GEOGRAFIA, RISCOS E PROTEÇÃO CIVIL

HOMENAGEM AO PROFESSOR DOUTOR LUCIANO LOURENÇO

VOLUME 2

Coordenadores:
Adélia Nunes
António Amaro
António Vieira
Fátima Velez de Castro
Fernando Félix

RISCOS - ASSOCIAÇÃO PORTUGUESA DE RISCOS,
PREVENÇÃO E SEGURANÇA

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Ficha Técnica

Título: Geografia, Riscos e Proteção Civil.
Homenagem ao Professor Doutor Luciano Lourenço.
Volume 2

Edição: RISCOS - Associação Portuguesa de Riscos, Prevenção e Segurança

Coordenação: Adélia Nunes, António Amaro, António Vieira, Fátima Velez de Castro e Fernando Félix

Capa e contracapa: Fernando Félix

Concepção gráfica e paginação: Fernando Félix

Impressão: Simões & Linhares, Lda.

ISBN: 978-989-9053-05-2 **ISBN digital:** 978-989-9053-06-9

DOI: https://doi.org/10.34037/978-989-9053-06-9_1.2

Depósito Legal: 487457/21

1.ª Edição

Parceiros

Este trabalho é Financiado por Fundos Nacionais através da FCT – Fundação para a Ciência e a Tecnologia no âmbito do projeto "UIDB/GEO/04084/2020".

This work is Financed by National Funds through the FCT - Foundation for Science and Technology under the project "UIDB/GEO/04084/2020".

Luciano Lourenço nos 25 anos de Escuteiros da fundação do grupo de Alboraia (Valência), com a esposa Maria da Graça Lourenço, em 08/02/1995.

Fotografia cedida por Maria da Graça Lourenço, 2021.

Companheiros de jornadas de investigação,
o filho João Nuno Lourenço e o Tio Agostinho, em junho de 2000.

Fotografia cedida por Maria da Graça Lourenço, 2021.

Luciano Lourenço, no Chile, na exposição de material de combate a incêndios florestais, na abertura de uma faixa de defesa da floresta contra incêndios florestais e visita a uma Corporação de Bombeiros, em 12/11/1995.
Fotografia cedida por Maria da Graça Lourenço, 2021.

Num almoço do Dia de Corpo de Bombeiros de Macau, com a receção do Escudo de Armas do CB de Macau, estando representadas Delegações de Hong Kong, Província de Guangdong (RPC), Macau e a Escola Nacional de Bombeiros, Portugal, a 2 de maio de 1998.

Fotografia cedida por Maria da Graça Lourenço, 2021.

Luciano Lourenço, em representação da ENB - Escola Nacional de Bombeiros, na recepção a Delegação de Bombeiros de Macau, em abril de 2000.

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Luciano Lourenço na Visita do Presidente da República Mário Soares às instalações do NICIF, a 14/04/1994 e, ao lado, com o Ministro da Administração Interna Jorge Coelho e o Presidente da Liga dos Bombeiros Portugueses, Lourenço Batista, em 28/04/1997.

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Luciano Lourenço numa Alocução durante um EPRIF - Encontros Pedagógicos sobre Risco de Incêndio Florestal, em 20/11/1995.

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Luciano Lourenço, numa das reuniões do PREFER - *Space-based Information Support for Prevention and Recovery of Forest Fires Emergency*, desenvolvido por um consórcio de 8 instituições, oriundas de 5 países, em 04/06/2015.

Fotografia cedida por Maria da Graça Lourenço, 2021.

Luciano Lourenço, na Sessão de Encerramento do III Simpósio Ibero-Afro-Americano de Riscos, a 20 de junho de 2019, no Instituto de Geografia, Campus Santa Mônica, da Universidade Federal da Uberlândia, Minas Gerais, Brasil.

Fotografia dos arquivos da RISCOS - Associação Portuguesa de Riscos, Prevenção e Segurança, 2021.

PENSAR A FLORESTA NA PERSPETIVA DOS RISCOS

Dos incêndios florestais à diversidade ecológica

Luciano Lourenço, na selva Amazónica em 16/06/2012.

Fotografia cedida por Maria da Graça Lourenço, 2021.

Is native forest an alternative to prevent wildfire in the WUI in Central Portugal?

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Abstract

The expansion of the 2017 mega-fires in Portugal was observed to be locally halted by native forest patches. Here we present spatial simulation scenarios of fire behaviour to assess whether native forest cover mitigates fire spread during extreme wildfire conditions in wildland-urban interface (WUI) areas around Industrial Zones (IZs). Our results suggest that broadleaved forest cover can reduce fireline intensity and rate of spread around IZs up to 20 and 8 times, respectively, on average. Thus, our results support the need to discuss forest management in Portugal to better prevent WUI fires.

Keywords: Forest management, spatial fire simulation, industrial zones.

Resumo

A floresta nativa é uma alternativa para prevenir os incêndios florestais na IUF no Centro de Portugal? O avanço dos mega incêndios de 2017 em Portugal foi interrompido localmente por algumas manchas de floresta nativa. Aqui, apresentamos cenários de simulação espacial do comportamento do fogo para avaliar se a cobertura florestal de folhosas tem um efeito positivo na prevenção de incêndios florestais. As análises foram realizas para condições extremas de incêndio, em áreas IUF, especificadamente, em torno de Zonas Industriais (ZIs). Nossos resultados sugerem que a cobertura nativa de folhosas é capaz de reduzir a intensidade do fogo e a velocidade de propagação em torno das ZIs, em média, até 20 e 8 vezes, respetivamente. Esses dados, portanto, suportam a necessidade de discutir a gestão florestal em Portugal para melhor prevenir incêndios em IUF.

Palavras-chave: Manejo florestal, simulação espacial de incêndios, zonas industriais.

DOI: https://doi.org/10.34037/978-989-9053-06-9_1.2_05

Introduction

Managing wildland-urban interface (WUI) fires requires an understanding of ignitions and dynamics in urban structures and fire behaviour in surrounding forests (Manzello & Foote, 2014). In recent years, WUI fires have caused thousands of structural, human and environmental losses in Portugal (CTI, 2018; Ribeiro *et al.*, 2020) and in several other countries (Manzello *et al.*, 2007; Vacca *et al.*, 2020). Although challenging, WUI fire management demands identifying the new patterns of fire regimes that are associated with greater urban expansion into rural areas, significant changes in land use and land cover and climate change.

Fire events are highly sensitive to weather conditions and fire regimes respond quickly to climate dynamics (Laurance & Williamson, 2001). Most of the Portuguese mainland is under the influence of a Mediterranean climate, in which recurrent periods of drought arise (Keeley *et al.*, 2011). These periods, combined with strong winds (Moreira, 2017), such as *Hurricane Ophelia* in 2017, may trigger extremely intense and tthreaten WUI fires. In addition to climatic factors, WUI fires also result from poor land and fuel management (Fernandes *et al.*, 2016; Vacca *et al.*, 2020), associated with the abandonment of agricultural activities, and from anthropic ignitions (Fernandes *et al.*, 2014; Moreira *et al.*, 2001). Former forests and agricultural spaces have been massively transformed since the 1970s into shrubland and dense, continuous monospecific forest stands that are more susceptible to fire (Fernandes *et al.*, 2019; Silva *et al.*, 2011).

In Portugal mainland, decrease in land use intensity in marginal productivity areas promoted a positive feedback for fire, with increasingly larger patches of the landscape occupied by continuous and homogeneous fuel after each large fire, which in turn results in potentially larger fires (Moreira *et al.*, 2001). In contrast, some fragments and reserves of native forests have been shown to be able to partially interrupt this cycle and locally slow down fire spread (Pinto & Fernandes, 2014). Mata da Margaraça, a native broadleaved forest with 68 ha, located in central Portugal, is an important example. The intense Arganil fire, which occurred in 2017, has entered the Mata da Margaraça but lost intensity, to the point of extinguishing and failing to reach the humid heart of the forest (CTI, 2018). Other studies suggest the existence of a microclimate in native broadleaved forests that contributes to increase fine fuel moisture and decrease wind speed, compared to other landscape types, and therefore decrease fire hazard (Fernandes *et al.*, 2010; Pinto & Fernandes, 2014). These findings suggest that the conversion to native broadleaved forests may be a potential alternative to prevent forest fires, namely in areas of urban-forest and industrial-forest interface. Despite the existence of previous work on this topic, there is a lack of literature testing the effect of native broadleaved cover under conditions conducive to extreme fire behaviour.

Here we present spatial simulation scenarios of fire behaviour to assess whether native broadleaved forest cover has a positive effect in fire prevention under extreme wildfire conditions, using an example from 2017 in Portugal. The study was carried out in WUI areas around Industrial Zones (IZs), located in the centre of Portugal. Our particular objective was to ascertain whether these forests could be an alternative land use in the 100-m management buffer around industries, as a way to prevent WUI fires. According to the Portuguese law (Decree-Law n.º 10/2018) land owners have to manage this buffer according to very specific technical guidelines. To this end, we combined a series of fire behaviour variables and used real-world data from the 2017 fires (CTI, 2018) to try to reproduce, through spatial modelling, those same fires in Mata da Margaraça (MM) and in the IZs under analysis: Oliveira do Hospital (OH), Mira, and Tocha. Subsequently, we adopted the same fuel model and canopy cover (81-100%) from Mata da Margaraça in the buffer surrounding the IZs to create alternative fire behaviour scenarios. Thus, we were able to assess whether a hypothetic conversion to native forest that has greater canopy cover would prevent fire to propagate into the IZs.

Materials and Methods

Data Collection

Fire spread over the landscape around the four studied areas (Mata da Margaraça and three IZs: Oliveira do Hospital (23 ha), Mira (56 ha) and Tocha (12 ha) was reproduced using the reports from people living in these areas. This field work was developed shortly (a few months) after the 15 October 2017 fire, and was used to support the production of 1-hour fire spread isochrones, together with satellite data (MODIS and VIIRS), technical reports (from the agencies involved in fire suppression), and also videos and photos provided by citizens and technicians from public administration (CTI, 2018). We used 133 georeferenced points corresponding to the arrival time of the fire front to reconstruct the Quiaios occurrence (which affected the Tocha and Mira IZs), and 528 for the reconstruction of the Esculca-Arganil event (which affected the Oliveira do Hospital IZ). Data for fire behaviour simulation included, road network, hydrography, infrastructure, digital terrain model (25m x 25m), administrative limits and other georeferenced data provided by the Intermunicipal Community of the Region of Coimbra (CIM-RC, 2021). We also acquired data on land cover for the year 2015 (COS 2015), made available by the General Directorate of the Territory (DGT, 2015). All the necessary meteorological data for the year 2017 were provided by the IPMA - Portuguese Institute for Sea and Atmosphere (www.ipma.pt).

Spatial Simulation of Fire Behaviour

To simulate the behaviour and growth of the fire, we used the Farsite fire behaviour modelling framework (www.firelab.org/project/farsite). Farsite uses spatial data on topography and fuels, together with meteorological and wind data files. Fuel input data, was based on fuel models developed by Fernandes *et al.*, (2009) by converting the land covers of COS 2015 into the most likely fuel models, according to our knowledge of local conditions (Table I). We prepared the meteorology and wind archives, with data for the 14th, 15th, 16th and 17th of October from Lousã, Nelas, Coimbra, and Figueira da Foz meteorological stations, as they are the nearest to the Mata da Margaraça and Oliveira do Hospital, Mira, and Tocha IZs, respectively (Table I). Fine fuel moisture was obtained from fine fuel moisture code (FFMC) of the FWI - Fire Weather Index (CWFIS, 1976) system. Farsite adjusts, throughout the simulation, the fine fuel moisture according to the local terrain and forest cover conditions through the model of Nelson (2000).

The fires were associated with intense spotting. Therefore, we used with a spotting rate of 5% for Farsite to calculate crown fires with spotting (Table I). We identified this spotting rate based on a continuous calibration exercise of the fire model in Mira, which contained observed evidence of fire spotting, through camera registrations. As the fires of October 15 had similar behaviour, influenced by *Hurricane Ophelia*, we adopted the same spotting rate to simulate the fires in Mata da Margaraça and in the other Industrial Zones (Table I).

The fire simulation parameters (Table I) were tuned by using the isochrones of the actual fires, to reproduce as close as possible fire propagation in the vicinity of Mata da Margaraça and the IZs. Subsequently, we simulated the fire behaviour in the IZs using two specific scenarios: (A) with the 100-m management range covered by the same fuel model as Mata da Margaraça, that is, native broadleaved forests, and (B) with a 500-m zone surrounding IZs using the same fuel model (native broadleaved forests). All simulations were carried out within a 5-km buffer from the IZs to capture fire dynamics.

Table I - Variables and main input data for fire behaviour and growth simulation.

Fuel, Meteorological, and Wind data							
Model[1]	**Dead fuel Moisture**	**Elevation *Avg.***	**RH**[2] ***Avg.***	**Wind *Avg.***	**T° *Avg.***	**Fuel Models**[3]	
	1h (%)	**m**	**%**	**km/h**	**C°**	**Model**	**Canopy Cover**
Margaraça	4	750	19	15	30	F-FOL Broadleaves	81-100%
Mira	5	43	26	17	29	M-EUC Eucalyptus	51-80%
OH	5	534	29	12	27	M-PIN Maritime Pine	51-80%
Tocha	5	38	50	12	24	M-PIN Maritime Pine	51-80%

Parameters of Fire Behaviour							
Adjust.[4]	**Forest Fire**	**Fire Start**	**Fire End**	**Time Step**	**Perimeter Resolution**	**Spot Fires**	**Enable Crown fire**
		hour (day)	**hour (day)**	**hour**	**m**	**%**	
M.M (3)	Arganil	11h00 (15)	6h00 (16)	1h00	30	5	Wagner (1977) Rothermel (1991)
Mira (12)	Quiaios	20h00 (15)	4h00 (17)	1h00	30	5	
O.H (3)	Arganil	13h00 (15)	7h00 (16)	1h00	30	5	
Tocha (8)	Quiaios	16h00 (15)	21h00 (16)	1h00	30	5	

[1] The weather data is for the 15th of October 2017; [2] RH - relative humidity; [3] predominant fuel model up to 500m from the IZs and the Mata da Margaraça in 2015 according to COS 2015; [3]Access to ICNF (2012) to consult the 18 standard fuel models for Portugal; [4]rate of spread adjustment; avg (average).

Source: See all sources in the Data Collection section.

Results

The Arganil fire started near Mata da Margaraça (fig. 1). This fire had a rate of spread of 1.0 to 4.5 km/h, the main direction was NNE and head fire intensity ranged between 30,000 and 45,000 kW/m (CTI, 2018). The simulated data matched the isochrones of the Arganil fires, and both reconstructed and simulated data indicate that the fire entered Mata da Margaraça but did not reach its inner core, about 100-200 meters north of the forest and 600 meters on its left flank. The simulated data also showed NNE direction for the fire fronts and head fire intensities reaching 65,000 kW/m (fig. 1). The rate of spread was underestimated, reaching maximum values of 2.8 km/h, 0.3 km/h on average (Table II). At the border of Mata da Margaraça, fire intensity was thirty-four times lower than the average fire and the rate of spread was 0.02 km/h. The data indicated a heat release of 25,000 kJ/m^2, on average, and a value three times lower at the border (200 m) of Mata da Margaraça (Table II).

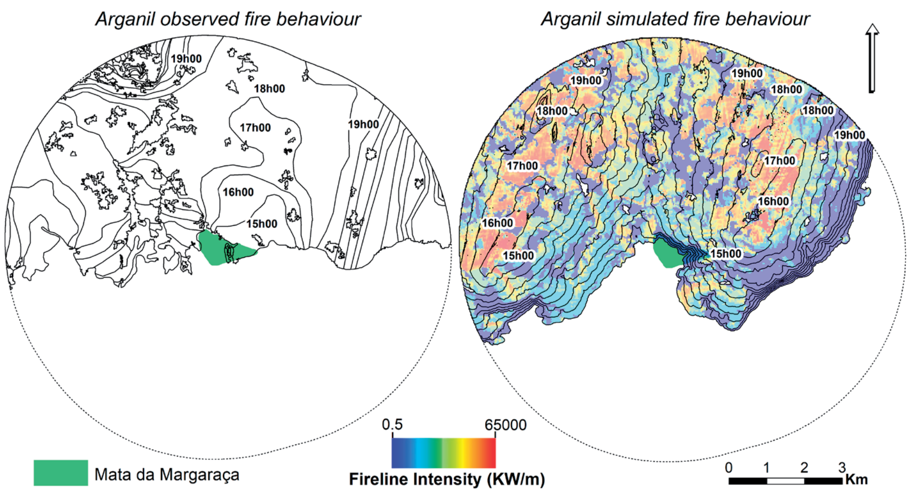

Fig. 1 - Arganil Fire. Isochrones of reconstructed time of arrival (left) and simulated isochrones (right) around Mata da Margaraça.

TABLE II - Fire Behaviour Variables.

Simulations			Fireline Intensity (km/h)		Rate of Spread (km/h)		Flame Length (m)		Heat per Area (kJ/m²)	
			Avg	SD	Avg	SD	Avg	SD	Avg	SD
M.M	in 200 m border		95.7	222.4	0.027	0.026	0.5	0.4	9383	5182
	200 m to 5 km		3277	7224	0.270	0.370	4.0	6.3	25015	25576
O.H	*Scen. A*	up to 100 m	201	1002	0.046	0.070	0.7	1.1	9163	9469
		100 m to 5 km	3136	5548	0.390	0.340	4.2	5.4	22075	23381
	Scen. B	up to 500 m	83.2	64.7	0.041	0.036	0.6	0.2	7379	1210
		500 m to 5 km	3042	5549	0.370	0.330	4.1	5.4	21678	22823
Mira	*Scen. A*	up to 100 m	82.1	162.8	0.030	0.028	0.5	0.3	8682	4123
		100 m to 5 km	1008	1434	0.170	0.133	2.0	1.9	21315	14735
	Scen. B	up to 500 m	70.7	105.5	0.028	0.021	0.5	0.2	8049	3100
		500 m to 5 km	927	1396	0.160	0.135	1.8	1.8	20586	14405
Tocha	*Scen. A*	up to 100 m	360.5	1345	0.042	0.066	0.9	1.8	12544	13453
		100 m to 5 km	3944	7873	0.327	0.429	4.6	6.9	28670	25622
	Scen. B	up to 500 m	109.7	517.6	0.033	0.026	0.5	0.6	8592	5293
		500 m to 5 km	3726	7467	0.320	0.421	4.5	6.6	28025	24979

Notes: Avg (average); SD (Standard Deviation);
Scen. A (Scenario A: 100m buffer with F-FOL);
Scen. B (Scenario B: 500m buffer with F-FOL).

Source: Simulation models results.

The Arganil fire had a maximum fireline intensity of 38,000 kW/h for all simulation scenarios in O.H (fig. 2). The rate of spread of 1.7 km/h (0.4 km/h on average), was also underestimated (Table II).

Scenario A indicates spread rate and intensity seven times lower in the 100 m management range covered by broadleaves. Scenario B, on the other hand, shows that the fire did not fully reach the IZ, mainly to the north of the 500 m buffer. Although rate of spread was similar in both scenarios (max. 0.8 km/h), intensity was 2.4 times lower in the 500 m buffer compared to the 100 m buffer (fig 2).

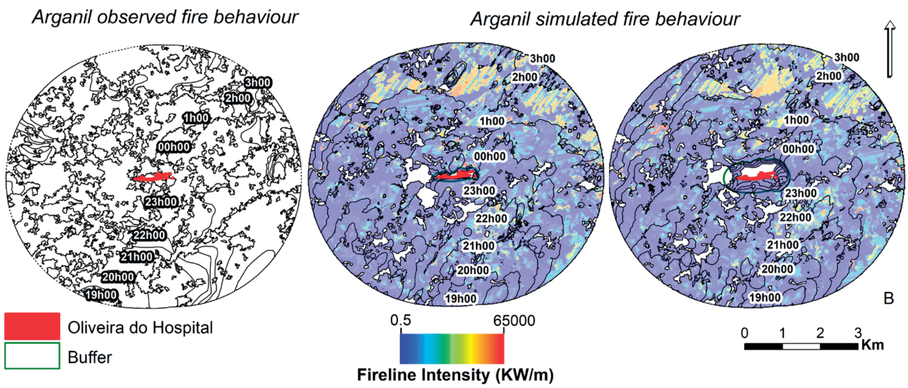

Fig. 2 - Arganil Fire. Isochrones of reconstructed time of arrival (left) and simulated isochrones (right – (A-100 m buffer and B-500 m buffer)) around Oliveira do Hospital IZ.

The Quiaios fire near the coast attained a maximum rate of spread of 5.4 km/h (CTI, 2018). The simulated data indicated a fireline intensity of 16,000 kW/h and a rate of spread of 1 km/h for this fire in Mira (fig. 3). None of the scenarios with F-FOL coverage prevented the fire from reaching the Mira I.Z. However, intensity was reduced by twelve and thirteen times in 100- and 500-m buffers, respectively, and spread rate decreased 6-fold, in both scenarios. The same occurs in Tocha IZ (fig. 3). Although it was not able to prevent fire spread around the IZ, the F-FOL cover was able to reduce intensity in the 100-m buffer by ten times and thirty-four times in the 500-m buffer. The simulation of the Quiaios fire in Tocha resulted in a rate of spread and maximum intensity of 2.0 km/h and 47,000 kW/h, respectively.

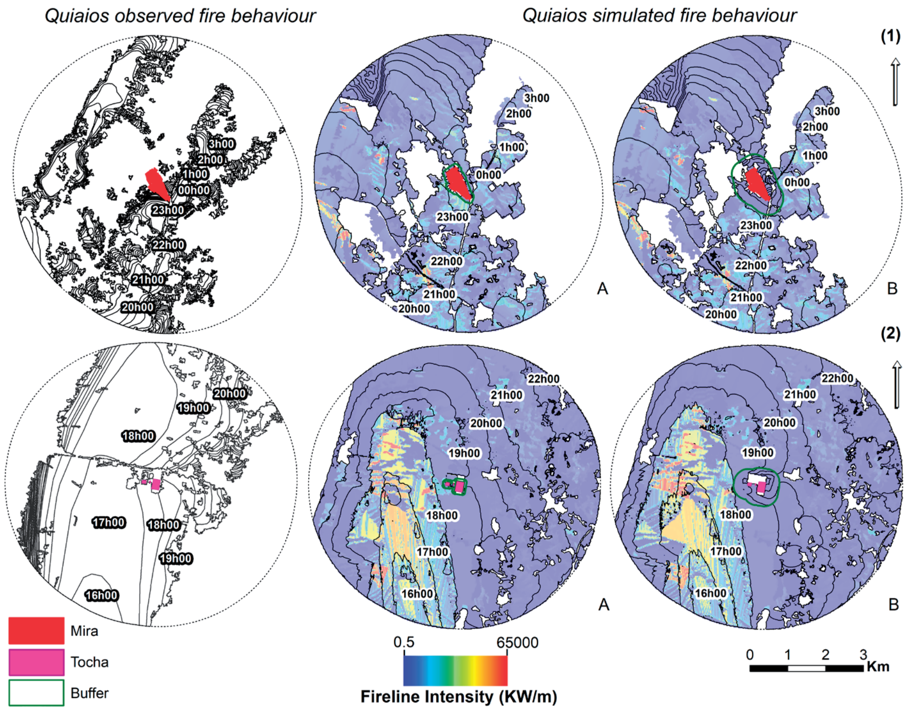

Fig. 3 - Quiaios Fire. Isochrones of reconstructed time of arrival (left) and simulated isochrones (right – (A-100 m buffer and B-500 m buffer)) around Mira IZ (1) and Tocha IZ (2).

Discussion

Our results demonstrate that the coverage of native broadleaved forest can be an alternative to reduce fire spread in areas of urban-forest and industrial-forest interfaces. Specifically, our results suggest that: (1) a broadleaved cover is capable of reducing fireline intensity and rate of spread, and (2) the reduction is more drastic and occurs progressively as the surrounding area covered by broadleaves increases from 100m to 500m.

The higher canopy cover adopted for broadleaves and the adopted fuel model (F-FOL), were possibly the main factors involved in the changing fire behaviour. Canopy cover is used to define the shading level that induces a reduction in wind speed. It also influences the higher moisture content of surface fuels (Finney, 1998). Fire behaviour, therefore, varies with forest composition and structure, reflecting micrometeorology and the fuel complex (Pinto & Fernandes, 2014). In this respect, as the simulation progresses in Farsite, the moisture contents of the fuels are adjusted based on changes in the climatic conditions over time by Nelson (2000) model. In comparison with other models, Nelson's model has been widely used for presenting greater accuracy in modelling the dead fuel moisture with meteorological data of 1 hour (Carlson, 2005). Local topography (elevation, slope, aspect) also influences the adjustment of the moisture content of fuels in Farsite. Mata da Margaraça is located at a higher altitude, oriented to the north. These characteristics do not favour fire spread (CTI, 2018), which probably contributed to its extinction in Mata da Margaraça. Even though the surroundings of the IZs do not have a similar topography, our results show a very positive effect of native broadleaved cover in reducing the fire behaviour in these areas.

The reduction in fireline intensity and rate of spread implies a lower fire severity (as the impact on vegetation) (Keeley, 2009) and also increases the likelihood of effective fire control operations. On the other hand, the progressive reduction of fire intensity with higher coverage of broadleaves around the IZs raises the need for discussing the current legislation. The studied fires were characterised by intense spotting due to the strong wind, resulting in burning material being sent over long distances (greater than 500 m, according to the observed evidence of fire spotting, through camera registrations in Mira IZ). In this context, a management strip of 100 meters would not be able to protect the forest-urban from fire. Our results suggest, therefore, that wider green fuelbreaks would be needed.

The 2017 mega-fires were extreme events that could overrun any preventive measure. The cover of native broadleaved indicated a damping effect on these fires, which indicates the potential of this type of forest to restrain the spread of smaller fires, which commonly occur every year in the country. In addition, microclimatic factors, topography, wind, and the fire front direction may also have influenced our results. This explains the better results of Oliveira do Hospital in view of its similar environmental conditions with Mata da Margaraça. Our work supports the need to discuss forest management in Portugal for improved fire prevention at the WUI.

Acknowledgements

This study was developed under the frame of the InduForesFire project (www.induforestfire.pt) funded by the Fundação para a Ciência e Tecnologia (FCT) through research grant PCIF/MOS/0129/2018.

References

Carlson, J. D. (2005). Field verification of the Nelson dead fuel moisture model and comparisons with National Fire Danger Rating System (NFDRS) predictions. *Sixth Symposium on Fire and Forest Meteorology*.

CIM-RC. (2021). *Comunidade Intermunicipal da Região de Coimbra - GeoPortal*. URL: https://geo.cim-regiaodecoimbra.pt/modulos

CTI. (2018). *Avaliação dos Incêndios ocorridos entre 14 e 16 de outubro de 2017 em Portugal Continental*. URL: https://www.parlamento.pt/Documents/2018/Marco/RelatorioCTI190318N.pdf

CWFIS. (1976). *Natural Resources Canada - Canadian Forest Fire Weather Index (FWI) System*. Natural Resources Canada. URL: https://cwfis.cfs.nrcan.gc.ca/background/summary/fwi

Diário da República n.º 32/2018, Série I de 2018-02-14 - Sistema Nacional de Defesa da Floresta contra Incêndios. Ministério da Administração Interna, Pub. L. No. Decreto-Lei n.º 10/2018 (2018). URL: https://dre.pt/application/conteudo/114685734

DGT. (2015). *Direação Geral do Territorio - Carta de Uso e Ocupação do Solo de 2015*. URL: http://mapas.dgterritorio.pt/

Fernandes, P. ., Gonçalves, C. ., Fernandes, M., Costa, T., Cruz, M. ., & Botelho, H. (2009). Modelos de combustível florestal para Portugal. *Actas Do 6º Congresso Florestal Nacional*, 348–354.

Fernandes, P. M., Guiomar, N., & Rossa, C. G. (2019). Analysing eucalypt expansion in Portugal as a fire-regime modifier. *Science of the Total Environment*, *666*, 79–88.

Fernandes, P. M., Loureiro, C., Guiomar, N., Pezzatti, G. B., Manso, F. T., & Lopes, L. (2014). The dynamics and drivers of fuel and fire in the Portuguese public forest. *Journal of Environmental Management*, *146*, 373–382.

Fernandes, P. M., Luz, A., & Loureiro, C. (2010). Changes in wildfire severity from maritime pine woodland to contiguous forest types in the mountains of northwestern Portugal. *Forest Ecology and Management*, *260*(5), 883–892.

Fernandes, P. M., Monteiro-Henriques, T., Guiomar, N., Loureiro, C., & Barros, A. M. G. (2016). Bottom-up variables govern large-fire size in Portugal. *Ecosystems*, *19*(8), 1362–1375.

Finney, M. A. (1998). *FARSITE, Fire Area Simulator--model development and evaluation* (Issue 4). US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

ICNF. (2012). *PPlano Municipal de Defesa da Floresta Contra Incêndios (PMDFCI)*. Direcção de Unidade de Defesa da Floresta. URL: https://www.icnf.pt/api/file/doc/4e29373d8ddc17ff

Keeley, J. E. (2009). Fire intensity, fire severity and burn severity: a brief review and suggested usage. *International Journal of Wildland Fire*, *18*(1), 116-126.

Keeley, J. E., Bond, W. J., Bradstock, R. A., Pausas, J. G., & Rundel, P. W. (2011). *Fire in Mediterranean ecosystems: ecology, evolution and management*. Cambridge University Press.

Laurance, W. F., & Williamson, G. B. (2001). Positive Feedbacks among Forest Fragmentation, Drought, and Climate Change in the Amazon. *Conservation Biology*, *15*(6), 1529–1535. DOI: https://doi.org/10.1046/j.1523-1739.2001.01093.x

Manzello, S. L., & Foote, E. I. D. (2014). Characterizing firebrand exposure from wildland–urban interface (WUI) fires: results from the 2007 Angora Fire. *Fire Technology*, *50*(1), 105–124.

Manzello, S. L., Maranghides, A., & Mell, W. E. (2007). Firebrand generation from burning vegetation. *International Journal of Wildland Fire*, *16*(4), 458. DOI: https://doi.org/10.1071/WF06079

Moreira, F., Rego, F. C., & Ferreira, P. G. (2001). Temporal (1958–1995) pattern of change in a cultural landscape of northwestern Portugal: implications for fire occurrence. *Landscape Ecology*, *16*(6), 557–567. DOI: https://doi.org/10.1023/A:1013130528470

Moreira, N. (2017). Condições meteorológicas associadas ao incêndio de Pedrógão Grande de 17 junho 2017. *IPMA-Instituto Português Do Mar e Da Atmosfera*.

Nelson Jr, R. M. (2000). Prediction of diurnal change in 10-h fuel stick moisture content. *Canadian Journal of Forest Research*, *30*(7), 1071-1087.

Pinto, A., & Fernandes, P. (2014). Microclimate and Modeled Fire Behavior Differ Between Adjacent Forest Types in Northern Portugal. *Forests*, *5*(10), 2490–2504. DOI: https://doi.org/10.3390/f5102490

Ribeiro, L. M., Rodrigues, A., Lucas, D., & Viegas, D. X. (2020). The Impact on Structures of the Pedrógão Grande Fire Complex in June 2017 (Portugal). *Fire*, *3*(4), 57. DOI: https://doi.org/10.3390/fire3040057

Rothermel, R. C. (1991). *Predicting behavior and size of crown fires in the Northern Rocky Mountains* (Vol. 438). US Department of Agriculture, Forest Service, Intermountain Forest and Range.

Silva, J. S., Vaz, P., Moreira, F., Catry, F., & Rego, F. C. (2011). Wildfires as a major driver of landscape dynamics in three fire-prone areas of Portugal. *Landscape and Urban Planning*, *101*(4), 349–358.

Vacca, P., Caballero, D., Pastor, E., & Planas, E. (2020). WUI fire risk mitigation in Europe: A performance-based design approach at home-owner level. *Journal of Safety Science and Resilience*, *1*(2), 97–105.

Wagner, C. E. Van. (1977). Conditions for the start and spread of crown fire. *Canadian Journal of Forest Research*, *7*(1), 23–34.

Indice

Luciano Lourenço viajando pelo Amazonas ao pôr do sol, em 15/06/2012.

Fotografia cedida por Maria da Graça Lourenço, 2021.

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Rua do Fetal, Lote 5
3020-923 Coimbra

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Setembro de 2021

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