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Original Article

European stranding networks as a tool for monitoring marine mammal populations (Part II): assessing their utility to monitor bycatch mortality

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Abstract

Fisheries bycatch is an important source of direct human-induced mortality for marine mammals worldwide. Despite its significance, monitoring and quantifying bycatch mortality remains challenging. The examination of stranded animals can provide key information to assess the importance of bycatch mortality, contributing to understanding its impact on populations, and identifying the fisheries responsible. However, the utility of data from strandings remains underexplored. Based on an expert consultation using a questionnaire carried out under the auspices of the International Council for the Exploration of the Sea Working Group on Marine Mammal Ecology, this study assessed the potential of stranding networks in Western Europe to support the assessment of marine mammal population status and impacts of stressors. The present paper (the second of two) focuses on information on bycatch collected from strandings, and its utility for monitoring and assessing bycatch mortality. Responses from 45 organizations in 19 countries indicated that extensive information on marine mammal bycatch mortality is collected and can sometimes be used to identify the species or populations most affected by bycatch, reveal spatio-temporal trends in bycatch mortality, and determine the fisheries and/or fishing gear involved. However, the survey identified several limitations that hinder the contribution of stranding data to bycatch impact monitoring and assessment. There is a need to strengthen data collection and reporting, especially for certain taxa and regions, and for wider adoption and harmonization of best practise protocols for diagnosing causes of mortality and understanding its context, e.g. by determining health status, estimating demographic parameters, helping to identify the fishing gears responsible for bycatch mortality, and appropriately

communicating the degree of uncertainty associated with interpretations. Carcass drift models could enable stranding data to be used to estimate total bycatch mortality and contribute to assessing the impact on populations. The need for adequate baseline funding for stranding networks to carry out their activities and for streamlined data reporting was widely recognized. Achieving coordinated, harmonized, large-scale and long-term data and samples collection following best practices will be essential to ensure that data from strandings on bycatch mortality can be integrated into bycatch impact assessments to inform management.

Keywords cetaceans, seals, strandings, questionnaire, bycatch, monitoring

Introduction

Fishery bycatch is the main known anthropogenic cause of direct mortality for most marine mammal species worldwide (Perrin *et al*. 1994, Read 2008, Lewison *et al*. 2009, 2014, Avila *et al*. 2018). Bycatch has resulted in the decline of various endangered, threatened, and protected (ETP) species and populations, including several marine mammals (Brownell *et al*. 2019) such as the vaquita (*Phocoena sinus*) (Gulland *et al*. 2020) and the Atlantic humpback dolphin (*Sousa teuszii*) (Collins *et al*. 2017), and contributed even to the extinction of others, such as the Yangtze River dolphin or baiji (*Lipotes vexillifer*) (Turvey *et al*. 2007). Certain populations are particularly vulnerable because of their restricted distribution and low abundance, such as the Baltic Proper subpopulation of harbour porpoises (Amundin *et al*. 2022, Carlström *et al*. 2023).

Assessment of the amount of bycatch mortality and its impact on marine mammals is required in European and adjacent waters under environmental legislation and supported by several international bodies and regional agreements [e.g. Common Fisheries Policy (CFP, Regulation 2017/1004), Habitats Directive (Council Directive 92/43/EEC), Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC), International Whaling Commission (IWC), International Council for the Exploration of the Sea (ICES)] (see ICES 2026a). In the Northeast Atlantic, marine mammal bycatch is primarily associated with fixed nets (including gill and trammel nets), trawls (especially high vertical opening trawls), and purse seines (Morizur *et al*. 1999, López *et al*. 2003, Mannocci *et al*. 2012, Marçalo *et al*. 2015, ICES 2023b). Particularly high mortality has been reported for harbour porpoises (*Phocoena phocoena*), common dolphins (*Delphinus delphis*), and grey seals (*Halichoerus grypus*) (Taylor *et al*. 2022). Bycatch levels for several populations, especially common dolphins in the Bay of Biscay, as well as harbour porpoises and grey seals in certain northern European areas, exceed established sustainability limits, posing serious conservation concerns, including risks of extinction for some particularly vulnerable populations (Hammond *et al*. 2008, HELCOM 2013, Cervin *et al*. 2020, ICES 2021, Taylor *et al*. 2022, 2023c, Koschinski *et al*. 2024, Pierce et al. 2024a, b). Despite the increasing adoption of various mitigation measures such as acoustic deterrents and temporary fishery closures (e.g. Regulation 2019/1241, ICES 2023a, Government of France 2023), bycatch remains a significant threat to many marine mammal populations.

The ICES Working Group on Bycatch of Protected Species (WGBYC) provides annual estimates of bycatch mortality of marine mammals in European and adjacent waters. Estimates are mainly based on bycatch data from on-board observers or, more recently, also on-board remote electronic monitoring (ICES 2023b). However, in practice, on-board observer data have major limitations, such as generally low observer coverage across fisheries, which precludes robust, precise, and accurate bycatch mortality estimates in many cases, with a tendency towards underestimation where observer coverage is especially low (e.g. Benoît and Allard 2009, Moore *et al*. 2021). Bycatch may go completely unrecorded, evidently so in illegal fisheries but also in artisanal fisheries where small vessel size precludes deployment of observers, and for species with low abundance for which bycatch events are consequently very rare (McCluskey and Lewison 2008, Dmitrieva *et al*. 2013, Bartholomew *et al*. 2018, Taylor *et al*. 2022, ICES 2024).

Reflecting the generally high level of concern about bycatch mortality of ETP species in European fisheries (Curtis and Carretta 2020, ICES 2026a), and the limitations of the current monitoring programmes, reinforcement of the current European monitoring programme to enhance and extend data collection has been repeatedly recommended (e.g. STECF 2021, Castro *et al*. 2024, ICES 2024, 2026b). A complementary approach is to maximize the amount and quality of information derived from alternative data sources, and to ensure that such data are integrated into bycatch assessment. Potential alternative data sources include logbooks (as reinforced by Regulation 2023/2842), questionnaire surveys of fishers (see Tubbs and Berggren 2024), and the monitoring of stranded animals (e.g. ICES 2026a, Peltier *et al*. 2016, Murphy *et al*. 2022), the latter being the focus of the present study.

For many years, strandings have been used as an indicator of bycatch occurrence, potentially providing minimum bycatch levels (e.g. Meager and Sumpton 2016), whilst strandings are also useful to help identify areas with high bycatch and/or to determine which fisheries were involved (e.g. Adimey *et al*. 2014). More recently, by using drift models to estimate the probability that the carcase of a bycaught animal will strand (Peltier *et al*. 2016, 2021), estimates of the total number of bycatch deaths of common dolphins in the northern Bay of Biscay were obtained (ICES 2020, 2023c). Furthermore, reverse drift modelling can allow us to infer the place and time of death of stranded animals (e.g. Peltier *et al*. 2020, 2021). Thus, stranding data can be used to complement bycatch mortality estimates obtained from onboard observations, to provide bycatch mortality estimates where observer data are not available, or to provide additional temporal resolution to the bycatch seasonal pattern (Peltier et al. 2016, ICES 2023c). Strandings can potentially provide information on bycatch in a wide range of fisheries, including those involving small vessels on which observers cannot be placed, and illegal, unreported and unregulated (IUU) fisheries. Although it is not always possible to identify the responsible fleet based on the examination of stranded bycaught animals, sometimes the fleet involved can be inferred by determining the likely time and area of mortality (e.g. via reverse drift modelling; Peltier *et al*. 2021). Strandings can provide insights into the type and parts of fishing gear in which the animal gets trapped (e.g. inside a net or on a creel line), which helps to understand

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the mechanisms of the interaction event. Furthermore, strandings could also provide information on mortality caused by Abandoned, Lost or Discarded Fishing Gears (ALDFG), which can have a significant impact on some species and populations, provided that the materials and signs left by ALDFG can be distinguished from those associated with active fishing gear (Dmitrieva *et al*. 2013, Mustika *et al*. 2014, Darmon *et al*. 2022).

Examination of stranded animals can inform us not only about bycatch, but also about other threats, such as pollutants, maritime traffic and pathogens, and about individual's health status. This can provide a better contextualization for understanding the impacts of different stressors, as well as insights into the cumulative effects of multiple stressors and the identification of emergent threats. As such, marine mammals can serve as indicator and sentinel species in relation to a range of threats (Bossart 2011, Santos and Pierce 2015). Lethal effects of bycatch at the individual level can be characterized based on post-mortem examinations of stranded animals, while demographic information derived from analysis of samples taken from the carcase (e.g. teeth and gonads for determination of age and reproductive status), whether or not an animal is necropsied, contributes to understanding population dynamics and thus to assessing impacts at population level. Data on age, maturity and reproductive status (e.g. pregnant, lactating) of individuals can be used to infer the age structure, age at sexual maturity, pregnancy rate, and mortality rate of a population, which are essential data for the assessment of the status of a population as well as the impact of accidental capture and other threats on different segments of the population.

Stranding monitoring programmes can offer long-term monitoring data covering large areas and different species. The associated databases could provide the opportunity to analyse spatio-temporal trends in the importance of bycatch mortality and other threats, as well as changes in biological parameters, and potentially enable us to both identify the need for mitigation measures and evaluate the effectiveness of those already implemented (e.g. Rouby *et al*. 2025).

Common protocols for the standardization of data and sample collection from stranded animals, e.g. during necropsies, have been developed by the European Cetacean Society (ECS), Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (ACCOBAMS), and the Society for Marine Mammalogy (SMM) (e.g. Kuiken and Hartmann 1991, Geraci and Lounsbury 1993, Pugliares *et al*. 2007, Raverty *et al*. 2014, IJsseldijk *et al*. 2019, Jauniaux *et al*. 2019). The Global Stranding Network and the International Whaling Commission (IWC) Strandings Initiative were also created to enhance collaboration and improve the response and attendance to strandings globally (Stockin *et al*. 2019, Gulland and Stockin 2020). Most recently, ASCOBANS has been scoping the development of a common European stranding database (Brownlow *et al*. 2023, 2024).

Despite all these previous efforts, there remains a need for further standardization and evaluation of the limitations of the data currently collected from stranded marine mammals. Reviewing and assessing the data collected from strandings, the methods used to collect the data (from carcase detection and reporting, through decisions about which animals to sample and/or necropsy, to the diagnosis of cause of death and evaluation of health status), and how data are curated and reported (e.g. to capture uncertainty), are necessary step towards optimizing the utility of stranding information to monitor the status of marine mammal populations and the impacts of stressors. To help achieve this goal, an expert consultation exercise was carried out, involving a questionnaire completed by coordinators of marine mammal stranding networks and other organizations involved in handling stranded marine mammals, in European countries with Atlantic coasts (including, where relevant, also their Mediterranean coasts). The results obtained from this exercise are presented in a two-paper series. Part I focused on the organization, functioning, and data collection methods of the stranding networks (Petitguyot *et al*. 2025).

The present paper (Part II) focuses on assessing the utility of stranding networks as a tool for monitoring bycatch mortality of marine mammals in Europe. To achieve this objective, we describe (i) the design of the monitoring programmes, the data collected, and the methods used to identify, contextualize, and report bycatch mortality; (ii) the frequency of bycatch mortality and spatio-temporal trends in bycatch, as well as inferences about the fisheries involved; and (iii) the limitations faced by networks regarding the monitoring of bycatch mortality. Finally, drawing on these results, we propose recommendations to enhance the utility of stranding networks as monitoring tools to understand and quantify bycatch impact on marine mammals informing European-level bycatch impact assessments.

Methods

The present paper is the second of a two-part study based on the information obtained from an expert consultation in the form of a questionnaire developed by the ICES Working Group on Marine Mammal Ecology (WGMME). Further information from the questionnaire may be found in Part I (hereafter referred to as Petitguyot *et al*. 2025).

Coordinators of organizations and networks involved in attending live and dead strandings of marine mammals in ICES member countries with European Atlantic coastlines [also including their Mediterranean regions and Atlantic archipelagos (see Fig. 1)], were invited to participate in this consultation exercise as respondents to the questionnaires and to contribute to the subsequent review and discussion of results as co-authors. In the case of countries where stranding networks are not centralized at national level and different regional networks exist, multiple organizations participated for the same country. Additionally, in countries where some stranding networks focus on cetaceans only, wildlife rescue centres attending pinnipeds were also included.

A subgroup of co-authors from the WGMME designed and tested the questionnaire before it was distributed, in both English and Spanish, to the network coordinators between 2021 and 2023. The questionnaire comprised 40 questions (see Supplementary Material S1), arranged in six sections to capture both general information about the functioning of the stranding networks (see Petitguyot *et al*. 2025) and more specific information about the monitoring of bycatch:

1. Organization of the networks (including the types of entities involved, staffing, funding, and perceived limitations).

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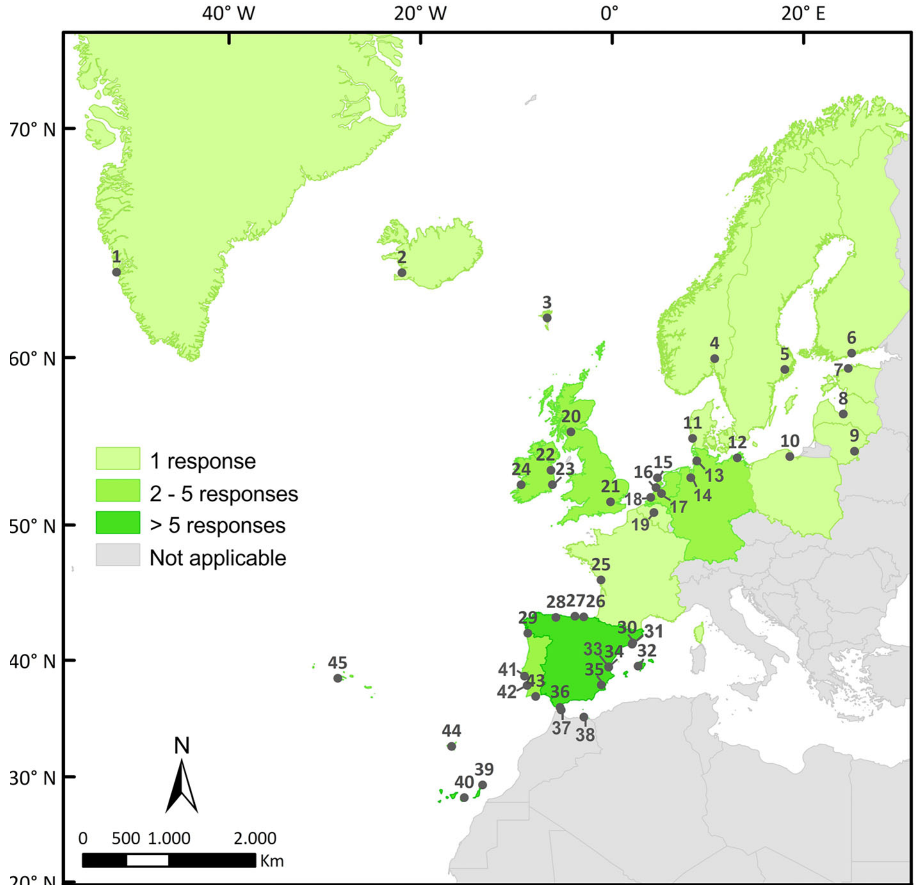

1	GINR	Greenland	16	DSN-RTZ		31	XRFM-CRAM	
2	MFRI	Iceland	17	DSN-UWNO	Netherlands	32	FPAQ	
3	FAR-HFMRI	Faroe	18	DSN-A Seal		33	RVCTMCV-UV	
4	NOR-IMRN	Norway	19	MARIN	Belgium	34	RVCTMCV-FO	
5	SMNH-SVA	Sweden	20	SMASS	United Kingdom	35	RVCTMRM	Spain
6	FIN-SMNH	Finland	21	CSIP		36	RVCTMA	
7	EST-MARE	Estonia	22	IR-ISS		37	RVM	
8	LAT-BIOR	Latvia	23	IR-SRI	Republic of Ireland	38	RVC	
9	LIT-VU	Lithuania	24	IWDG		39	RVCIC-OAPN	
10	PSN	Poland	25	RNE	France	40	RVCIC-IUSA	
11	NCP	Denmark	26	RVE		41	RALVT	
12	MPDM		27	ReVarCa		42	ARROJAL	
13	SH	Germany	28	RVA	Spain	43	RAAlg	Portugal
14	GM		29	RVG		44	RACAM	
15	DSN-ECOMARE	Netherlands	30	XRFM-UAB		45	RACA	

Figure 1 Countries responding to the questionnaire sent by the WGMME, either by completing a full questionnaire or providing a shorter response, are shown in green. The colour gradient indicates the number of responses received per country, which is related to the number of stranding networks operating in each country to our knowledge, although it does not necessarily imply a 100% response rate. From lighter to darker green: 1 response, 2 to 5 responses, and more than 5 responses. Black dots and numbers indicate the locations of the organizations that responded to the questionnaire. Countries from which no response was obtained and countries outside the scope of the study area are coloured in grey. For a complete list of acronyms of the organizations and stranding networks responding to the questionnaire, see Supplementary Material Table S1.

2. Procedures involved in attending strandings (e.g. reporting systems, decision-making processes, search effort, and how it has changed over time).
3. General characteristics of stranded marine mammals (e.g. species composition, numbers of strandings).
4. Types of data and samples collected (e.g. photographic documentation, teeth for age determination, and gonads for maturity state determination).
5. Frequency of necropsies (e.g. proportion of animals necropsied) and protocols followed, including those for determination of causes of death.
6. Incidence of bycatch mortality, and spatio-temporal trends therein, as inferred from stranded animals and, where relevant, from other sources (e.g. information collected from collaboration with fishers).

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The questionnaire included both closed and open-ended questions, the latter aimed at capturing respondents' opinions and providing relevant context and detail, e.g. to support the formulation of recommendations. As such, both qualitative and quantitative data were extracted from the answers to the questions. The respondents were consulted when doubts arose about the interpretation of their responses. If any such issue could not be resolved during the additional consultations, the associated response was excluded from the analysis. In addition, the complete manuscript was shared with all recipients of the questionnaire and all co-authors, allowing clarification of any further doubts, discussions about interpretation and refinement of conclusions and recommendations. The number of responses for each question is reported since it varies between questions, for example due to missing or inconsistent information in the responses, and/or because some questions were not applicable to all respondents (e.g. questions about necropsies in the case of respondents who indicated that they did not perform necropsies).

We requested that numerical responses, such as the annual number of strandings reported, should be based on the year 2019, if possible (although it was not always possible since some networks started their activities more recently), to avoid potential bias in responses derived from effects of the COVID-19 pandemic. For questions with numerical responses, the average (mean), minimum, and maximum values are reported. For responses in the form of percentages, we also report the mean, minimum, and maximum of the percentages reported by respondents. To visualize information by country on the perceived importance of bycatch mortality, when multiple organizations were present and multiple responses per country were obtained, the highest values were represented, thus showing only one value per country.

Maps were generated using ArcGIS software (ArcMap 10.4.1, ESRI 2016). Shapefiles for the European countries covered in this study were obtained from Sevdari and Marmullaku (2023) and www.gadm.org. For the purpose of contextualizing the data extracted from the questionnaires, these shapefiles were used to estimate an approximate length of the coastline in the regions where the stranding networks operate. The fine scale of these shapefiles means that coastline features such as estuaries are included in the estimates.

Results

A total of 45 responses were received from stranding networks and other organizations involved in attending strandings across 17 countries and 2 self-governing territories, including 40 completed questionnaires and 5 short email responses (Fig. 1). To the authors' knowledge, the responses obtained provided a high level of coverage of the existing networks in each country surveyed, with 100% coverage achieved in most cases. The number of responses per country may be interpreted as indicating the approximate number of stranding networks and related organizations operating in each country at the time the questionnaires were completed. It should be noted that the number of responses per country also reflects the ways in which stranding monitoring is organized in each country, with fewer responses expected from countries with centralized systems compared to those with distributed roles or multiple independent networks (see Fig. 1 from Petitguyot *et al*. 2025).

Information on bycatch collected by stranding networks

Respondents collect a wide range of data and samples from stranded individuals. Nearly all respondents record the stranding location, date, sex, length, state of decomposition, body condition index for each individual, as well as the number of stranded individuals and the occurrence of mass stranding events. See Petitguyot *et al*. (2025) for further details on the basic data collected from stranded animals and the frequency of strandings of different species. Here, we report on the methods used to diagnose bycatch cases and the bycatch-related information collected and reported by respondents.

a. Determining bycatch-related strandings

Bycatch is diagnosed as a cause of death based on post-mortem examination of stranded animals, by almost two-thirds of the respondents (65%, 22 out of 34 respondents). The remaining 12 (35%) respondents based their diagnosis on external signs only. Most respondents reported relying on a broad suite of direct and indirect bycatch signs derived from published sources, both external (i.e. traces of fishing gear or marks, cuts and mutilations, and good body condition) and internal (i.e. presence of recently ingested prey, no evidence of other possible causes of death, lung lesions such as froth in the airways and pulmonary oedema, intravascular gas bubbles, and haemorrhages) (Fig. 2). These signs range from those which provide direct evidence of fatal interaction with fishing gear (e.g. traces or marks of gear on the body) to those that offer only circumstantial evidence (e.g. good body condition).

Necropsies allow the identification of the internal bycatch signs, and characterization of the effects of bycatch on individuals (e.g. internal damage caused by bycatch and how bycaught individuals die), while also providing information on the context of bycatch (e.g. health status of the individual). On average 40% of the recorded dead stranded marine mammals are necropsied by respondents, although the percentage varies widely among organizations, from 3% to 100%. Additional information on the necropsies conducted, including which animals are selected for necropsy, who performs these necropsies, in which facilities, and which protocols are followed, can be found in Petitguyot *et al*. (2025).

An index of uncertainty is applied to the diagnosed cases of bycatch by slightly more than half of the stranding networks and organizations involved (53%, 18 out of 34 respondents). A level of uncertainty is assigned based on the robustness of the criteria used to diagnose bycatch mortality. Although the terminology associated with the uncertainty levels varies slightly between respondents, and indeed the signs recorded also vary between networks, the classification is usually as follows: (i) 'Certain bycatch,' for confirmed bycaught individuals (e.g. based on direct reports from fishers); (ii) 'Highly likely bycatch,' when most of the indicators are present; (iii) 'Probable bycatch,' based on fewer indicators; and (iv) 'Possible bycatch,' when even fewer indicators suggest bycatch. An example of the classification of uncertainty used by some networks in Spain can be found in Table 5 in MITECO (2022).

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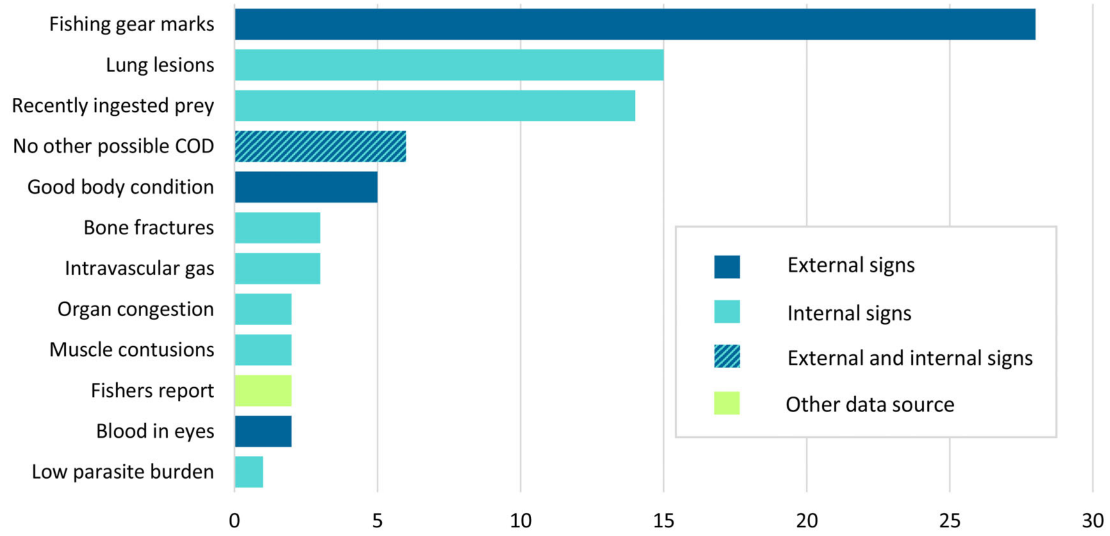

Figure 2 Number of respondents using each of the listed external and internal signs to assign a stranded animal as bycaught. COD: cause of death.

The guidelines most commonly followed by the respondents for bycatch diagnosis are Kuiken (1996) and Moore and Barco (2013), although several respondents have adapted these criteria based on their own experience and local circumstances (e.g. Fernández-Maldonado 2016, Bernaldo de Quirós *et al*. 2018, IJsseldijk *et al*. 2021).

Some stranded animals that are reported to stranding networks are also sampled (e.g. to collect skin, blubber, and teeth), while others are sampled and necropsied. Thus, the type of information collected varies as does the certainty associated with the diagnosis of the cause of death (for further information see Petitguyot *et al*. 2025). Information on external bycatch signs is collected from necropsied animals by the majority of respondents (30 out of 35, 86%), and many also collect such information from sampled animals that were not necropsied (20/35, 57%) and from animals neither necropsied nor sampled (17/35, 49%). In the case of necropsied animals for which bycatch is suspected as the cause of mortality, most of the respondents routinely carry out gross pathological examination (25/30, 83%) and many also carry out histopathological (15/30, 50%), bacteriological (14/30, 47%), and parasitological (13/31, 42%) analyses. Virology and persistent organic pollutant analyses are mainly performed on an *ad-hoc* basis by 13 and 12 respondents, respectively, out of 30 (i.e. 43% and 40% respectively). In addition, two networks specified that they perform computed tomography scans on an *ad-hoc* basis. Some networks depend on the availability of funds from specific projects or collaboration with other organizations to perform some of the above-mentioned analyses.

Photographs of sufficient quality, showing the entire body, from every side, are a potentially important tool for recording external evidence of bycatch or the absence thereof (see also Leopold *et al*. 2015, Puig-Lozano *et al*. 2020, Martino *et al*. 2025). Most respondents systematically collect (84%) and archive (97%) photographs from a high proportion of stranded animals. Three-quarters of the respondents (21 out of 28 respondents) have photographs of animals showing bycatch signs. However, photographs considered suitable for detecting evidence of bycatch (if present), were available on average for only 38% of the stranded animals, and the percentage varied widely between respondents, from 0% to 100%.

b. Additional information from stranding networks about fisheries interactions

Some respondents indicated that they also collect additional information about fisheries interactions. Stomach content analysis can provide information on potential interactions between marine mammals and fisheries, by providing evidence of very recent feeding as well as the presence of commercial species or fishing gear in the stomach, although this might also be observed in the case of other types of trauma death. Most stranding networks collect stomach contents (85%, 29 out of 34 respondents), among which 12 (35%) do so routinely and 17 (50%) on an *ad-hoc* basis. Almost all networks reported that they routinely analyse the diet themselves or in collaboration with other organizations, although a few stated that they store samples for future analysis. When such analysis occurs typically depends on the availability of students and/or relevant projects. Evidence of marine mammal feeding in or around fishing gear based on stomach contents was reported by the stranding networks in Valencia, Galicia and Ceuta (Spain), Madeira and Algarve (Portugal), Belgium, and the Netherlands. This evidence consisted of observations of net fragments and intact prey in the digestive tract. In mainland Portugal, evidence of interactions of common dolphins and bottlenose dolphins (*Tursiops truncatus*) with purse seine fisheries and bottom-set net fisheries was obtained from stomach content analysis and on-board fisheries observers. Similarly, in Madeira, diagnosis of interactions between bottlenose dolphins and fisheries was informed by stomach content analysis and onboard observations. In the Netherlands, harbour porpoises that were bycaught in bottom set-nets had a predominance of demersal prey species in the stomachs (see Leopold 2015).

Twenty-three (out of 30) respondents reported having identified fishing gears involved in marine mammal bycatch mortality, including different types of gillnets, trawls, purse seines, traps, and pole and line. Both recreational and commercial fisheries were reported to have been implicated in marine mammal bycatch. In addition, illegal fishing may be the main source of bycatch mortality in some European regions such as Ceuta, where the illegal swordfish fishery and the legal ‘almadraba’ fishery

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(a traditional trap net set fishery targeting eastern bluefin tuna (*Thunnus thynnus*) used in Italy, Morocco, Portugal, and Spain) were the two main fisheries identified as being responsible for the high prevalence of marine mammal bycatch in the area, even though the 'almadraba' tuna fishery was associated with a low mortality rate among bycaught animals. These associations were reported in responses to the questionnaire, but it is important to note that the questionnaire did not specifically request details of the evidence on which the fishing gears involved in bycaught stranded animals were identified. Associations may have been inferred from specific marks on the carcasses from external examination, described during necropsy and/or based on local knowledge of fishing activity.

Aquaculture installations are another potential source of (culture) fisheries-related interactions with marine mammals, and stranding networks sometimes collect related information directly from attended animals stranding on the beach or in the water, or from indirect observations recorded by the networks. Of the 28 responses to the corresponding question, 12 reported evidence of some type of interaction of cetaceans and/or seals with aquaculture installations, while 16 reported no evidence of such interactions. Half of the regions in which evidence was found were island dependencies. Most of the reports are observations of animals present in the vicinity of aquaculture installations. Some networks in Spain have reported bottlenose dolphins as being the most common marine mammal species around these installations (see Crespo-Picazo *et al*. 2021). Interactions of cetaceans, mainly bottlenose dolphins, with staff and the general public around aquaculture installations have been observed in the Canary Islands (Spain). Marine mammals are suspected to feed on cultured fish that are accidentally released from the installations in Madeira. Stranding networks also reported few cases of cetaceans trapped in aquaculture structures. Cetaceans, mainly bottlenose dolphins, were observed within the nets delimiting fish and mussel farms in Galicia (Spain), including one example of entanglement: the remains of a net, from which a bottlenose dolphin had previously been disentangled, caused it to become entangled again in the structure of a 'batea' (mussel aquaculture raft) in Galicia (Spain). Cases of entanglement were also reported for common dolphins entrapped in oyster farms in France. In addition, a minke whale was seen inside a salmon (*Salmo salar*) fish cage in the Republic of Ireland and a humpback whale calf was fatally trapped in an aquaculture net in Scotland (UK). Some respondents reported cases of seal depredation in set nets (France) and salmon cages (Scotland, UK), as well as instances of seals damaging fishing nets (Lithuania). Some governments issue licences to shoot seals as a way to control seal depredation (Denmark, Scotland (UK), and Sweden), although the number of licences granted in recent years has decreased in regions such as Scotland (Scottish Government 2025). It may also be noted that there is extensive published evidence of seal and cetacean (bottlenose dolphin) depredation at fish farms, e.g. in Scotland and the Mediterranean respectively (Piroddi *et al*. 2011, Northridge *et al*. 2013), as well as accounts of a wide range of non-lethal mitigation approaches employed to reduce such interactions (e.g. Quick *et al*. 2004, Coram *et al*. 2014, Todd *et al*. 2021).

Strandings can provide demographic information, including on life history parameters such as individual age, maturity and reproductive status, which can be used to estimate population mortality rate, pregnancy rate and age at sexual maturity, and hence potentially contribute to the assessment of total and bycatch-related mortality within a population and to identify the population components that are more susceptible to bycatch. The majority of the respondents collect samples of teeth (30/31) and reproductive organs (29/30), and record whether a foetus is present (31/31). Many also report determining the age (29/36), maturity (30/36), and reproductive status (30/35) of at least some individuals, either themselves or in collaboration with other organizations. Two networks indicated that they use life history data to produce life tables (Krebs 1994) in collaboration with external research groups (see Mannocci *et al*. 2012, Read *et al*. 2013, Read 2015, Saavedra 2017, Pierce *et al*. 2020, 2024b, Torres-Pereira et al. 2023a). It should be noted that fewer than half of the networks routinely determined age and maturity status, and these are usually inferred by indirect methods based on body length rather than analysing teeth and gonads (for further details on the samples collected and analysis performed, see Petitguyot *et al*. (2025)).

The majority of the networks collaborate with fishers (72%, 26 out of 36 respondents) to obtain information about bycatch mortality. In the majority of these cases, collaboration involves recording cetacean bycatch that is reported by fishers (21/34) and some networks perform necropsies on bycaught animals provided by fishers (14/36). Eight respondents said that they considered records and carcasses reported directly by fishers separately from strandings, whereas seven said that they did not treat this information separately. Several respondents collaborate with fishers by assisting with disentanglement and release of live bycaught animals (12/34). In Latvia, respondents indicated that fishers have collaborated in bycatch research by replying to questionnaires, and some participated in self-sampling based on an agreement with the Institute of Food Safety, Animal Health, and Environment (BIOR).

Most European countries undertake some level of on-board monitoring of cetacean bycatch, and in some cases, this is coupled with carcass tagging programmes, which usually involve organizations related to strandings monitoring. Within the surveyed area, such programmes have been implemented to some extent in four countries, the UK, the Netherlands, France, and Spain, through collaborations between stranding networks and fishers. In these programmes, dead bycaught cetaceans are tagged onboard the vessel which caught them and then released at sea. Subsequent reports of their location, especially those that arrive on the shore, are then used to validate drift models, linking stranding locations to the likely area of death. These models can be used to support estimation of total bycatch mortality from stranding data (see Peltier *et al*. 2016, ICES 2020, 2023c, 2025). In France, the stranding network recorded the stranding of 19% (78 out of 407) of tagged common dolphin carcasses and 13% (6 out of 48) of tagged harbour porpoise carcasses (Peltier *et al*. 2025). In the other countries, the tagging programmes mentioned have been markedly less extensive (at least at the time of the consultation exercise). In Galicia (Spain), 28% of the tagged common dolphin carcasses were recorded stranded (8 out of 29 tagged carcasses, see Martínez-Cedeira *et al*. 2011). In the UK, none of the four tagged cetacean carcasses were reported as stranded (see de Boer *et al*. 2012). In the Netherlands, a tagging programme for bycaught harbour porpoises was proposed as part of a remote electronic monitoring project, but finally no porpoises were tagged (see Scheidat *et al*. 2018).

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c. Reporting of information to management entities

Thirty respondents reported on the bycatch information they send to external organizations and/or governmental bodies for monitoring and management purposes, while five respondents stated that they do not report bycatch information to any such bodies. Most commonly, bycatch information is reported to the national government (25 out of 34 respondents), the IWC (17/35), and ASCOBANS (12/35). In addition, five respondents stated that they report information to ICES, another five to their regional or local governments, two to the Baltic Marine Environment Protection Commission (HELCOM), one to the European Commission, and one to the North Atlantic Marine Mammal Commission (NAMMCO). Respondents most commonly report annually, as requested by some of these organizations, but the reporting frequency varies from bimonthly to once every 6 years. Note that, in some cases, stranding information is also made available on the networks' own websites, albeit usually in summary form.

Patterns in bycatch mortality inferred from stranding data

This section summarizes information on patterns in the importance and prevalence of bycatch mortality that the respondents were able to detect based on the cause-of-death data they collect from stranded animals. For data consistency, we requested averaged information on the number of seals and cetaceans reported in 2019 (to avoid the possible influence of the COVID pandemic on reporting) or a more recent year if the organization was created after 2019. To provide context, based on the length of the coastline of the country or region in which respondents operate, we estimated the density of the reported strandings along the coastline for each of these countries or regions (number of reported strandings/kilometres of coastline). In addition, we requested information on spatiotemporal patterns in bycatch occurrence. As highlighted in the previous section, respondents use varying criteria to determine the occurrence of bycatch and other causes of death and, as such, while responses are based on the best available estimates of the number and percentage of individuals dying from bycatch, the degree of confidence associated with these estimates is likely to be variable.

a. Relative importance of bycatch as a source of mortality

Overall, bycatch was most frequently diagnosed as a cause of death for pelagic delphinids (on average 28% of stranded pelagic delphinids were diagnosed as dying from bycatch, range 1%–90%, 14 respondents), porpoises (average 24%, range 0%–40%, 12 respondents), and baleen whales (average 20%, range 0%–80%, 9 respondents). Large odontocetes are the cetacean group least frequently diagnosed as dying due to bycatch (average 13%, range 0%–80%, 8 respondents; see proportions for each region in Table 1). The wide range of responses seen for every taxon should be noted.

Compared to cetaceans, seals diagnosed as dying from bycatch were reported relatively less frequently (on average 11% of seal strandings, range 0%–30%, 9 respondents), although it should be kept in mind that the proportion of animals stranded alive is higher in seals than in cetaceans. The highest percentages of bycatches among stranded pelagic delphinids were reported in Ceuta (Spain, 90% of the stranded individuals were diagnosed as bycaught), France (75%), and the Algarve (Portugal, 50%); for porpoises it was Galicia (Spain, 40%), France (30%), the Algarve (30%), Sweden (25%), and Alentejo (Portugal, 25%); for baleen whales, Ceuta (80%), Scotland (UK, 40%), and Galicia (33%); for large odontocetes, Ceuta (80%); and for seals, Belgium (30%) and France (20%). For further details on the percentages of bycaught individuals for each species group by region, see Fig. 3 and Table 1.

Some respondents highlighted that, based on strandings, bycatch mainly affects certain species within the species groups mentioned. In Scotland (UK), the Republic of Ireland and the Canary Islands (Spain), the percentage of bycatch mortality, compared to other known or unknown causes of death, is highest in large whales, specifically minke whale (*Balaenoptera acutorostrata*) and humpback whale (*Megaptera novaeangliae*) in the northern regions, and minke whale and Bryde's whale (*Balaenoptera edeni*) in the southern regions. In England, Wales, and Northern Ireland, bycatch has been diagnosed only for common dolphins (34%) among the pelagic delphinid species. In Belgium, bycatch has been occasionally recorded for white-beaked dolphins (*Lagenorhynchus albirostris*). As indicated by two of the four respondents in the Spanish autonomous communities of Catalonia and Comunidad Valenciana, the percentage of strandings attributed to bycatch mortality among marine mammal species is highest in bottlenose dolphins (60% and 63%, respectively) and striped dolphins (*Stenella coeruleoalba*) (28% and 21%, respectively) (see also Cuvertoret-Sanz *et al*. 2020).

Respondents were asked to provide their expert opinion on the importance of bycatch as a cause of marine mammal mortality in their regions. Two-thirds of the respondents (66%, 23/35 respondents) considered it to be 'very important' (10/35) or 'important' (13/35). Bycatch was considered to be of 'regular' importance by 26% of respondents (9/35) and either 'unimportant' or 'very unimportant' by 2 and 1 respondents, respectively (Fig. 4, Table 1). It is worth noting that bycatch impact was classified as 'very unimportant' in the Basque Country reflecting only the evidence obtained from stranded animals in that region, where the advanced decomposition of most carcasses and the limited veterinary expertise constrained the diagnosis of the cause of death. Nevertheless, respondents acknowledged that data from other sources, such as fisheries observers, suggests that bycatch is a considerable cause of mortality in this region. It should be highlighted that the assignment of categories such as 'very important,' 'important,' etc. is based on the opinions of respondents. In addition, several respondents highlighted that bycatch is the main cause of death for some marine mammal species in their regions, including the Baltic Proper harbour porpoise subpopulation, which is catalogued as critically endangered (Hammond *et al*. 2008, HELCOM 2013).

b. Spatio-temporal trends in bycatch mortality

Looking at reported overall temporal trends in the number of animals diagnosed as dying due to bycatch, upward trends were reported most frequently for seals, as observed by four respondents, in the Netherlands, Belgium, France, and Galicia (Spain), while three respondents did not observe any trend. For pelagic delphinids, an upward trend was reported by five respondents, in France and Spain (Cantabria, Galicia, Comunidad Valenciana, and Ceuta), with 11 respondents reporting no trend. For porpoises, an upward trend in bycatch-related strandings was reported by two respondents, in France and Spain (Galicia), with two reporting a downward trend, in the Netherlands and Belgium, and six report-

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Table 1 Summary of the responses obtained to questions about bycatch concerning: (i) respondents' opinions about the importance of bycatch in their region (VI = Very Important, I = Important, R = Regular, UI = Unimportant, and VUI = Very unimportant); (ii) the proportion of stranded animals diagnosed as bycaught per group of species (from darker to lighter grey: ≥50%; ≥25%; ≥10%; <10%); (iii) the identified current temporal trends in the prevalence of bycatch (↗ = upwards; ↘ = Downwards; ∼ = None; F = fisheries-related); (iv) whether respondents identified specific areas where bycatch is concentrated (Yes/No) or (v) seasonal patterns (Yes/No/Susp. = suspected trend; F = fisheries-related); and (vi) whether the fisheries implicated were identified (Yes/No). To provide context, information is included on the number of marine mammal strandings reported by each respondent in 2019 (when possible), the approximate length (km) of coastline of each region or country and the density of reported strandings (i.e. the number of reported strandings in relation the length of coastline of each region; darker blue: ≥0.5 strandings/km; lighter blue: ≥0.1 strandings/km). Note that population trends across regions are relevant for interpreting the bycatch trends; this point is further explored in the discussion. Definitions of the organizations' abbreviations are found in Supplementary material S1. Note that this table does not include regions and organizations from which no response to these questions was obtained: Estonia, Faroe Islands, Finland, Germany (GM), the Netherlands (RTZ), Norway, and Spain (RVA, CRAM, and OAPN). Blank cells represent data gaps (except in the case of 'Bycatch importance,' for which only one answer could be selected). Data source for the calculation of the coastline length: Sevdari and Marmullaku (2023) and www.gadm.org

Country	Organisation	Nº strandings			Km coastline	Density (strandings / km)	Bycatch importance					Bycaught strandings (%)					Bycatch temporal trends					Areas higher impact	Seasonal patterns	Identified fisheries
		Seals	Cetaceans	Marine mammals			VI	I	R	UI	VUI	Porpoises	Pelagic delphinids	Large odontocetes	Baleen whales	Seals	Porpoises	Pelagic delphinids	Large odontocetes	Baleen whales	Seals			
Iceland	*MFRI*			150	6453	0.02		I															Yes (F)	Yes
Sweden	*SMNH & SVA*			400	23559	0.02		I				25				6							Susp.(F)	Yes
Latvia	*LAT-BIOR*				1115		VI																Yes	
Lithuania	*LIT-VU*	78			1195	0.07		I													↗(F)		Yes (F)	Yes
Poland	*PSN*			270	1924	0.14	VI									10	∼				∼		Yes	Yes
Denmark	*NCP*			406	8252	0.05		I				12											No	
Germany	*MPDM*			145	1878	0.08	VI																Yes	Yes
	GM			291	1417	0.21											∼				∼			
	SH				1674			I															Yes	Yes
Netherlands	*DSN-UWNO*			518	1320	0.39			R			15					↘						Susp.(F)	Yes
	DSN-ECOMARE			114	88	1.30			R															
	DNS-A Seal		166		536	0.31			R							4				∼				Yes
Belgium	*MARIN*			125	140	0.89			R			10			10	30	↘(F)			∼	↗		Yes	Yes
United Kingdom	*SMASS*			770	16564	0.05	VI					2	2	3	40	5	∼	∼	∼	↗			Yes	Yes
	CSIP			1142	8178	0.14	VI					7	0	0	0		∼	∼	∼	∼		Yes	Yes	Yes
Republic of Ireland	*IWDG*		263		7660	0.03		I				16	13									Yes	Yes	Yes
	IR-ISS				7660			I								10			↗			Yes	Yes (F)	Yes
	IR-SRI	660			7660	0.09			R													Yes	Yes	No
France	*RNE*			2282	9193	0.25	VI					30	75			20	↗	↗			↗		Yes	Yes
Spain	*RVE*			48	283	0.17					VUI													No
	ReVarCa			37	394	0.09			R			100[1]	5.7				↗[1]	↗					Yes	No
	RVA			36	493	0.07		I															No	
	RVG			393	1843	0.21	VI					40	26.5	0	32.6	10.1	↗	↗	∼	∼	↗	Yes	Yes	Yes
	XRFM-UAB			20	788	0.03		I					27					∼					No	
	FPAPM			23	1426	0.02			R				10					∼					No	No
	RVCTMCV-UV			31	684	0.05		I										↗(F)					No	Yes
	RVCTMCV-OC			31	684	0.05		I										∼					No	Yes
	RVCTMRM			7	344	0.02			R				13	0	0			∼	∼	∼			No	No
	RVCTMA			145	1538	0.09		I				0	25	0	0	0	∼	∼	∼	∼	∼	Yes	Yes	Yes
	RVM			2	12	0.12		I										∼	∼		∼		No	No
	RVC		30		29	0.97	VI						90	80	80			↗	∼	∼			Yes (F)	Yes
	RVCIC-IUSA			104	1813	0.06			R				1.2					∼		↗			Susp.(F)	Yes
Portugal	*RALVT*			62	635	0.10		I					23	0								Yes	No	No
	ARROJAL			34	324	0.10		I				25	34		0		∼	∼		∼		No	No	Yes
	RAAlg			68	535	0.13	VI					30	50	20	20		∼	∼	∼	∼			Yes	Yes
	RACAM			11	382	0.03				UI								∼					No	No
	RACA			14	941	0.01				UI													No	Yes

[1] The proportion is based on a single stranded harbour porpoise in Cantabria, which was diagnosed as bycaught. Therefore, this value was not considered for the statistical analysis.

ing no trend. In addition, two respondents reported an upward trend for baleen whales in Scotland and Spain (Canary Islands), with eight observing no trend. No trend in bycatch was observed for large odontocetes by any of the seven respondents. For further information on the temporal trends in bycatch per species groups by region, see Table 1.

Some respondents also reported perceived temporal trends in strandings associated with bycatch at species level. In Madeira, the reported incidence of bycatch mortality is similar for bottlenose and Atlantic spotted dolphins (*Stenella frontalis*) (i.e. 17% and 18%, respectively), with no trend observed in the number of bycatch cases of either species. One of the two Spanish networks

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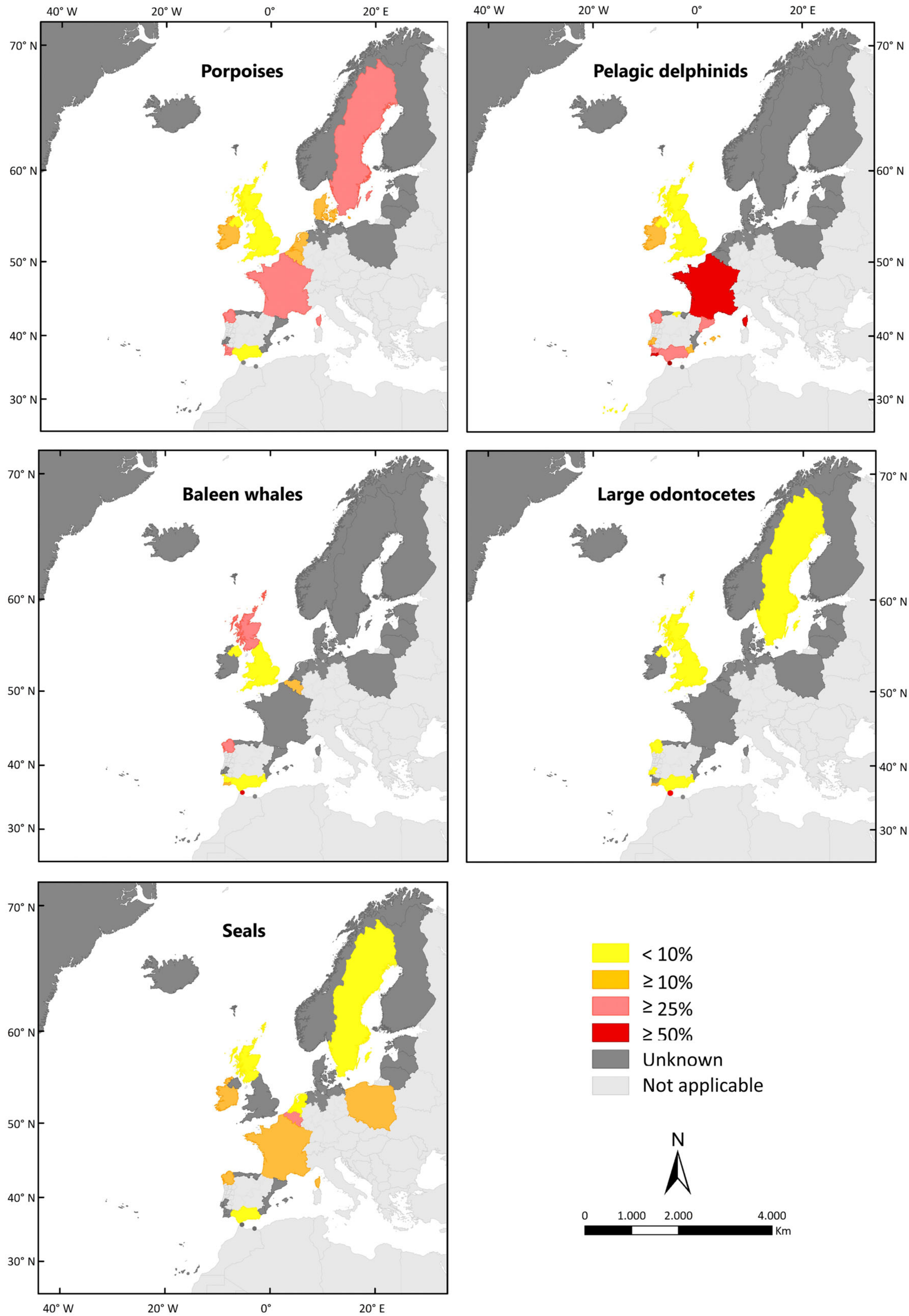

Figure 3 Maps showing the proportion of strandings classified as bycaught individuals for pelagic delphinids, porpoises, large odontocetes, baleen whales, and seals. Regions for which there was no response to the corresponding question or where only one individual or no strandings of the corresponding species group were recorded, are classified as unknown.

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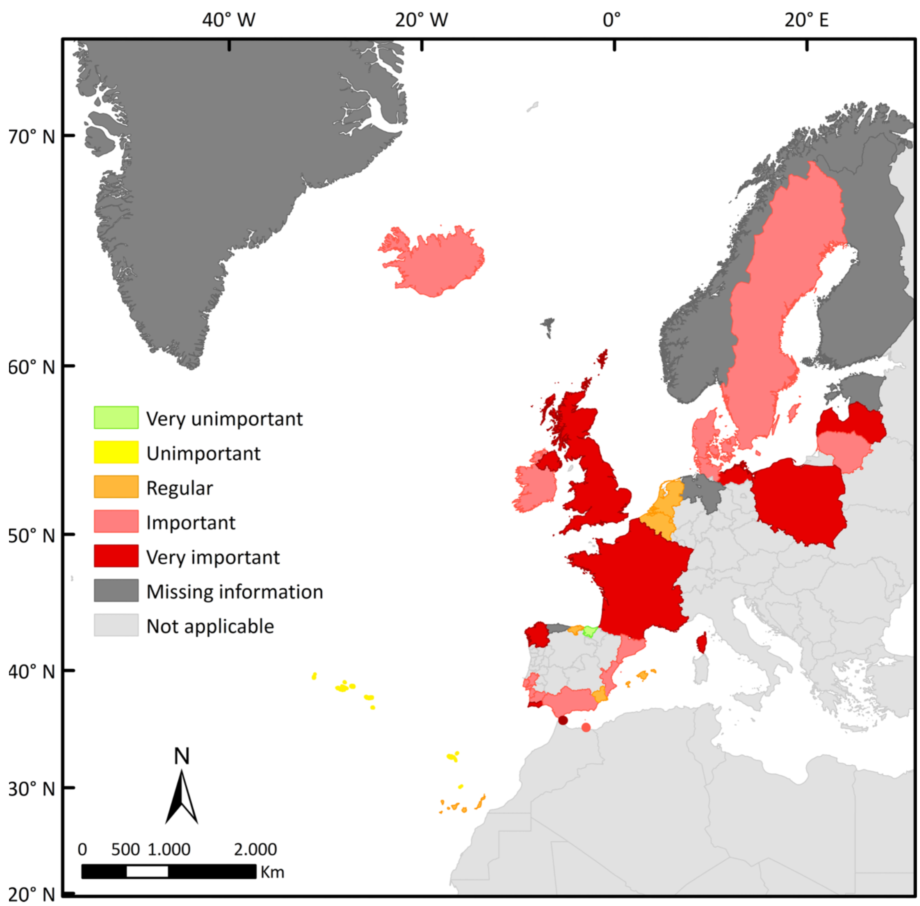

Figure 4 Map showing the perceived importance of bycatch impact on marine mammals in each region based on the responses to the questionnaire. Note that we illustrate the highest level of importance reported for that country or region where more than one stranding network or organization provided information (for Ireland, two networks consider bycatch mortality as Important and another one as Regular, and for Germany, one network considers bycatch as Very Important while another one as Important, see Table 1).

in the Comunidad Valenciana reported that there was no apparent current trend in the number of striped dolphins dying of bycatch, but that there was an upward trend for the locally endangered population of bottlenose dolphins (see Izquierdo-Serrano *et al*. 2022), although this trend was not observed by the other network in the region, possibly due to the shorter time series and the later involvement of veterinarians in diagnosing causes of death. A few respondents observed trends associated with changes in fisheries. In Belgium, porpoise bycatch mortality has dropped to almost zero since 2015, when recreational gillnets and tangle nets were banned close to shore. However, there are other possible explanations, including a reduction in fishing effort and a decreasing number of porpoises close to shore despite evidence of an overall increase in porpoise abundance in the southern North Sea over the last few decades (Haelters *et al*. 2012a, Peschko *et al*. 2016, Nachtsheim *et al*. 2021, Gilles *et al*. 2023). However, in the same region, the number of stranded seals diagnosed as bycaught is increasing (with a seasonal peak in March–April 2021), possibly due to increasing numbers of seals present, and bycatch taking place in static gear in Belgium and neighbouring countries (see Haelters *et al*. 2022). In Lithuania, strandings of grey seals have increased since 2016, coinciding with the use of fish traps instead of nets (see Vanhatalo *et al*. 2014, Survilienė 2020).

Approximately two thirds of respondents recorded higher bycatch prevalence during particular times of the year (21/32 respondents), while the remainder (11) did not find seasonal patterns in bycatch mortality. Five respondents provided further detailed information regarding the concentration of bycatch in specific areas within their regions. In the Spanish autonomous community of Andalusia, the highest bycatch prevalence was found in the Bay of Algeciras and Málaga throughout the year, often peaking in spring. In England, Wales, and Northern Ireland, a higher prevalence of bycatch-related mortality of common dolphins was found in southwestern England during winter months (December–April), while harbour porpoises were most frequently bycaught in the English Channel, the northeast coast and Cardigan Bay, with little seasonal variation (see also Kirkwood *et al*. 1997, Deaville *et al*. 2018). A higher prevalence of bycaught stranded common dolphins is recorded between December and April particularly along the Bay of Biscay coast in France, while an increase in summer has been observed in southern Brittany in recent years. In addition, bycaught harbour porpoises are recorded stranded all year round in France, although most commonly in August–September and January–February. In Galicia (Spain), bycaught stranded common dolphins were concentrated in winter and on the west coast.

Out of the 21 respondents who observed seasonal patterns in the prevalence of bycatch mortality, seven explicitly associated

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these patterns with the seasonality of specific fishing activities, although it should be noted that co-occurrence does not itself prove that there is a cause–effect relationship. Few respondents specifically stated the evidence used to identify an association between bycatch and a specific fishery, although it should be noted that a majority of networks record multiple indicators of death due to bycatch, including the marks on carcasses produced by fishing gear (Fig. 2). In Iceland, bycatch of seals and porpoises increases in late winter and spring during the gillnet fishery season targeting gadoids [mainly cod (*Gadus morhua*), but also haddock (*Melanogrammus aeglefinus*) and saithe (*Pollachius virens*)] and lumpfish (*Cyclopterus lumpus*). In Sweden, records of bycaught porpoises are more frequent in spring, during the lumpfish fishing season. In the Republic of Ireland, one of the stranding networks reported that some clusters of dead seals in certain areas coincided with inshore fishing activities, such as the sprat (*Sprattus sprattus*) pair trawling fishing season in autumn and winter. In Lithuania, between 80% and 90% of all grey seal strandings, regardless of the cause of death, occur in May and June, coinciding with the spring fishing season for Baltic herring (*Clupea harengus membras*) and sprat (see Vanhatalo *et al*. 2014, Survilienė 2020). In the Netherlands, one of the networks related the highest recorded bycatch rates of porpoises to the commercial trammel net fishery, which operates mainly in winter and spring, overlapping with the period of highest density of porpoises in Dutch coastal waters. In Belgium, strandings of bycaught harbour porpoises used to peak in spring and in an area coinciding with the bottom-set gillnet fishery targeting mainly Dover sole (*Solea solea*) (see Haelters *et al*. 2012b). In Ceuta (Spain), cetacean bycatch mortality increases during the season of illegal shark and swordfish (*Xiphias gladius*) fishing in Morocco. In the Canary Islands (Spain), the number of bycaught dolphins increases in spring and summer months during the bluefin tuna (*Thunnus thynnus*) fishing season.

Limitations associated with bycatch data from strandings

Stranding networks highlighted several important factors that limit their ability to monitor the incidence of bycatch mortality in marine mammals. These limitations include operational constraints and data-related challenges, and may be intrinsic or extrinsic to the stranding networks. These limitations may be summarized as follows.

Variation in search effort and activities of the networks over time, as influenced by events like the COVID-19 pandemic, leading to inconsistencies and gaps in the data, which might hamper the assessment of trends. In principle, it is possible to account for some sources of biases for example recording the amount of search effort, although the documentation and quantification of search effort by networks is currently limited, inconsistent, and largely unsystematic. The decision processes by which stranded animals are attended and necropsied also affect the homogeneity and/or representativeness of spatio-temporal coverage for every species. A relevant factor is the amount of funding available to attend and examine strandings, including to do necropsies, and indeed whether such funding is attached to particular monitoring or research objectives. Limited and varying financial and human resources were the most commonly mentioned important challenges faced by networks that influence the determination of the incidence of marine mammal bycatch mortality from strandings.

Differences in the expertise and experience of the staff who perform necropsies and identify bycatch signs, in the availability and capacity of facilities for necropsies, and in the protocols used for sampling and necropsy of animals, may all condition the information extracted and the comparability of data over time and space. Respondents also referred to inconsistent data collection across taxa, such as for seals in the UK and the Netherlands (which can arise, e.g. if different organizations deal with seals and cetaceans), while Lithuania and the Republic of Ireland mentioned the lack of official or systematic data collection.

The high frequency of highly decomposed stranded animals was reported as another limitation for the identification of evidence of bycatch. Finally, miscommunication, unsystematic data reporting, and bias in reported data, are common difficulties reported by respondents in relation to their collaboration with fishers to obtain bycatch information. Further detailed information on limitations of European stranding networks is included in Petitguyot *et al*. (2025).

Discussion

The responses to the consultation exercise indicated that extensive information on marine mammal bycatch mortality is collected by stranding networks, and showed that stranding data, at least sometimes, can be used to identify the species or populations most affected by bycatch including of less common and more offshore species with limited information available, to reveal spatio-temporal trends in bycatch mortality, and to determine the types of fisheries and/or fishing gear involved.

These data already provide a valuable contribution to national and international monitoring and reporting obligations regarding bycatch mortality, notably in relation to EU Directives such as the MSFD. As noted earlier, stranding data have been used to complement data from onboard observations when estimating total bycatch mortality of common dolphins in the northern Bay of Biscay (Peltier *et al*. 2016, ICES 2020, 2023c, 2025). Stranding schemes also provide information for various bycatch-related purposes, such as impact assessments, to several international organizations, such as ASCOBANS, ACCOBAMS, IWC, HELCOM, OSPAR, the North Atlantic Marine Mammal Commission (NAMMCO), and ICES.

However, the survey also identified several limitations that constrain the quality, consistency and completeness of data collection across taxa, regions, and over time, hence the ability of stranding networks to monitor bycatch mortality. Many of these limitations reflect broader challenges affecting the role of stranding networks in monitoring marine mammal populations more generally, as discussed in the first part of this analysis (see Petitguyot *et al*. 2025). Here, we focus on bycatch monitoring, including recommendations to strengthen the contribution of stranding networks to bycatch monitoring and to support European-level bycatch mortality assessments.

Optimizing the functioning of stranding networks

Optimizing the functioning of stranding networks is a necessary step to strengthen their broader role as tools for monitoring marine mammal populations. The first part of the analysis of questionnaire responses identified several limitations that must be ad-

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dressed to achieve this objective (further detailed in Petitguyot *et al*. 2025). The identified needs include expanding spatial coverage, as stranding networks are absent in several European regions and countries, and increasing attention to pinnipeds and non-mammal marine taxa, which are frequently underrepresented in current strandings monitoring efforts. Enhancing the coordination of strandings monitoring activities at both national and international levels is also necessary, as is improving the standardization of protocols for the collection and analysis of general and specific bycatch-related data. An increased number of necropsies and associated sample analyses, the systematic collection of information from less fresh carcasses, and the recording of metrics reflecting search effort, would also contribute to improving data quality. Further streamlining the reporting of results and ensuring their accessibility to relevant stakeholders are essential. Achieving these objectives will depend on the provision of systematic and adequate funding to stranding networks, in accordance with their needs related to resources and training. These recommendations generally apply to population-level monitoring, and consequently they will ultimately enhance the networks' capacity to assess the population impact of bycatch mortality.

Promoting and assuring best practice and harmonization for cause of death diagnosis

Necropsies are essential for reliably determining the cause of death of stranded animals, and they should be performed by experienced personnel, involving veterinary pathologists if possible, following a standardized protocol consistent with best practice. Evidently, various practical considerations may preclude performing necropsies on every animal (or limit what can be diagnosed if a necropsy is performed), not least due to varying decomposition states and limited resources; as such, the freshest animals may be prioritized.

The survey highlighted that not all stranding networks routinely performed necropsies, and that some networks lacked veterinary pathology expertise. Our analysis also showed differences among networks regarding the protocols followed when performing necropsies (see Petitguyot *et al*. 2025), and differences in the criteria used for diagnosis of bycatch cases.

Accurate diagnosis of the cause of death is crucial for identifying and quantifying threats to marine mammal populations (e.g. determining bycatch mortality and its relative importance compared to other potential threats). This implies being able to recognize the signs of all known causes of death, both natural (e.g. diseases, predation) and anthropogenic (e.g. bycatch, maritime traffic, and marine litter), as well as being able to rule them out. To some extent, this is aspirational, e.g. when death was caused by a novel threat. A case in point is the occurrence of spiral (or 'corkscrew') lacerations in seals and harbour porpoises, which were variously attributed to collisions with ship propellers and attacks by sharks. More recent observations indicated that adult grey seals were responsible and these attacks represented predation and sometimes cannibalism (see Haelters *et al*. 2012a, van Bleijswijk *et al*. 2014, Leopold *et al*. 2015, Brownlow *et al*. 2016, van Neer *et al*. 2020, Langley *et al*. 2026). Coordination across networks is highly important to facilitate communication and adaptation to new knowledge.

Diagnosis and subsequent classification can be particularly challenging for causes of death that result in non-unique or pathognomonic signs (i.e. lesions not specific to or distinctly characteristic of a unique pathology). This is the case for causes of death related to some types of fisheries interactions. Non-target species such as marine mammals can become trapped in fishing gear (e.g. inside a net or on a line) while the gear is actively fishing (commonly recognized as "bycatch") but also in abandoned, lost or discarded fishing gear (ALDFG), which arguably counts as marine litter. On the one hand, to identify mortality directly caused by interactions with fishing gear actively fishing, it is arguably more important to determine whether the interaction cause death than to distinguish between incidental capture inside a fishing net and interaction with a line or other part of the fishing gear. Nevertheless, in order to identify appropriate mitigation methods, it is important to characterize how the interaction occurs, including in which fishing gear and parts of it.

On the other hand, in order to estimate bycatch mortality, and indeed to identify appropriate mitigation methods, it is important to distinguish between deaths due to active gear and those due to ALDFG. This presents two challenges, one obvious and the second perhaps less so. First, the signs are often similar (e.g. Bernaldo de Quirós *et al*. 2018, IJsseldijk *et al*. 2021) and more research is needed to ensure discrimination between these two causes of death. Second, there is a need for greater awareness of entrapment in ALDFG as a cause of death and a potential source of bias when estimating bycatch mortality from stranded animals. Interactions with ALDFG are known worldwide, but are barely recognized in classification schemes for relevant threats and possible causes of stranding and death in ETP species (e.g. Avila *et al*. 2018, Liria-Loza *et al*. 2021). It does not help that the terms 'bycatch' and 'entanglement' have been used in both contexts. Thus, the word 'entanglement' is used to describe entrapment in both active gear (e.g. baleen whale entanglement in creel lines) and ALDFG (see INDICIT 2019). Nonetheless, specific and distinct definitions exist for deaths due to active gear and those due to ALDFG, and several criteria have been proposed to distinguish between them (e.g. degradation of materials and biofouling attached to remains of gear encountered during animals' examination) in different taxa of marine megafauna. In addition, a Standard Protocol has been developed to record entanglement of marine biota in different types of marine debris (see ACCOBAMS 2019, INDICIT 2019, 2021).

While the various stranding networks use similar external and internal criteria to diagnose a stranded marine mammal as bycaught (see Fig. 2), some variation was apparent among and even within networks. Many of these bycatch signs are well known and have been described numerous times (Kuiken 1996, Cox *et al*. 1998, Knieriem and Hartmann 2001, Jepson *et al*. 2013, Moore and Barco 2013, Bernaldo de Quirós *et al*. 2018, Epple *et al*. 2020, IJsseldijk *et al*. 2021). We recommend further efforts to implement protocols using harmonized criteria for diagnosing bycatch, with the aim of eliminating remaining differences and avoiding consequent bias in the interpretation and use of the collected data.

External observations of marks caused by contact with fishing gear on the body are strong indicators of bycatch, as long as the animal is in good state of conservation (i.e. relatively fresh) because the decomposition process can obscure such marks as well as erasing evidence of other possible causes of death. The presence of fresh, undigested prey (especially species likely to have

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been present in and around the fishing gear) in the stomach contents, although consistent with bycatch, is not conclusive on its own. Intravascular gas bubbles have been linked to bycatch (Jepson *et al*. 2003, Moore *et al*. 2009) but they have also been related to cetaceans naturally hunting prey at depth (Fernández *et al.* 2017) and to panic responses in the vicinity of naval activities (Jepson *et al*. 2003), and they are not always observed in stranded bycaught cetaceans (IJsseldijk *et al*. 2021). Changes and lesions in the respiratory tract, such as pulmonary oedema and emphysema, may be consistent with bycatch but are not specific to bycatch mortality and do not rule out other causes as can also be associated with, e.g. predatory attacks and pulmonary diseases (Haelters *et al*. 2012a, Bernaldo de Quirós *et al*. 2018, Epple *et al*. 2020, IJsseldijk *et al*. 2021). Multi-organ congestion and blood in the eyes are considered to be less reliable signs, which nevertheless are frequently observed in bycaught animals (Bernaldo de Quirós *et al*. 2018, IJsseldijk *et al*. 2021).

Other criteria mentioned by respondents, such as bone fractures and muscle contusions, can be linked to bycatch but can also be associated with several other causes of death (Morell *et al*. 2017, IJsseldijk *et al*. 2021). Criteria such as low parasite burdens are indicative of good health rather than any specific cause of death and, in general, such signs can be seen as indicative of acute death rather than death due to ill health. Lack of evidence of other possible causes of death is a particularly unreliable criterion to determine bycatch, especially in the absence of an exhaustive and comprehensive search for evidence via complete external and internal examination of the animal plus various diagnosis tests. Conversely, diseased animals may also be bycaught, and ill health may indeed be a predisposing factor, leading to animals being less able to escape from fishing gear and perhaps more risk prone in the first place (IJsseldijk *et al*. 2021).

It is important to recognize that diagnosis of bycatch deaths is often not straightforward. The cause of death in bycaught marine mammals include (wet) drowning, asphyxiation (dry drowning, more usual in cetaceans) or injuries sustained (e.g. Jepson *et al*. 2000, Knieriem and García Hartmann 2001). Diagnosis of death due to drowning is complicated since there are no pathognomonic lesions specifically associated with drowning (Lunetta and Modell 2005, Piette and De Letter 2006). In any case, bycatch lesions differ among species (e.g. seals *vs* pelagic delphinids vs. baleen whales), and pathologies associated with bycatch can differ according to the types of fishing gear involved in bycatch mortality.

In order to achieve greater reliability, consistency and credibility in bycatch diagnosis various recommendations can be made. Even though much effort has been devoted to harmonize best practice protocols for monitoring, sampling and necropsy (e.g. Kuiken 1996, Moore and Barco 2013, IJsseldijk *et al*. 2019), further steps are still needed to implement them throughout Europe, and to minimize remaining differences, e.g. by ensuring that an adequate number of necropsies is carried out and that they are—as far as possible—representative, e.g. in relation to species, sex, age class, season, region, and decomposition status. The survey revealed that approximately half of the stranding networks performed analytical tests (e.g. histopathology, parasitology, and toxicology) to confirm bycatch as the cause of death when it was suspected. It is strongly recommended that necropsies routinely include both gross and histopathological assessment and ancillary tests, as these can provide a comprehensive understanding of individual and population health. We recommend further investigations, standardization and use of relevant analytical tests to diagnose the cause of death. This includes agreement on the importance attached to each type of evidence (and to the lack of such evidence) in the context of the condition of the carcase and the nature of the examination process (e.g. external examination only or full necropsy), standardization of the criteria used to determine the degree of certainty associated with the diagnosis, and standardization of the way bycatch diagnosis is reported (ensuring that the process followed is transparent).

Other tools, such as external examination and/or photographs, may represent the only available documentation on the possible cause of death in many stranded animals. We argue that it is valuable to collect such information, provided that its potential limitations are recognized and reported. In some cases, photographs can be used to confirm or reject bycatch as the probable cause of death or stranding, even if the lack of further investigations on other contributing factors precludes certainty (Parton *et al*. 2019, Puig-Lozano *et al*. 2020, Haelters *et al*. 2022, Martino *et al*. 2025) and various protocols exist for the use of photographs to identify lesions caused by bycatch in gear actively fishing or entanglement in ALDFG (e.g. Cornwall Wildlife Trust Marine Strandings Network 2020, INDICIT II 2021). However, even though the majority of the stranded marine mammals are photographed, only a small proportion of those photographs meet the quality and body coverage requirements to be considered suitable to identify potential external bycatch-associate lesions if present. Thus, it is recommended to take photographs routinely, ensuring high quality and images with full body coverage, and to store them systematically.

Approximately half of the stranding networks applied an index of uncertainty to each bycatch diagnosed case. It would be useful to adopt a standardized 'uncertainty index' associated with the determined cause of death, which would take into account factors such as the criteria followed to determine bycatch, the level of examination (e.g. external only, necropsy, etc.), and the training of personnel—even if some of these issues could be minimized by increased harmonization of protocols (and increased funding). It may still be difficult to calculate confidence intervals around the estimated proportion of stranded animals that died due to bycatch (aside from confidence intervals that account for sampling error alone). However, by analogy with the use of bycatch data from onboard observers, where estimates are used by ICES WGBYC only if a sufficient proportion of fleet activity and sub-strata was monitored (ICES 2025), it would become possible to filter bycatch estimates from strandings and use only those associated with a sufficient level of confidence (e.g. bycatch estimates based on only 'certain' diagnoses). This could also allow for a more accurate estimation of the proportion of animals affected by each threat.

Addressing the credibility and quality of stranding data supporting bycatch assessments

The utility of stranding data for conservation management depends on its credibility which in turn relates to the perceived quality and reliability of the findings (see Petitguyot *et al*. 2025). In relation to bycatch assessment, firstly and most obviously this relates

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to the reliability of bycatch diagnosis (coupled with reporting of associated uncertainty as discussed in Section 'Promoting and assuring best practice and harmonization for cause of death diagnosis'). A further important step would be to place greater emphasis on strengthening the collection and reporting of supporting data that can help us to understand the context in which bycatch occurs and its impact on populations. This includes information on search effort (see also 4.1.), and criteria used to select carcases for necropsy, and to collect various kinds of samples such as teeth and gonads, for analysis of life history parameters.

The investigation of stranded animals can inform us, at very least, about the minimum number of animals that die due to bycatch. Accounting for factors that potentially affect the probability of detection of stranded animals, and the certainty of the diagnosed cause of death, would allow us to obtain more accurate estimates of the total number of bycaught animals reaching the shore, and consequently, provide improved power to determine spatio-temporal trends. The probability of detection and reporting rate for stranded animals may be influenced by a range of factors, including the coastal morphology, environmental conditions, species distribution and abundance, human population density and the seasonality of tourism, and even changes in legislation. Some of these factors can be investigated and accounted for through statistical models such as those developed by Authier *et al*. (2014). For more accurate estimates of the number of stranded animals, a measure of the search effort for stranded animals is needed, and a possible way to achieve this is for network personnel and volunteers to use a mobile phone application when searching, such as 'Beach Track' which was developed by SMASS and used by their volunteer team in Scotland (ten Doeschate *et al*. 2024). A means to quantify the 'search effort' by members of the general public who opportunistically report strandings is also needed and this remains a significant challenge.

Assessing bycatch mortality rates and their potential impacts at the population level requires the integration of multiple data sources. Examining stranded animals can provide essential information on demographic parameters and mortality rates that, when combined with bycatch mortality data from other sources (e.g. fisheries observers) and estimates of species abundance and distribution, can be used to model population trajectories and assess the impacts of bycatch mortality, including the calculation of bycatch limits and the evaluation of the effects of potential mitigation measures (Barlow and Boveng 1991, Wade 1998, Arrigoni *et al*. 2011, Saavedra 2018, Taylor *et al*. 2022, Authier *et al*. 2024). Life history data originally obtained from strandings is widely used as part of the bycatch assessment process while the use of mortality data from strandings remains less frequent. Interpreting the outputs of population models remains challenging due to the inherent limitations and uncertainties associated with each data source, including stranding data. Wide confidence intervals in cetacean abundance and mortality estimates can complicate these assessments, but their calculation gives us a chance to carefully consider and quantify the spectrum of plausible population responses. Continued efforts to reduce uncertainty, quantify and correct for biases, and improve data quality across all sources are therefore crucial. Particularly, for small or local populations, collaboration with other monitoring programmes, such as those producing photo-identification catalogues, may provide additional insights into the impacts of bycatch on these populations, where these datasets overlap (e.g. NOAA 2025).

In principle, the number of bycaught animals among strandings can be used to estimate total bycatch mortality in at least two ways. First, the application of drift models—designed to estimate the probability of a carcase reaching the shore—can provide an estimate of the number of animals that died from bycatch, given the number found on the shore. In addition, reverse drift modelling can indicate where the mortality is likely to have occurred (Peltier *et al*. 2012, 2016, 2020, 2021, 2025). As a note of caution, data or assumptions about the distribution of live animals at sea are needed to inform the drift models.

In addition, combining the estimated annual mortality rate, as derived from life history data, with the percentage of mortality due to bycatch among stranded animals can provide an estimate of the annual bycatch mortality rate. Multiplying this figure by population size provides an estimate of the total number of animals bycaught (e.g. Read *et al*. 2013, Read 2015, Pierce *et al*. 2020, Neimanis *et al*. 2022, 2024, Torres-Pereira et al. 2023a). This potentially provides an additional method to estimate bycatch mortality from strandings. A key assumption is that both the age structure and the percentage of the individuals that died from bycatch among the stranded animals are representative of the population. There are various reasons to expect biases in the data (e.g. the youngest animals are probably underrepresented among strandings and the life table method assumes a stable age structure). However, there are also potential solutions, including correction of the age distribution by reference to a mortality-at-age model (e.g. the Siler model (Siler 1979, Saavedra 2018)).

Additional limitations apply to the estimation of birth rates from stranded animals since strandings are expected to be biased towards unhealthy animals. In this case, stranded animals that died due to trauma (including bycatch) offer a subset that could be more representative of the living population (Murphy *et al*. 2009). Only one respondent specified that they collaborate with research teams to calculate life tables to estimate mortality rates at age. The collection and analysis of demographic parameters (e.g. counting of growth layer groups in dentine and/or cementum of teeth to determine age, examining ovarian scars to determine female maturity, and recording the presence of a foetus and evidence of lactation to determine reproductive state) provide essential data to estimate population parameters like age-specific birth and mortality rates, and to develop life tables (see Krebs 1994). Data to infer demographic parameters are collected by most of the respondents, although the analytical methods applied are variable, as results from Petitguyot *et al*. (2025) have shown. The comprehensive collection of such data from stranded animals following best practice is highly recommended. The use of age-length relationships and size-at-maturity estimates to infer age and maturity is not recommended if other techniques can be applied (e.g. analysis on teeth and gonads), as it precludes obtaining the most reliable demographic data and, will not permit detection of changes in growth and maturation patterns in a population over time (Murphy *et al*. 2009, 2020).

Finally, the susceptibility of species to bycatch may fluctuate over time and space due to a range of factors, including changes in their distribution range and abundance, the distribution of prey species and the distribution of fishing activity and practices, all of which may of course be inter-related and ultimately reflect external drivers such as ocean warming. Strandings monitoring can help to detect changes in species distribution related to climate-driven environmental changes, as observed in the British Isles

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(MacLeod *et al*. 2005, Leeney *et al*. 2008, Williamson *et al*. 2021) and other areas such as Brazil (Prado *et al*. 2016) and Australia (Schumann *et al*. 2013). For this reason, it is important to guarantee consistent data collection across time, space and species, as well as to complement information from strandings with other data sources such as abundance and distribution sightings surveys (both dedicated surveys and citizen science initiatives).

Improving the identification of fishing gears from strandings

This study has shown that many stranding schemes report information about the type of fishing gear thought to be responsible of bycatch mortality in marine mammals. The reported types of gear include those associated with artisanal and illegal fishing (e.g. in the Republic of Ireland, and Ceuta and Galicia in Spain), which are thought to be important sources of fisheries interactions but whose impacts are difficult to assess (Moore *et al*. 2021, Wade *et al*. 2021). A systematic characterization of recovered materials and detectable remains, or signs observed during the examination of the stranded animals (and recorded in photographs), can provide valuable insights into the fisheries responsible for bycatch mortality. Furthermore, this would greatly enhance our ability to distinguish between different types of interaction (e.g. an animal trapped in trap or pot line, vs. inside a gillnet or trawl net), to better understand how the interaction occurs, and ultimately to help propose effective mitigation measures. In addition, some carcases are handed to networks by fishers. Local knowledge and the application of reverse drift modelling may also suggest which fisheries were responsible.

Further development of guidelines and protocols to identify fishing gears involved in bycatch in the North-east Atlantic (based on knowledge of regional fishing in the focal areas, recovery of gear remains, and analysis of marks on the animals), is therefore highly recommended. In addition, as for the diagnosis of bycatch mortality, it is essential that the basis for these conclusions is made clear and that any uncertainty is also communicated. A comprehensive characterization and classification of gears involved in strandings, and further research on the possible specific associated body signs, would be useful for the management of bycatch impact.

Expanding tagging programmes in support of developing drift models

The probability of a carcass reaching the shore and being recorded by a stranding network, can be inferred through carcass tagging programmes, and it varies depending on factors such as carcass buoyancy, currents and predominant winds. These are taken into account to estimate total numbers of bycaught animals from strandings, by applying drift modelling (Peltier *et al*. 2012, 2025). Results from reverse drift models can be correlated spatiotemporally with fishing effort by particular métiers and ultimately help indicate the type of fisheries involved in bycatch cases (Peltier *et al*. 2020, 2021). However, carcass tagging programmes have so far been carried out in only four of the surveyed countries, for common dolphins and harbour porpoises in the UK (between 2004 and 2009), in the Netherlands (between 2013 and 2017), along the Spanish northwest coast (between 2002 and 2011), and along the French coast of the Bay of Biscay (between 2004 and 2009, and since 2017) (Martínez-Cedeira *et al*. 2011, de Boer *et al*. 2012, Scheidat *et al*. 2018, Peltier *et al*. 2025)—and only the last of these has generated sufficient data to validate drift models. The approach developed by (Peltier *et al*. 2015, 2016) has potential application in other European regions. However, model parameters such as buoyancy, and the proportion of carcasses that sink or float, may vary between species and regions—but also according to the size and condition of the animals. This affects the drift and stranding probabilities, and thus the representativeness of strandings in relation to deaths at sea. Therefore, more extensive tagging programmes and model adaptation across different areas are recommended, as well as the collection of basic data (e.g. body length and girth), plus photos prior to release of a tagged carcass.

Extending collaboration with fishers

There is considerable ongoing collaboration between the respondent stranding networks and fishers. Collaboration between stranding networks and fishers can provide valuable information for identifying fishing gear, the behaviour of marine mammals in the vicinity of the fishing gear, handling techniques to increase survival of bycaught animals, and the efficiency of potential mitigation measures, etc. (e.g. López *et al*. 2003, Goetz *et al*. 2014, Barz *et al*. 2020, Karamanlidis *et al*. 2020). Thus, strengthening collaboration between fishers, stranding networks, the scientific community and management decision-makers could both improve our understanding of the importance of bycatch mortality and facilitate the development of ways to reduce it.

Many networks record cetacean bycatches reported by fishers, and some networks perform necropsies on carcasses brought to land by fishers. Responses suggested some variation in how bycaught animals brought to land by fishers are included in the databases of the receiving stranding network. It is recommended to record the origin of animals notified and brought to land by fishers (e.g. as 'reported by fishers'), to distinguish them from animals found 'stranded at the beach' or 'drifting at sea.' Including those animals directly bycaught and reported by fishers with the stranded animals will inevitably inflate the estimated proportion of bycaught animals in the database and could lead to an overestimate of the proportion of stranded animals that were bycaught. We recommend that the origin of the animals in the database is clearly identified to avoid such bias. We also encourage including in the database the location where the animal was caught.

Streamlining the reporting of bycatch data

Availability and accessibility to stranding data varies among stranding schemes (see Petitguyot *et al*. 2025). Several international organizations request stranding data (mainly for cetaceans) for various purposes, including ASCOBANS, ACCOBAMS, ICES, IWC, and the European Commission, in addition to the European Cetacean Society and the General Fisheries Commission for the Mediterranean, which have done so occasionally or in the past. The frequency of these requests may be tied to the funding mechanism, the frequency with which external bodies review stranding data (annually in the case of ASCOBANS, ICES, and (until recently) the IWC), and the 6-year reporting cycle of EU directives such as the MSFD. However, the drivers of reporting frequency

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were not specifically investigated by the questionnaire. In the case of ICES, stranding data are requested for use by ICES WGBYC, although this is not part of the official data call (ICES 2026). These data can be used to complement on-board and/or logbook data, to estimate bycatch mortality, and to evaluate proposed measures to reduce bycatch, e.g. for common dolphins in the northern Bay of Biscay (ICES 2020, 2023a) and for seals and harbour porpoises in the Baltic Sea (HELCOM 2023). In the case of harbour porpoises in Iberian waters, stranding data were not included in the estimations of bycatch mortality in the latest OSPAR assessment, but the high number of stranded porpoises due to bycatch was used as evidence that the agreed OSPAR threshold (of zero bycatch) was critically exceeded (Taylor *et al*. 2022). The IWC also compiles stranding data and promotes their use for national conservation management purposes.

Sharing bycatch information with national and international scientific and management organizations is a common practice among stranding networks operating along the Atlantic coast of Europe. Some inconsistencies exist in relation to what is reported and not all respondents report their data to the same organizations (e.g. reporting variously to national governments and/or the organizations mentioned above). Most respondents agreed to provide detailed data to a possible centralized data call which potentially might lead to a unique common database (Brownlow *et al*. 2023, 2024), operating under data sharing agreements with the capacity to feed every national and international data request. As discussed by Petitguyot *et al*. (2025), this initiative would facilitate the transfer of information and the use of these data into management, avoid additional and unnecessary work for stranding networks (which normally have limited staff and funding), save time and money, and facilitate the incorporation of new initiatives and protocols for data collection. Given the importance of sustained support for stranding networks, there is a need to review the perspectives, interests and needs of the organizations that manage and fund these networks, as well as those that ultimately use the information collected. This would help us to better understand current levels of support, improve the flow of information among different actors involved in the collection and use of stranding data, and to identify areas where further support and/or guidance may be need. It could also offer a mechanism for data checking and quality control.

Integrating stranding data into bycatch management

The survey demonstrated the capacity of stranding networks to contribute to the monitoring of bycatch, by identifying the species or populations most affected by bycatch, revealing spatial, temporal and seasonal trends in bycatch mortality, and determining the types of fisheries and/or fishing gear involved—while also highlighting limitations and variation between networks, in what is currently achieved. Overall, the information obtained from the questionnaires confirmed that bycatch is a concerning source of direct anthropogenic mortality affecting marine mammals along the Atlantic coasts of European countries, as well as their archipelagos and Mediterranean coastlines. Based on their own experience and perspectives, most of the respondents considered bycatch to be an important or very important cause of mortality for marine mammals in their respective region. The situation is particularly concerning for the critically endangered Baltic Proper subpopulation (Hammond *et al*. 2008) and Iberian population of harbour porpoise, which is considered critically endangered in Portugal and in danger of extinction in Spain according to national assessments (Torres-Pereira *et al*. 2023b, BOE-A-2023–344), and which has been identified as a genetically distinct population and potentially as a separate subspecies together with the Northwest African porpoise population (Fontaine *et al*. 2014, Fontaine 2016, Ben Chehida *et al*. 2021).

The responses have highlighted some regions and species groups for which the bycatch impact is apparently higher. For example, the regions of Ceuta (Spanish enclave on the North African coast), the French Atlantic coastline of the Bay of Biscay, and the Iberian Peninsula, specifically southern continental Portugal (Algarve and Alentejo) and northwest of Spain (Galicia), had the highest percentages of marine mammals stranded due to fisheries bycatch. It should be noted that this study did not receive information from northern Portugal, where the highest rates of cetacean strandings in the country have been recorded (e.g. Torres-Pereira *et al*. 2023a, Pierce *et al*. 2024a). Both cetaceans and seals were affected by bycatch, although there is important regional variation (see Table 1, and Fig. 3). Evidently, results based on percentages do not tell the whole story, and it is important to consider absolute numbers of bycaught animals (in relation to population, abundance, distribution, and status), and to take into account the length of the surveyed coastline (Table 1). For example, only 30 cetaceans stranded in Ceuta in 2019, while 2282 marine mammal strandings were reported in France, but when considering the length of their coastlines (42 km and 9193 km, respectively), Ceuta has a higher density of reported strandings per km than France (0.97 and 0.25, respectively).

The temporal trends in bycaught stranded animals that were detected (see Table 1) may reflect changes over time in the number of stranded marine mammals that died due to bycatch in the various Northeast Atlantic coastal areas. However, it is important to note that other factors such as distribution shifts, changes in abundance, improved diagnosis of bycatch mortality, changes in fishing techniques and effort, etc., need to be considered to validate the interpretation of the observed trends. For example, the reported decrease in the number of stranded bycaught porpoises in Belgium and the Netherlands is possibly linked to the prohibition of beach-set gill and tangle nets in Belgian recreational fisheries close to the shore, although other possible explanations, such as a decrease in fishing effort and a change in porpoise distribution to offshore waters, should be further investigated. Further analysis of temporal trends in bycatch mortality rates, potential confounding factors and possible drivers, is necessary. Furthermore, some of the limitations reported by respondents may prevent networks from surveying consistently and from detecting bycatch trends. Providing networks with necessary resources and tools to ensure strong and consistent data collection is, once more, recommended.

Despite the substantial information on bycatch mortality derived from stranding data, the integration of such data into bycatch assessment in European seas remains limited. The most notable exception is the application of stranding data to estimate common dolphin total bycatch mortality in the northern Bay of Biscay, leading to advice about mitigation measures such as the implemented periods of fisheries closure implemented in France (ICES 2020, 2023a, c, Government of France 2023). Improving the incorpora-

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tion of stranding data into bycatch assessment and management frameworks therefore remains a critical priority (e.g. Oliveira *et al*. 2024). Ensuring adequate financial resources for stranding monitoring, implementation of best practice and improved coordination, as previously mentioned, are evidently part of the solution but we also recommend fostering collaborations among stranding networks, fishers, scientists, regulatory authorities, international organizations and the general public, not least to ensure a broader recognition of the value of stranding data.

Conclusions

Stranding networks in Europe have proven to be important sources of information for understanding and quantifying occurrence and variability of bycatch mortality in marine mammal populations. These networks collect key data from strandings that inform us about the prevalence and importance of bycatch compared to other threats, the frequency and distribution of bycatch cases, spatial, seasonal and temporal bycatch trends, the fisheries involved (including artisanal and illegal fisheries), and estimates of total bycatch mortality. Strandings allow the investigation of animals killed in fishing gears and in areas for which no other data exist (e.g. on-board observers or remote electronic monitoring). Overall, results from the questionnaires have confirmed that bycatch is an important cause of anthropogenic direct mortality to marine mammals along the coasts of Atlantic European countries. Although bycatch impact is widespread, differences exist among regions and between species affected.

Moreover, European stranding networks also collect much supplementary data (e.g. on population demographic parameters) needed to provide context, determine the profile of bycaught animals, assess impacts on population trajectories, calculate bycatch thresholds, and explore the efficiency of possible mitigation measures. The survey showed that the data on bycatch mortality available from strandings currently have limitations, which vary across networks, but stranding data from the French coast in the north of the Bay of Biscay, have already been used to inform drift models and to estimate bycatch mortality in common dolphins. In other words, it is already considered feasible to provide relevant data of appropriate quality based on strandings—but it remains important to try to overcome existing limitations and, where this is not possible, make sure the limitations are appreciated by potential end-users.

We propose a number of recommendations aimed at overcoming current limitations, through coordinated efforts among multiple stakeholders. We highlight the need to address limitations of funding and experienced staff for consistent data collection across time, regions and species, to improve the capacity of stranding networks to monitor marine mammal bycatch. We recommend strengthened coordination across stranding networks, adoption of common protocols for diagnosis, and enhanced data collection on life history and health status. Moreover, we encourage the expansion of research to ensure representative monitoring and enhance credibility and use of data collected, including at-sea carcass tagging programmes to refine bycatch estimates. Greater collaboration among networks, centralized data reporting, and the development of a common European stranding database would improve data quality, comparability, and the integration of stranding data into bycatch assessment and population management.

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Supplementary material

Supplementary material is available at *ICES Journal of Marine Science* online.

Conflicts of interest

None declared.

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Data availability

The datasets generated and analysed during the current study will be shared on reasonable request to the corresponding author with permission of the stranding network coordinators.

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