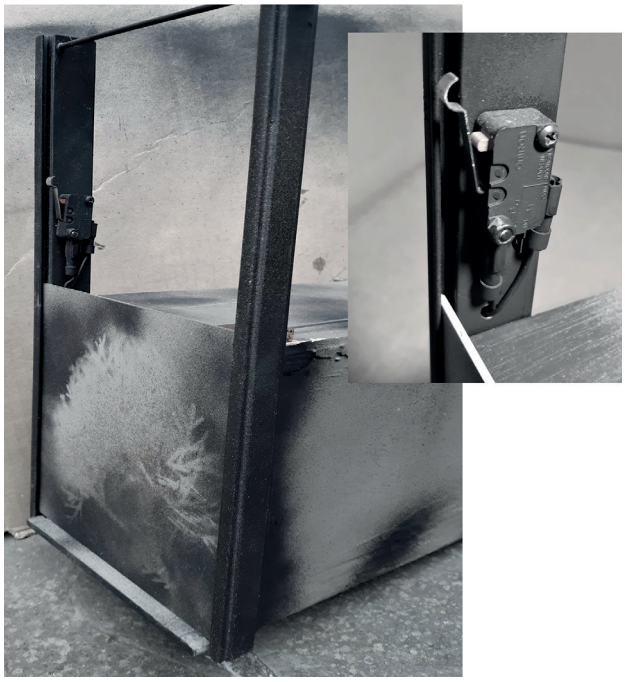


Figure 18 - View of the microswitch mounted on the inside of the right-side vertical bracket; trap door is down (as if owl was captured).

Figura 18 - Vista do micro-interruptor instalado no interior do suporte vertical do lado direito; a porta de guilhotina da armadilha está fechada (como quando um mocho é capturado).



basic/snap-action miniature switch, part D3V-014-1C23, simulated roller lever) was mounted to the inside of the right metal upright (Fig. 18). When the door was up, the microswitch was closed, but when the door dropped down, the microswitch was open, and the LED light came on. The light was mounted to the bottom of the trap, as most nest boxes were about 4-5 m above the ground, and the light projected from the bottom was more easily seen. This allowed researchers to determine when an owl was captured in the trap and likewise to stay away from the nest site when the light was off, thereby minimizing disturbance to the owls.

Acknowledgments

We thank Paolo Galeotti and Duccio Centili (Italy), Katarina Denec (Slovenia) and Joan Carles Abella (Spain) for their important contributions to the nest box design. We very much thank James A. Lueck and Bernard V. Davey (both USA) for their insights, skills, and shop time for helping with the design and engineering of the patio traps and lighting array. James R. Duncan and Dave Oleyar provided helpful comments on an earlier manuscript draft.

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Owl telemetry – a comparison of transmitter designs and harness methods for Ural Owls (*Strix uralensis*) in Austria

Telemetria de aves de rapina noturnas – comparação de emissores e arneses para coruja dos Urales (*Strix uralensis*) na Áustria

Ingrid Kohl[1*], Christoph Leditznig[2], Franz Aigner[2]

1 REWILD Institute – Research on Ecosystems and Wilderness, A-1130 Vienna, AUSTRIA

2 Dürrenstein Wilderness Area Administration, Brandstatt 61, A-3270 Scheibbs, AUSTRIA

*** Corresponding author:** office@rewild.institute



ABSTRACT

From 2009 to 2017, 142 young Ural Owls (*Strix uralensis*) were reintroduced into the mountain forests of the Dürrenstein Wilderness Area of Austria. To monitor owl dispersal and survival, 110 transmitters, consisting of five transmitter models and three telemetry systems were used. These models and systems are compared relative to design, signal transmission rates, attachment methods, break-away harness materials and relative costs. The best units were battery powered GPS-GSM transmitters with break-away perbunan rings and leg-loop harness mounts. Further improvements of predetermined breaking points such as cotton threads and perbunan seal rings are still in process. Advancements in transmitter technology have aided the successful reintroduction of Ural Owls to Austria's forests.

Keywords: Dürrenstein Wilderness Area, owl telemetry, predetermined breaking points, transmitter designs, transmitter mounting methods

RESUMO

De 2009 a 2017, foram reintroduzidos 142 juvenis de corujas dos Urales (*Strix uralensis*) nas florestas montanhosas da Área Silvestre de Dürrenstein, na Áustria. Para monitorizar a sua dispersão e a sobrevivência, foram utilizados 110 emissores, constituídos por cinco modelos de emissores e três sistemas de telemetria. Esses modelos e sistemas foram comparados em termos de desenho, taxas de transmissão de sinal, métodos de fixação, materiais usados no arnês e custos relativos. As melhores unidades foram os emissores GPS-GSM alimentados por bateria, com anéis de rutura de nitrilo e com montagem de arnês no tarso. Estão em desenvolvimento outras melhorias nos pontos de rutura pré-determinados, tais como fios de algodão e anéis vedantes de nitrilo. Os avanços na tecnologia de emissores contribuíram para o sucesso da reintrodução da coruja dos Urales nas florestas da Áustria.

Palavras-chave: desenho de emissores, métodos de instalação de emissores, pontos de rutura pré-determinados, Área Silvestre de Dürrenstein, telemetria de aves de rapina noturnas

Introduction

Telemetry and its variants, such as geolocators, are increasingly used in field research to obtain large amounts of data with relatively little effort (Meyburg et al. 2016, Vlček & Schmidberger 2014). Exo et al. (2013) describe the benefits of telemetry for recording environmentally relevant animal behavior to inform conservation action. The use of telemetry as a research tool to gather information must be matched to specific research questions and hypothesis testing (Leditznig 1999, Leditznig & Langer 2017). Examples include documenting foraging behaviour and habitat use (Kubetzki 2013, Mendel & Garthe 2010, Schmajohann 2013).

In the first half of the 20th century the Ural Owl (*Strix uralensis*) (Fig. 1, 2) became extirpated in Austria. In 2008, the Research Institute of Wildlife Ecology (FIWI) and the Dürrenstein Wilderness Area Administration (DWA) began a Ural Owl reintroduction project in the DWA. The project used transmitter data to estimate survival and mortality, document reproduction and breeding dispersal, and to assess the viability and connectivity of restored populations (Kohl & Leditznig 2012, Leditznig & Kohl 2013, Kohl & Leditznig 2017). Over 10 years the DWA worked with Biotrack/Lotek and ECOTONE to develop transmitter designs suited to the natural history and adaptations of the Ural Owl and in steep mountain forests (Kohl & Leditznig 2017). This included the development of transmitter mounts and harness predetermined breakaway mechanisms to release transmitters when batteries expired. This paper discusses the advantages and disadvantages of specific telemetry systems used in the above project. Other telemetry attachment systems (i.e., neck, leg or implant) are not covered here (Wikelski et al. 2015, König et al. 2016). Peer-reviewed humane wild animal handling protocols were followed to minimize stress to the owls (Kurt 1995, Leditznig 1999).

Figure 1 - Adult Ural Owl (*Strix uralensis*) in Austria. Adaptations of owls are challenges for telemetry (photo: Christoph Leditznig).

Figura 1 - Adulto de coruja dos Urales (*Strix uralensis*) na Áustria. As adaptações das aves de rapina noturnas são um desafio para a telemetria (Foto: Christoph Leditznig).



Figure 2 - Young Ural Owl (*Strix uralensis*) in Austria. Young owls were released at about 90 d old and tracked with telemetry (photo: Christoph Leditznig).

Figura 2 - Coruja dos Urales juvenil. Os juvenis foram libertados com uma idade de cerca de 90 dias e seguidos por telemetria (foto: Christoph Leditznig).



Figure 3 - Primeval Forest Rothwald in the Dürrenstein Wilderness Area, Austria (photo: Hans Glader).

Figura 3 - Floresta Virgem de Rothwald na Área Silvestre de Dürrenstein, Áustria (foto: Hans Glader).



Table 1 - Comparison of the different transmitter models - a summary.

Tabela 1 - Comparação dos diferentes modelos de emissores - resumo.

	RADIO-TELEMETRY (TAIL FEATHERS MOUNTING)	RADIO-TELEMETRY (PELVIS HARNESS MOUNTING)	SATELLITE TELEMETRY	GPS-GSM-TELEMETRY (SOLAR-POWERED)	GPS-GSM-TELEMETRY (BATERY-POWERED)
Mounting	tail	pelvis	pelvis	pelvis	pelvis
Weight	17 g	23 - 27 g	20 g	27 g	31 g
Proportion weight (800g)	2.1 %	2.8 %	2.5 %	3.3 %	3.8 %
Costs transmitter	200 €	250 €	2,500 €	1,150 €	720 €
Follow-up costs / transmitter / month	ca. 400 €	ca. 400 €	5 €	13 €	13 €
Follow-up costs / transmitter / year	ca. 5,000 € (travel expenses, mileage allowance)	ca. 5,000 € (travel expenses, mileage allowance)	60 €	160 €	160 €
Work associated with telemetry technology	Radio-Telemetry & data processing & transfer to server (web map & database)	Radio-Telemetry & data processing & transfer to server (web map & database)	Data processing & transfer to server (web map & database)	Data processing & transfer to server (web map & database)	Data processing & transfer to server (web map & database)
Working hours / transmitter / year	approx. 140	approx. 140	approx. 40	approx. 40	approx. 40
Transmission period	1 year	1.5 years	1.5 years	1 month without sun exposure, else several years	1.5 to 2years
Number of used transmitters	18	46	3	5	38
Years	2009, 2010	2010 - 2014	2012 (2013)	2013	since 2014
Characteristics				Discovery of nest box broods	Discovery of tree hole broods
Advantage(s)	timely search, relatively low burden for the bird	timely search, reception over larger distances	Data transmission	GSM data transmission, (in theory: transmission duration)	GSM data transmission, costs, less emissions, data handling, brood search, temperature measurement
Disadvantage(s)	Personnel expenses, travel expenses, emissions, transmitter loss before breeding season	Personnel expenses, travel expenses, emissions, transmitter loss before breeding season, antenna bitten off by owl - signal became weaker	Cost, inaccuracy, data handling, search difficult	Use of solar panel not possible due to owl plumage	Search harder / delayed, transfer stop when in breeding cavity

Study Area

The Dürrenstein Wilderness Area (DWA - 3,500 ha; 600 to 1,878 m a.s.l), including the 400 ha Primeval Forest Rothwald (Fig. 3), offered ideal Ural Owl habitat with a relatively high abundance of deadwood and tree cavities. The DWA is classified as IUCN Strict Nature Reserve Category Ia, IUCN Wilderness Area Category Ib and an UNESCO Natural World Heritage Site. Tree species present include Norway Spruce (*Picea abies*), European Silver Fir (*Abies alba*) and European Beech (*Fagus sylvatica*). European Larch (*Larix decidua*) and the Sycamore Maple (*Acer pseudoplatanus*) were also important tree species present. Sycamore Maple and Norway Spruce form cavities used by owls and other wildlife. The DWA is ideal habitat for other owls (Tengmalm's Owls *Aegolius funereus*) but also for woodpeckers (White-backed Woodpecker *Dendrocopos leucotos*). Geologically it is part of the Northern Limestone Alps with an annual precipitation of 1,700 to 2,400 mm. Two Ural Owl release aviaries were located at 725 and 785 m a.s.l. and transmitter-marked owls dispersed up to 150 km (Kohl & Leditznig 2017).

Monitoring Tools

From 2009 to 2017, 110 transmitters (five models, three systems) were used to monitor success of the Ural Owl reintroduction project (Fig. 4) and yielded more than 14,000 owl positions (Fig. 5). Radio-telemetry Tail Mount (RT1), Radio-telemetry Pelvis Mount (RT2), Satellite Telemetry (ST), GPS-GSM Solar (GTS) and GPS-GSM Battery (GTB) transmitters were used with various mounting methods and associated predetermined breaking points (Table 1).

Transmitter weight should not exceed a maximum of 5% of bird body weight (Brander & Cochran 1969, Barron et al. 2010, Naef-Daenzer et al. 2005) but this may not apply to every bird species or mounting method. Hence, as a precaution, we chose not to exceed 4% of Ural Owl weight (range 2.1 to 3.8%). An 800 g owl mass was used to calculate the relative transmitter weight (Table 1) as it was between that of light males (600 g) and larger females (>1,000 g).

Results and Discussion

The five telemetry transmitters used between 2009 and 2016 differed in terms of technical and financial parameters that were important for the Ural Owl recovery project (Table 1; Kohl & Leditznig 2017). The advantages and disadvantages of each type and attachment and release mechanisms are discussed below (see also Table 1).

Transmitter Systems

Radio-telemetry Tail Mount (RT1) and Radio-telemtry Pelvis Mount (RT2) Transmitters

Eighteen Biotrack radio-telemetry transmitters (RT1) were attached to the central tail feathers (Fig. 9). The duration of these units was up to one year. Forty-six slightly heavier Biotrack radio-telemetry transmitters (RT2) were attached with the pelvis harness mounting method (Fig. 10). The duration of these units was up to 1.5 years. For RT1 and RT2, RX 98 hand-held receivers with hand-held H directional external antennas (Followit Lindesberg AB, formerly Televilt) were used to locate owls by signal triangulation; one RX 98 receiver had an integrated antenna. In addition, three round car antennas and two recording units were used. A Lotek/Biotrack hand receiver and automatic recording units were also used to track frequency of visits of young owls to feeding tables.

These units were light weight and relatively inexpensive. They enabled accurate and prompt relocations facilitating transmitter recovery, especially RT2s with stronger batteries. The stronger RT2 signals could be

Figure 4 - Number of Ural Owls (*Strix uralensis*) released in Austria with and without transmitters.

Figura 4 - Número de corujas dos Urales libertadas na Áustria com e sem emissores.



Figure 5 - Number of daily Ural Owls (*Strix uralensis*) positions per transmitter type in Austria (2009-2017).

Figura 5 - Número de posições diárias registadas por tipo de emissor na Áustria (2009-2017).

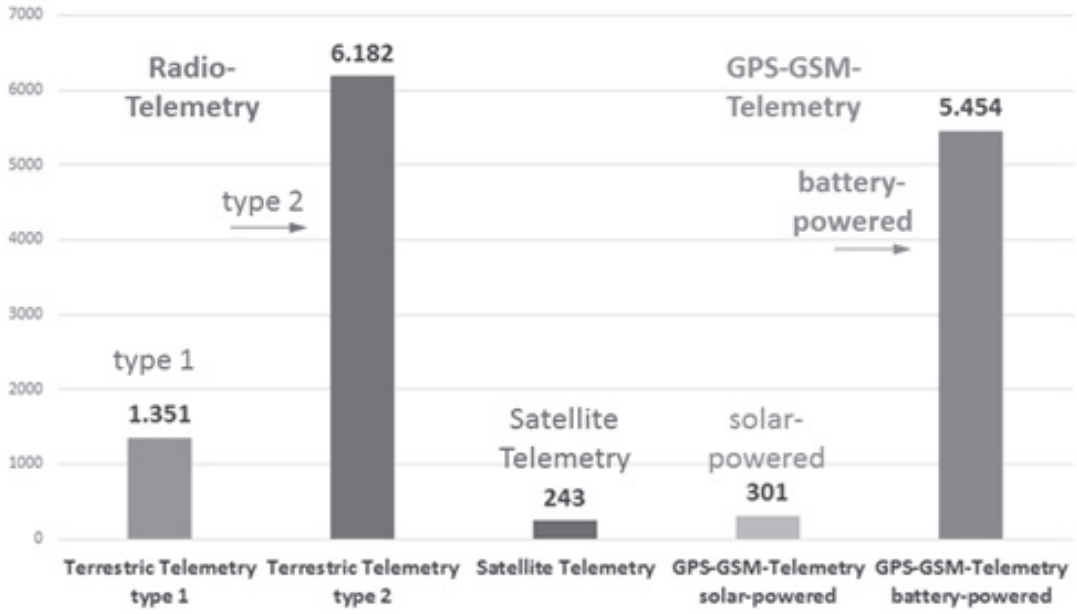


Figure 6 - Cotton thread predetermined breaking point (photo: Adrian Äbischer).

Figura 6 - Ponto de rutura predefinido em fio de algodão (foto: Adrian Äbischer).

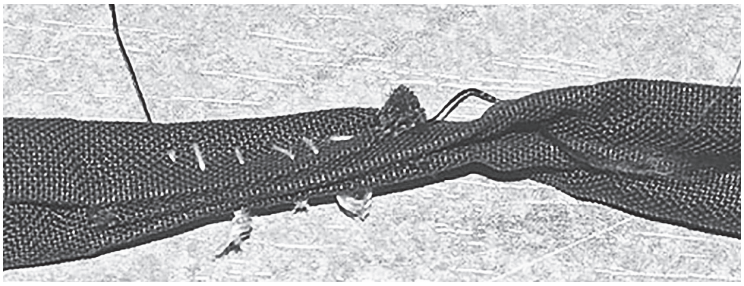


Figure 7 - Perbunan seal ring predetermined breaking points (photo: Christoph Leditznig).

Figura 7 - Pontos de rutura predefinidos feitos com anéis vedantes de nitrilo (foto: Christoph Leditznig).



Figure 8 - Radio-transmitter type 1 – central tail feathers mounting method (photo: Christoph Leditznig).

Figura 8 - Rádio-emissor tipo 1 - método de fixação nas retrizes centrais (foto: Christoph Leditznig).

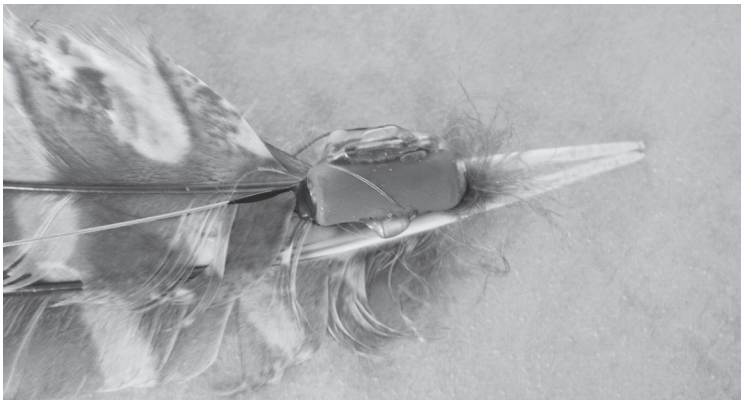


Figure 9 - Radio-transmitter type 2 – pelvis harness mounting method. Photo taken after the perbunan seal ring predetermined breaking point separated and showing half of the antenna removed by a Ural Owl (*Strix uralensis*) (photo: Christoph Leditznig).

Figura 9 - Rádio-emissor tipo 2 – método de fixação por arnês pélvico. Foto tirada após a quebra do anel vedante de nitrilo (ponto de rutura predefinido) e com metade da antena removida pela coruja dos Urales (*Strux uralensis*) (foto: Christoph Leditznig).

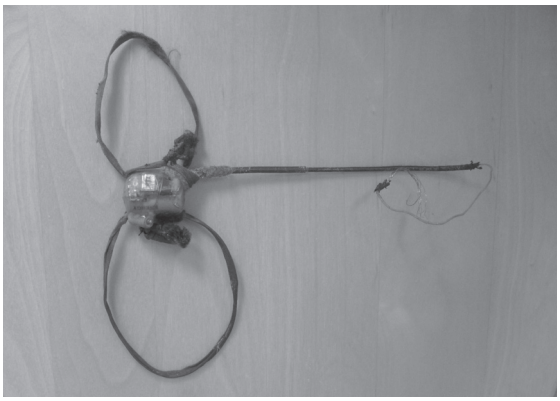


Figure 10 - Satellite transmitter attached by a pelvis harness mount to an adult Ural Owl *(Strix uralensis)* (photo: Wilhelm Leditznig).

Figura 10 - Emissor de satélite montado com o método de fixação por arnês pélvico num adulto de coruja dos Urales (*Strix uralensis*) (foto: Wilhelm Leditznig).



Figure 11 - One of several solar-powered GPS-GSM-transmitters tested on Ural Owls (*Strix uralensis*) showing a feather shield and two solar panels (photo: Christoph Leditznig).

Figura 11 - Exemplo de um tipo de emissor GPS-GSM alimentado a energia solar testado na coruja dos Urales (*Strix uralensis*), mostrando o protetor das penas e dois painéis solares (foto: Christoph Leditznig).

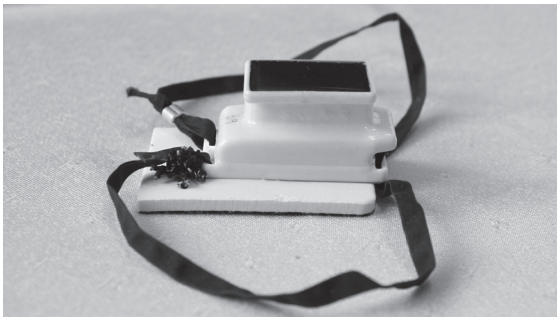


Figure 12 - GPS-GSM-transmitter backpack mounting method with internal predetermined breaking point (photo: Christoph Leditznig).

Figura 12 - Emissor GPS-GSM com montagem no dorso (tipo "mochila") com ponto de rutura predefinido (foto: Christoph Leditznig).

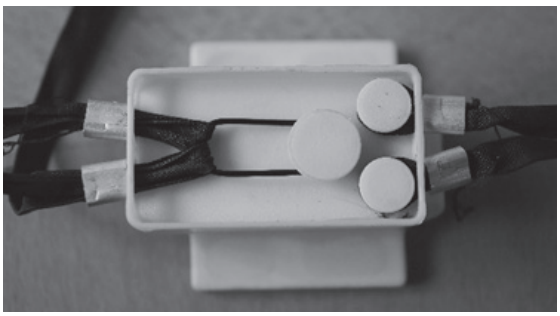


Figure 13 - The first battery-powered GPS-GSM-transmitter used on Ural Owls (*Strix uralensis*). The soft cover was destroyed when owls bit it within a few days (photo: Christoph Leditznig).

Figura 13 - O primeiro emissor GPS-GSM alimentado por bateria usado na coruja dos Urales (*Strix uralensis*). A cobertura macia foi destruída pelas corujas em poucos dias (foto: Christoph Leditznig).

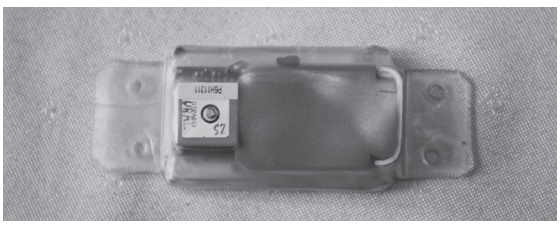


Figure 14 - The hard-covered battery-powered GPS-GSM-transmitter that withstood owl bites (photos: Christoph Leditznig).

Figura 14 - Emissor GPS-GSM alimentado por bateria com cobertura rígida que resistiu às bicadas das corujas (fotos: Christoph Leditznig).

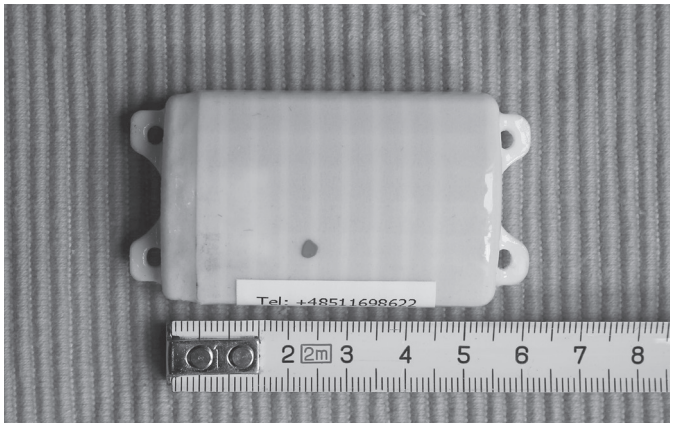


Figure 15 - The final battery-powered GPS-GSM-transmitter design in use since 2014 (photo: Ingrid Kohl).

Figura 15 - Versão final do emissor GPS-GSM alimentado por bateria, usado no projeto desde 2014 (foto: Ingrid Kohl).



detected up to 50% farther than RT1 signals. Stronger signals resulted from slower signal frequency and a longer signal duration. Three transmitter signals types could be distinguished: rest, activity and inactivity (nesting, transmitter loss, mortality). The associated Lotek/Biotrack receiving unit better detected signals whereas Followit receivers were lighter and easier to handle.

Disadvantages included short detection range and battery life (RT1) and early tail feather moulting (RT1) which limited the location of post-release roosts, nest cavities and breeding areas. RT2 batteries lasted up to 1.5 yr and with the pelvis mount enabled more owl relocations. It was difficult to track owls in mountainous areas and with inactivity signals. In 2011, up to 21 young Ural Owls were relocated daily which took > 10 person hours per day. This generated high fossil fuel emission and fuel and time cost while driving about 50,000 km over 4 years by three research team members. Mountainous terrain often shielded signals precluding relocating marked owls, and owls often damaged antennae reducing detection distance.

Satellite (ST) Transmitters (Fig. 11)

Three light weight (20g) pelvis mounted North Star satellite transmitters with ARGOS data transmission and storage were used in 2012 and 2013. These units enabled the tracking of wide-ranging owls and assessment of reintroduction program with an automatic low-cost data collection system that saved the project staff time and money. A hand-held receiver could be used to search for signals.

Disadvantages included a high initial cost and large relocation inaccuracies (one in Atlantic Ocean). Small-scale owl movements in mountain valleys often resulted unsuitable signals. Batteries lasted up to 1.5 yr and provided signals for about 1 hr/day at a low rate (1 per min) and made obtaining relocations difficult and lengthy. All the aforementioned made it impossible to find nest cavities.

GPS-GSM Solar (GTS) Transmitters

Five GTS specially designed pelvis mount solar powered SULA and URAL units were developed by ECOTONE and DWA (Fig. 8, 12, 13, 14, 15, 16, 17) to incorporate Ural Owl natural history and plumage. The advantages and disadvantages below also apply to the one back-pack mount GTS used on an adult bird in 2014 (Fig. 13).

The GTS unit had two small solar panels that failed to charge its battery due to unfavorable weather, owls roosting by day in dark forests, and especially feathers obscuring solar panels. If GTSs had worked they could have provided reliable locations in the mountainous study area, enabled the tracking of wide-ranging owls and assessment of the reintroduction program, and the automatic low-cost data collection would have saved staff time and money. They were relatively light (27 g) and well suited for Ural Owls. The initial cost of these units was relatively high. Unfavorable GTS positions prevented GPS or GSM network reception and hence transmitter relocation. This resulted in much time spent searching for transmitters.

GPS-GSM Battery (GTB) Transmitters

GTBs were used since 2014 and are still in operation providing location data of released Ural Owls (Fig. 8, 14, 15, 16, 17). GTB weight was higher (31g) and only used on owls 750 g or heavier. For both the GTS and GTB units, position coordinates and temperatures were stored daily and transmitted every 4 days over the GSM net and downloaded. After downloading the data were processed, stored in a database and displayed on a DWA internal web map.

Advantages of these 31 g units included reliable automated telemetry signals in the mountainous study area. Tracking wide-ranging owls and assessment of reintroduction program was possible due to an operational battery life of 1.5 to 2 yr. The automatic low-cost data collection saved project staff time and money.

Figure 16 - Battery-powered GPS-GSM-transmitter attached to a Ural Owl (*Strix uralensis*) by the pelvis harness mount (photo: Christoph Leditznig).

Figura 16 - Emissor GPS-GSM alimentado por bateria, montado numa coruja dos Urales (*Strix uralensis*) através de arnês pélvico (foto: Christoph Leditznig).



Figure 17 - An active Ural Owl (*Strix uralensis*) natural tree cavity nest located by telemetry (photo: Christoph Leditznig).

Figura 17 - Ninho ativo de coruja dos Urales (*Strix uralensis*) numa cavidade natural localizado por telemetria (Foto: Christoph Leditznig).



Disadvantages included relatively heavier unit weight and high acquisition costs. More time was spent searching for transmitters when they were in an unfavorable position for network reception and they had infrequent (every 4 d) data transmissions. It was difficult to find nest sites in natural tree cavities as the units switched off when owls were breeding.

Mounting Systems

Central Tail Feather Mount

RT1s were mounted to the base of the two central tail feathers (Fig. 9). A sliced straw was slipped over the two central tail feathers and the tube, which was attached to the transmitter, was pulled over the feathers. After the straw was removed the transmitter was tied and glued to the feather bases. This attachment method is suitable when the weight of the transmitter is relatively low. There was no risk of bodily injuries such as harness abrasion or ingrowth and the transmitter was easily released when the tail feathers moulted. Other advantages included its relatively simple and fast mounting process (ca. 15 min/owl; see also Bowman & Aborn 2001). Disadvantages included occasional damage to the central tail feathers and early transmitter release due to premature moult of the supporting feathers.

Pelvis Harness Mount

RT2s, STs, GTSs and GTBs were attached to the lower back of the bird with two Teflon straps placed around the legs in the groin area (Fig. 7, 10, 11, 12, 16, 17; Rappole & Tipton 2009). This pelvis mount enabled the quick (10 min/owl) use of heavier transmitters with stronger transmitter signals and longer reception range. There was little plumage damage and less nutrition-related size variation in the pelvis region compared to the backpack mounting method. However, new plumage growth under the transmitter would not occur until after the transmitter detached. In one case an autopsy of a recovered owl revealed a healed skin abrasion caused by an overtightened leg loop but that the abrasion was not the cause of death.

Backpack Mount

One backpack mount transmitter (Fig. 13) was tested on a captive adult Ural because of the known risks such as injury or mortality due to fluctuations in pectoral muscle size and damage to new feather growth (Hirons et al. 1979, Morton et al. 2003, Robert et al. 2006, Bedrosian & Craighead 2007, Peniche et al. 2011, Michael et al. 2013). This attachment method can accommodate heavier radio transmitters with stronger transmitter signals and longer reception range. However, Ural Owl feathers covered the recharging panels of solar-powered transmitters (Äbischer pers. comm. 2011) and it took longer to attach the transmitter (>30 min/owl).

Predetermined breaking points

It is important to install a breaking point in the transmitter mount to release it at the end of the expected transmission period to free the owl unharmed and to retrieve the transmitter. For the pelvis harness mounts predetermined breaking points located at the junction of the teflon loop included cotton threads (Fig. 6), perbunan seal rings (Fig. 7) or metal staples (aluminium sleeves), depending on the expected transmitter life (Kohl & Leditznig 2017). Unfortunately there were no such mechanisms available for backpack mounts to avoid the risk of harness entanglement with the body or wings.

Pelvis (and backpack) mounting: Cotton threads

Sewing a cotton thread (Fig. 6) to the teflon harness was successfully used on Eagle Owls *Bubo bubo* in Switzerland (Äbischer et al. 2010, Äbischer pers. comm. 2011) however, Frey (pers. comm. 2017) reported that Bearded Vultures (*Gypaetus barbatus*) "greased" the threads which prevented the

dissolution of the threads beyond the desired release date. All but two cotton thread breaking points used in this project separated after about a year thereby prematurely releasing transmitters and precluded the location of most post release broods. One Ural Owl carried its transmitter half a year after its first breeding season, and another carried its transmitter for 3 years. We concluded that abiotic conditions, wing movements and the biting of threads resulted in premature separation and transmitter loss and that this method was not reliable.

Perbunan seal rings

Perbunan or rubber seal rings were used (Fig. 7, 8) on Bearded Vultures (Hegglin pers. comm. 2011, Néouze et al. 2016, Frey pers. comm. 2017). These rings are threaded through a tube on the transmitter and fatigue fractures form over time where they bend due to abiotic influences, such as temperature fluctuations. After the rubber breaks, the pelvis mounted transmitters become loose and fall off. However, to stay within acceptable transmitter unit weight limits only thin Perbunan rings could be used resulting in premature transmitter loss and limited location of post-release broods.

Rubber band

A rubber band predetermined breaking point inside the transmitter cover was developed by ECOTONE and WMA for the backpack transmitter (Fig. 13). In theory, the rubber band should enable flexibility to accommodate variation in breast muscle size over time, a break in the rubber band should release both rear Teflon straps simultaneously. However, backpack mounted transmitters were not used after one trial assessment with a captive Ural Owl.

Aluminium sleeves

A new breaking point system is being tested on five transmitters in consultation with ECOTONE that consists of an aluminum sleeve that holds the teflon straps together. It is unknown how long it will take for the teflon straps to abrade and release. Therefore, until the release times for this method are documented, two small perbunan seal rings are being used as breaking points for all other Ural Owl transmitter units.

Conclusions

In the first nine years of the project more than 13,500 locations of Ural Owls were registered by telemetry (Fig. 5, Table 1). The GTBs were the optimal telemetry system for assessing the Ural Owl reintroduction project and are still in operation and gathering position data (Kohl & Leditznig 2017). GTBs provided precise positions and automatically transmitted stored GPS and temperature data but were difficult to relocate as they did not send recovery-specific radio signals. Repeated same position signals and decreased temperature indicated transmitter recovery was needed. GTBs were also successful with Barn Owls (Brandt 1999) and Eagle Owls (Äbischer et al. 2010).

Transmitter and Mounting Methods Effects

Negative effects of transmitter or mounting methods are rarely reported which makes it difficult to learn from past studies. Telemetry should not affect animals (Kenward 1987). The low impact of tail mounted radio transmitters has made it popular, including in Eagle Owl and Ural Owl reintroduction programs (Frölich 1986, Schäffer 1990). Tail feathers are only temporarily damaged if the transmitters are sutured to them. However attachment of a transmitter to growing or recently grown tail feathers resulted in their premature moult (Leditznig 1999) and only light transmitters with a relatively short range can be used. Smaller solar-powered transmitters can now also be used (*e.g.* http://www.ecotone-telemetry.com/en) but transmission duration is limited by the tail feather moult cycle.

Backpack mounted radio transmitters have been used for decades (Exo 1987, Larsen et al. 1987, Nicholls & Fuller 1987, Exo 1988) but negative effects were not published. This mounting method is still common, especially for solar-powered and satellite-based transmitters (Herzog 2014, Meyburg et al. 2016, Néouze et al. 2016, Stickroth 2016, A. Gamauf pers. comm. 2014, N. Schönemann pers. comm. 2016). Consideration of breast musculature condition is particularly important when using backpack mounts to avoid damaging birds (Peniche et al. 2011, Robert et al. 2006, Michael et al. 2013, Bedrosian & Craighead 2007, Morton et al. 2003).

Peniche et al. (2011) examined 345 Red Kites *Milvus milvus* (1989 to 2009) as part of a reintroduction project using tail mounts (203 kites, 1989 to 2000) and backpack mounts (143 kites, 2000 to 2009). Since 2009, 180 dead kites have been autopsied. Four of 18 dead kites with backpack mounts carried the transmitters significantly longer than the others and were deemed to have died from harness related injuries such as lesions. There was no death among the birds who carried the transmitters for the average duration or for an under-average length of time. No injuries were found among tail-mounted Red Kites. It is likely that additional harness-related deaths occurred due to unrecorded recoveries of dead far-migrating kites.

Äbischer (pers. comm. 2011) did not detect any injuries on 40 young Eagle Owls with backpacks. All transmitters dropped off without problems using cotton thread predetermined breaking points. When contacted the telemetry company ECOTONE stated they lacked experience with owls and suitable predetermined breaking point mechanisms (Iliszko pers. comm. 2017). Such research and development is needed, especially with Bearded Vultures where backpack transmitters have been observed hanging down having failed to fall.

Pelvis mounts (leg-loop, hip-pack, Rappole mounting; Rappole et al. 2009) are relatively safer. Bowman & Aborn (2001) used backpack and pelvis mounts on Florida Scrub-Jays (*Aphelocoma coerulescens*) and concluded that only those with pelvis mounts did not significantly change their behavior. Pelvis mounts can be used successfully on small birds such as kingfishers (Kesler 2011) as well as on larger birds (Bearded Vulture, Néouze et al. 2016). Pelvis mount transmitters are located near a bird's centre of gravity, perhaps enabling birds to better accommodate the resulting added physical forces from the transmitter's weight.

All transmitter mounting methods should be monitored carefully and reported on. One Ural Owl in our study with a pelvis-mounted transmitter was found dead with a healed skin abrasion in the groin area due to the Teflon harness. While this abrasion did not cause the owl's death it presumably affected its behaviour.

Transmitter Weight

Special attention must be paid to ensuring that the 5% rule does not apply to every mounting method or bird species (Brander & Cochran 1969, Barron et al. 2010, Naef-Daenzer et al. 2005). While birds of prey and owls can carry heavier loads such as prey, this does not apply to all birds. Scherzinger (pers. comm. 2017) reported that in the Bavarian Forest grouse were tracked with 12 g transmitters, well below the 200 g or 5% maximum, taking into account a more realistic limit based on the species life history. It is also important to consider the nutritional status of birds. Annual weight fluctuations of 20% are possible suggesting the lowest weight be used to calculate acceptable transmitter weight. Bowman & Aborn (2001) showed that jays with backpack-transmitters that were only 2% of body mass traveled short distances on foot rather than un-marked birds flying the same route.

It is important to consider which transmitter model can be used depending on the maximum transmitter weight, the mounting option and the tracking objectives. More

options are available, in general, the larger the bird. The large Bearded Vulture can be equipped with a large satellite transmitter with multiple solar panels, a large battery and comprehensive data storage media. In addition, a VHS transmitter can be integrated into this transmitter enabling locating the transmitter manually over land after the transmitter drops or if the bird dies. For our study, the 31 g GPS-GSM-transmitter was the 5% weight limit for lower weight Ural Owls and only owls >700 g were used.

Position of Transmitter

The shape and position of the transmitter on the body of the bird must be streamlined to reduce drag to minimize impacts to flight (or swimming) and life-sustaining behaviors such as preening (reaching the oil gland), foraging, courtship, copulation, breeding or other essential movements or behaviors. The animal's welfare must come first, so the transmitter or harness must not harm the animal directly or indirectly, e.g. by tangling or causing injury.

Measuring Reintroduction Project Success

It is difficult to definitively measure success in reintroduction programs for small at-risk populations. Statistically robust conclusions require large sample sizes, such as those from England on Red Kites (Peniche et al. 2011). Smaller programs tend to provide inconclusive anecdotal evidence of success. The potential confounding effect of transmitters is another potential barrier to measuring outcomes (A. Gamauf, Honey Bussards, pers. comm. 2015, Meyburg et al. 2016, Thomson & Kaatz 2010). A multi-year study on Prairie Falcons (*Falco mexicanus*) (Steenhof et al. 2006) with backpack transmitters could not documented short-term effects of transmitters on breeding success and behavior could but the survival rate for birds with transmitters was lower than that for birds without transmitters (49% vs. 87%) over the same period. Bowman & Aborn (2001) showed that Florida Scrub-Jays (*Aphelocoma coerulescens*) with backpack transmitters flew less, were busier and were more susceptible to predators. In contrast, the telemetry of White Storks (*Ciconia ciconia*) in Switzerland is carried out successfully (http://www.storch-schweiz.ch/361.html). Studies using pelvis mounted transmitters (Mong 2005, Kesler 2011, Mallory et al. 2008, Hegglin pers. comm. 2011) or tail feather mounts (Leditznig 1999) indicate that these methods did not negatively affect breeding success. Twenty-three of 107 released Ural Owl with transmitters were found dead but transmitters were not found to be the cause of death.

If, after careful consideration, researchers decide that the use of telemetry is necessary then further consideration of the type, transmission duration, and predetermined breaking points are important relative to the welfare of the birds involved. It is imperative that an examination of the potential role of the transmitter and mounting system in the death of marked birds be conducted and published. Promoting awareness that a telemetry project is underway is important, especially for the reintroduction of extirpated or endangered species, as this may inhibit illegal poaching or poisoning of birds of prey including larger owls.

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Use of telemetry for guiding the reintroduction of Ural Owls (*Strix uralensis*) in Austria

Uso de telemetria para guiar a reintrodução de coruja dos Urales (*Strix uralensis*) na Áustria

Ingrid Kohl[1*], Christoph Leditznig[2], Franz Aigner[2], Theresa Walter[3], Richard Zink[3]

1 REWILD Institute – Research on Ecosystems and Wilderness, A-1130 Vienna, AUSTRIA

2 Dürrenstein Wilderness Area Administration, Brandstatt 61, A-3270 Scheibbs, AUSTRIA

3 Research Institute of Wildlife Ecology (FIWI), Savoyenstraße 1a, A-1160 Wien, AUSTRIA

*** Corresponding author:** office@rewild.institute



ABSTRACT

In the first half of the 20th century the Ural Owl *Strix uralensis* became extirpated from Austria. From 2008, the Research Institute of Wildlife Ecology (FIWI) and the Dürrenstein Wilderness Area Administration (WGD) began reintroducing the owls to Austria's woodlands. Between 2009 and 2018, 142 young Ural Owls were released into the Dürrenstein Wilderness Area. Telemetry was used to monitor success, improve reintroduction strategies and to expand the nest box network in the region. A total of 107 young owls were tracked, and the ideal age for release was determined (i.e., young at 90 days old). We found survival rates of about 75% in the first year after release, and recorded various causes of death (e.g., predation, starvation, endoparasites, etc.). As of 2018, 15 owl territories were identified, and of these, 10 were confirmed to have breeding activities. From 2012-2018, a total of 29 nests with 53 hatched chicks were found in the Wilderness Area region. Young owls routinely dispersed, with movements

of 150 km recorded, providing proof of connections between the Wilderness Area and adjacent populations. Telemetry also informed about Ural Owls' biology including habitat selection, territory sizes, foraging preferences, and dependence on beech mast and small mammal cycles. Transmitters of five models employing three telemetry systems were used; GPS-GSM-telemetry has replaced the other telemetry systems because of its comparatively low cost, high accuracy, automatic storage of GPS-data and transfer via the GSM net. Telemetry will continue to be used in the reintroduction project to collect valuable data and guide success.

Keywords: Austria, dispersal, reintroduction, telemetry, *Strix uralensis*

RESUMO

Na primeira metade do século XX, a coruja dos Urales (*Strix uralensis*) extinguiu-se na Áustria. A partir de 2008, o *Research Institute of Wildlife Ecology* (FIWI) e a administração da Área Silvestre de Dürrenstein (WGD) iniciaram a introdução de corujas nas florestas austríacas. Entre 2009 e 2018, 142 corujas dos Urales juvenis foram libertadas na Área Silvestre de Dürrenstein. Através da telemetria, foi monitorizado o sucesso do programa de reintrodução, foram melhoradas as respetivas estratégias e foi expandida a rede de caixas-ninho na região. No total, 107 corujas juvenis foram seguidas, tendo sido determinada a idade ideal para a sua libertação (i.e. 90 dias de idade). A taxa de sobrevivência foi de ca. de 75% no primeiro ano após a libertação, tendo sido registadas várias causas de mortalidade (e.g., predação, fome, endoparasitas, etc.). A partir de 2018, foram identificados 15 territórios, tendo-se registado atividade reprodutiva em 10 destes territórios. No período 2012-2018, foram encontrados no total 29 ninhos com 53 juvenis eclodidos na região da Área Silvestre. No geral, as corujas juvenis dispersaram, tendo registado movimentos até 150 km, confirmando assim a ligação entre as populações da Área Silvestre e de áreas adjacentes. A telemetria permitiu ainda conhecer melhor a biologia da coruja dos Urales, incluindo seleção de habitat, dimensão dos territórios, preferências de alimentação e dependência dos ciclos de produção de sementes das faias e dos ciclos de micromamíferos. Foram usados cinco modelos de emissores e três sistemas de telemetria; a telemetria GPS-GSM substituiu outros sistemas de telemetria devido ao menor custo, maior precisão, armazenamento automático de dados de GPS e transferência através da rede GSM. A telemetria vai continuar a ser usada no projeto de reintrodução para recolha de dados e ajudar a melhorar o sucesso do mesmo.

Palavras-chave: Áustria, dispersão, reintrodução, telemetria, *Strix uralensis*

Introduction

Reintroducing Ural Owls to Austria

The Ural Owl *Strix uralensis* became extirpated as a breeding bird in Austria in the first half of the 20th century due to direct poaching and loss of massive trees with big cavities for breeding (Bauer 1997; Glutz & Bauer 1994; Sterry et al. 2000). Reintroduction projects are ambitious efforts with important requirements, including a monitoring component to provide information about the progress of the project and allow for adaptive management during project implementation. Early efforts of reintroducing the owl back into Austria failed (Engleder 2007). Along with the IUCN Guidelines for Reintroduction (1998), development of a Ural Owl reintroduction program was made. The program included clarification of genetic aspects (Kühn 2009), an action plan for the Ural Owl in Austria (Zink & Probst 2009), and a habitat evaluation for the Dürrenstein Wilderness Area region (Steiner 2007). The region was considered as suitable given the known habitat requirements of the Ural Owl (Bauer & Berthold 1997, Stürzer 1998, Mebs & Scherzinger 2008, Steiner 1999, Steiner 2001, Steiner 2007).

In 2008, our reintroduction project began, as a collaboration between the Dürrenstein Wilderness Area Administration and the Research Institute of Wildlife Ecology (FIWI) of the Veterinary University of Vienna. The reintroduction method was based on international experiences and results of efforts in the Bavarian Forest and Bohemian Forest national parks (Scherzinger 1987, Scherzinger 2006, Scherzinger 2007, Müller 2007). The goals of the reintroduction project were to establish a Ural Owl population in Austria, and to build population 'stepping stones' to reconnect the owls in the Bavarian Forest and the Bohemian Forest (Czech Republic) where in the last 40 years reintroductions were carried out, as well as Slovenia (Pietiäinen & Saurola 1997, Prešern & Kohek 2001, Scherzinger 1987, Scherzinger 2006, Scherzinger 2007, Svetličič & Kladnik 2001, Vrezec 2000a, Vrezec & Kohek 2002, Vrezec & Tutis 2003, Vrezec 2006, Mebs & Scherzinger 2008). Two release areas were established in the Wienerwald Biosphere Reserve in the surroundings of Vienna and in the Dürrenstein Wilderness Area in southwestern Austria.

Scherzinger (pers. comm. 2009) identified the following requirements for the success of the reintroduction project: breeding in captivity, natural rearing of the young owls, reaching fertility, species-specific habitat, species-specific behavior (habitat selection, foraging behavior, dispersion movements), display behavior, nesting, oviposition, breeding, brood care, social behavior, establishment of a viable population, age structure of the population, connection to the neighboring populations, integration into the wild population and species-specific polymorphism. In the Wilderness Area, the following monitoring tools were undertaken to fulfill the requirements of a comprehensive monitoring program: telemetry (radio-telemetry, satellite telemetry and GPS-GSM-telemetry), automated data collection receivers at the feeding table or in an owl territory, photo traps, light barrier cameras, recording owl display behaviors, direct observations, nest box checks, and the ringing and genetic analyses of released birds and owls hatched in the wild.

Telemetry is one of the best tools for evaluating reintroduction projects (Frölich 1986, Kenward 1987, Klaus et al. 2009, Kohl & Leditznig 2012, Leditznig 1999, Leditznig et al. 2007, Leditznig & Langer 2017, Nicholls & Fuller 1987, Schäffer 1990, Unsöld & Fritz 2014). Out of 142 released Ural Owls, transmitters were attached to 107 young owls. In the first few months after release, juvenile owls often made remarkable movements in the area around the Wilderness Area, affirm-

Figure 1- Dürrenstein Wilderness Area – IUCN category Ia (Strict Nature Reserve) and Ib (Wilderness Area) and UNESCO World Heritage Site, view to the Dürrenstein Mountain, 1893 m a.s.l. (photo: Ingrid Kohl).

Figura 1 - Área Silvestre de Dürrenstein – categoria Ia (Reserva Natural Estrita) e Ib (Área Silvestre) da IUCN e Sítio Património Mundial da UNESCO, vista para a montanha de Dürrenstein, 1.893 m (foto: Ingrid Kohl).



ing that a well-functioning tracking system was required. Telemetry enabled the determination of survival rates, dispersal timing and distances, habitat analyses, territory analyses, enabled the finding of nests in natural tree holes, and confirmed that owls were traveling between the two release areas and the broader regional populations. Based on the locations/territories of the owls, a network of nest boxes was established. The use of nest boxes pursued two main goals: a) compensate for the lack of natural breeding cavities, and b) provided a means of more readily monitoring the nesting success of the owls.

The focus of this paper is on how telemetry data has generated critical monitoring data and ecological insights that continue to enhance the reintroduction of Ural Owls in Austria.

METHODS

The Dürrenstein Wilderness Area (3,500 ha; 600 - 1,878 m a.s.l.; Fig. 1) including the Primeval Forest Rothwald (400 ha; Fig. 2) offers ideal owl habitat with an incomparably high abundance of deadwood and tree cavities. The Dürrenstein Wilderness Area is an IUCN Category Ia Strict Nature Reserve, Ib Wilderness Area and UNESCO World Heritage Site. Stand-forming tree species are Norway Spruce (*Picea abies*), European Silver Fir (*Abies alba*) and European Beech (*Fagus sylvatica*). Also the European Larch (*Larix decidua*) and the Sycamore Maple (*Acer pseudoplatanus*) play an important role. In particular, the Sycamore Maple and the Norway Spruce form cavities used by owls and other wildlife. The Wilderness Area includes

Figure 2 - Primeval Forest Rothwald (photo: Hans Glader).

Figura 2 - Floresta Virgem de Rothwald (foto: Hans Glader).



Figure 3 - One of two aviaries for release in the Dürrenstein Wilderness Area (photo: Christoph Leditznig).

Figura 3 - Um dos dois aviários para libertação na Área Silvestre de Dürrenstein (foto: Christoph Leditznig).



Figure 4 - Young Ural Owl on the feeding table (photo: Christoph Leditznig).

Figura 4 - Juvenil de coruja dos Urales na mesa de alimentação (foto: Christoph Leditznig).



important habitat for some owl species (e.g., Boreal Owl *Aegolius funereus*) as well as for woodpecker species (e.g., White-backed Woodpecker *Dendrocopos leucotos*). Geologically it is part of the Northern Limestone Alps with an annual precipitation of 1,700 to 2,400 mm. The topography is steep and mountainous.

In the years 2009 to 2017, 142 young Ural Owls were soft-released in the vicinity of the Dürrenstein Wilderness Area. The young owls were from the breeding network (led by R. Zink, FIWI), and brought to the Wilderness Area from owl and raptor stations, zoos and private breeders. In 2009 a release aviary was used in the Wilderness Area (Fig. 3), and a second breeding and release aviary in the vicinity of the Wilderness Area was added in 2010, managed by team member Franz Aigner. The two release aviaries were located at altitudes of 785 and 725 m a.s.l. Once at one of the two release aviaries, the young owls spent a few weeks adapting to the climate and the soundscape of the area before release; in most cases the young owls spent their last weeks with adult owls in order to be able to learn from their behaviors. Young owls were released at the age of about 90 days (the majority reach a suitable age for release around July). In the first weeks after their release, food (rats and poultry chicks) were offered to them on six 'feeding tables' (Fig. 4) until they learned to hunt independently.

Nest boxes offer additional support for cavity breeders, especially for the Ural Owl which requires big cavities for breeding (Englmaier 2007). Nest boxes made out of larch wood, of a size of 40 x 40 x 60 cm, with a hole of 15 x 20 cm, mounted at a height of 5 m, normally mounted at elevations below 1,000 m a.s.l., were offered for the reintroduced Ural Owls (Fig. 5). As of 2017, 101 nest boxes have been mounted in the Dürrenstein Wilderness Area region.

Figure 5 - Nest box of larch wood, 40 x 40 x 60 cm, 25 kg, at a height of about 5 m (photo: Christoph Leditznig).

Figura 5 - Caixa-ninho em madeira de pinheiro-negro, com 40 x 40 x 60 cm e 25 kg, a uma altura de cerca de 5 m (foto: Christoph Leditznig).



Different monitoring tools were implemented to survey the success of the project: telemetry, camera traps, light barriers in combination with cameras, monitoring of nest boxes, ringing, genetics, call surveys and direct sightings. During the breeding season all nest boxes, often in steep terrain with snow cover, are visited with a telescope stick and a camera (photo camera or video camera) for monitoring the breeding status of the Ural Owls. The genetic analyses was carried out by the Research Institute of Wildlife Ecology (FIWI).

Five different transmitter designs using three different telemetry systems were used in this project: VHF radio-telemetry, satellite telemetry, and GPS-GSM telemetry. The majority (n=92) of transmitters were attached to the owls with the pelvis harness (leg-loop) method. In the first nine years of the project more than 13,500 daily owl positions were registered by means of telemetry. Battery-powered GPS-GSM transmitters proved to be the best fit for our project. Details on the transmitters and telemetry systems used are described in a companion paper in this volume (see: Kohl et al. 2020).

Results

Survival rates and Mortality

With the use of telemetry it was possible to improve our reintroduction strategies over time. The age of the young owls at the time of release had a significant effect on their first-year survival rates. From 2009-2017, all owl releases occurred between 15 June and 6 September. Particularly dramatic were the consequences of the first releases in 2009. Young owls were mostly released in the second half of August, at the age of more than

Figure 6 - Ural Owl female with GPS-GSM-transmitter at the first brood in a natural tree cavity that was first found in 2014 (photo: Christoph Leditznig).

Figura 6 - Fêmea de coruja dos Urales com emissor GPS-GSM com a sua primeira ninhada, numa cavidade natural encontrada pela primeira vez em 2014 (foto: Christoph Leditznig).



120 days. As a result, no owls visited the feeding table and a mortality rate of 67% (6 of 9 birds) was recorded. Additionally, making the survival situation even more difficult that year, was that the small rodent population was at a minimum. The release strategy was changed in the following years and survival rates from 2010 and after increased significantly (Leditznig & Kohl 2013, Leditznig 2013). Releases of owls that were 90 days of age (depending on the hatching date, between mid-June and end of July), resulted in over-winter survival rates of about 78%. With an age of significantly more than 100 days at release, this value decreased to about 33% (Leditznig & Kohl 2013, Leditznig 2013). The perished birds died on average 43.3 days after release; two-thirds died during the first 50 days after release and the remaining third died within the next 50 days. Of the 19 owls that did not survive, mortality was determined to be: predation (25%), starvation (25%), endoparasites (25%), road kill (10%), electrocution (5%), heart defect (5%) and one unidentified case due to the late finding (5%). Young Ural Owls were predated by the Eurasian Eagle-owl (*Bubo bubo*), Golden Eagle (*Aquila chrysaetos*), Northern Goshawk (*Accipiter gentilis*) and Pine Marten (*Martes martes*).

Table 1 - Number and success of Ural Owl nests, 2010 to 2018.

Tabela 1 - Número de ninhos e sucesso reprodutor da coruja dos Urales de 2010 a 2018.

YEAR	TOTAL OWL NESTS	SUCCESSFUL NESTS (YOUNG TO FLEDGING)	FAILED NESTS (FAILED AT EGG OR YOUNG STAGE)
2010	0	0	0
2011	0	0	0
2012	2	2	0
2013	1	0	1
2014	4	3	1
2015	8	5	3
2016	7	7	0
2017	10	7	3
2018	0	0	0
Total	29	21	8

Breeding success

Successful nesting by owls began in 2012, and breeding success has been monitored since (Table 1) (Steiner 2007; Zink & Probst 2009; Böhm & Zink 2010; Leditznig & Kohl 2013). In 2011 the first pair of Ural Owls was found in the vicinity of the Wilderness Area. In 2012, the first two successful nests with a total of 11 eggs and 8 hatchlings were observed. One of the two breeding pairs that was first found in 2012 consisted of a one-year old male released in the Wilderness Area and a two-year old female released in the Wienerwald Biosphere Reserve. The finding of their nest confirmed the connection between the two release areas. In 2013, one Ural Owl nest was found, the egg was subsequently abandoned; one Tawny Owl nest was found, and its egg was also abandoned.

In 2014, a total of four nests were confirmed, including two in larch nest boxes. Two nests in 2014 were a special feature - for the first time in the history of the Austrian Ural Owl reintroduction, successful nests in natural tree cavities were confirmed (Figs. 6, 7). Remarkable was the timing of the nests. While two pairs started nesting in the first half of March, the two other pairs did not start to breed until the end of April, after heavy snowfalls in the first half of April. Both nests were found via females equipped with GPS-GSM transmitters, and each were in natural beech cavities. One of the natural cavity nests was about 10 km from the release area and it fledged four young. The second natural tree cavity was found in the vicinity of the Wilderness Area and fledged one young (before it could be ringed). The female at this latter site was a one-year-old female.

With GPS-GSM telemetry, we confirmed eight successful nests in 2015. Three of the eight nests were found in the eastern part of the Wilderness Area. Four of the successful nests had a total of 10 surviving juveniles. The pair with the last confirmed brood in

Figure 7 - Four young fledged from this tree cavity. Only through the use of telemetry it was possible to find Ural Owl broods in natural tree cavities (photo: Christoph Leditznig).

Figura 7 - Quatro juvenis foram criados com sucesso nesta cavidade natural. Apenas foi possível encontrar ninhadas de coruja dos Urales em cavidades naturais através do uso da telemetria (foto: Christoph Leditznig).

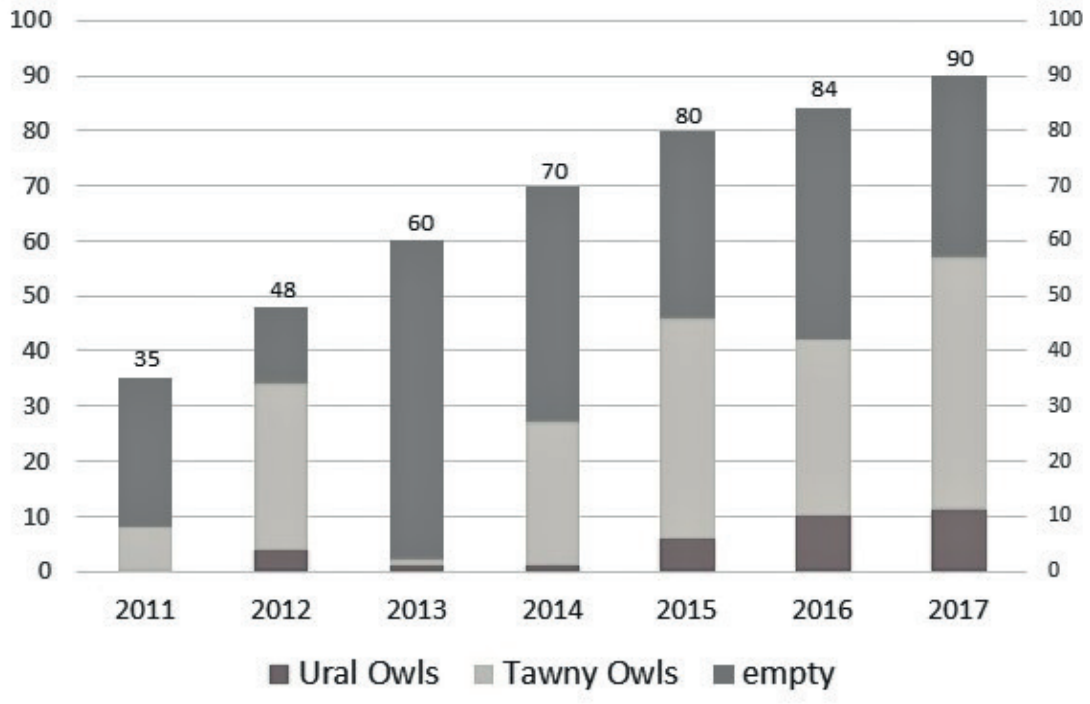


2014 started breeding about 27 April 2015. The female owl left the release area on the 25 September 2014 and moved to the south-east edge of the Kalkalpen National Park. The bird stayed there until 9 March 2015. Then she moved to Maria Seesal where she stayed one day before returning to Kalkalpen National Park on the 17 March. She left the Park on the 10 April to arrive in the final breeding area on 12 April (the linear distance between the Kalkalpen National Park and the breeding area was about 40 km). The start of breeding was about 2 weeks after her arrival. These valuable findings were only possible through the use of telemetry.

During the breeding seasons of 2016 and 2017, the total numbers of successful nests were seven and 10, respectively. Breeding success is highly dependent on the small rodent population. Peaks in small rodent numbers were 2012 and 2017, however, breeding success in 2017 was reduced by heavy snowfalls of up to 2 m of snow within 12 hr in late April.

Figure 8 - Results of the nest box occupancy checks between 2011 and 2017.

Figura 8 - Resultados da monitorização das caixas-ninho entre 2011 e 2017.



As of 2017, 15 owl territories were identified, and of these, 10 were confirmed to have breeding activities. Thus, from 2012-2017, a total of 29 nests with 53 hatched chicks were found in the Wilderness Area region.

In 2018, due to very low small mammal numbers, no Ural Owl nests were recorded.

Foraging preferences

Observations of breeding success during the last decade showed that successful nests are highly dependent on small rodent populations, especially the Bank Vole and the Yellow-necked Mouse. In peak small rodent years, one-year-old Ural Owls have had successful nests with up to six eggs, and up to 5 fledged young. In years with late snowfalls in April, Ural Owls started their nests either before or after the period with snow but not a single pair within the snow period. In years with very low small rodent populations (e.g., 2013, 2018) owls did not successfully breed. In such years adult Ural Owls become food generalists, feeding on Common Frog (*Rana temporaria*), Common Toad (*Bufo bufo*), insects, shrews (*Soricidae*) and birds (e.g., Eurasian Jay *Garrulus glandarius*). Within the last decade one case was observed of a female Ural Owl feeding on a Tawny Owl.

In the Wilderness Area beech masts take place about every 4-5 years resulting in small rodent population peaks (i.e., 2004, 2008, 2012 and 2017). The first two successful Ural Owl nests found in 2012 in the vicinity of the Wilderness Area benefitted from peaking populations of small rodents due to a beech mast in late 2011 and early 2012. During

2012, we were able to assess prey delivery rates and prey species analyses at breeding sites with a light barrier camera (Kohl & Leditznig 2012, Leditznig & Kohl 2013). An 8-day analysis with the camera at one of the two nests (5 eggs, 3 young owls fledged) reflected this situation: out of 123 recorded prey animals from one breeding pair, 100% were small mammals. Species or genus could be determined for 112 of the prey: 79 Bank Voles (*Myodes glareolus*; 70.5%), 29 individuals of *Apodemus* species – mainly Yellow-necked Mouse (*Apodemus flavicollis*) or Wood Mouse (*Apodemus sylvaticus*; 25.9%), and 4 individuals of *Microtus* species (3.6%); the other 10% (n = 11) of the prey mammals could not be determined. On average, 15.4 prey mammals were brought to the nest per day. Compared to the Tawny Owl that is mostly active at night (Melde 2004), Ural Owls also feed the nestlings regularly at daylight (Leditznig & Kohl 2013, Leditznig 2013). Since 2002, a small mammal monitoring has been carried out in the Dürrenstein Wilderness Area by the Institute of Wildlife Biology and Game Management of the University of Natural Resources and Life Sciences in Vienna (Kempter & Nopp-Mayr 2013) providing valuable data for the owl projects.

Movement routes

The dispersal of young Ural Owls varied over the years. There may be some correlation to availability of prey during small mammal cycles. In 2010, several released young started to disperse. With a radio-telemetry and search scheme initially focused within a 50 km radius of the release areas, we were able to relocate four of the owls. Two owls left the Wilderness Area region and were found within 20 days (in early- and mid-October) more than 100 km away from the release area (the two owls were released from two different release aviaries) in Upper Austria in the Traun valley. The two owls moved to Upper Austria on two different movement routes and found each other more than 100 km away to spend about six months in the same area until both dropped their telemetry transmitters in March and June 2011. In early 2012 when prey availability was very high, no spring dispersal occurred. In early 2013 there were at least three owls that started to disperse, after being relatively stationary during the winter. The furthest confirmed dispersal movement routes of young released Ural Owls so far were 150 km to the north (Sumava Forest, Czech Republic), 100 km to the west-northwest (Traun valley, Upper Austria), 80 km to the east (Schneeberg Mountain, Lower Austria) and 60 km to the southwest (Gesäuse National Park, Styria, and Kalkalpen National Park, Upper Austria) (Fig. 8). Importantly for the reintroduction program, the dispersal of owls to Lower Austria, and the Sumava Forest in the Czech Republic confirm the connectivity of owls to these areas of Ural Owl distribution.

Habitat selection

In the Lower Austrian Limestone Alps the preferred forest type of the Ural Owl are spruce-fir-beech-forests with different mixture proportions. The average size of breeding territories was 2.6 km², and the average size of territories of single birds 6.9 km², and the home range size was 4.2 – 9.8 km² (average 5.9 km²). Detailed analyses showed that the owls preferred territories with an exposure of southwest to southeast. Analyses showed that for the Ural Owl the description "forest owl" is justified. Around 75% of the habitat was covered by forest, 20% covered by open landscape such as meadows and temporarily unstocked area in the forest, and only 5% was covered by anthropogenic infrastructure. In each territory water bodies of different sizes were present. The Ural Owl does not prefer a special forest type but selects its territory based on the availability of small mammal prey, large, old cavity-bearing trees, often

Figure 9 - Overview of selected movements of Ural Owls from and to the Wilderness Area region between 2010 and 2017.

Figura 9 - Vista geral dos movimentos de corujas dos Urales de e para a região da Área Silvestre, entre 2010 e 2017.

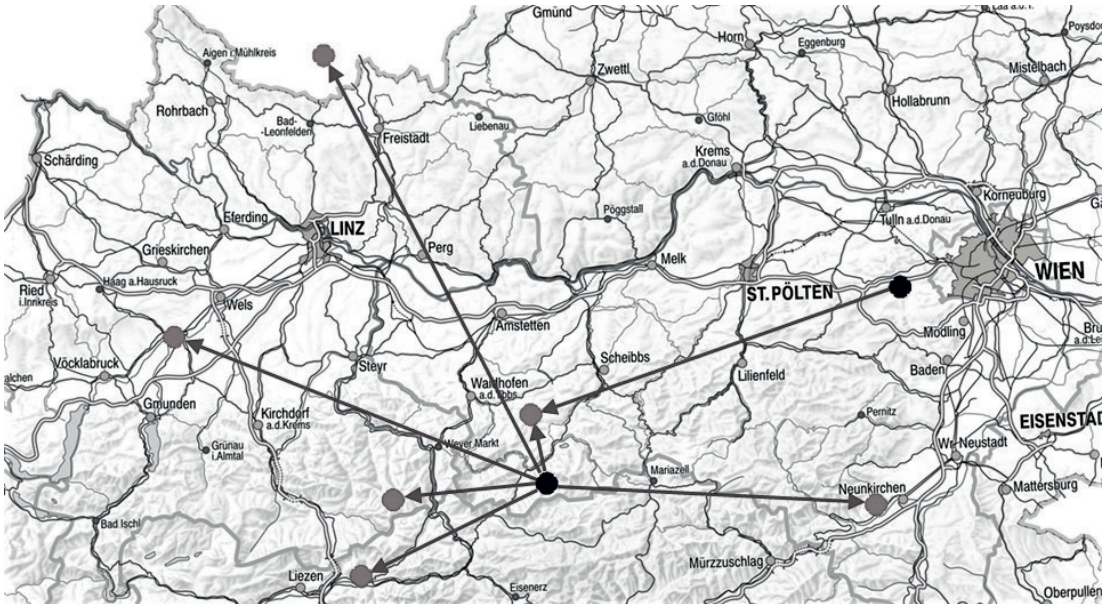
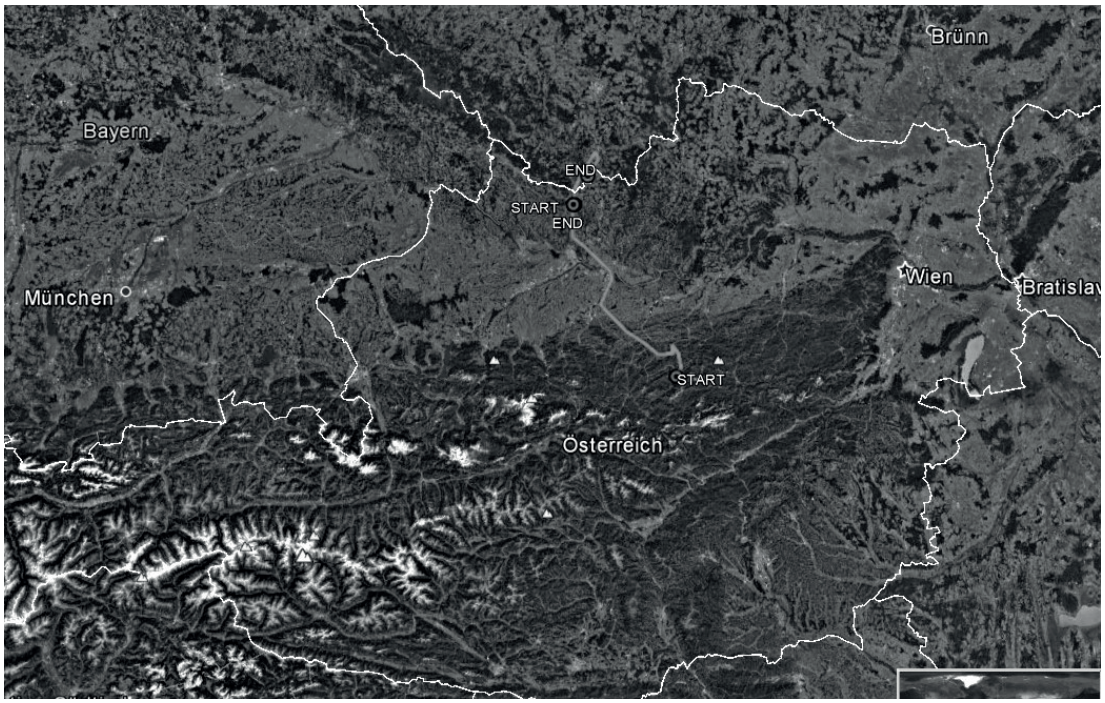


Figure 10 - Position of the 150 km movement route of a young Ural Owl released in July 2017 in the Dürrenstein Wilderness Area (Austria), migrating in August 2017 and reaching the Bohemian Forest (Czech Republic) in early September 2017.

Figura 10 - Rota de dispersão de 150 km de um juvenil de coruja dos Urales libertado em julho de 2017 na Área Silvestre de Dürrenstein (Áustria), migrando em agosto de 2017 e atingindo a Floresta da Boémia (República Checa) no início de setembro de 2017.



with dead tree trunks. More than 80% of the daily owl positions were located at elevations between 600 and 1,000 m, but only 50% of the study area was located in that range. Evergreen conifers are especially preferred during the inactive/resting daytime period.

DISCUSSION

With its central location between the Bavarian Forest, Sumava Forest and Slovenia, the Austrian study area was considered as an ideal stepping stone between existing populations of the Ural Owl. Scherzinger (1985 and 1996) describes the Ural Owl with its size and requirements for large tree cavities as a "primeval forest species", conditions that we confirmed with our decade of work in Austria.

Owl telemetry implies certain challenges due to the nocturnal activity of most owl species and the volume of their plumage. Within the last decade the Dürrenstein Wilderness Area Administration together with monitoring equipment companies developed different transmitter designs to find the ideal telemetry system for the telemetry of Ural Owls (Kohl & Leditznig 2017). The GPS-GSM-telemetry system and a battery-powered GPS-GSM-transmitter with temperature sensor, a hard cover and an internal antenna as protection against the owls' strong beak became our system of choice. The GPS-GSM-telemetry has replaced the other telemetry systems and transmitter models because of comparatively low costs, high accuracy, automatic storage of GPS-data and the automated transfer via the GSM net (Kohl & Leditznig 2017).

We established that the ideal age for the release of young Ural Owls was an age of about 90 days. The owls must be old enough to have a sufficient escape reflex and be able to fly accordingly. However, at the release they must not be so old that the intraspecific aggression potential and dispersal behavior are developed so far that the young owls no longer visit the feeding tables and avoid intraspecific social contacts (Scherzinger 2006). When older than 100 days - the owls start to be independent (Mebs & Scherzinger 2008) – they start to disperse, do not visit the offered feeding tables and immediately start hunting independently. While some birds may well be able to survive without a feeding table immediately after release, the majority of the young owls are dependent on the feeding tables as long as they learn to hunt independently. A few of some young owls that did not visit the feeding tables died of starvation or disease.

Survival rates of young in the wild are significantly lower during their first year of life than subsequent years. Rates can be around 60% and still fall significantly if there is a lack of prey (Mebs & Scherzinger 2008). In the first years of radio-telemetry 66 of 70 released owls were tracked daily. Twenty perished owls were found in the first years of the project (Kohl & Leditznig 2013), almost all owls that died were found during the first phase after release or in the first few weeks of independence before the beginning of winter. Nineteen mortalities (95%) were due to natural causes (predation, starvation, endoparasites, disease) and one case (5%) was anthropogenically caused by electrocution at a transformer during the dispersal phase). Between 2010 and 2013, the average survival rate was 79%. In later years with the GPS-GSM-telemetry also two cases of road kill were found. Mihok & Frey (2013) describe that the predation by the Golden Eagle (*Aquila chrysaetos*) seems to play an essential role. This also applies to the northern Limestone Alps. For example in the first years of radio-telemetry, two of the six young owls that were predated, were predated by the Golden Eagle (2 of 19 = 11% of natural losses). Two owls were predated by the Pine Marten, one owl by the Eurasian Goshawk and one owl by the Eurasian Eagle-owl. The Eurasian Eagle-owl seems to be one of the most important predators of Ural Owls in addition to the Golden Eagle. The location

of the aviaries was therefore chosen to be as far as possible from known Eurasian Eagle-owl territories (Leditznig 1999, Leditznig & Leditznig 2006).

Breeding success of owls varies significantly with the small mammal populations regulated by the beech mast. Two extreme years were 2012 with a small mammal peak and very successful owl reproduction, and 2013 with a significant small mammal population decrease and no successful owl brood within the whole nest box network. While 2012 was a small mammal peak year, small rodent populations in the Dürrenstein Wilderness Area have been subject to a 4 to 5 year cycle, with population declines in 2009, 2010, and 2013 (Kempter & Nopp-Mayr 2013). The Ural Owl population in Finland runs synchronously with the 3-4 year cycles of voles (Pietiäinen & Saurola 1997, Brommer et al. 1998, Saurola 2003).

In 2012, when small mammal populations peaked, three of four breeding Ural Owls were one year old and one breeding bird was two years old. These results were surprising, as studies in Finland have established that Ural Owls there did not start to breed until an age of three to four years (Saurola 1992, Saurola 1997).

Nest boxes were a useful tool for our reintroduction efforts, even in areas relatively rich in cavity-bearing trees. Other species found nesting in our nest boxes included the Tawny Owl (*Strix aluco*), Stock Dove (*Columba oenas*), European Pied Flycatcher (*Ficedula hypoleuca*) and Eurasian Nuthatch (*Sitta europaea*). In Finland, where forestry actions have severely limited natural nest cavities, nest boxes have increased the nesting population of Ural Owls.

Like researchers in other regions, we also found that female Ural Owls tend to vigorously defend their offspring, especially during nest inspections. The females tend to attack people if they approach the nest too closely. Appropriate protection is essential for these visits, especially when ringing the chicks. Important for the protection of the owl as well as the ringer are a padded jacket and a helmet with a corresponding face shield for protection of the ringers' eyes. The padded jacket softens the attack of the adult bird and should prevent the female from being injured. In Finland, a pad is added to the top/back of the helmet for the safety of the owls' feet. There are significant individual differences in the behavior of the Ural Owls. While many females attack unflinchingly, others clearly hold back and make warning calls from neighboring trees. Ural Owl males hardly tend to attack, but usually show their presence by territory calls or warning calls (Leditznig & Kohl 2013, Leditznig 2013).

The food of Ural Owls in our study was very similar to that found in other regions. Vrezec (2001) describes the food composition of winter food in Slovenia by pellet analyses, regarding to the numbers of prey items, of 94% mammals, 2.7% insects, 1.6% birds and 1.6% amphibians. In contrast to the winter food, dormice are the main prey for the Ural Owl in Slovenia in summer time. Due to the dormouse population it is assumed that the females delay the oviposition (1 April to 11 June) in anticipation of a better prey situation ("waiting strategy hypothesis"). Hatchlings can be found until the beginning of July and fledglings until August (Vrezec & Kohek 2002). The autumn food in Slovenia, regarding to the number of prey items, consists of 59% dormice, 36% mice and 6% insects (Vrezec 2000b). Through radio-telemetry we could observe hunting behavior. Search flights were seen, but we mainly observed owls hunting while sitting on a tree and scanning the ground. For this kind of hunting, owls mostly used trees but also also used posts along the main road (Leditznig & Kohl 2013).

In the Dürrenstein Wilderness Area region we found Ural Owl home range sizes of 1.0-2.4 (average 1.7) pairs per 10 km². In Slovenia, a density of 2.2 pairs per 10 km² (4.5 km² per breeding pair) was reported (Vrezec 2000a, Prešern & Kohek 2001). Prešern & Kohek (2001) describe Ural Owl density of

2 to 5 pairs per 10 km². Pietiäinen & Saurola (1997) describe a density of 0.8 to 1.0 breeding pairs per 10 km² for Finland. In Sweden, Finland and Russia densities of 0.6 to 2.4 breeding pairs per 10 km² are found; in Poland 3 breeding pairs per 10 km².

In our Austrian study, more than 80% of the daily owl positions of Ural Owls were located at elevations between 600 and 1,000 m a.s.l. Mihelič et al. (2000) describes the elevational range of owls in Slovenia from 150 to 1,600 m a.s.l; the highest occurrence was 1,796 m. The distribution of owls in Slovenia is described as 700 to 1,100 m a.s.l., or an average of 850 m; during the breeding season, the majority of Ural Owls occur at elevations of 800 to 990 m a.s.l. (Prešern & Kohek 2001, Svetličič & Kladnik 2001, Mihelič et al. 2000). The distribution is more dependent on the habitat and the succession of forests where the percentage of old trees is high.

In the Dürrenstein Wilderness Area and the Primeval Forest Rothwald the abundance of tree stumps, hollow trees and tree cavities is incomparably higher than in commercial forests. Of preeminent importance for maintaining a vital, well-distributed owl population is the maintenance of natural breeding sites - cavities in large, old, dead or partially-dead trees. The larger goal must be in managing large, old forest conditions that provide the long-term nest site solution for the owls and other wildlife. Within this framework, the use of nest boxes should be considered only a transitional solution (Englmaier 2007, Lundberg & Westman 1984, Lohmus 2003, Scherzinger & Zink 2010, Lambrechts et al. 2012).

After the first successes of the project and the establishment of a basis for a future population of Ural Owls, it will be important (according to the criteria of W. Scherzinger), to take further steps towards a sustainable age distribution among the population, to connect the reintroduced animals to the "wild" population and to enhance the polymorphism that is typical for the species. It is planned to continue the reintroduction project for a few more years and to continue the telemetry of the young Ural Owls that will be released in the Dürrenstein Wilderness Area. Such work will make further efforts in closing distribution gaps, collect more valuable data for reintroduction projects, and especially to create awareness for the importance of deadwood in commercial forests – for our largest "forest owl" as well as for all wildlife.

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Habitat degradation and climate change as drivers of long-term declines of two forest-dwelling owl populations in boreal forest

Degradação do habitat e alterações climáticas enquanto causas de declínio de longo-termo de duas populações de rapinas noturnas em florestas boreais

Erkki Korpimäki[1*]

1 Department of Biology, University of Turku, FIN-20014 Turku, Finland

*** Corresponding author:** ekorpi@utu.fi



ABSTRACT

To understand how world-wide land-use changes interact with climate change and biotic interactions (competition and predation) to modify population dynamics of animals is particularly important in boreal forest ecosystems facing large intensification of forestry practices and fast climate change. The settlement decisions, reproductive success and food-hoarding behaviour of Eurasian Pygmy-owls (POs; *Glaucidium passerinum*) were studied during 2002-2017 in long-term (>40 yr) study area (1300 km^2) of their larger competitor and intra-guild predator, Boreal Owls (BOs; *Aegolius funereus*). POs strongly avoided breeding close to conspecifics but did not avoid the vicinity of BO nests. Proportion of occupied nest-boxes by breeding POs increased with vole abundance in the previous autumn. POs had lower hatching success at high conspecific density. Even though breeding POs did not spatially avoid BOs, the increasing density of BOs reduced fledging success of POs. The results suggest that joint costs of exploitative and interference competition as well as intra-guild predation risk by BOs on reproductive success of POs were lower than those induced by intraspecific competition only. This result might be due to that BOs are only twice as large as POs. Increasing frequency of days with precipitation during the autumn generated a reduction in the total prey biomass stored, the number of bank voles (main prey) in food stores, and in the body condition of female POs during the food-hoarding season (Oct to Dec). Rainy autumns probably could decline the vulnerability of voles to predation by POs, since long-term temporal stability in local vole abundance negates the alternative hypothe-

sis that climate change drives fading of vole cycles. Breeding density of POs declined during the 15-year study period, and the long-term decline (2% per year) of BO populations was evident both locally and nation-wide. These declines are mainly attributable to the loss of mature and old-growth forests offering refuges against larger predators and better availability of main and alternative prey. The decline of POs was probably also contributed by climate change resulting in deteriorating vulnerability of small mammals during the food-storing season due to increased rainfall.

Keywords: *Aegolius funereus*, food limitation, *Glaucidium passerinum*, habitat selection, population dynamics

RESUMO

Compreender como as alterações globais nos usos do solo interagem com as alterações climáticas e as interações bióticas (competição e predação) para modificar as dinâmicas das populações animais é particularmente importante nas florestas boreais, face à grande intensificação das práticas florestais e à rapidez com que as alterações climáticas se manifestam nestes ecossistemas. A decisão de estabelecer um território, o sucesso reprodutor e o comportamento de armazenamento de alimento do mocho-anão (MAs; *Glaucidium passerinum*) foram estudados durante 2002-2017 numa área de estudo (1300 km^2) de longo termo (>40 anos) do seu competidor, com maior tamanho corporal e predador intra-guilda, o mocho-funéreo (MFs; *Aegolius funereus*). Os MAs evitaram nidificar na proximidade de conspecíficos mas não evitaram a proximidade de ninhos de MF. A proporção de ninhos ocupados por MAs nidificantes aumentou com a abundância de cricetídeos no outono anterior. O sucesso da eclosão dos MAs foi inferior nos casos de elevada densidade de conspecíficos. Apesar de os MAs nidificantes não evitarem espacialmente os MFs, o aumento da densidade de MFs reduziu o sucesso da emancipação dos MAs. Os resultados sugerem que as consequências negativas da competição por exploração e interferência, assim como do risco de predação intra-guilda por MFs no sucesso reprodutor dos MAs foram inferiores às consequências negativas da competição intraespecífica. Este resultado pode dever-se ao facto de os MFs terem apenas o dobro do tamanho corporal dos MAs. O aumento da frequência de dias com precipitação durante o outono causou uma diminuição na biomassa total de presas acumuladas, no número de *Myodes glareolus* (presa principal) nos armazéns alimentares, e na condição física das fêmeas de MA durante a estação de armazenamento de alimento (outubro a dezembro). Outonos chuvosos podem reduzir a vulnerabilidade dos cricetídeos à predação por MAs, uma vez que a estabilidade temporal de longo-termo da abundância local de cricetídeos contradiz a hipótese alternativa de que as alterações climáticas determinam o desaparecimento dos ciclos de cricetídeos. A densidade de casais reprodutores de MAs diminuiu durante o período de 15 anos do estudo, e o declínio de longo-termo (2% por ano) das populações de MF foi evidente a nível local e nacional. Estes declínios devem-se sobretudo à perda de florestas maduras e longevas, que proporcionam refúgios contra predadores de maior dimensão corporal e maior disponibilidade de presas principais e alternativas. O declínio de MAs poderá também ter sido agravado pelas alterações climáticas, resultando num aumento da vulnerabilidade à deterioração dos micromamíferos acumulados durante a estação de armazenamento de alimento, devido ao aumento da precipitação.

Palavras-chave: *Aegolius funereus*, dinâmica populacional, *Glaucidium passerinum*, limitação do alimento, seleção de habitat

Introduction

To understand how world-wide land-use changes interact with climate change to modify dynamics and persistence of animal populations is a primary goal in present-day ecological research. This is particularly important in boreal forest ecosystems facing fast climate change (Ruckstuhl et al. 2008) and intensification in forestry practices (Kuuluvainen 2009). In addition, biotic interactions, such as competition and predation, may complicate our understanding of the effects of climate change on animal populations under changing forest habitat composition. Large predators impose a mortality risk for small predators, and habitat degradation and climate change may reduce availability of primary prey, which together will lead to population declines and possibly to local extinction. How changes in the forest habitat composition and climate interact to modify trophic interactions and demography of avian predators has yet to be studied, particularly in altering boreal forests.

Our team has studied the nest-site occupancy, habitat selection, reproductive success, survival, dispersal and food-hoarding behaviour of Eurasian Pygmy-owls (*Glaucidium passerinum*; hereafter Pygmy Owl) in the same long-term study area where we have also installed a wide nest-box network for Boreal Owls (*Aegolius funereus*). Boreal and Pygmy Owls subsist on the same main foods (i.e. voles of the genera *Microtus* and *Myodes*) in North European boreal forests (Korpimäki & Hakkarainen 2012). In Finland, where this study was conducted, these voles fluctuate in 3-year high-amplitude (100 to 200-fold) population cycles (Korpimäki et al. 2005). Boreal Owls are approximately twice as large as Pygmy Owls, and therefore, they can intimidate and even kill smaller allo-specifics (i.e. intra-guild predation; Morosinotto et al. 2017).

In this paper, my first intention is to review studies on nest-site occupancy, habitat selection and reproductive success of Pygmy Owls under varying levels of food competition and predation risk imposed by Boreal Owls. The second aim is to review how food-store contents and body condition indices of Pygmy Owls in the food-hoarding season are associated with varying autumn climate conditions and forest composition. The final intention is to examine long-term trends of Pygmy and Boreal Owl populations in our study area.

Material and methods

The study area covered approximately 1300 km^2 in the Kauhava region, western Finland (63° N, 23° E). The landscape consisted of commercially managed pine- and spruce-dominated forests with some birch-dominated patches, interspersed with clear-cut areas, agricultural land and peatland bogs (Korpimäki 1987, Korpimäki & Hakkarainen 1991, 2012, Hakkarainen et al. 2003). The proportion of old-growth forest in our study area was low as a consequence of forestry practices (i.e. clear-cutting and thinning; Hakkarainen et al. 2003), and thus suitable natural cavities for Boreal and Pygmy Owls were scarce. Therefore, nest-boxes for Boreal Owls were provided from 1966 onwards, and for Pygmy Owls during 2001-17. The diameter of the entrance hole of Boreal Owl boxes was 80 to 100 mm, and that of Pygmy Owl boxes was 45 mm. The total number of Boreal Owl nest-boxes was approx. 420 during 1983-1987 and 470 from 1988 onwards, and these nest-boxes and known natural cavities (approx. 30) made by Black Woodpeckers (*Dryocopus martius*), were inspected each spring (Korpimäki 1987, Korpimäki & Hakkarainen 1991, 2012).

The nest-box project for Pygmy Owls was initiated in 56 forest patches in autumn 2001. From 2004 onwards the number of forest

patches was 150 and reached a maximum of 285 patches in 2015 (mean no. of patches 211 per year during 2002-17). In each forest patch (hereafter called as box-site), two nest-boxes for Pygmy Owls were provided during 2002-2017. Two boxes were placed per site 80-100 m apart because Siberian flying squirrels (*Pteromys volans*) also use nest-boxes for roosting and reproduction throughout the year and this ensured availability of the nest-site and food-storing site for Pygmy Owls. Approximately 80 natural cavities, excavated by Great Spotted Woodpeckers (*Dendrocopos major*), are also available for breeding Pygmy Owls in the study area. The two owl species do not compete for available cavities; Pygmy Owls do not breed in cavities with large entrance-holes and Boreal Owls cannot enter the cavities used by Pygmy Owls (Korpimäki & Hakkarainen 2012, Morosinotto et al. 2017).

The density of Boreal Owl nest-boxes in our study area (approximately 1 nest-box per 2 km^2) does not substantially differ from natural conditions: the density of suitable natural cavities in pristine coniferous forests of southern Finland is 0.5-1.5 per km^2 (Virkkala et al. 1994). In addition, in coniferous forests managed for forestry in Central Sweden, the density of natural cavities made by Black Woodpeckers, the size of which also is suitable for Boreal Owls, is 0.3-0.4 per km^2 (Johnsson et al. 1993). The two owl populations in our study area were not constrained by the availability of nesting sites, because even in good vole years characterized by highest numbers of owls, only 33% of Boreal Owl and 31% of Pygmy Owl boxes were occupied. Nest boxes were also homogeneously distributed across the landscape (average distance between available Pygmy Owl nest-box sites 1429 m; and between available Boreal Owls boxes 760 m).

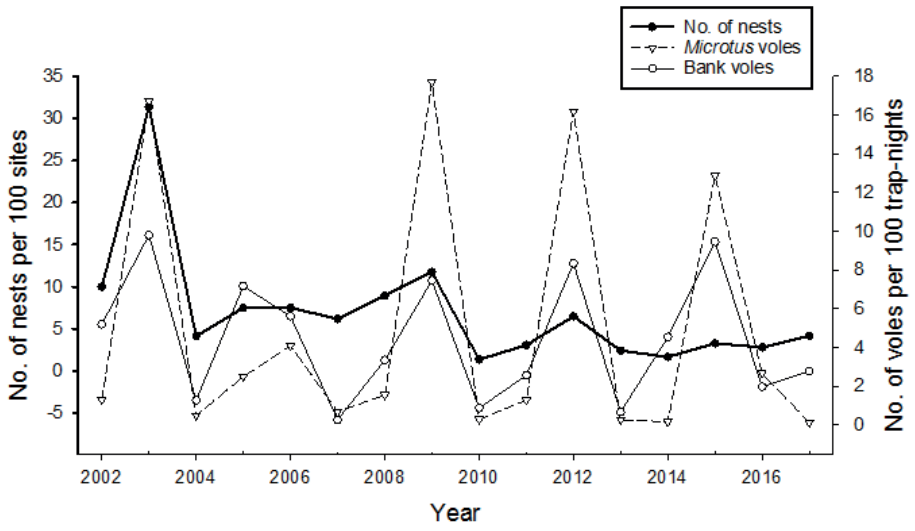
All owl boxes, and known natural cavities, were inspected twice every spring (in April and again in late May to early June) to detect breeding attempts. In all nests of both owl species, clutch size, hatching date, and number of hatchlings and fledglings were recorded, as well as fledglings were ringed and a majority of the parent owls were ringed and/or re-captured (see Korpimäki & Hakkarainen 1991, 2012, Morosinotto et al. 2017).

The nest-boxes of Pygmy Owls were inspected to find stored prey items twice during the autumn, from late October to mid-December during 2002-2017. Prey items were usually stored as whole, and thus species identification, sexing, ageing and weighing was possible in most cases. Prey items in food stores were also marked by toe-clipping (birds) or tail-clipping (mammals) to avoid double counting. The total number and mass of prey items, as well as for the five main groups of prey (i.e. bank voles, *Microtus* voles, shrews, mice and birds), were calculated by summing up the fresh prey items counted in the two visits (see Terraube et al. 2017, Masoero et al. 2018). During the food-hoarding season in 2002-2017, Pygmy Owls were captured, measured and ringed for individual identification (a total of 327 individuals during 2002-2016). The vast majority of owls was captured with nest-box traps (a copy of the food store-box equipped with swing door). The captured Pygmy Owls were sexed and aged, their wing and tail lengths were measured and body mass taken. To estimate the body condition of Pygmy Owls, the Scaled Mass Index was calculated (see Peig & Green 2009). Sexing was based on wing length, tail length and body mass (females larger and heavier than males; E. Korpimäki unpublished data, Masoero et al. 2018).

Abundances of voles have been estimated by snap-trappings each year in mid-May and in late September in four sample plots (i.e. cultivated field, abandoned field, spruce for-

Figure 1 - Number of nests of Eurasian Pygmy Owls per 100 box-sites inspected (solid line and dots; left y-axis) and number of *Microtus* voles (the field vole *M. agrestis* and the sibling vole *M. rossiaemeridionalis*; triangles) and bank voles (*Myodes glareolus*; circles) trapped per 100 trap-nights (right y-axis) in the previous autumn during 2002-2017. Spearman rank correlation between breeding density and *Microtus* voles r_s=0.64, p=0.007, n=16 and bank voles r_s=0.60, p=0.015, n=16.

Figura 1 - Número de ninhos de Mocho-anão por 100 parcelas com caixas-ninho inspecionadas (linha contínua e pontos; eixo vertical da esquerda) e número de *Microtus* (*M. agrestis* e *M. rossiaemeridionalis*; triângulos), e *Myodes glareolus* (círculos) armadilhados por 100 noites de amostragem (eixo vertical da direita) no outono anterior durante 2002-2017. Correlação de Spearman entre a densidade de casais reprodutores e de *Microtus* r_s=0.64, p=0.007, n=16 e de *Myodes glareolus* r_s=0.60, p=0.015, n=16.



est, pine forest; see Korpimäki et al. 2005 for more details on trapping methods and vole cycles). Fifty to one hundred Finnish metal mouse snap traps were set at 10 m intervals in vole runways in each plot and were checked once a day for three-four days. Thus, the area of a sample plot ranged from 0.5 to 1.0 ha. The results from 3-4-night trapping periods were pooled and standardized to the number of animals caught per 100 trap nights.

Results

Nest-site occupancy, habitat selection and reproductive success of Pygmy Owls

The proportion of occupied nest-sites by Pygmy Owls varied between years, from 1 nest per 100 sites (in 2010) to 31 nests per 100 sites (in 2003) during 2002-2017 (Fig.1). The proportion of nest-boxes occupied by breeding Pygmy Owls augmented with increasing abundance of voles in the previous autumn (Fig. 1), whereas there was no similar relationship to vole abundance index in the current spring. Nest-site occupancy of Pygmy Owls also amplified with increasing proportions of spruce forests, mature and old pine forests and farmlands (see Fig. 2 in Morosinotto et al. 2017).

Habitat selection of breeding Pygmy Owls varied in relation to the distance to breeding conspecifics, main food abundance, and food competitors and intra-guild predators, Boreal Owls (Morosinotto et al. 2017). The proportion of nest-site occupancy of Pygmy Owls increased with the augmenting distance to the conspecific nest, but when vole abundance was high, avoidance among conspecific Pygmy Owls decreased (Fig. 1 in Morosinotto et al. 2017). This relationship was, however,

partly modified by the distance to the nearest nest of Boreal Owls. Nest-site occupancy of Pygmy Owls increased closer to a nest of Boreal Owls, but only as the distance to the nearest Pygmy Owl nest also increased (Fig.1 in Morosinotto et al. 2017).

Pygmy Owls bred earlier in sites with a large proportion of agricultural lands within 1000 m-radius of the nest-box. Despite that increasing proportion of agricultural land advanced start of egg-laying in the early phase of the breeding season, a large proportion of agricultural land within 1000 m from the nest decreased both hatching and fledging success of Pygmy Owls (Fig. 5 in Morosinotto et al. 2017). The high proportion of mature spruce forest at a local scale (300 m) around the nest increased the hatching success of Pygmy Owls (Morosinotto et al. 2017).

Food-stores and body condition of Pygmy Owls

There appeared to happen marked changes in the autumn climate (October to December) during the food storing season of Pygmy Owls and in habitat composition around nest-box sites of Pygmy Owls during the study period. The number of days with rainfall in autumn significantly increased (0.15 ± 0.006 d per year), whereas the number of days with frost (minimum temperature <0°C) significantly decreased (-0.24 ± 0.006 d per year) during the 12 year study period (2001-2012; Fig. S2 in Terraube et al. 2017). The proportion of clear-cuts within a radius of 1500 m around the food stores of Pygmy Owls significantly increased during the 12-year study period (Fig. S3 in Terraube et al. 2017).

Overall, 15850 prey items from a total of 436 nest-boxes distributed on 218 box-sites were identified and weighted during 2001-2012. Pygmy Owls stored mainly bank voles (*Myodes glareolus*; 47% of prey items and 47% of prey biomass) and *Microtus* (*M. agrestis* and *M. rossiaemeridionalis*) voles (33% of prey items and 43 % of prey biomass). Alternative prey groups included mainly small passerine birds (6% of prey biomass) and shrews (3%; Terraube et al. 2017). The total biomass of prey items cached per nest-box increased in relation to pooled vole abundance in the current autumn. The total biomass of prey items decreased with the increasing number of days with rainfall and the number of days with frost during October to December (Fig. 1 in Terraube et al. 2017).

The number of bank voles found per food-store decreased during the study period and was positively related to the abundance index of bank voles. The number of bank voles declined with augmenting number of days with rainfall and with the increasing number of frost days during October to December (Fig. 2 in Terraube et al. 2017). When the proportion of clear-cuts around the nest-box was low, the number of bank voles found in food-stores increased with augmenting local abundance of voles (Terraube et al. 2017).

The body condition index (as estimated by the scaled mass index) of female Pygmy Owls decreased with increasing number of frost days, whereas it remained relatively stable for males independently of the number of days with frost (Fig. 5 in Terraube et al. 2017). Males had a lower body condition index than females.

Long-term trends of owl populations

Linear regression between year and density estimate of Pygmy Owls (the number of nests per 100 box-sites) revealed that breeding Pygmy Owl population in our study area significantly declined during 2002-2016 (Fig. 2, $r=0.580$, $R^2=0.336$, $p<0.05$). The similar trend was not significant for Boreal Owls during 2002-2016 (Fig. 2), but earlier analyses showed that Boreal Owl population in our study area declined 2% per year during 1973-2009 (Fig. 13.7. in Korpimäki & Hakkarainen 2012).

Discussion

Determinants of nest-site occupancy, habitat selection and reproductive success of Pygmy Owls

The probability of nest-site occupancy of Pygmy Owls increased with abundance of main prey (voles) in the previous autumn, whereas there was no obvious relationship to vole abundance in the current spring. The importance of vole abundance in the previous autumn rather than in the current spring is probably attributable to the fact that Pygmy Owls store larger number and biomass of prey items in their food stores in autumns with abundant voles (Masoero et al. 2018; see also Solheim 1984). These food stores are then consumed during forthcoming winter (Järvi 1986), and more Pygmy Owls are probably in high body condition in the next spring and can thus initiate a breeding attempt which results in their increasing breeding densities. This interpretation is supported by the fact that in Boreal Owls breeding in the same study area, the abundance of voles in the current spring rather than in the previous autumn determines the breeding density (Korpimäki & Hakkarainen 1991, 2012). Boreal Owls do not collect large food stores in nest-boxes and natural cavities in autumn, probably because these boxes and cavities with a large entrance hole are accessible to robbers and enemies including, for example, pine martens (*Martes martes;* Korpimäki 1987). Pine martens also roost and reproduce in boxes and cavities of Boreal Owls so that they could easily find food-stores of Boreal Owls in tree-holes. Nest-boxes and natural cavities in which Pygmy Owls breed and store food are not accessible to pine martens, but can be entered by smaller mustelids, such as stoats (*Mustela erminea*) and weasels (*M. nivalis*). However, these smaller predators hunt mainly on the open ground (Klemola et al. 1999) and do not often climb on trees.

The proportion of nest-site occupancy of Pygmy Owls increased with the augmenting distance to the conspecific nest, but when vole abundance was high, avoidance among conspecific Pygmy Owls decreased. Therefore, Pygmy Owls largely avoided their conspecifics when selecting a breeding site, probably as a consequence of food and interference competition. The fact that avoidance in settlement decreased with abundant food suggests that high vole availability led to weaker intraspecific competition for food and probably also to reduced territory size. The degree of intraspecific competition for high-quality territories among Pygmy Owls is probably also increased by the fact that suitable habitat for Pygmy Owls (mature and old-growth forest) has substantially declined in our study area during the study period. However, the number of nest-sites did not limit the breeding density of Pygmy Owls in this case, because even at the highest breeding densities only 31% of nest-boxes were occupied by Pygmy Owls.

Boreal Owls are twice as large as Pygmy Owls. This small size difference probably led to a reduced number of lethal interactions among two owl species, although there are at least three recorded cases where Boreal Owls have killed Pygmy Owls (review in Korpimäki & Hakkarainen 2012). In addition, the non-lethal costs of presence of Boreal Owls may still persist in Pygmy Owl populations. Nevertheless, the joint costs of interspecific competition and intra-guild predation risk imposed by Boreal Owls on Pygmy Owls appeared to be lower than those induced by competition by conspecifics only. In earlier intra-guild predation studies on birds of prey, the intra-guild predators were considerably larger (>3-times) than the intra-guild prey (review in Sergio and Hiraldo 2008).

Pygmy Owls had delayed start of breeding and lowered hatching success when breeding at high conspecific density, probably due to the exploitative competition for food and interference competition for high-quality territories (Morosinotto et al. 2017). Unex-

pectedly for a small (approx. 55 to 80 g) owl species, the detrimental effects of conspecific neighbours on reproductive success were evident at relatively large radius (500 to 3000 m) of the nest (Morosinotto et al. 2017). The main reason probably is the overall scarcity of small mammal and bird prey in boreal forests compared to more southern temperate environments. In addition, it might be necessary to ensure a sufficiently large hunting territory to reduce interference competition with other neighbours during the breeding season, because small birds are efficient at warning and mobbing against Pygmy Owls (Dutour et al. 2016).

Unexpectedly, occupancy of nest-boxes by Pygmy Owls increased closer to Boreal Owl nests, but only when conspecific nests were farther away (Morosinotto et al. 2017). This tendency of attraction of Pygmy Owls to the vicinity of Boreal Owls is probably due to a conjunction in habitat preference for the two owl species. There is ample evidence that Boreal and Pygmy Owls prefer mature and old-growth coniferous forest habitats both in North and Central Europe (reviews in Schönn 1980, Korpimäki & Hakkarainen 2012; see also Santangeli et al. 2012 for Boreal Owls; Strøm & Sonerud 2001, Barbaro et al. 2012, Morosinotto et al. 2017 for Pygmy Owls). Mature and old-growth spruce- and pine-dominated forests offer rich patches of main (bank voles) and alternative (shrews and small birds) prey and refuges against larger avian predators including e.g. Ural Owls (*Strix uralensis*), Northern Goshawks (*Accipiter gentilis*) and Eurasian Sparrowhawks (*A. nisus*).

Despite that Pygmy Owls were attracted close to Boreal Owls during the nest-site selection period, proximity of Boreal Owls induced lowered hatching and fledging success of Pygmy Owls (Morosinotto et al. 2017). This detrimental effect of hetero-specific density on reproductive success of Pygmy Owls probably arises from both the exploitative and interference competition, since these species have largely overlapping diets (mostly small rodents and small passerines birds; Korpimäki & Hakkarainen 2012. Owls and other predators have been shown to reduce high density patches of cyclic voles in North Europe (Korpimäki et al. 2002, 2005). Vole patches and densities of small birds in the vicinity of these breeding owl species are probably rapidly depleted, which in turn would lead to lower hatching and reproductive success of the smaller Pygmy Owl.

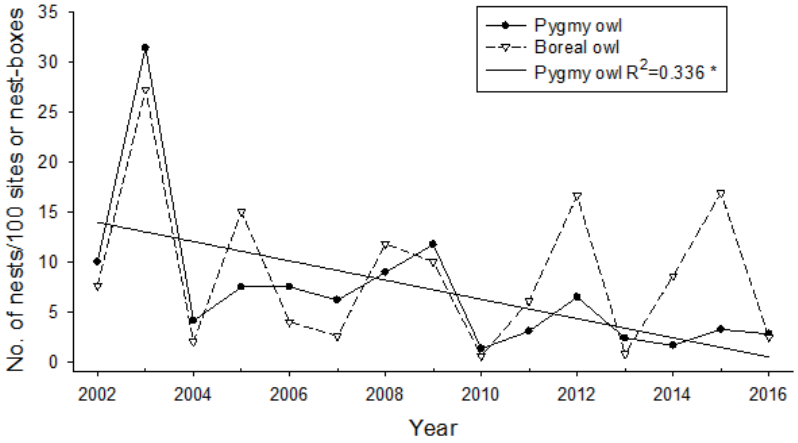
The probability of nest-site occupancy of Pygmy Owls was higher if nesting happened in the box-site of the previous year (Morosinotto et al. 2017). The high-quality of the habitat in the surrounding of these frequently-used nest-box sites probably explains why the same individuals tend to occupy the same box-sites year after year or why newcomers are attracted to these high-quality sites (Newton and Marquiss 1986, Korpimäki 1987). Yet, nest-site fidelity of adult Pygmy Owls appeared to be an unlikely explanation, because >80% of the females and >70% of the males trapped and ringed in the study area during the breeding season were one-time breeders (E. Korpimäki unpublished data). Therefore, the occupancy pattern of box-sites found is probably due to the preference of immigrant Pygmy Owls for these high-quality forest patches.

Habitat change, climate change and long-term decrease of owl populations

Total prey biomass in food-stores of Pygmy Owls decreased over the study period .The number of days with rainfall and of frost days were negatively related to the total biomass of prey in stores, numbers of main prey (bank vole) in stores and individual body condition of Pygmy Owls. Unexpectedly, we did not find any close relationship between the biomass of stored prey and the proportion of clear-cut areas (or the proportion of old spruce forests) around the food-stores

Figure 1 - Number of nests of Eurasian Pygmy Owls per 100 box-sites (solid line and dots), and number of nests of Boreal Owls per 100 nest-boxes (dashed line and triangles) during 2002-2016 in the Kauhava region, western Finland.

Figura 1 - Número de ninhos de Mocho-anão por 100 parcelas com caixas-ninho amostradas (linha contínua e pontos), e número de ninhos de Mocho-funéreo por 100 caixas-ninho (linha tracejada e triângulos) durante 2002-2016 na região de Kauhava, oeste da Finlândia.



(Terraube et al. 2017). The most intensive food-hoarding period of Pygmy Owls happens before the permanent snow layer (Järvi 1986), as >70% of prey items were hoarded during this period (Halonen et al. 2007). Cold autumns are generally associated with early snowfalls and permanent snow cover from November to April in the study area. Small Pygmy Owls are too light to penetrate the deep snow layer and catch small rodents below the snow layer, which explains why Pygmy Owls store more small mammals in warm and snowless autumns. However, autumns are getting warmer in Finland, and therefore variation in autumn temperatures cannot be associated with the decrease in prey biomass in food stores of Pygmy Owls.

The prey biomass stored by Pygmy Owls decreased with the increasing number of days with rainfall in late autumn. Densities of voles did not show any marked long-term trend in our study area but fluctuated in regular 3-year cycles during 2002-2017 (Korpimäki et al. 2005, Korpimäki & Hakkarainen 2012; see also Fig. 1). This shows that climate-driven long-term decreases in abundances of vole populations are not the likely explanation for the declining prey biomass in food-stores of Pygmy Owls. Rainfall could impose a direct detrimental effect on the foraging activity and success of Pygmy Owls, but this decline of prey items in stores emerged only for small mammal prey, whereas the number of passerine birds in stores did not show any temporal trend over the study period (Terraube et al. 2017). Increasing rainfall likely decreases activity of small mammals, because energetic costs of thermoregulation of small mammals due wet fur in cold environments are substantial (e.g. Conley & Porter 1986). These costs can limit their above-ground activity and reduce the vulnerability of small mammals to avian predators. In addition, the noise of rainfall makes small mammals more difficult to hear to avian predators and moist leaf and needle litter makes less noise than dry one. All in all, precipitation may reduce mobility and prey detectability of small mammals to avian predators thus decreasing their foraging success.

Female Pygmy Owls captured during the food-storing season were in poorer body condition during cold and rainy autumns than during warm and less-rainy ones, whereas body condition indices of males remained stable over the years (Terraube et al. 2017). This indicates that ongoing increase in autumn rainfall may have detrimental consequences for fitness of female Pygmy Owls. Male owls are smaller than females and larger aerial agility may make them more efficient hunters in dense mature and old-growth forests (Hakkarainen & Korpimäki 1991), particularly for prey with higher escape ability like birds. Indeed, the proportion of small birds was higher in food stores of males than in those of females (Terraube et al. 2017, Masoero et al. 2018). Therefore, males have probably been able to better respond to the climate-driven reduction in capture success of small mammals by catching more birds. On the contrary, larger females probably are less agile in capturing birds. Further research is badly needed to find out whether these different trends in body condition indices between male and female pygmy owls may have carry-over effects on over-winter survival and future reproductive success at the population-level.

The present results indicate that there was no apparent decrease of breeding Boreal Owl population in our study area during 2002-2016 (Fig. 2). However, a divergent trend emerged when putting our results in more long-term viewpoint. Owl monitoring schemes of 20 local ornithological societies in Finland revealed that there was a 2% annual decline of nation-wide Boreal Owl population during 1973-2009 (Korpimäki & Hakkarainen 2012), and the nation-wide raptor grid monitoring also showed similar (2%) annual decline of Boreal Owl population during 1982-2016 (Meller et al. 2017). Therefore, our present results should be interpreted with caution, especially because wide cyclic among-year fluctuations due to the 3-year vole cycle happen in northern Boreal Owl populations.

The most probable reason for remarkable long-term decline of Boreal Owl population in Finland is degradation and loss of forest habitat due to clear-cutting, because over-winter survival of Boreal Owls is higher in home ranges including >10% of old-growth forests (Hakkarainen et al. 2008). In addition, the lifetime reproductive success of owl males is higher in home ranges including an increasing proportion of old-growth and middle-aged forests (Laaksonen et al. 2004). Middle-aged and old-growth forests offer more refuges against larger avian predators, such as Ural owls (see Hakkarainen & Korpimäki 1996), and there also are less main (bank voles) and alternative (shrews and small birds) prey items in sapling areas and young forests.

The results showed a local decline of breeding Pygmy Owl population during 2002-2016 (Fig. 2), and a weak declining trend also emerged in the Pygmy Owl population breeding in Finland during 2000s on the basis of nation-wide raptor grid monitoring (Meller et al. 2017). The similar declining trend of Pygmy Owl is also apparent during the food storing season in autumn during 2002-2016 in our study population (E. Korpimäki & G. Masoero, unpublished data). Because abundances of main prey (voles) did not show any apparent long-term trends (Fig, 1), this long-term decline is probably associated with the degradation and loss of forest habitat and climate change. During the 15-year study period, the coverage of middle-aged, mature and old-growth forests (main habitat for Pygmy Owls) in our study area has reduced by approx. 20% (E. Korpimäki, unpublished data). Currently, our study area is mostly a mosaic of agricultural fields, clear-cut and sapling areas, as well as young thinned forest plantations with very small coverage of middle-aged, mature and old-growth forests. Therefore, forest management resulted in a habitat degradation, which probably induced a decline of breeding and wintering population of Pygmy Owls. This decline was proba-

bly also contributed by climate change resulting in increased rainfall in late autumn to early winter, which has declined the number and biomass of prey items in the food stores and body condition of female Pygmy Owls (Terraube et al. 2017). During 2000s, warmer temperatures in late autumn to early winter have also often induced decay of food-stores of Pygmy Owls (E. Korpimäki unpublished data), which may even steepen the decline of Pygmy Owl populations in the future. In an another food-storing bird species (the Grey Jay *Perisoreus canadensis*) in boreal forest of Canada, warming autumn temperatures also induced food store spoilage with detrimental consequences for reproductive success in the next spring (Waite & Strickland 2006, Sechley et al. 2015).

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Estimating the population and distribution trends of owls in Portugal using citizen science data from Program NOCTUA-Portugal and other sources

Estimativa da tendência populacional e distribuição das aves de rapina noturnas em Portugal usando dados de ciência cidadã do Programa NOCTUA-Portugal e outras fontes

Rui Lourenço[1,2*], Sara Moreira[2], Inês Roque[1,2], Ricardo Tomé[1,3]

1 Grupo de Trabalho sobre Aves Noturnas da SPEA (Sociedade Portuguesa para o Estudo das Aves)

2 MED – Instituto Mediterrâneo para a Agricultura, Ambiente e Desenvolvimento, LabOr - Laboratório de Ornitologia, Universidade de Évora, Núcleo da Mitra Ap.94 7002-554, Évora, Portugal

3 STRIX, Ambiente e Inovação.

*** Corresponding author:** lourenco@uevora.pt



ABSTRACT

During the last eight years (2010-2017), the Working Group on Nocturnal Birds of SPEA (GTAN-SPEA) has carried out a volunteer monitoring program (NOCTUA-Portugal) to determine the population trends of seven owl species at a national scale. We used generalized estimating equations models to assess trends. In addition, we used the distribution data from breeding bird atlases, observations sent by collaborators, and data from the public online database PortugalAves/eBird to detect changes in distribution in a four-decade period (1978-2017). We defined four periods to study potential changes in distribution of owls in Portugal: 1978-1984 (1st breeding bird atlas); 1999-2005 (2nd breeding bird atlas); 2006-2014 (interval between 2nd and 3rd breeding bird atlases); and 2015-2017 (ongoing 3rd breeding bird atlas). Three species had negative population and distribution trends: Common Barn-owl (*Tyto alba*), Eurasian Scops-owl (*Otus scops*), and Little Owl (*Athene noctua*). The Eurasian Eagle-owl (*Bubo bubo*) had a slightly positive population and distribution trends, while the Tawny Owl (*Strix aluco*) was sta-

ble or slightly declined. The population trend of the Northern Long-eared Owl (*Asio otus*) was unknown because of large fluctuations, and due to the low number of records it was not possible to determine a population trend for the Short-eared Owl (*Asio flammeus*).

Keywords: Citizen-science, distribution change, owls, population trend, Portugal

RESUMO

Durante os últimos oito anos (2010-2017), o Grupo de Trabalho sobre Aves Noturnas da SPEA (GTAN-SPEA) realizou um programa voluntário de monitorização (NOCTUA-Portugal) para determinar a tendência populacional de sete espécies de aves de rapina noturnas à escala nacional. Usámos modelos de equações de estimação generalizadas para avaliar tendências populacionais. Adicionalmente, usámos dados de distribuição de atlas das aves nidificantes, observações enviadas por colaboradores e dados inseridos na base de dados online PortugalAves/eBird para detetar alterações na distribuição durante um período de quatro décadas (1978-2017). Definimos quatro períodos para estudar mudanças potenciais na distribuição das aves de rapina noturnas em Portugal: 1978-1984 (1º atlas das aves nidificantes); 1999-2005 (2º atlas das aves nidificantes); 2006-2014 (intervalo entre o 2º e o 3º atlas das aves nidificantes); e 2015-2017 (3º atlas das aves nidificantes, em curso). Três espécies apresentam tendências negativas de distribuição e população: coruja-das-torres (*Tyto alba*), mocho-d'orelhas (*Otus scops*) e mocho-galego (*Athene noctua*). O bufo-real (*Bubo bubo*) aparentemente apresenta tendências de distribuição e população ligeiramente positivas, enquanto a coruja-do-mato (*Strix aluco*) parece estável ou em ligeiro declínio. A tendência da população bufo-pequeno (*Asio otus*) é desconhecida uma vez que apresenta grandes flutuações e, devido ao baixo número de registros, não foi possível determinar a tendência populacional para a coruja-do-nabal (*Asio flammeus*).

Palavras-chave: alterações na distribuição, aves de rapina noturnas, ciência cidadã, Portugal, tendência populacional

Introduction

Owls are cryptic, exist at low densities, and are mostly nocturnal or crepuscular birds. Consequently their distribution and population status are often less well known when compared to other groups of birds (Vrezec et al. 2012). Owls are top predators within food webs, being important monitors to ecosystem health (Lourenço et al. 2011, Espín et al. 2016, Movalli et al. 2017). Monitoring owls requires specific methods (e.g. Redpath 1994, Zuberogoitia & Campos 1998, Hardey et al. 2009) and this group is under sampled by general bird atlas, census and other such programs (Palma 2012, Lourenço et al. 2015). This affects the quality of information on owls to inform conservation and management programs.

Many European owl species are threatened by human persecution, infrastructures like roads and powerlines, agriculture intensification and environmental contamination (Burfield 2008, BirdLife International 2004). As a result, many of the seven owl species that occur regularly in Portugal are at risk. According to the most recent Portuguese vertebrate red list (Cabral et al. 2005) the

Short-eared Owl (*Asio flammeus*) is endangered, the Eurasian Eagle-owl (*Bubo bubo*) is nearly threatened, the Eurasian Scops-owl (*Otus scops*) and Northern Long-eared Owl (*Asio Otus*) are data deficient, and only three species are of least concern: the Common Barn-owl (*Tyto alba*), the Little Owl (*Athene noctua*) and the Tawny Owl (*Strix aluco*). All species are resident, except the Eurasian Scops-owl, which only occurs during breeding period, and the Short-eared Owl, which is a winter migrant (Lourenço et al. 2015).

While information on owl population status and distribution in Portugal has increased in the last two decades, it is still limited due to insufficient spatial coverage and a lack of atlas and monitoring programs using methods to detect less common species (Palma 2012, Lourenço et al. 2015). Owl populations in Portugal are not cyclical (Lourenço et al 2015), however monitoring efforts are important to detect annual variations due to irruptions or nomadism (e.g. Northern Long-eared Owls). In the last decade knowledge of owls in Portugal has improved from the creation of the long-term monitoring program NOCTUA-Portugal (Lourenço et al. 2015, GTAN-SPEA 2017), the completion of the 1st wintering and migration bird atlas, the initiation of the 3rd breeding bird atlas, and increased information from birdwatchers from eBird and other on online data portals. Citizen science is a useful tool that can collect widespread data and contribute to the conservation of owls (Sullivan et al. 2017). This paper used available information to estimate owl population and distribution trends in Portugal.

Methods

This study covered continental Portugal, but not the archipelagos of Madeira and Azores (for additional information see Lourenço et al. 2015).

Estimating population trends of owls

The NOCTUA-Portugal is a long-term (2010-2017) monitoring program aimed at assessing the population trends of nocturnal birds in continental Portugal (GTAN-SPEA 2017; methods and annual reports available at www.spea.pt/pt/participar/grupos-de-trabalho/aves-noturnas/) that used 10 x10 km sampling units derived from a UTM grid. A subset of sampling units was visited once during each of the three periods (1 Dec - 31 Jan; 1 Mar - 30 Apr; 1 May - 15 Jun) each year. During each visit, the same five point count locations, separated by at least 1.5 km, were sampled during 10 minutes of passive listening. Point counts were performed in the first 2 hours after sunset, in days with favourable weather conditions. Individual owls detected were recorded to estimate the minimum number of breeding pairs. As of 2017, 81 sampling units (8% of the total number of units in continental Portugal) have been sampled: two in each of 8 years, six in 7 years, four in 6 years, five in 5 years; six in 4 years; 11 in 3 years; 19 in 2 years; and 28 in 1 year (total = 230 sampling units × year).

To estimate population trends (2010-2017) we produced generalized estimating equations models (GEE-GLM) with Poisson distribution, using the minimum number of breeding pairs detected per sampling unit in each year. We only considered those units in which the species was detected at least once over the sampling period. Year was the only explanatory variable included in the models. We used the identifier of each sampling unit as clusters in the GEE-GLM and considered an auto-regressive correlation structure (AR1). GEE models were computed in the software R 3.4.3 (R Core Team 2017) with the package "geepack" (Højsgaard et al. 2006).

Estimating long-term trends in the distribution of owls

We identified four periods during which a representative sampling effort capable of

Table 1 - Eight-year population trend estimates for the owl species in Portugal (2010 – 2017). Results from generalized estimating equations models (GEE-GLM): estimate, SE, Wald and P. Categorical trends defined based on the estimate, SE, significance level, and sample size (number of squares where each species was present).

Tabela 1 - Estimativas de oito anos da tendência populacional das aves de rapina noturnas em Portugal (2010 – 2017). Resultados dos modelos de equações de estimação generalizadas (GEE-GLM): coeficiente, erro padrão, parâmetro de Wald, P. As tendências categóricas foram definidas com base no coeficiente, erro padrão, nível de significância e tamanho da amostra (número de quadrículas onde a espécie esteve presente).

	ESTIMATE	SE	WALD	P	N SQUARES	TREND
Common Barn-owl (*Tyto alba*)	-0.09	0.05	3.474	0.06	36	Decrease
Eurasian Scops-owl (*Otus scops*)	-0.13	0.10	1.878	0.17	24	Decrease
Eurasian Eagle-owl (*Bubo bubo*)	0.02	0.04	0.208	0.6	17	Slight increase
Little Owl (*Athene noctua*)	-0.24	0.09	6.529	0.01	65	Decrease
Tawny Owl (*Strix aluco*)	-0.07	0.07	0.829	0.36	58	Slight decrease
Northern Long-eared Owl (*Asio otus*)	-0.004	0.07	0.005	0.9	13	Unknown

Table 2 - Distribution trend estimates for the owl species in Portugal (1978 – 2017). Percentage of the sampling units with breeding/presence information; in brackets – variation in the distribution percentage in relation to the immediately preceding sampling period. BBA1 – 1st breeding bird atlas, BBA2 – 2nd breeding bird atlas; inter-atlas – period between 2nd and 3rd breeding bird atlases; BBA3 – 3rd breeding bird atlas.

Tabela 2 - Estimativas da tendência da distribuição para as aves de rapina noturnas em Portugal (1978 – 2017). Percentagem das unidades de amostragem com informação de nidificação/presença; entre parêntesis – variação da percentagem de distribuição em relação ao período de amostragem imediatamente anterior. BBA1 – 1º atlas de aves nidificantes, BBA2 – 2º atlas de aves nidificantes; inter-atlas – period entre o 2º e o 3º atlas de aves nidificantes; BBA3 – 3º atlas de aves nidificantes.

	1978-1984 (BBA1)	1999-2005 (BBA2)	2006-2014 (INTER-ATLAS)	2015-2017 (BBA3)
Common Barn-owl (*Tyto alba*)	68%	59% (-9%)	43% (-16%)	36% (-8%)
Eurasian Scops-owl (*Otus scops*)	54%	33% (-21%)	15% (-18%)	16% (0%)
Eurasian Eagle-owl (*Bubo bubo*)	22%	22% (0%)	30% (+8%)	22% (-7%)
Little Owl (*Athene noctua*)	92%	74% (-18%)	64% (-9%)	65% (+1%)
Tawny Owl (*Strix aluco*)	62%	61% (0%)	51% (-10%)	58% (+7%)
Northern Long-eared Owl (*Asio otus*)	7%	9% (+2%)	9% (0%)	10% (+1%)
Short-eared Owl (*Asio flammeus*)	--	--	7%	7% (0%)

providing a general picture of the distribution of the owl species was carried out in continental Portugal. The first period (1978-1984) was the first breeding bird atlas of Portugal (Rufino 1989; hereafter designated as BBA1), which sampled 20 x 32 km rectangles (total of 180 rectangles). The second period (1999-2005) was the second breeding bird atlas of Portugal (Equipa Atlas 2008; hereafter designated as BBA2), which sampled 10 x10 km UTM squares (total of 947 squares). These two atlases did a complete census of continental Portugal, although it is assumed that they under sampled owls, especially in remote rural and interior areas of the country, with relatively low census effort (Rufino 1989, Equipa Atlas 2008). All categories of presence reported in the atlas (possible, probable and confirmed breeding) were used to quantify owl distribution.

The third period (2006-2014) was an "inter-atlas" period, when there was no country-wide owl census. The distribution data for this period was gathered from several sources: (1) NOCTUA-Portugal program (started in 2010); (2) additional records sent by NOCTUA-Portugal collaborators; (3) records from a public online database called PortugalAves/eBird (SPEA, Audubon, Cornell Lab of Ornithology; ebird.org/content/portugal/; Sullivan et al. 2009); (4) records sent to the newsletter of SPEA (Noticiário Ornitológico, www.spea.pt); and (5) published literature on owl studies, particularly regional atlases and monitoring studies (Tomé et al. 2008, Aguiar et al. 2010, Lourenço et al. 2011, Grilo et al. 2012, Silva et al. 2012, Santos et al. 2013, Lourenço et al. 2015). As in the BBA2, we used 10 x10 km UTM squares as sampling units. To determine the distribution of owls during this period we used all records for resident and wintering species. For the Eurasian Scops-owl (breeding but absent in winter) we only included records from April to August. There was incomplete coverage of all census units during this period, and therefore we only considered 740 sampling units that had at least one owl record.

The fourth period (2015-2017) corresponded to the ongoing third breeding bird atlas (BBA3), which used 10 x10 km ETRS squares as sampling units. We used all owl data from the PortugalAves/eBird (atlas visits and additional records) and observations sent by NOCTUA-Portugal collaborators. When this paper was prepared this atlas had not been completed and therefore we only included those sampling units with at least one owl record (n = 581) in our analysis.

To estimate the changes in the distribution of owl species in Portugal over time we calculated the percentage of sampling units censused that contained owls for each period and then determined how this varied relative to those obtained in the immediately preceding period.

Results

The Common Barn-owl population and distribution both declined (Tables 1, 2; Figs. 1, 2). The Eurasian Scops-owl population had a non-significant decline (Table 1, Fig. 3), yet it had the largest loss in distribution relative to other owl species (Table 2, Fig. 4). The Eurasian Eagle-owl population had a slight non-significant increase (Table 1, Fig. 5), accompanied by small increase in its distribution (Table 2, Fig. 6). The Little Owl population had the steepest decline (Table 1, Fig. 7), and its distribution declined from the first to the third census periods and then stabilized (Table 2, Fig. 8). The Tawny Owl population had a non-significant decline (Table 1, Fig. 9), together with an overall small reduction in its distribution (Table 2, Fig. 10). The Northern Long-eared Owl population trend is unknown since it shows considerable fluctuations (Table 1, Fig. 11) while its distribution increased slightly (Table 2, Fig. 12). It was not possible to estimate the population trend of wintering Short-eared Owls due to insufficient data but its distribution stable for the latter two periods (Table 2, Fig. 13).

Figure 1 - Annual abundance estimates (number of breeding pairs per sampled 10 x10 km square with 95% confidence intervals) for the Common Barn-owl (*Tyto alba*) in the period 2010-2017 resulting from the NOCTUA-Portugal monitoring program.

Figura 1 - Estimativas da abundância anual (número de casais reprodutores por quadrícula 10 x 10 km amostrada e intervalos de confiança de 95%) para a coruja-das-torres (*Tyto alba*) no período 2010-2017 resultantes do programa de monitorização NOCTUA-Portugal.

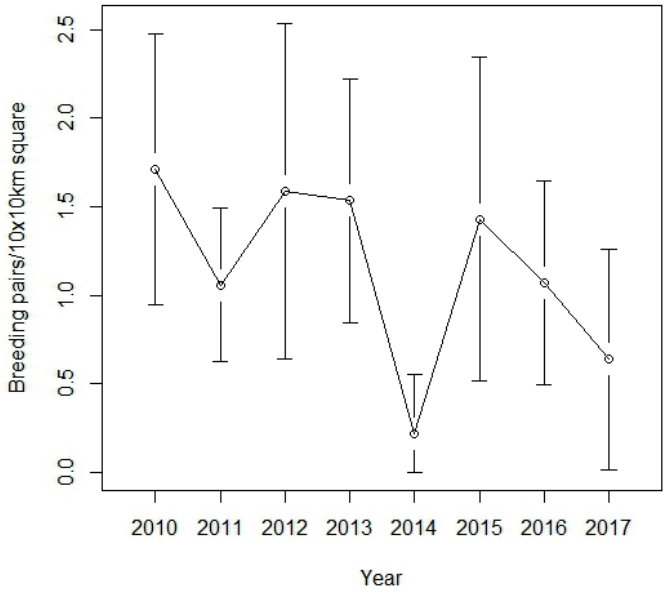


Figure 2 - Distribution of the Common Barn-owl (*Tyto alba*) in the four sampling periods: 1st breeding bird atlas BBA1 (1978-1984); 2nd breeding bird atlasBBA2 (1999-2005); period between 2nd and 3rd breeding bird atlases – inter-atlas (2006-2014); 3rd breeding bird atlas BBA3 (2015-2017).

Figura 2 - Distribuição da coruja-das-torres (*Tyto alba*) nos quatro períodos de amostragem: 1º atlas de aves nidificantes BBA1 (1978-1984); 2º atlas de aves nidificantesBBA2 (1999-2005); período entre o 2º e o 3º atlas de aves nidificantes – inter-atlas (2006-2014); 3º atlas de aves nidificantes BBA3 (2015-2017).

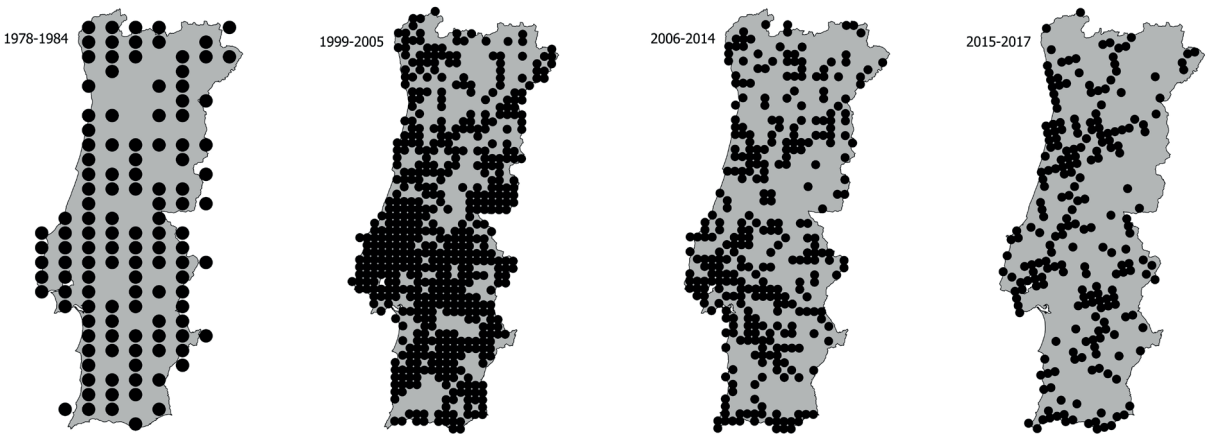


Figure 3 - Annual abundance estimates (number of breeding pairs per sampled 10 x10 km square with 95% confidence intervals) for the Eurasian Scops-owl (*Otus scops*) in the period 2010-2017 resulting from the NOCTUA-Portugal monitoring program.

Figura 3 - Estimativas da abundância anual (número de casais reprodutores por quadrícula 10 x 10 km amostrada e intervalos de confiança de 95%) para o mocho-d'orelhas (*Otus scops*) no período 2010-2017 resultantes do programa de monitorização NOCTUA-Portugal.

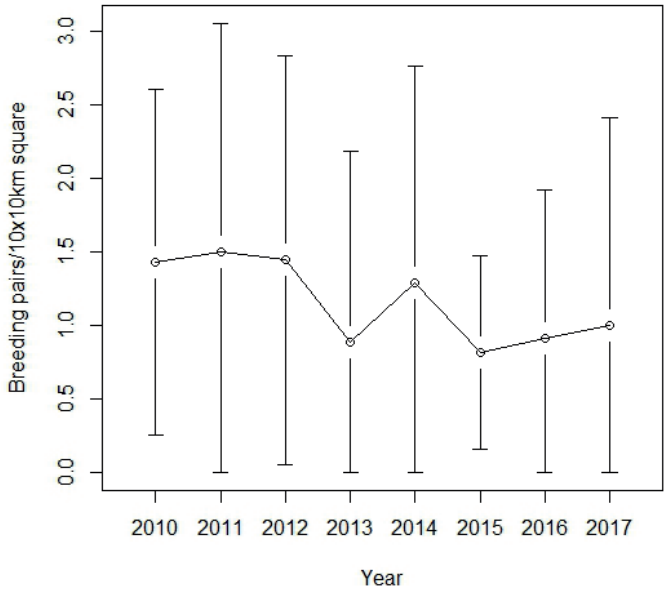


Figure 4 - Distribution of the Eurasian Scops-owl (*Otus scops*) in the four sampling periods: 1st breeding bird atlas BBA1 (1978-1984); 2nd breeding bird atlasBBA2 (1999-2005); period between 2nd and 3rd breeding bird atlases – inter-atlas (2006-2014); 3rd breeding bird atlas BBA3 (2015-2017).

Figura 4 - Distribuição do mocho-d'orelhas (*Otus scops*) nos quatro períodos de amostragem: 1º atlas de aves nidificantes BBA1 (1978-1984); 2º atlas de aves nidificantesBBA2 (1999-2005); período entre o 2º e o 3º atlas de aves nidificantes – inter-atlas (2006-2014); 3º atlas de aves nidificantes BBA3 (2015-2017).

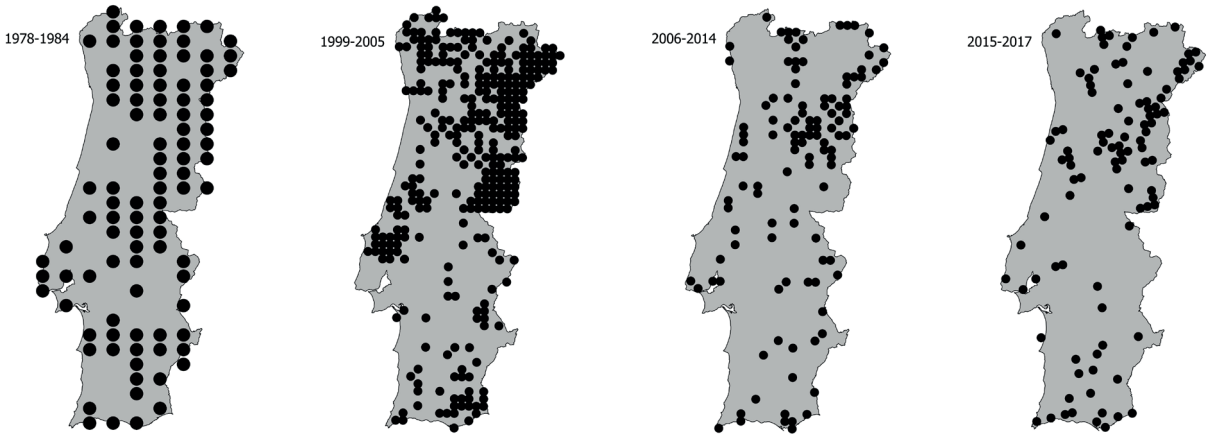


Figure 5 - Annual abundance estimates (number of breeding pairs per sampled 10 x10 km square with 95% confidence intervals) for the Eurasian Eagle-owl (*Bubo bubo*) in the period 2010-2017 resulting from the NOCTUA-Portugal monitoring program.

Figura 5 - Estimativas da abundância anual (número de casais reprodutores por quadrícula 10 x 10 km amostrada e intervalos de confiança de 95%) para o bufo-real (*Bubo bubo*) no período 2010-2017 resultantes do programa de monitorização NOCTUA-Portugal.

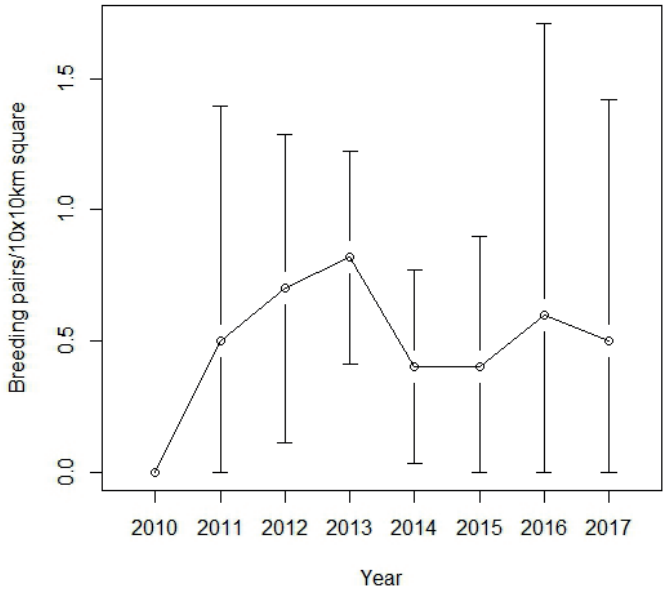


Figure 6 - Distribution of the Eurasian Eagle-owl (*Bubo bubo*) in the four sampling periods: 1st breeding bird atlas BBA1 (1978-1984); 2nd breeding bird atlasBBA2 (1999-2005); period between 2nd and 3rd breeding bird atlases – inter-atlas (2006-2014); 3rd breeding bird atlas BBA3 (2015-2017).

Figura 6 - Distribuição do bufo-real (*Bubo bubo*) nos quatro períodos de amostragem: 1º atlas de aves nidificantes BBA1 (1978-1984); 2º atlas de aves nidificantesBBA2 (1999-2005); período entre o 2º e o 3º atlas de aves nidificantes – inter-atlas (2006-2014); 3º atlas de aves nidificantes BBA3 (2015-2017).

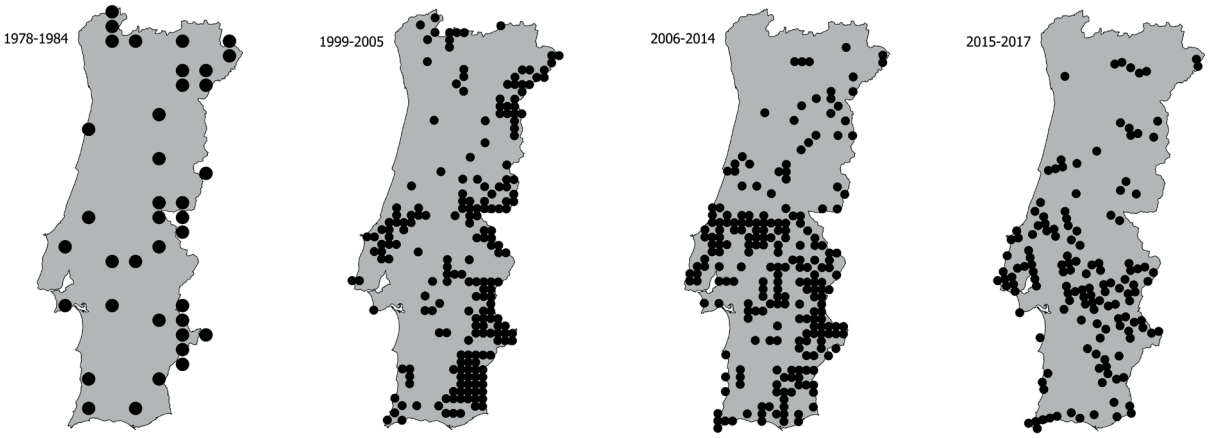


Figure 7 - Annual abundance estimates (number of breeding pairs per sampled 10 x10 km square with 95% confidence intervals) for the Little Owl (*Athene noctua*) in the period 2010-2017 resulting from the NOCTUA-Portugal monitoring program.

Figura 7 - Estimativas da abundância anual (número de casais reprodutores por quadrícula 10 x 10 km amostrada e intervalos de confiança de 95%) para o mocho-galego (*Athene noctua*) no período 2010-2017 resultantes do programa de monitorização NOCTUA-Portugal.

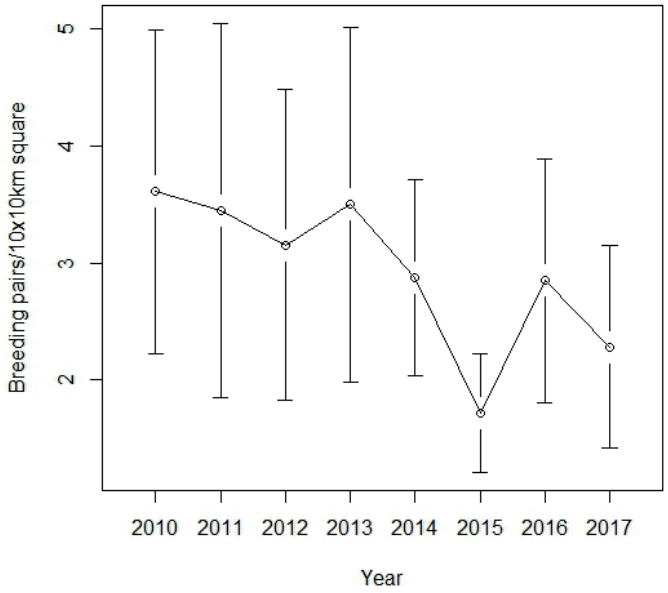


Figure 8 - Distribution of the Little Owl (*Athene noctua*) in the four sampling periods: 1st breeding bird atlas BBA1 (1978-1984); 2nd breeding bird atlasBBA2 (1999-2005); period between 2nd and 3rd breeding bird atlases – inter-atlas (2006-2014); 3rd breeding bird atlas BBA3 (2015-2017).

Figura 8 - Distribuição do mocho-galego (*Athene noctua*) nos quatro períodos de amostragem: 1º atlas de aves nidificantes BBA1 (1978-1984); 2º atlas de aves nidificantesBBA2 (1999-2005); período entre o 2º e o 3º atlas de aves nidificantes – inter-atlas (2006-2014); 3º atlas de aves nidificantes BBA3 (2015-2017).

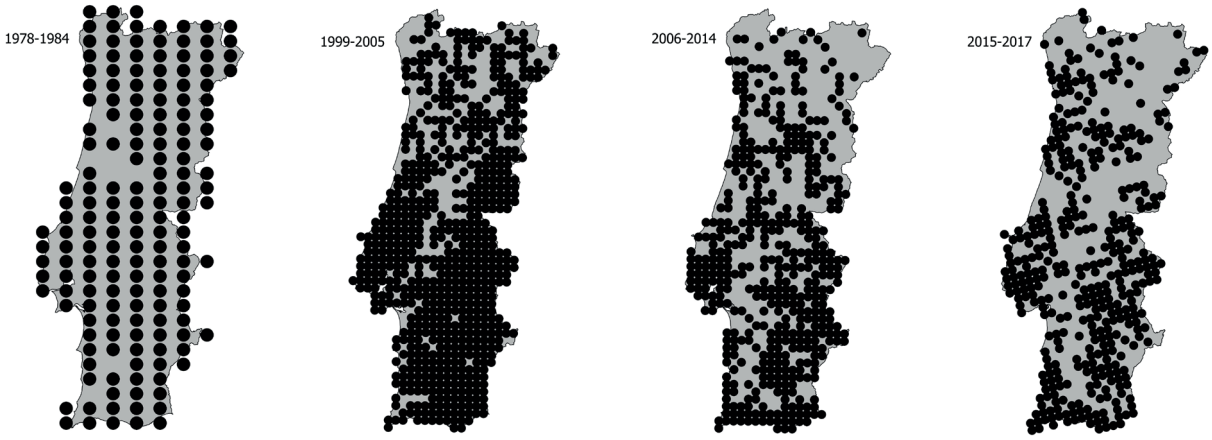


Figure 9 - Annual abundance estimates (number of breeding pairs per sampled 10 x10 km square with 95% confidence intervals) for the Tawny Owl (*Strix aluco*) in the period 2010-2017 resulting from the NOCTUA-Portugal monitoring program.

Figura 9 - Estimativas da abundância anual (número de casais reprodutores por quadrícula 10 x 10 km amostrada e intervalos de confiança de 95%) para a coruja-do-mato (*Strix aluco*) no período 2010-2017 resultantes do programa de monitorização NOCTUA-Portugal.

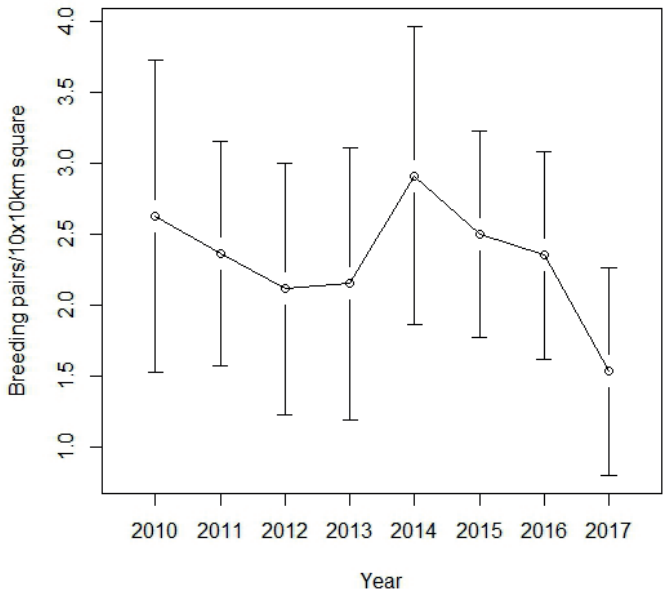


Figure 10 - Distribution of the Tawny Owl (*Strix aluco*) in the four sampling periods: 1st breeding bird atlas BBA1 (1978-1984); 2nd breeding bird atlasBBA2 (1999-2005); period between 2nd and 3rd breeding bird atlases – inter-atlas (2006-2014); 3rd breeding bird atlas BBA3 (2015-2017).

Figura 10 - Distribuição da coruja-do-mato (*Strix aluco*) nos quatro períodos de amostragem: 1º atlas de aves nidificantes BBA1 (1978-1984); 2º atlas de aves nidificantesBBA2 (1999-2005); período entre o 2º e o 3º atlas de aves nidificantes – inter-atlas (2006-2014); 3º atlas de aves nidificantes BBA3 (2015-2017).

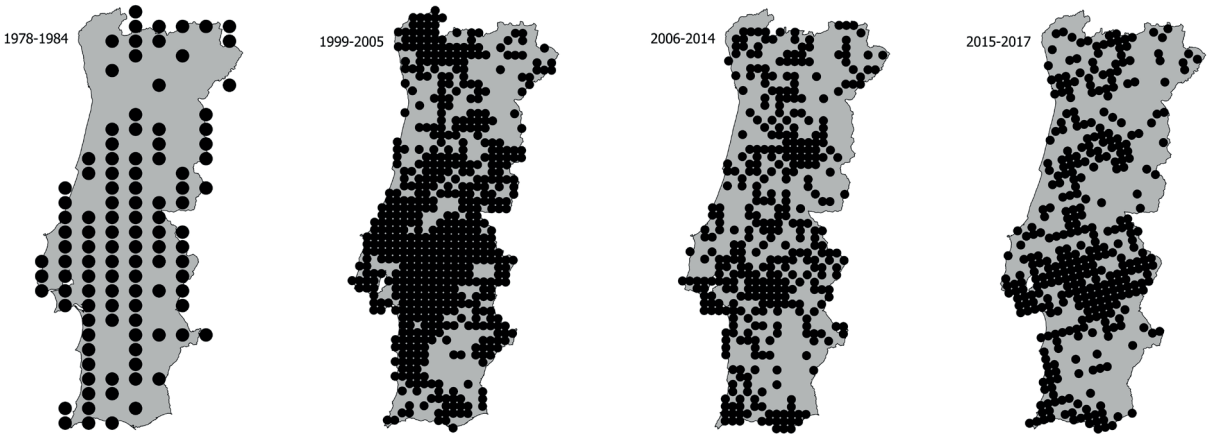


Figure 11 - Annual abundance estimates (number of breeding pairs per sampled 10 x10 km square with 95% confidence intervals) for the Northern Long-eared Owl (*Asio otus*) in the period 2010-2017 resulting from the NOCTUA-Portugal monitoring program.

Figura 11 - Estimativas da abundância anual (número de casais reprodutores por quadrícula 10 x 10 km amostrada e intervalos de confiança de 95%) para o bufo-pequeno (*Asio otus*) no período 2010-2017 resultantes do programa de monitorização NOCTUA-Portugal.

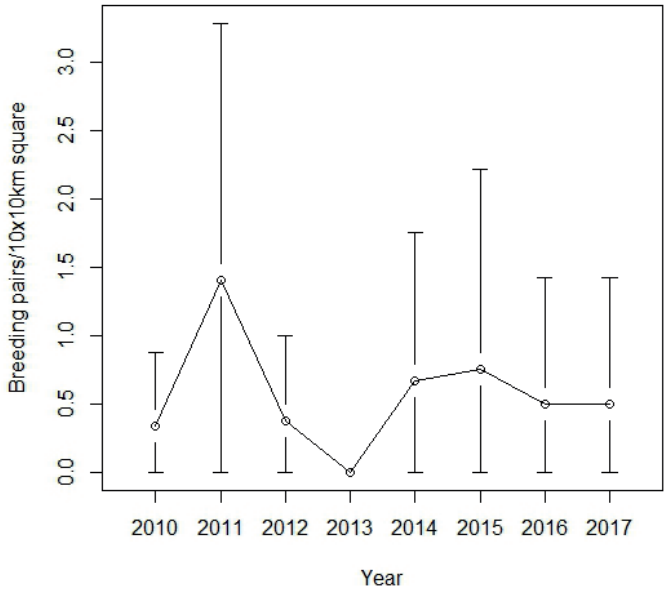


Figure 12 - Distribution of the Northern Long-eared Owl (*Asio otus*) in the four sampling periods: 1st breeding bird atlas BBA1 (1978-1984); 2nd breeding bird atlasBBA2 (1999-2005); period between 2nd and 3rd breeding bird atlases – inter-atlas (2006-2014); 3rd breeding bird atlas BBA3 (2015-2017).

Figura 12 - Distribuição do bufo-pequeno (*Asio otus*) nos quatro períodos de amostragem: 1º atlas de aves nidificantes BBA1 (1978-1984); 2º atlas de aves nidificantesBBA2 (1999-2005); período entre o 2º e o 3º atlas de aves nidificantes – inter-atlas (2006-2014); 3º atlas de aves nidificantes BBA3 (2015-2017).

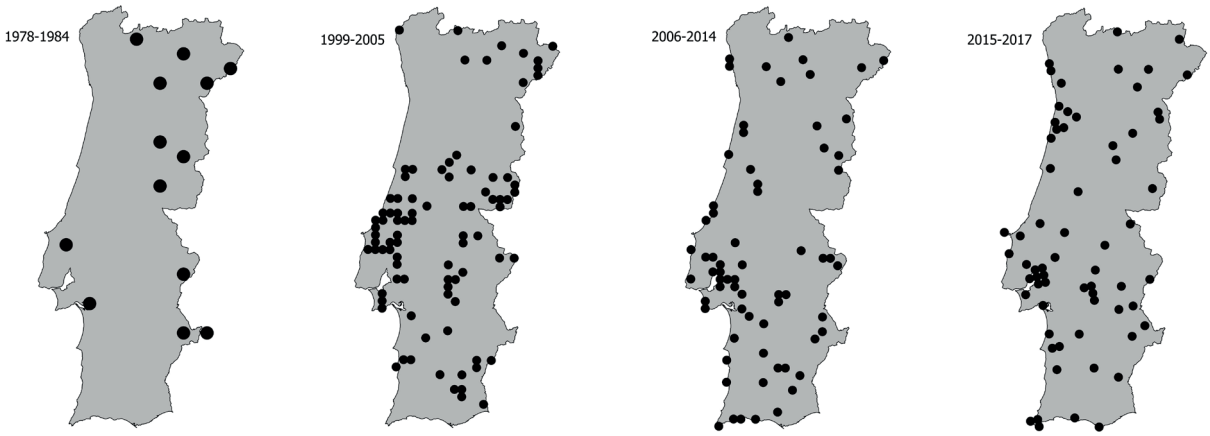
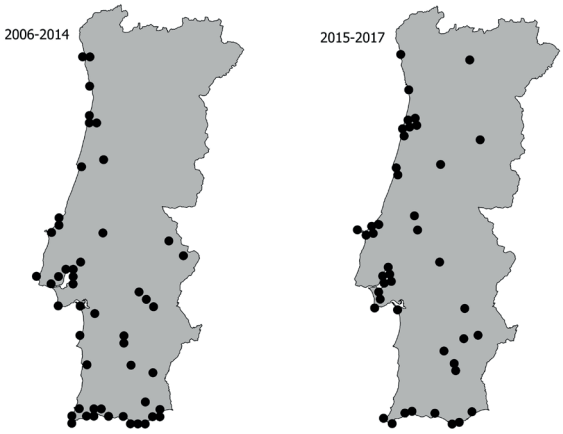


Figure 13 - Distribution of the Short-eared Owl (*Asio flammeus*) in two sampling periods: period between 2nd and 3rd breeding bird atlases – inter-atlas (2006-2014); 3rd breeding bird atlas BBA3 (2015-2017).

Figura 13 - Distribuição da coruja-do-nabal (*Asio flammeus*) nos dois períodos de amostragem: período entre o 2º e o 3º atlas de aves nidificantes – inter-atlas (2006-2014); 3º atlas de aves nidificantes BBA3 (2015-2017).



Discussion

Eight years of monitoring by NOCTUA-Portugal has provided a reasonable amount of information to estimate the short-term population trend of owls in continental Portugal. Owl population trend estimates were more reliable for the most common species, although even these should be interpreted with caution due to relatively low sampling effort. Our estimates are the most accurate available to date in Portugal. Owl population trend estimates reported here in were somewhat similar to those of NOCTUA-Spain (2006-2017; SEO/BirdLife 2018), suggesting that owl populations in the Iberian Peninsula are continuous and subject to similar threats.

Although the baseline information available to estimate long-term trends in owl distribution was relatively heterogeneous (different sampling unit size used in BBA1, and incomplete coverage in inter-atlas and BBA3), we consider that our results are an early warning for substantial distribution declines, as seen for the Common Barn-owl and Little Owl.

The Common Barn-owl is also declining in Spain (SEO/BirdLife 2018) and several other European countries (BirdLife International 2004, Burfield 2008). In Portugal, its decline may be due to changes in agricultural landscapes, namely conversion of traditional crops into intensive olive groves, irrigated fields and forestations (Lourenço et al. 2015). In contrast, in some interior areas, a reduction in human population resulted in abandoned agricultural land being replaced by scrubland less favourable to Common Barn-owls.

The slight decline of the Eurasian Scops-owl in Portugal appears to be consistent with the moderate decline shown in Spain (SEO/BirdLife 2018), although the overall population trend in Europe remains unknown (BirdLife International 2004, Burfield 2008). The Eurasian Scops-owl may also be negatively affected by the intensification in agricultural practices. This has been more pronounced in southern Portugal, coinciding with where the distribution of the Eurasian Scops-owl seems to be shrinking the most

(Lourenço et al. 2015).

The slight increase in the Eurasian Eagle-owl population in Portugal is consistent with the concurrent trend in Spain (SEO/BirdLife 2018) and in most western European countries, where the species is recovering after a large historical decline (BirdLife International 2004). In Portugal, it may be benefiting mostly from a decrease in human persecution resulting from greater environmental awareness and rural depopulation.

The decline of the Little Owl in Portugal is in line with its decline in Spain and in most European countries (Burfield 2008, van Nieuwenhuyse et al. 2008, SEO/BirdLife 2018). The main cause behind its negative status in Portugal seems to be nesting habitat loss and decreased prey availability due to agriculture intensification.

The non-significant decline of the Tawny Owl suggested it may be stable in Portugal, which is consistent with its estimated status in Spain and throughout most European countries (BirdLife International 2004, SEO/BirdLife 2017). The apparently stable long-term population trend of the Tawny Owl in Portugal (Lourenço et al. 2015) may start to decline due to degradation and management changes in habitat, e.g., in montado landscapes, shaped by human activity (Pinto-Correia & Godinho 2013). Tawny Owls are also frequent victims of collision with vehicles in Portugal (Santos et al. 2013), therefore current increases in vehicle use may also contribute to future population declines.

Large annual fluctuations in abundance associated with the very small distributional increase and relative scarcity make population estimates for the Northern Long-eared Owl unreliable. For similar reasons, the status of the Northern Long-eared Owl in Spain is unknown (SEO/BirdLife 2017), whereas across Europe it seems stable (Burfield 2008). Due to its cryptic behaviour and low abundance, a longer monitoring period and/or monitoring scheme with a much larger sampling effort or a species-specific census method is required to produce a more accurate estimate of its population and distribution trend.

The Short-eared Owl occurs in Portugal in winter concentrations mostly in large wetlands along the coast, therefore a specific and coordinated census in this habitat is required to obtain a population estimate. Still, its wintering distribution area seems stable, at least in the last decade. Likewise, its population census estimate was not available in NOCTUA-Spain, but in Europe its trend is apparently stable (Burfield 2008).

The current monitoring scheme and the bird atlases in Portugal have gathered important information on the population and distribution trends of owl species. NOCTUA-Portugal is a long-term monitoring program that will produce more reliable trends for owls and other nocturnal birds over time. Such data, combined with habitat, landscape management and other information, can be used to address and mitigate threats to owls to further their conservation in Portugal.

Acknowledgments

We are indebted to the crucial contribution of GTAN-SPEA and NOCTUA-Portugal collaborators; CERVAS and RIAS wildlife rehabilitation centres from ALDEIA; the participants in bird atlas, and all birdwatchers that made their records available on Portugal/eBird. Thanks to Andrew Coughlan, James Duncan, and Todd Whiklo for reviewing the manuscript.

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A review on the captive propagation and conservation of the Western Burrowing Owl (*Athene cunicularia hypugaea*) in British Columbia, 1983-2017

Revisão sobre a reprodução em cativeiro e conservação da coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) na Colúmbia Britânica, 1983-2017

Lauren Meads[1*], Aimee Mitchell[2], Mike Mackintosh[3]

1 The Burrowing Owl Conservation Society of BC, 132 Hemlock Av, Kaleden, BC V0H1T0, Canada

2 Athene Ecological, 4-2422 Hawthorne Ave, Port Coquitlam, BC V3C 6K7, Canada

3 The Burrowing Owl Conservation Society of BC, 118-119 west 22nd Street, North Vancouver, BC V7L1L7, Canada

*** Corresponding author:** lmeads81@gmail.com



ABSTRACT

The Western Burrowing Owl (*Athene cunicularia hypugaea*), is a Species at Risk in Canada and was extirpated from British Columbia (BC) in the 1980s. In Canada, populations of Burrowing Owls migrate southwards in the fall and winter to Mexico and the southern United States. With a loss or degradation of native habitat, both in nesting and overwintering grounds, along with the decline in fossorial mammals, and the possible effects of climate change, Burrowing Owl populations continue to decrease in BC and Canada. In 1990, volunteers initiated a comprehensive re-introduction program, including three captive breeding facilities, artificial burrow networks and field monitoring research. The Burrowing Owl Conservation Society of BC (formed in 2000) produces over 100 owls each yr to release in the Thompson-Nicola and South Okanagan grasslands of BC. Artificial burrows are installed on private ranch land, provincial land, Non-government Organization properties, and indigenous lands. Improved release techniques, including soft-release caging, have resulted in higher adult survival and greater numbers of wild-hatched offspring. Recent years have seen an increase in the rate of returning owls, however BC still does not have a self-sustainable population. Our next step is to work on understanding their migratory movements and needs to increase survivability. This will involve working across Canada and internationally.

Keywords: *Athene cunicularia hypugaea*, captive breeding, migration, reintroduction, soft release

RESUMO

A coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) é uma espécie em risco no Canadá e extinta na Colúmbia Britânica (BC) na década de 1980. No Canadá, as populações de corujas-buraqueiras migram para sul no outono, e no inverno migram para o México e para o sul dos Estados Unidos. Com a perda ou degradação do habitat nativo, tanto nas áreas de reprodução como de invernada, juntamente com o declínio de mamíferos fossoriais e os possíveis efeitos das mudanças climáticas, as populações de coruja-buraqueira continuam a diminuir na BC e no Canadá. Em 1990, um grupo de voluntários iniciou um programa abrangente de reintrodução, incluindo três instalações de reprodução em cativeiro, redes de tocas artificiais e monitorização no campo. A *Burrowing Owl Conservation Society* de BC (fundada em 2000) produz mais de 100 corujas por ano para serem libertadas nos campos de Thompson-Nicola e South Okanagan em BC. As tocas artificiais são instaladas em terrenos particulares, em terrenos estatais, em propriedades de organizações não governamentais e em territórios indígenas. Técnicas de libertação aperfeiçoadas, incluindo gaiolas de libertação gradual, contribuíram para o aumento da sobrevivência dos adultos e a produção de um maior número de juvenis selvagens. Nos últimos anos, houve um aumento na taxa de retorno de corujas, no entanto, a BC ainda não possui uma população autossustentável. O nosso próximo passo é estudar os seus movimentos migratórios e as suas necessidades, com objetivo de promover a capacidade de sobrevivência. Para tal, o trabalho terá de abranger todo o Canadá e também outros países.

Palavras-chave: *Athene cunicularia hypugaea*, libertação gradual, migração, reintrodução, reprodução em cativeiro

Introduction

The distribution of the Burrowing Owl (*Athene cunicularia*) has contracted in Canada in recent decades, and they currently breed in the grasslands of Saskatchewan, Alberta, and Manitoba. Historically, they were found in the grasslands of the Thompson-Nicola region and the South Okanagan of British Columbia (BC). In early fall (September and October); the Canadian owls migrate to their overwintering areas in the southern United States and Mexico (Holroyd et. 2001, Wellicome et al. 2014). These owls return to their breeding grounds in BC in March and early April.

In Canada they are endangered, and in British Columbia they were deemed extirpated in the 1980s (Blood and Low 1998). Populations in Alberta and Saskatchewan are still decreasing, and the population in Manitoba was also deemed extirpated in the late 1990s (DeSmet 1997).

There are many potential reasons for declines in Burrowing Owl populations. Some of the more commonly accepted are: loss of habitat due to land development, loss of rodent and insect prey species possibly due to agricultural spraying; and the loss of burrowing animals (badgers, ground squirrels, marmots) which dig the holes Burrowing Owls utilize. In BC at least, survival of owls released in the breeding areas seems reasonably good, but there are apparently large losses during migration, as few birds return in subsequent years. The multiple factors deemed likely responsible for the decline of this species, when combined with possible effects of climate change, make this a complex, multi-national conservation issue.

Methods

In the early 1990s a group of dedicated volunteers led by Mike Mackintosh initiated a captive breeding and reintroduction program for Burrowing Owls in BC. In 2000, the Burrowing Owl Conservation Society of BC (BOCS) was established to facilitate recovery through captive breeding, field activities, education programs and increasing scientific knowledge.

As of 2017 the society monitors 14 active release properties located on private ranch land, provincial crown land, The Nature Conservancy of Canada, The Nature Trust of BC and indigenous lands all located between Kamloops and Merritt, and in the South Okanagan.

Breeding Facilities

The first release of captive-bred owls in BC occurred in 1992 when nine owls were placed into artificial burrows in the Thompson-Nicola region. The breeding and release program has flourished over the last 20 yr, and now close to 50 pairs of young owls are released each year in the Thompson-Nicola and the South Okanagan. Three breeding facilities are found in distinct geographically separate areas in BC to maintain capacity, and to provide additional protection for the limited gene pool of breeding birds.

Genetics, Sexing and Breeding

A stud book is used to help maintain the genetic diversity of owls released to the wild by documenting and recommending pairing of Burrowing Owls in the captive facilities. Wild owls from Washington and Oregon that have been brought in over the years for the purpose of breeding stock and are not released. A few days before the April release, all of the one yr-old male and female owls are caught up to be processed for release (See Processing and Banding section).

Our female breeders are generally productive from one yr-old up to about 7 yr-old, after which the production of eggs decreases dramatically. Males can keep breeding well into old age, which can be 10-12 yr old (Mackintosh et al. 2004).

Processing and Banding

An aluminum green over black alpha numeric band (Acraft Sign and Nameplate Company, Edmonton, Alberta) is placed on the right leg of all released burrowing owls. In April, all of the owls from all of the facilities are brought together, examined, weighted, and paired up for release. Once assessed to be suitable for release, an aluminum U.S. Geological Survey band is placed on the left leg. Each owl is paired with a suitable mate and designated a burrow for release.

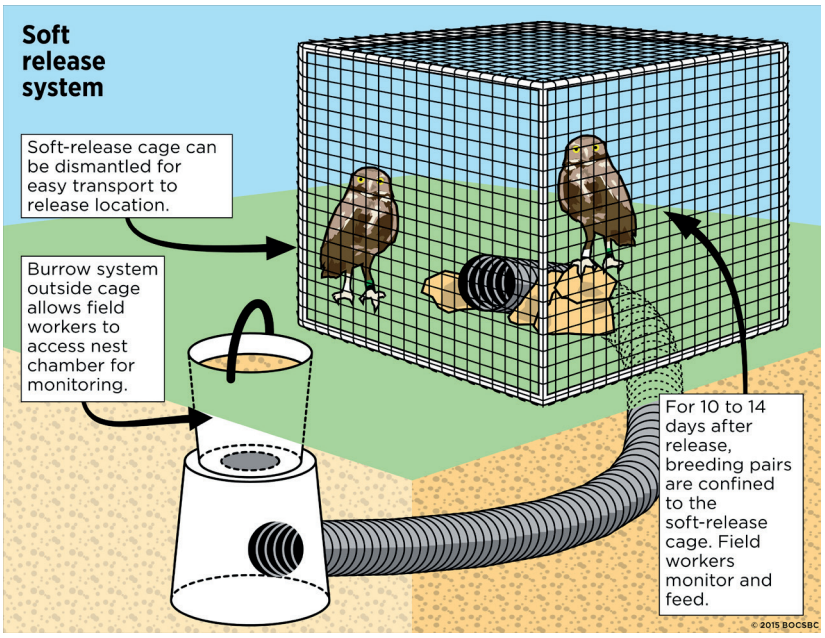
Burrow construction and installation

Most Burrowing Owl recovery strategies take into account the possible need to provide burrows, the perspective being that natural burrows are limited. With the general decline in BC of many fossorial mammals the presumption is that there is a lack of natural burrow systems. Since 1991, the society has built and installed over 800 artificial burrows. The artificial burrow system is constructed using landscaping buckets (#10 Listo Product 38 L) and 3 m long 'Big-O' (15.2 cm diameter) pipe buried (about 0.7 m) in the ground.

Only the entrance to the tunnels and the top of the landscaping bucket are visible above ground. The top of the bucket system can be removed so that the nest chamber can be easily accessed. Burrows are placed in groups of two or three in close proximity, with other groupings being placed approximately 200 m away. All burrows have individual numbers painted on the top lids with matching metal tags on the pipe. The GPS coordinates for each burrow are recorded for mapping and relocation.

Figure 1 - Graphic of burrow system design and soft-release cage (Graphic by Nick Murphy)

Figura 1 - Representação gráfica de um sistema de toca e gaiola de libertação gradual (ilustração de Nick Murphy).



Release techniques

Hard release

In a hard release, yearling owl pairs were placed inside the nest chambers of artificial burrows in which the outer entrances have been blocked and retained there overnight (Leupin and Low, 2001). Owls were released simply by unblocking their burrowing entrances the next day (Mitchell 2008).

Soft release

Soft release involves placing predator-proof enclosures over the artificial burrow in April shortly before the placement of owls at the release sites. The structure is a 1.2×1.2×1.2 m enclosure made with a 12.7 mm PVC pipe frame. Covered with strong nylon mesh (2.5 cm x 2.5 cm) and attached to the ground with 12 cm long spikes, thus securing the cage and also preventing any predators from accessing the cage. Because some enclosures can be destroyed by cattle, electric fencing is used in areas with cattle, set back approximately 1 m from the enclosure. Electric fencing proved to be a safe and effective cattle deterrent.

Pairs are placed inside artificial burrows, in the same manner as in hard releases, with enclosures already installed. Burrow entrances are blocked for the same period of time as in hard releases (overnight). Enclosures are removed approximately 10-14 days after pairs were placed in the enclosures (Fig 1). We consider this a minimum for enclosure time and longer duration is being evaluated with other studies. In 2005 and 2006, both hard-release and soft-release techniques were used equally among the various release sites, ensuring that the two treatments were spatially interspersed and could be compared. Survival and productivity of soft-released birds was about twice that of hard-released birds as of 2007 (Mitchell 2008). Now all birds are soft-released, unless one is needed as a mate for returning birds. In that case, selected birds are hard-released near the burrow occupied by a known returning bird.

Table 1 - Number of Released and Recruited Burrowing Owls in British Columbia, Canada from 1992-2017 (adapted from Mitchell, 2008).
* The number of owls that returned from migration each year
** Years employing the soft-release method

Tabela 1 - Número de corujas-buraqueiras libertadas e recrutadas na Colúmbia Britânica, Canadá, em 1992-2017 (adaptado de Mitchell 2008).

YEAR	NO. RELEASED	NO. PRODUCED	TOTAL NO. RECRUITED TO POPULATION*	WILD-HATCHED JUVENILES PRODUCED PER OWL (CAPTIVE + RECRUITED)
1992	9	0	0	0.00
1993	15	0	0	0.00
1994	21	10	1	0.45
1995	18	11	3	0.52
1996	21	5	2	0.22
1997	24	2	0	0.08
1998	37	7	2	0.18
1999	34	3	2	0.08
2000	33	16	2	0.46
2001	71	60	7	0.77
2002	46	45	7	0.85
2003	29	13	8	0.35
2004	53	46	9	0.74
2005**	81	103	10	1.13
2006**	91	130	15	1.23
2007**	120	200	18	1.45
2008**	116	132	16	1.00
2009**	103	213	15	1.81
2010**	99	168	23	1.38
2011**	89	259	19	2.40
2012**	81	167	21	1.64
2013**	84	130	15	1.31
2014**	100	191	17	1.63
2015**	67	189	50	1.62
2016**	53	160	40	1.72
2017**	96	183	27	1.49

Supplemental feeding

The diets of released owls in the soft-release cages are supplemented every 3–4 days during regular nest visits, with the equivalent of 1.5 food items (frozen laboratory mice, *Mus musculus,* and domestic chicks, *Gallus gallus domesticus*), averaging 42.5 g per adult per day, from immediately after placement in burrows through to fledging of chicks, which is defined as 28–35 days-post-hatch. Although the pairs not housed in enclosures are free to hunt for natural prey items, both groups are provided equivalent amounts of supplemental food. After fledging, only one food item per bird observed is provided at each visit. Once the wild-hatched juveniles of the released owls reach 4-5 wk-old they are banded with a U.S. Geological Survey aluminum band and a metal green/black alpha-numeric (Acraft) band (Mitchell 2008).

Results

Survival and Productivity of released owls

The use of the soft release technique (or enclosure-based soft-releases) showed that owls released in this manner were more likely to survive and produce offspring (Table 1). The average breeding season survival (e.g., April to August) of released owls after the introduction of the soft-release method in 2005 increased from 50% for hard-released birds to 70% for soft-released birds. Productivity of released owls also increased by 40% for clutches initiated, 26% for eggs hatched, and 16% for juveniles fledged (Mitchell et al. 2011). Since 2005, the number of juveniles produced per released bird has ranged from 1.0 up to 2.4 (Table 1).

Returning and Migrating Owls

Returning Owls

Since 1992, 329 Burrowing Owls have returned to release sites. Summary from work comparing soft- and hard-release birds from 2005-2007 showed that more offspring from soft-release pairings returned than those from hard-release. From 2005-2007, 0.17 offspring were recruited into the local wild breeding population per soft-released pair, compared to 0.05 local recruits per hard-released pair (Mitchell et al. 2011). Over these years of study, wild-hatched offspring also returned at a higher rate than captive-hatched owls.

Sightings of Migrating Owls

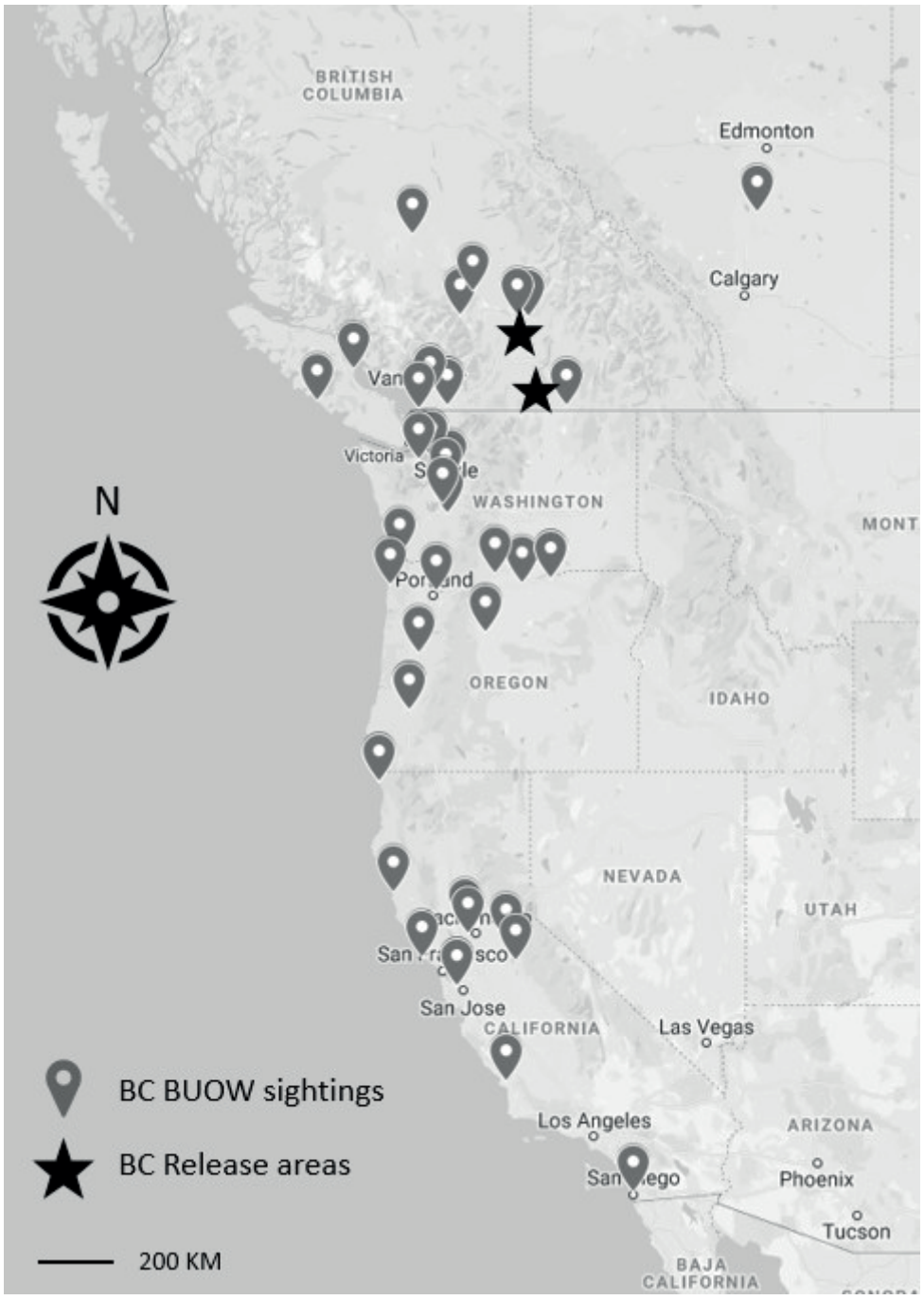
From 1989 to 2017, 47 BC Burrowing Owls have been encountered within BC and throughout the coastal western US, with most encounters occurring in October and November. While most owls were encountered once, two owls were encountered two years in a row. The furthest sighting has been reported in San Diego, California, very close to the Mexican border at 1,960 km; the average distance to encounter was 627 km. Evidence from encounters appears to indicate a selection for a coastal rather than an interior migration route for BC Burrowing Owls (Fig. 2). Results also show that wild-hatched owls (32 of 47; 68%) were more frequently encountered than captive-hatched owls (9 of 47; 20%). There were 6 (6 of 47; 13%) owls that were not able to be defined as their band numbers were not able to be read, however they were confirmed to have green over black bands (BC specific).

Comparisons to other areas

From USGS Bird Banding Laboratory data, for the period of 1 January 1992 through to 31 December 2017, a total of 42,163 Burrowing Owls were banded; during this same time a total of 428 (1.02%) banded owls were 'encountered' (e.g., band recoveries, re-sightings, etc.) (David H. Johnson pers. comm. 2019). For banded owls released and wild-hatched in British Columbia from 1992-2017, 375 (46 sighted during 1992 to 2014

Figure 2 - Encounters (band re-sights and recoveries) of 47 British Columbia Burrowing Owls from 1989 to 2017.

Figura 2 - Registos (recapturas visuais de anilhas e recapturas de aves) de 47 corujas-buraqueiras na Colúmbia Britânica de 1989 a 2017.



migration and 329 returned to release sites from 1992 to 2017) out of 4,034 or 9.3% were encountered. Juvenile return rates in particular appear higher in BC owls, with 71 of 1,797 (3.95%) banded juveniles returning to the Regina Plain area of Saskatchewan from 1992 to 2001 and 7 of 121 (5.78%) in the study years 2005-2007 in BC (Troy Wellicome pers. comm. 2017, Mitchell et al. 2008).

Discussion

Restoring imperiled species is a complex and difficult task which implies growing scientific basis for wildlife reintroductions, including captive breeding and release (Jachowski et al. 2016). In terms of owls, captive breeding and release is uncommon thus far. For example, the Northern Spotted Owl Breeding Programme in BC is currently perfecting the breeding process and has yet to release any individuals (Jasmine McCulligh pers. comm. 2018). In Manitoba, although currently on a small scale (n>15), efforts are being made in an attempt to increase Burrowing Owl breeding, and there are hopes of improved funding and release opportunities (Alexandra Froese pers. comm. 2019). In Europe there has been successful breeding and releasing of Ural Owls into the forests of Germany (Ingrid Kohl pers. comm. 2018).

The longest running captive breeding and release program for Burrowing Owls in North America has been with the Burrowing Owl Conservation Society of BC. Many years have been spent developing multi-faceted approaches to applied conservation. The society continues to be successful at producing and releasing captive-hatched owls (n=100) and improving released owl survival, nesting success, and the number of wild-hatched young produced. Some of the methods developed and improved upon through the years in BC are being utilized in other translocation and conservation programs, e.g., captive breeding methods as well as design of artificial burrow design, installation and maintenance. Translocation and release programs in California, Arizona, Florida, Minnesota, Oregon, Manitoba and Alberta have benefited from this program.

Ongoing Burrowing Owl recovery work in BC will focus on continuing to monitor and survey released and returning owls, increasing our knowledge of their migration route, identifying factors contributing to decline, working cooperatively to implement mitigation measures on a continental scale, expanding public education about grassland ecology, and supporting landowners in their stewardship efforts. Future effort will include greater scientific analyses of the program and how it fits into the overall recovery of the Burrowing Owl in North America.

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Impact of the environment on the number of Tawny Owl (*Strix aluco*) territories in beech forests, Slovakia

Impacto do ambiente no número de territórios de coruja-do-mato (*Strix aluco*) em florestas de faia, Eslováquia

Vladimír Nemček[1,2*]

1 Raptor Protection of Slovakia, Trhová 54, 841 01 Bratislava, Slovakia

2 Saola - Conservation Biology, Ľubovníková 34, 841 07 Bratislava, Slovakia.

*** Corresponding author:** nemcek@dravce.sk



ABSTRACT

It is important to know the impact of the environmental parameters for the effective conservation of forest owls. This study aims at a better understanding of the relationship between an opportunistic predator - the Tawny Owl (*Strix aluco*) and the environment in typical beech forests in Slovakia. Our study area covers 44 km^2 in the oak-beech forests of the Malé Karpaty mountains, Slovakia. Altogether 11 squares were selected for research in the vicinity of the city of Bratislava. Eight 2x2 km squares Tawny Owl territories were recorded using overnight audio recordings. In three squares owls were counted during night visits with playback. These were recorded during the autumn and spring in 2013-2016. 34 territories were recorded in the samples squares (mean = 3.1 terr./survey square, or 0.77 terr./km^2). The relationship between the environment and the number of territories was examined using the following parameters: old forest cover, length of the watercourses, area of forest loss, elevation and forest management category. Results showed no significant relationships between these selected parameters and the number of Tawny Owl territories. This study supports the idea of Tawny Owl as plastic species with a wide ecological niche, even in typical beech forests in Slovakia.

Keywords: density, forest management, habitat, population, *Strix aluco*

RESUMO

O conhecimento do impacto de parâmetros ambientais é importante para a conservação efetiva de rapinas noturnas florestais. Este estudo pretende compreender a relação entre um predador oportunista – a coruja-do-mato (*Strix aluco*) e o ambiente em florestas de faia típicas da Eslováquia. A área de estudo compreende 44 km^2 de florestas de carvalhos e faia nas montanhas de Malé Karpaty, Eslováquia. Foram registados os territórios de coruja-do-mato em onze quadrículas de 2x2 km através de gravações de áudio noturnas. Em três quadrículas, as corujas foram contadas em visitas noturnas com emissão de vocalizações conspecíficas. A monitorização decorreu no outono e na primavera, entre 2013 e 2016. Foram registados 34 territórios nas quadrículas amostradas (média = 3,1 territórios/quadrícula, ou 0,77 territórios/km^2). A relação entre o ambiente e o número de territórios foi analisada através dos seguintes parâmetros: cobertura de floresta antiga, comprimento de linhas de água, perda de área florestal, altitude e categoria de gestão florestal. Os resultados revelaram que não existem relações significativas entre os parâmetros selecionados e o número de territórios de coruja-do-mato. Este estudo suporta a ideia de que coruja-do-mato é uma espécie plástica com um nicho ecológico amplo, mesmo em florestas de faia típicas da Eslováquia.

Palavras-chave: densidade, gestão florestal, habitat, população, *Strix aluco*

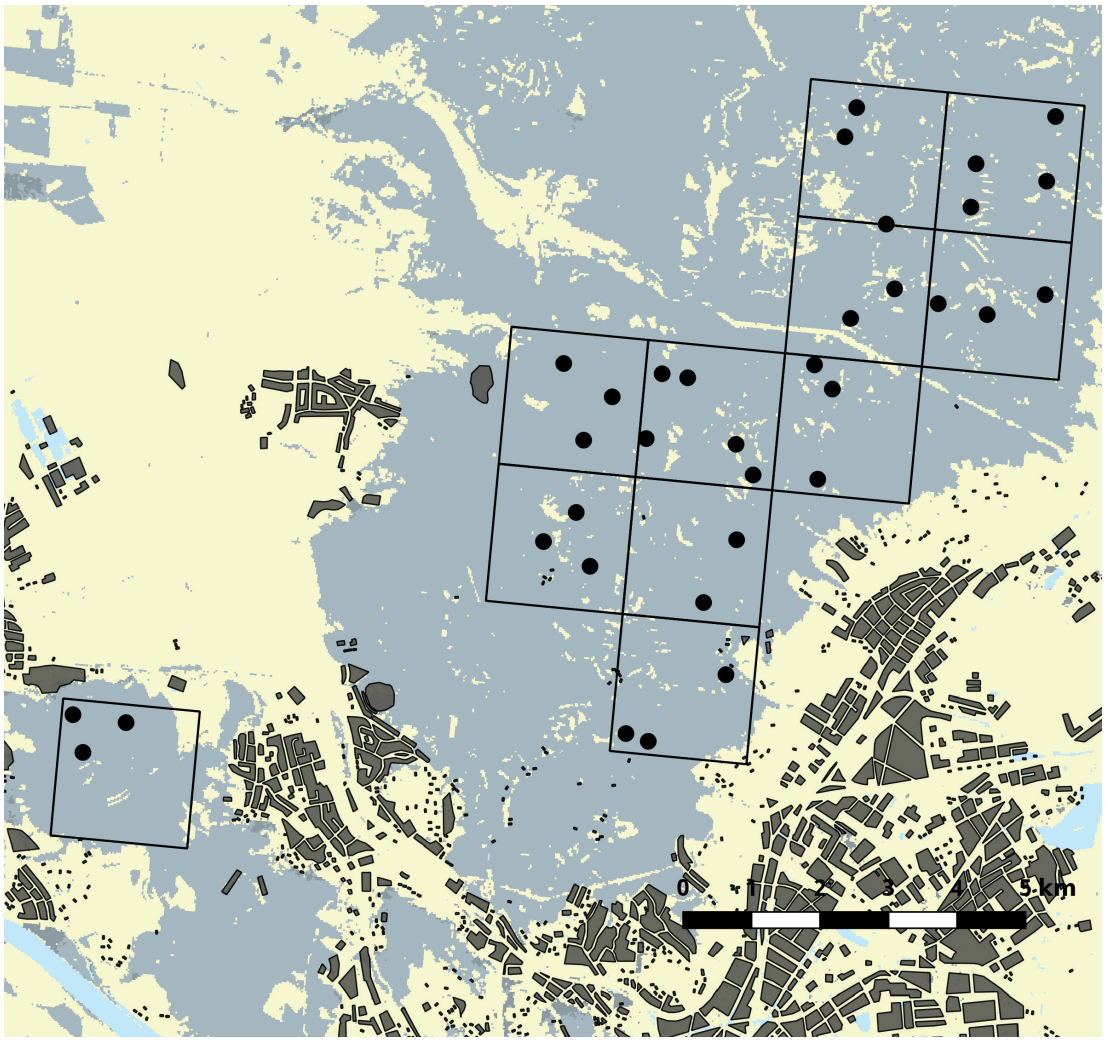
Introduction

Tawny Owl (*Strix aluco*) is a common owl species occupying especially deciduous and mixed forests (Mikkola 1983) and is distributed across most European countries. It is a cavity dweller, but when appropriate cavities are lacking nestboxes and nests of other birds are occupied (Galeotti 2001). One of the key topics of its conservation science is to understand how the species are influenced by the environment (Laurance 2010). Forest species are often related to the parameters like age of the trees (Poulsen 2002), cover of forest (Villard et al. 1999, Bélisle et al. 2001), forest fragmentation (Robinson et al. 1995, Fahrig 2003) or forest management (Martin & Eadie 1999). Since main parts of forests in Europe are managed for wood production (de Rigo et al. 2016), effective conservation measures need to be identified and understood leading to the key environmental parameters for the species.

Although the habitat and forest characteristics inhabited by Tawny Owls were researched in a multitude of studies, there is a lack of information about the influence of the environment within mainly beech forests. This is a dominant type of the forest habitat in Slovakia (Paule 1994). In this study we study the territory density of Tawny Owl in the mixed oak-beech and beech forests in Slovakia and the possible relationship of the number of territories with specific environmental parameters.

Figure 1 - Map of the study area with eleven 2x2 km squares and centres of Tawny Owl (*Strix aluco*) territories (points).

Figura 1 - Mapa da área de estudo com onze quadrículas de 2x2 km e centros dos territórios de coruja-do-mato (*Strix aluco*).



Methods

The study area covers 44 km² (Fig. 1) in Malé Karpaty mountains (Slovakia). These mountains are part of the Carpathian mountain system. A square (2x2 km) from the square network covering the area of Slovakia was defined as a basic unit. Altogether 11 squares were selected for the research in the vicinity of the city of Bratislava. All squares were located in the southern part of the mountains (lat:48.233303, long:17.118257). Habitats of the study area dominantly consisted of beech (*Fagus*), oak (*Quercus*) and hornbeam (*Carpinus*). Human settlements are limited to the edge of the mountains. Part of the study area was affected by the wind calamities in previous years (2004 and 2010). The squares were counted using audio recorders (8 squares) and night visits (3 squares) during the autumn and spring of 2013 - 2016. The owls were recorded from points (recorders -

Table 1 - Descriptive statistics of environmental parameters in the eleven 2x2 km squares beech forest (Slovakia).

Tabela 1 - Estatísticas descritivas dos parâmetros ambientais em onze quadrículas de 2x2 km em floresta de faia (Eslováquia).

CATEGORY	MEAN	SD	MIN	MAX
Length of the watercourses (km)	3.91	1.64	1.08	5.90
Area of the forest loss (ha)	18.41	14.25	0.04	43.43
Area of the economic forest (ha)	94.71	109.11	0.00	367.77
Mean elevation (m)	417.69	60.64	321.72	516.10
Area of the old forest (>100 years) (ha)	100.85	63.27	37.91	212.23

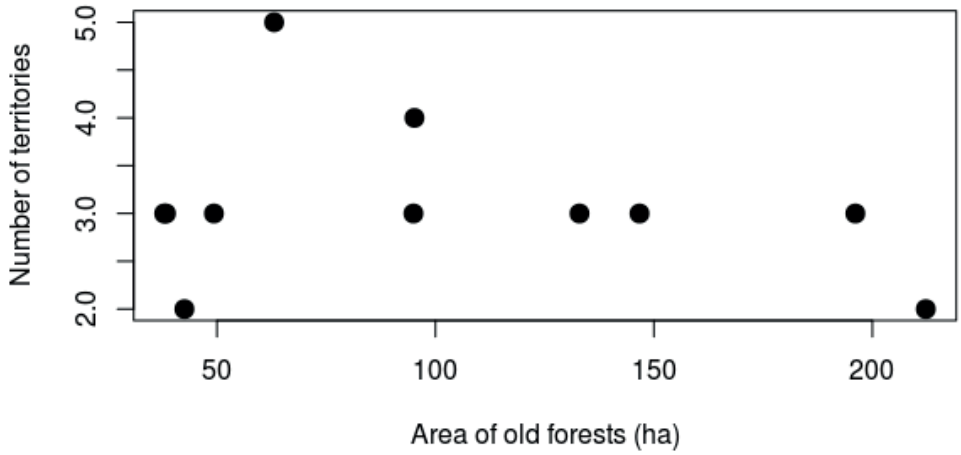
Table 2 - The relationship between environmental parameters and the number of Tawny Owl (*Strix aluco*) territories using GLM (Poisson distribution).

Tabela 2 - Relação entre os parâmetros ambientais e o número de territórios de coruja-do-mato (*Strix aluco*) com base em GLM (distribuição de Poisson).

	DEGREES OF FREEDOM	ESTIMATE	STD. ERROR	Z VALUE	PROBABILITY > Z
Area of the old forests	10	-0.001	0.003	-0.381	0.703
Length of the watercourses	10	0.000	0.000	0.203	0.839
Area of the forest loss	10	0.000	0.000	0.160	0.873
Area of the economic forests	10	-0.001	0.002	-0.545	0.586
Mean elevation	10	0.000	0.003	0.041	0.967

Figure 2 - Relationship between the number of Tawny Owl (*Strix aluco*) territories and the area of old forests using GLM (Poisson distribution).

Figura 2 - Relação entre o número de territórios de coruja-do-mato (*Strix aluco*) e a área de floresta longeva com base em GLM (distribuição de Poisson).



3-4 per square, night visits - 2-3 per square) spread across each square. During the night visits owls were counted during the calm night from points (each point separately for 45 minutes after sunset) with the call imitation (first 5 minutes, repeated after 10 minutes). The count of squares by night visits was repeated three times for more accurate results. Audio recorders recorded two nights from sunset to sunrise. Recordings were converted to spectrograms using the Audacity software program for easier manipulation and exploration. Each owl call position was identified by the strength and direction of the voice of different recordings. Territories were identified based on the current registration of two or more territorial calls and disputes or they were distinguished by the characteristic of the male voice (spectrogram visual analysis).

The area of the economic and old forests was identified by online application (LGIS, 2017). The area of the forest loss (Global Forest Watch, 2014), length of the watercourses and the elevation were analysed in a GIS application (Qgis, GRASS GIS). We used a generalized linear model - GLM (Poisson distribution) for the analysis of the relationship between the number of territories and some environmental parameters. Data were processed and analysed in the statistical programme R (R Development Core Team 2008). The statistical significance was set at $\alpha \leq 0.05$.

Results

Table 1 illustrates the environmental parameters and the number of owl territories.

34 owl territories were recorded (mean = 3.1 +- 0.83 territory/square, range 2-5 terr./square, mean density = 0.77 territory/km^2) in 11 squares. The GLM analysis did not confirm statistical significant influence of the selected parameters on the number of territories (Tab. 2). A high variability of evaluated environmental parameters was recorded. Results show that the environment with the smaller area of old forests can be also occupied by a higher number of owls (Fig 2). Each square contained min. 9 % (max. 53 %) of forest stands older than 100 years, which were distributed unevenly within the study

Figure 3 - Relationship between the number of Tawny Owl (*Strix aluco*) territories and the area of economic forests using GLM (Poisson distribution). Relationship between the number of Tawny Owl (Strix aluco) territories and the area of economic forests using GLM (Poisson distribution).

Figura 3 - Relação entre o número de territórios de coruja-do-mato (*Strix aluco*) e a área de florestas de exploração, com base em GLM (distribuição de Poisson).

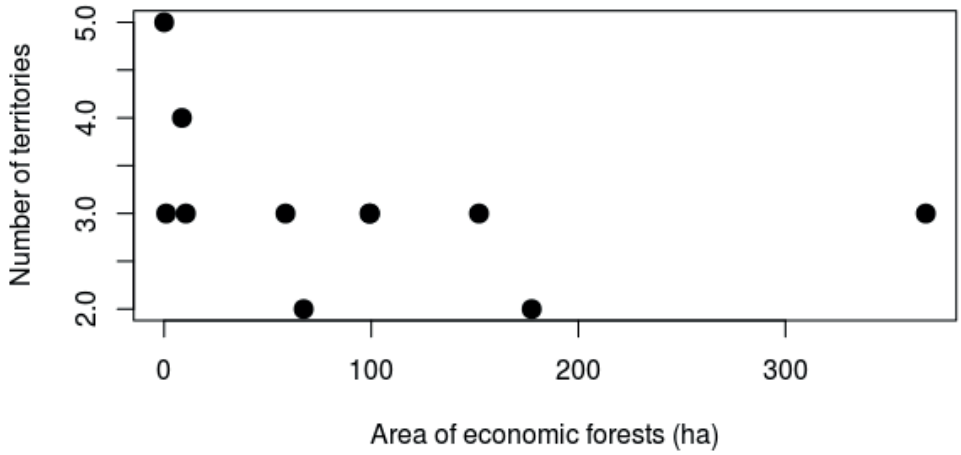


Figure 4 - Relationship between the number of Tawny Owl (*Strix aluco*) territories and the area of the forest loss using GLM (Poisson distribution).

Figura 4 - Relação entre o número de territórios de coruja-do-mato (*Strix aluco*) e a área florestal perdida, com base em GLM (distribuição de Poisson).

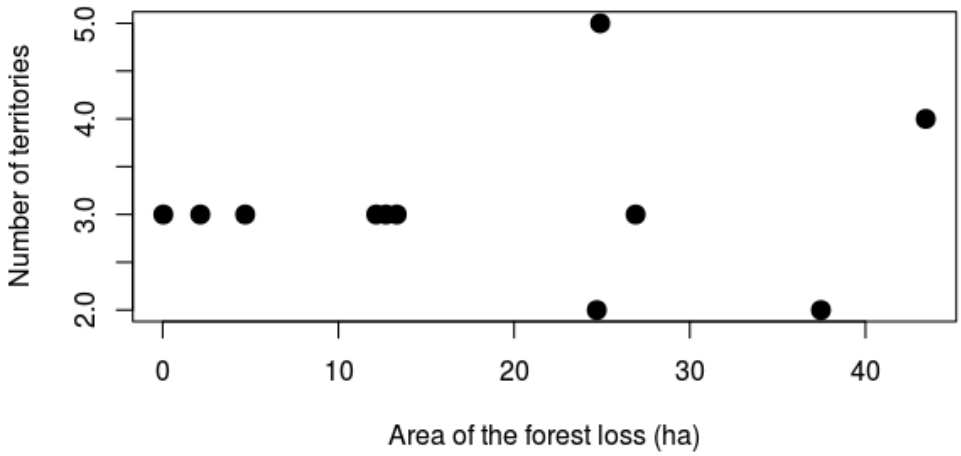


Figure 5 - Relationship between the number of Tawny Owl (*Strix aluco*) territories and the elevation using GLM (Poisson distribution).

Figura 5 - Relação entre o número de territórios de coruja-do-mato (*Strix aluco*) e a altitude, com base em GLM (distribuição de Poisson).

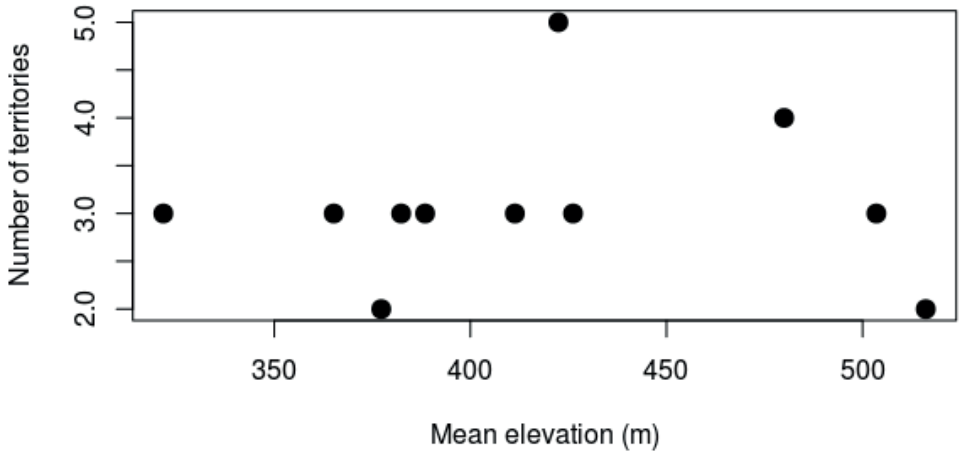
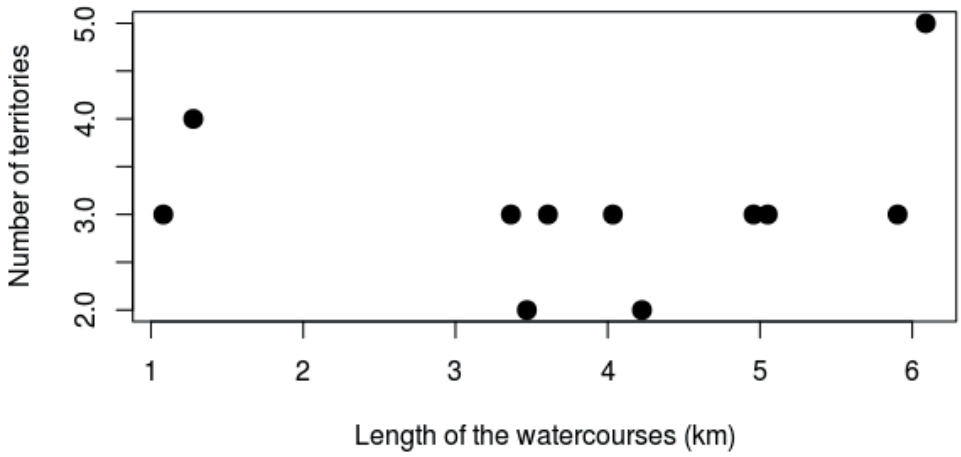


Figure 6 - Relationship between the number of Tawny Owl (*Strix aluco*) territories and the length of the watercourses using GLM (Poisson distribution).

Figura 6 - Relação entre o número de territórios de coruja-do-mato (*Strix aluco*) e o comprimento de cursos de água, com base em GLM (distribuição de Poisson).



area. In each square at least small groups of older stands were present. Squares with higher number of territories (4 and 5 terr.) contained limited or no areas of economic forests (Fig. 3). The area of the forest loss, average elevation and the length of the watercourses was similar in the squares with high or low numbers of territories (Fig. 4, 5, 6).

Discussion

Tawny Owl is a very plastic species that inhabits various environments, mainly forest habitats (Galeotti 2001). Results from the study were compared with areas in neighboring countries and similar habitats. Population density reached similar values as in Poland - 0.7 terr./km^2, where the study area consisted of various forest areas (Matysek et al. 2015). Higher density in alluvial floodplain forests near the Danube (1 terr./km^2) and Morava river (1.6 terr./km^2) is probably related to high quality environments in protected areas (Nagl et al. 2013). In the study from mountains with beech and mixed forests in Slovenia (Vrezec 2003), Tawny Owl density was lower (0.44 terr./km^2), because higher altitudes are occupied especially by the Ural Owl (*Strix uralensis*), a main competitor of Tawny Owls. During our research the presence of the Ural Owl was not confirmed in the area. The highest densities (3.8 - 5.2 terr./km^2) in beech forests were recorded in central Italy (Ranazzi et al. 2001), where territories were located in the higher altitudes - over 1000m asl and with the cover of mature stands. In other areas in Slovakia generally lower values are reported - max. 0.46 terr./km^2 (Danko et al. 2002). These values were obtained during a census where habitats of lower quality also were included. Specialized studies aimed at measuring the density of forest owls from Slovakia are not available today. In Austrian alluvial forests (Nagl 2015) the occurrence of Tawny Owl was positively related to cover of old forest, amount of standing deadwood and the openland. Similar results were confirmed for Romania (Bolboacă et al. 2013) where Tawny Owl showed the highest affinity to old forests compared to other forest age groups. However the influence of the area of old forest on the owls is unclear. No relationship was found between the number of territories and the area of old stands. This study shows that squares with the highest cover of old forests did not contain the highest number of territories, probably because all squares contain relatively high cover of old stands. The importance of open land was shown in studies which analysed the habitat composition in different countries and environments (Nagl 2015, Rumbutis 2017). In Finland, clear-cut areas had a positive impact on the boreal owl nest success (Hakkarainen et al. 1995). Due to the high territory fidelity (Southern 1970, Hirons 1985, Saurola 1987), owls can be negatively influenced by forest management (Newton 1994). Especially intensive forest management reduces old trees with cavities in stands (Lindenmayer et al. 2013, Walankiewicz et al. 2014). They are important for nesting and roosting (Sunde et al. 2003) and as food resource for the prey (Jędrzejewski et al. 1994). As an opportunistic species Tawny Owl can survive in a changing environment, however lower habitat quality can influence reproduction parameters (Rumbutis et al. 2017). Beside the forest management, also natural processes like wind calamities can cause forest loss. However, our results did not show a positive nor negative relationship between forest loss and the number of Tawny Owl territories.

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History of Northern Saw-whet Owls (*Aegolius acadicus*) in North America: Discovery to present day

História do mocho-amolador (*Aegolius acadicus*) na América do Norte: desde a descoberta até ao presente

Mitchell L. Pruitt[1*], Kimberly G. Smith[1]

1 Department of Biological Sciences, University of Arkansas, Fayetteville, Arkansas, USA

*** Corresponding author:** mlpruitt@uark.edu



ABSTRACT

The Northern Saw-whet Owl (*Aegolius acadicus*) is a small forest owl breeding throughout southern Canada and the mountains of the Unites States, including Alaska, and Mexico. It was first described from a specimen taken in Nova Scotia in 1791, but confusion existed for the next 100 years about its distribution; its relationship to its congener, the Boreal (or Tengmalm's) Owl (*Aegolius funereus*); and its juvenile plumage, which was described as belonging to a separate species. It also took many decades in the 20th century to establish its migratory and irruptive behavior in fall. A major breakthrough was the discovery in 1986 that saw-whets can be captured using audio lures during fall migration. They can also be sexed based on wing length and weight and aged based on ultraviolet patterns on their underwing. Since 1969, nearly 300,000 Northern Saw-whet Owls have been banded in North America, yet the winter distribution remains unclear, particularly in the southern United States and Mexico, and little is known about spring migration and the species' breeding biology. Here, we trace the complicated history of this species from discovery to the present.

Keywords: *Aegolius acadicus*, history, Northern Saw-whet Owl

RESUMO

O mocho-amolador (*Aegolius acadicus*) é uma pequena rapina noturna florestal encontrada no sul do Canadá e nas montanhas dos Estados Unidos, incluindo o Alasca e o norte do México, durante a época de reprodução. Foi descrito pela primeira vez a partir de um espécime proveniente da Nova Escócia em 1791, mas nos 100 anos seguintes não houve certeza sobre a sua distribuição; a sua relação com o seu congénere mocho-funéreo (*Aegolius funereus*); e a sua plumagem juvenil, que foi descrita como pertencente a uma espécie diferente. Também demorou várias décadas no século XX para conhecer o seu comportamento migratório e irruptivo no outono. Um grande avanço foi a descoberta, em 1986, de que os mochos-amoladores podem ser capturados durante a migração do outono através de atração por vocalizações conspecíficas. Podem também ser sexados com base no comprimento da asa e no peso, e a idade pode ser estimada com base em padrões de ultravioleta na parte interior da asa. Desde 1969, foram anilhados na América do Norte cerca de 300 mil mochos-amoladores, mas a sua distribuição no inverno ainda não está clara, particularmente no sul dos Estados Unidos e no México, e pouco se sabe sobre a migração de primavera e a biologia da espécie. Neste artigo descrevemos a história complexa desta espécie, desde a sua descoberta até ao presente.

Palavras-chave: *Aegolius acadicus*, história, mocho-amolador

Introduction

The Northern Saw-whet Owl (*Aegolius acadicus*) (hereafter saw-whet) is a small forest owl that breeds throughout most of southern Canada, northern United States including Alaska, coniferous habitats of the Appalachian Mountains in eastern United States, coniferous habitats of the Rocky Mountains in western United States, and south along the Cordillera into Mexico. Its winter distribution is poorly known, particularly in the southern United States, primarily due to it being nocturnal and usually silent in winter. Saw-whets are migratory and experience flight years, usually 4 years apart, when large numbers move south, due to increased nesting success when small mammal populations are high (Beckett & Proudfoot 2011, Henry et al. 2015). After it was discovered, in the 1980s, that migrating saw-whets respond to audio lures and can be captured in mist nests, banding stations began to proliferate in Canada and the United States.

Due to their secretive nature, few studies have been conducted on the breeding biology of saw-whets. It has been suggested that they are nomadic prior to breeding, typically do not nest in the same place year-to-year (low philopatry), and almost all young disperse from their breeding ground (Marks & Doremus 2000, Marks et al. 2015). Saw-whets are unusual among owls in that, for several months, juveniles have a plumage that looks nothing like the adult plumage.

Here we trace the species' discovery, including early confusion with its congener, Boreal Owl (*Aegolius funereus*); description of juveniles as a new species; the debate during the first half of the 20th Century about whether saw-whets were migratory; and recent advances since the introduction of audio lures in the 1980s.

Figure 1 - Acadian Owl (bottom left) from Latham (1781). Based on a specimen shot by a British officer in the 1770s, while on tour of duty in Nova Scotia during the American Revolution.

Figura 1 - "Mocho acádico" de Latham (1781). Baseado num espécime filmado por um oficial britânico na década de 1770, durante uma missão na Nova Escócia durante a Revolução Americana.



1781-1862

The first mention of saw-whet appeared in the first volume of *A General Synopsis of Birds*, written by Latham (1781). His painting of the species is less than realistic, based on both a dead specimen and a sketch from Captain Thomas Davies, but it is apparently of a saw-whet nonetheless (Fig. 1). Davies was an officer in the British Army, a naturalist, and talented painter who had a passion for painting landscape scenes, people, and nature. Davies was twice stationed in Halifax, Nova Scotia during the early years of the American Revolution and likely collected the specimen then, which Latham dubbed "Acadian Owl". Latham's (1781) written description of this owl is as good as any, capturing all the highlights of an adult saw-whet.

Not given a Latin name by Latham (1781), Acadian Owl is mentioned again by Gmelin (1788), who published an official account to name the species in the 13th edition of Linnaeus' *Systema Naturae*. The saw-whet remained commonly known as Acadian Owl, but now had its first binomial Latin name: *Strix acadica*. Little was written about the species in Gmelin (1788), but it was based on Latham's (1781) description. Various other naturalists gave accounts of Acadian Owl around the turn of the 19th-century. A description of "Chouette d'Acadie" or, *Strix acadica,* made a brief appearance in Daudin (1800). However, problems arose in several other volumes. Pennant (1785) mentioned a species called Little Owl (*Strix passerina*) as being common from Hudson Bay to New York, as well as frequent in Russia and occasional to Siberia. He cited Latham's 1781 account of *Strix acadica,* but a range to Russia and Siberia raises a red flag. Pennant (1785) noted a size variation of 7 - 8 inches (18 -20 cm) in length, stating "the smallest I have seen is from Nova Scotia; which has white circlets about the eyes, and fewer white spots on its plumage". Almost certainly, Pennant was referring to a saw-whet in this part of his account. However, the range he gave and a description of the bill being "whitish brown" suggests Boreal Owl.

Wilson (1811) seemed similarly confused. In his account of Little Owl, again listed as *Strix passerina*, he noted the species as being "…a general and constant inhabitant of the middle and northern states…found as far north as Nova Scotia, and even Hudson's bay…", but also as frequent in Russia. In size, the author noted a length of 7.5 inches (19 cm) and an "extent" of 18 inches (46 cm). He also mentioned a blackish, horn colored bill, a feature the Boreal Owl lacks. Despite the described range, all other notes by Wilson seemed to match that of saw-whet, rather than Boreal Owl. His illustration of the species is very clearly a saw-whet and is of a specimen shot near Great Egg Harbor in New Jersey (Fig. 2).

It seems likely that both Pennant and Wilson believed Boreal Owl and saw-whets to be conspecific. Latham (1821) listed both Acadian Owl (*Strix acadiensis*) and Little Owl (*S. passerina*) as separate species; however, ranges of the two were still muddied by nonexistent overlap into northern Europe. Latham wrote that Acadian Owl was an inhabitant of North America, mentioning again the specimen collected by Davies some 40 years earlier, but he also described the species as occurring in the mountainous regions of Germany. He believed Little Owl was common throughout various regions of Europe and India, but also around Hudson Bay in Canada.

In addition, Bonaparte (1828), ornithologist and nephew of Napoleon Bonaparte, confused ranges of the two owls. He remarked that *S. acadica* occurs in "the north of both continents, but [is] more common in America, in the northern and middle states…" He cites Wilson's Little Owl as a visual complement to his brief account.

It was not until Swainson & Richardson (1831) that the issue was resolved. This work encompassed multiple volumes filled with

Figure 2 - Wilson (1811) was accurate in his illustration but mistook part of the range for that of the Boreal (Tengmalm's) Owl.

Figura 2 - Wilson (1811) foi preciso na sua ilustração mas confundiu parte da área de distribuição com a do mocho-funéreo.



fauna documented during two separate expeditions through northern Canada, led by Sir John Franklin. John Richardson was brought on as surgeon and naturalist during the first expedition (1819-1822) and again for the second expedition (1824-1827). He was assisted by William Swainson and Thomas Drummond. Natural history was not the primary aim of the expeditions and none of the trio were ornithologists. However, they successfully documented 240 avian species during the expeditions, with accounts of 27 others based on the writings of their predecessors (Swainson & Richardson 1831).

At the beginning of the second volume on birds, Swainson & Richardson (1831) addressed Pennant's mistakes: "…unaccompanied by specimens, prefixing the names of nearly-resembling European birds, which an actual comparison would have shown to have been quite distinct; and in this way several species have been enumerated in systematic works as natives of Hudson's Bay, which do not actually exist there." They went on to say, "in common with other ornithological works of that period, it [*Arctic Zoology*] includes many specific names, attached merely to a different state of plumage resulting from age or sex."

Swainson & Richardson (1831), for what appears to be the first time, listed *S. acadica* and *S. passerina* as two distinct species, with none of the former confusion as to range and physical appearance. Accounts for both species were quite detailed and noted differentiating features of plumage and size. In their account of *S. acadica*, which they termed "American Sparrow Owl", Wilson's *S. passerina* was confirmed with "no doubt" to be *S. acadica*. As for Pennant, they stated "… it is impossible to ascertain what particular bird the author had in view. It appears highly probable that he considered the two American species, with another found in Sweden to be mere varieties…" The naturalists of the Franklin expedition did not encounter *S. acadica* on expedition routes, but obtained two specimens from New Caledonia, in present day British Columbia (Swainson & Richardson 1831).

Audubon (1831) beautifully illustrated the Little (Acadian) Owl *S. acadica* as its own species for the first time (Fig. 3) and did the same for Tengmalm's Owl (*S. tengmalmi*) seven years later (Audubon 1838). The plates and descriptions of both species are stunning and accurate. Audubon's accounts for each were written in pleasing flowery, if not exaggerated prose, typical of the naturalist. He encountered *S. acadica* during some travels in the eastern states, purportedly finding nests as far south as Louisiana and Natchez (southwestern Mississippi). This has great potential for inaccuracy, as these saw-whets would have been much farther south than is typical during the breeding season today. He went on to note the species as breeding in greater abundance in the northeastern United States, where it is commonly encountered. Audubon mentions *S. acadica* as occurring farther south than *S. tengmalmi*, an accurate observation.

During a time when naturalists commonly conducted their own work with little collaboration, it would only be natural for there to be some continued confusion over *S. acadica*. It is difficult to determine what Nuttall (1832) made of *S. acadica*, other than it was separate from Wilson's *S. passerina* and *S. tengmalmi*. This is interesting, because between Wilson (1811) and Nuttall (1832), *Strix passerina* appeared to fall out of use in favor of *S. tengmalmi*. Nuttall (1832) began his account with a comment about *S. acadica* being an inhabitant of the northern portions of North America and Europe. He went on to say the species rarely wandered from northern Europe, whereas in North America, it was common farther south to New Jersey and Pennsylvania. Though not the same species, the account of range is somewhat accurate, as Tengmalm's (Boreal) Owl is not migratory, but irruptive in northern Europe. Saw-whets are migratory, explaining *S. acadica*'s occurrence farther south in North America. Nuttall's species description fits that of

Figure 3 - *S. acadica*, fearsomely illustrated in Audubon's Birds of America: Vol. 2 (1831).

Figura 3 - Ilustração de *S. acadica* com aspeto assustador em Audubon's Birds of America: vol. 2 (1831)



saw-whets. He closed his account with a note of personal communication with Bonaparte: "…in a letter to W. Cooper, Esq. says, he [Bonaparte] has recently ascertained that this species differs from all the other European small kinds of the genus". So why write such a bewildering account?

Up to this point, the saw-whet had been known by its first Latin name, *Strix acadica*, but that was changed by Bonaparte (1838). Bonaparte lived in America only a short time to complete Alexander Wilson's *American Ornithology*, after which he returned home to Italy and completed his own work in 1838, giving the saw-whet its second Latin name, *Nyctale acadica*, after the splitting of genus *Strix*.

The usage of *Strix acadica* materialized again when Gray (1844) compiled a *List of the Specimens of Birds in the Collection of the British Museum*. He also used *Glaucidium passerinum* for Little Owl, citing Linnaeus, Temminck, Daudins, and several others. However, with specimens from Germany and present-day Slovenia, it seems unlikely Gray was referring to the North American species. Another Latin name for the Acadian Owl, *Ulula acadica*, appeared in two publications (de Kay 1844, Giraud 1844), but did not gain popularity.

By 1860, expansion into western territories was increasing our knowledge of the saw-whet's range. In 1858, Spencer Baird, John Cassin, and George Lawrence, under direction of Secretary of War, Jefferson Davis and the Smithsonian Institution, were tasked to compile species accounts for bird specimens collected during railroad expeditions of the early 1850s, listing *N. acadica* as "the smallest owl found in the eastern and middle States of North America" (Baird 1858). Based on specimens from the expeditions, they also reported it as a likely resident of the "entire temperate regions of this division of the continent", as well as being found in California. Two specimens were collected by Suckley: one near Fort Dalles, Oregon Territory on 7 December 1853 and the other near Fort Vancouver, Washington Territory on 3 February 1854 (Cooper & Suckley 1860). A third specimen was collected in Texas by Captain John Pope, leader of the "Far Southern Route", which explored the possibility for a railroad along the 32nd parallel. Pope's party travelled east from El Paso to the Red River Valley from January to May 1854. Another saw-whet reportedly collected in Fort Smith, Arkansas, in July 1853 by the Whipple Expedition has been largely dismissed (see Pruitt & Smith 2016).

Gradually, the natural history of the saw-whet became much more transparent than it was for nearly 100 years. Cassin (1862) wrote that *N. acadica* was found in "the whole of North America". He cited several sources to aid in drawing this conclusion, including Townsend (1839, Oregon), Gambel (1846, California), Audubon (1831, Kentucky and Louisiana), Kirtland (1838, Ohio), and Hoy (1852, Wisconsin).

The Mystery of the White-fronted Owl

During the time that genera *Strix* and *Nyctale* were being sorted out, an old taxonomical error resurfaced. This originated in the late 18th century when Shaw & Nodder (1789) described the White-fronted Owl (*Strix albifrons*), which surfaced again in Latham (1801), with a specimen collected in Quebec by Thomas Davies in 1790. Latham (1801) described the owl as having upperparts of dark brown, white around the eyes, extending down from the lower mandible, as well as white speckling on the wings and tail. The bird's breast and throat were a ruddy chestnut. Based on Latham's note of the owl "frequently erecting two feathers over the eye", Vieillot (1807) classified the species with eared owls. He proposed the possibility of "le hibou a front blanc", being a juvenile form of the red-eared owl (*Bubo asio*), today's Eastern Screech-Owl (*Megascops asio*).

German zoologist Lichtenstein (1838)

delved deeper after receiving specimens collected along the west coast of America. After addressing the mix-up between *Strix acadica* and its European counterparts, he went on to comment about *Strix frontalis* (the Latin name he used for White-fronted Owl). He stated (in German) that "Latham's *Strix acadica*… [is] nothing more than the immature plumage of our *Strix frontalis*". To be clear, when Lichtenstein referred to adults, he was picturing chocolate-brown *S. frontalis* and when he referred to juveniles, he was picturing a typical-looking adult of *S. acadica*. He supported this hypothesis with an interesting idea. Several specimens obtained came from eastern North America and were in "immature" plumage, really the adult plumage of *S. acadica*; others, collected in California, were dark brown "adult" specimens. He concluded the west must be within the owl's resident range and "immature" birds migrate to the eastern part of the continent. Lichtenstein came closer to an accurate conclusion than any naturalist before him but was still wrong. He was correct in believing a relationship between *S. frontalis* and *S. acadica* but was incorrect in his order of operations. The cocoa-and-buff-colored birds dubbed *frontalis* are, in fact, immatures of *acadica*. However, misclassification would continue for over 30 years.

Hoy (1852) re-described White-fronted Owl as *Nyctale kirtlandii*. One cannot be sure, but it is feasible Hoy had never seen Lichtenstein's (1838) paper. According to Hoy (1852), this species is of similar size to *Nyctale acadica*, but colored quite differently. Specimens used by Hoy in his description include a bird captured in October 1821 and another collected in July 1852.

Three years later, Strickland (1855) authored *Ornithological Synonyms*, a book he hoped would combat the problem of synonymy in scientific naming, which had become a dilemma for ornithologists working around the world. An Englishman, it is plausible Strickland was in contact with or had obtained Lichtenstein's (1838) paper. As a result, he placed *S. albifrons*, *S. frontalis*, and several other names for White-fronted Owl on the list of synonyms for *N. acadica*, which was still the official species name.

In America, classification of *N. kirtlandii* was further supported by Cassin (1862) with a lengthy description and a plate in his guide (Fig. 4). He briefly noted resemblance to Lichtenstein's *S. frontalis* but said nothing more and identified Hoy (1852) as first to describe *N. kirtlandii*. Cassin stated it to be an uncommon species, observed during the breeding season and winter, assuming it to be a resident in its range. Knowing typical immature saw-whets have completely molted into adult plumage by mid-September (Weidensaul 2015), Cassin's winter records were probably based on often-inaccurate written or verbal accounts with no supporting specimens.

N. kirtlandii continued to be supported by various ornithologists until Ridgway (1872) wrote a response to a paper published just months earlier by Elliot (1872), who compared adult and immature *Nyctale tengmalmi* (Boreal Owl) to *N. kirtlandii*. Elliot concluded that, given size and plumage similarities of immatures of both species, individuals of the so-called *N. kirtlandii* are really immatures of *N. tengmalmi*. In his analysis, Elliot also compared adults of *N. tengmalmi* from Europe and *N. richardsonii* from North America, concluding these species (eventually Boreal Owl) are conspecific.

In response, Ridgway (1872) addressed Elliot's changes, disagreeing with his placement of *N. kirtlandii* as immature individuals of *N. tengmalmi*. Ridgway stated that *N. kirtlandii* was identical in many aspects to *N. acadica* and, being little more than half the size of *N. tengmalmi*, cannot be conspecific with the latter. He countered Elliot's argument by proposing *N. kirtlandii* to be the young of *N. acadica*, providing five reasons why he believed this to be so, based on his examination of specimens from the Smithsonian Institution: (1) all specimens of *N. kirtlandii* are clearly immature birds; (2) all specimens of

N. acadica are clearly adult birds and there is no description of the species' young; (3) the ranges of both "species" are the same, as are some plumage characteristics, both having white "scalloping" on the alula, similar location and number of white bars on the tail and similar white spots on the primaries; (4) one of four *N. kirtlandii* specimens was an extremely dark individual exhibiting a facial disk of uniform brown and lacking spots on the forehead, likely a very young bird; and (5) three of four *N. kirtlandii* specimens exhibited a white-and-brown streaked facial disk and a streaked forehead, similar to that of adult *N. acadica*, likely older juveniles that had already begun molting into adult plumage. Ridgway (1872) ended by stating that those five facts "point conclusively to the identity of the *Nyctale 'albifrons'* [kirtlandii] and *N. acadica*."

Turn of the Century Developments

Perhaps because of Ridgway's paper, Coues (1872) listed the several names given to juveniles as figments of the past, settling into the usage of Acadian Owl (*Nyctale acadica*), and his text was among the first to use "Saw-whet Owl" as a major common name. The updated range in his book showed saw-whets to occur in the United States, north into Canada, and south into Mexico. *N. acadica*'s presence in Mexico was described, with little more detail, in Cooper (1870) as ranging to Oaxaca in southern Mexico.

Knowledge of the saw-whet's range continued to expand around the turn of the 20th century. Documentation of breeding birds in the central Sierra Nevada Mountains (Ray 1903), Arizona (Mearns 1890), and Colorado (Cooke 1897) widened the saw-whet's distribution down the Rocky Mountain Cordillera into Mexico. Its Mexican range was expanded in Salvin & Godman (1904), though the species was noted as uncommonly encountered. Two specimens existed at the time of publishing, an old specimen from Oaxaca and a more recent one from Chimalpa. In addition, the authors mentioned a specimen collected near Quetzaltenango, Guatemala. They noted this bird resembled the young brown plumage of *N. acadica*. However, it was most likely that this specimen was an Unspotted Saw-whet Owl (*Aegolius ridgwayi*), a new species that would be described by Alfaro (1905).

From the late-1870s through the 1890s, accounts of breeding and/or nesting saw-whets began to appear. One of the first well-documented accounts of juveniles being captured at breeding sites came from Massachusetts during summer 1876. The account described three encounters, including one individual captured by an inmate in his cell at the Deer Island Prison, near Boston (Deane 1877).

Massachusetts' saw-whets continued to impress the ornithological community with the acquisition of a full set of eggs from Tyngsboro in April 1881. Brewster (1881) stated that prior to the collection of this clutch, a single egg at the National Museum in Washington was the only known example. Brewster excitedly received the eggs along with both adults, which had attended the nest. Several months later, Brewster's contact from Tyngsboro sent him four nestling saw-whets. Brewster prepared three as specimens and raised one to adulthood, publishing a detailed narrative of its molt into adult plumage. In so doing, he confirmed the combination of *N. kirtlandii* and *N. acadica*, whose molt had never been documented. By the first of September, the immature bird "had become a remarkably beautiful Saw-whet Owl" (Brewster 1882).

Saw-whet eggs were first depicted in Bendire (1892), who expressed the importance of recent breakthroughs in nesting habits of the saw-whet, describing many accounts of nesting in both the eastern and western United States during the decade prior to publishing his book.

As reports of breeding and nesting saw-whets were being published, a variety of

names for the species remained in use. In September 1883, the American Ornithologists' Union (AOU) was formed to aid the development of ornithology and bird conservation in North America. The AOU also took over official taxonomy of American birds. In the first edition of the *Check-List of North American Birds* (AOU 1886), genus *Nyctale* was replaced with *Nyctala*, but the two were used interchangeably in the last decades of the 1800s. Also, in that checklist, the common name was officially changed to Saw-whet Owl; afterwards, the usage of "Acadian Owl" would fade away. A new genus name, *Cryptoglaux* ("hidden owl"), was proposed by Richmond (1901) and received the AOU's seal of approval in the 11th supplement to the 2nd second edition *Check-List* (AOU 1902). The change was necessitated by the occupation of the name *Nyctalus* for a genus of mammals. In the 14th supplement to the 2nd edition (AOU 1908), the genus *Cryptoglaux* was briefly shortened to *Glaux*, but was returned to *Cryptoglaux* in the 3rd edition of the checklist two years later (AOU 1910).

In 1901, just before *Nyctala* was removed as an avian genus, a putative subspecies to the saw-whet was described by Osgood (1901) based on a single specimen collected by John H. Keen 12 December 1896, on the Queen Charlotte Islands (now Haida Gwaii), British Columbia, Canada. Osgood detailed his *Nyctale acadica scotaea* as similar to *N. acadica*, but with all markings decidedly darker. He remarked that, during his 1900 expedition to the islands, a single individual flying over their anchored boat was the only saw-whet seen, and no specimens were collected. However, Osgood was generous in concluding the new owl must be common along the "humid Pacific coast". The subspecies *N. a. scotaea* was officially adopted in the 11th supplement to the 2nd edition of the *Check-list* (AOU 1902). It saw the same name changes as the nominate subspecies. With the new subspecies came the need to identify saw-whets found throughout the rest of North America. In the 3rd edition of the AOU checklist (1910), *Cryptoglaux acadica acadica* became the name to complement the range-limited northwestern subspecies.

Ridgway (1914) was skeptical of *C. a. scotaea* and Osgood's single referenced specimen, refusing to accept it as anything more than an individual with a color aberration. He wrote that he was "of the opinion that these characters will not prove constant when more specimens from the Queen Charlotte Islands have been examined". It was determined the plumage aberrations noted by Osgood were not far off from variant forms of nominate *C. a. acadica* from elsewhere in North America. Lack of support led to the removal of the subspecies from the 1916 AOU checklist (Sealy 2013). Supported by a collection date of 12 December, it has been proposed the original *C. a. scotaea* specimen was an individual of *C. a. acadica,* an occasional migrant to the islands (Brooks & Swarth 1925). Seasonal presence of the nominate subspecies on the islands during non-breeding season was not well documented until later (Withrow et al. 2014). Two years later, Fleming (1916) compared many specimens of saw-whet from across North America to four he obtained from Haida Gwaii, as well as the *C. a. scotaea* specimen. He concluded the four Haida Gwaii individuals were very different from both the mainland *C. a. acadica* and Osgood's *C. a. scotaea*, making note of extensive dark, reddish browns. Fleming ended his account with a motion to rename the four Haida Gwaii specimens *C. a. brooksi*, after renowned ornithologist and painter Allan Brooks. The Latin name, accompanied by the common name "Island Saw-whet Owl" was officially accepted in the 18th supplement to the AOU checklist (1923). Eventually, the subspecies status of *brooksi* was confirmed by genetic analysis, likely diverging around 16,000 years ago (Withrow et al. 2014).

The genus of the saw-whet would remain *Cryptoglaux* until it was changed to its current *Aegolius* in the 22nd supplement to the 4th edition of the *Check-List* (AOU 1947) based on Kaup's (1829) usage. The subspe-

cies epithet of *A. a. acadica* was changed to *A. a. acadicus* and adopted as the species epithet several years later, leaving the Latin name as *Aegolius acadicus*. The common name, "Northern Saw-whet Owl", was officially accepted in the 34th supplement to the *Check-List* (AOU 1983).

A New Age of Saw-whetting: Migration

In early accounts, saw-whets were rarely listed as common or abundant. For years, most authors did not mention seasonality, unless it was in respect to the Kirtland's Owl, which was suspiciously found only during summer or early fall. Today, saw-whets are known to be both regularly migratory and "irruptive" on roughly four-year cycles (Henry et al. 2015). Irruptions occur in autumn following a very successful breeding season when there are more individuals in the population, resulting in a heavier southward migration (Brittain et al. 2009). Most of this knowledge would not come until much later.

Possibly the earliest mention of saw-whet seasonality was made by Snow (1873), who stated simply that saw-whets are rare migratory visitors to Kansas. He provided no more information, so how he came to this conclusion cannot be determined. Langdon (1879) added to the suspicion of seasonal movements, citing the collection of three specimens and concluding saw-whets to be rare winter visitors in the Cincinnati, Ohio area. More accounts of saw-whets as "rare winter visitors" emerged in the latter part of the 19th century. Several reports came from Washington, D.C.: one ornithologist described seven autumn encounters with the species (Webster 1887) and five saw-whets were taken during winter of 1890-1891 (Hasbrouk 1891). If irruption years have held true to roughly four-year cycles, 1890 may have been an irruption. In the same decade, wintering birds appeared in coastal Virginia (Rives 1890) and coastal North Carolina (Brimley 1893), neither location within the known breeding range. Bendire (1892) acknowledged that saw-whets migrate from the northern breeding range to winter in the "Middle States", where they are often found "in considerable numbers". He cited W. E. D. Scott, who collected 21 specimens in December 1878 in New Jersey. This record, and others, led Fisher (1893) to his partially correct deduction in calling the owl an "irregular wanderer", seeking food in fall and winter. Such a large number collected, and timing of irruption cycles could point towards 1878 having been another irruption.

Reports of autumn and winter records continued into the 20th century, some from the central U.S., with saw-whets being captured or collected in Indiana (Ulrey & Wallace 1895), Cleveland, Ohio (Jones 1906), and Iowa (Wilson 1906). Jones (1906) stated the species was common in the vicinity of Cleveland in late fall and winter. The story is similar in Iowa, where Wilson (1906) listed it as rare in winter, with records from February 1889, April 1890, and March 1891.

In the East, more winter records outside the saw-whet's normal breeding range were reported. A female was captured alive near Weston, South Carolina on 11 November 1909 (Wayne 1911), whereas another female was collected near Tybee Island, along the northern coast of Georgia on New Year's Day 1911 (Hoxie 1911). These records set the stage for future autumn migration studies throughout eastern and central North America.

Perhaps the most interesting observation of the saw-whet's mysterious seasonality was made by Saunders (1907) and Taverner & Swales (1911). Saunders chronicled a "migration disaster" along the shores of Lake Huron near Port Franks, Ontario. During a large winter storm in October 1906, birds undergoing a "heavy migration" never made it across the lake, washing up in the following days by the thousands. Saunders arrived at the site on 21 October to find 1,845 carcasses along several km of shoreline. Among the dead were 24 saw-whets. At the time, this species was considered rare in western

Figure 5 - Photo taken by Percy A. Taverner at Point Pelee, 15 October 1910. Featured on the cover of *Canadian Geographical Journal* in 1938.

Figura 5 - Fotografia da autoria de Percy A. Taverner tirada em Pont Pelee em 15 de Outubro de 1910. Capa do *Canadian Geographical Journal* em 1938.



Ontario. Saunders speculated that saw-whets might migrate "in considerable numbers".

Taverner & Swales (1911) documented an earlier event, an anecdote from passengers on the steamship *Helena*. While the ship was near Little Duck Island on Lake Huron, passengers noticed a large evening migration of small owls fitting the description of saw-whets, some of which reportedly landed to rest on the ship's deck during the night.

The authors' premise was that saw-whets probably migrate more extensively than believed. On 30 October 1908, while working in the cedar thickets at Point Pelee on the north shore of Lake Erie, Swales discovered fresh remains of two saw-whets that he suggested could have been taken by a Cooper's Hawk (*Accipiter cooperii*). Two years later, on 15 October 1910, Taverner found the remains of another saw-whet in the same thicket. It was not long before the two captured a live bird perched near the ground; nearby another was feeding on a mouse. In under two hours, the authors found 26 saw-whets. Returning to camp for a camera, they eventually managed to photograph one (Fig. 5). Along with saw-whets, Taverner & Swales (1911) found six Long-eared Owls (*Asio otus*) and two Short-eared Owls (*Asio flammeus*). No owls of any species were found the next day. They remarked that similar counts of saw-whets had been found about 96 km east at Long Point, Ontario. Their contacts there told how saw-whets could be captured by spanning gill nets, typically used to catch fish, across woodland roads in fall. Evidently, enough owls were caught in this manner to render the outrageous story believable. Taverner & Swales (1911) close with a statement that would eventually be proven: "… the close tallying of all the dates point to the conclusion that from the middle to the end of October the Saw-whet Owls migrate in considerable numbers…".

One of the earliest documented bandings of a saw-whet occurred in March 1928. An owl was found during the day near a banding station in Cohasset, Massachusetts and, after a chase, was captured in a butterfly net (Harding 1929). Another banding report in November 1929, was of a bird captured at the Stone Bird Sanctuary in Babson Park, Massachusetts. The bander captured it in an insect net (Smith 1930).

During the 1930s and 1940s, extensive autumn banding occurred around Toronto, Ontario. Lambert (1949) wrote a brief statement summarizing 15 years of owl banding 1934-1948, during which their group banded over 200 individuals. Their passive methods involved simply erecting mist nets in areas that seemed good for capturing the birds, which usually included clearings, woodland edges, and woodland trails, small open areas where a saw-whet might be hunting. Initially, they averaged 1-3 owls per year between 1934 and 1938, then 18-25 owls per year from 1939-1947, and an unprecedented 62 owls in 1948. If the roughly four-year cycles of irruption have held true over the last 70 years, 1948 could have been an irruption year.

Capturing saw-whets for banding was attempted again on 18 October 1958 at Point Pelee, about 320 km west of Toronto. Eight mist nets were set that night and three saw-whets were captured. This meager number was enough to spur the Ontario Bird Banding Association (OBBA) to start a long-term banding project for the species. Around the same time, disagreement over the ethics of bird banding caused Point Pelee National Park to restrict operations, leading the OBBA to move much of its banding east along Lake Erie to Long Point. By 1973, all banding, other than that conducted in support of a specific study, was ceased at Point Pelee. One of the first projects to be approved after the enactment of research restrictions was a saw-whet migration study (O'Neill 2006).

Both Point Pelee and Long Point are peninsulas jutting into Lake Erie and are prime locations for banding operations. These features create a funnel for migrants that travel overland as long as possible before making the potentially costly lake crossing into the United States (Woodford 1959). Examples

of "peninsular effect" can be found around the world, especially for raptors, which are particularly cautious of making long-distance water crossings (Bildstein 2006).

While the shores of Lake Erie were early sites of saw-whet banding, the secretive owl was being captured elsewhere. On 6 November 1960, Walkimshaw kept his mist net open during the night to save time setting up the following morning at Battle Creek, Michigan. Just before daylight, he examined the net in his backyard and discovered a saw-whet. Over five years, Walkimshaw (1965) captured ten in similar manner, all in mid-October except for one November bird.

Further west, near Milwaukee, Wisconsin, the Cedar Grove Ornithological Station (CGOS) was also leaving nets up through the night to avoid extra work early in the morning. In 1956, they captured their first saw-whet in this way. By the end of the 1961 field season, 45 saw-whets had been captured in September and October. In fall 1962, CGOS researchers broadened their netting repertoire and range to include more nets with a larger mesh size spread out over a wider area (Mueller & Berger 1967). The group averaged 53 nights afield from 1962 to 1964 (September to November) and captured 168 saw-whets. The latter two years of the study saw a more than doubling of the 1962 capture rate. Based on the roughly four-year irruptive cycles, 1964 could have been such a year.

According to some sources, autumn 1965 may have been an irruption year as well. Birders and banding stations in Ontario and the northeastern U.S. documented 400 encounters with saw-whets: 285 of these were banded from September to December, whereas the others were seen by observers or found dead. Saw-whets were captured at banding stations at Long Island, New York, Massachusetts, and Toronto. Others were documented in Rhode Island, New Jersey, West Virginia, and northern Florida. One owl even roosted on a tractor engine in a Pan American hangar at Kennedy International Airport in New York (Davis 1966).

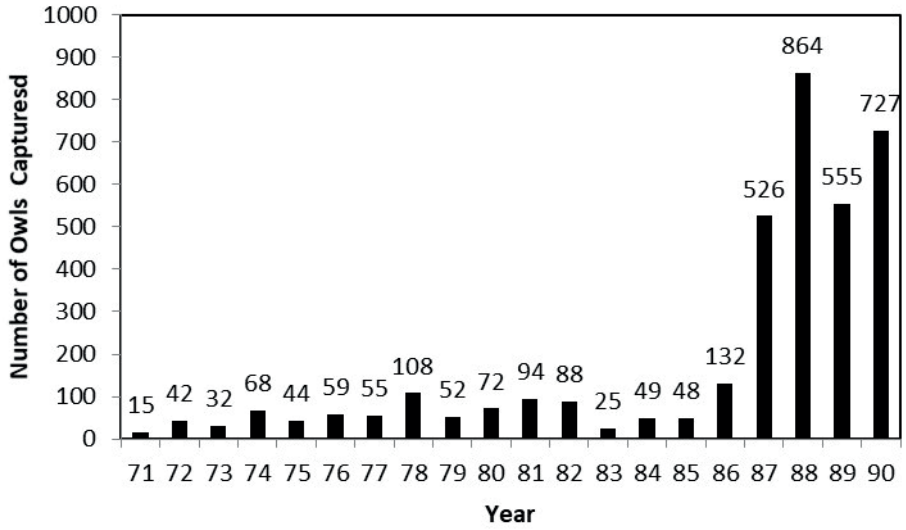
Holroyd & Woods (1975) summarized banding data from 1955 to 1969, the first period where a greater effort was put into capturing saw-whets. During this time, 4,802 saw-whets were banded in North America, 92% east of the Mississippi River. By far, early fall banding efforts were centered in southwestern Ontario, along the northern shores of Lake Erie and Lake Ontario. At this time, researchers in Wisconsin, Michigan, New York, New Jersey, and Maryland also banded their fair share of saw-whets. The authors acquired data on 52 band recoveries, leading them to suggest the existence of two major migratory pathways: one encompassing the Ohio and Mississippi River valleys, the other along the Atlantic Coast from Maine to North Carolina. Both pathways continue to be recognized.

A study conducted at Prince Edward Point, Ontario from 1975 to 1978 further demonstrated the apparently easy work of capturing saw-whets during fall migration, even using passive netting methods popular at the time. A total of 1,128 saw-whets was banded during those 3 years. Based on weather data from Prince Edward Point, they demonstrated that saw-whets were captured most often on calm, clear nights following the passage of a cold front (Weir et al. 1980).

By the early 1900s, there was no longer any question as to the migratory habits of saw-whets but capture methods had not been perfected to maximize captures for the amount of effort spent in the field. The major downfall to using passive netting techniques on a secretive migratory owl was that a banding station needed to increase the number of mist nets to increase capture rates. Raising many nets in hopes a saw-whet might fly in left much to chance. This became burdensome for many stations, either from lack of funding or personnel, which is why the introduction of the audio lure in 1986 was such a monumental development. Audio lures for saw-whets were first used at the Little Suamico Ornithological Station (LSOS), near Green

Figure 6 - Use of audio lures started in Wisconsin in 1986 and dramatically increased the number of saw-whets captured in fall migration (redrawn from Erdman & Brinker 1997).

Figura 6 - O uso de atração por vocalizações conspecíficas teve início no Wisconsin em 1986 e aumentou muito o número de mochos-amoladores capturados na migração de outono (redesenhado a partir de Erdman & Brinker 1997).



Bay, Wisconsin, and consisted of a cassette tape player, an amplifier, and two weather-proof speakers attached to a power supply. The species' solicitation call was broadcast into the night on a continuous loop. The distance at which this call could be heard was nearly 2 km. From 1971 to 1985, LSOS operated using passive netting techniques and captured an average of 57 individuals each fall, ranging from 15 in the least productive year to 108 in the most productive year (Fig. 6). In the audio lure period, 1986 to 1995, average number of captures per year jumped to an incredible 636, ranging from 526 in the least productive year to 864 in the most productive year (Erdman & Brinker 1997). The results, replicated at two sites in Maryland, were staggering and audio lures became standard protocol for saw-whet researchers across North America.

A concern with audio lures is the potential bias it introduces to the sex ratio of captures. The male's solicitation call is the most charismatic of the saw-whet's sounds, making it a natural choice for audio lures, but broadcasting a male-only call may create female-bias. This was demonstrated during a spring migration study in Michigan, where male-only lures were shown to attract more females than a male-female lure, which attracted a more equal proportion (Neri et al. 2018). Whether or not this is also true for fall migration is unknown. An alternate hypothesis is that standard field sexing methods are inaccurate. Beckett and Proudfoot (2012) found that most owls are correctly sexed comparing field sexing methods to more accurate genetic sexing, but that nearly 40% of saw-whets identified as unknown sex in the field were actually males. This could explain some of the skewed female to male capture ratio, but even without the designation of "unknown", there still are more females captured than males. Another hypothesis is that saw-whets have sex-specific migration strategies. This strategy is not uncommon in migratory birds and has been documented in the similar Boreal (Tengmalm's) Owl (Hipkiss 2002). Males and females may have differing dietary needs, not uncommon in birds of

prey because of their reversed sexual dimorphism (females are larger). These needs may only be satisfied if larger females migrate farther to places where food is more plentiful and the climate is milder. Males may benefit from staying farther north in winter so they are closer to the most prime breeding territories in spring. This strategy may explain why higher numbers of immature males are captured in irruption years. Immatures, with a lack of experience in hunting and finding premier territories, may not fare well farther north where winter food is less abundant and competition with more experienced adult males is higher (Beckett & Proudfoot 2011). Although females still dominate mist nets, males are captured in increasing numbers with increasing latitude, further supporting the idea that more males winter farther north. None of the hypotheses completely explain the skewed sex ratio.

Other milestones in banding of saw-whets were a chart based on wing length and weight for sexing birds as female, male, or unknown (Brinker 2000) and the demonstration that birds could be aged by the ultraviolet pattern of the underwing (Weidensaul et al. 2011). Saw-whets possess the pigment porphyrin that fluoresces as bright pink in a new feather and fades with time (pictured in Pruitt & Smith 2016). This allows easy determination of hatch-year birds (immatures) from after-hatch-year birds (adults). Additionally, saw-whets that are 1 year old can usually be distinguished from birds that are 2 years or older.

Since 1969, more than 298,000 saw-whets have been banded in North America. This is the result of considerable effort, largely in the north-central and northeastern U.S. and eastern Canada. In 1994, Project Owlnet (http://www.projectowlnet.org) was created by David Brinker and others to provide a network for banders working with saw-whets. As of autumn 2017, more than 150 banding stations were a part of this network (S. Huy pers. comm.). Researchers are concentrated in the northeastern states, the Upper Midwest, and Ontario, with scattered efforts along the Atlantic Coast and Appalachian Mountains to Georgia, and west to Alabama, Tennessee, Missouri, Arkansas, Oklahoma, Nebraska, Alberta, Saskatchewan, and southwestern British Columbia. There are fewer banding stations studying saw-whets west of the Mississippi River in the United States, with large data gaps in the Great Plains, Rocky Mountains, and along the West Coast. Knowledge of the species in the west is further muddied by altitudinal movements (Weidensaul 2015).

Perhaps one of the greatest questions remaining is: where do these migrants spend the winter? The answer is mostly unknown. Winter records exist for every state, including Texas, Florida, and Louisiana (Beyer 1900, Lesser & Stickly 1967, Miller & Loftin 1984). Two winter records even exist for Bermuda (data from Bird Banding Laboratory). The status of migratory individuals in winter in Mexico is not well understood, but there may be some overlap with resident saw-whets. Their winter range likely expands during irruption years and could explain isolated records mentioned above. Nevertheless, lack of research in the south makes it difficult to draw a line for the southern extent of their regular wintering range.

Historically, saw-whets have been associated with low, dense winter roosting sites in cedars, firs, or other short conifers less than five meters off the ground (Bent 1938). A few recent studies have shown this not to be universally true, demonstrating saw-whets seem to prefer whatever conifers are available for roosting. They appear to seek winter roost sites that will provide the most cover, usually coniferous trees, regardless of species or height above ground. In shorter Douglas-firs (*Pseudotsuga menziesii*) or cedars, roosts will be low because most available foliage is low. In taller red pines (*Pinus resinosa*), ponderosa pines (*P. ponderosa*), short-leaf pines (*P. echinata*), and their relatives, roosts are higher because that is where foliage is densest (Swengel & Swengel 1992, Fig. 7). Recent research shows saw-whets to be regular win-

Figure 7 - Typical tree shape, foliage density, and saw-whet roost locations in five tree species, from left to right: eastern red cedar (*Juniperus virginianus*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), red pine (*Pinus resinosa*), and Norway spruce (*Picea abies*). Arrows indicate mean roost height and distance of roost from trunk (from Swengel & Swengel 1992).

Figura 7 - Forma típica da árvore, densidade da copa e localização dos poisos de mocho-amolador em cinco espécies de árvores, da esquerda para a direita: cedro-da-virgínia (*Juniperus virginianus*), pícea-branca (*Picea glauca*), pinheiro-cinzento (*Pinus banksiana*), pinheiro-silvestre (*Pinus resinosa*), e o abeto-falso (*Picea abies*). As setas indicam a altura média dos poisos e a distância destes ao tronco (adaptado de Swengel & Swengel 1992).



ter residents of open pine forest in northwestern Arkansas (M.L. Pruitt unpubl. data). This type of habitat is vast in the southern U.S. and could provide plenty of wintering habitat for saw-whets that seem to disappear after fall migration. Saw-whets have been located wintering in similar habitats in other places, where pines or other coniferous species dominate. Widespread records, irruptive tendencies, and a seeming ability to adapt to roosting in locally abundant species of conifer, seems to support the idea that saw-whet winter range may be dynamic.

A species that undergoes an autumn migration will naturally undergo some sort of return migration, but the saw-whet's spring migration is much less studied than autumn migration. A spring migration was first mentioned in the literature by Eaton (1914), who reported that saw-whets were often found by bird watchers in western New York in April and May. Further documentation of spring migration followed in the next several decades. Ornithologists suggested saw-whets were likely to be found in nearly any patch of forest along the southern shore of Lake Ontario in early April, especially following a warm front from the south (Barry 1952). It has been suggested that spring concentrations on the Great Lakes' southern shores are caused by birds waiting on suitable conditions to begin crossing the lake (Catling 1971). Today, stations in high-concentration areas are the most successful at capturing saw-whets during spring migration. One of the best examples is Whitefish Point Bird Observatory, located at the tip of Michigan's Upper Peninsula, likely also a result of pen-

insular effect. Conversely, some areas on the northern shores of the Great Lakes also see high concentrations, likely because migrants need rest and food after making the crossing.

A more comprehensive study was done by Catling (1971), conducted during a three-year period near Toronto. Saw-whets were found to begin their spring migration into the area in late-March, peaking in mid-April, and ending by late-April. Similarly, saw-whets on winter territories in the area no longer occupied that territory by late-March. Several saw-whets located during the study period clutched songbirds, suggesting migrant songbirds to be a food source during spring migration (Catling 1971). Banding data from 1955 to 1969 further supported this timing for southeastern Canada and the northern U.S, showing a peak in migration in late-March for New Jersey, mid-April for Ontario, and May for Michigan (Holroyd & Woods 1975).

Far fewer saw-whets are banded in spring compared to fall. Why this is can only be left to speculation, but there are several probable reasons. Foremost is the lack of effort to capture the species in spring. Considerably more effort is invested in capturing saw-whets in autumn. Secondly, saw-whets are seemingly less attracted to the audio lure used in fall. Additionally, the effect of periodicity in regional prey species, like *Microtus* and *Clethrionomys* has also been suggested as a reason for year-to-year variations in breeding saw-whets and, therefore, reduced capture rates during spring (Duncan et al. 2009).

A great deal has been learned about the Northern Saw-whet Owl in the last 100 years, before which very little was known about this secretive species. However, there is clearly much more to be learned about the saw-whet's breeding biology, winter distribution, and spring migration. Though widely captured during fall migration, even vast banding efforts provide little information in regard to movement ecology, specifically extent of migration, as recapture rates are low and few banding stations are located in the south. More comprehensive studies over a wider range will be required to fully understand the ecology of this species.

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TytoTagus Project: Common Barn Owl post-fledging dispersal and survival in the Tagus Valley, Portugal

Projeto TytoTagus: dispersão pós-natal e sobrevivência da coruja-das-torres no Vale do Tejo, Portugal

Inês Roque[1*], Ana Marques[1], Rui Lourenço[1], J. Tiago Marques[2,3,4], Carlos Godinho[1], Pedro Pereira[1], João E. Rabaça[1,5]

1 MED – Instituto Mediterrâneo para a Agricultura, Ambiente e Desenvolvimento, LabOr - Laboratório de Ornitologia, Universidade de Évora, Núcleo da Mitra Ap.94 7002-554, Évora, Portugal

2 MED – Instituto Mediterrâneo para a Agricultura, Ambiente e Desenvolvimento, Núcleo da Mitra Ap.94 7002-554, Évora, Portugal

3 CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade de Évora, Pólo de Évora, Casa do Cordovil 2o Andar, 7000-890 Évora, Portugal

4 cE3c – Centre for Ecology, Evolution and Environmental Changes, Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal

5 Departamento de Biologia, Escola de Ciências e Tecnologia, Universidade de Évora, Núcleo da Mitra, Ap.94 7002-554, Évora, Portugal

*** Corresponding author:** iroque@uevora.pt



ABSTRACT

The Tagus Estuary hosts a high concentration of juvenile Common Barn Owls (*Tyto alba*) during the post-fledging dispersal period with more than 15 owls/km detected along roads in the south floodplain of Vila Franca de Xira (SF). The Tyto Tagus project examined the origin of these birds with six re-sightings of 136 colour-ringed nestlings (2006–2008) and subsequently (2009-2012) with 41 VHF radio-marked juveniles from three areas: 16 in Benavente, 13 in the SF and 12 in Coruche. Five re-sightings were of colour-ringed juveniles from nests in Benavente (<15 km from the SF) and one from a nest from Coruche (45–60 km from the SF). One tag failed while the owl was still near the nest, contact was lost with 19 radio-marked owls (15 during fledging), 19 owls were found dead (13 during fledging), and the battery was used up for two owls. One juvenile was found dead immediately after leaving the nest, but 11 others were tracked during

dispersal, in which they used a succession of temporary settlements with single or several roosts alternating with longer movements. Six of these owls moved towards SF. Others remained in Coruche or roosted in a northern area of the floodplain near their nests. The distance between roosts and hunting areas was generally <3 km, but some juveniles hunting in the SF had roosts >11 km away. Juvenile Common Barn Owls mainly roosted in trees along roadsides and riparian areas but also in forest patches (i.e., in mixed stands of cork oak (*Quercus suber*) and pine (*Pinus* spp.), montados and pine forests) adjacent to open agricultural areas. Between 7.3% and 43.9% of the owls survived the post-fledging dispersal period. Future studies should assess the impact of road mortality near the SF and consider the use of new technologies to track juveniles until they nest.

Keywords: colour marking, juvenile dispersal and survival, Tagus Estuary, telemetry, *Tyto alba*

RESUMO

O Estuário do Tejo reúne um elevado número de corujas-das-torres (*Tyto alba*) durante o período de dispersão pós-natal, com valores de abundância superiores a 15 indivíduos/km ao longo de algumas estradas não pavimentadas na lezíria sul de Vila Franca de Xira (SF). O Projeto TytoTagus avaliou a origem destas aves através de seis recapturas visuais de 136 juvenis marcados com anilhas coloridas (2006-2008) e, subsequentemente (2009-2012), através de 41 juvenis marcados com emissores VHF em três áreas: 16 em Benavente, 13 na SF e 12 em Coruche. Cinco recapturas corresponderam a juvenis provenientes de Benavente (<15 km da SF) e uma recaptura correspondeu a um juvenil de Coruche (45–60 km da SF). Um emissor falhou ainda no ninho, foi perdido o contacto com 19 juvenis (16 durante a emancipação),19 juvenis foram recapturados mortos (13 durante a emancipação), e duas corujas foram seguidas até ao fim de vida da bateria. Uma coruja foi encontrada morta imediatamente após dispersar, e 11 outras foram seguidas durante a dispersão, que consistiu na ocupação sucessiva de áreas de fixação temporárias, onde foi usado um único ou vários poisos próximos, alternando com movimentos longos de dispersão. Seis destes indivíduos aproximaram-se da SF. Nos outros casos, as corujas permaneceram em Coruche ou na área norte da lezíria, na proximidade dos seus ninhos. A distância entre poisos e áreas de caça foi no geral <3 km, embora os juvenis a caçar no estuário tivessem poisos diurnos a mais de 11 km. As corujas usaram como poiso principalmente árvores ao longo de estradas e galerias ripícolas, bem como áreas florestais (i.e., povoamentos mistos de sobreiro (*Quercus suber*) e pinheiro (*Pinus* spp.), montados e pinhais) contíguas a áreas agrícolas abertas. Entre 7.3% e 43.9% das corujas sobreviveram ao período de dispersão pós-natal. Estudos futuros deverão analisar o impacto da mortalidade por atropelamento nas imediações da SF e considerar a utilização de novas tecnologias que permitam seguir os juvenis até à primeira nidificação.

Palavras-chave: dispersão e sobrevivência de juvenis, Estuário do Tejo, marcação com anilhas coloridas, telemetria, *Tyto alba*

Introduction

The Common Barn Owl (*Tyto alba*) [hereafter Barn Owl] occupies farmland habitats, feeds mainly on small mammals and nests in man-made structures (Bunn et al. 1982, Roulin et al. 2002), and is an effective alternative to toxic pest control chemicals (Kross et al. 2016). It also is an indicator of environmental contamination (Sheffield 1997, Roque et al. 2016). On the other hand, its close association with people exposes it to several threats such as the loss of hunting habitat and increased road mortality (Hindmarch et al. 2017, Arnold et al. 2018) and it has experienced short-term declines in Portugal (Lourenço et al. 2015), Spain and in several other European countries, often due to changes in agricultural practices (Hagemeijer and Blair 1997, Martí and Del Moral 2003, BirdLife International 2004a,b, SEO/ BirdLife 2013).

The Tagus Valley has one of the highest concentrations (> 15 owls/km along roads, I. Roque unpublished data) of Barn Owls globally. Previous studies in the south floodplain of Vila Franca de Xira (SF), in the Tagus Estuary, suggest its importance as feeding area for Barn Owls during the post-fledging dispersal period (Tomé 1994, Tomé and Valkama 2001). The TytoTagus Project marked owls from the SF and adjacent nesting populations to determine the origin of birds congregating in the SF, which factors influenced their aggregation in the SF, and what management measures will be needed to conserve them.

Barn Owls disperse along linear landscape features like water courses to locate prey (van der Hut et al. 1992, de Bruijn 1994, Taylor 1994). They also disperse as predicted by the balanced dispersal hypothesis: an equal exchange of individuals between any two areas (Pulliam 1988, McPeek and Holt 1992). Marginal vegetation (i.e., natural hedges) provides good microhabitat for small mammals, the main prey of the Barn Owl (Sabino-Marques and Mira 2011, Arnold et al. 2018). The Tagus Estuary floodplains contain suitable Barn Owl hunting habitat; open farmland with ditches bordered by dense vegetation (Tome and Valkama 2001). Moreover, the SF has abundant fence poles used as perches by hunting owls (Tomé and Valkama 2001).

Therefore, we predicted that the Tagus River and its tributaries continue to support a high number of non-breeding Barn Owls and serve as an ecologically important dispersal corridor for juveniles (Tomé and Valkama 2001). These predictions were supported by (1) the high density of breeding pairs along the Sorraia River which flows into the Tagus (Roque and Tomé 2004); (2) the very low number of breeding pairs in the SF, where potential nesting sites are very scarce (Tomé 1994); and (3) the dispersal period coinciding with the increase of owl density in the SF (Tomé 1994, Roque 2003). These predictions fit with known dispersal patterns of juvenile raptors which prefer non-breeding areas with abundant prey and few territorial adults (Ferrer and Harte 1997, Balbontin 2005, Fasciolo et al. 2016). The goals of this study were to document Barn Owl post-fledging dispersal movements to the Tagus Estuary, identify priority conservation habitats and roosts relative to hunting areas, and to determine survival and threats to owls and the habitats on which they depend.

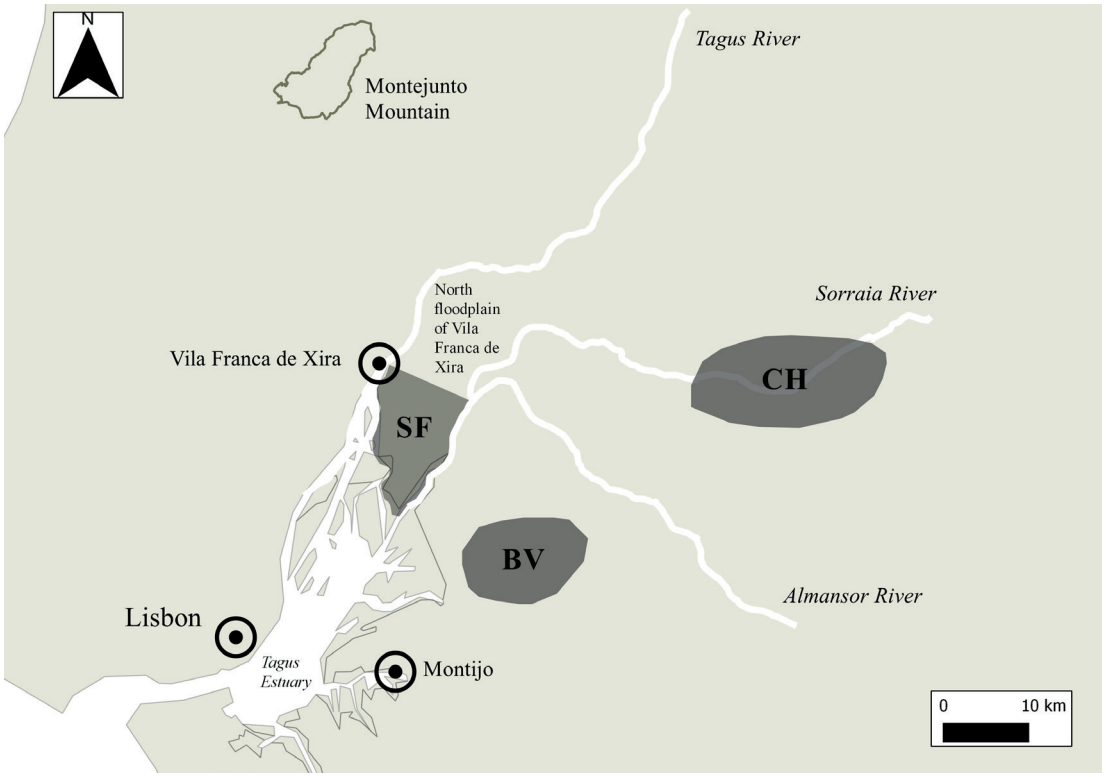
Methods

Study area

The study area was in west-central Portugal, southwest of Lisbon, and was comprised of (1) south floodplain (SF) of Vila Franca de Xira (*lezíria*) in the Tagus Estuary (38°50'N, 8°80'W); (2) Coruche (CH), the floodplain of the Sorraia River (the main tributary of Tagus River); and (3) Benavente (BV), contiguous woodland areas known as *charneca* and dominated by cork oaks (*Quercus suber*) and maritime pines (*Pinus pinaster*) (Fig.1). Winters are mild and wet, and summers hot and

Figure 1 - Common Barn Owl study area, Portugal. South floodplain (SF) of Vila Franca de Xira (Tagus Estuary), Benavente (BV) woodlands, and Coruche (CH) floodplain of Sorraia.

Figura 1 - Área de estudo. SF – Lezíria Sul de Vila Franca de Xira (Estuário do Tejo). BV – Benavente (10–20 km da SF). CH – Coruche (20–40 km da SF).



dry. The floodplains encompass temporary small-scale polyculture and intensive crops (>100 ha) of maize, rice, tomato and sugar beet. The Sorraia River flows into Tagus River in an area known as Ponta da Erva in the south floodplain of Vila Franca de Xira, an alluvial plain of ~6,219 ha on the left bank of the Tagus Estuary. The area is almost totally occupied by agricultural fields (mainly rice) and pastures. Farming plots are delineated by a vast system of wire fences, dirt roads and ditches. Natural salt marsh vegetation subsists only in narrow plot edges and in ditch margins. A small number of houses and barns are the only buildings present. The area is part of a National Nature Reserve, a Special Protection Area for Birds (Directive 79/409/EC), and an Important Bird Area (IBA 021 – Tagus Estuary; Heath and Evans 2000).

Colour-ringing study

An intensive nest search was conducted in 2006 followed by an annual monitoring through to 2012 during which 302 Barn Owl nestlings were ringed. From 2006 to 2008, 136 were also marked with colour rings (coded by nest location) to later identify them by spotlight along 22.2 km of transects on dirt roads in the SF (Fig. 2). Transects were driven twice a week in 2007 and every week thereafter (2008-2012) between August and

Figure 2 - Car transect in the south floodplain of Vila Franca de Xira (Tagus Estuary), Portugal.

Figura 2 - Transecto na Lezíria Sul de Vila Franca de Xira (Estuário do Tejo).

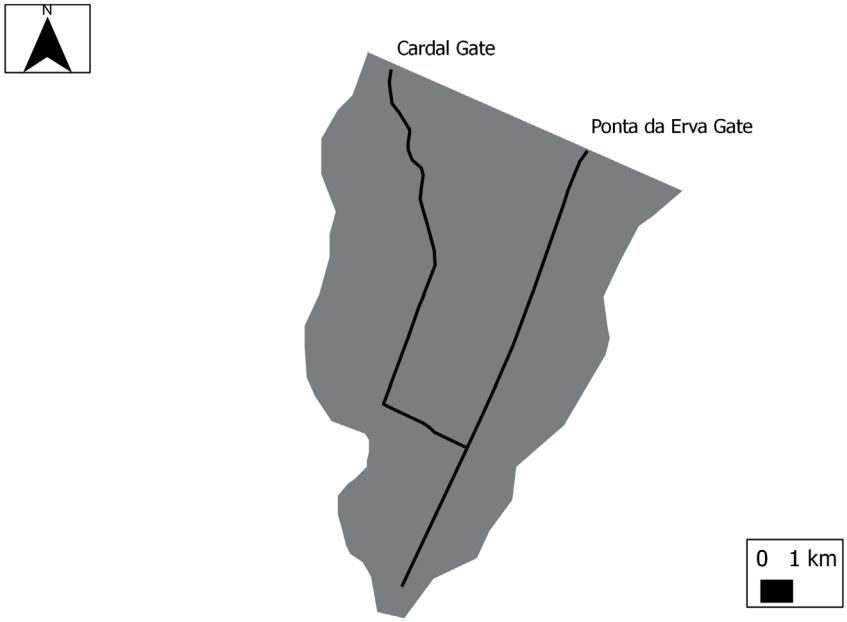
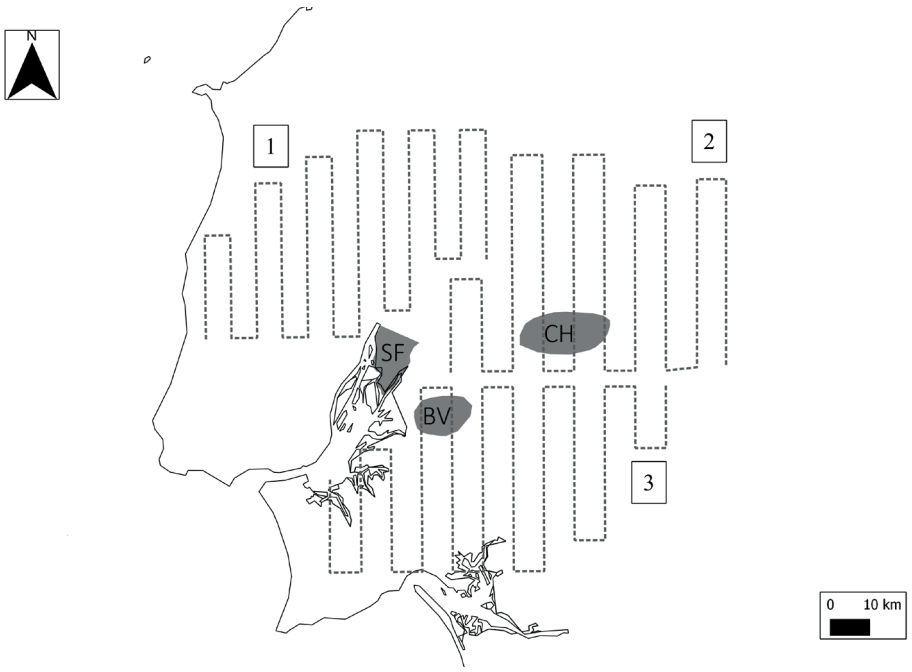


Figure 3 - Aerial telemetry sampling grids in the Tagus Estuary and adjacent area: 1 – North Grid, 2 – Northwest Grid, and 3 – South Grid. Shaded areas are South Floodplain (SF), Benavente (BV), and Coruche (CH), Portugal.

Figura 3 - Grelhas de amostragem de telemetria aérea (1 100 km) cobrindo uma área de 40–70 km em redor da lezíria sul de Vila Franca de Xira (Estuário do Tejo). 1 - Grelha Norte (cobrindo o norte da lezíria sul de Vila Franca de Xira). 2 - Grelha Noroeste (cobrindo a área de Coruche). 3 - Grelha Sul (cobrindo a área de Benavente).



December, when Barn Owls frequent the area. Transects were driven at ~40 km/h, with stops to identify colour ringed owls, and started alternately at Ponta da Erva and Cardal gates (Fig. 2). Owls were surveyed in the first transect pass through the non-circular transect to avoid double-counting.

Ground radio-tracking

Between May 2009 and September 2012, 41 Barn Owl juveniles (34–58 d after hatching) were radio-marked with VHF Biotrack TW3 transmitters (~11g) attached by backpack mount. Owls were radio-marked in three areas (Fig. 1) based on the earlier colour-marking study as follows: BV area – 9, 2 and 5 owls in 2009, 2010 and 2012, respectively; CH – 6 owls in 2009 and 6 in 2010; SF – 6, 4 and 3 owls in 2010, 2011 and 2012, respectively. Owls were radio-tracked until January 2013 and visually relocated at their day roosts by homing or triangulation, and by triangulation when hunting outside the estuary. The presence of radio-marked owls was also noted during nocturnal car transects in SF (2009–2012).

Aerial radio-tracking

Aerial searches for lost radio-marked owls were conducted using two directional "H" (two-element) type RA-2A antennas (Telonics™) mounted on a Cessna 172 aircraft via TAB-1 brackets (www.telonics.com/literature/aircraft/). The antennas were connected to a TAC-2 switch system, which allowed directional relocation of radio-transmitter signals. Two radio operators recorded GPS coordinates associated with maximum signal intensity, and then ground searches to locate the transmitters were conducted the following days. Three sampling grids covered 40–70 km around the SF but excluded a prohibited area near the Lisbon airport (Fig.3). The detectability of known transmitters was confirmed and we aerially searched for a total of 12 hr from the Santa Cruz (Torres Vedras) aerodrome (20-22 January 2011).

Data analysis

The locations of unobserved radio-marked owls were estimated using bearings from at least two georeferenced points (LOAS 4.0 Ecological Software Solutions). Dispersal and other distances were calculated and maps created in Quantum GIS 1.8.0 Lisboa software.

Results

Preliminary mark-recapture study

In 2007 and 2008, six Barn Owls were visually identified (100 to 745 d after colour-marking) in SF car transects and confirmed that BV (15 km from SF) and CH (61 km from SF) were the source of some of the owls using the estuary during dispersal (Table 1).

Radio-tracking

On average, 40 radio-marked owls were tracked for 125 ± 124 d (range 0–555 d); one transmitter failed while the juvenile was near its nest. During the fledging phase, 15 transmitters were lost and 13 radio-marked juvenile owls died. A total of 551 relocations from 12 radio-marked juveniles were obtained during the post-fledging dispersal phase (mean ± SD: 50 ± 15) (Table 2). One of these owls was found dead immediately after dispersal. Most of the juvenile owls from CH (63%) were tracked during dispersal and most from BV (43%) died after fledging. None of the owls radio-marked in SF were tracked during dispersal and most (69.2%) were lost during fledging (Table 2).

Table 1 - Re-sightings of colour-marked Common Barn Owls during nocturnal car transects in the Tagus Estuary in 2007–2008, Portugal.
a) Identified by area-specific ring colour code.

Tabela 1 - Recapturas visuais de corujas-das-torres durante os transectos nocturnos no Estuário do Tejo em 2007–2008.

RING NO.	RINGING DATE	RECAPTURE DATE	ORIGIN	DISTANCE TO NEST (KM)	DIRECTION FROM NEST (DEGREES)	NO. DAYS
M27887	09/05/2007	23/10/2008	Coruche	61	106	745
M27728	21/05/2007	24/09/2007	Benavente	15	291	126
M27732	21/05/2007	03/09/2007	Benavente	15	291	105
M27743	21/05/2007	29/08/2007	Benavente	15	291	100
N/A a)	2007	29/08/2007	Benavente	NA	NA	NA
N/A a)	2008	17/09/2008	Benavente	NA	NA	NA

Table 2 - Origin, tracking period, reason for the end of tracking, and last location of 41 Common Barn Owls tracked in the Tagus Valley, Portugal, 2009–2012. Legend: D – death; EB – end of battery; LC – loss of contact; TF – tag failure; F – fledging; PD – post-fledging dispersal.
* Tags recovered and reused in the next year.

Tabela 2 - Origem, período de seguimento, motivo para o fim do seguimento e última localização de 41 corujas-das-torres seguidas no Vale do Tejo, Portugal, em 2009–2012. Legenda: D – morte; EB – fim da bateria; LC – perda de contacto; TF – falha do emissor; F – emancipação; PD – dispersão pós-natal.

ORIGIN	TAG	START DATE	END DATE	STATE	PHASE	LAST LOCATION
Coruche 1	1	21/05/2009	13/09/2009	D	PD	South floodplain, Vila Franca de Xira
Coruche 1	2	21/05/2009	19/11/2009	LC	PD	Adema, Benavente
Coruche 2	3	01/06/2009	28/09/2010	D	PD	Quinta Grande, Coruche
Coruche 2	4	01/06/2009	14/07/2009	LC	F	Nest, Coruche
Coruche 3	5	21/05/2009	21/05/2009	TF	F	Nest, Coruche
Coruche 3	6	21/05/2009	02/09/2009	LC	PD	Casal dos Apupos, Alcochete
Benavente 1	7	02/06/2009	21/07/2009	D	F	Catapereiro, Benavente
Benavente 1	8	02/06/2009	21/12/2009	LC	PD	Fatel, Vila Franca de Xira
Benavente 1	9	02/06/2009	09/12/2010	EB	PD	Atalaia, Montijo
Benavente 2	10	02/06/2009	30/07/2009	LC	F	Nest, Benavente
Benavente 2	11	02/06/2009	10/03/2010	LC	F	Carrasqueira, Benavente
Benavente 2	12	02/06/2009	03/09/2009	LC	F	Nest, Benavente

ORIGIN	TAG	START DATE	END DATE	STATE	PHASE	LAST LOCATION
Benavente 3	13	02/06/2009	14/12/2009	D	F	Nest surroundings, Benavente
Benavente 4	14	15/06/2009	31/05/2010	LC	PD	Margin of Sorraia river, Samora Correia
Benavente 4	15	15/06/2009	09/02/2010	D	PD	Adema, Benavente
Coruche 1	17	24/06/2010	19/04/2011	EB	PD	Cavaleiros, Coruche
Coruche 1	18	24/06/2010	11/08/2010	D	F	Montinhos, Coruche
Coruche 4	19	06/07/2010	31/01/2011	D	PD	Pancas, Benavente
Coruche 4	20	06/07/2010	22/01/2011	D	PD	Campelos, Bombarral
Coruche 4	21	24/06/2010	13/09/2010	LC	F	Nest, Coruche
Coruche 4	22	24/06/2010	11/11/2010	D	F	Nest, Coruche
V. Franca 1	23	30/07/2010	21/09/2010	LC	F	Porto Alto, Benavente
V. Franca 1	24	30/07/2010	21/09/2010	LC	F	South floodplain, Vila Franca de Xira
V. Franca 1	25	30/07/2010	22/09/2010	D	F	South floodplain, Vila Franca de Xira
V. Franca 1	26	30/07/2010	11/01/2011	LC	F	Margin of Sorraia river, Samora Correia
V. Franca 1	27	30/07/2010	21/09/2010	LC	F	South floodplain, Vila Franca de Xira
V. Franca 1	28	30/07/2010	21/09/2010	LC	F	Nest, Vila Franca de Xira
Benavente 2	29*	16/08/2010	17/09/2010	D	F	Nest, Benavente
Benavente 2	30*	16/08/2010	07/09/2010	D	F	Nest, Benavente
V. Franca 2	29	20/06/2011	28/08/2011	LC	F	Nest, Vila Franca de Xira
V. Franca 2	30	20/06/2011	25/07/2011	LC	F	Nest, Vila Franca de Xira
V. Franca 2	31	20/06/2011	24/08/2011	LC	F	Nest, Vila Franca de Xira
V. Franca 2	32	20/06/2011	17/08/2011	D	F	Nest, Vila Franca de Xira
Benavente 5	33	01/08/2012	03/12/2012	D	PD	Adema, Benavente
Benavente 5	34	27/07/2012	28/09/2012	D	F	Poceirão - Fonte Lobo, Benavente
Benavente 5	35	01/08/2012	17/09/2012	D	F	Poceirão - Fonte Lobo, Benavente
Benavente 6	36	01/08/2012	16/08/2012	LC	F	Cabeço do Aranha, Benavente
Benavente 6	37	01/08/2012	20/09/2012	D	F	Cabeço do Aranha, Benavente
V. Franca 2	38	10/09/2012	10/09/2012	LC	F	South floodplain, Vila Franca de Xira
V. Franca 2	39	12/10/2012	25/01/2013	D	F	South floodplain, Vila Franca de Xira
V. Franca 2	40	10/09/2012	11/10/2012	D	F	South floodplain, Vila Franca de Xira

Table 3 - Dispersal distances moved by 11 Common Barn Owls in the first 120 days after fledging in the Tagus Valley, 2009-2013, Portugal.

Tabela 3 - Distâncias de dispersão percorridas por 11 juvenis de coruja-das-torres nos primeiros 120 dias após a emancipação no Vale do Tejo, entre 2009 e 2013.

DAYS AFTER FLEDGING	MEDIAN DISTANCE (RANGE)	AVERAGE DISTANCE (± SD)
7	784.0 (84.6–3 876.5)	1,143.7 ± 1,224.8
14	909.3 (120.2–19 267.1)	2,816,7 ± 5,585,7
30	3,363.6 (565.5–18,890.8)	6,978.2 ± 6,588.2
60	20,029.3 (4,013.3–38,516.7)	20,393.9 ± 11,551.7
90	18,666.4 (4,020.7–38,516.7)	19,938.0 ± 12,434.0
120	20,057.3 (4,323.5–38,516.7)	21,042.6 ± 12,384.8

Movement patterns

Juvenile Barn Owls dispersed between June and August; most in June (58.3%) and July (25%), when they were on average nine weeks old (range 6–11 weeks). Dispersing owls used successive temporary settlement areas (TSA) and roosted by day in one or more nearby roosts. TSA distance from nests increased in the first two months post-fledging but this decreased in the next month (Table 3). At the end of radio-tracking, the average distance (nest to post-dispersal area) moved by the owls was 20.7 ± 11.8 km (mean ± SD; median 19.9, range 3.86–38.5). Owls remained in a TSA from 3-166 d (mean ± SD 51.3 ± 48.5; median 35) and got successively closer to SF: four from CH (Fig. 4) and two from BV (Fig. 5). Two owls from CH remained in their nest areas (Fig. 4), and three owls from BV (Fig. 5) were in TSAs equidistant to SF. Average dispersal direction in the first (and longest) movement of owls from BV was NNE (327.6º ± 16.7º) and from CH was W (270.2º ± 43.1º). The two owls from CH that remained in their nest areas dispersed to the N and SW. Therefore, most (82%) of the radio-tracked owls dispersed in the direction of and/or to the Tagus Estuary.

Lost and found

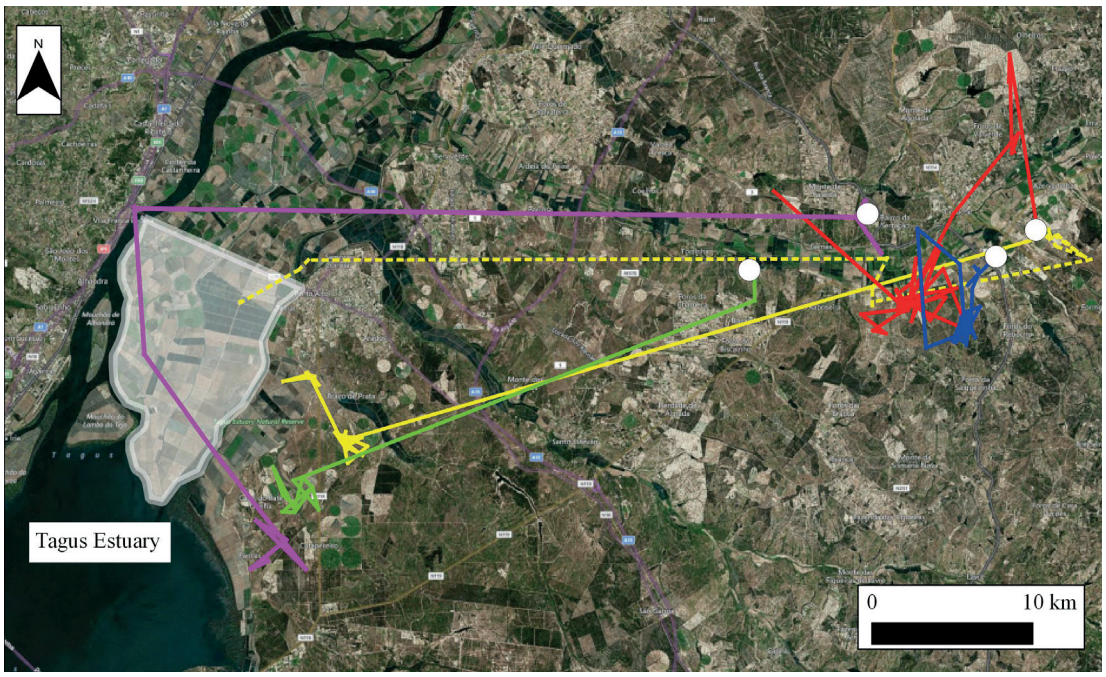
Only two lost radio-marked owls were relocated by aerial radio-tracking; one was located dead on a road ~60 km NW of its nest, while the lost transmitter of the other owl was found in an area 40 km SW from its nest. The first had never been detected in the Tagus Valley, and most likely had flown over Montejunto Mountain to reach its position. The latter was transmitting a signal ranging only ~50 m and therefore it could not be detected during regular ground searches.

Roosting sites during dispersal

The habitats and roosting sites most used during dispersal were mixed cork oak and pine stands (28.9%) and isolated trees (26.9%), followed by cork oak woodlands

Figure 4 - Post-fledging dispersal roost locations of six Common Barn Owls from nests located in Coruche (20–40 km from the south floodplain of Vila Franca de Xira), 2009-2010, Portugal. Lines uniting locations are to assist reading and do not represent owl movements. Same colour represents owls from the same brood. White circles – nest sites. White shaded area – south floodplain of Vila Franca de Xira.

Figura 4 - Localização dos poisos diurnos de seis corujas-das-torres provenientes de ninhos localizados em Coruche (20–40 km da lezíria sul de Vila Franca de Xira) durante a dispersão pós-natal em 2009 e 2010. As linhas que unem as localizações servem para facilitar a leitura e não representam os movimentos das corujas. Linhas da mesma cor representam corujas da mesma ninhada. Círculos brancos - locais de nidificação. Zona sombreada a branco – lezíria sul de Vila Franca de Xira.



(12.9%), tree rows (8.7%), pine stands (8.2%), riparian galleries (3.5%), buildings (3.1%) and urban gardens (3.1%). Individual owls demonstrated considerable variation in roost site preferences.

Distances between roosting sites and hunting areas

Five fledged owls tagged at nests in the SF roosted 0.82–8.6 km from their hunting areas. One owl from BV also hunted in SF while roosting 4.9–11.7 km away. Another individual from CH hunted in SF but returned to its nest the next day, documenting that juveniles can carry out exploratory flights up to 30 km prior to dispersal.

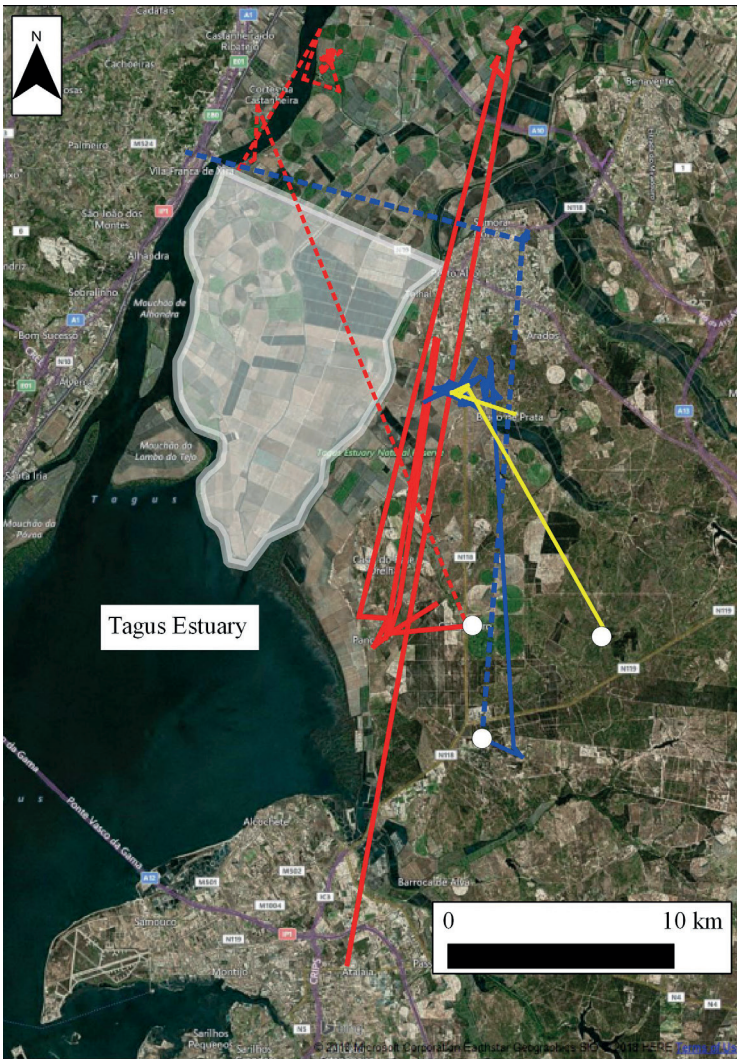
Five out of 11 dispersing owls roosted in the floodplains of Vila Franca de Xira; two from CH and three from BV (two of the latter were also detected hunting in the estuary). Other distances between roosts and hunting areas were 0.36–2.9 km in CH and 1.6–2.0 km near Montijo (Fig. 1).

Survival and causes of mortality

Of 41 radio-marked owls, 19 were lost, one transmitter failed (prior to fledging), and 19 died; of the latter, 12 died while fledging and six died during dispersal (Table 2). On average, the owls that died during fledging were 104 ± 40.8 d old (mean ± SD; range 56–192 d; n = 10); and the owls that died during dispersal were 205 ± 49.7 d old (range 160–250; n = 4). Two owls that survived until the transmitter battery expired were 351 and 602 d old. Causes of mortality included vehicle collision, possible predation, shooting and starvation; when carcasses were found partly eaten, it is possible they were scavenged after the owl had died from other causes.

Figure 5 - Post-fledging dispersal roost locations of five Common Barn Owls from nests located in Benavente (10–20 km from the south floodplain of Vila Franca de Xira), 2009–2012, Portugal. Lines uniting locations are to assist reading and do not represent owl movements. Same colour represents owls from the same brood. White circles – nest sites. White shaded area – south floodplain of Vila Franca de Xira.

Figura 5 - Localização dos poisos diurnos de cinco corujas-das-torres provenientes de ninhos localizados em Benavente (10–20 km da lezíria sul de Vila Franca de Xira) durante a dispersão pós-natal, em 2009 e 2010. As linhas que unem as localizações servem para facilitar a leitura e não representam os movimentos das corujas. Linhas da mesma cor representam corujas da mesma ninhada. Círculos brancos - locais de nidificação. Zona sombreada a branco – lezíria sul de Vila Franca de Xira.



Discussion

The Tagus Estuary as a temporary settlement area

The observed convergence of post-fledging dispersing juvenile Barn Owls from different areas to the Tagus Estuary confirms its importance as a TSA. The use of TSAs as a survival strategy is common in raptors (Delgado et al. 2009, Mellone et al. 2011, Prommer et al. 2012) and familiarizes them with regional habitats (Stamps and Krishnan 1999). The Tagus Estuary is used by several other raptor species during the non-breeding period including the Common Kestrel (*Falco tinnunculus*), Osprey (*Pandion haliaetus*), Eurasian Buzzard (*Buteo buteo*), and Black-winged Kite (*Elanus caeruleus*; Lourenço et al. 2018). The Eurasian Buzzard also is likely to use the estuary as a TSA, since its abundance increases when juveniles disperse. The SF is also an important wintering area for the Short-eared Owl (*Asio flammeus*), where it reaches its highest densities in Portugal (Catry et al. 2010).

The selection of TSAs by raptors can be based on habitat preferences (Balbontín 2005), prey availability, predator avoidance, and/or landscape composition (Ontiveros et al. 2005, Palma et al. 2006, Cadahía et al. 2010). The SF is open, low farmland with seasonal habitat variation such as rice fields with flood-drought phases and pastures with grazing rotation. While a small number of Barn Owls nest in the SF, more owls are counted there in the non-breeding season (I. Roque, unpublished data). They are seen hunting while perched on fence posts along dirt roads and ditches bordered by dense vegetation, or when flying or hovering along the roadsides, and in grazed pastures. Owls are more often seen in rice fields in autumn, when these are dry and harvested, possibly because fallen seeds attract large numbers of prey (Tomé and Valkama 2001). The percentage of small mammals trapped in rice fields in autumn was 32.5% higher than in pastures with cattle grazing rotation (H. Vale Gonçalves, unpublished data). It is possible that cattle grazing concentrated small mammal prey in the vegetation margins along ditches and roadsides (Santos et al. 2007, Sabino-Marques and Mira 2011, Ruiz-Capillas et al. 2013), which could explain the use of these marginal habitats by Barn Owls in the Tagus Estuary and its value in sustaining this population of owls.

Movement patterns

The Barn Owl post-fledging dispersal in Portugal starts earlier (June–August) than in northern populations (UK: August–September, Barn Owl Trust 2012; Netherlands: September–November, de Bruijn 1994), consistent with latitudinal climate variation. Post-fledging dispersal distance in the Iberian population (this study) appears to be intermediate between the British and central-European populations. Recovery distance of Barn Owls in Spain was 13.9 km (geometric mean, Martínez and López 1994) whereas the median ring recovery distance of juvenile Barn Owls was 7.5 km in the UK (Wernham et al. 2002), while in Germany, 40% of the Barn Owls were recovered at distances over 50 km from their nests (Bairlien 1985).

One of our Barn Owls was recovered as a roadkill ~60 km away from the nest 200 d after fledging and had flown over Montejunto Mountain (543 m asl, Fig. 1). Another owl flew at least 30 km from CH to SF and back in one night before starting dispersal. The Barn Owl often flies over hills rather than following valleys, disregarding favourable hunting grounds (Barn Owl Trust 2012). Random movements during exploratory flights are described in other owl species, and probably are the best strategy to cover

larger areas while learning new surroundings, when the birds are still developing their flight and other abilities (Delgado et al. 2009). In raptors, floaters wander over large areas prospecting vacant territories and gathering information on habitat quality for future settlement (Tanferna et al. 2013, Whitfield et al. 2009). Most (82%) of the tracked owls approached and/or used the Tagus Estuary during dispersal; therefore, it is likely that there are strong ecological factors leading the Barn Owl to the area. Seven TSAs were used at some point by two or more owls with different geographical origins and in different years: three patches of riparian vegetation (in CH, BV, and Vila Franca de Xira), three areas of cork oak forest (one in CH and two in BV), and the floodplain of the Tagus Estuary. Further examination of individual dispersal patterns is needed to understand what ecological factors might be driving different owls to these TSAs in the Tagus Valley.

Roosting sites and hunting areas during dispersal

Dispersing juvenile Barn Owls generally used habitats in proportion to their availability in the study area and this varied by location. Forest habitats, especially Mediterranean woodlands, were mainly used by owls >20 km from the Tagus estuary. In contrast, owls used a higher diversity of roosting sites and habitats in and within 20 km of the open agricultural fields and farmland of the floodplains of the Tagus and Sorraia Rivers. Isolated trees and tree rows consistently were used for roosting throughout the study area. The use of trees by the Barn Owl as day-time roosts during post-fledging dispersal was also noted by Seel et al. (1983). Owls hunting in the Tagus Estuary had to move further between their roosts and foraging areas (up to 11.7 km) than owls hunting in other areas (up to 2.9 km) due to the scarcity of roost sites in open farmland and in adjacent dense human settlements near Lisbon.

Survival and causes of mortality

Two of eight radio-marked owls whose signals were lost were relocated through aerial radio-tracking and confirmed dead. The fate of the remaining six was unknown and they may have dispersed further. Hence, between 7.3% and 43.9% of the owls survived the post-fledging dispersal period. These estimates were more extreme than the range of values previously reported for juvenile Barn Owl (15–35%; Sauter 1956; Bairlein 1985; De Bruijn 1994; Taylor 1994; Altwegg et al. 2009). The lower estimate may explain the negative short-term population trend of the species in Portugal (Lourenço et al. 2015), and negative short- and long-term trends in Spain and in other European countries (Hagemeijer and Blair 1997, Martí and Del Moral 2003, BirdLife International 2004a,b, SEO/ BirdLife 2013). These trends have been attributed to mortality related to land-use changes such as expanding road networks (Ramsden 2003, Gomes et al. 2009, Hindmarch et al. 2012).

Mortality from vehicle collisions was common in our study area and in Spain (Martínez and López 1994). Extensive roads and intense traffic near the Tagus Estuary resulted in high post-fledging mortality in September; up to 1.13 owls/km per road transect (I. Roque, unpublished data). In southern Portugal, road mortality estimates were reported to be 0.49 owl/km/year (Silva et al. 2008, Gomes et al. 2009). Overall, road mortality estimates for Barn Owls are among the highest for raptors, ranging between 0.07 and 2.61 owls/km/year (Illner 1992; Boves and Belthoff 2012).

Conclusions

The Tagus Estuary is a key TSA for the Barn Owl due to high prey availability, but its role in sustaining this species is not fully understood. The convergence of Barn Owls

to the SF, and their use of other TSAs, suggests post-fledging dispersal movements in our study area were non-random. Mortality during the post-fledging dispersal period was higher in and near the Tagus Estuary since owls had longer foraging flights while hunting there than in other TSAs. The impact of, and mitigation measures to counter road mortality should be examined and developed along with examining other mortality factors (e.g., power lines, land-use, pesticides, predation). Radio-tracking raptors during the post-fledging dispersal is challenging due to their ability to move long distances quickly resulting in signal loss prior to their first breeding efforts. The use GPS-GSM telemetry with longer battery life (~1 year), reduced weight, greater range for tracking location, and practical data recovery would address these issues and provide more reliable data and dispersal and survival estimates. These estimates are needed to determine if this population is a source or a sink population, and to develop and assess effective mortality mitigation measures to sustain this population of the Barn Owl.

Acknowledgments

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Field observations of Pere David's Owl (*Strix davidi*) in central China,140 years after its first description

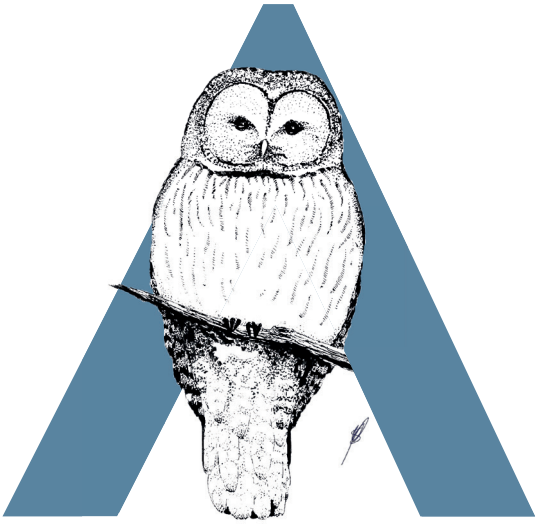
Observações da coruja de Sichuan (*Strix davidi*) na China central, 140 anos após a descrição da espécie

Wolfgang Scherzinger[1*], Yun Fang[2], Mei Shi[2], Yue-Hua Sun[2]

1 Bavarian Forest National Park (former) 83483 Bischofswiesen, Germany.

2 Institute of Zoology, Chinese Academy of Science 100 101 Beijing, China

*** Corresponding author:** W.Scherzinger@gmx.de



ABSTRACT

Due to the detection of Pere David's Owls in Lianhuashan Reserve, in Province of Gansu, we collected data on appearance, plumage, vocalization, behaviour and breeding activity of at least two territorial pairs. Our aim was to actualise our knowledge of this rare species, as observations are largely lacking since the first collection of a specimen by Pere David in 1869. From 1995 we managed systematic documentations by photographs and nest-box-videos, tape recordings, measurements of fledglings, and protocols of courtship, copulations, prey-delivery and feeding of fledglings, as well as nest defence and attacks against enemies within several stays in the reserve. Up to 2017 we could confirm > 15 broods, with a minimum of 23 nestlings. Our results allow a basic revision of the general description of Pere David's Owl, as misleading characters are labelled in literature, caused on the one hand by wrong interpretations of the original description by Sharpe in 1875, and by fundamental confusion of several owl species, named synonymic in the 19th century on the other hand. We present photographic documents of male and female plumage, of eggs, nestlings, and fledglings for the very first time. A first step is done, to design

the structure of the vocal inventory, but sonographic analysis is still open. Future projects should also clarify the prey-list in concern to local fauna. Comparisons of appearance, plumage, and vocalization of *Strix davidi* and *Strix uralensis* confirm that these species match in main characters, and are to merge in a "super-species".

Keywords: habit and plumage, *Strix davidi*, taxonomic comparisons, vocalization

RESUMO

Devido à deteção de coruja de Sichuan na Reserva Lianhuashan, na província de Gansu, recolhemos dados sobre aspeto geral, plumagem, vocalizações, comportamento e atividade reprodutora de pelo menos dois casais. O objetivo era atualizar o conhecimento sobre esta espécie rara, uma vez que existem muito poucas observações desde a recolha do primeiro espécime por Pere David em 1869. Nas várias visitas que efetuámos à reserva desde 1995, recolhemos registos sistemáticos através de fotografias e vídeos em caixas-ninho, gravações áudio, biometrias de juvenis e comportamentos de corte, copulação, entrega de presas e alimentação de juvenis, bem como defesa do ninho e ataques de intrusos. Até 2017 confirmámos mais de 15 ninhadas, e o número mínimo de 23 juvenis. Os nossos resultados permitem uma revisão básica da descrição da coruja de Sichuan, uma vez que existem características incorretamente descritas na literatura. Estas devem-se, por um lado, a interpretações erradas da descrição original de Sharpe em 1875 e, por outro, por confusão entre várias espécies consideradas sinónimas no século XIX. Apresentamos pela primeira vez fotografias da plumagem do macho e da fêmea, de ovos, e de juvenis no ninho e na fase de emancipação. Damos o primeiro passo no sentido de desenhar a estrutura do inventário vocal da espécie, no entanto, ainda será necessária a análise de sonogramas. Estudos futuros deverão ainda clarificar a lista de presas no contexto da fauna local. Comparações do aspeto geral, plumagem e vocalizações entre *Strix davidi* e *Strix uralensis* confirmam que estas espécies apresentam muitas características comuns e podem formar uma "super-espécie".

Palavras-chave: comparações taxonómicas, hábitos e plumagem, *Strix davidi*, vocalização

Introduction

In 1869, during his famous expedition in the mountainous forests of the Chinese Province of Sichuan, the French missionary Pere Armand David shot a wood-owl near Moupin (today Baoxin), different from other well known species. Due to the owl's size and its relatively dark plumage David (1871) believed this specimen was the Ural Owl of southern Japan, and therefore named it *Ptynx fuscescens*. Consecutively Jules Verreaux from the National Museum of Natural History in Paris determined this owl as *Ptynx fulvescens* (what was criticised later, as this name fits an owl species known from Guatemala/Central America). But, when sent to the British Museum, Sharpe (1875) recognized in this male specimen a new species, clearly differentiated from the more common Himalayan

Figure 1 - Pere David´s Owl looks strong and powerful. Its appearance is characterized by a dark plumage in dull brown and coarsely marked. Mostly active in dawn and night, the big wood-owl hunts also in full daylight during the breeding season. (Female chasing mobbing crows; Lianhuashan Reserve 2012).

Figura 1 - A coruja de Sichuan parece forte e robusta. O seu aspeto geral é caracterizado por plumagem castanho-escura baça com marcas grosseiras. Apesar de estar ativa sobretudo durante a noite e ao nascer do sol, no período reprodutor esta grande coruja tipicamente florestal também caça durante o dia. (Fêmea em perseguição de corvídeos que a tentavam atacar; Reserva de Lianhuashan 2012).



Owl (*Strix nivicola*), the Ural Owl (*Strix uralensis*) and Great Grey Owl (*Strix nebulosa*). He named the Moupin-owl *Syrnium davidi*, in respect to its collector. The very first depicture of this owl species was published under this new name by David & Oustalet (1877).

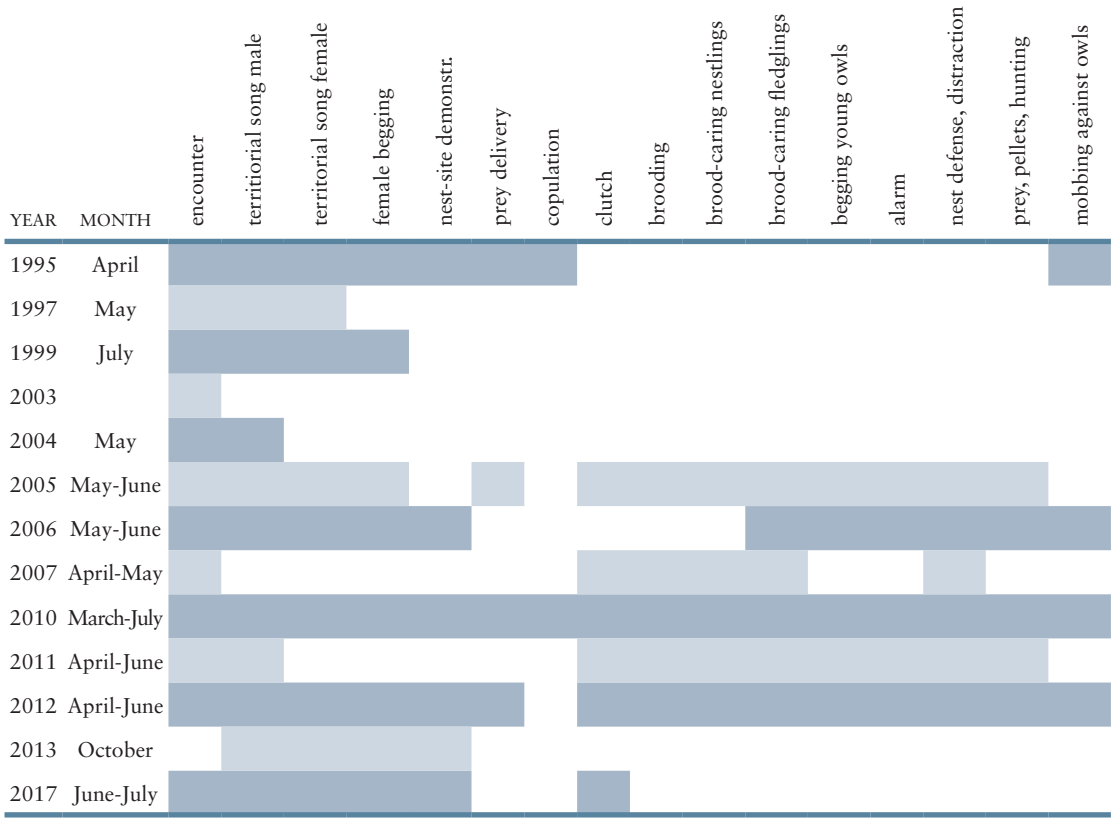
Apart from a second male, which was collected around 1914 by H. Weigold in Hwang-lung-sze (southern Sichuan Province, see map in Fig. 8) and described by Stresemann (1923), a third exemplar (a male also) was shot in the Sichuan Province by Smith 1931 (in Traylor 1967). In the local museum of the Lianhuashan Reserve a further specimen is on exhibition, poorly mounted, but probably a female (Scherzinger 2005). Although photos of Pere David's Owl were posted sporadically on the internet during recent years (mostly from northern Sichuan Province, especially from Jiuzhaigou National Park; Tab. 5-b), focused studies on this rare bird still are lacking since its first description 140 years ago.

Methods and study areas

Due to the detection of at least two territorial pairs of Pere David's Owl in Lianhuashan Reserve (southern Province of Gansu, Central China; 34°56-58´N, 103°44-48´E; Sun et al. 2001), we collected data on appearance, plumage, vocalization, behaviour and breeding activity (Fig. 1). Our aim was to improve knowledge on this species by systematic documentation during several campaigns in the

Table 1 - Timetable of stays in Lianhuashan Reserve, 1995 to 2017. By shifting times we covered all important seasons by field studies within 20 years. (Breeding activity of *Strix davidi* in nest boxes from 2005).

Tabela 1 - Calendário das estadias na Reserva de Lianhuashan, de 1996 até 2017. Ao alternar entre vários períodos do ano, abrangemos todas as fases importantes do trabalho de campo ao longo de 20 anos. (Atividade reprodutora de *Strix davidi* em caixas-ninho desde 2005.)

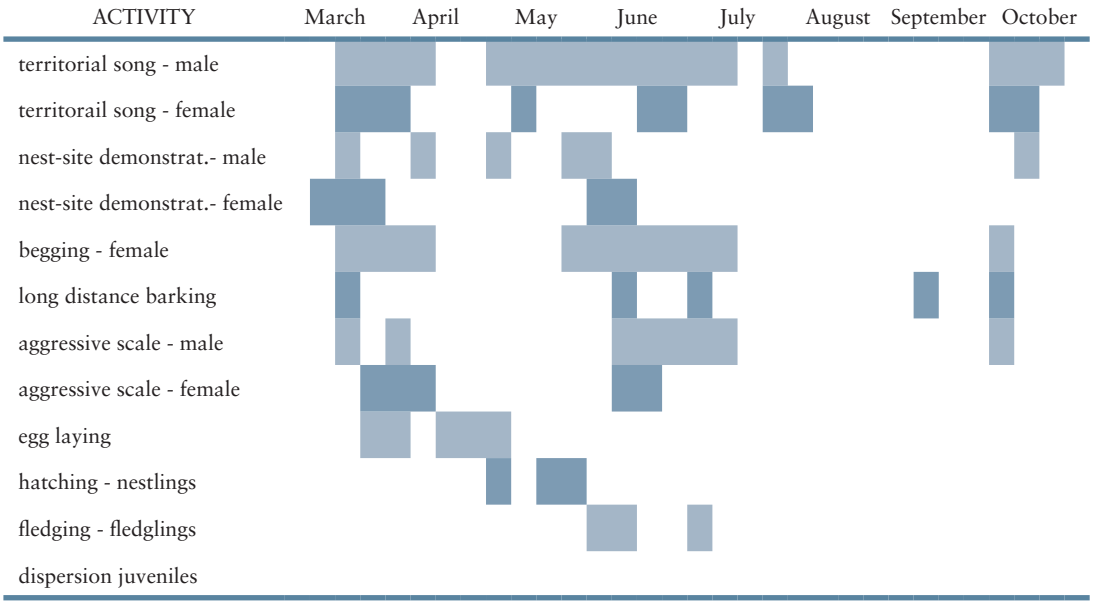


field. From our first discovery of a singing male in 1995 until 2017 we invested 14 visits to this forest-reserve, in different seasons (Tab. 1). In the years between our activities were limited to incidental findings and sporadic nest-controls only. Beside this main study area we visited the Jiuzhaigou National Park (Sichuan Province) twice, with its famous relicts of primary forests. Here we managed to record vocalizations of two males.

The Lianhuashan Reserve is situated in the limestone mountains at the eastern border of the Tibetan plateau. This area was confirmed as hotspot of biodiversity, as three distinct geographic zones, four separate landform zones (Eastern Monsoon Zone, Qinghai-Tibet Alpine-cold Zone, and North-western Arid Zone), five floristic zones, and six faunistic sub-zones meet here (Lei et al. 2006, Linxin 2013). Therefore the former provincial Forest Reserve was ranked as National Nature Reserve. It covers about 12,550 ha of high mountainous and alpine landscape, reaching elevations of 3,578 m at its highest summit ("Lotus Mountain", idolized as a Buddhist sanctuary). Due to extensive areas above the timberline and dry thorn bush on sunny slopes, older coniferous forest of suitable habitat for large wood-owls is limited to only 1,170 ha. Although the forest lost older age classes due to logging in the 1980's, today tree-stands can be classified as rather natural, in concern to their autochthonous origin and their diversity of trees, bushes and fur-

Table 2 - Summation of phenological data on *Strix davidi* in Lianhuashan Reserve, from 1995 to 2017: time of egg-laying may span over 4 weeks, and territorial song of males reach from early spring to late summer, and can also be heard in autumn occasionally.

Tabela 2 - Resumo dos dados de fenologia de *Strix davidi* na Reserva de Lianhuashan, de 1995 a 2017: as posturas podem ocorrer durante 4 semanas, e o canto territorial dos machos ocorre desde o início da primavera até ao final do verão, podendo ainda ser ouvido ocasionalmente no outono.



ther vegetation. Habitats are dominated by fir (*Abies fargesii*) and spruce (*Picea aspera*, *P. purpurea* and *P. wilsonii*), which grow mostly on humid slopes in northern exposures (Fig. 2).

Due to an obvious lack of breeding sites in the younger tree stands, natural nest sites on broken tree-stumps or in large tree-cavities are largely absent, and as a result the owls breed in perilous rock crevices. Because of the rough terrain, nesting sites are extremely hard to find in the rocky faces. Therefore about 40 spacious nest-boxes were mounted, enabled by support of the British Petrol Conservation Programme (Fang 2005). This infrastructure was immediately accepted by the owls, and enabled us to know courtship and breeding activity for the very first time. We made systematic life-history documentation through photographs and videos, tape recordings, protocols of courtship, copulation, prey-delivery and feeding fledglings, as well as nest defence and attack against enemies (Fig. 3). Long-time management of breeding, release and monitoring of Ural Owls in the Bavarian Forest National Park, Germany, provided us with comparisons of appearance, behaviour, and vocalizations in this closely related owl species (Scherzinger 2006).

Results

Phenology and reproduction

Due to our shifting schedule, our observations covered the courtship-season from the middle of March to the middle of April, and the time of breeding and rearing the offspring from the beginning of May to the middle of July. Although territorial activity is also performed in autumn, we could only be present during some weeks in October (Tab. 1, 2).

Figure 2 - Typical habitat of *Strix davidi* in Lianhuashan. Within the reserve of 120km2 about 12km2 of mountainous forests are available for the owls, at elevations between 2,500-3,100m above sea level, dominated by fir and spruce in northern slopes, by shrubs and pastures in southern slopes. Although the forest loss high age classes by logging in the 1980-ies, today tree stands can be classified as rather natural in concern to their autochthonous origin and their diversity in trees, bushes and further vegetation.

Figura 2 - Habitat típico de *Strix davidi* em Lianhuanshan. Dos 120 km2 da reserva, estão disponíveis para as corujas 12 km2 de floresta de montanha com elevação entre 2200 e os 3100 m de altitude, dominados por abetos e coníferas nas encostas a norte, e por arbustos e pastagens nas encostas a sul. Apesar do desaparecimento das árvores longevas nesta floresta, devido à exploração desde os anos 1980, atualmente os povoamentos florestais podem ser classificados como naturais, tendo em conta a sua origem autóctone e a diversidade do extrato arbóreo, arbustivo e demais vegetação.



Albeit fragmentary, the phenological data of territorial song, courtship, and breeding show a broad variety in timing: from the middle of March at least the territorial song of male and female are performed on a high level, accompanied by aggressive scales and occasional long-distance barking (Tab. 2). While the male keeps on singing (with a broad variety of full territorial song, soft song, reduced song with introductory or finishing syllables only) until moulting in the middle of summer, the female changes to begging notes as soon as she gets ready to breed. This vocalization goes along the whole of the breeding season, in highly variable enunciation. While examining different breeding sites, both sexes utter soft notes of an ascending scale during the nest site evaluation (Tab. 7).

Egg laying mostly started at the beginning of April, but in some years was delayed for up to 4 weeks. This might be dependent on weather condition or/and low accessibility of prey, due to a persistent snow cover in early spring. In such cases fledglings may leave the nest box as late as the beginning of July. In 2014 we documented the predation of a freshly laid egg by a Siberian Weasel (*Mustela sibirica*). But we cannot explain why females abandoned their clutch in some years – just after laying the first eggs (e.g., in 2017; Fig. 4).

Figure 3 - Due to an obvious lack of breeding sites in the growing up tree stands, a good number of spacious nest-boxes were mounted, what attracted the owls – and enabled us getting to know courtship and breeding activity for the first time ever.

Figura 3 - Devido à grande escassez de locais de nidificação nos povoamentos florestais em crescimento, foi instalado um elevado número de caixas-ninho, o que atraiu as corujas – e possibilitou o estudo do comportamento de corte e reprodução da espécie pela primeira vez.



Figure 4 - As is typical for owls, the eggs of *Strix davidi* are nearly pure white also, with a fine grained surface. Surprisingly the measures of single eggs can differ distinctly (eggs from two abandoned clutches; Lianhuashan Reserve 2017).

Figura 4 - Tal como é típico nas rapinas noturnas, os ovos de *Strix davidi* são claros e com uma superfície finamente granulada. As medidas podem diferir marcadamente entre ovos (ovos de duas posturas abandonadas; Reserva de Lianhuashan 2017).

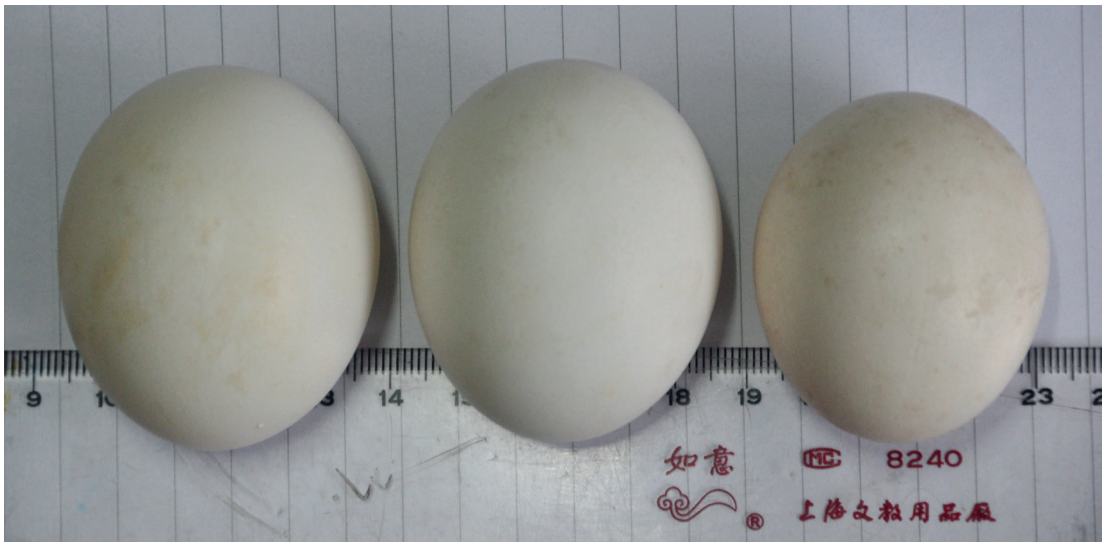


Table 3 - Measures and weight of eggs of *Strix davidi* in Lianhuashan Reserve: Due to the supply of several nest boxes we could collect some eggs for measurements (3 from abandoned brood, 5 freshly laid). Size and weight between eggs differ substantially.

Tabela 3 - Medidas e peso de ovos de *Strix davidi* na Reserva de Lianhuashan. Devido à instalação de várias caixas-ninho foi possível recolher alguns ovos para medição (3 de posturas abandonadas, 5 de posturas recentes). O tamanho e o peso variaram substancialmente entre ovos.

BROOD YEAR	MEASURES OF EGGS - MM			WEIGTH - G	
	max. length	breadth 1	breadth 2	egg shell	whole egg
2005	49.1	42.2			41.5
	50.1	40.8			42.1
2010	53.0	42.4			52.1
	53.4	42.5			53.2
2012	50.0	41.0	40.0	4.3	
2017	47.8	40.2	40.0	3.4	35.4
	52.4	43.6	44.0	(4.7)	54.0
	52.4	43.0	43.2	3.9	52.5
mean	51.1	42.0	41.8	4,1	47.3

Table 4 - Due to a strict dependency on sufficient prey abundance, the demanding wood-owls do not breed in years with a shortage of prey. As clutch size and number of fledglings are astonishingly low, the rate of reproduction seems alarming insufficient. Within 12 years we confirmed 6 breeding attempts in the eastern pair, and 9 attempts in the western pair, with only 16 fledglings altogether (1.5 and 2.2 young per successful broods).

Tabela 4 - Devido a uma forte dependência da abundância de alimento, as corujas florestais não se reproduzem em anos de escassez de presas. Uma vez que o tamanho da postura e o número de juvenis voadores são muito baixos, a taxa de reprodução parece criticamente insuficiente. Em 12 anos confirmámos 6 tentativas de reprodução do par com a localização mais oriental, e 9 tentativas do par mais ocidental, resultando na produção de apenas 16 juvenis voadores (1,5 e 2,2 juvenis por ninhada com sucesso).

Reproductive activity of *Strix davidi*, in the Lianhuashan Forest Reserve

YEAR	TERRITORIES	PAIRS	BREEDING ACTIVITY	BREEDING SITE	EGGS	NESTLINGS	FLEDGLINGS	YOUNG OWLS
1995	> 1	A-Line	probably	rock cave ?				
1997	> 1	B-Line	possible					
1999	> 1	B-Line	possible					
2003 2004	about 40 nest boxes offered							
2005	> 2	B-Line	confirmed	nest box	2	2	2	2
		rocky crest	confirmed	unknown	> 1	> 1	0	0
2006	4 ?	B-Line	possible					
		rocky crest	confirmed	rock crevice	> 2	> 2	2	?
2007	> 2	B-Line	confirmed	nest box	3	3	3	0
		rocky crest	confirmed	rock crevice	> 2	> 2	0	0
2010	> 2	B-Line	confirmed	nest box	2	2	2	2
		rocky crest	possible					
2011	> 2	B-Line	confirmed	nest box	1	1	0	0
		rocky crest	confirmed	nest box	> 3	3	?	?
2012	> 2	B-Line	confirmed	nest box	> 2	2	2	?
		rocky crest	confirmed	nest box	2	1	1	?
2013	> 2	B-Line	confirmed	unknown	> 2	> 2	> 2	2
		rocky crest	possible					
2014	> 1	B-Line	confirmed	nest box	2	0	0	0
2015	> 1	B-Line	confirmed	nest box	> 2	2	2	2
		rocky crest	unknown					
2016	(2)		unknown					
2017	> 3	A-Line	possible					
		B-Line	confirmed	nest box	2	0	0	0
		rocky crest	confirmed	nest box	1	0	0	0
S	2 - 4	2 - 3	15		> 29	> 23	> 16	> 8
mean			confirmed		1,9	1,5	1.0	0,6

Figure 5 - *Strix davidi* nestlings leave their nesting site in age of about 4 ½ weeks. Fledglings are characterised by a fluffy and wooly mesoptile, with a dark facial disc and pink eye-lids (Lianhuashan Reserve 2012).

Figura 5 - Os juvenis de *Strix davidi* deixam o ninho com cerca de 4,5 semanas de idade. Os juvenis voadores apresentam mesóptilo macio, disco facial e pálpebras cor-de-rosa (Reserva de Lianhuanshan 2012).



Although we confirmed full courtship, with prey-deliveries and copulation in 1995, data on reproductive success are scarce for the years without artificial nesting sites, and mostly based on observations of rangers or mushroom collectors in the reserve. Breeding attempts in the rocky cliffs are extremely hard to discover, but rangers reported remnants of nestlings, which had fallen from such an exposed nesting site in former years. Beside such accidental records we were able to detect a successful brood with 2 fledglings in the eastern rock area in 2006. But due to the nest box project we were able to confirm a total of 11 breeding attempts in these artificial sites, beside another one in the western forest area and at least two in the rocks; the outcome of this are 15 breeding attempts from 2005 through 2017.

Considering the high risk of nest abandonment by disturbed females, we principally avoided checking the clutch size when the female was incubating. Altogether we were able to measure eight eggs from four clutches (5 freshly laid, 3 abandoned but still fresh). The average weight was 47.3 g, length was 51.1 mm, and breadth was 41.8 mm, but single eggs differ in size to an astonishing degree (Tab. 3). By avoiding any unnecessary disturbance we had to estimate the number of eggs relative to the number of nestlings in several years. In 13 years of monitoring (2005 - 2017) we confirmed 15 broods (of two pairs), with a minimum of 29 eggs and 16 confirmed fledglings. On average, this means 1.1 eggs per pair and year, and 1.9 eggs per clutch, respectively. In consequence we recorded an average of 0.6 fledglings per pair and year, and 1.0 fledgling per confirmed breeding-attempt. With regard to successful broods, we recorded an average of 1.5 fledglings in the eastern pair (in the rock-area) and 2.2 fledglings in the western pair (in the forest area; Tab. 4).

This alarming low success of reproduction may be caused by a fundamental lack of an abundant main-prey. Although we collected all the remnants from nest boxes and monitored partly prey deliveries at the nesting site, the prey list of *Strix davidi* in the mountainous forest is quite incomplete. The largest items were Flying Squirrel (*Aeretes melanopterus*, > 500g), Chinese Grouse (*Bonasa sewerzowi*, 350g), and Northern Nutcracker (*Nucifraga caryocatactes*, 150g). More common were Pika (*Ochotona dauurica*), Hamster (*Cansumys canus*), diverse mice and medium sized birds (e.g., Elliot's Laughingthrush, *Garrulax elliotii*).

The species´ description needs a revision

As all the depictures in literature of *Strix davidi* are based on the descriptions of only two embalmed museum specimens (type from David in Paris, male – described by Sharpe 1875, Sharpe & Gunther 1875; specimen from Weigold in Dresden, male – described by Stresemann 1923), they show a broad variety of characters - even wrong ones. Especially the quite confusing comparisons with Ural Owl and Great Grey Owl in Sharpe´s first description of *Syrnium davidi* (1875) misled some artists to pass characters of these species to the image of Pere David's Owl - by mistake. In consequence these images erroneously show strong concentric rings in the facial disc (assigned from *Strix nebulosa*), also horizontal lines on feathers of breast and belly (assigned from *Strix nivicola*; König & Weick 2008), faintly spotted rings in facial disc (del Hoyo et al. 1999), bow-shaped eyebrows and chequered pattern in facial disc (Eck & Busse 1973), or a white coronoid band on the upper rim, and barred central tail feathers (Mac-Kinnon & Phillipps 2000; Fig. 5).

Figure 6 - Due to quite confusing comparisons with Ural Owl (*Strix uralensis*) and Great Grey Owl (*Strix nebulosa*) in Sharpe´s text (1875), some artists passed characters of these species to the image of *Strix davidi* - by mistake. Therefore depictions in literature differ considerably in several characters.

Figura 6 - Devido a comparações confusas com a coruja dos Urales (*Strix uralensis*) e coruja-lapónica (*Strix nebulosa*) no texto de Sharpe (1875), alguns artistas representaram por engano algumas características destas espécies em *Strix davidi*. Por esse motivo, as descrições de algumas características na literatura diferem consideravelmente.



Figure 7 - *Strix davidi*'s appearance is identified by a bulky head, with dark brown eyes in a tiny mottled facial disc, which is framed by a dark pearl-spotted rim. The forceful body is covered by a dull brownish plumage, with coarse dots on wing and shoulder. The long tail is typical for large wood-owls, like the related Ural Owls (photo: Lianhuashan Reserve).

Figura 7 - O aspeto geral de *Strix davidi* é caracterizado por cabeça volumosa, com olhos castanho-escuros num pequeno disco facial pintalgado, delimitado por um rebordo com pintas escuras. O corpo robusto é coberto por plumagem acastanhada com pintas largas nas asas e escapulares. A cauda é longa, típica das corujas florestais como a coruja dos Urales (foto: Reserva de Lianhuashan).



Figure 8 - Pere David´s Owl´s size is similar to the largest subspecies of Ural Owl (*Strix uralensis macroura*), but differs by its dull darkish brown appearance. When highly excited, the facial disc gets spread maximally, performing its whitish pearl spotted rim and patches beside the beak also (aroused female during researchers nest inspection; Lianhuashan Reserve 2012).

Figura 8 - A dimensão corporal da coruja de Sichuan é semelhante à da maior subespécie de coruja dos Urales (*Strix uralensis macroura*), mas a primeira distingue-se pela sua aparência baça e castanho-escura. Quando excitada, o disco facial expande-se, exibindo o seu rebordo escuro com pintas brancas e também as manchas brancas dos lados do bico (fêmea excitada durante a inspeção do ninho pelos investigadores; Reserva de Lianhuashan 2012).



Based on direct field observations and a great number of photos, but also on the specimen in the Lianhuashan collection, we are able to revise the description of *Strix davidi* in critical characters: As Stresemann (1923) diagnosed, Pere David's Owl appears much darker and duller in its basic colour than Ural Owls or Great Grey Owls. Due to the species´ appearance in our study area the plain dark chocolate-brown shoulders seem to be characteristic, which turns in the backside of similar colour, down into the unicoloured, brown tail coverts. In accordance with Sharpe & Gunter (1875) a row of coarse, whitish drops runs along the border between the scapulars and lesser wing coverts. A similar pattern runs across the wing (Fig. 6). The light coloured breast feathers are marked with dark stripes, arranged denser and broader on the upper part. Crossing bars of dull ochre may occur on belly and flanks.

Plumage on forehead is of mottled brown, what contrasts with a white pattern, forming a clear V. In concern with changing behavioural moods, this conspicuous pattern may appear in variable shapes. The facial disc is nearly circular in males, but more broad-oval in females. It is framed by a dark rim with contrasting white pearl-spots. The disc's surface is mainly marked by darker radial streaks. As is typical for owls, the shape and extent of the "face" may vary by mimic expression: In camouflage posture the disc gets pressed laterally and the contrasting white patterns get covered. But when highly excited, the owl presents not only the fully spread pearl-spotted facial rim, but in addition two white half-moon-shaped patches aside the chin, separated by dark feathers below the beak (Fig. 7). Bushy bristles beside the beak reach down to the "cheeks". The beak is light to deep yellow. The corners of the beak are fleshy coloured.

The colour of the dark brown eyes contrasts not only with the pinkish eyelids but also with a light ring, framing the eye. Black superciliar "eye-shadows" demarcate the disc to the whitish bushy eyebrows, which determine the strong facial expression.

Tarsi and toes are densely plumed and furry, with a fine marbling pattern. The strong and long claws are of corneous ochre to grey. Except the central feathers the fanned tail shows three crossing bars on the upper side, and four bars on the underside. The undertail coverts are marked by coarse and dark crossbars. The central, slightly pointed tail feathers are prolonged and of dark brown colour, in some cases marked with inconspicuous scribbling (Scherzinger et al. 2014).

In his first description Sharpe (1875) pointed at the uniform and dark brown colour of the central feathers in *Syrnium davidi*, what was confirmed with the second specimen by Stresemann (1923), and therefore this character got emphasized as species specific. But all descriptions of *Strix davidi* in the literature are based on male specimens. Comparing the tail feathers of the specimen of the Lianhuashan collection (which probably is a female) the central feathers show some dots and light bars (Fig. 8). The free-ranging female in the reserve clearly showed the same "aberrant" pattern. In this concern an examination of more individuals could clarify if sexual dimorphism in this owl is possible.

Due to increasing interest in the fauna and flora in China, specialised organisations bring birdwatchers from the entire world to the remotest mountains in Yunnan, Sichuan, Gansu, and even at the Tibetan Plateau, especially to sample the famous endemic bird fauna (Tab. 5-a). Therefore a large number of records, observations and photo-documents of *Strix davidi* have been acquired during the last 12 years. By correspondence, obscure literature, and the internet, we accumulated about 30 photos (four from Gansu Province, 26 from Sichuan Province and eastern Tibet, respectively), and seven records of observations in the forests of Sichuan (mostly from Gonggangling Pass and Jiuzhaigou National Park; Tab. 5-b). In summation these records from the recent past help to enlarge and specify our knowledge of the distribution and habitat characteristics of this still relatively unknown owl species.

Table 5a - In the recent past a relevant number of organisations offer special birdwatching tours to remote mountain areas, to seek rare endemics of Chinese avifauna, including Pere David´s Owl in particular (following the internet, rare guided tours accumulate at Gonganggling Pass and in Jiuzhaigou National Park).

Tabela 5a - No passado recente, um elevado número de organizações ofereceu visitas especiais de observação de aves a àreas montanhosas remotas, para procurar espécies endémicas e raras, incluindo a coruja de Sichuan (segundo informação online, as visitas guiadas para observação de raridades de avifauna ocorreram sobretudo em Gonganggling e no Parque Nacional de Jiuzhaigou).

Prospective observations of Pere David´s Owl (from internet searches 2017)				
PROVINCE	LOCATION	PHOTO	OBSERVATION	GUIDED BIRDWATCHER TOUR
Sichuan	Gongganglíng	•		China-Birding-Tour
Sichuan	Gongganglíng	•		Summer-Wong-Bird-Tours
Sichuan	Gongganglíng	•		heatherlea, UK Birdwatching
Sichuan		•		Ph. He - Alpine Birding´s
Sichuan	Gongganglíng		•	Tropical Birding
Sichuan	Gongganglíng		•	China Dreams Tour
Sichuan	Gongganglíng		•	Rockjumper Birding Tours
Sichuan	Jiuzhaigou		•	China-Holidays-Tour
Sichuan	Jiuzhaigou		•	Bird Finders - Birdwatching
Sichuan	Jiuzhaigou		•	Splendid China Tours
Sichuan	Jiuzhaigou		•	Wings Birding Tours
Sichuan	Jiuzhaigou		•	Sichuan Highlight Birding Tour
Sichaun	Jiuzhaigou		•	Birding Eco Tours
Sichuan	Jiuzhaigou		•	Panda China Tour
Sichuan	Baizha		•	Jason Tour / China Exploration
Sichuan-W	Minya Konka		•	Western Sichuan Tours
Sichuan	Ruoergai		•	Bird-Quest-Tour
Sichuan	Tangjiahe		•	Parrotbill-Tour
Sichuan	Wanglang		•	Donald Camac - Birding Asia
Sichuan	Wawushan		•	South China Birder

Table 5b - Since China opened up for tourism, a surprising number of ornithologists and birders got the chance to experience the outstanding diversity of avifauna in even remote areas of this huge country. Therefore the number of field records of *Strix davidi* increased promptly during the last decade (data from literature and internet). Observations and photos contribute to our knowledge of distribution and habitat characteristics.

Tabela 5b - Desde que a China se abriu ao turismo, um elevado número de ornitólogos e observadores de aves tiveram a oportunidade de experienciar a extraordinária diversidade da avifauna deste vasto país, incluindo em áreas remotas. Consequentemente, o número de registos de *Strix davidi* aumentou rapidamente durante a última década (segundo dados na literatura e online). Observações e fotografias contribuíram para o conhecimento da distribuição da espécie e das características do seu habitat.

Records of Pere David´s Owl in China, 1869-2017 (literature and internet searches)						
YEAR	PROVINCE	LOCATION	SPECIMEN	PHOTO / SOUND	OBSERVA-TION	SOURCE / AUTHOR
1869	Sichuan	Moupin	•			A. David
1914	Sichuan	Hwanglunszhe	•			H. Weigold
1931	Sichuan	Red Basin	•			F. Smith
1985 ?	Gansu-S	Lianhuashan	•			students at field studies
1995	Gansu-S	Lianhuashan		•		W. Scherzinger
2006	Gansu-S	Lianhuashan		•		Yun Fang
2013	Gansu-S	Lianhuashan		•		Li Linxia
1999	Sichuan	Jiuzhaigou		•		F. Lambert
2006	Sichuan	Jiuzhaigou		•		W. Scherzinger
2006	Sichuan	Jiuzhaigou		•		Luopingzhou
2006	Sichuan			•		Demeulenmeester
2008	Sichuan			•		Demeulenmeester
2010	Sichuan-NW	Baxi		•		M. Francis
2010	Sichuan	Baxi		•		M. Francis
2011	Sichuan-N	Jiuzhaigou		•		J. Eaton
2012	Sichuan-NW	Baxi		•		M. Francis
2012	Sichuan-N			•		J. Wu
2013	Sichuan	Jiuzhaigou		•		E. Hui
2013	Sichuan	Gonggangling		•		Zoothera Birding
2013	Sichuan	Jiuzhaigou		•		D. Shapiro
2014	Sichuan-N			•		S. Wong
2015	Sichuan	Jiuzhaigou		•		Flora-Fauna-Field-Tours
2015	Sichuan			•		D. Lopez
2015	Sichuan			•		K. & L. Youngs
2015	Sichuan-N	Yalan		•		J. Eaton

Records of Pere David´s Owl in China, 1869-2017 (literature and internet searches)						
YEAR	PROVINCE	LOCATION	SPECIMEN	PHOTO / SOUND	OBSERVA-TION	SOURCE / AUTHOR
2015	Sichuan	Gongganglin g		•		J. Lee
2016	Sichuan	Gongganglin g		•		J. Tang
2016	Sichuan-NW	Linzhi		•		Y-H. Sun
2017	Sichuan			•		Zoothera Birding
2017	Sichuan	Gongganglin g		•		Rockjumper Birding Tours
	Sichuan	Gouwa		•		Y. Muzika
	Sichuan			•		B. Demeulenmeester
	Sichuan			•		R. McIntyre
	Sichuan			•		China Wild Tour
2005	Sichuan	Wawushan			•	Ch. Artuso
2010	Sichuan	Emeishan			•	Victor Emanuel Venture Tours
2015	Sichuan	Ruoergai			•	P. Hottala
2017	Sichuan	Gongganglin g			•	H. Laussmann & I. Kuehn
2017	Sichuan	Gongganglin g			•	North Thailand Birding
2017	Sichuan	Jiuzhaigou			•	P. Holt & Q. Wang
2017	Sichuan	Jiuzhaigou			•	M. Nelson, Birdtour Asia
2017	Sichuan				•	Ch. Hesse, Tropical Birding

Discussion

Specification of Pere David's Owl's taxonomic status

The overall appearance of *Strix davidi* clearly resembles the shape and size of Ural Owls (*Strix uralensis*), and therefore this Asiatic wood-owl was broadly accepted as a dark and big subspecies of the latter in former times (e.g., Stresemann 1923, Vaurie 1965, Eck & Busse 1973, Glutz & Bauer 1980. Scherzinger & Fang 2006). Due to the huge distribution area of the Ural Owl – from Japanese islands to northern Europe – the diverse subspecies developed a broad differentiation in size, basic colour and pattern of plumage: with small and reddish representatives in southern Japan, nearly black or dark brown to light brownish birds in the Balkans (SE-Europe), light grey owls in Fennoscandia and silvery-white exemplars in Siberia (illustrations by Weick, in Scherzinger et al. 2014). In consequence, the colour and pattern of plumage conform in many details between these two species: dark backside, V-shaped eye-brows, pinkish eyelids, vertical streaks on breast and flanks, row of white dots on shoulder (scapulars), furry feathers on tarsi, pearl-spotted rim of facial disc etc. (Tab. 6). But the plain and unicoloured central tail feathers and a black superciliar stripe are really unique characters of Pere David's owl.

A similar pattern of concordance was found in the vocal inventories of *Strix uralensis* and *Strix davidi*, although the analysis of vocalization may be preliminary in the latter. Interspecific comparisons in Tab. 7 point to a high degree of overlap: e.g., the character of

Table 6 - Simplified tabulation of characteristics of Pere David´s owls plumage, in comparison to typical features of Ural Owls. Due to a broad variability of colours and patterns within the eight accepted subspecies of *Strix uralensis*, there is a large overlap in detailed characteristics. But the dark brown, uniform and plain central tail-feathers are a species-specific character of *Strix davidi*.

Tabela 6 - Lista simplificada das características da plumagem da coruja de Sichuan, em comparação com as características típicas da coruja dos Urales. Devido a uma grande variação das tonalidades e padrões dentro de oito subespécies de *Strix uralensis* reconhecidas, existe uma grande sobreposição nestas características. O padrão característico de *Strix davidi* corresponde à presença de retrizes centrais lisas com coloração uniforme castanho-escura.

Which characters of plumage are significant and specific for Pere David´s Owl ?										
		Strix davidi	*Strix uralensis*							
CHARACTERISTICS	OF PLUMAGE		fuscescens	hondoensis	japonica	nikolskii	yenisseensis	uralensis	liturata	macroura
basic colour, breast a. flanks	whitish light				•			•		
basic colour, breast a. flanks	off-white	•		•	•	•	•	•	•	•
basic colour, breast a. flanks	light grey	•		•		•	•	•	•	•
basic colour, breast a. flanks	greyish brown			•		•	•		•	•
basic colour, breast a. flanks	yellowish brown		•						•	•
basic colour, breast a. flanks	pale tawny brown		•							•
basic colour, breast a. flanks	dark brown		•				•			•
eye-brows	V-shaped	•	•	•	•	•	•	•	•	•
vibrissae	A-shaped	•	•	•	•	•	•	•	•	•
accentuaton of eyes	pinkish eyelids	•	•	•	•	•	•	•	•	•
plumage on breast and flanks	vertical streakes	•	•	•		•	•		•	•
central tail feathers	long and wedged	•	•	•	•	•	•	•	•	•
shoulder (scapulars)	row of white spots	•	•	•	•	•			•	•
accentuaton of eyes	white half-moons	•	•	•	•	•	•	•	•	
beside the beak	white half-moons	•	•	•	•	•	•	•	•	•
tarsi and toes	furry plumage	•		•	•	•	•	•	•	•
rim of facial disc	pearl-spotted	•	•	•	•	•	•	•	•	•
design of facial disc	radial streaks	•	•	•	•	•	•	•	•	•
white pattern on forehead	V-shaped	•	•	•	•	•	•		•	•
wing (secundaries)	row of white spots	•	•	•	•	•		•	•	•
backside and mantle	dark-brown	•	•	•						•
accentuaton of eyes	black superciliar	•	•	•	•			•	•	•
central tail feathers	plain, unicolour	•	•							
backside and mantle	coarse mottled	•			•	•	•	•	•	•
plumage on breast and flanks	pale bars across	•	•	•	•					•

Which characters of plumage are significant and specific for Pere David´s Owl ?										
		Strix davidi	*Strix uralensis*							
CHARACTERISTICS	OF PLUMAGE		*fuscescens*	*hondoensis*	*japonica*	*nikolskii*	*yenisseensis*	*uralensis*	*liturata*	*macroura*
plumage on breast and flanks	strong arrowy	•	•							•
design of facial disc	concentric dots	•								•
central tail feathers	scribbled, patchy	•								
central tail feathers	markedly barred		•	•	•	•	•	•	•	•
plumage on breast and flanks	thin vertical lines				•			•		
tarsi and toes	thin bristled		•			•				

Figure 9 - All descriptions of *Strix davidi* in literature (by Sharpe 1875 and Stresemann 1923) are based on male specimens. Therefore the central "uniform coloured" tail feathers got a species specific character, and the main difference to the divers subspecies of *Strix uralensis*. (But a sexual dimorphism is supposable, as females show some dots and bars in the tail? Left: male in flight. Right: female specimen).

Figura 9 - Todas as descrições de *Strix davidi* na literatura (por Sharpe 1875 e Stresemann 1923) são baseadas em espécimes do sexo masculino. Consequentemente, a presença de retrizes centrais lisas com coloração uniforme castanho-escura foi assumido como a principal distinção relativamente às diversas subespécies de *Strix uralensis*. (Contudo, é possível que ocorra dimorfismo sexual, uma vez que as fêmeas apresentam algumas pintas e barras na cauda. Esquerda: macho em voo. Direita: espécime fêmea.).





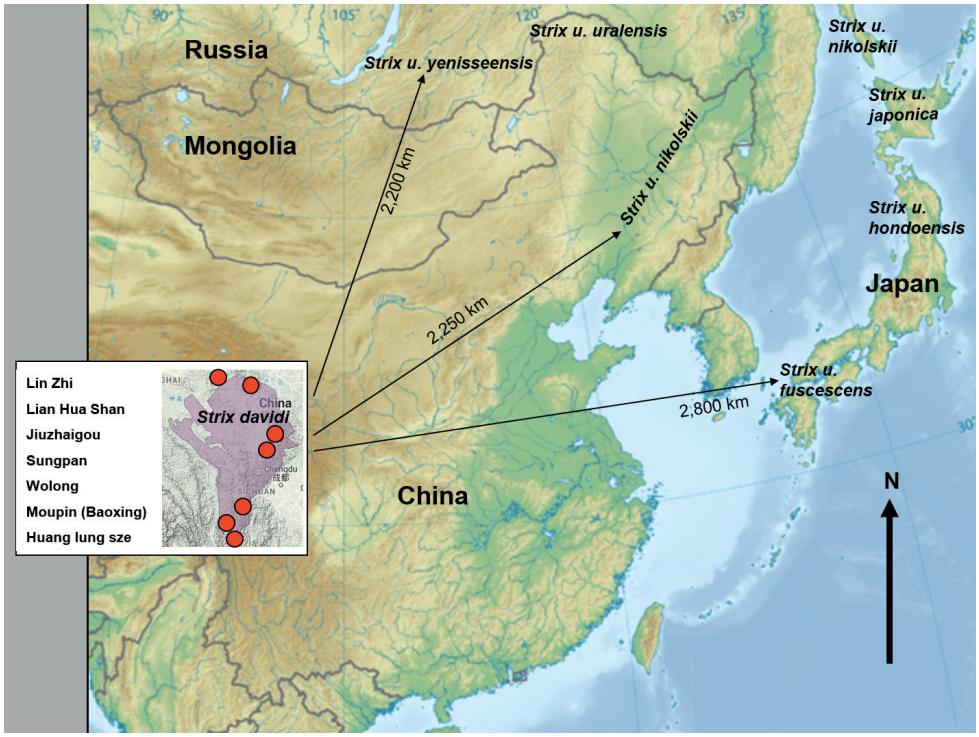
Table 7 - Comparisons of vocal utterances show a broad overlap in the inventories of *Strix davidi* and *Strix uralensis*, as songs, begging-, alarm-, and feeding notes resemble each other in rhythm, acoustic colour and meaning.

Tabela 7 - A comparação de vocalizações mostra uma grande sobreposição entre os repertórios de *Strix davidi* e *Strix uralensis*, uma vez que o canto e as vocalizações de pedido de alimento, alarme e alimentação se assemelham em termos de ritmo, timbre e significado.

Vocal inventory of *Strix davidi* (preliminary analysis)			*Strix uralensis*
JUVENILE	FEMALE	MALE	JUV. + FEMALE + MALE
	territorial song	territorial song	territorial song
		introductory syllables	introductory syllables
		introd. syllables + stutter	
		variable combinations (song + scale)	
		finishing syllabels	finishing syllabels
		soft song	soft song
	feeding stimulation		feeding stimulation
	low "bwuhh"	attracting low "moo"	
	nestsite demonstration	nestsite demonstration	nestsite demonstration
	aggressive scale	aggressive scale	aggressive scale
		copula twitter	copula twitter
	contact note (*kjwäk*)	contact note (*kjwäk*) ?	contact note (*kjwäk*)
	"begging" (*kjuwäk*)		"begging" (*kjuwäk*)
		extended alarm (?) call	extended alarm (?) call
	arousal note (*kuja*)		
	arousal note "barking"		
			long range "barking"
	arousal (*kuwack, guo*)		arousal (*kuwack, guo*)
begging (*kschjitt*)			begging (*kschjitt*)
moaning			moaning
shivering			shivering
bill snapping	bill snapping	bill snapping	bill snapping

Figure 10 - The map of eastern Asia clearly shows the small area of *Strix davidi* distribution in the mountainous forests of central China, limited by the Himalayan mountains in the west, the Gobi desert to the north, an arid semi-desert to the east, and the subtropical forest to the south. (Dots correlate with the records of this owl from the literature, internet and our observations.) The high degree of isolation from distribution areas of neighbouring subspecies of *Strix uralensis* justifies the ranking of *Strix davidi* as a discrete species. Map from wikimedia: East Asia topographic map.org.

Figura 10 - O mapa da Ásia oriental mostra claramente a pequena área de distribuição de *Strix davidi* nas florestas montanhosas da China central, limitada pelos Himalaias a oeste, pelo deserto de Gobi a norte, por um semideserto árido a este e pela floresta subtropical a sul. (Os pontos representam registos desta coruja descritos na literatura, online e observações deste estudo.) O elevado grau de isolamento relativamente às áreas de distribuição de subespécies vizinhas de *Strix uralensis* justifica a classificação de *Strix davidi* como uma outra espécie. Mapa retirado de wikimedia: East Asia topographic map.org.



male's territorial song (and its soft version), a soft ascending scale for "nest site demonstration" in both sexes, copula twitter of the male, females' contact note, begging and stuttering trill (to stimulate nestlings while feeding), harsh notes of arousal and alarm. But a low pitched mooing (both sexes) and variable utterances of arousal are unique in the Asiatic wood-owl. The main utterances of nestlings sound widely identical between these both species.

Despite the high degree of correspondence in detailed characters, the status of Pere David's Owl as a discrete species is broadly accepted nowadays (e.g., Mikkola 2012, Global Owl Project 2013). The justification is based in the long geographic isolation of *Strix davidi*, with a distribution strictly-limited to the old coniferous forest in the high mountains of central China and eastern Tibet, respectively. Bordered by the high mountains of Himalaya in the west, by the Gobi desert in the north, by an extensive man-made steppe in the east and the transition to subtropical forests in the south, the distances to neighbouring populations of *Strix uralensis* are minimally 2,200 km (to *Strix u. yenisseensis* and *nikolskii*), but 2,800 km to *Strix u. fuscescens* on the southernmost island of

Japan, which was suggested as closely related in former times (Fig. 9). Therefore *Strix davidi* counts as a rare endemic bird of central China (red List of China). But the former recommendation by Eck (1971) to merge *Strix uralensis* and *Strix davidi* as a super-species seems to fit best with the biological relatedness.

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Population Dynamics and Conservation of the Western Burrowing Owl (*Athene cunicularia hypugaea*) in the United States and Canada: a 20-year update

Dinâmica populacional e conservação da coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) nos Estados Unidos e no Canadá: atualização após 20 anos



Steven R. Sheffield[1*]

1 Department of Natural Sciences, Bowie State University, Bowie, Maryland USA

*** Corresponding author:** srsheffield@comcast.net

ABSTRACT

The Western Burrowing Owl (*Athene cunicularia hypugaea*) has been the focus of much research, monitoring, and conservation efforts since the first indications of population declines in the 1960s. Despite this focus and continuing declines, burrowing owls remain endangered in Canada, threatened in Mexico, and while not yet listed at the federal level in the United States of America (US), they are listed as endangered, threatened, or a species of concern in most western states. I examined the population dynamics of Western Burrowing Owls using two major long-term, standardized avian counts, the Breeding Bird Survey (BBS) and Christmas Bird Count (CBC), and reviewed their conservation status as I did 20 years ago to assess changes occurring over this time. BBS data for the US and Canada reveal that the 1966-2017 trend is slightly more than a 1% loss per year. Almost all western US states continue to show declining numbers (0.2-4.9%). CBC data for the US indicate that relatively few owls are seen on CBCs (0.03-0.05 owls/party hour), limiting its use. In addition to BBS and CBC data, a review of the peer-reviewed literature from 1997-2017 reveals that slight to steep population declines have been reported in the US and Canada, and that in many locations where Western Burrowing Owls formerly were common, they have disappeared at an alarming rate. Surveys conducted at historical nesting sites

have found that only a small percentage of the sites are still occupied. Elimination of fossorial mammals through control programs, habitat loss, and disease appears to be a primary factor responsible for owl declines. I suggest that the most effective way to conserve this owl is to protect fossorial mammals and their habitats, which should include eliminating control programs and placing real limits on changing land-use for agricultural and other development. Further, the conservation status of this owl at the federal and state levels in the US should be revisited and adjusted to more accurately reflect its continuing decline.

Keywords: *Athene cunicularia hypugaea*, survey techniques, conservation, population dynamics, Western Burrowing Owl

RESUMO

A coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) tem sido o foco de vários esforços de investigação, monitorização e conservação desde os primeiros indícios de declínio da população na década de 1960. Apesar desse esforço, o declínio tem sido contínuo e a coruja-buraqueira continua classificada como "em perigo" no Canadá, "ameaçada" no México e, embora ainda não esteja listada ao nível federal nos Estados Unidos da América (EUA), está classificada como "em perigo", "ameaçada" ou "preocupante" na maioria dos estados ocidentais. Examinei a dinâmica populacional de corujas-buraqueiras-ocidentais usando duas contagens de aves padronizadas de longo prazo, o *Breeding Bird Survey* (BBS) e o *Christmas Bird Count* (CBC), e revi seu estatuto de conservação, como fiz há 20 anos, para avaliar as alterações ocorridas durante esse período de tempo. Os dados do BBS para os EUA e o Canadá revelam que a tendência de 1966-2017 é ligeiramente superior a um declínio de 1% por ano. Quase todos os estados do oeste dos EUA continuam a apresentar um declínio (0,2-4,9%). Os dados do CBC para os EUA indicam que são observadas relativamente poucas corujas (0,03-0,05 corujas/hora), o que limita a sua utilização. Além dos dados das contagens BBS e CBC, a revisão da literatura de 1997-2017 revela que foram relatados declínios populacionais ligeiros a acentuados nos EUA e no Canadá, e que a espécie desapareceu a um ritmo alarmante em muitos locais onde anteriormente era comum. Pesquisas realizadas em locais históricos de nidificação revelaram que apenas uma pequena percentagem dos locais ainda continua ocupada. A eliminação de mamíferos fossoriais através de programas de controlo, perda de habitat e doenças parece ser o principal fator de declínio da coruja-buraqueira. A medida mais eficaz de conservação desta espécie deverá ser a proteção dos mamíferos fossoriais e dos seus habitats, o que deve incluir a eliminação dos programas de controlo e a imposição de limites reais às alterações do uso do solo relacionadas com o desenvolvimento agrícola e outros. Adicionalmente, o estatuto de conservação da coruja-buraqueira aos níveis federal e estatal nos EUA deve ser revisto e ajustado para refletir com mais precisão o seu contínuo declínio.

Palavras-chave: *Athene cunicularia hypugaea*, conservação, coruja-buraqueira-ocidental, dinâmica populacional, técnicas de monitorização

Introduction

The Western Burrowing Owl (*Athene cunicularia hypugaea*; hereafter BUOW) is an obligate species of prairie grassland ecosystems of the mid-western and western United States, Canada, and Mexico (Klute et al. 2003; Poulin et al. 2011) (Fig. 1.). They are found primarily in open areas with short vegetation and bare ground in grassland, desert, and shrub-steppe habitats. The vast majority of BUOWs are dependent upon the presence of fossorial mammals whose burrows are used for nesting and roosting (Klute et al. 2003; Johnsgard 2002; Poulin et al. 2011).

Populations of BUOWs have declined both locally and regionally over their range in North America (Sheffield 1997*a*; Holroyd et al. 2001; Klute et al. 2003; Poulin et al. 2011). Some population declines have been very serious (e.g., > 10% annually; Klute et al. 2003; Poulin et al. 2011). The primary threat across their range is habitat loss due to changes in land-use, conversions for agriculture and urban development, and habitat degradation and loss due to major reductions of fossorial mammal populations (Davidson et al. 2012).

The close ecological association between BUOWs and prairie dogs, mainly black-tailed prairie dogs, is well-established and unequivocal (Butts and Lewis 1982; Desmond et al. 2000; Sidle et al. 2001; Winter and Cully 2007; Poulin et al. 2011). Widespread conversion of grassland to agriculture, extensive overgrazing, and desertification have resulted in 20-80% declines in grassland area across all continents (White et al. 2000). This has resulted in substantial reductions in the amount of preferred habitat for fossorial mammals, and subsequent population declines in fossorial mammals and the large number of species which rely on them (Ceballos et al. 2010). In addition, intensive control programs (poisoning, shooting) and sylvatic plague epizootics have seriously reduced prairie dog populations by an estimated 98% since 1900 (Hoogland 2006).

Burrowing Owls generally are found at low densities with relatively large distances between individual or loose clusters of pairs. Estimating the population size of BUOWs over large areas is difficult; this is a species which requires concerted effort in which to survey due to their distribution and particular life history traits. One way in which to attempt to assess burrowing owl population sizes and trends is the use of two long-term avian surveys, the Breeding Bird Survey (BBS) and the Audubon Christmas Bird Counts (CBC). The BBS is a standardized, early summer survey of breeding birds administered by the US Geological Survey (USGS), and has been conducted every year since 1966. The Audubon CBC is a standardized, early winter survey of birds administered by the National Audubon Society (NAS), and has been conducted every year since 1900. Together, the BBS and CBC can provide an estimate of avian population sizes and trends throughout the year (Kirk and Hyslop 1998; Butcher and Niven 2007; Langham et al. 2015). The strengths of these databases are that they are long-term, are standardized, include measures of effort recorded for each count, and are peer-reviewed (Sauer et al. 2004; Soykan et al. 2016; Rosenberg et al. 2017).

The objectives of this study were to (1) utilize long-term avian databases (e.g., BBS, CBC) to assess population status and trends of BUOWs; (2) follow up on similar analysis conducted by Sheffield (1997) and Klute et al. (2003) to assess estimated population changes over time; (3) compare the conservation statuses of BUOWs from 1997-2017; and (4) examine the scientific literature from 1997-2017 for papers dealing with BUOW population status and trends.

Figure 1 - North American distribution (from Klute et al. 2003) of the Western Burrowing Owl.

Figura 1 - Distribuição da coruja-buraqueira-ocidental na América do Norte (adaptado de Klute et al. 2003).

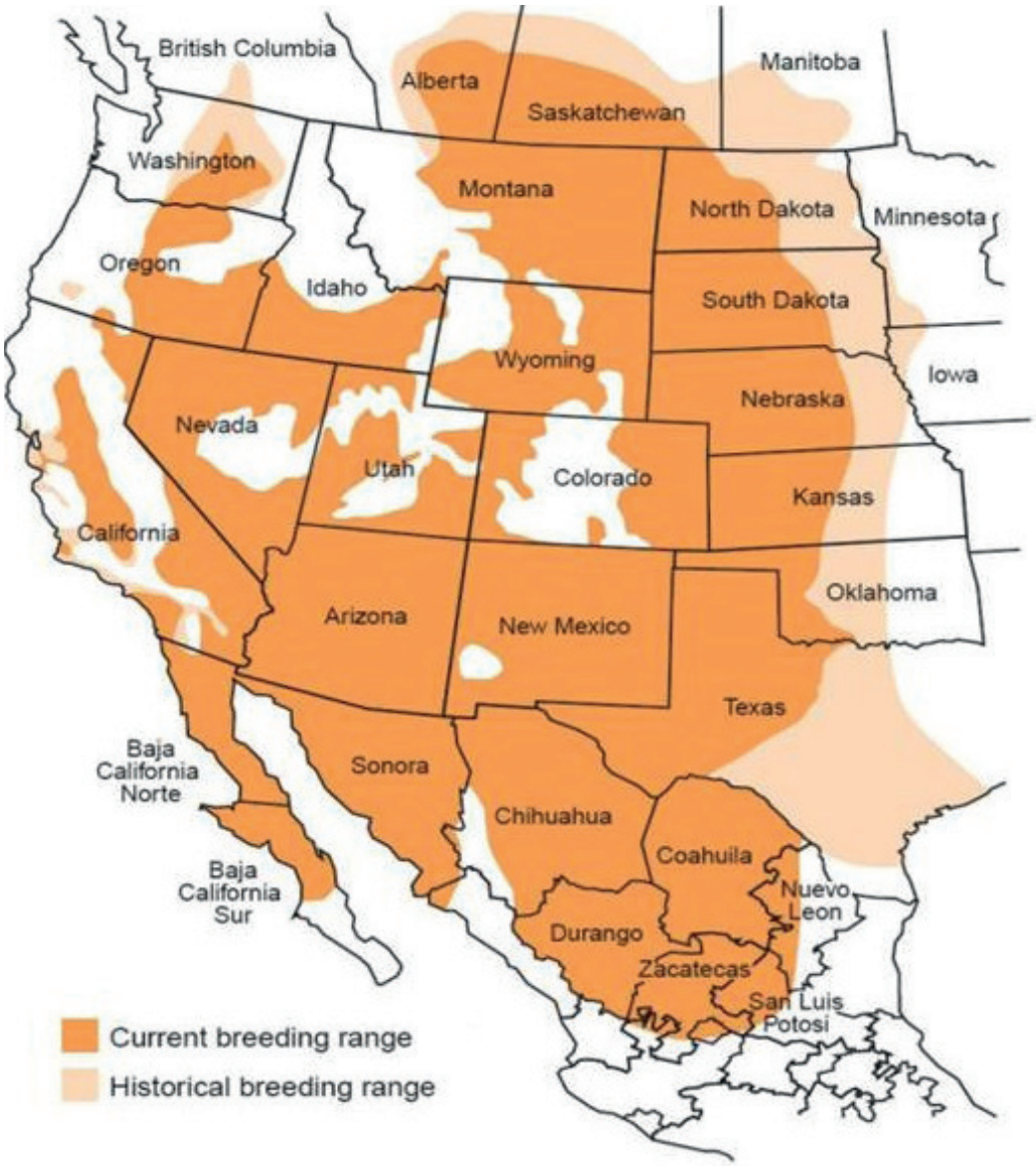


Figure 2 - Western Burrowing Owl Breeding Bird Survey relative abundance data (2011 versus 2017).

Figura 2 - Abundância relativa da coruja-buraqueira-ocidental no Breeding Bird Survey (2011 versus 2017).

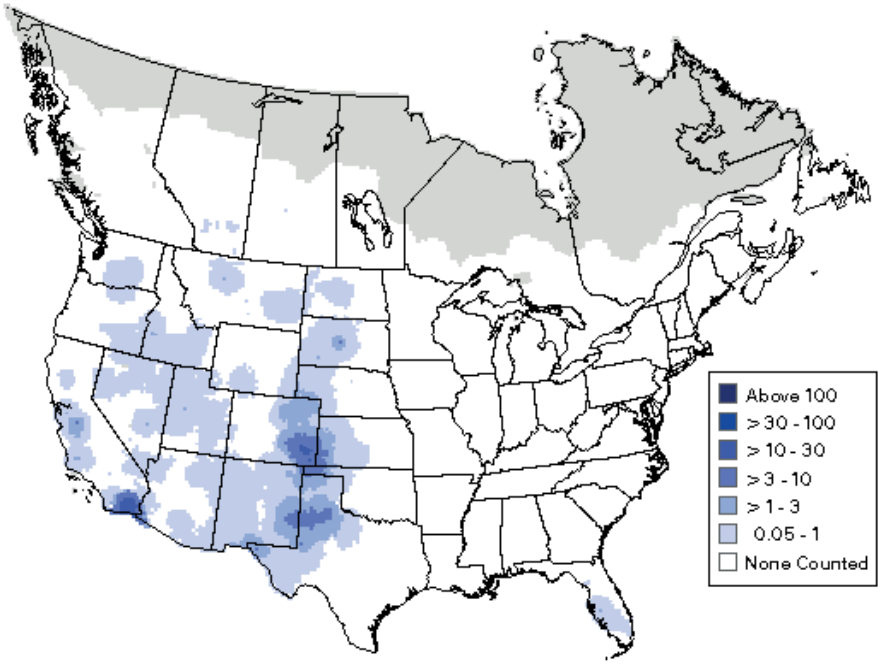


Figure 3 - Western Burrowing Owl Breeding Bird Survey trend data (2011 versus 2017).

Figura 3 - Tendência da coruja-buraqueira-ocidental no *Breeding Bird Survey* (2011 *versus* 2017).

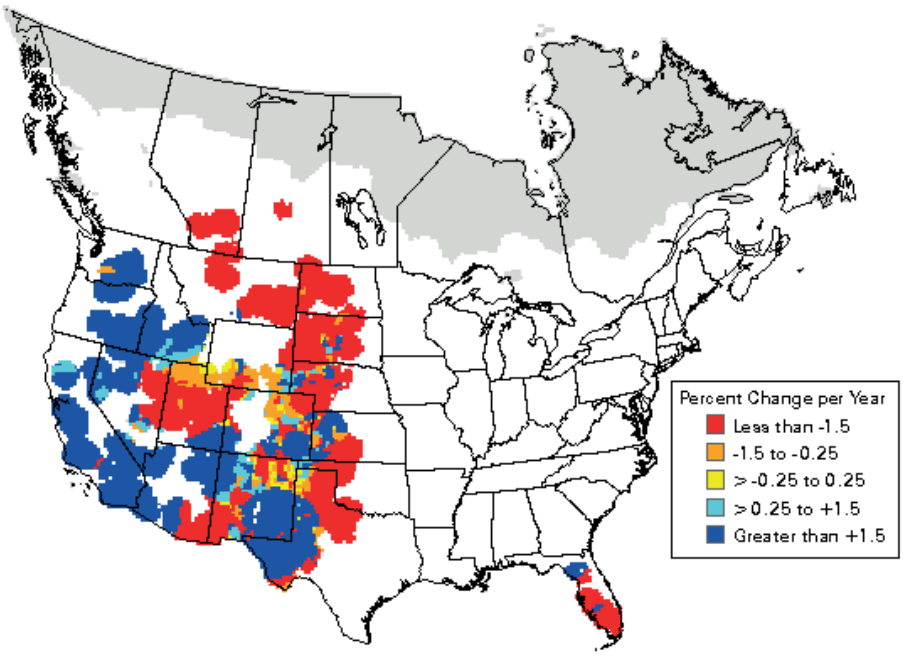


Table 1 - Western Burrowing Owl population monitoring - Breeding Bird Survey (% change/year) per country.
* = p<0.05

Tabela 1 - Monitorização da população da coruja-buraqueira-ocidental – *Breeding Bird Survey* (% alteração/ano) por país.

AREA	1966-1994	1966-2006	1966-2011	1966-2015
United States	- 0.5 (n=238)	- 1.5 (n=334)	- 1.0 (n=553)*	- 0.91 (n=555)*
Canada	n/a (n=7)	- 13.5 (n=7)	- 7.8 (n=25	- 6.42 (n=28)
North America	- 0.6 (n=245)	- 1.6 (n=341)	- 1.1 (n=578)*	- 1.1 (n=578)*

Table 2 - Western Burrowing Owl population monitoring - Breeding Bird Survey (% change/year) per state (US).
* P<0.05

Tabela 2 - Monitorização da população da coruja-buraqueira-ocidental - *Breeding Bird Survey* (% alteração/ano) por estado (EUA).

STATE	Sheffield (1997)	Sauer et al. (2007)	Sauer et al. (2011)	Sauer et al. (2017)
California	5.3 (32)*	4.2 (33)*	-1.8 (60)	-1.79 (61)
Colorado	-3.8 (25)	-5.8 (44)	-1.0 (55)	-0.43 (55)
Nebraska	6.0 (15)	32.8 (16)	3.2 (29)	0.85 (26)
New Mexico	-0.6 (22)	3.4 (39)	1.0 (56)	1.08 (54)
North Dakota	4.2 (16)	-3.8 (13)	-4.9 (28)*	-6.08 (28)*
South Dakota	-5.8 (19)	-4.8 (11)	-2.2 (32)	-2.92 (32)*
Texas	-1.4 (22)	0.2 (36)	-1.5 (54)	-1.22 (51)

Methods

Population numbers and trends presented here are derived from 50 years (1966-2016) of North American Breeding Bird Survey (BBS) data (Sauer et al. 2017) and 116 years (1900-2016) of Christmas Bird Count (CBC) data (National Audubon Society 2017). Long-term avian population databases such as the BBS and CBC are acknowledged to be potentially valuable indicators of patterns of avian biogeography and population trends (Sauer et al. 2004; Sauer et al. 2013). The BBS and CBC data allow analysis of abundance and distribution of avian species during the breeding season (late spring/early summer) and during early winter, respectively. Importantly, studies which have analyzed both CBC and BBS data together have found CBC trend estimates to be broadly congruent with estimates based on the BBS (Link and Sauer 2007; Soykan et al. 2016). Further, I compared state, provincial, and national conservation statuses of BUOWs to look for changes over this 20-year period. Finally, I examined the burrowing owl scientific literature over this 20-year period for papers dealing with BUOW trends, distribution, or conservation status in order to provide additional insight into local and/or regional population dynamics.

Results

Breeding Bird Survey

In the United States, the national BBS data show over a 50-year period a fairly consistent and statistically significant decline of 0.91%/yr, including a 0.41%/yr decline over the past 20 years, in the overall BUOW population (Table 1, Fig. 2 and 3). For North America overall, the BBS data show over a 50-year period a decline of 1.1%/yr, including a 0.38%/yr decline over the past 20 years, in the overall BUOW population (Table 1). In Canada, the BBS data show over a 50-yr period a precipitous decline of 6.42%/yr. In the United States, the BBS data by state indicate that, of the seven states (California, Colorado, Nebraska, New Mexico, North Dakota, South Dakota, Texas) analyzed by Sheffield (1997*a*), five states (California, Colorado, North Dakota, South Dakota, Texas) have demonstrated 20-year (long-term) declining population trends (Table 2). Population declines in both North Dakota (6.08%/yr) and South Dakota (2.92%/year) were statistically significant. Overall, the states of California and North Dakota have shown the sharpest declines in numbers in the past 20 years; California went from an increase of 5.3%/year in 1997 to a decline of 1.79%/yr in 2017, and North Dakota went from an increase of 4.2%/yr in 1997 to a decline of 6.08%/yr in 2017 (Table 2).

There are BBS data for 10 additional states (Arizona, Idaho, Kansas, Montana, Nevada, Oklahoma, Oregon, Utah, Washington, Wyoming), and of these states, seven of them show population declines ranging from 0.17%/yr in Oklahoma to 4.70%/yr decline in Washington; the decline of 4.04%/yr in Kansas was the only one which was statistically significant (Table 3).

In Canada, BUOW declines were 6.90%/yr in Alberta and 6.17%/yr in Saskatchewan (Table 3).

Christmas Bird Count

The CBC data indicate that BUOWs are exceedingly rare winter inhabitants of Canada (only three records in the past 20 yrs), and uncommon inhabitants of the United States (the majority of BUOWs winter in Mexico), with a mean of only 454.2 owls found in the United States each year over the past 20 years (Table 4). Over this time, annual numbers ranged from 291-600 owls, with the number of BUOWs/party hours (a measure of effort) being low (0.0039) across the United States, ranging from 0.0028-0.0049. This low average number of BUOWs/party hour means that CBC participants would need to search 256.4 hrs to find one BUOW. As far as BUOWs at the state level, California has the most early winter burrowing owls by far (=168.4), followed by Texas (=33.5), Arizona (=23.0), and New Mexico (=14.6). At the state level, the number of BUOWs/party hours ranges from 0.0047-0.0127. BUOWs in southern portions of California and Arizona are year-round residents, and this may complicate CBC trend data.

Conservation Status

On the international level, Burrowing Owls have a Global Heritage Rank of G4 (Table 5), which means that they are apparently secure globally though the species may be quite rare in parts of its range. The IUCN lists Burrowing Owls as Least Concern ranking on the IUCN Red List, largely because of their large distribution throughout the Western Hemisphere (IUCN 2017). Further, Burrowing Owls are a CITES Appendix II species, which means that, although they are not necessarily threatened with extinction, they may become so unless trade is closely controlled (CITES 2017). The legal trade in wild BUOWs from North America was an exceedingly rare activity between 1975-2015 (Panter et al. 2019), and there are no strong

Table 3 - Western Burrowing Owl population monitoring - Breeding Bird Survey (% change/year) per state (US) and province (Canada).

Tabela 3 - Monitorização da população da coruja-buraqueira-ocidental - *Breeding Bird Survey* (% alteração/ano) por estado (EUA) e província (Canadá).

OTHER STATES	Sauer et al. (2007)	Sauer et al. (2011)	Sauer et al. (2017)
Arizona	18.7 (11)	1.2 (21)	1.66 (23)
Idaho	10.2 (9)*	-0.1 (16)	-0.72 (14)
Kansas	2.6 (17)	-3.2 (24)	-4.04 (24)*
Montana	-15.2 (11)	-2.1 (25)	-2.08 (24)
Nevada	8.0 (11)	-0.2 (19)	1.96 (19)
Oklahoma	-4.8 (11)	-0.2 (13)	-0.17 (13)
Oregon	1.1 (11)	-1.0 (18)	-0.94 (21)
Utah	7.9 (21)	-1.5 (42)	0.01 (46)
Washington	-4.0 (8)	-2.3 (17)	-4.70 (17
Wyoming	-20.1 (12)	0.7 (28)	-0.19 (31)
PROVINCES			
Alberta	-11.9 (5)	-6.2 (12)	-6.90 (15)
Saskatchewan	-26.0 (2)	-8.5 (12)	-6.17 (13)

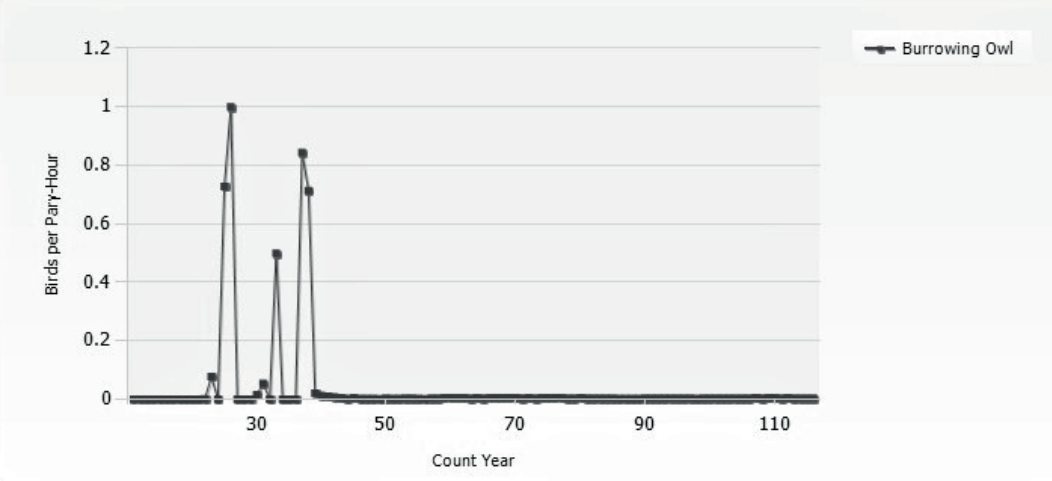
Table 4 - Western Burrowing Owl population monitoring in 1900-2016, from Christmas Bird Count data (National Audubon Society 2017).

Tabela 4 - Monitorização da coruja-buraqueira-ocidental no *Christmas Bird Count* entre 1900 e 2016 (National Audubon Society 2017).

STATE	# (1997-2016)	mean # / yr	# / party hrs (effort)
United States	9,084	454.2	0.0039
California	3,368	168.4	0.0127
Texas	670	33.5	0.0047
Arizona	459	23.0	0.0074
New Mexico	292	14.6	0.0108

Figure 4 - Western Burrowing Owl population monitoring in 1900-2016, from Christmas Bird Count data (National Audubon Society 2017).

Figura 4 - Monitorização da coruja-buraqueira-ocidental no *Christmas Bird Count* entre 1900 e 2016 (National Audubon Society 2017).



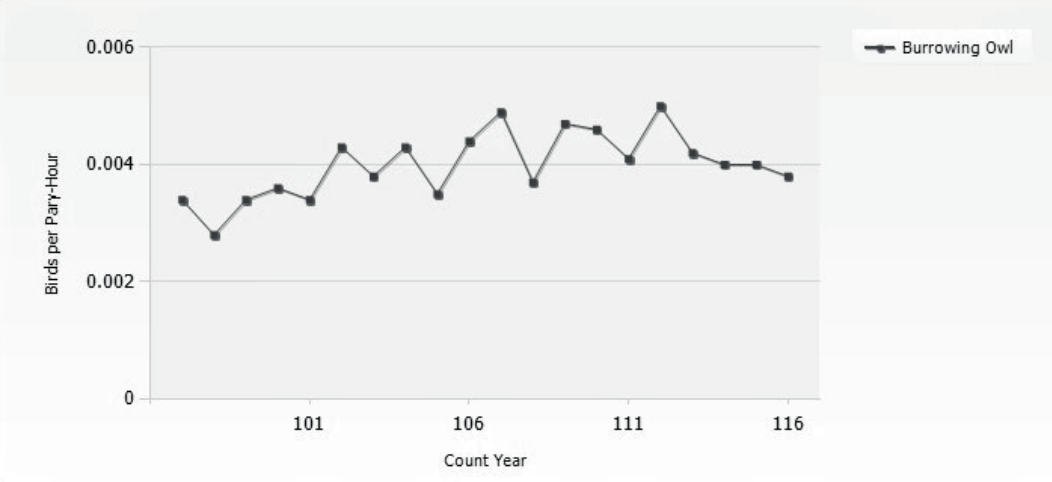
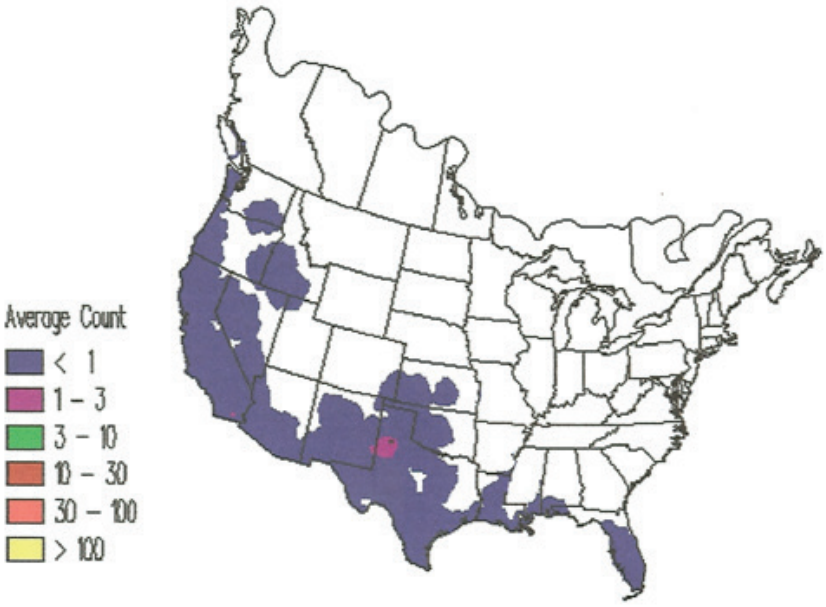


Figure 5 - Western Burrowing Owl population monitoring in 1959-1988, from Christmas Bird Count data (Sauer et al. 1996).

Figura 5 - Monitorização da coruja-buraqueira-ocidental no *Christmas Bird Count* entre 1959 e 1988 (Sauer et al. 1996).



cultural beliefs that suggest legal or illegal trade of this species in North America (D.H. Johnson, pers comm). At the federal level, BUOWs are listed as endangered in Canada, threatened in Mexico, and not listed in the United States. Burrowing Owls are federally protected in the United States, Canada, and Mexico by the Migratory Bird Treaty Act. In the United States, BUOWs were included as a Category 2 Candidate Species from 1994-1996. The US Fish and Wildlife Service's Birds of Conservation Concern reports (USFWS 2003, 2009) include the BUOW as a Bird of Conservation Concern at the national level, in 3 USFWS Regions, and in 9 Bird Conservation Regions.

At the provincial level in Canada, BUOWs are listed as endangered in Alberta, British Columbia, Manitoba and Saskatchewan. In the United States, BUOWs are listed as endangered in Iowa and Minnesota, threatened in Colorado, and of special concern in Arizona, California, Montana, Oklahoma, Oregon, Utah, Washington, and Wyoming. In Idaho, the BUOW is listed as a species of greatest conservation needs in the state wildlife action plan, and in North Dakota, the BUOW is listed as a level II species of conservation priority. The BUOW is not listed in Kansas, Nebraska, Nevada, New Mexico, South Dakota or Texas. Over the past 20 years, the Canadian provincial designations have not changed, and the United States state designations have changed slightly in favor of more protection for the BUOW. Notable upgrades in status have come in Arizona (from no listing to Special Concern) and Colorado (from undetermined to Threatened).

Western Burrowing Owl Scientific Literature (1997-2017)

Overall, the literature regarding population status/trends for BUOW indicates that slight to steep declines over decades have occurred across its range in the United States and Canada (Table 6). These declines are particularly steep in Canada. In locations where

Table 5 - Conservation Status for the Western Burrowing Owl – International, National, and State/Provincial levels.

Tabela 5 - Estatuto de conservação da coruja-buraqueira-ocidental – níveis Internacional, Nacional e de Estado/Província.

INTERNATIONAL LEVEL	Global Heritage Rank – G4 (apparently secure globally though it may be quite rare in parts of its range). CITES Appendix II IUCN Least Concern	
	COUNTRY	**STATUS**
FEDERAL LEVEL	Canada United States Mexico	Endangered None*1 Threatened
	COUNTRY	**STATUS**
STATE/PROVINCIAL LEVEL	Canada	Endangered – Alberta, British Columbia, Manitoba, Saskatchewan
	United States	Endangered – Iowa, Minnesota

BUOWs were formerly common (e.g., California, North Dakota, Texas), they are disappearing at an alarming rate. Major threats are habitat fragmentation/loss, human disturbance, vehicle collisions, continued pesticide use (especially rodenticides), prairie dog control, and prairie dog mass mortality due to sylvatic plague, and climate change, including accelerated extreme climatic events (e.g., extreme rainfall, drought, etc.). Returning to conduct surveys at historical nesting sites is very important; such efforts have generally found that only a small percentage of these sites are still occupied.

Discussion

Over the past 20 years, based on BBS and CBC data, BUOW populations have continued to decline in most locations in the United States and Canada. BBS data show that the rate of annual decline for the United States and Canada combined over 50 years was 1.1%/yr, and over 20 years was 0.38%/yr. The rate of annual decline in Canada over 50-years was 6.42%/yr - an incredibly sharp decline.

In the United States, six of the seven states examined by Sheffield (1997*a*) have demonstrated 20-year substantially declining population trends, and the other state (New Mexico), which showed a slightly positive population trend, has other (non-BBS) evidence of substantial population declines (Arrowood et al. 2001; Cruz-McDonnell and Wolf 2016; Grimason 2016). Three United States states which serve as good case studies for serious declines of BUOWs are Oklahoma, North Dakota, and California. These states have shown the sharpest declines in the numbers of owls over the past 20 years. Sheffield and Howery (2001) found that BUOWs in Oklahoma had declined 4-7% over the past 10 yrs (1990-2000). They estimated 800-1000 BUOWs breeding in the state, most occurring in the three panhandle counties. BBS data show that BUOW populations have significantly decreased (12.3% annually) in the state. BUOW populations in

North Dakota have declined >11.0% over 20 years, and loss of habitat due to greatly accelerating rates of industrial (oil/gas) development has been a major driver of these declines. In California, BUOWs have gone from an increase of 5.3%/yr to a decline of 1.79%/yr over this 20-year period, a decrease of >7.0%. BUOWs in the state were found to be disappearing from many historic locations, especially in rapidly urbanizing areas, and a few disjunct populations were found in areas where they were not known to occur, such as adjacent to water conveyance structures in the Sonoran Desert (Wilkerson and Siegel 2011). In southern California, BUOWs were found to have experienced a 27% drop in the numbers of breeding individuals in the Imperial Valley (Manning 2009). This decline is of considerable concern because >80% of California's BUOWs are found in the Imperial Valley (Manning 2009). Further, BUOWs in San Diego County declined from 250-300 pairs in the late 1970s-early 1980s to only 46 pairs in 2007 (Lincer and Bloom 2007). In northern California, long-term censusing of BUOWs revealed declining populations in many cases, especially in urban areas such as the San Francisco Bay and Bakersfield areas (Barclay et al. 2010; Townsend and Lenihan 2007; Wilkerson and Siegel 2010). In the case of California, greatly accelerating rates of habitat loss through urbanization and agricultural expansion across much of the state is a major driver of these declines.

The CBC data show that an average of 454.2 owls along with relatively low number of owls/party hours counted each year over the past 20 years, meaning that BUOWs are not common winter residents in the United States or Canada, and thus the usefulness of CBC data for BUOWs is limited.

These findings are consistent with the overall BBS and CBC data for BUOWs, which have shown a decline in numbers since at least the mid-1970s (James and Ethier 1989; Sheffield 1997*a*). In the United States, BBS data has been used to document changes in distributional limits of the BUOW from 1967-2008 (Macias-Duarte & Conway 2015). They found that its breeding range has been receding near its northern, western, and eastern edges. Their statistical model also detected population declines in California and eastern Washington, locations where maps based on BBS route-specific estimating equations predicted significant population increases. While there are few BBS routes in Mexico, limited observations in northwestern Mexico indicate that BUOW distribution may be changing as they seemingly are attracted to the expansion of irrigated agriculture, constructed waterways, and suburban areas in arid deserts. Another study which used BBS data examined geographic patterns in population trends of BUOWs throughout their breeding range in the United States in relation to presence of burrowing mammals (Conway 2018). Findings include that population declines were most precipitous on the northern and southern edges of their breeding range, and that population declines were most apparent in portions of their range where they rely primarily on Richardson's ground squirrels (*Urocitellus richardsonii*), California ground squirrels (*Otospermophilus beecheyi*), black-tailed prairie dogs (*Cynomys ludovicianus*), and badgers (*Taxidea taxus*; Conway 2018). In Canada, Kirk and Hyslop (1998) used a combination of BBS data (1966-1994 and 1985-1994) nationally and for seven separate ecozones, CBC data (1959-1988), migratory counts from hawk watches, and specific research projects to examine population trends and status of 37 taxa of Canadian raptors, including BUOWs. BBS data showed significant declines for BUOWs in Canada.

A large and very important unknown with BUOWs is their status in Mexico (Klute et al. 2003; Poulin et al. 2011). There are a very limited number of BBS routes and CBC count circles in Mexico, so regional or national population estimates and trends are not available. As far as strengths and weaknesses of BBSs and CBCs related to BUOWs, the strengths are that BUOWs are crepuscular, territorial, and the openness of the land-

scapes they occupy is advantageous for visual detection. The major weakness of BBSs is that many BUOW populations do not occur near roads, so they would not be detected by the road-based BBS efforts. Uneven topography, even slight hills, significantly reduces BUOWs detection rates as owls within 400 m of survey points are blocked from view (D.H. Johnson, pers comm.). This results in substantially reduced detection rates of owls. The major weaknesses of CBCs are that most BUOWs do not winter in Canada or the United States, and owls detected within CBC areas are likely year-round residents, so numbers are both very low and detecting trends in migratory owls are unreliable at best.

Threats

BUOWs face a number of threats to their populations, including habitat degradation/loss, which is highlighted by land conversion for agriculture and urban development, burrowing mammal population reduction, contaminants, climate change, vehicle collisions, disturbance, energy production, and cumulative effects.

Habitat degradation/loss through land conversion for agricultural expansion also includes related actions such as mowing, burning, and grazing. Between 2008 and 2016, >80% of new cropland in the United States came from grassland ecosystems and, of those converted grasslands, about 880,000 ha were intact grasslands (Lark et al. 2018). However, despite a slowdown in cropland expansion during the most recent years, widespread conversion of habitat to crop production has continued at a rate of nearly 400,000 ha/yr (Lark et al. 2018). This represents a clear and continuing threat to natural ecosystems and the wildlife populations who occupy them. Habitat degradation/loss through land conversion for urban development, including residential and commercial development, has been continual and ever-expanding for many decades (Alig et al. 2004; d'Amour et al. 2017). In the United States, there was a 34% increase in the amount of land devoted to urban areas between 1982 and 1997 (Alig et al. 2004). The main factors involved in this sharp increase in urbanization were increased population density and personal income. In the United States, urban areas are projected to increase by 79% by 2030, raising the proportion of the total land base which is developed from 5.2% to 9.2% (Alig et al. 2004). Globally, urban areas are forecast to triple between 2000 and 2030 (d'Amour et al. 2017).

BUOWs strongly prefer undisturbed, open grassland habitat with active colonial sciurid populations present. Clayton and Schmutz (1999) found that a loss of grassland habitat with burrows for roosting and nesting is occurring throughout the central Great Plains ecosystem. They concluded that these changes are irreversible on a scale which would be required to help this owl and that this species may face extinction in Canada – the northern limit of its range in North America. Habitat fragmentation was found to be negatively correlated with persistence of breeding BUOWs in Saskatchewan (Warnock 1997). In the United States, even though there is ever-increasing urbanization and land-use changes, BUOWs were found to be able to live in urbanized environments with <40% developed land cover, provided that water and suitable soils are available (Beebe et al. 2014). However, in studying post-fledging survival rates of young owls from greenspace, urban and agricultural sites, Griffin et al. (2017) concluded that programs managing for BUOWs in human-altered landscapes should avoid establishing artificial burrows and translocation sites in greenspace adjacent to urban areas, and, in the southwestern United States, should focus on agricultural areas.

Black-tailed prairie dog and other burrowing mammal population reductions (e.g., control programs, introduced sylvatic plague) have severely impacted BUOW populations in North America (Sheffield 1997*a*; Klute et al. 2003). Prairie dog control programs have

decimated black-tailed prairie dog populations by more than 98% since 1900 (Sheffield 1997*a*). In addition to direct mortality of prairie dogs, epizootics of sylvatic plague have decimated prairie dog populations throughout their North American range.

In addition, carnivore control programs have also led to declines in BUOW populations, albeit through indirect effects. The extirpation of gray wolves and increased tree cover on the North American grasslands have allowed populations of other mammalian and avian predators to increase, most likely to the detriment of BUOW populations (Poulin et al 2011). Further, owls using small, isolated habitat fragments may be more vulnerable to predation by mesopredators (White 1994).

Contaminants (agricultural, rangeland pesticides, etc.) are among the threats to BUOWs. Owls in general, including BUOWs, are known to be sensitive to exposure to pesticides and other contaminants (Sheffield 1997*b;* Gervais and Anthony 2003). Insecticides can be acutely toxic to BUOWs, and rodenticides can cause secondary poisoning through consumption of exposed small mammals (Justice-Allen and Loyd 2017), and both types of pesticides can suppress prey populations and may negatively impact survival of BUOWs (James and Fox 1987; Fox et al. 1989; James et al. 1990; Sheffield 1997*b*).

Another threat which is perhaps more serious as those outlined above is climate change. Using a combination of BBS and CBC data with correlative distribution modeling, Langham et al. (2015) assessed geographic range shifts for North American birds and found that more than half of all species are projected to lose more than 50% of their geographic ranges across three climate change scenarios through the end of the century. In addition to BBS and CBC data, field research has demonstrated that BUOWs are vulnerable to predicted climate change scenarios in which there are increases in the frequency and severity of extreme climatic events. For example, Fisher et al. (2015) found that BUOW annual productivity over a 7-year period varied inversely with breeding season precipitation anomalies, estimating a decrease in mean annual productivity of 12% from 1960-2012. Further, from 1998-2013, Cruz-McDonnell and Wolf (2016) found that the breeding population of BUOWs in Arizona declined 98% (from 52 pairs to 1 pair), and nest success and fledgling output also declined significantly. These trends were strongly associated with the combined effects of decreased precipitation and increased air temperature. The entire breeding process was significantly delayed due to extreme weather conditions, and body masses of all BUOWs were significantly reduced (7.9-20.0%). Thus, climate change resulting in an increasingly warm and dry climate may contribute to the further decline of BUOWs, especially in the arid southwestern United States (Cruz-McDonnell and Wolf 2016).

Finally, any discussion of threats to BUOWs is not complete without including cumulative effects. Cumulative effects of these threats are unknown, but conservatively could be considered additive at a minimum (Hodgson and Halpern 2019).

Conclusions

Overall, BBS data indicate substantial annual BUOW declines in the United States (mainly the northern states, but also some southern states as well) and especially in Canada. The CBC data indicate that, in the United States, BUOWs spend early winter mainly in four states (California, Texas, Arizona, and New Mexico), and overall, numbers are quite low and generally large efforts are needed to find them on CBCs. In Canada, BUOWs are exceedingly rare in winter. The situation with wintering populations of BUOWs in Mexico is becoming somewhat clearer, but more work is really needed.

The peer-reviewed literature from this 20-year interval reveals that population declines have occurred in the United States and Canada, and that in many locations

Table 6 - Western Burrowing Owl (*Athene cunicularia hypugaea*) population status/trends from the literature (1997-2017).

Tabela 6 - Estado/tendência da população de coruja-buraqueira-ocidental (*Athene cunicularia hypugaea*) de acordo com a literatura (1997-2017).

LOCATION	POPULATION STATUS/TREND	REFERENCE
Arizona (USA)	Original state database had 281 burrowing owl locations; in 2001, 164 of those locations surveyed; burrowing owls found at only 29 of these sites, and also 4 new sites; 19% detection; most burrows found along concrete-lined irrigation canals in agricultural areas instead of in prairie dog towns or creosote flats; apparent population decline in the state; burrowing owls not found in 82.3% of original nesting locations.	Brown and Mannan (2002)
California (USA)	Burrowing owl populations declined in Santa Clara and San Francisco areas; 11 years of censuses (1999-2009) available; all 3 populations declining; positive growth rate necessary to lower probability of extinction (population size not enough); reason for decline not specified.	Barclay et al. (2010)
California (USA)	Decline in burrowing owl population attributed to habitat disturbance/loss during expansion of airport; population analysis suggested the key factor was reduction of adult survival.	Barclay et al. (2011)
California (USA)	In San Diego County, 250-300 pairs of burrowing owls found in late 1970s-early 1980s, compared to only 46 pairs in 2007; habitat fragmentation/loss, human disturbance, and vehicle collisions among the main factors involved in the decline; need for immediate management plan for burrowing owls.	Lincer and Bloom (2007)
California (USA)	Reviewed status of the burrowing owl in the greater San Francisco Bay area; historically, the most abundant populations were in Alameda, Contra Costa, and Santa Clara Counties, and that populations were locally abundant within portions of Solano and San Mateo Counties; breeding burrowing owls are extirpated from 4 of 10 area counties (Napa, Marin, San Francisco, and Santa Cruz) and likely extirpated from two others ((sw Solano and San Mateo Counties); burrowing owls are no longer abundant and maybe disappearing entirely from w. Contra Costa, w. Alameda, and Santa Clara Counties; threats for these burrowing owls include habitat loss, current eviction methods (both passive and active), inadequate mitigation practices, pest management, and rodent poisoning; the San Francisco Bay area burrowing owl population has already undergone a substantial decline in abundance and is greatly diminished in extent from its former distribution.	Townsend and Lenihan (2007)
California (USA)	Surveyed the entire breeding range of the burrowing owl in California (except islands); relying on volunteers, 860 5km x 5 km blocks were surveyed and exact locations of 1,758 pairs were documented; using data from randomly-selected blocks, a statewide breeding population of 9,187 pairs was extrapolated; compared results to DeSante et al. (2007) using identical methods and study area boundaries during 1991-1993; our 2006-2007 estimate of 8,128 pairs was 10.9% lower than the previous estimate, but difference was not statistically significant; burrowing owls appear to have declined particularly sharply in two urban areas – San Francisco Bay area and Bakersfield; surveys of previously unsurveyed portions of species range yielded few or no owls in the Modoc Plateau/Great Basin, n. Mojave/e. Sierra Nevada, e. Mojave, and Sonoran Desert regions, but detected relatively large populations in the Palo Verde Valley and the w. Mojave Desert region.	Wilkerson and Siegel (2010)

LOCATION	POPULATION STATUS/TREND	REFERENCE
California (USA)	Systematic surveys for burrowing owls were conducted during the 2006 and 2007 breeding seasons across portions of the state's se deserts which had not previously been surveyed for this species; found few or no burrowing owls in n. or e. portions of the Mojave Desert or in the Sonoran Desert (excluding Palo Verde Valley); however, there was a substantial concentration of burrowing owls in the w. Mojave Desert (estimated up to 560 breeding pairs); also documented 179 breeding pairs of burrowing owls along the banks of water conveyance structures in Palo Verde Valley in the Sonoran Desert region; these two disjunct populations comprise a significant portion of the population of burrowing owls in the entire state.	Wilkerson and Siegel (2011)
Colorado (USA)	Estimated abundance of burrowing owls in three habitats within the Colorado shortgrass prairie ecosystem – prairie dog colonies, grasslands not occupied by prairie dogs, and dryland agriculture; est. 3,554 burrowing owls in e. Colorado; burrowing owl density on prairie dog colonies (3.04 birds/100 ha) was significantly higher than densities in either grassland or dryland agricultural plots; results suggest that increasing prairie dog colonies would positively influence the abundance of burrowing owls.	Tipton et al. (2009)
New Mexico (USA)	Populations of Western Burrowing Owls surveyed through different methodologies; increasing or decreasing depending upon site; loss of suitable habitat responsible for population declines.	Arrowood et al. (2001)
New Mexico (USA)	From 1998-2013, the breeding population of BUOWs on Kirtland Air Force Base in Albuquerque declined 98.1%, from 52 pairs to 1 pair, and nest success and fledgling output also declined significantly; these trends were strongly associated with the combined effects of decreased precipitation and increased air temperatures; all breeding activities were significantly delayed, and body masses of juveniles and adult BUOWs decreased significantly over time; an increasingly warm and dry climate may be contributing to continuing BUOW in the arid sw United States.	Cruz-McDonnell and Wolf (2016)
New Mexico (USA)	Decline of burrowing owls in the Santa Fe area from 68 to 6 pairs (2011) in less than a decade.	Grimason (2016)
North Dakota (USA)	Surveyed historical sites where burrowing owls were most commonly found 15-30 years ago (the Missouri Coteau and adjoining Drift Plain in central and nw North Dakota) and prairie dog colonies in sw North Dakota; burrowing owls were detected at 23-60% of prairie dog towns surveyed during 1994-1999, which was lower than figures reported for burrowing owls at prairie dog colonies across other Great Plains states; e. and n. of the Missouri River, breeding burrowing owls have changed from fairly common or uncommon to rare in the best potential habitat that remains, and have disappeared from the E one-third of the state; populations apparently declined sharply during the past 5-15 years; in sw North Dakota, burrowing owl population trend is unclear but probably tied closely to prairie dog abundance, which may still be declining.	Murphy et al. (2001)
Oklahoma (USA)	Recent survey of black-tailed prairie dog colonies indicated that total colony area in the state continues to decline, decreasing by 4-7% over the past 10 years; estimated 800-1,000 breeding pairs of burrowing owls occur in the state, vast majority of these are relegated to the three panhandle counties (Cimarron, Texas, Beaver); BBS data show significant declines (12.3%/year) in the state; CBC data, although limited, also suggest declining numbers of burrowing owls in the state.	Sheffield and Howery (2001)

LOCATION	POPULATION STATUS/TREND	REFERENCE
Texas (USA)	Analyzed BBS (1966-1999) and CBC (1960-2001) data along with Texas Breeding Bird Atlas (1987-1992) data to construct a distribution map for burrowing owls in Texas (by county); no significant changes found in mean number of burrowing owls during the breeding season, but slope was negative, indicating a population decline; mean number of burrowing owls was consistently low; significant decline seen in mean number of wintering owls; there have not been any large peaks in mean number of burrowing owls recorded since the early 1970s; Lubbock County consistently has reported the highest numbers of owls in winter (average 3-10 owls/count circle).	McIntyre (2004)
Texas (USA)	Burrowing owls found to have declined 6.9% from 1980-2005.	Skrei (2001)
Texas (USA)	Investigated historical range of burrowing owls in s Texas by reviewing accounts of early ornithological collecting expeditions, examining species accounts and reviews, and gathering information from museum specimens collected in Texas; burrowing owls were widespread and relatively abundant in coastal prairies until brushland became the dominant ecosystem in s Texas in the 1890s; clearing of brush for agricultural development in the early 1900s allowed burrowing owls to persist as winter residents in south Texas; burrowing owls extirpated as breeding species by about 1950; status of burrowing owls on managed grasslands of private ranches in s Texas remains unknown.	Woodin et al. (2008)
Washington (USA)	Analyzed North American BBS data using two analytical approaches to determine population trajectory in e Washington; used a mixed model analysis to estimate rate of decline in number of burrowing owls detected between 1968 and 2005; the slope in the number of burrowing owls detected was negative for 12 of the 16 BBS routes in Washington which detected them; numbers of breeding burrowing owls detected in e Washington declined at a rate of 1.5% annually.	Conway and Pardieck (2006)
Wyoming (USA)	Went back and re-sampled historical nesting locations (n=103); only 18% of these were occupied in 1999; surveyed 85 plots selected at random northern mixed- and short-grass prairies; only 1 owl found on random surveys; study highlights the importance of historical nesting sites to burrowing owls in Wyoming.	Korfanta et al. (2001)
Alberta (CAN)	Standardized diurnal call-playback surveys for burrowing owls conducted between 1991-2000 near Hanna, and between 1993-2000 near Brooks; both survey areas are located within the historical breeding distribution of burrowing owls in native mixed-grass prairie habitat; Hanna surveys indicated that density of nests (13.7 nests/100 km^2) declined significantly between 1991 and 2000; the Brooks surveys indicated that the density of nests (8.9 nests/100 km^2), although lower than Hanna, did not decrease during the course of the surveys; the significant decline in Hanna most likely indicative of contraction of the northern edge of the breeding distribution of burrowing owls in Alberta, and suggests that the population will soon become extirpated from that area.	Shyry et al. (2001)
Saskatchewan (CAN)	In 1988, Operation Burrowing Owl members (n=352) reported 681 burrowing owl pairs, considerably more than the 54 burrowing owl pairs reported by Operation Burrowing Owl members (n=459) in 2000; following application of a correction factor, the annual census indicated a 95% decline in estimated numbers of pairs over 13 years from 1988 (1,032 pairs) to 2000 (56 pairs); this represents an average decline of 21.5%/year; by 2000, 94% of all formerly occupied sited had 0 burrowing owls.	Skeel et al. (2001)

where BUOWs formerly were common, they are disappearing at an alarming rate. Returning to conduct surveys at historical nesting sites is very important; efforts to date generally have found that only a small percentage of sites are still occupied. Documented threats to BUOWs are numerous and varied, and range from localized habitat loss, substantial reductions in fossorial mammal populations, pesticides, to range-wide issues of urbanization, agricultural intensification, and climate change.

Long-term databases such as the BBS and CBC, as well as surveying of historic and current breeding sites, and use of citizen science (e.g., eBird, iNaturalist, etc.) should be included as part of a more comprehensive plan to monitor BUOW populations in the face of the above-mentioned continuing threats. The US Fish and Wildlife Service's Birds of Conservation Concern 2003 and 2009 reports both had BUOWs listed nationally, regionally, and in each United States/Canada Bird Conservation Region in which they occur. This denotes the need for upcoming Endangered Species Act (ESA) listing/protection unless immediate and substantial conservation actions are taken on their behalf.

Recommendations

In the United States, evidence for declines in BUOW populations in most locations is strong, and with the substantial number of threats they face, it is now time for serious consideration of BUOWs for national protection under the Endangered Species Act.

States with no protective conservation status for BUOWs (n=7) all have substantially declining populations, and each state should consider providing conservation protection for BUOWs and their habitat.

At the state/provincial level, surveys for BUOWs should also include surveys of prairie dogs and ground squirrels and the extent of their towns, as well as flea populations (vectors for sylvatic plague).

Prairie dog and other colonial sciurid towns are crucial habitat for BUOWs in North America and must be conserved and maintained to preserve ecological integrity of grassland ecosystems.

When plague epizootics eradicate prairie dog towns, recolonization should be encouraged and reintroductions should be conducted in order to maintain towns prior to any potential land-use conversion.

Indirect impacts of prairie dog sylvatic plague on BUOWs may be substantial in some cases and requires further analysis.

Conservation and management measures, education, and changes in both public attitudes and policies are necessary for the continued existence of viable pops of BUOWs and grassland sciurids in North America (see Holroyd et al. 2001).

There is a need to increase the number of BBS routes and CBC count circles for BUOWs in Mexico in order to derive reliable population estimates and trend data in that country.

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Using bioacoustics to study vocal behaviour and habitat use of Barred Owls, Boreal Owls and Great Horned Owls

Estudo bioacústico do comportamento vocal e do uso de habitat por coruja-barrada, mocho-funéreo e bufo-real-americano

Julia Shonfield[1*], Erin M. Bayne[1]

1 Department of Biological Sciences, University of Alberta, Edmonton, AB T6G 2E9

*** Corresponding author:** julia.shonfield@gmail.com



ABSTRACT

Bioacoustics is the study of sound produced by animals, and autonomous recording units (ARUs) are increasingly used to research and monitor birds by recording vocalizations because of the benefits of reduced observer bias and the ability to collect data over longer time scales. We used ARUs to study owl vocal behaviour and habitat use by passively recording owls calling during the breeding season. We scheduled ARUs to record for 10 min every hr on a 24-hr basis, and deployed the units at sites throughout northeastern Alberta from mid-March through mid-May in 2013, 2014, and 2015. We scanned all recordings collected using automated recognizers to detect territorial vocalizations of Barred Owls (*Strix varia*), Great Horned Owls (*Bubo virginianus*), and Boreal Owls (*Aegolius funereus*). We found that territorial vocal activity was high for all owls throughout the nocturnal period, with differences between species in the onset and end of vocal activity around sunset and sunrise. Barred Owls called occasionally during daylight hours, but this was infrequent for Great Horned Owls and rare for Boreal Owls. Based on our results, we recommend that surveys for these species start 1 hr after sunset and end 1 hr before sunrise. Locations of owl detections indicated that Barred Owls were more likely to be found

calling in mixedwood forests and less likely to be found in more disturbed areas. Boreal Owls were more likely to be found calling in coniferous forests in both disturbed and undisturbed areas, and Great Horned Owls were equally likely to be found calling in all habitats surveyed. This research contributes to our understanding of the behaviour of these owls, demonstrates the utility of new bioacoustic technology, and has practical implications for conducting passive surveys to study and monitor owls.

Keywords: automated species recognition, autonomous recording unit, passive acoustic monitoring, territorial behaviour, vocalizations

RESUMO

A bioacústica é o estudo do som produzido por animais, e as unidades de registo automático (ARUs) são cada vez mais usadas para investigar e monitorizar aves através do registo de vocalizações, devido às vantagens da redução do erro do observador e da capacidade de recolher dados em escalas de tempo alargadas. Utilizámos ARUs para estudar o comportamento vocal de rapinas noturnas e o seu uso de habitat, através de gravações passivas de vocalizações de rapinas noturnas durante a época de reprodução. Configurámos as ARUs para gravar durante 10 minutos por hora durante cada período de 24h, e instalámos as unidades em todo o nordeste de Alberta, de meados de março até meados de maio em 2013, 2014 e 2015. Examinámos todas as gravações recolhidas usando reconhecedores automáticos para detetar vocalizações territoriais de coruja-barrada (*Strix varia*), bufo-real-americano (*Bubo virginianus*) e mocho-funéreo (*Aegolius funereus*). Verificámos que todas as espécies apresentaram elevada atividade vocal territorial durante a noite, embora com diferenças entre si no período de início e de fim da atividade vocal na proximidade do ocaso e do nascer do sol. A emissão de vocalizações durante o dia ocorreu ocasionalmente para a coruja-barrada, ainda menos frequentemente para o bufo-real-americano e raramente no caso do mocho-funéreo. Com base nos resultados, recomendamos que a monitorização destas espécies comece 1 hora após o ocaso e terminem 1 hora antes do nascer do sol. O registo das localizações das aves indicou que a probabilidade de ouvir uma vocalização de coruja-barrada é maior em áreas florestais mistas e menor em áreas mais perturbadas. A probabilidade de ouvir mocho-funéreo é maior em florestas de coníferas, e igual em áreas perturbadas e não perturbadas, enquanto a probabilidade de ouvir o bufo-real-americano é igual em todos os habitats monitorizados. Este estudo contribui para a nossa compreensão do comportamento destas espécies, demonstra a utilidade das novas tecnologias bioacústicas e tem implicações práticas para a realização de gravações passivas para investigar e monitorizar rapinas noturnas.

Palavras-chave: comportamento territorial, monitorização acústica passiva, reconhecimento automático de espécies, unidade de registo automático, vocalizações

Introduction

Bioacoustics is the study of sound produced by animals. The field of bioacoustics has gained momentum in recent years with relatively new technology that is able to record sound autonomously in a variety of environments. Autonomous recording units (ARUs) are increasingly used to monitor and study birds by recording vocalizations; the numerous benefits include reduced observer bias, and the ability to collect data over longer time scales (Shonfield & Bayne 2017a). Several different models of autonomous recording units (ARUs) can be purchased commercially and can be programmed to record on a set schedule. ARUs have a downside that the volume of recordings collected can be very time consuming to process. Automated species recognition is emerging as a valuable tool in the field of bioacoustics and has the potential to efficiently process a large volume of recordings within a manageable timeframe (Knight et al. 2017).

Research and monitoring projects focusing on owls frequently use acoustic surveys to determine presence or abundance (Goyette et al. 2011; Rognan et al. 2012) because many owl species are effectively detected by their vocalizations. Owls are especially vocal during the breeding season, and they use territorial vocalizations to attract mates and defend territories from conspecifics (Johnsgard 2002; Odom & Mennill 2010a). Acoustic surveys for owls often broadcast a recorded owl call (Clark & Anderson 1997; Sater et al. 2006; Grossman et al. 2008; Kissling et al. 2010). Broadcasting owl calls can increase the probability of detecting an owl by eliciting territorial individuals to respond (Kissling et al. 2010), but there are drawbacks to this survey method. Call-broadcast surveys are known to draw owls in from a distance (Zuberogoitia et al. 2011), and can also affect detection of other owl species (Crozier et al. 2006; Bailey et al. 2009; Wiens et al. 2011). Thus, this survey method could affect conclusions about habitat associations of owls, and limits the information we can obtain on the natural calling behaviour of different owl species.

Passive acoustic survey methods using recent bioacoustic technology are potentially an efficient approach for studying owls. Passive acoustic surveys using ARUs have been found to be useful for surveying rare and elusive species (Holmes et al. 2014, 2015; Campos-Cerqueira & Aide 2016) and for conducting nocturnal surveys for species such as owls (Rognan et al. 2012). An important benefit of using ARUs for nocturnal owl surveys is that the units can be set up at any time and left out for extended periods. By recording on a set schedule for several days or weeks, this can increase the cumulative detection probability of owls by increasing the number of sampling occasions while still only requiring two visits by field personnel. In this regard, ARUs can reduce the problem of lower detection probabilities of passive surveys and provide data on vocal behaviour and habitat use of owls. For these reasons, using ARUs for passive acoustic surveys appears to be a promising new approach for studying and monitoring owls.

Acoustic datasets collected with ARUs over extended time periods can be large and daunting to process. Automated species recognition of animal vocalizations is changing this. This process involves matching recording segments to a template, often termed a 'recognizer', derived from training data and registering a hit when a similarity threshold is reached. Previous studies have shown that using recognizers can be an effective and efficient tool to process acoustic recordings for birds and amphibians (Buxton & Jones 2012; Frommolt & Tauchert 2014; Taff et al. 2014; Colbert et al. 2015; Holmes et al. 2015; Brauer et al. 2016). We have shown recently that recognizers are highly useful for detecting owls on recordings because of relatively low detection rates of owls from listening to recordings (Shonfield et al. 2018). Owl

calls are well-suited to automated species recognition because the calls overlap infrequently with conspecifics (except for some minimal overlap during male-female calling in some species), and very few other species are vocally active at the same time since owls call nocturnally.

There are a few examples in the literature of studies using unsolicited calling behaviour of owls, including Eurasian Eagle-owls *Bubo bubo* (Delgado & Penteriani 2007), Little Owls *Athene noctua* (Zuberogoitia et al. 2008), Tawny Owls *Strix aluco* (Lourenço et al. 2013), and Barred Owls *Strix varia* (Odom & Mennill 2010b). A couple of these studies include descriptions of nightly owl calling patterns (Delgado & Penteriani 2007; Lourenço et al. 2013) but only one study did this over a 24-hr period (Odom & Mennill 2010b).

In this study, we used ARUs to conduct acoustic surveys for owls in northeastern Alberta and processed the recordings using recognizers. We used separate recognizers to identify the calls of three owl species found throughout Canada and the United States: the Barred Owl (*Strix varia*), the Boreal Owl (*Aegolius funereus*), and the Great Horned Owl (*Bubo virginianus*). Our objectives were to document unsolicited vocal behaviour of these species, evaluate owl habitat use, and compare the results from our passive acoustic surveys to accounts of vocal behaviour and habitat use of these owl species in the peer-reviewed literature.

Methods

Study Area

We surveyed for owls in upland forested areas in northeastern Alberta, Canada. Sites were located within an area south of Fort McMurray, north of Lac la Biche and northwest of Cold Lake (see Shonfield & Bayne 2017b for additional details on study area). Forests in the study area were primarily composed of trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*), and black spruce (*Picea mariana*) trees.

Acoustic Surveys

We conducted passive acoustic surveys for owls using a commercially available ARU: the SM2+ Song Meter (Wildlife Acoustics Inc., Maynard, Massachusetts, USA). We programmed each ARU to record in stereo format at 44.1 kHz with a 16-bit resolution. We tested each ARU and both microphones prior to deployment to identify any units with non-responsive channels or degraded microphones. We used gain settings of 48 dB for both the left and right channel microphones. We installed ARUs at each site for approximately two weeks in late winter/early spring, when owls are actively calling (Clark & Anderson 1997; Kissling et al. 2010). We conducted surveys at 54 sites in 2013, in 2014 we surveyed 27 of the same sites and added 18 new sites, and in 2015 we surveyed 35 sites that were surveyed in one or both of the previous two years. In 2013 ARUs were out and recording between 18 March and 18 May, in 2014 ARUs recorded between 21 March and 6 May, and in 2015 ARUs recorded between 24 March and 5 May. We attached ARUs at a height of approximately 1.5 m on trees with a smaller diameter than the width of the ARU (18 cm).

At each site, we deployed five ARUs in a square formation, with one at each corner spaced 1.6 km apart, and one in the center positioned 1.2 km from each corner (hereafter each individual location with an ARU is referred to as an 'ARU station'). The spacing of ARU stations is similar to the spacing of point count stations used in traditional owl surveys with broadcast calls (e.g. Morrell et al. 1991; Kissling et al. 2010). As part of a study looking at the effects of industrial noise on owls, some of the ARUs we deployed were located close to noise sources (e.g. compressor stations) or near roads. We found that owls were not strongly avoiding noise

sources or roads (Shonfield & Bayne 2017b), however there were some effects on detection probability of owls, particularly for Boreal Owls. To minimize potential effects of noise masking on the results reported here, we only included ARUs with an estimated relative noise level less than 90 dBA (see Shonfield & Bayne 2017b for details on how sound measurements were made from recordings).

Processing Recordings

We used the program Song Scope 4.1.3A (Wildlife Acoustics Inc., Maynard, Massachusetts, USA) to build recognizers to detect owl territorial calls: the two-phrased hoot of the Barred Owl (Odom & Mennill 2010b), the staccato song of the Boreal Owl (Bondrup-Nielsen 1984), and the territorial hoot of the Great Horned Owl (Kinstler 2009). Song Scope uses hidden Markov models to match recording segments to a recognizer template derived from training data and registers a hit when a similarity threshold is met (Wildlife Acoustics 2011). For each detected vocalization, Song Scope provides two values: a quality value (between 0.0 and 99.9) that indicates where the vocalization fits within a statistical distribution of parameters from the training data used to build the recognizer, and a score value (between 0.00 and 99.99) indicating the statistical fit of the vocalization to the recognizer model (Wildlife Acoustics 2011). A minimum quality and minimum score threshold are set by the user each time a recognizer scans a set of acoustic data. Based on our previous work with these recognizers (Shonfield et al. 2018) we used a minimum quality setting of 50 and a minimum score setting of 60 when scanning recordings. See Shonfield et al. (2018) for further details on how we built these recognizers in Song Scope and their overall performance.

The results from each recognizer had a number of false positives (i.e. hits that were not the target owl species), so trained observers verified all hits generated by the program before compiling the data. After removing stations with an estimated relative noise level greater or equal to 90 dBA, we compiled data from 236 ARUs deployed in 2013, 191 ARUs deployed in 2014, and 150 ARUs deployed in 2015. We calculated the number of 10-min recordings with an owl calling for each hour of the day to obtain an estimate of vocal activity across a 24-hr period for each species. In addition, we calculated the time to sunrise and sunset for each recording with an owl calling based on the longitude and latitude of the ARU station and the date of the recording. We binned the data by hour relative to sunrise and sunset times to summarize the vocal activity data and quantify how often owls call in daylight and darkness, especially since hours of daylight change markedly in our northern study area during the period we surveyed. The range of sunrise times varied from 07:34 hr during the start of our surveys in mid-March, to 04:54 hr in mid-May. Sunset times varied from 19:42 hr at the start of our surveys in mid-March to 21:52 hr in mid-May.

Habitat Use Analysis

We used an occupancy modelling approach to evaluate habitat use by owls. Occupancy modelling uses repeat observations to estimate detectability and account for imperfect detection when estimating the probability of a species occupying a site or patch (MacKenzie et al. 2002). To build our models to evaluate habitat use, we first extracted variables on forest composition, forest age, and human disturbance in ArcGIS 10.3.1 (Environmental Systems Research Institute, Inc., Redlands, California, USA). We used an 800-m radius buffer around each ARU station, approximating the maximum detection radius of an ARU to detect owls calling (Yip et al. 2017). For forest composition, we calculated the proportion of coniferous forest present weighted by area from the Alberta Vegetation Inventory (AVI) within each 800-m buffer. We also

calculated mean forest age weighted by area from the AVI layer. For human disturbance, we calculated the proportion of human footprint in the buffer area from Alberta Biodiversity Monitoring Institute's Human Footprint layer 2012 version 3 (http://www.abmi.ca/home/data-analytics). Disturbances in this layer include linear features (roads, seismic lines, pipelines, transmission lines and railways), industrial and resource extraction features (well pads, compressor stations, processing plants, mines and other facilities), and forest cut blocks.

To analyze habitat use we only used unique ARU locations with an estimated relative noise level less than 90 dBA. Given these criteria, we included 236 stations surveyed in 2013 and 74 stations surveyed in 2014 in this analysis. We compiled detection histories for each ARU station from the presence/absence data for each owl species derived from the recognizers. We defined each 'sampling occasion' in our detection history as a 24-hr period (a total of 24 ten-min recordings processed by the recognizers). We had a total of nine sampling occasions in our detection history because ARUs were deployed for a minimum of nine days. Stations with ARUs that failed at some point during the deployment (n = 5) and did not record for all nine days were indicated in the detection history as 'missing observations' on days that they did not record. An advantage of occupancy modeling is that it can account for 'missing observations' (MacKenzie et al. 2002).

Owl occupancy was modeled using 'single species single season' occupancy models (MacKenzie et al. 2002) using the package 'unmarked' (Fiske & Chandler 2011) in R version 3.4.3 (R Core Team 2017) with RStudio version 1.1.383 (RStudio Team 2017). We ran models with proportion coniferous forest, proportion disturbed by humans, and mean forest age as continuous predictor variables for the occupancy parameter to evaluate habitat use by owls. For Barred Owls, we included a quadratic term for proportion coniferous forest, since previous research indicates they prefer mixedwood forests (Mazur et al. 1998; Livezey 2007; Russell 2008). For Boreal Owls and Great Horned Owls, we did not include a quadratic term for proportion coniferous forest since Boreal Owls prefer coniferous forests (Hayward et al. 1993; Lane et al. 2001) and Great Horned Owls are found in a wide variety of forest types (Johnsgard 2002). We included Julian date as a predictor variable for the detection probability parameter, as the probability of detecting owls calling could change as the breeding season progresses. In the occupancy modelling literature, time of day is often included as a survey-specific variable in the detection parameter to account for differences in detectability at different times of day. We did not include time of day in our models because we surveyed during all hours and then pooled the detections on a daily basis for this analysis. Since owls are unlikely to be found consistently within the area around a single ARU station due to movement, and the same owl could be found at more than one station within a site on different sampling occasions, the occupancy estimates from these models should be interpreted as an estimate of owl 'use' (MacKenzie 2006).

We included a null model (with no variables), a global model (with all variables), and models fitted for all possible combinations of variables (proportion coniferous, proportion disturbed, forest age, and Julian date) without interactions. We used an information-theoretic approach (Burnham & Anderson 2002) for model selection. We ranked models using Akaike's Information Criteria (AIC), and made model-averaged predictions using the R package 'MuMIn' (Barton 2017). Model averaging of top models can be a robust method to obtain parameter estimates and predictions, and is recommended when the weight of the top model is less than 0.9 (Grueber et al. 2011). Models within 2 ΔAIC were chosen as the top model set for model averaging (Burnham & Anderson 2002).

Figure 1 - Daily vocal activity (estimated by the number of recordings with an owl calling) for Barred Owls (BADO), Boreal Owls (BOOW), and Great Horned Owls (GHOW). Hours are using the 24-hr clock, with the zero hour being midnight. The vertical dashed lines indicate the range of sunrise and sunset times during the survey period.

Figura 1 - Atividade vocal diária (estimada a partir do número de gravações contendo rapinas noturnas a vocalizar) para coruja-barrada (BADO), mocho-funéreo (BOOW) e bufo-real-americano (GHOW). As horas seguiram o formato de relógio de 24 horas, com a hora zero sendo a meia-noite. As linhas tracejadas verticais indicam o intervalo de horas do nascer do sol e do ocaso durante o período da monitorização.

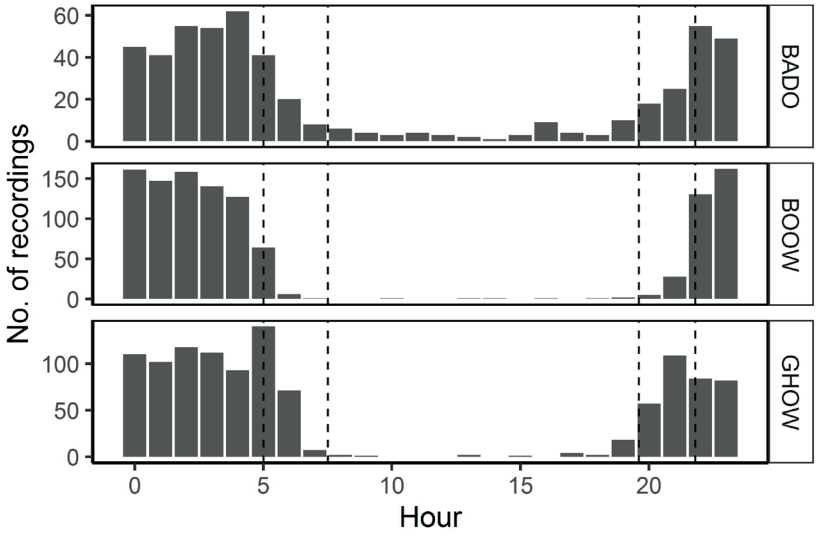
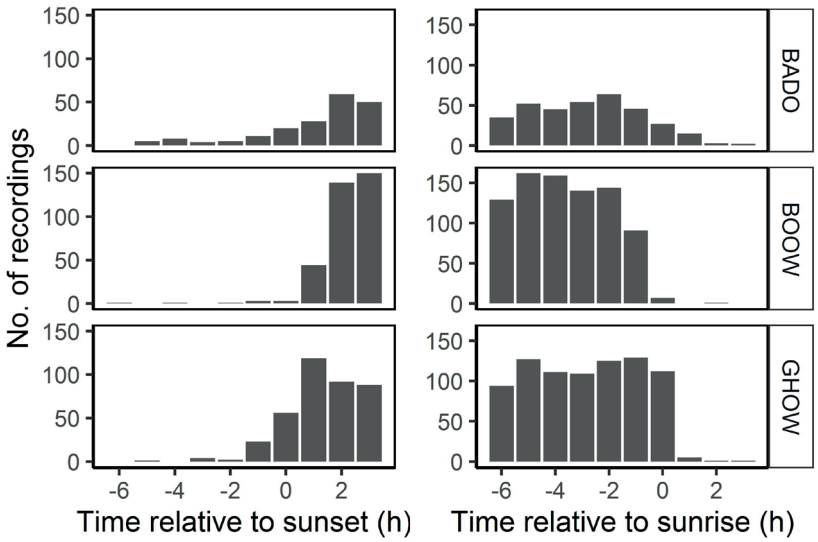


Figure 2 - Daily vocal activity (estimated by the number of recordings with an owl calling) relative to sunset and sunrise times for Barred Owls (BADO), Boreal Owls (BOOW), and Great Horned Owls (GHOW). Negative numbers indicate hours prior to sunset/sunrise, zero indicates the hour of sunset/sunrise, and positive numbers indicate hours after sunset/sunrise.

Figura 2 - Atividade vocal diária (estimada a partir do número de gravações contendo rapinas noturnas a vocalizar) em relação ao ocaso e nascer do sol para coruja-barrada (BADO), mocho-funéreo (BOOW) e bufo-real-americano (GHOW). Os números negativos indicam horas antes do ocaso/nascer do sol, zero indica a hora do ocaso/nascer do sol e números positivos indicam horas após o ocaso/nascer do sol.



Results

Vocal Activity

Over the three years that we surveyed for owls using ARUs, we collected a very large acoustic dataset: 125,844 10-min recordings in 2013; 84,518 10-min recordings in 2014; and 53,791 10-min recordings in 2015. The recognizers scanned all recordings and detected Barred Owls calling on a cumulative total of 548 recordings over all three years, Boreal Owls were detected calling on 1,178 recordings, and Great Horned Owls were detected calling on 1,202 recordings.

While all three species showed a strong nocturnal pattern in their calling activity, Barred Owls had a tendency to call more during daylight hours than the other two species (Fig. 1). For Barred Owls, 10% of recordings with vocalizations were during daylight hours between 08:00 hr and 19:00 hr. For Great Horned Owls, only 2.5% of recordings with vocalizations were between 08:00 hr and 19:00 hr. Boreal Owls were more strictly nocturnal in their vocal behaviour than the other two species, with only 0.7% of recordings with vocalizations between 08:00 hr and 19:00 hr.

We found there were differences between species in their onset and end of vocal activity around sunset and sunrise. Barred Owls showed a steady increase in the hours before sunset, and a steady decrease in the hours after sunrise (Fig. 2). The other two owl species showed more abrupt changes in vocal activity, for example Boreal Owls rarely vocalized at sunset but showed a marked increase in vocal activity two hours after sunset (Fig. 2). Great Horned Owls on the other hand often called at sunset, and their vocal activity peaked an hour after sunset (Fig. 2). At sunrise Great Horned Owls continued to call frequently, and then an hour after sunrise this activity dropped off markedly, in contrast Boreal Owls decreased their vocal activity an hour before sunrise and then their activity dropped off at sunrise (Fig. 2).

Habitat Use

We surveyed for owls between March 18 and May 18, and included date as a predictor for the detection probability parameter in our occupancy models to evaluate habitat use. We found that date did not have a strong effect on detection of Barred Owls or Great Horned Owls (Figure 3). There was an effect of date on detection probability of Boreal Owls, with later dates leading to greater detection probability for this species (Fig. 3).

Forest composition varied between stations from 0% to 100% coniferous forest with a mean of 50%. Proportion of the area disturbed by humans varied from 0% to 94% with a mean of 18%. For Barred Owls the top model included forest composition and human disturbance as predictor variables for occupancy (Table 1). For Boreal Owls the top model included forest composition as a predictor variable for occupancy, and date as a predictor variable for detection probability (Table 1). For Great Horned Owls the top model was the null model with no predictor variables for occupancy or detection probability (Table 1). Occupancy of stations (hereafter 'use') by Barred Owls was highest when the forest was a mix of deciduous and coniferous trees and declined with increasing disturbance by humans (Fig. 3). Forest composition and human disturbance had no effect on Great Horned Owl habitat use (Fig. 3). There was no effect of human disturbance on use by Boreal Owls, but there was a weak trend for them to use more coniferous forests (Fig. 3).

There was limited variation in forest age at the locations surveyed, mean forest age around each ARU ranged from 21 to 153 yr (overall mean of 93 yr), 97% of stations were surrounded by mature forest (50+ yr old), and 84% of stations were surrounded by old forest (80+ yr old). We found no effect of forest age on owl habitat use for any of the three species (Figure 3).

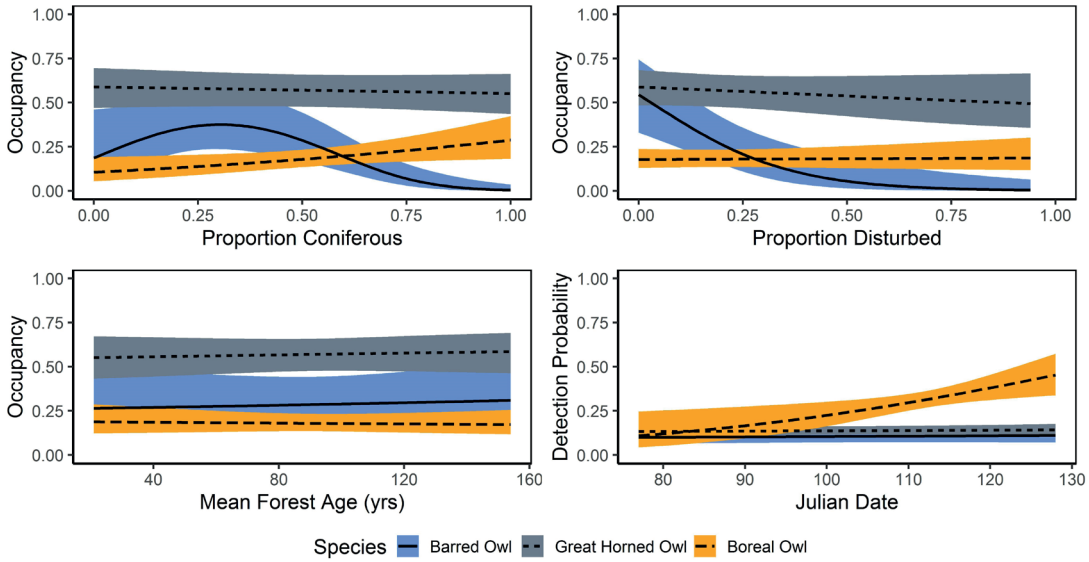
Table 1 - Occupancy models for each of the three owl species. Models are ranked by AIC weights (w_i). K is the number of parameters. We report only those models with strong support (ΔAIC ≤ 2) that made up our top model set for each species. Mean forest age (Age), proportion coniferous forest (Con) and proportion of the area disturbed by humans (Dist) were included as predictor variables for the occupancy parameter (Psi). Julian date (Date) was included as a predictor variable for the detection probability parameter (p).

Tabela 1 - Modelos de ocupação para cada uma das três espécies de rapinas noturnas. Os modelos são classificados por pesos de AIC (w_i). K é o número de parâmetros. Reportamos apenas os modelos com forte suporte (ΔAIC ≤ 2) que compunham o nosso modelo de topo para cada espécie. A idade média da floresta (Age), a proporção de floresta de coníferas (Con) e a proporção da área afetada pelo homem (Dist) foram incluídas como variáveis preditivas do parâmetro de ocupação (Psi). A data juliana (Date) foi incluída como uma variável preditiva para o parâmetro de probabilidade de deteção (p).

SPECIES	MODEL	K	AIC	ΔAIC	w_i
Barred Owl †	Psi(Con + Con^2 + Dist),p(.)	5	556.57	0.00	0.47
	Psi(Con + Con^2 + Dist),p(Date)	6	557.97	1.40	0.23
	Psi(Age + Con + Con^2 + Dist),p(.)	6	558.26	1.69	0.20
Boreal Owl	Psi(Con),p(Date)	4	844.19	0.00	0.40
	Psi(Age + Con),p(Date)	5	846.02	1.84	0.16
	Psi(Con + Dist),p(Date)	5	846.12	1.93	0.15
Great Horned Owl	Psi(.),p(.)	2	1484.39	0.00	0.17
	Psi(Dist),p(.)	3	1485.11	0.71	0.12
	Psi(.),p(Date)	3	1485.57	1.18	0.09
	Psi(Con + Dist),p(.)	4	1486.01	1.62	0.07
	Psi(Age),p(.)	3	1486.03	1.64	0.07
	Psi(Con),p(.)	3	1486.09	1.70	0.07
	Psi(Dist),p(Date)	4	1486.27	1.88	0.06
	Psi(Age + Dist),p(.)	4	1486.30	1.91	0.06

Figure 3 - Model averaged predictions from occupancy models (models within 2 ΔAIC of the top model; Table 1) for all three owl species. Occupancy estimates are shown as a function of forest composition (proportion coniferous forest), landscape disturbance (proportion of the area disturbed by humans resulting in loss of forest cover), and forest age. Detection probability estimates are shown as a function of Julian date (day 80 is March 21 and day 130 is May 10). The solid or dashed lines are the model averaged predictions, and the grey bands are the 95% confidence intervals.

Figura 3 - Previsões do modelo-médio dos modelos de ocupação (modelos dentro de 2 ΔAIC do modelo de topo; Tabela 1) para as três espécies de rapinas noturnas. As estimativas de ocupação são apresentadas em função da composição da floresta (proporção de floresta de coníferas), alteração da paisagem (proporção da área perturbada pelo homem resultando em perda de cobertura florestal) e idade da floresta. As estimativas de probabilidade de deteção são apresentadas como uma função da data juliana (o dia 80 é 21 de março e o dia 130 é 10 de maio). As linhas contínuas ou tracejadas são as previsões do modelo-médio e as faixas cinzas são os intervalos de confiança de 95%.



DISCUSSION

The vocal activity of these three owl species was predominantly nocturnal; however, there were some differences in vocal activity patterns between species, particularly in the onset and end of vocal activity around sunset and sunrise. Barred Owls were most active at night but called more frequently during daylight hours than the other two species. This is consistent with results of a passive acoustic study on vocal behaviour of Barred Owls that found they called throughout the day, though they were more vocally active at night with the peak from 02:00 hr to 05:00 hr (Odom & Mennill 2010b). We similarly found that Barred Owl vocal activity peaked from 02:00 hr to 04:00 hr. We also found that Barred Owls showed a more gradual increase in vocal activity in the hours leading up to sunset, and in the hours after sunrise compared to other two owl species that showed more abrupt changes in vocal activity around sunset and sunrise.

Boreal Owls were almost exclusively nocturnal in their calling behaviour, and rarely vocalized during daylight hours. Boreal Owls did not often vocalize in the hour when the sun rose or set, but showed a large increase in vocal activity one and two hours after sunset

and prior to sunrise. We could not locate any published accounts of the daily vocal activity patterns of Boreal Owls obtained from passive acoustic surveys. A study on Boreal Owl vocalization behaviour in Wyoming using call-broadcast surveys found that they were most vocal within the first hour after sunset (Clark & Anderson 1997). We noted some vocal activity in the first hour after sunset, but much greater activity two hours after sunset. Our results suggest if conducting passive surveys, it would be preferable to survey for Boreal Owls starting 2 hours after sunset.

Vocal activity of Great Horned Owls was mostly nocturnal, and they only infrequently called during daylight hours. Onset and end of vocal activity for Great Horned Owls appeared to be timed with when the sun set and rose, and they did not vocalize very often in the hour prior to sunset or in the hour after sunrise. There appear to be no published accounts of the daily vocal activity patterns of Great Horned Owls obtained from passive acoustic surveys. A study using broadcast calls for Great Horned Owls in Pennsylvania, found their vocal activity peaked from 0:00 hr to 02:00 hr (Morrell et al. 1991). We found that the vocal activity of Great Horned Owls was high during this period, but was also high throughout the night and that passive surveys for Great Horned Owls could occur anytime from an hour after sunset to sunrise.

Understanding vocal activity patterns of owls is important because many monitoring and research projects rely on detecting the vocalizations of owls to collect data on presence or absence of owl species and to provide insight on their habitat use. Based on our results, we would suggest that the optimal survey time for these three owl species is between an hour after sunset to an hour before sunrise. Studies that have collected data using acoustic surveys (either with or without a broadcast call) on one or more of the three owl species we studied, typically start either at sunset (Laidig & Dobkin 1995; Clark & Anderson 1997), or a half-hour or an hour after sunset (Lane et al. 2001; Grossman et al. 2008; Kissling et al. 2010; Munro et al. 2016) and end anywhere from 5 hours after sunset to sunrise. Thus, our recommendation is not very different from the survey times that owl researchers are already using. But seeing as there are so few published accounts with detailed descriptions of owl daily vocal activity patterns, and even fewer based on passive acoustic surveys, we believe the information provided here will be useful as justification for the methods of future owl research projects.

In addition to understanding daily vocal activity patterns of these owls, it is also important to understand seasonal vocal activity patterns. While it was not one of our objectives to document vocalization behaviour across the breeding season, we did include date as a variable for the detection probability parameter in our occupancy models to evaluate habitat use. We sampled within a date range that we believed would correspond to when these owls were most vocally active, and this assumption was supported by studies using a similar range of dates for surveys of these owl species in the boreal forest (Bondrup-Nielsen 1984; Clark & Anderson 1997; Grossman et al. 2008). We found no effect of date on the detection probability of Barred Owls and Great Horned Owls, suggesting that this range of dates was within the period when these species are vocally active. For Boreal Owls, we found a higher detection probability with later dates, suggesting that surveys for this species could be more effective if they occurred in the second half of our survey period (from April into May). More research using ARUs is needed to know when in the season vocalizations taper off for these three owl species.

The forest composition of locations we surveyed varied in the amount of deciduous and coniferous forest, and varied in how disturbed they were by humans. Results from telemetry studies of Barred Owls in northern Alberta and northern Saskatchewan suggest they prefer older mixedwood forests in the northern boreal forest (Mazur et al. 1998; Russell 2008). A study in northern Alberta

using call-broadcast surveys found that Barred Owls were most likely to occur in landscapes with >66% forest cover (Grossman et al. 2008). We did not find an effect of forest age, but we suspect this was due to the fact that most locations surveyed were in mature forest. Similar to previous studies using telemetry or call-broadcast methods, the results from our passive acoustic surveys are in support of Barred Owls preferring mature mixedwood forests, and suggest they are sensitive to human disturbance that results in the loss of forest cover.

Great Horned Owls are considered a generalist species and are found in a wide range of habitats throughout North America (Johnsgard 2002; Bennett & Bloom 2005). We found that Great Horned Owls were equally likely to use all habitats we surveyed, and that forest composition, forest age and human disturbance had no effect on their habitat use. Similarly, a study in New Jersey, USA, found that Great Horned Owls were not associated with any particular habitat type (Laidig & Dobkin 1995). Great Horned Owls may be more tolerant to disturbance, as they are often associated with heterogeneous landscapes. A previous study found Great Horned Owls were prevalent in landscapes with intermediate levels of forest cover (Grossman et al 2008). Our results are in support of Great Horned Owls being habitat generalists and relatively tolerant to human disturbance.

We found a weak trend for Boreal Owls to use areas with more coniferous trees, but no effect of forest age, and no effect of human disturbance on probability of habitat use. Long-term studies of Boreal Owls in Finland have established this owl to be closely associated with old-coniferous forests (Korpimäki and Hakkarainen 2012). A study tracking Boreal Owls with telemetry found they inhabit mixed-conifer, spruce-fir and Douglas fir forests in Idaho, western Montana, and northwestern Wyoming (Hayward et al 1993). Another study using passive acoustic surveys in Minnesota found Boreal Owls used older mixedwood forests (Lane et al 2001). Not many studies have examined the effects of disturbance on Boreal Owls, but one study using telemetry and call-broadcast surveys found sites occupied by Boreal Owls contained a greater proportion of disturbed areas (clearcuts, forest stands with silviculture treatments, and forest stands with wind or insect mortality) than unoccupied sites (Munro et al. 2016).

We found that using new bioacoustics tools, ARUs in combination with recognizers, was effective in surveying for owls to obtain data on vocal behaviour and habitat use. These tools allowed us to efficiently conduct passive surveys for three owl species, and this approach is likely to be useful for studying many other owl species that vocalize frequently. One of the benefits of this approach is that it is less invasive and requires less time in the field compared to studies using telemetry or call-broadcast survey methods. This research contributes to our understanding of the vocal behaviour of these owls, and can serve to inform owl researchers designing survey protocols.

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Age and sex of Snowy Owls (*Bubo scandiacus*) during summer irruption on Beliy Island, Yamal in 2015

Idade e sexo de coruja-das-neves (*Bubo scandiacus*) durante a irrupção estival na Ilha de Beliy, Yamal em 2015

Roar Solheim[1*], Aleksandr Sokolov[2]

1 Natural History Museum, Agder University, P.O. Box 422, N-4604 Kristiansand, Norway

2 Arctic research station of Institute of plant and animal ecology Ural branch Russian academy of sciences 629400, Zelenaya Gorka Str., 21, Labytnangi, Yamal-Nenets Autonomous District, Russia

*** Corresponding author:** roar.solheim@uia.no



ABSTRACT

In early summer 2015 a super peak of lemmings (*Lemmus sibiricus*) appeared on Beliy Island north of Yamal peninsula, Russia (73°19'N, 70°15'E). Considerable numbers of Snowy Owls (*Bubo scandiacus*) were present, possibly as a result of the abundance of lemmings. On 7, 9, 13, and 15 July a total of 69.7 km was covered on foot. Snowy owls were approached and 344 images of perching and flying birds were captured. At most 89 individual Snowy Owls were seen from one vantage point.

Images were sorted by number, time and date recorded on the image files. Images suitable to sex and age the owls were treated in Photoshop to enhance details of molt and bar patterns in wings. The birds were aged analyzing molt patterns, and individuals were recognized by bar and molt patterns in their wings.

Eleven males and 14 females were aged, of which 14 (56%) were second calendar year (2CY) birds hatched in 2014. Six owls were in their second or third wing feather molt, thus classified

as 3CY-4CY birds, while only five were birds with no juvenile flight feathers left (5CY+). Several individuals only photographed perching on the ground appeared to be juvenile 2CY birds, but these were not included in the sample due to lower certainty of identifying individuals and aging perched birds from images. Although two nesting pairs were recorded, the majority of the Snowy Owls on Beliy Island in July 2015 were young, presumably non-breeding birds.

This study shows that photographying as many Snowy Owls as possible during an irruption may reveal the age and sex distribution of the birds present.

Keywords: *Bubo scandiacus*, irruption, photo identification, sex and age distribution, Snowy Owl

RESUMO

No início do verão de 2015, ocorreu um superpico de lemingues (*Lemmus sibiricus*) na Ilha de Beliy, no norte da península de Yamal, Rússia (73°11'N, 71°17'E). Neste período houve também um aumento considerável no número de indivíduos de coruja-das-neves (*Bubo scandiacus*), possivelmente como resultado da abundância de lemingues. Nos dias 7, 9, 13 e 15 de julho foram percorridos a pé 69,7 km, tendo sido registadas 344 imagens de aves pousadas e em voo. No máximo, 89 indivíduos de coruja-das-neves foram registados a partir de um ponto de observação.

As fotografias foram ordenadas por número, hora e data. As imagens adequadas para a determinação do sexo e da idade das aves foram tratadas no Photoshop para melhorar os detalhes dos padrões de muda e das barras nas asas. A idade foi estimada através da análise dos padrões de muda e os indivíduos foram identificados pelos padrões de barras das asas e pelas mudas.

Foi determinada a idade de 11 machos e 14 fêmeas, dos quais 14 (56%) correspondiam a aves no segundo ano (2CY), nascidas em 2014. Seis aves estavam na segunda ou terceira muda, tendo sido classificadas como aves 3CY-4CY, e cinco eram aves já sem penas de voo de juvenil (5CY +). Os indivíduos que foram apenas fotografados pousados no chão, aparentando ser juvenis 2CY, foram excluídos da amostragem devido à incerteza na identificação e estimativa da idade a partir de imagens de aves pousadas. Embora tenham sido registados dois pares nidificantes, a maioria das corujas-das-neves na Ilha Beliy, em julho de 2015, eram aves juvenis, presumivelmente não reprodutoras.

Este estudo mostra que fotografar o maior número possível de corujas-das-neves durante uma irrupção pode revelar a distribuição de idades e sexo das aves presentes.

Palavras-chave: *Bubo scandiacus*, coruja-das-neves, distribuição de idades e sexo, identificação fotográfica, irrupção

Figure 1 - Location of Beliy Island (red circle), Russia, where Snowy Owls were seen in great numbers in July 2015.

Figura 1 - Localização da Ilha de Beliy (círculo vermelho), Rússia, onde um número muito elevado de corujas-das-neves foi registado em julho de 2015.

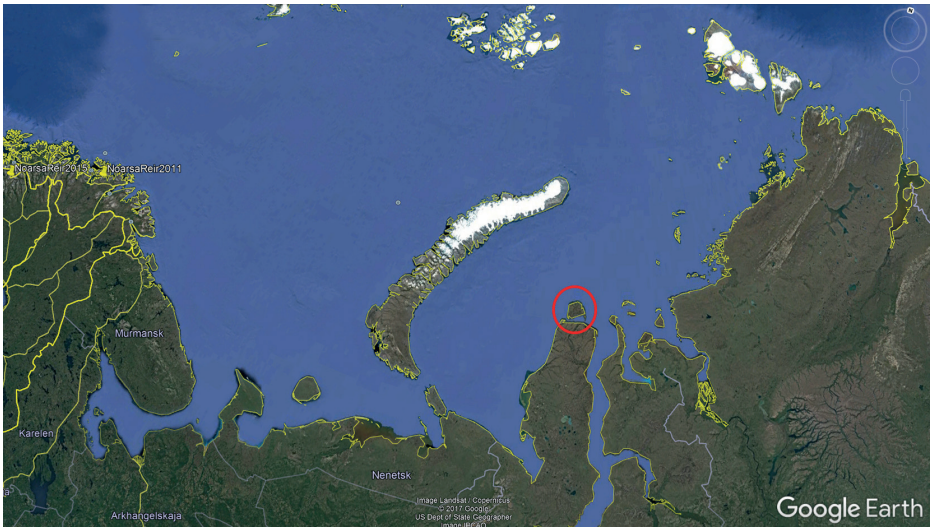


Figure 2 - Walking routes (July 2015) from where Snowy Owls were encountered and photographed on Beliy Island, Russia. Blue = 7 July, Yellow = 9 July, Red = 15 July, and Green = 17 July. Key and locations of sexed and aged birds (see text) appear below the Google map.

Figura 2 - Transetos percorridos a pé na Ilha de Beliy, Rússia (julho de 2015) para registo fotográfico de corujas-das-neves. Azul = 7 de julho; amarelo = 9 de julho; vermelho = 15 de julho; e verde = 17 de julho. A chave e as localizações das aves com sexo e idade determinados (ver texto) aparece abaixo do mapa.

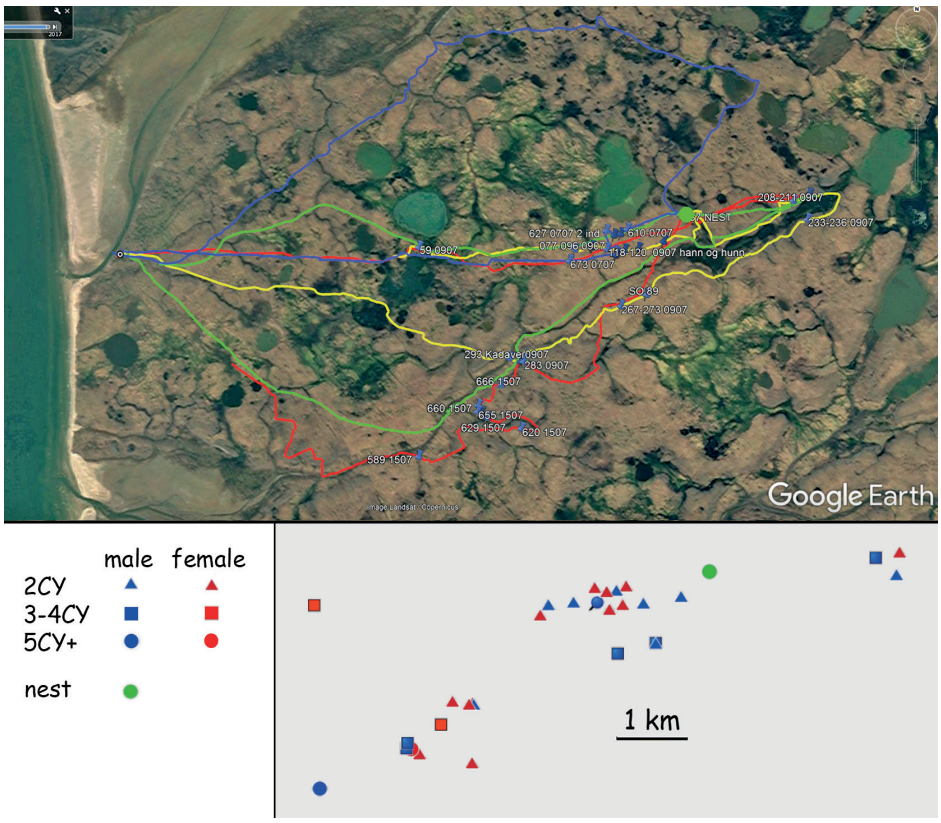


Figure 3 - Original, unedited image (left) of flying female Snowy Owl on Beliy Island, Russia, with Photoshop-edited image (right). On the left wing this female has molted P7, while on right wing both P7 and P8 have been molted. The bird is a second calendar year (2CY) individual in its first molt.

Figura 3 - Imagem original (à esquerda) de uma fêmea de coruja-das-neves em voo na Ilha de Beliy, Rússia, e a mesma imagem editada (à direita). Na asa esquerda esta fêmea mudou a P7, enquanto que na asa direita foram mudadas a P7 e a P8. A ave está no segundo ano de calendário (2CY) e está a fazer a primeira muda.



Introduction

Snowy Owls (*Bubo scandiacus*) have a circumpolar distribution, and can be found in the Arctic of Eurasia and North America as far north as 82°N and south to around 60°N (Portenko 1972). They are known to appear in great numbers at irregular intervals both on breeding grounds in summer, and on winter staging grounds (Portenko 1972). The international Snowy Owl Working Group (ISOWG) recognizes that the total world population of Snowy Owls may be far smaller than formerly believed, as indicated by DNA studies (Marthinsen et al. 2008), satellite tracking results (Therrien et al. 2008, Solheim et al. 2008, Jacobsen et al. 2009, Solheim et al. 2014) and also as proposed by Potapov & Sale (2012).

In North America Snowy Owls regularly migrate south during winter to prairie landscapes in Canada and the US, but with great fluctuations in the number of birds (Kerlinger et al. 1985, Smith 1997). When large numbers of birds appear, they are often mostly juveniles from last summer's breeding in the Arctic (Holt et al. 2015). However, also adult, older birds may appear invasionlike south of their breeding range. The methods described herein will help future studies document the percentage of different age groups of Snowy Owls during such invasions and shed light on the influence of variation in prey abundance and reproductive success on the migration of this apex predator of the Arctic.

Methods

In early summer 2015 a super peak of lemmings (*Lemmus sibiricus*) was registered on Beliy Island north of Yamal peninsula (73°19'N, 70°1'E; Figure 1). The abundance of lemmings was estimated by snap-trapping. Considerable numbers of Snowy Owls settled here as a result of the abundance of lemmings. On 7, 9, 13, and 15 July a total of 69.7 km was covered on foot (Figure 2, Table 1). Snowy owls were approached and photographed with a Nikon D90 with a 70-300 mm Nikon lens.

Images were sorted by number, time and date recorded on the image files. Images suitable to sex and age the owls were treated in Adobe Photoshop to enhance details of molt and bar patterns in wings (Figure 3). The birds

Figure 4 - Snowy Owl images 619 and 644 taken 7 July at 13:13:52 and 13:38:18 on Beliy Island, Russia. The points where the images were captured are plotted along the track route, both points linked with the yellow line. The images were captured 240 m apart, and with almost 25 minutes between them. The enhanced images of the males seem to be uncannily similar, judged by spots and marks on the bodies. On both instances the birds took flight shortly thereafter and were photographed flying (images 621 and 657). When comparing the dark bars on the primaries, it is obvious that these images depict the same individual. The bird must have landed further away along the track route, to be encountered again 25 minutes after first observation. This male has molted P7 on both wings, and is a second calendar year (2CY) bird in its first molt.

Figura 4 - Fotografias 619 e 644 de coruja-das-neves obtidas no dia 7 de julho às 13:13:52 h e às 13:38:18 h na Ilha de Beliy, Rússia. Os pontos onde as fotografias foram tiradas estão marcados ao longo do transecto e unidos por uma linha amarela. As imagens distam 240 m e estão desfasadas cerca de 25 min. As imagens melhoradas destes machos parecem muito semelhantes, tendo em conta as pintas e marcas corporais. Em ambos os casos a ave levantou voo pouco após a fotografia ser tirada, tendo sido fotografada também em voo (imagens 621 e 657). Quando comparadas as barra escuras nas primárias, é muito claro que as imagens representam mesmo indivíduo. A ave provavelmente pousou mais à frente no transecto, tendo sido encontrada novamente 25 minutos após a primeira observação. Este macho tinha mudado a P7 em ambas as asas, sendo um indivíduo no segundo ano de calendário (2CY) e a efetuar a primeira muda.

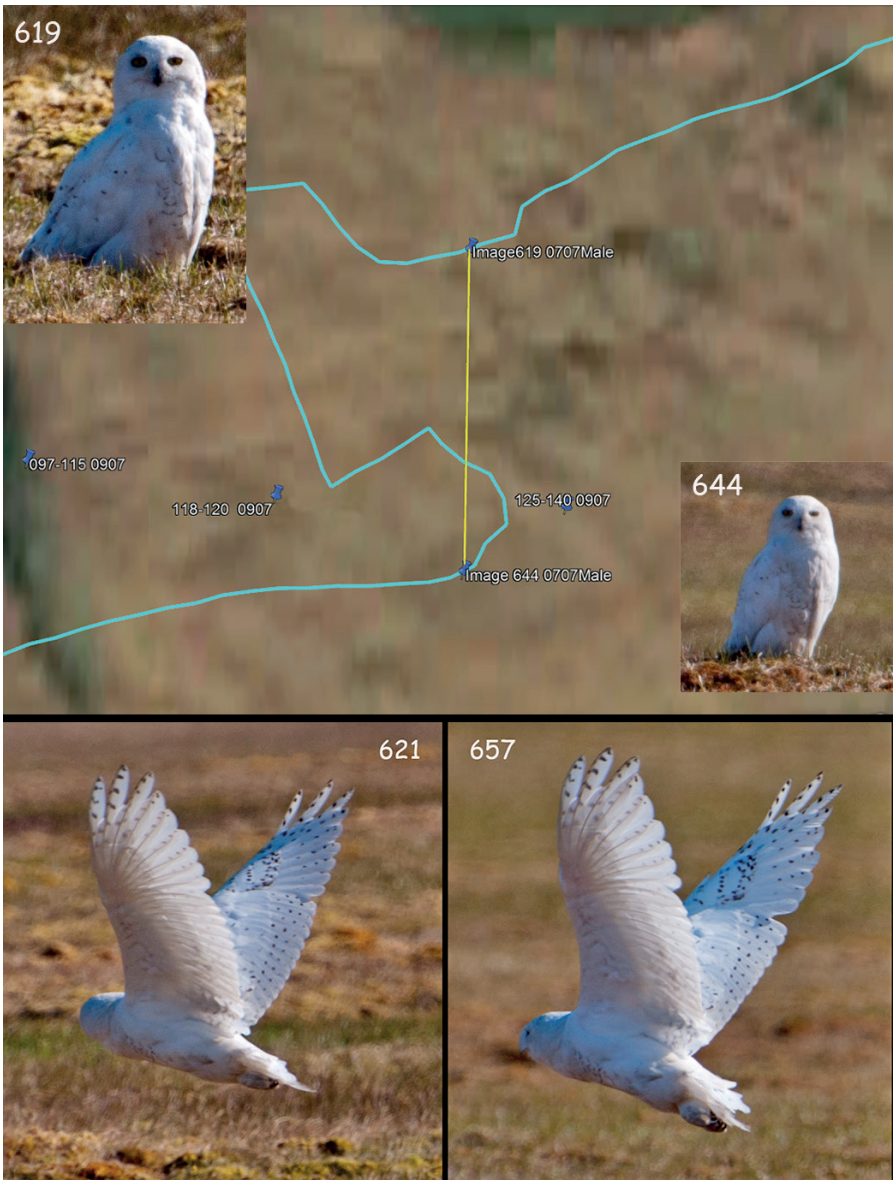


Table 1 - Distance in km travelled on foot during four days on tundra on Beliy Island, July 2015, number of photos of owls taken, and number of images enhanced and checked for molt and individuality.

Tabela 1 - Distância em km percorrida a pé durante quatro dias na tundra da Ilha de Beliy em julho de 2015, número de fotografias tiradas, e número de imagens melhoradas e usadas para determinação das mudas e identificação individual.

DATE	KM	IMAGES	USED
7 July	20.4	64	28
9 July	18.3	167	48
13 July	8.6	32	7
15 July	22.4	81	31
Total	69.7	344	114

Figure 5 - Snowy Owl images 666 and 673 captured 7 July at 13:41:59 and 13:51:30 on Beliy Island, Russia. Dark bar number four on inner vane from the tip of P10 and P9 is differently aligned with bars on outer vane on these two images, demonstrating that these are two different individuals. Both are second calendar year (2CY) birds in their first molt.

Figura 5 - Imagens 666 e 673 de coruja-das-neves, obtidas no dia 7 de julho às 13:51:30 h na Ilha de Beliy, Rússia. Na extremidade da P10 e da P9, a quarta barra escura interior está desalinhada relativamente às barras exteriores, demonstrando que se trata de indivíduos diferentes. Ambos são aves no segundo ano de calendário (2CY) a efetuar a primeira muda.



Figure 6 - Snowy Owl images 092 and 094 captured 9 July on Beliy Island, Russia. It is a second calendar year (2CY) male taking off, showing the upper side of right and left wing. The bird has molted P7 in both wings, all other primaries are juvenile.

Figura 6 - Imagens 092 e 094 de coruja-das-neves obtidas no dia 9 de julho na Ilha de Beliy, Rússia. Macho no segundo ano de calendário (2CY) a levantar voo, revelando a parte externa de ambas as asas. A ave mudou a P7 em ambas as asas e todas as outras primárias são de juvenil.

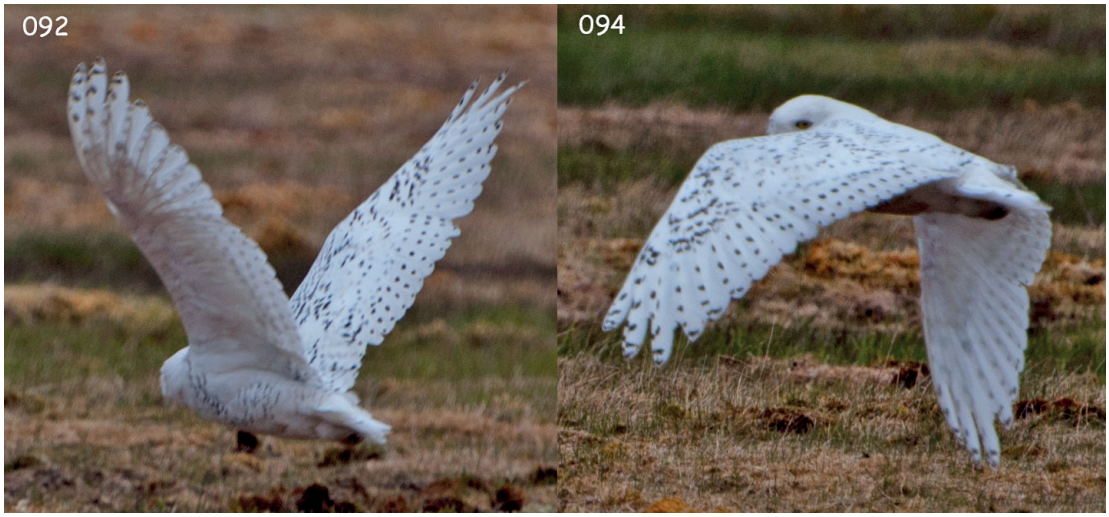


Figure 7 - Snowy Owl image 616 captured 15 July on Beliy Island, Russia. This female has formerly molted P7 and P8, while P9 has been molted in 2015. P10 is still juvenile, as are three of the innermost primaries. P6 is growing, while P5 may have been molted, or may be the outermost of the three juvenile feathers in line inwards. The bird has at least molted once before 2015, and most possibly twice. To judge if it is a third or fourth calendar year bird, all secondaries would have to be inspected, which is not possible on this image. The owl is thus classified as a third-fourth calendar year (3-4CY) bird.

Figura 7 - Imagem 616 de coruja-das-neves obtida no dia 15 de julho na Ilha de Beliy, Rússia. Esta fêmea tinha mudado a P7 e a P8 anteriormente, tendo mudado a P9 em 2015. A P10 ainda é de juvenil, bem como as três primárias mais internas. A P6 está em crescimento, e a P5 pode ter sido mudada ou pode ser a mais externa de três primárias juvenis alinhadas. A ave efetuou pelo menos uma muda antes de 2015, possivelmente duas. Para determinar se esta ave estaria no terceiro ou no quarto ano de calendário, teriam de ser observadas todas as penas secundárias, o que não é possível nesta imagem. A ave foi classificada como estado entre terceiro e o quarto ano de calendário (3-4 CY).



Table 2 - Age and sex of Snowy Owls on Beliy Island, July 2015, as judged from images.
* Bird found dead

Tabela 2 - Idade e sexo da coruja-das-neves na ilha de Beliy em julho de 2015, estimados a partir das imagens.

DATE	MALES			FEMALES			SUM
	2CY	3-4CY	5CY+	2CY	3-4CY	5CY+	
7 July	1			4			5
9 July	3		2	3	1*	1	10
13 July	1			1			2
15 July		2	2	1	3		8
Sum	5	2	4	9	4	1	25

were aged analysing molt patterns described by Solheim (2012) and later collected molt data (Solheim 2017), and individuals were recognized by bar and molt patterns in their wings (cnf. Solheim 2016).

A GPS track file was used to record the location of the owls that were photographed and subsequently aged and sexed (Figure 2). The spacing of the images helped when comparing images of birds of similar age to determine if they were the same (Figure 4) or different individuals (Figure 5).

Results

The lemming trap-index reached 13.7 animals per 100 trap-nights, which is the highest value ever measured on the Yamal peninsula since 1999 (Unpublished Data). At most 89 individual Snowy Owls were seen from one vantage point. Judged by the number of owls encountered along the track routes, probably at least 150 Snowy Owls were present in the area surveyed. A total of 344 images were captured of both perching and flying birds. Of these 114 images showed flying birds and could be used for closer inspection to check the birds´ age and identity. Many of these images were however series of the same bird as it took off. The best images showing the upper side of one wing and later the other wing (upstroke and downstroke from side view; Figure 6) were used to determine molt stage. It was possible to age 11 males and 14 females (Table 2). Fourteen individuals were juvenile or second calendar year birds (2CY) in their first molt (five males, nine females). Six birds (two males, four females) were in later molt stages with still recognisable juvenile flight feathers in their wings (Figure 7), while only five individuals (four males, one female) were classified as adult 5CY+ birds in their fourth molt stage or later, recognised by the total lack of juvenile flight feathers in their wings.

Discussion

When encountering Snowy Owls it is recommended to take as many flight images as possible before the bird advances too far off. With modern digital photography there are no serious limitations to how many images one can secure, as in former days when photography was expensive. The camera should be set to multiple image shooting at the highest speed for the camera at hand, and usually at ISO values of 1000-3200 to freeze the wing motion of a flying owl.

It is usually possible to use images to recognise molt stage 2 and 3 in Snowy Owls based on number of juvenile feathers left in the wings and differences in contrast and wear of molted, adult feathers (Solheim 2012, 2017), provided that the image clearly shows all secondaries and primaries (see Solheim 2016). On images of flying birds, the innermost secondaries may be hard to judge, and non-adult birds after their first molt have thus been categorized as 3-4CY, although several of the aged birds in this category seemed to be in their third molt (4CY).

Only five individuals (20%) of the aged birds were fully grown, thus hatched in 2011 or earlier, while the 14 juvenile birds made up more than half of the aged birds (56%). These birds were hatched in 2014, while the rest of the group (six individuals; 24%) were hatched in 2012 or 2013.

Since 80% of the aged Snowy Owls on Beliy in summer 2015 were hatched in the period 2012-14, the question arises where did they originate from. Snowy Owls were found nesting in Fennoscandia in 2007, 2011 and 2015. The Norwegian Snowy Owl Project equipped three male and nine female Snowy Owls with satellite transmitters in Norway in 2011 (Jacobsen et al. 2012). During summer 2012 and 2013 these owls moved along the Russian Arctic from Kola peninsula to Novaja Zemlya and Vaygach Islands, with Novaya Zemlya as the most probable area for breeding (Jacobsen et al. 2013). Adult Snowy Owls equipped with satellite transmitters in Norway documented that Snowy Owls breeding in Scandinavia in peak lemming and vole years move to Russia as far east as the Taimyr peninsula (75° N 100° E) (Solheim et al. 2008, Jacobsen et al. 2009, 2013), and even to the October Revolution Island (80° N 99° E) (Jacobsen et al. 2014) during years with no or few lemmings in Scandinavia.

According to information provided through the arctic birds conditions survey (www.arcticbirds.net), 2014 was a good breeding year for Snowy Owls in western Taymyr (Kharitonov, 2014). It is thus highly probable that the young 2-4CY Snowy Owls which made up most of the Snowy Owls on Beliy in July 2015, may have been hatched in the same part of the Russian Arctic, between Novaja Zemlya and Taimyr. Snowy Owls thus seem to make up one sub-population from Fennoscandia to Taimyr.

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Home range, perching height and reaction to approaching humans by radio-tagged Ural Owls

Área vital, altura dos poisos e reação à aproximação de humanos por parte de corujas dos Urales marcadas com rádio-emissores

Roar Solheim[1,*], Geir A. Sonerud[2], Hallvard Strøm[3]

1 Natural History Museum, Agder University, P.O. Box 422, N-4604 Kristiansand, Norway

2 Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, P. O.Box 5003, N-1432 Ås, Norway

3 Norwegian Polar Institute, Framsenteret, P.O. Box 6606 Langnes, N-9296 Tromsø

*** Corresponding author:** roar.solheim@uia.no



ABSTRACT

Four breeding Ural Owls (*Strix uralensis*) (one pair, one female and one male) were radio-tagged at the nest and tracked on foot with portable equipment in Hedmark county in SE Norway. The owls´ positions were determined by cross-triangulating or by direct observations. A total of 105 plotted locations were obtained. The mated male and female were located 58 and 22 times on 30 and 17 separate days, respectively, in 1989, while the other female was located 18 times on 15 separate days in 1989, and the other male 7 times on 4 separate days in 1990. From October 1989 on, presumably after the young became independent, the first male moved out of his summer range and eastwards into Sweden. Home range areas were treated as summer areas until this date, and winter areas thereafter. Calculated as 100% minimum convex polygon, the summer (May - September) home range for this male was 11 km^2, while his winter (October - December) home range was 63 km^2. The corresponding home ranges for his mate were 7 km^2

and 20 km², while for the other female they were 27 km² and 32 km². Overall home range for the whole tracking period was 112 km² for the mated male and 42 km² for his mate, and 40 km² for the other female. There was negligible overlap between the home ranges of the two females nesting 8 km apart. A kernel analysis of the male´s summer range data showed that he spent half his activity within an area of 5 km² around his nest. The owls perched 2.3 - 8 m above ground, with an average of 5.0 m, usually in the lower half of the perch tree. The owls often took off before they were spotted. On the occasions when the owls were seen and flushed, the flight initiation distance ranged 8-35 m, with an average of 20 m. No pellets were found below the perches, and only once was an owl located when ingesting a prey.

Keywords: Home range, perching height, reaction to human approach, *Strix uralensis*, telemetry

RESUMO

Quatro corujas dos Urales (*Strix uralensis*) reprodutoras (um casal, uma fêmea e um macho) foram marcadas com rádio-emissores no ninho e seguidas a pé com equipamento portátil no condado de Hedmark, no sudeste da Noruega. As posições das corujas foram determinadas por triangulação ou por observações diretas. Foram obtidas 105 localizações. O macho e a fêmea acasalados foram localizados 58 e 22 vezes em 30 e 17 dias diferentes, respetivamente, em 1989, enquanto a outra fêmea foi localizada 18 vezes em 15 dias em 1989, e o outro macho 7 vezes em 4 dias em 1990. A partir de outubro de 1989, presumivelmente depois de os juvenis se terem tornado independentes, o primeiro macho abandonou a sua área de verão e deslocou-se para leste, para a Suécia. As áreas vitais foram tratadas como áreas de verão até essa data e, posteriormente, como áreas de inverno. Calculada como polígono convexo mínimo de 100%, a área vital de verão (maio - setembro) desse macho foi de 11 km², enquanto a área vital de inverno (outubro - dezembro) foi de 63 km². As áreas vitais correspondentes da sua companheira foram de 7 km² e 20 km², enquanto para a outra fêmea foram de 27 km² e 32 km². A área vital total para o período de seguimento foi de 112 km² para o macho acasalado, 42 km² para a sua companheira e 40 km² para a outra fêmea. Ocorreu uma sobreposição negligível entre as áreas vitais das duas fêmeas a nidificar a 8 km de distância. A análise *kernel* das localizações do macho durante o verão revelou que este passou metade da sua atividade numa área de 5 km² em torno do ninho. As corujas usaram poisos entre 2,3 e 8,0 m acima do solo, com uma média de 5,0 m, geralmente na metade inferior da árvore. As corujas levantavam frequentemente voo antes de serem avistadas. Nas ocasiões em que as corujas foram avistadas e fugiram, a distância de início do voo variou entre 8 e 35 m, com uma média de 20 m. Não foram encontradas regurgitações debaixo dos poisos, e uma coruja foi encontrada a ingerir uma presa apenas uma vez.

Palavras-chave: altura do poiso, área vital, reação à aproximação de humanos, *Strix uralensis*, telemetria

Introduction

The Ural Owl (*Strix uralensis*) is a cavity-nesting prey generalist that inhabits the northern taiga from Japan across Russia to Fennoscandia, and its westernmost distribution reaches across Sweden into Hedmark county in SE Norway (Mikkola 1983, Cramp 1985). Before 1985 very few nests had been found in Norway (Solheim 1985). In 1979 a nest box study was initiated, and from 1985 a total of 86 nest boxes were available in potential Ural Owl habitat in Hedmark county (Solheim et al. 2009). The sparse data recorded in Norway before 1985 indicated that Ural Owl clutch sizes were smaller than those reported from Sweden and Finland (Solheim & Bjørnstad 1987). We thus suspected that food availability could be a limiting factor resulting in smaller clutch sizes in Norway. In Finland Ural Owls show a functional response to microtine rodents, and otherwise prey on shrews, hares, birds and frogs (Korpimäki & Sulkava 1987). Because Ural Owls in Fennoscandia do not migrate during winter and tend to reside within their established territories, they may be more exposed to poor hunting conditions during harsh winters and low microtine rodent populations. According to Lundberg (1980, 1981), the availability of microtine rodents during winter and early spring is the main regulatory factor for breeding success of Ural Owls in Sweden. Solheim & Bjørnstad (1987) thus proposed to use radio telemetry to follow adult Ural Owls in SE Norway during autumn and winter to study their hunting habits and diet. To this end, three nesting Ural Owls were fitted with radio transmitters in 1989 and one in 1990, and located until the transmitters expired. Here, we present results on home range size and perching behaviour from this study.

Methods

In 1989 two Ural Owl nests situated 8.3 km apart were located at c. 60°46´N, 12°16´E in Hedmark county in SE Norway. One nest was located in a cavity in a partly dead aspen (*Populus tremulus*) (loc. 1), which was first found with nesting Ural owls in 1984. The other nest was in one of the project nest boxes (loc. 2), which had been available but unoccupied since autumn 1979. In each nest, two young fledged c 1 June. We used mist nets to capture the adults on 19 May (male 1; body mass 720 g), 1 June (female 2; body mass 815 g) and 8 June (female 1; body mass 840 g). Male 1 and female 1 were paired, while we did not succeed in capturing the mate of female 2. In 1990, a new male (here denoted as male 3) had occupied loc. 1 and nested with female 1. He was captured on 19 May (body mass 733 g).

The owls were fitted with a transmitter (model Biotrack SR-1) mounted as a backpack and attached by tubular Teflon tape (Bally Ribbon Mills, PA, USA) as harness. The total backpack including harness weighed c. 20 g, thus amounting to less than 2.7 % of the body mass of the lightest owl. The transmitters had a mercury switch which changed the signal to a more rapid pulse when the owls were flying or leaning forward, thus making it easier to cross-triangulate the owls and interpret their behaviour.

The owls were cross-triangulated during day-time to locate roost sites, and tracked during the evening and night hours to locate their hunting grounds and to watch their hunting behaviour. This was done on foot using a portable receiver (model Televilt RX-81) and a hand-held 4-element yagi-antenna. When tracking the owls during daytime and signals indicated that they were roosting, we usually tried to approach the owl at an

angle to circle it and avoid flushing it before it could be spotted. Whenever the owls were seen perched, we noted the perching height. Locations of the owls were marked on copies of aerial photos. By using modern digital maps, web-based aerial photos, and Google earth, the locations were recently transferred to Google earth maps. This gave GPS data for each marked location and allowed modern analyses of the owls´ home ranges. Male 1 was located from 20 May until 26 December, while female 1 and female 2 were tracked from 16 June until 26 December, and from 15 June until 9 December, respectively, in 1989. Male 3 was located from 19 May until 15 June in 1990. Young Ural Owls are usually dependent on their parents´ feeding efforts until late August, after which they start dispersing (Valkama et al. 2014). We treated locations during May-September as representing summer home range of the owls, and locations obtained during October-December as representing winter home range. All locations of the females were made after the young had fledged. The transmitters on male 1 and female 1 had expired on 7 January 1990, and that on female 2 on 20 December 1989. The transmitter on male 3 had expired prematurely on 30 June 1990.

We obtained a total of 98 locations in 1989 and 7 locations in 1990. Male 1 and female 1 (the mated pair) were located 58 and 22 times on 30 and 17 separate days, respectively, while female 2 was located 18 times on 15 separate days. Male 3 was located only 7 times on 4 separate days, so home range size was not calculated.

Of the locations of male 1, approximately half were termed diurnal (made when the sun was above the theoretical horizon) and half were termed nocturnal (made when the sun was below the theoretical horizon. Of the locations of the two females, approximately two third were diurnal.

The time interval between successive locations of the same owl varied from 2 minutes to 34 days 22 hours, with a median of 12 hours 29 minutes. Because 98% of the intervals were longer than 5 minutes, and 90% were longer than 21 minutes, we regard the locations as fairly independent.

Home ranges were calculated by use of two methods in the package "adehabitatHR" in the statistical software R (R Development Core Team 2017); minimum convex polygon (MCP) and kernel (Wolton 1989). The former was used to enable comparison with a previous study. Means are presented with standard error (SE).

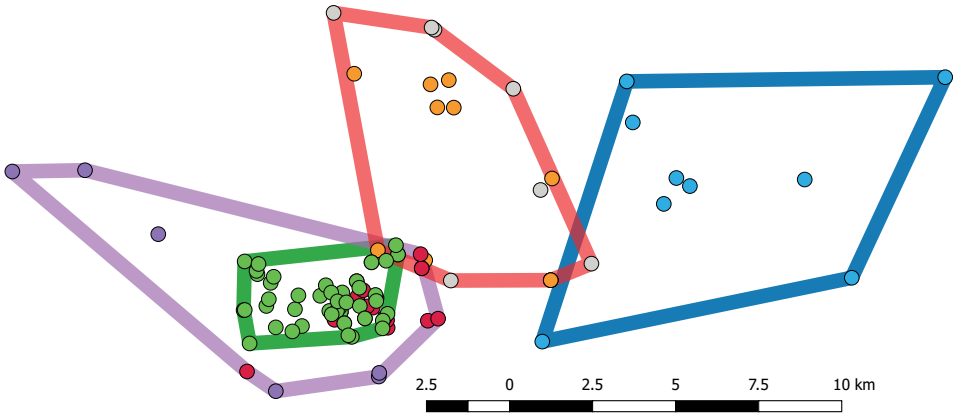
Results

When home range was calculated as 100% MCP it covered 41.9 km^2 for female 1 and 39.7 km^2 for female 2, with hardly any overlap between these two neighbours, and 112.0 km^2 for male 1 overall (Fig. 1). When it was calculated as separate 100% MCP ranges for the offspring dependence period (May - September) and the ensuing non-breeding period (October - December). it covered 11.2 km^2 (49 locations) and 62.8 km^2 (9 locations), respectively, for male 1, with no overlap (Fig. 1). The male had moved 9 km between the last location in the offspring-dependence period (25 September) and the first location in the non-breeding period (2 October). For female 1 the corresponding ranges were 7.3 km^2 (16 locations) and 19.5 km^2 (6 locations), while for female 2 they were 26.7 km^2 (11 locations) and 31.7 km^2 (7 locations), respectively.

The number of locations of the females was too small to calculate home range as kernel. The same was the case for the male in the non-breeding period. For the male during the offspring dependence period (May - Septem-

Figure 1 - Home ranges of the three Ural owls radio-tracked in 1989, expressed as 100% MCP, with each plotted location shown. Green colour denotes the range of the male during May - September, and blue colour his range during October - December. The overall range of his mate (female 1) is denoted by purple colour, with locations from June - September in red colour and locations from October - December in purple colour. The overall range of the other female (female 2) is denoted by orange colour, with locations from June - September in orange colour and locations from October - December in grey colour.

Figura 1 - Áreas vitais das três corujas dos Urales seguidas por rádio-telemetria em 1989, expressas como 100% MCP, com cada localização representada. A cor verde indica a área ocupada pelo macho entre maio e setembro, e a cor azul a área ocupada entre outubro e dezembro. A área ocupada pela sua companheira (fêmea 1) é indicada pela cor roxa, com as localizações de junho a setembro a vermelho, e as localizações de outubro a dezembro a roxo. A área ocupada pela outra fêmea (fêmea 2) é indicada pela cor laranja, com as localizações de junho a setembro a laranja e as localizações de outubro a dezembro a cinza.



ber) 95%, 75%, 50%, 25% and 10% kernel range covered 21.8, 11.2, 5.4, 1.9 and 0.6 km^2, respectively (Fig. 2). His nest was located within the 25% (and higher) kernel range, but outside the 10% kernel range (Fig. 2).

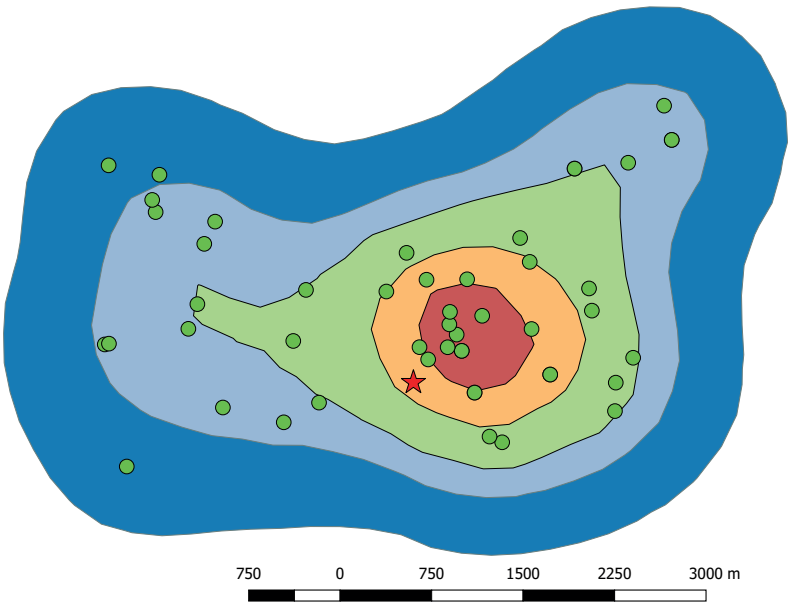
When we approached perched owls during daytime, they either took off before we could see them or at the moment we spotted them, or they stretched out in camouflage posture trying to avoid detection. On 24 occasions the owls were observed before they took off, and their perching height could be measured. The owls were usually perching in the lower half of the tree, typically on the lowest thick branches of a pine, and were never seen perching in the top of a tree. Perching height was on average 5.0 ± 0.3 m and ranged 2.3 - 8 m, with no significant variation between the four individuals ($F_{3,20} = 0.29$, $p = 0.83$). In seven of these cases we measured the height of the perch tree, and it ranged 6 - 15 m, with an average of 10.8 ± 1.4 m. The perching height relative to the tree height ranged 0.30 – 0.83, with an average of 0.48 ± 0.06.

On the 14 occasions when the owls were seen and flushed, the flight initiation distance ranged 8-35 m, and was on average 19.7 ± 2.4 m, with no significant variation between the four individuals ($F_{3,10} = 1.72$, $p = 0.23$). This flight initiation distance was not significantly related to perching height ($F_{1,12} = 0.37$, $p = 0.55$).

We did not attempt to measure the owls´ habitat preferences, i.e. habitat use against available habitat types. During the seven months we were able to follow the Ural Owls, we did however get a good impression of where the owls moved while hunting. They were often found in swampy pine or mixed coniferous forest, and never seen perching in open areas like bogs or clear-cuts. When the male of the mated pair was flying towards the nest, he crossed some clear-cuts usually in tree-top height. When the owls were flying

Figure 2 - Home range of the Ural owl male during May - September, expressed as kernel utilization distributions, with each plotted location shown in green colour. Brown colour denotes 10%, yellow 25%, green 50%, light blue 75%, and dark blue 95% utilization. The red star denotes the position of the nest.

Figura 2 - Área do macho de coruja dos Urales durante os meses de maio a setembro, expressa em distribuições de utilização de kernel, com cada localização estimada na cor verde. A cor castanha indica 10%, amarelo 25%, verde 50%, azul claro 75% e azul escuro 95% de utilização. A estrela vermelha indica a posição do ninho.



in forest, they often flew close to the ground (0.5-1.5 m).

We did not find any pellets at the sites where owls were located perching during daytime. The movements of the owls indicated that they did not establish specific roost sites after the chicks had left the nest, and ended up resting wherever their nightly hunting had brought them at the dawn of day. On the very last tracking day we located female 1 with prey. When we triangulated her after 11.30 pm in the dark in snowy weather on 26 December, the transmitter signals indicated that she was eating (alternating quick and slow pulse of signals from a stationary position). The owl was flushed from a carcass of a female Capercaillie (*Tetrao urogallus*) on the ground. The bulging eyes of the carcass indicated that the prey was recently killed, and thus most likely killed by the Ural Owl herself.

Discussion

Home range

During May – September 1989, when providing for offspring, the Ural Owl male had a home range covering 11 km^2 when calculated as 100% MCP. In comparison, a Ural Owl male radio-tracked for 9 weeks during May - July in 1991 in Värmland county in Sweden, in the same boreal forest region as our study area and less than 100 km towards southeast, had a 100% MCP home range covering 21 km^2 (Bolin et al. 1992). These areas were 5-10 times larger than those found for 100% MCP home ranges of providing males of the Boreal Owl (*Aegolius funereus*) and the Northern Hawk Owl (*Surnia ulula*) in boreal forests c. 100 km northwest of our study area in 1983-85 (Sonerud et al. 1986, Bækken et

al. 1987, Jacobsen & Sonerud 1987). The two latter species are smaller than the Ural Owl, so would be expected to need smaller ranges, given the same access to prey. Moreover, the Boreal Owl and the Northern Hawk Owl are more specialized on small mammals as prey than is the Ural Owl (Mikkola 1983, Cramp 1985), and therefore depend on higher small mammal abundance to nest. Thus, the home range estimates obtained for Boreal Owls and Hawk Owls were probably on average representing higher small mammal abundances than were those obtained for the Ural Owl. In the low vole year 1993, Eurasian Pygmy-owl (*Glaucidium passerinum*) males in a mixed boreal forest-farmland area c. 100 km northwest of our study area had 100% MCP home ranges averaging 3 km^2 (Strøm & Sonerud 2001).

The kernel analysis of the locations obtained for the Ural Owl male suggests that during the provisioning period he was as likely to be located within an area of 5 km^2 around the nest as further away. Thus, a substantial part of his movement seemed to be concentrated on a rather small area.

The overall home ranges of the two Ural Owl females (100% MCP) had strikingly similar size (40 km^2 and 42 km^2). It is also striking that these neighbours, nesting 8 km apart, had 100% MCP home ranges just touching each other, with minimal overlap. Ural Owl males are strongly territorial (Mikkola 1983, Cramp 1985), and our data suggest that this applies to the females as well. While one of the females had a smaller 100% MCP home range in the offspring-dependence period (7 km^2) than in the non-breeding season (19 km^2), this was not the case for the other female (27 km^2 and 32 km^2, respectively). The former female had a similar home range size in the offspring-dependence period as her mate (7 km^2 and 11 km^2, respectively).

Young Ural Owls depend on their parents for food until late August (Valkama et al. 2014). This may explain why the male Ural Owl did not start expanding his home range until October, and thereafter moved 20 km towards the east into Sweden. His mate nested in the same cavity in the aspen tree with a new male (male 3) in 1990, but thereafter she relocated 1 km eastwards to a nest box, which she used for breeding in later years. Thus, the male may have been evicted from his territory by the new male in fall 1989.

Perching height

The Ural Owls did not tolerate humans at close distance. We were thus unable to closely follow the Ural Owls and observe their hunting behaviour, as is possible for Boreal Owls (see Bye et al. 1992). On average, the Ural Owls perched 5 m above ground when located. In comparison, radio-tagged Boreal Owls on average perched 3 m above ground when hunting at night, and 4 m above ground when roosting during daytime (Bye et al. 1992). We did not discriminate perches used for hunting from perches used for roosting by the Ural Owls, but apparently they perched higher than Boreal Owls when hunting. Although the Ural Owl is less constrained to nocturnal hunting than is the Boreal Owl, both use auditorial cues to locate prey (Cramp 1985). Because Ural Owl males are twice as large as Boreal Owl males by linear body measures (Cramp 1985), the distance between their ears is larger, so they would be able to determine the exact position of a ground-dwelling prey by acoustic cues at a larger distance (cf. Norberg 1970, 1978).

Prey

Unfortunately, we were unable to document prey taken by the radio-tagged Ural Owls to reveal their diet during fall and winter, with one exception (see below). The owls obviously did not use permanent roost sites outside the breeding season, and pellets were thus very hard to find. The way Ural Owls seemed to avoid close contact by humans

made it even more difficult to locate roosts sites and pellets. This shy behaviour was quite similar to that found in radio-tagged individuals of the closely related Tawny Owl (*Strix aluco*) and Great Grey Owl (*Strix nebulosa*) (pers. obs.).

The only prey item we were able to record was a female Capercaillie being ingested by female 1 close to midnight in late December. This prey weighs c. 2 kg, which is 2-3 times as much as a female Ural owl (c. 800 g). By feeding mammalian and avian prey to owls in temporal captivity, and video recording the owls´ prey handling, Slagsvold & Sonerud (2007) and Slagsvold et al. (2010) found that ingestion rate decreased with prey size, and was higher for mammalian than for avian prey. From figs. 2 and 3 in Slagsvold & Sonerud (2007), we estimated that a microtine rodent weighing 20 g, thus c. 2.5% of a female Ural Owl (800 g), would be ingested at a rate of 30 g/min, thus in 40 s, whereas an avian prey weighing more than twice as much as the owl would be ingested at a rate of less than 1g/min. Although only c. 70% of the body mass of the latter prey would be consumed (fig. 1 in Slagsvold et al. 2010), it would still take the owl c. 24 hours or more to consume the prey. Thus, the probability of locating a Ural Owl while it is consuming a microtine rodent is negligible compared to the probability of locating it when it is consuming a female Capercaillie. This would explain why the only prey we recorded was a female Capercaillie, and why we never found the owls while they were consuming smaller prey.

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Snowy Owl (*Bubo scandiacus*) males select the highest vantage points around nests

Os machos de coruja-das-neves (*Bubo scandiacus*) selecionam os poisos mais altos nas imediações dos ninhos

Roar Solheim[1*], Ingar Jostein Øien[2], Tomas Aarvak[2], Karl-Otto Jacobsen[3]

1 Agder University, Natural history museum, P.O. Box 422, N-4604 Kristiansand, Norway

2 Norwegian Ornithological Society - NOF-BirdLife Norway

3 Norwegian institute for nature research – NINA

*** Corresponding author:** roar.solheim@uia.no



ABSTRACT

In July 2007 we collected a total of 309 Snowy Owl (*Bubo scandiacus*) pellets from 35 vantage points in an area where we located four Snowy Owl territories in northern Norway. The number of pellets found at each vantage point ranged from 1 to 39 (mean: 8.8, median: 6, SD ± 1.8). While the four nests were situated 513, 522, 524 and 529 m asl respectively (mean 522 m, SD ± 4.1), the vantage points with pellets were situated from 515 to 590 m asl (mean: 550.2 m, median: 548 m, SD ± 16.3). We found the highest number of pellets at the highest vantage points. The increase of pellets with higher elevation above the nest site indicates that Snowy Owls spent more time on the highest vantage points in the territory. Although some pellets may have been cast by the females before they started incubating, the majority of pellets were most likely cast by males. We hypothesise that the presence of elevated mounds, rocks or heights around the nest site of Snowy Owls may be an important feature for the Snowy Owls when selecting the breeding territory, increasing the male´s ability to scrutinize his territory for both prey and possible threats to the nest and himself.

Keywords: breeding, *Bubo scandiacus*, hunting behaviour, pellets, vantage points

RESUMO

Em julho de 2007 recolhemos 309 regurgitações de coruja-das-neves (*Bubo scandiacus*) em 35 poisos, numa área no norte da Noruega onde localizámos quatro territórios da espécie. O número de regurgitações encontrado em cada poiso variou entre 1 e 39 (média: 8,8; mediana: 6,0). Enquanto os quatro ninhos estavam situados a 513, 522, 524 e 529 m de altitude, respectivamente (média: 522 m), os poisos com regurgitações situavam-se entre 515 e 590 m de altitude (média: 550,2 m; mediana: 548 m). Nos pontos mais elevados encontrámos um maior número de regurgitações. O aumento do número de regurgitações com o aumento da elevação do local relativamente ao ninho indica que os coruja-das-neves passaram mais tempo nos pontos mais elevados. Embora algumas regurgitações possam ter sido produzidas pelas fêmeas antes do início da incubação, a maioria das regurgitações foi mais provavelmente produzida pelos machos. A nossa hipótese é que a presença de montículos elevados, rochas ou outras elevações nas imediações dos ninhos de coruja-das-neves pode ser uma característica importante para a seleção do território de reprodução, aumentando a capacidade do macho observar o seu território, tanto para deteção de presas como de possíveis ameaças.

Palavras-chave: *Bubo scandiacus*, coruja-das-neves, distribuição de idades e sexo, identificação fotográfica, irrupção

Introduction

In a feeding study of captive owls and raptors Slagsvold et al. (2010) found that small mammalian prey were more likely to be swallowed whole than bird prey, and that large vole-specialists more often ate small mammals whole than did smaller raptors. Owls usually consume most of their prey, and subsequently regurgitate indigestible parts, such as bones, skin, fur and feathers as pellets (Mikkola 1983). Although some prey may be ripped apart, crania, bones, fur and feathers are usually also swallowed. Owls do not dispose of pellets at specific sites, but cast them wherever they happen to perch when it is time to regurgitate. Owls in general seem to produce two pellets per day (Mikkola 1983), while Snowy Owls (*Bubo scandiacus*) usually cast 1-3 pellets per day (Portenko 1972). The number of pellets at a specific site may thus reflect the time an individual owl spends at the site. On wintering grounds in farmland in Michigan, USA, Chamberlin (1980) observed a Snowy Owl continuously from prey capture to pellet casting and found that the owl required between 5 h 38 min and 7 h 11 min for pellet formation.

Snowy Owls usually place their nests at elevated mounds in the terrain (Watson 1957, Hagen 1960, Portenko 1972, Potapov & Sale 2012). According to Watson (1957), the female ensures that she has a commanding view of the area surrounding the nest site, while the male appears to keep the nest site in view when he is hunting. Sutton & Parmelee (1956) found that although Snowy Owls placed their nests on elevated mounds, nests were usually not situated at the highest points of the terrain. When Norwegian lemmings (*Lemmus lemmus*) peaked in 2007, we located four breeding pairs of Snowy Owls. In order to uncover the hunting behaviour by male Snowy Owls and their selection of vantage points during hunting, we thoroughly examined the surroundings of three of the

Figure 1 - Male Snowy Owl at a typical vantage point in the study area, photographed in 2011.

Figura 1 - Macho de coruja-das-neves num poiso típico na área de estudo, fotografado em 2011.



nest sites. The Snowy Owl male usually hunts within a couple of hundred m away from his nest site (e.g. Watson 1957). We therefore assume that it was the territorial Snowy Owl males belonging to the nearest nest that used the vantage points that we located. We hypothesize that the males select the highest vantage points around their nests when searching for prey.

Methods

In 2007, we located four Snowy Owl nests in a mountain area in Finnmark County, northern Norway (70°N 24°E). The study area is a barren tundra characterized by small valleys with lakes in the bottom surrounded by hilltops, and the nests were situated in rocky, undulating mountain terrain above the tree line. We located the nests based on information from locals observing Snowy Owls present in the area in May and June 2007, and the first nest was found on 14 June. We carried out fieldwork in the period 9-17 July after the eggs had hatched, and found three more nests by scanning the landscape with binoculars and telescopes in order to spot brooding female Snowy Owls, or males bringing food to the chicks (nest 4).

We collected pellets near nests 2, 3 and 4. All vantage points in the surrounding terrain of the nests where hunting Snowy Owl males had been observed were visited and searched for pellets. Our main goal during this fieldwork was to catch breeding Snowy Owls at these nest sites and equip them with satellite transmitters, and we did so with two females and one male at nest sites 2, 3 and 4 (Solheim et al. 2007, Jacobsen et al. 2008). We observed where males and females preferred to perch when hunting or watching while we were walking in the terrain, and we searched all mounds and rock hilltops where we either had observed Snowy Owls or expected them to have been perching (Fig. 1). We searched each elevated point for pellets, which we collected (Fig. 2). We further recorded the number of pellets at each vantage point, and stored

Figure 2 - Collecting pellets at a vantage point in the study area.

Figura 2 - Recolha de regurgitações num poiso na área de estudo.



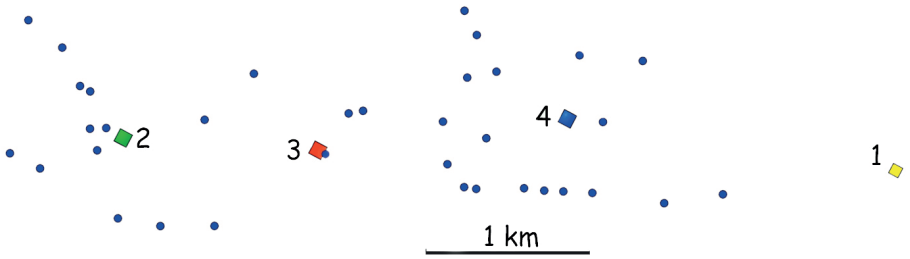
Figure 3 - Snowy Owl pellets collected at a vantage point.

Figura 3 - Regurgitações de coruja-das-neves recolhidas num poiso..



Figure 4 - Nests and vantage points where pellets were collected.

Figura 4 - Ninhos e poisos onde as regurgitações foram recolhidas.



them separately. When we found broken pellets where parts fitted like bits in a jigsaw puzzle, they were counted as one pellet. All pellets were fresh without any mould, algae or indication of older age than that they had been cast during spring and summer 2007.

The size of owl pellets usually reflects the size of the species that produce the pellet (Mikkola 1983). While small owls obviously are not able to produce large pellets, large owls may sometimes produce small pellets. Pellets may also break when they dry up in the terrain, resulting in many small fragments from a single pellet. However, when collecting pellets in the terrain, it is usually possible to see if a pellet has broken into 2-3 separate pieces (see Fig. 3).

The length of Snowy Owl pellets are usually at least 7 cm (and often more than 9 cm) and the thickness is approximately 2-3 cm (Portenko 1972). Snowy Owl pellets are thus only surpassed in size by pellets from Eurasian Eagle Owls (*Bubo bubo*). Pellets from Short-eared Owls (*Asio flammeus*) and Rough-legged Buzzards (*Buteo lagopus*) may be similar in length to small or fragmented pellets from Snowy Owls, but are usually possible to distinguish from the latter species because they are thinner. However, we never encountered Short-Eared Owls or Rough-legged Buzzards in our study area, so we concluded that all collected pellets were cast by Snowy Owls. We were not able to separate pellets cast by male and female Snowy Owls. However, based on observations of males perched at the higher elevation sites during our fieldwork and that females spent almost all their time at the nest during the incubation and early nestling phase, we believe that the males had cast the majority if not all of the pellets collected.

We plotted the vantage points with pellets by using GPS (Garmin), and registered the altitude for each point (Fig. 3). We were not able to assign vantage points to specific nests, since no males at this time were equipped with transmitters. We only observed the male at nest 4 capturing a lemming and bringing the prey to his nest. The pellet data thus represent a pseudoreplication. However, since the four nests were located at almost the same elevation with only 11 m difference between highest and lowest location, and 33 of the 35 vantage points all were located at higher elevations than the highest nest, we believe that the data reflects that all males selected vantage points higher than their nest sites.

Results

The four nests were located almost along a straight line, with 4.7 km between the two most distant nests (Fig. 4, 5). The neighbour distances were 1.2 km (nest 2 and 3), 1.5 km (nest 3 and 4), and 2.0 km (nest 1 and 4). The nests 1-4 were located at 513, 522, 524

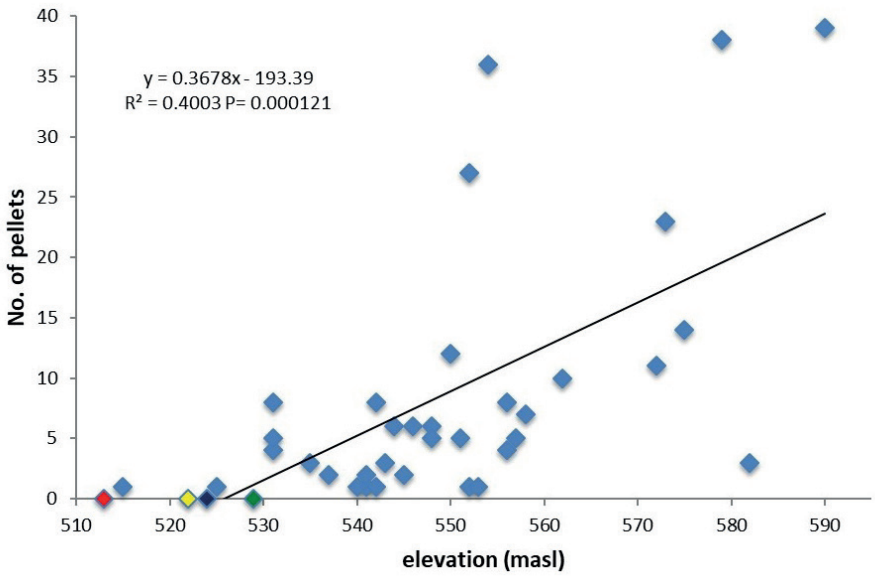
Figure 5 - The central part of the Snowy Owl nesting area in 2007, showing structure of the terrain.

Figura 5 - Relevo da zona central da área de reprodução da coruja-das-neves em 2007.



Figure 6 - Number of pellets found at each vantage point in relation to the elevation of the vantage point above sea. The elevation of the four nest sites are shown by the differently coloured squares. Colours match colours of nest sites in figure 4.

Figura 6 - Número de regurgitações encontradas em cada poiso em relação à altitude do ponto. A altitude dos quatro locais de nidificação é expressa por quadrados com cores diferentes. As cores correspondem aos locais de nidificação na figura 4.



and 520 m asl respectively (mean: 522 m, SD ± 4.1). We collected 309 pellets from 35 vantage points (Fig. 4). The number of pellets found at vantage points ranged from 1 to 39 (mean 8.8 per point, median 6, SD ± 1.8). We collected the pellets at vantage points ranging from 515 to 590 m asl (mean 550.2 m, median 548 m, SD ± 16.3), and all collected pellets were within 1.1 km from nest sites 2-4. The majority of the pellets were located on vantage points at higher altitudes than these nest sites. The number of pellets at each vantage point increased with increasing altitude ($y = 0.36x - 193.39$, $R^2 = 0.40$, $P = 0.000121$; Fig. 6).

Discussion

Although the four nest sites were on top of elevated mounds or rock formations in the terrain, all but two vantage points where we found pellets were situated higher that the nests (Fig. 6). This implies that the males spent most of their time perching higher than their respective nest locations. The correlation between number of pellets and altitude of vantage points indicates that Snowy Owl males prefer to perch as high as possible in the territory when hunting or guarding the nest site. This is in accordance with the description of hunting behaviour of Snowy Owls on Baffin Island in Arctic Canada (Watson 1957). Hunting Snowy Owls can themselves fall prey to raptors like Golden Eagles (*Aquila chrysaethos*), and Gyrfalcons (*Falco rusticolus*). In a survival study of satellite tagged Snowy Owls only three of 28 individuals were confirmed predated by unknown species of raptors (Heggøy et al. 2017). In 2011 one male in our study area had been killed and partly eaten (presumably by a gyrfalcon) when we found his female on the nest (Jacobsen et al. 2011). Perching at the highest vantage points may give the Snowy Owls better possibilities to spot other predators, and thus reduce the risk of the Snowy Owl to be taken by surprise by another raptor.

Few other studies describe the hunting behaviour of Snowy Owls in the breeding period, but on wintering grounds in farmland near Edmonton, Canada, Höhn (1973) studied the choice of hunting perches and the attack distances for wintering Snowy Owls. Hunting Snowy Owls most frequently perched up to 5 m above ground on haystacks and secondly up to 7 m above ground on electricity poles. From these perches, hunting Snowy Owls could detect small mammal prey at distances of up to 160 m in flat farmland habitat. Höhn (1973) found that Snowy Owls did not hunt from the ground. Chamberlin (1980), however, described three hunting methods that were employed by one individual wintering Snowy Owl in Michigan, USA: still-hunting, ground-hunting and coursing. During still-hunting the owl scanned the surrounding area from a commanding perch on (in decreasing order of frequency) utility poles, fence posts and the tops of hillocks. Still-hunting was used most often (92.5%). Ground-hunting (6.8%) involved walking or hopping on the surface and breaking through the snow either with the talons or with the beak. Coursing is a low, search flight over the ground that allows the hunting of a large area with few high perches. Coursing was only registered rarely in winter (0.7% of total hunting time) and was limited to snow-free areas. However, according to Watson (1957), systematic quartering over the ground was a common hunting method of breeding owls in the summer on Baffin Island, Arctic Canada. In our study area, still-hunting would minimize energy expenditure considerably because a large area can be monitored from a single high vantage point. During our fieldwork still-hunting was the only hunting method observed, and we assume that it was overall the most common hunting method among the territorial Snowy Owls in our study area. By perching on the highest vantage points in the territory, the Snowy Owl´s view is considerably enhanced, as perching on the highest tops

often provides a 360 degree view that would otherwise be blocked from the hillsides in the territory. All the nests in the study area were surrounded by hilltops.

In 1993, in a similar habitat in another area in Finnmark, northern Norway, Solheim (2021) measured the distance a hunting Snowy Owl male could detect a moving lure mimicking a vole or a lemming to be at least 1 km distance (Solheim 2021). This is in line with our observation of the hunting Snowy Owl male belonging to nest 2 in our study area in 2007. It started a hunting flight from a high vantage point on one side of the territory, passed the nest site, made two small stops when waiting for a Norway Lemming to make another movement before finally catching its prey on the third flight. We measured the distance on the map to be > 1km. Perching on the most elevated vantage points in the territory may thus increase the area that the male can effectively scan during hunting, increasing his chance of spotting prey. This is in accordance with what Sonerud (1992) found for diurnal hunting Hawk Owls *Surnia ulula*, which also detects prey primarily by eyesight.

Using the most elevated vantage points would also provide the male a better view for spotting potential threats to the nesting female, such as Arctic Fox (*Vulpes lagopus*), Red Fox (*Vulpes vulpes*), Golden Eagles, Gyrfalcons or humans. The use of high vantage points would also increase the male´s view of adjacent territories to monitor neighbouring males´ movements, thus increasing his chances to prevent extra-pair copulations with his own female. We therefore assume that the presence of elevated mounds, rocks or heights around the nest site of Snowy Owls may be an important feature for the Snowy Owls when selecting the breeding territory. Both the male and the female may benefit from choosing such nest sites, however we have no observational data to support how the behaviour of the owls govern the selection process at the start of the breeding season.

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Snowy Owl hunting behaviour and prey spotting distances revealed by vole lures

Uso de chamarizes para avaliar o comportamento de caça e de deteção de presas de coruja-das-neves

Roar Solheim[1*]

1 Natural History Museum, Agder University, P.O. Box 422, N-4604 Kristiansand, Norway

*** Corresponding author:** roar.solheim@uia.no



ABSTRACT

When Snowy Owls (*Bubo scandiacus*) turned up in Finnmark, northern Norway in summer 1993, a vole lure on a line was used to test if the owls would detect, approach and attack the lure in the same way that Great Grey Owls (*Strix nebulosa*) do (Nero 1980). When a Snowy Owl was spotted more than 100 m away the lure was placed on the ground some 5-10 m away from me. When the owl looked towards me, the line was pulled to make the lure move. The reaction of the owl was observed through a telescope, and noted as positive if the owl stretched and bobbed its head or negative if no obvious reaction could be seen. I was sitting on the ground (n=4) or in a car (n=7) when pulling the lure. A total of 11 tests were carried out between 11-15 July, on nine different individuals (six males, two females, one owl not sexed). All males reacted to the lures from distances up to at least 1 km. The two females did not show any detectable reaction to the lures. Two males approached from at least 500 m and more than 100 m distance and attacked the lure, while another approached from at least 350 m distance to ca 100 m away. A male which sat just over 1 km away detected the lure but did not attack. Movement distances (n=29) were noted for eight undisturbed owls hunting natural prey. These owls most often flew 50-200 m between vantage points (mean 158 m, median 100 m). Short flights of 10-40 m were linked to predation attempts, presumably on lemmings or voles.

Keywords: *Bubo scandiacus*, flight distances, prey detection, Snowy Owl, Norway

RESUMO

Quando corujas-das-neves (*Bubo scandiacus*) surgiram em Finnmark, no norte da Noruega, no verão de 1993, foi usado um chamariz puxado por uma linha, simulando um roedor, para testar se a espécie detetaria, abordaria e atacaria a falsa presa da mesma forma que a coruja-cinzenta (*Strix nebulosa*; Nero 1980). Quando uma coruja-das-neves era avistada a mais de 100 m de distância, o chamariz era colocado no chão a cerca de 5-10 m de distância do observador. Quando a coruja olhava na direção do observador, este puxava a linha de forma a mover o chamariz. A reação da coruja foi observada através de um telescópio, e anotada como positiva se a coruja se esticasse e balançasse a cabeça, ou negativa, se nenhuma reação óbvia fosse observada. O observador estava sentado no chão (n=4) ou numa viatura (n=7) ao puxar o chamariz. No total, foram efetuados 11 testes entre os dias 11 e 15 de julho, em nove indivíduos diferentes (seis machos, duas fêmeas, e um não sexado). Todos os machos reagiram aos chamarizes até distâncias de pelo menos 1 km. As duas fêmeas não apresentaram nenhuma reação detetável. Dois machos aproximaram-se a partir de cerca de 500 m e 100 m de distância, tendo atacado o isco, enquanto outro se aproximou de uma distância de pelo menos 350 m, tendo mantido uma distância ao chamariz de cerca de 100 m. Um macho que estava a pouco mais de 1 km detetou o chamariz, mas não atacou. Foram registadas as distâncias de movimento (n=29) de oito corujas não perturbadas que caçavam presas reais. Estas corujas, na maioria das vezes, voaram 50-200 m entre poisos elevados (média: 158 m, mediana: 100 m). Voos curtos de 10-40 m foram associados a tentativas de predação, presumivelmente de lemingues ou roedores.

Palavras-chave: *Bubo scandiacus,* coruja-das-neves, deteção de presas, distâncias de voo, Noruega

Introduction

Based on success with radio-tracked Boreal Owl (*Aegolius funereus*) and Ural Owls (*Strix uralensis*) (Sonerud et al. 1986, Solheim et al. 2021) I became interested in learning how to capture and radio-tracking Snowy Owls (*Bubo scandiacus*). While mist nets are used efficiently to capture Eurasian Pygmy-owls (*Glaucidium passerinum*), Boreal Owls, Northern Hawk-owls (*Surnia ulula*) and Ural Owls for banding purposes it was not obvious that they would be efficient for catching Snowy Owls. Based on Nero´s (1980) method of using a vole-like lure and a fishing rod to capture Great Grey Owls (*Strix nebulosa*), and success with this method in Norway for capturing Northern Hawk-owls (unpubl. data), I wanted to test if Snowy Owls would react, approach and attack them. In 1981 the late Norwegian nature filmmaker Hans Vide Bang (pers. comm.) observed a hunting male Snowy Owl in Abisko, Sweden. Vide Bang noted that the lemming population had crashed after the chicks had hatched, and observed the male owl start to hunt alternative prey such as waders and other wetland birds. He observed the male owl fly 600 m in a straight line to capture a Redshank (*Tringa totanus*) chick. This observation also inspired me to test the reactions of hunting Snowy Owls to a lure.

Figure 1 - Location on the Nordkynn peninsula (white circle), in Northern Norway, where an irruption of Snowy Owls was observed 11-15 July 1993.

Figura 1 - Localização na península de Nordkynn (círculo branco), no norte da Noruega, onde foi detetado um boom de corujas-das-neves em 11-15 de julho de 1993.



Figure 2 - Landscape along the main road across the Nordkynn peninsula, Norway, where Snowy Owls were observed hunting.

Figura 2 - Paisagem ao longo da estrada principal que cruza a península de Nordkinn, Noruega, onde foram efetuadas as observações do comportamento de caça de coruja-das-neves.



Figure 3 - Snowy Owls usually sit with their head held low, even while turning their head from side to side when scanning the landscape (left image). When an owl spots potential prey, it raises its head (right image), and bobs its head from side to side before taking flight to attack it.

Figura 3 - A coruja-das-neves normalmente permanece imóvel com a cabeça baixa, mesmo enquanto vira a cabeça de um lado para o outro para observar a paisagem (imagem da esquerda). Quando uma coruja avista uma presa potencial, levanta a cabeça (imagem da direita), e agita-a de um lado para o outro antes de iniciar o voo para atacar.



Methods

In July 1993 an invasion of Snowy Owls occurred on the Nordkynn peninsula in Finnmark, northern Norway (Fig. 1), with at least 16 individuals regularly hunting along the main road across the peninsula. The landscape was tundra-like and undulating with bare rocks, vegetation and water, but no trees or shrubs (Fig. 2). Distant Owls were sometimes approached so they could be watched through a telescope. Owls perched 100 m or closer from the road were usually watched from the car to prevent disturbing the birds. The owls were usually watched for 2-3 hours before their reaction to the lure was tested. When the owls were observed hunting, time of movement was noted, and the distance moved was estimated from the point of observation.

A *Microtus* vole-like lure was made with a wooden core with a steel clip at one end to attach the string. The core was wrapped with soft material and covered with dark brown artificial fleece fur. A short leather string was attached giving the lure a short tail.

Owls were sexed based on visual observations of plumage (Josephson 1980, and various contemporary bird guides). An owl´s reaction to the lure was tested by placing it either on snow or ice some meters away from the observer only when the owl was looking away from the observer. When owls were sitting far away, their reaction was watched through a Mirador telescope. The lure was pulled towards the observer when the owl was looking in the direction of the lure. A Snowy Owl usually perches on the ground with its head low between the shoulders, even when turning the head around to search for prey. When the owl sees movement, it usually stretches its head up, and bobs the head from side to side, clearly demonstrating that something has caught the birds´ attention (Portenko 1972, Höhn 1973, Fig. 3). It was thus easy to judge whether the movement of the lure caught the owl´s attention or not. If the owl took off and approached, the reaction was noted as a capture attempt.

Table 1 - Response to a vole-like lure by Snowy Owls.
* Test failed halfway, ** Lure caught by Rough-legged Buzzard, *** Undetermined reaction, [1] Same male.

Tabela 1 - Resposta da coruja-das-neves ao chamariz simulando um roedor.

DATE	SUBSTRATE	DISTANCE TO OWL (m)	SEX	RESPONSE TO LURE	
				Detected	Attacked
11 July	Snow	>500	M	+	+
12 July	Snow	>100	M	+	-
	Snow	>100	M	+	+
13 July	Snow	250-300	M	+	-
14 July	Snow	350		+	+/-*
	Veg.	>100	M	+	**
	Veg.	>450	M[1]	+	-
	Veg.	>450	M[1]	+	-
	Veg.	1000-1100	M[1]	+	-
15 July	Veg.	>100	F	-	-
	Snow	>100	F	+***	-

Figure 4 - A male Snowy Owl attacking the vole-like lure on snow covered ground 10-15 m away from the observer.

Figura 4 - Um macho de coruja-das-neves a atacar um chamariz simulando um roedor no solo coberto de neve a 10-15 m de distância do observador.



Table 2 - Distances (m) moved by hunting male Snowy Owls in July 1993.
*Behaviour after flight judged as hunting attempt, **Moved between two poles, ***Owl searching for Eurasian Golden Plover (*Pluvialis apricaria*) chicks.

Tabela 2 - Distâncias (m) percorridas por machos de coruja-das-neves a caçar em julho de 1993.

DATE	ESTIMATED DISTANCES MOVED BETWEEN PERCHES						
11 July	75	100	200	50-75	50-75		
12 July	100	150	150	50-75	200		
	50	150-175	100	250	15*	100	10*
13 July	100	1000					
	4**	200	>200				
	200	30-40*					
14 July	150	250	>500				
16 July	10***	75					

Results

Eleven trials were performed with the lure placed either on snow-covered (n=6) or on bare vegetation (n=5, Table 1). Eight trials were on males, two on females and one on an unsexed owl. In ten of 11 trials the owl clearly saw and reacted to the movement of the vole lure by stretching and bobbing its head (Table 1). In two instances the owl flew and attacked the lure. A third attack was terminated when the line came loose and the lure ceased to move. In one trial done from the car, a male Snowy Owl showed interest in the lure but a Rough-legged Buzzard (*Buteo lagopus*) flew in to grab the lure before the owl could take off.

One male owl was tested three times, and reacted positively with head-bobbing all times, although it did not approach; one trial was at a distance >1 km (Table 1). The first male tested on 11 July came in from >500 m away to grab the lure on a snow patch just a few meters away from me (Fig. 4).

On 29 occasions, an undisturbed (by me) owl was watched flying between vantage points hunting for prey. Most owls moved 50 to 200 m between hunting perches (mean 158 m, median 100 m, Table 2). Only when directly chasing prey or moving between two wooden poles did an owl move shorter distances.

Discussion

Much has been written on the diet of Snowy Owls (Portenko 1972, Potapov and Sale 2012), and on the eyes of the birds (Potapov and Sale 2012), however none of these authors described the distance at which Snowy Owls are able to detect prey. Cramp (1985) mentions an observation made by M. Robinson from Shetland where a Snowy Owl flew ca 700 m from a vantage point to attack a prey. Höhn (1973) observed four different Snowy Owls hunting on farmland in Alberta, between 21 January and 24 March 1973, over a total of 11 hrs 28 min. The average waiting time for an owl before moving to a new vantage point was 22 min.,

although sometimes an owl would sit for up to 1 hr before moving. On 12 occasions an owl moved 27 to 160 m from a perch to a strike attempt on a prey (mean 90 m). This is shorter than the mean distance which owls moved between two vantage points in this study. However, Höhn did not note the distance moved between perches when the owl did not make any strikes at prey.

One male Snowy Owl in this study spotted the lure from >1 km; further than hitherto reported. Dan Zazelenchuk and Marten Stoffel (pers. comm.) indicated that Snowy Owls in open prairie landscapes in Saskatchewan, Canada, detect and attack caged (for owl banding purposes) hamsters (Cricetinae) > 500 m away. They also report Snowy Owls able to detect moving mice and voles as far as 2 km. Snowy Owls wintering in this landscape are ideal for performing future field tests of the owls´ detection distances.

In this study Snowy Owls moved on average 158 m which was far less than the observed maximum prey or lure detection distance (>1 km). The study area terrain was undulating with numerous small mounds and rocks that could hide many voles from ground perched hunting owls. Therefore the shorter distances between hunting perches observed in this study were probably required for the owls to hunt voles and lemmings in this terrain effectively.

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The quality of protein sources for egg production in Tawny Owls (*Strix aluco*) and Eurasian Sparrowhawks (*Accipiter nisus*)

A qualidade das fontes de proteína para a produção de ovos em coruja-do-mato (*Strix aluco*) e gavião (*Accipiter nisus*)

Arnold Van den Burg [1,2*]

1 Biosphere Science Foundation, Onderlangs 17, 6731BK Otterlo, The Netherlands

2 Department of Environmental Science, Radboud University Nijmegen, the Netherlands

*** Corresponding author:** bsp@upcmail.nl



ABSTRACT

The Netherlands is second after the USA in the export of agricultural and dairy products, which comes at a high price for the Dutch environment and biodiversity. In order to document the effects of nitrogen deposition and soil acidification therefrom on forest fauna, we study several bird species – e.g. Great Tit (*Parus major*), Eurasian Sparrowhawk (*Accipiter nisus*), Tawny Owl (*Strix aluco*) – on the Veluwe, a large forested area in the Netherlands. Effects of forest degradation include large-scale tree mortality of common oak (*Quercus robur*), lowered protein synthesis in trees, shifts in the composition of free amino-acids in trees, severe calcium deficiency in Great Tits, and amino-acid deficiencies in reproducing Eurasian Sparrowhawks. Raptor species have strongly declined, but, surprisingly, Tawny Owls have not. We hypothesized that this was due to amino-acid producing cecal bacteria present in (Tawny) owls, which lack in diurnal birds of prey. In contrast, Eurasian Sparrowhawks break down breast muscle tissue to

complement dietary amino-acid deficiencies. I compared amino-acid compositions of owl eggs, Wood Mice (*Apodemus sylvaticus*), owl cecal sacs, owl breast muscles, and Eurasian Sparrowhawk eggs and breast muscles to determine whether protein amino-acid composition varies with protein source, and to compare egg amino-acid requirements between Eurasian Sparrowhawks and Tawny Owls. Amino-acid measurements were done commercially by a certified food-quality research facility (TNO). Results show that wood mice and breast muscle tissue of both bird species were short in several essential amino-acids, up to -56% for cysteine, compared to egg requirements. The amino acid content of the cecal sacs was also low in cysteine but only -16%. In addition, cecal sac amino acids are renewed continuously, whereas breast muscle protein is a limited source of amino-acids. As Eurasian Sparrowhawks lack cecal sacs, they are more vulnerable to dietary amino acid-shortages in degenerated forests than Tawny Owls.

Keywords: *Accipiter nisus*, amino-acids, egg production, protein source, *Strix aluco*

RESUMO

A Holanda ocupa o segundo lugar, após os EUA, na exportação de produtos agrícolas e laticínios, o que tem consequências para o ambiente e a biodiversidade holandeses. A fim de documentar os efeitos da deposição de azoto e da acidificação do solo na fauna florestal, estudámos várias espécies de aves – por exemplo, chapim-real (*Parus major*), gavião (*Accipiter nisus*), coruja-do-mato (*Strix aluco*) – em Veluwe, uma grande área florestal na Holanda. Os efeitos da degradação florestal incluem mortalidade em larga escala de carvalho comum (*Quercus robur*), baixa síntese proteica em árvores, mudanças na composição de aminoácidos livres em árvores, deficiência severa de cálcio em chapim-real e deficiências de aminoácidos em gavião durante a reprodução. As espécies de aves de rapina apresentaram grandes declínios, mas, surpreendentemente, a coruja-do-mato não. A nossa hipótese defende que essa resistência se deve a bactérias cecais produtoras de aminoácidos presentes na coruja-do-mato, que não ocorrem em aves de rapina diurnas. Por outro lado, o gavião consome músculo peitoral para complementar as deficiências dietéticas de aminoácidos. Neste estudo comparei a composição em aminoácidos dos ovos de coruja, no rato-do-campo (*Apodemus sylvaticus*), em cecos de coruja, e em músculo peitoral e ovos de gavião, para determinar se a composição em aminoácidos varia com a fonte de proteína e comparar os requisitos de aminoácidos do ovo entre o gavião e a coruja-do-mato. As medições de aminoácidos foram efetuadas por um laboratório certificado de análise da qualidade alimentar (TNO). Os resultados mostram que os ratos e músculo peitoral de ambas as espécies de aves apresentavam quantidades reduzidas de vários aminoácidos essenciais, até -56% para cisteína, em comparação com as exigências dos ovos. O conteúdo em aminoácidos dos cecos também apresentava reduzida cisteína, mas apenas -16%. Adicionalmente, os aminoácidos dos cecos são renovados continuamente, enquanto a proteína do músculo peitoral constitui uma fonte limitada de aminoácidos. Como os gaviões não possuem cecos, são mais vulneráveis à falta de aminoácidos na dieta em florestas degeneradas do que as corujas-do-mato.

Palavras-chave: *: Accipiter nisus,* aminoácidos, fonte de proteína, produção de ovos, *Strix aluco*

Introduction

Studying nature in the Netherlands cannot be done without taking into account possible effects of high nitrogen deposition levels. In my study area on the Southwest-Veluwe nitrogen deposition mounts up to 4500 mol per hectare per year (data RIVM[1]). According to the World Trade Organisation (WTO, on the website of the Dutch Central Bureau of Statistics[2]) the Netherlands is the second-largest exporter of agricultural products in the world after the USA, and followed by Germany, Brazil, and France (in declining order). As the Netherlands only comprises 0,4% of the land surface area of the USA and 11.6% of Germany, the magnitude and efficiency of its agricultural sector are astonishing. Regrettably this economic 'success' comes at a high price for the quality of the Dutch environment and biodiversity. According to PBL (a Dutch governmental agency for the environment) 2014, the Netherlands has lost 85% of its biodiversity during the last century[3]. This is mainly caused by (semi-) natural habitats being converted into intensive farmlands which are extremely poor in biodiversity (e.g. only 3% of plant species-rich grasslands is remaining[4]). Additionally, the Dutch agricultural system makes ample use of neonicotinoids (Hallmann et al. 2014), glyphosate, and many other pesticides (e.g. Toumi et al. 2016).

The use of artificial fertilizer and the import of cattle feed from abroad (like soy-protein from tropical South America) represents a flow of nitrogen flow towards the Netherlands, which is only partially compensated by the export of meat and dairy products. Ammonia evaporating from fields and stables reacts in the air to ammonium, which is not only deposited in close proximity of intensive cattle farms, but nation-wide. In nature areas on dry sandy soils, this causes soil acidification (De Vries et al. 2017), low soil mineral and plant nutrient levels (Bergsma et al. 2016, Van den Burg 2017a), and excessive nitrogen availability. Mineral nutrient deficiencies in degraded forest ecosystems also affect fauna, as they cause, among others, poor egg shell formation and broken bones in nestling songbirds, such as Great Tits (*Parus major*; Van den Burg 2017[a]). The combination of low mineral availability and excessive nitrogen results in a cascade of changes in forest and heathland ecosystems and a further loss of biodiversity (Van den Burg & Vogels 2017). Currently, forests of Common Oak (*Quercus robur*) are dying at a large scale and soil acidification and excess nitrogen availability have also been implicated in causing this process (Lucassen et al. 2014[a,b]). This forest decay equals the local destruction of the entire oak forest ecosystem. Regrettably, nitrogen deposition is not only a problem of the Netherlands, but as wide-spread as intensive livestock farming (Duce et al. 2008).

Another route of detrimental effects of nitrogen deposition on biodiversity is through altered plant physiology (Van den Burg & Vogels 2017). In plants which are not nitrogen but mineral nutrient (e.g. K, Mn, or Ca) limited, amino-acid and protein production are reduced. Also, the composition of free amino acids is shifted towards types that contain more than a single nitrogen atom, such as arginine – studied in Scots Pine (*Pinus sylvestris*; Perez-Soba 1995). The overall reduction of amino-acids is propelled up the food chain, affecting the reproduction of raptors such as Eurasian Sparrowhawks (*Accipiter nisus,* Siepel et al. 2009).

To compensate shortages of particular amino-acids due to feeding on poor quality protein, birds can metabolize their breast muscles (especially the greater flight muscles, *pectoralis major*) to enable egg production (Houston et al 1995, Selman & Houston 1996). Birds adopt this strategy if the amino acid make-up of the diet does not match the

requirements for egg production, but not to compensate a general deficiency of protein, i.e. food shortage. Of special importance in this respect are the so-called essential amino-acids, that the avian body cannot synthesize itself, but must be derived from dietary intake, or, as explained below, from bacterial sources.

We demonstrated the use of breast muscle by Eurasian Sparrowhawks in order to produce eggs, next to other indicators of amino-acid shortages in this species (Van den Burg 2009). Also, Eurasian Sparrowhawks (and other bird of prey species) have strongly declined in forest habitats during the nineteen nineties where they used to be abundant (Van den Burg 2009). This coincided with the peak-period of nitrogen deposition. In contrast, Tawny Owl populations have remained stable over time, and I hypothesized that this may be due to physiological differences between diurnal raptors and owls (Van den Burg 2009). Owls have large intestinal blind sacs (ceca) which lack in Eurasian Sparrowhawks. In owls, the ceca are used to recycle uric acid, as bacteria within utilize the nitrogen from uric acid to synthesize their own amino-acids and proteins (Denbow 2000). Uric acid is excreted as waste material by the kidney, but is transported anti-peristaltically from the cloaca to the ceca (Clench & Mathias 1995). Owls harvest amino-acids from the ceca by excreting proteases and absorbing the free amino-acids from digested bacterial protein. If the amino-acid supply from the ceca complements dietary intake, this may explain why owls are not amino-acid limited for egg production whereas birds of prey living in the same forest are. As such, this may also explain why both bird groups differ in population trend despite their similar diets, consisting mainly of small mammals and birds.

For this paper, I compared amino-acid compositions of Tawny Owl eggs, breast muscles, cecal sacs, Wood Mice (*Apodemus sylvaticus*), and Eurasian Sparrowhawk eggs and breast muscles to determine whether protein amino-acid composition varies with protein source, and to compare egg amino-acid requirements between Eurasian Sparrowhawks and Tawny Owls.

Material and methods

Sample origins and handling

Tawny Owl and Eurasian Sparrowhawk carcasses (N=3 for each species) were road casualties provided by members of the Dutch public, mostly in winter and spring. Carcasses came from the central and eastern parts of the Netherlands. Fresh Tawny Owl eggs (N=3) were from nests in the Gelderse Vallei region, that had been deserted in extreme cold weather and got frozen in the breeding cavity (or nest box). Land use in this area is predominantly intensive agriculture, interspersed with small patches of old woodland. Dead woodmice (N=3) were collected from Tawny Owl nest boxes on the South-west-Veluwe, a forested area centrally in the Netherlands. Stored prey items in the late egg and early chick stage were removed from the nest and replaced by day-old poultry chicks. Three specimens were randomly selected for amino acid analyses. Eurasian Sparrowhawk eggs (N=30) were collected fresh during the egg-laying period from nests on the South-west-Veluwe for an earlier study into environmental impacts on egg quality in this species (e.g. Van den Burg 2006). All samples originated from the time period 2002-2009.

Samples were stored at -20 ^{0}C before further sample preparation. Egg samples were homogenized prior to amino-acid analysis. Breast muscles (*pectoralis major*) were dissected from adult owl and hawk carcasses. In owls, the intestine was spread out to reveal the cecal sacs. These were dissected from the intestine and emptied by gently pressing. Soft tissues from dead mice were stripped from the bone, and offered for amino acid analyses. Also the fur was excluded, as most of

the hairy material is regurgitated into pellets. Amino-acid measurements were done commercially by a certified food-quality research facility (TNO). The methodology used included acid digestion of all protein. To reduce costs, only a selection of amino-acids was determined (Glycine (Gly), Alanine (Ala), Glutamic acid (Glu), Aspartic acid (Asp), Lysine (Lys), Arginine (Arg), Methionine (Met), Isoleucine (Iso), Leucine (Leu), Cysteine (Cys), Threonine (Thr), Valine (Val), Serine (Ser), Tryptophan (Trp). The choice for this selection was based upon the inclusion of the Sulphur-containing amino-acids (Met, Cys). As these are also crucial in feather-formation, birds have a relatively high need for these compounds. Trp was measured separately, as acid digestion of protein destroys this amino acid. As it is one of the rarest essential amino acids and crucial in energy metabolism (also as precursor of Niacin, vitamin B3), I opted to include this amino acid in the analyses.

Statistics

All amino-acids measurements were analyzed using relative data, i.e. only focusing on the protein make up and not concentration. Clearly, protein concentration in solid tissues (muscle) is higher than watery samples such as eggs and cecal content. A Principal Component Analysis (PCA) was performed in Genstat to see variance and similarity among samples. Using the same data I also studied the balance of each source of amino-acids relative to the amino-acid levels found in the eggs of both species. This method gives better insight into the magnitude of amino-acid limitations for egg production. For each amino-acid I determined the amount (in gram) per 100 gram egg protein and each protein source. From this I calculated for each amino-acid the amount of source-protein required to produce 100 gram egg protein. So, for example, if it takes 200 gram breast muscle protein to free enough Cys to produce 100 gram egg protein, breast muscle protein has a -50% Cys unbalance compared to egg production requirements.

Results

PCA yielded clear separation of protein amino acid content of most sample types (Fig. 1; explained variance x-axis 80.4%,y-axis 12.5%). Muscle tissues were similar in amino-acid composition in both species. As the mouse samples comprised a greater variety of tissue types, it is not surprising to find them slightly different in composition (variation on the y-axis only) from the birds muscle proteins. The egg samples had a completely different composition, and also differed between Tawny Owls and Eurasian Sparrowhawks. The latter could be expected, as egg proteins have in the past been used to clarify avian phylogeny (Sibley 1960). Eggs were particularly rich in Ser (Fig. 2), but this is of minor importance in terms of food quality, as Ser can be synthesized by the birds themselves. Of the essential amino-acids, Thr, Val, Cys, and Leu have higher levels in eggs compared to food (mouse) and muscle protein sources. The amino-acid composition of the cecal sacs content was different from both egg and tissue samples, most likely due to its bacterial origin. The cecal sacs were intermediate on the x-axis between tissue samples and egg samples.

Of the amino-acids that are in short supply for egg production in animal tissue samples, Cys was the most limiting (Eurasian Sparrowhawk, Fig 3; Tawny Owl, Fig. 4). As the relative Cys availability in muscle and mouse protein is about 50% lower than required for egg production, meat consumption (either from food or body reserves) to make a single egg should be twice the amount of total egg protein content (e.g. 40 grams meat protein is required to produce 20 grams of egg protein). Cys is in fact semi-essential as it can also be produced by birds from Met, but not from other amino-acids, because only Met and Cys

Figure 1 - Clustering of avian samples and mice with respect to their amino-acid composition after principal component analysis (PCA) (explained variance x-axis 80.4%,y-axis 12.5%). Muscle tissue of both bird species clusters together, and, on the x-axis, ground mice is also very similar in amino acid composition. Quite opposite on the x-axis (right hand side) is the amino-acid composition required for egg production, i.e. tissue samples clearly differ from eggs. Intermediate are the cecal proteins, which are for a great extent of bacterial origin and show most variation along the y-axis.

Figura 1 - Agrupamento das amostras de aves e de mamíferos, relativamente à composição em aminoácidos, em análise de componentes principais (PCA) (variância explicada: eixo horizontal 80,4%, eixo vertical 12,5%). O tecido muscular das aves surge agrupado e, no eixo horizontal, a composição em aminoácidos do rato é também muito semelhante. Em oposição, a composição em aminoácidos necessária para a produção de ovos surge no lado direito do eixo horizontal, i.e. as amostras de tecido muscular diferem claramente das amostras de ovo. As proteínas presentes nos cecos ocupam uma posição intermédia, sendo maioritariamente de origem bacteriana e apresentando a maior variação ao longo do eixo vertical

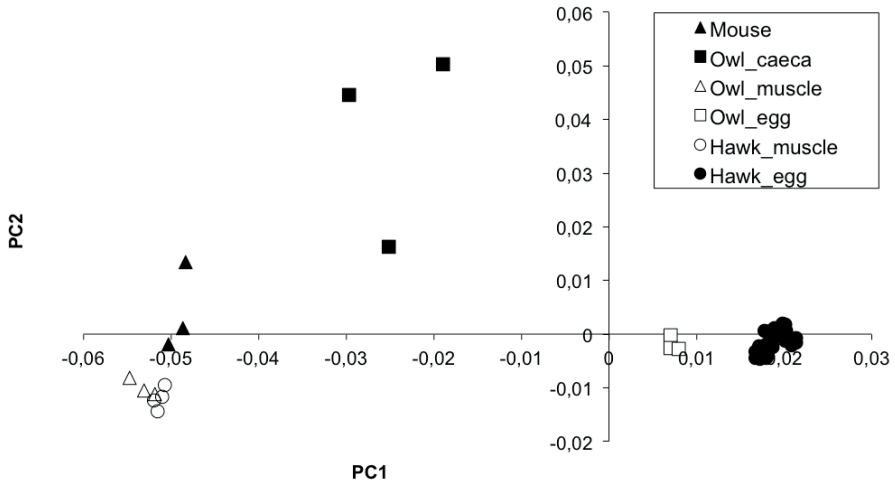


Figure 2 - End-points of vector loadings after principal component analysis (PCA) on the amino-acid composition of animal samples (samples and axes identical to Fig. 1). Essential amino-acids which cannot be synthesized by birds are indicated separately. Eggs are particularly rich in Ser, but of the amino-acids that are food-derived Thr, Val, Cys and Leu have higher levels in eggs compared to other animal samples.

Figura 2 - Terminação dos vetores dos "loadings" da análise de componentes principais (PCA) relativamente à composição de aminoácidos de amostras de animais (amostras e eixos idênticos à Fig. 1). Os aminoácidos essenciais que não são sintetizados pelas aves são indicados separadamente. Os ovos são particularmente ricos em Ser mas, dos aminoácidos derivados de alimentos, a Thr, a Val, a Cys e a Leu apresentam níveis mais elevados nos ovos, em comparação com outras amostras de animais.

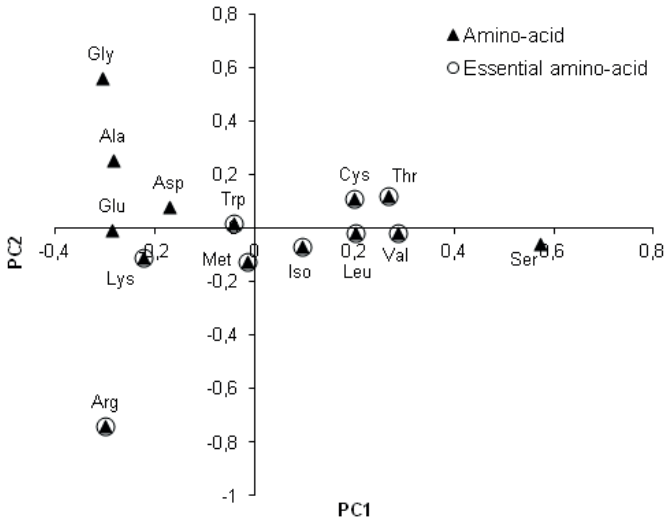


Figure 3 - Average surpluses and deficiencies of amino-acids of animal samples relative to what is required for egg production (zero on the y-axis depicts the average amino-acid level inside an egg) in Eurasian Sparrowhawks. In both food and the hen's breast muscle, Cys is the amino that is most limited for egg production; for example a Eurasian Sparrowhawk should consume about 40 gram of breast muscle or mouse protein to free sufficient Cys to produce 20 gram of egg protein.

Figura 3 - Valores médios dos excedentes e das deficiências de aminoácidos em amostras de animais, relativamente às quantidades necessárias para a produção de ovos em gavião (zero no eixo vertical representa o nível médio de aminoácidos dentro de um ovo). Tanto no alimento quanto no músculo peitoral da galinha, a Cys é o aminoácido mais limitante para a produção de ovos; por exemplo, um gavião deve consumir cerca de 40 gramas de músculo peitoral ou proteína do rato para libertar Cys suficiente para produzir 20 gramas de proteína do ovo.

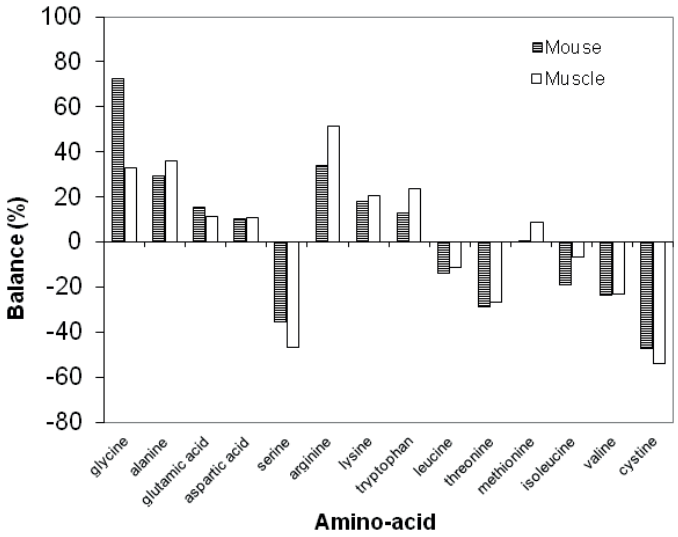
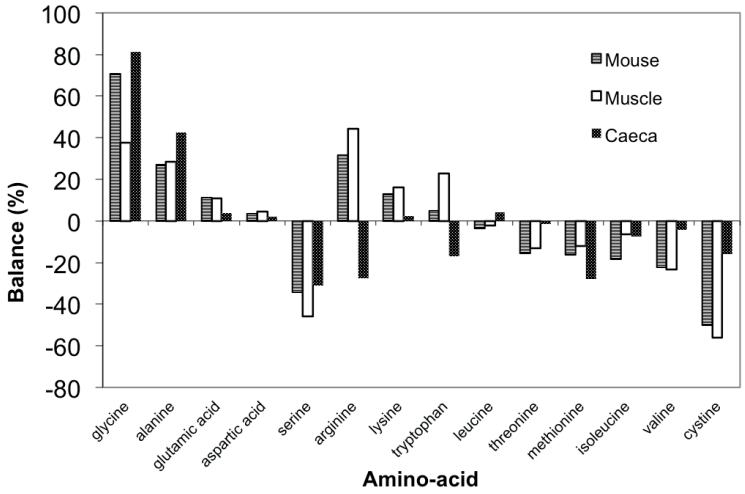


Figure 4 - Average surpluses and deficiencies of amino-acids of animal samples relative to what is required for egg production (zero on the y-axis depicts the average amino acid level inside an egg) in Tawny Owls. In both food and the hen's breast muscle, Cys is the amino that is most limited for egg production; for example a Tawny Owl should consume about 42 gram of breast muscle or mouse protein to free sufficient Cys to produce 20 gram of egg protein. However, it requires only 24 grams of cecal protein for 20 grams egg protein.

Figura 4 - Valores médios dos excedentes e das deficiências de aminoácidos em amostras de animais, relativamente à quantidade necessária para a produção de ovos em coruja-do-mato (zero no eixo vertical representa o nível médio de aminoácidos dentro de um ovo). Tanto no alimento quanto no músculo peitoral da galinha, a Cys é o aminoácido mais limitante para a produção de ovos; por exemplo, uma coruja deve consumir cerca de 42 gramas de músculo peitoral ou proteína do rato para libertar Cys suficiente para produzir 20 gramas de proteína do ovo. No entanto, requer apenas 24 gramas de proteína dos cecos para 20 gramas de proteína do ovo.



contain Sulphur-groups. As Met is also in too short supply, this transition would not ease the amino-acid limitation: a reduction in the deficiency of one amino-acid would increase the deficiency of another. As Tawny owls have cecal sacs, they carry another protein source, which is much better for Cys. It only requires 24 grams of cecal protein to synthesize 20 grams egg protein. Cecal sac protein was, however, short in Arg and to a lesser extent Trp.

Discussion

Egg proteins serve very different functions than proteins in animal tissues, as many egg proteins are involved in making eggs resistant to bacterial invasion, and only some (especially vitellogenin) have the prime function of supplying the young embryo the amino-acids it needs to grow (e.g. Van den Burg 2017[b]). Hence the amino-acid build-up of egg protein is much different from animal tissues, and it is the natural condition that some amino acids are relatively short in the diet. So to produce a single egg, birds need to consume more protein than the total protein content of that egg, as to compensate for the rarer amino acids in the diet compared to egg requirements. Due to nitrogen deposition, lowered plant protein production therefrom, and shifts in amino acid content, such as excess Arg in free plant amino-acids (Perez-Soba, 1995),the chances of particular amino-acids shortages in birds may increase, making it more difficult to produce eggs. We observed Eurasian Sparrowhawks to increase the use of their breast muscles to facilitate egg production, but not owls (Van den Burg 2009).

The present data indicate that owls may benefit from cecal sac proteins during egg formation, as the cecal sacs provide some amino-acids proportionally better compared to prey or muscle proteins. So, adverse effects of nitrogen deposition that result in lowered amino-acid availability can be, at least in part, mitigated by bacterial proteins from the cecal sacs. The magnitude at which egg amino-acids in owls are indeed derived from cecal sacs is thus far unknown. However, as these amino acids enter the blood stream similarly as dietary amino acids, it is unlikely that they will be treated differently during egg production. Therefore, it is likely that amino acids from the ceca are indeed used to build proteins for the purpose of egg formation.

The ceca are small compared to egg volume in Tawny Owls, so to be of significance during egg production, the rate of transport of uric acid to the ceca and amino-acid absorption therefrom should be large enough to keep up with egg laying. Regrettably the magnitude of the uric acid and amino-acid fluxes into and from the ceca, appear unknown. Interestingly, whereas Barn Owls invest less lipid into their eggs compared to Eurasian Sparrowhawk eggs of the same size, they allocate more protein for egg production (Van den Burg 2002). Perhaps, this is a reflection of cecal bacteria activity in the owls, which lacks in Eurasian Sparrowhawks.

It is highly unlikely that the cecal sacs in meat-eaters originated (or did not regress) during evolution in order to cope with adverse dietary amino-acid compositions. The current situation regarding nitrogen deposition has never occurred before in history, so adaptive behavior or physiology could not have developed in the past. Instead, the ceca have most likely evolved or been maintained in owls as a source of energy, in which case the amino-acids are used as fuel.

As the ceca themselves also provide proteins that are short in some amino-acids for egg production, dietary protein intake is still important to obtain a suitable mixture of essential amino acids for egg production. Surely, without dietary amino-acid intake no eggs would be produced in neither of the studied species. In poor food years there may be a trade-off in the use of cecal sac protein between egg quality and energy availability

for egg production. As a result of deteriorated dietary amino-acid composition, owls may, more frequently compared to several decades ago, be forced not to lay at all in poor food years. As such an effect will be very difficult to discriminate from general food shortage, it will most likely go unnoticed to human observers.

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Male Little Owl (*Athene noctua*) attempting brood care after loss of nesting female

Mocho-galego (*Athene noctua*) macho tenta cuidar da ninhada após desaparecimento da fêmea

Ronald van Harxen[1*], Pascal Stroeken[2]

1 STONE, Scholtenenk 47, 7101 SJ Winterswijk, The Netherlands

2 STONE, De Kistemaker 12, 1852 GW Heiloo, The Netherlands

*** Corresponding author:** r.vharxen@gmail.com



ABSTRACT

In 2017 a Little Owl (*Athene noctua*) breeding pair was observed through webcams within the framework of Beleef de Lente by Birdlife International partner Vogelbescherming Nederland. The monitored nestbox is located in a 6 m high 100 year old pear tree in Winterswijk (The Netherlands). Within less than four days - from 22 May 03:08 until 26 May 1:34 - an attack by a Stone Marten (*Martes foina*) occurred, the female disappears, the male attempts brood care, the nestlings die and are removed from the nest box by the male and a new female arrives. This paper describes the remarkable behavior of the male attempting brood care. This behavior has never been documented before in Little Owls, nor in any other owl species. Our results confirm webcam observations and monitoring by citizen scientists as a new and promising research method revealing new insights into owl behavior.

Keywords: *Athene noctua*, citizen science, male brood care, nest box, webcam

RESUMO

Em 2017 um casal reprodutor de mocho-galego (*Athene noctua*) foi observado através de câmaras na rede de Beleef de Lente pelo parceiro da BirdLife International Vogelbescherming Nederland. A caixa-ninho monitorizada está localizada a uma altura de 6 m numa pereira com 100 anos em Winterswijk (Holanda). Em menos de quatro dias – entre as 03h08 do dia 22 de maio e a 1h34 do dia 26 de maio – ocorreu um ataque de fuinha (*Martes foina*), a fêmea desapareceu, o macho tentou cuidar da ninhada, os juvenis morreram e foram removidos da caixa-ninho pelo macho, e chegou uma nova fêmea. Este artigo descreve o comportamento do macho na tentativa de criar a ninhada sozinho. Este comportamento nunca foi descrito antes em mocho-galego, nem em nenhuma outra espécie de rapina noturna. Os nossos resultados confirmam a observação através de câmaras e a monitorização por cientistas cidadãos como um novo e promissor método de investigação, proporcionando uma nova perceção do comportamento das rapinas notunas.

Palavras-chave: : *Athene noctua,* câmara web, caixa-ninho, ciência cidadã, cuidado da ninhada pelo macho

Introduction

Just like the other European owls (Mikkola 1983, Mebs & Scherzinger 2007) and other owls with known brood care (König & Weick 2008, Del Hoyo 2015), Little Owls (*Athene noctua*) have a strict allocation of tasks during the breeding period (Schönn et al. 1991, Van Nieuwenhuyse et al. 2008). Only the female incubates and during the first part of the nestling period she stays most of the time in the nest to provide the chicks with her body warmth and food. Her contribution to the prey supply is rather limited in this period (Van Harxen & Stroeken 2011). Males are responsible for prey supply, both in the incubation and nestlings period (Schönn et al. 1986, Van Nieuwenhuyse et al. 2007). When the male enters the nest box he hands over the prey to the female. She feeds the nestlings. If the male gets lost in the first half of the nestling period, in most cases the brood will fail, because the female has to spend most of her time keeping the nestlings warm and feeding them. She cannot spend much time hunting at the same time. However, also the disappearance of the female in this period means that the nest is doomed to fail. Although the male keeps delivering prey items to the nest, he is not capable of fragmenting the prey (Schönn et al. 1991). In most cases the outside temperature is too low to keep the body temperature of the chicks high enough without the continuous body warmth of an adult (thermal dependence). As a consequence of the loss of the female, the nestlings will have to put much effort in maintaining their body warmth by themselves. Therefore their need for food will increase. This vicious circle will ultimately be broken by the death of the chicks. Several authors have found dead nestlings among a pile of prey in several birds of prey and owls (Schmutz et al. 2014). In Little Owl we observed this several times (Picture 1).

Even in the case of sequential polyandry, which occasionally happens in Boreal Owls (*Aegolius funereus*) (Korpimäki & Hakkara-

Picture 1 - Dead nestlings amongst a pile of mice and voles.

Imagem 1 - Juvenis mortos sobre uma pilha de micromamíferos.



inen 2012), the female does not desert the nest until the nestlings are 3 to 4 weeks old (Eldegard & Sonerud 2009), until they are thermally independent. Also in polyandrous Common Barn-owls (*Tyto alba*) the female deserts her first brood no sooner than that the male is capable of raising the nestlings by himself (Béziers & Roulin 2015).

It was therefore surprising that a male Little Owl attempted autonomous brood care in a nest box observed by three webcams. This paper describes the behavior of a male Little Owl attempting brood care after the female disappeared after a Stone Marten (*Martes foina*) attack.

Methods

Since the start in 2007 the Little Owl is one of the monitored species in Beleef de Lente, the webcam project of Vogelbescherming Nederland. In this project several birds are observed every year by three webcams accessible for the general public on the internet. The nest box for the Little Owl is located in a 6 m high and more than 100 years old pear tree in the countryside of Winterswijk, a small town in the eastern part of the Netherlands (Fig. 1).

The nest box is equipped with 3 cameras, 1

Figure 1 - Winterswijk, in the eastern part of the Netherlands.

Figura 1 - Winterswijk, na zona este da Holanda.



on the outside and 2 on the inside and so it is possible to see the direct surroundings of the nest and also observe breeding and prey supply. The cameras are online from the beginning of March until the beginning of July, 24 hours per day, 7 days per week. They register the complete breeding season, from courtship and egg laying till hatching and fledging. The footage is not only being watched by tens of thousands enthusiastic spectators, but is also digitally stored and available to download as MP4 for the staff and a selected group of volunteers. They can watch the footage as many times as they like. Prey supply is meticulously registered by a group of experienced volunteers. Partly by observing live, and partly by downloading the data (especially the night scenes) afterwards (Van Harxen & Stroeken 2010). The female was unmarked and the male was banded which made distinction easy.

Results

In 2017 the first of the 4 eggs is laid on 14 April and on 16 May, at 18:26 the first young hatches. The other 3 follow within 14 hours. On 22 May at 3:08, the nestlings are

5 days old and still in their downy plumage, the female leaves the nest box quickly when hearing a sound outside, probably the climbing noise made by a Stone marten. The Stone marten makes fierce attempts to enter the nest box. Meanwhile he is attacked several times probably by both the female and the male. The female probably gets fatally injured just outside the vision of the outside camera. It is certain that she did not return to the nest box after the Stone marten retreated unsuccessfully. The male appears a little over half an hour after the Stone marten left for the first time on the branch the nest box is put on. Clearly he is hesitating to enter the nest box. A few seconds later he disappears out of sight of the camera. This recurs several times, despite the peeping of the nestlings that can clearly be heard. When he finally enters the nest box with a caterpillar in his beak he finds 3 nestlings, loudly begging for food, who nonetheless do not accept the caterpillar. With the prey still in his beak he goes outside. Shortly afterwards he comes in for the second time, this time without prey, and sits down on the nestlings obviously attempting to keep them warm. At 21:05 he gazes upon a vole (*Myodes glareolus/Microtus arvalis*) in the nearest corner of the nest box. He drags it to the nestlings, meanwhile uttering the same noises female's use to encourage their young to accept and eat the prey that is being offered to them (Schönn et al. 1991). He tries to feed them very small chunks of the vole, but does not seem very successful. Despite aiming his beak at the nestlings aim , they do not succeed in getting hold on the barely visible pieces. At 13:45 he tries it again, but this time the chunks he rips off are considerably bigger. It can clearly be seen that the nestlings really try to take the pieces. However they probably still don't swallow substantial parts of the vole. In the meantime they are so hungry that one of them tries to rip off some bits of the vole by himself. These feeding attempts recur several times in the next day.

On 23 May at 07:36, almost 30 hours after the attack by the Stone marten, the male enters the nest box with a decapitated vole. He tries again to feed the nestlings. It is clearly seen that a large chunk is being swallowed by one of the nestlings. A piece that fell is picked up and offered again. Most of the time he stays in the nest box and every now and then he sits on the nestlings, in order to keep them warm. Sometimes he feeds them with little pieces of the rest of the vole, every nestling getting its share.

At 20:00 he tries to feed an earthworm he just caught. The chicks are very hungry and beg loudly. The clumsy size of the worm makes is difficult for him. While holding the worm with one paw, he tries to cut off little parts with his beak, which he then tries to feed to the nestlings. In most cases he fails and the piece of worm falls at the bottom of the nest box, or he eats it himself. Once in a while a piece of the worm disappears in the stomach of the chick that calls the most. A May Beetle (*Melolontha melolontha*), caught a bit later, is not even offered to the chicks, but is being swallowed by the male in one piece.

During the whole period, but especially in the night from 23 to 24 May, the male is often outside to hunt. In total he brings 43 prey items to the nest box, comparable with the supply in the days before the attack (black bars in Fig. 2).

On 23 May at 13:50 the last chunk of mouse is being fed and the stock is depleted. Almost 16 hours later the first new mouse is supplied, before that it was mainly small prey like caterpillars and larvae (Tab. 1).

When he returns with a Wood Mouse (*Apodemus sylvaticus*), the chicks lay stretched out at the bottom, almost motionless. They do not react to his encouraging sounds, also not when sometime later he enters with a larva. The exact moment of time cannot be determined, but in the course of that day all three young die.

The very same day, at 17:12, the first of the three dead nestlings is being taken out of the nest box by the male and is probably

Figure 2 - Prey supply by male and female to the nestlings in 2017. On the x-axis the age of the young in days and on the y-axis the number of prey items. From day 6 onwards (shaded) the male is alone.

Figura 2 - Presas fornecidas pelo macho aos juveus em 2017. O eixo horizontal representa a idade dos juvenis em dias e o eixo vertical o número de presas. A partir do dia 6 (sombreado) o macho está sozinho.

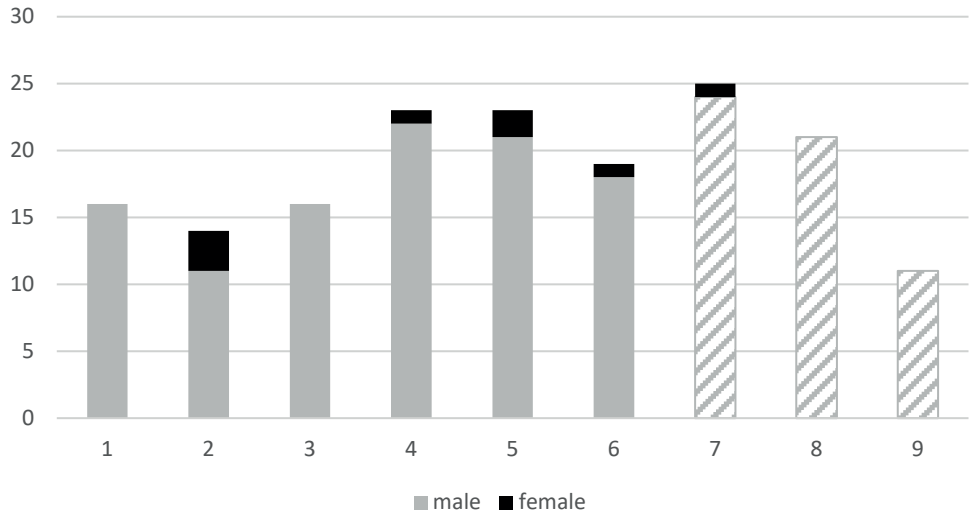


Table 1 - Prey supply by the male after the attack by the Stone Marten. The first prey item was delivered on 22 May at 04:07 (well over an hour after the attack) and the last (a vole) on 24 May at 05:42. At that time the young already didn't take the prey any more.

Tabela 1 - . Presas fornecidas pelo macho após o ataque de fuinha. A primeira presa foi entregue às 4h07 do dia 22 de maio (mais de uma hora após o ataque) e a última às 5h42 do dia 24 de maio. Nessa altura os juvenis já não se encontravam a aceitar as presas.

Date	Insect	Larvae	May beetle	Small item	Earthworm	Caterpillar	Mouse (Sp.)	Vole (Sp.)	Total
22-5-2017		1	2	3		5			11
23-5-2017	1	1		2	3	13	1		21
24-5-2017	1	3				4	1	2	11
Total	2	4	2	5	3	22	2	2	43

dropped somewhere. Number two shares the same fate some time later. The third one lays in the nest box for some time, but ultimately - at 25 May at 17:19 - it is being brought outside too. The nest box is then completely empty.

Earlier that day, at 5:00 for the first time the male utters his mating call, sitting on the branch on which the nest box is put. He probably intends to interest a new female for the vacancy. Nearly 20 hours later, on 26 May at 1:34, a new female arrives. After a few unsuccessful attempts to pair, she follows him at 16:30 into the nest box for the first time. During the next days and weeks the newly formed couple visits the tree and the nest box regularly, cuddles each other, and mate several times, but they do not start a new clutch. It is probably already too late in the season. The major events are summarized in Tab. 2.

Table 2 - Events between 22 May and 26 May 2017.

Tabela 2 - Eventos entre 22 de maio e 26 de maio de 2017.

DATE	TIME	EVENT
		Prior to the attack by the Stone Marten (*Martes foina*)
14-4-2017	19:21	first egg
22-4-2017	02:00	fourth and last egg
16-5-2017	18:26	first young hatches
17-7-2017	09:11	fourth and last young hatches
		After the attack by the Stone Marten
22-5-2017	03:08	attack by a Stone marten, female leaves the nest box
22-5-2017	03:14	female possibly hurt
22-5-2017	03:15	Stone marten leaves
22-5-2017	03:55	female arrives for the first time
22-5-2017	04:27	male tries to feed a larvae, the young don't take it
22-5-2017	09:05	male tries to fees a vole, the young don't take it
22-5-2017	09:06	male sits on the young in order to keep them warm
22-5-2017	13:45	male feeds little chunks of a vole
23-5-2017	07:40	male arrives with a fresh vole and feeds little chunks to the young
24-5-2017	06:05	male arrives with a fresh vole; the young are dying
24-5-2017	00:00	first young dead, the other 2 follow later that day
24-5-2017	12:29	for sure all 3 young dead
24-5-2017	17:12	the male removes the first young out of the nest box
25-5-2017	05:00	male utters mating call for the first time
25-5-2017	17:19	last dead young is being removed from the nest box
26-5-2017	01:34	new female arrives for the first time
26-5-2017	04:30	new female enters the nest box for the first time

Discussion

Within less than four days - from 22 May 03:08 until 26 May 01:34 - an attack by a Stone Marten occurs, the female disappears, the male attempts brood care, the nestlings die and are removed from the nest box by the male and a new female arrives. Especially the male attempting brood care is interesting from a biological point of view. Particularly remarkable - and as far as we know not previously described - was that he actually ripped off pieces of a vole and tried to feed little chunks to the nestlings. This behavior has never been registered before in Little Owls, nor in any other owl.

The disappearance of the female prompted the male to take responsibility for feeding the nestlings and keeping them warm. Because hunting costs a lot of time, and taking place in the coldest hours of the day, it was inevi-

Figure 3 - Length of stay (in hours per day) in the nest box by the female from day 1 (hatching day not included) until day 11 in 4 nests, in 2015-2017. On the x-axis the age of the young in days and on the y-axis the hours. W2017 is the nest referred to in this study. W = Winterswijk, D = Dongen

Figura 3 - Período de permanência (em horas por dia) da fêmea na caixa-ninho desde o dia 1 (dia da eclosão não incluído) até ao dia 11 em 4 ninhos, em 2015-2017. O eixo horizontal representa a idade dos juvenis em dias e o eixo vertical a hora. W = Winterswijk, D = Dongen).

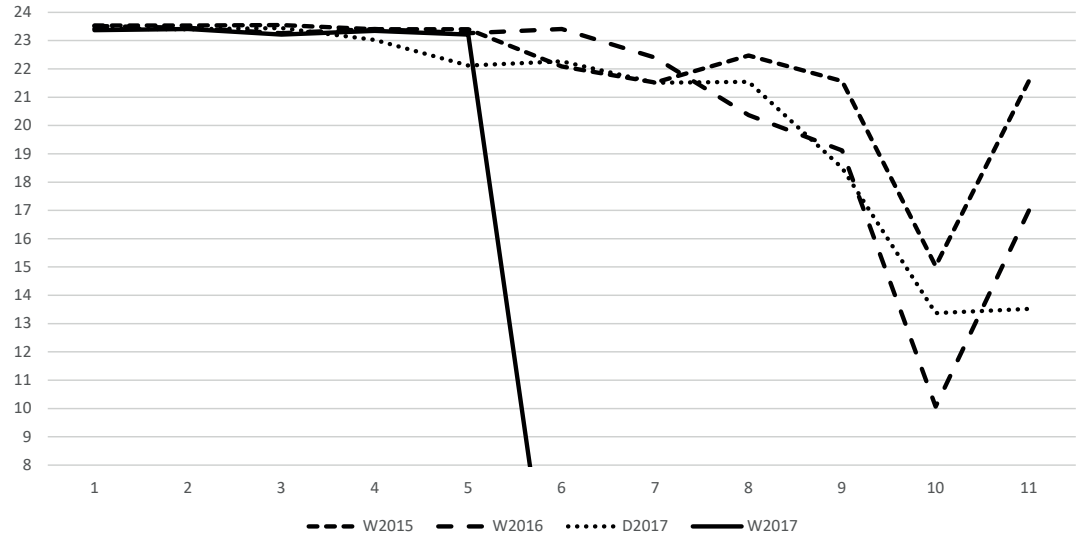


table that he failed in keeping his offspring warm during this period which is essential. Normally the female stays in the nest most of the time, at least during the first two weeks (Fig. 2).

The length of stay in previous years (W2015, W2016 and D2017) clearly illustrates (Fig. 3) that the female normally still spends a lot of time in the nest box after day 5. Only from day 10 onwards the length of stay decreases strongly. The male of W2017 should have spent almost the complete day in the nest box during 5 days to compensate for the time the female would have spent with her offspring. In reality he stayed in the nest box only 20 hours and 21 minutes from the more than 58 hours that elapsed between the disappearance of the female and the death of the last nestling (35,5%). Thereof he spends somewhere between 5 and 9 hours actually sitting on the nestlings. Compared with the time females usually spend in the nest box (93%) during that period, it was significantly less and hence insufficient to keep the body temperature of the nestlings at the level needed.

The inadequate prey supply is also important. After the disappearance of the female the male continued hunting and delivering prey. Though he brings in 43 prey items in total (Fig. 1 & Tab. 1), the biomass of these items is little compared to the mean in 14 other nest in the period 2002-2017; 136 opposed to 381 g (35,7%, range 183-546 g) (Van Harxen & Stroeken in prep). Even if he would have been able to feed all the prey to the nestlings, an average of 15 g per day per young still would have been relatively modest. The nestlings in the 14 nests mentioned before received on average 43 g per day (range 27-88 g), almost 287% more. The greater part of the prey however is eaten by the male himself, so actually they will have received significantly less than 15 g.

The combination of food shortage, too irregular feeding and cooling down probably was fatal to the nestlings. Similar cases are known from other owls e.g. the Burrowing

Owl (*Athene cunicularia*) (pers. comm. D. Johnson) and the Eurasian Eagle-owl (*Bubo bubo*) (pers. comm. H. Frey). In all these situations the young were too small to be left alone for a longer period of time. Overskaug & Øien (2002) describe a study where two female Tawny Owls (*Strix aluco*) were predated, but in this study the young Tawny Owls had deserted the nest before.

The remarkable thing in this case is that the male actually did try to raise the nestlings all by himself. This calls for the question whether breeding and feeding by male Little Owls somewhere in evolution was still present and disappeared from the behavior repertoire later on. Schmutz et al. (2012) suggest that possibly the dominant behavior of the female might prevent the male from doing his share of the brood care. In this respect it is remarkable that the same male tried to incubate the eggs during a short absence of the female on 11 and 13 May. Behavior like that has not been described before. He only ceased to do so until the female entered the nest box and pushed him away gently. Occasionally this kind of behavior seems to occur in other owls too. David Ramsden (pers. comm.) mentions a captive male Common Barn-owl (*Tyto alba*) that tried to incubate. In previous years we observed several times male Little Owls that tried to feed downy young, especially when the female was not present. This was not always successful, but when the prey was a caterpillar or a similar small item at least one of the nestlings would eventually take the prey.

The question whether this kind of behavior was specific for this male or occurs more frequently, will probably be difficult to answer. Standard controls of nest boxes during the breeding season will not be able to reveal this. Hence the chances in observing similar behavior with a different male in another situation are small. Only experimental research could provide an answer or perhaps more camera research like Beleef de Lente.

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Molecular taxonomy and systematics of owls (Strigiformes) - An update

Atualização da taxonomia e sistemática moleculares em rapinas noturnas (Strigiformes)



Michael Wink[1*], Hedi Sauer-Gürth[1]

1 Heidelberg University, Institute of Pharmacy and Molecular Biotechnology, INF 364, D-69120 Heidelberg, Germany

*** Corresponding author:** wink@uni-heidelberg.de

ABSTRACT

According to the latest genomic avian tree of life hypothesis, owls are closely related to diurnal raptors, but different from falcons and nightjars. We reconstructed a molecular phylogeny based on nucleotide sequences of a mitochondrial gene (cytochrome b) and a nuclear gene (RAG-1), and used it as a taxonomic framework. In accordance to the rules of cladistics, several changes (splitting or lumping of taxa) have been proposed. Strigiformes are divided into 2 families Tytonidae and Strigidae. The Tytonidae are subdivided into the subfamilies Tytoninae (with 25 species of *Tyto*) and Phodilinae (with *Phodilus*). The Strigidae cluster in 3 subfamilies: Striginae, Surniinae and Ninoxinae (with the genera *Ninox* and possibly the monotypic *Uroglaux* and *Sceloglaux*). The Surniinae are subdivided into 2 tribes Surniini (with *Surnia, Athene, Glaucidium*) and Aegolini (with *Aegolius*). The Striginae are subdivided into 6 tribes: Bubonini (with *Bubo,* including the former *Nyctea, Ketupa, Scotopelia*), Strigini (with *Strix*, *Jubula*), Pulsatrigini (with *Pulsatrix, Lophostrix*), Megascopini (with *Megascops, Psiloscops*), Otini (with *Otus, Mimizuku*), and Asionini (with *Asio, Ptilopsis,* and possibly the monotypic *Nesasio*). New sequence data show that *Ninox superciliaris* from Madagascar does not group with *Ninox* but with *Athene* and thus should become *Athene superciliaris*. Sequences from *Scotopelia peli* and *S. ussheri* cluster within the genus *Bubo* and should better be classified as *Bubo peli* and *Bubo ussheri*.

Keywords: cytochrome b, owl systematics, phylogeny, phylogeography, RAG-1

RESUMO

De acordo com a mais recente árvore genómica aviária da hipótese da vida, as rapinas noturnas apresentam uma relação estreita com as rapinas diurnas, mas diferem dos falcões e dos noitibós. Através da construção de uma filogenia molecular baseada em sequências de nucleótidos de genes mitocondriais (principalmente o citocromo b) e de genes nucleares (por exemplo, RAG-1), foi estabelecida uma estrutura taxonómica. Em conformidade com as regras da cladística, foram propostas várias alterações (divisão ou agregação de táxones). Os Strigiformes estão divididos em 2 famílias Tytonidae e Strigidae. O Tytonidae estão subdivididos nas subfamílias Tytoninae (com 25 espécies de *Tyto*) e Phodilinae (com *Phodilus*). Os Strigidae dividem-se em três subfamílias: Striginae, Surniinae e Ninoxinae (com o género *Ninox* e possivelmente os monotípicos *Uroglaux* e *Sceloglaux*). Os Surniinae estão subdivididos em duas tribos Surniini (com *Surnia*, *Athene* e *Glaucidinum*) e Aegolini (com *Aegolius*). Os Striginae estão subdivididos em 6 tribos: Bubonini (com *Bubo*, que inclui as formas anteriores *Nyctea*, *Ketupa*, *Scotopelia*), Strigini (com *Strix*, *Jubula*), Pulsatrigini (com *Pulsatrix*, *Lophostrix*), Megascopini (com *Megascops*, *Psiloscops*), Otini (com *Otus*, *Mimizuku*) e Asionini (com *Asio*, *Ptilopsis* e, possivelmente, o monotípico *Nesasio*). Novos dados de sequenciação mostram que *Ninox superciliaris* de Madagascar não agrupa com *Ninox* mas sim com *Athene*, devendo portanto passar a *Athene superciliaris*. Sequências de *Scotopelia peli* e *S. ussheri* agrupam-se dentro do género *Bubo* e deveriam ser classificadas como *Bubo peli* e *B. ussheri*.

Palavras-chave: *:* citocromo b, filogenia, filogeografia, RAG-1, sistemática

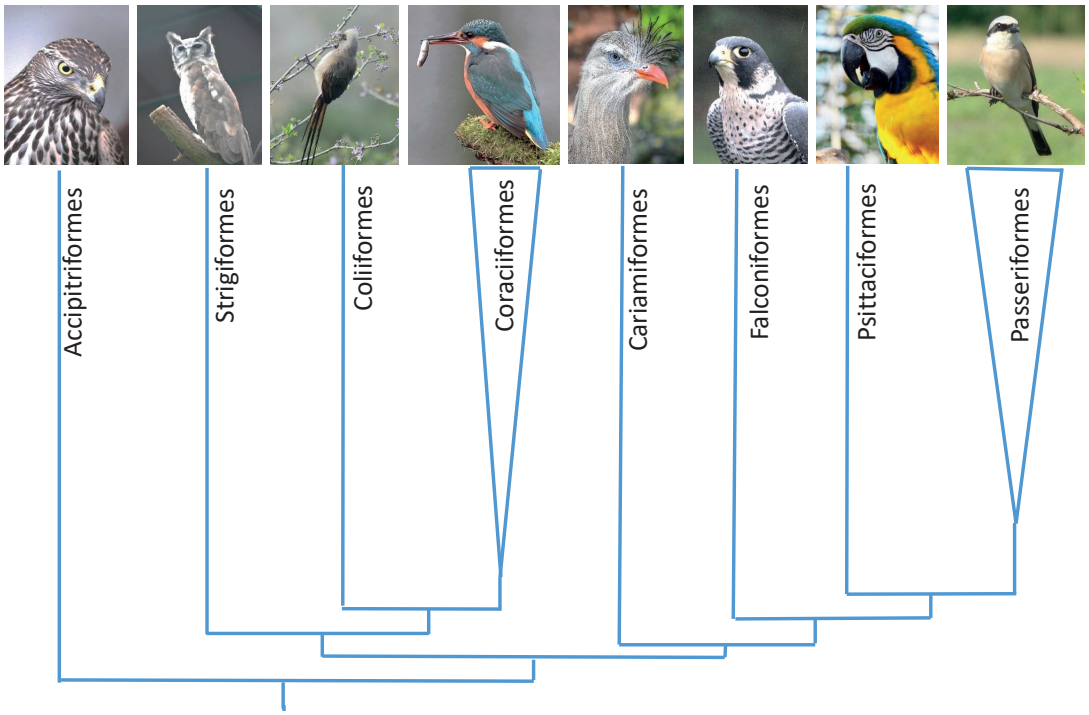
Introduction

For a long time, ornithologists have discussed the phylogenetic position of owls among birds. Since owls exhibit a raptorial lifestyle, Linné had included them in the Accipitres. Already in 1927 L'Herminier separated the owls from diurnal raptors as an independent order. Nocturnal birds, such as owls, nightjars and stone-curlews share a number of common characters, such as large eyes and camouflaged plumage. Consequently, owls and nightjars had been regarded as closely related bird orders (Fürbringer 1888, Gadow 1892, Mayr & Amadon 1951, Sibley & Ahlquist 1990). However, Cracraft (1981) assumed a closer relationship between owls and falcons. The recent genome analyses (Zhang et al. 2014, Jarvis et al. 2015, Prum et al. 2015) have largely settled this open question (Fig. 1). Thus, falcons and nightjars are not related to owls. Diurnal raptors, the Accipitriformes (including New and Old World vultures, ospreys, secretary bird, eagles, kites, harriers, buzzards and hawks) take a position at the base of a clade of land birds, which includes two other major lineages. One lineage comprises owls, mouse birds (Coliiformes) and Coraciimorphae (trogons, hoopoes, bee-eaters, hornbills, kingfishers, woodpeckers and toucans), the other lineage Seriema, falcons (which no longer belong to diurnal raptors), parrots and the large order of Passeriformes (also see Kraus & Wink, 2015, Wink 2011, 2013, 2015a, Zhang et al. 2014).

Almost 30 years ago, we started to analyse systematics and phylogeny of raptors and owls by sequencing their DNA, mostly the mitochondrial cytochrome b and the nuclear

Figure 1 - Position of owls in the avian tree of life (simplified after Prum et al. 2015). The original phylogeny comprises genome sequences of 198 species (259 nuclear genes with 390 000 nucleotides for each taxon).

Figura 1 - Posição das rapinas noturnas na árvore da vida aviária (simplificada de acordo com Prum et al. 2015). A filogenia original compreende sequências dos genomas de 198 espécies (259 genes nucleares com 390 000 nucleótidos por cada táxone).



RAG-1 (Seibold et al. 1993; Wink 1995, 2000, 2014; Wink & Sauer-Gürth 2000, 2004; Wink & Heidrich 1999, 2000; Wink et al. 1996, 2000, 2004, 2008, 2009). In 2009, and we had presented a global phylogeny of owls, which was based on nucleotide sequences of the cytochrome b and RAG-1 genes (Wink et al. 2009).

Owls are monophyletic: the Strigiformes are divided into two monophyletic families Tytonidae and Strigidae (Sibley & Monroe 1990, Del Hoyo et al. 1999, Weick 2006, 2013, König & Weick 2008, Mikkola 2013). The Tytonidae are a small owl family with two subfamilies with a single genus each (*Tyto*, and *Phodilus* with two species). The Strigidae can be grouped into three subfamilies Striginae, Ninoxinae and Surniinae with more than 230 species (Table. 1; Fig. 2).

In this work, we summarize the existing data and add sequences of *Ninox superciliaris, Scotopelia peli, Scotopelia ussheri*, new subspecies of some owls and DNA sequences which had been submitted to GenBank (from other studies, Appendix S1). Our analysis thus provides a rather comprehensive update on the phylogeny of owls, although some taxa are still missing.

Methods

This publication is a follow-up of Wink et al. (2009) and includes DNA sequences, which were submitted to Genbank and previously published by us. They are included in Appendix S1, in that they show both an Institute of Pharmacy and Molecular Biotechnology (IPMB) and Genbank accession number. In case of DNA sequences from other laboratories, an IPMB number is absent. In this

Table 1 - Systematics of owls according to nucleotide sequences of mtDNA and the nuclear RAG-1 gene (after Wink et al. 2009).

Tabela 1 - Sistemática das rapinas noturnas com base em sequências nucleotídicas de mtDNA e do gene nuclear RAG-1 (Wink et al. 2009).

FAMILY	SUBFAMILY	TRIBE	GENERA
Tytonidae	Tytoninae		*Tyto*
	Phodilinae		Phodilus
Strigidae	Striginae	Bubonini	*Bubo* (including the former genera *Nyctea, Ketupa, Scotopelia*)
		Strigini	*Strix*, *Jubula*
		Pulsatrigini	*Pulsatrix*, *Lophostrix*
		Megascopini	*Megascops, Psiloscops*
		Asionini	*Asio*, *Ptilopsis*
		Otini	*Otus, Mimizuku*
	Surniinae	Surniini	*Surnia, Glaucidium, Taenioglaux, Athene,*
		Aegolini	*Aegolius*
	Ninoxinae		*Ninox*, *Uroglaux*, *Sceloglaux*

study, we also included nucleotide sequences of taxa, which were not studied before.

For the new samples, we isolated DNA from blood, tissues, feathers or buccal swabs of owls. Using polymerase chain reaction (PCR), the cytochrome b gene was amplified (primer sequences and PCR conditions were identical as in Wink et al. 2009) and sequenced (>1000 base pairs). The Sanger sequencing was executed on an ABI 3730 automated capillary sequencer (Applied Biosystems, Carlsbad, CA, USA) with the ABI Prism Big Dye Terminator Cycle Sequencing Ready Reaction Kit 3.1 (carried out by STARSEQ GmbH, Mainz, Sequencing Germany).

Sequences from our own collection and from GenBank (Appendix S1) were aligned and evaluated with standard software programmes, such as MEGA7. In most cases, one or two sequences per taxon were selected for the illustration, although over 800 sequences exist in our database from samples stored at the Institute of Pharmacy and Molecular Biotechnology at Heidelberg University (Germany). Results of such analyses are phylograms, which reflect the phylogenetic relationships between species, genera, tribes, families and subfamilies (Fig. 2). The methodology has been described in more detail in Wink & Sauer-Gürth (2000, 2004), Wink et al. (2009), Storch et al. (2013) and Wink (2013).

The Molecular Phylogenetic analysis was done by the Maximum Likelihood method using MEGA7 (Kumar et al. 2016): The evolutionary history was inferred by using the Maximum Likelihood method based on the General Time Reversible model (Nei & Kumar, 2000). The tree with the highest log likelihood (-32973,50) is shown in Figure 2. The percentage of trees in which the associated taxa clustered together is shown next to the branches. Initial tree(s) for the heuristic search were obtained automatically by applying Neighbor-Join and BioNJ

algorithms to a matrix of pairwise distances estimated using the Maximum Composite Likelihood (MCL) approach, and then selecting the topology with superior log likelihood value. A discrete Gamma distribution was used to model evolutionary rate differences among sites (5 categories (+*G*, parameter = 0.8414)). The rate variation model allowed for some sites to be evolutionarily invariable ([+*I*], 24.87% sites). The tree is drawn to scale, with branch lengths measured in the number of substitutions per site. The analysis involved 200 nucleotide sequences (mostly, two per taxon). Codon positions included were 1st+2nd+3rd+Noncoding. There were a total of 1,143 positions in the final dataset. A green dot indicates the nodes, which are supported by bootstrap values (500 replications) above 80% (for both NJ and ML analyses). GenBank accession numbers are documented in Appendix S1.

Results and Discussion

Tytonidae

Barn Owls look morphologically very similar over their entire range and Linné therefore classified them as a single species, *Tyto alba*, with cosmopolitan distribution. It has become evident however during the last decades, especially through DNA studies, that *Tyto alba* represents a taxon-rich species complex. Several new species and altogether 25 species have been defined already (Sibley & Monroe 1990, König et al. 1999; Weick 2006, 2013; König & Weick 2008, Mikkola 2013). As Barn Owls are typically resident birds, even more distinct taxa might exist on islands or in other isolated places.

Two major lineages are apparent from DNA studies, which are probably separated by more than 15 million years (Fig. 2): Lineage 1 comprises several Barn Owls from the Australasian region (except *T. capensis*) including *T. novaehollandiae*, *T. sororcula, T. almae, T. manusi, T. castanops*, *T. multipunctata*, *T. longimembris, T. capensis* and *T. tenebricosa*. It is surprising that *T. capensis* occurs in southern Africa far away from its closely related Asian sisters. Lineage 2 leads to three sublineages: one Australasian sublineage comprises the widely distributed *T. delicatula* (including *T. sumbaensis*, and a few other species from oceanic islands) and *T. javanica* (Fig. 2). The next two lineages are sister groups: One comprises Barn Owls from Europe and Africa (*Tyto alba* with the subspecies *T. a. alba, T. a. guttata, T. a. ernesti, T. a. erlangeri, T. a. gracilirostris* and the African *T. a. affinis*), the other Barn Owls of the New World (the widely distributed *T. furcata* in the North, Central and South America with further local species/subspecies, and *T. glaucops* from Hispaniola*). Tyto soumagnei* from Madagascar clusters at the base of the European/African/New World clade.

Strigidae

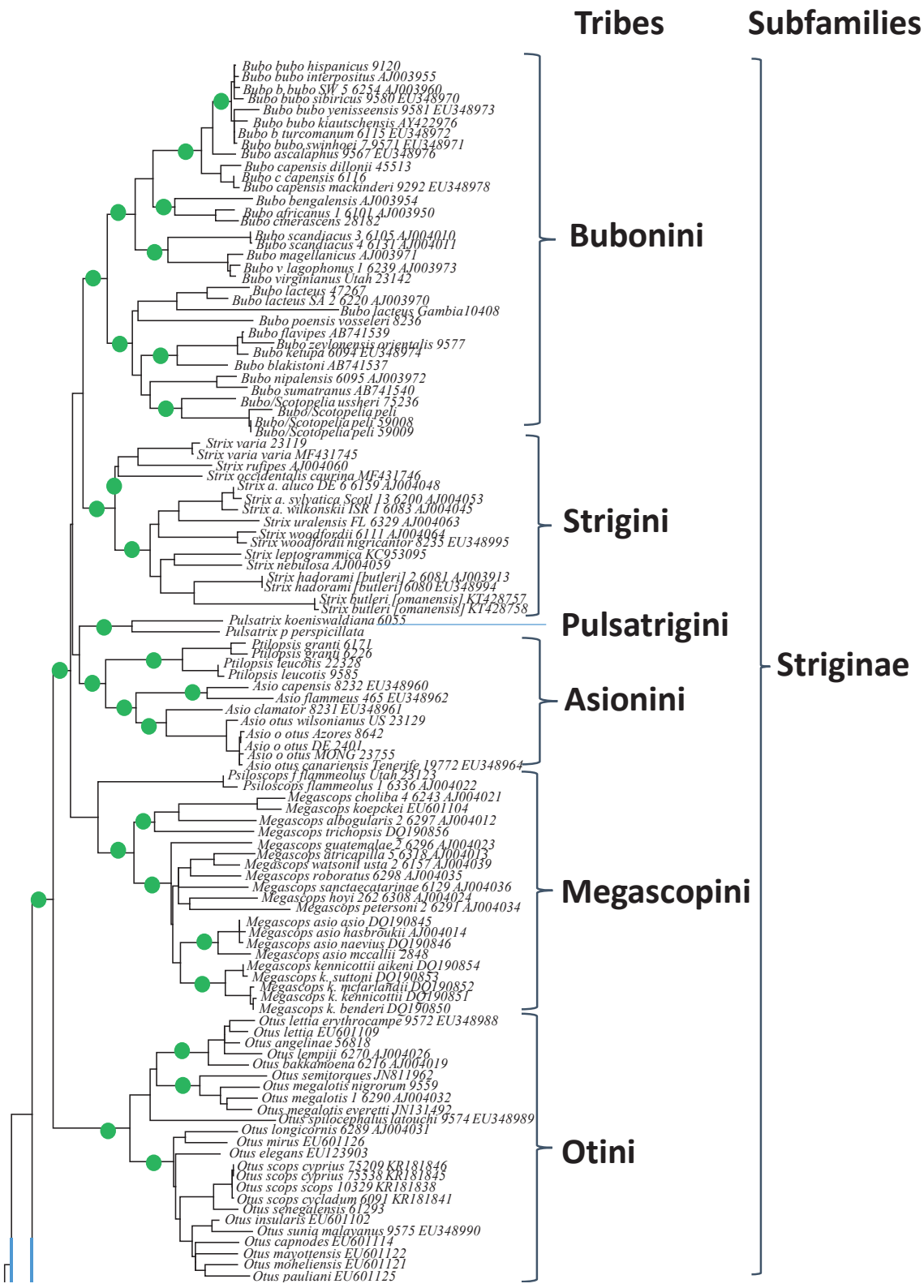
The Strigidae comprises over 230 species and is thus the biggest family in the order Strigiformes. The Strigidae are subdivided into three subfamilies according to DNA data: Striginae, Ninoxinae and Surniinae. The Striginae has been further divided into six tribes: Strigini, Bubonini, Pulsatrigini, Asionini, Megascopini and Otini (Table. 1).

In the tribe Strigini we find the genera *Strix*, and possibly *Jubula lettii* (West and Central Africa). *Strix* is a monophyletic genus with 23 species (Mikkola 2013), which clusters as a sister group to the *Bubo* complex (Bubonini) (Fig. 2). *Strix woodfordii* occurs in East Africa, and Africa and in the Near East. Two distinct taxa have been discovered which are not closely related to *Strix woodfordii*: *Strix butleri* (= *S. omanensis*) from Oman to Iran and *S. hadorami* for all other areas (formerly described as *S. butleri*) (Robb et al. 2016).

The genus *Pulsatrix* occurs in the New World and comprises three species (Mikkola 2013). A cytochrome b sequence in Gen-

Figure 2 - Molecular phylogeny of owls based on the analysis of the cytochrome b gene (see Methods). Nodes supported by bootstrap above 80% are marked with a green dot.

Figura 2 - Filogenia molecular das rapinas noturnas com base na análise do gene citocromo b (ver Métodos).



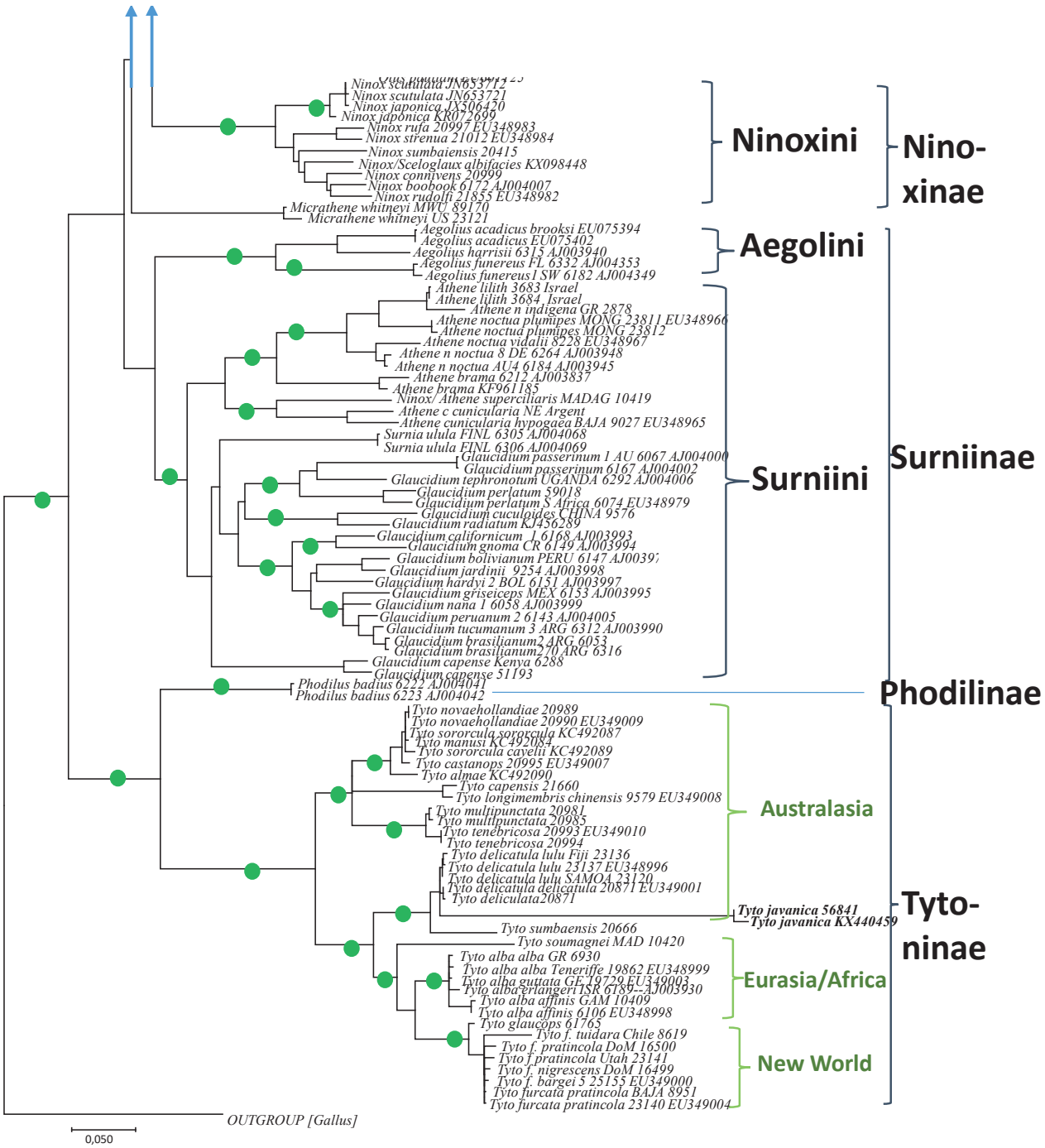
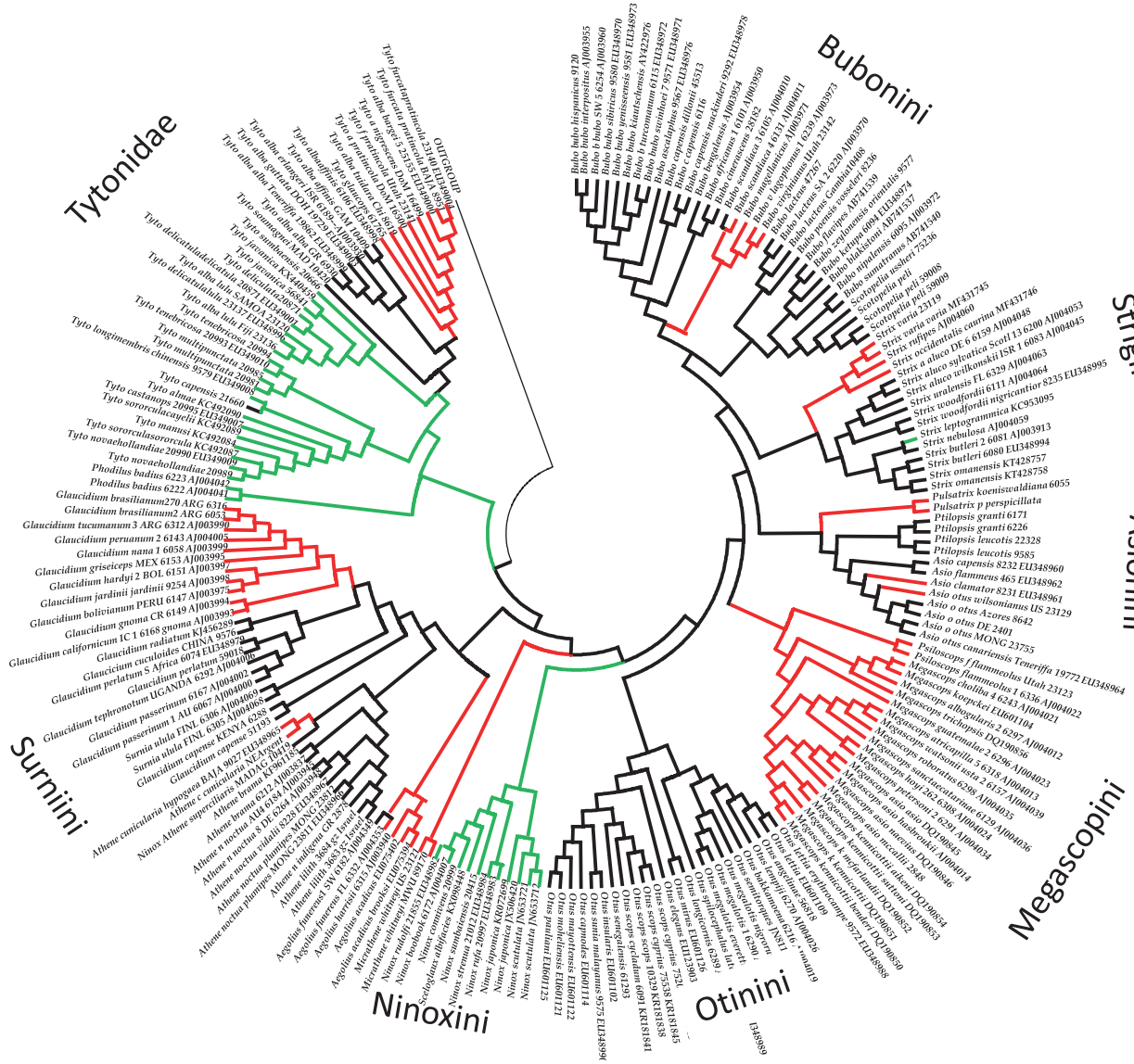

Ninox scutulata JN653712
Ninox scutulata JN653721
Ninox japonica JX506420
Ninox japonica KR072699
Ninox rufa 20997 EU348983
Ninox strenua 21012 EU348984
Ninox sumbaiensis 20415
Ninox/Sceloglaux albifacies KX098448
Ninox connivens 20999
Ninox boobook 6172 AJ004007
Ninox rudolfi 21855 EU348982
Micrathene whitneyi MWU 89170
Micrathene whitneyi US 23121
Aegolius acadicus brooksi EU075394
Aegolius acadicus EU075402
Aegolius harrisii 6315 AJ003940
Aegolius funereus FL 6332 AJ004353
Aegolius funereus1 SW 6182 AJ004349
Athene lilith 3683 Israel
Athene lilith 3684_Israel
Athene n indigena GR 2878
Athene noctua plumipes MONG 23811 EU348966
Athene noctua plumipes MONG 23812
Athene noctua vidalii 8228 EU348967
Athene n noctua 8 DE 6264 AJ003948
Athene n noctua AU4 6184 AJ003945
Athene brama 6212 AJ003837
Athene brama KF961185
Ninox/ Athene superciliaris MADAG 10419
Athene c cunicularia NE Argent
Athene cunicularia hypogaea BAJA 9027 EU348965
Surnia ulula FINL 6305 AJ004068
Surnia ulula FINL 6306 AJ004069
Glaucidium passerinum 1 AU 6067 AJ004000
Glaucidium passerinum 6167 AJ004002
Glaucidium tephronotum UGANDA 6292 AJ004006
Glaucidium perlatum 59018
Glaucidium perlatum S Africa 6074 EU348979
Glaucidium cuculoides CHINA 9576
Glaucidium radiatum KJ456289
Glaucidium californicum 1 6168 AJ003993
Glaucidium gnoma CR 6149 AJ003994
Glaucidium bolivianum PERU 6147 AJ00397
Glaucidium jardinii 9254 AJ003998
Glaucidium hardyi 2 BOL 6151 AJ003997
Glaucidium griseiceps MEX 6153 AJ003995
Glaucidium nana 1 6058 AJ003999
Glaucidium peruanum 2 6143 AJ004005
Glaucidium tucumanum 3 ARG 6312 AJ003990
Glaucidium brasilianum2 ARG 6053
Glaucidium brasilianum270 ARG 6316
Glaucidium capense Kenya 6288
Glaucidium capense 51193
Phodilus badius 6222 AJ004041
Phodilus badius 6223 AJ004042
Tyto novaehollandiae 20989
Tyto novaehollandiae 20990 EU349009
Tyto sororcula sororcula KC492087
Tyto manusi KC492084
Tyto sororcula cavelii KC492089
Tyto castanops 20995 EU349007
Tyto almae KC492090
Tyto capensis 21660
Tyto longimembris chinensis 9579 EU349008
Tyto multipunctata 20981
Tyto multipunctata 20985
Tyto tenebricosa 20993 EU349010
Tyto tenebricosa 20994
Tyto delicatula lulu Fiji 23136
Tyto delicatula lulu 23137 EU348996
Tyto delicatula lulu SAMOA 23120
Tyto delicatula delicatula 20871 EU349001
Tyto deliculata20871
Tyto javanica 56841
Tyto javanica KX440459
Tyto sumbaensis 20666
Tyto soumagnei MAD 10420
Tyto alba alba GR 6930
Tyto alba alba Teneriffe 19862 EU348999
Tyto alba guttata GE 19729 EU349003
Tyto alba erlangeri TSR 6187–AJ003930
Tyto alba affinis GAM 10409
Tyto alba affinis 6106 EU348998
Tyto glaucops 61765
Tyto f. tuidara Chile 8619
Tyto f. pratincola DoM 16500
Tyto f pratincola Utah 23141
Tyto f. nigrescens DoM 16499
Tyto f. bargei 5 25155 EU349000
Tyto furcata pratincola BAJA 8951
Tyto furcata pratincola 23140 EU349004
OUTGROUP [Gallus]
0,050
Ninoxini
Aegolini
Surniini
Australasia
Eurasia/Africa
New World
Nino-
xinae
Surniinae
Phodilinae
Tyto-
ninae

Figure 3 - Phylogeography of owls. The phylogeny is illustrated as a radiary cladogram. The colour of branches indicate their main distribution areas: Black = Europe, Africa, Central and East Asia; green = Australasia; red = New World.

Figura 3 - Filogenia das rapinas noturnas representada por um cladograma radial. A cor das ramificações indica as suas principais áreas de distribuição: preto = Europa, África, e Centro e Este da Ásia; verde = Australásia; vermelho = Novo Mundo



Bank (which was not included in our analysis because it was too short) suggests, that *Lophostrix cristata* (Central and South America) is a sister to *Pulsatrix* (Wink et al. 2008); it has been suggested to create a new tribe Pulsatrigini for the genera *Lophostrix* and *Pulsatrix*. Alternatively, these taxa could be included in the tribe Asionini as they appear to have a common ancestor (Fig. 2 & 3).

The tribe Bubonini is monophyletic and traditionally included the genera *Bubo, Nyctea, Ketupa* and *Scotopelia*. DNA analyses have shown, that the taxa of *Nyctea, Ketupa* and *Scotopelia* all cluster within the genus *Bubo* which would become paraphyletic (Fig. 2) (Wink & Heidrich 1999, König & Weick, 2008, Wink et al. 2008, Mikkola 2013, Omote et al. 2013, Wink 2013). The former members of the Fish-owls *Ketupa* cluster as sister to *Bubo nipalensis* and *B. sumatranus,* which share morphological similarities. In order to avoid paraphyletic groupings we had suggested to lump these genera and include them in a common genus *Bubo* (Fig. 2) (Wink & Heidrich 1999, König & Weick, 2008, Wink et al. 2008; Wink 2013, Mikkola 2013). This suggestion has been widely accepted for *Nyctea* and *Ketupa*. In this publication, we have included sequences from two species of the African Fishing-owl *Scotopelia*, which cluster together with *Bubo nipalensis* and *B. sumatranus*, as do the Asian Fish-owls. Therefore, we suggest lumping *Scotopelia* in *Bubo*.

We had detected three lineages in the former tribe Otini (with the genera *Otus*, *Megascops*, *Macabra*, *Pyrroglaux*, *Gymnoglaux*, *Psiloscops* and *Mimizuku*), which revealed several para- and polyphyletic groups. Therefore, we had suggested to change genus names and genus delimitations and to create three new tribes: Asionini, Megascopini and Otini (Wink & Heidrich 1999, König & Weick 2008, Wink et al. 2009, Mikkola 2013). Screech-owls of the New World with 28 species no longer belong to *Otus* but to the genus *Megascops* (Wink et al. 2008, 2009). Only *Otus flammeolus* was maintained in a monotypic *Psiloscops flammeolus* because of its isolated position at the base of the lineage leading to *Megascops* (Penhallurick 2002, Weick 2006, König & Weick 2008, Wink et al. 2009, Mikkola 2013, Dantas et al. 2015). The species-rich Old World Scops-owls (at least 47 species) remain in the genus *Otus* (Wink et al. 2009, Mikkola 2013). Pons et al. (2013) have analysed the systematics of Scops-owls of Socotra, East Africa and the Arabian peninsula. For Cyprus, a new species *Otus cyprius* was described recently (Flint et al. 2015). Within *Otus*, two lineages are apparent: A lineage with mostly European/ African taxa (*Scops* clade), the other with mostly East Asian taxa (*Lettia* clade). It is likely that more *Otus* taxa have been overlooked and exist.

The African White-faced Owls (formerly *Otus leucotis)* cluster differently from *Otus* as a sister to *Asio* (Fig. 2) and were placed in a new genus *Ptilopsis*. White-faced Owls from Central and southern Africa differ in plumage and DNA sequences: They have been split into two taxa: *P. leucotis* (West-, Central- and East Africa) and *P. granti* (southern Africa) (König & Weick 2008, Wink et al. 2009, Mikkola 2013).

The genus *Asio* with Long-eared and Short-eared Owls (Mikkola 2013) and the monotypic genus *Nesasio* were traditionally placed in Asioninae (Weick 2006). Since *Asio* clusters as a sister to *Ptilopsis* (Fig. 2) it could be treated as a tribe Asionini (Table 1).

The Surniinae has been traditionally divided into three tribes (Weick 2006): Surnini, Aegolini and Ninoxini. The tribe Surnini comprises the species-rich genus of Pygmy-owls (*Glaucidium*) with 33 species and the monotypic Hawk-owl *Surnia*, whose populations are quite similar around the Arctic circle. Pygmy-owls share similar morphology and a wide distribution in the Old and New World. However, they strongly differ in vocalisations and DNA sequences (König 1994b, Heidrich et al. 1995b). Pygmy owls of the Old World are monophyletic, as are the Pygmy owls of the New World; both groups might have been separated since more than 6

million years (Wink & Heidrich 1999). The African *G. capensis* clusters away from the other Pygmy-owls (Fig. 2) and apparently represents a different genetic lineage, which has been placed in the subgenus *Taenioglaux* Kaup 1848 with nine other species in the Old World (König & Weick 2008, Mikkola 2013, Wink et al. 2008). König & Weick (2008) suggest the use of the genus *Taenioglaux* for these species.

Little Owls (*Athene*) form another genus within the Surniinae with traditionally three species: *Athene noctua* (in Eurasia), *A. brama* (SE Asia) and *A. blewitti* (India); the latter taxon has been separated as *Heteroglaux blewittii* (Mikkola 2013). DNA data suggest that *Athene noctua* is a species complex, which might be subdivided into new species, like the situation in the *Tyto* complex (Fig. 2) (see van Nieuwenhuyse et al. 2008). *A. n. plumipes* from Mongolia and China apparently is a distinct taxon (Fig. 2; Mikkola 2013), which is also true for *A. lilith* in the Middle East (Fig. 2). The Burrowing Owls of the New World (formerly *Speotyto*) cluster as a sister to the Old World Little owls, separated by roughly 6 million years (König et al. 1999, König & Weick 2008, Wink et al. 2009). Burrowing Owls represent a species complex, with several geographically defined subspecies. As discussed later in the *Ninox* section, *Ninox superciliaris* from Madagascar clearly clusters as a sister to *A. cunicularia*. Its taxonomic position thus needs to be changed.

Boreal Owls (genus *Aegolius* with 4 species) are monophyletic and cluster as a sister to the formerly described tribe Surniini and are better separated in its own tribe Aegolini (Fig. 2). Within populations of *A. funereus* genetic differentiation is low (Wink et al. 2009), but a little bit higher than within the two subspecies of the New World *A. acadicus* (Withrow et al. 2014).

The Australasian genus *Ninox* is species-rich with at least 26 taxa. Superficially, they resemble Pygmy and Little Owls and replace them in the Australasian region (Mikkola 2013). They are better placed in a subfamily Ninoxinae: the former tribes Aegolini and Surniinae differ strongly from the tribe Ninoxini (Table. 1; Fig. 2). Gwee et al. (2017) reported a phylogeny based on a multilocus analysis of 24 taxa of the *Ninox* complex exploring the radiation of this genus in Wallacea. The White-browed Owl from Madagascar (*Ninox superciliaris*) is not a member of the genus *Ninox* but much closer to the genus *Athene* (Fig. 2). Wink (2014) had suggested changing its name to *Athene superciliaris*. The extinct *Sceloglaux albifacies* is a member of the genus *Ninox* and should be lumped within it.

Global Phylogeography of Owls

The ancestors of owls evolved with the beginning of the Tertiary, about 66 million years ago; the split between Tytonidae and Strigidae occurred in the middle of the Eocene (Prum et al. 2015). Owls occur on all continents, but several lineages are geographically restricted. The basal taxa of Barn Owls occur in the Australasian region (Fig. 3), suggesting that owls developed in Australia. A second lineage of Barn Owls leads to a clade of African/European taxa on one hand and a clade with American Barn Owls on the other hand; both lineages are sister clades. This suggests that the American Barn owls came from the Old World (Fig. 3).

The Surninae has its main distribution in Europe, Asia and Africa. A few taxa, however, colonized the New World, such as the Burrowing Owl (*Athene cunicularia*) where it developed into a species complex. The genus *Aegolius* has one species, the Boreal Owl *A. funereus*, with a circumpolar distribution, whereas all the other three taxa of this genus are restricted to America (Fig. 3). In the genus *Glaucidium*, a sister group with two main lineages is apparent, one with Pygmy-owls

of America, the other with Pygmy-owls of Europe, Asia and Africa. A similar split can be seen in the genus *Strix*, in which Old and New World taxa diverge as separate lineages. *Strix nebulosa* clusters in the Old World lineage but developed a subspecies *S. n. nebulosa* in North America (Fig. 3). The genus *Ninox* has its centre of distribution in the Australasian region, where it partly replaces Pygmy and Little Owls (Fig. 3).

Whereas Screech-owls of the genera *Megascops* and *Psiloscops* are exclusively New World taxa, *Scops* owls replace them in Europe, Africa and Asia (Fig. 3). According to Fig. 3, the ancestors of *Megascops* probably came from the Old World.

The members of the tribe Asioninae are mostly Old World taxa, except for the Latin American *Asio clamator*. Among Short-eared and Long-eared Owls, a radiation occurred from the Old World to the Americas with the evolution of several subspecies.

Eagle-owls (genus *Bubo*) has a centre of radiation in Europe, Africa and Asia. However, it also comprises a New World clade, with Great Horned Owl and Snowy Owl (Fig. 3). The latter species probably evolved in America but presently shows a circumpolar distribution.

Conclusions

Although research on the biology, vocalisations and molecular phylogeny of owls has intensified during the last decades (König & Weick 2008, Weick 2013, Mikkola 2013), many questions remain as most owl taxa have not been studied in detail.

Phylogenetic analyses have discovered that several owl species represent species complexes which can be divided in several new taxa (e.g., within *Tyto, Athene, Glaucidium, Scops, Megascops, Bubo, Strix*). Since many owls are mainly resident (not migratory), we can expect isolated and genetically divergent populations on islands, in mountains or in the tropical rain forests, which differ from recognized species. Consequently, the number of owl species will go up. Because many isolated owl populations are small and threatened by habitat loss some will likely become extinct in the future.

Phylogenetic analyses have discovered several para- and polyphyletic groups. As a result paraphyletic species are either lumped together with the majority of related species in a common genus (such as some genera of the *Bubo* complex, including *Ketupa, Nyctea* and *Scotopelia*) or existing genera are split into new genera (as shown for members of the former genus *Otus*).

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The Population Density of the Eurasian Scops-owl (*Otus scops*) Along the Eastern Adriatic Coast

Densidade populacional do mocho-d'orelhas (*Otus scops*) ao longo da costa leste do Adriático

Tjaša Zagoršek[1*], Al Vrezec[2]

1 Cankarjeva ulica 11, 3240 Šmarje pri Jelšah, Slovenia.

2 National Institute of Biology, Department of Organisms and Ecosystems Research, Večna pot 111, SI-1000 Ljubljana, Slovenia

*** Corresponding author:** tzagorsek@gmail.com



ABSTRACT

The Eurasian Scops-owl (*Otus scops*) is one of least studied owl species in Europe. From the area of eastern Adriatic coast (western Balkan Peninsula) there have been few studies on the species from Croatia and Slovenia. We aimed to determine the population density of the species along the eastern Adriatic coast by field surveys and literature review. We surveyed calling male owls at seven study sites distributed along the coast from Slovenia, Croatia to Montenegro in the breeding seasons of 2012 through 2017. We combined field survey results and literature data on published densities from the regions. A significant decrease in the density of calling males was found along a 250 km gradient from the sea coast inland to continental Slovenia (density range: 0.05 – 1.0 males/km^2), but not along a 600 km long north-south region of the eastern Adriatic coast (density range: 0.06 – 2.0 males/km^2). The eastern Adriatic coast is probably one of the most important breeding sites of the Eurasian Scops-owl in Europe.

Keywords: Mediterranian region, *Otus scops*, playback method, singing males, survey

RESUMO

The Eurasian Scops-owl (*Otus scops*) is one of least studied owl species in Europe. From the area of eastern Adriatic coast (western Balkan Peninsula) there have been few studies on the species from Croatia and Slovenia. We aimed to determine the population density of the species along the eastern Adriatic coast by field surveys and literature review. We surveyed calling male owls at seven study sites distributed along the coast from Slovenia, Croatia to Montenegro in the breeding seasons of 2012 through 2017. We combined field survey results and literature data on published densities from the regions. A significant decrease in the density of calling males was found along a 250 km gradient from the sea coast inland to continental Slovenia (density range: 0.05 – 1.0 males/km^2), but not along a 600 km long north-south region of the eastern Adriatic coast (density range: 0.06 – 2.0 males/km^2). The eastern Adriatic coast is probably one of the most important breeding sites of the Eurasian Scops-owl in Europe.

Palavras-chave: emissão de vocalizações conspecíficas, machos a vocalizar, monitorização, *Otus scops*, região Mediterrânica

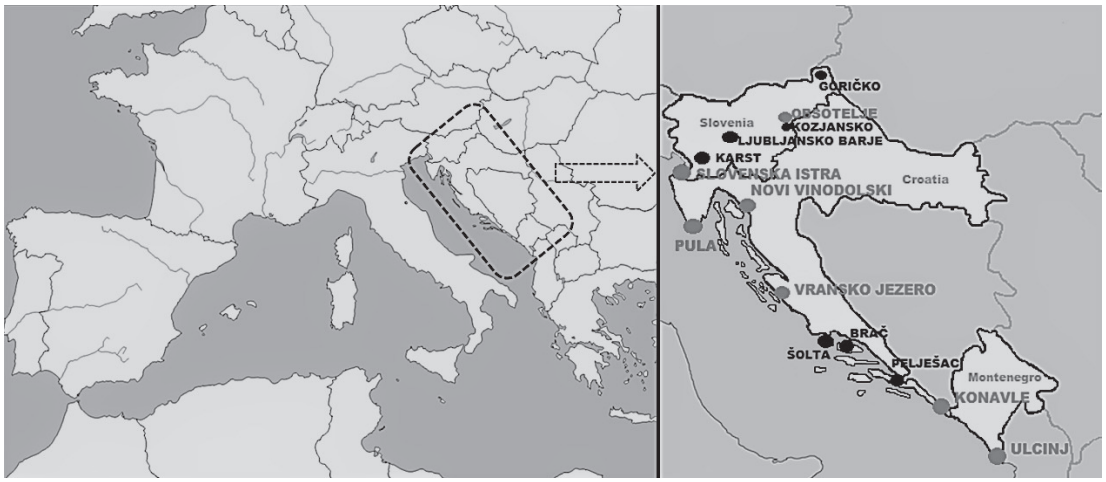
Introduction

The Eurasian Scops-owl (*Otus scops*) is a small insectivorous owl, using open and semi-open grassland habitats rich in large insects (Marchesi & Sergio 2005, Šušmelj 2011). It is a widespread summer breeder across much of southern and eastern Europe (Bavoux et al.1997). The species is a long-distance migrant and spends the winter in sub-Saharan Africa. Resident populations are known from Cyprus, Mallorca and Crete (Mikkola 1983). In Europe it is one of the least studied and monitored owl species (Vrezec et al. 2012), and its abundance in many European countries is declining (Sergio et al. 2009; BirdLife International 2017). One of the species population strongholds in Europe is situated along the eastern Adriatic coast (west Balkan Peninsula) including countries of Slovenia, Croatia, Bosnia and Herzegovina and Montenegro, which holds 10-13% of the total European population (BirdLife International 2017). The most recent population estimate in Slovenia is 600 – 1000 pairs (Denac et al. 2011), which is based on many systematic surveys across the country (Štumberger 2000, Jančar & Trebušak 2000, Denac 2003, Denac 2009, Kmecl et al. 2010, Šušmelj 2011). In Slovenia the species meets its northern breeding range limit with only a few pairs breeding further north in Austria (Malle & Probst 2015). To the south in Croatia, the Eurasian Scops-owl is much more abundant with a population estimate of 20.000–25.000 breeding pairs (BirdLife International 2017), which is the second largest in Europe (Bavoux et al. 1997, BirdLife International 2017), if excluding Russia and Turkey. However, the accuracy of this estimate is low due to the lack of systematic surveys, although locally the species was found in high densities (Vrezec 2001). Further south, along the Adriatic coast in Montenegro, the population was recently estimated at 2.000–3.000 breeding pairs (BirdLife International 2017), but the reliability of this estimate is low as there are no published surveys of the species.

The aim of this study is to give a first overview of the population density of Eurasian Scops-owl along the eastern Adriatic coast in Slovenia, Croatia and Montenegro combin-

Figure 1 - Study areas distributed along the Adriatic coast from Slovenia to Montenegro where Eurasian Scops-owls (*Otus scops*) were surveyed.

Figura 1 - Áreas de estudo distribuídas ao longo da costa do Adriático, da Eslovénia a Montenegro, onde decorreu a monitorização de mocho-d'orelhas (*Otus scops*).



ing field survey and literature data on published densities from the region (Denac 2000, Jančar & Trebušak 2000, Štumberger 2000, Vrezec 2001, Mužinić & Purger 2008, Bordjan & Rozoničnik 2010, Kmecl et al. 2010, Denac et al. 2011, Šušmelj 2011, Denac et al. 2015).

Methods

Study Area

We conducted field surveys at seven study sites and collected survey data from the literature from an additional seven areas distributed along the Adriatic coast in Slovenia, Croatia, and Montenegro (Table 1, Fig. 1).

Slovenia is situated in central Europe, at the confluence of four distinct regions – the Alps, the Dinaric Alps, and the Pannonian and Mediterranean basins. The climate ranges from alpine through temperate continental to mediterranean (Orožen Adamič 2004). We conducted surveys in the Slovenian Istria and Obsotelje, and reviewed data from the Karst, Ljubljansko, Kozjansko and Goričko areas (Table 1).

Croatia is a geographically very diverse country: flat agricultural plains in the NE (lowland Pannonia), mountainous Dinaric lying NW-SE, with the highest mountains along the edges and the coastal Adriatic with islands. Along the 6278 km coast, there are 1,246 islands (Kos et al. 2002). The climate varies from Mediterranean along the Adriatic coast, with hot, dry summers and mild, rainy winters, to continental inland, with cold winters and warm summers (Kos et al. 2002). We conducted our surveys in four areas: Pula, Novi Vinodolski, Vransko jezero and Konavle, and reviewed data from the Pelješac peninsula and the islands of Šolta and Brač (Table 1).

Montenegro is a country located in the west-central Balkans at the southern end of the Dinaric Alps (Allcock et al. 2018). The country is geographically divided into three regions: northern high mountains, central part is a segment of the Karst region of the western Balkan Peninsula and a narrow (2-6

Table 1 - Descriptions of study areas surveyed within this and other studies. Description data are from Perko et al. (1999), Njavro (2000), Kos et al. (2002), Perko (2004), Clancy (2007), and ARSO (2018).

Tabela 1 - Descrições das áreas de estudo monitorizadas neste e noutros estudos. A descrição foi adaptada de Perko et al. (1999), Njavro (2000), Kos et al. (2002), Perko (2004), Clancy (2007) e ARSO (2018).

COUNTRY	STUDY AREA	GEOGRAPHICAL COORDINATES	MEAN ELEVATION [M, A.S.L.]	MEAN JULY TEMP	PREVAILING HABITAT TYPE	SCOPS OWL DATA SOURCE
Slovenia	Slovenian Istria	45°31'- 45°31' N 13°54' - 13°38'E	180	22°C	flysch low hills with vineyards and orchards	this study
Slovenia	Karst	45°50' - 45°36' N 13°47' - 14°06' E	330	20.8°C	flat to hilly, predominantly limestone area	Šušmelj (2011)
Slovenia	Ljubljansko barje	45°59' - 45°57' N 14°20' - 14°33' E	297	19°C	isolated hills within a surrounding plain	Denac (2000)
Slovenia	Kozjansko	46°07' - 45°59' N 15°33' - 15°38' E	306	19°C	hilly and mostly forested area, which gradually flatten out onto a plain by the River Sotla	Kmecl et al. (2010), Denac et al. (2011)
Slovenia	Obsotelje	46°13' - 46°16' N 15°26' - 15°49' E	307	18.6°C	hilly and mostly forested area	this study
Slovenia	Goričko	46°49' - 46°43' N 16°01' - 16°20'E	275	19.1°C	hillocky landscape overgrown by trees, many marshes and wet meadows	Štumberger (2000), Denac et al. (2015)
Croatia	Pula	44°50'- 44°48' N 13°52'- 13°54' E	30	23.7°C	densely populated city and lies on and beneath seven hills on the inner part of a wide gulf	this study
Croatia	Novi Vinodolski	45°15' - 45°07' N 14°36' - 14°47' E	140	23°C	divided into three areas: coastal area, flysch valleys and steep high hills of Gorski kotar	this study
Croatia	Vransko jezero	43°57' - 43°49' N 15°33' - 15°40' E	44	24.1°C	the area with the largest natural lake, rare natural habitats, freshwater springs and rich biodiversity	this study
Croatia	Šolta	43°24' - 43°20' N 16°12' - 16°23' E	102	23°C		Mužinić & Purger (2008)
Croatia	Brač	43°20' - 43°17' N 16°26' - 16°52' E	440	24.5°C	third largest island in Croatia, region with thermophilous evergeen forests and Mediterranean scrub	Bordjan & Rozonićnik (2010)
Croatia	Pelješac	43°01' - 43°56' N 17°10' - 17°29' E	470	23.5°C	region with thermophilous evergeen forests and important cultural plants olive tree and vine	Vrezec (2001)
Croatia	Konavle	42°36' - 42°25' N 18°17' - 18°29' E	575	25.1°C	karstic valley between mountain Sniježnica and the Adriatic sea	this study
Montenegro	Ulcinj	42°01' - 41°51' N 19°09' -19°21' E	85	25.2°C	its southern part borders the river Bojana, in its central part is Lake Shas, and in the hinterland is the mountain massif of Rumia	this study

km wide) coastal plain (Allcock et al. 2018). Although the major part of Montenegro is mountainous, it has two climate regions that create two distinct landscapes. The southern and central regions belong to the Adriatic Sea basin with a Mediterranean climate, with dry summers and mild, rainy winters, and the northern regions north of the capital Podgorica belong to the Black Sea basin and have a Continental Alpine climate zone with hot, humid summers and cold winters with heavy snowfall (Allcock et al. 2018, Clancy 2007). In Montenegro, we conducted our study in the southern-most Montenegrin area of Ulcinj (Table 1).

Field Surveys

Breeding-season field surveys were conducted from 2012 through 2017. We used the playback method as suggested by Samwald & Samwald (1992). At each survey point we first listened for spontaneously calling males for one minute, then broadcast playback of a male call for one minute, and then waited three minutes more for responses (Samwald & Samwald 1992, Denac 2009). In all study areas the survey was conducted only once. Points in each study area were spaced 500 to 1500 m apart, depending on the openness and forest cover of the terrain (Samwald & Samwald 1992, Denac 2009). All survey points were selected in a way that allowed us to cover almost the entire surface of the selected area. We conducted each survey after sunset and finished it one hour before sunrise. Survey nights were dry with little or no wind. We had two survey areas in Slovenia: in the Slovenian Istra we surveyed an area of 338 km^2 from 308 points, and in Obsotelje we surveyed an area of 242 km^2 from 231 points. In Croatia we conducted surveys at four survey areas: in Pula we surveyed an area of 42 km^2 from 44 points; in Novi Vinodolski an area of 37 km^2, from 30 points; by Vransko jezero an area of 42 km^2 from 38 points; and in Konavle an area of 211 km^2 from 88 points. In Montenegro we conducted a survey in Ulcinj where we 52 km^2 from 38 points.

Data Analysis

Crude density of Eurasian Scops-owl males was estimated by dividing the total number of singing males obtained from a single survey area by the total size of that study area (km^2). We explored the data for any changes in the population densities along the eastern Adriatic coast (north to south) and with the distance from the sea (west to east). Statistical analysis was conducted with the program PAST, version 3.16 (Hammer et al. 2001).

Results

Overall, a total of 498 singing Eurasian Scops-owl males were detected at 272 of the 777 (35%) survey points. A total of 964 km^2 was surveyed. Population densities in our field surveys ranged from 0.09–1.6 males/km^2, and were from 0.06 – 1.0 males/km^2 in the published literature (Table 2).

In Slovenia, the population density of Eurasian Scops-owls was highest in the Slovenian Istria (0.7 males/km^2) (Fig. 2). From the sea coast to 250 km inland, densities gradually decreased (r_S = -0.84, p <0.05). In the area of Karst (0.3 males/km^2; Šušmelj 2011) population density was very similar to that of Goričko (0.2–0.5 males/km^2; Štumberger 2000, Denac et al. 2015) and Ljubljansko barje (0.2–0.4 males/km^2; Denac 2000). Very low densities were recorded in the areas of Kozjansko (0.05–0.3 males/km^2; Jančar & Trebušak 2000, Kmecl et al. 2010, Denac et al. 2011) and Obsotelje (0.09–0.12 males/km^2), probably because both areas are very densely forested and there is very little suitable habitat for the species.

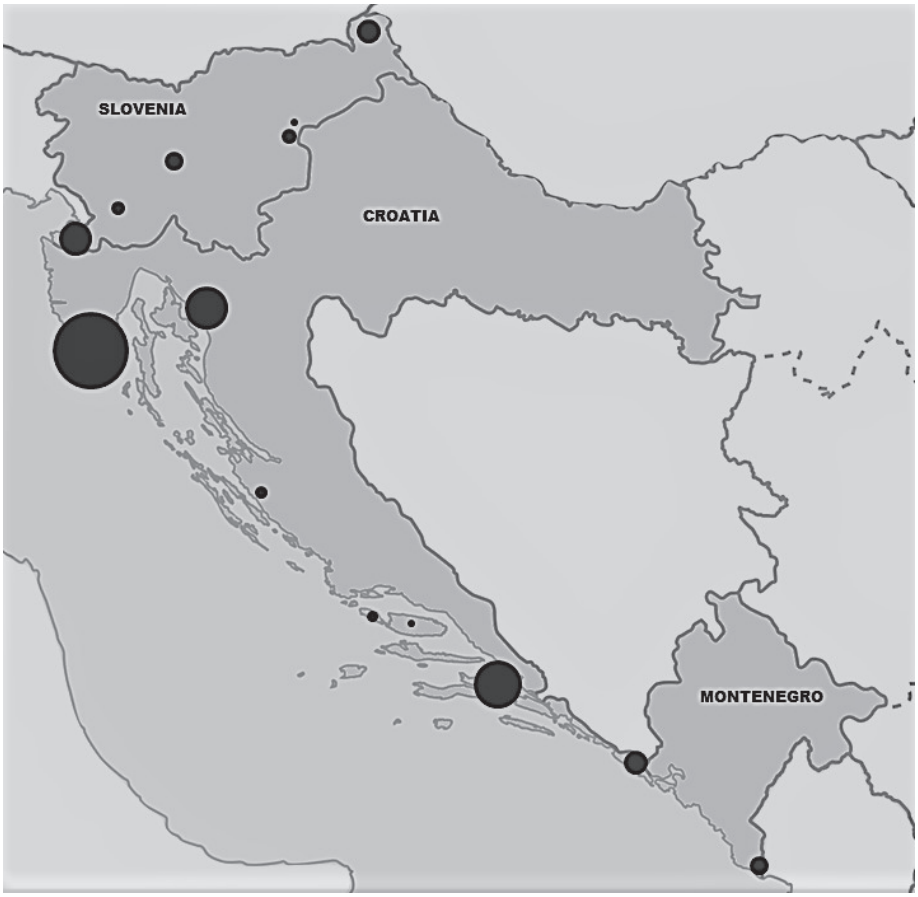
Table 2 - Distribution and population density of the Eurasian Scops-owl (*Otus scops*) in Slovenia, Croatia and Montenegro (this study and published literature). The size of dots represent the calling density of males/km2.

Tabela 2 - Distribuição e densidade populacional do mocho-d'orelhas (*Otus scops*) na Eslovénia, Croácia e Montenegro (neste estudo e na literatura), O tamanho dos pontos representa a densidade de machos detetados a vocalizar por km2.

SURVEY AREA	SURVEY YEAR	BREEDING DENSITY (males/km^2)	SURVEY AREA (KM^2)	NUMBER OF CALLING MALES	NUMBER OF SURVEY POINTS	NUMBER OF CALLING MALES PER SURVEY POINT (males/survey point)	SOURCE
Goričko (SI)	1997	0.5	442	210	247	0.9	Štumberger (2000)
Goričko (SI)	2015	0.2	408	77	418	0.2	Denac *et al.* (2015)
Obsotelje (SI)	2015	0.09–0.12	242	21	231	0.09	this study
Kozjansko (SI)	2010	0.07	206	15	-	-	Kmecl *et al.* (2010)
Kozjansko (SI)	2001–2010	0.3	206	60-70	-	-	Denac *et al.* (2011)
Kozjansko (SI)	1999	0.05-0.1	198	10-20	-	-	Jančar & Trebušak (2000)
Ljubljansko barje (SI)	1998	0.4	163	64	-	-	Denac (2000)
Ljubljansko barje (SI)	1999	0.2	163	40	-	-	Denac (2000)
Karst (SI)	2006, 2008	0.3	665	347	406	0.9	Šušmelj (2011)
Slovenian Istra (SI)	2013	0.7-1.0	338	239	308	0.8	this study
Pula (HR)	2012	1.6-2.0	42	69	44	1.6	this study
Novi Vinodolski (HR)	2016	0.9-1.4	37	34	30	1.1	this study
Vransko jezero (HR)	2016	0.2-0.3	42	8	38	0.2	this study
Šolta (HR)	2008	0.25	52	13	-	-	Mužinić & Purger (2008)
Brač (HR)	2003	0.06	395	24	-	-	Bordjan & Rozoničnik (2010)
Pelješac (HR)	1998	1.0–1.5	93	90	-	-	Vrezec (2001)
Konavle (HR)	2012	0.5–1.5	211	103	88	1.2	this study
Ulcinj (ME)	2017	0.4–0.8	52	24	38	0.6	this study

Figure 2 - Distribution and population density of the Eurasian Scops-owl (*Otus scops*) in Slovenia, Croatia and Montenegro (this study and published literature). The size of dots represent the calling density of males/km^2.

Figura 2 - Distribuição e densidade populacional do mocho-d'orelhas (*Otus scops*) na Eslovénia, Croácia e Montenegro (neste estudo e na literatura), O tamanho dos pontos representa a densidade de machos detetados a vocalizar por km^2.



Along the eastern Adriatic coast from Slovenia to Montenegro densities of Eurasian Scops-owls did not show any trends, even at the 600 km distance (r_S = -0.37, p = 0.33) (Fig. 2). The highest densities were found in Pula (1.6–2.0 males/km^2) and the Pelješac peninsula (1.0–1.5 males/km^2; Vrezec 2001). Also high was the density in Novi Vinodolski (0.9–1.4 males/km^2). In the most southern area of Ulcinj (0.4–0.8 males/km^2) and in Konavle (0.5–1.5 males/km^2) densities were also high and similar. Densities in the central part of Dalmatia were very low: in Vransko jezero (0.2–0.3 males/km^2) and in islands of Šolta (0.25 males/km^2; Mužinić & Purger 2008) and Brač (0.06 males/km^2; Bordjan & Rozoničnik 2010).

Discussion

The present study is an overview of the population density of Eurasian Scops-owls along the eastern Adriatic coast in Slovenia, Croatia, and Montenegro, which showed a significant decrease of density in a gradient from the sea coast inland, but not north-south along the sea coast. The Eurasian Scops-owl more or less uniformly populated areas with a Mediterranean climate, but there is a great switch toward a more continental climate a few hundred km to the north. For example, in Slovenia the highest abundance was found in the Slovenian Istria, which is probably the largest population in Slovenia,

but the density was almost half in Goričko, 250 km to the north. Several climate-driven factors contribute to changes in the vegetation structure, which is mainly forest (Perko et al. 1999), altering the overall species assemblages, especially within the owl guild, with larger intraguild predatory owls, such as the Tawny Owl *(Strix aluco)* (Galeotti & Gariboldi 1994, Sergio et al. 2009), which is rarer in the Mediterranean region, but more common in continental areas (Sovinc 1994, Geister 1995).

In three areas of Croatia, population densities were much higher compared to other study sites. One of the characteristics of the species is that it can be locally very concentrated (Vrezec 2001) or it can form calling groups (Štumberger 2000). This agrees with the statement from Glutz von Blotzheim & Bauer (1980) that Eurasian Scops-owls can form colonies where conditions are favourable. Comparing the number of calling males per survey point in our study areas, we can see that in some study sites like in Pula (1.6 males/survey point), in Novi Vinodolski (1.1 males/survey point) and in Konavle (1.2 males/survey point) calling males were distributed evenly along the study area, while in other study sites calling males were very dispersed. In two study sites in Obsotelje (0.09 males/survey point) and in Goričko (0.2 males/survey point) calling males were very rare. This may be because of the unfavourable habitat conditions for this species (dense forest and open panoramas with fields) and that Eurasian Scops-owl is uncommon summer visitor in the continental regions (Mikkola 1983) meanwhile, along the eastern Adriatic coast it is a very common but locally distributed.

Population density (measured as calling males per km^2) is an important metric for assessing population status. We suggest that one of the owls' population strongholds in Europe is situated along the eastern Adriatic coast including the countries of Slovenia, Croatia, and Montenegro. The eastern Adriatic coast appears to be a very important breeding area for this species in comparison with continental regions, where the species is also decreasing as shown by the data from Goričko in the NW part of Slovenia (Denac et al. 2015). Data suggest that the owl is well distributed in the coastal areas of Slovenia in Slovenian Istria, and also in Croatia, in Pula, Novi Vinodolski, Peninsula Pelješac and in Konavle. We urge future studies in Montenegro, to assess the distribution, density and population size of Eurasian Scops-owls in that country.

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Reintroducing the Ural Owl (*Strix uralensis*) to Austria – Requirements for a successful comeback

Reintrodução da coruja dos Urales (*Strix uralensis*) na Áustria – requisitos para um regresso bem-sucedido

Richard Zink[1,*], Theresa Walter[2], Christoph Leditznig[3], Ingrid Kohl[4]

1 Austrian Ornithological Centre, Konrad Lorenz Institute of Ethology, Veterinary University of Vienna, Savoyenstraße 1a, 1160 Wien, Austria

2 Conservation Medicine Unit, Research Institute for Wildlife Ecology, Veterinary University of Vienna, Savoyenstraße 1, 1160 Wien, Austria

3 Dürrenstein Wilderness Area Administration, Brandstatt 61, A-3270 Scheibbs, Austria

4 REWILD Institute – Research on Ecosystems and Wilderness A-1130 Vienna, Austria

*** Corresponding author:** richard.zink@vetmeduni.ac.at



ABSTRACT

The Ural Owl (*Strix uralensis*) became locally extinct in Austria (Europe) around 60 years ago. Since 2008 a reintroduction project for the Ural Owl takes place to re-establish the species in the Austrian woods. A renewed distribution in the Alps will establish an essential connection between the remaining populations south (Slovenia, Italy) and north (Germany, Czech Republic) of Austria and the alpine arch. Individuals that occasionally disperse between the newly established population in Austria and the ones in the neighbouring countries will ensure a genetic flow within European meta-populations, which is vital for the survival of the species in the long term. Since the start of the project and until the end of 2017, 300 owls have been released. Between 2011 and 2017 and a minimum of 58 breeding attempts in the wild could be verified with a total number of 115 owlets fledged. The average number of owlets fledged in the field was 2.6 per successful brood.

We present an overview of the most important factors for a successful reintroduction project in the three main areas of breeding, release and monitoring. Requirements for successful breeding of Ural Owls for release as well as administration and development of the breeding network are discussed. The method of release is explained and lessons learned from 9 years of experience are demonstrated. For the monitoring section, we show that the combination and interconnection of monitoring methods used, helps to re-identify birds on a regular basis and keep an eye

on the development of the population in the field. Monitoring methods addressed and evaluated include the installation of nest boxes, special colour rings with inserted RFID Chips for re-identification, telemetry and establishment of a genetic monitoring system.

Keywords: Austrian Alps, monitoring methods, reintroduction, *Strix uralensis*

RESUMO

A coruja dos Urales (*Strix uralensis*) tornou-se localmente extinta na Áustria (Europa) há cerca de 60 anos. Está em curso, desde 2008, um projeto de reintrodução da coruja dos Urales para restabelecer a espécie nas florestas austríacas. Uma nova distribuição nos Alpes estabelecerá uma ligação essencial entre as populações remanescentes no sul (Eslovénia, Itália) e no norte (Alemanha, República Checa) da Áustria, e o arco alpino. Os indivíduos que migram ocasionalmente entre as populações recém-estabelecidas na Áustria e aqueles nos países vizinhos garantirão um fluxo genético entre meta-populações europeias, o que é fundamental para a sobrevivência da espécie a longo prazo. Desde o início do projeto, e até ao final de 2017, foram libertadas 300 corujas. Entre 2011 e 2017 foram verificadas 58 posturas (incluindo tentativas de reprodução mal sucedidas), tendo sido contabilizados no total 115 juvenis voadores. O número médio de juvenis voadores foi de 2,6 por ninhada bem-sucedida.

Apresentamos uma visão geral dos fatores mais importantes para o sucesso de um projeto de reintrodução, focando as três principais áreas de atuação: reprodução, libertação e monitorização. São discutidos os requisitos para o sucesso da reprodução de coruja dos Urales para liberação, bem como a administração e desenvolvimento da rede de reprodução. O método de libertação é explicado e as lições aprendidas em nove anos de experiência são demonstradas. Na componente de monitorização, mostramos que a combinação e a interligação dos métodos de monitorização utilizados ajudam a re-identificar as aves numa base regular, e permite acompanhar o desenvolvimento da população no campo. Os métodos de monitorização abordados e avaliados incluem a instalação de caixas-ninho, de anilhas coloridas especiais com chips RFID para re-identificação, telemetria e estabelecimento de um sistema de monitorização genética.

Palavras-chave: Alpes Austríacos, métodos de monitorização, reintrodução, *Strix uralensis*

Introduction

The Ural Owl (*Strix uralensis*) is a medium sized owl within the *Strix* genus including several subspecies with a distribution ranging from Europe to Northern Asia and Japan. In Europe there are two strongholds: one in northern and one in southern Europe. While there are still substantial populations in the Dinaric Alps and the Carpathians, in central Europe, it became locally extinct in Germany, as well as in Austria during the 20th century (Zink 2007, Zink & Probst 2009). Since the 1970s a successful reintroduction project has been carried out on the bohemian plateau in Germany and since 1995 in the Czech Republic (Bufka & Kloubec 2001,

Beran 2005, Scherzinger 2006). In 2006 an expert meeting to discuss further conservation actions for the Ural Owl in Central Europe was held in Grafenau, Germany. It was decided in the meeting that the European meta-populations have to be connected in the future in order to ensure sufficient gene flow between the populations. To reach this goal, the re-establishment of the former Alpine population was considered necessary. This renewed population is supposed to establish the essential connection between the remaining populations south (Slovenia, Italy) and north (Germany, Czech Republic) of Austria and the alpine arch. Dispersing individuals between the newly established population in Austria and the ones in the neighbouring countries can bridge the distances and ensure genetic flow on the long term.

Previous to starting the reintroduction project a feasibility study was performed (Steiner 2007, Zink 2007). This study addressed former extinction risks and their current status, availability of suitable habitat and food resources, as well as the potential of bridging the genetic gap between the Central European populations. Before the start of the re-introduction project it is essential to research the reasons for the former extinction of a species to assess their current relevance (IUCN/SSC 2013). For the Ural Owl in Austria the main driving forces that lead to extinction were poaching (Zink & Scherzinger unpub. data) and due to changes in forestry the loss of massive deadwood stumps or old trees with holes in them for breeding, as it was the case in Scandinavia (Lõhmus 2003). Poaching of Ural Owls is no longer permitted in Austria (Zink & Probst 2009), nor is it of any interest to the hunters. With the establishment of protected areas, where trees are not harvested, the first steps towards minimizing the lack of nest sites for Ural Owls were taken. Furthermore the project planned to set up nest boxes in managed forests. It was also verified whether dispersal is actually sufficient to bridge the gap between subpopulations. The approximate distance between the German and the Slovenian/Italian population is about 220 km. According to data from Saurola & Francis (2004) the vast majority of Ural Owls disperse over a distance of less than 50km. About 5-10% of the surveyed individuals dispersed beyond 100 km. These individuals would be able to connect the meta-populations starting in Austria at the northern slopes of the Alps when considering only dispersal distance.

In 2008 the re-introduction project of the Ural Owl in Austria started. It is conducted by the Austrian Ornithological Centre (Veterinary University of Vienna) in cooperation with the Wienerwald Biosphere Reserve and the Dürrenstein Wilderness area. The first releases of young owls took place in 2009 and are ongoing. Reintroduction projects call for careful planning and long-term actions. In this article we outline the requirements for a successful reintroduction of the Ural Owl in Austria. This includes the setting up of a captive breeding stock with a managed studbook, the care for best release techniques, the usage of effective monitoring methods as well as the involvement of all relevant stakeholders.

Material and Methods

From the beginning of the project on, it was essential to establish a captive breeding network cooperating with many institutions in Central Europe (e.g. Zoos, wildlife parks, private institutions). The aim of the studbook was to get a gene pool from the nearest populations, without taking birds from the wild in order to avoid weakening or diminishing the neighbouring populations. To achieve this, fresh bloodlines are incorporated by receiving injured birds from nature, which cannot be released again. Agreements on this have been installed with Slovenia, Slovakia and Croatia. Another option is to receive

young birds from Zoos which are keeping animals from the neighbouring populations. A main point of concern is the avoidance of imprinting through hand rearing. All birds used in the reintroduction project have to be "behaviourally intact". Birds in the breeding network should be given adequate and best quality food in order to produce offspring with high fitness.

For a successful release several pre-conditions have to be met: The extinction risk of the species has to be lower than when it went extinct, stakeholders - for example hunters and foresters – have to be involved in the project, and a check for habitat suitability in the area of release as well as immediately around the release site is necessary. The possible impact of the reintroduced species on other species and ecosystem functions should be considered.

Before Ural Owls are released they have to be able to acclimatise for three weeks at the place of release. Training with live prey has to be ensured during this time period. Ural Owls in our experience have to be released between 90 and 100 days of age. Then they can rely on additionally supplied food on feeding tables (without human contact) until their hunting abilities are fully developed. When released later, the birds tend to disperse immediately and cannot be supported with food. This can lead to high mortality in released birds. After release, surplus food has to be offered immediately next to the place of release on feeding tables that are secure for the birds. This mimics parental care in the wild, which lasts until the autumn when juveniles are approximately half a year old (Scherzinger 1980). Adoption by wild couples is possible. Supporting these couples with extra food might be necessary in years with bad food conditions. It is also necessary to care for suitable and sufficient nest sites in the vicinity of release sites before releasing birds.

Concerning different monitoring methods after release, it's important to avoid usage of single methods. Different methods can focus on various aspects (e.g. genetics, survival, reproduction). Ensure operational liability of monitoring methods on the long term (e.g. durability of nest boxes or marking techniques). We use the following monitoring methods within the reintroduction project of Ural Owls in Austria: genetic monitoring including genetic fingerprints from every bird used within the studbook and born in the project (breeding network and in the wild), nest boxes with mirror / camera, colour rings with inbuilt RFID- microchip, telemetry, acoustic recorders, observations and camera traps. Within this article we focus on the use of genetics and nest boxes. The genetic monitoring is carried out at the genetics lab of the Department of Interdisciplinary Life Sciences at the University of Vienna. We use different types of next boxes within the project. The main type used is made out of recycled dustbins provided by the city of Vienna (material is polyvinyl chloride - PVC) with a mirror on the upper inside for monitoring. Through the mirror breeding birds can be monitored with binoculars without distracting the bird. Nest boxes are controlled 3 times minimum per breeding period to assess breeding status.

The final important point for a successful reintroduction project is to create a network of partners and supporters, as well as to secure sufficient finances before the start of the project. The project was and is funded by the EU through the European Agricultural Fund for Rural Development, the federal states Lower Austria and Vienna, the Austrian State Forests and many others. For a complete list have a look at the webpage: www.habichtskauz.at.

Results

Since the start of the Ural Owl reintroduction project in Austria in 2008 a captive breeding network with an average of 50 active couples could be established. The number of

active couples varies from year to year. Ural Owl couples within the breeding network are being kept in Austria, Germany, Switzerland, Italy, Czech Republic and Poland. We have data of over 100 new couple formations and information on 891 birds from twelve different European countries in our database. This database also includes the DNA-fingerprints of more than 500 individuals, which are used for genetic analysis.

Between 2009 and 2017 a total of 300 birds have been released in two different release areas (Figure 1). The number of released birds varied between 22 in 2009 and 45 in 2016 with an average of 33.3 birds per year. In the Wienerwald Biosphere Reserve 5 release sites are available, where 159 birds (females n = 71, males n= 81) were released (mean 17.6 birds per year). In the Wilderness Area Dürrenstein two release sites are available, where 141 birds were released (females n = 63, males n = 75, unknown sex n = 3) (mean 15.6 birds per year). This equals a total sex ratio of released birds of 47% females, 54% males and 0.01% birds of unknown sex.

We focus in this paper on reporting about two of our monitoring methods. With DNA fingerprints from all released birds the tracking of parenthood of offspring fledged in the wild can be determined. Since the start of the project 47 individual breeding birds could be identified either through their own feather samples or through those of their offspring. With help of the geneticist we are also able to keep track of the sex ratio – both of released and of birds born in nature. For the subpopulation in the Wienerwald Biosphere Reserve it can be shown that when accounting for released birds and birds born in nature the sex ratio is skewed towards a male surplus (females n = 103, males n = 134).

The project aimed to provide sufficient nest sites in managed forests where natural nest site availability is not always sufficient. Nest boxes were fixed in release areas as well as along potential migration corridors to facilitate gene flow. So far more than 450 nest boxes have been fixed, whereof 433 are currently in function. Through the control of nest boxes (and in some cases through the combination with telemetry) roughly 30 territories could be localised along the northern slopes of the Alps. Nest boxes are also willingly used by Tawny Owls (*Strix aluco*), with occupation rates of up to 80% in years with good food availability. The mean installation height of nest boxes is 10 m.

The network supporting the return of the Ural Owl to Austria consists of a cooperation of 21 zoos all over Europe, the involvement of 13 institutions also being part of the breeding network. A lot of time has gone into organizing volunteers who check nest boxes during the breeding season. Currently 60-70 people are involved every year and each of them surveys between one and 50 nest boxes for the project.

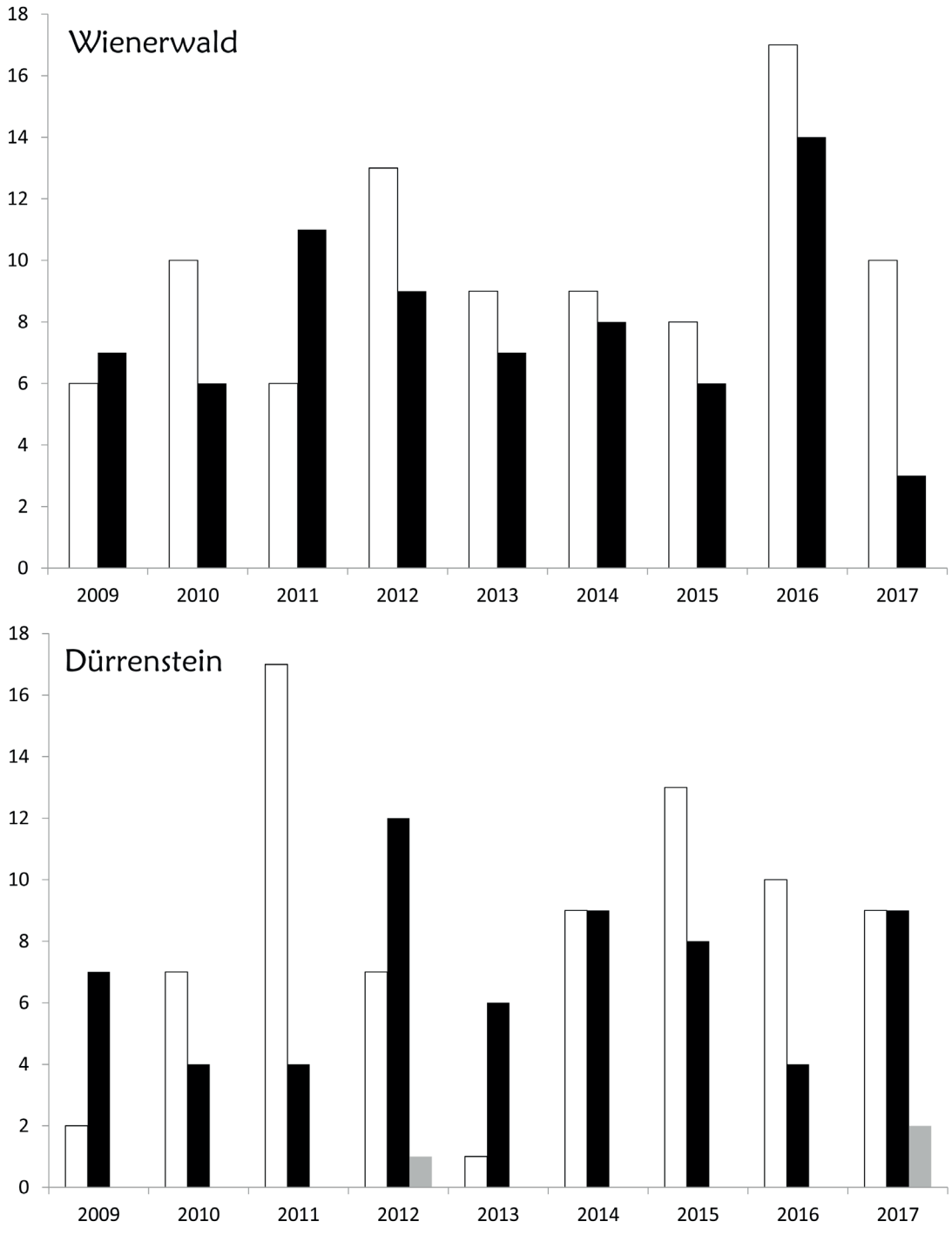
So are we successful with re-introducing the Ural Owl to Austria? Between the first release of birds and the end of 2017 we obtained the following results. All together we found 27 different breeding pairs, at least 58 broods could be recorded, out of which 44 broods were definitely successful. 115 owlets fledged successfully equalling 1.98 chicks for all broods and 2.61 chicks per successful brood.

Discussion

The reintroduction of any species has to be considered carefully, both before and during the implementation. Preceding considerations of the Ural Owl reintroduction were the following: From a European conservation perspective, the population of the species has been slightly increasing both in the northern and southern sub-populations during recent years (Bird Life International 2017). However, the former distribution range in Austria has not been autonomously recolonized for many decades, even though

Figure 1 - Annual number of released birds for the two release areas Biosphere Reserve "Wienerwald" and Wilderness Area "Dürrenstein" (white = males, black = females, grey = sex unknown).

Figura 1 - Número de aves libertadas anualmente na Reserva da Biosfera de Wienerwald e na Área Selvagem de Dürrenstein (branco = machos, preto = fêmeas, cinzento = sexo indeterminado).



healthy population strongholds are known to exist south and east of Austria. A reintroduced population in Austria would not only cover the former distribution area, it also can facilitate gene flow between northern and southern sub-populations. In our project, the species also acts as a flagship species for illustrating the importance of forest ecosystems. From an ecological point of view, the impacts of a reintroduced predator have to be considered. Korpimäki & Hakkarainen (2012) stated that the occurrence of the Ural Owl has a negative impact on smaller owls such as the Boreal Owl (*Aegolius funereus*) in coniferous forests. On the other hand Vrezec & Tome (2004) found that in Slovenia Boreal Owls profit from the presence of Ural Owls, when Tawny Owls (*Strix aluco*) are present in the same ecosystem. Due to the complexity of ecosystems it is difficult to have a complete view on all species interactions. Since the Ural Owl used to be part of the Austrian forest ecosystem, we assume that it will again take its place within this forest owl guild.

For the implementation of reintroductions, careful planning and learning from the experiences others already made, helps to avoid mistakes and increases the chances of success. Based on our experience with the reintroduction of the Ural Owl in Austria, we recommend the establishment of a captive breeding network including a managed studbook, the identification and use of the best release techniques, the usage of effective monitoring methods as well as the involvement of all relevant stakeholders.

Using birds for release that are born within a captive breeding network poses the advantage that no remaining populations in the wild are threatened by removal of birds for the reintroduction somewhere else. In the reintroduction of Ural Owls it became obvious that knowing the date of birth and therefore the age of released birds is crucial for their survival after release. When birds are born within a breeding network, this data is known. Keeping a well-managed studbook is crucial to allow the organization of breeding pairs to enhance genetic variability and avoid inbreeding. Extensive research of the genetic origin of birds within the breeding network is highly recommended in order to consider the "best" genetic origin of founder birds (Scherzinger 2014). Refrain from hand-raising chicks to avoid imprinting and miss-behaviour at later life stages especially during their reproduction.

Of all influencing factors on the success of release, the time of release is the most important to consider. Scherzinger (2007) recommended releasing Ural Owls with about 100 days of age. Through telemetry and intensive monitoring of feeding stations with camera traps we could improve this recommendation. Hence, we recommend releasing Ural Owls at the age of 90 to 100 days before their dispersal phase starts and birds cannot profit from surplus food provided after release. When Ural Owl couples are already present, adoption by wild breeding pairs could be observed. We recommend using only young birds, since older birds are already accustomed to dead food and have not developed hunting skills during growing up.

It is necessary to set up a genetic monitoring program for every reintroduction program. Only through a comprehensive monitoring of genetic origins of birds genetic variance in released birds as well as in the newly established population can be followed. Also genetic monitoring allows to manage for a balanced sex ratio in released birds. Release has to occur continuously to ensure proper demographic development. Do not release more than 8-10 birds per release site as this may lead to intraspecific competition amongst juveniles after release. Limit competition among birds and therefore do not release where couples have already settled and reproduce, except if surplus feeding can be provided and therefore adoption is made possible.

When choosing monitoring methods for reintroduction projects these methods should

monitor all important aspects (i.e. survival/ mortality of released birds, dispersal, pair formation, reproduction, genetics, food sources and availability of nest sites) to enable an evaluation of the project. We recommend securing staff, equipment and finances on the long-term when choosing monitoring methods and balancing outcome and costs, especially when using expensive techniques like telemetry or sound recording. Do not underestimate the value of simple techniques like behavioural observation.

With help of the geneticist we are able to keep track of the sex ratio – both of released and of birds born in nature. This is essential to trace demographic development of the growing but still fragile population. Finally knowledge about sex distribution helps to decide where to release the next females/ males in order to try to balance sex ratios.

Another valuable monitoring method used in the project are nest boxes. We decided to use nest boxes made from materials that do not decay in order to safeguard their long-term existence. The function of wooden nest boxes expires usually after 10-15 years and maintenance can be time consuming. It can happen that the material in wooden nest boxes spills out through cracks that develop between the wooden boards. This can lead to owls not using the nest box when it is completely empty when all nesting material has spilled out or to the failure of breeding attempts due to an insufficient amount of nesting material. Boxes made out of PVC are long lasting and easy to maintain. Fixing a mirror in the nest box enables controls from the ground without disturbing the bird. Considering the aggressive behaviour of females during rearing period, we fix nest boxes in heavily used recreation areas above 10-15m. Thus we have never had any attacks so far. Monitoring through nest boxes is useful to find territories when a species distribution is scarce. It might be argued that birds which are reared in nest boxes in captivity will only breed again in nest boxes in the wild. However, we have already verified territories with birds breeding in natural cavities. This was possible by the use of telemetry or the periodic reporting of sightings from interested people within territories.

In less than a decade it was possible to build up two new population nuclei of about 15 couples each. We know that a high proportion of adults kept their territory for several and up to 9 years. We could show that reproduction parameters equal those of well-known populations e.g. in Finland median 1986-2007 =2.19 / successful brood (Saurola 2009), in Sweden 2.15 (Lundberg & Westman 1984). Even though we know through radio tracking that we lose 10-20% of released birds during their first year (Kohl & Leditznig 2014), we are still lacking sufficient knowledge about adult mortality. Possible mortality risks for Ural Owls include traffic collisions, illegal persecution, electrocution, predation (through Golden Eagles (*Aquila chrysaetos*), foxes (*Vulpes vulpes*) and most probably Eurasian Eagle-owls (*Bubo bubo*)) and collision with fences, glass or aerial cable. In how far rodenticides and genetic isolation can be a risk for the newly established population is not clear yet. However, we assume that genetic isolation is not an immediate risk, since we were able to verify a couple of long distance movements (Kohl & Leditznig 2014). They show us that gene flow to and from adjacent subpopulations is definitely possible.

As it is already well known for Ural Owl populations in Finland and Sweden (Brommer, Pietiäinen et al. 2002, Brommer, Pietiäinen et al. 2002, Sundell, Huitu et al. 2004) we also observed a strong dependence of the reproductive outcome and mice/vole years. In our area mice gradation almost exclusively depends on beech mast seeding. The events of mast seeding seem to occur more often (maybe due to climate change). However, mice/vole gradations are not as regular as observed in more northern areas. If we compare the number of released birds

versus those fledged in nature we can expect a balance soon. This will be a signal to lower release activity and focus on the monitoring of further population development.

Conclusions

Our vision to re-establish the Ural Owl in the Alps has almost become true. Through a strong network of zoo-collaborations it was possible to release noteworthy numbers of young owls within a relatively short period of time. We implemented successful release techniques and could prove pair formations and reproduction in the wild. The monitoring methods we chose helped to follow population development and to evaluate the re-introduction process. Reproductive data in the recovered habitat are good and mortality seems to be acceptable. Via long distance dispersal we could prove cross linking of populations. Last but not least a lucky choice of project partners secured funds needed to carry out the project. Stakeholders involved approve of the project and support the return of the Ural Owl. In the future we will focus on further monitoring the population development, broaden the genetic basis by releasing rare genetic lineages, thus increasing the quality of released birds, but reduce the quantity of releases when appropriate.

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The Eurasian Eagle-owl (*Bubo bubo*) as a breeder on buildings in Germany

O bufo-real (*Bubo bubo*) como nidificante em edifícios na Alemanha



Martin Lindner[1*]

1 German Association for the Protection of Owls (Owls Working Group), Parkstraße 21, 59846 Sundern, Germany

*** Corresponding author:** martin.lindner@ageulen.de

SUMMARY

In Germany, Eurasian Eagle-owls (*Bubo bubo*) have been known to breed on man-made structures since the middle of the 16th century. Frequent use was made of such sites, mainly ruins, castles and churches, until the middle of the 19th century with the last documented cases in the 1880s. There was one isolated record in 1927. Since 1975, more than 170 man-made structures have been used as breeding including radio towers, bridges, houses, power stations, ruins, castles, churches, and industrial buildings. In 2016, more than 60 buildings were reportedly occupied by pairs. Although some sites have been used for up to 20 years, most are used for 1-3 years, probably due to disturbance. Many breeding attempts were unsuccessful, particularly those in ruins or churches occupied for 1-2 years. Breeding sites in industrial buildings and buildings in rock quarries and sand or gravel pits are generally used for longer periods. In recent years, Peregrine Falcon nest boxes on buildings have been increasingly used. Particularly at breeding sites in towns, Eurasian Eagle-owls suffer from Trichomonosis and Hepatosplenitis infectiosa strigum infections from feral pigeons (Columbidae), the main prey of the owls in such areas. The captive breeding and release of Eurasian Eagle-owls into the wild has likely contributed to recent increased use of buildings and it is anticipated that a great variety of building types will be used over time. Its population will also increase in larger cities in response to prey availability despite human disturbances in cities. Nests on buildings have also been found in Spain, Sweden, Belarus, Austria, Belgium, Italy, Finland, France and Mongolia.

Keywords: building breeder, Eurasian Eagle-owl, Hepatosplenitis infectiosa strigum, nest box, Trichomonosis

RESUMO

Na Alemanha, o bufo-real (*Bubo bubo*) é conhecido por nidificar em estruturas artificiais desde meados do século XVI. Essas estruturas foram usadas com frequência até meados do século XIX, sobretudo ruínas, castelos e igrejas, datando os últimos casos documentados da década de 1880. Existe um registo isolado de 1927. Desde 1975, mais de 170 estruturas artificiais têm sido usadas para reprodução, incluindo antenas de telecomunicações, pontes, edifícios de habitação, estações elétricas, ruínas, castelos, igrejas e edifícios industriais. Em 2016 foram reportados mais de 60 edifícios ocupados por casais de bufo-real. Apesar de alguns locais terem sido usados durante períodos de até 20 anos, a maioria é usada durante 1-3 anos, provavelmente devido a perturbação. Várias tentativas de reprodução não foram bem-sucedidas, sobretudo aquelas em ruínas ou igrejas ocupadas durante 1-2 anos. Os locais de nidificação em edifícios industriais, pedreiras e locais de extração de areia ou cascalho são geralmente usados por períodos mais longos. Recentemente, a espécie tem usado cada vez mais caixas-ninho para falcão-peregrino instaladas em edifícios. Em particular nos locais de nidificação em cidades, os bufos-reais são infetados com tricomoníase e Hepatosplenitis infectiosa strigum por pombos assilvestrados (Columbidae), a principal presa da espécie nessas áreas. A libertação de bufos-reais criados em cativeiro contribuiu para o recente aumento do uso de edifícios e prevê-se que uma grande variedade de estruturas artificiais venha a ser usada ao longo do tempo. A sua população irá ainda aumentar nas grandes cidades em resposta à disponibilidade de presas, apesar da perturbação humana. Foram também encontrados ninhos de bufo-real em edifícios em Espanha, Suécia, Bielorrússia, Áustria, Bélgica, Itália, Finlândia, França e Mongólia.

Palavras-chave: bufo-real, caixa-ninho, Hepatosplenitis infectiosa strigum, nidificante em edifícios, tricomoníase

Introduction

Due to massive persecution in Germany as well as throughout western and central Europe, Eurasian Eagle-owl (*Bubo bubo*) populations collapsed in the 19th century. The persecution was boosted by shooting bonuses and the removal of young Eurasian Eagle-owls from nests for use as hunting lures; hunters shot birds of prey and crows that mobbed tethered Eurasian Eagle-owls. In 1900, only 150-155 breeding pairs still survived in Germany within today's borders. In 1930 this had decreased to 50-70 Eurasian Eagle-owl breeding pairs restricted to inaccessible rock faces because of intense persecution on buildings and in accessible places. By 1965, only about 70-80 breeding pairs remained in Germany (Lindner 2014). As a rule, literature on Eurasian Eagle-owls did not mention breeding on buildings or only mentioned it in relation to the 19th century.

In fact, the Eurasian Eagle-owl is the most flexible of the Palaearctic owl species in its choice of nesting sites, including natural rock faces, quarries and steep slopes in mountains and low mountain ranges. In the lowlands they use nests built by other large birds and on the ground (Glutz von Blotzheim & Bauer 1994, Görner 2013). Since the 1980s, the Eurasian Eagle-owl population in Germany has increased sharply. This is due to conser-

vation measures and to the release of more than 4060 captive-bred Eurasian Eagle-owls between 1955 and 2002. Reintroduction has significantly contributed to today's almost nationwide Eurasian Eagle-owl distribution. The majority of the population is made up of direct descendants of introduced owls (Lindner 2015). Information sources differ regarding the Eurasian Eagle-owl population size in Germany. Territory mapping carried out from 2005-2009 for a distribution atlas indicated 2100 to 2500 territories (Gedeon et al. 2014). However, this is almost certainly an underestimate, as the mapping was not specifically aimed at owls. Another estimate is that 4000 to 5000 breeding territories are occupied in Germany (Mikkola 2013). Today Eurasian Eagle-owls can appear anywhere in Germany including on buildings and structures in urban areas.

The data in this paper has been derived from my 31 years of experience with nesting Eurasian Eagle-owls in Germany, many specific nest site records from the literature, and from personal conversations.

Results and Discussion

Nesting on buildings had been widely known in the former German empire since the 16th century (Gessner 1555). Gessner wrote in 1555 that the Eurasian Eagle-owl readily bred in ruins and churches. Breeding on buildings was by no means peculiar to Germany in former times, but occurred in many countries. In 1622, for example, Giovanni Pietro Olina noted that in Italy the Eurasian Eagle-owl inhabited dilapidated ruins, holes in walls and the roofs of deserted houses (Olina & Macdonald 2018). Until the end of the 19th century, almost all literature about the Eurasian Eagle-owl mentioned breeding on buildings. The last three confirmed breeding occurrences on buildings took place in the 1880s. After that, there was a gap in documented cases until one in 1929 and then a further gap until 1975. In 1990, there were for the first time more than 10 cases of breeding on buildings (Lindner 2016). After 2007, the number of documented cases increased strongly. From 1975 to 2016 at least 170 buildings in Germany were known to be Eurasian Eagle-owl breeding sites. These comprised 45 castles and castle ruins, 50 industrial buildings and commercial buildings, 20 buildings in quarries and sand and gravel pits, 27 churches, eight road and railway bridges, four telecommunications towers, four detached houses, two multi-storey buildings and ten other structures. Extreme cases were nests on a funerary monument, an ammunition bunker, a submarine bunker and a bullet trap of a firing range. Prior to 1975, only ruins, castles, fortifications and churches had been known as breeding places (Lindner 2016). In 2016, at least 60 buildings were occupied by nesting Eurasian Eagle-owls. At least 30 other buildings were occupied by single Eurasian Eagle-owls. These records are minimal estimates as there are data gaps. Breeding on hunters' raised hides (blinds), which are being increasingly reported in Germany, are not included in the data.

Eurasian Eagle-owls generally lay their eggs in scratched-out depressions at the breeding site. If possible, they also scrape such depressions on buildings. But they also readily make use of sites where it is impossible to do so. In 2014, Eurasian Eagle-owls successfully bred on a double U-steel girder on dust and some pigeon feathers in an active warehouse in Karlsruhe. People were working in the warehouse during the day, and goods were handled with large cranes and other heavy equipment such as wheel loaders. The Eurasian Eagle-owls had to fly into the warehouse to reach their nest (Havelka & Scholler 2014).

Many of the successful and long-established breeding sites on buildings are located

on quiet, often shut-down industrial plants and structures in quarries and gravel pits. In many cases, abandoned buildings in quarries and gravel pits were used because the quarries or pits were small and had very low rock or gravel walls without sheltered breeding sites. The period that individual buildings were occupied varied from 1-25 years. Only eight buildings were occupied for more than 10 years. However, many nesting sites on buildings were occupied for only 1-2 years. In cases where breeding ceased, Eurasian Eagle-owl pairs or single birds sometimes remained for some time, occasionally for several years, at the building or in its surroundings. Quite often, Eurasian Eagle-owlsusing breeding sites on buildings were discovered during the autumn display period prior to the first breeding. Since 1975, the Eurasian Eagle-owl initially only nested on buildings in rural areas, but it is now also colonizing urban areas.

Buildings used by nesting Eurasian Eagle-owls are often unused by humans, at least when the owls start to nest. The owls are still sensitive to disturbance directly at the nest site. On the other hand, they tolerate noise and direct illumination at the nest site. Suitable nearby undisturbed roosts are also important and are typically protected from inclement weather, offer commanding views, and have an unhindered flight access. When Eurasian Eagle-owls are breeding in buildings, they may also use nearby tree roost sites.

On several occasions, breeding took place at sites 50 to 70 m above ground. In 2017, a Peregrine Falcon (Falco peregrinus) nest box 100 m high was used but was abandoned after human disturbance (Kladny 2017). In Germany, Eurasian Eagle-owls abandoned their clutches on a number of occasions after human disturbance, and the owls usually gave up such disturbed sites permanently. Young Eurasian Eagle-owl fledged when 45 days old (Penteriani et al. 2004) by jumping from building nests with considerable risk of injury or death. Hard edges, fences and other sharp objects as well as shafts in the landing area increase the risk of injury to the young birds. In 2009, a fledgling survived the jump from a height of 50 m (Lindner 2016). In 2017, one of two fledglings that jumped from a height of 65 m was killed (Löver 2018). There have been repeated cases of young Eurasian Eagle-owls being picked up and brought to rehabilitation stations after jumping to the ground in inner cities. These were then reared in captivity and later returned to the wild (Lindner 2016). In one extreme case in 1992, young Eurasian Eagle-owls were returned to a nest in a church 22 times until they fledged successfully (Harbeck 1995) because of a lack of understanding that young owls leave their nests before they can fly. In other cases, fledged young were placed in areas closed off to humans in safe areas in which they could mature and disperse (Harms 2016, Löver 2018).

Eurasian Eagle-owls in towns and cities face greater threats due to collisions with vehicles, trains and power lines. In cities, but also in rural areas, dead or sick adult and young Eurasian Eagle-owls infected with Hepatosplenitis infectiosa strigum and Trichomonosis have been found on a number of occasions. These infections are transmitted by feral pigeons (Columbidae), a main prey item in such areas (Lindner 2016).

In Germany, Continuous Ecological Functionality (CEF) measures are invoked when buildings with Eurasian Eagle-owl breeding sites are demolished. These may include the installation of specific artificial nesting sites (nesting or resting boxes) according to § 44 (5) of the German Nature Protection Law (BNatSchG). Such boxes measure 200 cm x 165 cm x 130 cm (width x depth x height) and are installed on other nearby structures (Brandt 2014).

Eurasian Eagle-owl nests on buildings have also been found in Spain, Sweden, Belarus, Austria, Belgium, Italy, Finland, France, Russia, and Mongolia. Today, in

many parts of Europe, Eurasian Eagle-owls are increasingly found nesting on buildings, even in large cities such as Stockholm, Helsinki, Madrid, Córdoba, Jerez de la Frontera, Trento, Budapest, Lyon and Marseille (Lindner 2016). This list of the countries and cities with Eurasian Eagle-owl nests on buildings in very probably incomplete.

The use of buildings by nesting Eurasian Eagle-owls is increasing in Germany. Prey availability is likely higher in cities than in many agricultural areas with their endless expanses of maize monoculture. Suitable prey species typically found in towns and cities include pigeons, the Brown Rat (*Rattus norvegicus*), European Rabbit (*Oryctolagus cuniculus*) and waterfowl (Anatidae) on city waters. The house/street pigeon (*Columba* spp.) is practically always among the main prey items of urban Eurasian Eagle-owls. Telemetry studies of urban Eurasian Eagle-owls have shown that they hunt in areas with a high density of prey species, such as waterfowl, brown rats and pigeons (Lindner 2016). In the future, prey availability for Eurasian Eagle-owls is unlikely to deteriorate in Europe's towns and cities. Therefore Eurasian Eagle-owl numbers in cities and their use of diverse buildings for nesting will continue to grow over the next few years. This may result in increased disturbance by humans requiring more protections by conservationists to prevent or minimize disruption and rescue fledgling owls. It is likely that the Eurasian Eagle-owl will breed most successfully on buildings in rural areas where towers, bridges and industrial buildings have fewer surrounding flight obstacles and young Eurasian Eagle-owls probably have better chances of survival during fledging and post-fledging dispersal.

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The irruptive nature of Snowy Owls: an overview of some of the recent empirical evidence

A natureza irruptiva da coruja-das-neves: visão geral de algumas das recentes evidências empíricas

Jean-François Therrien[1*], Gilles Gauthier[2], Tom McDonald[3], Norman Smith[4], Scott Weidensaul[5], David Brinker[6], Rebecca McCabe[1,7], Audrey Robillard[2], Joël Bêty[8], Nicolas Lecomte[9]

1 Hawk Mountain Sanctuary, PA, USA

2 Université Laval, QC, Canada

3 Rochester, NY, USA

4 Massachussetts Audubon, MA, USA

5 Ned Smith Center, PA, USA

6 Department of Natural Resources, MD, USA

7 McGill University, QC, Canada

8 Université du Québec à Rimouski, QC, Canada

9 Université de Moncton, NB, Canada

*** Corresponding author:** therrien@hawkmountain.org



ABSTRACT

Irruptive movements resulting in large and periodical fluctuations in number of a species in a given area is thought to happen in some owl species. Although impressive, empirical details of such a phenomenon remains however very limited. The Snowy Owl is a classic example of such a species but until recently, the limited empirical evidence did not allow a thorough description of its behavioral ecology over its complete life cycle. We have studied Snowy Owls for 25 years in North America using nest monitoring, diet analyses and individual tracking to understand the species' movement ecology over a full annual cycle. On the Arctic breeding grounds, nesting density of Snowy Owls varies tremendously annually, mirroring the high-amplitude variations in abundance of its main prey (lemmings). Indeed, during the breeding season, Snowy Owls have a highly specialized diet almost entirely made of lemmings. Tracking individuals revealed that adults are displaying some of the greatest breeding dispersal distances ever measured annually

in a bird species and that most of them breed every year, in areas where lemmings are abundant. Individual fidelity to a breeding area is thus very low. During winter, most adults remain at high latitudes and individuals tend to be more faithful to their wintering than their breeding areas. Periodic winter irruptions south of the boreal forest occurring roughly every 4 years follow successful breeding conditions in the Arctic and are mainly composed of juvenile individuals. Body condition of winter irruptive individuals is usually good. Even if some aspects of the behavioral ecology of the Snowy Owl still remain to be assessed, those results provide a clear overview of its irruptive nature over a complete annual cycle.

Keywords: *Bubo scandiacus,* behavioral ecology, breeding dispersal, prey abundance, satellite telemetry

RESUMO

Pensa-se que os movimentos irruptivos que resultam em grandes flutuações periódicas na abundância de uma espécie numa determinada área ocorram em algumas espécies de aves de rapina noturnas. Embora impressionante, esse fenómeno ainda está associado a detalhes empíricos muito limitados. A coruja-das-neves é um exemplo clássico de uma dessas espécies mas, até há pouco tempo, as poucas evidências empíricas não permitiam uma descrição completa da sua ecologia comportamental ao longo de todo o seu ciclo de vida. Estudamos a coruja-das-neves na América do Norte há 25 anos, através de monitorização dos ninhos, análise da dieta e seguimento de indivíduos, para compreender a ecologia dos movimentos da espécie ao longo de um ciclo anual completo. Nas áreas de reprodução do Árctico, a densidade de corujas-das-neves nidificantes varia muito anualmente, refletindo a grande amplitude das variações na abundância das suas principais presas (lemingues). Durante a época de reprodução, as corujas-das-neves têm uma dieta altamente especializada, quase inteiramente composta por lemingues. O seguimento de indivíduos revelou que os adultos apresentam algumas das maiores distâncias de dispersão de reprodução alguma vez medidas anualmente numa espécie de ave, e que a maioria deles reproduzem-se todos os anos em áreas onde os lemingues são abundantes. A fidelidade dos indivíduos a uma área de reprodução é, assim, muito reduzida. Durante o Inverno, a maioria dos adultos permanece em latitudes elevadas, e os indivíduos tendem a ser mais fiéis às suas áreas de invernada do que de reprodução. As irrupções periódicas de Inverno a sul da floresta boreal, que ocorrem aproximadamente de 4 em 4 anos, decorrem de condições de elevado sucesso reprodutivo no Árctico e são compostas principalmente por indivíduos juvenis. Os indivíduos que fazem movimentos irruptivos no Inverno estão, geralmente, em boa condição corporal. Apesar de alguns aspetos da ecologia comportamental da coruja-das-neves ainda estarem por avaliar, estes resultados fornecem uma visão clara da sua natureza irruptiva ao longo de um ciclo anual completo.

Palavras-chave: abundância de presas, *Bubo scandiacus*, dispersão de reprodução, ecologia comportamental, telemetria por satélite

Introduction

Irruptive movements resulting in large and periodical fluctuations in the number of individuals of a given species, in a given area (Newton 2006, 2008), occur in species specializing their diet on pulsed resources (i.e. highly variable and unpredictable; Ostfeld and Keesing 2000). Irruptive behavior has been described in seed-eaters (e.g. crossbills, *Loxia* sp. siskins, *Spinus* sp.) which feed heavily on cone crops varying greatly in abundance from one year to the next in a given area, and some raptor species (especially owls) specializing their diet on fluctuating small mammals (reviewed in Newton 2008). Empirical details of such behavior however remains very limited for any of those species.

The Snowy Owl (*Bubo scandiacus*) is a classic example of an irruptive species, but until recently, the limited empirical evidence did not allow a thorough description of its behavioral ecology over a complete annual cycle. Indeed, several authors have already described the highly specialized diet almost entirely composed of lemmings (*Lemmus* and *Dycrostonyx* spp.) during the breeding season across its circumpolar range (reviewed in Holt et al. 2015) as well as the highly variable breeding densities recorded over consecutive years on a given area for this species (Gilg et al. 2006, Therrien et al. 2014). In addition, several authors have also suggested that the varying abundance of Snowy Owls recorded annually in the southern part of their range in North America (southern Canada, northern United States) were related to the abundance of prey on their breeding grounds (Holt and Zetterberg 2008, Robillard et al. 2016).

The 5th World Owl Conference held in Evora, Portugal in 2017, provided us with an opportunity to look back at the last 25 years of monitoring Snowy Owls and to connect the different pieces of information we have collected over time. We hereby provide an overview of some of the recent empirical evidence in Snowy Owl movements by combining breeding density in relation to prey abundance, breeding dispersal over consecutive years and age composition and body condition of Snowy Owls irrupting in the southern part of their range in winter. We acknowledge that many of those aspects have previously been published in the scientific litterature, but are combined here for the first time in a complete annual cycle story.

Methods

We have monitored Snowy Owl and lemming populations for 25 years (1993-2017) on their breeding grounds at our long-term study site of Bylot Island, Nunavut (Canada; 73°N, 80°W; see Therrien et al. 2014 for details). Every year in mid-June, we measured nesting density of Snowy Owls by covering on foot a 100 km2 area to record each nest. Nesting white Snowy Owls are quite conspicuous on the greenish tundra and display territorial defense behaviors. We are thus confident that our detection probability is close to 100%. In addition, we have conducted opportunistic surveys at two additional sites in the eastern Canadian Arctic (Mary River 71°N, 79°W in 2008 and 2011, and Deception Bay 62°N, 74°W, in 2013). For all nests found, we estimated the clutch size (minimum number of eggs and/or chicks) and revisited nests periodically to assess diet, by identifying and counting the number of prey at the nest and, when possible, by collecting pellets of prey remains.

We measured annual lemming abundance at our main study area using a combination of snap- and live-trapping on two permanent grids (see Bilodeau et al. 2013 for details). Lemming abundance was also estimated at the two additional sites using snap traps (see Therrien et al. 2014b for details).

We have installed a total of 31 satellite transmitters on breeding Snowy Owls. On Bylot Island, we deployed 12 transmitters in

July 2007 and 8 transmitters in July 2014, all on females. One transmitter was put on a male in Mary River in July 2011 and 10 transmitters in Deception Bay in July 2013. All transmitters (30g, battery-powered; Microwave Telemetry and Northstar Technologies) were affixed using a harness made of Teflon ribbon following Steenhof et al. (2006; see Therrien et al. 2012 for details).

Between 1991 and 2017, live Snowy Owls were routinely trapped and banded in several areas of the species' wintering range in temperate North America, including regular (Alberta, Manitoba, North Dakota, Saskatchewan, South Dakota) and irregular (Connecticut, Delaware, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Brunswick, New Hampshire, New Jersey, New York, Nova Scotia, Ohio, Ontario, Pennsylvania, Québec, Rhode Island, Vermont, and Wisconsin) wintering areas. We assessed sex, age class and body condition of all trapped birds (see Curk et al. 2018 and Santonja et al. 2018 for details).

To assess annual winter population abundance, we used Christmas Bird Count (CBC) data (National Audubon Society 2010), a well-known citizen-science database gathering annual birding records of thousands of volunteers made during a single day between December 14 and January 5 across North America. The surveys include the number of hours spent in the field per party (i.e., a group of persons counting birds together), and observer effort is thus calculated in party-hr. We used the number of Snowy Owls reported per party-hr from 1991 to 2015 in regular and irregular winter areas. We assessed if the abundance of Snowy Owls during winter was synchronized among the two areas by correlating the residual values annually for each area (Buonaccorsi et al. 2001). Since none of the areas exhibited any trend with time, the residual values were simply the difference to the mean. We did the graphs and analyzes using SigmaPlot 11.0.

Results

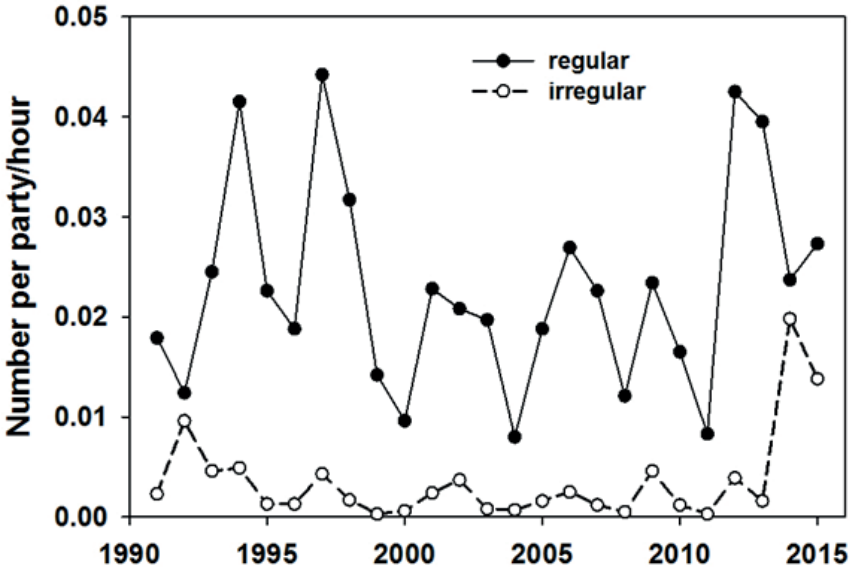
Nesting density of Snowy Owls varied annually, mirroring the high-amplitude variations in lemming abundance (Therrien et al. 2014a). Over the years, the average clutch size (±SE) remained relatively high for an owl species at all studied sites (Bylot Is. = 7.1 ± 0.2; Mary River = 7.0 ± 0.6; Deception Bay = 6.6 ± 0.4). During the breeding season, all breeding Snowy Owls had a highly specialized diet almost entirely made of lemmings. Indeed, diet analyses from all three sites revealed that >95% of their prey were lemmings (Bylot Is. = 96%; Mary River = 100%; Deception Bay = 98%).

Tracked individuals from the breeding grounds exhibited extended breeding dispersal (average = 715 km, range = 18 – 2224; Therrien et al. 2014b, Robillard et al. 2018). During each winter for which we had tracked birds, around 80% of them remained at high latitudes (range of latitudes = 56°N – 80°N) despite some of them wintering south of the boreal forest (see Therrien et al. 2011, Robillard et al. 2018 for details). Overall, individuals tend to be more faithful to their wintering areas than breeding areas (Robillard et al. 2018).

Winter abundance south of the boreal forest varied annually both in regular and irregular areas. Not surprisingly, owl abundance was almost always higher in regular wintering areas than in irregular ones (Figure 1). Despite some peaks occuring simultaneously, the two areas didn't show much synchrony ($r = 0.20$, $t = 0.99$, $df = 23$, $p = 0.33$). In irregular wintering areas, periodic winter irruptions occurred roughly every 4 years and were mainly composed of juvenile individuals (Santonja et al. 2018). Body condition of all age and sex-classes is usually good (similar to breeding individuals) with a very low percentage (<2%) of individuals approaching the emaciation threshold (Curk et al. 2018).

Figure 1 - Winter abundance of snowy owl recorded on Christmas Bird Counts in regular and irregular areas.

Figura 1 - Abundância de coruja-das-neves no inverno, registada no censo *Christmas Bird Counts* em áreas de presença regular e irregular da espécie.



Discussion

The Snowy Owl has been referred to as an irruptive migrant for a long time (reviewed in Newton 2006). Until recently however, detailed empirical evidence was lacking to describe the full annual cycle of its movement ecology, in part because of the challenge to track this species. For the first time, our long-term study combined surveys from the breeding and wintering grounds as well as tracking of individuals, and now allows for a complete understanding of their annual cycle. Furthermore, it is expected that the improvements in technology combined with ongoing long-term studies will allow for similar description of behavior in other species (especially owls).

Indeed, it is likely that other owl species behave in a very similar way. For example, the Northern Hawk-owl (*Surnia ulula*) also seems to be raising large clutches when breeding conditions are good and its populations seem to be composed of a high proportion of juveniles when irrupting during winter (Cramp 1985). The Short-eared Owl *(Asio flammeus*) is also known for invading a site during the summer when breeding conditions are good and to irrupt during winter (Holt and Leasure 1993, Keyes 2011, Johnson et al. 2013, Johnson et al. 2017). The miniaturization in tracking devices is likely to allow researchers to track these species breeding in far apart regions over consecutive years in the near future.

On the other hand, the irruptive behavior observed in other owl species might be caused by a different combination of factors and life-history traits among species. In the Great Grey Owl (*Strix nebulosa*) for exam-

ple, it was suggested that irruptions occur when food sources are depleted and that reproduction has been very limited, resulting in most individuals irrupting during winter being adults in bad body condition (Graves et al. 2012). However, the limited empirical information available to date limits our ability to assess the phenomenon accurately (but see Duncan 1987 and Duncan 1992). More long-term monitoring combining breeding and wintering ground surveys in addition to individual tracking is thus needed to understand movement ecology in these species.

Even if some aspects of the behavioral ecology of the Snowy Owl still remain to be studied in detail (e.g. breeding pair fidelity, dispersal behavior of juveniles), our results provide empirical details of its irruptive nature over a complete annual period.

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