

A Transição Florestal e a Governança do Risco de Incêndio em Portugal nos últimos 100 anos

Forest transition and wildfire risk governance in Portugal - the last 100 years

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TESE ELABORADA PARA OBTENÇÃO DO GRAU DE DOUTOR EM ENGENHARIA FLORESTAL E DOS
RECURSOS NATURAIS

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"A CONSERVATIONIST IS ONE WHO IS HUMBLLY AWARE
THAT WITH EACH STROKE [OF THE AXE] HE IS WRITING
HIS SIGNATURE ON THE FACE OF THE LAND."

ALDO LEOPOLD,
in a Sand County Almanac

A TRANSIÇÃO FLORESTAL E A GOVERNANÇA DO RISCO DE INCÊNDIO EM PORTUGAL NOS ÚLTIMOS 100 ANOS

RESUMO

Em meados do séc. XIX Portugal inverteu o milenar processo de desflorestação e iniciou uma rápida expansão da área arborizada. No entanto, desde 1970, o equivalente a metade do país foi percorrido pelo fogo e as estatísticas reflectem um decréscimo da superfície florestal. Para compreender o presente e prospectar o futuro, investiga-se a transição florestal e a governança do risco de incêndio ocorridas nos últimos 100 anos.

Construída a base de dados geográfica da ocupação do solo para 1910, 1960, 1970, 1990 e 2006, através da análise de *clusters* identificam-se quatro percursos de transição e discutem-se os resultados à luz da história agrícola e florestal recente. Conclui-se que existiram condições necessárias e suficientes para a transição florestal e reflecte-se sobre as condicionantes que a tornam vulnerável.

Constrói-se uma cronologia da evolução do enquadramento institucional e, por análise de conteúdos à legislação sobre incêndios publicada entre 1910 e 2013, investiga-se o percurso da governança do risco. Discute-se como o contexto, a formulação do problema e os actores contribuíram para as diferentes soluções, em cada época. Conclui-se que o sistema formal de comando único que administrava um risco simples evoluiu para um sistema tripartido com múltiplos actores que gerem um risco complexo e ambíguo.

Empregando simulação do comportamento do fogo, evidencia-se que só o contributo dos tratamentos de combustíveis lineares é insuficiente para a mitigação do risco, da área ardida e transmissão do fogo entre municípios. Sugere-se esta metodologia para mobilizar as partes interessadas a cooperar entre si, melhorando o processo de governação de risco.

Nesta dissertação, defende-se a Tese que no Portugal Mediterrânico e Atlântico a expansão florestal mantém-se enquanto as soluções informais e locais funcionam, estando estas intimamente ligadas à gestão e ao conhecimento da floresta e do território. Investigados os percursos da transição florestal e da governança do risco de incêndio, parece ser difícil assegurar uma transição florestal sustentada.

Palavras chave: *Análise de conteúdos; Alteração do uso do solo; Governança do risco de incêndios florestais; Transição florestal; Portugal*

FOREST TRANSITION AND WILDFIRE RISK GOVERNANCE IN PORTUGAL IN THE LAST 100 YEARS

ABSTRACT

In the mid-nineteenth century Portugal reversed its age-old deforestation process and started a fast expansion of forest area. However, since 1970 an area equivalent to half the country territory burnt and the statistics reflect a decrease in forest cover. To improve our understanding of the present and better foresee the future, we investigate the forest transition and wildfire risk governance in the last 100 years.

Having built a geographic database of land cover for 1910, 1960, 1970, 1990 and 2006, we use *cluster* analysis to identify four transition pathways, and discuss the results in the light of agricultural and forest history. We conclude that necessary and sufficient conditions for forest transition were present and discuss the conditions that make it vulnerable.

We develop a chronology of the evolution of the institutional framework and apply content analysis to governmental regulation published between 1910 and 2013 to investigate the evolution of wildfire risk governance. We discuss how the context, the framing of the problem and the actors, contributed to the adopted solutions, at different times. We conclude that a formal single command system that managed a simple risk evolved into a tripartite system with multiple agents managing a complex and ambiguous-ridden risk.

Using stochastic fire simulation, we found that linear fuel treatments alone are insufficient to mitigate risk, and reduce the burnt area and the transmission of fire between municipalities. The methodology is suggested as a useful tool to mobilize stakeholders to cooperate, improving the risk governance process.

In the Mediterranean and Atlantic Portugal, the forest expansion endured for as long as informal and local solutions worked, as they were related to the management and knowledge of forest and territory. Investigated the forest transition and fire risk governance paths, it seems difficult to ensure a sustained forest transition.

Keywords: Forest transition; Wildfire risk governance; Land cover change; content analysis; Portugal

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RESUMO ALARGADO

Nos últimos 150 anos o País inverteu o milenar processo de desflorestação, registando uma rápida expansão da área florestal na primeira metade do séc. XX. No entanto, nas últimas décadas os incêndios percorreram mais 1/4 do território e o inventário florestal registou em 2010 um decréscimo da área arborizada. Pese as múltiplas tentativas para “resolver o problema” incluindo o investimento num musculado sistema de combate, os danos resultantes têm sido crescentes e continuam a referenciar Portugal como um dos países do mundo com maior incidência de fogo. Para compreender o presente e prospectivar o futuro investiga-se a transição florestal e a governança do risco de incêndio nos últimos 100 anos.

A primeira secção aborda o tema da Transição Florestal nos últimos 100 anos. No artigo *“Is Forest transition in Portugal, going up in Smoke?”*, publicado no Journal of Land Use Policy investigamos onde de facto, a transição florestal aconteceu em Portugal. Temos hoje a noção que o País se arborizou ao longo do últimos 150 anos e que os incêndios têm vindo a contribuir para a perda de área arborizada. No entanto, desconhecemos a que ritmos as transições aconteceram, quando aconteceram, onde aconteceram e que transferências de áreas ocorreram entre grandes ocupação do solo (floresta, matos, agrícolas) ao logo do tempo e do espaço. Recolhida informação em formato digital sobre a ocupação do solo harmonizam-se as legendas e escalas e constrói-se uma base geográfica da ocupação do solo para 1907, 1955, 1970, 1990 e 2006. Utilizando a unidade de análise do concelho, calcula-se a percentagem de ocupação florestal para cada momento e com recurso a análise de clusters identificam-se os concelhos que evoluíram de forma semelhante entre si. Até aos anos 1960, a expansão da área arborizada ocorreu simultaneamente com a expansão da agricultura, através da retracção das áreas de matos. Com a redução das áreas agrícolas de 1960 em diante, a par da autonomização da floresta enquanto produtora de bens industriais para o mercado global, a área arborizada continuou a sua expansão até a década de 90, reduzindo-se com os incêndios. Mas este percurso não foi homogéneo no espaço e no tempo, tendo identificado quatro percursos geograficamente distintos. O primeiro, que designamos por “Failed transition”, retrata as áreas mais montanhosas. O segundo, que se localiza no centro litoral, foi designado “Endangered transition”, e o terceiro, nas planícies do Alentejo, “Slow transition”. Identificámos um quarto cluster, na zona raiana norte e em volta de Lisboa, onde não houve transição e ao qual chamámos “No transition”. Explorando-se a teoria da Transição Florestal, caracterizam-se cada um dos percursos à luz das referências da história agrícola e florestal no contexto das profundas alterações sociais e económicas do último século. Os nossos resultados sugerem que nas áreas mais produtivas, onde a floresta teria condições necessárias e suficientes para persistir, os incêndios florestais constituem

uma limitação e contribuem para a inversão do processo de transição. Nas áreas menos produtivas do sul, a transição florestal materializa-se através da agro-florestal.

Na segunda secção aborda-se o tema da Governança do Risco de incêndio florestal. No artigo *“Wildfire Risk Governance – from a simple issue to a complex risk challenge”*, submetido ao Journal Ecology and Society investigámos como evoluiu o sistema de governança de risco de incêndio em Portugal nos últimos 100 anos. Durante o séc. XX vários países sofreram crescentes incêndios e foram adaptando as suas políticas, regulamentos, organizações e sistemas operacionais para proteger as populações e florestas. Numa primeira fase investigámos a evolução do quadro institucional e, numa segunda fase, examinámos através da análise de conteúdo de 101 diplomas governamentais publicados entre 1910 e 2013, como foi ao longo do tempo formulado o problema e que soluções foram propostas. Numa terceira fase, caracterizámos as estruturas de governação e resumimos a leitura dos documentos e os resultados da análise de conteúdos, numa cronologia que retrata a evolução do sistema. Concluímos que o sistema de governação do risco adaptou e evoluiu, reagindo as áreas ardidas. Esta elasticidade da produção legislativa às áreas ardidas evidencia uma preocupação dos governos em reagir, mas dado o resultado medido através da área ardida e pela perda de área florestal, é importante conhecer em detalhe como é o sistema evoluiu. Os nossos resultados sugerem que à medida que os incêndios provocaram danos não só nas áreas florestais, nomeadamente nas pessoas, nos seus bens e infraestruturas, as partes interessadas influenciaram a evolução do sistema de gestão de risco de incêndio, o seu desenho, as capacidades e prioridades. Discute-se como o contexto, a formulação do problema e os actores contribuíram para definir as soluções adoptadas. Conclui-se que o sistema formal de comando único que geria um risco simples evoluiu para um sistema tripartido de multiactores que gere um risco complexo e ambíguo. Colocamos a hipótese que deficiências de governança tenham dificultado e continuem em parte a dificultar, o surgimento de um sistema coeso e capaz de executar de forma eficaz através do tempo e no espaço um programa equilibrado e flexível de gestão de risco.

Na terceira secção avaliamos a eficácia da rede primária de gestão de combustíveis. No artigo *“Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission”*, publicado no International Journal of Wildland Fire investigámos o potencial efeito na redução da área ardida se fosse construída uma rede regional de faixas de gestão combustíveis. A compartimentação da paisagem através da rede de faixas com largura de 125 metros, para além de uma solução técnica complementar a outras medidas de uma estratégia de redução de risco é, fundamentalmente um produto do sistema de governação do risco em resultado dos incêndios de 2003/2005. Testando para o Algarve e sul do Alentejo um metodologia que está em desenvolvimento no Estado Unidos da América investigamos qual o efeito na redução da área ardida e na probabilidade condicional de incêndio e se pode esta infraestrutura alterar a transmissão do fogo entre municípios vizinho. Com base em simulação do comportamento do fogo para cenários meteorológicos acima do percentil 90, replicamos as condições de 150.000 incêndios com duração de 24 horas. Estimamos como é que o tamanho médio dos incêndios simulados e a probabilidade de arder se modificariam se fossem construídas as faixas de gestão de combustíveis empregando duas intensidades de tratamento (remoção total ou parcial de combustíveis). Concluímos que se as redes

fossem totalmente construídas com recurso ao tratamento mais intenso, seria de prever uma redução da área total ardida em 17% e reduzir-se-ia a probabilidade ocorrerem grandes incêndios (>10,000ha). No entanto, ponderadas as vantagens e limitações associadas ao uso da modelação de comportamento do fogo e considerando que o âmbito da aplicação da metodologia é uma avaliação ex-ante das intensidades alternativas de tratamento de combustíveis em faixas lineares, é possível concluir que não permitem por si só, reduzir substancialmente a proporção e severidade do fogo ou bloquear de forma relevante a transmissão de fogo entre municípios. Atendendo a existência de frequências de fogo distintas dentro da área de estudo e ao elevado custo da criação e manutenção destas faixas concluiu-se que realizando só cerca de metade dos hectares previstos se atingem 87% dos resultados. Para além dos resultados e conclusões mais operacionais que este método permite na esfera da mobilização de actores e governança do risco de incêndio à escala regional, a metodologia desenvolvida permite que se testem outras soluções lineares, avaliem outros pressupostos ou cenários meteorológicos, superiores durações de incêndios, ou se testem as vantagens de incluir um conjunto significativo de hectares a serem tratados pelos proprietários particulares, por exemplo, medido as vantagens em termos de área ardida e bloqueio da transmissão. A metodologia de simulação e análise de rede permite quantificar o benefício directo para o proprietário ou comunidade que efectuar o tratamento estimando o benefício para terceiros, isto é, os seus vizinhos.

Na quarta secção apresentam-se dois trabalhos complementares. No primeiro artigo *“Forest fire management to avoid unintended consequences: A case study of Portugal using system dynamics”* abordam-se as relações complexas entre o sistema físico e político na gestão do risco de incêndio em Portugal. O segundo artigo *“Cohesive fire management within an uncertain environment: A review of risk handling and decision support systems”* apresenta uma revisão bibliográfica dos sistemas de apoio à decisão em uso em vários países do mundo e para diversos níveis de investimentos de gestão de risco de incêndio.

Nesta dissertação, defende-se a Tese que no Portugal Mediterrânico e Atlântico a expansão florestal mantém-se enquanto as soluções informais e locais funcionam, estando estas intimamente ligadas à gestão e ao conhecimento da floresta e do território. Investigados os percursos da transição florestal e da governança do risco de incêndio, parece ser difícil assegurar uma transição florestal sustentada.

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I. INTRODUÇÃO

1.1. NOTA INTRODUTÓRIA

O documento que se submete para apreciação do Júri constitui a versão provisória da dissertação apresentada sob a forma de três artigos científicos (dois publicados e um submetido para publicação). Dada a complementaridade com o conteúdo da dissertação, apresentam-se outros dois artigos já publicados de que o candidato é co-autor e que, igualmente, suportam a Tese que se defende.

Atendendo ao tema que a dissertação aborda e dado o interesse particular que as matérias estudadas têm no âmbito do País, entendeu-se redigir em língua portuguesa a tese, em que se apresentam cada um dos artigos científicos e se resumem as conclusões. Para além de o seu conteúdo se tornar mais acessível também por este documento, facilita-se à comunidade técnica e científica lusófona o enquadramento dos assuntos tratados. Atendendo à dimensão nacional do tema, no texto da dissertação divulgam-se contributos que, não se encontrando inscritos e publicados nos artigos, complementam a argumentação da Tese que se defende.

A dissertação desenvolve-se assim, em três capítulos. No primeiro, apresentamos e formulamos o problema que constitui o objecto de investigação, bem como a Tese. No segundo, introduzem-se os contributos originais dos trabalhos científicos no fio condutor da Tese, aportando-se informação de âmbito nacional e apresentam-se as questões de investigação abordadas nesses artigos. No terceiro capítulo retomam-se para o alinhamento da Tese os conteúdos mais relevantes da discussão e as conclusões inscritas em cada artigo.

Importa alertar que as referências bibliográficas apresentadas no final desta dissertação apenas se referem aos trabalhos citados neste documento, repetindo, ou não, as referências mencionadas em cada artigo.

O autor escreve de acordo com a antiga ortografia.

1.2. FORMULAÇÃO DO PROBLEMA

Nos últimos 150 anos o país inverteu o milenar processo de desflorestação (Kaplan *et al.*, 2009; Reboredo e Pais, 2014), registando uma rápida expansão da área florestal na primeira metade do séc. XX, continuando a crescer a um ritmo menor até ao início da década de 90 (Devi-Vareta, 1993). No entanto, desde 1970 os incêndios percorreram o equivalente a metade¹ do território e as estatísticas oficiais (referenciadas pelo inventário florestal – ICNF, 2013) registaram um sensível decréscimo da área de floresta no período 1995-2010, associando-o aos incêndios. No relatório sobre a avaliação dos recursos florestais mundiais (FRA, 2015) a Organização das Nações Unidas para a Alimentação e Agricultura (FAO) constata que a área florestal em Portugal diminuiu desde 1990 à razão de 0.3% ano⁻¹. Fazendo parte do grupo de países com elevado rendimento (PIB per capita superior a \$12746 USD), onde a área florestal para o mesmo período cresceu 0.05% ano⁻¹ (Keenan *et al.*, 2015), a perda de área florestal em Portugal é surpreendente. Para o mesmo grupo dos países desenvolvidos, analisando dados entre 1990 e 2005, Kauppi *et al.* (2006) sugerem que o aumento da área e do volume está associado a vários factores socioeconómicos e a políticas, como leis, instituições florestais e da conservação da natureza, educação ou esforço associado a rede viária e fomento da arborização, que em conjunto materializam a conservação das superfícies arborizadas.

Das iniciativas para “resolver o problema” empreendidas desde 1970 (ISA-APIF, 2005) e após 2003/2005 (LPN, 2009; Beighley e Hyde, 2009; IESE, 2015) sobressai hoje um investimento num musculado sistema de combate² (AR, 2015). Os indicadores estão longe das metas definidas nos planos e estratégias oficiais e os danos são crescentes (AR, 2015). Pese embora as estatísticas sejam construídas com informação não homogénea, internacionalmente Portugal está referenciado como um dos países do mundo com maior proporção de área florestal afectada pelo fogo, a par do Chade, Senegal, Gana e Botsuana (FAO, 2010, pág. 75). Comparativamente aos países do sul da Europa, desde 1980

¹ Considerando 4,446 milhões de hectares de área ardida. Soma de 3.856 Mha cartografada entre 1975-1984 (ISA) 1985-2009 (ICNF/ISA) mais 0.471 Mha ICNF (2010-2013), mais 0.120 mil entre 1970 e 1974 (CESE, 1996). Do total desta área, 70% foi percorrida pelo menos duas vezes pelo fogo. (ver contributos originais capítulo 2.1)

² De acordo quadro 8 do relatório da AR (2015) de 2006 até 2013 os prejuízos em valor foram de 982M€ (39,6€ha⁻¹ano⁻¹ arborizado) a que se devem somar os investimentos de 224M€ (9,0€ha⁻¹ano⁻¹ arborizado em prevenção e os custos 559M€ em supressão (22,5€ha⁻¹ano⁻¹ arborizado). Ainda de acordo com este relatório os encargos com meios aéreos quase que duplicaram entre 2006 e 2010.

(CESE, 1996) exhibe valores de incidência do fogo (área e ignições) sempre acima dos seus congêneres europeus. Turco *et al.* (2016) usando dados de 1980 a 2011 mostram que Espanha, Itália, França, e Grécia exibem uma tendência e decréscimo em área ardida e número de incêndios, mas Portugal exhibe uma tendência crescente até 2005, expressando desde aí um sinal misto. Como resulta da comparação com países onde ocorreram alterações de uso do solo e de migrações populacionais semelhantes às que ocorreram em Portugal, embora em momentos e ritmos diferentes (Jepsen *et al.*, 2015), e com condições favoráveis a incêndio meteorológico também comparáveis (Trigo *et al.*, 2013), são ainda mais surpreendentes os resultados produzidos pelo modelo português.

Pyne (2006) e Velez (2001) sintetizam as causas do fogo na bacia mediterrânea e Moreira *et al.* (2011) e outros (Rego, 1992; Fernandes *et al.*, 2014), associam-no à escala da paisagem em resultado do abandono agrícola, da ausência de gestão florestal activa, da continuidade das áreas de florestas e de matos. Pereira *et al.* (2005), relacionando área ardida e meteorologia (1980-1999), demonstram que mais de 80% da sua variabilidade inter-anual é explicada pelas condições meteorológicas. Com o agravamento do perigo meteorológico (Durão e Corte-Real, 2006; Sousa *et al.*, 2015), o País tenderá a ser ainda mais vulnerável aos factores climáticos.

Após os grandes incêndios de 2003/2005, do planeamento da recuperação dessas áreas resultou, entre outras propostas para o aumento da resistência e resiliência da floresta, a criação das redes de defesa (CNR, 2005; Pinho *et al.*, 2006). Para além de caminhos e pontos de água e tratamentos em torno do edificado, este modelo de prevenção à escala da paisagem, complementar a uma estrutura de mosaicos, divide o território com faixas lineares de redução do combustível com um mínimo de 125 metros de largura, aproveitando e fomentando as descontinuidades já existentes na paisagem (agricultura, massas de água, etc..) em áreas com baixa carga combustível. Nos relatórios do Conselho Nacional de Reflorestação inscrevia-se que o delineamento destas áreas deveria recorrer a metodologias que assegurassem o seu posicionamento estratégico.

Para reduzir a área ardida de grandes incêndios, criando oportunidades para um combate ao fogo mais eficaz, criou-se uma elevada expectativa só sobre

as faixas de gestão de combustíveis, e não sobre os mosaicos, os quais, inversamente, mereceram menor atenção por parte de técnicos e decisores. Tal poderá talvez dever-se ao facto de aquelas terem um conceito linear, mais intuitivo e simples de comunicar, e constituírem uma actividade preventiva mais fácil de planear e executar, que é, também, politicamente visível. Em 2012 (Tavira) e 2013 (Tondela) onde a rede de faixas, embora desenhada, não chegou a ser executada no terreno, e dado o insucesso dos meios combate em evitar dois grandes incêndios, o debate nos meios mais especializados em torno das conclusões do relatório de Viegas *et al.* (2012), amplificou as expectativas sobre o papel das faixas.

Estimando-se que melhorias (graduais) no sistema de combate induzem só uma baixa redução da área ardida (Fernandes *et al.*, 2016), e dada a estratégia de prevenção apostar nas faixas (p.e. apoios comunitários como o POSEUR), perante resultados de épocas mais difíceis, o problema de como defender a floresta do fogo voltará ao debate público. Confirmada a exaustão das soluções tentadas dos últimos 40 anos e o insucesso do seu resultado (em contraciclo com países com equivalente, ou até menor, nível de recursos), o problema da defesa da floresta centrar-se-á sobre a complexidade socio-ecológica, os actores e as instituições que têm assegurado a governança do risco de incêndio em Portugal.

1.3. MOTIVAÇÃO

O esforço de recuperação do revestimento florestal do País desde meados do séc. XIX (Radich e Alves, 2000) constituiu uma das mais rápidas expansões de área florestal na Europa (Mather e Pereira, 2006). Este investimento privado e público de várias gerações criou um valor que herdámos e que se bem gerido e até incrementado, constituirá um legado para os nossos filhos.

Hoje, e com base no Inventário Florestal Nacional (ICNF, 2013), estima-se que os espaços florestais arborizados ocupem 35% do território e as áreas de matos e pastagens naturais, cerca de 32%. Nestes espaços, que juntamente com os designados “improdutivos” e algumas áreas húmidas interiores representam mais de 67% da superfície do País, para além da beleza, do silêncio, da memória e identidade, produzem-se bens e serviços muito relevantes para a economia

nacional. Com base na transformação e exportação dos seus produtos (12% do total nacional) é possível compensar o défice alimentar, criar mais de 65.000 postos de trabalho directos (2,4% do total nacional), dinamizar economias locais, partilhar valor com milhares de proprietários florestais, gerar 5% da energia que consumimos e contribuir em 10% para o valor acrescentado bruto (VAB) industrial (AIFF, 2014). Somam-se a tudo isto serviços ambientais, que embora de difícil contabilização, representam cerca de 514M€ por ano (ENF, 2015), e o valor paisagístico, relevante para setores como o turismo, o recreio e lazer. O valor económico, social, ambiental e cultural da floresta tem sido destacado em inúmeros planos e estudos que desde 1980 (PFP/BM, 1981) têm sido produzidos, nomeadamente CESE (1996), BPI *et al.*, (1996) e ISA-APIF (2005), entre outros, ou mais recentemente AIFF (2012).

Os documentos oficiais têm enquadrado e reflectido o tema e a sua importância para o desenvolvimento do País (PNPOT, ENDS, ENCN), e as medidas de apoio recentes (PDR2020) como as do passado (ISA-APIF, 2005) têm mobilizado recursos importantes para as florestas. Mas será que estes recursos têm sido proporcionais à importância económica da floresta? E como têm evoluído, em comparação com outros sectores, como por exemplo a agricultura ou a saúde? Não obstante, Beighley e Quesinberry (2004), ao observar o resultado das medidas operacionais que a sociedade portuguesa desenvolveu para lidar com o fogo, questionam *“se o valor que Portugal atribui aos seus espaços florestais e rurais será suficiente para forçar as mudanças que poderiam estancar a perda de produtividade e os danos crescentes provocados pelos incêndios”*³.

A conservação e manutenção das florestas e da sua resiliência às perturbações tornaram-se recentemente ainda mais importantes pelo seu papel na mitigação das alterações climáticas (IPCC, 2014; Pan *et al.*, 2011; Millar *et al.*, 2007) e constituem um dos objectivos de desenvolvimento das Nações Unidas (UN, 2015), reforçado pelo compromisso de Sendai (UN, 2015b), sendo Portugal signatário de ambas as iniciativas. Apesar de se questionar o contributo

³ In p.6 Beighley e Quesinberry (2004). This report falls on the heels of 3 previous reports from American wildland fire experts delivered in 1982, 1996, and 2003. Many of the same recommendations exist in all 4 reports. The real question is: how much does Portugal value its forests and rural agricultural lands? Is it enough to make the necessary changes that could stop the continuing erosion of productivity resulting from increasing wildland fire damage. This is a problem of political and social priorities.

da gestão florestal europeia para a mitigação do aquecimento global (Naudtsetal, 2016), a perda de área florestal tem sempre um impacto nas variáveis regionais biofísicas, nomeadamente na temperatura (Alkama e Cescatti, 2016) e no acréscimo de CO₂, em particular quando o processo da desflorestação ocorre através do fogo (Bowman *et al.*, 2009). Para Portugal, os estudos sobre a evolução da ocupação do solo, têm sido desenvolvidos nos domínios da silvicultura (Almeida, 1929), da geografia (Devy-Vareta, 1993; Sá Marques, 2005), da ecologia da paisagem (Correia *et al.*, 2006; Godinho *et al.*, 2016), da sociologia e da economia (Estevão, 1983; Caldas, 1998; Mendes e Dias, 2002; Baptista, 2010) ou da história contemporânea (Brouwer, 1993; Radich e Baptista, 2005).

Por outro lado, os inventários florestais nacionais em Portugal iniciaram-se em finais da década de 60, exibindo uma leitura recente e parcial, quando olhamos para a evolução no tempo longo. Radich e Alves (2000) analisaram a evolução da ocupação florestal, das ideias, e das técnicas ao longo dos dois últimos séculos, seguindo os trabalhos de Devy-Vareta (1982, 1989, 1993). Estes trabalhos mostram-nos a evolução à escala nacional ou, com base em estudos de caso (Devy-vareta, 1993; Moreira *et al.*, 2001; Aguiar e Azevedo, 2011), a dedução de hipóteses explicativas para o todo. Mather e Pereira (2006) analisaram a evolução da ocupação florestal (usando os mesmos dados de Radich e Alves, 2000) relacionando-a com o problema do fogo à escala distrital, mas não analisando espacialmente o processo da transição florestal e os seus possíveis padrões. Dada a heterogeneidade da matriz mediterrânica e atlântica (Ribeiro, 1963) a evolução da ocupação florestal terá acontecido no último século em intensidades e velocidades distintas. Conhecer os ritmos da evolução e os percursos subjacentes permitirá discutir os mecanismos que geraram as alterações do uso do solo. Dado o seu papel no problema do fogo (Moreira *et al.*, 2011), a compreensão do processo pelo qual transformamos as paisagens é fundamental para o desenho de políticas e estímulos que abordam o risco de incêndio. Tal é particularmente relevante para Portugal, onde a incidência do fogo tem padrões espaciais distintos e 97% da propriedade florestal é privada, sendo muito relevantes os comportamentos dos actores, tipificados por Baptista e Santos (2005) e Novais e Canadas (2010).

As causas para os incêndios na região Mediterrânica são antropogénicas e o problema desenvolve-se num contexto geográfico e meteorológico onde a vegetação e o homem coexistem (Velez, 2000; Rackman e Grove, 2001). A ocupação do solo evolui em função das dinâmicas populacionais e oportunidades económicas, mediadas pelas instituições (Lambin *et al.*, 2001), sendo o fogo a síntese (consequência) destas dinâmicas (Pyne, 2006). Vários estudos em Portugal têm analisado o problema do fogo nos domínios da ecologia, da geografia física, das ciências da terra e do espaço, entre outras, como se constata na síntese⁴ da produção científica (ISA-APIF, 2005). Numa revisão recente da produção científica nas fileiras florestais (AIFF, 2015), os autores concluem que o tema dos incêndios, no global da produção científica (1986 e 2014) do sector florestal, tem uma importância relativa baixa, em particular nas fileiras do eucalipto e sobreiro. Reis e Oliveira (2007) analisam o papel do conhecimento no planeamento e política de incêndios em Portugal e concluem que, apesar da capacidade científica medida não ser o factor limitante, o sistema de gestão de risco incorpora pouco conhecimento disponível, associando esta baixa capacidade de absorção, ao baixo capital social dos actores e a debilidades institucionais.

Enraizada na transdisciplinaridade dos trabalhos de estimação e avaliação do risco, e da sua gestão, regulação e análise política (van Asselt e Renn, 2011), por governança de risco (*risk governance*) entendem-se os arranjos institucionais (actores, regras, convenções, processos e mecanismos) para a recolha, análise e comunicação de informação, e a forma como as decisões de gestão de risco são tomadas (Renn, 2005). A governança de risco procura fazer a ponte entre gestores de risco, partes interessadas, e decisores, abordando o risco num contexto alargado (IRCG, 2005). Visa através de princípios de cooperação, participação, prudência, transparência e sustentabilidade reduzir a exposição e vulnerabilidade aos riscos tecnológicos e naturais, minimizando perdas humanas e económicas (Renn, 2005). Apesar das diversas publicações sobre estimativa e avaliação do risco em Portugal (resumidas em Verde, 2015), nas áreas da gestão e governança de risco, também é exígua a produção científica nacional. O tema da governança do risco é abordado por Tavares e Santos (2014) num estudo de caso, examinando vários perigos naturais e tecnológicos. Ribeiro *et al.* (2015), também através de um estudo de caso, investigam a percepção do problema dos

⁴ Relatório intercalar do PNDFCI, Capítulo 5 – conhecimento www.isa.utl.pt/pndfci

incêndios na comunidade técnica, nas instituições e habitantes e na vertente mais social. Através de inquéritos realizados no Algarve, Paton e Tedim (2013) avaliam a preparação das comunidades e a gestão do risco. Sobre políticas para incêndios florestais, Carreiras *et al.* (2014) comparam genericamente os instrumentos de política entre Portugal e a região de Valência e concluem sobre a relevância das experiências prévias, características locais e envolvimento das partes interessadas. Sobre as políticas que abordaram incêndios, para além de relatórios técnicos destacam-se dois ensaios (Soares e Oliveira, 2006; Mateus e Fernandes, 2014) que abordam perspectivas dos autores sobre momentos relevantes da evolução da gestão do risco de incêndio.

Conclui-se, assim, que a base de conhecimento científico no tema das políticas e da governança do risco é diminuta. Esta situação contrasta com outras regiões onde os temas foram analisado e publicados em revistas de ecologia humana (Seijo, 2009; Seijo, 2005; Seijo e Gray, 2012; Henderson *et al.*, 2005), da ciência florestal e da ecologia do fogo (Gill, 2005; Gill *et al.*, 2013; Stephens e Ruth, 2005; Moritz *et al.*, 2014; North *et al.*, 2015; Steelman, 2016), da ciência do risco (Calkin *et al.*, 2015; O'Neill e Handmer, 2012; Pezsatti *et al.*, 2013; Ager *et al.*, 2017) ou em políticas públicas (Busenberg, 2004; Davis, 2006; Muller *et al.*, 2011; Montiel *et al.*, 2010; Aguiar e Montiel, 2011; San-Miguel-Ayanz *et al.*, 2013). Estes trabalhos atestam a importância de sistematizar o conhecimento em políticas de gestão do fogo e da sua governança num contexto de sistemas socio-ecológicos, concluindo com um conjunto de recomendações para a sustentabilidade dos sistemas florestais e sua resiliência às crescentes pressões ambientais e sociais.

Considerando a importância da floresta para o País, atendendo à sua predominância territorial e produção de bens e serviços, e dada a dificuldade demonstrada pelo sistema em reduzir os danos do fogo, entende-se pertinente aprofundar o estudo da evolução da floresta e da governança do risco de incêndio. Assim, estudar o passado para compreender o presente e melhor perspectivar o futuro, constitui a principal motivação do autor.

Para além do contributo para a ciência de um melhor entendimento da evolução do uso do solo e da gestão e governança do risco à escala internacional, acredita-se que os resultados desta investigação possam

influenciar em Portugal as políticas e as práticas de gestão e contribuir para que no futuro a floresta seja menos vulnerável a uma das suas principais ameaças.

1.4. OBJECTIVOS

Esta investigação tem como objectivo compreender a evolução da ocupação florestal e da governança do risco de incêndio em Portugal no último século e avaliar a eficácia da principal proposta de prevenção que o sistema formulou após a crise de 2003/2005.

Atendendo à rápida expansão da ocupação florestal verificada nos últimos 100 anos e aos resultados produzidos pelos sistemas desenhados para gerir o risco de incêndio, os objectivos da investigação são analisar:

a) A evolução da ocupação do uso do solo;

Continuando o trabalho anterior de Radich e Alves (2000) e de Mather e Pereira (2006), que usam a teoria da transição para descrever a evolução da ocupação do solo, iremos aprofundar no espaço e no tempo os percursos da evolução do uso do solo. Através do estudo e avaliação da cartografia de 1907, 1955, 1970, 1990 e 2006 (recuperada para formato digital por outras fontes) iremos mostrar que a expansão florestal ocorreu com padrões e ritmos distintos, sendo este o primeiro contributo pioneiro e inovador da investigação.

b) A evolução da governança do risco;

Conhecida a evolução do uso do solo para os últimos 100 anos, a questão da governança do risco e da sua evolução parece determinar, em particular e para o caso português, a dificuldade em proteger as florestas dos incêndios. Através da lente da governança de risco iremos descrever a evolução institucional e o processo legislativo governamental, empregando análise de conteúdos para avaliar a evolução da formulação do problema e as soluções propostas.

c) A eficácia das faixas lineares de gestão de combustíveis, enquanto um dos produtos conceptuais da última crise de governança de risco;

Dada a expectativa sobre as faixas de gestão de combustível enquanto produto conceptual do edifício da governança do risco, através de um estudo de caso regional e com recursos a metodologia de simulação de comportamento do fogo, iremos analisar, *ex-ante*, a sua eficácia para reduzir a área ardida e alterar o padrão de transmissão do fogo entre comunidades.

Dos três objectivos enunciados acima e dos métodos aplicados resultam contributos científicos relevantes e inovadores no contexto internacional e úteis para a melhoria das políticas, gestão e operações que permitem a salvaguarda do património florestal.

1.5. APRESENTAÇÃO DA TESE

Nesta dissertação, defende-se a Tese que no Portugal Mediterrânico e Atlântico a expansão florestal mantém-se enquanto as soluções informais e locais funcionam, estando estas intimamente ligadas à gestão e ao conhecimento da floresta e do território. Investigados os percursos da transição florestal e da governança do risco de incêndio, parece ser difícil assegurar uma transição florestal sustentada.

II. CONTRIBUTOS ORIGINAIS

2.1. A TRANSIÇÃO FLORESTAL

Este capítulo enquadra na Tese o artigo "*Is Portugal's forest transition going up in smoke?*" publicado no *Journal of Land Use Policy*, em que se investiga, em profundidade, o processo de evolução da área florestal nos últimos 100 anos, através de uma abordagem espacialmente explícita. Nos parágrafos que se seguem faz-se uma pequena introdução sobre a recuperação do revestimento florestal até meados do séc. XX, apresenta-se o conceito de transição florestal e a teoria subjacente, e define-se o âmbito e a questão de investigação.

As profundas transformações económicas e sociais que ocorreram em Portugal desde meados do séc. XIX (Lains e Ferreira, 2005; Lains, 2003; Barreto 1996, 2005) conduziram a alterações significativas por todo o território. Ribeiro (1945), Ribeiro *et al.* (1988), Ferrão (2004), De Sá (2003, 2005) e Correia (2006), nos domínios da geografia física e humana, caracterizaram a paisagem e a sua ocupação em diferentes períodos e reflectiram sobre os factores que moldaram esses territórios. Cabral (1974), Baptista (1994), Amaral (1994) e Caldas (1998), no domínio da economia e sociologia rural, e Radich e Alves (2000), Radich e Baptista (2005) e Baptista (2010), abordando especificamente a questão florestal, caracterizaram as dinâmicas que marcam as alterações nos territórios rurais ou ainda os conflitos políticos e sociais associados à expansão florestal, como documentado por Estevão (1983), Devy-Vareta (1993), Brouwer (1993), Schmidt (2008) ou as relações entre o mundo rural e urbano (Nunes, 1964; Ferrão, 2000).

O País modificou-se drasticamente nos últimos 100 anos. Não se pretende aqui descrever ou analisar o processo socioeconómico que gerou a evolução da paisagem ou modificou a relação entre o Homem e o campo, ou entre as lógicas da vida urbana e da vida rural, mas apenas introduzir o tema que foi objecto de análise no artigo publicado sobre a evolução da ocupação florestal nos últimos 100 anos.

a) JARDIM DA EUROPA, À BEIRA MAR PLANTADO

Estudando a desflorestação pré-histórica e pré-industrial na Europa, Kaplan et al. (2009) sugerem que 74% do País estaria arborizado mil anos antes do nascimento de Cristo. Dois mil anos depois, estes autores estimam que cerca 43% do País estaria arborizado, tendo diminuído acentuadamente para cerca de metade até à Peste Negra⁵, e recuperado para 33% nos 50 anos que se lhe seguiram. Desde a Dinastia de Aviz até cerca de 1850, seguiu-se um intenso processo de desflorestação, atingindo o coberto florestal um mínimo de 7% do território. O número sugerido é equivalente ao do levantamento de Pery em 1875. As causas da desflorestação podem ser aprofundadas através dos trabalhos de Devy-Vareta (1985, 1986), Neves (1980-1993), tendo sido mais recentemente resumidas por Reboredo e Pais (2014).

A carta de Carlos Ribeiro e Nery Delgado, em 1867, revela a magnitude da ocupação do País por incultos que, a par da escassez de recursos florestais documentada por Pery em 1875, mobilizam o poder político para um conjunto de medidas de protecção e fomento (Radich e Alves, 2000). O proteccionismo político fomenta a expansão da cultura cerealífera desde o final da última década do séc. XIX, durante quase um século, não obstante em 1908 Sertório Monte Pereira reconhecer a fraca aptidão do país para a cultura (Baptista e Radich, 2010). Com o crescimento demográfico, a agricultura expandiu-se sobre as áreas ocupadas por matas, matos, brenhas, charnecas e incultos, talvez quase a par com a arborização que avançava pelo proprietário florestal, em resultado de políticas públicas de privatização de vastas propriedades eclesiásticas e comunitárias com interesse silvícola. Em “Valorização dos terrenos incultos”, Almeida (1904) refere o dinamismo do privado e propõe medidas para aproveitar os terrenos baldios dos corpos e corporações administrativas e do Reino. Após 25 anos, na conferência de Sevilha (1929), o retrato da Nação é já distinto (Almeida, 1929). Por curiosidade, na figura 1 exibem-se as capas das duas referências.

Recentemente, Baptista e Radich (2010) abordam a evolução da agricultura, da floresta e dos incultos, descrevendo e explicando os principais factores que exerceram o seu efeito na globalidade do território e a co-evolução destas ocupações durante o último século.

⁵ Terá chegado a Portugal em 1348 e terá dizimado 1/3 da população (Oliveira Marques 1995)

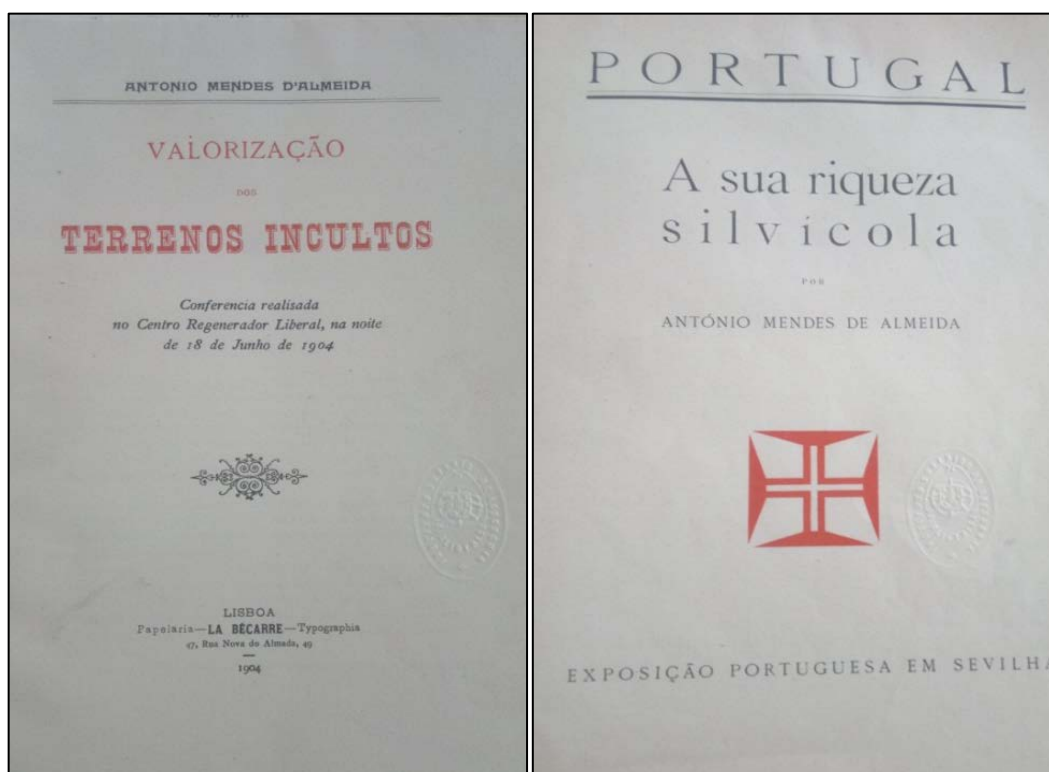


Figura 1: Capa das obras de Mendes de Almeida (1904 e 1929) consultadas na Biblioteca do ISA. Fotos do autor.

Por oposição ao aproveitamento local para a pastagem e carvão das áreas incultas ou ao menor interesse económico da arborização em pequenas áreas, “porque a orientação das populações ruraes ainda é arboricida” (Almeida, 1904, página 19), a ideia do aproveitamento “racional” dos incultos foi progredindo. Não obstante o principal contributo para a expansão florestal tenha sido privado, a conquista dos incultos e matos pela floresta foi empreendida e conseguida igualmente em projectos de iniciativa pública com maior dimensão, numa primeira fase através da fixação e arborização dos sistemas dunares móveis (figura 2), seguida depois do Plano de Povoamento Florestal de 1938-1972 (sobretudo nas serras do Norte e do Centro e Ilhas Adjacentes), da arborização dos terrenos do Sul em abandono da cultura cerealífera, e mais tarde pelo Projecto Florestal Português (BM/PFP1981).

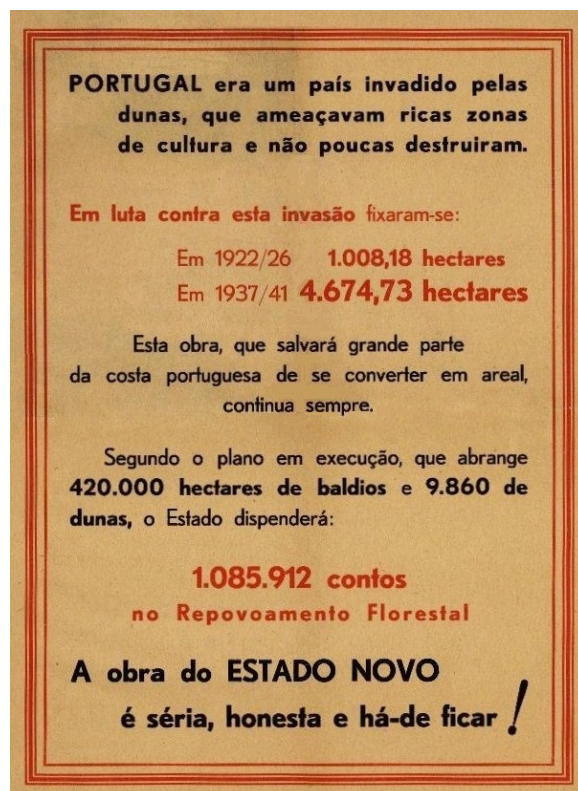


Figura 2: A imagem da esquerda retrata a instalação do ripado móvel na Mata Nacional do Urso nos anos 20. A imagem da direita, refere-se a um cartaz de 1941 produzido pela União Nacional, onde se resume o trabalho nas dunas e se perspectiva o futuro (ambas as imagens recolhidas no arquivo fotográfico histórico ICNF).

Mas é também interessante observar a figura 3, que resume uma previsão realizada em 1943 por José Themudo (no contexto da execução do Plano de Povoamento Florestal) para a evolução do uso do solo até 2000. Este gráfico “estende” a visão do País rural até ao final do século, numa época e num regime onde o sector primário era fulcral e a ruralidade, um dos seus traços ideológicos mais marcantes. Ou, como sugerido em Rosas (2001), o “mito da ruralidade”, onde a harmonia e a ordem definem o contexto do jardim da Europa, à beira mar plantado⁶. Um sonho ou um pesadelo em função do ponto de vista, antes das grandes transformações que se iniciariam na década de 60.

⁶ Expressão vulgarizada que tem origem num poema de Tomás Ribeiro (1831-1901)

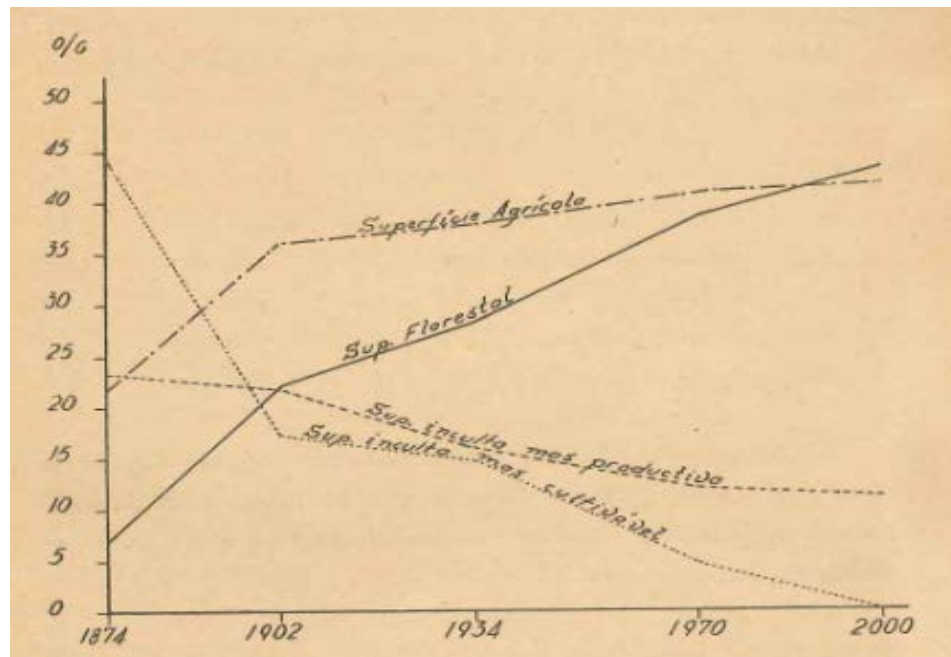


Figura 3: Previsão da evolução do uso do solo para o ano 2000. Imagem retirada da obra Repovoamento Florestal (Themudo, 1943)

Em 1995, segundo o ICNF (2013), a ocupação florestal era de 37%, as áreas agrícolas representavam 27%, e os matos 29%. Enquanto a previsão florestal de Themudo (1943) se materializou, a sua visão para o sector agrícola não se cumpriu. Interessa-nos mais, no âmbito desta tese, compreender como é que a floresta evoluiu, mas como veremos adiante, a sua evolução está interligada com as da agricultura e dos matos.

b) A TEORIA DA TRANSIÇÃO FLORESTAL

As transformações na ocupação do solo são sintetizadas pela Teoria da Transição Florestal de Mather (1992) que explica o crescimento da ocupação da área arborizada pelas mudanças tecnológicas e demográficas. Consubstancia-se por uma reversão da perda de área florestal num dado território, isto é, quando o saldo líquido entre as áreas que transitam para a ocupação florestal e as que se perdem para outros usos é positivo. Esta transição pode ser natural ou artificial, quando promovida por sementeiras ou plantações. No mesmo período ou desfasado deste, pode ainda ocorrer uma alteração dos objectivos de gestão das áreas florestais, alterando-se o paradigma desses modelos que, de acordo com Mather (1990), se designam por pré-industrial, industrial e pós-industrial. Exemplificando, uma floresta que é gerida para satisfazer localmente as necessidades das populações locais (p.e. lenhas, abrigo e alimentação) nos

modos tradicionais, segue o modelo pré-industrial, enquanto uma floresta explorada para a maximização do volume do lenho para fins industriais, segue um modelo industrial. Pode ainda suceder que a principal função atribuída aos espaços florestais seja satisfazer a procura por serviços ecológicos (regulação do ciclo da água, paisagem, recreio, sequestro de carbono, entre outras) não só da população local, mas de uma região mais alargada. Designaremos este modelo de gestão, conforme proposto pelo autor, pós-industrial.

Estudando o caso português, Mather e Pereira (2006) referem que a transição florestal foi excepcionalmente rápida e original, ocorrendo a par da expansão da agricultura e aumento da população, na primeira metade do século, seguida de uma segunda fase em que foi paralela com o abandono dos campos, o declínio da sociedade rural e a urbanização. De acordo com os autores, o caso da expansão florestal portuguesa gerou problemas específicos, a par das crises da ruralidade, colocando às instituições e actores desafios extraordinários de adaptação à mudança, em particular nos regimes de gestão da terra.

Após a conquista dos incultos, no último quartel do séc. XX intensifica-se a redução da população agrícola e área agricultada (Baptista, 2010), mas apesar dos intensos programas de arborização dos anos 80 e 90, a expansão florestal estabiliza e a produção lenhosa não materializa as auspiciosas previsões do projecto do Banco Mundial (BM/PFP 1980). O Inventário Florestal Nacional regista, para o período 1995-2010, a primeira redução na cobertura florestal, explicada, segundo o ICNF (2013), pelos incêndios recorrentes.

É neste contexto que se introduz a figura 4, que ilustra o triângulo do fogo na agricultura europeia sugerido por Pyne (1997) e adaptado por Alves *et al.* (2006), que permite ilustrar a modificação dos três grande grupos de ocupação: a Agricultura (*Ager*), a Floresta (*Silva*) e as Pastagens (*Saltus*), este últimos designados na secção anterior como “incultos”.

Num equilíbrio que estabelece com o território, o homem usou o fogo para desmatar as florestas, para caçar ou afugentar animais, para preparar a terra para agricultura, para produzir carvão e para renovar pastagens. Com as alterações tecnológicas e demográficas, de acordo com a teoria da transição, este equilíbrio local desfaz-se.

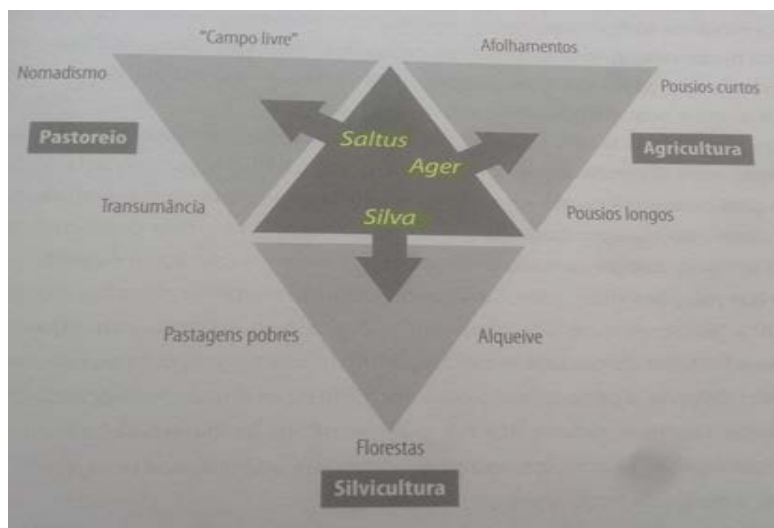


Figura 4. Esquema proposto por Pyne (1997) para ilustrar o triângulo do fogo europeu e adaptado por Alves *et al.* (2006), onde grandes tipos clássicos de ocupação do solo estão representados e o fogo desempenha um papel relevante. Reprodução autorizada pelo Prof. J. S. Pereira

Havendo menos população e com a intensificação do modelo produtivo, há menos pressão sobre a terra que sobra para os matos e incultos e que pode ser convertida em pastagem. Não havendo uso destes territórios por gado ou intervenção do homem para domesticar o bravo que se forma, nomeadamente através de silvicultura de gestão da regeneração natural, acumulam-se cargas elevadas de combustíveis. No caso das paisagens mediterrâneas, este processo significa aumento do perigo de incêndio que é amplificado quando o fogo recorrente e pouco intenso é excluído da paisagem ou não se eliminam os arbustos lenhosos e herbáceas mecanicamente ou através da pastorícia.

Pyne (2001), Grove e Rackham (2003), Pausas (2010), Seijo e Grey (2012) e Moreno *et al.* (2013), entre outros, para paisagens semelhantes (atlânticas e mediterrânicas) associam as dinâmicas da ocupação do solo à acumulação de combustível e sua continuidade, promovidas pelo abandono da agricultura, a arborização e a introdução de políticas de exclusão do fogo. Para Portugal, Rego (1992), usando dados de incêndios em matas nacionais e comunitárias, através de uma analogia semelhante à da figura 4, discute o aumento do perigo de incêndio resultante de mudanças de ocupação e sugere políticas mais adequadas. Também para Portugal, Fernandes (1995) sugere a gestão do fogo enquanto ferramenta para contrariar a acumulação da vegetação e Moreira *et al.* (2001), para um estudo de caso no noroeste de Portugal, associam a arborização ao

fogo, tal como, mais recentemente, Fernandes *et al.* (2014), que associam o aumento de combustível (arborização nas áreas públicas e comunitárias) à área ardida. Mas a arborização por si só não explica a área ardida. Moreira *et al.* (2009) referem a preferência pelos matos, e Barros e Pereira (2014) referem que incêndios maiores não expressam selectividade por uso de solo. Para as áreas arborizadas ardidas e considerando o período entre 1996 e 2014, Fernandes e Guiomar (2017) observam que os incêndios incidem bastante mais nos carvalhais, resinosas e eucaliptais do norte e centro do país. Associados à causa da desflorestação, de acordo com Mather e Pereira (2006), os incêndios talvez sejam um sintoma das tensões inerentes da transição florestal.

A relação entre transição florestal e incêndios é interessante, mas não está totalmente esclarecida. Ao analisarem à escala do distrito, Mather e Pereira (2006) só encontram evidências gráficas entre as tendências demográficas e o número de incêndios, não havendo relação com a área ardida. Assim, os estudos acima referidos só permitem extrapolações para áreas semelhantes às que foram estudadas. Não é objecto de investigação desta dissertação esclarecer esta questão, no entanto, resultante do nosso trabalho, ficará disponível uma base de dados que poderá contribuir para abordar o assunto de forma mais robusta.

Temos hoje a noção que o País se arborizou ao longo dos últimos 150 anos e que os incêndios têm vindo a contribuir para a perda de área florestal (ICNF, 2013; Fernandes e Guiomar, 2017), mas desconhecemos a que ritmos as transições aconteceram, quando aconteceram, onde aconteceram, e que transferências de áreas ocorreram entre grandes ocupações do solo ao longo do tempo e do espaço. Assim, a pergunta de investigação que se formula é:

- Quando e onde aconteceu, de facto, a transição florestal?

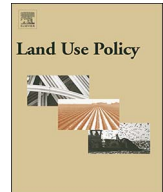
Compatibilizadas as legendas e as escalas das cartas de ocupação do solo para cinco momentos dos últimos 100 anos (1907, 1955, 1970, 1990 e 2006) por análise de *clusters*, identificam-se concelhos com percursos similares de transição florestal. À luz da história agrícola e florestal, discutem-se os *drivers* relevantes.

[Is Portugal's forest transition going up in smoke? \(2017\)](#)

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Is Portugal's forest transition going up in smoke?



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ABSTRACT

The turnarounds from decrease to expansion in forest areas that took place during the last century have been examined through the lens of forest transition theory (FTT). Among temperate and Mediterranean European countries that have seen an expansion of forest cover, Portugal stands out as the only case in which this trend has recently been reverted. In this study, we explicitly map and document the forest transition (FT) in the country over the period 1907–2006, and investigate when and where forest transition happened *de facto*, and which were the land use transition pathways that resulted from the shrublands, agriculture, and forest interplay dynamics. After thematic and geometric harmonization of land cover maps from 1907, 1955, 1970, 1990, and 2006, a cluster analysis established four typologies, and a transition matrix was constructed to assess land cover dynamics. We found that up to 1955, FT occurred simultaneously with agricultural expansion, as shrubland areas diminished. Afterwards, with the retraction of agricultural area and the consequential decoupling of forest management from local actors, FT gained momentum and expanded up to the 1990s. While during the first half of the 20th century, forest expansion followed the “Scarcity” and “State Policy” pathways fostered by local socio-ecological feedback loops, throughout the second half of the century forest transition was driven by exogenous socio-economic forces, following “Economic Development” and “Globalization” pathways. We show how, despite these forces, FT can be derailed by endogenous factors such as wildfires, which limited and in some areas even reverted the afforestation process, initiating a deforestation phase. Since the necessary conditions for FT (technology shift, urbanization, agriculture retraction and public afforestation programs) were available in mainland Portugal, we advance the hypothesis that critical wildfire risk governance deficits may have been responsible for arresting FT. Considering the critical role of forests and other wooded areas in supporting climate change mitigation and sustainable development, our work provides useful evidence and insights for public decision makers on previously unaddressed dimensions of FTT.

1. Introduction

Conserving resilient forests is one of the development goals of the United Nations (UN, 2015) due to their role in providing multiple ecosystem and societal services (Miura et al., 2015; Ninan and Inoue, 2013; Simončič et al., 2015; Vizzarri et al., 2015), as well as in mitigating climate change (IPCC, 2014; Pan et al., 2011; Millar et al., 2007). Understanding the relative contribution of different drivers to land use change is critical to address the abovementioned challenges (e.g. Hersperger and Bürgi, 2009; Jepsen et al., 2015; van Vliet et al., 2015). Europe, for instance, experienced a process of anthropogenic deforestation since the mid-Holocene, but in the last two centuries inverted its deforestation pathway (Kaplan et al., 2009; Williams, 2000). Mather (1992) designated this turnaround from decrease to

expansion in the forest area of a region as “forest transition” (FT), and Mather and Needle (1998) have sought to explain it with the Forest Transition Theory (FTT), in which urbanization and industrialization processes first lead to a deforestation phase, and then rural depopulation, land abandonment, and the concentration of agricultural activities on fertile soils create the conditions that allow forests to recover.

Mather's seminal work (Mather, 1992) was followed by national studies dealing with forest transitions in Denmark, France, Switzerland, Scotland, Asia (Mather, 1998, 2001, 2004, 2007) and Portugal (Mather and Pereira, 2006). Studying the post-FT process in the eastern United States, Drummond and Loveland (2010) and Jeon et al. (2014) have documented a new decline in forest area due to urban sprawl. FTT has framed several studies unveiling the drivers of land use process dynamics at global scale (e.g. Rudel et al., 2005; Baptista and Rudel,

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2006; Pfaff and Walker, 2010; Meyfroidt and Lambin, 2011), as well as studies analyzing afforestation and deforestation phases in different biotas (e.g. Rudel et al., 2010; Bae et al., 2012; Oduro et al., 2015), and their teleconnections in a globalized world (Meyfroidt et al., 2010). Barbier et al. (2010); Barbier and Tesfaw (2015) have concluded that in low to moderate income countries governance issues had a relevant role in explaining the timing and magnitude of FTs.

1.1. Forest transition pathways

Complexity and non-trivial interdependencies between several drivers set the challenging stage of land-cover change. FT processes differ among countries and time periods, with population dynamics and poverty alone not being among its major causes, as people's responses to economic opportunities are mediated by institutional factors (Lambin et al., 2001). Moreover, globalization of commodities, capital and people amplified teleconnection effects upon local land use changes (Meyfroidt et al., 2010; Lambin and Meyfroidt, 2011). A complex set of factors is implicated (Mather, 1992; Rudel et al., 2005), with land use transitions operating through endogenous forces and exogenous socio-economic mechanisms, according to Lambin and Meyfroidt (2010), who considered two kinds of drivers: 1) *mostly endogenous forces*, due to negative socio-ecological feedbacks that prompt actions towards afforestation and conservation, as local stakeholders perceive a decline in previously available goods and services; and 2) *mostly exogenous forces*, due to socio-economic dynamics unrelated to local land cover changes, such as markets, globalization, innovation, and supranational afforestation and conservation policies. They also concluded that, in the former, landowner awareness was of utmost importance to stop inadequate land use practices, while in the latter, the exogenous drivers might require investment to allow perceived opportunities to be captured.

Detailing the mechanisms underlying FT, Oduro et al. (2015) summarized the pathways previously proposed by Rudel et al. (2005) and Lambin and Meyfroidt (2010) in five FT types: 1) *Economic development pathway*, related to rural exodus to urban and industrialized areas due to labour shortage, fostering land abandonment and therefore allowing forest regrowth (e.g. Aide et al., 1995; Bowen et al., 2007; Prévosto et al., 2011; Klooster, 2003; Mather and Pereira, 2006; Rudel et al., 2005); 2) *Forest scarcity pathway*, where private or public agents value or anticipate a valuation of goods and services provided by forests and support afforestation programs, or enforce laws to protect woodlands, promoting the increase of forest area (e.g. Frayer et al., 2014; Holmgren et al., 1994; Singh et al., 2017); 3) *Globalization pathway*, related to the exposure of open economies to international markets, international conventions and agreements, and socio-political pressure from environmentalist organizations, fostering investments in afforestation for commodities and protection of forest areas (e.g. Hecht et al., 2006; Li et al., 2015); 4) *State forest policy pathway*, where forest expansion is conducted for strategic national goals, such as poverty alleviation, society modernization, land control, and greening of the economy (e.g. Bae et al., 2012; Mather, 2007); and 5) *Smallholder, tree-based land use intensification pathway*, which is associated with tree-planting for restoration purposes, ecological diversification and resilience of small-scale rural communities (e.g. Blay et al., 2008; Singh et al., 2017).

1.2. Forest transition and wildfires

The statistics that reveal the extent of the impact of wildfires on forest area were not yet available when Mather and Pereira (2006) analyzed the role of fire in the Portuguese FT, but they proposed the hypothesis that fires were jeopardizing private and public afforestation efforts. According to IFN (2013), FAO (2015), and Uva (2015), this forest expansion reversal trend is being documented since 1995 and appears to be a consequence of extensive vegetation burning (e.g. Moreira et al., 2001; Silva et al., 2011; Jones et al., 2011). The role of

fire as a driver of land cover change, as land abandonment and afforestation increased fuel loads, has also been discussed by Rego (1992), Fernandes et al. (2014), Pausas and Fernández-Muñoz (2012) and Oliveira et al. (2012).

1.3. Portugal as a case study in the western world

According to FAO (2015), Portuguese total forest cover declined at about 0.3% yr⁻¹ since 1990. Being part of the group of higher income countries, whose forest area increased at 0.05% yr⁻¹ during the same period (Keenan et al., 2015), Portugal features an unexpected trend, as Kauppi et al. (2006) also suggest. Mather and Pereira (2006, p. 259) considered that Portugal “presents a spectacular example of operation of forest (area) transition”, as it was greater and faster than in several other European countries. Through historical analysis of land use and demographic data at national level, they documented the increase in forest area between 1875 and 2000 from about 7% to near 40% of the country's mainland area. In addition to this expansion, during that period forest management goals changed from meeting local agrarian needs to global industrial wood commodity markets. More recently, forest management is also being challenged to satisfy both industrial procurement and a growing demand for environmental services. This paradigm shift also embodies a FT (Mather and Pereira, 2006), framed as a globalization FT pathway (Rudel et al., 2005).

1.4. Aim and scope

Our aim is to expand upon Mather and Pereira (2006) and perform an in-depth, spatially explicit analysis of FT in Portugal during the last 100 years. Without using *a priori* historical narratives or demographic transition, which have been criticized by Robbins and Fraser (2003) and Perz (2007), we use FTT as a framework to anchor the discussion of results from land use transition pathway analysis. We formulate the hypothesis that FT described at national level may mask the existence of sub-national transition dynamics, regional drivers and pathways that ultimately substantiate the national-level process. We thus ask where and when did forest areas expand and contract. Similarly to other authors who have linked forest land cover evolution with wildfire and its risk management strategies (Badia et al., 2002; Seijo and Gray, 2012; Moreira et al., 2011), we discuss our results unveiling the role that fire and its mismanagement may have had to arrest a sustainable FT, and showing that although its necessary endogenous and exogenous conditions were present, they were not sufficient to ensure the expected forest area change process.

2. Study area

The study was conducted in mainland Portugal, at the municipal level (LAU 1–Local Administrative Units) (Fig. 1). With the majority of its ~10 million inhabitants living in densely urbanized coastal areas, forest, shrublands and pastures occupy ~67% of the country (ICNF, 2013), while agricultural areas cover another ~24%. Portugal is an open economy, integrated in the European Union, and with most of its workforce employed in the tertiary sector. The country has a Mediterranean climate, with dry, warm summers in the northern half, and dry, hot summers in the southern half. Maritime pine (*Pinus pinaster*) and eucalypt (*Eucalyptus globulus*) plantations cover broad areas of rugged terrain in the northern part of Portugal, while the woodlands of the undulating southern plains are dominated by evergreen oak woodlands (*Quercus suber* and *Quercus rotundifolia*) of diverse density in a mosaic with croplands.

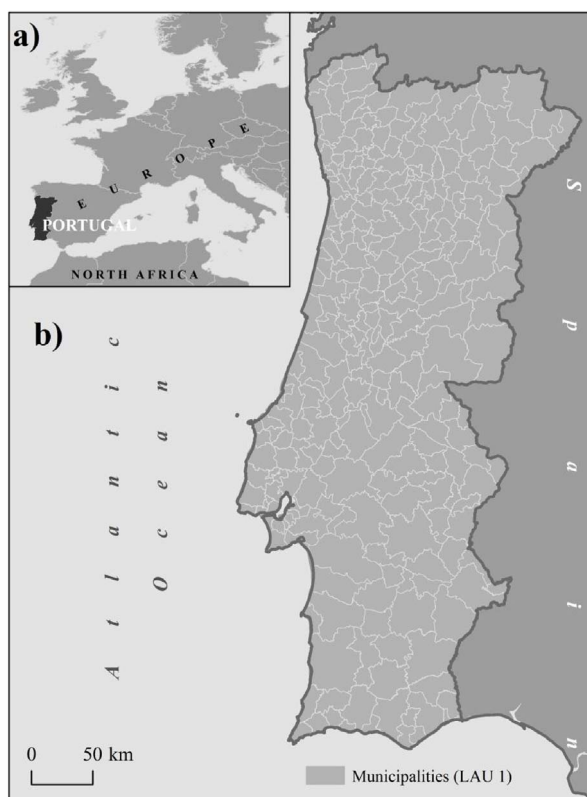


Fig. 1. Portugal in the context of southern Europe (a) and the boundaries of its 278 municipalities (b) (Official Administrative Map of Portugal 2015).

3. Data and methods

3.1. Forest maps: data sources and thematic homogenization

We used land cover maps from five different dates to assess forest dynamics in Portugal since the beginning of the 20th century. After an extensive review of the maps available for that period, documenting the major land uses (agriculture, forest, shrublands, urban areas, and bare surfaces and water bodies) and thus candidate to supporting the reconstruction of land cover dynamics, we selected five sources of information at national level: the Agriculture and Forest Map of 1910, at the scale 1:500,000, with final fieldwork done in 1907 (Radich and Alves, 2000), the reference year used herein; the Agriculture and Forest Map, published in three sheets (1960, 1964, and 1965) at the scale 1:250,000, with fieldwork mostly carried out between 1950 and 1955, with subsequent updates up until 1960 (Daveau, 1995); the first National Forest Inventory of 1970 (fieldwork carried out from 1965 to 1982) and the CORINE Land Cover maps of 1990 (updated version from 1986/87 satellite images) and 2006, at the scale 1:100,000 (Caetano et al., 2005, 2009a,b; Painho and Caetano, 2006). Because equivalent, but not similar, definitions of land cover and mapping techniques were used in each map, we carried out a thematic and geometric harmonization process, detailed below.

To match the definitions of forest from the five different maps, and due to known differences between the dominant species and their function at landscape level, especially in Mediterranean land use systems, we divided the wooded areas in two classes: “forest stands” (hereafter forests) and “evergreen oak woodland” (hereafter oak woodlands).

Oak woodlands represent the typical agroforestry systems of the southwestern Iberian Peninsula (*montados* in Portugal, *dehesas* in Spain), and can be characterized by their multi-functionality, comprising areas with dominance of evergreen oaks in the tree layer (mainly cork and holm oaks), and an understory formed by annual crops,

pastures, or shrub cover (Pinto-Correia et al., 2011). They are well defined in the oldest map (1907), the only one to explicitly use the term *montado* (additionally distinguishing between cork oak and holm oak woodlands). Given the differences in the criteria used to define these areas between the 1955 and 1990/2006 data sources, we used the datasets of Guiomar et al. (2015) and Godinho et al. (2016), who identified and addressed these limitations. The data produced by Godinho et al. (2016) are also based on CORINE Land Cover and ancillary data to map oak woodlands in 1990 and 2006. Guiomar et al. (2015) also used the Agricultural and Forest Map, together with maps of cork and holm oak distribution at the 1:250,000 scale, to map the boundaries of these multiple-use oak woodlands in 1955. Considering the abovementioned characteristics, we aggregated patches classified as cork oak and holm oak in the 1970 data source to obtain the oak woodlands for this reference year.

In both the 1907 and 1955 maps, forest areas are represented by a single land cover class. In the case of the 1970 map, forest areas result from the aggregation of evergreen and deciduous forest types, excepting oak woodlands. For the 1990 and 2006 maps (based on CORINE Land Cover), they were obtained from the spatial aggregation of the three main forest land cover classes (311–broad-leaved forest, 312–coniferous forest, and 313–Mixed forest). According to Nery (2007) and Guiomar et al. (2009), “transitional woodland/shrub” (CORINE Land Cover class 324) represents forest degradation, regeneration, and recolonization, or transitional stages related to forest management operations (e.g. clearcutting), without loss of identity as forest area. To classify those areas as forests or shrublands in 1990 and 2006, two land cover change maps were created (1990–2000 and 2006–2012) using the available CORINE Land Cover datasets. The areas classified as “transitional woodland/shrub” in 1990 and in 2006, and as forests (land cover classes 311, 312 and 313) in 2000 and 2012 respectively, were also considered forests. Areas that remained in the “transitional woodland/shrub” class between the earlier and later dates were classified as shrublands.

Agricultural and shrubland areas for the 1990 and 2006 maps were also taken from CORINE Land Cover maps. While agricultural areas result, for all reference years, from the aggregation of more detailed classes present in each reference map, the definition of shrublands had to ensure thematic consistency. In the 1907 and 1955 reference year maps, shrublands are aggregated with other land cover classes, in a broad class of “uncultivated areas”. This land cover class includes rock outcrops, sand beaches and dunes, and water bodies, in addition to shrublands. Thus, and assuming the temporal stability of the non-vegetated land cover types, we used the CORINE Land Cover 1990 classes 331 (beaches, dunes, sands) and 332 (bare rock) to disaggregate the “uncultivated areas” of 1907 and 1955. The process was similar for water bodies, but we had to take into account the year of construction of each dam to use only those that had been built up to the date of each reference year. Built-up or artificial areas were not considered in our analysis given the complexity of evaluating transitions related to urban sprawl. Thus, the “artificial surfaces” identified in CORINE Land Cover 2006 were used to mask out these areas from the older maps.

This set of operations produced, for each reference year, a five-class land cover map (agriculture, shrublands, forests, oak woodlands, and bare surface) with a minimum mapping unit of 25 ha.

3.2. Cluster analysis and transition matrix

The percentages of forests and oak woodlands for each of the five periods (1907, 1955, 1970, 1990 and 2006) were calculated at municipal level. Ten out of 278 municipalities were excluded from further analysis, as they had less than 5% of forest or oak woodland cover area throughout the whole period or had become mostly urban municipalities, such Lisboa, Oeiras, and Porto. A hierarchical cluster analysis (HCA) was performed on this dataset to group municipalities according to their land cover trajectories, using Ward’s method (Ward,

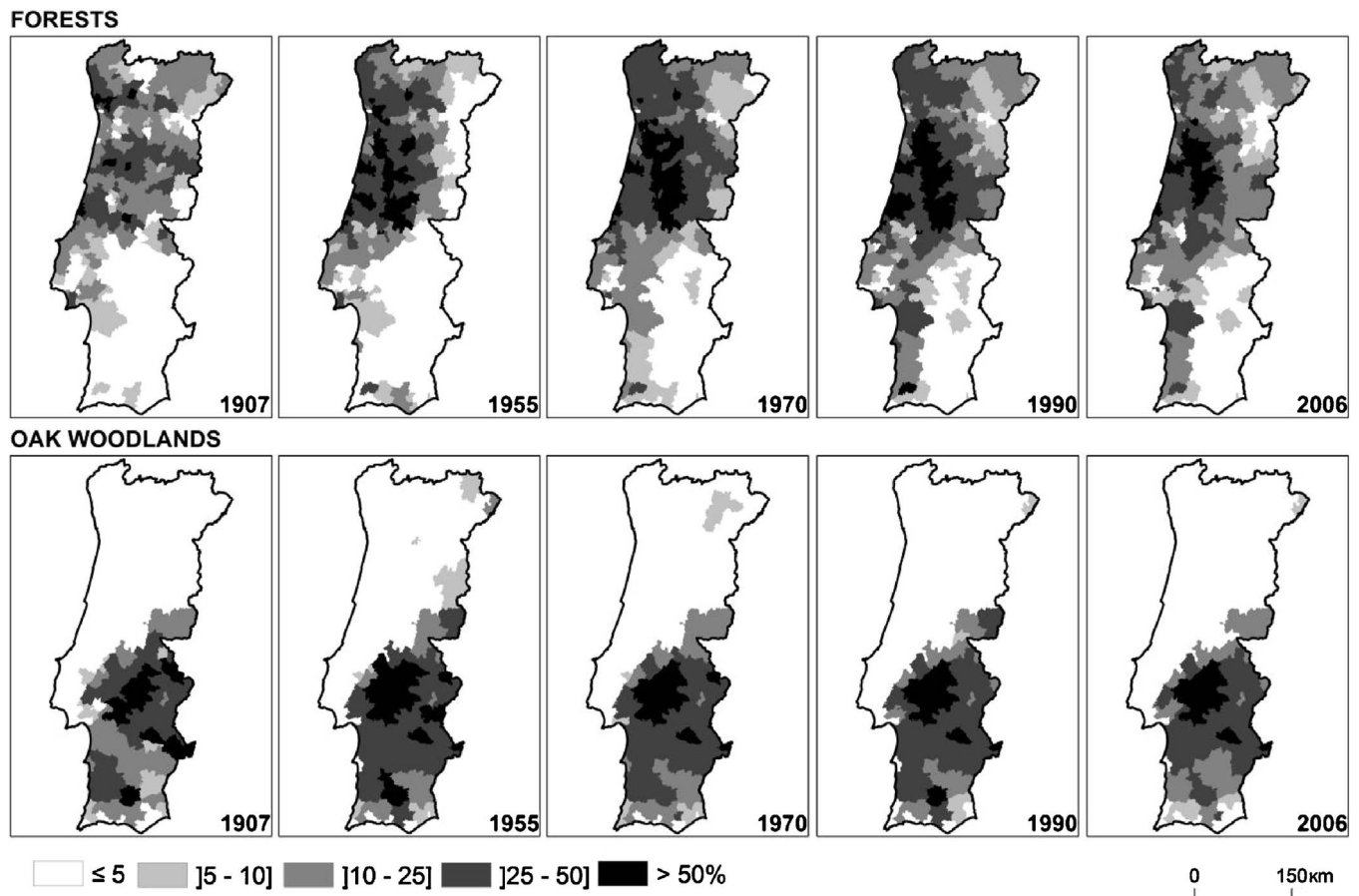


Fig. 2. Dynamics of the percentage (at municipal level) of forest (a) and oak woodland (b) covers between 1907 and 2006.

1963) and the Euclidean distance metric. Connectivity (Handl et al., 2005), Dunn index (Dunn, 1974) and silhouette width (Rousseeuw, 1987) were used to evaluate the results of the cluster analysis and to select the number of clusters. While Dunn index and silhouette width are non-linear combinations of compactness (cluster homogeneity) and separation (distance between cluster centroids), connectivity measures the extent to which neighboring observations share the same cluster (Handl et al., 2005; Brock et al., 2008). To select the number of clusters, Dunn index and silhouette width should be maximized, while connectivity should be minimized (Brock et al., 2008). All analyses were performed using R 3.1.3 software (R Development Core and Team, 2015), through the native R functions for clustering, as well as the *clValid* and *NbClust* packages (Brock et al., 2008; Charrad et al., 2014). Box plots (McGill et al., 1978) were then used to compare the means and ranges of the proportions of forests and oak woodlands between clusters.

For each cluster, and considering the major land cover classes (agriculture, shrublands, forests, oak woodlands, and bare surface), four transition matrices were calculated for the periods 1907–1955, 1955–1970, 1970–1990 and 1990–2006 using the cross tabulation function of IDRISI Selva (Eastman, 2012). Prior to this calculation, a vector-raster conversion was performed for each land cover map, with a 250 m cell size. The generated datasets were used to calculate the annual rate of land cover change in each period, for each cluster and each municipality.

3.3. Forest transition drivers

To identify drivers of forest transition, we collected data on burnt area, population censuses, sheep and goat censuses and data on afforestation area. To analyze the role of fire, we used the fire perimeter

atlas from 1975 to 2006 described by Oliveira et al. (2012). Population data from 1911 to 2006 were obtained from national censuses (Santos, 2016; Pordata, 2015). Sheep and goat densities were determined using the dataset of Santos (2016). From this dataset we discarded cattle livestock, which are not restricted to extensive grazing. Data on funds spent in public afforestation programs and incentives are from Carvalho and Morais (1996), CESE (1996), Mendes and Dias (2002) and ISA (2005). Private afforestation efforts for 1907–1955 and 1955–1970 were estimated as the difference between total wooded area and public afforestation expenditures, neglecting losses due to biotic and abiotic disturbances. Because wildfire losses after 1970 are very significant, we were unable to calculate private expenditures for 1970–1990 and 1990–2006. Land cover trajectories for each cluster were interpreted taking into account milestones in Portuguese forest and agricultural history, and classified according to the FT pathways proposed by Rudel et al. (2005) and Lambin and Meyfroidt (2010).

4. Results

Here, we provide a spatially explicit description of the temporal trajectories of wooded area change in Portugal, and organize them as a set of geographically coherent clusters.

4.1. The evolution of wooded areas: forests and oak woodlands (1907–2006)

In 1907 wooded areas covered only about 27% of the country area, with oak woodlands accounting for 14%, and forests for the remaining 13%. Agriculture and shrublands dominated the landscape, occupying more than 2/3 of Portugal's mainland. One hundred years later, wooded areas covered 32%, with 14% of oak woodlands, and 18% of

Table 1
Values of connectivity, Dunn index and silhouette width to select the number of clusters.

Number of clusters	Connectivity	Dunn index	Silhouette width
4	31.51	0.08	0.37
5	34.35	0.08	0.35
6	51.16	0.08	0.34

forests. Observing five time steps, we found that maximum woody vegetation cover (37%) was recorded in 1990, when forests peaked at 22% and oak woodlands were at 15%, declining from their maximum of 18% in 1955.

When examining the geography of those changes at municipal level, expressed as percentages of areas occupied by forests (Fig. 2a) and oak woodlands (Fig. 2b), we observe that in the North and in the Southwest of Portugal, the forest cover increased up to the 1990s and then decreased, while in the South oak woodlands reached their peak area in the middle 1950s and then declined.

4.2. Where and when did woody vegetation areas expand?

The dendrogram generated by the hierarchical cluster analysis is available as **supplementary material** and the indicators supporting the selection of the number of clusters are summarized in Table 1. Since the Dunn index is constant and the four clusters case features the highest silhouette width and lowest connectivity values, it was considered the best choice.

Fig. 3 shows the distribution of forests and oak woodlands between 1907 and 2006 for each of the four clusters. Each cluster aggregates municipalities that displayed similar land cover change processes.

Fig. 4 shows the spatial distribution of the four clusters, highlighting the different regional patterns for forest and oak woodland areas change. Detailed information for each municipality can be found in the **supplementary material**.

Cluster 1 represents 99 municipalities (Fig. 4) that had an average 24% of wooded cover in 1907 and expanded during more than 65 years, reaching an average of 32% cover in 1970 (Fig. 3). Afterwards, they underwent a deforestation phase of similar magnitude, but concentrated in 2/3 of the time previously required for the forest area expansion process, with the forest and oak woodland areas shrinking to an average of about 26% in 2006.

Cluster 2 represents 53 municipalities that had an average of 28% forest cover in 1907 and twice that area 83 years later. Forest areas expanded from 28% to 51% between 1907 and 1955. In the following period (1955–1970) forests stalled, regaining its momentum subsequently (1970–1990) to reach an average area of 56%, but finally decreasing to under 48%.

Cluster 3 includes 57 municipalities, where oak woodlands expanded on average from 32% to 43% of the cluster area up to 1955. Afterwards, their area retreated and forests expanded until 1990, while oak woodlands ceased to decline. After one hundred years, oak woodlands covered just 2% more area than in 1907, while forests grew from 4% to 8% of the cluster area.

Cluster 4 has 59 municipalities, where wooded areas represent about 10% of the area. They featured, on average, a deforestation trend between 1907 and 2006, affecting both forests and oak woodlands. After an initial decrease, forest cover expanded between 1955 and 1970, but decreased again in the final period of analysis. Oak woodland areas increased from 1907 to 1970, but contracted afterwards.

Fig. 5 illustrates the temporal dynamics of wooded areas for each cluster, considering the sum of forest and oak woodland areas divided by the total area of the cluster. Expressing different proportions of cluster cover, all clusters exhibited a downward concave trajectory. Clusters 2 and 3 illustrate the fastest forest cover expansion up to 1990, although cluster 3 exhibited from 1955 to 1970 a substantial contrac-

tion of woody vegetation, while it remained stable in cluster 2. Cluster 1 has overall lower forest and oak woodland cover and a downward concave trajectory, with the highest values occurring between 1970 and 1990. Finally, cluster 4 has the lowest woody vegetation cover which decreased throughout the study period, with a small peak in 1970.

4.3. Forest transitions and pathways

The matrix of net transitions between the three major land cover types is shown in Fig. 6, and the rate of change for each land cover type is given in Table 2. Both summarize land use dynamics and were used to typify the land use change pathways summarized in Table 5.

1907 to 1955: Wooded areas expanded in all clusters in tandem with agriculture, except in cluster 2, where the former retreated. We found that this simultaneous growth occurred at a rate of 0.6% yr⁻¹, but was faster in cluster 2 (1.6% yr⁻¹) due to the conversion of agricultural areas to forest. About 1814 kha of shrublands (−1.3% yr⁻¹) were converted to wooded areas (780 kha, including 430 kha of oak woodlands) and agriculture (1055 kha). In cluster 3, shrublands decreased sharply at 1.9% yr⁻¹, while agriculture expanded at 1.3% yr⁻¹ and oak woodlands grew at 0.7% yr⁻¹.

1955 to 1970: Wooded areas retreated 11 kha, as forests expanded 240 kha (1.0% yr⁻¹) but oak woodlands lost 251 kha. Except for cluster 2, where forest area remained constant and agriculture grew, areas occupied by agriculture declined 286 kha (−0.4% yr⁻¹), while shrublands grew 270 kha, notably in clusters 3 and 4, expanding respectively at 14.4 and 3.9% yr⁻¹. Remarkably, in cluster 3 oak woodlands lost 222 kha to agriculture, forests and shrublands.

1970 to 1990: Forests expanded by 217 kha and oak woodlands decreased 43 kha, namely in clusters 1 and 4. Forest expansion reached a 5.0% yr⁻¹ rate in cluster 3 and retreated 1.0% in cluster 4. Total decline in agriculture areas amounted to 308 kha, leading towards expansions of forests and shrublands in all clusters except cluster 1. In all clusters, but especially in 1 and 2, 288 kha of forest cover were converted to shrublands, as forest area expanded 217 kha. In this period, wildfires affected more than 1,535 kha of area in clusters 1, 2 and 4, where the average annual percent burnt area was 1.7%, 1.8% and 1.6% yr⁻¹, respectively.

1990–2006: Wooded cover retreated by 400 kha (309 kha of forest and 91 kha of oak woodlands), notwithstanding strong public support towards afforestation, that reached 324 kha in that period (Table 4). Agriculture lost a total of 50 kha to shrublands and gained 24 kha from wooded areas. Farmed area decreased in all clusters, except for cluster 3 (see Table 4). Fires burnt more than 2,201 kha converting various land covers to shrublands, which increased 450 kha.

Table 3 shows that fires were relevant in all clusters, except #3. Cluster 1 had the highest fire density, the highest annualized burnt area growth rate in the period 1990–2006, and also the highest proportion of burnt area (2/3).

Table 3 also includes data on the population, and shows that between 1907 and 2006 the total population density more than doubled in cluster 4 and almost doubled in cluster 1, while it had only a small increase in cluster 3. If we consider the rural population density (2006) and assume that in 1907 most of the areas were rural, we can observe that it was reduced in half in cluster 3, had a small retraction in clusters 1 and 4, and increased in cluster 2.

Still in Table 3, the available farmed area statistics (1989–2009) show a reduction of farmed area twice faster in cluster 2 than in clusters 1 and cluster 4, while for cluster 3 an increase of 0.3% yr⁻¹ is observed. Regarding the data for sheep and goats, which closes Table 3, in clusters 1 and 4 they were half as abundant in 2006 as in 1911/20, while their density decreased by a factor of 3 in cluster 2 and remained stable in cluster 3.

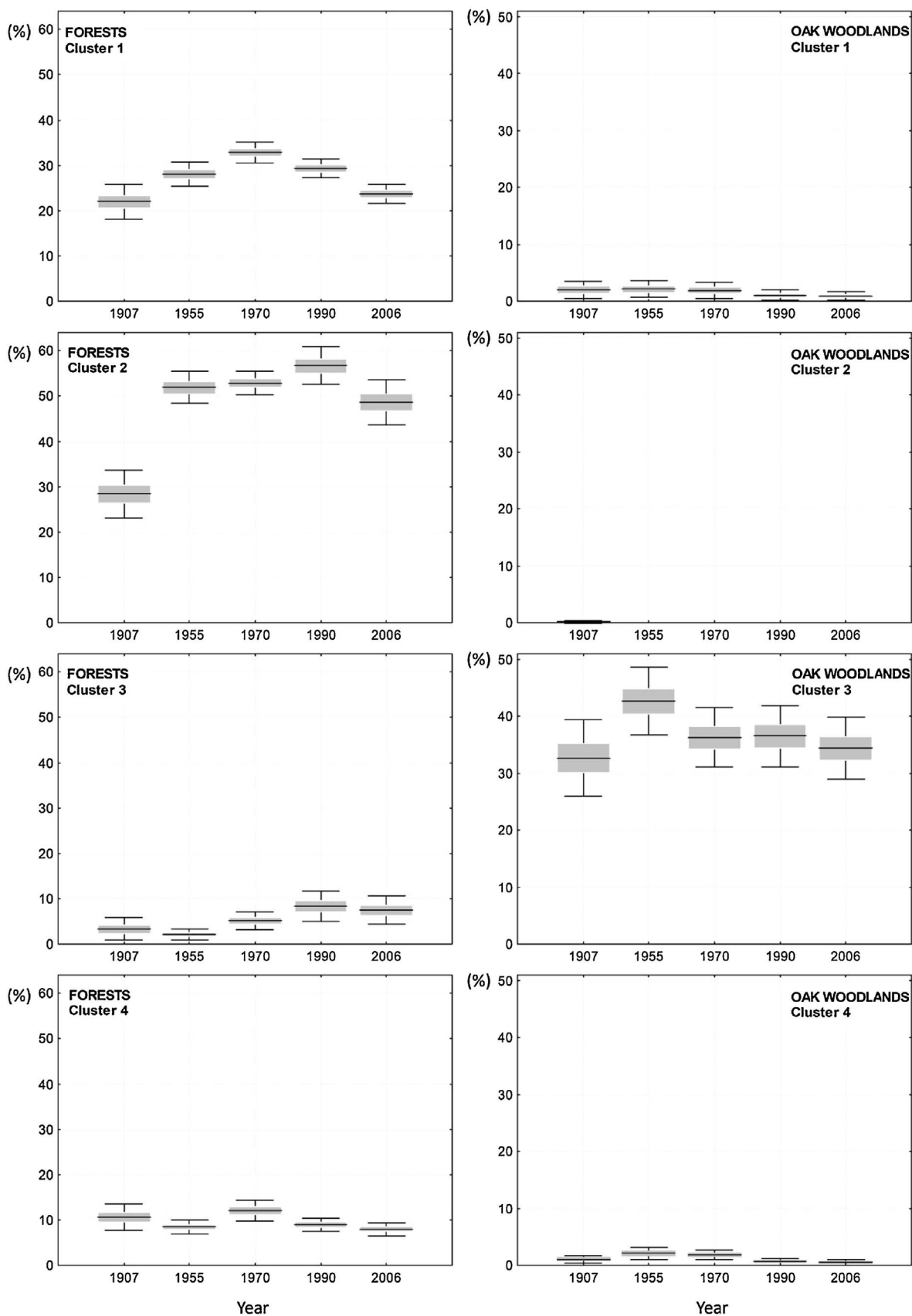


Fig. 3. Boxplots representing the distribution of the mean values (mean ± standard error, mean ± 0.99 confidence interval) of the percentage of forests and oak woodlands at the municipal level in each cluster.

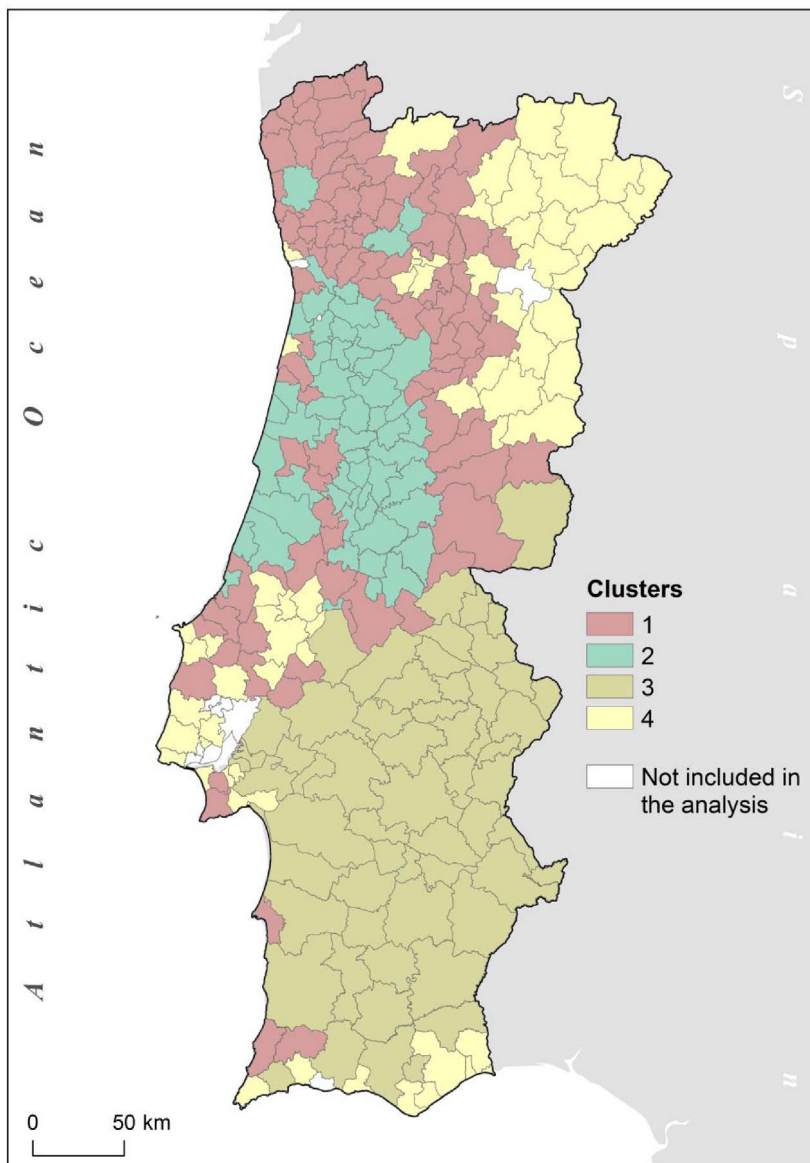


Fig. 4. Spatial distribution of four Forest Transition clusters, with municipality boundaries overlaid.

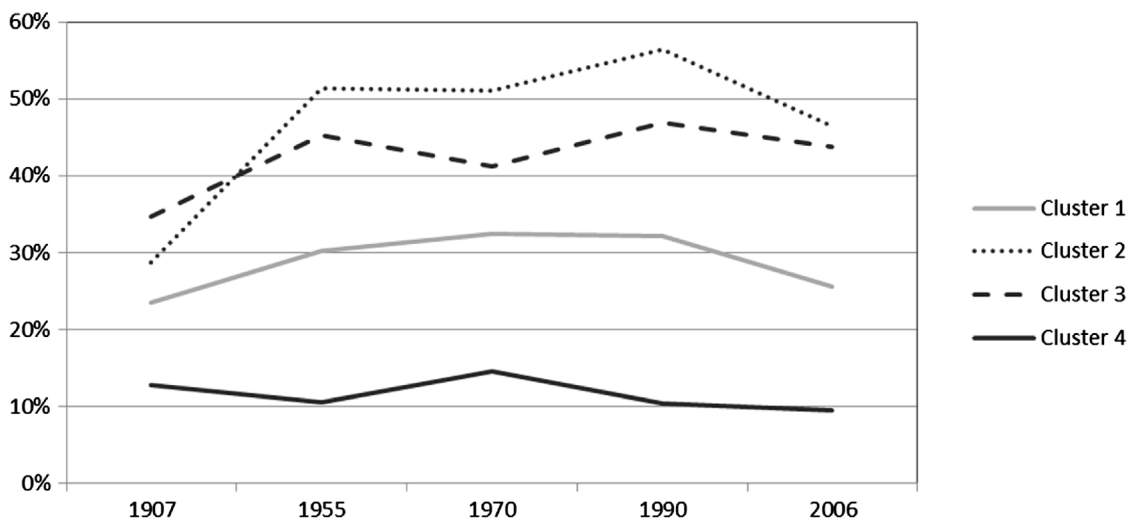


Fig. 5. Forest and oak woodland extent as a proportion of each cluster area (X-axis not to scale).

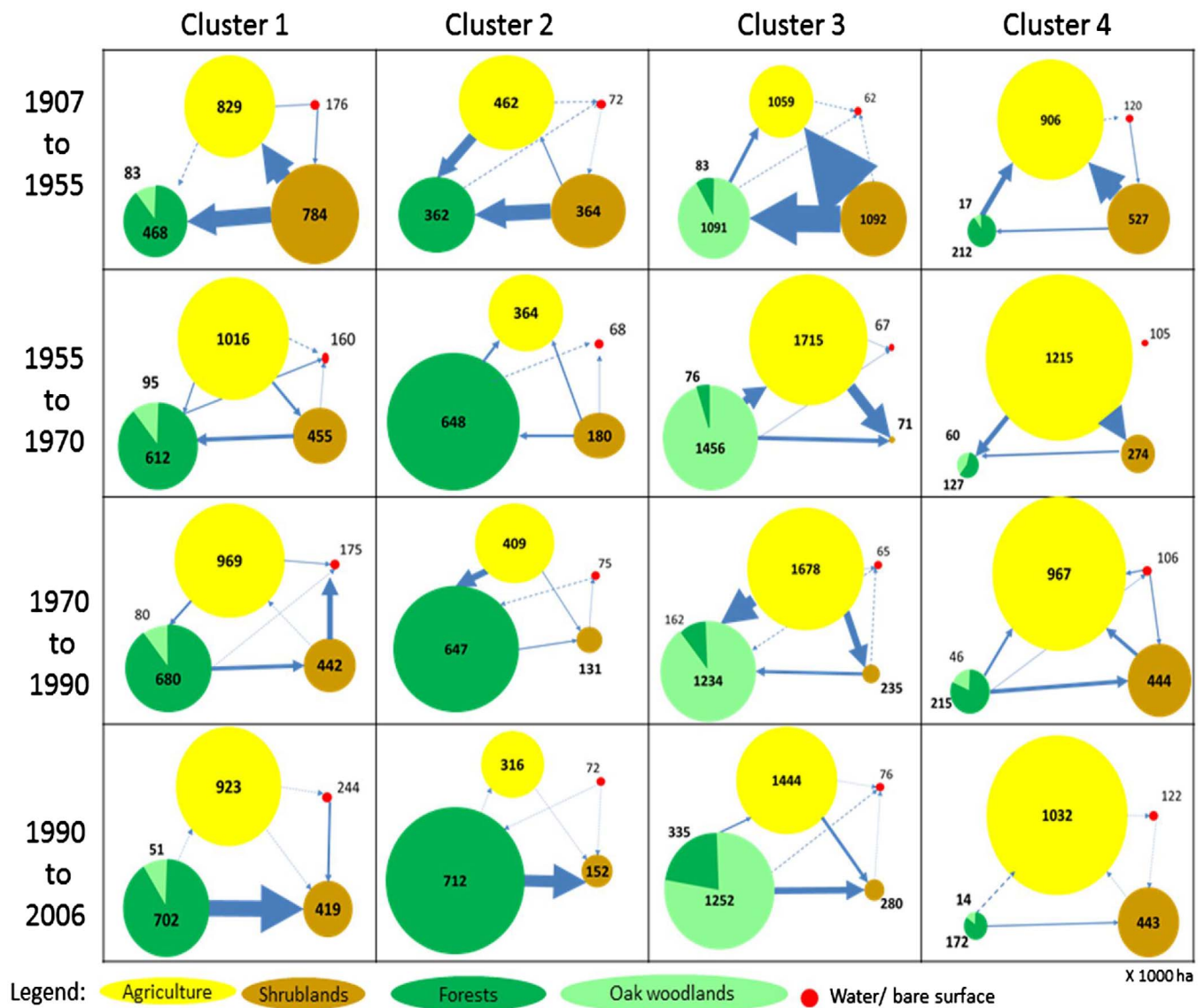


Fig. 6. Land cover transition matrix (size of circle is proportional to % of cluster area and arrow width is proportional to transferred area).

5. Discussion

Our results show that wooded areas grew from 1907 to 2006, confirming the national FT process previously analyzed by Mather and Pereira (2006). We clustered municipalities with similar land cover change trajectories and found that, depending on the cluster considered, maximum wooded area was attained either in 1970 or in 1990, and decreased afterwards. Forest expansion occurred simultaneously with agricultural area growth between 1907 and 1955, as shrublands area decreased. In a second phase, from 1955 to 1990, forests kept expanding, as agricultural areas and oak woodlands retreated. After 1990, croplands and wooded areas reverted to shrublands. Our findings confirm an originality of the Portuguese FT, in comparison with other processes (Mather, 2001, 2007; Rudel et al., 2005), first pointed out by Mather and Pereira (2006): for decades, forests expanded in tandem with agricultural area, and also with population. Although the forest expansion rate was higher later, when the agricultural area started to decrease between 1955 and 1990, the forest area subsequently contracted, again in tandem with croplands.

Our results indicate that from 1907–1955, agricultural area expansion may have contributed to the reduction of about 100 kha of forest areas in clusters 3 and 4 and, to a lesser extent, to the conversion of

forests to oak woodlands. In this period, population increased (national population censuses in Table 3) and interventionist agricultural policies (Caldas, 1991) supported traditional small-scale farming, mostly in the areas corresponding to clusters 1 and 2, and promoted the expansion of cereal crops and vineyards, mostly in clusters 3 and 4. Local farmers fostered the expansion and protection of wooded areas, as they produced understory biomass (used to improve soil fertility), firewood, timber, resin, cork, or as a domestic multiuse raw material. Based on Mendes and Dias (2002) data, we estimate that private landowners afforested more than 561 kha (Table 4) of pine stands in northern Portugal (clusters 1 and 2) and evergreen oaks in the agroforestry land use systems of southern Portugal (cluster 3). The need for energy, and industrial and social development policies, were behind the public afforestation program (Estevão, 1983) and forest regulation (Radich and Alves, 2000). From 1907–1955, the Portuguese Forest Service afforested 199 kha of coastal sand dunes and mountain areas (Carvalho and Morais, 1996; CESE, 1996; Mendes and Dias, 2002 and ISA (2050); summarized in Table 4), notably in clusters 1 and 2. Given the endogenous needs of agricultural areas for goods and services provided by wooded areas and industrial demand for timber and cork, which drove the private and public afforestation effort from 1907 to 1955, we argue that forest expansion followed the *Forest scarcity* and *Public forest*

Table 2

Annual rate of land cover change in each period, for each cluster.

	Annual rate (% yr ⁻¹)	Country	Cluster 1	Cluster 2	Cluster 3	Cluster 4
1907–1955	Forests	+0.6	+0.6	+1.6	-0.1	-0.8
	Oak	+0.7	+0.3	+0.8	+0.7	+5.2
	woodlands	+0.6	+0.4	-0.4	+1.3	+0.7
	Agriculture	-1.3	-0.9	-1.0	-1.9	-1.0
	Shrublands	-0.1	-0.2	-0.1	+0.2	-0.2
Water/Bare surface						
1955–1970	Forests	+1.0	+0.7	=	+7.0	+4.3
	Oak	-1.0	-0.9	-2.8	-1.0	-1.5
	woodlands	-0.4	-0.3	+0.8	-0.1	-1.3
	Agriculture	+1.7	-0.2	-1.7	+14.4	+3.9
	Shrublands	+0.5	+0.4	+1.0	+0.8	+0.2
Water/Bare surface						
1970–1990	Forests	+0.6	+0.2	+0.5	+5.0	-1.0
	Oak	-0.2	-1.8	-4.3	+0.1	-3.3
	woodlands	-0.4	-0.2	-1.1	-0.7	+0.3
	Agriculture	+0.2	-0.2	+0.8	+0.9	=
	Shrublands	+1.0	+2.1	-0.1	=	+0.5
Water/Bare surface						
1990–2006	Forests	-0.9	-1.2	-1.0	-0.4	-0.5
	Oak	-0.4	-0.9	=	-0.4	-1.1
	woodlands	+0.0	=	=	-0.1	=
	Agriculture	+2.0	+2.5	+5.0	+2.4	+0.3
	Shrublands	=	-0.6	-0.3	+1.2	-0.2
Water/Bare surface						

policy pathways.

From 1955–1970, shrinking of agricultural land and public afforestation programs boosted the necessary conditions for forest area expansion, which occurred at a rate 1% yr⁻¹ higher than in the previous period, in line with FTT. These land use dynamics occurred as the Portuguese society and economy faced major changes, during the 1960s (Barreto, 2005), mechanization and fertilizers were introduced in the cereal plains of the South (Baptista, 1993), and industrialization and urbanization promoted economic growth (Lains, 2003). Portugal's economy opened up to wider markets as Portugal joined the European Free Trade Agreement (EFTA), rural exodus to various European countries and Portugal's coastal cities (see Table 3) made rural labour scarce, and inflation raised agriculture production costs, undermining its profitability, which later led to land abandonment (Amaral, 1994; Baptista, 1994) or extensive grazing. Notably, in cluster 3, the number of sheep and goat increased in this period (see Table 3), possibly reflecting a shift towards extensive agriculture. As the public afforestation effort, which had started in 1938 and represented 2/3 of forest expansion (Table 4), was coming to an end, a program for afforestation of low productivity cereal croplands was launched (Radich and Alves, 2000). Thus, from the above, large private landowners in the southern part of the country (cluster 3) had a relevant role in forest expansion, as they sought alternative income sources for their available land, formerly under agricultural or agro-forestry systems. Establishment of pine sawmills and resin industries in the North and four eucalypt pulp mills in the center and South of the country may have increased the earnings prospects of landowners, fostering investment in pine and eucalypt plantations. Forest management goals shifted towards an industrial perspective, as forests became uncoupled from local land use dynamics, and exogenous demand for industrial goods increased. We found that during this period forest expansion followed three different pathways: *Forest scarcity*, *Economic development* and *State forest policy*.

From 1970–1990 agricultural areas kept declining and wooded areas expanded. In this period socio-economic changes were even more dramatic with an urbanized life style being adopted by the majority of

Table 3

Cluster information for total burnt area (1975–2006), fire density, total population density, rural population density (people living in locations with less than 2000 inhabitants), sheep and goat density. Burnt areas for 1975–2006 were calculated with data from Oliveira et al. (2012) Population records from 1911 to 2011 were obtained from national censuses (Santos, 2016; Pordata, 2015). Sheep and goat densities were determined using the dataset of Santos (2016).

	Units	Cluster 1	Cluster 2	Cluster 3	Cluster 4	
Fire profile						
Burnt area (1975–2006)	kha	1556	791	360	978	
Burnt area/cluster total	%	66	63	11	55	
area	%	79	66	23	74	
Burnt area (x two or more)	%	57	32	5	51	
Burnt area (x three or more)	km ⁻²	11.0	7.4	0.5	4.7	
Fire density						
Annual burnt rate (1989–1975)	%yr ⁻¹	+1.7	+1.8	+0.2	+1.6	
Annual burnt rate (2006–1990)		+2.6	+2.3	+0.5	+1.9	
Population						
1911/1920	Population density (PD)	km ⁻²	88	82	22	59
1907–1955	PD (1960–1911)	%yr ⁻¹	+0.9	+0.7	+0.7	-1.0
1955–1970	PD total (1970–1960)		-0.2	-0.2	-1.7	+0.3
	PD rural ^{a,b}		0.0	=	-1.2	-0.3
1970–1990	PD (1991–1970)		+0.8	+0.5	-0.1	+1.7
	PD rural ^c		-0.4	-0.3	-0.5	-0.4
1990–2006	PD (2006–1991)		+0.5	0.5	+0.3	+0.3
	PD rural ^d		-1.1	-0.6	-0.8	-1.0
2006	PD ^e	km ⁻²	155	127	25	130
	PD rural ^e		79	85	12	46
Agro-statistics						
1989–2009	Farmed area	%yr ⁻¹	-1.2	-2.1	+0.3	-1.1
Sheep and Goats						
1911/1920	Sheep/goats	km ⁻²	65	65	54	68
1907–1955	Sheep/goats (1955–1920)	%yr ⁻¹	-0.5	-0.6	-0.2	-0.8
1955–1970	Sheep/goats		-2.3	-2.2	+0.6	-2.0
1970–1990	Sheep/goats		+0.3	-0.8	-0.1	+1.3
1990–2006	Sheep/goats		-0.5	-1.5	-0.2	-0.4
2006	Sheep/goats	km ⁻²	31	19	56	36

^a Total population living in villages with less than 2000 inhabitants. In 1960, the rural population density was (km⁻²) 103, 97, 20, and 58, respectively, for clusters 1–4. In 1981 it was 104, 97, 15, and 55, respectively, for clusters 1–4.

^b Difference between values for 1981 and 1960.

^c Difference between the mean of the 2001 and 1981 values, and the mean of the 1981 and 1960 values.

^d Difference between the value for 2006 and the mean of the 2001 and 1981 values.

^e Mean of the values for 2011 and 2001.

the population (Barreto, 2005), as global and regional drivers triggered a decline of agriculture (Pinto et al., 1984; Baptista, 2010). Within the forest sector, three more pulp mills were built (two for pine and one for eucalypt), resin prices dropped (Mendes and Dias, 2002), a network of protected areas was established and green movements emerged (Mansinho and Schmidt, 1994; Figueiredo et al., 2001). FT drivers were now exogenous, as international demand for wood fiber supported a Portuguese World Bank Forest project (pine and eucalypt plantations) and other national and European afforestation public incentives (*Economic development*), and environmental awareness emerged in urban population (*Globalization*).

After 1990, we found a reversal in wooded and shrubland areas expansion. Our results suggest that fire has played a major role in the conversion of forest cover to shrublands (Table 3), namely in cluster 1, where 53% of the total burnt area (1975–2006) has burnt three times. As documented by IFN (2013), for the region corresponding to cluster

Table 4
Forest area change by period of analysis. Data for public direct and indirect afforestation effort adapted from Carvalho and Morais (1996), CESE (1996), Mendes and Dias (2002) and ISA (2005).

	1907–1955	1955–1970	1970–1990	1990–2006	100 yr total
	x 1000 ha				
Wooded area change	760	– 11	173	– 400	522
Forests	340	240	216	– 309	487
Oak woodlands	420	– 251	– 43	– 91	35
Public direct and indirect afforestation effort	199	152	251	324	926
Private afforestation	562	87	–	–	–

Bold values are total value from (forest + Oak woodlands).

2, since 1990 there has been a shift in forest composition, from maritime pine stands to eucalypt, namely in the westernmost municipalities of the central and northern parts of the cluster. This shift may explain the resilience of FT in cluster 2, which has retained a high forest area (> 40%), in spite of a fire incidence similar to cluster 1. In Fig. 7, we illustrate the frequency of total burnt area in 1975–2006 superimposed in each cluster, observing lower fire incidence in cluster 3. Notably, we found that farmed area decreased in all clusters except cluster 3, as Common Agriculture Policy drove farmers first to set aside traditional croplands, and later to concentrate on farming of niche products (wine, vegetables, milk, beef, and olive oil) and extensive cattle (Avilhez, 2015).

With an increase in fire frequency or severity, the extent of change from forest or oak woodland to shrubland areas is likely to increase (Silva et al., 2011). Although it is very common to find in the scientific literature that most of the Mediterranean forest species are well-adapted to fire, it must be highlighted that “plants are not adapted to fire *per se* but to fire regimes” (Keeley et al., 2011). Thus, post-fire response of plants and vegetation communities can be different following changes in fire regime. Despite the high post-fire resilience of maritime pine (*Pinus pinaster*), seedling densities can decrease if the following fire occurs before the reproductive maturity (Fernandes and Rigolot, 2007), facing an immaturity risk due to high fire frequency (in the sense of Keeley et al., 1999), or if affected by high severity fires (Maia et al., 2012). Increase in fire frequency and fire severity also constrains post-fire survival and regeneration of cork oaks (*Quercus suber*; Díaz-Delgado et al., 2002; Catry et al., 2009a; Moreira et al., 2009; Schaffhauser et al., 2011). Transitions from cork oak to persistent shrublands have in addition related with the cumulative effect of disturbances, such as fire followed by drought (Acácio et al., 2009),

Table 5
Forest transition paths suggested for each cluster by period. Adapted from Rudel et al. (2005), Lambin and Meyfroidt (2010), Oduro et al. (2015) and Bae et al. (2012).

	Country level	Cluster 1 <i>Failed transition</i>	Cluster 2 <i>Endangered transition</i>	Cluster 3 <i>Slow transition</i>	Cluster 4 <i>Non-existent</i>
Wooded area expansion from 1907 to 2006	23%	8%	62%	27%	– 26%
1907–1955	<ul style="list-style-type: none"> • Endogenous drivers, due to socio-ecological feedback loops 	<ul style="list-style-type: none"> • State forest policy • Forest scarcity 		<ul style="list-style-type: none"> • Forest scarcity 	
1955–1970	<ul style="list-style-type: none"> • Mostly exogenous forces, due to socio-economic dynamics 	<ul style="list-style-type: none"> • State forest policy • Economic development 			
1970–1990		<ul style="list-style-type: none"> • Forest scarcity • State forest policy 			
1990–2006		<ul style="list-style-type: none"> • Economic development • Globalization 			

or following large fires (Guiomar et al., 2015). Although eucalypt is a fire-resilient species, forest plantations are also vulnerable to fire, as fire-induced steam mortality is inversely correlated with tree diameter and post-fire tree mortality and top-kill increase with fire severity (Catry et al., 2013). A lower rate of post-fire conversion from eucalypt to shrublands highlighted by Fernandes and Guiomar (2017) is explained by the active role of forest owners in maintaining these high economic value forest stands.

Using the national forest inventory from 2005/2006 and Markov chain models, Rego et al. (2013) acknowledged the role of wildfire as a key driver to decrease timber availability, but admitted the possibility of a reversal, if annual fire incidence were reduced. Using a small county in Catalonia (Spain) as case study, Marull et al. (2015) examined 160 years of land cover change and criticized the alleged opportunity for ecosystem recovery in face of land abandonment, as FT can homogenize landscape and reduce biodiversity. Although these authors did not posit the wildfire threat, Badia et al. (2002), associated the decline of the traditional mosaic to unmanaged high fuel load landscapes that fueled large fire events in central Catalonia. For Galicia, in northwestern Spain, Corbelle-Rico et al. (2015) considered farmland abandonment a consequence of Spain’s accession to the European Union, and identified a reduction in shrubland area and an increase in forest cover, between 1956 and 2005.

Although afforestation programs did not fully compensate for the extensive annual burnt area after 1970 (Table 3 and Fig. 7), they appear to have minimized the magnitude of the reversal in southern forest and oak woodlands (Table 2).

Considering the land use change trajectories documented above and the extent of wooded area change in each cluster between 1907 and 2006, we named the forest transitions of clusters 1–4 as *Failed*, *Endangered*, *Slow* and *Non-existent*, respectively.

No land use change analyses for other fire-prone regions of the world document a FT reversal of this magnitude. For example, in Galicia (Seijo and Gray, 2012) and Catalonia (Badia et al., 2002; Marrul et al., 2015), which also experienced rural land abandonment and publicly-subsidized afforestation, wildfire incidence is lower than in Portugal (Turco et al., 2016), and forest statistics show solid forest expansion trends in Spain, France, Italy, Greece, Turkey and Morocco (FAO, 2015).

Further research may reveal reasons behind this policy failure. We hypothesize that necessary conditions fostered the conversion of land covers towards forest but sufficient conditions to mitigate wildfire risk were not in place, such as risk governance deficits (IRGC, 2009). If agricultural land abandonment apparently led to an old-field vegetation succession, with an early shrubland stage followed by naturally regenerated forest, forest expansion policies ought to have invested earlier in programs to manage the natural regeneration process, combined with extensive fuel management to promote fire-smart landscapes (Fernandes, 2013).

Drummond and Loveland (2010) first documented how FT dy-

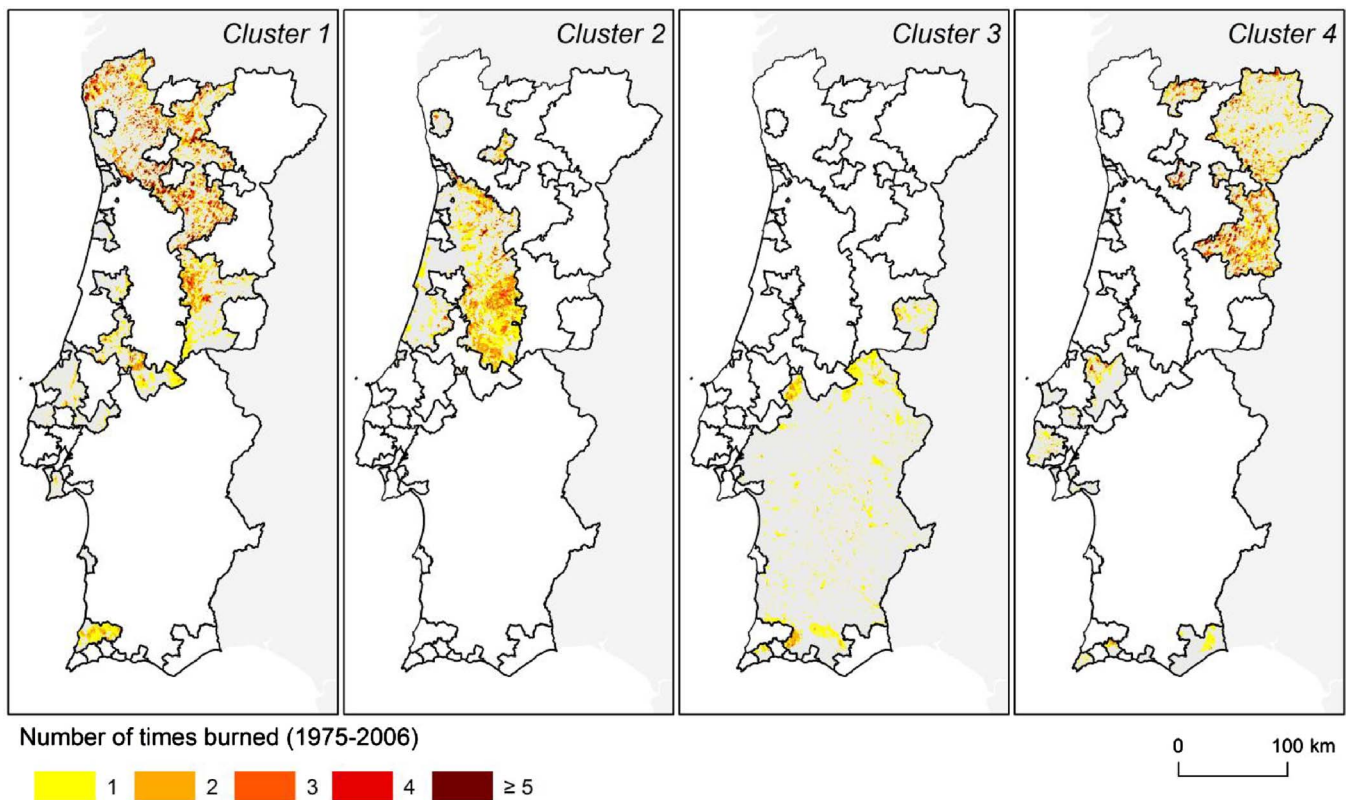


Fig. 7. Wildfire frequency (1975–2006) overlaid on the four Forest Transition clusters.

namics ended in the eastern United States due to urban sprawl. As people left rural landscapes, rewilding of forest cover and land abandonment has been suggested as an opportunity for nature conservation (Navarro and Pereira, 2012), but in the Portuguese landscapes, lack of active management and suppression driven wildfire policies promote fuel accumulation (Collins et al., 2013) and bigger and recurrent fires set an important disturbance, jeopardizing forest and conservation goals.

Wildland fire dynamics and causes, including their social and economic drivers, vary across the clusters, and raise different challenges for fire risk management. Fire frequency expressed by the fire return interval, exhibits regional variability (Oliveira et al., 2012) due to fuel accumulation rate, spatial distribution of wildfire ignitions, land cover, slope and extreme meteorological events (Pereira et al., 2006; Verde and Zêzere, 2010). Most ignitions are located in densely populated areas (Catry et al., 2009b; Pereira et al., 2011), and 85% of all ignitions occur at the urban-rural interface, with 98% located less than 2 km from the nearest roads (Catry et al., 2009b). Moreover, the distribution of wildfire ignitions shows high spatial autocorrelation, since 46% of ignitions are concentrated within just 10% of Portugal mainland (Fernandes et al., 2017). In contrast, the largest burned areas are found in more sparsely populated areas and unbroken forest landscapes (Fernandes et al., 2016). According to ICNF (2014), negligent use of fire (accidents with machinery) and lightning are responsible for the few fires that occur in cluster 3, while for clusters 1 and 2 wildfire ignitions are related with intentional use of fire (pastoral and agricultural burns, arson). Additional research is needed to explore relations between drivers of fire ignitions and FT clusters, as a social manifestation of the relationships of local populations with forest landscapes, and to support the design of appropriate instruments and strategies for risk prevention and mitigation, exploring opportunities to reduce ignition probability, and to identify critical areas for fuel management. Non-trivial effects of socio-economic drivers on the landscape must be well understood, so that proper wildfire policies may be enacted, and climate change challenges ahead can be better

addressed (Pausas and Keeley, 2014).

6. Conclusions

In this work we explicitly map and document the Portuguese FT over a period of 100 years, starting in 1907. After thematic and geometric harmonization of land cover maps from 1907, 1955, 1970, 1990, and 2006, we identify four types of land use transition pathways, using cluster analysis. In mainland Portugal, since 1907, hundreds of thousands of hectares of shrublands were converted to wooded areas up to 1990. Since then, and in particular for clusters 1 and 2 (in the North), we found a dramatic decrease in forest areas toward shrublands. Up to the 1960s, FT occurred simultaneously with population growth and agricultural expansion, as extensive uncultivated areas covered by shrublands were converted to satisfy human needs. Afterwards, with the abandonment of agriculture in marginally productive lands, and with stimuli from global commodity markets and public afforestation programs, FT gained momentum and expanded until about 1990. We posit that the pattern of agricultural land abandonment was different in the North (clusters 1 and 2) and South (cluster 3). While in the large size tenure lands of the South (cluster 3) farmers shifted their income sources to extensive grazing and subsidized farming kept the landscape mosaic with low fuel loads, in the North (clusters 1 and 2), land abandonment led to unbroken landscapes with heavy fuel loads highly exposed to fire. In here, we show that FT dynamics can be derailed by endogenous local factors, namely wildfires, despite the presence of necessary conditions that foster forest expansion, such as exogenous socio-economic and ecological drivers. Our work provides evidence and insights on conditions not foreseen in FTT, useful for public decision making relating to management of rural landscapes, forest and wildfire policies for climate mitigation, and sustainable development.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at <http://dx.doi.org/10.1016/j.landusepol.2017.04.046>.

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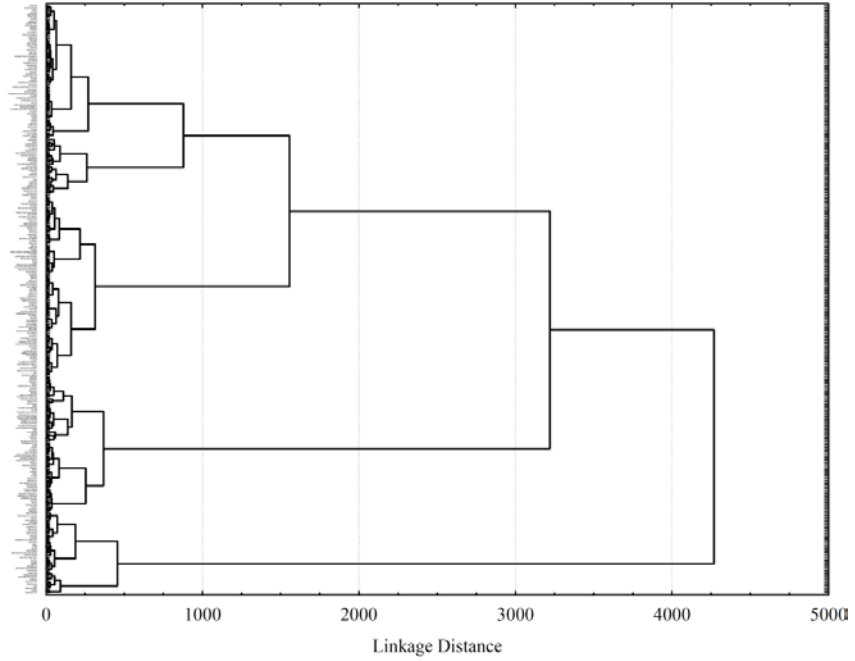


Fig. 1. Cluster analysis dendrogram based on the distribution of forest and oak woodlands at municipal scale (Ward's method, Euclidean distance)

Table 1 - Supplementary material - Percentages of cover (Oak woodland, Forest and wooded areas) by period

Municipality	Cluster	Municipality _area_ha	Oak woodland					Forest					Wooded areas					Change W2006-1907
			OW1907	OW1955	OW1970	OW1990	OW2006	F1907	F1955	F1970	F1990	F2006	W1907	W1955	W1970	W1990	W2006	
ABRANTES	1	71.471	21%	27%	22%	16%	13%	14%	21%	22%	40%	35%	36%	49%	44%	56%	48%	12%
ÁGUEDA	2	33.528	0%	0%	0%	0%	0%	42%	53%	55%	70%	69%	42%	53%	55%	70%	69%	27%
AGUIAR DA BEIRA	1	20.677	0%	0%	0%	0%	0%	22%	34%	45%	42%	26%	22%	34%	45%	42%	26%	3%
ALANDROAL	3	54.269	43%	52%	48%	46%	45%	0%	0%	2%	5%	5%	43%	52%	49%	50%	51%	7%
ALBERGARIA-A-VELHA	2	15.883	0%	1%	0%	0%	0%	42%	59%	59%	61%	60%	42%	60%	59%	61%	60%	18%
ALBUFEIRA	4	14.067	0%	0%	0%	0%	0%	1%	9%	2%	0%	0%	1%	9%	2%	0%	0%	0%
ALCÁCER DO SAL	3	149.991	18%	42%	36%	39%	37%	8%	6%	16%	27%	26%	26%	48%	52%	66%	63%	37%
ALCANENA	4	12.733	2%	0%	2%	0%	0%	19%	16%	14%	7%	5%	21%	16%	16%	7%	5%	-16%
ALCOBAÇA	1	40.815	0%	0%	0%	0%	0%	21%	36%	33%	39%	35%	21%	36%	33%	39%	35%	14%
ALCOCHETE	3	12.837	9%	26%	27%	28%	27%	24%	4%	4%	1%	3%	33%	30%	32%	29%	30%	-3%
ALCOUTIM	3	57.538	11%	11%	16%	10%	5%	0%	0%	1%	2%	1%	11%	11%	17%	11%	6%	-5%
ALENQUER	4	30.423	3%	0%	3%	1%	1%	1%	12%	14%	15%	15%	4%	13%	17%	16%	16%	12%
ALFÂNDEGA DA FÉ	4	32.195	0%	1%	3%	0%	0%	5%	3%	5%	5%	8%	5%	4%	8%	5%	8%	3%
ALIÓ	1	29.761	0%	0%	2%	0%	0%	45%	28%	28%	18%	11%	45%	29%	30%	18%	12%	-33%
ALJEZUR	1	32.351	5%	10%	9%	3%	3%	3%	4%	12%	23%	23%	8%	13%	20%	26%	25%	17%
ALJUSTREL	3	45.848	14%	25%	18%	18%	15%	0%	0%	1%	1%	2%	14%	25%	19%	19%	17%	3%
ALMADA	4	7.021	0%	0%	0%	0%	0%	10%	8%	14%	12%	12%	10%	8%	14%	12%	12%	2%
ALMEIDA	4	51.800	0%	7%	2%	1%	1%	25%	2%	16%	8%	7%	25%	8%	18%	9%	8%	-17%
ALMEIRIM	1	22.213	16%	21%	18%	14%	13%	7%	14%	20%	20%	21%	23%	35%	38%	34%	34%	11%
ALMODÓVAR	3	77.790	56%	60%	45%	59%	49%	0%	1%	1%	3%	1%	56%	60%	46%	62%	51%	-6%
ALPARÇA	4	9.537	8%	8%	11%	3%	3%	8%	7%	11%	14%	13%	16%	16%	23%	17%	16%	0%
ALTER DO CHÃO	3	36.208	50%	55%	49%	46%	45%	0%	0%	1%	5%	5%	51%	55%	49%	52%	50%	0%
ALVAÍZERE	1	16.048	0%	1%	0%	0%	0%	6%	39%	32%	38%	30%	6%	40%	32%	38%	30%	24%
ALVITO	3	26.486	28%	40%	38%	37%	37%	0%	0%	2%	1%	2%	28%	40%	40%	38%	39%	11%
AMARANTE	2	30.134	0%	0%	0%	0%	0%	29%	49%	47%	32%	28%	29%	49%	47%	32%	28%	-1%
AMARÉS	1	8.196	0%	0%	0%	0%	0%	28%	35%	34%	35%	32%	28%	35%	34%	35%	32%	4%
ANADIA	2	21.664	0%	1%	0%	0%	0%	52%	42%	49%	54%	53%	52%	43%	49%	54%	53%	0%
ANSIÃO	1	17.610	0%	3%	0%	0%	0%	3%	41%	31%	34%	30%	3%	43%	31%	34%	30%	27%
ARCOS DE VALDEVEZ	1	44.761	0%	0%	0%	0%	0%	20%	24%	29%	23%	18%	20%	24%	29%	23%	18%	-2%
ARGANIL	2	33.285	0%	0%	0%	0%	0%	35%	54%	53%	62%	53%	35%	54%	53%	62%	53%	18%
ARMAMAR	1	11.724	0%	1%	0%	0%	0%	14%	31%	36%	18%	10%	14%	32%	36%	18%	10%	-4%
AROUCA	2	32.911	0%	0%	0%	0%	0%	9%	36%	48%	54%	47%	9%	36%	48%	54%	47%	38%
ARRAIÓLOS	3	68.376	61%	62%	55%	58%	59%	0%	0%	2%	1%	0%	61%	62%	56%	59%	59%	-1%
ARRONCHES	3	31.465	74%	62%	54%	48%	48%	0%	0%	0%	1%	1%	74%	62%	54%	49%	49%	-26%
AVEIRO	1	19.758	0%	1%	0%	0%	0%	19%	19%	22%	21%	19%	19%	20%	22%	21%	19%	0%
AVÍS	3	60.598	74%	65%	59%	57%	56%	0%	0%	2%	6%	6%	74%	65%	61%	62%	62%	-12%
AZAMBUJA	1	26.266	5%	0%	0%	2%	2%	9%	21%	27%	24%	24%	14%	21%	27%	26%	27%	12%
BAIÃO	1	17.453	0%	0%	0%	0%	0%	19%	29%	28%	20%	16%	19%	29%	28%	20%	16%	-3%
BARCELOS	2	37.891	0%	0%	0%	0%	0%	32%	39%	48%	42%	35%	32%	39%	48%	42%	35%	3%
BARRANCOS	3	16.842	63%	90%	71%	81%	81%	0%	0%	2%	1%	1%	63%	90%	73%	82%	82%	19%
BARREIRO	4	3.639	0%	0%	2%	0%	0%	25%	19%	21%	15%	8%	25%	19%	22%	15%	8%	-18%
BATALHA	1	10.342	0%	0%	0%	0%	0%	22%	26%	29%	32%	29%	22%	26%	29%	32%	29%	7%
BEJA	3	114.646	17%	35%	27%	25%	21%	0%	0%	1%	1%	1%	17%	35%	28%	26%	22%	5%
BELMONTE	4	11.876	0%	3%	0%	0%	0%	15%	7%	16%	7%	11%	15%	10%	16%	8%	11%	-4%
BENAVENTE	3	52.140	30%	42%	35%	33%	31%	8%	8%	14%	19%	14%	37%	51%	50%	52%	46%	8%
BOMBARRAL	4	9.129	0%	0%	0%	0%	0%	23%	7%	8%	4%	5%	23%	7%	8%	4%	5%	-18%
BORBA	3	14.519	16%	18%	17%	16%	18%	0%	0%	2%	5%	2%	16%	18%	19%	20%	20%	4%
BOTICAS	1	32.197	0%	0%	0%	0%	0%	2%	19%	37%	23%	16%	2%	19%	37%	23%	16%	14%
BRAGA	1	18.340	0%	0%	0%	0%	0%	15%	22%	31%	30%	28%	15%	22%	31%	30%	28%	13%
BRAGANÇA	4	117.360	1%	5%	2%	0%	0%	11%	8%	19%	12%	13%	1%	1%	21%	12%	13%	1%
CABECEIRAS DE BASTO	1	24.183	0%	0%	0%	0%	0%	26%	25%	36%	28%	24%	26%	25%	36%	28%	24%	-2%
CADAVAL	1	17.490	0%	0%	0%	0%	0%	6%	15%	27%	28%	33%	6%	15%	27%	28%	33%	27%
CALDAS DA RAINHA	1	25.570	1%	0%	0%	0%	0%	24%	22%	20%	23%	23%	24%	22%	20%	23%	23%	-2%
CAMINHA	1	13.653	0%	0%	0%	0%	0%	23%	31%	43%	30%	19%	23%	31%	43%	30%	19%	-4%
CAMPO MAIOR	3	24.721	36%	33%	30%	15%	16%	0%	0%	0%	0%	0%	36%	33%	31%	15%	16%	-20%
CANTANHEDE	2	39.089	0%	0%	0%	0%	0%	27%	52%	52%	52%	50%	27%	52%	52%	50%	50%	23%
CARRAZEDA DE ANSIÃES	1	27.925	0%	1%	9%	0%	0%	29%	26%	24%	24%	18%	29%	27%	33%	24%	18%	-11%
CARREGAL DO SAL	2	11.690	0%	0%	0%	0%	0%	47%	46%	49%	43%	36%	47%	46%	49%	43%	36%	-12%
CARTAXO	4	15.818	6%	6%	5%	4%	3%	12%	11%	11%	10%	10%	18%	17%	16%	14%	13%	-5%
CASCAIS	4	9.740	0%	0%	0%	0%	0%	1%	8%	23%	5%	5%	1%	8%	23%	5%	5%	4%
CASTANHEIRA DE PÉRA	2	6.678	0%	0%	0%	0%	0%	16%	48%	46%	53%	58%	16%	48%	46%	53%	58%	42%
CASTELO BRANCO	1	143.823	19%	20%	15%	12%	11%	21%	16%	25%	30%	18%	39%	36%	40%	42%	30%	-10%
CASTELO DE PAIVA	2	11.501	0%	0%	0%	0%	0%	5%	56%	58%	69%	66%	5%	56%	58%	69%	66%	61%
CASTELO DE VIDE	3	26.492	9%	28%	13%	28%	27%	34%	1%	18%	8%	7%	43%	29%	31%	36%	33%	-9%
CASTRO DAIRE	1	37.905	0%	0%	0%	0%	0%	19%	29%	35%	31%	22%	19%	29%	35%	31%	22%	3%
CASTRO MARIM	4	30.085	5%	8%	6%	4%	2%	1%	2%	2%	4%	4%	6%	10%	8%	7%	6%	0%
CASTRO VERDE	3	56.946	17%	20%	15%	19%	15%	0%	0%	1%	1%	17%	20%	15%	19%	17%	0%	0%
CELORICO DA BEIRA	4	24.722	0%	1%	0%	0%	0%	24%	9%	26%	7%	3%	24%	10%	26%	7%	3%	-21%
CELORICO DE BASTO	1	18.108	0%	0%	0%	0%	0%	55%	45%	47%	37%	34%	55%	45%	47%	37%	34%	-20%
CHAMUSCA	3	74.602	31%	54%	46%	37%	33%	4%	11%	14%	39%	39%	35%	66%	59%	76%	72%	37%
CHAVES	1	59.125	0%	2%	0%	0%	0%	11%	22%	24%	19%	14%	11%	24%	24%	19%	14%	3%
CINFÃES	1	23.929	0%	0%	0%	0%	0%	19%	23%	24%	27%	20%	19%	23%	24%	27%	20%	1%
COIMBRA	1	31.941	0%	0%	0%	0%	0%	17%	36%	33%	38%	35%	17%	36%	33%	38%	35%	18%
CONDEIXA-A-NOVA	1	13.868	0%	0%	0%	0%	0%	15%	33%	34%	36%	35%	15%	33%	34%	36%	35%	20%
CONSTÂNCIA	1	8.037	15%	3%	14%	3%	2%	11%	34%	24%	38%	34%	27%	37%	38%	40%	36%	9%
CORUCHE	3	111.575	50%	68%	52%	53%	52%	1%	5%	13%	22%	21%	51%	72%	65%	76%	72%	21%
COVILHÃ	1	55.561	0%	2%	0%	0%	0%	20%	28%	35%	31%	21%	21%	29%	35%	31%	21%	0%
CRATO	3	39.808	41%	49%	38%	44%	41%	7%	0%	10%	17%	17%	48%	49%	48%	61%	57%	9%
CUBA	3	17.209	36%	38%	33%	28%	28%	0%	0%	0%	0%	0%	36%	38%	33%	28%	28%	-8%
ELVAS	3	63.130	32%	37%	30%	34%	34%	0%	0%	1%	0%	0%	32%	37%	31%	34%	34%	2%
ENTRONCAMENTO	4	1.373	0%	0%	0%	0%	0%	0%	9%	7%	6%	5%	0%	9%	7%	6%	5%	5%
ESPINHO	1	2.106	0%	0%	0%	0%	0%	5%	16%	31%	26%	28%	5%	16%	31%	26%	28%	22%
ESPOSENDE	1	9.541	0%	0%	0%	0%	0%	29%	35%	39%	35%	31%	29%	35%	39%	35%	31%	2%
ESTARREJA	1	10.818	0%	1%	0%	0%	0%	19%	24%	28%	28%	28%	19%	25%	28%	28%	28%	8%
ESTREMOZ	3	51.381	39%	40%	36%	37%	37%	0%	0%	6%	8%	5%	39%	40%	42%	45%	42%	3%
EVORA	3	130.711	29%	41%	34%	37%	38%	0%	0%	2%	2%	1%	29%	41%	35%	39%	39%	10%
FAFE	1	21.909	0%	0%	0%	0%	0%	28%	34%	35%	29%	25%	28%	34%	35%	29%	25%	-3%
FARO	4	20.185	0%	0%	0%	0%	0%	0%	12%	3%	2%	1%	0%	12%	3%	2%	1%	0%
FELGUEIRAS	1	11.																

Municipality	Cluster	Municipality _area_ha	Oak woodland					Forest					Wooded areas					Change W2006-1907
			OW1907	OW1955	OW1970	OW1990	OW2006	F1907	F1955	F1970	F1990	F2006	W1907	W1955	W1970	W1990	W2006	
FREIXO DE ESPADA À CINTA	4	24.415	0%	0%	1%	0%	0%	0%	2%	7%	7%	6%	0%	2%	8%	7%	6%	6%
FRONTEIRA	3	24.860	30%	39%	37%	29%	29%	0%	0%	1%	2%	3%	31%	39%	38%	31%	32%	1%
FUNDAO	1	70.022	0%	2%	1%	1%	1%	29%	25%	29%	27%	23%	29%	27%	30%	28%	24%	-6%
GAVIAO	1	29.460	26%	28%	27%	14%	11%	2%	8%	15%	43%	29%	28%	36%	43%	58%	40%	12%
GOIS	2	26.331	0%	0%	0%	0%	0%	11%	36%	51%	57%	69%	11%	36%	51%	57%	69%	58%
GOLEGÁ	4	7.662	8%	2%	3%	2%	2%	5%	12%	8%	3%	3%	13%	14%	11%	5%	4%	-9%
GONDOMAR	2	13.187	0%	0%	0%	0%	0%	35%	54%	48%	37%	34%	35%	54%	48%	37%	34%	0%
GOUVEIA	4	30.062	0%	0%	0%	0%	0%	32%	14%	23%	14%	11%	32%	14%	23%	14%	11%	-21%
GRÁNDOLA	3	82.596	18%	38%	34%	35%	35%	5%	6%	20%	35%	29%	23%	44%	54%	70%	64%	41%
GUARDA	4	71.211	1%	7%	0%	0%	0%	25%	7%	26%	14%	10%	26%	14%	27%	14%	10%	-17%
GUIMARÃES	1	24.096	0%	0%	0%	0%	0%	12%	28%	32%	26%	22%	12%	28%	32%	26%	22%	10%
IDANHA-A-NOVA	3	141.637	15%	30%	25%	26%	24%	3%	2%	8%	15%	15%	18%	31%	33%	41%	39%	20%
ILHAVO	1	7.354	0%	0%	0%	0%	0%	16%	17%	22%	20%	20%	16%	17%	22%	20%	20%	4%
LAGOS	3	21.300	9%	15%	14%	10%	8%	0%	1%	8%	9%	9%	9%	16%	21%	19%	16%	7%
LAMEGO	4	16.543	0%	2%	0%	0%	0%	12%	10%	20%	13%	8%	13%	11%	20%	13%	8%	-5%
LEIRIA	2	56.510	0%	0%	0%	0%	0%	36%	49%	48%	50%	45%	36%	49%	48%	50%	45%	9%
LOULÉ	3	76.441	10%	31%	20%	28%	24%	6%	18%	5%	3%	2%	16%	49%	25%	31%	26%	10%
LOURES	4	16.912	0%	0%	0%	0%	0%	5%	5%	7%	9%	8%	5%	5%	7%	9%	8%	3%
LOURINHÃ	4	14.718	0%	0%	0%	0%	0%	15%	8%	7%	7%	9%	15%	8%	7%	7%	9%	-6%
LOUSÃ	2	13.840	0%	0%	0%	0%	0%	19%	56%	55%	57%	53%	19%	56%	55%	57%	53%	34%
LOUSADA	1	9.608	0%	0%	0%	0%	0%	28%	41%	37%	21%	18%	28%	41%	37%	21%	18%	-10%
MAÇO	2	39.999	0%	0%	0%	0%	0%	37%	54%	54%	72%	23%	37%	54%	54%	72%	23%	-13%
MACEDO DE CAVALERIOS	4	69.916	0%	5%	7%	0%	0%	14%	5%	9%	11%	12%	15%	9%	16%	11%	12%	-2%
MAFRA	4	29.166	0%	0%	0%	0%	0%	14%	15%	15%	12%	11%	14%	15%	15%	12%	11%	-3%
MAIA	1	8.300	0%	0%	0%	0%	0%	45%	26%	38%	16%	16%	45%	26%	38%	16%	16%	-29%
MANGUALDE	1	21.926	0%	0%	0%	0%	0%	50%	42%	44%	36%	19%	50%	42%	44%	36%	19%	-30%
MANTEIGAS	1	12.198	0%	0%	0%	0%	0%	7%	36%	32%	35%	27%	7%	36%	32%	35%	27%	20%
MARCO DE CANAVESES	1	20.190	0%	0%	0%	0%	0%	23%	27%	30%	17%	15%	23%	27%	30%	17%	15%	-8%
MARINHA GRANDE	2	18.726	0%	0%	0%	0%	0%	63%	81%	75%	78%	63%	63%	81%	75%	78%	63%	0%
MARVÃO	3	15.490	33%	20%	15%	17%	13%	24%	5%	12%	14%	11%	56%	25%	27%	31%	25%	-32%
MATOSINHOS	4	6.242	0%	0%	0%	0%	0%	15%	12%	19%	7%	7%	15%	12%	19%	7%	7%	-8%
MEALHADA	2	11.066	0%	0%	0%	0%	0%	30%	47%	41%	48%	46%	30%	47%	41%	48%	46%	16%
MÉDA	4	28.606	1%	4%	2%	0%	0%	7%	11%	15%	8%	5%	8%	15%	17%	8%	5%	-3%
MELGAÇO	1	23.825	0%	0%	0%	0%	0%	17%	18%	26%	17%	16%	17%	18%	26%	17%	16%	-1%
MÉRTOLA	3	129.290	7%	13%	11%	14%	14%	0%	0%	1%	2%	2%	7%	13%	13%	15%	17%	9%
MESÃO FRIO	4	2.665	0%	0%	0%	0%	0%	18%	18%	19%	12%	8%	18%	18%	19%	12%	8%	-10%
MIRA	2	12.404	0%	0%	0%	0%	0%	16%	59%	62%	54%	51%	16%	59%	62%	54%	51%	35%
MIRANDA DO CORVO	2	12.638	0%	0%	0%	0%	0%	26%	58%	57%	60%	59%	26%	58%	57%	60%	59%	33%
MIRANDA DO DOURO	4	48.720	1%	15%	1%	9%	9%	19%	1%	5%	9%	8%	20%	16%	6%	19%	17%	-2%
MIRANDELA	4	65.897	0%	2%	5%	0%	0%	11%	5%	6%	7%	8%	11%	7%	11%	7%	8%	-4%
MOGADOURO	4	76.067	0%	3%	3%	0%	0%	8%	2%	6%	13%	12%	9%	5%	9%	13%	12%	4%
MOIMENTA DA BEIRA	1	21.997	0%	3%	0%	0%	0%	14%	21%	28%	22%	13%	14%	23%	28%	22%	13%	-2%
MOITA	4	5.526	0%	0%	2%	0%	0%	3%	7%	11%	6%	4%	3%	7%	13%	6%	4%	1%
MONÇÃO	1	21.131	0%	0%	0%	0%	0%	20%	33%	48%	41%	33%	20%	33%	48%	41%	33%	13%
MONCHIQUE	1	39.531	15%	15%	11%	10%	7%	6%	25%	37%	51%	49%	21%	40%	48%	61%	56%	35%
MONDIM DE BASTO	2	17.208	0%	0%	0%	0%	0%	17%	54%	54%	49%	38%	17%	54%	54%	49%	38%	21%
MONFORTE	3	42.026	49%	49%	43%	45%	45%	0%	0%	0%	0%	0%	49%	49%	43%	46%	45%	-4%
MONTALEGRE	4	80.548	0%	0%	0%	0%	0%	5%	9%	19%	10%	9%	5%	9%	19%	10%	9%	5%
MONTEMOR-O-NOVO	3	123.300	53%	72%	63%	62%	60%	1%	0%	3%	8%	8%	54%	72%	66%	70%	68%	14%
MONTEMOR-O-VELHO	1	22.897	0%	0%	0%	0%	0%	24%	30%	32%	31%	29%	24%	30%	32%	31%	29%	5%
MONTUJO	3	34.862	2%	31%	28%	26%	24%	17%	5%	21%	30%	25%	19%	35%	49%	56%	50%	31%
MORA	3	44.396	77%	78%	71%	73%	72%	0%	0%	3%	2%	2%	77%	77%	74%	75%	74%	-3%
MORTAGUA	2	25.118	0%	0%	0%	0%	0%	39%	60%	69%	84%	85%	39%	60%	69%	84%	85%	46%
MOURA	3	95.848	50%	46%	39%	33%	30%	0%	0%	2%	4%	5%	50%	46%	41%	37%	35%	-15%
MOURÃO	3	27.864	28%	37%	28%	30%	26%	0%	0%	1%	1%	1%	28%	37%	29%	31%	27%	-1%
MURÇA	4	18.938	1%	1%	0%	0%	0%	9%	14%	22%	15%	11%	10%	15%	22%	15%	11%	1%
MURTOSA	4	7.309	0%	0%	0%	0%	0%	4%	11%	16%	22%	19%	4%	11%	16%	22%	19%	15%
NAZARÉ	2	8.244	0%	0%	0%	0%	0%	33%	58%	57%	57%	49%	33%	58%	57%	57%	49%	16%
NELAS	1	12.572	0%	0%	0%	0%	0%	45%	49%	47%	41%	21%	45%	49%	47%	41%	21%	-24%
NISA	3	57.569	28%	25%	21%	20%	18%	7%	0%	8%	21%	21%	34%	25%	29%	41%	39%	7%
ÓBIDOS	1	14.156	3%	0%	0%	0%	0%	16%	19%	27%	27%	26%	19%	19%	27%	27%	26%	7%
ODEMIRA	3	172.064	26%	31%	29%	27%	23%	1%	1%	5%	20%	20%	27%	32%	35%	47%	43%	16%
ODIVELAS	4	2.654	0%	0%	0%	0%	0%	2%	4%	5%	6%	6%	2%	4%	5%	6%	6%	5%
OLEIROS	2	47.111	0%	0%	0%	0%	0%	10%	68%	66%	73%	40%	10%	68%	66%	73%	40%	30%
OLHÃO	4	13.087	0%	0%	0%	0%	0%	0%	7%	1%	0%	0%	0%	7%	1%	0%	0%	0%
OLIVEIRA DE AZEMÉIS	2	16.111	0%	0%	0%	0%	0%	20%	54%	57%	56%	53%	20%	54%	57%	56%	53%	34%
OLIVEIRA DE FRADES	2	14.535	0%	0%	0%	0%	0%	18%	46%	54%	64%	62%	18%	46%	54%	64%	62%	44%
OLIVEIRA DO BAIRO	1	8.732	0%	0%	0%	0%	0%	36%	28%	30%	35%	35%	36%	28%	30%	35%	35%	-1%
OLIVEIRA DO HOSPITAL	2	23.452	0%	0%	0%	0%	0%	46%	46%	51%	54%	47%	46%	46%	51%	54%	47%	1%
OURÉM	1	41.669	0%	0%	0%	0%	0%	38%	47%	45%	43%	24%	38%	47%	45%	43%	24%	-14%
OURIQUÊ	3	66.333	43%	53%	43%	49%	40%	0%	0%	1%	3%	4%	43%	53%	44%	52%	43%	0%
OVAR	2	14.771	0%	0%	0%	0%	0%	14%	43%	48%	46%	45%	14%	43%	48%	46%	45%	30%
PAÇOS DE FERREIRA	1	7.099	0%	0%	0%	0%	0%	39%	38%	42%	28%	20%	39%	38%	42%	28%	20%	-19%
PALMELA	3	46.513	6%	29%	28%	22%	20%	13%	14%	18%	12%	9%	20%	44%	46%	34%	29%	10%
PAMPILHOSA DA SERRA	2	39.647	0%	0%	0%	0%	0%	13%	47%	56%	46%	30%	13%	47%	56%	46%	30%	16%
PAREDES	1	15.676	0%	0%	0%	0%	0%	45%	50%	48%	29%	22%	45%	50%	48%	29%	22%	-24%
PAREDES DE COURA	1	13.819	0%	0%	0%	0%	0%	14%	21%	30%	38%	38%	14%	21%	30%	38%	38%	24%
PEDRÓGÃO GRANDE	2	12.875	0%	0%	0%	0%	0%	27%	65%	64%	65%	62%	27%	65%	64%	65%	62%	36%
PENACOVA	2	21.674	0%	0%	0%	0%	0%	44%	67%	61%	76%	76%	44%	67%	61%	76%	76%	33%
PENAFIEL	1	21.225	0%	0%	0%	0%	0%	7%	34%	38%	25%	21%	7%	34%	38%	25%	21%	14%
PENALVA DO CASTELO	1	13.434	0%	0%	0%	0%	0%	37%	40%	43%	36%	22%	37%	40%	43%	36%	22%	-14%
PENAMACOR	1	56.372	0%	5%	5%	2%	2%	8%	6%	16%	34%	34%	8%	11%	20%	36%	36%	28%
PENEDONO	1	13.371	1%	1%	0%	0%	0%	5%	10%	33%	15%	5%	6%	11%	33%	15%	5%	-1%
PENELA	2	13.480	0%	0%	0%	0%	0%	6%	32%	38%	49%	47%	6%	32%	38%	49%	47%	41%
PENICHE	4	7.755	0%	0%	0%	0%	0%	12%	11%	11%	10%	10%	12%	11%	11%	10%	10%	-2%
PESO DA RÉGUA	4	9.486	0%	0%	0%	0%	0%	21%	15%	16%	7%	5%	21%	15%	16%	7%	5%	-16%
PINHEL	4	48.453	0%	4%	3%	0%	0%	17%	4%	15%	6%	3%	18%	8%	18%	6%	3%	-15%
POMBAL	2	62.602	0%	0%	0%	0%	0%	32%	50%	50%	51%	45%	32%	51%	50%	51%	45%	13%
PONTE DA BARCA	1	18.212	0%	0%	0%	0%	0%	9%	22%	26%	20%	16%	9%	22%	26%</			

Municipality	Cluster	Municipality _area_ha	Oak woodland					Forest					Wooded areas					Change W2006-1907
			OW1907	OW1955	OW1970	OW1990	OW2006	F1907	F1955	F1970	F1990	F2006	W1907	W1955	W1970	W1990	W2006	
PROENÇA-A-NOVA	2	39.541	0%	0%	0%	0%	0%	23%	43%	42%	63%	25%	23%	43%	43%	63%	25%	3%
REDONDO	3	36.952	36%	55%	47%	47%	45%	0%	0%	7%	9%	3%	36%	55%	53%	56%	49%	12%
REGUENGOS DE MONSARAZ	3	46.401	28%	39%	35%	35%	31%	0%	0%	1%	4%	2%	28%	39%	36%	39%	33%	5%
RESENDE	4	12.335	0%	0%	0%	0%	0%	17%	17%	16%	13%	10%	17%	17%	16%	13%	10%	-7%
RIBEIRA DE PENA	1	21.747	0%	0%	0%	0%	0%	2%	26%	40%	35%	30%	2%	26%	40%	35%	30%	28%
RIO MAIOR	1	27.277	0%	0%	1%	0%	0%	21%	30%	35%	39%	43%	21%	30%	36%	39%	43%	22%
SABROSA	1	15.693	0%	0%	0%	0%	0%	34%	34%	29%	21%	20%	34%	34%	29%	21%	20%	-14%
SABUGAL	4	82.272	1%	9%	0%	1%	1%	27%	4%	29%	16%	15%	28%	13%	29%	17%	16%	-12%
SALVATERRA DE MAGOS	1	24.394	23%	24%	20%	15%	14%	13%	21%	25%	30%	24%	36%	45%	44%	45%	38%	2%
SANTA COMBA DÃO	2	11.195	0%	0%	0%	0%	0%	50%	42%	49%	56%	50%	50%	42%	49%	56%	50%	-1%
SANTA MARIA DA FEIRA	2	21.588	0%	0%	0%	0%	0%	24%	50%	56%	48%	48%	24%	50%	56%	48%	48%	24%
SANTA MARTA DE PENAGUIÃO	1	6.928	0%	0%	0%	0%	0%	32%	26%	26%	22%	23%	32%	26%	26%	22%	23%	-10%
SANTARÉM	4	56.026	3%	2%	1%	1%	1%	9%	11%	11%	12%	12%	13%	13%	13%	13%	13%	0%
SANTIAGO DO CACÉM	3	105.972	40%	47%	43%	45%	43%	2%	3%	6%	13%	12%	42%	50%	49%	57%	55%	12%
SANTO TIROSO	1	13.660	0%	1%	0%	0%	0%	52%	43%	44%	36%	31%	52%	44%	44%	36%	31%	-22%
SÃO BRÁS DE ALPORTEL	3	15.337	15%	44%	33%	42%	37%	0%	6%	1%	4%	1%	15%	50%	34%	47%	39%	23%
SÃO JOÃO DA MADEIRA	4	794	0%	0%	0%	0%	0%	1%	19%	22%	6%	6%	1%	19%	22%	6%	6%	5%
SÃO PEDRO DO SUL	2	34.896	0%	0%	0%	0%	0%	32%	40%	52%	44%	34%	32%	40%	52%	44%	34%	2%
SARDOAL	2	9.215	4%	1%	1%	0%	0%	49%	55%	60%	70%	44%	53%	56%	60%	70%	44%	-9%
SÁTÃO	1	20.195	0%	0%	0%	0%	0%	16%	39%	45%	46%	32%	16%	39%	45%	46%	32%	16%
SEIA	1	43.570	0%	0%	0%	0%	0%	24%	38%	43%	45%	21%	24%	38%	43%	45%	21%	-3%
SEIXAL	1	9.550	0%	0%	1%	0%	0%	31%	29%	31%	19%	15%	31%	29%	32%	19%	15%	-16%
SERNANCELHE	1	22.862	0%	1%	0%	0%	0%	13%	21%	35%	24%	11%	13%	23%	35%	24%	11%	-3%
SERPA	3	110.566	24%	43%	35%	40%	34%	0%	0%	2%	2%	2%	24%	44%	35%	42%	36%	12%
SERTÃO	2	44.674	0%	0%	0%	0%	0%	15%	64%	57%	73%	36%	15%	64%	57%	73%	36%	21%
SESIMBRA	1	19.548	0%	2%	0%	2%	2%	29%	36%	3%	41%	30%	29%	38%	3%	43%	32%	3%
SETÚBAL	4	23.033	2%	4%	7%	3%	3%	9%	9%	12%	12%	10%	11%	13%	19%	15%	13%	2%
SEVER DO VOUGA	2	12.988	0%	0%	0%	0%	0%	22%	62%	58%	75%	74%	22%	62%	58%	75%	74%	53%
SILVES	3	68.008	14%	17%	13%	16%	9%	0%	8%	7%	7%	5%	14%	24%	21%	23%	15%	1%
SINES	1	20.331	17%	3%	18%	5%	4%	2%	16%	17%	32%	32%	18%	19%	35%	37%	37%	18%
SINTRA	4	31.924	0%	0%	0%	0%	0%	7%	14%	14%	15%	15%	7%	14%	14%	15%	15%	9%
SOURÉ	2	26.507	0%	0%	0%	0%	0%	27%	42%	40%	41%	40%	27%	42%	40%	41%	40%	12%
SOUSEL	3	27.933	60%	44%	44%	37%	36%	0%	0%	0%	0%	0%	60%	44%	45%	37%	37%	-23%
TÁBUA	2	19.979	0%	0%	0%	0%	0%	42%	51%	50%	62%	56%	42%	51%	50%	62%	56%	15%
TABUAÇO	1	13.386	0%	2%	0%	0%	0%	16%	26%	35%	25%	11%	16%	28%	35%	25%	11%	-5%
TAROUCÁ	1	10.009	1%	5%	0%	0%	0%	5%	20%	36%	30%	16%	6%	25%	36%	30%	16%	10%
TAVIRA	4	60.698	5%	9%	6%	7%	5%	0%	3%	1%	3%	2%	5%	12%	7%	10%	7%	2%
TERRAS DE BOURO	1	27.747	0%	0%	1%	0%	0%	8%	21%	28%	26%	24%	8%	21%	28%	26%	24%	16%
TOMAR	1	35.121	1%	0%	1%	0%	0%	35%	40%	35%	37%	31%	35%	40%	36%	37%	31%	-4%
TONDELA	2	37.123	0%	0%	0%	0%	0%	40%	49%	52%	60%	57%	40%	49%	52%	60%	57%	17%
TORRE DE MONCORVO	4	53.157	0%	1%	4%	0%	0%	6%	5%	6%	7%	5%	7%	6%	10%	7%	5%	-2%
TORRES NOVAS	4	27.000	2%	0%	1%	0%	0%	12%	9%	9%	5%	5%	14%	9%	10%	5%	5%	-9%
TORRES VEDRAS	1	40.716	0%	0%	0%	0%	0%	21%	20%	20%	18%	18%	21%	20%	21%	18%	18%	-3%
TRANCOSO	1	36.153	0%	4%	0%	0%	0%	20%	18%	32%	23%	10%	20%	22%	32%	23%	10%	-10%
TROFA	1	7.202	0%	0%	0%	0%	0%	63%	60%	57%	33%	31%	63%	60%	57%	33%	31%	-32%
VAGOS	2	16.492	0%	0%	0%	0%	0%	23%	47%	49%	46%	48%	23%	47%	49%	46%	48%	25%
VALE DE CAMBRA	2	14.734	0%	0%	0%	0%	0%	4%	46%	51%	55%	44%	4%	46%	51%	55%	44%	39%
VALENÇA	1	11.713	0%	0%	0%	0%	0%	22%	26%	38%	31%	21%	22%	26%	38%	31%	21%	-1%
VALONGO	1	7.513	0%	0%	0%	0%	0%	54%	55%	43%	26%	27%	54%	55%	43%	26%	27%	-28%
VALPAÇOS	4	54.875	0%	1%	1%	0%	0%	19%	14%	16%	9%	7%	19%	16%	17%	9%	7%	-13%
VENDAS NOVAS	3	22.239	19%	57%	51%	45%	40%	6%	6%	12%	26%	23%	25%	63%	63%	71%	63%	38%
VIANA DO ALENTEJO	3	39.368	28%	45%	37%	42%	42%	0%	0%	2%	2%	1%	28%	45%	39%	45%	43%	15%
VIANA DO CASTELO	1	31.903	0%	0%	0%	0%	0%	28%	36%	43%	34%	26%	28%	36%	43%	34%	26%	-2%
VIDIGUEIRA	3	31.662	10%	43%	33%	29%	28%	0%	0%	1%	6%	7%	10%	44%	35%	36%	35%	25%
VEIIRA DO MINHO	1	21.645	0%	0%	0%	0%	0%	10%	22%	28%	28%	27%	10%	22%	28%	28%	27%	17%
VILA DE REI	2	19.155	0%	1%	0%	0%	0%	56%	80%	61%	78%	19%	56%	80%	61%	78%	19%	-38%
VILA DO BISPO	4	17.906	2%	1%	6%	0%	0%	0%	3%	5%	5%	4%	2%	4%	11%	5%	5%	2%
VILA DO CONDE	1	14.903	0%	0%	0%	0%	0%	56%	36%	43%	32%	29%	56%	36%	43%	32%	29%	-27%
VILA FLOR	4	26.582	0%	1%	5%	0%	0%	14%	9%	8%	8%	8%	14%	10%	13%	8%	8%	-6%
VILA NOVA DA BARQUINHA	2	4.953	2%	0%	0%	0%	0%	18%	54%	45%	53%	33%	20%	54%	45%	53%	33%	13%
VILA NOVA DE CERVEIRA	1	10.847	0%	0%	0%	0%	0%	15%	33%	48%	40%	32%	15%	33%	48%	40%	32%	17%
VILA NOVA DE FAMILICÃO	1	20.160	0%	0%	0%	0%	0%	38%	28%	40%	27%	25%	38%	28%	40%	27%	25%	-12%
VILA NOVA DE GAIA	1	16.847	0%	0%	0%	0%	0%	18%	26%	38%	24%	23%	18%	26%	38%	24%	23%	6%
VILA NOVA DE PAIVA	1	17.554	0%	0%	0%	0%	0%	1%	16%	29%	18%	10%	1%	16%	29%	18%	10%	10%
VILA NOVA DE POIARES	2	8.446	0%	0%	0%	0%	0%	18%	61%	56%	57%	60%	18%	61%	56%	57%	60%	42%
VILA POUÇA DE AGUIAR	1	43.708	0%	1%	0%	0%	0%	11%	34%	38%	30%	18%	11%	35%	38%	30%	18%	7%
VILA REAL	1	37.881	0%	0%	0%	0%	0%	23%	25%	34%	26%	20%	23%	25%	34%	26%	20%	-3%
VILA REAL DE SANTO ANTÓNIO	4	6.125	4%	1%	1%	1%	1%	1%	10%	9%	9%	8%	5%	11%	10%	10%	9%	4%
VILA VELHA DE RÔDÃO	1	32.992	26%	17%	12%	5%	4%	5%	7%	45%	27%	21%	31%	25%	57%	32%	25%	-6%
VILA VERDE	1	22.867	0%	0%	0%	0%	0%	21%	25%	26%	26%	24%	21%	25%	26%	26%	24%	3%
VILA VIÇOSA	3	19.486	43%	46%	39%	45%	45%	0%	0%	1%	3%	1%	43%	46%	40%	48%	46%	3%
VIMIOSO	4	48.160	1%	3%	1%	1%	1%	6%	2%	1%	10%	11%	6%	2%	11%	11%	11%	5%
VINHAIS	4	69.478	1%	4%	0%	0%	0%	16%	8%	14%	12%	14%	16%	12%	14%	12%	14%	-2%
VISEU	2	50.711	0%	0%	0%	0%	0%	36%	50%	53%	40%	36%	50%	53%	40%	50%	40%	5%
VIZELA	1	2.470	0%	0%	0%	0%	0%	33%	26%	24%	12%	16%	33%	26%	24%	12%	16%	-16%
VOUZELA	2	19.370	0%	0%	0%	0%	0%	23%	42%	48%	53%	52%	23%	43%	48%	53%	52%	28%

2.2. A GOVERNANÇA DO RISCO DE INCÊNDIO FLORESTAL

Este capítulo enquadra na Tese o artigo "*Wildfire risk governance – From a simple issue to a complex risk challenge*" submetido à revista *Ecology and Society*. Aí, apresentamos os resultados da investigação realizada sobre a evolução temporal da governança do risco de incêndio, em Portugal, entre 1910 e 2013. Nos parágrafos que se seguem apresentamos o conceito de governança do risco de incêndio, enquadrámos historicamente o problema do fogo antes de 1910, e após um resumo da revisão bibliográfica (apresentada mais profundamente no artigo) formulamos a questão de investigação abordada no artigo.

a) O RISCO, A GESTÃO E A GOVERNANÇA DE RISCO

No presente trabalho adoptamos a definição proposta por Robert Kates e inscrita no glossário do International Risk Governance Council (IRGC, 2005), entendendo-se que risco é a consequência incerta de um evento ou actividade em relação a algo que os humanos valorizam. Para gestão do risco (*risk management*) adoptamos a definição de Granger Morgan (1990), que a define como a tarefa de gerir o risco, uma vez feito o juízo sobre a sua razoabilidade (limiar de aceitabilidade ou intolerância), incluindo as tarefas de evitar, prevenir, reduzir, transferir e aceitar potenciais perdas. Ou seja, pressupõe-se que há uma identificação, uma avaliação (quantificada, de preferência) e uma definição de prioridades, após as quais se aplicam os recursos para minimizar, acompanhar e controlar a probabilidade do evento e suas consequências.

Por governança de risco (*risk governance*) entende-se os arranjos institucionais (actores, regras, convenções, processos e mecanismos) relacionados com a forma como a informação é recolhida, analisada e comunicada, e como as decisões de gestão de risco são tomadas (Renn, 2005). Inclui, assim, a gestão de risco num contexto alargado, ao qual, para além dos aspectos regulamentares, estão também associadas a cultura e as dimensões social e económica do sistema.

b) DO DESGOVERNO DO FOGO À GOVERNANÇA DO RISCO DE INCÊNDIO

Alves *et al.* (2006) num texto sobre a floresta e o fogo através dos tempos, resumem as referências conhecidas sobre o uso do fogo desde tempos pré-históricos até ao início do séc. XX. Segundo estes autores e citando Neves (1980-1993), as primeiras referências para coimas pesadas a quem fizer fogo nas coutadas, datam do séc. XV, estando presentes tanto nas Ordenações Manuelinas como nas Filipinas.

Para o início do séc. XIX, os autores já incluem outras referências como José Bonifácio de Andrada e Silva (1815), que refere as queimadas dos pastores, ou o Regulamento da Guarda Florestal (1824), que prevê o degredo para África para quem fizer lume no pinhal. No final do séc. XIX, Sousa Pimentel em 1888, citado por Natividade (1950, pág. 45), referia o desprezo aos montados alentejanos e o regime devastador a que estiveram submetidos, escrevendo "*Frequentes vezes os incêndios, que durante dias ou semanas vagueavam pelas charnecas, transformavam em imenso cinzeiro matos e arvoredos... Outras vezes, as árvores eram abatidas para aproveitarem a casca ou serem reduzidas a carvão*".

E em 1901, o artigo 54 do regulamento do Regime Florestal (que só se aplicava numa pequena área do País) referia "*O proprietário limitrophe da mata que desejar fazer alguma queimada a menos de 200 metros do seu perímetro, deverá pedir previamente auctorização ao silvicultor, para este lhe marcar o dia e hora, e mandar exercer pelos guardas, no local da queimada, a necessária vigilância contra o fogo.*" Na figura 5, documenta-se uma patrulha a cavalo de guardas florestais na Mata Nacional de Leiria no principio do séc XX.

Dos trechos acima resulta que havia formas de proteger as áreas arborizadas por via das leis e outros dispositivos (ver 2.3), mas face à diminuta área florestal que os então Serviços Florestais e Aquícolas administravam, o fogo só estaria governado em torno dessas florestas, ou seja, "andaria à solta pelo monte".

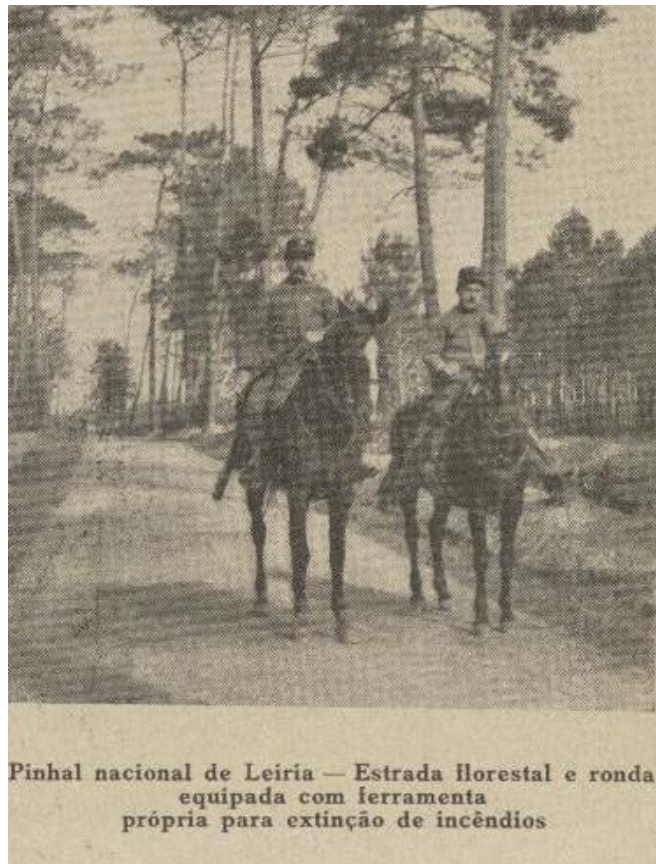


Figura 5. Imagem extraída de Mendes (1932) onde se ilustra uma brigada de guardas florestais equipados com ferramentas de combate a incêndios na Mata Nacional de Leiria.

Os próximos parágrafos ilustram a evolução do tema do risco entre 1953 e 2013, procurando sintetizar a multiplicidade de perspectivas.

Num relatório sobre políticas florestais na Europa (FAO, 1953) encontramos uma síntese das práticas de gestão do risco de incêndio nas florestas públicas e privadas portuguesas. Sobre as áreas privadas informa-se que estas não são objecto de atenção devida, nomeadamente em medidas de prevenção referindo que o controlo dos fogos é feito sem disciplina por habitantes das comunidades. Caso os incêndios se tornassem maiores, haveria o apoio de brigadas de incêndios que se deslocavam de longe e até de forças militares. Para as áreas públicas, no referido relatório de 1953, descreve-se a situação para as matas em planícies e para as matas em regiões montanhosas. Para as primeiras descreve-se detalhadamente o sistema de protecção contra o fogo, realçando o profissionalismo e eficácia, referindo a estrutura dos aceiros e arrifes, com intervenções cada 2 anos. Assinala-se que o modelo de protecção desenhado para as áreas montanhosas necessitava de melhorias, mas a protecção contra o

fogo dos povoamentos jovens (maioritariamente estabelecidos no âmbito do PPF de 1938) era difícil, pelos custos que já então implicava.

Em 1954 é publicado o DL 39 931 que alarga o âmbito de actuação dos Serviços Florestais até 3 Km do limite da mata nacional ou comunitária, permitindo a intervenção das brigadas de sapadores de incêndios nesta área, o que estendeu o sistema de uma cobertura nacional de 5% para 22%, maioritariamente localizada no norte do Continente (figura 6).

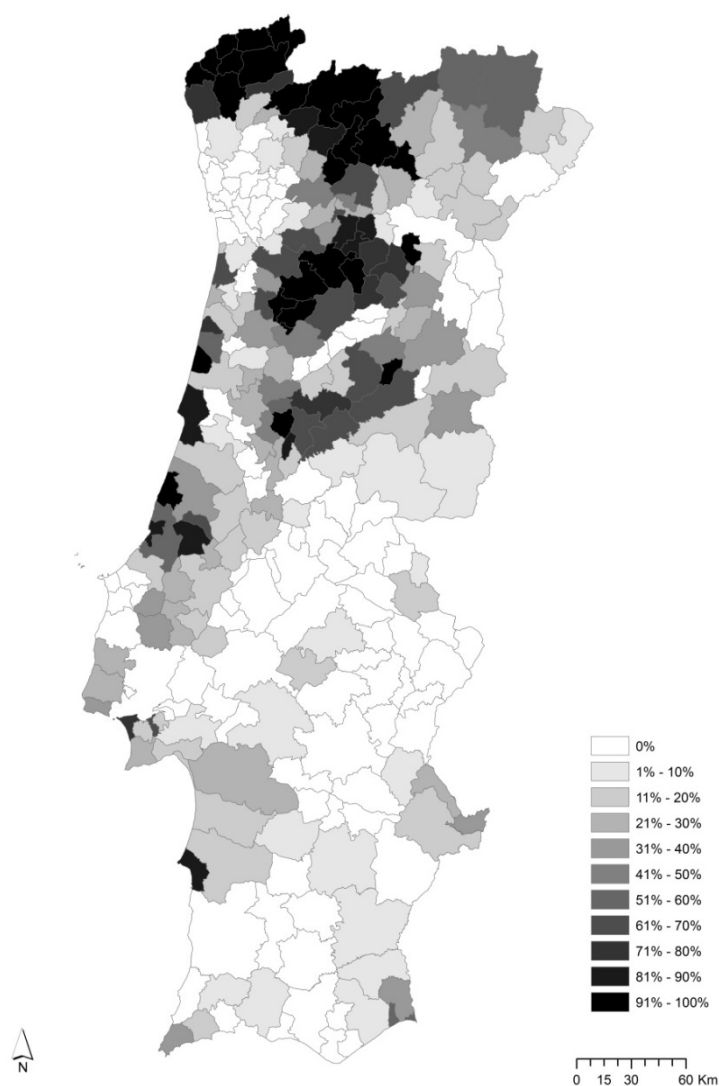


Figura 6: Proporção da área de território por município incluída nos 3km de protecção dos Serviços Florestais em 1980 (com base nas áreas geridas à data, de acordo com ICNF).

As figuras 7, 8, 9 e 10 ilustram detalhes sobre a recolha, análise da informação e dispositivo de extinção gerido pela estrutura dos Serviços Florestais entre 1950 e 1983.

DIRECÇÃO-GERAL DOS SERVIÇOS FLORESTAIS E AQUÍCOLAS

3ª. Repartição Técnica
Ficha Individual do Fogo

Circunscricção do Porto Cab. de Basto
Local Pala D'Onça Freguesia Bucos Concelho Cab. de Basto Perímetro ou Mata Cab. de Basto

Data 5-3-1960

1 - Horas: Início 1,40 Alarma 8 Extinção 9,30

2 - Origem: Dentro Perímetro

3 - Vento: Intensidade Moderada Direcção Norte

4 - Causa:
a) Negligência (cigarros, fósforos)
b) Fogos (queimadas, fogueiras, carvoeiros)
c) Cam. de Ferro
d) Malvadez (incendiária)
e) Outras causas (raios, balões, fogo de art.)
f) Diversas
g) Desconhecida

5 - Características do povo vizinho (amigo ou inimigo) há inimigos, mas o povo não o é dum modo geral

6 - Combate ao fogo: Transporte utilizado a pé
Material utilizado ramos de pinheiros e enxadas
Pessoal utilizado 3 pessoas

7 - Deficiências no apetrechamento da luta contra o fogo que este revelou:
Rede Divisional não há
Vigilância sim
Alarma 8 horas
Vias de Comunicação sim não há
Transporte a pé
Material ramos de pinheiro e enxadas
Pessoal 3 pessoas

8 - Prejuízos: Área queimada 1.580 m.q. = 0,158 ha
Natureza do povoamento Plantação
Idade do povoamento 5 anos
Estimativa do prejuízo em esc. 705,800
Estimativa da despesa com a extinção do incêndio em esc. nada

9 - Observações diversas (escrever no verso)

Nota: Em 4 e 5 sublinhar o que interessa.

Figura 7. Ficha de incêndio preenchida (Direcção-Geral dos Serviços Florestais e Aquícolas, 1960).

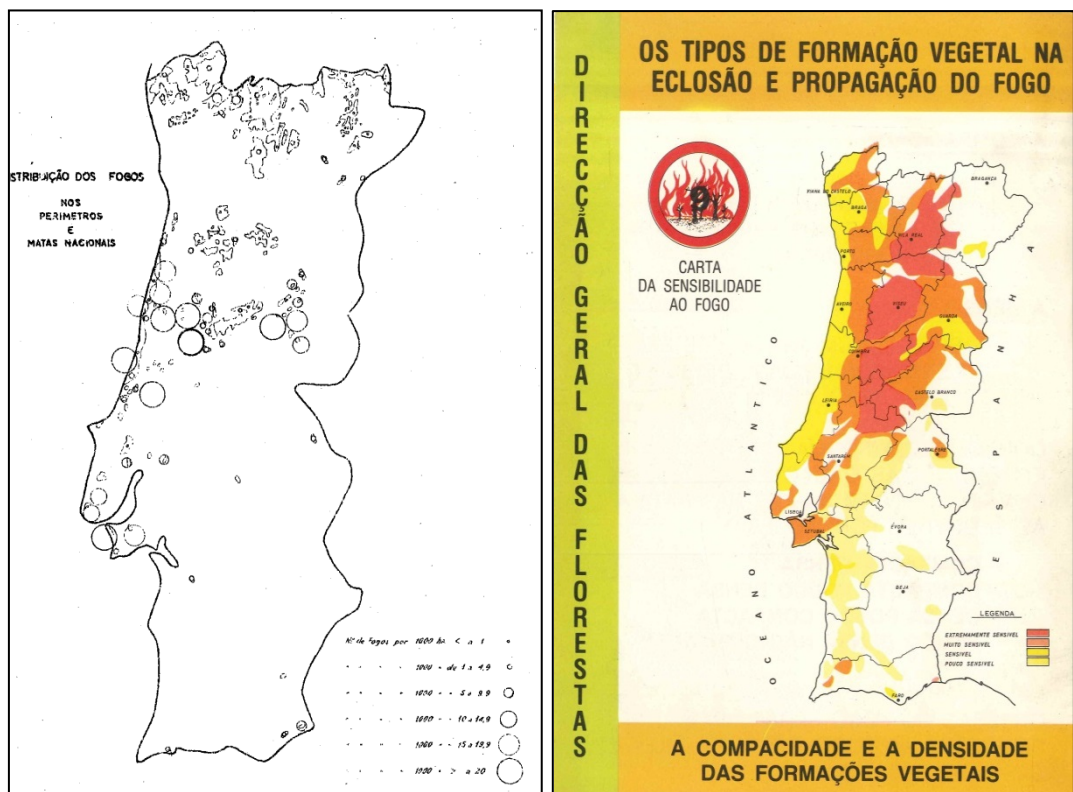


Figura 8. A imagem da esquerda, extraída de Dias (1955), exhibe o primeiro mapa à escala nacional que retrata o risco de incêndio e terá sido produzido em 1955. Na imagem da direita (DGF, 1981) ilustra-se através de um cartaz, o mapa de sensibilidade ao fogo, similar ao constante no Decreto Regulamentar n.º 55/81.



Figura 9. Imagem que mostra 3 aviões de combate a incêndios (Grumman Ag Cat Airtanker) estacionados na pista da Lousã em Julho de 1980 (recolhida no Arquivo Fotográfico Histórico do ICNF). A eficiência operacional foi estudada por Alves (1985) comparativamente com outras pistas e aparelhos.



Figura 10. Localização das pistas de aviação e brigadas helitransportadas em 1983, quando o sistema de meios aéreos de combate era gerido ainda pelo Serviços Florestais (extraído de Nogueira, 1983).

Na figura 11 apresentam-se dois recortes de notícias publicadas entre 1979 e 1981. Na primeira procuram-se medidas de urgência para estancar o problema e na segunda noticia-se a perda de casas em incêndios florestais.

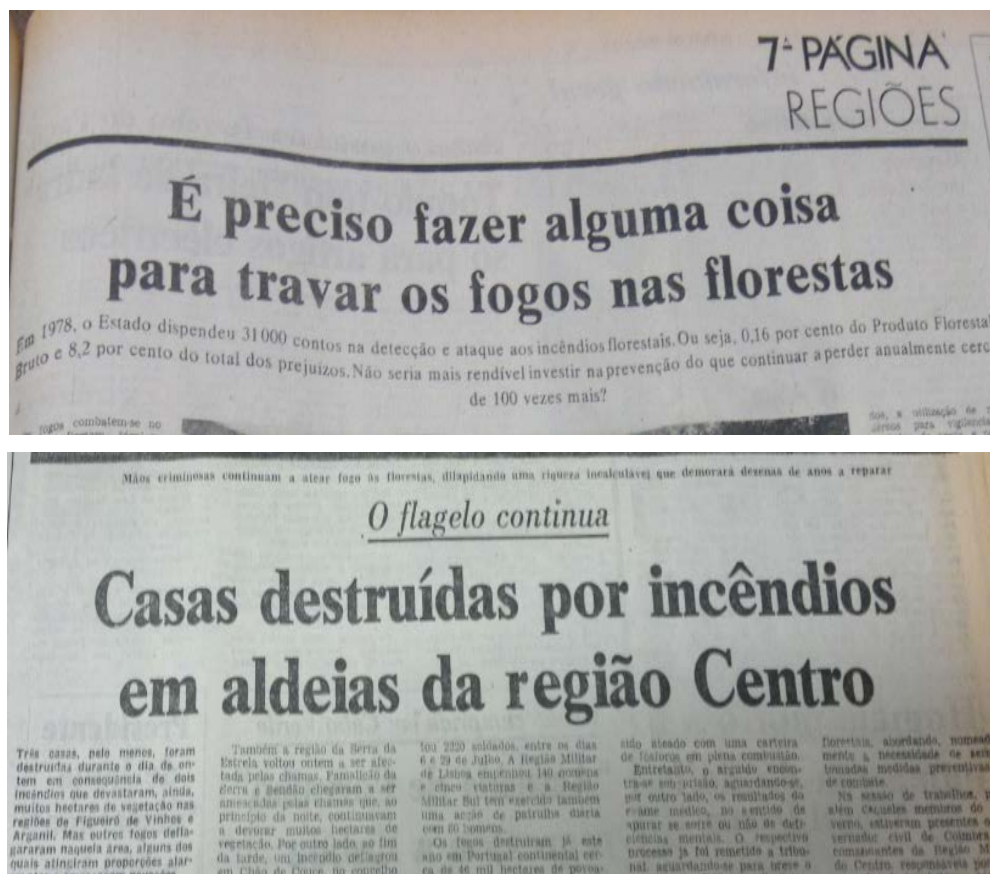


Figura 11. Recortes de imprensa entre 1979 e 1981 que reflectem a urgência em encontrar “quaisquer medidas” e a emergência das perdas de habitações. (Foto do autor na Hemeroteca)

Em Novembro de 1984 em conferência organizada na Sociedade de Geografia, o Subdirector-Geral refere o afastamento institucional dos Serviços Florestais do combate aos fogos, mas assegura o seu empenhamento nas acções de prevenção e detecção, indicando, no entanto, que, por razões financeiras, já existiam atrasos na implementação dos planos, nomeadamente da expansão da rede de torres de vigia a toda a área arborizada¹ (Cabral, 1985).

Em comunicação do mesmo encontro, Serrão Nogueira (1985), então responsável pela Protecção do Arvoredo, refere que as medidas de prevenção estão a ser colocadas em prática “dentro dos condicionalismos impostos pelos

¹ Referindo-se a área privada, uma vez que por esta altura a cobertura dos postos de vigia (101) abrangia a quase totalidade das áreas administradas pelo Estado.

meios humanos e materiais e pela possibilidade de actuação na floresta privada". Na mesma comunicação, recorda a doutrina de defesa contra incêndios:

"A prevenção abrange todas as medidas que levam a protecção (...), iniciam-se com o planeamento da arborização, prolongam-se com a forma de condução e exploração do povoamento (...) campanhas de elucidação e educação do público" e "O melhoramento de caminhos que facilitem o acesso dos meios de combate a incêndios e uma melhor exploração florestal, a constituição de linhas corta-fogo, de redes divisionais, de embalses e depósitos de água em locais estrategicamente situado, o melhoramento dos meios aéreos, a preparação do pessoal de combate, a melhoria dos meios de combate, a utilização do fogo controlado para a diminuição do combustível acumulado nas matas, a limpeza de aceiros e arrifes, são entre outros os meios com que se procura proteger a floresta portuguesa."

A figura 12 exhibe a recorrência do fogo entre 1975 e 2013. Dos 4,3 milhões de hectares que foram percorridos pelo fogo em 39 anos, cerca de 70% acontecem em áreas que tinham já ardido pelo menos uma vez. Observamos ainda que a maioria se concentra nas serras do Norte e no Centro.

No relatório sobre incêndios florestais da Assembleia da República (AR, 2015) em resultado dos trabalhos da 5.^a Comissão constituída após os incêndios de 2013 (outras comissões abordaram o tema em 1990, 2003, 2005, 2007), o Presidente desta Comissão baixa as expectativas dos menos avisados leitores sobre o impacto do relatório *"Sem prejuízo do espaço próprio de cada um dos órgãos de soberania, caberá ao Governo (actual e futuros), seleccionar e programar, articuladamente com a Administração Local e as instituições com responsabilidades nesta problemática dos Incêndios Florestais, a sua implementação."*

Área ardida acumulada entre 1975 e 2013

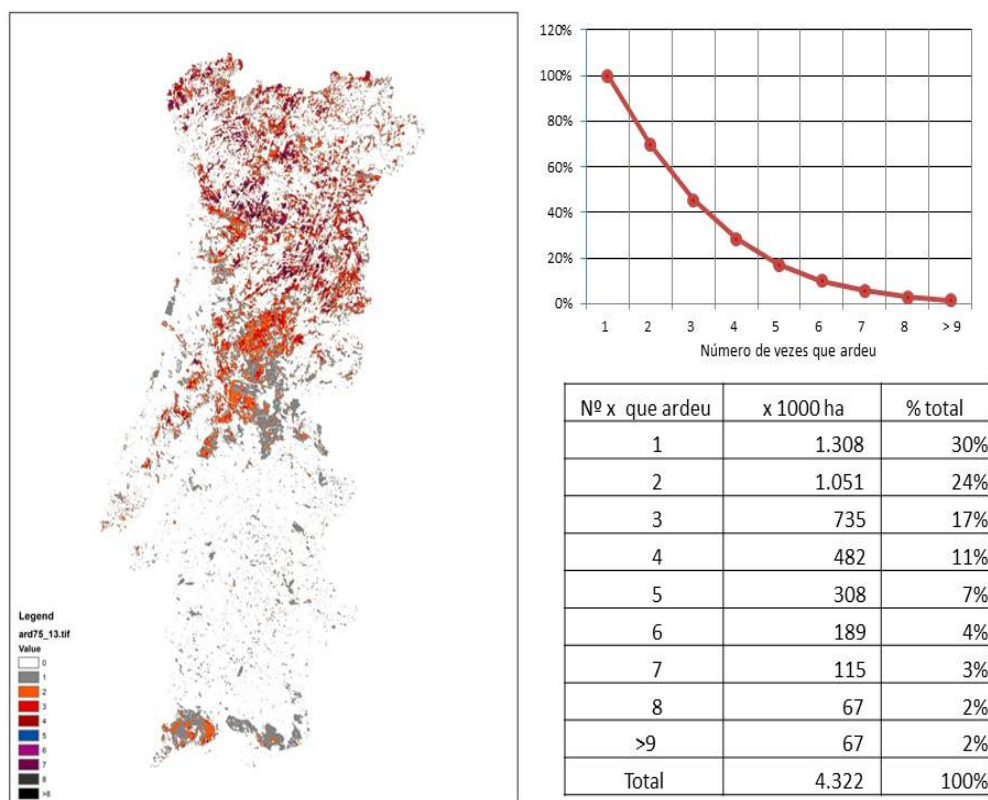


Figura 12. Mapa com as áreas ardidas entre 1975 e 2013, utilizando dados do ISA (1975-1984), ICNF/ISA (1985-2009) e ICNF (2010-2013).

c) UMA ENTRE MUITAS PERGUNTAS

Durante o séc. XX vários países sofreram crescentes incêndios, e adaptando as suas políticas, regulamentos, organizações e sistemas operacionais para proteger as populações e florestas. Para os Estados Unidos da América, várias publicações discutem as consequências não intencionais de políticas que foram desenvolvidas (Pyne, 2001; Busenberg, 2004), abordando, Muller e Schulte (2011), Cortner e Gale (1990), Busenberg (2004) e Steelman (2016), especificamente, as questões de governança do risco de incêndio. Para o sul da Europa, Aguilar e Montiel (2011) abordaram o desafio da governança e do desenvolvimento sustentável, e Caballero (2014) discutiu as mudanças institucionais e de governança das áreas comunitárias florestais na Galiza, através da lente da nova economia institucional. Para Portugal, analisando a multifuncionalidade da gestão sustentável, Carvalho-Ribeiro *et al.* (2010) ilustraram as dificuldades do desenvolvimento de sistemas de governança, e Mendes (2004), reflectindo sobre as políticas florestais desde 1996, chama a

atenção para a incapacidade das autoridades públicas em assumir compromissos duradouros, a emergência de novos actores, e a evolução ainda ténue do processo de construção das políticas florestais. Na área dos incêndios, para a Grécia, Morehouse *et al.* (2011) investigaram a forma como as políticas, regulamentos e práticas afectam a governança de fogo. Para a Espanha, Badia *et al.* (2001) apresentaram um quadro para a abordagem ao problema que realça a importância das políticas dirigidas às raízes ambientais, sociais e económicas do problema, em vez de reativas às suas consequências. Seijo (2005) e Seijo e Grey (2012) discutiram o papel dos programas de arborização e políticas de exclusão de incêndios em regime de fogo pré-industrial.

Para Portugal, várias análises técnicas sobre o problema do fogo foram publicadas. Enquanto em FAO (1953), Quintanilha (1958) e Quintanilha *et al.* (1965) se reflecte sobre a importância de desenvolver um sistema que assegurasse a protecção das áreas particulares, os documentos publicados após 1980 parecem insistir na necessidade de planeamento e coordenação das instituições e operações (FAO, 1982; Nogueira *et al.*, 1985; CESE, 1996; Stauber, 1996; Beighley e Quesinberry, 2004; ISA-APIF, 2005; Beighley e Hyde, 2009). No entanto, não encontramos estudos científicos que tenham investigado com profundidade as questões de governança do risco de incêndio florestal em Portugal, para além de Tavares e Santos (2013), que através do quadro metodológico do Internacional Risk Governance Council (Renn, 2005) descrevem, à escala de um município, a abordagem aos riscos naturais, e Mateus e Fernandes (2014) que discutem as alterações institucionais após os grandes incêndios de 2003.

Muitas perguntas poderiam ser colocadas sobre o percurso descrito. Qual a razão das opções tomadas? Por que foi assim, ou que elementos externos estiveram presentes, levando as opções do decisor num dado sentido em vez de outro? São perguntas legítimas e cuja resposta se revela de grande oportunidade, face à permanente tendência para alterações organizacionais em resposta a eventos catastróficos. No entanto, a informação não está estruturada por forma a permitir uma leitura temporal imediata, por exemplo, sobre a evolução dos recursos (materiais ou humanos) ou sobre as sucessivas instituições ou regulamentos que foram produzidos.

Depois dos primeiros esforços para organizar informação, optou-se focar a pergunta de investigação:

- Como evoluiu o sistema de governança de risco de incêndio?

Compilando um conjunto de relatórios técnicos (alguns já mencionados acima), outra documentação que referisse a evolução da floresta e do fogo em Portugal, e toda a legislação produzida pelo Governo e pela Assembleia da República (legislação da República, de nível nacional), construiu-se uma cronologia da evolução do sistema de gestão de risco. Através de análise de conteúdos aos preâmbulos dos diplomas do governo entre 1910 e 2013, investigou-se a evolução da formulação do problema e as soluções que foram sendo propostas.

Wildfire risk governance – From a simple issue to a complex risk challenge

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Research

Wildfire risk governance - From a simple issue to a complex risk challenge

Version: 1 Submitted: 2017-06-14

1.

ABSTRACT

2. Throughout the 20th century several countries evolved their policies, regulations, organizations and
3. operational systems to assure the protection of populations and forests against wildland fires. This
4. paper examines the evolution of wildfire risk governance during the last 100 years in Portugal, the
5. country with the highest fire incidence in Europe, based on content analysis of official regulations
6. for fire management. We adopted an analytical socio-ecological framework to describe the system's
7. adaptive capacity and built a chronology of its evolution. We found that most regulatory instruments
8. were shaped in crisis contexts and the system evolved differently according to the relative
9. magnitude of social and ecological changes, which ultimately drove the way how the problem was
10. framed and, consequentially, the adopted solutions. Since the 80s, we found that framing
11. misrepresented the dynamics of socio-ecological processes that were fostering fuel accumulation and
12. amplified socio-technological failures to explain fire occurrences. A simple risk problem that was
13. being managed with informal and local solutions up to the 1960s escalated to a complex and
14. ambiguity-ridden risk problem. The formalization of the wildfire management system occurred under the
15. umbrella of civil protection, setting a paradigm shift that undermined forest protection. We
16. formulate the hypothesis that critical governance deficits hindered the emergence of a cohesive
17. system able to perform effectively, guaranteeing low fire risk exposure for forests, infrastructure
18. and human lives, while at the same time ensuring a professional and profitable management of forest
19. resources, overwhelmingly managed by private owners.

20. Key words: Content analysis; climate change; forest; risk governance; wildfire policy

21.

INTRODUCTION

22. National governments recently approved, as part of the UN's development goals (UN 2015b), a specific
23. goal for the conservation and maintenance of resilient forests, for their role in poverty
24. alleviation and climate change mitigation (IPCC 2014, Pan et al. 2011). The strengthening of risk
25. governance systems has been acknowledged by the OECD (2014) and the UN (2015a), through the Sendai
26. framework for risk reduction 2015-2030, as key for achieving that goal, by helping to minimize
27. losses from natural or technological disasters. Fire-induced deforestation is a relevant cause of
28. losses and source of CO₂ (Bowman et al. 2009), presenting a clear threat to that goal and requiring
29. specific risk governance solutions. Throughout the twentieth century, several nations experienced
30. growing economic and non-economic losses from increasingly large wildland fires (Moritz et al.
31. 2014), and adapted their policies, regulations, organizations, and operational risk management
32. systems, to protect people and forests. In the following subsections, we review the research that
33. has looked at this evolution of the wildfire management systems and introduce the analytical
34. framework adopted for the study.

35. **Evolution of wildfire management systems**

36. The evolution of wildfire management systems has been documented for a variety of fire prone regions
37. in the world. Pyne (2001) described how the culture to suppress fire from landscapes in North
38. America fostered large and severe events. Busenberg (2004) examined the political process that
39. reinforced wildfire suppression in the US, and concluded that there is a need to balance that
40. strategy with fuel reduction programs. Stephens and Ruth (2005), summarizing wildfire policy and
41. future challenges, alerted the US Congress to the need for long term commitment from all decision
42. making bodies. Davis (2006) used content analysis and punctuated equilibrium theory to analyze how
43. administrative and legislative policy has shifted in response to crises and media attention. Framing
44. wildfire management as a wicked problem, Carroll et al. (2007) highlighted the need for long term
45. thinking, instead of short term fixes. North et al. (2015) appealed to the US Forest Service to
46. review organizational incentives, which have been limiting the achievement of certain policy goals.
47. In a review of wildfire governance, Steelman (2016) suggested that in the face of a changing
48. socio-ecological context, a goal reorientation and the steering of the system ought to be focused on
49. social and ecological resilience.

50. Tacconi et al. (2004) analyzed the fire problem in the Indonesia tropical forest, and observed that
51. livelihood, financial, and economic drivers may undermine fire prevention and suppression efforts,
52. thus requiring improved wildfire governance solutions. For Australia, Gill (2005) found that
53. multiple, partial solutions to the landscape fire problem may appear in different places and at
54. different times, due to different combinations of land management perspectives, social contexts, and

55. fire response systems. Stressing governance issues, the author also recalled the need for "perpetual
 56. vigilance of all parties". In Catalonia, Spain, Badia et al. (2001) examined the conventional forest
 57. fire management approach and found critical resistances to acting upon the social and landscape
 58. dynamics that ultimately drive the fire problem, instead of the mere tackling of the consequences.
 59. Also for Spain, but at a national level, Aguilar and Montiel (2011) discussed participatory
 60. initiatives in the scope of wildfire management processes, and how the European Union could help to
 61. leverage policies, by promoting fire-wise practices. For Portugal, Collins et al. (2013), examined
 62. the interplay between the physical and political dimensions of wildfire management and found that
 63. quick fixes were setting a fire-fighting trap, with long run negative unintended consequences.
 64. Recognizing the complexity and uncertainty of Socio-Ecological Systems (SES), Moritz et al. (2014)
 65. recommended the coordination of land use planning and wildfire risk management. For southern France,
 66. Ruffault and Mouillot (2015) studied the outcomes of the 1980s wildfire policies and how they
 67. reshaped the fire-weather relationship and altered the fire regime. Summarizing the causes and
 68. consequences of the wildfire problem worldwide, Gill et al. (2013) recalled the need to always heed
 69. the changes in the landscape and in the stakeholders, because "*there is no single, simple, solution*"
 70. and "*perverse outcomes can occur.*"

71. The review above illustrates the range of research that has been addressing the fire problem from
 72. the perspectives of environmental history, policy analysis, system dynamics, fire ecology, and risk
 73. management, recognizing the complexity and uncertainty that challenge the governance of SES. The
 74. findings of this research point to the insufficiencies of approaching complex wildfire problems with
 75. narrowly focused technological fixes, or looking for simple answers to "*deduce universal solutions*
 76. or panaceas", in the words of Ostrom (2007:1).

77. **Analytical framework**

78. When handling risks in complex environments, in which the causes and the social framing of risks are
 79. continuously changing, risk governance has been suggested by the IRGC (2005) as key to bridge the
 80. gap between stakeholders, risk managers and decision makers. Rooted in transdisciplinary work at the
 81. interface of risk assessment, risk management, regulatory sciences, and policy analysis (van Asselt
 82. and Renn 2011), risk governance refers to "*the totality of actors, rules, conventions, processes,*
 83. and mechanisms concerned with how relevant risk information is collected, analyzed and communicated
 84. and management decisions are taken" (IRGC 2005: 22).

85. Although prior works used the term "fire (or wildfire) risk governance" when examining wildfire
 86. policies (Henderson et al. 2005, Morehouse et al. 2011, Muller and Schulte 2011, Cheng et al. 2011,
 87. Steelman 2016) or wildfire risk management systems (Pacheco et al. 2015, Ager et al. 2017), none
 88. have explicitly used IRGC's risk governance framework. Difficulties in documenting all its

89. variables, qualitatively and quantitatively, with consistent depth, or its static nature, are some
90. of the potential reasons for such absence.

91. The way society handles risk evolved from hierarchical and centralized approaches (command and
92. control) to multiple-level governance systems (Renn et al. 2011) including horizontal and vertical
93. integrations of institutional arrangements (Assmuth et al. 2010) and adaptive co-management
94. (Armitage et al. 2009). As institutions and their contexts evolve in a continuum or through crises,
95. and with path dependencies, adaptive SES governance approaches are able to capture the dynamics of
96. those changes explicitly, through social learning (Folke et al. 2005) and socio-technical transition
97. (Smith et al. 2005) processes.

98. Adopting the concept of triple-loop learning from organization theory, Pahl-Wostl (2009) introduced
99. a conceptual framework for analyzing this type of adaptive capacity in resource governance regimes
100. (Fig. 1). In the single-loop learning process, improvements to established routines occur through
101. incremental changes, without altering assumptions or goals, while in the double-loop process, actors
102. reflect on goals and problem framing, and embrace a discussion process that ultimately drives a
103. change of assumptions and boundaries, and later on a change of actions. In the triple-loop process,
104. actors recognize that paradigms, values and beliefs no longer encompass the problem and set off a
105. transition in the governance regime. The framework also highlights four major characteristics of
106. governance regimes: a) formal and informal institutions; b) the role of state and non-state actors;
107. c) multi-level interactions; and d) governance modes.

108. The above framework, which later came to be known as the Management and Transition Framework (MTF),
109. was initially designed for water systems, but has in the meantime found broader application in risk
110. governance. In fact, in a comparison of 10 frameworks for analyzing SES, Binder et al. (2013)
111. emphasized the fact that the MTF explicitly considers environmental hazards that pose threats to
112. human well-being, and that its "*dynamics are driven through changes in environmental awareness at*
113. *different hierarchical levels of the social system, the learning processes, and the different types*
114. *of feedbacks*" (Binder et al. 2013:7).

115. One of the key tools used by the IRGC, very closely related to the MTF, is the risk chain model
116. (Hohenemser et al. 1982). This coarse model describes a causal sequence in risk management, and has
117. been used to explore the pathways between human values and needs, and the technology choices to
118. prevent or to react to hazard consequences. It has been previously applied to analyze the evolution
119. of the wildfire problem in Catalonia (Badia et al. 2002), in tandem with the evolution of the
120. context of human needs and wants. In the scope of IRGC's broader risk governance framework, human
121. wants and needs, and problem perceptions, correspond to the understanding phase, in which the
122. problem is framed. The choices of the technologies and the processes adopted to handle risk are

123. within the sphere of decisions, in which solutions are designed and implemented.

124. In order to examine the evolution in time of wildfire risk governance, its broader social,
125. institutional, political and economic context must be taken into account (Kleine and Renn 2012).
126. Wildfires are a synthesis of the landscape (Pyne 2006), shaped in the complexity of socio-ecological
127. resource governance regimes. In the face of environmental hazards, according to Pahl-Wostl (2009)
128. and Binder et al. (2013), change in these regimes emerges from a stepwise social and societal
129. learning process, which MTF can capture, thus being able to offer a dynamic perspective bridging to
130. the causal risk chain adopted by the IRGC (2005) and by Badia et al. (2002). From Fig. 1, *Context*
131. would refer to the governance structure and the socio-ecological conditions of the forest, *Frames*
132. would be characterized by how the problem is perceived, and *Actions* would consist of the envisioned
133. or proposed solutions, from which different *Outcomes* (results) would be expected. For this study,
134. the four dimensions of governance regimes considered in the MTF were captured through formal
135. analysis of regulatory and binding documents (fire legislation), complemented with extensive reading
136. of essays, documents and technical reports. Using the MTF, we were able to map the evolution in time
137. of how reality was perceived by government entities and which solutions were favored, and to examine
138. the learning process within the scope of wildfire risk governance. In addition to the development of
139. this institutional timeline, we also characterized the formal and informal institutions, the actor
140. network, and the multi-level interactions and governance modes.

141. **Portugal as a case study**

142. According to the FAO's 2015 Forest Resources Assessment (FRA 2015), Portugal is among the few
143. countries in the northern hemisphere to feature a reduction in forest area between 1990 and 2015.
144. Throughout the last century, Portugal had the fastest forest expansion rate in Europe (Mather and
145. Pereira 2006), but in the last 25 years it also had the highest fire incidence in Europe (Turco et
146. al. 2016). Examining in detail the forest transition process in Portugal between 1907 and 2006,
147. Oliveira et al. (2017) suggested that this process was arrested due to fire risk governance
148. deficits. The country's forest cover pathway provides a unique case study allowing the analysis of
149. the evolution of a wildfire risk governance system over a period of 100 years. With climate change
150. expected to increase fire hazard and foster crisis events that will test the limits of governance
151. systems, evidence from case studies can play an important role in improving adaptation processes and
152. their effectiveness.

153. **Aims and structure of the paper**

154. In this paper, we analyze the evolution of wildfire risk governance in Portugal, over the last 100
155. years. Examining the contents of governmental wildfire regulation issued throughout that period, we

156. mapped how the problem was framed and which actions were adopted. As the broader context changed
157. along the study period, we also describe the evolution of the actor network, the multi-level
158. interaction, and the governance modes. This research presents an innovative approach to investigate
159. how wildfire risk is addressed by policy-makers, and raises new hypotheses in the scope of adaptive
160. socio-ecological systems governance and risk governance.

161.

STUDY AREA

162. Portugal is located in southwestern Europe (Fig. 2) and has an area of 92.000 km², including the
163. Atlantic archipelagos. With the majority of its 10 million inhabitants living in the densely
164. urbanized coastal region, forests, shrubland and pasture areas occupy 67% of the country, while
165. agriculture covers another 24% (ICNF 2013). Portugal is an open economy fully integrated in European
166. Union with most of its work force employed in industry and services. The forest sector represents 3%
167. of its GDP and 12% of its exports (AIFF 2014). The country has a wet Mediterranean climate, with a
168. longer rainy season and warm summers in the northern half of the country Mainland, and hot summers
169. in the southern half.

170. North of the Tejo river, maritime pine (*Pinus pinaster*) and blue gum (*Eucalyptus globulus*)
171. plantations cover broad areas of rugged terrain, with shrublands occupying the higher elevation
172. areas. South of the Tejo, undulating plains are occupied by a mosaic of evergreen oak woodlands and
173. croplands. Since 1975, more than 4.3 million ha of afforested and shrubland areas were burnt,
174. corresponding to one of the highest forest fire incidences in the world (FAO 2010: 75). Since the
175. last quarter of the 19th century, afforestation surpassed deforestation and Mainland Portugal
176. underwent a forest transition. As extensively examined by Oliveira et al. (2017), the evolution of
177. forest cover exhibited four transition pathways, characterized by an expansion of wooded lands up to
178. the 90s, then followed by a decline due to wildfires. In addition to this land cover dynamics, the
179. goals of forest management also changed through time, as endogenous and exogenous social and
180. economic conditions evolved (Oliveira et al. 2017).

181.

METHODS

182. The methodology used in this study unfolded in three steps. First, we collected data from a
183. legislative dataset, and obtained official and technical reports. Next, we performed a content
184. analysis of the preambles of wildfire-related laws published between 1910 and 2013, to capture how
185. the problem was framed and actions adopted. Finally, we mapped the evolution of formal and informal
186. institutions, the actor network, multilevel interactions, governance modes, learning cycles and risk

187. governance deficits through findings from the content analysis and from the reading of the collected
188. documents.

189. Data collection

190. We used two main sources of data:

1. The national forest authority legislative datasets (ICNF 2015, ICNF 2017), cross-checked with the ISA - APIF (2005) legislative national fire plan reports. The timeline under analysis starts with the end of the monarchy, in 1910, and ends at the start of this research, in 2013. We built a legislative database with all legislation published between 1910 and 2013 that directly addressed wildfires, namely Parliament laws (L), Parliament Resolutions (PRtG), Parliament reports (PR), Government decrees and decrees-laws (DL), and Council of Ministers Resolutions (CMR). We excluded all European regulations, non-wildfire related forest regulations, and internal organizational guidelines, such as ministerial, forest authority, or civil protection organic laws, and minor ordinance such as ministerial and public agencies orders. The above regulations were extracted in Microsoft Word format from <https://dre.pt/> and <https://dre.tretas.org/>. Regulations prior to 1974 were obtained from the library of the Assembleia da República (the national Parliament), either from <http://www.parlamento.pt/ArquivoDocumentacao/Paginas/default.aspx> or in paper. Three senior administrative forest experts independently checked for missing or wrongly included documents. At the end of the process, the dataset had 134 regulations, as summarized in Table 1.
2. A total of 183 documents were collected, including research papers, book or book chapters, essays, official and technical reports referring wildfires, collected from the libraries of the national forest authority, the National Civil Protection Authority and the School of Agriculture of the University of Lisbon. The distribution of documents by type and period of analysis is summarized in Table 1 (complete list in Appendix 1 - Table A1.1).

191. Content analysis

192. According to the Portuguese 1976 Constitution (fundamental law), the government is responsible for
193. developing policies and for providing guidelines for the public administration to execute them under
194. the existing legal framework, being unable to modify fundamental citizen rights without approval by
195. a majority in the Parliament. For example, to change the severity of a penalty for misuse of fire,
196. or to transfer responsibilities from the central to the local administration, a L must be approved.
197. The government will then approve one or several DLs, depending of the complexity of the issue, which
198. must be promulgated by the President of the Republic. The inclusion of the L in the content analysis

199. would bias the results, leading to the oversampling of some of the issues; simultaneously, most of
 200. the Ls do not have a preamble. These facts led to the exclusion of 18 Ls. We also excluded PRtGs and
 201. PRs as they are not legally binding to the Government. Thus, 14 PRtGs and 5 PRs were excluded from
 202. the content analysis.

203. We analyzed 42 DLs and 59 CMRs, in a total of 101 documents, using MAXQDA 10. We performed a mixed
 204. content analysis (Ghiglione and Malton 2005), with some of the categories defined *a priori*, based on
 205. the reviewed literature, and others emerging *a posteriori*, from the data analysis. Because the
 206. preamble of each regulation summarizes the way the problem was framed, and the major actions
 207. envisioned, we used the full text of the 101 regulations in MAXQDA 10.

208. The preambles were analyzed considering two main topics:

1. Frame, understood as the way the wildfire phenomenon was perceived at the time of publication of the regulation. For this topic, we considered three themes: *Fire occurrences*, *Expressed values*, and *Reasons for intervention*.
 1. *Fire occurrences* captures the causes and motivations behind the fire phenomenon, and is divided into two categories: *Causes* and *Motivation*.
 1. *Expressed values* describes the type of value to be protected, and is divided into the categories *Economic* and *Non-economic*.
 1. *Reasons for intervention* refers to reasons put forward to justify actions that seek a change. This last theme unfolds into six categories: *Economic losses*, *Non-economic losses*, *Metapolicy*, *System design*, *Resource use*, and *Law-related*.
2. Actions, understood as the body of beliefs, principles and solutions foreseen to solve the problem or minimize losses. We considered only one theme, *Proposed solution*, which was coded looking for the risk management solutions adopted through time by the governments, considering the five major wildfire activities or categories: *Planning*, *Prevention*, *Pre-suppression*, *Suppression*, and *Rehabilitation*.

209. Considering also sub-categories, the final dictionary consisted of 50 different codes (Appendix 2
 210. Table A2.1). We used a semantic segmentation of the corpus, which generated 779 coded segments in
 211. total, within 4 themes, 15 categories, and 45 sub-categories. Inter-rater reliability was assessed
 212. by allowing another independent coder to code around 30% of the total corpus based on the final
 213. categories dictionary (Krippendorff's $\alpha = .73$).

214. **Evolution and chronology of institutions, actor network, multilevel interactions and governance**

215. modes

216. A statistical analysis was performed using the sum of the numbers of DLs and CMRs and the total
217. annual burnt area, using data reported in CESE (1996) for 1970-1974, the fire perimeter atlas
218. (Oliveira et al. 2012) for 1975-2009, and national forest authority data (ICNF 2014) for 2010-2013.
219. To explore the variation of the number of new laws published each year, due to the small number of
220. observations (44), we used simple linear regression analysis, in Microsoft Excel.

221. Extensive reading of historical forest literature, official and technical reports (Table 1), jointly
222. with insights from the content analysis, allowed us to describe the evolution of the four governance
223. structures and the learning loops suggested by Pahl-Wostl (2009) throughout the period of analysis.

224.

RESULTS

225. We begin this section with a broad characterization of the collected wildfire regulation. We then
226. present the results of the content analysis and report our findings on the evolution of the
227. governance structure. Towards the end of the section, we summarize the results and findings in a
228. chronology. The section closes with a presentation of the evolution of the levels of learning
229. throughout the period of analysis, highlighting the critical deficits that we have found more
230. relevant.

231. **Regulations by period of analysis and burnt areas**

232. We found that in the two-year period after severe fire seasons, governments tend to react by issuing
233. new regulations. Because of the long timespan associated with the issuing of new regulations, to
234. analyse the variation of the number of laws published in each year we used the moving average of the
235. area burnt in the same year and in the previous year as explanatory variable (Fig. 3), and evaluated
236. the strength and the direction of the linear relationship between these two variables (Fig. 4).

237. We obtained a strong correlation of 0.796 (coefficient of determination of 63.3%). This simple
238. linear regression analysis shows that government issuing of regulation has been sensitive to burnt
239. area, with about two thirds of the total variation observed in the last four decades for the number
240. of issued regulations explained by a linear relationship with the average burnt area in the year of
241. publication and the previous year.

242. The majority of the governmental regulations that we analysed were published after 1996, and more
243. than one third after 2003. In the period from 1981 to 1985, the average annual number of new
244. regulations was above 2.5, while for the remaining periods the new regulation rate was lower.

245. Table 2 presents the evolution in time of the number of governments, ministers and directors of the
 246. national forest authority. We found that prior to the revolution in 1974, ministers changed more
 247. often than directors. Afterwards, the duration of the tenures of the directors decreased to 2 - 2.5
 248. years, and the initial instability in the ministerial appointments gave way to longer tenures of
 249. about 2 years on average. The periods of analysis were defined considering ruling political cultures
 250. and wildfire management milestones, as explained ahead in sub-section Chronology.

251. Content analysis results

252. Results from the content analysis are presented in three parts - problem framing, actions, and
 253. co-occurrence between frames and actions - using the relative frequency of segments (f/s) by
 254. category, and by time period. For an improved reading of results, we suggest using the Code
 255. dictionary (Appendix 2 Table A2.1). Only 4 regulations were found dated from 1910 to 1974, which
 256. were condensed in a period hereafter designated "before 1975".

257. *How was the problem framed?*

258. We found that the wildfire problem was mostly framed through *Reasons for intervention*. *Fire*
 259. occurrences and *Expressed values* were three to four times less frequent, and their frequencies
 260. decreased over time (Table 3).

261. Within the theme *Reasons for intervention*, we have found that the arguments have changed over time.
 262. The *Economic losses* and *Non-economic losses* segments were more frequent up to 1980, but their
 263. frequencies then decreased, particularly in the case of the former. Between 1975 and 1986, the
 264. frequency of segments coded as *Resource use* decreased, but regained relative importance in the last
 265. period. Segments coded as *Metapolicy* increased their frequency over time, and segments referring to
 266. *Law* and *System design* were only moderately frequent before 1980 and from 1986 to 1995.

267. Regarding *Fire Occurrences*, the preambles mostly referred to *Motivation*, except from 1981 to 1985,
 268. for which references to *Causes* were more frequent.

269. In the case of *Expressed Values*, *Economic* and *Non-economic* values were equally frequent throughout
 270. time, with the latter being more relevant from 1975 to 1980.

271. A deeper analysis of each category has revealed additional relevant details in the way the problem
 272. was framed, and the issues that were used to anchor views and arguments.

273. In *Reasons for intervention* (Table 4), for the period 1986-1995, we have found an increase in
 274. references to legal matters, both in the *Law* (e.g. "*On the other hand, it appears that the penalties*
 275. *provided in L 19/86, of 19 July, lack some adjustments*", in DL 334/90) and in the *Metapolicy* (e.g.

276. "in line with the policy objectives set out in the Basic Law on Forest Policy and continuing with
277. the main guidelines for structural reform of the forest sector", in DL 154/2004) sub-categories.

278. Under *Economic losses*, references to *Market* concerns (e.g. "Being, however, diagnosed a lack of
279. woody material necessary for the maintenance and development of our round wood industry", in DL
280. 368A/83), increased up to 1985 and then diminished. Issues related with the protection of the
281. *Forestlands* were more frequent in the period before 1975 and up to 1995, decreasing afterwards.

282. Regarding *Non-economic losses, People and Property* (e.g. "livestock and crops", in DL 12625/1926)
283. were the only two issues mentioned before 1975. After 1975 and up to 1986, *Property, Social* and
284. *Public trauma* were more frequent. After 2004, *Social, Public trauma* and *Environmental and cultural*
285. (e.g. "due to which there are already huge losses and risks for the population", in CMR 123/2004)
286. were the most mentioned topics.

287. Within the sub-category *Resource use, Timeliness* (e.g. "the need for urgent measures", in DL 170/76)
288. was the most frequent issue, except for the periods 1981-1985 and 1996-2003, when the need to
289. improve *Pre-suppression* and *Suppression* ranked as more frequent. Across all periods, the relevance
290. of *Prevention* improvement featured the lowest frequency as an argument for change.

291. Under *System design*, references to *Emerging players* were more frequent from 1975 to 1995, and
292. replaced by the need for *Institutional change* in subsequent periods.

293. Within *Fire Occurrences* (Table 5), under the direct causes of fire ignition, captured through
294. *Causes, the Negligent use* sub-category (e.g. "Whereas, for the most part, the fires were caused by
295. human factors, often by carelessness or negligence", in DL 327/80) was more frequently stated in the
296. period before 1975 and represented half of the segments that addressed fire causes in regulations
297. published after 1996 (e.g. "associated with negligent behaviors", in CMR 178/2003). However,
298. *Arsonist* was perceived as the major cause of fire (e.g. "... frequently criminal in nature", in DL
299. 327/80) between 1981 and 1995. *Natural causes* (e.g. "dry thunders storms...", in DL 306/2003) were
300. mentioned only in 1996-2003. Considering the *Motivations* sub-category, *Private owner behavior* (e.g.
301. "lack of forest management", in CMR 178/2003) and *Stakeholders behavior* (e.g. "...thus to sustain a
302. phenomenon driven by agents at the service of unmentionable interests whose broad outlines and main
303. beneficiaries we know", in DL 368/83) were relevant issues in 1975-1980 and to a less extent in
304. 1986-1995. *Increase in fuels* had a single segment before 1975, and another in 1986-1995 (e.g. "... a
305. fuel that contributes for the fire to spread with greater speed, making it difficult to control and
306. combat", in DL334/90), but was then mentioned three times after 2004. Before 1975, *Land Use*
307. *Planning*, which aimed to capture issues such as lack of planning, land tenure, or afforestation
308. options or techniques, was relevant. However, it is not mentioned from 1975 to 1985 and from 1996 to

309. 2003. Moreover, we have only found one reference to this issue in the period 1986-1995, and four
 310. times after 2004. The explanation of fires with *Meteorological* factors increased in relevance in the
 311. two last periods (e.g. "*Weather in June, July and August was favourable for fires*", in CMR
 312. 126/2004).

313. Overall, the results suggest that before 1975 fire occurrences were perceived as caused by
 314. negligence or unwise use of fire, and motivated by land tenure and landowner behavior. Arsonist and
 315. meteorological conditions were regarded as irrelevant. Conversely, from 1975 to 1995, arsonist and
 316. stakeholder or private owner behaviors were referenced to explain fires. From 1996 to 2013, fire
 317. occurrences seem to be explained by all causes (arsonist, natural and negligence) and land
 318. management issues became key motivations.

319. *Which were the most frequently proposed actions?*

320. Actions proposed as solutions were divided in five categories: *Planning*, *Prevention*,
 321. *Pre-suppression*, *Suppression* and *Rehabilitation*. Please see the definitions in the Code Dictionary
 322. in Appendix 2 (Table A2.1).

323. As shown in Table 6, *Planning* was the most frequently cited category in all time periods, followed
 324. by *Prevention* and *Rehabilitation*. The *Pre-suppression* and *Suppression* segments together represented
 325. less than 17% of the references, considering all the time periods. Before 1980, no references to
 326. *Pre-Suppression* were found, but they reached their maximum in the period of 1981-1985. The same
 327. pattern was found for *Suppression*, which featured minor relevance before 1975, no relevance from
 328. 1975 to 1980, and a peak around 1981-1985, diminishing after.

329. In a deeper analysis of *Planning*, we found that the references were mostly related with the
 330. establishment of *New entities and responsibilities* (27%), followed by *Legal and Law organization*
 331. (22%). All other issues, such as *Landowner engagement*, *Funding facilities*, *Research and development*
 332. or *Economic stimulus policy* represented together less than 23% of the coded segments, being less
 333. frequent in more recent periods. Before 1975, 33% of the segments were related to *Landowner*
 334. engagement (e.g. "*reinforce forest owners technical capacity*", in DL 63/2004) and *Economic policy*
 335. stimulus (e.g. "*financial policy instruments to give priority to forest planning and management*
 336. projects", in DL 17/2005). However, the number of references to those issues decreased to half in
 337. subsequent periods.

338. Most actions related to *Prevention* were focused on *Law enforcement* (between 38% and 80% of
 339. occurrences, depending on the period). *Education and information* (e.g. "*By strengthening public*
 340. information and awareness campaigns", in DL 423/93) was addressed in one-third of the actions, a
 341. proportion that decreased to one-fifth during the last period. *Fuel treatment* started to be

342. mentioned after 1986, with the majority of segments concentrated in the last period (e.g. "to
343. implement fuel management treatments in strategic areas", in DL 124/2006).

344. Under *Pre-suppression*, sub-category *Coordination* (e.g. "The intervention of the Government members
345. responsible for the services most directly involved in the prevention, detection, surveillance and
346. control of forest fires is foreseen in order to obtain better coordination.", in CMR 9/91) emerged
347. as the most relevant action, accounting for 48% of the overall occurrences. Nonetheless, before 1980
348. no references to this issue were found. Its peak was observed in the 1986-1995 period, and was
349. followed by a gradual reduction. *Infrastructure* and *Detection* had similar overall references, and no
350. clear pattern of variation over time.

351. In category *Suppression* (e.g. "requiring the intervention of the administrative authorities,
352. supported, though, by all liable entities, namely to forest services, that are made responsible from
353. technical guidance", in DL 488/70) was mostly referred to during the 1981-1985 period, and after
354. 2004.

355. Finally, within *Rehabilitation*, actions were mostly focused on *Compensation* (e.g. "they should be
356. compensated for the amounts involved", in DL 401/83) and *Reforestation* (e.g. "actions leading to
357. reforestation of the burned areas", in CMR 106B/2003). *Compensation* was mentioned in all periods,
358. more frequently in the 1981-1985 and 1996-2003 periods. References to *Wood yards* (e.g. "the
359. Administration may open temporary reception sites [of salvaged burnt timber] in places where the
360. installation is considered essential.", in CMR 363D/79) were more frequent (33%) in 1975-1980, and
361. references to *Damage evaluation* (25%) during 2004-2013.

362. *Co-occurrences between frames and actions*

363. When framing the problem through *Reasons for intervention*, 86% of the regulations that mentioned the
364. need for *Institutional Change* (references to any specific change in existing institutions, such as
365. the creation of new entities, fusion of existing ones, etc.), the actions preferably recommended
366. were *New entities and responsibilities*, as well as *Law enforcement* (50%). *Creation of new entities*
367. was also commonly mentioned in the regulations that considered *Resource use* (references to the lack
368. of human or material resources or to their ineffectiveness) as a major *Reason for intervention*
369. (71%), as well as *Suppression* (57%). When the problem was framed as *Public trauma* (54%) (e.g.
370. "affecting entire populations", in CMR 160/2005) or *Rehabilitation* (55%) (e.g. "to speed up the
371. normalization of life in communities and families that were victims of fires", in CMR 126/2004),
372. *Compensation* was envisioned as a possible action.

373. When the problem was framed through *Fire occurrences*, *Law enforcement* seems to have been a
374. frequently proposed action (e.g. "Fines have increased by about 40%, adjusting to the economic

375. reality and the due proportion of protection and forest." in DL 124/2006). *Law enforcement* was also
 376. a frequent option (43%) when fire was framed as associated with *Negligent use*, as well as when
 377. *Private owner behavior* was perceived as a major cause (60%). If the fire problem was framed as due
 378. to *Meteorological conditions*, *Compensation* was perceived as an adequate action, whereas if the
 379. problem was framed as *Increase in fuel* (60%), *Land use planning* (40%) and *Arsonist* (30%), we found a
 380. tendency to focus the actions on the creation of *New entities and responsibilities* (e.g.
 381. "*possibility of establishing specialized teams*.", in DL 179/199).

382. **Institutions, actor network, multilevel interaction and governance modes**

383. *Evolution of institutions: From single to multiparty organization*

384. From 1910 to 1938, fire events in rural, forest, or shrubland areas owned or managed by private
 385. owners and local communities (97% of land tenure) were dealt with directly by the rural population.
 386. The coastal national forests, as well as the Gerês, Estrela, and some other state-managed
 387. forest in the mountains, were an exception where, according to Almeida (1904, 1929) and Sousa
 388. (1926), a formal and professional wildfire management system was in place. The State Forest Service
 389. (FS) personnel were engaged only when afforestation projects were threatened. No information or
 390. reports were found that reliably describe the number or extent of wildfires in this period. However,
 391. according to Dias (1958) and Vieira (2006: 68-74), from 1910 to 1950 large wildfires were uncommon
 392. events, as most of the landscape had a patchy mosaic with low levels of fuel, which was intensively
 393. used or controlled by the forest owners and villagers (through gathering biomass for domestic uses,
 394. grazing, resin tapping, etc.)

395. From 1938 to 1954, fires in the majority of the country were fought by villagers, with the support
 396. of the FS when nearby public forests or afforestation projects were being threatened, local
 397. volunteer firefighters (LVF) when available, or the Army in the case of extreme events (Pinto 1943,
 398. FAO 1953). Forest fire statistics on state managed lands started to be produced (1943) and a new
 399. regulation for forest rangers and forest lands under the forest regime (DL 39931/1954) extended the
 400. scope of the prevention and suppression activities of the FS to an external buffer of up to 3 km, to
 401. protect the investments promoted by the National Afforestation Plan (1938-1972). That would expand
 402. to cover 22% of country by 1980, mostly in the North of Portugal (Appendix 3 Fig. A3.1). We have
 403. identified the existence of a formal command and control system within this buffer area, staffed
 404. with forest officials, forest guards and rural workers employed by the FS, with pre-suppression
 405. structures in place (lookout towers, forest roads and fuel breaks) and a suppression system
 406. operating effectively (Silva 1995, Dias 1955, Dias 1964, Nogueira 1983), managed at a regional and
 407. sub-regional level. Nevertheless, according to Dias (1958), the 1957 fire season, with more than
 408. twice the burnt area (8000ha in private and public land) of previous years, sparked a reflection

409. about the need to reinforce human resources, manage the growing fuel loads and continuities, and
410. execute more firebreaks (Quintanilha 1958).

411. After unprecedented fire seasons (1962/63 and 1965/66), with significant human losses, which raised
412. some discussion in the National Assembly (AN 1962-1969), a high level inter-ministerial commission
413. was created in 1963 (Neves 1970). We were not able to find the report produced by that commission,
414. but following this debate Quintanilha et al. (1965) presented a set of strategies and solutions that
415. were later published under regulation DL 488/70, establishing for the first time a national wildfire
416. system. The initial paragraph of this regulation recognized complexity and private ownership as the
417. relevant issues that were driving the system: "*The prevention, detection, and fighting of forest*
418. *fires are of extreme complexity, given their multiple implications. This is why it is recognized, at*
419. *least in relation to private forest ownership, that there is a need for concerted action by various*
420. *entities, including the FS, which ought to play a role of primary importance*". In our content
421. analysis, both segments were classified under the frame category *Reasons for intervention* and the
422. sub-category *System design*.

423. This regulation was in implementation until 1980/81, when it was replaced by the new regime created
424. under DL 327/80. According to its preamble, the need to change was due to "*Considering as well that*
425. *firefighting needs to be based on an articulated and conjugated system, in which the efforts of*
426. *multiple official and private entities are coupled and coordinated in order to mitigate the*
427. *consequences...*" Although we were unable to find any technical documents supporting this change,
428. which was sparked both by the Carnation Revolution of 1974 and the disastrous 1975 fire season, the
429. discussion reached the Parliament. Opposing arguments were offered, defending the increase in the
430. resources to implement prevention activities, as imposed by DL 488/70, or defending the urgent need
431. of limiting fire losses through suppression, taking advantage of the existence of LVF and the
432. forthcoming firefighting and civil protection systems, which were not in place to handle the task,
433. as recognized by their leaderships (vote declaration from one of the parties). With the new
434. regulation approved by a large majority, the wildfire management system responsibilities were
435. divided by two agencies: FS kept prevention, law enforcement, and detection, and the National
436. Firefighters Service (NFS) and LVF hereafter became responsible for suppression.

437. During the 1981-1985 period, the approved transfer of knowledge and responsibilities did not occur
438. (Nogueira et al. 1984), and FS kept managing aerial and other firefighting resources up to 1985, as
439. LVF units fought wildfires on the ground, under the regional and national coordination of NFS (and
440. CPS). As a proxy of this effort, we found that the number of fixed wing engines doubled from 1985 to
441. 1986 and the number of helicopters tripled in 1991 (Appendix 3 Fig. A3.2),

442. Since 1981, municipalities were made responsible for planning actions within local fire councils. In

443. 1987, a national entity - CNEFF - was created under CPS to coordinate the prevention efforts of
444. municipalities, namely in infrastructure, education and research (CMR 30/87). Up to 1991 it worked
445. only with private funding from pulp companies (CESE 1996), but when placed under the direct
446. responsibility of the Minister of the Interior (CMR 9/91), public funding sponsored several
447. infrastructures (helipads, airfields, water reservoirs and forest roads), education campaigns and
448. pre-suppression pilot projects. In 2003, CNEFF was merged with the NFS and CPS, forming the National
449. Civil Protection Authority (NCPA).

450. After the extremely severe 2003 fire season, a forest reform was launched by the Minister of
451. Agriculture and approved by the Government through the CMR 179/2003. A new regulation (DL 156/2004)
452. reorganized the wildfire management system, a forest prevention-focused fund (Permanent Forest Fund,
453. FFP in Portuguese) was finally established by DL 63/2004, and the new system was coordinated by a
454. new state agency within the Ministry of Agriculture (APIF - DR 5/2004). Several other regulations
455. that fostered planning initiatives and landowner engagement were also created (Soares and Oliveira,
456. 2005), some of which (like the "forest intervention zones") had been first proposed in the 1960s and
457. 1970s and postponed after the Parliament debate on forest fire in 1980-1981 (Pinho, 2014).

458. Although references to lives and properties being threatened by wildfires are available since the
459. 60s, as well as mandatory guidelines for fuel treatments around houses and infrastructures since
460. 1981, the wildland urban interface (WUI) was stressed for the first time as a strategical issue by
461. Beighley and Quesinberry (2004), as it was harnessing the engagement in the protection of forest
462. resources of LVF, who would leave fires unattended. Despite the fact that the technical proposal for
463. the National Fire Protection Plan recommended the creation of an organization dedicated to
464. prevention and suppression in forests, in accordance with the Forest Policy Act (L 36/96), political
465. decision makers chose instead to refit pre-suppression and suppression. NCPA was empowered, the
466. century-old FS forest guards corps extinguished, professional firefighting units were created in the
467. National Republican Guard (NRG) and in NCPS, and forest fire detection and law enforcement were both
468. transferred from FS to the NRG (DL 124/2006). Since then, three agencies have shared the
469. responsibility for the management of the wildfire system: FS for prevention and infrastructures, NRG
470. for surveillance, law enforcement and detection, and CPS for suppression.

471. *Actor network: Exiting of experienced actors and emergence of rookies*

472. Urbanization, emigration to Europe and the colonial war (from 1961 to 1974) promoted a rural exodus,
473. and labour for fire prevention and suppression became scarce, as acknowledged in the preamble of DL
474. 488/70. With this farmer exodus, the numbers of cattle, goat and sheep heads also decreased (Brouwer
475. 1995).

476. After the 1974 revolution, which replaced the dictatorial regime, the first national elections were
477. held, and in 1976 a new Constitution was approved. In 1976, national, regional (in Azores and
478. Madeira), municipal, and parish representatives were freely elected and a new model of communal land
479. management was established (representing more than 75% of the area under the jurisdiction of FS).

480. After the 1975 fire season, LVF claimed for more resources and their Union (Liga dos Bombeiros
481. Portugueses - LBP) gained momentum in 1980 (DL 327/80), later on becoming a relevant stakeholder
482. within CPS and NFS (CMR 83/85). Also at a local level, after 1981 the municipalities established
483. wildfire councils in which local actors were represented. Municipalities became more relevant after
484. 1986, as the National Association of Municipalities acquired political power in the legislative
485. process (Lobo, 2005) and in the above mentioned CNEFF.

486. The national parks and nature reserves, established after 1970 under FS jurisdiction, were
487. transferred in 1985 to the Ministry of Environment, and simultaneously a new network of parks and
488. conservation areas had been established after 1975 by the National Park Service (created under the
489. Secretary of State for the Environment). The non-governmental environmental movement led its first
490. national campaign against nuclear energy in 1976, and in support of the Iberian lynx protection
491. efforts, against afforestation, in 1978 (Schmidt 2009).

492. The World Bank Forest project (19080/1981) promoted afforestation, jointly with European
493. afforestation programs (Portugal joined the European Economic Community - EEC - in 1986). In the
494. meantime, the capacity of FS to devote staff to protection programs diminished (AFN 2012). After
495. joining the EEC, agriculture lost political, economic, and demographic importance in Portuguese
496. society. Notably, the first forest owners associations (mainly cooperatives) were established in the
497. 70s and only flourished in the 90s (Louro, 2016). Table 7 presents a summary of exit and emerging
498. actors.

499. *Multilevel interaction: From single to triple command*

500. Based on the previous subsections, Fig. 5 illustrate the magnitude of the prevention,
501. pre-suppression, and suppression efforts of all entities, with proportional arrow widths and circle
502. radiuses to describe the evolution of the organizations that handled the wildfire problem. It shows
503. how Public administration dispersed its responsibilities from a single command (with prevention and
504. suppression efforts managed together) to a tri-party organization. We found that the system expanded
505. geographically as the problem was worsening, encompassing the incoming threat. In the meantime,
506. vertical dispersion also occurred, as local entities were first engaged in suppression, and later
507. took more responsibility in planning and prevention. Between 1981 and 1985, CPS and NFS became fully
508. responsible for suppression, and districts and municipalities became more engaged in planning,

509. adding a multilevel dimension to the system. As the need for coordination of new infrastructure
 510. development was felt after 1985, a national organization (CNEFF) was created, and its role was
 511. reinforced in 2004 and 2006 with APIF. With the political decision in 2006 to bring in the NRG for
 512. law enforcement and detection improvement, the system had now a triple command in four vertical
 513. levels.

514. *Governance modes*

515. Up to 1938, as described above, wildfires were mostly handled informally by rural populations at a
 516. local level, as a hierarchical and formal system covered only a small proportion of the country (2%
 517. - 5%) and expanded up to 1980 to cover about 22% of the country. When available, this system helped
 518. farmers, herders, villagers, and LVF to protect their private forests, properties and lives when
 519. threatened by fire.

520. After 1980, CPS and NFS became responsible for suppression operations Wildland fire risk management
 521. moved its focus to civil protection. Top resources were focused in coordination and command tasks of
 522. informal spatial network of more than 400 LVF (humanitarian and associative organizations), local
 523. stakeholders and private and non-governmental forest actors. Only after 2006, when CFS and NFS
 524. became a unique agency (National Authority for Civil Protection - NACP), a nation-wide hierarchical
 525. command and control extended to all LVF (DL 134/2006).

526. **Chronology**

527. During the period covered by our analysis, spanning from 1910 to 2013, several international and
 528. national drivers and events shaped political contexts and regimes, and the ruling cultures within
 529. which wildfire risk governance was established. Based on the analysis of an extensive set of
 530. documents (Table 1), we developed a chronology that describes, for each time period, the external
 531. context, major forest and fire milestones, the way the fire problem was framed and the solutions
 532. that were adopted (Appendix 4, Table A.4.1)

533. As presented previously in Table 2, we have found nine time periods. The first one starts with the
 534. 1st Republic (1910) and ends with the military coup d'état of 1926. Hereafter, a military
 535. government set the stage for a dictatorial regime that lasted 48 years, a period that we divide in
 536. three parts: up to 1938, as the autocratic regime set in and the communal lands survey was executed;
 537. since 1938, with the beginning of the national afforestation plan, and up to 1962; from 1963, when
 538. the occurrence of severe fires called the attention of national leaders and prompted a reflection
 539. and, at the same time, the "agriculture crises" paved the way to a higher public investment in the
 540. afforestation of private infertile and degraded agricultural lands (Gomes 1969), to 1974, when the
 541. revolution occurred. The following period starts with the 1974 revolution and first democratic

542. elections (1975) and ends in 1980, when fire management responsibilities were moved from the FS to
543. civil protection and firefighter organizations, ending the single and formal command ruling
544. structure, at least in the most heavily forested regions in northern and central Mainland. Because
545. we have found a transition process regarding resources and duties, we set here another period of
546. analysis from 1981 to 1985. The next period starts when the country joined the EEC, in 1986, and
547. ends in 1995, after two consecutive governments that ruled with the support of a large parliament
548. majority. According to Lobo (2005), this period set a new paradigm, as the elected government
549. consolidated the role of the Council of Ministers and its legislative process. The period that
550. starts in 1996 ends in 2003, in the aftermath of the country's worst fire season. Starting with the
551. subsequent fire management changes in 2004, the following period extends until 2013.

552. **Learning cycles and critical risk governance deficits**

553. Using the findings described above and relying on the characteristics suggested by Pahl-Wostl
554. (2009), we assigned to each period of our chronology the level of learning that we found to have the
555. best fit. The key characteristics of change observed are summarized in Table 8, and a detailed
556. description is presented in Appendix 5.

557. Through the lens of risk governance, analyzing the results from the content analysis, chronology and
558. learning cycles, we have identified and present in Table 9 some hypotheses for critical risk
559. governance deficits (IRGC, 2009) in the scope of frames and actions.

560.

DISCUSSION

561. Our results show that governments are sensitive to the outcomes (measured as burnt area) of fire
562. seasons, as a strong relation exists between the number of issued regulations and the burnt area
563. two-year moving average, suggesting that the wildfire problem governance is crisis-driven. This
564. finding is in line with Fernandes et al. (2016).

565. The production of regulations by the government was found to be higher in the period after 2004. The
566. system changed twice, and the average time in office for ministers and directors decreased. This
567. finding is in line with the observations of Mateus and Fernandes (2014) that associate this rotation
568. to the instability in pursuing wise and balanced wildfire public policies in Portugal. Prior to
569. 1974, the wildfire governance system produced less than four regulations and relied on
570. administrative stability to implement regulations. Conversely, after 1974, regulation expanded and a
571. higher instability in institutional management settled in.

572. The results of our content analysis suggest that all governments react by providing compensations

573. for losses (including wood yards in the worst years), promoting reforestation and increasing
574. penalties for negligent or arsonist fires. The least preferred solutions were actions that fostered
575. the engagement of private forest owners and placed restrictions on harvest operations and timber
576. markets (these only occurred prior to 1985, when the country was not yet a member of the EEC). Since
577. 1989, land use planning emerged as a solution, and forest and fire plans became prominent after
578. 2004.

579. Some of the above patterns were found to tend to co-occur with specific problem framings, when
580. considering the whole period of analysis, e.g., when fire occurrences were perceived as arson, the
581. actions would tend to include law enforcement, and when stakeholder behavior was referred to as
582. motivation for fires, the actions would tend to focus on land use planning and zoning, and economic
583. stimulus policy.

584. In the period between 1975 and 1986, arson was the most frequently mentioned cause, and associated
585. with the stakeholder attitude to push timber or properties prices down. As a consequence of this
586. problem framing, and to discourage such intended use of fire, government actions focused on ruling
587. timber markets and harvesting, establishing wood yards and reviewing the penalties. In the period
588. from 1986 to 1995, arson also featured the highest frequencies, associated with coded segments
589. mentioning stakeholder and forest owner motivations. However, in this period, the coded segments
590. refer to land use conversion as the alleged motivation for arson, with governments therefore
591. reacting by ruling land use planning and zoning.

592. Regulation preambles barely mention the increase in fuel load, which is referred to only once in the
593. period before 1975, once again in the 1986-1995 period, and then three times after 2004. Evidence of
594. fuel accumulation due to agricultural abandonment and lack of fuel treatment in forestlands, has
595. existed at least since the work of Quintanilha et al. (1965). At the time, the forest authority was
596. aware of the phenomenon, and consequently regulation DL 488/1970 acknowledged that critical issue in
597. its first paragraph (see the Results section). Notably, and in spite of the existence of technical
598. reports (Silva 1986) and research (Rego 1992) on fuel accumulation, only after more than 20 years
599. did the issue emerge again, in 1990, to fade again thereafter, and re-emerge in 2003. Considering
600. its relevance, why did government regulations not include it, when framing the problem? Were there
601. other actions, such as populist measures against arsonists, or improvements to detection,
602. infrastructures or suppression, easier to implement and featuring a more positive public impact, in
603. time for the following elections? Or did wildfire doctrine and beliefs undermine this driver? Or was
604. technical evidence absent from the debate prior to the issuing of regulations?

605. Over time, the expression of the values associated with the forest and the perceived fire causes
606. lost relevance, and reasons for intervention grew even more important. We hypothesize that this

607. might be related with the higher number of regulations that were issued after 1986, and the fact
608. that segments considering reasons for intervention reflected operational needs that were emotionally
609. conveyed in the decision-making process. The same may hold for the higher frequency that relates
610. fires with meteorology.

611. References to European regulations (captured under the Metapolicy category) increased over time, and
612. tend to co-occur with solutions that created new entities and responsibilities. As national and
613. international institutions became more relevant, regulations from other sectors, e.g. environment,
614. land use planning and economic development, began to interact with forest and fire issues.

615. To accommodate external pressures toward the system (environment, landowners, emerging actors, and
616. public opinion), governments issued four legal regimes (in 1970, 1980, 2004, and 2006) that changed
617. the system structure and the way risk was handled. As illustrated in Fig. 5, the wildfire risk
618. management system was initially commanded and controlled by a single National organization that
619. protected regions with public and communal forest lands through a formal process, while in most of
620. the country an informal system (rural populations) fought fires. Over time, political culture and
621. the social and ecological context changed. Some actors partially left and new actors entered the
622. system, which evolved to a multi-agency structure, with the participation of public and private
623. actors, and the presence of operational planning and coordination in all levels. Indeed, we observed
624. that from 1981 to 1995 the emergence of new players triggered the creation of a coordinating entity.
625. After 1985, the results from our content analysis reveal an increase in the frequency of references
626. to solutions that promote coordination (1987), fire plans (1993), regional forest plans (1996), and
627. the national fire protection plan (2004). The operational system evolved to encompass other players
628. (NRG and private forest owner organizations), but operational responsibilities were fragmented in a
629. slack command and control mode.

630. Through time we found that the system evolved from incremental, reframing and transformational
631. loops, reacting to crises, and solutions supported by the actors were crafted as a direct, almost
632. linear, consequence of the framing. A transformational loop occurred only once (1980-1985), when the
633. civil protection paradigm replaced the forest approach and new actors set a new centrality and
634. priorities. Although new ideas emerged and presented alternatives views, subsequent crisis in 2003,
635. 2005 or 2013 could not trigger yet, another transformation loop that balance risk governance
636. trajectory towards forest protection..

637. The physical or ecological context also changed dramatically since the 60s (Oliveira et al. 2017),
638. but from our analysis, we found that rural abandonment and fuel accumulation issues were absent from
639. the framing of the fire problem from 1975 to 2003. That knowledge was available, but was not
640. conveyed to decision makers. Wildfires were instead mistakenly regarded as a consequence of a

641. growing number of ignitions, lack of surveillance and patrolling, poor detection, lack of
642. suppression resources, land use and forest planning or landowner behavior. Consequences were
643. erroneously identified as causes, as simple and linear explanations and quick fixes and panaceas
644. dominated the discourse. Unrealistic expectations regarding suppression, linear thinking, and the
645. neglecting of the complexity and the socio-economic drivers of forest transition processes, may have
646. paved the way for the system to evolve upon simple solutions that "abruptly" failed in 1985, 1991,
647. 2003, 2005, 2013 and 2016, in spite of the growing capacity to detect and suppress fires. From the
648. above, we argue that the system moved towards a more complex organization, in which risk is handled
649. through a multi-agency structure with different value priorities (human lives vs forest goods and
650. environmental services) and political leverage (urban vs rural voters). This path has also been
651. observed in the US, Australia, and southern European countries, including France, Greece, and Spain
652. (Velez 2006). As in those countries, technology-based solutions using aerial and terrestrial
653. mechanical and hydraulic suppression were adopted, within the spirit of a culture and doctrine
654. focused on extinguishing all fires. This drove the system to reinforce aerial and terrestrial
655. resources and to rely on pre-suppression and suppression, undermining fuel treatments programs
656. (Collins et al. 2013).

657. Our results also show that over time non-economic losses replaced economic losses as reasons for
658. intervention, with social and environmental issues being frequently referred to in more recent
659. years. This is in line with the escalating threat that wildfires represent in rural and urban
660. interfaces in Portugal (ISA-APIF 2005), and the growing environmental awareness of Portuguese
661. society (Schmidt 2009). These findings are also in line with fuel management and value-orientation
662. trends observed in the public debate in the US, also using content analysis (Bengston 2004). The
663. growing problems in the wildland urban interfaces in fire prone regions (California, Southern
664. France, Catalonia, Greece, or Australia) are challenging fire organizations (Gill et al., 2013) as
665. anticipated for Portugal by Beighley and Quesinberry (2004). Over time, risk managers and decision
666. makers have been challenged to simultaneously protect forest, environment, life, and properties. We
667. hypothesize that this diversity drove the risk handling system to escalate from a simple problem to
668. a complex and ambivalent problem. To illustrate this evolution, we adapted the risk escalator
669. framework suggested by the IRGC (2005) to the Portuguese wildfire problem (Table 10).

670. We collected extensive historical documentation and built a legislative database with all wildfire
671. regulations, to describe how wildfire risk governance evolved. In the future, in the fields of
672. public policy (e.g., using coalition analysis, or punctuated equilibrium), resource governance
673. (e.g., supporting the framework of Ostrom 2009), political sciences or new institutional economics
674. (e.g., as illustrated for Galicia in Spain by Cabalero, 2015), explanations may be developed for the
675. path that we found and documented. Further work could also move beyond the analysis of

676. co-occurrences, to explore segment correlation using statistical methods, e.g., to examine how
677. coding frequency is related with the evolution of the use of aerial resources, among other relevant
678. questions.

679. Nalau and Handmer (2015) have discussed the limitations of established operational processes when
680. approaching complex disaster risk management events or processes, advancing the need of shifting the
681. focus to incremental evolution. Governance issues have had an important role in explaining the
682. timing and magnitude of forest expansion in developed countries (Barbier and Tesfaw 2015), but few
683. studies have examined quantitatively how modern society has reacted and adapted its risk management
684. systems when faced with an escalating fire problem. Analyzing a global dataset of natural disasters,
685. Raschky (2008) showed that countries with higher income and experienced institutions had fewer
686. losses. If the maintenance of forest cover is critical for climate change mitigation efforts and the
687. threat from wildfires is escalating, it is important to understand how systems that are expected to
688. maintain losses from fire within "acceptable" boundaries adapted and evolved in response to previous
689. socio-technical and ecological context changes.

690.

CONCLUSION

691. Our results suggest that as wildfire threatened ambivalent values (lives, infrastructure, and
692. forests), the emergence of influential stakeholders helped to shape the wildfire risk management
693. system, its focus, and organization roles and capabilities. Our analysis led to the conclusion that
694. a simple risk problem that was being managed in part through a formal organization up to 1960,
695. escalated to a complex and ambiguity-ridden risk problem over time, with the participation of
696. multiple stakeholders shaping the system evolution.

697. Since the problem of fuel accumulation in private areas was not fully addressed by the fire risk
698. management system designed in the 60s and 70s, due to the lack of resources under the changing
699. political and social culture, the system failed to include prominent and influential stakeholders,
700. and providing a short-term solution. With the crises originated by worsening fire seasons in the
701. late 70s and early 80s, political leadership redesigned the way fire risk was handled. From this
702. point forward, the framing of the problem misrepresented the dynamics of socio-ecological processes
703. that exacerbated fuel accumulation. With a reactive top-down government approach focused on tackling
704. the consequences of the problem, instead of the causes, linear and simple solutions were adopted and
705. the system was captured in the "wildfire suppression firefighting trap". The transformation loop in
706. the 80s twisted the system to satisfy civil protection paradigms and undermined forest protection.
707. Upon the failure (from a forest perspective) of the evolution path, the next wildfire crisis could

708. be an opportunity for recognizing that ecological context had changed and thus set a transformation
 709. loop, for the system to deliver different results.

710. As decision making is strongly biased by risk perceptions of lay people, robust science could have a
 711. role in helping foster an evidence-based framing process. We raise the hypothesis that critical
 712. governance deficits hindered the emergence of a cohesive system able to perform effectively through
 713. time, guaranteeing a low fire risk exposure to forests, property, and lives, in both rural and urban
 714. interfaces. From the analysis of risk governance evolution, and in the face of the escalating
 715. complexity and ambiguity ahead, upon IRGC's recommendation (IRGC 2005), we suggest the reinforcement
 716. of the system with an umbrella leadership council empowered with risk communication capabilities,
 717. capable of unlocking misconceptions through science, developing pilot projects, and fostering the
 718. diffusion of best practices in risk governance.

719.

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Table 1. Summary of collected documents

	1910 - 1925	1926 - 1937	1938 - 1962	1963 - 1974	1975 - 1980	1981 - 1985	1985 - 1995	1996 - 2003	2004 - 2013	Total
Laws and regulations	0	2	2	1	10	14	23	12	70	134
L			1		1	2	5	1	5	15
PRtG							1		13	14
PR									4	4
DL		2	1	1	8	5	11	6	25	59
CMR					1	7	6	5	23	42
Other documents	2	3	22	17	6	16	29	18	72	183
Research paper				1		1	7	3	30	42
Book or chapter			2	2	1		2	2	16	23
Essay	2	3	4	7	1	3	5	1	3	27
Official working paper			2		3	2	3	2	3	19
Technical report			14	7	1	10	12	10	20	72
Total	2	5	24	18	16	30	52	30	142	317

Table 2. Number of regulations, burnt area, number of Governments, and average durations of minister and forest director appointments, by period of analysis

	1910 - 1925	1926 - 1937	1938 - 1962	1963 - 1974	1975 - 1980	1981 - 1985	1985 - 1995	1996 - 2003	2004 - 2013	Total
DL + CMR		2	1	1	9	12	17	21	38	101
Years	16	12	24	11	6	5	11	8	10	104
Regulations/yr		< 1			1.5	2.5	1.5	2.7	3.8	59
Brunt area (1000 ha)	na	na	na	na	346	590	1063	1212	1061	4272
Annual mean burnt area (1000ha)					58	118	106	152	1066	110
# governments	45	1	1	1	12	2	3	3	4	
Average duration of Minister appointment (yr)	0.2	0.8	3.4	1,6	0.6	1.3	2.8	2.7	2.0	
Average duration of Director appointment (yr)	7.5	4.0	12.0	5.5	2.0	2.0	2.2	2.7	1.7	

Table 3. Segment frequencies for problem framing categories and sub-categories by period of analysis

Coded segment	< 1975		1975-1980		1981-1985		1985-1995		1996-2003		2004-2013		All periods	
	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)
Theme: Frame														
Expressed values	7	19	4	9	7	10	8	13	5	7	14	7	45	9
Economic	3	43	1	25	5	71	4	50	2	40	8	57	23	51
Non-economic	4	57	3	75	2	29	4	50	3	60	6	43	22	49
Fire Occurrences	8	22	3	7	8	11	12	20	7	10	22	10	60	12
Cause	3	38	1	33	5	63	4	33	2	29	4	18	19	32
Motivation	5	63	2	67	3	38	8	67	5	71	18	82	41	68
Reasons for intervention	22	59	39	85	57	79	40	67	58	83	178	83	394	79
Law	4	18	2	5	5	9	8	20	7	12	10	6	36	9
Metapolicy	2	9	2	5	7	12	5	13	14	24	37	21	67	17
Economic losses	6	27	12	31	12	21	10	25	12	21	32	18	84	21
Non-Economic losses	5	23	10	26	11	19	5	13	9	16	44	25	84	21
Resource use	2	9	8	21	19	33	7	18	11	19	45	25	92	23
System design	3	14	2	13	3	5	5	13	5	9	10	6	31	8

Table 4. Code frequencies under the Reasons for intervention category by period of analysis

Coded segment	< 1975		1975-1980		1981-1985		1985-1995		1996-2003		2004-2013		All periods	
	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)
Reasons for intervention														
Law	4	18	2	5	5	9	8	20	7	12	10	6	36	9
Metapolicy	2	9	2	5	7	12	5	13	14	24	37	21	67	17
Economic losses	6	27	12	31	12	21	10	25	12	21	32	18	84	21
Market	1	17	4	33	5	42	2	20	3	25	3	9	18	21
General	2	33	4	33	1	8	2	20	1	8	13	41	23	27
Burnt areas			1	8	2	17	2	20	6	50	11	34	22	26
Forestlands	3	50	3	25	4	33	4	40	2	17	5	16	21	25
Non-Economic losses	5	23	10	26	11	19	5	13	9	16	44	25	84	21
People	3	60	1	10	3	27			4	44	9	20	20	24
Property	2	40	4	40	3	27			2	22	11	25	22	26
Social			2	20	1	9	1	20	1	11	8	18	13	15
Public trauma			2	20	3	27			1	11	8	18	14	17
Environ. & cultural			1	10	1	9	4	80	1	11	8	18	15	18
Resource use	2	9	8	21	19	33	7	18	11	19	45	25	92	23
Prevention					1	5			1	9	7	16	8	9
Pre-suppression			1	13	6	32	2	29	4	36	6	13	13	14
Suppression	1	50			4	21			3	27	8	18	12	13
Rehabilitation			2	25	3	16	1	14			5	11	8	9
Timeliness	1	50	5	63	5	26	4	57	3	27	19	42	32	35
System design	3	14	5	13	3	5	5	13	5	9	10	6	31	8
General	1	33							2	40	5	50	8	26
Emergent player	1	33	4	80	3	100	5	100			1	10	14	45
Institutional change	1	33	1	20					3	60	4	40	9	29

Table 5. Code frequencies under the Fire occurrences category by period of analysis

Coded segment	< 1975		1975-1980		1981-1985		1985-1995		1996-2003		2004-2013		All periods	
	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)
Fire Occurrences														
Causes	3	38	2	50	5	63	4	33	2	29	4	18	20	33
Arsonist	1	33	1	50	4	80	3	75			2	50	11	55
Natural									1	50			1	5
Negligent	2	67	1	50	1	20	1	25	1	50	2	50	8	40
Motivation	5	63	2	50	3	38	8	67	5	71	18	82	41	67
Stakeholders behavior			1	50	1	33	2	25			1	6	5	12
Private owners behavior	1	20	1	50	1	33	1	13			1	6	5	12
Increase fuel loads	1	20					1	13			3	17	5	12
Land use planning	2	40					1	13			4	22	7	17
Meteorological	1	20			1	33	3	38	5	100	9	50	19	46

Table 6. Code frequencies under the Solution proposed category by period of analysis

Coded segment	< 1975		1975-1980		1981-1985		1985-1995		1996-2003		2004-2013		All periods	
	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)	#	f/s (%)
Theme: Actions														
Planning	6	40	15	63	16	36	18	56	23	58	68	54	146	52
Coordination							1	6	1	4	6	9	8	5
Funding facilities					2	11					4	6	6	4
Applying knowledge			4	27	1	6	1	6			2	3	8	5
Planning Land use zoning			1	7	5	28	4	22	3	13	12	18	25	27
Research & Development	2	33	1	7	2	11	1	6	1	4	1	1	8	5
Landowners engagement	1	17	1	7	1	6	3	17	2	9	6	9	14	10
Economic policy stimulus	1	17	1	7	1	6			1	4	1	1	5	3
Legal and law organization	1	17	2	13	3	17	3	17	7	30	17	35	33	23
New entities and responsibilities	1	17	5	33	1	6	5	28	8	35	19	28	39	27
Prevention	6	40	3	13	5	11	8	25	2	5	21	17	45	16
General					1	20	2	25	1	50	2	10	6	13
Law enforcement	4	67	2	67	4	80	3	38	1	50	10	48	24	53
Fuel treatment							1	13			5	24	6	13
Education & information	2	33	1	33			2	25			4	19	9	20
Pre-Suppression					5	11	3	9	4	10	13	10	25	9
Coordination					3	60	2	67	2	50	5	38	12	48
Infrastructures					1	20			1	25	5	38	7	28
Detection					1	20	1	33	1	25	3	23	6	24
Suppression	1	7			8	18	1	3	1	3	11	9	22	8
Rehabilitation	2	13	6	25	10	23	2	6	10	25	12	10	42	15
Reforestation	1	50	1	17	1	10	1	50	1	10	3	25	8	19
Wood yards			2	33	1	10			1	10			4	10
Damage evaluation					1	10			2	20	3	25	6	14

(con'd)

Compensation	1	50	3	50	7	70	1	50	6	60	6	50	24	57
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Table 7. Exiting and emerging actors

	Existing actors	Emerging actors
60s	Self-sufficiency farming and forest management Traditional cattle, goat, and sheep herders	FS modern forest fire prevention/suppression teams in regions with public lands
70s	Autocratic ruling	National and local democratic elections Public environment agency and Non-Governmental organizations National Firefighters Service and Civil Protection Service Free media
80s	Central planning Forest Service wildfire expertise	Wildfire urban interface Market economy Pulp companies with wildfire system European Economic Common regulation and funding Rural development program and common agriculture policy Wildfire scientific community
90s	Forest service technical and administrative capacity towards active land management	Forest owners association Forest prevention and suppression teams under forest owners association, local authorities and communities
2000s	Extinction of the National Forest Guards Corps	National Republican Guard

Table 8. Learning cycles identified

Key characteristics of change	Single - loop	Double - loop	Triple- loop
1910 - 1962	Incremental improvements in established routines and system expansion to protect mountain afforestation investments		
1963 - 1974		Multilevel interactions increased and problem was reframed and forest protection reinforced	
1975 - 1980		Alternative views questioned established routines	
1981 - 1985			Emergence actors set new centrality and priorities under the civil protection paradigm
1985 - 2003	Vertical coordination in a multiple stakeholder polycentric environment		
2004 - 2013		New ideas emerged but system resilience kept priorities and reinforced command and control suppression routines	

Table 9. Risk governance deficit hypotheses for frames and actions

Frames	Actions
Failure to understand how the components of a complex system interact or how the system behaves as a whole	Failure to design effective risk management strategies
Lack of ability to recognize fast or fundamental changes in the system	Adequate evaluation of costs and benefits (efficiency) of various options and how these are distributed (equity);
Misrepresentation of information about stakeholders	Lack of adequate organizational capacity and/or suitable culture to ensuring managerial effectiveness
Inability to overcome cognitive barriers to imagining that events outside expected paradigms are possible;	Multiple departments or organizations responsible for a risk's management act individually and not cohesively

Table 10. The risk management escalator for wildfire risk problem in Portugal (adapted from IRGC 2005)

Time	1910 - 1962	1963 - 1980	1981 - 2013
Description of the Fire Risk Problem	Moderate to low fuel loads, mosaic of landscapes	High and continuous fuel loads, local solutions to be effective need to be planned in advance	Inter-sectoral policies coordinating effort is needed for effective regional risk reduction
	Local preventive and mitigation are effective	Suppression capacity is the quick fix solution	Effectiveness of planned actions are uncertain or beyond cognitive human capacity
Risk problem	Simple	Complex	Multiple values are in stake, some are very difficult to measure Ambiguity ridden
Actors	Agency staff	Agency staff Direct affected groups External experts	Agency staff Direct affected groups External experts Stakeholders Public
Type of conflict	Instrumental	Cognitive	Cognitive/ Evaluative
Remedy	Statistical risk analysis	Probabilistic Risk Analysis	Probabilistic risk modeling Risk balancing Analysis > deliberation Risk Trade-off

Fig. 1. Learning cycles in triple-loop learning (extracted from Pahl-Wostl, 2009)

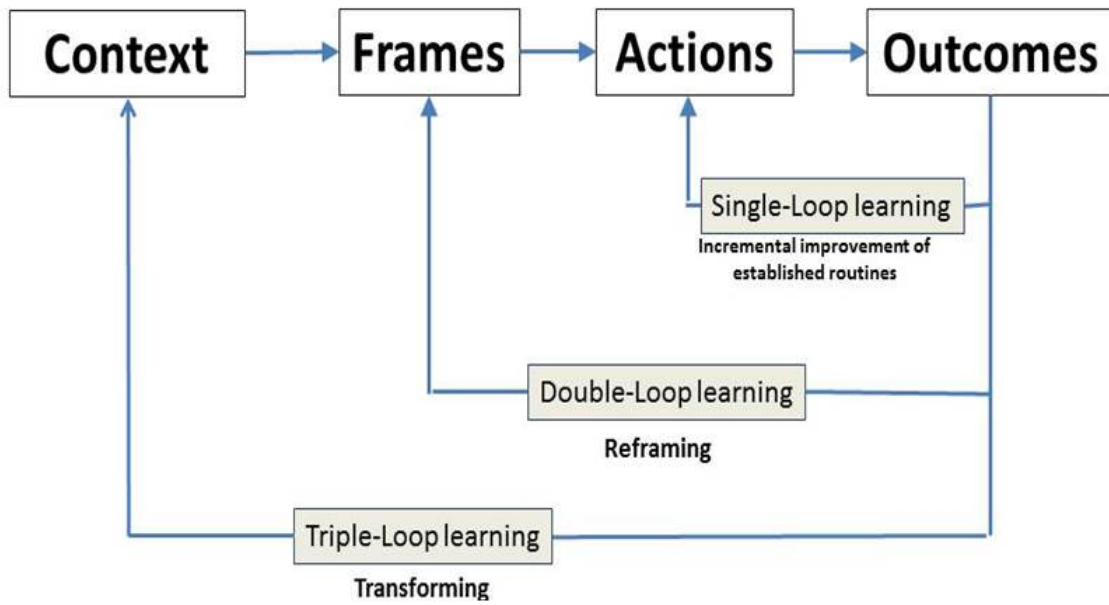


Fig. 2. Portugal in southwestern Europe



Fig. 3. Evolution in time of the burnt area (moving average) and the number of issued regulations

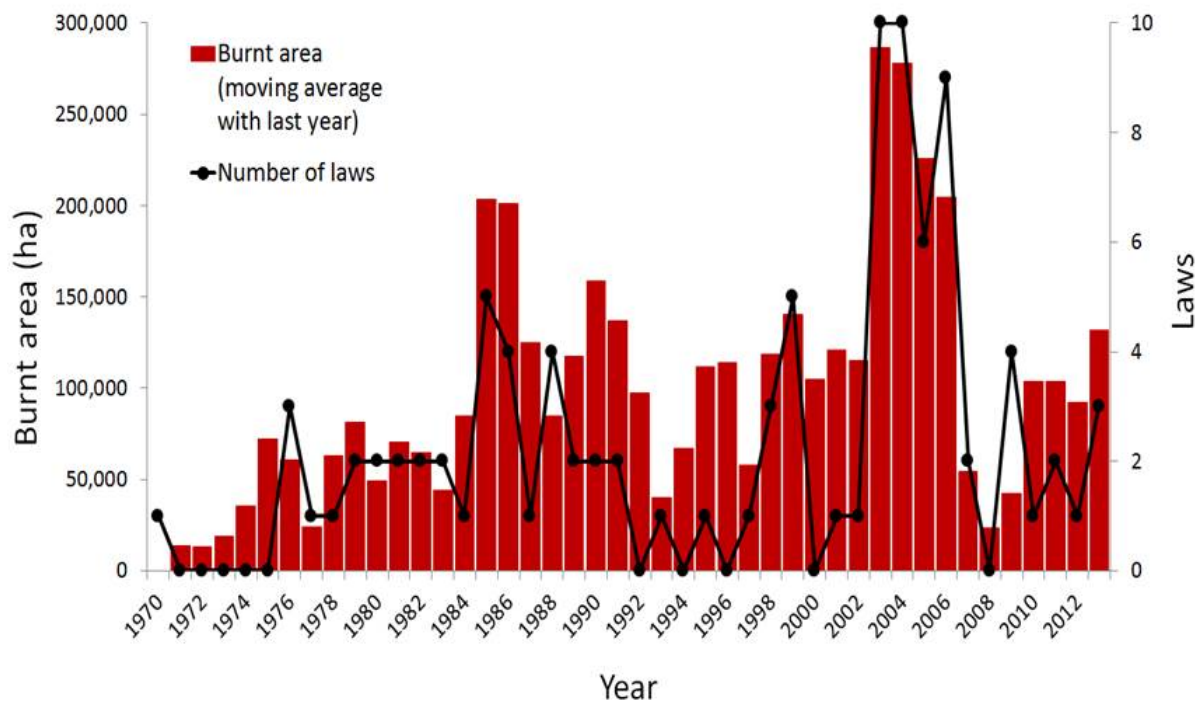


Fig. 4. Number of regulations issued, as a function of the 2-year moving average of area burned

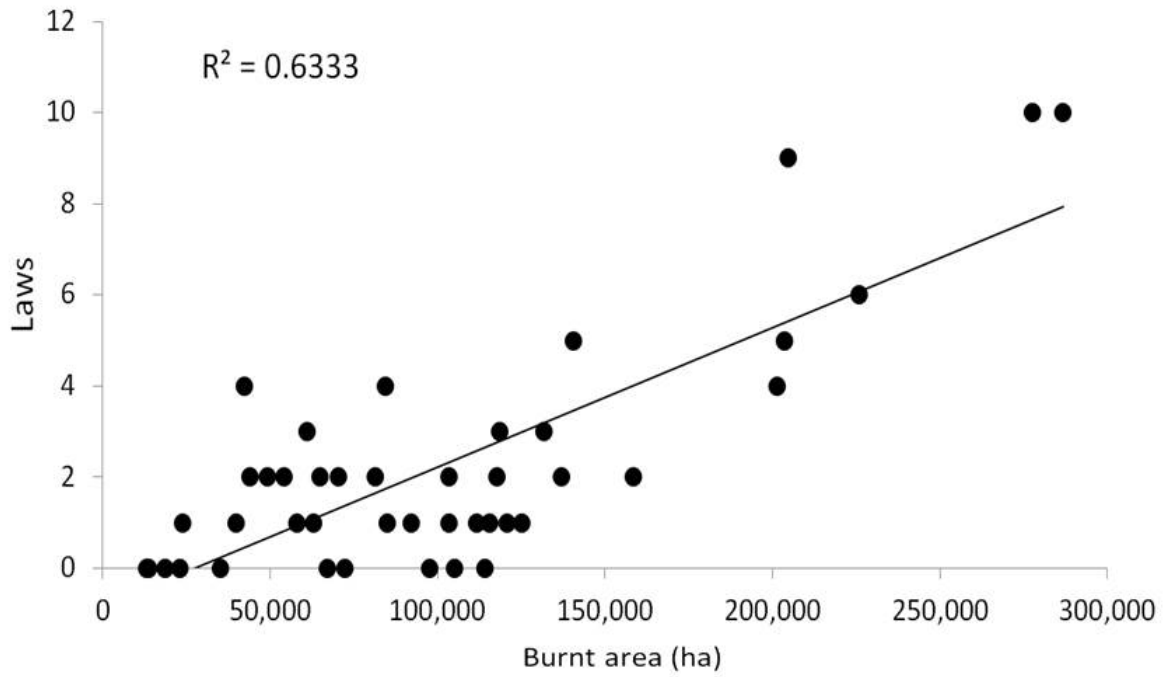
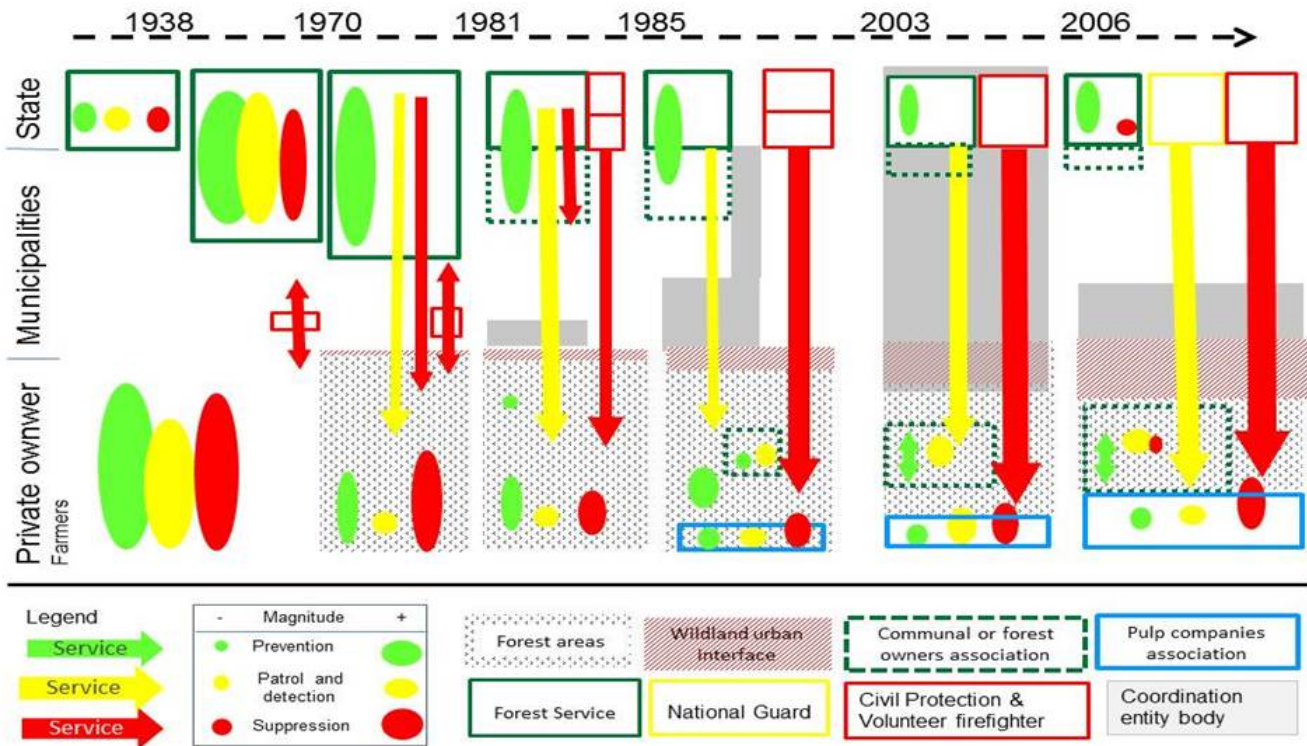


Fig. 5. Illustration of the evolution of the actor network and the multilevel interactions to handle fire risk



Appendix 1.

Table A1.1. Complete list of collected materials (legislative, scientific, technical and essays)

Year	Type of document	Reference	Period
1904	Essay	Almeida, A.M. (1904). Valorização dos terreno incultos. Conferência realizada no Centro Regenerador Liberal na noite de 18 de Junho de 1904. pp19	1910 - 1925
1914	Essay	Sousa, T.M (1914). A Serra, As pastagens e os Gados. Boletim da Direção Geral da Agricultura. Nº 2. 12 ano. Ministério do Fomento. Lisboa. pp 8	1910 - 1925
1926	Essay	Sousa, T.M. (1926). Matas do Gerês – Subsídios para uma monografia florestal. Separata D'a Voz do Lavrador. Várias páginas	1926 - 1937
1926	DL	D_12625/26	1926 - 1937
1927	DL	D_13658/27	1926 - 1937
1929	Essay	Almeida, A.M. (1929) Portugal e a sua riqueza silvícola. Exposição Portuguesa em Sevilha. Lisboa pp12	1926 - 1937
1931	Essay	Almeida, A.M. (1931) Importância da "Associação na defesa da riqueza florestal contra incêndios". Conferência no dia das associações agrícolas. Boletim do Ministério da Agricultura. Ano XIII-Nº 5 III Serie. 13 pp	1926 - 1937
1938	Official working paper	SPN (1938).O Estado novo e a Agricultura. Serviço Propaganda Nacional. Lisboa. pp 20	1938 - 1962
1938	L	L 1971	1938 - 1962
1941	Technical report	Pinto, A. (1943). Fogos. Publicação dos Serviços Florestais portugueses. Vol X – Tomo II. 354-372	1938 - 1962
1943	Essay	Natividade, J.V. (1943). O Ressurgimento Florestal do País. I Congresso Nacional de Ciências Agrárias. Sumário do 4º Symposium. Lisboa. pp 11	1938 - 1962
1943	Essay	Themudo, J. C. F. (1943). Repovoamento Florestal. Coleção "Cadernos do Ressurgimento Nacional". Secretariado Nacional de Informação, Lisboa pp 80	1938 - 1962
1943	Technical report	SNI (1943). Repovoamento Florestal. Cadernos do Ressurgimento Nacional. Lisboa. pp 80	1938 - 1962
1943	Technical report	Themudo, J. C. F. (1943). Repovoamento Florestal. Coleção "Cadernos do Ressurgimento Nacional". Secretariado Nacional de Informação, Lisboa pp 80	1938 - 1962
1950	Book or chapter	Natividade JV (1950). Subercultura. 2.ª Edição: Lisboa, Direcção-Geral das Florestas, 1990, 387 pp	1938 - 1962
1951	Technical report	Guerreiro (1951). Valorização da Serra Algarvia. A erosão, a cobertura vegetal e a água. Direcção Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 14	1938 - 1962
1952	Technical report	Rodrigo, J. J. (1952). O Parque Florestal de Monsanto. Camara Municipal de Lisboa. Lisboa. pp 65	1938 - 1962
1953	Book or chapter	FAO (1953). National Forest Policies in Europe. Portugal fire p162-165	1938 - 1962
1954	DL	DL_39931/54	1938 - 1962
1955	Essay	Silva, Z. (1955). Defesa Contra Fogos no Perimetro Florestal da Serra da Lousã. Relatório de Tirocinio do curso de engenheiro silvicultor. pp 22	1938 - 1962
1955	Technical report	Dias, A. B. (1955). Elementos para a organização da defesa contra fogos no património florestal. Ministério da Economia. Direcção Geral dos Serviços Florestais e Aquícolas. Estudos e Informação 52-E6. pp 77	1938 - 1962
1957	Technical report	Dias, A. B. (1957). Como calcular o Risco momentâneo de incêndio na Floresta? Direcção Geral dos Serviços Florestais e Aquícolas. Estudos e Informação 88-E6. pp 12	1938 - 1962
1958	Technical report	Dias, A. B. (1958). Risco Permanente de Incêndio no Património Florestal. Ministério da Economia. Direcção Geral dos Serviços Florestais e Aquícolas. Estudos e Informação 92-E6. pp 12	1938 - 1962
1958	Technical report	Dias, A. B. (1958). Defesa Contra Incêndios. Direcção Geral dos Serviços Florestais e Aquícolas in Jornadas Florestais. pp 4	1938 - 1962
1958	Technical report	Dias, A. B.(1958). O desbaste e o risco do fogo. Direcção Geral dos Serviços Florestais e Aquícolas in Jornadas Florestais. Amarante. pp 2	1938 - 1962
1958	Technical report	Martins, E. (1958). Breves considerações sobre o estabelecimento das redes divisionais nos perimetros florestais serranos e a localização dos incêndios. Secretaria de Estado da Agricultura. Direcção Geral dos Serviços Florestais e Aquícolas. In Jornadas Florestais Amarante. pp 4	1938 - 1962
1958	Technical report	Quintanilha, V.A. (1958). Breves apontamentos sobre as actividade da Circunscrição Florestal de Vila Real. In Jornadas Florestais. 25 pp	1938 - 1962
1960	Technical report	Dias, A. B.(1960). Ocorrências de Incendios nos Perimetros e Matas Nacionais em 1959. ecretaria de Estado da Agricultura. Direcção Geral dos Serviços Florestais e Aquícolas. In Jornadas Florestais. Manteigas. pp 24	1938 - 1962
1960	Technical report	Martins, E. (1960). Defesa Preventiva, contra fogos, nas matas do domínio privado. Secretaria de Estado da Agricultura. Direcção Geral dos Serviços Florestais e Aquícolas. In Jornadas Florestais. Manteigas. pp5	1938 - 1962
1961	Official working paper	Reis, F. (1963). Oficio dirigido ao Director Geral dos Serviços Florestais e Aquícolas sobre o incendio de Boticas 1963. Director Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 7	1938 - 1962
1963	Book or chapter	Ribeiro, O. (1963). Portugal, o Mediterrâneo e o Atlântico. Coimbra Editora. pp 241	1963 - 1974
1963	Essay	Carvalho, J. (1963). O Inconcebível. Editorial Gazeta das Aldeias nº 2501. Porto. pp 1	1963 - 1974
1963	Essay	Fernandes, J.J. M. (1963). Defendamos do fogo as florestas. Gazeta das Aldeias nº 2496 Porto. pp 5	1963 - 1974
1964	Essay	Alvarez, M. (1964). A educação como meio de defesa preventiva contra o incêndio na floresta recama-nos. Gazeta das Aldeias nº 2524. Porto. pp 6	1963 - 1974
1964	Essay	Mendonça, J. C. (1963). Fantasia Verde. Gazeta das Aldeias nº 2511. Porto. pp 5	1963 - 1974
1964	Research paper	Nunes, A. S. (1964). Portugal, sociedade dualista em evolução. Análise social, 407-462	1963 - 1974

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Table A1.1. Complete list of collected materials (legislative, scientific, technical and essays)

Year	Type of document	Reference	Period
1964	Technical report	Gaio (1964). Industrias Florestais e o desenvolvimento económico. Conferencia proferida em Leiria. Secretaria de Estado da Agricultura. Lisboa. pp 12	1963 - 1974
1964	Technical report	DGSFA (1964). Nota biográfica de Egeberto Pedro. Direcção Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 2	1963 - 1974
1965	Technical report	Dias, A. B. (1965). Defesa dos povoamentos – Pragas, Doenças e Fogos. Ministério da Economia. Direcção Geral dos Serviços Florestais e Aquícolas. Texto de Formação Profissional. Pp 135	1963 - 1974
1965	Technical report	Quintanilha, V., Silva, E. J. da, Silva, J. M. da, 1965. Princípios Básicos de Luta Contra Incêndios na Floresta Particular Portuguesa. Direcção-Geral dos Serviços Florestais e Aquícolas. Porto. 51 p.	1963 - 1974
1970	Book or chapter	Neves, C.M.B (1970). A natureza e a humanidade em perigo. Volume II. Secretaria de Estado da Agricultura. Direcção-Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 370	1963 - 1974
1970	Essay	Leónidas (1970). A importância Económica e Social da Floresta. Discurso na Feira Nacional da Agricultura. Secretaria de estado da agricultura. Lisboa. pp 5	1963 - 1974
1970	DL	DL_488/70	1963 - 1974
1972	Technical report	PNPG (1972). Plano Director do Parque Nacional Peneda Geres. Direcção Geral dos Serviços Florestais e Aquícolas. Secretaria de Estado da Agricultura. pp 2	1963 - 1974
1974	Essay	Mendonça, J.C. (1974). Política Florestal. Proposta de Discussão. Direcção Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 12	1963 - 1974
1974	Technical report	DGSFA (1974). Ofício interno sobre incêndio na mata dos medos. DGSFA. Lisboa. pp 3	1963 - 1974
1974	Technical report	DGSFA (1974). Proposta floresta privada. Direcção Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 19	1963 - 1974
1976	DL	DL_170/76	1975 - 1980
1976	DL	DL_39/76	1975 - 1980
1976	DL	DL_613/76	1975 - 1980
1976	Official working paper	Countinho, N. (1976). Política Florestal. Bases para discussão. Direcção Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 41	1975 - 1980
1977	Book or chapter	Goes, E. (1977). Capítulo 12 - 278-284. in Os eucaliptos. Ecologia, Cultura, Produções e Rentabilidade. Lisboa	1975 - 1980
1977	Essay	Governo (1977). Vencer a Crise. Preparar o futuro. Um ano de Governo Constitucional. Lisboa. pp 14	1975 - 1980
1977	DL	DL_439/77	1975 - 1980
1977	Official working paper	DGOGF (1983). Plano de mudança da Agricultura - Subsector Florestal. Ministério da Agricultura Comércio e Pescas. pp 11	1975 - 1980
1977	Official working paper	MPCE (1977). Plano 77-80. Ministério do Plano e Coordenação Económica. Secretaria de Estado do Planeamento. Lisboa. pp 13	1975 - 1980
1978	DL	DL_215/78	1975 - 1980
1979	DL	DL_63/79	1975 - 1980
1979	CMR	RCM_363D/79	1975 - 1980
1979	Technical report	DGSFA (sem data). Fogo o maior inimigo da floresta. Direcção Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 16	1975 - 1980
1980	DL	DL_327/80	1975 - 1980
1980	DL	DL_510/80	1975 - 1980
1980	L	Lei n.º 27/80. D.R. n.º 171, Série I de 1980-07-26	1975 - 1980
1981	DL	DR_55/81	1981 - 1985
1981	L	Lei n.º 10/81. D.R. n.º 156, Série I de 1981-07-10	1981 - 1985
1981	Technical report	DGF (1981). Folheto com Carta da Sensibilidade ao Fogo. Direcção Geral das Florestas. Lisboa. pp 4	1981 - 1985
1981	Technical report	FAO (1981) An Institutional Basis for Forest Sector Administration in Portugal. Documento traduzido. Sem autor. pp 7	1981 - 1985
1981	Technical report	Mendonça, J. C. (1981). A Silvicultura no Planeamento Regional do Território Português. Estudos e Informação n 290. Ministério Agricultura, Comércio e Pescas. Lisboa. pp 98	1981 - 1985
1982	DL	DL_157/81	1981 - 1985
1982	CMR	RCM_183/82	1981 - 1985
1982	CMR	RCM_84/82	1981 - 1985
1982	Official working paper	CNEFF (1982). Relatório das acções levadas a efeito durante o ano de 1992. Ministério da Administração Interna. Pp 58	1981 - 1985
1982	L	Código Penal de 1982	1981 - 1985
1982	Technical report	DGOGF (1982). Floresta - Informação. Boletim Direcção Geral de Ordenamento e Gestão Florestal. Lisboa. pp 16	1981 - 1985
1982	Technical report	FAO (1982). Estratégia para o desenvolvimento do sub-sector florestal. pp 113	1981 - 1985
1982	Technical report	Montague, R., Griggs, R.X. and B. Lyon (1982) Final Report of findings from a study of forest fire control operations in Portugal. Lisbon.	1981 - 1985
1983	DL	DL_368/83	1981 - 1985
1983	DL	DL_401/83	1981 - 1985
1983	Research paper	Estevão, J.A. (1983) A floresta dos baldios. Análise Social. 19, 1157 e 1260.	1981 - 1985
1983	Technical report	Nogueira C.D.S. (1983). A floresta portuguesa e a problemática dos incêndios. Direcção Geral das Florestas. Secretaria de Estado da Agricultura. Ministério da Agricultura, Florestas e Alimentação. Lisboa. pp. 44	1981 - 1985

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Year	Type of document	Reference	Period
1984	CMR	RCM_33/84	1981 - 1985
1984	Technical report	Nogueira C.D.S., Silva C.G., Vasco A.B. e S.A Correia (1984). Incêndios Florestais. Rescaldo do III Forum Nacional sobre Fogos Florestais. Relatório . pp.19	1981 - 1985
1984	Technical report	SNPC (1984). Relatório da campanha de incêndios florestais de 1984. Ministério da Defesa Nacional. pp 142	1981 - 1985
1985	Essay	Cabral, L.G.S. (1985). Prevenção e detecção de incêndios florestais. Os Fogos, A floresta e o Ambiente. Paineis de 21 a 22 de Novembro de 1984. Separata do Boletim da Sociedade de Geografia de Lisboa. pp 55-57	1981 - 1985
1985	Essay	Mendonça, J.C. (1985). Uma reflexão sobre a Silvicultura Portuguesa no Final do Século XX. Lisboa. pp 12	1981 - 1985
1985	Essay	Nogueira, C.D.S. (1985). Prevenção e detecção de incêndios florestais. Os Fogos, A floresta e o Ambiente. Paineis de 21 a 22 de Novembro de 1984. Separata do Boletim da Sociedade de Geografia de Lisboa. p. 59-79	1981 - 1985
1985	DL	DR_67/85	1981 - 1985
1985	CMR	RCM_23/85	1981 - 1985
1985	CMR	RCM_39/85	1981 - 1985
1985	CMR	RCM_42A/85	1981 - 1985
1985	CMR	RCM_42B/85	1981 - 1985
1985	Official working paper	DGF (1985). Expansão e Beneficiação a cargo da DGF. Direcção Geral das Florestas. Lisboa. 6	1981 - 1985
1985	Technical report	Germano, M.A.T (1985). Plano de Defesa Contra o Fogo na zona Critica Z17. Relatório de estágio do Curso de Engenheiro Silvicultor. Instituto Superior de Agronomia. Universidade Técnica de Lisboa. pp 40	1981 - 1985
1986	DL	DL_84/86	1985 - 1995
1986	CMR	RCM_20/86	1985 - 1995
1986	CMR	RCM_45/86	1985 - 1995
1986	CMR	RCM_89/86	1985 - 1995
1986	L	Lei n.º 19/86. D.R. n.º 164, Série I de 1986-07-19	1985 - 1995
1986	Technical report	Alves, P.I.P.S (1985). Incêndios Florestais e a utilização dos meios aéreos no seu combate. Subsídios para a Análise Estatística da sua eficácia. Relatório de estágio do Curso de Engenheiro Silvicultor. Instituto Superior de Agronomia. Universidade Técnica de Lisboa. pp 83	1985 - 1995
1986	Technical report	Nogueira, C.D.S. (1986). La Protection de la Forêt Portugese. Relatório do Seminário sobre Métodos e Materiais a Utilizar para Prevenir Incêndios Florestais. Seminário Internacional Valencia ONU/FAO. 30 Sept a 4 Oct. Direcção Geral dos Serviços Florestais e Aquícolas. Lisboa. pp 33	1985 - 1995
1986	Technical report	Pedroso, M.M. (1986). Relatório do Seminário sobre Métodos e Materiais a Utilizar para Prevenir Incêndios Florestais. Instituto dos Produtos Florestais. Secretaria do Comercio Externo. Lisboa. pp 13	1985 - 1995
1987	CMR	RCM_30/87	1985 - 1995
1987	L	Lei 21_87 de 20 de junho	1985 - 1995
1987	Technical report	Silva, J.M. (1986). Methodes Sulvicoles propres à reduire les risques d'incendie. Relatório do Seminário sobre Métodos e Materiais a Utilizar para Prevenir Incêndios Florestais. Seminário Internacional Valencia ONU/FAO. 30 Sept a 4 Oct. Direcção Geral dos Serviços Florestais e Aquícolas. Porto. pp 10	1985 - 1995
1988	Essay	Ferreirinha, M. (1988). Incêndios Florestais. Um problema nacional. Instituto dos Produtos Florestais. pp 9	1985 - 1995
1988	DL	DL_139/88	1985 - 1995
1988	DL	DL_172/88	1985 - 1995
1988	DL	DL_459/88	1985 - 1995
1988	DL	DR_36/88	1985 - 1995
1988	Official working paper	DGF (1988). Legislação Florestal. Pacote Florestal. Direcção Geral das Florestas. pp 16	1985 - 1995
1988	Technical report	ACEL (1988). Relatório sobre incêndios florestais. Associação das empresas de celulose e papel. Sem autor. 18 p	1985 - 1995
1988	Technical report	SNPC (1988). Incendios Florestais 1988. MAI. Lisboa. pp 61	1985 - 1995
1989	DL	DL_180/89	1985 - 1995
1989	CMR	RCM_30/89	1985 - 1995
1989	Research paper	Devy- Vareta, N. (1989) Os serviços florestais no século XIX. Os homens e as ideias, Finisterra, Lisboa, XXIV, 47, pp. 105-116	1985 - 1995
1989	Technical report	DGF (1989). Meeting Global Wildland Fire Challenges. Boston Massachusetts. USA. MAPA. Direcção Geral das Florestas. Lisboa. pp 54	1985 - 1995
1990	DL	DL_327/90	1985 - 1995
1990	DL	DL_334/90	1985 - 1995
1990	PRtG	Resolução da Assembleia da República n.º 15/90. D.R. n.º 149, Série I de 1990-06-30	1985 - 1995
1991	Book or chapter	Caldas, E.C. (1991). A agricultura Portuguesa através dos tempos. Instituto Nacional de Investigação Científica, Lisboa, 653 pp	1985 - 1995
1991	Essay	Pinheiro, L. (1991). Prevenção de Fogos Florestais. DGF informação nº 7.. Direcção Geral das Florestas. Ministério de Agricultura e Pescas. Lisboa. pp 3	1985 - 1995
1991	DL	DL_13/91	1985 - 1995

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Table A1.1. Complete list of collected materials (legislative, scientific, technical and essays)

Year	Type of document	Reference	Period
1991	CMR	RCM_95/91	1985 - 1995
1991	L	Lei n.º 54/91, de 8 de Agosto	1985 - 1995
1991	L	Lei n.º 113/91 de 29 de Agosto	1985 - 1995
1992	Official working paper	CNEFF (1992). Relatório das acção levadas a efeito durante o ano 1992. MAI. Lisboa pp 58	1985 - 1995
1992	Research paper	Rego, F.C. (1992) Land use changes and wildfires. In A. Teller, P. Mathy and J.N.R Jeffers (eds). Responses of Forest Ecosystems to Environmental Changes, pp 367-373 Elsevier. London	1985 - 1995
1993	Book or chapter	Baptista, F.O. (1993). A política agrária do Estado Novo. Edições Afrontamento. Porto. pp 414	1985 - 1995
1993	Essay	Devy-Vareta, N. (1993) A questão da florestação em Portugal, um processo de longa duração, Sociedade e Território, Porto, Afrontamento, nº 19: Política Florestal, pp. 47-70.	1985 - 1995
1993	Essay	Devy-Vareta, N. (1993). A floresta no espaço e no tempo em Portugal: a arborização da Serra da Cabreira 1919-1975.	1985 - 1995
1993	DL	DL_423/93	1985 - 1995
1993	Official working paper	CNEFF (1993). Relatório vigilância aérea de fogos florestais. CNEFF. Coimbra. pp 32	1985 - 1995
1993	L	Lei n.º 68/93 de 4 de Setembro	1985 - 1995
1993	Research paper	Brouwer, R.(1993). The forestry services and the commons in Portugal. Forest Conservation History 37, 160-168.	1985 - 1995
1993	Research paper	Devy-Vareta, N. (1993). A questão da florestação em Portugal: um processo de longa duração. Sociedade e Território, 19, 49-70.	1985 - 1995
1993	Technical report	ACEL (1993). Apoio concedido a CNEFF 1987-2002. ACEL. Lisboa. 1p	1985 - 1995
1993	Technical report	SNPC (1993). Relatório final incêndios 1993. MAI. Lisboa. pp 34	1985 - 1995
1994	Essay	CFN (1994). Manifesto Florestal. II Congresso Florestal Nacional. Figueira da Foz. pp 5	1985 - 1995
1994	Research paper	Amaral, L. (1994). Portugal e o passado: política agrária, grupos de pressão e evolução da agricultura portuguesa durante o Estado Novo (1950-1973). Análise Social, vol XXIX -128 pp 889-906	1985 - 1995
1994	Research paper	Baptista, F. O. (1994) A agricultura e a questão da terra - do Estado Novo à Comunidade Europeia. Análise Social, vol XXIX -128 pp 907-921	1985 - 1995
1994	Research paper	Mansinho, M.I., Schmidt, L. (1994). A emergência do ambiente nas ciências sociais: análise de um inventário bibliográfico. Análise Social 29, 441-481	1985 - 1995
1994	Technical report	IF (1994). Memorando sobre o Sector Florestal. Instituto Florestal. Lisboa. pp 58	1985 - 1995
1995	DL	DL_316/95	1985 - 1995
1996	Official working paper	Carvalho, J. B and Morais, C.J.E., (1996). Análise da Florestação em Portugal 1966-1995. Informação Florestal 15: 3-13	1996 - 2003
1996	L	Lei nº 33/96	1996 - 2003
1996	Technical report	BPI, Agro.Ges and Jaakko Pöyry (1996) "Propostas para o desenvolvimento sustentável da floresta portuguesa. Um estudo independente preparado para a Portucel, Sonae e Soporcel, pelo Banco Português de Investimento, AgroGes e Jaakko Pöyry,"	1996 - 2003
1996	Technical report	CESE (1996). Capítulo 6.4. Incêndios florestais. in O sector florestal português. Lisboa. pp 74	1996 - 2003
1996	Technical report	Stauber, R.L (1996) Análise e Avaliação das Estratégias e Estrutura Organizativa relativas a fogos florestais em Portugal. Estação Florestal Nacional, pp. 66	1996 - 2003
1997	DL	DL_247/97	1996 - 2003
1998	Book or chapter	Caldas, E. C. (1998). A Agricultura na história de Portugal. EPN. pp 599	1996 - 2003
1998	DL	DL_111/98	1996 - 2003
1998	DL	DL_20/98	1996 - 2003
1998	CMR	RCM_23/98	1996 - 2003
1998	Technical report	SNPC (1998). Relatório sobre incêndios florestais. MAI. Lisboa. pp 44	1996 - 2003
1999	DL	DL_179/99	1996 - 2003
1999	DL	DL_204/99	1996 - 2003
1999	DL	DL_34/99	1996 - 2003
1999	CMR	RCM_27/99	1996 - 2003
1999	CMR	RCM_88/99	1996 - 2003
1999	Technical report	SNB (1999). Dispositivo de combate a incêndios florestais 1999. Serviço Nacional de Bombeiros. MAI. Lisboa. pp 33	1996 - 2003
2000	Book or chapter	Radich, M. C. e Alves, A. A. M. (2000). Dois séculos da floresta em Portugal. CELPA. Pp 226	1996 - 2003
2001	CMR	RCM_23/2001	1996 - 2003
2001	Research paper	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	1996 - 2003
2001	Research paper	Velez R. (2001). Fire causes in Mediterranean Basin. Conference paper Risk Management and sustainable forestry. pp 5	1996 - 2003
2001	Technical report	DGF (2001). Resumo da actividade do CNGF em serviço de "Fogos Florestais". Direção Geral das Florestas. MADRP. Lisboa. pp 22	1996 - 2003
2002	Essay	Rolo, F. (2002). Engenharia e História. Percursos Cruzados. Lisboa. pp 34	1996 - 2003
2002	CMR	RCM_310/2002	1996 - 2003

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Table A1.1. Complete list of collected materials (legislative, scientific, technical and essays)

Year	Type of document	Reference	Period
2002	Official working paper	CNEFF (2002). Relatório de 2002. Ministério da Administração Interna. Pp 48	1996 - 2003
2002	Research paper	Mendes, A. M. C., & da Silva Dias, R. A. (2002). Financial Instruments of Forest Policy in Portugal in the 1980s and 1990s. <i>Financial Instruments of Forest Policy</i> , 95	1996 - 2003
2002	Technical report	CELPA (2002). Análise da eficiência dos meios aereos para combate a incêndios 1992 a 2001. CELPA. Lisboa. pp 22	1996 - 2003
2002	Technical report	SNB (1997). Dispositivo de combate a incendios florestais 1999. Serviço Nacional de Bombeiros. MAI. Lisboa. pp 51	1996 - 2003
2002	Technical report	SNB (2002). Relação Incendios Florestais. Serviço nacional de bombeiros. MAI. Lisboa. pp 41	1996 - 2003
2002	Technical report	SNPC (2002). Análise das épocas de fogos florestais de 2000, 2001 e 2002. SNPC. MAI. Lisboa. pp 68	1996 - 2003
2003	Book or chapter	Grove, AT, Rackham, O (2003) 'The Nature of Mediterranean Europe.' (Yale University Press: New Haven, CT	2004 - 2013
2003	Essay	Oliveira, T e P. Reis (2003). A procura e a oferta de ID nos incêndios florestais em Portugal. Trabalho final do Curso de pós graduado de Políticas de Ciência e Tecnologia. Instituto Superior Técnico. P25	2004 - 2013
2003	DL	DL_211/2003	2004 - 2013
2003	DL	DL_219/2003	2004 - 2013
2003	DL	DL_253/2003	2004 - 2013
2003	DL	DL_306/2003	2004 - 2013
2003	DL	DL_49/2003	2004 - 2013
2003	CMR	RCM_106A/2003	2004 - 2013
2003	CMR	RCM_106B/2003	2004 - 2013
2003	CMR	RCM_161/2003	2004 - 2013
2003	CMR	RCM_178/2003	2004 - 2013
2003	CMR	RCM_64/2003	2004 - 2013
2003	L	Lei n.º 107/2003. D.R. n.º 284, Série I-A de 2003-12-10	2004 - 2013
2003	PrtG	Resolução da Assembleia da República n.º 25/2003. D.R. n.º 78, Série I-A de 2003-04-02	2004 - 2013
2003	PrtG	Resolução da Assembleia da República n.º 71/2003, de 22 de Agosto	2004 - 2013
2003	PrtG	Resolução do Conselho de Ministros n.º 60/2003 (2.ª série), de 23 de Agosto	2004 - 2013
2003	PrtG	Resolução do Conselho de Ministros n.º 123/2003, de 25 de Agosto	2004 - 2013
2003	PrtG	Resolução da Assembleia da República n.º 74/2003. D.R. n.º 218, Série I-A de 2003-09-20	2004 - 2013
2003	Research paper	De Sá Marques, T. (2003). Dinâmicas Territoriais e as relações Urbano-Rurais. Revista da Faculdade de Letras – Geografia I seria, Vol. XIX. Porto pp 507-521	2004 - 2013
2003	Research paper	Lains, P. (2003). Catching up to the European core: Portuguese economic growth, 1910–1990. <i>Explorations in Economic History</i> , 40(4), 369-386	2004 - 2013
2004	Book or chapter	FLAD (2004). Prevenção, Detecção e Combate de Fogos Florestais. Fundação Luso Americana. Lisboa. pp 211	2004 - 2013
2004	Essay	Ferrão, J. (2004). Dinâmicas territoriais e trajetórias de desenvolvimento: Portugal 1991–2001. <i>Revista de Estudos Demográficos</i> , 34, 17-25	2004 - 2013
2004	DL	DL_155/2004	2004 - 2013
2004	DL	DL_156/2004	2004 - 2013
2004	DL	DL_38/2004	2004 - 2013
2004	DL	DL_63/2004	2004 - 2013
2004	DL	DL_94/2004	2004 - 2013
2004	DL	DR_5/2004	2004 - 2013
2004	CMR	RCM_123/2004	2004 - 2013
2004	CMR	RCM_126/2004	2004 - 2013
2004	CMR	RCM_17/2004	2004 - 2013
2004	CMR	RCM_8/2004	2004 - 2013
2004	L	Lei nº 9/2004 de 13 de Março	2004 - 2013
2004	L	Lei n.º 14/2004. D.R. n.º 108, Série I-A de 2004-05-08	2004 - 2013
2004	PrtG	Resolução da Assembleia da República n.º 19/2004, de 16 de Fevereiro	2004 - 2013
2004	PrtG	Resolução da Assembleia da República n.º 26/2004 de 2 de Março	2004 - 2013
2004	PrtG	Resolução da Assembleia da República n.º 27/2004 de 5 de Março	2004 - 2013
2004	Technical report	Beighley, M., & Quesinberry, M. (2004). USA&Portugal Wildland Fire Technical Exchange Project e Final Report. <i>USDA Forest Service. Lisbon</i> , pp 54	2004 - 2013
2004	Technical report	COTEC (2004). Iniciativa COTEC sobre Incêndios Florestais. Benchmarking de Sistemas de Prevenção e Combate a incêndios florestais. Porto. pp 133	2004 - 2013
2004	Technical report	Mendes, Américo M. S. Carvalho. (2004). Portugal: The forest policy process since 1996. In <i>Forests for the Future: National Forest Programmes in Europe. Country and Regional Reports from COST Action E19</i> , David Humphreys (ed.). Luxembourg: Office for Official Publications of the European Communities. pp. 231-252.	2004 - 2013
2005	Book or chapter	Baptista, F. O., & Santos, R. T. (2005). Os proprietários florestais: resultados de um inquérito. Celta Editora	2004 - 2013
2005	Book or chapter	Barreto, A. (2005). Mudança social em Portugal, 1960-2000. In Pinto A.C. (Ed.), <i>Portugal contemporâneo Publicações Dom Quixote. Lisboa</i> . pp. 137–162.	2004 - 2013
2005	Book or chapter	Lains, P. & A. F. da Silva (2005). História económica de Portugal, 1700-2000.	2004 - 2013

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Table A1.1. Complete list of collected materials (legislative, scientific, technical and essays)

Year	Type of document	Reference	Period
2005	DL	DL_17/2005	2004 - 2013
2005	CMR	RCM_160/2005	2004 - 2013
2005	CMR	RCM_23/2005	2004 - 2013
2005	CMR	RCM_58/2005	2004 - 2013
2005	CMR	RCM_63/2005	2004 - 2013
2005	CMR	RCM_88A/2005	2004 - 2013
2005	Official working paper	CNR (2005). Orientações estratégicas para a recuperação das áreas ardidas em 2003 e 2004. Ministério da Agricultura, do Desenvolvimento Rural e das Pescas. Conselho Nacional de Reflorestação. P 117	2004 - 2013
2005	PrtG	Resolução da Assembleia da República n.º 54/2005. D.R. n.º 190, Série I-A de 2005-10-03	2004 - 2013
2005	PrtG	Resolução da Assembleia da República n.º 56/2005. D.R. n.º 193, Série I-A de 2005-10-07	2004 - 2013
2005	Research paper	Pereira, M. G., Trigo, R. M., da Camara, C. C., Pereira, J. M., & Leite, S. M. (2005). Synoptic patterns associated with large summer forest fires in Portugal. <i>Agricultural and Forest Meteorology</i> , 129(1), 11-25.	2004 - 2013
2005	Research paper	Radich, M.C. e F. O. Baptista (2005). Floresta e sociedade: Um percurso (1875-2005) (<i>Forest and society. A route, 1875-2005</i>). <i>Silva Lusitana</i> , 13: 143–157	2004 - 2013
2005	Research paper	Seijo, F. (2005) The politics of fire: Spanish forest policy and ritual resistance in Galicia, Spain. <i>Environmental Politics</i> , 14, 380 e 402.	2004 - 2013
2005	Technical report	CNR (2005). Orientações estratégicas para a recuperação das áreas ardidas em 2003 e 2004. Conselho Nacional de Reflorestação. MADRP. Lisboa. pp 117	2004 - 2013
2005	Technical report	ISA (2005). Proposta técnica do Plano Nacional de Defesa da Floresta contra incêndios – Relatório intercalar . Universidade Técnica de Lisboa. pp 580	2004 - 2013
2005	Technical report	MAI (2005). Comissão para o estudo dos meios aéreos de combate aos incêndios florestais. MAI. Lisboa. pp 21	2004 - 2013
2005	Technical report	MAI (2005). Relatório da comissão especial para o estudo dos meios aéreos de combate aos incêndios florestais. Lisboa. pp21	2004 - 2013
2005	Technical report	MAI/MD (2005). Relatório do grupo de trabalho para avaliação da operação dos Puma no combate incêndios. Lisboa. pp 87	2004 - 2013
2006	Book or chapter	ISA (2006). Incêndios Florestais em Portugal. Caracterização, Impactes e Prevenção. Instituto Superior de Agronomia. ISAPress. Lisboa. pp 515	2004 - 2013
2006	Book or chapter	Vieira, P.A. (2006). Portugal: O vermelho e o Negro. Dom Quixote. Lisboa. pp 469	2004 - 2013
2006	DL	DL_124/2006	2004 - 2013
2006	DL	DL_131/2006	2004 - 2013
2006	DL	DL_134/2006	2004 - 2013
2006	DL	DL_22/2006	2004 - 2013
2006	DL	DL_68/2006	2004 - 2013
2006	CMR	RCM_114/2006	2004 - 2013
2006	CMR	RCM_36/2006	2004 - 2013
2006	CMR	RCM_5/2006	2004 - 2013
2006	CMR	RCM_65/2006	2004 - 2013
2006	L	Lei n.º 12/2006. D.R. n.º 67, Série I-A de 2006-04-04	2004 - 2013
2006	PR	AR (2006). Relatório da Comissão Eventual para os Fogos Florestais. Lisboa. pp 167	2004 - 2013
2006	Research paper	Fernandes, P.M., Monteiro-Henriques, T., Guiomar, N., Loureiro, C., Barros, A.M., (2016). Bottom-up variables govern large-fire size in Portugal. <i>Ecosystems</i> 19, 1362–1375	2004 - 2013
2006	Research paper	Loureiro, C, Fernandes, P, Botelho, H, Mateus, P (2006) A simulation test of a landscape fuel management project in the Marao range of northern Portugal. <i>Forest Ecol. Manag</i> 234S:S245	2004 - 2013
2006	Technical report	CNEFF (2006). Fogos Florestais: Desafios e Respostas. Síntese de encontro de seminário na Assembleia da república. Lisboa. pp 5	2004 - 2013
2006	Technical report	CONAF (2006). Relatório sobre incêndios florestais em Portugal. Governo do Chile. Lisboa. pp 40	2004 - 2013
2006	Technical report	Mckinsey (2006). Protecção contra incêndios. Um passo para o futuro. Relatório Mckinsey. Lisboa. pp 36	2004 - 2013
2007	DL	DL_109/2007	2004 - 2013
2007	DL	DL_55/2007	2004 - 2013
2007	PR	AR (2007). Relatório da Comissão Eventual para os Fogos Florestais. Lisboa. pp 73	2004 - 2013
2007	PrtG	Resolução da Assembleia da República n.º 18/2007. D.R. n.º 93, Série I de 2007-05-15	2004 - 2013
2007	Research paper	Reis, P., & Oliveira, T. (2007). The role of technical and scientific knowledge production, transfer and dissemination in fire planning and policy. In 4th International Wildland Fire Conference in Seville.	2004 - 2013
2008	Book or chapter	Schmidt, L. (2008). Ambiente e políticas ambientais: escalas e desajustes. In Itinerários: A Investigação nos 25 Anos do ICS” org. Villaverde Cabral, Manuel, Wall, Karin, Aboim, Sofia e Silva, Filipe Carreira da, Ed. Imprensa de Ciências Sociais, Lisboa, (pp. 285-314).	2004 - 2013
2008	PR	AR (2008) Comissão Eventual de Acompanhamento e Avaliação da Política Nacional de Defesa da Floresta Contra Incêndios. Lisboa. pp 242	2004 - 2013

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Table A1.1. Complete list of collected materials (legislative, scientific, technical and essays)

Year	Type of document	Reference	Period
2008	Technical report	AFN (2008). Acompanhamento e Avaliação do Plano Nacional de Defesa da Floresta Contra Incêndio 2007-2009. AFN. MADRP. Lisboa. pp 221	2004 - 2013
2008	Technical report	UTAD (2008). Avaliação do Desempenho do Ataque Ampliado a Incêndios Florestais. Relatório final. UTAD. Vila Real. pp 89	2004 - 2013
2009	DL	DL_15/2009	2004 - 2013
2009	DL	DL_16/2009	2004 - 2013
2009	DL	DL_17/2009	2004 - 2013
2009	DL	DL_254/2009	2004 - 2013
2009	L	Lei 20/2009 de 12 de Maio	2004 - 2013
2009	Research paper	Acácio, V., Holmgren, M., Rego, F., Moreira, F., Mohren, G.M. (2009). Are drought and wildfires turning Mediterranean cork oak forests into persistent shrublands? <i>Agrofor Syst</i> 76: 389-400	2004 - 2013
2009	Research paper	Catry, FX, Rego, FC, Bação, FL, Moreira, F (2009) Modeling and mapping wildfire ignition risk in Portugal. <i>International Journal of Wildland Fire</i> 18, 921-931.	2004 - 2013
2009	Research paper	Fernandes, P., (2009). Combining forest structure data and fuel modelling to classify fire hazard in Portugal. <i>Annals of Forest Science</i> , 66	2004 - 2013
2009	Technical report	Beighley, M., & Hyde, A. C. (2009). Systemic Risk and Portugal's Forest Fire Defense Strategy: An Assessment of Wildfire Management and Response Capability. Beighley Consulting LLC. Lisbon. Pp 51	2004 - 2013
2009	Technical report	LPN (2009). Incêndios Florestais 5 anos após 2003. Editores Silva JS, Deus E e L Saldanha. Liga para a Protecção da Natureza e Autoridade Florestal Nacional. Lisboa. pp 108	2004 - 2013
2010	Book or chapter	Baptista, F. O. (2010). O Espaço Rural, Declínio da Agricultura. Celta Editora, Lisboa.	2004 - 2013
2010	CMR	RCM_95/2010	2004 - 2013
2010	PrtG	Resolução da Assembleia da República n.º 118/2010, de 12 de Novembro	2004 - 2013
2010	Research paper	Verde, J. C., Zêzere, J.L. (2010). Assessment and validation of wildfire susceptibility and hazard in Portugal. <i>Nat. Hazard. Earth Sys. Sci</i> , 10(3), 485-497	2004 - 2013
2010	Technical report	AFN (2010). Monitorização e Avaliação do Plano Nacional de Defesa da Floresta Contra Incêndios (2009-2010). AFN. MADRP. Lisboa. pp 190	2004 - 2013
2011	Book or chapter	Rolo, M.F., Amaral, J.F. e J.M. B. Brito (2011) Portugal e a Europa Cronologia. Tinta da China. Lisboa pp 470	2004 - 2013
2011	DL	DL_114/2011	2004 - 2013
2011	CMR	RCM_41/2011	2004 - 2013
2011	Research paper	Fernandes, PM, Loureiro, C, Palheiro, P, Vale-Gonçalves, H, Fernandes, MM, Cruz, MG (2011) Fuels and fire hazard in blue gum (<i>Eucalyptus globulus</i>) stands in Portugal. <i>Boletín del CIDEU</i> 10, 53-61	2004 - 2013
2011	Research paper	Pereira, M. G., Malamud, B. D., Trigo, R. M., & Alves, P. I. (2011) The history and characteristics of the 1980-2005 Portuguese rural fire database. <i>Natural Hazards and Earth System Science</i> , 11(12), 3343-3358.	2004 - 2013
2011	Research paper	Rosa, IMD, Pereira, JMC, Tarantola, S (2011) Atmospheric emissions from vegetation fires in Portugal (1990-2008): estimates, uncertainty analysis, and sensitivity analysis. <i>Atmospheric Chemistry and Physics</i> 11, 2625-2640	2004 - 2013
2011	Research paper	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. <i>Landsc. Urban Plan.</i> 101, 349-358.	2004 - 2013
2012	Book or chapter	Alves, A. M., Correia, A. V., & Pereira, J. S. (2012). Silvicultura: a gestão dos ecossistemas florestais. FCG. Lisboa. Pp 597	2004 - 2013
2012	CMR	RCM_88/2012	2004 - 2013
2012	PrtG	Resolução do Conselho de Ministros n.º 88/2012, de 18 de outubro	2004 - 2013
2012	Research paper	Barros, A.M.G., Pereira, J.M.C., Lund, U.J. (2012) Identifying geographical patterns of wildfire orientation: A watershed-based analysis. <i>Forest Ecology and Management</i> 264, 98-107	2004 - 2013
2013	DL	DL_72/2013	2004 - 2013
2013	CMR	RCM_57/2013	2004 - 2013
2013	CMR	RCM_59/2013	2004 - 2013
2013	Official working paper	ICNF, (2013) Áreas dos usos do solo e das espécies florestais de Portugal continental. Instituto da Conservação da Natureza e Floresta. 35 pp	2004 - 2013
2013	Research paper	Collins, R. D., de Neufville, R., Claro, J., Oliveira, T., & Pacheco, A. P. (2013). Forest fire management to avoid unintended consequences: A case study of Portugal using system dynamics. <i>Journal of environmental management</i> , 130, 1-9	2004 - 2013
2013	Research paper	Fernandes, P. M. (2013). Fire-smart management of forest landscapes in the Mediterranean basin under global change. <i>Landscape and Urban Planning</i> , 110, 175-182.	2004 - 2013
2013	Research paper	Pacheco, A. P., Claro, J., & Oliveira, T. (2013). Simulation analysis of the impact of ignitions, rekindles, and false alarms on forest fire suppression. <i>Canadian Journal of Forest Research</i> , 44(1), 45-55.	2004 - 2013
2013	Research paper	Rego, F., Louro, G., Constantino, L. (2013). The impact of changing wildfire regimes on wood availability from Portuguese forests. <i>For. Policy Econ.</i> 29, 56-61	2004 - 2013
2013	Technical report	Viegas, D.X. (2013) Relatório do Incêndio Florestal e os acidentes mortais, ocorridos em 2013. Parte I. Centro de Estudos sobre Incêndios Florestais, ADAI/LAETA. Universidade de Coimbra. (Coimbra, Portugal) pp 111	2004 - 2013

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Table A1.1. Complete list of collected materials (legislative, scientific, technical and essays)

Year	Type of document	Reference	Period
2014	Book or chapter	Mateus, P., & Fernandes, P. M. (2014). Forest fires in Portugal: dynamics, causes and policies. In <i>Forest Context and Policies in Portugal</i> . Springer International Publishing. pp. 97-115	2004 - 2013
2014	Research paper	DaCamara, CC, Calado, TJ, Ermida, SL, Trigo, IF, Amraoui, M, Turkman, KF (2014) Calibration of the Fire Weather Index over Mediterranean Europe based on fire activity retrieved from MSG satellite imagery. <i>International Journal of Wildland Fire</i> 23, 945-958	2004 - 2013
2014	Research paper	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. <i>Journal of environmental management</i> . 146. 373-382	2004 - 2013
2014	Research paper	Reboredo, F., & Pais, J. (2014). Evolution of forest cover in Portugal: A review of the 12th–20th centuries. <i>Journal of forestry research</i> , 25(2), 249-256.	2004 - 2013
2014	Technical report	IESE (2014). Avaliação intercalar do Plano Nacional de Defesa da Floresta Contra Incêndios (2006-012). Lisboa. pp 201	2004 - 2013
2015	Book or chapter	Avillez, F. (2015). A agricultura Portuguesa. As últimas décadas e perspectivas para o futuro. <i>Ensaios da Fundação Francisco Manuel dos Santos</i> . Lisboa. 110pp	2004 - 2013
2015	PR	AR (2015). Relatório final – grupo de trabalho para a análise da problemática dos incêndios florestais. <i>Assembleia da República</i> . pp 286	2004 - 2013
2015	Research paper	Fernandes, PM (2015) Empirical Support for the Use of Prescribed Burning as a Fuel Treatment. <i>Current Forestry Reports</i> 1: 118-127.	2004 - 2013
2015	Research paper	Guiomar, N., Godinho, S., Fernandes, P.M., Machado, R., Neves, N., Fernandes, J.P. (2015). Wildfire patterns and landscape changes in Mediterranean oak woodlands. <i>Sci. The Total Environ.</i> 536. 338–352.	2004 - 2013
2015	Research paper	Ribeiro, C., Valente, S., Coelho, C., & Figueiredo, E. (2015). A look at forest fires in Portugal: technical, institutional, and social perceptions. <i>Scandinavian Journal of Forest Research</i> . 30(4). 317-325	2004 - 2013
2015	Research paper	Verde, J.C. (2015) - Wildfire susceptibility modelling in mainland Portugal, PhD thesis, Instituto de Geografia e Ordenamento do Território, Universidade de Lisboa. pp 210	2004 - 2013
2015	Technical report	ANPC (2015). Directiva operacional nacional nº 2 DECIF 2015. Autoridade Nacional da Protecção Civil. Pp 125	2004 - 2013
2015	Technical report	IESE (2015). Avaliação do Plano Nacional de Defesa da Floresta Contra Incêndios. Relatório preliminar. Lisboa. 25 p	2004 - 2013
2016	Book or chapter	Pereira, J. S. (2016). O Futuro da Floresta em Portugal. FFMS. 92 p	2004 - 2013
2016	Essay	Santos, H.P.(2016). Evolução da paisagem rural do continente português no século XX. PhD thesis Faculdade de Letra da Universidade do Porto. 185 pp.	2004 - 2013
2016	Official working paper	TC (2016). Auditoria Orientada às Transferências Financeiras da Autoridade Nacional de Protecção Civil para as Associações Humanitárias de Bombeiros. Ano 2013. Tribunal de contas. 82 p	2004 - 2013
2017	Research paper	Oliveira, T. M., Guiomar, N., Baptista, F. O., Pereira, J. M., & Claro, J. (2017). Is Portugal's forest transition going up in smoke?. <i>Land Use Policy</i> , 66, 214-226.	2004 - 2013
2017	Research paper	Fernandes, P.M., Guiomar, N. (2017). Os incêndios como causa de desarboreização em Portugal. <i>AGROTECH</i> 22, 28–32	2004 - 2013
1990	Technical report	CMA (1990). Projecto de Defesa Florestal Contra Incêndios - Projecto Piloto Agueda. Câmara Municipal de Águeda. 40 p	1985 - 1995
1988	Technical report	Agueda (1988). Projecto Defesa da floresta contra incêndios em Agueda. In Viegas, D.X. (1989). <i>Actas das Jornadas Científicas sobre Incêndios Florestais</i> . 11 p	1985 - 1995
1966	Essay	Calheiros (1966). Editorial sobre incêndio Serra de Sintra. <i>Cadernos do Gabinete de Estudos Económicos e Estatísticos da Direcção-Geral dos Serviços Florestais e Aquícolas</i> . Ano VI, Nº3. 3 p	1963 - 1974
1961	Essay	Silva, T (2011). Foi há 50 anos que o inferno passou pelo Vale do Rio. <i>A Comarca</i> . Figueiro dos Vinhos. 3 p	1938 - 1962
2006	Book or chapter	Vieira, J.A. (2006). Portugal: o vermelho e o negro. Edições Dom Quixote, Lisboa. 469 p.	2004 - 2013
2016	Book or chapter	Louro, V. (2016) A Floresta em Portugal: Um apelo à inquietação cívica. Gradiva, Lisboa, 268 p	2004 - 2013

Appendix 2.

Table A2.1 Code dictionary

Theme	Category	Definition	Sub-category	Definition	Examples	
1. Fire occurrences						
Causes behind forest fires phenomenon, that impact on its ignition, rekindle and/or magnitude of events	Causes	References to the direct causes of fire ignition	Negligent use of fire	Explanation of ignition by careless human activity (cigarettes, fire camps, picnics etc.)	associadas a comportamentos negligentes	
			Natural causes	Explanation of the ignition by natural phenomena such as volcanos or lightening	da ocorrência de trovoadas secas	
			Arsonist	Explanation of fire ignition by criminal activity, regardless of its motivation	prática dolosa do fogo ou a negligência no seu impedimento e combate	
	Motivation	References to explanations regarding the motives behind the fire causes		Land use planning	References to the formal and institutional ordering and regulations of land use, aimed at providing convenient, balanced, equitable, healthful and attractive environments	Acrecece ainda que as acções de reabrorização subsequentes aos incêndios nem sempre se têm mostrado as mais adequadas do ponto de vista técnico e ambiental, pelo que deverão ser sujeitas a certos condicionamentos.
				Increase in fuels	References to practices related to the maintenance and management of the goods and environmental services provided by the land (crops, stands, leisure areas, etc.) that contribute to the increase in fuel load and area	um combustível que concorre para que o fogo se propague com maior velocidade, dificultando o seu controlo e combate.
				Stakeholder's behavior	References to practices related to use by stakeholders of goods and environmental services provided as an explanation of the phenomenon	assim, de suster um fenómeno accionado por agentes ao serviço de interesses inconfessáveis de que se conhecem os grandes contornos e os principais beneficiários
				Private owners' behavior	References to practices related to use private forest owner regarding land management as an explanation of the phenomenon, as responsible for land management	No caso concreto contemplado por este diploma, o hábito generalizado de uma exploração aleatória dos maciços florestais
				Meteorological	References to the correlation between meteorological conditions and fire ignition and/or intensity	Por outro lado, as condições de clima, com períodos prolongados de seca bem marcada, contribuem decisivamente para o aumento do número de incêndios e, bem assim, para que os mesmos possam tomar grandes proporções.
2. Expressed values						
What is valued for considering the preservation of the forest	Economic	References to the potential economic and strategic value of the forest, not considering losses. References to forest and/or its specific products as strategic provider of materials references for (strategic) development of the country and/or its people; references to the importance of the forest for other (economic) activities			A floresta desempenha um papel fundamental na vida da nossa comunidade, quer pelos bens que faculta	

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Table A2.1 Code dictionary

Theme	Category	Definition	Sub-category	Definition	Examples
	Non-economic	References to the potential non quantifiable value of the forest and environmental services;			A contribuição da floresta para a preservação dos equilíbrios fundamentais, designadamente dos recursos hídricos, do solo, da fauna, da flora e mesmo do clima, tem de ser cada vez mais reconhecida e estimulada
3. Reasons for intervention					
Reason for action or needs that prompts action or behavior that seeks a change	Economic losses	References to the need to mitigate direct and indirect economic damages and losses or potential misused	Markets	Reference to market perturbation or losses including disruptions in value or quantitate of products	Os elevados fluxos de madeira originados pela anormal dimensão dos incêndios de 2003 e a inadequação da capacidade de corte existente no País face às necessidades de escoamento da madeira atingida tiveram como resultado a permanência ainda na floresta de elevados volumes de madeira atingida pelos incêndios, cujo escoamento importa assegurar.
			General	References to potentially economic losses including potential without specifying its type or nature	os fogos florestais têm causado grandes prejuízos no continente, designadamente nas regiões do interior Norte e Centro, onde a floresta desempenha uma função de maior relevância económica
			Forestlands	References to losses comprising timber, wood and forest products	dizimando o nosso património silvícola, nomeadamente o produtor de lenho e de resina.
			Burnt area	References to losses in terms of the extinction, location and/or proportion of burnet area, without specifying forest products	Considerando a extensão do fogo, consubstanciada em 9180 ha de floresta ardida
	Non-economic Losses	References to the need to mitigate non-economic damages and losses causes by fires and its effects upon lives, property and non-economic values that are perceived but are very difficult to measure and quantified	Social	References to non quantifiable losses without specifying its type or nature	com elevado impacte na vida social
			Property	References to loss of non timber tangible goods, such as infrastructures, equipment's, houses, utilities, husbandry and/or crops	Sucede, por vezes, que estas casas são pasto das chamas provindas de incêndios florestais, o que acarreta a destruição dos respectivos recheios, com graves prejuízos para os seus moradores.
			People	Reference to loss of lives and injuries (civil and firefighters) and populations in general	dos quais resultaram lamentavelmente perdas de vidas humanas
			Public trauma		geraram na sociedade portuguesa justificada emoção e apoio quanto à necessidade de se alterar profundamente a nossa relação com a floresta.
			Environment and cultural	References to non quantifiable losses considering the environment and specific species conservation, as well as the cultural heritage of the country	a terra queimada trás consigo a desolação ecológica, com as inerentes consequências na qualidade de vida das populações
	Metapolicy	References to existing national or international policies, reports and regulations that Portugal must comply with			No contexto da política florestal nacional, tal como se encontra concebida e em cuja implementação o Governo está empenhado

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Table A2.1 Code dictionary

Theme	Category	Definition	Sub-category	Definition	Examples
	System design	References to the conception, architecture and/or functioning of the existing institutions	General	Reference in general to conception, architecture, design or function of existing institutions	A prevenção, a detecção e o combate a incêndios florestais revestem-se de extrema complexidade, dadas as suas múltiplas incidências
			Change in institutions	References to any specific change in existing institutions, such as the creation of new entities, fusion of existing ones, etc.	Tanto o incremento das tarefas que lhe têm sido cometidas como o crescimento das solicitações por parte das comissões especializadas de fogos florestais municipais e distritais impõem
			Emergent players	References to new institutions	A nova visão política conseguida com a mudança política em Portugal levou à criação da Secretaria de Estado do Ambiente
	Resources uses	References to the lack of human and/or material resources or to its ineffectiveness	Pre-suppression	the need to improve detection response of surveillance system and to improve coordination of players and institutions	entende-se ser da maior vantagem a intensificação do esforço em ordem a um melhor aproveitamento dos recursos existentes e a uma mais aperfeiçoada articulação entre as estruturas envolvidas
			Prevention	the need to educate, inform and treat fuel load and forest management	face à necessidade de dar primazia à gestão e preservação do património florestal existente.
			Suppression	the need to improve effectiveness of fighting resources	subsistiram as dificuldades de articulação entre os vários serviços e sectores envolvidos nas operações de socorro, agravadas em situações de intervenção de outros agentes do sistema nacional de protecção e socorro
			Rehabilitation	the need to implement emergency and rehab operations	há que proceder ao corte, descasque e colocação em estaleiro desse material
		Timeliness	references to the needs to shorten/increase the time limits for actions	Considerando que, apesar das dificuldades financeiras que o País atravessa, é urgente	
	Law related	References to the absence or ineffectiveness of existing regulations and policy instruments or the to execute law and assure that it is implemented by all players			importa proceder à adequação de legislação florestal - cujos principais diplomas datam de há meio século
	4. Actions				
Bodie of beliefs, principals and actions foresee as solutions to solve the problem or minimize the losses	Planning	References to actions related to systematic technological and administrative management process of designing organization, facilities, and procedure to protect wildland from fire	Coordination	References for solutions that encompass and seek a improvement in capacity to coordinate, command and control throughout all of the phases	com a missão de concertar estratégias e compatibilizar e orientar acções concretas de prevenção e protecção da floresta contra incêndios.
			Legal and Law organization	Reference to regulations and procedures developed to foster the system to be more effective, lean or according the metapolicy needs	medidas susceptíveis de contribuir para uma mais clara definição e delimitação das responsabilidades de cada uma das entidades participantes.

Appendix 2.

Table A2.1 Code dictionary

Theme	Category	Definition	Sub-category	Definition	Examples
			Economic policy stimulus	Reference to actions tailed to foster a key player or stakeholder to behave positively in the system	Por último, é de referir que são estabelecidas as condições de preferência dos proprietários dos prédios rústicos incluídos e aderentes à ZIF na compra e venda ou dação em cumprimento de prédios rústicos sítos nessa área
			Landowners engagement	Reference to actions that increase the commitment and engagement of landowners or risk holders	medidas imediatas que estimulem, mobilizem e apoiem os proprietários florestais, as organizações sócio-profissionais do sector e as instituições locais.
			New entities/responsibilities	References to solutions based on the creation of organization or a change in its assignment and role in the system	a criação de conselhos distritais de prevenção, detecção e combate dos incêndios florestais
			Research and development	Reference to the study of critical issues or investment in R&D	proceder-se-á a estudos destinados à adopção de medidas com o objectivo de detectar ou eliminar as causas dos incêndios florestais, determinar-se-ão as "épocas de perigo»,
			Planning_Landuse_zooning	Reference to planning tool, mechanisms that promote the balance of actions, land use and prescribe a best occupation for the land	Tomar providências para que nenhuma área florestal ardida, independentemente da superfície, possa ser utilizada para fim diverso daquele para que se utilizava antes de afectada por incêndios, salvo se para o efeito for obtida a autorização fundamentada da Direcção-Geral das Florestas.
			Application of knowledge	Reference to the application of technical knowledge or outreach to players and stakeholders	delimitando uma nova cartografia quantitativa da probabilidade de incêndio florestal em Portugal continental,
			Funding facilities	Reference to capital made available to cope with problems or support envision solutions	gratuita
	Prevention	References to actions in fire management, fuel management, forest management, forest utilization and concerning the land users and the general public, including law enforcement, that may result in the prevention of outbreak of fires or the reduction of fire severity and spread	General	Reference to actions focused on prevention, without specifying	quer através do reforço de medidas de prevenção e protecção da floresta contra os incêndios
			Education and information	Reference to actions that contributes to raise the awareness and social capital of all or any agents and stakeholders	a aposta na sensibilização e educação, com a divulgação coordenada de campanhas;
			Fuel treatment	Reference to actions towards fuel manipulation or removal that reduce the likelihood of ignition and/or to lessen potential damage and resistance to control (e.g., lopping, chipping, crushing, piling and burning)	de tratamento de áreas florestais num esquema de mosaico e de intervenção silvícola
			Law enforcement	Reference to investments or actions towards a effective compliance of all players with the law	As coimas apresentam um agravamento de cerca de 40%, ajustando-se à realidade económica e à devida proporção da protecção do bem floresta
	Pre-suppression	References to fire intelligence and preparedness in advance of fire occurrence to ensure effective suppression action. Includes	Coordination	References for solutions that encompass and seek a improvement in capacity to coordinate, command and control throughout all of the phases	coordenação e formação de meios e agentes envolvidos

Appendix 2.

Table A2.1 Code dictionary

Theme	Category	Definition	Sub-category	Definition	Examples
		planning the organization, recruiting and training, procuring equipment and supplies, maintaining fire equipment and fire control improvements, and negotiating cooperative and/or mutual aid agreements.	Detection	Reference to investments or actions towards improvements in the detection operations for discovering, locating and reporting wildfire incidents	quer da melhoria dos meios de detecção;
			Infrastructure	Reference to investments or actions toward the improvements of infrastructures as communications, roads, water deposits and fuel breaks	aconselhável a instalação e utilização de uma infra-estrutura única que sirva de suporte às radiocomunicações das diversas entidades
	Suppression	Reference to investments or actions towards improving the controlling and extinguishing a fire following its detection		Ponderadas as diversas alternativas, optou-se pela aquisição imediata de 2 conjuntos MAFFS (Modular Airborne Fire Fighting Systems), que se destinam a equipar outros tantos aviões C-130 da Força Aérea Portuguesa.	
	Rehabilitation	The activities necessary to repair damage or disturbance caused by wildfire or the wildfire suppression activity	Damage evaluation	Reference to actions that evaluate the damages cause directly or indirectly by fires	inventariação dos danos, fazer o levantamento de situações de necessidade de socorro
			Compensation of losses	Reference to solution that mitigate losses of people or private organizations	devam ser compensados dos respectivos montantes.
			Wood yards	Reference to the construction or use of wood yards	extracção e parqueamento dos salvados das zonas atingidas pelos incêndios através da criação de novos estaleiros estrategicamente colocados em relação às manchas florestais atingidas ou, preferentemente, pelo aproveitamento da rede dos estaleiros já existente.
			Reforestation and recovery	Reference to investments or actions towards	desencadear acções conducentes à rearborização das áreas ardidas.

Appendix 3.

Figure A3.1. Proportion of municipality area within the 3 km buffer of Forest Service managed areas by 1980.

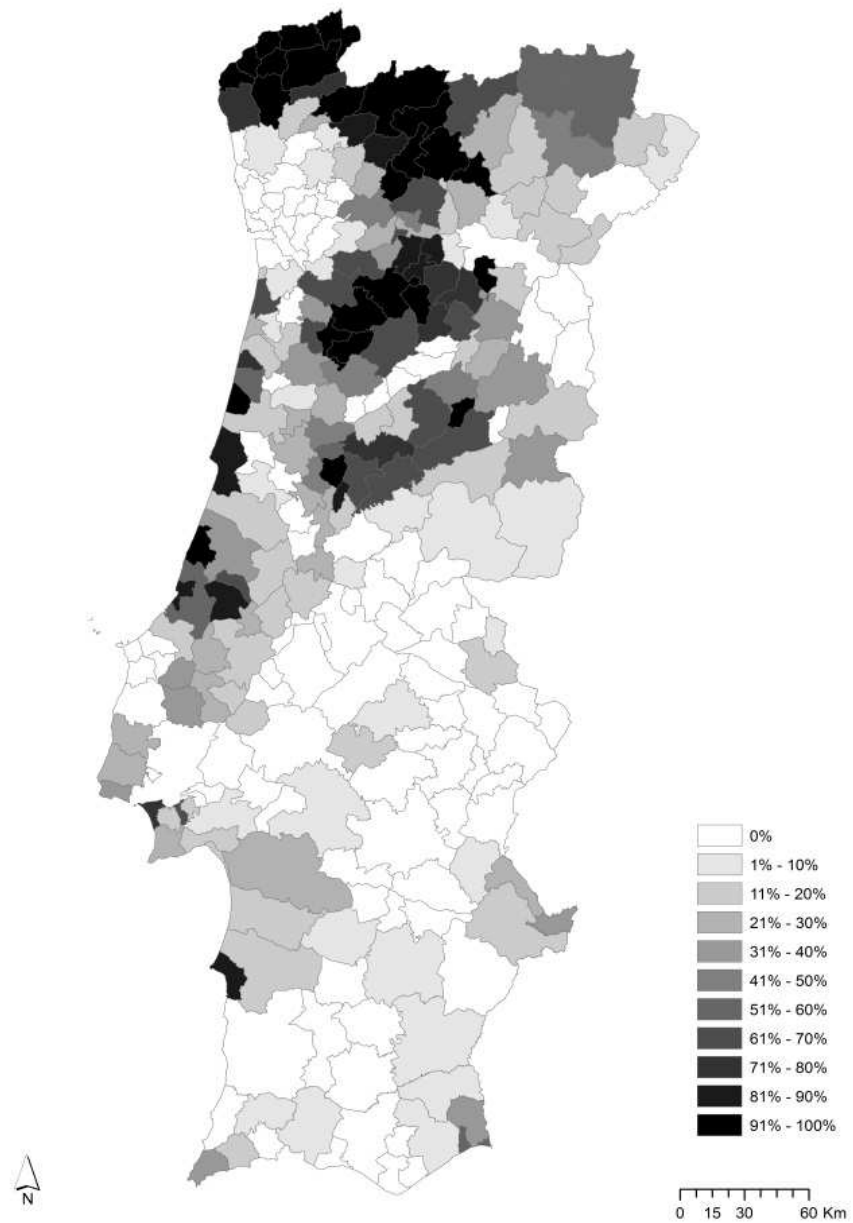
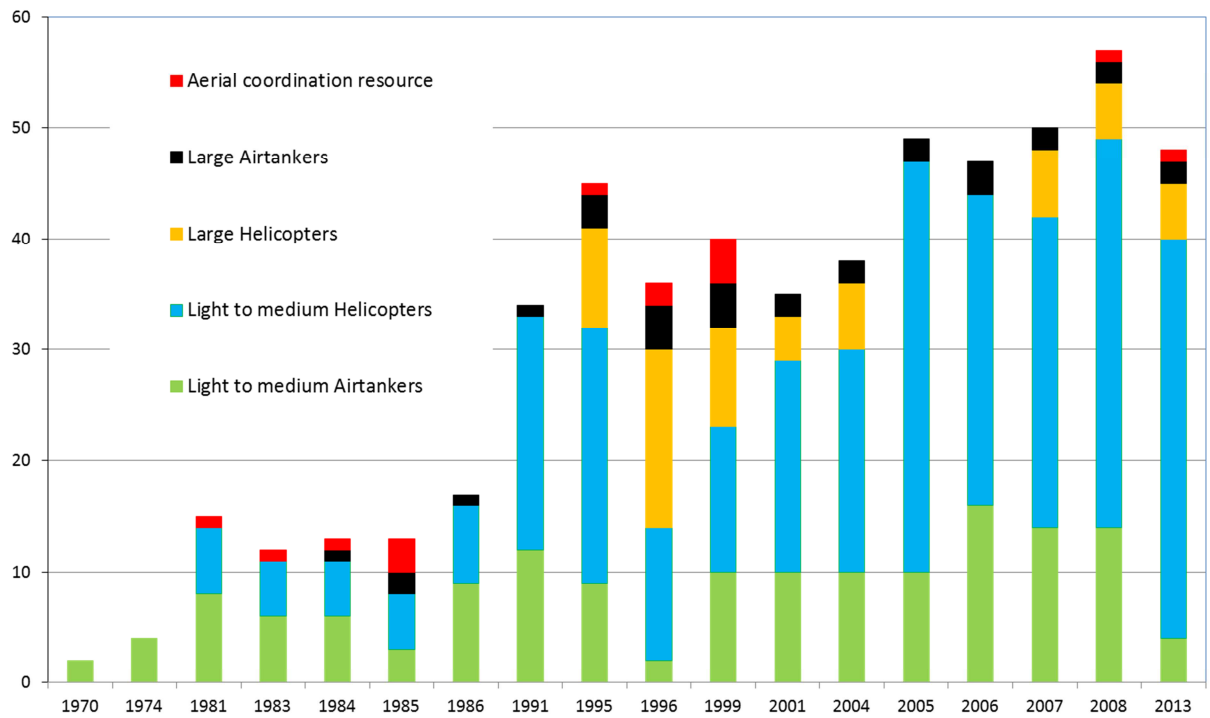


Figure A3.2. Evolution of aerial suppression resources by year.



Appendix 4.

Table A4.1. Chronology of framing and solution adopted

	International and national context	Forest and fire context	Problem Framing	Solution adopted
1910 to 1925	<ul style="list-style-type: none"> · Republican revolution · I WW · Political instability 	<ul style="list-style-type: none"> · Development of local systems to protect coastal national forest areas with Forest Guards Corps, lookout towers, fuel breaks and fire suppression personnel. · Use of traditional prescribed fire techniques in some mountain areas · Communal lands survey 	<ul style="list-style-type: none"> · Forest Service investments (less < 2% of country) needed to be protected, along with soil and river basin protection, in mountains and coastal sand dunes 	<ul style="list-style-type: none"> · National forests protected by Forest Guards, fuel breaks and hand-tool equipped personnel and biomass removal for domestic and industrial use
1926 to 1937	<ul style="list-style-type: none"> · Establishment of a right-wing dictatorial regime · High unemployment rate in rural areas, namely during the Great Depression · Agriculture and forestry among “Estado Novo” key policies towards economic self-sufficiency 	<ul style="list-style-type: none"> · Private forests (vast majority) without a formal wildfire protection system, except for incipient communal organization in a small number of parishes (in mountain and coastal areas) and some private large properties 	<ul style="list-style-type: none"> · Escaped fires from croplands and pastures and train steam engines. · Low fuel load landscapes 	<ul style="list-style-type: none"> · New wildfire regulation for effective law enforcement with improved forest police (set by the Forest Regime Act of 1901 and by its revision of 1926)
1938 to 1962	<ul style="list-style-type: none"> · Marshall Plan helps the establishment of pulp and fertilizer industries and mechanization in lowland agricultural areas · High unemployment rate in rural areas, namely during and after II WW · Portugal joins European Free Trade Agreement · Beginning of socioeconomic development of overseas territories · Overseas or colonial war 	<ul style="list-style-type: none"> · National Afforestation Plan 38-72 · State forest organization responsible for conservation, silvo-technology and market regulation · Private forests (vast majority) without a formal wildfire protection. Fires are fought by local villagers, urban firefighter if available, exceptionally with support from Forest Service and military personnel · Fire management expertise and knowledge transferred through training and written guidelines and books · Large private properties in central and southern Mainland (about 1 M ha) are voluntarily submitted to the forest regime and have forest guards 	<ul style="list-style-type: none"> · Recognition of need to protect forest public investments (5% of country area) · Escaped fires from croplands and pastures, train steam engines and some fires were intentionally set inside forest plantation · First severe wildfire season in 1957 and in 1961 in central Portugal. A small village was destroyed by a wildfire. · Fuel load in young plantations in steep terrain is expensive to manage 	<ul style="list-style-type: none"> · Expansion of forest protection system that existed in coastal areas to mountain areas (Forest Guards, lookout towers, fuel breaks and fire suppression teams) · After 1954, preventive and if needed suppression activities in a 3km buffer, extending territorial influence of Forest Service to 20% of country. · Updated fire regulation for effective law enforcement, with an improved forest guard organization. · Fire risk prediction tools and fire prevention and suppression manuals to train and transfer knowledge · First public awareness campaigns (50s and 60s)

Appendix 4.

Table A4.1. Chronology of framing and solution adopted

	International and national context	Forest and fire context	Problem Framing	Solution adopted
<p>1963</p> <p>to</p> <p>1974</p>	<ul style="list-style-type: none"> · Colonial war in most African territories · Policy focus on industrialization plans and overseas territories development undermines agriculture and forest as national priorities · Mechanization and fertilizers decouple croplands from forests · Rural exodus increases labor costs , generating an “agricultural crisis” · Political revolution of 1974 (Carnation Revolution) 	<ul style="list-style-type: none"> · Forest Service mobilized for afforestation of the southern plains and mountains, mostly private owned · Big fires spark technical reflection > political decision · National forest fire strategy increased fuel break network, lookout towers, number of forest guards and initial fire attack system with 4x4 vehicles, wildfire engines, hand-tools and radios to prevent and suppress fire in national and communal lands. Extends operation to fires spreading from outside Forest Service jurisdiction areas 	<ul style="list-style-type: none"> · Fires threaten forests, property and people · Escaped fires from croplands and pastures · Lack of forest management and depopulation in private pine forests increases fuel loads · Fire protection system is recognized outside expert community · Lack of resources to create fuel breaks and perform fuel treatments 	<ul style="list-style-type: none"> · First systemic regulation aiming at organizing prevention, pre-suppression and suppression · Forest guards supplemented with hand-tool equipped teams, deployed in high risk areas, and supported with aerial resources to defend national and communal forests (beginning in 1970) · Education and information campaigns addressed to general public. · Compensation for wildfire losses and reforestation subsidized
<p>1975</p> <p>to</p> <p>1980</p>	<ul style="list-style-type: none"> · Democracy and centralized planned economy · Oil crisis and 1st IMF bailout · National and local democratic elections. Extinction of “Legião Portuguesa” and its equipment transfer to firefighting volunteer corps · Creation of governmental agencies for the environment, and emergence of environmental NGO 	<ul style="list-style-type: none"> · National forest fire strategy increased number of lookout towers, forest guards and initial fire attack system with 4x4 vehicles and fire engines, aerial suppression resources, hand-tools and radios to prevent and suppress fire in national and communal lands and 3km buffer. · In remaining areas, fires are fought by unequipped villagers, supported by volunteer urban firefighter, lacking wildfire suppression expertise · Education and information campaigns addressed at general public and schoolchildren 	<ul style="list-style-type: none"> · Wildfires threaten private and public property, human lives, social stability, and the environment · Fire perceived to be related with stakeholders (loggers) and lack of management in private forest stands · Urgency drives improvements 	<ul style="list-style-type: none"> · Salvage harvesting and sale of timber subject to regulation · Reinforce of suppression resources · Expansion of lookout tower network · Compensation of wildfire losses and reforestation · Law enforcement · Education and information

Appendix 4.

Table A4.1. Chronology of framing and solution adopted

	International and national context	Forest and fire context	Problem Framing	Solution adopted
<p>1981</p> <p>to</p> <p>1985</p>	<ul style="list-style-type: none"> · Consolidation of democracy · 2nd IMF bailout · World Bank Forest Project enhances afforestation dynamics in former croplands and shrublands · Emergent players/actors Ø New pulp plants Ø Environmental movement 	<ul style="list-style-type: none"> · Forests services mission is confined to prevention and detection. · Firefighters area made responsible for suppression · Wildfire management expertise not transferred to the new fire suppression organization · Education and information campaigns addressed at general public 	<ul style="list-style-type: none"> · Fires disrupt markets, destroy forest value, property, cause social unrest · Arson fires perceived to be related with timber loggers, land developers and negligence 	<ul style="list-style-type: none"> · System change · Salvage harvesting and sale subject to regulation · Reinforcement of suppression resources Expansion of lookout tower network · Focus Law enforcement · Zoning to prevent land use change in burned areas. · Focus on coordination and infrastructures
<p>1986</p> <p>to</p> <p>1995</p>	<ul style="list-style-type: none"> · Portugal joins the European Economic Community · Transition to market economy · European union inflow of regulations and money · Modernization of economy and society · Primary sector economic importance reduced, but forest industries strengthened 	<ul style="list-style-type: none"> · Forests services focused on wood production and market regulation, after creation of autonomous public agency for nature conservation becomes an · Afforestation and forestry EU funded projects (PAF/PAMAF) · Pulp companies develop their own fire protection systems 	<ul style="list-style-type: none"> · Fires destroy forest assets, cause social unrest and damage environment · Fires are perceived to be related with stakeholder and private owner behavior lack of management · Need to improve laws / regulations · Need to plan and improve cooperation among public agencies and improve infrastructures 	<ul style="list-style-type: none"> · New equipment for local volunteer fire brigades and strong increase aerial resources · Innovative project about fire cause investigation, expansion of lookout tower network and ground surveillance · Zoning to prevent landuse change in burned areas. Development of fire risk management plans · Stricter penalties for illegal fire use · Reforestation and compensation of fire damages · Intra-governmental coordination agency · Investments in pre-suppression infrastructure: road network, airfields and water ponds · Education and information campaigns

Appendix 4.

Table A4.1. Chronology of framing and solution adopted

	International and national context	Forest and fire context	Problem Framing	Solution adopted
<p>1996</p> <p>to</p> <p>2003</p>	<ul style="list-style-type: none"> · European single currency and strengthening of European integration · Emergent players/actors <p>Ø Municipalities forest role</p> <p>Ø Forest owners organization</p>	<ul style="list-style-type: none"> · Afforestation and forestry EU funded projects (PDF/Agro) · Forest policy law approved in Parliament · Chronical lack of resources in prevention and detection, state forest guards removed from forest management · Dispersion of responsibilities within Public administration, dismantling Forest Service management procedures, underfinanced activities in public and communal lands 	<ul style="list-style-type: none"> · Burned areas, people and property are highlighted as reason for action · Negligent and natural fires · Worsening of meteorological conditions · Need to improve infrastructures and suppression 	<ul style="list-style-type: none"> · Effort to promote intra-governmental coordination and planning fire infrastructures · Reinforcement of suppression resources · Prevention program – forestry brigades, jointly managed by Forest Service and local forest owner associations, parishes, and counties. · Legislative focus on land use and zoning and forest planning · Compensation for losses
<p>2004</p> <p>to</p> <p>2013</p>	<ul style="list-style-type: none"> · 3rd FMI bailout · Emergent players/actors <p>Ø National guard</p>	<ul style="list-style-type: none"> · Worst fire seasons · After initial reformist approach (2004), with minister in charge of forests having the lead, civil protection leadership and the urgency to have short term results led to the re-equipment of local volunteer fire fighters, creation of professional special corps to deal with firefighting (within national guard and firefighting agency) and more aerial resources 	<ul style="list-style-type: none"> · Burned areas, social and environment are highlighted as reason for action · Fires perceived to be set by arsonist and negligence, exacerbated by climate warming · Stakeholder and private owner behavior lack of management · Increased in fuel loads 	<ul style="list-style-type: none"> · Political action towards system change · Increase in suppression resources and interagency coordination · Salvages timber yards · Zoning to prevent land use change in burned areas. · Regional and municipalities forest fires planning become mandatory · Increase fire use penalties · Public forest and nature conservation agencies reorganization (multiple times)

Appendix 5.

Table A5.1. Detailed description of selected learning loop for each period

Period	Loop	Description
1910 – 1925 . 1937 - 1962	Single	The system followed a incremental improvements to established routines, and expanding FS codes and best practices that had been well tested in the coastal afforested areas, to the interior mountains. Improvements materialized and new regulation that extended fire management activities of FS to a 3km buffer zone was published in 1954. After the 1957 fire season, internal technical reports (e.g. Dias 1958, Quintanilha 1958) claimed for preventive investments, such as firebreaks, lookup towers and Forest Guards reinforcement. Calling into question the existing guiding assumptions, a new approach resulted from a reframing of the problem and the ways to handle it. The publication of DL 488/70, in a time the political regime was also trying to reform itself, reinterprets the established roles of institutions, and sets for the first time a national fire management system. Under this regulation, other entities such as LVF, or district or local councils, that provided help to FS to better manage prevention and handle fire events, became more visible.
1963 - 1974	Double	In this period we observed a gradual learning process fostered change, the system opened up to the participation of non-expert communities, and although a hierarchical formal organization extended its influence, network and multilevel interactions increased, even though changes in private forest management in high risk areas, needed to solve the serious land and forest abandonment problem, were largely unsuccessful, due to lack of political support and resistance by private owners and other stakeholders (Louro 2016).
1975 – 1980	Double	The regulatory framework was found to constrain innovation, and strong arguments for alternative views emerged, questioning the dominant governance logic, and the established routines that were in place to manage risk. In a post-revolutionary and decolonization context, new actors emerged and informal networks helped to shape the discourse, as is clear from the parliament discussion in 1980. Frequent command incidents between the Forest Service and the LVF, especially in areas of overlapping responsibilities, as well as an abyssal difference of cultures and technical capacity in the field of forest fire fighting, created an environment of dispute between the different actors (Nogueira et al 1984).

1981 - 1985	Triple	The system suffered a transformation. The incumbent system was replaced by a new one that promised to control the manifestation of the problem, i.e., the fire effects on local communities and forests. A new regulatory framework modified the roles of existing organizations and created new entities, assuming a new centrality and supporting a new power structure and the emergence of other value structures, such as the relevance of civil protection in the face of forest protection. Multilevel interactions also became more polycentric and actor participation was formally established at a local and district level, as local authorities' power became stronger (in responsibilities, technical and human resources and budget).
1985 - 2003	Single	The system performance improved, as vertical coordination was established between actors within its network, in a multiple stakeholder polycentric environment. The animosity between the various players, aggravated by the 1981 transformation and the evident lack of coordination in the following period, made cooperation very difficult in order to make better use of the available resources, with frequent exchanges of accusations after large fires or disastrous fire seasons (Vieira 2006). Although regulations and the status quo fostered routines, some discussions claimed for change (e.g. rekindles Pacheco et al. 2014), but alternatives were dismissed.
2004 - 2013	Double	In the aftermath of the summer of 2003 fire season, new, widely accepted ideas emerged, and established norms were questioned. Placed under the spotlight, the dominant governance and power structure was called into question. New organizations were created and the roles of existing organizations were modified. Several reports added contributions to the debate, increasing informal knowledge exchanges among all levels. Nevertheless, the change did not modify the governance mode, nor set a new paradigm to approach the problem and foster a new frame of reference and corresponding actions. Although the problem was framed acknowledging fuel accumulation and lack of preventive measures, the adopted organization, resources, and actions favoured suppression performance and the reduction of ignitions, and did not foster a transformation and paradigm shift in the risk management practices and the dominant culture. Small improvements in the prevention area, namely the regaining of technical capacities and the creation of highly specialized units on forest fires in the Ministry of Agriculture agencies, were rapidly dismantled between 2008 and 2011, and the support to private forest management (through ZIF or other public policies promoting landowner's association) kept a low profile in the government agenda and public resources allocation (both at national and municipal levels) (Mateus and Fernandes, 2014).

2.3. ANÁLISE À EFICÁCIA DA REDE PRIMÁRIA DE GESTÃO DE COMBUSTÍVEL

Esta secção da dissertação enquadra o artigo "*Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission*", publicado no *International Journal Wildland Fire*, onde se avalia o potencial efeito na redução da área ardida caso fosse construída uma rede regional de faixa de combustíveis. Nos parágrafos seguintes apresenta-se a definição de "aceiro", "faixa de gestão de combustível" e "rede regional de faixas da rede primária".

Para compreender a formulação do problema investigado e a sua relevância para a governança do risco de incêndio, documenta-se a evolução do conceito de "aceiro" e suas aplicações desde o final do séc. XIX em Portugal. Neste percurso histórico destaca-se o papel que assumiram no sistema local que geria e guardava as florestas dos incêndios, a importância do seu desenho para serem eficazes, a ligação com as técnicas de combate, os seus custos, os planos para a sua implementação nas áreas privadas e as expectativas que hoje sobre elas recaem enquanto solução preventiva. Apresenta-se o contexto e âmbito da investigação e formulam-se as questões de investigação abordadas no artigo.

a) DEFINIÇÃO DE FAIXA DE GESTÃO DE COMBUSTÍVEIS

Os aceiros e arrifes ou, na terminologia mais recente, as faixas de gestão de combustível, são constituídas por parcelas mais ou menos lineares das quais se removeu total ou parcialmente a biomassa florestal através da afectação de usos não florestais, ou com recurso à silvopastorícia, ou empregando técnicas silvícolas, com vista a reduzir o perigo de incêndio (Pinho *et al.*, 2006). Segundo o único glossário em português sobre incêndios florestais (ISA-APIF, 2005), podem ter uma largura de até 10 metros nos sistemas silvo-pastoris, e superior, no caso dos sistemas silvo-lenhosos, delimitando e interrompendo a continuidade horizontal do complexo combustível. Constituídas e mantidas com pouca ou até nenhuma vegetação, estas faixas têm como objectivo, no caso de ocorrer um incêndio que as intercepte, alterar o comportamento do fogo, limitando a sua velocidade e intensidade de propagação. Esta modificação permite, em tese, que o combate por métodos directos ou indirectos seja mais eficaz e seguro, apoiando a contenção da propagação e limitando os danos.

Tradicionalmente, na ciência florestal e sua prática, um povoamento florestal ou mata (da qual a Mata Nacional de Leiria será uma referência na organização do espaço) encontra-se delimitado por um aceiro exterior (22 metros de largura) e no seu interior por faixas limpas de vegetação, umas paralelas aos ventos dominantes (aceiros) e outras perpendiculares (arrifes, que podem ser mais estreitas). Esta estrutura no seu conjunto define a rede divisional e delimita os talhões homogêneos, compartimentando o território para efeitos de gestão, exploração ou defesa da floresta contra incêndios.

Com a publicação do DL 124/2006 as faixas de gestão de combustível podem assumir diversos escalões, nomeadamente ser uma faixa primária, secundária ou terciária, consoante a largura média e os objectivos de protecção que visaram a sua construção ou manutenção. Caso a rede seja definida à escala de uma região, com largura mínima de 125 metros e diversas outras prescrições técnicas, constitui uma rede regional denominada “rede primária de faixas de combustíveis”.

No glossário da FAO (2003) as faixas designam-se, em inglês, por *fuelbreak* e, em castelhano, por *area cortafuegos*, correspondendo também a estruturas lineares com larguras entre os 20 e 300 metros. Quando várias faixas delimitam o território, designam-se por *fuelbreak network* ou *fuelbreak system*. O glossário da FAO distingue as definições anteriores de *firebreak* ou *cortafuegos* por estes se destinarem especificamente ao controlo do fogo e toda a vegetação e matéria orgânica ter sido removida até ao solo mineral. Na terminologia portuguesa, estas últimas definições encontram correspondência no vocabulário técnico na expressão *corta fogos*.

b) PERCURSO HISTÓRICO DO CONCEITO E DA PRÁTICA

Não sendo objecto deste capítulo a investigação histórica sobre os aceiros e a sua prática, pretende-se documentar sumariamente o percurso do conceito e seu uso.

A primeira referência que encontramos sobre aceiros, enquanto medida preventiva aos fogos, é em 1699, através de uma citação de Baeta Neves (1972) ao referir o “Regimento dos Verdes e Montados do Campo de Ourique” que determinava a abertura no Pinhal do Rei (Mata de Leiria) de um aceiro a Norte e

a Sul. Baeta Neves (1972) transcreve ainda as medidas decretadas pelo então Administrador do Real Pinhal (Eng. Correia Alardo) na reacção aos fogos de 1815, que determina percursos para os guardas florestais que a cavalo ou a pé, têm de percorrer o "Aseiro Geral". Outras referências posteriores (Varnhagen 1825; Barros Gomes, 1874; Magalhães, 1875) mencionam a presença e uso de aceiros nos pinhais do litoral, demonstrando que faziam parte do sistema de prevenção e combate a incêndios. Será com Barros Gomes em 1862 que fica implementado um sistema técnico de rede divisional de aceiros e arrifes (Alves *et al.*, 2006).

É de destacar a primorosa descrição técnica sobre as práticas de "Atalhadas" ou aceiros por Pimentel (1876), em "Os incêndios nas Florestas – Meios de os prevenir e atalhar". Pimentel documenta magistralmente os objectivos e utilidades das faixas, expressando até as suas limitações. Reproduzimos parcialmente na Fig. 13, um pequeno trecho em que o autor recomenda que para a defesa de montados e pinhais, a construção de aceiros com 15 metros de largura seja realizada na direcção Norte-Sul, e em outras condições se aproveitasse o relevo e a disposição do terreno para a sua implementação. Recomenda que estes aceiros sejam cortados por outros aceiros transversais, com 6 metros de largura, subdividindo o talhão, facilitando a circulação e simplificando o acesso e o trabalho de extinção do fogo. Para além de eficazes auxiliares pontos de partida para um contra-fogo, serviriam de caminhos de exploração que compartimentariam extensas áreas de floresta. Refere que embora fossem um grande auxílio, *"são inúteis muitas vezes quando a nortada sopra violentamente e o terreno está coberto por abundante vegetação de mattos, pois não evitam que as chamas avancem e façam grande devastação. A roça do matto dificulta e torna menos damnosos os incêndios, porque nada os alimenta e aviva como estas plantas sub-arbustivas"*.

No nosso paiz, o que geralmente se pratica são as atalhadas ou aceiros, que consistem em largos caminhos desprovidos de qualquer vegetação, os quaes dividem a floresta em talhões e tendem a circumscrever o incendio á parte em que se manifestou, servindo assim de guarda fogo, de isoladores para as outras parcelas da floresta. Devem ter uma largura de 15 metros e a direcção norte a sul, que é tambem a do vento dominante no verão. Outras condições se devem ainda ter em vista na directriz dos aceiros; o relevo ou a disposição do terreno póde ser utilmente aproveitada.

Quando o fogo chega a um ponto culminante depois de ter subido a encosta, parece que se difficulta um pouco progredir na descida, o que é devido ás correntes atmosphericas que então se estabelecem; esta circumstancia deve ser utilizada, augmentando-se n'aquelle ponto o obstaculo ao incendio por meio de um aceiro, que siga a cumiada do terreno.

Além dos aceiros principaes devem ainda formar-se outros, que são secundarios, de 6 metros de largura, os quaes cortam aquelles perpendicularmente, e, subdividindo os talhões, tornam mais livre a circulação, menos confuso o trabalho da extincção do fogo, podendo os operarios chegar facilmente aos logares que é urgente defender. Os aceiros são pois auxiliares efficazes, pontos de partida para um contra fogo, servindo além d'isto de caminhos de exploração, não tendo a sua multiplicidade algum inconveniente, pois não desaproveita terreno para a produção lenhosa, visto o maior desenvolvimento do arvoredo marginal.

Compreende-se bem quanto é mais facil operar dentro de uma matta assim cortada e subdividida, do que em outra que apresente extensos e continuos povoamentos, cujo accesso interior sempre difficil, torna-se muitas vezes impossivel na occasião do incendio.

Convém que os aceiros não limitem superficies muito extensas, mas proporcionaes á área total, para o incendio ser facilmente cortado e não destruir grandes extensões de matta. Devem tambem ser estabelecidos systematicamente, at-

dinagem, o matto brota vigoroso e é necessario destruil-o por meio da roça.

Convém conservar-se em pequenas pausas sobre o solo, não se transportando para fóra, porque assim não embarça o crescimento do novodio nem a regene-

tendendo não só ao fim de que tractamos, mas ainda ás exigencias da exploração florestal, facilitando a extracção dos productos, separando os successivos cortes periodicos ou annuaes, o que não é difficil conciliar, observando-se bem as condições physicas da matta.

Mas, apesar do grande auxilio que os aceiros prestam, são inúteis muitas vezes, quando a nortada sopra violentamente e o terreno está coberto por abundante vegetação de matto, pois não evitam que as chammas avancem e façam grande devastação.

A roça do matto difficulta e torna menos damnosos os incendios, porque nada os alimenta e aviva como estas plantas sub-arbustivas. Bastava só este inconveniente para promover a sua destruição; mas, além d'isto, os mattoes esgotam o terreno, roubando a nutrição á essencia cultivada e oppõem-se ao bom resultado da sementeira natural, impossibilitando as sementes de encontrarem um meio commo para a germinação, o que torna indispensavel a roça nas mattoes bem exploradas.

Demais, esta operação não é muito dispendiosa e só de annos a annos se repete no mesmo terreno: o custo da roça d'un hectare de matto, variavel com a força e bastidão d'este, difficilmente poderá exceder a 3\$000 reis.

Todos os terrenos de floresta têm forte e natural tendencia a cobrirem-se de matto, onde se encontra variada vegetação, figurando principalmente a *Urze*, *Esteva*, *Tojo*, *Alecrim*, *Carvalhiga*, *Carraço*, etc., plantas rusticas e selvagens, que todas precisam muito da influencia atmospherica, prejudicando-as qualquer abrigo que lhes impeça o ar e a luz.

Póde-se, pois, evitar a sua maior propagação e desenvolvimento, conservando a continuidade dos povoamentos, de modo que o arvoredo furte o solo aos agentes atmosphericos, o que tambem aproveita, e mais principalmente, ás essencias cultivadas, conservando o humus e facilitando a sua formação, obrigando as arvores a crescerem directas e regulares, etc.; mas onde o arvoredo está mais raro, como succede nos pontos em que se fizeram cortes de sementeira ou de jar-

ração natural; depois de apodrecido fertilisa o solo, o que é importante pela aridez dos terrenos destinados a florestas.

C. A. DE SOUSA PIMENTEL.

Figura 13. Extrato do artigo Pimentel (1876) Incêndios nas florestas. Meios de os prevenir e atalhar. *Jornal de Horticultura Pratica*. Vol XII

Adoptados também como uma solução técnica para isolar as arborizações das vizinhanças de onde progrediam os fogos, nomeadamente proveniente de queimas agrícolas, do caminho-de-ferro e de outras vias de comunicação, os aceiros ou atalhadas foram implementados desde a arborização das dunas móveis do litoral e como técnica complementar de redução de risco de incêndio

de investimentos florestais (Almeida, 1904) ou em áreas de produção de cortiça (Natividade, 1950) e o seu exemplo extrapolado para outras áreas.

Numa comunicação intitulada "Importância da Associação na Defesa da Riqueza Florestal Contra Incêndios", proferida em Setúbal em Janeiro de 1931 no dia das associações de agricultores, Mendes de Almeida (Almeida, 1932), antevendo o aumento da área arborizada que se iria operar no País e inspirado no exemplo francês das *Landes*, recomenda a constituição de associações mútuas de seguros florestais e a adopção de um dispositivo semelhante ao existente no Pinhal de Leiria. Enaltecendo as qualidades do modelo, destaca o uso dos aceiros, a pronta detecção e ataque inicial por guardas a cavalo ou de bicicleta e propõe que se desenvolva um sistema similar através da "*Associação Sindical de defesa contra incêndios da riqueza florestal do distrito de Setúbal*", para o qual os Serviços Florestais poderiam contribuir com conhecimento. Por Mendes (1932), sabemos que o modelo de Leiria era usado como exemplo para outras zonas planas e arborizadas, como se verificou sobretudo após a II Guerra Mundial.

Para as zonas montanhosas, a primeira referência que encontramos de um dispositivo de protecção que destaca o papel dos aceiros é Sousa (1926). Com base na sua experiência de administrador das Matas do Gerês, recomendava uma rede de caminhos a construir de 200 em 200 metros e linhas de fogo (aceiros) com largura entre os 5 e os 20 metros, dependendo da inclinação e dos matos, propondo ainda que nas zonas de maior declive estas linhas tivessem 10 metros de largura, aludindo até à necessidade de pequenas regueiras para evitar erosão. Sousa (1926) referia que estas redes delimitavam parcelas de 10 e 20 hectares. Já mais tarde, e também tendo por base a sua experiência enquanto administrador da 3.^a Divisão Florestal – Matas do litoral, Pinto (1943) recomendava a expansão do modelo de aceiros e arrifes para as zonas montanhosas, prevendo no entanto que não poderiam ser implementadas com uniformidade das zonas planas, devendo ser adaptadas à sinuosidade do terreno, para limitar as confrontações entre as áreas agrícolas e áreas de "pastoreação". Pinto (1943) recomenda ainda a arborização com folhosas formando descontinuidades e a manutenção das atalhadas limpas com recurso a pastorícia, nomeadamente gado caprino.

Como mencionado na secção anterior, citando FAO (1953), para a maioria das áreas montanhosas ainda não existiam na altura sistemas eficazes de detecção de incêndios, e a divisão em talhões geométricos não era executável, referindo-se que no Buçaco e em Sintra se teriam conseguido distribuir os aceiros e arrifes pelas linhas de curva de nível e cumeadas. Dias (1955) refere que estas foram estabelecidas por ele em 1953, seguindo trabalhos de Campos Andrade e Cunha Rei para o Marão, mas com dificuldades operacionais e também de disponibilidade financeira para as executar, devido ao elevado custo.

Na sequência da expansão florestal que o plano de povoamento florestal de 1938 consagrou para as áreas baldias serranas e que o relatório da FAO (1953) analisa, encontramos diversos trabalhos finais do curso de Silvicultura do Instituto Superior de Agronomia que foram abordando as lacunas de conhecimento que iam surgindo. Silva (1955) aborda a questão do tema da defesa contra o fogo propondo (figura 13) para os perímetros florestais da Lousã uma rede de aceiros e arrifes com largura variável que visavam delimitar as plantações juvenis das queimadas das áreas de matos que os "povos" realizavam com frequência.



Figura 13 – Mapa de projecto de instalação da rede de aceiros e arrifes (Silva, 1955)

Neste trabalho com várias fotografias, estão bem presentes os princípios da doutrina da protecção florestal inspirada em Leiria, nomeadamente com as soluções de mitigação de risco, tais como a rede de aceiros a delimitar o território, um corpo de guardas que as vigiava e regulava os comportamentos dos actores locais, um dispositivo de observação, detecção e alerta, sistemas de comunicação, e a logística necessária para abrigar e equipar as brigadas de ataque inicial, incluindo uma descrição pormenorizada das ferramentas, equipamentos (incluindo archotes e petróleo para o contra-fogo) e justificação da localização destas equipas em função de um estudo de ocorrências dos fogos.

Os conteúdos técnicos e fotografias deste trabalho glosavam as boas práticas de prevenção e combate a incêndios que Dias (1955), então responsável pela Divisão de Protecção do Arvoredo, consolidava em sólido corpo de conhecimento. Este saber, executado por uma estrutura operacional, mantinha protegidas do fogo, extensas áreas florestais geridas pelo Estado e alicerçava as propostas para melhorar a protecção contro o fogo no privado (Dias, 1955). É inovadora, ainda hoje, a proposta de um técnico da DGSFA, Martins (1960), que apresentou para matas privadas um modelo para a implementação de aceiros com um sistema de quotas para a sua manutenção.

Após os incêndios dos anos 60, que suscitaram um debate público que inclusivamente se alargou à Assembleia Nacional (in Diários 1960 a 1972), o relatório técnico de Quintanilha *et al.* (1965) refere extensamente as redes divisionais como estrutura complementar de uma estratégia de defesa contra o fogo, nomeadamente no seu papel na delimitação dos núcleos de protecção florestal, inclusive das áreas florestais privadas. Elas permitiriam o emprego seguro e eficaz das técnicas de supressão de incêndios, com recurso a ferramentas manuais em brigadas apeadas de 20 homens, que as usariam para ancorar manobras de contra-fogo. O texto de formação profissional dos Serviços Florestais de protecção florestal da autoria de Dias (1965) refere detalhadamente as técnicas de extinção directas e indirectas a aplicar, apoiando as operações na rede de aceiros e arrifes. Dado o seu papel como elemento estruturante da prevenção e da supressão, a rede divisional (ou faixas) ficaria inscrita no Decreto-Lei n.º 488/70, que estrutura o sistema de protecção da floresta (ver secção anterior).

As referências históricas acima atestam que o conhecimento sobre a delimitação do bem a proteger, através de faixas, fez doutrina, justificando-se para compartimentar a floresta, separá-la das áreas de onde surgiam os incêndios, e por constituir um elemento preventivo, na medida em que potencia as técnicas de supressão com recurso a ferramentas manuais e ao contra-fogo. Nos anos 70 e 80 era frequente observar nas áreas florestais geridas pelo Estado a existência destas infraestruturas, conforme documentado em Silva (1986), que refere que em 1982 e só para o Entre-Douro-e-Minho, se abriram mais de 500 km de aceiros. No entanto, o relatório da Direcção-Geral das Florestas (DGF) para 3.º Fórum sobre Fogos Florestais (Nogueira *et al.*, 1984) refere que existiam planos e estudos feitos para a sua implementação em zonas críticas, mas que *"as causas para a sua não execução encontravam-se na ausência de meios, sobretudo financeiros, no que respeita às matas sob administração do Estado, e às dificuldades de intervenção nas matas particulares"*.

Na década de 80, os projectos de arborização do Banco Mundial e do Programa de Acção Florestal (PAF) já contemplavam para áreas públicas e privadas um conjunto de infraestruturas, nomeadamente rede viária e divisional e de pontos de água, na expectativa de permitir um ataque rápido ao fogo, sustendo-o dentro de compartimentos definidos pelos caminhos e aceiros ou corta-fogos ou para-fogos, como refere Macedo e Sardinha (1987) e criando uma oportunidade para os bombeiros operarem com os seus dispositivos hidráulicos (Montague *et al.*, 1982).

No início dos anos 80, quando o sistema sofreu uma transformação (ver secção anterior), tanto os bombeiros como os serviços florestais reclamavam a necessidade de alargar as redes de aceiros ao domínio privado (DGF, 1984; SNPC, 1984) criando condições e oportunidade para o combate, ficando claramente expressa no Decreto Regulamentar n.º 55/81 a necessidade de planear e executar "redes de linhas de corta-fogos", para as "zonas críticas" (art.º 12.º, n.º3), já então se prevendo a sua possível declaração como "de utilidade pública" e a consequente expropriação.

Como referido em relatório da Associação das Empresas de Celulose (ACEL, 1988), a rede de caminhos e divisional era fundamental para compartimentar as manchas florestais, mas realçava-se também a dificuldade de actuar no domínio

florestal privado, à qual se juntava o fraco empenho das autarquias (responsáveis pela protecção civil desde 1980), mesmo depois de em 1987 ter sido criada a Comissão Nacional Especializada de Fogos Florestais (CNEFF) para dinamizar a participação das autarquias na prevenção.

De acordo com o relatório CNEFF (1992) foi apoiada a abertura e a conservação de caminhos, pontos de água e helipistas, mas não há referências à construção de aceiros ou arrifes. No relatório do CESE (1996), citando o coordenador da CNEFF, refere-se, para o ano de 1995, a limpeza de matos em 1500 km de aceiros e contra-fogos, 7000 km de caminhos novos ou beneficiados, e a construção de 300 pontos de água e 110 pistas (helipistas e centros de meios aéreos), sendo que não se refere se as actuações ocorriam no domínio das áreas florestais públicas ou privadas. Sete anos depois, o relatório da CNEFF (2002) indica a afectação de 20% do seu orçamento à rubrica das infraestruturas e financia a construção e beneficiação de 3735 km de caminhos¹, 195 pontos de água e somente 230ha de aceiros, maioritariamente no Sul.

c) AS FAIXAS, ENQUANTO PROPOSTA DE PREVENÇÃO À ESCALA REGIONAL

Na sequência dos grandes incêndios de 2003, o Conselho Nacional de Reflorestação (CNR, 2005) mobilizou o acervo centenário de conhecimento existente em Portugal e acima resumido, incluindo as normas do DR n.º 55/81, e interpretando-o à luz das boas práticas e exemplos internacionais (Agee *et al.*, 2000; Rigolot 2002; Agee e Skinner, 2005) produziu as recomendações e orientações técnicas que marcaram as políticas e regulamentos nacionais posteriores. As redes regionais de defesa da floresta, nas quais se inserem as faixas de gestão de combustível (FGC), prevêem ainda um mosaico de parcelas de gestão de combustível, rede viária, rede de vigilância e pontos de água, tendo todo este edifício a função de reduzir a taxa anual de incidência do fogo (Pinho *et al.*, 2006), optimizando a utilização dos recursos disponíveis. Na redefinição do sistema de defesa da floresta contra incêndios, materializada pelo DL 156/2004 (revogado pelo DL 124/2006), definem-se faixas de gestão de combustível como uma infraestrutura pública que compartimenta os espaços florestais e confere ao Estado e às autarquias força jurídica para intervir na propriedade privada, e

¹ Para se ter uma noção da escala de influência da CNEFF, estes valores podem ser comparados com o que o conjunto das empresas de pasta e papel com mais de 200.000 ha de terrenos trataram de combustíveis (29.000 ha/ano) e mais de 10.000 km e caminhos e aceiros (Celpa, 2016).

meios financeiros para compensar perdas de rendimento (fundo florestal permanente, criado pelo DL 63/2004 e programas comunitários). Com base nas orientações técnicas do CNR (2005), as comissões regionais de reflorestação (2004-2006) e, posteriormente, a DGRF e as comissões distritais e municipais de defesa da floresta contra incêndios, com o apoio de peritos locais, definiram entre 2006 e 2010, mais de 120.000 ha de faixas de rede primária de gestão de combustível, por vezes sem recurso a ferramentas analíticas ou conhecimento histórico que apoiassem a decisão de onde colocar as faixas. Não há referências sobre a área prevista para as parcelas de mosaicos, mas elas são fundamentais na sua complementaridade com as faixas, uma vez que estas não se destinam a parar o incêndio (Pinho *et al.*, 2006). Por razões financeiras, administrativas e outras, nem o Estado nem as autarquias fizeram uso da força jurídica e dos fundos disponibilizados, e poucos proprietários aderiram ou foram expropriados, tendo só sido implantada cerca de 18% da área prevista (ICNF, 2015).

Face à percepção pública sobre a vantagem em construir “aceiros” para limitar a propagação do fogo, como existiram no passado, e à expectativa gerada nas partes interessadas de que as faixas poderiam contribuir para reduzir os grandes incêndios e a área ardida, na discussão posterior aos grandes incêndios de Tavira (2012) e Tondela (2013) o papel destas faixas foi muito mencionado, como também referem Viegas *et al.* (2012), pois se tivessem sido construídas, aqueles incêndios poderiam não ter assumido tais proporções. Como infraestrutura de prevenção, e face à percepção do papel que podem ter na mitigação do problema, as entidades oficiais previram financiar a sua construção durante o período de programação de fundos comunitários 2014-2020. No entanto, consultados os programas comunitários, constatamos não haver evidências ou estudos técnicos que explicitem o seu benefício na redução da área ardida, como existem por exemplo na América do Norte, por modelação (Amiro *et al.*, 2001) ou avaliando a sua eficácia com casos reais (Syphard *et al.*, 2001).

d) AVALIAR A EXPECTATIVA DO TRATAMENTO LINEAR DE COMBUSTÍVEIS

Não há para Portugal estudos que avaliem o papel das faixas de gestão de combustível ou que permitam a sua comparação com outras soluções alternativas, como por exemplo estímulos políticos que mobilizem os proprietários a reduzir o risco nas suas propriedades. Assim, para além de ficarmos a conhecer previamente a eficácia de um investimento, constitui uma

motivação adicional dispor de uma metodologia que quantifique objectivamente as expectativas formuladas, num contexto que entretanto se alterou. As faixas e as redes divisionais parecem ter sido eficazes no passado, quando limitando áreas florestais geridas activamente (com baixas carga combustível), ou quando contíguas a áreas de matos queimadas recorrentemente ou muito pastoreadas, e enquanto integradas num modelo de supressão de incêndios que as sabia aproveitar como elementos táticos e para ancorar manobras e fogo. No entanto, mesmo que quintuplicada a largura das faixas agora propostas de 22 metros (referencial de aceiro exterior da Mata Nacional de Leiria) para 125 metros, será que para a carga combustível que hoje as paisagens contíguas exibem, serão ainda uma solução? Ou soluções de ontem são os problemas de hoje (Sterman, 2000)?

Métodos determinísticos para simular diferentes ocupações de solo, incluindo rede de aceiros ou faixas de gestão de combustíveis foram apresentados por Van Wagtendonk (1996) e tornaram-se especialmente explícitos através de Finney (1998), quando o simulador de comportamento do fogo Farsite foi usado para testar diferentes desenhos de padrões de tratamentos de combustível à escala da paisagem (Finney, 2001). Seguindo os desenvolvimentos metodológicos na avaliação e análise do risco e exposição propostos por Ager *et al.* (2007a e 2007b), outros autores examinaram também o efeito deste tipo de tratamentos (Moghaddas *et al.*, 2010 e Finney *et al.*, 2007). Mais recentemente, Ager *et al.* (2014), aplicando conceitos de análise de redes (Christley *et al.*, 2005), investigaram padrões de transmissão do fogo e a forma como tratamentos de combustíveis realizados numa ou mais áreas florestais alteram a transmissão do fogo em grandes paisagens. Estudando o modo como o risco é transmitido entre as florestas nacionais e o interface urbano-florestal, Ager *et al.* (2016) examinaram o impacto em objectivos de gestão da implementação de um programa de mitigação de risco para protecção das áreas urbanas.

No artigo publicado no *International Journal of Wildland Fire*, testando a metodologia no contexto português, concretamente no Algarve e no sul do Alentejo, examinamos o efeito de uma rede de gestão de combustíveis sobre o fogo e a sua transmissão entre 20 municípios. Especificamente, colocamos duas questões:

-
1. Qual o efeito de uma rede regional de gestão de combustíveis na redução da área ardida e na probabilidade condicional de incêndio?
 2. Pode a rede regional alterar a transmissão do fogo entre municípios vizinhos e estimular a cooperação entre eles?

Utilizando o método desenvolvido por Ager *et al.* (2016), investigamos o efeito de uma rede de faixas de gestão de combustível na transmissão do fogo entre comunidades vizinhas. Estimamos como o tamanho médio dos incêndios simulados e a probabilidade de arder se modificariam se fossem construídas as faixas de gestão de combustíveis empregando duas intensidades de tratamento (remoção total e remoção parcial de combustíveis). Como os grandes incêndios percorrem diferentes municípios, avaliamos o efeito da rede linear prevista sobre a transmissão de fogo entre os 20 concelhos que constituem o distrito do Algarve e parte do distrito de Beja.

Este esforço materializa a transferência de métodos de análise de risco ainda em desenvolvimento nos Serviços Florestais norte americanos para uma realidade europeia. Pese embora o desenho das faixas do Algarve tenha sido apoiado em 2004 por simulações em FlamMap (João Pinho, informação pessoal) a metodologia agora usada constitui inovação e um contributo científico na medida em que, pela primeira vez, é usada para realçar o papel das comunidades vizinhas, exibindo *ex-ante* as vantagens de os actores locais desenvolverem comportamento colaborativos. Da aplicação da metodologia fica visível a transmissão do fogo e qual o papel que as faixas podem desempenhar na alteração dessa transmissão entre vizinhos. Dado que o problema do fogo está espacialmente distribuído de forma assimétrica, e que o efeito das faixas não é linear, este método constitui assim uma ferramenta que facilita a cooperação e a negociação de soluções mais vantajosas para todos.

Em nosso entender, o método é uma poderosa ferramenta para a análise do risco à escala regional. Considerando o papel dos municípios na estratégia de defesa regional, em particular na redução dos grandes incêndios, e o facto de o método tornar possível a quantificação dos benefícios da cooperação, facilita-se o processo de comunicação de risco. Esta ferramenta faz a ponte entre a dimensão

técnica e a dimensão política e social da gestão do risco, pois reforça o método de análise e avaliação do risco, e facilita a comunicação entre as partes interessadas. Dadas as suas potencialidades, poderá permitir apoiar a governação do risco à escala regional.

[Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission \(2016\)](#)

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Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission

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Abstract. Wildfires pose complex challenges to policymakers and fire agencies. Fuel break networks and area-wide fuel treatments are risk-management options to reduce losses from large fires. Two fuel management scenarios covering 3% of the fire-prone Algarve region of Portugal and differing in the intensity of treatment in 120-m wide fuel breaks were examined and compared with the no-treatment option. We used the minimum travel time algorithm to simulate the growth of 150 000 fires under the weather conditions historically associated with large fires. Fuel break passive effects on burn probability, area burned, fire size distribution and fire transmission among 20 municipalities were analysed. Treatments decreased large-fire incidence and reduced overall burnt area up to 17% and burn probability between 4% and 31%, depending on fire size class and treatment option. Risk transmission among municipalities varied with community. Although fire distribution shifted and large events were less frequent, mean treatment leverage was very low (1 : 26), revealing a very high cost–benefit ratio and the need for engaging forest owners to act in complementary area-wide fuel treatments. The study assessed the effectiveness of a mitigating solution in a complex socioecological system, contributing to a better-informed wildland fire risk governance process among stakeholders.

Additional keywords: Portugal, risk governance, risk management, wildfire exposure.

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Introduction

The need for more advanced approaches to mitigating wildfire risk is becoming important as large and destructive wildfires in the fire-prone regions of the world continue to overwhelm fire suppression efforts. Fuel reduction treatments, e.g. thinning and prescribed burning, have long been identified as key to decreasing fire size and fire severity (Agee and Skinner 2005). Fuel treatments can hinder large-fire development and facilitate suppression if implemented on a sufficiently large spatial scale, as demonstrated by case studies in Australia, the USA and elsewhere (e.g. Boer *et al.* 2009). However, most evidence suggests that a large percentage of the landscape (e.g. 20–30%) needs to be effectively treated to substantially alter fire incidence (e.g. Finney *et al.* 2007; Price 2012), which is generally difficult to achieve owing to limited resources and opportunities. Nevertheless, other studies suggest that the final size of individual fires can be impacted by landscape treatment rates as low as 5% (Cochrane *et al.* 2012). Fire behaviour stochasticity and

the uncertainty in quantifying the complexity of fuel treatment–wildfire interactions in real time contribute to disparate findings.

Fuel isolation through linear fuel break networks is an alternative to landscape-wide fuel treatments in Europe (Rigolot 2002; Varela *et al.* 2014) and elsewhere (Amiro *et al.* 2001; Syphard *et al.* 2011). Here, the fuel break function is to enhance the effectiveness and safety of fire control operations (Omi 1996; Weatherspoon and Skinner 1996; Agee *et al.* 2000). Fuel breaks create a linear area where fuels are sufficiently modified to decrease potential fire intensity and rate of spread to a level where suppression resources succeed in containing the fire. Additionally, fuel breaks can be used to anchor indirect control using backfires. Deterministic fire growth modelling to test different fuel management scenarios, including fuel break networks (FBNs), was first used by van Wagendonk (1996). More recently, simulation modelling has been extensively applied to study fuel breaks and explore optimal treatment

arrangements and levels of treatment (Finney 2001; Loehle 2004; Finney *et al.* 2007; Wei *et al.* 2008; Moghaddas *et al.* 2010; Bradstock *et al.* 2012). Quantitative risk-based approaches to analyse the effects of simulated fuel treatments have also been developed, enabling probabilistic characterisation of fuel treatment impacts on fire-susceptible values (Ager *et al.* 2007a, 2010a, 2010b). Other studies include empirical observations, where for instance Syphard *et al.* (2011) analysed 641 fires in southern California and found that fuel breaks played an important role in 44% of the cases studied in terms of facilitating suppression activities, depending on weather, access and maintenance. However, as FBNs can slow fires but seldom are expected to stop them, fires generally burned through or crossed over them in the absence of active firefighting.

In southern Europe, fuel breaks (6–40 m wide) were implemented in coastal pine forests in the late 19th century and expanded throughout the 20th century as afforestation progressed and defensible infrastructure was needed to hinder fire growth. These fuel breaks were designed to define forest management units and delimit forest plantation from shrub or farmed land, and were strategically placed on ridgetops or critical locations where backfires could be anchored. In Portugal, Barros *et al.* (2012) using 31 years of mapped fires found preferential fire orientations at both local and regional scales, highlighting the need to integrate local information about fire spread patterns to design landscape FBNs. After the catastrophic 2003–05 fire seasons, the Portuguese Forest service coupled their existing experience with contemporary fuel management practices (Agee *et al.* 2000; Rigolot 2002; Agee and Skinner 2005) to put in place a nationwide set of coherent ‘regional fire protection networks’, which included an FBN, strategic fuel treatment mosaics and forest road and fire water reservoir networks, among others Conselho Nacional de Reflorestação – Algarve (CNR-A 2005). Owing to insufficient funding and limited private landowner engagement, ~10 years later, only 18% of the planned FBN has been implemented (R. Almeida, Instituto da Conservação da Natureza e Florestas, pers. comm.). In the aftermath of recent large wildfire events, Viegas *et al.* (2012) concluded that if the planned FBNs had been built, they might have played a relevant role in reducing wildfire size and losses of assets and lives. However, neither empirical nor modelled quantitative evidence exists regarding FBN effectiveness in southern Europe fire-prone landscapes, and thus its costs and benefits cannot be evaluated or compared among competing policy alternatives. The ongoing public debate about the fire-mitigating role of the FBN would be better informed if its effects were objectively quantified. In particular, it is important to understand FBN benefits when compared with alternatives that might offer better economic, social and ecological trade-offs.

In the present paper, we used simulation modelling to address the potential effectiveness of FBNs on a fire-prone area of southern Portugal. The fuels and fire regimes in the study area are characteristic of many other Mediterranean landscapes. We build on previous work on fire transmission and network analysis methods (Ager *et al.* 2014a, 2016; Haas *et al.* 2015) to examine the effect of FBNs in wildfire and the wildfire transmission between municipalities. Specifically, we ask (1) what is the effect of FBNs in terms of affecting expected

burned area and burn probability, and (2) can FBNs substantially alter fire transmission among neighbouring municipalities, and thus potentially demonstrate the value of collective and collaborative planning to implement the large-scale FBNs envisioned by policymakers?

Methods

Study area

The study area covered 5878 km² in southern Portugal (Fig. 1), comprising the Algarve region (Faro district) and the southern portion of the Alentejo region (Beja district), and encompassed 20 municipalities. Its geography (Fig. 2) is characterised by flat coastal areas and rugged mountain terrain that reaches elevations of 900 m in the west and 600 m in the centre and east. Climate is Mediterranean, with mild and wet winters and warm and dry summers; annual rainfall in the western area can reach 1200 mm. According to Corine land-cover data (European Environment Agency 2012) (Fig. 2b), urban and agricultural areas occupy 19 804 and 193 550 ha respectively, and together account for 36% of the area. Urban areas are located mostly along the coast and agriculture is located in valleys and around small inland villages. Forest and shrubland occupy 246 804 and 127 619 ha respectively, representing 64% of the study area. The region has experienced rural exodus from the interior mountains and fast coastal urbanisation since the 1960s (Vaz *et al.* 2012). Since then, afforestation with *Eucalyptus globulus* Labill (bluegum) and *Pinus pinaster* Aiton (maritime pine) has expanded in the western Algarve, resulting in continuous forest stands that dominate the landscape along with *Cistus ladanifer* L. (common gum cistus) shrubland. In the central and eastern parts of the study area, under drier climate and at lower elevation, afforestation projects used *Pinus pinea* L. (stone pine) and *Quercus suber* L. (cork oak), and the traditional agro-forestry mosaic has been encroached upon by *C. ladanifer*. In the valleys, tree orchards and horticulture are being replaced with maquis of *Olea europaea* L. (olive), *Pistacia lentiscus* L. (mastic tree) and *Quercus ilex* L subsp. *rotundifolia* (Lam.) (holm oak).

The historical fire perimeter atlas (Oliveira *et al.* 2012) updated with burned area maps from 2006 to 2012 (ICNF 2013) shows that 201 000 ha burned in the region from 1975 to 2012, ~45% of the available burnable area, corresponding to a mean annual fire incidence of 1.2% (Fig. 1). The proportion of burned area accounted for by large fires (>1000 ha) increased over the time period for which official records exist. Fires >1000 ha did not occur between 1975 and 1981, but 30 years later accounted for 92% of the burned area, including fires >20 000 ha that spread through more than two municipalities (Tedim *et al.* 2015). The regional drivers behind the fire regime suggest that rural exodus, agriculture abandonment, afforestation and fire exclusion policies were responsible for the observed change (Grove and Rackham 2003; CNR-A 2005). After the 2003 and 2004 fire seasons, efforts were undertaken to deal with the problem and a regional fire plan was approved in 2009, including the proposed FBN (Fig. 1). According to the regional reforestation commission report (CNR-A 2005), this FBN design was established after extensive fieldwork carried out by multidisciplinary teams of firefighter officers, forest

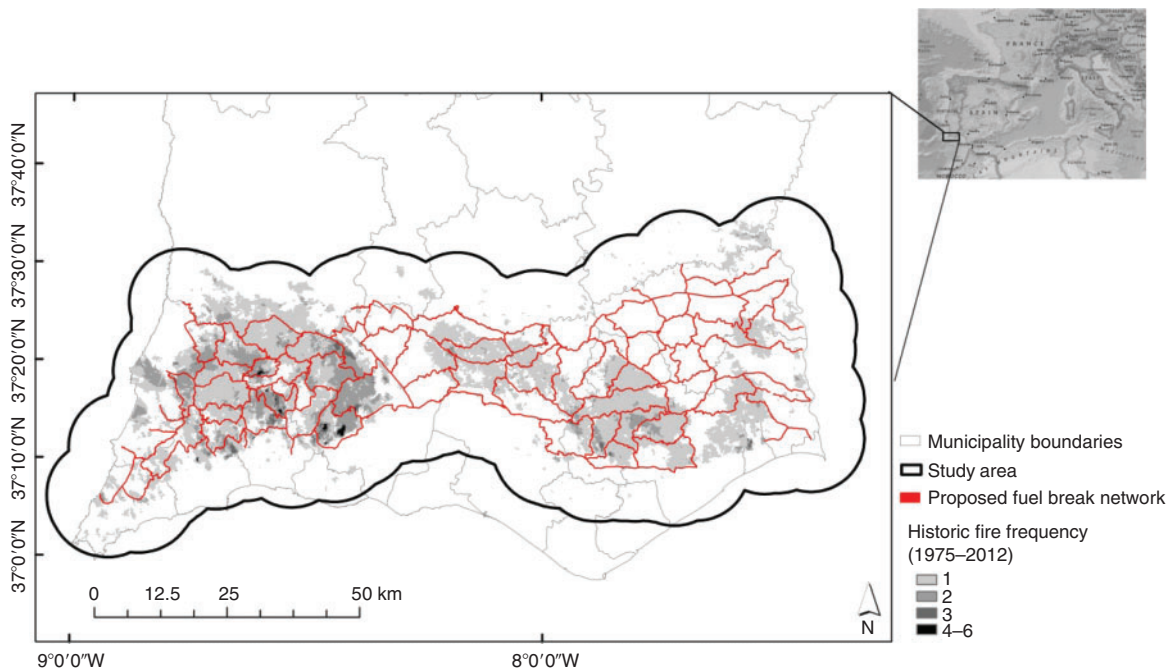


Fig. 1. Location of the study area in south-west Portugal and the 20 municipalities’ boundaries included in the study area, with a 10-km buffer from the fuel break segments.

managers, and civil protection and regional forest authority personnel. Several possibilities were explored and discussed through meetings, before the final layout approval. Without an analytical method or formal process to establish the FBN, as described in *CNR-A (2005)*, the rationale behind the FBN-layout draft design was based on historical fire patterns, local experience, and the existence of fire control anchor opportunities such as roads, rivers, irrigated valleys or mountain ridges, as they facilitate FBN implementation and coincided with municipalities boundaries. To minimise edge effects and let all possible fires ignite and burn into the FBN, the study area in the present paper included a 10-km buffer outside the FBN, as no fires have started farther away in the past (1975–2012).

Wildfire simulation models and data

To analyse the effects of the proposed FBNs on fire incidence, we used the minimum travel time algorithm (MTT) (*Finney 2002*) incorporated in *Randig*, a command line version of *FlamMap5*, a mechanistic landscape fine-scale fire spread model (*Finney 2006*). Fire growth is modelled with Huygens’ principle and the perimeter is solved using MTT given fuels, weather and terrain (*Finney 1998*). This algorithm considers all possible travel routes of fire in the landscape through a vector representation of fire spread using pixel characteristics. An average spread rate for the pixel is used, corrected for the elliptical dimension of fire spread relative to the heading direction. For each simulated ignition, the algorithm seeks slope, aspect, elevation, fuel model and canopy cover data for each grid cell in a raster file. Ignitions are randomly sampled on the landscape, based on a defined probability grid. The other

inputs are non-spatial and include dead and live fuel moisture contents and combinations of wind speed and wind direction with their corresponding probabilities of occurrence. The algorithm also requires specification of a burn period – the duration of the fire-spread simulation. The model calculates a flame length and a spread rate for each cell. We modelled major spread events, which typically account for most of the area burned. Thus, we held fuel moisture and weather conditions constant over the course of each simulated fire, as in previous studies (*Ager et al. 2014a*). The simulation system (MTT) has been extensively used to predict fire spread and growth in heterogeneous landscapes in the USA (*Stratton 2004; Ager et al. 2010b; Parisien et al. 2011*), in Europe (*Loureiro et al. 2006; Duguay et al. 2007; Salis et al. 2013*), and elsewhere (*Wu et al. 2013*).

We obtained aspect (degrees), slope (degrees) and elevation (m) information from a digital terrain model derived from ASTER imagery (*NASA Land Processes Distributed Active Archive Center (LP DAAC) 2001*). Land-cover maps by vegetation type were derived as in *Rosa et al. (2011)* from Corine 2006 (*European Environment Agency 2012*) land-use classification. We assigned a custom fuel model to each cover type from the set developed for Portugal (*Cruz and Fernandes 2008; Fernandes et al. 2009*) plus the model for eucalypt slash of *Cruz (2005)*. The canopy cover assigned to each fuel model was derived from an analysis of the National Forest Inventory plots (*Fernandes 2009*). Urban areas, greenhouses, irrigated agriculture, horticulture, orchards, roads and structures were classified as non-burnable (fuel model 99), and short grass (fuel model 232) was assumed for vineyards, non-irrigated agriculture, annual crops, agro-forestry systems, fruit orchards, olive groves and natural pastures. The Corine land-cover level-3

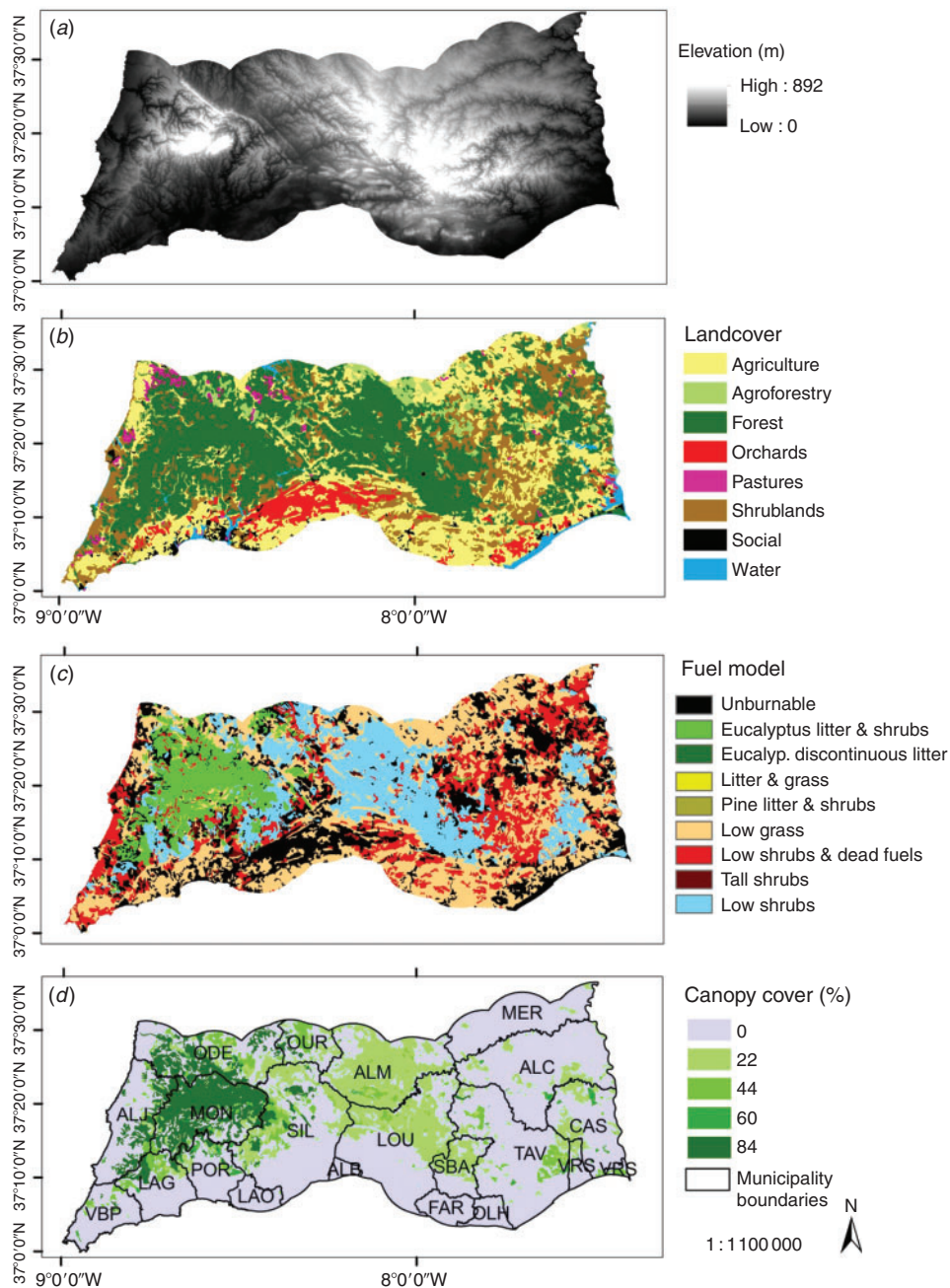


Fig. 2. Maps of elevation (a); land cover (b); fuel model (c); and canopy cover superimposed on municipalities (d) for the study area. The study area includes the municipalities of Albufeira (ALB), Alcoutim (ALC), Aljezur (ALJ), Almodôvar (ALM), Castro Marim (CAS), Faro (FAR), Lagoa (LAO), Lagos (LAG), Loulé (LOU), Mértola (MER), Monchique (MON), Odemira (ODE), Olhão (OLH), Ourique (OUR), Portimão (POR), São Brás de Alportel (SBA), Silves (SIL), Tavira (TAV), Vila do Bispo (VBP) and Vila Real de Santo António (VRS).

nomenclature and associated land-cover type, fuel model and canopy cover for the study area are listed in Tables S1 and S2 in the online supplementary material.

Fire modelling used spatially explicit input data (Fig. 2) at a 30-m pixel scale (slope, aspect and elevation) resampled to 120-m spatial resolution to reduce simulation time, to be consistent with the fuel break width and to accommodate the

90-m spatial resolution of Corine land-cover maps from which fuel model and canopy cover were derived. Weather scenarios (wind speed and direction) and their associated probabilities (Table 1) were based on the meteorological conditions associated with most burned area in the past. Based on the work of Pereira *et al.* (2005), who determined that 10% of summer days account for 80% of burned area in Portugal, we identified the

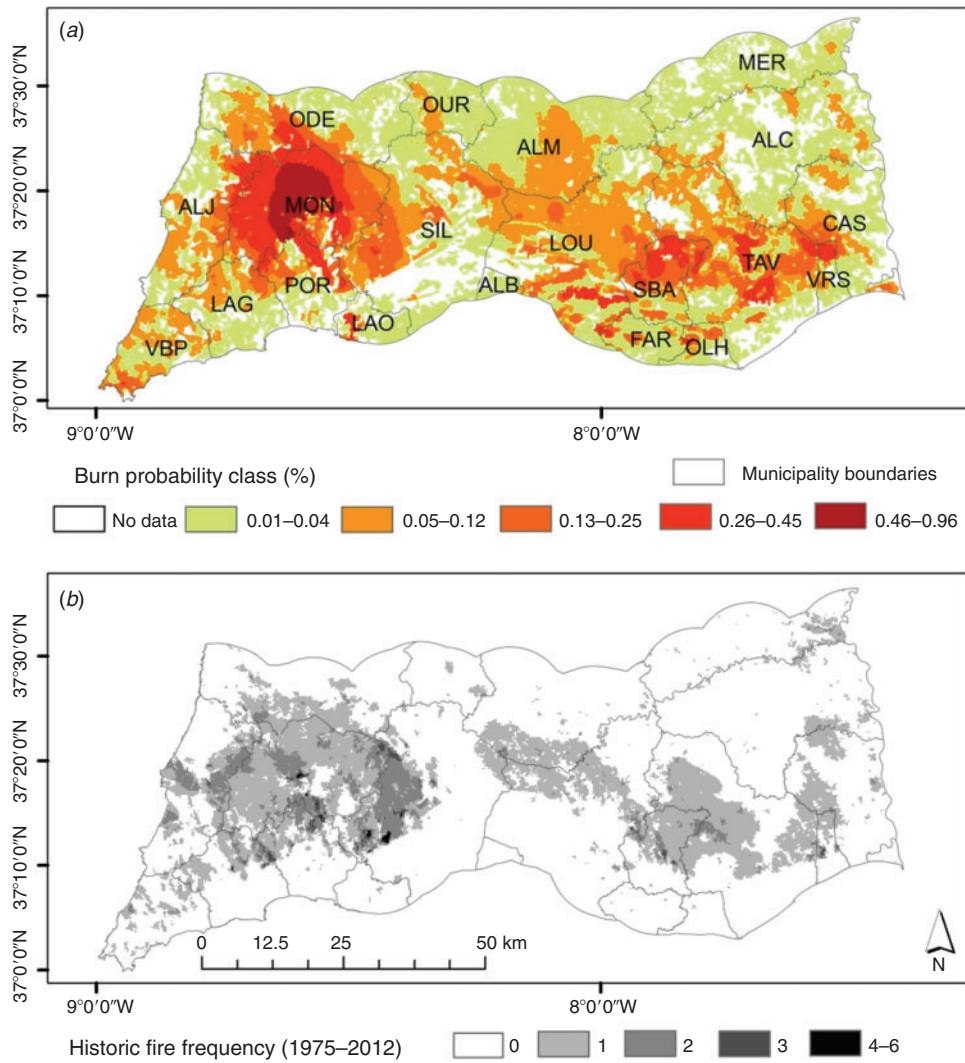


Fig. 3. Burnt probability class map (a) for non-treated landscape (NT); and (b) historic fire frequency (1975–2012). First figure includes municipalities of Albufeira (ALB), Alcoutim (ALC), Aljezur (ALJ), Almodôvar (ALM), Castro Marim (CAS), Faro (FAR), Lagoa (LAO), Lagos (LAG), Loulé (LOU), Mértola (MER), Monchique (MON), Odemira (ODE), Olhão (OLH), Ourique (OUR), Portimão (POR), São Brás de Alportel (SBA), Silves (SIL), Tavira (TAV), Vila do Bispo (VBP) and Vila Real de Santo António (VRS).

top 10% burned-area days, in the study area, between 1980 and 2005 (Pereira *et al.* 2005). Using daily meteorological fields of the ECMWF (European Centre for Medium-Range Weather Forecasts) provided by the University of Lisbon (DaCamara *et al.* 2014; Amraoui *et al.* 2015), we extracted wind speed and direction at noon for those days over a latitude–longitude 5-km regional grid. Combinations associated with probabilities ≤ 0.01 were excluded. Fuel moisture content was assumed at 6, 7 and 8% respectively for 1-, 10- and 100-h dead fuel size classes, based on air temperature and relative humidity for the above-mentioned set of fire days, and at 85% for live fuels (Fernandes 2009). Ignitions were spatially allocated to burnable land (Tables S1 and S2), located according to a sampling probability grid based on a fire-ignition logistic regression model (Catry *et al.* 2009); the model has an accuracy of 80% at the national scale and uses population density, human accessibility, land cover and elevation

as input variables. As most ignitions are anthropogenic, 85% occur within 2 km of urban areas or roads Catry *et al.* (2009). For spotting, and in the absence of empirical evidence, we assumed the default software probability of 10%. Each ignition was allowed to burn actively for a period of 24 h using a 120-m spatial resolution for the fire spread calculations, after which fire growth ceased. This burn period was based on trial runs and was set to allow a balanced representation of historical fire size distribution including very large fires. Moreover, similar visual analysis to that presented by Parks *et al.* (2011), suggested that a 24-h burn period resulted in accumulated fire perimeters resembling historical fire records (Fig. 3). The comparison between historical and simulated treatments regarding the proportion of burned area by fire class size was also reasonable except for fires >10 000 ha (Fig. 4b), which may occur even under more severe fire weather or have longer durations than simulated here.

Table 1. Wind speed, direction and probability of occurrence used for wildfire simulations

Values were calculated from the historical fire data (1980–2005) for days when fires events exceeded 100 ha

Wind speed (km h ⁻¹)	Azimuth (degrees)	Probability
12	45	0.073
28	45	0.021
12	90	0.094
28	90	0.031
12	135	0.125
28	135	0.104
44	135	0.021
12	180	0.052
12	315	0.063
28	315	0.021
12	360	0.146
28	360	0.250

Fuel treatment scenarios

We simulated a non-treatment scenario (NT) and two fuel treatment scenarios using an FBN layout (ICNF 2013) that consisted of a 120-m-wide linear infrastructure covering 17 964 ha (3% of the study area). The two treatment scenarios were:

- (1) Full Removal Fuel Break Network (FRFBN), resulting in a non-burnable area after all vegetation within the 120-m wide strip is removed, leaving bare soil or rocks (fuel model 99).
- (2) Shaded Fuel Break Network (SFBN), where vegetation is partially removed from the 120-m-wide strip, leaving canopy cover at 22% and an understorey typified by fuel models 224 (discontinuous litter), 226 (litter and grass) or 232 (short grass).

A map of treatments is presented in Fig. S1.

We simulated 150 000 ignitions for each scenario to ensure that each pixel burnt on average 30 times in the NT scenario, providing a robust sample for estimating burn probabilities as described below. The same simulation parameters (number of ignitions, burn period, ignition probability grid, meteorological scenarios and fuel moistures) were used to simulate fire behaviour and growth in the three treatment scenarios.

Analysis

Simulation outputs included a fire list containing the ignition location and size of each fire and a burn probability (BP) grid representing the burn likelihood of a pixel given a random ignition. To study fire transmission between municipalities, we followed Ager *et al.* (2014a) and intersected the fire perimeter and the ignition point with the municipality map, and then calculated burned area per municipality in relation to the municipality of the ignition point. All intersects were done using ArcGIS and the Geospatial Modelling Environment (Spatial Ecology LLC 2009).

Network analysis was used to visualise and characterise fire transmission and the change resulting from treatments. In network analyses, as we wanted to highlight the effect of the treatments to each municipality, nodes corresponded to municipalities and linkages represented burned area transmission between municipalities. Transmission from i to j occurs when a fire starting in municipality i burns a certain amount of area in municipality j . Transmitted fire area from i to j (TF_{ij}) is calculated as:

$$TF_{ij} = AB_{ij}/N_i \quad (1)$$

where AB_{ij} is the area burned in municipality j from fires started in municipality i and N_i is the number of ignitions in municipality i . The total area burned in each municipality from fires ignited within the municipality measures non-transmitted (or self-burning) fire (NonTF). The expected average burned area from fires that start in a municipality i and escape to its neighbour j is measured by outgoing transmitted fire (TF-Out), and the burned area of fires coming from neighbour municipalities j and burning in municipality i is measured by incoming transmitted fire (TF-In). Transmission among municipalities

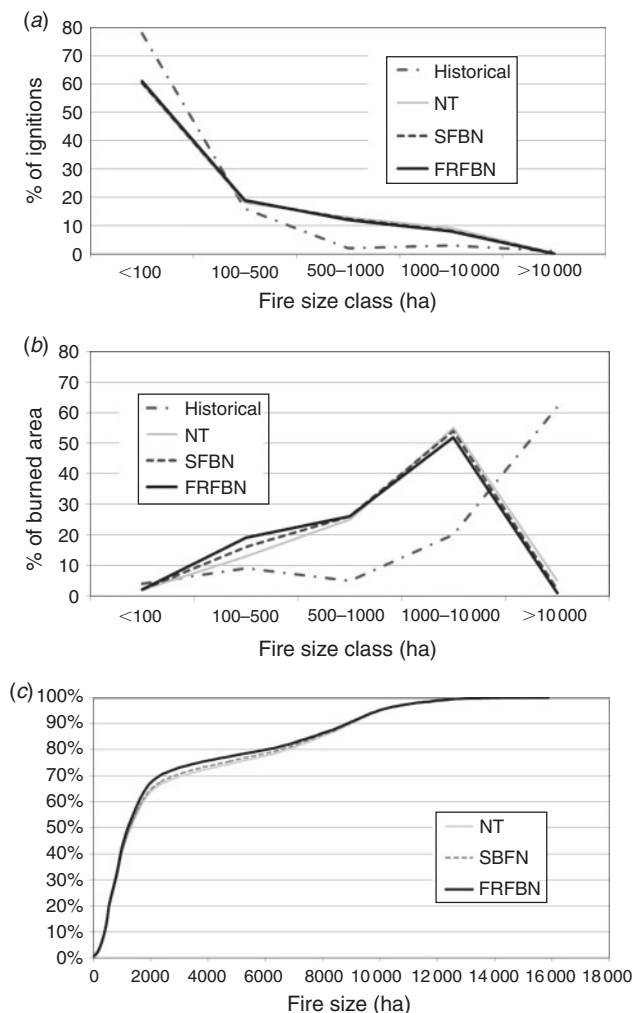


Fig. 4. Effects of different fuel treatments in distributions of ignition (a); burned area (b); and cumulative burned area (c). NT, non-treated landscape; SBFN, shaded fuel break; FRFBN, full reduction fuel break network.

Table 2. Differences in burn probability (BP) between treatments

Values represent percentage differences in pixel-level burn probability between the shaded fuel break network (SFBN) and full-removal fuel break network (FRFBN) treatments and the non-treated reference situation (NT) for each non-treatment BP class

		Burn probability class				
		0.01–0.04	0.05–0.12	0.13–0.25	0.26–0.45	0.46–0.96
SFBN-NT	Difference	–0.0006	–0.0052	–0.0138	–0.0268	–0.0625
	decrease (%)	4.1	6.4	7.5	8.2	10.7
FRFBN-NT	Difference	–0.001	–0.0095	–0.0284	–0.0644	–0.181
	decrease (%)	6.7	11.7	15.4	19.8	30.9

can be represented for each of the alternative landscape networks where nodes are arranged according to their geographic positions, and directional links correspond to the amount of TF. Networks for TF change between landscape treatments can also be created, highlighting the relative benefits of building the FBN for each municipality. We compared networks generated for the non-treated landscape with the network produced in the two FBN configurations and examined the benefits in terms of non-transmitted burned area (NonTF) and the expected burned area that each municipality imports (TF-In) and exports (TF-Out) to its neighbours. All network representations were done with *Visone* (Borgatti *et al.* 2002; Brandes and Wagner 2004).

Results

Effect of FBN on burn probability, fire size and burned area

Results showed that treating 3% of the study area to establish a regional FBN would reduce the average BP between 4 and 11% for the SFBN treatment scenario, and between 7% and 31% for the FRFBN scenario (Table 2). The spatial distribution of BP classes (Fig. 5) revealed that around Monchique and Tavira municipalities (central western area), a smaller area was in higher BP classes in the FRFBN scenario (Fig. 5c) compared with the SFBN scenario (Fig. 5b). Treatments decreased the number of pixels with higher BP and increased the number of pixels with lower BP. A pixel-scale map of each scenario is presented in Fig. S2.

For fires escaping initial attack and spreading for 24 h, implementation of the FBN would reduce mean fire size by 17 and 8% for the FRFBN and SFBN respectively, compared with the NT landscape. NT fire size was 377 ± 1002 ha (mean \pm standard deviation), with a coefficient of variation (CV) of 297%, and was reduced to 312 ± 765 ha (CV 245%) and to 348 ± 899 ha (CV 257%) in the FRFBN and SFBN scenarios respectively. The FRFBN was more effective in decreasing mean fire size and its variation. Results by fire size class (Table S3) showed that the change in fire size statistics brought about by the treatments was very small. Both treatments increased total burnt area for fires <500 ha and reduced it in the other size classes, especially in the >10 000 ha class, with a 92 and 58% reduction for FRFBN and SFBN respectively. As ignitions patterns and density were constant for all treatments, the overall reduction of expected burned area (17% for FRFBN and 8% for SFBN) was essentially due to a shift in fire size class distribution, with the treatments increasing the number of fires <500 ha and decreasing the number of fires >500 ha (Fig. 4b and 4c).

This can be due to the size of potential burn units or compartments, i.e. the area in between fuel breaks may be too large, reinforcing the small effect that, on average, the FBN had in reducing the overall burnt area.

Reduction in fire size was not equally distributed among the 20 municipalities in the study area. Comparing the mean fire size of the FRFBN landscape with the NT scenario, municipalities of Portimão, Monchique and Castro Marim (Fig. 6) exhibited a higher proportional reduction in fire size compared with the study area average (17%). The standard deviation decreased for the majority of the municipalities, except in Lagoa, Faro and Albufeira, where the expected average fire size increased slightly in the treatment scenarios. Although those municipalities were the only ones without FBN within their boundaries, their burnable area fraction is very small, and is mostly fragmented and located in gently undulating terrain. Negative difference values may have resulted from the randomness of the ignition and wind patterns, which produce a wider fire distribution with a slightly higher average. Because the average values are small, a small difference has a large effect on the proportion. Maximum fire size also decreased for the majority of municipalities, except for Mértola, Loulé, Lagoa, Faro, Vila Real de Santo António and Castro Marim where little change in fire size was documented.

Can FBN substantially alter fire risk transmission among municipalities?

For the non-treated landscape and all 20 municipalities, the transmission network diagram showed two major subnetworks within the study area: the western region centred in Monchique, and the eastern region around Tavira. Although the FBNs did not change the fire transmission diagram pattern, as shown by comparing the three diagrams in Fig. 7, it changed the magnitude of transmitted burned area. The networks diagrams in Fig. 7 illustrate the average area of fire being transmitted in the non-treated scenario (Fig. 7a) and a net benefit for the two treatment options in comparison with the non-treated landscape (Fig. 7b and 7c). We present the quantitative effects for all municipalities in detail in Tables S4, S5 and S6, and illustrate the rationale for two municipalities as an example. In the NT scenario, fires starting in Odemira are expected to burn on average 369 ha in Monchique, whereas 161 ha (less than half) burn in Odemira from fires starting in Monchique. For the FRFBN scenario, the expected burned area is 120 ha from fires starting in Odemira and spreading to Monchique. Area burned by fires starting in Monchique and spreading to Odemira is reduced by 41 ha on average. Under the SFBN scenario, fires starting in Odemira are

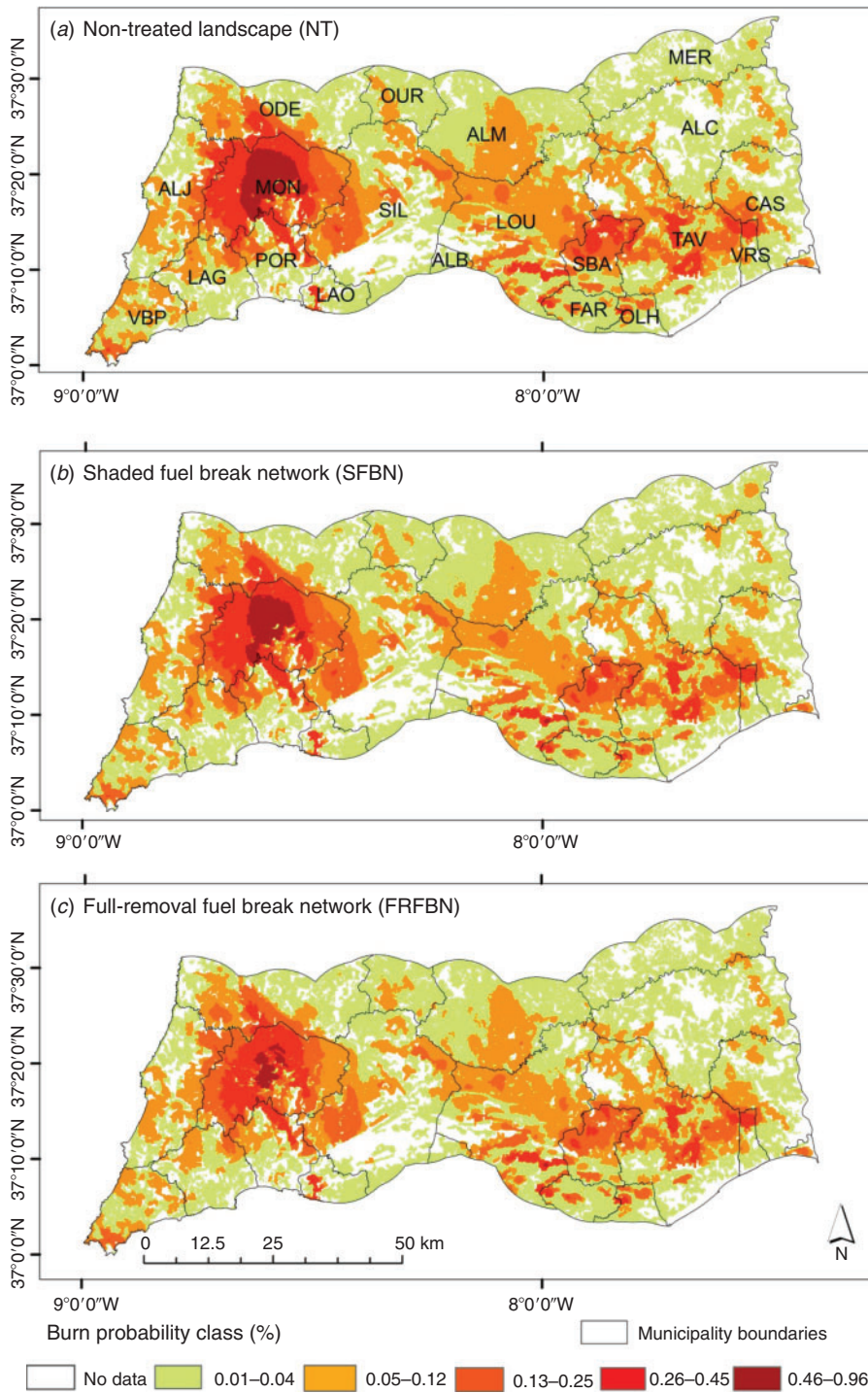


Fig. 5. Burn probability class map for (a) non-treated reference (NT); (b) shaded fuel break network (SFBN); and (c) full removal fuel break network (FRFBN) treatments. First figure includes municipalities of Albufeira (ALB), Alcoutim (ALC), Aljezur (ALJ), Almodôvar (ALM), Castro Marim (CAS), Faro (FAR), Lagoa (LAO), Lagos (LAG), Loulé (LOU), Mértola (MER), Monchique (MON), Odemira (ODE), Olhão (OLH), Ourique (OUR), Portimão (POR), São Brás de Alportel (SBA), Silves (SIL), Tavira (TAV), Vila do Bispo (VBP) and Vila Real de Santo António (VRS).

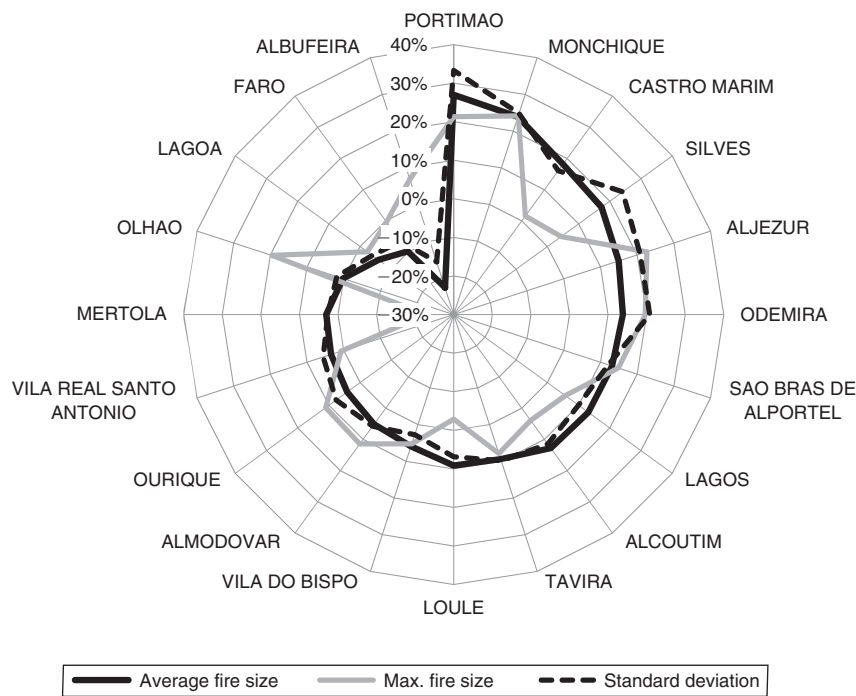


Fig. 6. Difference expressed in percentage in average, maximum and standard deviation of fire size between the full removal fuel break network and the non-treated landscape in each of 20 municipalities.

expected to burn 85 ha less in Monchique, while transmission from the latter to the former is reduced by 17 ha.

The proportion of area burned by fires that started in each municipality that were not transmitted to neighbours (NonTF) was 83% on average. The FBNs had a minor effect in changing NonTF except for Odemira, Aljezur, Portimão and Silves, where NonTF area burned in FRFBN increased from 6% up to 10% in comparison with the NT landscape (Fig. 8a). The FRFBN result was to increase the proportion of area burned within the communities, blocking fire spread to the adjacent communities. Again, the burnable area within FBN boundaries may be too large and fuel breaks may be too far apart, undermining the FBN potential to reduce burned area and alter fire transmission among municipalities. For the communities of Albufeira, Alcoutim, Faro and Castro Marim, the SFBN reduced the proportion of Non-TF burned area slightly, which may be related to the small proportion of burnable area and the grass-dominated fuel mosaic.

The net change in TF-Out and TF-In (Fig. 8b and 8c) from the FBN represents the potential benefit in terms of fire exposure to and from each of the 20 municipalities. For communities where incoming fire (TF-In) exceeded exported fire (TF-Out), the construction and maintenance of the FRFBN would be primarily to decrease fires coming in from adjacent municipalities and secondarily to reduce fire exposure to other communities. Thus, Monchique, Aljezur, Silves and Tavira municipalities all had relatively high values for TF-In, whereas Odemira, Portimão and Ourique had relatively high TF-Out values. Hence, the FBN effect from a risk transmission standpoint varied among the communities in terms of the expected benefits. We found that six of the municipalities accounted for 87% of the total TF-Out,

namely Monchique, Odemira, Aljezur, Portimão, Silves and Tavira. The FBN segments associated with these municipalities accounted for 52% of the total length of the regional FBN.

Discussion

Results suggest that full implementation of the regional FBN (3% of the study area) reduces the overall average fire size up to 17%, and decreases conditional BP up to 31%. Higher reductions are observed in the more intense treatments (FRFBN) when compared with the shaded fuel break scenario. These results are not surprising given the differences in fire potential between the two fuel treatment options. The general findings are similar to other studies (Ager *et al.* 2007b; Syphard *et al.* 2011; Bradstock *et al.* 2012; Price 2012) where treating a small proportion of the subject area resulted in minimal reduction in exposure, risk, and expected burned area. If the FRFBN is fully implemented, simulation results indicate an overall reduction in area burned up to 17%, corresponding to a decrease of 0.016 to 0.039 ha of burned area per hectare treated, considering the average and maximum number of observed events per year respectively. This leverage effect was calculated after examining the historical rural fire database from which we assessed that on average 4.3 events lasting over 24 h occurred annually, with a peak of 14 fires in 2003 and 2005. These leverage values are one to two orders of magnitude lower than observed where prescribed burning is used as an area-wide treatment (Price 2012). Conversely, our results are optimistic when compared with those of Finney (2002) and Ager *et al.* (2010b), where cumulative treatment rates of 20% were required to obtain similar reductions in BP and fire size.

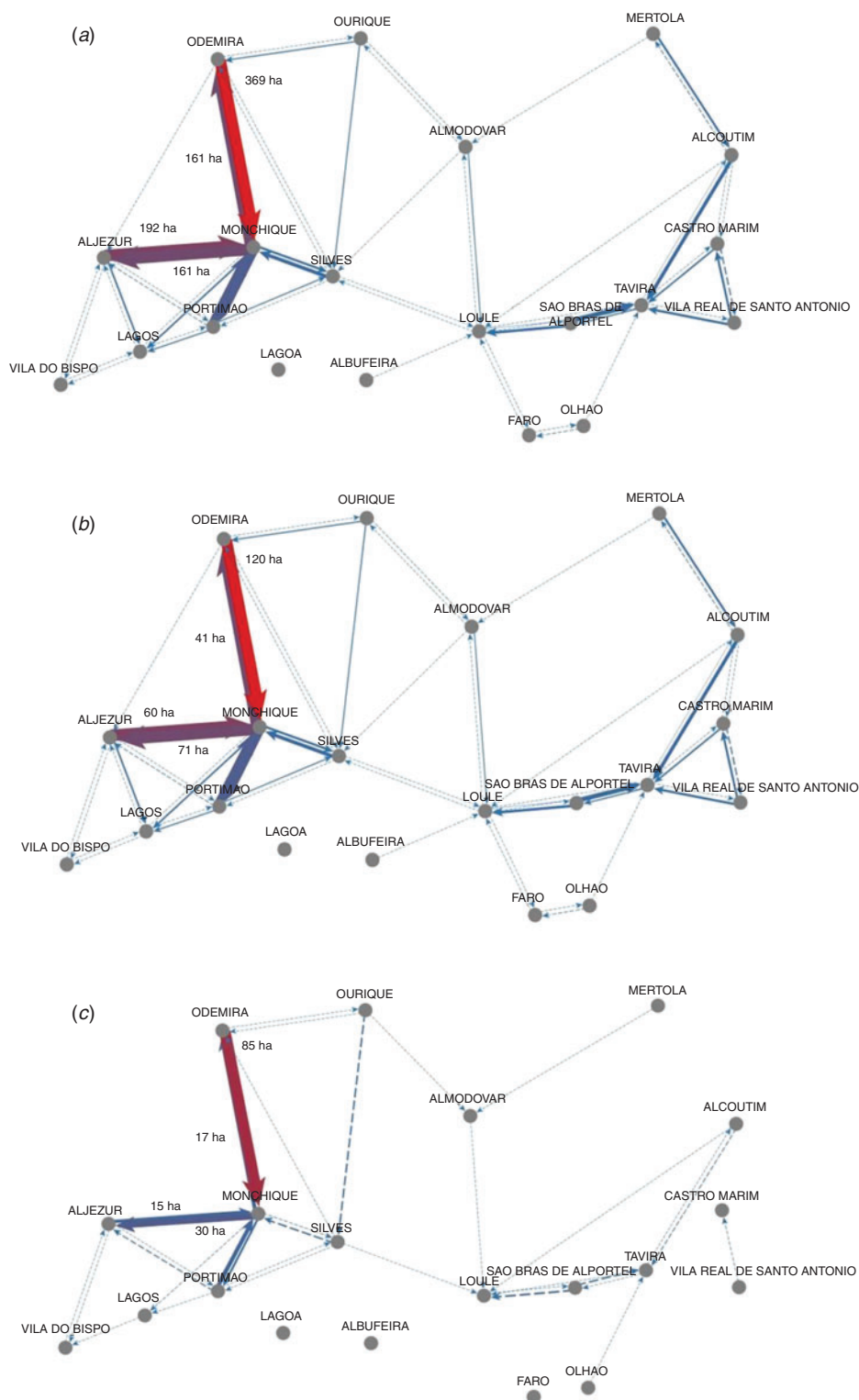


Fig. 7. Fire transmission network diagrams of the study area showing linkages of the 20 municipalities. For three municipalities, (a) presents absolute values of expected burnt area being transmitted in the non-treated (NT); (b) and (c) present net benefit expected in burnt area when comparing the full removal fuel break network (FRFBN) and the shaded fuel break network (SFBN) with the non-treated scenario respectively. Arrow width illustrates the reduction in burned area (ha) transmitted from ignition origin to destination (arrow direction). Transmitted burned area increases from light blue to dark red. Linkages below 10 ha are represented by dotted lines.

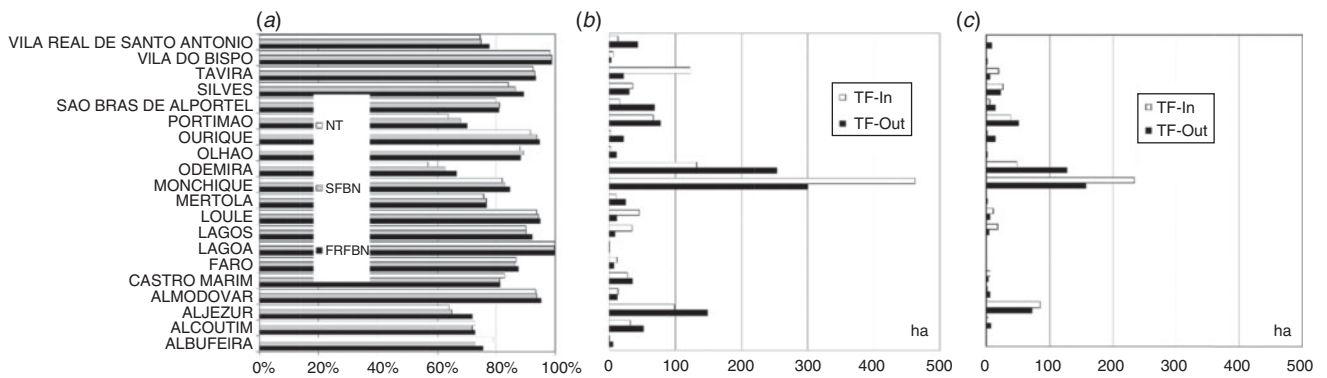


Fig. 8. (a) Percentage of non-transmitted burnt area (self-burning) in non-treated landscape (NT), shaded fuel break network (SFBN), and full-removal fuel break network (FRFBN) for each municipality; (b) incoming transmitted fire (TF-In) and outgoing transmitted fire (TF-Out) expressed in burnt area for each municipality in non-treated landscape; and (c) net change in incoming transmitted fire (TF-In) and outgoing transmitted fire (TF-Out) for each municipality between the simulated FRFBN and the non-treated reference landscape. TF-In represents the total burned area transmitted from neighbouring municipalities and TF-Out represents the total burned area transmitted to neighbouring municipalities. All values expressed in hectares (ha).

The expected effect of a fuel break is not to halt fire spread but to make firefighting operations more effective (Weatherspoon and Skinner 1996). This synergistic effect was not modelled, because current fire suppression practices in Portugal disregard fire perimeter control and are focussed on civil protection (Beighley and Quesinberry 2004). Moreover, it is difficult to coordinate suppression activities with linear fuel management infrastructure in large fires (Keeley 2002; Rigolot 2002; Finney *et al.* 2003). Fuel breaks, vs landscape-scale treatments, minimise area treated, and it has been suggested for Portugal (Fernandes *et al.* 2012) that an FBN strategy is more cost-effective than a fuel age mosaic established by area-wide treatments. However, fuel mosaics reduce fire severity across the landscape, in contrast with an FBN strategy, which our results also highlight: the decrease in fire incidence was due to a shift in the distribution of fires by size class towards fires <500 ha, but overall burnt area was reduced only by 17%. This can be due to excessively large compartments within the fuel breaks, as they were designed to minimise the chance of large fires (CNR-A 2005). Landscape-scale fuel treatments decrease fire intensity and fire growth rate, hence resulting in smaller and less severe fires than those occurring in untreated landscapes under the same conditions and with the same duration (Fernandes 2015).

We found that reduction in fire exposure in the presence of an FBN as defined by modelled burnt area is more relevant where fires are more frequent (Monchique and Tavira). Risk transmission among municipalities differs in the two subregions of the study area. We found that up to 50% of the FBN is located in six municipalities (mostly located in the western region and in the central east) and ignitions in these segments are responsible for 80% of the area burned being transmitted, very similarly to the non-treated landscape. This suggests that fire transmission in the region is determined by site-specific variables such as land cover, fuel composition, topography and ignition patterns, and the tested FBN layout had a minor effect in changing the transmission pattern. The burnt area received and transmitted by each municipality (Fig. 8) quantifies liability in respect to neighbouring communities. This information can facilitate mitigation planning and risk-sharing agreements, and potentially mobilise stakeholders to sponsor landscape-scale mitigation

or other designs. The graphical representation of potential wildfire risk transmission among communities (Fig. 7) and the balance between importers and exporters (Fig. 8) of fire as derived from simulation experiments can also facilitate more accurate risk perception where fires have not occurred in the recent past (e.g. in Odemira and Monchique communities). The arrangement of community ties relative to fire-prone environments in concert with spatial ignition patterns will have a strong influence on wildfire transmission. Reducing network ties among communities needs to be explored by examining the arrangement of fuels and their spread potential, and historical ignition patterns and their relationship to land-management activities.

Further in-depth work should look at the effects of reducing ignition density and extending fire simulation duration and examine alternative fuel treatment layouts that reduce the size of compartments within fuel breaks either based on ridgelines (linear FBNs as in the present study) or in strategically placed area-wide treatment units. Further work could also consider finding the optimal treatment effort necessary to assure specific burned area reduction, or explore the simulation results to produce fire event statistics such as quantifying how often fires crossed all or certain FBNs and identify critical crossing locations. To improve the quality of the results and reduce their uncertainty for planning use, sensitivity analysis could clarify how different individual parameters used as fire simulation input contributed to variation in model predictions. Considering the institutional effort put into the fuel isolation strategy, further studies should document and analyse the outcome of fire-FBN encounters, as in Syphard *et al.* (2011).

The methodology framework can assist fire management agencies in prioritising the construction and maintenance of more effective FBN segments, thus rationalising budget allocation. In the present case study, if totally built, costs could reach €15 million in a 10-year investment time frame, or €856 ha⁻¹ considering a 3% interest rate, €750 ha⁻¹ for construction and €150 ha⁻¹ for maintenance every 5 years. The very low leverage values we found suggest that to avoid 1 ha burned, 61 ha (on average) or 26 ha (for the year with the highest burned area on record) would have to be treated. Considering the highly unfavourable cost-benefit ratio, it is

critical that fire suppression operations take advantage of the FBN to reduce area burned beyond its passive effect. Results also indicate that half of the planned FBN could mitigate 87% of the transmitted risk, hence suggesting that the overall cost can be halved.

Limitations

The use of simulation modelling is an important tool to address policy questions pertaining to fuel management policy at the scale at which fuel management projects are implemented. Modelled outputs can provide important insights into the interactions between wildfire spread and spatial patterns of fuel treatments at landscape scales. Although historical fire records can provide broad trends in wildfire activity (Ager *et al.* 2014b), and site-specific observations on modifications in fire behaviour (Prichard and Kennedy 2012), they are grossly inadequate to study the effect of different fuel management strategies (area treated, treatment dimensions, orientation, treatment type) on quantitative wildfire risk, even in severely fire-prone regions like Portugal. Moreover, the inherent uncertainty in future wildfire events demands probabilistic risk-based approaches to wildfire management (Miller and Ager 2013). Although several studies have shown that the MTT family (*FSim*, *FSPro*, *Flammap5*, *Randig*) of simulation models can quantitatively replicate large wildfire events, in terms of predicting area burned (Finney *et al.* 2011) and size and shape of perimeters (Ager *et al.* 2014b; Salis *et al.* 2014), the simulation models have many well-known limitations, including: (i) simulated fire behaviour does not account for fire–atmosphere interactions and therefore is likely to underestimate crown fire activity and spread rates (Cruz and Alexander 2010); (ii) meteorological information used as input was derived from synoptic weather models adjusted to reflect major topographic features in the landscape, but likely underestimates wind speed under severe fire weather; (iii) in terms of the input data describing fuels, the assignment of fuel models to Corine land-cover classes is guided by expert opinion, adding additional uncertainty; (iv) the 120-m spatial resolution may not capture fuel bed discontinuities and natural fuel breaks associated with topographic conditions. Related to this point is that we modelled a fuel break that was only a single pixel, and thus where the treatments are linked by adjacent vertices (touching on the diagonal), wildfires can essentially spread through the fuel break without being affected by the fuels treatments. However, this effect would only be observed when the minimum travel time was aligned perpendicularly to the fuel break at that specific pair of vertices; (v) a significant fraction of our study area is dominated by unmanaged eucalypt stands, known for their spotting potential, which may exceed the 10% probability we assumed by default. This would allow fuel breaks to be breached by fire at higher rates than simulated, especially under burning conditions more severe or with longer fire durations than considered here (Fernandes *et al.* 2011; Cruz *et al.* 2012; Alexander and Cruz 2013). For Canadian boreal fires, Amiro *et al.* (2001) found that 1-km-wide fuel breaks would restrict spotting and fires larger than 10 000 ha if 15% of the landscape was treated.

Conclusions

Quantifying transmitted risk demonstrates interdependencies among communities in their potential exposure to wildfire and

the importance of collaborative planning at the regional scale with respect to wildland fire policy development. Demonstrating this interdependence through simulation studies can help improve risk perception and build the social capacity required for effective wildfire mitigation efforts (Fischer and Charnley 2012). The present analysis clearly demonstrated the potential benefits of coordinated fuel treatments among the landowner communities. Thus, the results from the study may help motivate the development of national and regional public policies towards an integrated, landscape-based ‘fire-smart’ approach (Fernandes 2013) to manage wildfire risk. Our analysis suggested that allocating 3% of the territory to an FBN would lower fire exposure and decrease the occurrence of large-fire events. If the goal of the decision-makers is to substantially reduce burned area and fire severity, we suggest further fuel treatment efforts are needed beyond the FBN investment, especially in the frequent-fire (high burn probability) subregions within the study area. These results can now be used to frame local fuel and forest management strategies that include cost–benefit analysis and risk assessment (Finney 2005; Rodríguez y Silva *et al.* 2012; Pacheco *et al.* 2015), to support collaborative decision-making among multiple stakeholders and land-tenure systems in Portugal.

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Supplementary material

Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission

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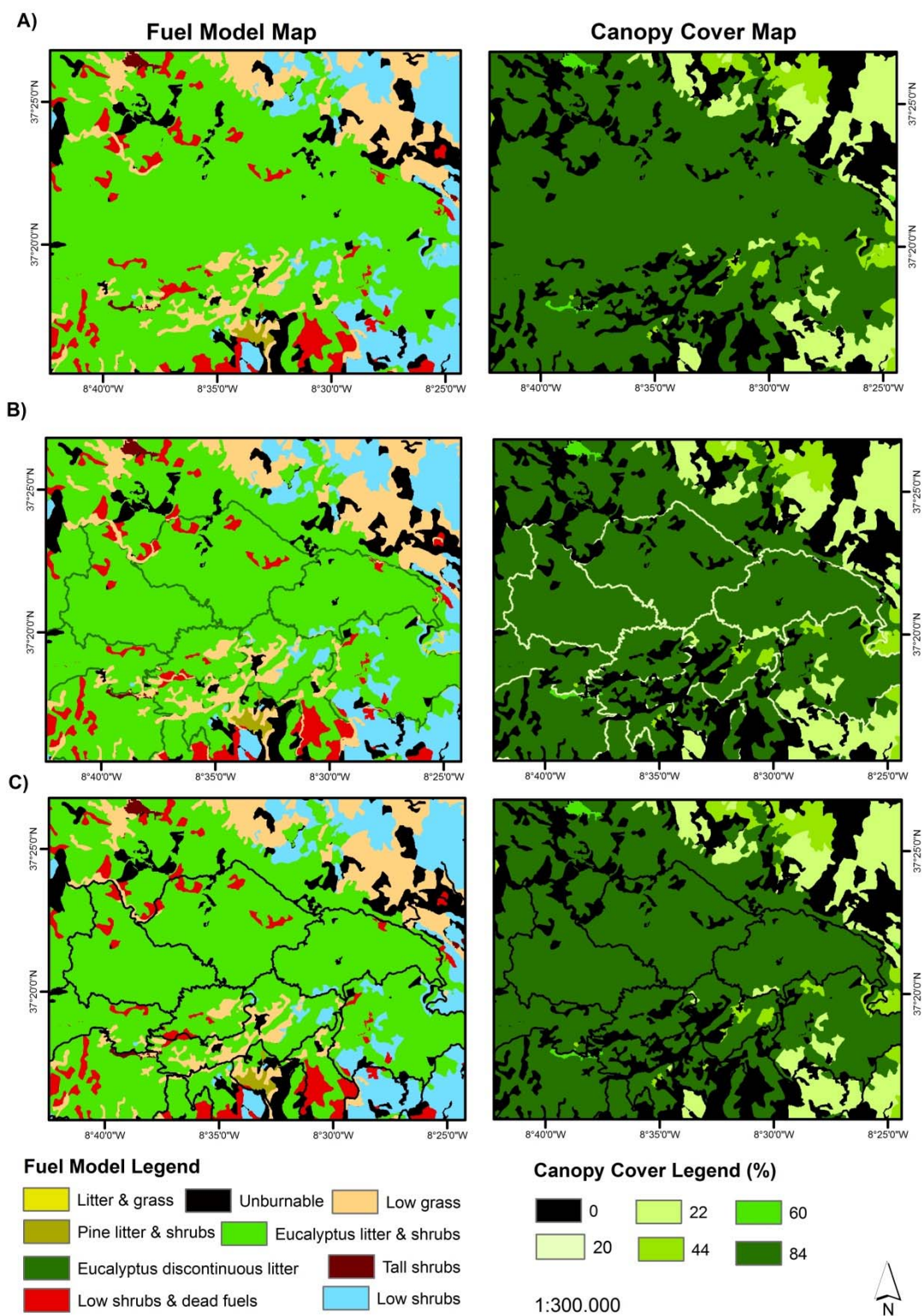


Fig. S1. Fuel model and canopy cover maps for three treatment scenarios: A) non-treated landscape, B) shaded fuel break network and C) full reduction fuel break network. All maps represented at same scale and location.

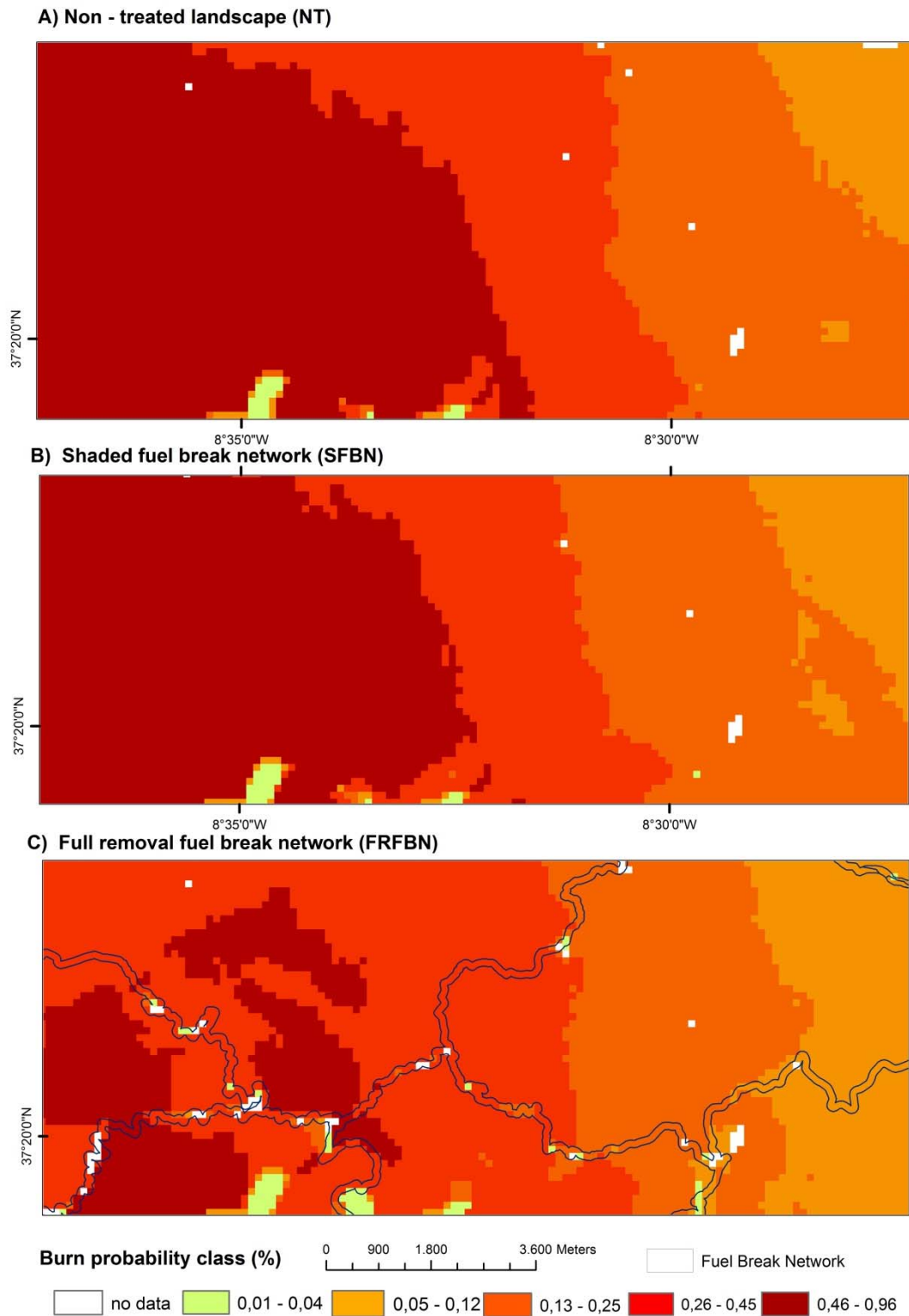


Fig. S2. Pixel-scale difference of burn probability maps for three treatment scenarios between A) non-treated landscape, B) shaded fuel break network and C) full reduction fuel break network. All maps represented at 120-m pixel size for same scale and location.

Table S1. Land cover and fuel models in the region

Corine land cover level 3 nomenclature (EEA, 2012) and common designations, and fuel model and canopy cover percentage for the reference non-treated and shaded fuel break network (SFBN) scenarios. In the full removal fuel break network (FRFBN) scenario, fuel model and canopy cover are set to zero. Custom fuel models are described in Table S2

Corine land cover level 3 nomenclature	Common designation for land cover	Non-treated landscape		SFBN	
		Fuel model type	Canopy cover (%)	Fuel model type	Canopy cover (%)
111 to 142	Artificial surfaces	99	0	0	0
212 and 213	Irrigated agricultural and rice fields	99	0	0	0
211, 242 and 243	Annual crops, arable land and natural pastures	232	0	232	0
221, 222 and 223	Vineyards, fruit trees and olive groves	232	0	232	0
231	Permanent pastures	232	0	232	0
244	Agro-forestry systems	232	22	232	22
313	Helm oak and cork oak forests	237	22	232	22
311	Cork oak forests	237	22	232	22
311	Other broad-leaved forests	237	44	226	20
312	Other coniferous forests	227	84	226	20
312	Maritime pine forests	237	44	226	0
312	Stone pine forests	236	60	226	0
311	Eucalyptus forest	223	84	224	20
313	Mixed forest stands (Helm oak X Eucalyptus)	237	44	226	20

313	Mixed forest stands (Cork oak X Eucalyptus)	237	44	226	20
313	Mixed forest stands (Eucalyptus X Stone pine)	223	84	226	20
313	Mixed forest stands (Eucalyptus X Cork oak)	223	84	226	20
313	Mixed forest stands (Maritime pine X Eucalyptus)	237	44	226	20
313	Mixed forest stands (Maritime Pine X Stone pine)	237	44	226	20
313	Mixed forest stands (Stone pine X Cork oak)	237	44	226	20
323 & 324	Sclerophyllous vegetation	234	0	232	0
321 & 333	Natural grasslands and sparsely vegetated	232	0	232	0
331, 332 & 334	Spaces with little or no vegetation and burnt areas	99	0	99	0

Table S2. Description of fuel models used in the study

Fuel models describe fuel bed characteristics quantitatively as inputs to fire behaviour models and their applications. In this study we assigned a custom fuel model to each land cover type from the fuel model collection developed for Portugal by Fernandes *et al.* (2009) plus the model for eucalypt slash of Cruz (2005)

Fuel model code	Fuel model no.	Land cover types	Fuel model description
No burn	99	Unburnable	Bare soil, rocks or paved
M-EUC	223	Eucalyptus plantations	Eucalypt litter and woody understorey
M-EUCd	224	Eucalyptus plantations	Discontinuous eucalypt litter
M-H	226	Forest types with a grassy understorey	Litter and grass
M-PIN	227	Pine forest	Pine litter and woody understorey
V-Hb	232	Non-irrigated agriculture, agroforestry	Low grass (<0.5 m)
V-MAb	234	Shrubland	Low shrubs (<1m), dead fuels are important
V-MMa	236	Shrubland, pine forest	Tall shrubs (>1 m)
V-MMb	237	Shrubland, oak woodland	Low shrubs (<1 m), dead fuels are unimportant

Table S3. Fire response summary statistics

Fire frequency, basal area (BA) and fire size statistics (mean, median, coefficient of variation (CV) and quantiles) for the shaded fuel break network (SFBN) and full removal fuel break network (FRFBN) treatments and the non-treated reference situation (NT) for each fire size class

Fire size class (ha)	Treatments	# fires	BA (Mha)	Change in BA (%)	Fire size (ha)						
					Median	CV	Mean	Q.90	Q.95	Q.97.5	Q.99
<100	NT	89 255	1.1		8	112.8	12	12	24	69	86
	SFBN	89 813	1.1	-2.9	8	115.2	12	12	33	72	87
	FRFNB	90 894	1.1	-1.5	8	114.2	12	12	28	67	87
100–499	NT	24 820	7.4		298	39.2	300	463	482	492	496
	SFBN	26 621	8.0	-7.8	300	39.1	301	463	482	491	496
	FRFNB	27 517	8.3	-11.7	305	38.7	302	462	480	491	496
500–999	NT	21 060	14.9		686	21.6	710	937	967	983	993
	SFBN	20 246	14.3	4.1	691	20.8	708	927	961	980	993
	FRFNB	19 665	13.8	7.4	685	20.6	704	920	956	977	992
1000–9999	NT	14 590	32.9		1483	88.3	2252	5132	7695	8862	9492
	SFBN	13 235	30.1	8.3	1474	85.5	2276	5543	7310	8368	9132
	FRFNB	11 950	25.8	21.5	1463	80.2	2159	4917	6563	7517	8641
>10 000	NT	274	3.1		10 894	9.3	11 181	12 582	12 985	13 856	14 502
	SFBN	121	1.3	57.7	10 617	5.3	10 701	11 379	11 645	12 032	12 840
	FRFNB	24	0.3	91.6	10 435	8.4	10 731	11 846	13 583	14 088	14 088

Table S4. Expected area burned in non-treated landscape from origin X and destination Y (values expressed in hectares)

Albufeira (ALB), Alcoutim (ALC), Aljezur (ALJ), Almodôvar (ALM), Castro Marim (CAS), Faro (FAR), Lagoa (LAO), Lagos (LAG), Loulé (LOU), Mértola (MER), Monchique (MON), Odemira (ODE), Olhão (OLH), Ourique (OUR), Portimão (POR), São Brás de Alportel (SBA), Silves (SIL), Tavira (TAV), Vila do Bispo (VBP), and Vila Real de Santo António (VRS)

	ALB	ALC	ALJ	ALM	CAS	FAR	LAO	LAG	LOU	MER	MON	ODM	OLH	OUR	POR	SBA	SIL	TAV	VBP	VRS
ALB									4											
ALC					7				3	10								40		
ALJ								19			192				5				5	
ALM									12					2			4			
CAS		5																19		15
FAR									5											
LAO																				
LAG			6								2				3				2	
LOU	1			3		3										6	2	1		
MER		24		3																
MON			161					19				161			92		25			
ODE			4								369			1			5			
OLH						9										1		2		
OUR				8								14					14			
POR			9					13			93						13			
SBA									30				1					52		

SIL				1					2		41	5			5					
TAV		6			3				2				1			14				1
VBP			4					2												
VRS					24													27		

Table S5. Expected area burned in Shaded fuel break network (SFBN) from origin X and destination Y (values expressed in hectares)

Albufeira (ALB), Alcoutim (ALC), Aljezur (ALJ), Almodôvar (ALM), Castro Marim (CAS), Faro (FAR), Lagoa (LAO), Lagos (LAG), Loulé (LOU), Mértola (MER), Monchique (MON), Odemira (ODE), Olhão (OLH), Ourique (OUR), Portimão (POR), São Brás de Alportel (SBA), Silves (SIL), Tavira (TAV), Vila do Bispo (VBP), and Vila Real de Santo António (VRS)

	ALB	ALC	ALJ	ALM	CAS	FAR	LAO	LAG	LOU	MER	MON	ODM	OLH	OUR	POR	SBA	SIL	TAV	VBP	VRS
ALB									6											
ALC				1	7				2	10								36		
ALJ								20			176	1			3				4	
ALM									10					2			4			
CAS		6																20		16
FAR									6				2							
LAO											2				2					
LAG			6																	
LOU	1			2		3										5	2	1		
MER		25		3																
MON			131					16				144			84		22			
ODE			5								285			1			5			
OLH						8										1		1		
OUR				7								13					6			
POR			4					10			74						11			
SBA									22									45		

SIL									2		34	3			3				
TAV		5			3				2				1			12			1
VBP			2					1											
VRS					21													29	

Table S6. Expected area burned in full reduction fuel break network (FRFBN) from origin X and destination Y (values expressed in hectares)

Albufeira (ALB), Alcoutim (ALC), Aljezur (ALJ), Almodôvar (ALM), Castro Marim (CAS), Faro (FAR), Lagoa (LAO), Lagos (LAG), Loulé (LOU), Mértola (MER), Monchique (MON), Odemira (ODE), Olhão (OLH), Ourique (OUR), Portimão (POR), São Brás de Alportel (SBA), Silves (SIL), Tavira (TAV), Vila do Bispo (VBP), and Vila Real de Santo António (VRS)

	ALB	ALC	ALJ	ALM	CAS	FAR	LAO	LAG	LOU	MER	MON	ODM	OLH	OUR	POR	SBA	SIL	TAV	VBP	VRS
ALB									5											
ALC				1	6				3	10								32		
ALJ								11			131								5	
ALM									9					2			1			
CAS		5																17		13
FAR									5											
LAO																				
LAG			4								2				2				1	
LOU	1			2		3										4	1	1		
MER		22		3																
MON			89					13				120			62		16			
ODE			1								249			1			3			
OLH						9										1		1		
OUR				8								9					5			
POR			2					9			56						10			
SBA									21				1					47		

SIL									1		23	3			3					
TAV		5			3				1				1			11				
VBP			2					1												
VRS					19															24

2.4. OUTROS CONTRIBUTOS ORIGINAIS

No âmbito do Programa MIT Portugal foi desenvolvido o projecto FIRE-ENGINE - *Flexible Design of Forest Fire Management Systems*, que teve por objectivo desenvolver métodos de desenho de soluções de gestão do risco de incêndio florestal nos domínios das políticas públicas, da gestão e da engenharia. Entre 2009 e 2013 mobilizaram-se competências da Engineering Systems Division (ESD) do Massachusetts Institute of Technology (MIT), do INESC TEC / Faculdade de Engenharia da Universidade do Porto (FEUP), do Instituto Superior de Agronomia (ISA), da Universidade de Trás-os-Montes e Alto Douro (UTAD), e da The Navigator Company (antes grupo Portucel Soporcel). No decurso do projecto, associou-se à equipa a Northern Research Station do USDA Forest Service. Das actividades da equipa de investigação resultaram mais de duas dezenas de contributos científicos que se encontram publicados (artigos em revista, capítulos de livro, e artigos em actas de congressos) e aplicações operacionais em uso e em desenvolvimento.

No contexto do projecto acima resumido foram publicados dois trabalhos científicos com relevância para o tema da governança do risco de incêndio florestal, dos quais o doutorando é co-autor, inscrevendo aí contributos significativos para a Tese que se apresenta. Nos parágrafos que se seguem introduz-se a lógica desses dois artigos no fio condutor da argumentação que suporta a Tese. No primeiro abordam-se as relações complexas entre o sistema físico e político na gestão do risco de incêndio em Portugal (Collins *et al.*, 2013) e, no segundo, apresenta-se uma revisão bibliográfica dos sistemas de apoio à gestão de risco de incêndio florestal (Pacheco *et al.*, 2015).

1) FOREST FIRE MANAGEMENT TO AVOID UNINTENDED CONSEQUENCES: A CASE STUDY OF PORTUGAL USING SYSTEM DYNAMICS

No decurso da transição florestal ocorrida desde o final do séc. XIX, e dos diferentes percursos analisados no artigo introduzido na secção 2.1, "*Is Portugal's forest transition going up in Smoke?*", resultaram as paisagens contemporâneas. Na secção 2.2, e no artigo aí introduzido "*Wildfire Risk Governance – From a simple issue to a complex risk challenge*", explica-se como evoluiu ao longo do último século a governança do risco de incêndio, adaptando-se em resposta aos efeitos dos incêndios e à crescente complexidade que o problema foi assumindo. Badia *et al.* (2001), Busenberg (2004), Davis (2005), Morehouse *et al.* (2011) ou Gill (2005), por exemplo, documentam políticas reactivas baseadas na exclusão do fogo e na aposta em poderosos e eficazes (até certo nível) sistemas de supressão à escala de um país. Estes trabalhos, como diversos outros, argumentam que as estratégias que privilegiam o combate têm que ser balanceadas com investimentos de prevenção, mas não apresentam cenários quantificados das consequências futuras destas políticas.

Para Portugal, relatórios de peritos produzidos em vários momentos nos últimos 50 anos, incluindo Quintanilha *et al.* (1965), Banco Mundial (1981), Beighley e Quesinberry (2004), ou Beighley e Hyde (2009), referem a necessidade de investir em prevenção para proteger a floresta, evitando o colapso dos dispositivos de extinção, independentemente das melhorias de eficácia identificadas em cada momento. No pós-2003, a gestão dos combustíveis (ver secção 2.2) assume maior prioridade, tendo propostas técnicas sido desenhadas e apresentadas ao poder político (ISA-APIF, 2005) para operacionalizar a prevenção. No entanto, as consequências da época de incêndios de 2005 voltam a influenciar o poder político no sentido de priorizar as soluções de supressão, através do reforço de meios e melhorias no ataque inicial em detrimento de uma aposta clara na operacionalização da redução da carga combustível, para além do reforço do planeamento e mecanismos legais de prevenção (Beighley e Hyde, 2009). Este relatório alertava para a necessidade de planeamento estratégico na gestão do sistema e um reforço da prevenção antecipando um futuro com épocas de incêndios dominadas pela meteorologia, pela volatilidade das áreas ardidadas e com uma probabilidade crescente para

grandes incêndios. Mas como tornar evidente a um leigo ou um decisor político sem suficientes conhecimentos técnicos, que investir só em combate pode ter graves consequências no futuro?

No âmbito do projecto FIRE-ENGINE, em que se estudava a incerteza em sistemas complexos, foi possível mobilizar competências para desenvolver um sistema que comparasse políticas reactivas e proactivas, tornando evidente no tempo presente as consequências futuras da simples atuação sobre os sintomas, por oposição à actuação sobre as causas do problema. Os nossos melhores esforços para resolver um problema, por vezes tornam-no pior, como refere Sterman (2000) ao ilustrar o conceito de *policy resistance*, que se define pela tendência para as intervenções serem derrotadas pela resposta do sistema, como no caso de abuso de antibióticos. Através de simulação com sistemas dinâmicos, é possível capturar as principais características de sistemas complexos e dinâmicos, com mecanismos de acumulação e fluxo (*stock and flow*) e auto-regulação através de realimentação (*feedback*), frequentemente diferida (*time delays*).

No trabalho intitulado "*Forest fire management to avoid unintended consequences: A case study of Portugal using system dynamics*" (Collins *et al.*, 2013) foi possível, com entrevistas às partes interessadas e acesso a relatórios, modelar um sistema dinâmico capaz de simular as consequências das políticas de gestão do risco de incêndio dos últimos 100 anos e prospectivar as consequências da sua continuidade ou alteração até 2050. O modelo é formado por um subsistema físico e um subsistema político. O subsistema físico tem como variáveis a carga combustível acumulada, a velocidade de propagação do fogo e a intensidade da linha de chama. O subsistema político usa como variável a área ardida do ano anterior, que se relaciona positivamente com os investimentos em supressão, na medida em que estes resultam da pressão da população sobre o governo para actuar sobre a dimensão visível do problema. Dado um orçamento finito, à medida que a área ardida aumenta, o subsistema político responde com o reforço dos meios de combate, reduzindo a disponibilidade orçamental para medidas direccionadas à prevenção. No curto prazo, alcançam-se os resultados desejados, mas nos anos subsequentes, através da dinâmica induzida no subsistema físico, observa-se que carga de biomassa combustível é crescente, levando a incêndios maiores, com maiores durações e severidades. Para capturar

as tendências de longo prazo, sem contudo pretender replicar os regimes históricos de fogo, o modelo foi parametrizado usando os três grandes momentos da transição florestal em Portugal, relacionando-os com a evolução do sistema de governança do risco de incêndio.

Como vimos na secção 2.1, entre 1910 e 1950 ocorreu uma expansão da área arborizada em coevolução com a agricultura, que mantinha a paisagem com cargas combustíveis baixas. Um segundo período, que se estende até ao final do séc. XX, caracteriza-se pelo êxodo rural, alteração da gestão florestal e extensificação das ocupações do solo. Para o terceiro período, que prospectiva a evolução até 2050, assume-se que o modelo entrou em equilíbrio após a transição florestal. Dados os pressupostos, que incluem o número de incêndios e uma taxa de acumulação de carga combustível constante de 1950 em diante, o modelo produz anualmente resultados expressos em carga combustível acumulada, duração média de incêndios, e área ardida. Estes resultados, quando lidos numa série temporal, permitem observar as consequências das decisões políticas sobre a distribuição proporcional de orçamentos prevenção/supressão.

CONTRIBUTO DO DOUTORANDO:

Neste trabalho, o autor colaborou designadamente nos seguintes aspetos:

- 1) Definição da problemática a investigar, estabelecimento do estado da arte, e articulação das questões de investigação;
- 2) Disponibilização de conhecimento sobre o sistema de gestão de incêndios florestais, a partir da experiência como especialista técnico e assessor de decisores políticos na formulação das políticas pós-2003;
- 3) Preparação do trabalho de campo;
- 4) Calibração do modelo desenvolvido e discussão dos resultados obtidos.

2) COHESIVE FIRE MANAGEMENT WITHIN AN UNCERTAIN ENVIRONMENT: A REVIEW OF RISK HANDLING AND DECISION SUPPORT SYSTEMS

Com o aumento da incidência do fogo e dos seus danos potenciais, os sistemas de gestão de risco foram evoluindo para responder a crescentes solicitações em contextos de recursos financeiros escassos. Desde cedo foram desenvolvidos esquemas rudimentares de apoio à decisão, que evoluíram para complexos sistemas que procuram fornecer ao decisor no âmbito das políticas, da gestão, ou da operação, um conjunto de soluções que maximizam a eficiência no uso de recursos, dado um conjunto de restrições (financeiras, legais ou operacionais) e uma ou mais funções objectivo.

Procurando assegurar um fluxo regular de bens e serviços florestais, o plano de Barros Gomes de 1864 para a Mata da Machada e Vale de Zebro (Radich e Alves, 2000) inaugura em Portugal o uso de modelos de decisão cientificamente fundamentados para a gestão das florestas. Os vários planos de ordenamento realizados até à primeira metade do séc. XX previram investimentos em prevenção e supressão, mas não equacionam formalmente a questão da eficiência na alocação destes recursos. Em Portugal, as primeiras evidências sobre a necessidade de maximizar a eficiente afectação de recursos para a protecção do arvoredo contra o fogo surgem em Dias (1955), com a publicação do primeiro mapa de risco de incêndio e a forma de calcular o risco meteorológico momentâneo (Dias, 1957) e permanente de incêndio florestal (Dias, 1958). Com a publicação do DR n.º 55/81 é oficializada uma versão actualizada do mapa de risco de incêndio e durante a década de 1980 vários trabalhos científicos dedicam-se à previsão do risco de incêndio e ao comportamento do fogo (Oliveira e Reis, 2003). A produção de cartografia de risco de incêndio foi incentivada através dos planos municipais de intervenção na floresta (DL n.º 423/93), tendo-se desenvolvido diversos métodos e aplicações para avaliar o risco espacial de incêndio.

É na década de 90 que os primeiros simuladores de comportamento do fogo são utilizados em ambiente universitário para a avaliação do risco de incêndio e desenvolvem-se modelos de propagação do fogo, como o GeoFogo (Uva *et al.*, 1997) que, tendo sido testados e divulgado o seu uso, não tiveram a aplicação por falta de capacidade de absorção dos utilizadores (Reis e Oliveira, 2007).

Para ultrapassar esta falha estrutural no desenho do sistema, associada a um baixo capital social e poucos incentivos à adopção da mudança (ISA-APIF, 2005), em 2001 e 2002 através da CNEFF foram produzidos e distribuídos mapas impressos com a localização das infraestruturas de protecção contra o fogo, familiarizando os potenciais utilizadores (técnicos municipais e bombeiros) com as noções de risco e o seu uso para definição de prioridades de actuação (CNEFF, 2002). Alguns trabalhos de fim de curso atestam a aplicação das ferramentas de simulação, mas a sua utilização operacional para suportar a decisão só ocorreu com as comissões regionais de reflorestação no período 2004-2006 (João Pinho, informação pessoal) e com os Grupos de Análise e Uso do Fogo em 2007-2009 (Pedro Palheiro, informação pessoal), a que se seguiram alguns gabinetes técnicos florestais municipais (Paulo Mateus, informação pessoal) e, por fim, só em 2013 em contexto de combate a incêndios e em tempo real, com o projecto FIRE-ENGINE.

Na esfera do combate a incêndios, e atendendo aos avultados investimentos associados, o emprego de modelos de apoio à decisão, em particular incorporando incerteza, pode potenciar a eficácia e a eficiência na gestão de meios, como exemplifica o trabalho de Pacheco *et al.* (2013) sobre o impacto dos reacendimentos e falsos alarmes no desempenho do sistema de supressão. No entanto, não há na prática uso ou referências a outros trabalhos, como se constata ao ler os relatórios do grupo de trabalho sobre meios aéreos (MAI, 2005) ou as orientações operacionais que estabelecem a distribuição espacial dos recursos ou a alocação de grupos de reforço (ANPC, 2015). No âmbito da gestão de ocorrências e meios de combate, existe desde 2012 na autoridade de protecção civil um sistema de apoio a decisão operacional (SADO) que permite a gestão administrativa de recursos de combate, que necessita de melhorias, não estando interligado com outros módulos (TC, 2016). Como notam as avaliações do Plano Nacional de Defesa da Floresta Contra Incêndios (IESE, 2015) a estrutura de gestão e os sistemas de informação administrados pelas diversas entidades não permitem o cruzamento de dados, o que inibe o emprego das ferramentas de apoio à decisão. A ausência de informação sobre a estimativa do valor de bens ou serviços a proteger ou a simples separação entre floresta, matos e área urbana permitiria um uso analítico de modelos de gestão de risco, como os testados por Verde (2015).

Atendendo em boa medida ao baixo nível de emprego de sistemas de apoio à decisão na governança e na gestão do risco de incêndio em Portugal, entendeu-se ser relevante estruturar sob a forma de uma publicação o resultado da pesquisa internacional realizada sobre modelos e sistemas em uso. Surgiu assim a revisão bibliográfica *“Cohesive fire management within an uncertain environment: A review of risk handling and decision support systems”* (Pacheco et al., 2015), que resume os modelos de propagação de fogo, os sistemas de suporte à decisão com base em modelos económicos usados em Espanha, Chile, Canadá, Estados Unidos da América, Austrália e África do Sul, e os modelos de planeamento florestal que incorporam o risco de incêndio.

Conclui-se que a evolução que tem ocorrido nestes países, dos modelos determinísticos de avaliação de risco para modelos mais integrados e com valências estocásticas, permite, fazendo uso do potencial informático hoje disponível, ganhos de eficiência na gestão operacional dos dispositivos de prevenção e combate no apoio à governança do sistema e das políticas.

Neste trabalho constata-se a evolução que os sistemas de gestão de risco têm sofrido numa tentativa de respostas a perguntas cada vez mais complexas dos técnicos e dos decisores. No artigo detectou-se, em particular, a tendência evolutiva de os sistemas enquadrarem o contexto socio-ecológico, aproximando-se assim da governança do risco.

CONTRIBUTO DO DOUTORANDO:

Os principais contributos do autor para este trabalho foram os seguintes:

1. Disponibilização de conhecimento sobre o funcionamento e a utilização de sistemas de apoio à decisão em gestão de risco de incêndio em vários países, incluindo referências técnicas e científicas e informação recolhida em trabalho de campo e visitas focadas na sua utilização, ao longo das duas últimas décadas;
2. Colaboração na conceptualização, e na redação de excertos da parte do artigo relativa ao tema da governança do risco de incêndio;
3. Colaboração na redação e revisão final do artigo.

[Forest fire management to avoid unintended consequences: A case study of Portugal using system dynamics \(2013\)](#)

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Forest fire management to avoid unintended consequences: A case study of Portugal using system dynamics



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ABSTRACT

Forest fires are a serious management challenge in many regions, complicating the appropriate allocation to suppression and prevention efforts. Using a System Dynamics (SD) model, this paper explores how interactions between physical and political systems in forest fire management impact the effectiveness of different allocations. A core issue is that apparently sound management can have unintended consequences. An instinctive management response to periods of worsening fire severity is to increase fire suppression capacity, an approach with immediate appeal as it directly treats the symptom of devastating fires and appeases the public. However, the SD analysis indicates that a policy emphasizing suppression can degrade the long-run effectiveness of forest fire management. By crowding out efforts to preventative fuel removal, it exacerbates fuel loads and leads to greater fires, which further balloon suppression budgets. The business management literature refers to this problem as the *firefighting trap*, wherein focus on fixing problems diverts attention from preventing them, and thus leads to inferior outcomes. The paper illustrates these phenomena through a case study of Portugal, showing that a balanced approach to suppression and prevention efforts can mitigate the self-reinforcing consequences of this trap, and better manage long-term fire damages. These insights can help policymakers and fire managers better appreciate the interconnected systems in which their authorities reside and the dynamics that may undermine seemingly rational management decisions.

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1. Introduction

This paper explores how dynamical interactions between the physical and political systems of forest fire management influence allocation of resources to the reactive suppression of fires and their proactive prevention. Portugal is the model case.

1.1. Motivation

Demographic, agricultural and climatic changes are altering the dimensions of forest fire management in many regions. Vast populations are moving from the countryside to urban areas. This depopulation of marginal agricultural areas leads to extensive afforestation, through either second growth woodlands that invade

previously tended fields or deliberate shifts to forest plantations (Pereira et al., 2006; Vallejo, 2005). Climate change also appears to be influencing patterns of rainfall and weather that can exacerbate fire damages, as witnessed in 2012 in the Western United States. Together, these changes increase forested area, the potential damage from forest fires, and thus the importance of informed expenditures on fire management.

Portugal is grappling with the consequences of these changes (Fig. 1). The number of forest ignitions increased by nearly a factor of ten between 1980 and 2010, from about 4000 to as many as 35,000 annually. The decadal average of burned area in that time period increased from approximately 73,000 to 102,000 to 152,000 ha (AFN, 2010). The years 2003 and 2005 together registered over 750,000 ha burned, that is, about 3000 square miles – an area of more than 50 miles on each side and almost 9% of the entire country. These damages motivated great attention to forest and fire management and led to significant expenditures on the country's capacity to suppress fires (Beighley and Hyde, 2009; Beighley and Quesinberry, 2004; Oliveira, 2005). Much of the recent research

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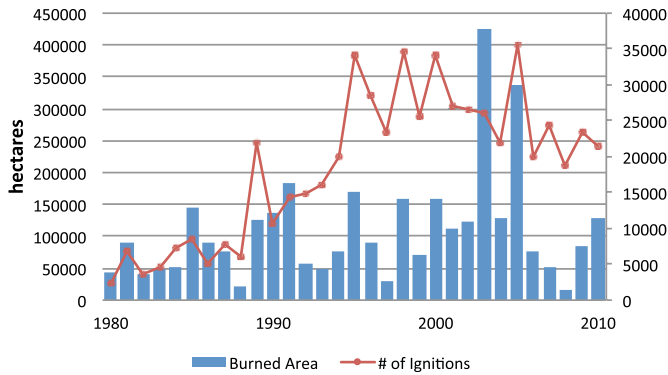


Fig. 1. Total burned area and ignitions in Portugal, 1980–2010 (AFN, 2010). Both are increasing and becoming increasingly volatile.

has sought to explain the growing fire occurrences statistically using a variety of physical and socioeconomic variables (Cattry et al., 2010; Marques et al., 2011; Moreira et al., 2009).

There are, however, underlying dynamics that have been impacting fire activity in Portugal for many years. Specifically, the country has witnessed the afforestation of pine on public lands (Brouwer, 1993), extensive commercial investments in eucalyptus plantations (Mendes et al., 2004), and thus a great increase in the total area of contiguous, fire-prone forest. Meanwhile, rural abandonment of farming and emigration into the coastal cities after the 1960s (DGRF, 2006; Gomes, 2006; Moreira et al., 2001), reinforced by European Union policies (Aguilar and Montiel, 2011), changed the susceptibility of the landscape to forest fires. Traditional farming practice had kept fuel levels reasonably stable through integrated agriculture, livestock grazing, and fuel management; however, as farms were abandoned, tall shrub lands and mixed forests began to dominate the landscape resulting in a 20–40% increase in fuel accumulation (Moreira et al., 2001). Increased fuel loads can increase the rate of fire spread, intensity and, all things equal, fire severity (Graham et al., 2004; Peterson et al., 2003; Weatherspoon and Skinner, 1996). This is particularly true in the northwestern Iberian Peninsula (Northern Portugal, Asturias and Galicia) due to high plant productivity (Vázquez et al., 2002). Despite these facts, Portuguese management strategy has generally promoted the exclusion of fire, as has been the case in other Mediterranean countries like Greece, Spain and Italy (Morehouse et al., 2011; Secco et al., 2010; Seijo and Gray, 2012). For further reading on Portuguese fire history, the reader should consult Grove and Rackman (2003) and Pereira (2006).

Effective management of the risk of forest fire balances suppression and prevention activities. As defined in this paper suppression seeks to extinguish fires already ignited, while prevention seeks to limit fire severity through fuel reduction, for example through prescribed fire. In Portugal, forest managers have used prescribed fire since the 1970s to mimic historical fire regimes (Silva, 1997), reflecting their knowledge of the ecosystem's dependence on fire for vitality and renewal. However, suppression expenditures have come to dominate the budget since the major fires in the mid-2000s (ISA, 2005). While fire (whether natural or prescribed) is often essential to the overall health of the forest ecosystem, the ecological benefits of fire are outside the scope of this study. Thus, when discussing forest fire management henceforth, the focus is on managing fire damages to protect people and property. Nonetheless, striking an appropriate balance between suppression and prevention efforts is a non-trivial policy goal, particularly when one action can potentially undermine another through complex and sociopolitical feedback effects.

1.2. Research approach

An essential premise of this paper is that a better understanding of the dynamical interactions between components of the forest fire management system can improve managerial prescriptions. Systems thinking is a general approach for developing this understanding. It trades losses in contextual detail of any one component of the system for subsequent gains in understanding of phenomena that emerge due to component interactions and feedback.

System Dynamics (SD) is a quantitative modeling tool that uses systems thinking to analyze the impact of feedback loops in complex, dynamic systems. This paper uses SD to model and then simulate the dynamics of a forest fire management system, focusing on the interactions between the physical aspects of forest fires and the political responses to fires over time. It provides a comparison between reactive and proactive policies: between immediate responses that target symptoms (suppression) and longer-term actions that address underlying causes (prevention). Finally, it explores the ways in which physical and political dynamics interact and may lead to unintended and unexpected consequences. It is a specific application of a general approach that has been applied in many other contexts.

The analysis runs over decades. This is the necessary, appropriate time scale for exploring the dynamic feedback effects of alternative strategic policies. This approach therefore differs from those that focus on short-run, static decisions concerning optimal allocation of firefighting resources.

The following two sections describe the modeling approach in more detail, and then apply it to forest fire management in Portugal. The subsequent two sections assemble the simulation and present results in light of the particular dynamics in Portugal.

2. Systems Dynamics modeling

Broadly speaking, Systems Dynamics (SD) is a modeling approach and simulation tool for modeling complex, dynamic systems. SD captures an essential feature of many systems: that they are self-regulating over time. This means that feedbacks among the system components incrementally adjust the state of the system. A change in one part of the system affects another that then affects others with some delay, some of which will eventually feedback to amplify or dampen the effect of the original change. In short, an SD model recognizes that changes do not occur in isolation and furthermore that many systems do not respond instantaneously to these changes.

Self-regulating systems are endemic in nature and society. They are particularly apparent in complex ecological and social systems, as well as systems that accumulate quantities, or stocks, of variables that are central to system function. A forest is a good example: fire sets off a cycle of regrowth, which leads to increased fuel loads over time and thus a greater propensity for fire. Similarly, bureaucratic changes take time to respond to new situations such that any subsequent equilibrium takes time to establish. For this reason, SD is a suitable approach to explore the interconnected and dynamic issues of forest fire management.

SD represents the interactions between the elements of the system through causal loops. For example, a year with particularly damaging fires may incite the government to increase the budget for firefighting. This leads to more firefighting equipment and personnel, reducing the damage that might arise from fires several years following the year that triggered the initial change. Such feedbacks with delays and influences from other system variables can produce nonlinear and unexpected behavior, such as self-reinforcing positive feedback. In general, feedback can lead to

unintended consequences of seemingly rational policy decisions (Sterman, 2000).

SD is a well-established and valid approach for analyzing the management of complex environmental systems. Examples include water resource management (Simonovic, 2002; Stave, 2003), agricultural development (Saysel et al., 2002) and global climate change (Sterman, 2011).

SD takes a holistic approach to analyze the impacts of complex dynamic interactions in a system. It captures the effects of feedbacks so that policies can be evaluated in light of their systemic ripple effects. SD represents systems by connecting each individual causal loop into an integrated causal loop diagram. These high-level diagrams usefully represent the overall feedback structures of complex, self-regulating systems.

2.1. Forest fire management model

Fig. 2 is a causal loop diagram that represents the high-level dynamics impacting a forest fire management system. The left-hand box represents the physical subsystem, how forest growth increases fuel load, fire severity and burned area. The right-hand box represents the political subsystem, showing the influence of human decision-making on forest fire management. While economic, socio-ecological, and other subsystems could be included in the model, the physical-political scope is sufficient for the aims of the paper. Variables within boxes are the stocks that define the state of the system at a given time.

An SD model simulates system performance over time by appropriately altering the variables. For each increment of time it

adjusts the level of each variable as determined by the net inflows and outflows. For example, the growth of the forest over the previous year increases fuel load, but the forest burning that occurs during the current year subsequently decreases fuel load.

Both the physical and political systems contain feedback loops. Within the physical system, the natural balancing loop is the *Native Fire Regime*. It represents the fact that fuel accumulates according to some growth rate; that as fuel load increases, so too does fire severity; this then increases burned area per year and subsequently drains the fuel stock through burning. It represents basic ecosystem dynamics of a forest undisturbed by human influence.

Within the political system there are two feedback loops. The balancing *Fire Control* loop depicts how an institution, or set of institutions, attempts to manage the frequency and severity of fires through enhanced fire suppression. Thus, as burned area per year increases, there is more pressure to control fire in order to protect people, property and industry. This leads to more suppression expenditures and subsequently shorter fire durations as crews can extinguish fires faster and more effectively with enhanced suppression technologies. With shorter fire durations, burned area per year decreases, representing the balancing effect.

The second political cycle is the reinforcing *Prevention Resource Scarcity* loop. Assuming a finite budget, increased suppression expenditures crowd out the resources available to prevention activities, such as prescribed fire. This in turn decreases the preventative removal of forest fuel, and the fuel stock increases, as Saveland (1998) indicated. Some authors contend that excess fuel accumulation is a direct consequence of fire exclusion, since small and medium fires are not allowed to burn (Minnich, 1983, 2001;

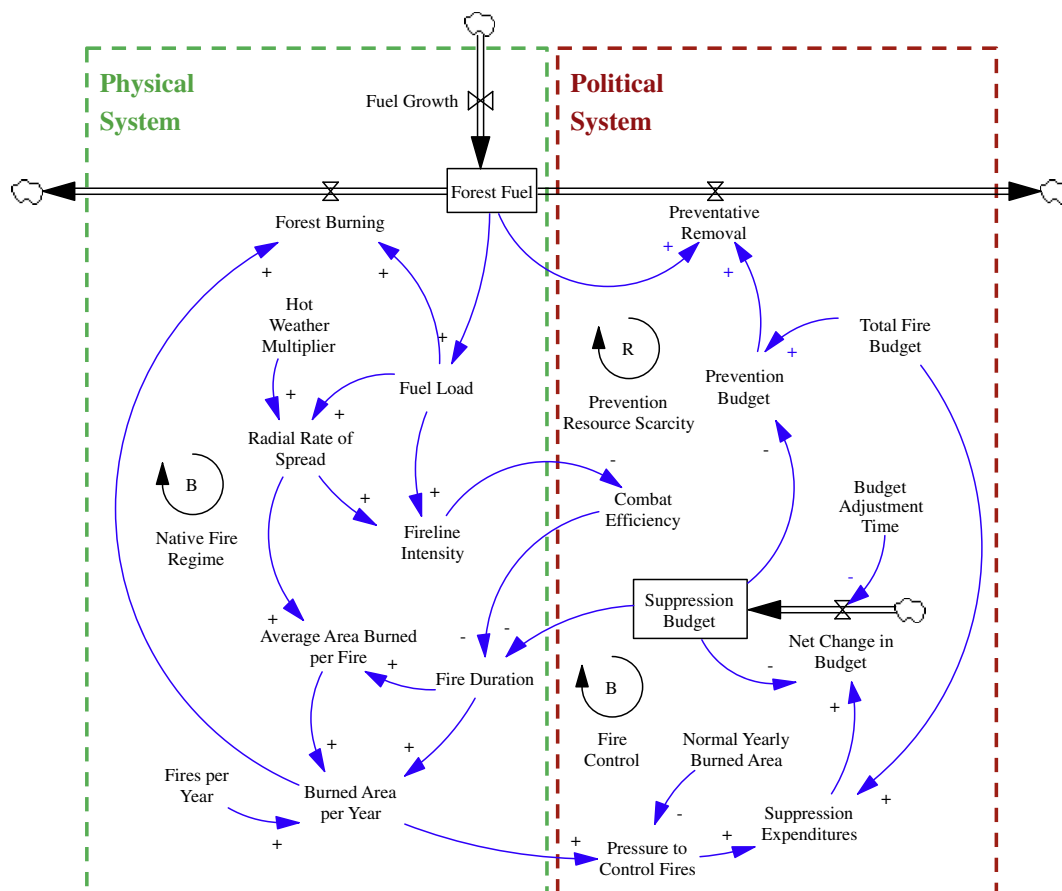


Fig. 2. Causal loop diagram of a forest fire management system. The diagram distills the complexity of the system into the major variables and feedback loops ('B' stands for "balancing" and 'R' for "reinforcing") between physical and political subsystems.

Minnich and Chou, 1997). While others dispute the basis for this dynamic (Keeley and Fotheringham, 2001; Keeley et al., 1999; Moritz et al., 2004), and it is likely to depend on the local vegetation structure, this feedback loop is important for appreciating the potential unintended consequences of decisions about managing forest fires.

2.2. The physical system

The complete forest fire management model involves significant detail for both the physical and political system. [Supplementary material](#) associated with this paper and [Collins \(2012\)](#) provide full particulars. This and the next section indicate salient elements of these details.

Fuel Load is the key variable that links fire suppression and prevention activities to eventual fires. Its units are metric tons per hectare, consistent with the measurements conducted for experimental burns in Portugal ([Fernandes, 2001](#); [Fernandes et al., 2009](#)).

The *Radial Rate of Spread* of fires is roughly proportional to the square root of fuel load, as in [Fernandes et al. \(2009\)](#). The *Hot Weather Multiplier*, which has a multiplicative effect on fire spread, is an annual index of weather conditions represented by the average dryness of fuel in a given fire season (year). It is a white noise process that generates truncated normally distributed random variables to reflect the occurrence of hot, dry weather particularly conducive to major fires, as done in [Li et al. \(1997\)](#). The model represents aggregate fire activity and thus all variables, including the weather multiplier, are aggregate measures taken over the entire year.

The *Fireline Intensity* is the rate of heat energy released per unit time per unit length of fire front ([Byram, 1959](#)). It reflects the associated reduction in firefighting *Combat Efficiency*. For example, direct attack with hand tools and assured control of prescribed fire is possible when intensity is less than 400–425 kW/m. Heavy mechanical equipment can usually control a fire if intensity is below 1700–1750 kW/m. Spot fires can become serious at 2000–2100 kW/m, and fires are completely uncontrollable when intensity exceeds 3500–3700 kW/m ([Chandler et al., 1983](#); [Hodgson, 1968](#)).

Burned Area per Year is calculated as the product of *Fires per Year* and *Average Area Burned per Fire*. The product of this value with *Fuel Load* determines the amount of *Forest Burning* that occurs each year.

The analysis focuses on yearly aggregate impacts. It ignores the distribution of individual fire durations and uses averages. Every fire in the model behaves in the same way; it has the same fireline intensity, radial rate of spread, and duration. However, the model does represent single extreme fire seasons, which ultimately are the impetus for subsequent government action. This is sufficient for modeling the high-level dynamics between humans and the forest.

2.3. The political system

Pressure to Control Fires is a dimensionless variable that encapsulates management action taken given fire damage from the previous year. It is defined as the quotient of *Burned Area per Year* and *Normal Yearly Burned Area*, and relates to the expenditure on suppression resources. This accords with the views of many Portuguese experts from academia, industry, and forest owners' associations who contend that forest management expenditures are driven largely by politics. In other words, pressure from the media and the public result in expenditures on high-tech firefighting solutions, such as helicopters and air tankers, because they resonate emotionally and psychologically with public opinion.

A first order information delay modulates the budgeting for suppression expenditures. This is essentially a smoothing function. When expenditures change in response to last year's fire season,

they are compared against the current budget and altered according to the adjustment time required to pass new budgets, which is assumed to be three years. The rationale behind using this structure is that the budget adjustment process can be slow, which dampens the budgetary impact of a particularly bad fire season. Such delays are widely used in stock and commodity forecasting to filter out short-term fluctuations in prices ([Sterman, 2000](#)).

A higher *Suppression Budget* increases firefighting capability, drives down *Fire Duration*, and decreases forest burning. This is the balancing mechanism of the *Fire Control* loop from Figure. The effect of more suppression resources is to decrease fire duration at a decreasing rate, in accord with the LCD model ([Sparhawk, 1925](#)). [Martell \(2001\)](#) proposes the same effect although through a different mechanism. *Combat Efficiency* reflects the effectiveness of a given *Suppression Budget* at decreasing *Fire Duration*.

The *Total Fire Budget* is the annual sum of resources allocated to suppression and prevention. Assuming finite budgets, increases in suppression expenditures decrease the resources devoted to prevention and fuel removal (e.g. via prescribed burns). Given the historical tendency of governments to favor fire exclusion ([Aguilar and Montiel, 2011](#); [Franklin and Agee, 2003](#)), there is thus a tendency to crowd out prevention activities.

3. Model adaptation to Portugal

To explore the implications of suppression- and prevention-based policies for fire management, we adapted the model to the past and current situation in Portugal and implemented it in the Vensim software package. It should be emphasized that the purpose of the model is to evaluate the aggregate dynamics of factors affecting the forest fire management system under alternative management scenarios, i.e. different allocations to suppression and prevention resources. It is *not* to reproduce historical fire regimes in Portugal.

To establish an adequate long-term view, the model covers three periods of forest fire management. The first is the past period of intense rural inhabitation and agriculture. The second represents the transition associated with the political and economic opening to continental Europe. This was a period of rural depopulation, extension of forest plantations, and shifts in forest management practices. The third phase is that of eventual stabilization after the transition. To permit adequate steady-state conditions before and after the transition period of about 50 years, we gave all periods equal length. Thus we set up the model to run for 150 years. For convenience, one can assume that the 150-year span begins in 1900 and runs until 2050. The simulation time step is one year, corresponding to the annual cycle of fire seasons and budgets.

Total Forested Area was set to an upper-bound estimate of the current coverage of forest and shrubland in Portugal, approximately 5.4 million hectares ([Oliveira, 2011](#)). *Fires per Year* were assumed constant at the prevailing 10-year average in Portugal, or 24,528 occurrences. The *Total Fire Budget* was set at the approximate 2009–2010 level of €150 million. The model increases *Fuel Growth* 1% per year in the transition period, from years 50–100. This exogenous ramp is an approximate portrayal of the afforestation and rural abandonment that started around the 1950s in Portugal. At the end of this phase, the model assumes that fuel growth rate stabilizes at a level roughly 50% greater than where it started.

The model is parameterized such that the system begins in equilibrium (before the onset of afforestation and rural abandon), with yearly burned area equal to the 10-year average in Portugal, approximately 150 thousand hectares. The notion of equilibrium in a forest ecosystem, let alone any system influenced by humans, may be a bit contrived. With high variance in yearly ignitions,

physically diverse regions, and general uncertainty surrounding human action, the forest system is almost constantly in flux. However, to identify the impact of relevant dynamics on the system, a baseline mode must be formulated from which to compare the results of various disequilibrium simulations. Development of the equilibrium operating mode (essentially where fuel into the system equals fuel out of the system) requires assumptions and should of course be subject to scrutiny. However, the initialization of equilibrium is less significant, since it is the *divergences* from equilibrium due both to afforestation and rural abandon and physical-political dynamics that are central to the analysis.

4. Assembling the baseline analysis

To explore and illustrate relevant dynamics and tradeoffs in fire management, we first examine the consequences of two divergent policies, one focused on suppression, the other on prevention (the chosen percentages produce outputs that depict well the effect of feedback on the system). The results characterize the impacts of these policies and help develop the understanding of the counter-intuitive effects of seemingly rational policies.

The two baseline policies are nominally defined as:

- *Suppression Policy*, which devotes 60% of initial resources to suppression, and
- *Prevention Policy*, which devotes 75% of initial resources to prevention.

These allocations of resources cannot be altered exogenously at later stages in the simulation. While this capability could be implemented, disallowing it in the current structure isolates the effect of the self-regulating behavior on the system, revealing potential future outcomes of different policies left unchecked. To implement the allocation of resources, the user inputs a fraction (between 0 and 1) of resources to prevention at the beginning of each simulation. With the exception of the allocation, all simulations are run under the exact same conditions.

Following the exploration of these two alternatives, we explore the possible effects of alternative policies. Results indicate the possibility of improving the overall performance of fire management through a balanced approach to suppression and prevention.

5. Results of baseline analysis

This section presents the salient outcomes of the two baseline policies. Following the three major feedback loops of Fig. 2, it tracks key output variables over time. Overall, the *Prevention Policy* produces less total burned area in the long run. The *Suppression Policy* confers short-term benefits in terms of shorter fire durations and less burned area. However, it produces overwhelming, self-reinforcing feedback effects after the onset of afforestation and rural abandon that lead to increasingly severe and volatile fire seasons.

5.1. Fire Control loop

Under the *Suppression Policy*, the suppression budget eventually approaches the total budget. As fuel loads increase, fires become more intense, prompting more efforts on suppression, thus less on prevention and its reduction of fuel loads. This propels full-scale efforts to suppression.

A focus on fire suppression results in shorter fire durations (Fig. 3) and therefore less burned area per year, which is the goal of fire suppression. This is the *intended* consequence of increased fire suppression and the *Fire Control* loop in general.

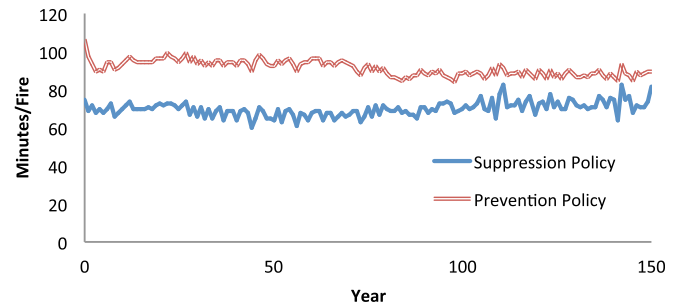


Fig. 3. Fire Duration. Fire durations (minutes/fire) are shorter under the *Suppression Policy*, which is the intended effect of the policy.

5.2. Prevention Resource Scarcity loop

Suppression Policy produces *unintended* consequences that become evident when we consider the *Prevention Resource Scarcity* loop. It is associated with increases in the rate of spread of each fire and dramatic increases in relative fireline intensity. Intense fires reduce the combat efficiency of fire suppression forces, decreases their ability to manage fires effectively, which in turn leads to longer fires. If not for the increases in intensity, the fire durations under fire exclusion would be shorter than shown in Fig. 3. In short, emphasis on suppressing fires can make them more severe.

The primary physical reason for the *unintended* consequences is that the *Suppression Policy* leads to an excessive accumulation of fuel, caused by its associated lack of investment in preventative fuel removal (Fig. 4).

The underlying political reason for this is that the *Suppression Policy* concentrates effort and resources on suppression, and thus drives down the budgets for prevention. As preventative fuel removal decreases, the stock of fuel increases, which leads to increases in fireline intensity (and associated decreases to combat

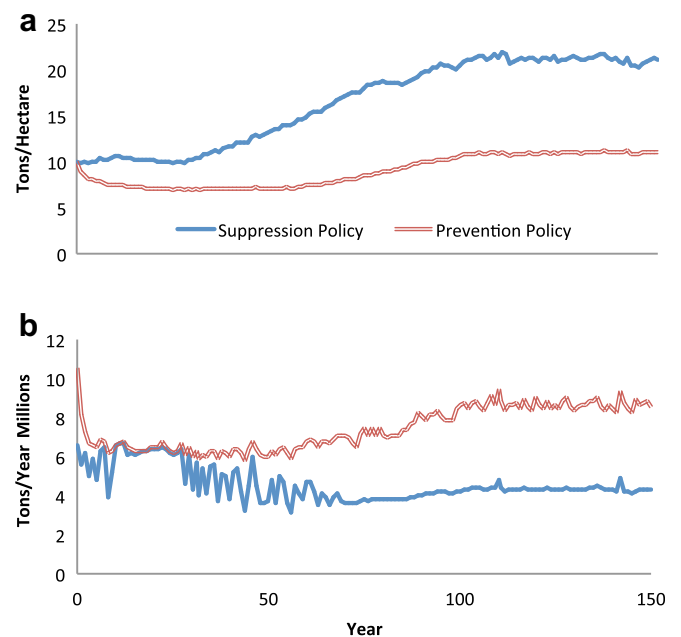


Fig. 4. a: Fuel Load. The *Suppression Policy* is associated with greater growth in fuel load (tons/hectare) compared to the *Prevention Policy*, which is the unintended effect of the policy. b: Preventative Removal. With a finite budget, excessive suppression expenditure under the *Suppression Policy* crowds out preventative removal. As the rate of preventative removal (tons of fuel per year) decreases, fuel load increases.

efficiency) and rate of spread. The combination of these factors translates to more burned area and further pressure to manage fires with additional suppression forces. Thus, increased suppression expenditure reinforces further expenditure, and the *Fire Control* loop has an *unintended* positive effect on the fuel stock.

5.3. Native Fire Regime loop

Examination of the native fire regime loop further reveals the *unintended* consequences of a focus on fire suppression. This loop recognizes that forest fires combine with preventative fires to reduce fuel loads. Since the *Suppression Policy* greatly increases the annual forest burning over time (Fig. 5), one might expect that the reduction greatly reduce the total fuel load. However, this is not the case (Fig. 4a). This means that the balancing effect of the *Native Fire Regime* loop is being overwhelmed by the lack of preventative removal stemming from the *Prevention Resource Scarcity* loop, which itself is driven by the unintended consequences of the *Fire Control* loop set into motion by afforestation and rural abandon.

5.4. Overall result

The overall result is that a focus on fire suppression provides immediate benefits but can become an inferior policy over time. The *Suppression Policy* leads to smaller burned area at first, but after the onset of afforestation and rural abandon, burned area per year surpasses that associated with the *Prevention Policy* and becomes more volatile (Fig. 6a). Correspondingly, the *Suppression Policy* leads to eventual greater total burned area (Fig. 6b).

An important goal of fire management policy is to manage total costs, for which the metric of total burned area is a proxy. From the perspective of this measure, *Suppression Policy* is the better policy initially through the transition period of rural abandonment and afforestation, that is, until approximately year 100. However, at some point during the transition period the reinforcing loops that increase burned area overcome the balancing loops seeking to decrease it, resulting in an increase in the rate at which the area burns. Because burned area continues to increase under the *Suppression Policy*, suppression expenditure remains at near maximum, perpetually undermining preventative fuel removal and thus keeping fuel loads high, which in the model is the underlying cause of severe fire activity. Overall, the *Suppression Policy* has the *unintended* consequence of increasing total fire damage.

6. Discussion of results

The results show how the reflex to fix a problem can, counter-intuitively, make matters worse. In the business management literature, this phenomenon is known as the *firefighting trap*, where “putting out fires” is understood allegorically. This section discusses

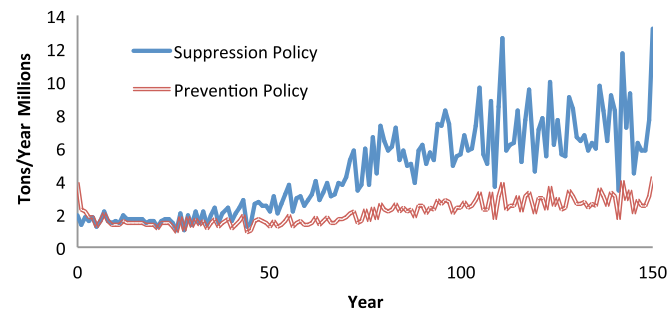


Fig. 5. Forest Burning. The rate of forest burning (tons of fuel per year) becomes larger and more volatile under the *Suppression Policy*.

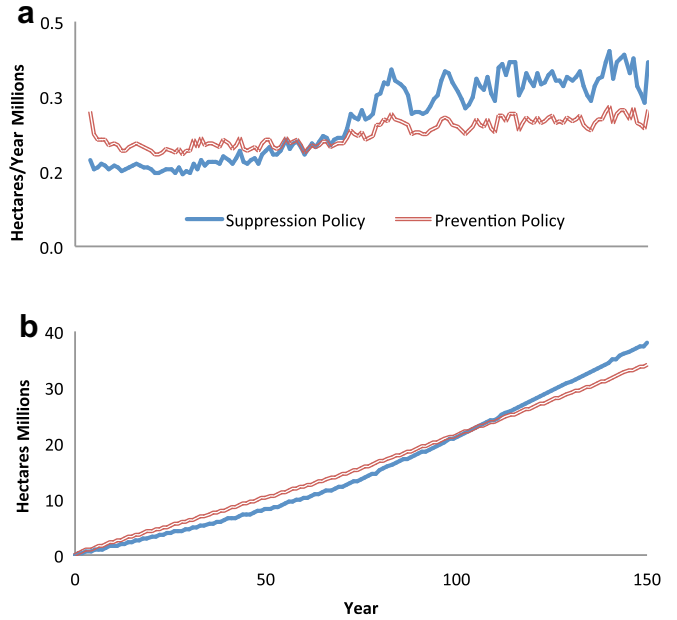


Fig. 6. a: Burned Area per Year, 5-year moving average. The *Suppression Policy* results in annual burned areas (hectares/year) that are mild at first, but in the long run become increasingly severe and volatile. b: Total Burned Area. The *Suppression Policy* results in total burned area (hectares) that is initially smaller but eventually larger than the *Prevention Policy*, revealing its long-term inferiority.

the trap and the related concept of policy resistance, and then offers solutions in the context of actual fire management.

6.1. Firefighting trap

Systems often get trapped in cycles of self-reinforcing feedback whereby the problem symptoms continue to grow yet the solution remains the same. Businesses often refer to this management syndrome as *firefighting*, defined as the short-term fixing of problems, or suppression of their symptoms, rather than understanding and addressing the underlying factors that cause the problems. System Dynamics has been used to analyze this problem in a number of different contexts outside of forest fire management (Godlewski et al., 2011; Repenning, 2001; Sterman, 2000). Absent external intervention or leadership, system managers continue to allocate resources to short-term fixing of symptoms instead of dealing with the causes of problems.

The model indicates that, to some extent, this is what is happening in Portugal. There is continuing emphasis on expenditures and efforts to suppress fires and address recent fire damages. Public pressure following a noticeably intense fire season begins a self-reinforcing feedback loop where preventative fuel removal is

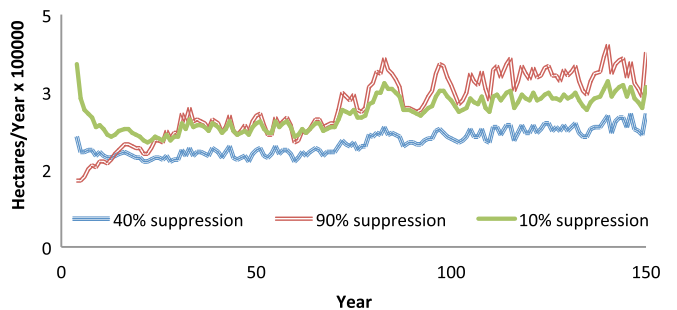


Fig. 7. Burned Area per Year, 5-year moving average. The appropriate balance of suppression and prevention efforts can greatly reduce yearly and total burned area.

diminished and fuel accumulates. More fuel in the system leads to more intense fires, more burned area, and thus further expenditures on suppression.

6.2. Policy resistance

The concept of *policy resistance* reflects the reality that interactions within a system may resist and undermine apparently rational management decisions (Stermann, 2000, 2006). A policy to deal with an issue may seem logical or rational, but has unintended consequences that actually exacerbate the problem. A major function of SD models is to illuminate the side effects or unintended consequences of seemingly rational decisions or policies, to expose the sources of policy resistance, and thus to point the way to deal effectively with an issue.

In the case of managing fires in Portugal, decision makers have expanded the suppression capacity of the country in an effort to reduce the frequency and severity of fires. However, the system shows resistance to this policy due to the unintended, positive effect on fuel load. In general, policy resistance is a precursor to self-reinforcing feedback effects and firefighting traps. Yet, despite the resistance of systems to seemingly rational policies, managers often adhere to them anyway due to entrenched mental models of how the system works and institutional or social pressures.

6.3. Balanced solutions

Preventing or mitigating the firefighting trap is possible if we allocate sufficient resources to prevention. However, if this allocation is too high, and thus the allocation to suppression too low, then the overall results are also poor.

To illustrate the merit of a balanced policy, we examine three allocations of resources to suppression: 90%, 40%, and 10% (the complements dedicated to prevention). The results show that disproportionate expenditures on either suppression or prevention have adverse long-term consequences (Fig. 7). While great emphasis on suppression can be counter-productive, an insufficient amount is also detrimental as fires burn longer and cause greater loss of property and life. As Fig. 7 indicates, policymakers and fire managers should pursue a balanced approach to suppression and prevention activities. The exact allocation is not meaningful, as the SD model does not seek numerical accuracy. Nonetheless, the realistic result, justified in light of the physical-political dynamics impacting fire management over time, is that a balance of suppression and prevention minimizes total burned area.

While the balanced “solution” to the firefighting trap is straightforward, shifting to this policy involves an important real-world tradeoff in forest fire management that may be difficult to achieve for three reasons:

1. A new emphasis on prevention (and away from suppression) allocates resources to different organizations using different forms of equipment. The established firefighting organizations are likely to contest this policy.
2. Investments in preventative fuel management lack immediate, visible short-term benefits, making them less attractive to both the public and policymakers with short terms of governance.
3. Managers and decision makers rarely receive credit for fixing or preventing problems that never occur (Repenning and Sterman, 2002). Moreover, they simply *cannot* receive credit since the prevention of the problem can never be attributed, with absolute certainty, to their preventative actions.

These obstacles, coupled with the physical-political feedback effects, help illustrate why a balanced approach to forest fire

management practice is neither universal nor standard despite the well-accepted tenet that strict adherence to fire suppression may ultimately lead to more severe fires. For example, within and across the US, Canada and Europe, authorities differ significantly in their approach to forest fire management (GAO, 2007; Hirsch and Fuglem, 2006; Montiel and Kraus, 2010), though there is evidence that the US is reversing its long history of fire exclusion (Reynolds et al., 2009). In contrast, preventative measures like prescribed burning are a well-accepted pillar of fire management in Australia; the debate instead centers on the appropriate amount to conserve biodiversity (Penman et al., 2011).

As regards Portugal, the SD model illustrates the tradeoffs between fire suppression and preventative fuel removal to inform balanced policy. Afforestation and rural abandon starting in the middle of the 20th century steadily increased fuel loads across Portugal, which led at least in part to the increase in fire activity over the past several decades. The symptomatic solution was to increase fire suppression capability in order to limit the damage of forest fires. Such a policy is immediately attractive: the public lauds decision makers for swiftly addressing the forest fire problem, and appreciates the decrease in fire durations across the country. However, a focus on fire suppression may not be sustainable in the long run, as the combination of high fuel load and severe weather can overwhelm the suppression capacity of Portugal, as was the case in 2003 and 2005 (Fig. 1). These model-assisted findings may help Portugal shift its current policy toward the more balanced approach that Australia has adopted.

6.4. Model limitations

This paper uses a System Dynamics model to derive insights about the unintended consequences of seemingly rational policies that arise due to system feedback. The general causality governing the model is consistent with the literature and the testimonies of Portuguese fire experts. But, SD models do not provide statistically valid estimates; rarely are they more than 40% accurate (Chahal and Eldabi, 2008). They provide a demonstration of the unintended consequences of certain actions that arise due to self-regulating feedbacks in the system. While the graphical outputs presented have absolute numerical axes, the numbers should not be taken at face value.

It is important to note that the shape of the model trends are sensitive to the monotonic functions in the model linking variables for which a physical equation or significant statistical relationship does not exist. The sign of all these relationships (i.e. positive or negative) is logical, but their exact shapes (i.e. range, domain, curvature) are either based on anecdotal evidence from experts or an informed guess by the research team. Further discourse with various experts and additional fieldwork could establish more reliable and data-driven functions.

While SD is useful for gaining overall insights into complex system behavior, one of its shortcomings is that it is a simulation tool based on deterministic causal processes. While some systems, such as manufacturing plants and assembly lines, are characterized by repeated actions, the reality is that most systems, and certainly forest fire management, are subject to great uncertainty. A lot of this uncertainty stems from the fact that humans constantly interact with systems in attempts to change them. As a result, a deterministic simulation model of a system, based on timeless relationships between political/social and physical/technical factors, never fully represents a system over time.

This limitation is particularly evident in the model of this paper. An initial allocation to suppression and prevention resources runs its course in the feedbacks of the system for 150 years. Due to the structure of the self-regulating feedbacks, it is never possible for

the system to increase the resources dedicated to prevention. They only change based on how suppression resources changed following a given fire year. Thus, after a severe fire year, the system will *always* invest heavily in suppression for the upcoming year, whereas investing heavily in fuel management is also a perfectly legitimate (and some might judge better) budget decision. To suggest that political decision makers will always spike suppression expenditures after an extreme fire season is to ignore the human ability to learn from the past and adapt decision making accordingly.

Finally, it is worth noting again that this paper does not consider the ecological benefit of fire when assessing the merits of different policies. While a balanced policy, as defined above, would appear to minimize total burned area, achieving this objective may be at odds with the broader forest management objectives of ecosystem stability and biodiversity conservation. The non-economic, ecological benefits of fire were not modeled explicitly in this paper, but future work focused on adaptive fire management, as opposed to damage control, should include a socio-ecological system in addition the physical and political systems. The expandability of model boundary to include other subsystems is one of the strengths of SD, though any increase in system scope needs to be traded off against potential loss in individual component specificity.

7. Conclusions

This work extends the field of forest fire management by developing a dynamic model that describes major feedbacks affecting system behavior. This broader systems perspective complements the range of available static and narrowly defined optimization studies.

This paper examines the unintended consequences of management decision-making when it focuses on fixing rather than preventing problems, a phenomenon coincidentally known in the business management literature as the firefighting trap. In the case of forest fire management, the finding is that the system succumbs to this trap when political influence increases emphasis on fire suppression and neglects fire prevention. While excessive year-to-year investment in fire suppression may mitigate fire damages in the short-term, in the long-term it can undermine preventative efforts, which becomes increasingly problematic as fuel accumulates. The analysis explored this issue through a case study of Portugal.

The insights from this paper may help policymakers and fire managers better appreciate the interconnected systems in which their authorities reside and the dynamics that may undermine seemingly rational policies. The model contributes to a long-standing debate between the relative merits of suppression versus prevention investments. As a tool, it provides long-term insights for risk communication to the public and exposes policymakers to the non-obvious feedback loops they may face when making management decisions. The results should be applicable to fire-prone countries, particularly those that have relied on policies of fire exclusion, such as Southern Europe and the United States, in addition to Portugal.

Future work could apply costs to different suppression and prevention activities, so that total managerial costs and fire damages of alternative policies can be evaluated. Furthermore, cost-constrained decision-making at later time periods could be implemented in the model instead of only choosing an initial allocation. The user could then use past information on system behavior and update decision making accordingly. Finally, it would be useful to incorporate additional stochasticity into the model, such that decision making would account for uncertainty in the variables currently assumed to be deterministic.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jenvman.2013.08.033>.

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Cohesive fire management within an uncertain environment: A review of risk handling and decision support systems (2015)

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Review

Cohesive fire management within an uncertain environment: A review of risk handling and decision support systems



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ABSTRACT

Wildfire management has been struggling in recent years with escalating devastation, expenditures, and complexity. Given the copious factors involved and the complexity of their interactions, uncertainty in the outcomes is a prominent feature of wildfire management strategies, at both policy and operational levels. Improvements in risk handling and in risk-based decision support tools have therefore a key role in addressing these challenges. In this paper, we review key systems created to support wildfire management decision-making at different levels and scales, and describe their evolution from an initial focus on landscape-level fire growth simulation and burn probability assessment, to the incorporation of exposure and economic loss potential (allowing the translation of ignition likelihood, fire environment – terrain, fuels, and weather – and suppression efficacy into potential fire effects), the integration with forest management and planning, and more recently, to developments in the assessment of values at risk, including real-time assessment. This evolution is linked to a progressive widening of the scope of usage of these systems, from an initial more limited application to risk assessment, to the subsequent inclusion of functionality enabling their utilization in the context of risk management, and more recently, to their explicit casting in the broader societal context of risks and decisions, from a risk governance perspective. This joint evolution can be seen as the result of a simultaneous pull from methodological progresses in risk handling, and push from technological progress in wildfire management decision support tools, as well as more broadly in computational power. We identify the key benefits and challenges in the development and adoption of these systems, as well as future plausible research trends.

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1. Introduction

Uncertain and highly unpredictable factors, such as weather forecasts, performance of suppression resources, and fire behavior, spread and effects, are the basis of fire management and policy decisions, across multiple levels and scales. Theoretical and computational progress in the last four decades has enabled the development of risk-based Decision Support Systems (DSS) that contribute to improve those decisions, namely by facilitating a structured assessment of the outcomes and costs associated with alternative policies, budgets, and suppression resource mixes.

In recent years, several authors have updated the state of the art on these tools and related challenges. [Minas et al. \(2012\)](#) have updated the review of [Martell et al. \(1998\)](#) on operations research methods applicable to wildfire management. [Thompson and Calkin \(2011\)](#) organize and align sources of uncertainty with decision support tools and methodologies, in order to facilitate cost-effective, risk-based wildfire management and planning efforts. [Mavsar et al. \(2013\)](#) present the economic efficiency analysis theory of fire management measures and use it as a framework to review four fire management DSS in use in America and Europe. [Papadopoulos and Pavlidou \(2011\)](#) make a comparative review of wildfire simulators and [Sullivan \(2009b\)](#) presents a comprehensive survey and review of surface fire spread simulation models. Indeed, some pre-defined spread model is incorporated in most of wildfire simulation models to simulate the behavior of fire across a landscape ([Thompson and Calkin, 2011](#)). [Bettinger \(2010\)](#) describes the methods used to integrate wildfires into forest planning models, using operations research techniques, going back to the seminal work of [Van Wagner \(1979\)](#), while more recently [Pasalodos-Tato et al. \(2013\)](#) review the use of decision support tools to address risk and uncertainty in forest management planning.

Our review adopts a higher-level perspective to provide a broader and more complete view of the evolution of the field. We concisely present several important risk-based decision support models for fire management, on the one hand highlighting their usefulness within the scope and the purposes that guided their development, but on the other rendering explicit a number of limitations that they present. Some of these limitations have also been discussed recently, although in a fragmented way, in the literature on challenges in the development and deployment of risk-based decision support systems. We bring together this set of observations, and highlight what seems to us to be an important trend of broadening of concerns from risk assessment, to risk management, to risk governance. This trend frames an increasingly ambitious utilization of these systems, gradually and successively broadened to address each of those areas of concern. This overall evolution pattern is the result of simultaneous methodological progress in risk handling, as well as specific technological progress in wildfire management decision support tools, and generic technological progresses in computation.

The remainder of the paper is structured as follows: in Section 2, we describe several fire growth simulators developed in recent decades in multiple parts of the world, and their

connections with different wildfire management DSS based on economic models, as well as developments in the integration of forest and fire management, and more recent efforts aiming at going beyond economic models; in Section 3, we characterize the trend of broadening of risk handling concerns from risk assessment, through risk management, to risk governance, in close connection with the previous section; in Sections 4 and 5 we close the paper, with a discussion and with the presentation of conclusions and suggestions for future work, respectively.

2. From fire growth simulation to economic models and beyond

2.1. Fire growth simulation models

A number of wildfire growth simulation models have been developed over the years ([Table 1](#)). Explicit spatial simulation of fire growth requires a fire spread model and the description and mapping of vegetation (fuel) as per the typology required by the spread model. Consequently, spatial fire modeling has been preceded by the ability to estimate fire behavior characteristics for a given point or location from a set of static fuel, weather and slope conditions. Fire spread models usable by fire managers are either semi-physical or empirical in nature. The [Rothermel \(1972\)](#) model is the best known of the former type and is widely used, being at the core of the U.S. fire modeling systems, from the stand – e.g., BEHAVE ([Andrews, 1986](#)), now BehavePlus ([Andrews, 2014](#)) – to the landscape-level – e.g., FARSITE ([Finney, 1993, 2004](#)). Rothermel's model has also been adopted for fire growth simulation elsewhere, e.g., CARDIN (initially based on BEHAVE and later named “Visual Cardin”) in Spain ([Millan et al., 1991](#); [Martin-Fernández et al., 2002](#); [Rodríguez y Silva and González-Cabán, 2010](#)) and in the module of fire simulation of the KITRAL system in Chile ([Julio et al., 1995](#)).

Canadian and Australian fire growth simulators depend on empirical fire spread models and systems ([Noble et al., 1980](#); [Forestry Canada, 1992](#)). The Canadian Prometheus has been in development since 1999 ([Tymstra et al., 2010](#)). The Australian SiroFire was launched in 1994 ([Coleman and Sullivan, 1996](#)) and has now been replaced ([Sullivan, 2009b](#)) by PHOENIX Rapidfire ([Saeedian et al., 2010](#); [Duff et al., 2012](#)) at the University of Melbourne as a component of a risk management model, being developed by the Bushfire CRC for southern Australia ([Tolhurst et al., 2008](#); [Taylor and Freeman, 2010](#)).

Vector-based simulation approaches for fire growth like those based on Huygens principle produce much more realistic fire shapes than raster-based simulations, or cellular automata, among other alternatives ([French, 1992](#); [Sullivan, 2009b](#); [Tymstra et al., 2010](#)). Raster-based models deal with heterogeneous fuels and weather better than vector-based models ([French et al., 1990](#)). Nevertheless, and although the procedure varies, all the existing North American and Australian fire growth simulators implement Huygens approach ([Cechet et al., 2014](#)). Given our focus on systems used by practitioners, there are several other important models

Table 1
Review of the characteristics of cited fire modeling systems (fire behavior, fire spread, and probabilistic fire spread simulators).

Name	Origin/ year	Primary attributes	Inputs	Outputs	Spread model/math. models	Deterministic/ stochastic	Planning context and decisions supported	Duration	Fires considered	Simulation type	Type of burn probability	Source of variation ¹	References
BehavePlus ^b	USA 1983 ^c	Fire behavior prediction and fuel modeling – Constant variation in time – Uniform variation in space (runs in a PC or Smartphone)	Interactive user input (generally ranges of values)	– Tables – Graphs – Simple diagrams	Over 40 mathematical fire models for ignition and tree mortality probability, crown scorch height, surface and crown fire behavior, maximum spotting distance, safety zone size, point source fire size and shape, and fire containment	D	– Predicting the behavior of an ongoing fire – Fuel treatment planning – Training (fuel hazard, fire behavior) – Post-fire analysis	Elapsed time for size or spread distance	Individual fire	One fire, one constant weather scenario	NA	None	Andrews (2007) Andrews (2014)
Visual-Cardin used by SINAMI ^{d,e}	Spain 1989 ^f	– Fire growth and behavior simulation modeling system – Initially based on BEHAVE, applies its algorithms in a discrete way to each pixel using raster maps (runs in a PC)	– Ignition area or line (set of pixels) with maximum slope and direction values, calculated from terrain topography (GIS) information – Fuel model in each pixel (cell) – Tree height, crown base height, and crown density – Fuel moisture and degree of protection – Wind speed and direction – Ambient temperature and humidity – Suppression resources spatiotemporal allocation	Maps of flame length and residence, directions, wind, fire line intensity, heat by unit area, and rate of spread (Rodríguez y Silva, 1999)	– 13 BEHAVE fuel models adapted to the Mediterranean ecosystems – Fire expansion is assumed to occur in a cardioid way (Cassini ovals), instead of elliptical as in BEHAVE – Simulation model through cellular automata (CA) using the more nearest neighbor (Rodríguez y Silva et al., 2014)	D ^g	– Predicting the behavior of an ongoing fire – Air and ground suppression actions planning – Fuel treatment planning – Post-fire analysis – Preventive forestry strategies design (Rodríguez y Silva, 1999)	–Minutes/hours of active burning with or without suppression –Proved to accurate for time intervals of 20 min (simulation/ reality emerged small discrepancies mean that the system should be updated every 20 min)	Individual fire (pixels ranging 20–50 m)	One fire, one weather scenario	NA	– Uniform wind speed and direction* – Air and live/dead fuel moisture content, and wind protection* – Fuelscape ^{ax} *These values can be updated during the simulation	Millan et al. (1991) Rodríguez y Silva (1999) Martín-Fernández et al. (2002) Rodríguez y Silva and González-Cabán (2010) Rodríguez y Silva et al. (2014)
FARSITE ^h	USA 1993	– Fire growth and behavior simulation modeling system – Variation in time, diurnally and by day – Variation in space across the landscape – Heterogeneous conditions of terrain, fuels, and weather (runs in a PC)	– Spatial (GIS) fuel, terrain, etc. data – User-defined fuel moisture and wind	Maps of fire growth, perimeter, intensity, etc.	– Richards partial differential equations to propagate each vertex along the fire perimeter ^l – Mathematical fire models for surface fire spread, crown fire initiation and spread, spotting, and dead fuel moisture ^k	D ^g	– Fire and land management decisions – Air and ground suppression actions simulation	Long time periods: hours/day of active burning or number of days for the simulation	Individual fire	One fire, one weather scenario	NA	– Wind speed – Wind direction – Fuel moisture content – Fuelscape ^{ax}	Finney (2004) and Andrews (2007)
SiroFire ^{1m}	Australia 1994	– Real-time bushfire spread simulator to help fire control officers predict the probable spread of a fire – Can consider suppressed sections of fire perimeter	– Topography (proprietary format with data derived from several GIS platforms) – Spatial fuel types (unburnable, other) – Fuel load and condition – Grass curing – Slope	– Map of the wild-fire predicted spread across the landscape – Fire perimeter predicted at regular intervals – Wind direction changes can be incorporated in the prediction	– Rothermel's model (ellipse based on local fuel fire growth) configured for Australian grass and forest litter fuel – McArthur Forest and Grassland Fire Danger Rating meters – CSIRO Grassland Fire Spread Meter	D	– Predicting the behavior of an ongoing fire – Suppression actions planning (e.g., applying firebreaks) – Used mostly as fire-suppression training tool	One day ⁿ (from one day 9am until next day 9am)	Individual fire	Up to ten fires over the landscape, one weather scenario	NA	Throughout the day: – Temperature – Relative humidity – Wind speed and direction Does not: – make corrections for elevation of temperature and humidity	Coleman and Sullivan (1995) Coleman and Sullivan (1996) Sullivan (2009b) Papadopoulos and Pavlidou (2011)

(continued on next page)

Table 1 (continued)

Name	Origin/year	Primary attributes	Inputs	Outputs	Spread model/math. models	Deterministic/stochastic	Planning context and decisions supported	Duration	Fires considered	Simulation type	Type of burn probability	Source of variation ¹	References
Prometheus ^{2,p} used by Burn-P3 ¹	Canada 1999 ⁷	- Subsumed into PHOENIX Rapidfire (runs in a PC)	- Weather (temperature, relative humidity) in a PC - Wind speed/direction - Selected fire spread models (one for forests, one for grasslands) - Spatial (GIS) topography (slope, aspect, and elevation) - Spatial fuel types (required) - Weather streams ¹ - Spatial landscape grids ¹ (option) - Wind speed/direction grids ¹ (option) - Foliar moisture content - Fire type and duration - Fuel breaks (spotting is allowed ¹)	- Spotting distance prediction ⁸ (not used to ignite new fires) - Statistics and raster views - Spread rate - Fuel consumption fraction burned and total (crown and surface) - Fire intensity - Spread distance - Fire area - Fire perimeter (at user-specified time step intervals)	- Does not simulate crown fires - Does not simulate Spotfires	D ¹	- Fire behavior training tool - Evaluate fire management alternatives/costs - Design of fuel management strategies for values at risk or in protected areas ² - Fuel treatment planning ^{3a} - Large fires management - Post-fire analysis - Recovery ^{3b} - planning ^{3b}	- One or many daily burning periods - Type and duration (only limited by length of weather data) of the simulation	Individual or multi-fire simulation (Alberta generally uses 100 m grids (sometimes 25 m) for operational purposes)	One or multiple ignitions, under one or more scenarios	NA	- Spatially across the landscape: - Fuelscape ^{3a,4} - Topographic conditions and temporally: - Weather conditions - Spatially and temporally: - Fuelscape ^{3a}	Johnston et al. (2005) Opperman et al. (2006) Sullivan (2009b) Tymstra et al. (2010) Papadopoulos and Pavlidou (2011)
FSPro ⁵ used by WFDSS ^{6,a,e} as RAVAR ^{4f}	USA 2006	- Variation in time, by day - Variation in space across the landscape - Runs remotely for authorized analysts with internet access	- Spatial (GIS) fuel and terrain data - Current fire perimeter - Weather stations for fire danger and wind climatology	- Map of probability of the fire reaching each point by the end of the simulation period	- Minimum travel time (MTT) fire spread algorithm (Finney, 2002)	S	- Suppression strategy development - Days to weeks of active burning or number of days for the simulation	Days to weeks of active burning or number of days for the simulation	Individual escaped fire	One fire, many weather scenarios	Conditional on current fire location and specified time period	- Wind speed - Wind direction - Fuel moisture content - Fuelscape ^{3a}	Scott et al. (2013) Finney et al. (2011a) Andrews (2007)
FSim ^{7,a,h} used by FPA ^{8,a,b}	USA 2008	Large-fire simulation system	- Landscape characteristics: Surface fuel model, aspect, elevation, slope, and canopy - Historic Energy Release Component (ERC) - Wind Data from a representative weather station or from NARR GRID data (BAH, 2012)	- Spatially explicit burn probability maps and fire size distributions (Pacheco et al., 2013) - Intensity (via flame length), size, and impacts of escaped ignitions ⁹ (BAH, 2012; Thompson et al., 2013b) - Fire intensity level table for each fuel model and percentage of treated surrounding area (- control and fuel treatment runs) ¹⁰ (BAH, 2012)	- Minimum travel time (MTT) fire spread algorithm (Finney, 2002) - Combines weather influences, ignition probability, fire spread, and containment success submodels (Thompson et al., 2013a)	S	- Fire management plan development - Preparedness and response planning - Fuel treatment planning	Entire fire season	All large fire ignitions	All fires, all weather scenarios	Annual (full fire season)	- Wind speed - Wind direction - Fuel moisture content - Fuelscape ^{3a} - Ignition location and probability - Containment probability - Fire duration	Scott et al. (2013) Finney et al. (2011b) Finney (2007) BAH (2012) Thompson et al. (2013a) Thompson et al. (2013b) Notes ¹¹ (about FlamMap alternative): Finney (2006) Ager et al. (2007) Ager et al. (2011) Ager et al. (2013)
PHOENIX Rapidfire ^{4k} used ¹¹ by FireDST ^{11m}	Australia 2006 ¹¹ⁿ	Spatially and temporally explicit dynamic fire behavior and characterization model ^{11o} used operationally:	- Fuel types ^{11p} - Wind reduction factors - Fire history - Topography - Assets and values - Road proximity - Linear disruptions - Weather - Suppression resources	- Maps of: - Fuel types ^{11p} - Wind reduction factors - Fire history - Topography - Assets and values - Road proximity - Linear disruptions - Weather - Suppression resources	- CSIRO grass ^{11q} , MK5 ^{11s} fire behavior models - Models for the effects of short to long distance spotting ^{11r} (<200 m to 30 km) by upper level winds	D	- Component of the Bushfire risk management model ^{11v} , for use by fire agencies, land managers, town and land planners, and policy makers to explore the strength and the interaction ^{11w} of:	- Short long periods of burning (minutes to days)	Individual or multi-fire simulation	One fire and multi-fire management scenarios, from the Bushfire risk management model ^{11v}	Fire likelihood at each cell location (when in multi-fire simulation) which can include the probability of a fire starting at the ignition point from	- Weather (wind speed/direction, temperature, humidity) - Fuelscape ^{3a} - Ignition location and probability - Suppression effects	Tolhurst et al. (2006)

Table 1 (continued)

Name	Origin/year	Primary attributes	Inputs	Outputs	Spread model/math. models	Deterministic/stochastic	Planning context and decisions supported	Duration	Fires considered	Simulation type	Type of burn probability	Source of variation [†]	References
		<ul style="list-style-type: none"> – to estimate the fire impact on specified values or assets – for training purposes – in real-time – for post-fire analysis (runs in a PC) 		<ul style="list-style-type: none"> – Fire origin, extent, intensity, and frequency – Flame height and depth – Rate of spread – Ember density – Size (area) – Time to impact (in each cell) – Spotting^{g,i} (explicitly and deterministically modeled) – Convective output 	<ul style="list-style-type: none"> – WindNinja^h wind field – Wind-slope interactions, fuel accumulation rates, fuel moisture models, road impact, self-extinction and fire suppression – Fuel accumulation (time since fire) – Point spread modeling (Huygen'sⁱⁱⁱ, discrete event CA) 		<ul style="list-style-type: none"> – Prevention – Disaster preparedness and response – Recovery – Fire regime management 	<ul style="list-style-type: none"> – 100–200 m – grid size is usually sufficient for operational purposes (as small as 5 m for very detailed analysis) 			historic data	<ul style="list-style-type: none"> – Fire conditions (e.g., spotfires increase the rate of spread, different fuel strata included or excluded as fire changes in intensity and over time) 	<ul style="list-style-type: none"> Tolhurst et al. (2008) Sullivan (2009b) Tolhurst and Chong (2009) Saeedian et al. (2010) Taylor and Freeman (2010) Duff et al. (2012) Pugnet et al. (2013) Cechet et al. (2014)

^a Relates to variability modeled with probabilities, or aspects which can vary in the course of the simulation, according to the system stochastic or deterministic nature.

^b <http://www.frames.gov/partner-sites/behaveplus>.

^c Considering the predecessor BEHAVE; BehavePlus 1.0 was released in 2001.

^d SINAMI, Sistema Nacional para el Manejo de Incendios Forestales.

^e ARCAR41 developed since late 1990s was abandoned.

^f Cardin first version (used with ARCAR41^e in the late 1990s in a strategic model for forest fire simulation and economic planning).

^g Spotting has a stochastic component.

^h <http://www.firelab.org/project/farsite>.

ⁱ Prometheus and FARSITE use the same method to propagate each vertex along the fire perimeter under heterogeneous conditions, but the models differ in the fire behavior modelling approaches and fuel typologies; Prometheus uses fuel types and the fire danger rating codes and equations of the CFFDRS,^x whereas FARSITE uses fuel models^k and is driven by Rothermel's model and related models^l (Tymstra et al., 2010); both were compared by Opperman et al. (2006).

^j FARSITE fire behavior models: Rothermel's (1972) surface fire spread model, Wagner's (1977) crown fire initiation model, Rothermel's (1991) crown fire spread model, Albin's (1979) spotting model, and Nelson's (2000) dead fuel moisture model.

^k A complete reference can be found on the technical documentation: http://ced.berkeley.edu/faculty/ratt/tool_time/fire_lab/lab7/farsite_stuff/ ("FARSITE Technical References").

^l The CSIRO bushfire spread simulator (<http://www.csiro.au/Outcomes/Safeguarding-Australia/SiroFire-Overview.aspx>).

^m CSIRO has been working on a replacement for SiroFire called Spark, intended to be an open-source fire perimeter propagation engine that is platform independent and scalable across processors (Hilton et al., 2015).

ⁿ The output of one simulation could be used as the input for the next, to overcome this limitation.

^o Developed by the Canadian Interagency Forest Fire Centre (<http://www.cifc.ca/>) and led by the Alberta Environment and Sustainable Resource Development (<http://esrd.alberta.ca/>).

^p Canadian Wildland Fire Growth Simulation Model (<http://www.firegrowthmodel.ca/>).

^q Burn-P3 (Probability, Prediction, and Planning), simulation model for the evaluation of the burn probability in a large fire-prone landscape (http://www.firegrowthmodel.ca/burnp3/overview_e.php).

^r Version 1.0 released in May of 2002 and used operationally for the first time in the same month to provide fire management decision support for the House River fire, a classic boreal wind-driven fire (248,243 ha), which became the second-largest fire in Alberta since 1961.

^s E.g., Pandora (to run any number of Prometheus simulations in a batch operation, also included in the Spatial Fire Management System), Pegasus (for fire management staff remotely access Prometheus via the internet), and Burn-P3 (a simulation model used to assess burn probability over a landscape).

^t Streams can be obtained from observations, forecasts or generated from the time of year and latitude average conditions;

^u Spatial landscape grids (an optional input) include degree of curing (grass), percent greenup (for mixedwood fuel types), percent conifer (for mixedwood fuel types), percent dead fir, crown base height, and tree height.

^v Prometheus optionally allows users to input wind direction and wind speed grids; these are usually derived from WindNinja.^h

^w Long-range spotting is not natively modeled in Prometheus: it includes a breaching function (for fuel breaks) but does not include spotting over features (usually long range spotting); spotting is implicitly included in the FBP sub-systems of the CFFDRS^x (i.e., ROS equations) because the FBP System is an empirically based model (Sullivan, 2009a); however, spotting can be added manually.

^x CFFDRS, Canadian Forest Fire Danger Rating System (<http://cwffs.cfs.nrcan.gc.ca/background/summary/fdr>).

^y Spotting and gusting winds are modeled as stochastic processes.

^z Fuel isolation and conversion.

^{aa} Including spatiotemporal smoke emissions estimates.

^{ab} Also less operational decisions supported as long-term projections (e.g., climate change);

^{ac} FSPro, Geospatial Fire Spread Probability model.

^{ad} WFDSS, Wildland Fire Decision Support System.

^{ae} WFDSS and FPA, both use LANDFIRE (Landscape Fire and Resource Management Planning Tools).

^{af} RAVAR, Rapid Assessment of Values at Risk.

^{ag} FSim is the FPA^{af} implementation of FSPro,^{ac} included in the Large Fire Module (LFM).

^{ah} FlamMap (Finney, 2006), widely used for planning fuel treatments (Ager et al., 2011), is an alternative to FSim because the access to it is not restricted to authorized personal; it can input fire lists that can be generated from statistical models, thereby making it quite advanced and simpler to use; the first paper (Ager et al., 2007) published on wildfire risk from simulation models uses FlamMap; Randig (Ager et al., 2013), the model first used for risk analysis, is a kind of command line version of FlamMap (as Pandora with Prometheus see ^s).

^{ai} FPA, Fire Program Analysis.

- ^{aj} Output of the Large Fire Module (LFM) of FPA^{ai} where FSim is included.
- ^{ak} <http://www.bushfirecrc.com/projects/a41/fire-management-business-model>.
- ^{al} <http://www.bushfirecrc.com/projects/2-2/enhancement-fire-behaviour-models>.
- ^{am} FireDST, Fire Impact and Risk Evaluation Decision Support Tool (<http://www.bushfirecrc.com/projects/2-1/risk-assessment-decision-toolbox>); development (as prototype) started in 2011, see [Cechet et al. \(2014\)](#).
- ^{an} The state of Victoria began using it operationally for the 2010–2011 fire season;
- ^{ao} PHOENIX Rapidfire was initially one component of a scenario based (non-spatially explicit) bushfire risk management and mitigation model^{ak} (developed by the University of Melbourne within the Bushfire CRC, Cooperative Research Centre) to quantify the impact^{aw} of several management choices^{av} in the resulting fire characteristics.
- ^{ap} Fuel moisture, flammability (heat absorption, combustion), embers (abundance, lofting, burnout, ignition), plume (energy release rate, total heat output, emissions), and suppression (radiation, embers, ease of extinction).
- ^{aq} Spotfires are created by burning embers and occurs when a fire produces firebrands that carried by the wind starts new fires beyond the main fire ([Saeedian et al., 2010](#)); this phenomenon happens in most bushfires, especially in eucalypt forests in Australia where large numbers of embers are produced ([Tolhurst and Chong, 2009](#)).
- ^{ar} CSIRO southern grassland fire spread model.
- ^{as} McArthur MK5 forest fire behavior model.
- ^{at} WindNinja is a computer program that computes spatially varying wind fields for wildland fire and other applications requiring high resolution wind prediction in complex terrain (<http://www.firelab.org/project/windninja>).
- ^{au} The Huygens approach used in PHOENIX Rapidfire has been taken from SiroFire.
- ^{av} 54 elements of bushfire management options, grouped in: prevention, preparedness, response, recovery, and fire regime management; these elements cover several management activities including: legislation, planning, public education, firefighter training, equipment development, prescribed burning, fuel management, fire detection, firefighting, use of aircraft, post-fire recovery, environmental rehabilitation and others.
- ^{aw} There are two types of interaction included in the model, the interchangeability and the interdependence between the elements.
- ^{ax} Fuelscape: «A raster-format geospatial characterization of ground, surface and canopy fuel across a landscape, typically consisting of one or more fuel characteristics data layers. For fire behavior modeling, a fuelscape consists of geospatial data layers representing surface fuel model, canopy base height and canopy bulk density. Other geospatial data layers required for geospatial fire modeling include topography characteristics (slope, aspect, elevation) and vegetation characteristics (forest canopy cover and height)», [Scott et al. \(2013\)](#).

that we do not consider, e.g., HFire (Highly Optimized Tolerance Fire Spread Model), a raster-based and computationally efficient model, which was designed to simulate long-term shrubland fire regimes but can be used for single fires (Peterson et al., 2011).

Prometheus and FARSITE are deterministic models with similar functionalities (Dupuy and Alexandrian, 2010). Both adopt the partial differential equations of Richards to propagate each vertex along the fire perimeter but differ in the fuel classification typology, weather-related inputs and fire behavior models used. Prometheus is based on the Canadian Fire Behavior Prediction System (Forestry Canada, 1992) that estimates fire behavior (adjusted for specific fuel types) from fire danger rating codes. FARSITE is part of the suite of U.S. landscape-level fire modeling systems, that also includes FlamMap (Finney, 2006) and the geospatial Fire Spread Probability (FSPro) model (Andrews, 2007), and relies on Rothermel's spread model and associated fuel models. Opperman et al. (2006) compared the two models for wildfires in grass, scrub, and forests, in New Zealand and Australia. Both performed very well. Despite the lack of site-specific fuel models and weather data, local users concluded that the fuel model choice was less important than expected, but having local wind data was imperative because local winds influence the final fire shape. Local users also concluded that the most important criteria in the choice of an application are usability and configuration flexibility.

SiroFire (Coleman and Sullivan, 1996) has been used in Australia as a fire-suppression training tool, using McArthur's fire spread models for grassland and forest as well as Rothermel's model (Sullivan, 2009b). Similarly, fire behavior characteristics in PHOENIX are derived from the CSIRO southern grassland fire spread model and the McArthur MK5 forest fire behavior model (Saeedian et al., 2010). PHOENIX does not adopt state-of-the-art fire spread models (e.g., (Cheney et al., 2012)) but incorporates additional models that enhance its dynamic ability, namely for the effects of spotting (also present in FARSITE), wind-slope interactions, fuel accumulation rates, fuel moisture models, self-extinction and fire suppression (Tolhurst and Chong, 2009; Saeedian et al., 2010; Papadopoulos and Pavlidou, 2011; Cechet et al., 2014).

The fire behavior module FSPro (Finney et al., 2011a) uses a computationally efficient form of the FARSITE calculations to simulate 2-D fire growth across the landscape, without suppression. It differs from FARSITE in that it simulates fire growth for thousands of possible weather scenarios, statistically derived from local weather stations data using the latest recorded fire perimeters. FSPro assigns a burn probability to each cell in the landscape by dividing the number of runs of the simulation in which the cell burns by the total number of runs (Calkin et al., 2007). FSim is an implementation of FSPro that simulates thousands of possible fire seasons, varying fuels, weather, suppression and treatments, to estimate burn probabilities and fire size distributions. It uses the minimum travel time fire spread algorithm (similarly to FlamMap), whose extensive application has established that it can be effectively used in heterogeneous landscapes, as is the case of the wildlands in the U.S. (Calkin et al., 2011a; Finney et al., 2011b).

Used for land-management planning (and also for fire research), Burn-P3 (probability, prediction, and planning) is a spatial fire simulation model that uses the Prometheus engine to simulate the ignition and spread of a very large number of fires. The inputs are topography, fuels, weather, and fire ignitions patterns (drawn from a probability density grid with Monte Carlo methods). Fire spread is driven by the weather conditions and fire length is modeled stochastically from user-supplied distributions. Burn-P3's main output is a burn probability map (Parisien et al., 2005, 2010).

Table 1 summarize a set of primary attributes (name, origin, year, primary attributes, inputs, outputs, spread model/mathematical

models, deterministic/stochastic, planning context and decisions supported, duration, fires considered, simulation type, type of burn probability, source of variation, and selected references) for the fire behavior, fire spread, and probabilistic fire spread simulators mentioned in this section.

2.2. Fire suppression models

The development of risk-based decision support tools has largely been directed to the management of active fires, especially during initial attack, aiming at preventing fires from escaping and causing damage, since the seminal paper of Fried and Fried (1996). Using some form of simulation, the fire is considered contained when the constructed length of fireline, dependent on the capacity of the firefighting resources employed, equals the fire perimeter determined by its rate of spread; in addition, other factors could be considered, like containment probability, interactions between fireline production and fire growth, fire danger rating, rate of spread, fuel type, or the diversion of resources for structure protection (Thompson and Calkin, 2011). Furthermore, to handle the lack of objective data about some aspects of suppression, expert judgment elicitation has been used by several authors to inform the modeling of the initial attack, e.g. Martell et al. (1999) and Hirsch et al. (2004).

The amount of resources to dispatch to each fire and how to prioritize scarce resources in a multiple fires scenario, are some of the dispatching decisions included in the initial attack and that often must be taken quickly and with limited information (Collins, 2012). The skills, experience, and intuition of the firefighters could be enhanced with this kind of DSS, potentiated by advances in computing power and geospatial data acquisition that enables massive geo-processing, rapid simulations, projection of fire behavior across the landscape and increases the accuracy of fuel conditions (Thompson and Calkin, 2011). Despite these advances, the modeling of escaped large wildfires is still an immature field with significant knowledge gaps since the factors contributing to suppression success remain poorly understood (Finney et al., 2009) and very little is known about the relationship between suppression inputs and fireline construction along the duration of extended attack episodes (Holmes and Calkin, 2013).

2.3. Wildfire management DSS based on economic models

With a limited amount of funding, equipment, and human resources, forest managers must decide the most efficient distribution among alternative fire management options such as prevention (e.g., education, public campaigns), fuel treatments (e.g., prescribed burning, mechanical treatments), pre-suppression (e.g., planning and preparedness, firefighters recruitment and training, maintenance of fuelbreaks and water points), suppression, and restoration measures (Mavsar et al., 2010). Accomplishing that requires the ability to evaluate how wildfires spread with and without suppression and their effects on the monetary value of the destroyed or damaged assets (Mendes, 2010). It further requires being able to assess stand-level prescriptions, including fuel treatments, as wildfire risk is related to stand structure and flammability, and the spatial allocation of prescriptions (e.g., harvest and fuel treatment decisions) in the forested landscape and its impact on the spread and intensity of wildfires.

The evaluation of fire spread and its effects, with and without suppression, requires an extensive amount of information, which is in many cases unavailable, especially concerning the overall social (e.g., ecological values, air pollution) and private (e.g., destroyed assets) costs associated with wildfires. The resulting knowledge uncertainty and substantial gap in the scientific understanding of both short and long-run effects (Brillinger et al., 2009)

lead to a lack of resource value measures to guide prioritization across fires and resources at risk (Thompson and Calkin, 2011). Even so, considerable theoretical progress has been achieved (Gorte and Gorte, 1979; González-Cabán, 2007; Mavsar et al., 2013), since the early work of Headley (1916), Lovejoy (1916) and Sparhawk (1925), until the more recent contributions of Donovan and Rideout (2003), including Simard (1976), Mills and Bratten (1982) and Rideout and Omi (1990). Generally, the economic analysis of fire management efficiency makes use of the “cost plus net-value-change” concept, C + NVC (Mavsar et al., 2010).

Starting with FEES, the Fire Economics Evaluation System (Mills and Bratten, 1982; González-Cabán et al., 1986), and even though not always adequately considering the effects on non-market resources (e.g., recreation, flora and fauna, soil, air and water quality, or cultural heritage) (Brillinger et al., 2009), the combination of computer simulation and Geographic Information Systems (GIS) with the economic evaluation of losses and wildfire fighting costs has enabled substantial advances toward the goal of providing “sufficient data to enable the efficient economic choice of the best combination of fire combat resources per fire type, the integration of cost–benefit analysis, modeling incidence probability as well as the spread of fires lines with and without intervention, per intervention and fire type” (Mendes, 2010).

Even if this goal has not yet been fully achieved, especially for the management of escaped large wildfires (Finney et al., 2009; Holmes and Calkin, 2013), examples of these systems currently in use include the Canadian “Level of Protection Analysis System”, LEOPARDS, the Chilean KITRAL (“fire” in the indigenous Mapuche language), U.S.A.’s “Fire Protection Analysis”, FPA, and the Spanish “Sistema Nacional para el Manejo de Incendios Forestales”, SINAMI. The latter is a more advanced and updated version of U.S.A.’s “California Fire Economics Simulation Model”, FPPS/CFES, operating under the same principles (Mavsar et al., 2013).

2.3.1. LEOPARDS

LEOPARDS (Martell and Boychuk, 1994, 1997) has been in use in Ontario, Canada, since 1995 (McAlpine and Hirsch, 1999a,b). It can model daily fire-suppression activities (Minas et al., 2012), emulating them with inputs that include historical fire weather, fire incidence data, land-use objectives, operational rules, infrastructure and suppression resource information. The system estimates three forms of outputs: physical outcomes (e.g., response time, escaped fires, burnt area), fixed and variable costs, and resource utilization information (McAlpine and Hirsch, 1999a,b; Podur and Wotton, 2010).

LEOPARDS is based on the initial attack model developed by Martell et al. (1983, 1984) and considers temporal queuing conflicts and spatial realities (multiple fire ignitions over a large area or a large number of fires in a small area and in a short time period) of forest fire suppression, situations that often lead to delays in initial attack resulting in more escaped fires (McAlpine and Hirsch, 1999a,b). Podur and Martell (2007) have used it in an attempt to model the more complex problem of the containment of large wildfires (Thompson and Calkin, 2011), wherein the combat is typically opportunistic and meteorologically driven (Martell, 2007; Finney et al., 2009). Currently, with the key improvements focused on the fire behavior simulator and the suppression deployment model, a second version of LEOPARDS is being prepared (Mavsar et al., 2013).

2.3.2. KITRAL

In development since 1993, and in usage after 1996, KITRAL uses simulation models to predict fire behavior including risk, danger, spread rate, wind velocity, flame length and priorities at several time and space scales, using an extensive geographical database (Pedernera and Alvear, 1999). By evaluating different fire

management alternatives, for pre-suppression and suppression, KITRAL enables daily (real time) allocation of resources, and strategic planning of activities (Mavsar et al., 2013).

For dispatch, the system locates the areas of reported fires, simulates the spread and the competing needs of simultaneous fires, and calculates the quantities and types of resources that should be sent to efficiently fight each fire (Pedernera and Alvear, 1999).

Tested under real conditions, the results reveal 90% accuracy in forecasts of fires larger than 60 ha, but less reliability in fires affecting less than 2 ha, probably because its grid has a minimum size of 25 m². However the system is fast, being capable of simulating a period of twelve hours in three minutes (Soto et al., 2004), and its use may lead to savings in the range of 15–50% of direct losses (Pedernera and Alvear, 1999).

More recently, an optimization model, using integer linear programming, aiming at minimizing the cost of fire control has also been developed and integrated with the system (Musa, 2004; Pedernera et al., 2004).

Soto et al. (2013) have used KITRAL to obtain a global territorial model of economic vulnerability to forest fire (considering direct costs), integrating risk, danger and damage potential, to facilitate the prioritization of suppression activities, even in the wildland urban interface (WUI), where fires are mainly caused by humans.

2.3.3. SINAMI

The research design of the SINAMI model, which includes CARDIN as a calculating tool, was presented in 2004 (Rodríguez y Silva, 2004) and finished in 2006 together with ECONOSINAMI, its module for economic analysis (Rodríguez y Silva, 2007).

SINAMI is a model exclusively intended for strategic fire management planning, using marginal analysis and the economic criterion of C + NVC to determine the most efficient fire management programs and budget levels, and considering a true representation of the historical analysis of the last 10-year average conditions. It enables managers to quantitatively explore the tradeoffs among budget levels and potential losses, and justify budget requests by easily identifying the potential consequences of a budget reduction or relocation. Furthermore, the model provides fire management program compositions and the number of necessary resources (Rodríguez y Silva and González-Cabán, 2010).

The model has continued to evolve, and by 2012 it had already included the impact of wildfires on a variety of tangible and intangible natural resources, such as timber, forage, underbrush, fruits, water, fishing, fauna, recreation, hunting and landscape (Mavsar et al., 2013). In that same year, a pilot project was implemented in two forest areas of Mexico (Rodríguez y Silva, 2010).

SINAMI has been applied to the evaluation of economic losses in Iberian swine production, which depends on privately held pasture lands that may be affected by wildfires, and more broadly, of the direct negative economic impact on rural development (Martínez et al., 2011). In a different application, SINAMI has been used to validate an extension of the thirteen Rothermel fuel models to better represent the Mediterranean ecosystems (Rodríguez y Silva and Molina-Martínez, 2012). The system has also been employed, in an extension of the principle of economic valuation to the concept of economic vulnerability, to provide a cartography of economic vulnerability and value of forest ecosystems, which may provide fundamental inputs for temporal and spatial budget optimization (Rodríguez y Silva et al., 2012).

2.3.4. Fire Program Analysis

In the U.S., in response to the National Fire Plan (Babbitt and Glickman, 2000), a report commissioned by President Clinton after the severe wildfires of 2000, and to the updated Federal Wildland Fire Policy (Interagency Working Group, 2001), the Hubbard report (Hubbard, 2001) proposed that the five federal wildland

firefighting agencies should develop and implement a single, common, uniform and performance-based interagency analysis process, including a software application tool to support wildland fire budgeting and planning decisions (Fairbanks et al., 2002).

To evaluate the effectiveness of alternative fire management strategies in time, that system should be objective-driven, performance-based, and should find the most cost-effective program encompassing the full scope of fire management activities (protecting life and property, using fire and other treatments to maintain and restore the health of ecosystems, and reducing hazardous fuels in fire-prone ecosystems), identifying resource needs and sharing opportunities across all jurisdictions. This endeavor was thereafter supported by the Congress, which further required that the resources sharing mechanism should also include non-federal partners (BAH, 2012).

The development of this system, called Fire Program Analysis (FPA), was initiated in 2002 (Rideout and Botti, 2002; Botti et al., 2004) and should have been completed by 2006. However, after the conclusion of the first part of the model in 2004, as the agencies began to use it, officials started raising concerns about the underlying science. As a result, in 2006 the agencies conducted a review, which questioned the basic modeling approach and led to a change from an optimization paradigm (which evaluated all possible combinations and locations of firefighting assets to identify the optimal combination for a given budget level) to a simulation paradigm, incorporating a tradeoff analysis. This change caused a delay of three years in the development of the system, with its expected cost rising from \$40 million to close to \$54 million (GAO, 2008).

This change on the modeling approach originated an important “knowledge fight” (Buuren and Edelenbos, 2004), i.e., a scientific disagreement featuring intellectual arguments stemming from different approaches to knowledge representation, in both arenas: public (e.g., Fried (2007), wildlandfire.com (2012), Olinger and Gorski (2012)) and academic (e.g., Rideout et al. (2008a,b), Yu et al. (2008), Bruins et al. (2010), Calkin et al. (2011a), Thompson et al. (2012)). The Government Accountability Office (GAO), the audit, evaluation, and investigative arm of Congress, expressed concerns about the simulation-based approach, since it provides considerable discretion to the agencies’ decision makers, and in doing so, requires full transparency in those decision processes (GAO, 2008, 2009b,a).

The FPA shares the fire simulation model, FSIm, and the Landscape Fire and Resource Management Planning Tools Project, LANDFIRE, with the Wildland Fire Decision Support System (WFdSS) (BAH, 2012; Ryan and Opperman, 2013). These modules are applied independently to each of the 134 Fire Planning Units that cover the continental U.S., and compared with historical data (Finney et al., 2011b), requiring a total simulation time of approximately four months to complete (BAH, 2012).

The required spatial information on fuel structure and topography are provided by LANDFIRE at a 30 m resolution (Finney et al., 2011b). These data are available on-line and are subject to continuous updating (Ryan and Opperman, 2013). However, the full set of simulations only needs to be run after a major LANDFIRE update (BAH, 2012).

After a decade, the FPA development has continued to be characterized by delays and revisions (GAO, 2011a, 2011b). The first results were intended to be used to develop the budget for the fiscal year of 2011 (GAO, 2009a,b), however the scope of usage in that year was limited to supporting the development of the budget request for 2013 (GAO, 2009a,b; BAH, 2012). The system was expected to be fine-tuned, calibrated and fully implemented in 2012 to inform the 2014 fiscal year budget (BAH, 2012), but in its current state, it is not yet suitable for field-level use (BAH, 2012; Thorsen and Hubbard, 2012).

The perception remains, for some stakeholders, that FPA has not achieved the goals set in the Hubbard report, and its current objectives have shifted from the original intent (BAH, 2012). However, FPA promises to achieve some of the key objectives established originally (GAO, 2008, 2009a) and there is no current alternative in the U.S. for the coordination of national fire investments (BAH, 2012).

2.4. Integrating forest and fire management

Recent research has been conducted to develop decision support tools to help integrate forest and fire management planning activities that are currently carried out mostly independently of each other. These tools focus on the support to wildfire prevention planning rather than the management and suppression of active fires. Bettinger (2010) discussed the potential of a wide range of techniques to enhance the integration of forest and wildfire management processes. Borges et al. (2014) presented and discussed the world-wide experience of developing forest management DSS. Packalen et al. (2013) provided a brief overview of this experience. In this section the reader is provided with additional detail about a typical forest management DSS (SADfLOR) to highlight the key functionalities needed to address efficiently and effectively the integration of forest and fire management.

The Portuguese SADfLOR is a DSS with a modular structure that encompasses an information management system, a prescription writer, a model base, a methods base, and a graphical user interface (Borges et al., 2003). Reynolds et al. (2008) provide a detailed description of its architecture. The system was developed with the participation of forest stakeholders ranging from the Forest Service to the forest industry and non-industrial forest owners. Its model base includes growth and yield models for the most important Portuguese species and its methods base includes both exact and heuristic approaches to forest management planning (García-Gonzalo et al., 2013). The system supports strategic and tactical forest management planning and among its applications we may list the development of strategic management plans for the Portuguese pulp and paper industry (Borges and Falcão, 1998), or more recently the Leiria National Forest management plan (García-Gonzalo et al., 2013).

This web-based multiple criteria spatial decision support system has recently been updated with tools to integrate forest and fire management planning. Emphasis was on integrating stand-level fuel treatment scheduling and landscape-level management planning to target socio-economic and ecological objectives while sustaining effective fire prevention levels. Specifically, the SADfLOR model base was updated with models to estimate the probability of stand-level wildfire occurrence according to composition, vertical structure and biometric variables. This is instrumental to understand the effect of stand characteristics on wildfire occurrence probability. The model base was further updated with models to estimate the proportion of trees in a given stand that will die as a consequence of a wildfire event and to understand how stand-level variables impact mortality. These models provide information about the impact of management options on wildfire occurrence probability (Botequim et al., 2013) and on wildfire damage (Marques et al., 2011) in the main forest cover types in Portugal. The new SADfLOR model base thus provides the functionality needed to project conditions and outcomes of interest (e.g., timber flows, carbon stocks) associated with each stand-level prescription under wildfire risk and generate the resulting feasible sets in the criteria space.

The SADfLOR methods base was updated to include management scheduling techniques that might process decision spaces under scenarios of wildfire risk. Specifically, non-linear optimization algorithms (e.g., Hook and Jeeves and populations methods)

and stochastic dynamic programming approaches (Ferreira et al., 2012) to stand-level management planning were developed to help managers and landowners: select the sequence of management activities, including fuel treatment and timber harvests, that maximizes soil expectation value for a stand where wildfire risk is related to stand structure and fuel loads; and assess trade-offs between objectives, as well as estimate opportunity costs of non-optimal prescriptions in a wildfire risk context. The methods base was also updated to include a mixed integer programming technique that maximizes the forest value while addressing timber even-flow and landscape wildfire resistance concerns (Ferreira et al., 2014). For this purpose the updated model base was used further to develop a stand-level wildfire resistance index.

2.5. Beyond economic models

Recent developments in near real-time risk-informed decision support (Zimmerman, 2012) for incident management feature a broader scope of concerns, addressing not only economic aspects, but also the likelihood of fire impact on the values at risk.

The Wildland Fire Decision Support System, WFDSS (Calkin et al., 2011b; Noonan-Wright et al., 2011; NFAEB, 2012; Zimmerman, 2012) and the Fire Impact and Risk Evaluation Decision Support Tool, FireDST (Cechet et al., 2014), have been developed as support tools for risk-informed decisions on the management of escaped fires, in the U.S. and Australia respectively.

Developed with the combined effort of several U.S. federal fire management agencies, to reduce redundancy, and in operation since 2009, WFDSS has replaced the former Wildland Fire Situation Analysis (WFSA), Wildland Fire Implementation Plan (WFIP), and Long-Term Incident Planning (LTIP) processes, in a scalable and flexible web based environment (Noonan-Wright et al., 2011; NFAEB, 2012; Zimmerman, 2012). Being a real-time system like Prometheus (Tymstra et al., 2010), Phoenix (Tolhurst et al., 2008) and CARDIN (Martin-Fernández et al., 2002; Rodríguez y Silva, 2004), WFDSS improves the management of escaped large wildfires by supporting integrated risk assessment and the communication between analysts and decision makers (Calkin et al., 2011b).

However, WFDSS differs in a fundamental way. Recognizing the limited understanding of suppression efficacy (Thompson and Calkin, 2011) and the opportunistic nature of suppression effects on large fires (Martell, 2007; Finney et al., 2009), WFDSS does not attempt to model the effectiveness of various alternatives of firefighting resources or suppression tactics, leaving that evaluation to the decision maker in the field. Instead, the system enables usable real-time exposure analysis of the likelihood of fire impact on the values at risk (Calkin et al., 2011b; Thompson and Calkin, 2011).

The two fundamental primary components of WFDSS are the fire behavior module FSPro (Finney et al., 2011a), and the resource impact model RAVAR, Rapid Assessment of Values at Risk (Thompson et al., 2012). Together they provide appropriate fire

behavior modeling, overlaid with geospatial identification of human and ecological threatened values (Calkin et al., 2011b; Thompson and Calkin, 2011).

RAVAR identifies the critical infrastructures (private structures, hazardous waste sites, public infrastructure and reserve areas) and the natural and cultural resources (sensitive wildlife habitat, natural resources, recreation zones, and restoration priority areas) within the threatened areas previously identified by FSPro (Thompson and Calkin, 2011; Thompson et al., 2012). This allows WFDSS to support management decisions regarding where and when to perform aggressive suppression or allow the fire to burn, protecting and enhancing ecosystem values (Thompson and Calkin, 2011).

The result of more recent developments in Australia, FireDST is a prototype simulation system based on PHOENIX, that provides an integrated fire risk-assessment framework (Cechet et al., 2014). The intrinsic uncertainty in fire weather (modeled with high-resolution 3-D forecasts), fire spread, exposure to fire and likely impact, are addressed probabilistically through the output of an ensemble of scenarios. By simulating the impacts of fire on community assets, infrastructure and people, FireDST delivers crucial fire-planning information that aids the allocation and prioritization of fire-fighting resources, enabling fast decisions in highly complex situations.

3. From risk assessment to management to governance

The developments described in the previous section have not followed a strictly linear path. This is naturally due in part to the parallel development efforts taking place in different parts of the world, focusing also on applications beyond broad, flexible and integrated forest fire management systems, e.g., emergency evacuation planning (Taylor and Freeman, 2010). Additionally, the decreasing costs of computer storage and computing power are defying well established paradigms, causing a swing in favor of raster-based models, more proficient at dealing with heterogeneous fuels than vector-based models, but requiring geographic data at a high enough resolution to obtain meaningful simulations results – rendering moot the decision between the two (Sullivan, 2009b). Also, as has become apparent in major developments such as the case of FPA, the path between science and practical implementation, involving multiple stakeholders, is often not clear and provides room for “knowledge fights”.

Nevertheless, starting from a scientific approach to establish fire spread models, with the early efforts related to the development of BEHAVE (Andrews, 1986) and CARDIN (Millan et al., 1991; Martin-Fernández et al., 2002), we identify in our review a broadening of focus from risk assessment to risk management, and then to risk governance (Fig. 1).

IRGC defines risk governance as the “identification, assessment, management and communication of risks in a broad context”, including “the totality of actors, rules, conventions, processes and

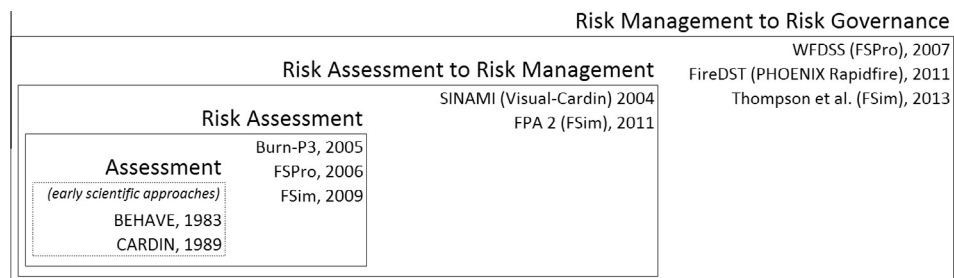


Fig. 1. Conceptual outline of the expanded focus, from risk assessment to management to governance, with examples.

mechanisms concerned with how relevant risk information is collected, analyzed and communicated, and how and by whom management decisions are taken and implemented” (IRGC, 2009). Risk governance’s broad picture of risk includes risk management, but also looks at coordination or reconciliation requirements when a variety of actors is present, and in an enhanced way at context to consider “historical and legal background, guiding principles, value systems and perceptions as well as organisational imperatives” (IRGC, 2005). In this context, the role of risk-based decision support is also challenged to be widened and encompass these additional aspects.

Bachmann and Allgöwer (2000) stressed early on the need for a consistent wildfire risk terminology, with a truly modern definition of fire risk, including fire behavior probabilities and fire effects. (Hardy, 2005) noted that at the time there was widespread ambiguity over the term “fire risk”, often used to mean only the probability of ignition. Considering the quantitative fire risk model of Finney (2005), incidentally published in the same year as the IRGC Risk Governance Framework (IRGC, 2005), the aim of the early fire spread models cannot be strictly described as being risk assessment, since the basic elements of risk (probability and effects) were largely absent from them. However, the fire behavior “assessment” that they provide became the basis for later true risk assessment systems, such as FSPRO and FSIM (and the systems using them, WFDSS and FPA, respectively), or any system using a deterministic simulation model together with probabilities (e.g., Burn-P3 with Prometheus, SINAMI with Visual-Cardin, or FireDST with PHOENIX RapidFire).

The progress at that level, together with the development of more effective models capable of taking into account large numbers of alternative scenarios, additionally supported by the availability of increasing computing power, have enabled more sophisticated analyses that could not be performed earlier. Indeed, we can establish a parallel, throughout the last decades, between the increasing comprehensiveness of risk handling and the developments from fire science (§2.1), to economic evaluation (§2.2, §2.3 and §2.4), and then to broader perspectives (§2.5).

3.1. Aligning decision support tools and practitioners

The evolution in these two trajectories, the development of more effective models enabling more sophisticated analyses and the broadening of focus to risk governance, has naturally led to misalignments between decision support tools and the practitioners adopting and implementing them, a fact that has been reflected in lower than expected levels of adoption (Calkin et al., 2011a). This is in fact also perceptible in the broader area of forest management and planning DSSs (Stewart et al., 2013).

On the social and organizational domains, difficulties have in part been linked with low levels of stakeholder engagement in the development and implementation of the DSSs, suggesting the need for improved interactions at the science–policy–practice interface, and the need to expand the absorbing capacity of user communities (Reis and Oliveira, 2007). In the specific case of risk assessment, Borchers (2005) highlights its incompatibility with an unwarranted desire for certainty that managers and policymakers often have, advocating an “embrace” of uncertainty, within a framework that considers the risk “marketplace” while addressing the challenge of “deciding how to decide”. Calkin et al. (2011a) also accentuate this organizational perspective, defending the implementation of a continuous improvement process, appropriate incentives, risk management training, and communication with stakeholders who have important socio-political influence. Pasalodos-Tato et al. (2013) add the difficulty in explaining methods for decision support under uncertainty to non-specialists, including difficulties in admitting certain outcomes, unfamiliarity

with concepts, and technical difficulties such as: large-scale problems, time-consuming analysis, managing the trade-off between simplicity and accuracy, knowledge about the uncertainties and risks, risk attitude, and interpretation difficulties.

But a focus on risk handling also brings added scientific challenges to the area of fire behavior and effects. Finney (2005) highlights the complexity associated with determining a location’s burning probability, related to its dependence on “ignitions occurring off-site and the fuels, topography, weather, and relative fire direction allowing each fire to reach that location”, and argues for a common scale to evaluate impacts on the diversity of fire-susceptible values.

Thompson and Calkin (2011) identify multiple sources of uncertainty, ranging from the unpredictability of wildfire behavior, to inaccurate or missing data, limited resource value measures, and an incomplete scientific understanding of ecological response to fire, fire behavior response to treatments, and spatiotemporal dynamics involving disturbance regimes and climate change. Using an uncertainty topology, the authors review decision support approaches for each class of uncertainty. Wildfire effects analysis and value uncertainty are identified as primary challenges to integrated wildfire risk assessment and wildfire management. Minas et al. (2012) also review Operations Research methods and discuss their ability to address some of the major challenges of wildfire management, including complexity, multiple conflicting objectives and uncertainty.

Calkin et al. (2011a) mention the need to address temporal considerations, the challenges that arise from the local scale of resource values, the uncertainty in resource response, aggravated by temporal and spatial concerns, and the social preferences for non-commensurate resources. Yousefpour et al. (2012), referring more broadly to adaptive forest management under climate change, stress the need to handle non-stationary and perhaps even belief-based parameters of stochastic processes to model climate change, and forest growth models that can estimate the production of timber and other resources, incorporate changes in climate, work across multiple scales, and feature a computational complexity that is commensurate with the evaluation of numerous scenarios and alternatives.

Mavsar et al. (2013) review four decision support systems aimed at improving the efficiency of the allocation of resources for fire protection programs, and conclude that in spite of improvements in the theoretical economic model, the advances are still not fully implemented in practice, in particular, the net value change component of the C + NVC model. This is mainly due to lacking knowledge about the impacts of different fire management measures on fire behavior and the resulting damages, and economic impacts, including market and nonmarket goods and services.

Hyde et al. (2013) point out the complexity and multidimensionality of the processes that drive ecosystem changes, and thus the need for tools that account for highly variable effects on multiple values-at-risk and balance competing objectives, and for an analysis framework that works across the range of fire-management activities. Miller and Ager (2013) state that quantitative frameworks are increasingly supporting multiple planning scales, from individual incidents or fuel treatments, to national and higher levels, but also placing a higher importance on the evaluation of multiple resource values, and the consideration of more than one risk factor at a time.

3.2. A holistic, risk-governance perspective

A more holistic view, integrating decision support and risk handling in the context of wildfire management and policymaking, and considering a broader spectrum of concerns and approaches to address the escalating costs and increasing threat to human and

ecological values posed by wildfires, has recently been emphasized by Calkin et al. (2011a), Thompson et al. (2013a), and Calkin et al. (2014).

Thompson et al. (2013a) suggest a framework for systematic risk assessment, integrating wildfire simulation and burn probability modeling, expert-based modeling of fire effects and multicriteria analysis addressing multiple sources of value, to be extended to include additional activities in the wildfire management spectrum, such as prefire planning.

Calkin et al. (2011a) point to the need of considering a broad spectrum of approaches, including communication with communities, partnerships with insurers, and engagement with planning boards on zoning and development standards, as has been the case of the “Firewise Communities Program” (www.firewise.org) or the “FireSmart Canada” (www.firesmartcanada.ca) initiatives. A view of fire management as a coupled human-natural system (Moritz et al., 2014; Spies et al., 2014) calls for the search for more than technical solutions alone. As suggested by Busenberg (2004), for this type of systems the use of an adaptive policy design framework (public participatory and learning process) may be useful to tackle uncertainties in wildland fuel reduction prescription, solving some fragilities in models, data and economic assumptions. For these purposes, Marcot et al. (2012) suggest the use of formal decision science procedures and tools in a context of structured decision making, and Calkin et al. (2014) suggest a strategic risk assessment framework to enable the evaluation of the impact of multiple strategic options on various risk factors, describing the advantages of approaching problems with a structured decision process, that allows for a well-structured problem statement and the integration of decisions made at varying spatial scales, at different points in time, by different individuals and organizations in the face of substantial uncertainty and complexity.

This resonates with the adoption of a broader view of risk governance, encompassing risk management in a broader scope, highlighting the coordination efforts among stakeholders to overcome societal challenges. In complex coupled human-environment systems with multi-stakeholder and multi-level decision-making, sound governance approaches are needed to deliver effective risk handling outcomes. In wildfire prone countries, wildfire hazard has been dealt with in ways that have evolved in time from simple risk management routines to integrated fire management frameworks, that address social, economic, cultural and environmental concerns, as well as the complexity and uncertainty in forest fire management systems (Aguilar and Montiel, 2011).

Muller and Yin (2010) have illustrated policy alternatives and their effects using low fidelity scenario prototypes for regional governance of wildfires, stressing the need to account for the multiple and interacting influences over risk that shape voluntary decision making by local authorities and management (Muller and Schulte, 2011). When DSSs are used in a broader framework, with multiple stakeholders who have different perceived values at risk, wildfire hazard mitigation must be regarded as a complex problem, characterized by uncertainty and ambiguity, thus reinforcing the importance of the governance side of risk handling. The scientific and technical support provided by DSSs may be distrusted, as they do not incorporate socio-cultural dimensions. However, if wisely utilized and communicated in the scope of participatory frameworks, DSSs can pave the way to consensus and acceptance of solutions, improving the robustness of management and policy-making.

4. Discussion

Uncertainty arises when physical or biological processes are not fully understood or behavior is not easily describe or predicted,

and so, it is unavoidably linked to risk (Morgan and Small, 1992). In the wildfire management decision making process, framed in the scope of coupled human-environment systems, uncertainty about fire behavior, e.g., due to the role of fuel or weather, amplifies ambiguity when social agents or time dependent variables tag along in modeling. Uncertainty challenges both analytical and organizational innovation for participants in risk governance and management process, because complexity and ambiguity change the way the decision making entities or agents perceive the risk or value at risk, thus conditioning their decisions (IRGC, 2009).

In this paper we present the state of the art of DSS available in Australia, Europe and America. The allocation of resources to prevent and suppress fire has gained sophistication with the availability of DSSs to help the national, state and local level managers decide where and how many hectares should be treated, building effective fire-risk reduction programs. The available reliable knowledge and tools can provide useful insights to incident commanders or can illustrate the potential consequences of alternative risk management strategies to managers or policymakers. Despite limitations, they can reliably inform fire management policies and activities such that trade-offs are addressed and resources are rationally allocated and result in effective risk mitigation.

However, despite all the efforts put into risk-based DSS for fire management applications, their adoption by policymakers and managers has been generally feeble, in part because of the perceived inherent uncertainty and ambiguity in the outputs, but probably also because of insufficient stakeholder involvement in DSS conception and development. It must be recalled that decision-making aids enhance but do not replace the experience and intuition of the decision makers (Martell, 1982; Mavsar et al., 2013). A large number of factors must be considered, many of which cannot be measured quantitatively, and fire programs must be placed within their institutional context and constraints. A DSS only quantifies some of the relevant factors in fire management planning, helping to trace complex interactions and relationships, too numerous to be easily followed by one person (Mavsar et al., 2013).

Decision-making aids require a careful implementation process for a successful assimilation in the routine operations of their adopters. In the context of fire management, these implementations are particularly complex, since they involve several stakeholders with very diverse levels and natures of concerns, as evidenced throughout this paper. It is also clear from the fire management DSS literature that these systems must be adapted to local contexts, and that their development is strongly affected by institutional and external pressures (Collins et al., 2013). The success of their implementation depends deeply on opinion leaders, who are affected by the perceptions that they develop about the DSSs. Furthermore, the use of these systems requires certain capabilities, sometimes absent from the operational field.

A framework systematizing the challenges of fire management DSS implementations could substantially benefit the outcomes of these implementations. Drawing from the implementation literature (Rogers, 2003; Greenhalgh et al., 2004), this framework would uncover factors concerning the systems, the context where they are being implemented, and their adopters, and how these factors influence the perceptions, decisions and actions related to the implementation process, which in turn have an impact on the outcome of the implementation. Empirical studies should verify whether the claims from the implementation literature, such as those outlined in the paragraphs below, apply to fire management DSSs.

The implementation literature suggests that the involvement of stakeholders and users in the decisions develops commitment, increases motivation, and helps internalize norms associated to

the system (Leonard-Barton, 1988; Rogers, 2003). Furthermore, most of the decisions and the perceptions of adopters are the result of contamination from external influences (Rogers, 2003). Perceptions are mostly related to the personal and global risk of adoption, specifically concerning the impact of the system on the activities of the adopters (Leonard-Barton, 1988; Greenhalgh et al., 2004). Moreover, the compatibility of the system with values, norms, past experiences, and needs of adopters affects their perceptions of the uncertainty related to the system (Rogers, 2003).

The alignment between the capabilities of the adopter and the capabilities required to use the system has also a key influence on perceptions about the system's complexity (Linton, 2002). The lack of that alignment usually leads to initial losses of productivity, which are overcome throughout the implementation project as the system's and the adopter's capabilities, and eventually their structures, are aligned with each other through mutual and dynamic adaptation cycles (Leonard-Barton, 1988). The implementation literature also shows that the flow of the implementation process and specifically its management throughout the adaptation cycles, are strongly influenced by: the characteristics of the technology, such as its complexity, triability, demonstrability, flexibility, and compatibility (Leonard-Barton, 1988; Rogers, 2003; Greenhalgh et al., 2004); the characteristics of the adopter, such as its structure, capabilities, culture, and strategy (Leonard-Barton, 1988; Edmondson et al., 2001; Rogers, 2003; Greenhalgh et al., 2004); the characteristics of the users, such as their perceptions, motivations, and capabilities (Leonard-Barton, 1988; Edmondson et al., 2001; Greenhalgh et al., 2004); and the characteristics of the context of the implementation, such as contamination of outer systems, specific policies, and market pressures (Rogers, 2003; Greenhalgh et al., 2004).

Other important challenges for implementations of fire management DSSs concern their management. Further research should therefore also focus on gathering important managerial insights from fire management DSS implementations that can be useful for later implementations. A main management challenge pointed out by the implementation literature is how to efficiently overcome misalignments between the system and the adopter. Addressing this type of challenge would most likely include systematizing information about the factors that influence a particular implementation project, identifying the misalignments, and promoting the adequate adaptation cycles while carefully managing user perceptions and motivations (Leonard-Barton, 1988; Edmondson et al., 2001; Rogers, 2003).

Additionally, a systematized framework can provide evidence on whether, in the course of fire management DSS implementations, delivery systems and the performance criteria of the adopters adapt to fit the system (Leonard-Barton, 1988), and the targeted users become more skilful, consistent, and committed to its use (Klein and Sorra, 1996). Or whether this transition is a period of strong inertia to change, favouring established routines (Greenhalgh et al., 2004). As several stakeholders are involved, many implementation decisions may have to be orchestrated between them, with dynamics that depend not only on each of them, but also on their mutual alignment (Linton, 2002). The framework should consider how the relations between stakeholders are managed during the implementation of the system. Studies of implementations of fire management DSSs should also explore which managerial practices help enhance the perceptions of the positive impacts, and reduce the negative impacts, and the importance of implementation management complying with the culture and the overall strategy of the multiple stakeholders.

Research on these topics should provide a global perspective about the implementation of fire management DSSs, and allow a

systematization of the knowledge about implementations in this particular and complex context.

5. Conclusions

A myriad of interacting social and ecological factors influence the severity of forest fires (Tedim et al., 2013). Thus, we need to understand the non-linear relationships between interconnected physical, biological, and cultural systems to be able to effectively reduce the vulnerability of ecosystems and human societies, through improved and proactive risk governance.

To perform an economic evaluation of the investment in a fire management program, an effective DSS to assist assessing alternatives and making decisions must consider multiple conflicting management options, subject to several sources of uncertainty, and their economic impact in the stream of goods and services disrupted by fire occurrence, establishing the ratio between prevention and suppression expenditures, in face of always present budgetary constraints.

The integration of forest fire risk concerns into forest planning processes is a significant step (Bettinger, 2010). However, more research is needed characterizing the impacts of alternative fire management options on market and nonmarket values at risk, and on the economic losses in goods and services triggered by the fire consequences that they try to mitigate (Thompson and Calkin, 2011; Mavsar et al., 2013). This is particularly important regarding the integration of suppression preparedness planning and fuel management (Minas et al., 2013) considering operational and ecological constraints (Minas et al., 2014).

As research evolves and the available computational power increases, it will be possible to tackle increasingly complex challenges raised by more frequent and destructive fires that threaten lives and homes, in particular in an expanding WUI. Problem structuring methods, system dynamics, simulation, decision analysis, and optimization (Minas et al., 2012), together with qualitative methods such as expert elicitation (e.g., Martell et al. (1999), Hirsch et al. (2004), or Rideout et al. (2008b)), open interviews, questionnaires, and surveys (e.g., Tedim et al. (2013)), can help model the dynamics and advance the understanding of these complex systems, gaining insight into problem structures, and better enabling the exploration of alternative management options. Guidelines on how these techniques may help improve specific aspects of decision-making are provided by Minas et al. (2012), on applications of operations research to wildfire management, and Thompson and Calkin (2011), on the alignment of sources of uncertainty with decision support tools and methodologies. Nevertheless, the performance of even the most accurate DSS will be limited by the quality of the input data. Indeed, the balance between input data errors and models accuracy should inform the need for greater precision since it increases the cost of data acquisition (Sullivan, 2009b). A good understanding of the different sources of uncertainty and their potential impact on losses, should guide the development of a DSS sufficiently easy to implement and use, and parsimonious in the amount of information decision makers need to consider (Pasalodos-Tato et al., 2013).

The implementation of DSSs raises other important challenges that emerge from our literature review, namely the involvement of multiple stakeholders who must be considered in the decision-making processes, the need for adaptation to local contexts (e.g., Opperman et al. (2006)), and the strong influence of external pressures and opinion leaders on adoption decisions and on how users perceive the system. It is vital that these and other implementation challenges are carefully managed. Research aiming at the development of a framework that systematizes knowledge about implementation challenges, and how to efficiently manage them, may

significantly benefit such management efforts, and the outcomes of implementation processes.

Risk-based analysis is required for the integration of risk handling and fire management, in order to improve the prioritization of future efforts to mitigate the risks associated with these natural and human caused disturbances. This asks for more research in biophysical and social sciences with a dynamic spatiotemporal perspective, from fire spread and effects models to fuel treatment effectiveness, climate change impacts, and social preferences. Risk assessment should also identify and characterize the importance and weight of uncertainties to improve the management of human and ecological resources at risk, in areas ranging from fuel mapping to how society values those resources (Thompson and Calkin, 2011).

Our review of DSSs in current use stresses the importance of the integration between risk handling and DSS development, to facilitate and improve the quality of decisions under uncertainty, and enable a cohesive fire management in an uncertain environment. It also points out the importance of understanding the institutional constraints of management programs within which forest fire mitigation programs develop, that along with ecological constraints and the need to engage stakeholders, need to be reflected in the usability and flexibility of these systems.

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V. CONCLUSÕES

Através da base de dados geográfica e da metodologia de análise de *clusters* analisámos a evolução da ocupação do solo entre 1907 e 2013. Até aos anos 1960, a expansão da área arborizada ocorreu simultaneamente com a expansão da agricultura, através da retracção das áreas de matos. Com a redução das áreas agrícolas de 1960 em diante, a par da autonomização da floresta enquanto produtora de bens industriais para o mercado global, a área arborizada continuou a sua expansão até a década de 90, reduzindo-se com os incêndios. Neste trabalho, concluímos que a transição florestal não foi homogénea no espaço e no tempo, tendo identificado quatro percursos geograficamente distintos. O primeiro, que designamos por *"Failed transition"*, retrata as áreas mais montanhosas. O segundo, que se localiza no centro litoral, foi designado *"Endangered transition"*, e o terceiro, nas planícies do Alentejo, *"Slow transition"*. Identificámos um quarto *cluster*, na zona raiana norte e em volta de Lisboa, onde não houve transição e ao qual chamámos *"No transition"*.

Os percursos da evolução da área arborizada na primeira metade do séc. XX resultaram de forças endógenas, motivadas pela escassez do recurso e por políticas públicas para o mundo rural. Na segunda metade do séc. XX, as forças exógenas vão-se tornando mais relevantes, não obstante haver ainda lógicas locais associadas à produção de bens industriais, ou arborização em resposta a estímulos públicos. Mas após os anos 1980, são o desenvolvimento económico e a globalização que definem as expectativas e enquadram o decisor (proprietário) com novos valores e preocupações. Não obstante estarem presentes as condições endógenas e exógenas necessárias para a expansão das áreas arborizadas, os incêndios constituíram uma força relevante, mas de sinal contrário, que contribuiu para a redução da área florestal e o aumento da área ocupada por matos, em particular a Norte. Nas planícies do Sul, onde poucos proprietários administram directamente um vasto território, o colapso do modelo agrícola e o seu abandono resolveu-se pela via da intensificação pecuária e silvícola, conseguindo-se com a sua intervenção efeitos à escala da paisagem, a escala adequada para o controlo do fenómeno dos incêndios florestais. Por outro lado, em vastas regiões arborizadas (a norte do Tejo) directamente ou indirectamente pelo Estado durante

o séc. XX, verificou-se a partir da década de 1980 uma retracção da presença activa da administração pública florestal, que actualmente quase não dispõe de meios técnicos e humanos para a gestão e conservação dessas florestas, em articulação com as comunidades locais.

Como ultrapassar a crónica dificuldade em mobilizar os pequenos e médios proprietários do norte e centro a adoptarem as melhores práticas de gestão florestal? Como estimular a absorção do melhor conhecimento e o reforço da capacitação institucional? Como mobilizar a capacidade operacional instalada para o aproveitamento da regeneração natural, aplicando silvicultura nas áreas que transitam de fronteira entre a agricultura e os matos, e entre estes e a floresta? Serão ainda possíveis soluções de "*empowerment*" das comunidades locais para a gestão das florestas que o Estado abandonou?

Através deste trabalho apresenta-se de forma pioneira a evolução da ocupação do solo no séc. XX e contribui-se com factos para o debate sobre o presente e o futuro de 67% do território. Se, até aos anos 70/80, as ideias do racional e integral aproveitamento da terra orientavam as políticas e a força dos homens na conquista dos matos, como se perfila o futuro? Um país que não tem vocação agrícola é necessariamente um país florestal? Sim, na medida em que os matos fazem parte do processo da transição e que, se conjuntamente com a floresta, também forem objecto de gestão, é possível assegurar que nestas áreas se produzam bens e serviços de que necessitamos e valorizamos. Como participam neste processo a pecuária extensiva do Norte e do Sul? Como encontrar o equilíbrio da sustentabilidade do território ou desenvolver os mecanismos adequados de compensação de falhas de mercado?

Mesmo com o esforço para arborizar artificialmente o território, na secção 2.1 observámos as consequências do descontrolo do problema dos incêndios. Caso a tendência se mantenha, a paisagem do País aproximar-se-á daquilo que era no início do séc. XX, quando os matos dominavam a paisagem.

Na secção 2.2, através da recolha de documentação técnica e da legislação, concluímos que o sistema de governação do risco procurou adaptar-se e evoluir, reagindo às áreas ardidas. Esta elasticidade evidencia uma preocupação dos governos em reagir às consequências do fogo, mas em face do resultado obtido (valores médios de área ardida) e dada a perda de área florestal, questiona-se a eficácia das medidas. Assim, é importante conhecer em detalhe como é que o sistema evoluiu, como se formulou sucessivamente o problema, que soluções emergiram e quais os actores que as suportaram. Numa primeira fase investigámos a evolução do quadro institucional e, numa segunda fase, examinámos através da análise de conteúdo de 101 diplomas governamentais publicados entre 1910 e 2013, como foi ao longo do tempo formulado o problema e que soluções foram propostas. Numa terceira fase, caracterizámos as estruturas de governação e resumimos a leitura do documento e os resultados da análise de conteúdos numa cronologia que retrata a evolução do sistema.

Os nossos resultados sugerem que à medida que os incêndios provocaram danos crescentes (florestas, agricultura, casas e vidas) as partes interessadas influenciaram a evolução do sistema de gestão de risco de incêndio, o seu desenho, as suas capacidades, e as suas prioridades. Até aos anos 50 o problema era informalmente resolvido à escala local, na maioria do território. Mas factores externos alteraram o contexto, que pressionou numa primeira fase a evolução do sistema formal existente nas matas públicas e comunitárias para dar resposta ao perigo crescente nas áreas privadas. Até meados da década de 70 houve capacidade de mitigar as consequências. Numa segunda fase, por razões talvez associadas à falta de recursos nos serviços públicos florestais, e à mudança da cultura política e social, parece não ter sido possível este sistema formal responder às pressões dos actores que, entretanto, emergiram com a democracia e o desenvolvimento económico e social. As medidas governamentais promoveram a evolução para um sistema tripartido, onde múltiplos actores participam na gestão do risco à escala local, regional e nacional.

Concluímos que as soluções adoptadas em cada momento resultaram da forma como o problema foi formulado, normalmente num contexto de crise. O sistema foi evoluindo ora de um forma incremental, ou através de reformulação ou alterações transformacionais. Ao longo destes mais de 100 anos apenas houve um

ciclo de mudança (1981-1985) que associamos à transformação, quando o paradigma da protecção civil substituiu a protecção florestal, com novos actores a assumirem a centralidade e a estabelecerem prioridades. Apesar de novas ideias terem emergido, ou exemplos operacionais demonstrarem que outros caminhos são possíveis, as crises de incêndios de 2003, 2005, 2013 e 2016 não conseguiram ainda suscitar um outro ciclo de transformação que equilibre o sistema de governação de risco no sentido da protecção da floresta.

Colocamos a hipótese de que deficiências de governança tenham dificultado, e continuem em parte a dificultar, o surgimento de um sistema coeso e capaz de executar de forma eficaz, sustentada no espaço e no tempo, um programa equilibrado e flexível de gestão de risco. Como é, então possível, assegurar que num futuro não muito distante o sistema permita uma baixa exposição ao perigo de incêndio, tanto para florestas como para as vidas humanas e edificado?

Será a próxima crise de incêndios a oportunidade para reconhecer que houve alterações profundas no contexto, agora ecológico, e que exigem uma transformação do sistema para que se atinjam resultados diferentes? As ideias alternativas estão difundidas, aceites e são suportadas pelos actores que podem suscitar a mudança?

A partir do percurso evolutivo da governança do risco e dado o seu contexto de complexidade e ambiguidade, sugerimos reforçar o sistema com um conselho de liderança de alto nível, que através da comunicação de risco e suportado pelo conhecimento científico ajude a desbloquear equívocos e promova as melhores práticas de governança de risco.

A abordagem que seguimos é inovadora na análise da política de defesa contra incêndios florestais e no recente corpo científico da governança de risco. Com os dados e informações que reunimos será possível aplicar métodos de investigação em processos de políticas públicas, como a teoria da coligação de actores ou os métodos da nova economia institucional, por exemplo. Como os sistemas socio-ecológicos estão cada vez mais expostos ao fogo e a preservação da floresta é

cada vez mais fundamental para os objetivos da ONU, incluindo no âmbito da mitigação das alterações climáticas, da análise realizada é possível extrair ensinamentos úteis para a melhoria do sistema português e de outros em contextos sociais e climáticos similares. Neste trabalho, não abordamos directamente o contexto climático, mas importa em trabalhos futuros compreender melhor a relação entre a variação do clima e a governança do risco de incêndio, ou melhor, entre a percepção do perigo e do risco.

Também do nosso trabalho, a adesão a comunidade económica europeia surge como um momento relevante no processo de governança do risco e na evolução da transição florestal. Em trabalhos futuros poderá ser interessante investigar a relação que possa existir com programas comunitários na esfera da agricultura e ambiente ou também aprofundando o cluster da transição com a incidência / regime do fogo.

Conforme pudemos concluir, ao longo do processo legislativo governamental foram poucas as medidas (directas ou indirectas) que interferiram positivamente no comportamento dos actores florestais (proprietários e utilizadores dos bens e serviços gerados pelos espaços florestais). Tal dever-se-á à crónica dificuldade do Estado em interferir na esfera do direito da propriedade florestal e à expectativa de soluções de curto prazo. Talvez reconhecendo essa crónica dificuldade, o Estado desde 2004 (DL 156/2005) previu a figura da indemnização pela expropriação da terra, caso esta ficasse afectada a infraestruturas de defesa da floresta contra incêndios. A compartimentação da paisagem com redes de faixas, sendo uma solução técnica complementar, é também um produto do sistema de governança do risco em resultado dos incêndios de 2003/2005. Com uma importância política acrescida e consequentes recursos associadas aos programas comunitários, que permitem realizar em curto prazo obra visível, é relevante saber se as expectativas existentes são próximas ou distantes dos resultados necessários.

Para o território do Algarve e parte do sul do Alentejo, através da metodologia e resultados apresentados no artigo *“Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission”* concluímos que

se as redes fossem totalmente construídas com recurso ao tratamento mais intenso, seria de prever uma redução da área total ardida em 17% e reduzir-se-ia a probabilidade ocorrerem grandes incêndios (> 10.000 ha).

No entanto, ponderadas as vantagens e limitações associadas ao uso da modelação de comportamento do fogo e considerando que o âmbito da aplicação da metodologia é uma avaliação *ex-ante* das intensidades alternativas de tratamento de combustíveis em faixas lineares, é possível concluir que estas faixas não permitem, por si só, reduzir substancialmente a proporção e severidade do fogo. Como realçado na discussão, investigou-se o efeito passivo das faixas uma vez que não foram contabilizados os esforços de eventual envolvimento de meios de combate, dado que a prática tem vindo a mostrar que em grandes incêndios os recursos de extinção ficam bloqueados na defesa de vidas e bens (ISA-APIF, 2005) e existem dificuldade de antecipação tática e movimentação operacional dos recursos de combate não especializados em técnicas indirectas (Beighley e Quesinberry, 2004; Beighley e Hyde, 2009).

Atendendo quer à existência de frequências de fogo distintas dentro da área de estudo (mais elevado em redor de Monchique e Tavira e mais baixo nas restantes áreas), quer ao elevado custo da criação e manutenção destas faixas, concluiu-se, e recomenda-se, que realizando só cerca de metade dos hectares previstos se atingem 87% dos resultados. Nestas sub-regiões, o efeito das faixas na transmissão do fogo entre municípios é relevante, destacando-se o facto importante de apenas 6 municípios (30% do total) beneficiarem da construção e manutenção das faixas, pois a distribuição das vantagens não é simétrica entre os vários concelhos. Para além dos resultados e conclusões mais operacionais que este método permite, em especial na esfera da mobilização de actores e governança do risco de incêndio à escala regional, as quais foram acima resumidas, a metodologia desenvolvida permite ainda que se testem outras soluções lineares, que se avaliem outros pressupostos, cenários meteorológicos, ou diferentes durações de incêndios, ou que se testem as vantagens de incluir um conjunto significativo de hectares a serem tratados pelos proprietários particulares, por exemplo, medindo as vantagens em termos de área ardida e bloqueio da transmissão. A metodologia de simulação e análise de rede permite

quantificar o benefício directo para o proprietário ou comunidade que efectuar o tratamento, e estimar o benefício para terceiros vizinhos.

Como vimos pelo percurso histórico resumido na introdução à secção 2.3, que enquadra a leitura sobre aceiros ou faixas para as condições portuguesas, a sua construção e manutenção em terrenos montanhosos sempre se revelou difícil e onerosa, exigindo para a maximização destes investimentos que o conhecimento e domínio pleno das táticas e técnicas de supressão indirectas estivessem disponíveis e a mobilização fosse atempada. Demonstrou-se, para a ocupação do solo do Algarve de 2006, que a expectativa da sua implementação, na ausência de outras medidas que reduzam a carga combustível no interior dos compartimentos, só por si não é suficiente para a desejada redução da área ardida e da severidade dos incêndios. Incentivos que mobilizem os proprietários florestais a tratar as suas áreas devem ser equacionados, retomando a linha do diagnóstico realizado nos anos 50/60 e as propostas do próprio Conselho Nacional de Reflorestação (2005).

O trabalho desenvolvido através de sistemas dinâmicos para compreender a gestão do fogo constituiu um trabalho pioneiro à escala mundial, tendo depois dele, outros autores desenvolvido semelhantes aplicações para os Estados Unidos da América (Calkin *et al.*, 2015) que respaldam propostas para reformar os processos de decisão nas políticas (North *et al.*, 2015; Zimmerman, 2016). Para Portugal, através deste contributo, evidenciou-se que ao priorizar os investimentos em supressão em detrimento de uma solução mais equilibrada com a prevenção, o sistema de governança de risco permanece num estado indesejado de “mais incêndios, mais meios”. No curto prazo, demonstra-se que o sistema satisfaz a redução da área ardida, mas no longo prazo por não haver tratamento da vegetação que continua a acumular-se, a variância e a dimensão dos incêndios aumenta, levando à destruição do que se desejava proteger. Os contributos deste trabalho permitem que as partes interessadas e os decisores políticos disponham das evidências antecipadamente às suas eventuais opções. Permitem ainda, compreender as resistências à adopção das mudanças e antecipar os pontos críticos para reverter o ciclo vicioso de “mais incêndios, mais meios”.

Para além da cartografia de risco de incêndio e índices meteorológicos que são empregues em Portugal, face ao estado do conhecimento e uso operacional de modelos de apoio à decisão em investimentos de prevenção e supressão (gestão de risco de incêndios florestais) reportado por Pacheco *et al.* (2015), observámos que há um atraso significativo das instituições e operadores em Portugal na adopção deste corpo de conhecimento e tecnologias associadas. Com este trabalho, ficámos a conhecer os dispositivos que são usados na gestão e na governança do risco de incêndio por outros países, facilitando a sua adopção e adaptação futura. Para que tal seja possível, será necessário desenvolver uma linha de trabalho interdepartamental que se dedique a avaliar junto dos utilizadores as suas necessidades, quais as soluções, de entre as existentes, que reúnem características mais interessantes para as nossas condições, e qual o esforço que exigem na recolha, arquivo, tratamento e distribuição da informação com interesse para a decisão.

Nesta dissertação, defende-se a Tese que no Portugal Mediterrânico e Atlântico a expansão florestal mantém-se enquanto as soluções informais e locais funcionam, estando estas intimamente ligadas à gestão e ao conhecimento da floresta e do território.

Investigados os percursos da transição florestal e da governança do risco de incêndio, parece ser difícil assegurar uma transição florestal sustentada.

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