ESCUELA DE DOCTORADO
INTERNACIONAL DE LA USC

Emanuel Renato
Sousa de Oliveira

Tesis doctoral

Marco del uso tradicional del fuego en Portugal y estudio de caso - incluyendo el régimen de fuego - del Alto Minho

Lugo, 2023

Programa de doctorado en Gestión Sostenible de la Tierra y del Territorio

TESIS DE DOCTORADO

MARCO DEL USO TRADICIONAL DEL FUEGO EN PORTUGAL Y ESTUDIO DE CASO - INCLUYENDO EL RÉGIMEN DE FUEGO - DEL ALTO MINHO

Emanuel Renato Sousa de Oliveira

ESCUELA DE DOCTORADO INTERNACIONAL DE LA UNIVERSIDAD DE SANTIAGO DE COMPOSTELA

PROGRAMA DE DOCTORADO EN GESTIÓN SOSTENIBLE DE LA TIERRA Y DEL TERRITORIO

SANTIAGO DE COMPOSTELA / LUGO

2023

USC
UNIVERSIDADE
DE SANTIAGO
DE COMPOSTELA

DECLARACIÓN DEL AUTOR/A DE LA TESIS

D./Dña. **Emanuel Renato Sousa de Oliveira**

Título de la tesis: *Marco del uso tradicional del fuego en Portugal y estudio de caso - incluyendo el régimen de fuego - del Alto Minho*

Presento mi tesis, siguiendo el procedimiento adecuado al Reglamento y declaro que:

1) La tesis abarca los resultados de la elaboración de mi trabajo.
2) De ser el caso, en la tesis se hace referencia a las colaboraciones que tuvo este trabajo.
3) Confirmo que la tesis no incurre en ningún tipo de plagio de otros autores ni de trabajos presentados por mí para la obtención de otros títulos.
4) La tesis es la versión definitiva presentada para su defensa y coincide la versión impresa con la presentada en formato electrónico.

Y me comprometo a presentar el Compromiso Documental de Supervisión en el caso que el original no esté depositado en la Escuela.

En **Lugo**, **07 de mayo de 2023**.

Firma electrónica

USC
UNIVERSIDADE
DE SANTIAGO
DE COMPOSTELA

AUTORIZACIÓN DEL DIRECTOR / TUTOR DE LA TESIS

Marco del uso tradicional del fuego en Portugal y estudio de caso - incluyendo el régimen de fuego - del Alto Minho

D. David Miranda Barrós

D. Paulo Alexandre Martins Fernandes

INFORMA/N:

Que la presente tesis, se corresponde con el trabajo realizado por D. Emanuel Renato Sousa de Oliveira, bajo mi dirección/tutorización, y autorizo su presentación, considerando que reúne los requisitos exigidos en el Reglamento de Estudios de Doctorado de la USC, y que como director de esta no incurre en las causas de abstención establecidas en la Ley 40/2015.

De acuerdo con lo indicado en el Reglamento de Estudios de Doctorado, declara también que la presente tesis doctoral es idónea para ser defendida en base a la modalidad de COMPENDIO DE PUBLICACIONES en los que la participación del doctorando fue decisiva para su elaboración y las publicaciones se ajustan al Plan de Investigación.

En Lugo, 6 de Mayo de 2023

A mi esposa

A mis hijos

A mis padres

A mis hermanos

Gracias por todo su apoyo

A nuestras comunidades rurales

por seguir resistiendo

«Sometimes culture and fire collude, sometimes they clash, and sometimes they just collide.»

Stephen J. Pyne, 2017

AGRADECIMIENTOS

Cuando me inscribí en el doctorado era consciente de que sólo estaba empezando un largo camino. Recordando las palabras del poeta Antonio Machado, «*Caminante, no hay camino se hace camino al andar*» y, así fue, me puse en camino rumbo a algo que deseaba ver. Un camino que hice por veces en solitario, dejando atrás a mí familia y amigos, pensando y meditando en las hipótesis y en los obstáculos que me surgían, otras veces escuchando la sabiduría de las gentes de la tierra, basada en los conocimientos ancestrales, o de lo que resta de ellos y, otras veces, en la compañía de guías experimentados, expertos en las más diversas áreas de la Academia, con quien pude quitar dudas, corregir rutas y evitar tropiezos. Con todos ellos pude aprender y con todos ellos hice este camino que acaba solo de empezar.

En este apartado del documento doctoral, aunque me falten palabras, es mí oportunidad para que consten mis agradecimientos públicos.

No puedo empezar sin agradecer a mí esposa e a mis tres “mosqueteros”, por los años que no pudieron contar conmigo en vacaciones y por mí ausencia en los innumerables días de fiesta y fines de semana, por el incondicional apoyo y por la fuerza que me dieron todo este tiempo. ¡Fueron ellos los más sacrificados! Así como mis padres y hermanos, a quien les agradezco todo el apoyo y comprensión.

Quiero aprovechar para agradecer a las comunidades tradicionales del Alto Minho, a las personas que aún llevan la llama viva del fuego como sus antepasados, en un mundo cada vez más distante de la ruralidad y de la Naturaleza que no entiende su papel al largo de los siglos en los ecosistemas y en la conservación de los paisajes. No puedo también olvidar mi gratitud para con el pueblo indígena “*Gavião Pykopjê*” de la Tierra Indígena de Governador, en el estado brasileño de Maranhão, con quien aprendo desde el 2019 y el cual me despertó en buscar las raíces del fuego tradicional, nativo de Portugal y entender también sus usos y como estos, durante siglos, moldearon nuestros paisajes. Agradecer también a mis colegas y amigos de las brigadas de zapadores forestales de Paredes de Coura (SF 07-111 y SF 23-111), por ayudarme a recuperar y a poner en práctica el uso del fuego tradicional.

También deseo dejar nota de agradecimiento a mis amigos y compañeros con quien compartí los problemas y las dudas relacionadas con el amplio abanico que envuelve los usos del fuego y los incendios, a los compañeros especialistas del extinto Observatório Técnico Independiente (OTI) del Parlamento de la República Portuguesa, con quien durante tres años pude discutir y aprender inmenso, al amigo Bruno Caldas de la Comunidad Intermunicipal del Alto Minho, a Vitor Pereira y Tiago Cunha, alcalde y vicealcalde del Ayuntamiento de Paredes de Coura, a los compañeros y amigos de los Gabinetes Técnicos Forestales de los ayuntamientos del territorio del Alto Minho que siempre me apoyaron y compartieron información importante para mí trabajo. Agradecer a José Luis Duce de *The Nature Conservancy* (EUA), a Santiago Couceiro de la empresa gallega Flanconorte, a João Rodrigues del Laboratório Rural de Paredes de Coura y Fillipe Tamiozzo de la Universidade Federal de Viçosa, en Minas Gerais (Brasil), por permitir compartir conocimientos sobre los usos tradicionales del fuego.

En este camino tengo que destacar la compañía de mis guías, mis consejeros y consejeras, mis maestros y maestras, con los cuales he compartido mis dudas y preocupaciones y me transmitieron sus conocimientos y experiencias. Agradecer a mi director y tutor, David Miranda, por aceptarme en el Programa de Doctorado en Gestión Sostenible de la Tierra y del Territorio y por su preocupación para que yo no saliera ni desistiera del camino. Agradecer a mi director y compañero del OTI, Paulo Fernandes, de la Universidade de Trás-os-Montes (Vila

Real, Portugal) por aceptar el reto de orientarme, por su paciencia y dedicación conmigo y por aceptar escribir con un novato los varios artículos dedicados a los varios resultados de esta investigación. Me faltan palabras para agradecer a mí amiga y “cotutora” Conceição Colaço, del Instituto Superior de Agronomia (ISA) de la Universidade Lisboa, que muchas veces me llevó al camino y no perder el enfoque de mí investigación. Agradecer también al amigo Nuno Guiomar, de la Universidade de Évora, por debatir conmigo por la noche adentro sobre el papel del fuego en los paisajes y aceptar escribir el último artículo que compone la tesis. No tengo como olvidarme de la joven investigadora, muy profesional y dedicada, compañera de redacción y amiga, Catarina Sequeira y su particular interés por la historia legislativa y los usos del fuego, así como la importante contribución de la investigadora Raquel Lobo do Vale en el artículo dedicado a los incidentes por el uso del fuego, ambas compañeras del ISA (UL).

Me faltan palabras para agradecer a cada uno de ellos y de aquellos que encontré por el camino que me permitieron llegar hasta aquí. Gracias por esto y por mostrar el camino hacia nuevos destinos que están más allá en este camino que «*se hace al andar*».

RESUMEN

En el Plan de Investigación presentado, el enfoque era exclusivamente dedicado al fenómeno de los grandes incendios forestales y sus impactos en el paisaje del territorio del Alto Minho. Una vez recopilada la información cartográfica oficial y con un primer análisis de control de calidad, utilizando imágenes de satélite, se encontraron varios errores que no permitían realizar un estudio, deseablemente riguroso, sobre los incendios forestales en el territorio. Por otra parte, durante las visitas sobre el terreno, se identificaron muchas zonas quemadas que no estaban cartografiadas en la base a fuentes oficiales. Estas condiciones obligaron a un esfuerzo añadido para crear una serie histórica de superficies quemadas con el máximo rigor y detalle posible, cuyo trabajo único en Portugal, al final, permitió identificar y describir el régimen de fuego y sus impactos reales en el territorio.

El fuego en el Noroeste Ibérico y muy particularmente, en la zona de estudio, no es un fenómeno aislado y ajeno al paisaje. Por lo contrario, los datos resultantes del largo proceso sistemático de obtención de superficies quemadas y su clasificación en cuanto a la tipología de fuego, permitieron identificar la existencia de un uso del fuego muy arraigado en determinadas zonas del territorio, donde no constaban grandes superficies quemadas resultantes de incendios forestales. Sin embargo, este uso del fuego por las comunidades rurales es completamente ilegal y, aun así, no originaba incendios forestales. Esto me llevó a intentar comprender su origen en un contexto de conocimiento tradicional y averiguar por qué este fuego está legalmente tan condicionado, cuando es tan recurrente en el Alto Minho. La investigación y revisión bibliográfica me hizo retroceder en el tiempo y los numerosos manuscritos y documentos legales históricos, obtenidos de varios siglos, me permitieron identificar patrones asociados a los diferentes usos del fuego y cuáles fueron los impactos normativos sobre este uso a lo largo del tiempo y como, en su conjunto, han condicionado los paisajes.

Por otro lado, la investigación sobre el uso tradicional del fuego ha permitido identificar un problema transversal al territorio nacional, particularmente en las zonas rurales, donde reside una población envejecida en un paisaje en continuo cambio. Los resultados revelaron un elevado número de accidentes mortales como consecuencia de este uso tradicional del fuego y permitieron abrir una línea de investigación en la que prácticamente no hay trabajos publicados.

Una vez finalizado el proceso de cartografiado de todas las superficies quemadas y clasificadas según su origen, fue posible identificar patrones asociados a un régimen de fuego en el territorio, así como su impacto en la alteración o conservación del paisaje del Alto Minho. Por último, el paisaje además de resultar como producto del impacto de los diferentes fuegos, también condiciona la evolución de futuros incendios forestales.

Palabras Clave: Paisaje; Fuego tradicional; Uso del fuego; Incendios forestales; Régimen de fuego; Legislación, Conocimiento tradicional del fuego, Noroeste Ibérico

RESUMO

No Plan de Investigación presentado, o foco era exclusivamente dedicado ó fenómeno dos grandes incendios forestais e os seus impactos na paisaxe do territorio do Alto Minho. Unha vez recollida a información cartográfica oficial e cunha primeira análise de control de calidade, mediante imaxes de satélite, constatáronse varios erros que non permitían realizar un estudo desexablemente rigoroso sobre os incendios forestais no territorio. Por outra banda, durante as visitas de campo identificáronse moitas zonas queimadas que non estaban cartografiadas na base das fontes oficiais. Estas condicións obrigaron a un esforzo engadido para crear unha serie histórica de superficies queimadas co máximo rigor e detalle posible, cuxo traballo único en Portugal permitiu, ó final, identificar e describir o réxime de lume e os seus impactos reais sobre o territorio.

O lume no noroeste ibérico, e particularmente na zona de estudo, non é un fenómeno illado alleo á paisaxe. Pola contra, os datos derivados do longo proceso sistemático de obtención de superficies queimadas e a súa clasificación en función do tipo de lume, permitiron identificar a existencia dun uso do lume moi arraigado en determinadas zonas do territorio, onde non existían grandes superficies queimadas derivadas dos incendios forestais. Non obstante, este uso do lume por parte das comunidades rurais é totalmente ilegal e, aínda así, non orixinaba incendios forestais. Isto levoume a tratar de comprender a súa orixe nun contexto do coñecemento tradicional e descubrir por que este lume está tan condicionado legalmente, cando é tan recurrente no Alto Minho. A investigación e a revisión bibliográfica levoume atrás no tempo e os numerosos manuscritos e documentos legais históricos, obtidos dende varios séculos, permitíronme identificar patróns asociados ós diferentes usos do lume e cales foron os impactos normativos sobre este uso ó longo do tempo e cómo no seu conxunto, condicionaron as paisaxes.

Por outra banda, a investigación sobre o uso tradicional do lume permitiu identificar unha problemática transversal ó territorio nacional, particularmente no rural, onde unha poboación envellecida reside nunha paisaxe en constante cambio. Os resultados revelaron un elevado número de accidentes mortais como consecuencia deste uso tradicional do lume e permitiron abrir unha liña de investigación na que practicamente non hai traballos publicados.

Unha vez finalizado o proceso de cartografía de todas as superficies queimadas e clasificadas segundo a súa orixe, foi posible identificar patróns asociados a un réxime de lume no territorio, así como o seu impacto na alteración ou conservación da paisaxe do Alto Minho. Por último, a paisaxe, ademais de ser produto do impacto dos distintos lumes, condiciona tamén a evolución dos futuros incendios forestais.

Palabras Chave: Paisaxe; Lume tradicional; Uso do lume; Incendios forestais; Réxime de incendios; Lexislación, Coñecemento tradicional do lume, Noroeste Ibérico

ABSTRACT

In the Research Plan presented, the focus was exclusively dedicated to the phenomenon of large wildfires and their impacts on the landscape of the Alto Minho territory. After compiling the official cartographic information and a first quality control analysis using satellite images, several errors were found that did not allow for a study, which should be rigorous, on wildfires in the territory. Furthermore, during field visits, many burnt areas were identified that were not mapped on the basis of official sources. These conditions obliged an additional effort to create a historical series of burnt areas with the greatest possible precision and detail, whose unique work in Portugal, in the end, made it possible to identify and describe the fire regime and its real impacts on the territory.

The fire in the Northwestern Iberian Peninsula, and particularly in the study area, is not an isolated and foreign phenomenon to the landscape. On the contrary, the data resulting from the long systematic process of obtaining burnt areas and their classification in terms of fire typology, made it possible to identify the existence of a very deep-rooted use of fire in particular areas of the territory, where large burnt areas resulting from wildfires were not recorded. However, this use of fire by rural communities is completely illegal and, even so, did not cause wildfires. This led me to try to understand its origin in a context of traditional knowledge and to find out why this fire is so legally conditioned, when it is so recurrent in the Alto Minho. The research and literature review took me back in time and the numerous manuscripts and historical legal documents, obtained from several centuries, allowed me to identify patterns associated with the different uses of fire and what were the regulatory impacts on this use over time and how, as a whole, they have conditioned the landscapes.

On the other hand, the research on the traditional use of fire allowed to identify a cross-cutting problem in the national territory, particularly in rural areas, where an ageing population resides in a continuously changing landscape. The results revealed a high number of fatal accidents as a consequence of this traditional use of fire and opened up a line of research in which there is practically no published work.

At the end of the process of mapping all burnt areas and classifying them according to their origin, it was possible to identify patterns associated with a fire regime in the territory, as well as its impact on the alteration or conservation of the Alto Minho landscape. Finally, the landscape, in addition to being the product of the impact of the different fires, also conditions the evolution of future wildfires.

Keywords: Landscape; Traditional fire; Fire use; Wildfires; Fire regime; Legislation, Tradicional Fire Knowledge, Northwestern Iberia

PUBLICACIONES DERIVADAS

ARTÍCULOS PUBLICADOS

de Oliveira, E. and Fernandes, P.M. (2023). **Uma cartografia aperfeiçoada das áreas ardidas no Alto Minho (Noroeste de Portugal) entre 2001 e 2020** [*Una cartografía perfeccionada de las superficies quemadas en el Alto Minho (Noroeste de Portugal) entre 2001 y 2020*]. Revista Finisterra. Status: Published (DOI: https://doi.org/10.18055/Finis28546) *– **Se refiere al Capítulo IV***

Contribución del Autor
Conceptualización, Metodología, Software, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

de Oliveira, E. and Fernandes, P.M. (2023). **Pastoral burning and its contribution to the fire regime of Alto Minho, Portugal** [*Las quemas pastorales y su contribución al régimen de incendios del Alto Minho, Portugal*]. Fire. Status: Published (DOI: https://doi.org/10.3390/fire6050210) ***– Se refiere al Capítulo V***

Contribución del Autor
Conceptualización, Metodología, Análisis formal, Investigación, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

de Oliveira, E.; Lobo-do-Vale, R.; Colaço, M. C. (2023). **Incident analysis of traditional burns in Portugal** [*Análisis de incidentes en las quemas tradicionales en Portugal*]. International Journal of Disaster Risk Reduction. Status: Published (DOI: https://doi.org/10.1016/j.ijdrr.2023.103852) ***– Se refiere al Capítulo III***

Contribución del Autor
Conceptualización, Metodología, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

de Oliveira, E.; Fernandes, P.M.; Barros, D.; Guiomar, N. (2023). **Unraveling the Effect of Fire Seasonality on Fire-Preferred Fuel Types and Dynamics in Alto Minho, Portugal (2000–2018)** [*Desvelando el efecto de la estacionalidad de los fuegos sobre los tipos de combustible más afectados y la dinámica de los fuegos en Alto Minho, Portugal (2000-2018)*]. Fire. Status: Published (DOI: https://doi.org/10.3390/fire6070267) ***— Se refiere al Capítulo VI***

Contribución del Autor

Conceptualización, Metodología, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

de Oliveira, E.; Fernandes, P.M.; Sequeira, C.; Colaço, M.C. (2023). **The use of vegetation fire in Portugal: Historical legislative and normative analysis** [*El uso del fuego en Portugal: análisis histórico legislativo y normative*]. Environment and History. Status: ***In Press – Se refiere al Capítulo I***

Contribución del Autor

Conceptualización, Metodología, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

de Oliveira, E.; Fernandes, P.M.; Colaço, M.C.; Sequeira, C. (2023). **Remains of the traditional fire use in Portugal: a historical analysis** [*Vestigios del uso tradicional del fuego en Portugal: un análisis histórico*]. Status: Trees, Forests and People. ***In Press – Se refiere al Capítulo II***

Contribución del Autor

Conceptualización, Metodología, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

PONENCIAS EN CONGRESOS Y JORNADAS TÉCNICAS

de Oliveira, E, (2017). *A prevenção à escala da paisagem para fazer frente aos grandes incêndios florestais* [Prevención a escala del paisaje para hacer frente a los grandes incendios forestales]. Seminário Internacional de Prevenção e Controle de Incêndios Florestais. Sociedade de Investigações Florestais e Universidade Federal de Viçosa - Minas Gerais – Brasil. 28 e 29 de Setembro de 2017 - *Relacionado con los Capítulos IV y VI*

de Oliveira, E, (2017). *A homogeneização da paisagem e o risco fenológico de incêndio. Padrões de propagação dos grandes incêndios florestais* [La homogeneización del paisaje y el riesgo fenológico de incendio. Patrones de propagación de los grandes incendios forestales]. 8º Congresso Florestal Nacional: Floresta em Português. Raízes do Futuro. Viana do Castelo – Portugal, 11 a 14 de Outubro de 2017 – *Relacionado con el Capítulo VI*

de Oliveira, E, (2018). *Incêndios Florestais e Produção Animal* [Incendios forestales y producción ganadera]. 39ª Reunião de Primavera da Sociedade Portuguesa de Pastagens e Forragens: Forragens e Pastagens no Noroeste Atlântico. SPPF – Portugal, 3 e 4 de Maio de 2018 – *Relacionado con el Capítulo V*

de Oliveira, E, (2019). *Os grandes incêndios florestais: um paradigma em mudança* [Grandes incendios forestales: un paradigma en proceso de cambio]. Seminário de Proteção e Defesa Civil, Secretaria de Estado da Defesa Civil de Santa Catarina – Governo de Santa Catarina. Universidade do Sul de Santa Catarina (UNISUL) – Pedra Branca, Palhoça. Santa Catarina – Brasil. 30 e 31 de Maio de 2019 – *Relacionado con los Capítulos I, II, IV y VI*

de Oliveira, E., Colaço. M.C. (2021). *Análise de Acidentes pelo Uso do Fogo* [Análisis de accidentes por el uso del fuego]. II Seminário da Rede Incêndios-Solo: Incêndios, Solo e Território: da Ameaça à Sustentabilidade. Centro de Investigação de Montanha – Instituto Politécnico de Bragança. Bragança, 13 a 15 de Outubro de 2021 – *Relacionado con el Capítulo III*

de Oliveira, E., Lobo-do-Vale, R., Colaço. M.C. (2022). *The last landscape gardeners: Incident analysis of traditional burns in Portugal* [Los últimos jardineros del paisaje: Análisis de incidentes en las quemas tradicionales de Portugal]. IX International Conference on Forest Fire Research, D.X. Viegas (ed.). Coimbra, 11 a 18 de Novembro de 2022 – *Relacionado con el Capítulo III*

de Oliveira, E. and Fernandes, P.M. (2023). Pastoral burning and its contribution to the fire regime of Alto Minho, Portugal [*Las quemas pastorales y su contribución al régimen de incendios del Alto Minho, Portugal*]. Poster presentado en 8th International Wildland Fire Conference, Porto, mayo de 2023. https://www.wildfire2023.pt/abstract/e-posters-list – *Relacionado con el Capítulo V*

ÍNDICE

PRÓLOGO

Puede decirse que inicié el proceso de investigación desde una posición basada en la experiencia como técnico sobre el terreno, del uso institucional del fuego, también conocido como quema prescrita (fuego controlado en Portugal) y de la lucha contra los incendios forestales. Aunque la experiencia es una parte fundamental, sobre todo en las múltiples cuestiones que se plantean, el conocimiento científico es imprescindible para encontrar las respuestas de forma razonada. Por ello, los principales motivos que desencadenaron el deseo de elaborar esta tesis fueron principalmente, continuar mis estudios dedicados a los incendios forestales y también buscar respuestas a cuestiones relacionadas con el impacto de los grandes incendios, cada vez más recurrentes y de mayores dimensiones.

Rehén de mi experiencia con los incendios, el enfoque inicial en la elaboración de esta tesis se basa en el impacto de los grandes incendios forestales en la región del Alto Minho, desde un enfoque de los incendios forestales como el problema. Por el contrario, según avanzaba la investigación, mi percepción de los grandes incendios fue cambiando. El cambio se debió principalmente al período de trabajo de investigación dedicado al levantamiento cartográfico y a la clasificación de los incendios. Una vez finalizado este trabajo, el proceso de clasificación me llevó a investigar los usos ancestrales, mediante la recopilación y lectura de documentos históricos, manuscritos y legislación. Esta etapa de la investigación, motivada también por mi experiencia de campo con comunidades tradicionales e indígenas, me llevó a buscar usos del fuego nativos de Portugal, de modo que sólo en los documentos históricos se puede identificar y recuperar información sobre técnicas y prácticas de comunidades pasadas. Esta tarea fue fundamental, la cual permitió ampliar la visión y comprender la evolución del uso del fuego en el territorio portugués, así como la relación con los grandes incendios forestales. Estos grandes incendios son, al final, una consecuencia y no el problema.

La gran cantidad de información y el detalle de los datos obtenidos convirtieron la investigación en un abordaje holístico respecto a todos los fuegos forestales que se propagan de diferentes formas en el paisaje del Alto Minho.

INTRODUCCIÓN

Antes del proceso de antropización, los incendios de origen natural formaron y condicionaron la distribución de los bosques durante millones de años (Pyne and Goldammer, 1997; Bowman et al., 2009; 2011). Con la humanización de los territorios, el fuego de origen antropogénico no sólo fue asumido como herramienta de trabajo, sino que dio paso a la primera era energética (Smil, 2004). Hace más de 300.000 años, cuando los seres humanos sustituyeron el uso oportunista y ocasional del fuego por un uso regular y habitual para obtener los beneficios del fuego, se produjo un proceso determinante en la humanización (MacDonald, 2018; Roebroeks and Villa, 2011). Este control de la energía y su uso regular, para procesar alimentos, protegerse de las inclemencias del tiempo, de la oscuridad de la noche y de los animales salvajes, para alterar las materias primas, para modificar deliberadamente el uso de la tierra, cambió la especie humana a nivel físico, cognitivo y social (Shimelmitz et al., 2014). A medida que avanzaba la humanización de los territorios, el fuego acompañaba, como aún hoy, los cambios del paisaje.

Las primeras poblaciones humanas se dedicaban sobre todo a la caza y la recolección de vegetales y frutos silvestres, por lo que el uso del fuego ha acompañado a las primeras sociedades nómadas (Fábregas Valcarce, 1988; Fábregas Valcarce and Otero, 1999; (Jorge, 2000). A partir del Neolítico, el uso del fuego permitió abrir claros para la instalación de pequeños asentamientos y las primeras tierras agrícolas (Aira Rodríguez and Ramil Rego, 1995). Con la domesticación de los animales se inició la actividad pastoril y el fuego desempeñó su papel en la renovación de los pastos. Sin embargo, estas prácticas se complementaban con la caza y la recolección (Bettencourt, 2008).

Las primeras sociedades agrosilvopastorales mantuvieron prácticas itinerantes, por lo que el fuego adquirió el mismo carácter itinerante (Fábregas Valcarce et al., 1997; Sanches, 2003). A medida que se desplazaban en el territorio y se expandía la población humana, el fuego acompañó los movimientos demográficos y migratorios. Con la aparición de los primeros asentamientos fijos, el fuego se hizo sedentario en el paisaje, manifestándose de forma recurrente por la mano del hombre, según las necesidades, para roturar nuevas tierras agrícolas, para quemar rastrojos y abonar los campos, para renovar pastos, para mantener alejados a los animales salvajes y para controlar plagas y enfermedades en los cultivos. Igualmente, según los registros históricos, el fuego también se ha manifestado en el territorio como resultado con fines defensivos en tiempos de guerra, de causas accidentales y por motivaciones asociadas a una intencionalidad para provocar daños. Desde entonces, estas prácticas han continuado a lo largo de los siglos en el Noroeste Ibérico y, en este caso, particularmente en el Alto Minho. El paisaje de esta región, así como el de otros territorios rurales, es un paisaje cultural resultante de usos y prácticas ancestrales, incluyendo el uso del fuego, de diferentes sociedades en la gestión de los recursos (Davidson-Hunt, 2003; Miller and Davidson-Hunt, 2010).

La firma humana en el paisaje fue el fuego, principalmente en los territorios donde la densidad demográfica era más elevada, lo que provocó a lo largo del tiempo la alteración de los ecosistemas, que a su vez se adaptaron a las prácticas y usos de las sociedades rurales (Pyne and Goldammer, 1997; Pyne, 1999; 2006). Los cambios de la sociedad, conllevan a cambios de usos y ocupaciones del suelo y éstos pueden derivar de políticas y medidas soportadas por la legislación en cada período de vigencia.

La necesidad de legislar sobre el uso del fuego se remonta a la época anterior a la fundación de Portugal, debido a la incompatibilidad de usos y ocupaciones del suelo, donde el régimen de propiedad tenía un peso considerable. Desde el momento en que la sociedad existe, se impone la necesidad del Derecho y éste evoluciona según la evolución de la sociedad y los conflictos que genera. Estos conflictos serán más diversos cuanto más desarrollada y organizada esté la sociedad, por lo que el establecimiento de normas y leyes es fundamental para su funcionamiento. La investigación sobre la evolución histórica legislativa nos permite identificar y comprender el impacto de determinados conflictos, en este caso particular los relacionados con el uso del fuego y los incendios forestales.

En la actualidad, los incendios forestales constituyen un importante impacto medioambiental, económico y social, y también tienen una fuerte repercusión mediática. Aunque la legislación ha evolucionado, más concretamente desde principios del siglo XX, y se ha reforzado en las dos últimas décadas, la población sigue utilizando el fuego de forma generalizada. Este uso popular surge de prácticas ancestrales, pero se puede constatar que no es más que un vestigio de usos pasados. Sin embargo, el uso del fuego está asociado al elevado número de incendios que se producen anualmente en el país. Identificar los usos del fuego en el pasado permite comprender el uso actual del fuego por parte de las poblaciones rurales y el fenómeno de los incendios forestales.

En las últimas décadas, el resultado de los cambios sociales ha tenido un impacto decisivo en el uso y la ocupación del suelo, concretamente la despoblación y el envejecimiento de la población. Un paisaje que fue construido por comunidades humanas está ahora cada vez más despoblado o tiene una población envejecida, lo que se traduce en un aumento de las zonas forestales no gestionadas y en el proceso de rewilding de tierras agrícolas, donde se acumulan elevadas cargas de biomasa. Si por un lado aumenta el riesgo de incendios por el uso del fuego, por otro aumentan considerablemente los incidentes con víctimas, esencialmente personas mayores. Sin embargo, este nuevo problema asociado a los incidentes con víctimas mortales fuera de la temporada (estival) de incendios no ha recibido la atención que merece, ni por parte del mundo académico ni de los responsables políticos.

El paisaje del territorio de estudio también es resultado de estos cambios. El Alto Minho, al igual que el Noroeste Ibérico, es una de las regiones de Europa con mayor número y recurrencia de incendios forestales (Pereira et al., 2006; Díaz-Fierros, 2019). Según datos oficiales del Instituto de Conservación de la Naturaleza y de las Florestas (ICNF), el territorio presenta para el periodo cubierto por esta investigación (2001 a 2020), un total de 28.223 incendios forestales que corresponden a una superficie total quemada de 179.283 hectáreas. Sin embargo, en el ámbito de esta investigación, tras un riguroso trabajo de cartografía y reconstrucción de los perímetros de las zonas quemadas, fue posible obtener datos muy diferentes de los datos oficiales, sobre todo en lo que se refiere a la superficie quemada y a los impactos reales de los fuegos pastorales, en su contexto más tradicional de uso del fuego.

Este trabajo de reproducción cartográfica y clasificación de superficies quemadas, también permitió identificar la coexistencia en el territorio de diversos tipos de fuegos según su origen. A través de este estudio, fue posible verificar la contribución de cada tipo de fuego en el proceso de cambios del paisaje, así como los efectos de la estacionalidad de los fuegos en los cambios de los tipos de combustible en las últimas dos décadas.

HIPÓTESIS Y OBJETIVOS

Portugal es el país de Europa con mayor número de incendios y superficie quemada, con importantes impactos ambientales, económicos y sociales (Tarín-Carrasco et al., 2021; Tedim et al., 2015). Los datos oficiales del ICNF (Instituto de Conservación de la Naturaleza y Florestas) indican una superficie quemada total acumulada de unos 2,7 millones de hectáreas, resultado de aproximadamente 400.000 incendios ocurridos entre 2001 y 2020 en el territorio continental.

En particular en la región del Alto Minho, como en otras regiones del Nororeste de la Península Ibérica, existe una relación íntima y larga con el fuego. Éste ha sido un elemento importante en la compartimentación y modelación del paisaje, asociado a las prácticas culturales del uso y ocupación milenaria del suelo, definiendo patrones paisajísticos de gran diversidad ecológica y cultural (Bowman et al., 2009; Fernandes et al., 2013; Johansson et al., 2012). Sin embargo, en las últimas décadas, los incendios forestales se presentan en el territorio con una elevada incidencia y recurrencia y cada vez más con mayores extensiones según su frecuencia. Esta característica, en particular, de los grandes incendios presenta una dupla acción, por una parte, el efecto directo sobre el paisaje, provocando serios daños y prejuicios y por otra parte conllevan a la homogeneización del paisaje y de los tipos de combustible presentes. Al contrario, también los incendios de menores dimensiones y bajas intensidades que ocurren en invierno, asociados muchas veces a actividades ganaderas y del uso del fuego tradicional, pueden presentar un rol importante en el paisaje. La distribución en el espacio y en el tiempo de estos fuegos, podrán contribuir para un paisaje más heterogéneo. Sin embargo, las políticas y acciones de supresión y exclusión total del fuego en Portugal están eliminando del paisaje este fuego de baja intensidad y de baja severidad, aunque la carga legislativa no ha disuadido su uso por parte de las comunidades rurales.

Esta investigación busca identificar patrones que describan el régimen de fuego en el territorio y cual la real contribución de los fuegos asociados a las prácticas tradicionales y que cambios están ocurriendo que determinan la ocurrencia de grandes incendios más frecuentes.

Objetivo general

- El principal objetivo de esta tesis es identificar el papel del fuego tradicional y su contribución para el régimen de fuego en la región del Alto Minho.

Objetivos específicos

1. Identificar los diferentes tipos de fuegos que se propagan el paisaje.
2. Comprender y evaluar la evolución histórica normativa y de conocimiento del uso tradicional del fuego al largo de los tiempos y sus riegos.
3. Identificar el régimen de fuego en el territorio de estudio.
4. Evaluar los impactos del fuego en los cambios del paisaje entre 2000 y 2020.

Para el cumplimento del primero y tercero objetivos fueron importantes los trabajos que permitieron producir los artículos integrados como Capítulo IV y V. Los Capítulos I, II y III responden al segundo objetivo. Finalmente, el artículo integrado como Capítulo VI responde al cuarto objetivo específico. El conjunto de los artículos que componen esta tesis responde integralmente a su objetivo principal.

MATERIAL CARTOGRÁFICO, ESTADÍSTICO Y BIBLIOGRÁFICO

Las series históricas de superficies quemadas constituyen una fuente de información esencial para caracterizar los regímenes de fuego, así como para definir las políticas de prevención de riesgos y de ordenación del territorio. El aumento del número de satélites y la mejora de los sensores, así como la facilidad de acceso a los numerosos datos procedentes de las distintas fuentes disponibles, condujeron a un rápido desarrollo de las técnicas y aplicaciones informáticas al servicio de la teledetección. Esta evolución tecnológica ha permitido un mejor y sistemático monitoreo espacial del territorio, como son los cambios en la cobertura del suelo y los impactos de los fuegos.

Esta tesis implicó varias etapas de investigación desde la raíz, es decir, supuso la obtención de datos, registros e información que no se habían recopilado o producido con anterioridad. Para el estudio de caso del Alto Minho, la investigación a esta escala, requería trabajar con los datos más fiables posibles, por lo que las incongruencias detectadas en una evaluación preliminar de la información cartográfica oficial exigieron un esfuerzo adicional (no previsto inicialmente) de reconstrucción y cartografía de los perímetros de las superficies afectadas por los fuegos.

La etapa inicial se caracterizó por la necesidad de producir cartografía de las superficies afectadas por los fuegos y su clasificación. En esta etapa, para el período correspondiente al trabajo de investigación, se adquirieron imágenes de los satélites Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager - OLI) y Sentinel-2 (Multispectral Instrument - MSI). Estas imágenes se obtuvieron a partir del Plugin de Clasificación Semiautomática (SCP) desarrollado por Congedo (2016), para el software QGIS y directamente a través de la plataforma del U.S. Geological Survey - Earth Explorer. En este proceso se obtuvieron alrededor de 450 imágenes de varios satélites, sin nubes o con una nubosidad mínima, con el fin de cubrir el máximo número de meses en cada año del periodo de análisis. A partir de las imágenes (NBR y RGB falso color), se digitalizaron los perímetros de las zonas quemadas, y el proceso se realizó de forma totalmente manual y supervisada, apoyándose en información auxiliar como ortofotos de alta resolución, con el fin de evitar interpretaciones erróneas derivadas de la aparición de cambios en la ocupación del suelo que pudieran alterar los resultados finales (Chuvieco and Congalton, 1988; Ruiz Gallardo, 2007; Tanaka et al., 1983). Una vez concluida la fase de digitalización, se procedió a la datación y clasificación de los tipos de fuegos. Las fechas de ocurrencia registradas por los Servicios Forestales y los datos de los focos de los sensores MODIS y VIIRS, con la superposición de imágenes de satélite, permitieron datar los perímetros obtenidos y clasificarlos según su origen. Del mismo modo, las fechas de obtención de las imágenes de satélite permitieron identificar la estacionalidad de los fuegos cuando no se disponía de registros o de información más precisa.

Esta producción cartográfica se desarrolló en dos periodos diferentes. En el primer periodo, la cartografía se generó entre los años 2001 y 2020, con el fin de superponer los datos estadísticos oficiales de ese periodo, así como otra información disponible que permitiera clasificar cada uno de los perímetros obtenidos: fuegos pastorales, incendios forestales y quemas prescritas.

Un segundo período de producción cartográfica fue acometido para el período 1995-2000, sólo basada en información recogida a partir de imágenes de satélite, ya que no existen datos fiables para la clasificación de los perímetros de los fuegos en este periodo. Únicamente fue posible diferenciar la ocurrencia estacional de los fuegos en aquel período. El objetivo de esta última elaboración de reconstrucción histórica de los perímetros de fuego y su clasificación estacional, fue identificar los efectos de la perturbación del fuego en el territorio en los cambios de los tipos de combustible. Junto con la producción cartográfica elaborada en la primera fase, permitió con más detalle comprender los cambios provocados por los fuegos en el territorio mediante la superposición y análisis de los mapas oficiales de ocupación del suelo producidos entre 1995 y 2018.

El proceso de investigación, en la fase intermedia, se tradujo en un proceso de recogida, recopilación y tratamiento de documentación histórica asociada al uso del fuego y las prácticas tradicionales y documentos legislativos centrados en la regulación del uso del fuego y la prevención de incendios forestales.

Los datos documentales se obtuvieron principalmente de bibliotecas digitales. El análisis siguió una metodología cualitativa con el enfoque exploratorio-descriptivo utilizando la técnica de análisis de contenido (Bardin, 1995). El criterio utilizado para los datos recogidos para este estudio fue que estuvieran disponibles en línea, fueran de libre acceso y estuvieran escritos en portugués o español. En esta fase, se recopilaron y analizaron 205 documentos legales, sentencias y cartas de perdón relacionados con el uso del fuego y los incendios forestales publicados entre los siglos V y XXI, así como 250 documentos históricos producidos entre los siglos VI a.C y XIX referentes a técnicas y prácticas relacionadas con el uso del fuego en actividades rurales.

Durante esta etapa de investigación bibliográfica, se obtuvo igualmente información y registros sobre incidentes relacionados con la quema de rastrojos y restos agrícolas y forestales por parte de la población rural entre 2008 y 2021. Se realizó una revisión exhaustiva de los periódicos nacionales y regionales, tanto impresos como en línea, desde 2008 hasta 2021 para recopilar datos sistemáticos sobre incidentes relacionados con el uso del fuego tradicional, particularmente asociado a las quemas de rastrojos y quemas de restos agrícolas y forestales amontonados. Para evitar posibles duplicidades, cada incidente notificado se contrastó en múltiples fuentes de los medios de comunicación (diferentes revistas, en línea e impresas), y la información recopilada de cada incidente se revisó minuciosamente para comprobar si estaba completa. La localización de cada incidente se georreferenció aproximadamente utilizando el centroide de la parroquia o municipio de la Carta Administrativa Oficial de Portugal de 2022.

La última etapa consistió en la obtención de los mapas del tipo de combustible que permitieran obtener información sobre los efectos de los diferentes tipos de fuegos y su estacionalidad en los cambios del paisaje.

Para este fin, se utilizaron los modelos de combustible desarrollados por Fernandes et al. (2009). Los tipos de combustible se construyeron combinando datos publicados e inventarios de campo y también del Inventario Forestal Nacional (DGF, 2001) que describe la composición y la estructura vertical de la vegetación. La combinación de criterios estructurales y de tipo de vegetación que define los modelos de combustible de Fernandes et al. (2009) permite su fácil reconocimiento sobre el terreno, así como su asociación con las clases de ocupación del suelo. Por lo tanto, la construcción de los mapas del tipo de combustible referidos a los años 2000 y 2018 se basó en los mapas oficiales de ocupación del suelo elaborados por la Dirección General del Territorio (DGT). Los diferentes mapas elaborados a la escala 1:25000, tienen una unidad cartográfica mínima de 1 ha, lo que permite un gran detalle en la obtención de los datos necesarios para el estudio. Esta serie de mapas tiene así una coherencia temática, espacial y temporal que permite realizar análisis comparativos entre distintos periodos (Caetano et al., 2018; DGT, 2019), incluidos los mapas de ocupación del suelo de los años 1995, 2007, 2010, 2015 y 2018. Como datos auxiliares para identificar divergencias y convergencias en las clases de cobertura del suelo, en particular entre 1995 y 2000, se utilizaron los datos de cobertura del suelo de CORINE Land Cover 2000 (CLC2000).

En la siguiente etapa, a partir de esta información, se elaboraron los artículos científicos que que conforman esta tesis que se presenta mediante compendio de artículos.

ESTRUCTURA DEL DOCUMENTO

El presente trabajo está estructurado en dos partes que suman seis capítulos.

La Parte I se compone de tres capítulos resultantes de la revisión documental histórica y legislativa y de los datos de incidentes obtenidos. Su contenido es transversal a todo el territorio nacional.

El Capítulo I se refiere a la evolución legislativa a lo largo de 17 siglos, cuya regulación ha evolucionado a medida que lo han hecho las sociedades y con los cambios en el régimen de la propiedad rústica. Este Capítulo reconstruye la historia legislativa, profundizando en la problemática de la regulación del uso del fuego, según la evolución de los conflictos generados en las diferentes sociedades, desde la Fundación de Portugal hasta 2021.

El Capítulo II es el resultado de la recopilación, revisión y análisis de un amplio conjunto de documentos históricos que describen los diferentes usos del fuego en los paisajes portugueses antes de la motorización agrícola y de la introducción de los fertilizantes químicos. Estos usos, similares en toda la Península, se practicaron durante varios siglos y los conocimientos tradicionales se transmitieron de generación en generación, siendo interrumpidos abruptamente por la fuerza de la ley. Sólo las comunidades rurales más remotas han conseguido mantener vestigios de este fuego tradicional o nativo, que desempeñó un papel esencial en la conformación y conservación de los paisajes durante todo el tiempo que ha perdurado. Este Capítulo reconstruye el uso del fuego nativo de Portugal, también Ibérico, según los registros escritos desde el siglo VI a.C., destacando los conflictos entre los usos y el régimen de propiedad. Estos conflictos se agravaron en la segunda mitad del siglo XIX con las reformas liberales y la introducción de nuevas prácticas asociadas a la modernización de la agricultura, esencialmente cerealista, la introducción de la motorización agrícola y los fertilizantes inorgánicos. Estos cambios tuvieron efectos legislativos y, por consiguiente, los cambios de usos y el abandono de prácticas milenarias produjeron profundos cambios en los paisajes.

El Capítulo III concluye la Parte I y aborda un tema de actualidad, aunque inédito, abriendo una nueva línea de investigación. Este Capítulo analiza desde una perspectiva más social, la evolución de los incidentes provocados por el uso del fuego por parte de la población rural, en la quema de rastrojos y de restos amontonados agrícolas y forestales, entre 2008 y 2021. Los incidentes son relacionados con el envejecimiento de la población rural, su aislamiento y la presión legislativa en materia de lucha contra incendios forestales.

La Parte II está compuesta igualmente por tres capítulos que resultan integralmente del trabajo de cartografía de las superficies afectadas por los fuegos y su clasificación en la región del Alto Minho.

El Capítulo IV presenta una metodología para la elaboración de una cartografía detallada y rigurosa de las superficies afectadas por fuegos en las dos últimas décadas (2001 a 2020) en el territorio del Alto Minho. Los resultados obtenidos muestran la necesidad de reconstrucción de las series históricas cartográficas. Todos los estudios realizados hasta ahora en Portugal se basaron en la cartografía oficial, aunque varios autores reconocen sus inconsistencias cartográficas y estadísticas. Esta falta de precisión tenderá a agravarse a una escala regional o municipal con consecuencias en los resultados finales, como la caracterización del régimen de fuego y sus impactos reales o implicaciones y limitaciones a la ciudadanía, por la aplicación de aquella cartografía en los planes de ordenación y desarrollo urbano y en la ejecución de medidas de prevención de incendios forestales. Una cartografía detallada es fundamental para caracterizar el régimen de incendios y estudiar sus impactos y efectos en los cambios del paisaje y en la aplicación de los planes de defensa contra incendios forestales.

El Capítulo V profundiza en la contribución de los incendios pastorales en el régimen de fuego de la región de estudio. La identificación de estos fuegos que ocurren en las estaciones de otoño, invierno y primavera resultó del trabajo de cartografía y clasificación descrito en el capítulo anterior, para los cuales no existe un registro de ocurrencia asociado a la base de datos oficial, por lo tanto, sin intervención de los equipos del dispositivo de extinción. Normalmente estos incendios están asociados a la renovación de pastos, y no siendo controlados acaban autoextinguiéndose. Aunque ilegales, representan una parte sustancial de la superficie total quemada en el territorio, contribuyendo a regímenes de incendios y ecosistemas más sostenibles.

El Capítulo VI analiza y describe los cambios en el paisaje como resultado de los diferentes fuegos, considerando los tipos de combustible en dos períodos, coincidiendo con las publicaciones de los Mapas de Uso y Ocupación del Suelo, producidos por la DGT, más concretamente entre 1995 y 2007 y entre 2007 y 2018. Para este capítulo fue necesario cartografiar los perímetros de los fuegos producidos entre 1995 y 2000, aplicando la misma metodología descrita en el Capítulo IV. En este capítulo se trató de identificar el efecto del fuego en la homogeneización del paisaje, diferenciando los efectos de los fuegos pastorales y de los incendios forestales en los cambios del paisaje.

Por último, culmina este trabajo con la discusión de los resultados según los hallazgos de otros autores y a continuación se exponen las conclusiones generales, derivadas de los principales resultados, a partir de una perspectiva global basada en la información y el aprendizaje adquirido en el proceso de investigación. También se presentan al final las futuras líneas de investigación.

CAPÍTULO I - THE USE OF VEGETATION FIRE IN PORTUGAL: HISTORICAL LEGISLATIVE AND NORMATIVE ANALYSIS

Abstract. Fire has been a widely used tool in habitat and landscape management, mainly associated with land use dynamics of deforestation, pasture renewal, hunting, and reclaiming new agriculture and rangeland areas. Ancient societies followed norms and rules to use fire. However, as these societies developed and land ownership changed, the conflicts generated by using fire triggered the need to regulate this practice by establishing the first laws. Such laws became of a broader type and narrower application over time until the twenty-first century. This research hypothesises that imposing constraints and regulations on using agro-silvopastoral fire throughout legislation in Portugal did not discourage its traditional use by communities. Through the historical legislative reconstruction of fire uses before Portugal's Foundation until 2021, it was possible to confirm the hypothesis and conclude that a paradigm change is needed by setting up an adequate legal framework for the different uses of fire in the land.

Keywords: Traditional fire use; fire legislation; sanctions; historical reconstructions.

Resumen. *El uso del fuego en Portugal: análisis histórico legislativo y normativo*

El fuego ha sido una herramienta ampliamente utilizada en la gestión de hábitats y paisajes, principalmente asociada principalmente a la dinámica del uso del suelo por deforestación, renovación de pastos, caza y recuperación de nuevas zonas agrícolas y pastizales. Las antiguas sociedades seguían normas y reglas para utilizar el fuego. Sin embargo, a medida que estas sociedades se desarrollaban y cambiaba la propiedad de la tierra, los conflictos generados por el uso del fuego desencadenaron la necesidad de regular esta práctica estableciendo las primeras leyes. Con el paso del tiempo, dichas leyes fueron de tipo más amplio y de aplicación más restringida, hasta llegar al siglo XXI. Esta investigación parte de la hipótesis de que la imposición de limitaciones y normativas sobre el uso del fuego agrosilvopastoral a través de la legislación en Portugal no desincentivó su uso tradicional por parte de las comunidades. A través de la reconstrucción legislativa histórica de los usos del fuego antes de la Fundación de Portugal hasta 2021, fue posible confirmar la hipótesis y concluir que es necesario un cambio de paradigma mediante el establecimiento de un marco jurídico adecuado para los diferentes usos del fuego en el territorio.

Palabras clave: Uso tradicional del fuego; legislación sobre incendios; sanciones; reconstrucciones históricas.

Resumo. *O uso do lume en Portugal: análise histórica lexislativa e normativo*

O lume foi unha ferramenta amplamente utilizada na xestión de hábitats e paisaxes, principalmente asociada principalmente á dinámica do uso do chan por deforestación, renovación de pastos, caza e recuperación de novas zonas agrícolas e pastos. As antigas sociedades seguían normas e regras para utilizar o lume. Con todo, a medida que estas sociedades desenvolvíanse e cambiaba a propiedade da terra, os conflitos xerados polo uso do lume desencadearon a necesidade de regular esta práctica establecendo as primeiras leis. Co paso do tempo, ditas leis foron de tipo máis amplo e de aplicación máis restrinxida, ata chegar ao século XXI. Esta investigación parte da hipótese de que a imposición de limitacións e normativas sobre o uso do lume agrosilvopastoral a través da lexislación en Portugal non desincentivó o seu uso tradicional por parte das comunidades. A través da reconstrución lexislativa histórica dos usos do lume antes da Fundación de Portugal ata 2021, foi posible confirmar a hipótese e concluír que é necesario un cambio de paradigma mediante o establecemento dun marco xurídico adecuado para os diferentes usos do lume no territorio.

Palabras chave: Uso tradicional do lume; lexislación sobre incendios; sancións; reconstrucións históricas.

1.1 INTRODUCTION

Fire has been essential to societies' development over time. Fire use, its constraints and conflicts, and the consequences arising from its use can be reconstructed based on historical legislative and normative analysis.[1,2] Worldwide, indigenous societies created their own rules for co-living, passing them between generations, and the Iberian Peninsula in southwestern Europe was no exception. Later, between the first century bce and the fourth century ce, the Roman Empire created the first laws.[3] After the fall of the Roman Empire and the beginning of the Middle Ages (fifth century ce), Germanic cultures, such as Visigoths and Swabians, dominated the Iberian Peninsula, which led to the continuous merging of their cultures and political organisations, along with the inherent laws. The Visigoth Law lasted until the fifteenth century when the Alfonsine Ordinances were published, giving rise to Portuguese Law.[4]

During the Visigoth period, the "village community" territorial organisation was established in the northern Iberia Peninsula, which now encompasses northern Portugal and Spain. This organisation was rooted in pre-Roman indigenous societies and consisted of autonomous communities without dependence on a landlord.[5] Each family had farmland and had the right to use common lands and shared farm tools, associate with other owners for shared cereal farming, or maintain shared flocks.[6] At that time, the use of fire would depend on each community's individual, family, or collective objectives, where the local practices and customs would solve the conflicts generated by its use.

Land use rearrangements were significant in the mid-Middle Ages since it was when the Iberian Kingdoms, including the Kingdom of Portugal, were founded. At that time, the Manorial regime was widespread, with land ownership passed to the king and his successors and shared among clergy and concessions to the nobles.[7] As a result, Portugal had a tripartite division of property, the Crown's, private and common assets; communities managed the latter according to Title LXVII "*Of the Sesmarias"*.[8]

King Ferdinand I of Portugal enacted the Sesmarias Law in 1375 to farm the land and reduce depopulation. It forced landowners to cultivate their lands under penalty of expropriation, encouraging the use of common lands for agro-silvopastoral activities as established by the Charter Letters, granted by the Portuguese Kingdom's first Monarchs to the local communities. Charter Letters were legal documents, mandatory for the communities, containing norms and essentially ruling public Law.[9,10] However, what was not included in public Law continued to be ruled by local practices and customs, which were transmitted orally

[1] C. Montiel (ed.), Presencia histórica del fuego en el territorio (Madrid: Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013).
[2] C.R. Sequeira, C. Montiel-Molina and F.C. Rego, 'Historical fire records at the two ends of Iberian Central Mountain System: Estrela massif and Ayllón massif', Investigaciones Geograficas 72 (2019): 31–52.
[3] E. Fernandes and A. Rêgo, História do Direito Português. Súmula das lições proferidas pelo Ex.mo Prof. Doutor Marcelo Caetano ao Curso do 1o Ano Jurídico de 1940-41 na Faculdade de Direito de Lisboa (Lisboa: Faculdade de Direito de Lisboa, 1941).
[4] M. Lobo da Costa, 'A Revogação da Sentença no Direito Lusitano (Perfil Histórico)'. Revista da Faculdade de Direito 78 (1983): 110–140.
[5] J.A.G. Cortázar, Organización social del espacio en la España medieval. La Corona de Castilla en los siglos VIII a XV, Working paper (Barcelona: Ariel, 1985).
[6] C. Fabião, 'O Passado Proto-Histórico e Romano', in J. Mattoso (ed.), História de Portugal, Volume I: Antes de Portugal (Lisboa: Círculo de Leitores, 1992), pp. 79-299.
[7] C. Barros, 'La humanización de la naturaleza en la Edad Media', Edad Media: Revista de historia 2 (1999): 169–194.
[8] J.J.A. Dias, Ordenações Manuelinas: Livros I a V. Reprodução em fac-símile da edição de Valentim Fernandes (Lisboa, 1512-1513), Volume V, First edition (Lisboa: Universidade Nova de Lisboa. Centro de Estudos Históricos, 2002).
[9] É. Carra, As Sesmarias do Reino à Colónia. (MsC Thesis, Universidade de Coimbra, 2020).
[10] E.C. Pereira, Concelhos e Ordens Militares na Idade Média. Relações de dependência e de confronto dos séculos XII a XIV. (MsC Thesis, Universidade do Porto, 2013).

until the mid-thirteenth century, when they started to be recorded in writing and be called *fori* and customs.[11]

Portuguese rural landscape started evolving in the Middle Ages with cereals and wine. The mercantilist economy and the Sesmarias Law fostering have led to the broader use of fire for clearing land, which allowed new agro-silvopastoral activities. However, this much broader use of fire also led to land use conflicts between landowners, triggering the need for official regulation.[12] Nevertheless, between the fifteenth and nineteenth centuries, there were no major changes in Law to use fire. Changes have only occurred by replacing the Ordinances with the Penal Code of 1886.

Portuguese forest legislation followed the European trend from the last decades of the twentieth century, in which the regulations and norms produced with a particular focus on wildfires sought to operationalise a wide range of measures aimed at the suppression in the short-term and mainly investing in excluding fire from the landscape.[13] Several authors have addressed and analysed the impact of Portuguese forest legislation over the last few decades, especially from the beginning of the twentieth century. Rego et al.[14] focused on the Portuguese Forest Regime's historical evolution and its impact on communities from the beginning of the twentieth century. Mourão et al.[15] studied the nature of legislation published between 1997 and 2017 on wildfires to argue that legislation is reactive to previous large wildfires, but their approach was simplistic and biased.[16] Devy-Vareta,[17] among other authors such as Trápaga Monchet,[18,19] Labrador Arroyo[20], Radich[21] and Melo,[22,23,24,25] analysed the evolution of protecting woodlands and Royal fenced-game lands in Portugal between the fifteenth and seventeenth centuries. Other authors, such as Costa Lobo,[26] Caldas,[27] Oliveira et al.,[12] Monteiro

---

[11] A.M. Pinto, O Lavrador de Forais - Estudo dos forais outorgados por D. Dinis. (Msc Thesis, Universidade de Coimbra, 2008).

[12] E.V. de Oliveira, F. Galhano and B. Pereira, Alfaia agrícola portuguesa (Lisboa: Etnográfica Press, 1995).

[13] C. Montiel-Molina, 'Comparative assessment of wildland fire legislation and policies in the European Union: towards a Fire Framework Directive', Forest Policy and Economics 29 (2013): 1–6.

[14] F. Rego and I. Skulska, 'Evolução Histórica do Regime Florestal em Portugal', in M.J. Antunes and D. Lopes (eds.), Florestas e Legislação: Que Futuro?, (Coimbra: Faculdade de Direito da Universidade de Coimbra, Instituto Juridíco, 2019), pp. 75-82.

[15] P.R. Mourao and V.D. Martinho, 'Discussing structural breaks in the Portuguese regulation on forest fires- An economic approach', Land Use Policy 54 (2016): 460–478.

[16] P.M. Fernandes, N. Guiomar, P. Mateus and T. Oliveira, 'On the reactive nature of forest fire-related legislation in Portugal: A comment on Mourão and Martinho (2016)', Land Use Policy 60 (2017): 12–15.

[17] N. Devy-Vareta and A.A.M. Alves, 'Os avanços e os recuos da floresta em Portugal - da Idade Média ao Liberalismo' in J.S. Silva (ed.), Floresta e sociedade, uma história em comum, (Lisboa: Público SA e Fundação Luso-Americana, 2007), pp. 55–75.

[18] K. Trápaga Monchet, 'El estudio de los bosques reales de Portugal a través de la legislación forestal en las dinastías Avis, Habsburgo y Braganza (ca. 1435-1650)', Philostrato. Revista de Historia y Arte 1 (1987): 5–27.

[19] K.Trápaga Monchet and F.L. Arroyo, 'Políticas forestales y deforestación en Portugal, 1580-1640: realidad o mito?', Ler História 75 (2019): 133–156.

[20] F. Labrador Arroyo, La Casa Real en Portugal (1580–1621) (Madrid: Polifemo, 2009).

[21] M.C. Radich and A.A.M. Alves, Dois Séculos da Floresta em Portugal (Lisboa: CELPA, 2000).

[22] C.J. de Melo, 'Guerra, impérios e Corte Joanina nas Coutadas de Caça: Alavancas de Regeneração Florestal em Portugal, em Meados do século XVIII', Manuscrits 42 (2020): 199–220.

[23] C.J. de Melo, 'Menos coutadas melhores pinhais: império, inundações, fisiocracia, guerra e especialização das matas reais em Portugal (1777-1824)', Tiempos Modernos 39 (2019): 456-487.

[24] C.J. de Melo, An Analysis of the Royal Preserves in Portugal: issues of privilege, power, management and conflict (Sheffield: Wildtrack Publishing, 2015).

[25] C.J. de Melo, Coutadas reais (1777-1824): privilégio, poder, gestão e conflito (Lisboa: Montepio Geral, 2000).

[26] A. Costa Lobo, História da Sociedade em Portugal no Seculo XV - Secção I: População; Aspecto Geral do Paiz e do seu Estado social; Pesos e Medidas; Moeda; Os Haveres Individuais (Lisboa: Imprensa Nacional, 1903).

[27] E.C. Caldas, A Agricultura na História de Portugal (Lisboa: Empresa de Publicações Nacionais, Lda., 1995).

Alves[28] and Pinho et al.,[29] studied general fire conflicts between agro-silvopastoral practices. However, none of the studies published to date address specifically what were the constraints imposed by the legislation regulating the use of fire in Portugal.

This paper aims to identify the source of the conflicts associated with the use of fire as an activity related to traditional practices and the respective associated legislation based on searching, compiling and analysing fire-use-related documentary sources, mainly legal documents until 2021. We hypothesise that despite the imposed legislative constraints on using agro-silvopastoral fire in Portugal, its traditional use by communities was not discouraged. Moreover, the disconnection between fire and landscape will likely decrease community empowerment and fire-resilient landscapes. We aim to answer two research questions: (1) Did the legislation type of approach to the uses of fire change over time?; and (2) Were sanctions/legislation applied consistently throughout the country?

1.2 Materials and methods

We retrieved, compiled and analysed documentary sources, namely legislation, judicial sentences and pardon letters related to the use of fire and wildfires, for the last seventeen centuries in Portugal's mainland. Data were retrieved according to the following criteria and availability of the sources: being publicly and freely available online; rules and norms concerning the use of fire in the Iberian Peninsula and later in Portugal, thus excluding other forest regulations. Although references are made to related actions, such as prevention, the study focuses on using fire as an activity above all related to traditional practices.

Documentary data were retrieved mainly from sixteen digital libraries (Table 1). Several types of legal documents were considered in the compilation, such as Laws, Decree-Laws, Orders, Ordinances, Regiments, Permits, Royal Decrees, Penal Codes and Royal Charters. In addition, Pardon Letters for damages caused by the use of fire were analysed to understand the sanctioning regime. Pardon letters are documents granting the King's pardon, regardless of what was established in the legislation, and show the relationships of power and negotiation of the time. The twentieth and twenty-first centuries specific documentation was retrieved from Portugal's Portuguese National Official Gazette. Judicial sentences and Pardon letters for damages caused by the use of fire were found in the three following sections of the Portuguese Digital Archive of Torre do Tombo: House of Abrantes (fourteenth century); Chancelleries of King Alfonso V of Portugal (fifteenth century); and Chancelleries of King Manuel I of Portugal (sixteenth century). Concerning all the other documentation, no library or repository platform was devoted to a specific century, and documents from different centuries were found in all archives mentioned above.

[28] A.A. Monteiro Alves, N. Devy-Vareta, Â.C. Oliveira and J. Santos Pereira, 'A floresta e o fogo através dos tempos', in J. Santos Pereira, J.M. Cardoso Pereira, F. Castro Rego, J.M. Neves Silva and T. Pereira da Silva (eds.), Incêndios Florestais em Portugal. Caracterização, Impactes e Prevenção (Lisboa: ISAPress, 2006), pp. 15–40.
[29] J. Pinho and P. Mateus, 'Retrato a carvão: A gestão do fogo no âmbito da Administração Florestal e do Ordenamento Florestal do Território. Subsídios para uma perspectiva histórica e de futuro', Territorium 26 (2019): 61–88.

Table 1. Sources of historical data retrieved for the study. Source: Elaborated by the authors.

Source	Available at
Portuguese National Digital Library	https://bndigital.bnportugal.gov.pt
Luso-Brazilian Digital Library	https://bdlb.bn.gov.br/acervo/browse
Portuguese Digital Library of the Court of Auditors	https://bdigital.tcontas.pt/titulos/o.shtm
National Digital Library of Brazil – SophiA	http://acervo.bndigital.bn.br/sophia/index.html
Brasiliana Guita and José Mindlin Library	https://digital.bbm.usp.br/handle/bbm/1
Digital Library of the Federal Senate of Brazil)	https://www2.senado.leg.br/bdsf/
Digital Library of the Chamber of Deputies of Brazil	https://bd.camara.leg.br/bd/
Centre for Historical Studies of the Nova University of Lisbon	https://ceh.fcsh.unl.pt
Digitalis Library of the University of Coimbra	https://digitalis-dsp.uc.pt
Digital Parliamentary Debates Library	https://debates.parlamento.pt
Portuguese National Official Gazzette of Portugal	https://dre.pt/dre/home
Digital Law Library of the State Agency of the Official Bulletin of Spain	https://www.boe.es/bibliotecajuridica/index.php?tipo=L&modo=2
Academic Library of the Spanish Royal Academy	https://www.rae.es/biblioteca/biblioteca-academica
Non-profit Digital Library Internet Archive	https://archive.org
Google Books	https://books.google.pt
Portuguese Digital Archive of Torre do Tombo	https://digitarq.arquivos.pt

First, the search was conducted by keyword in all digital libraries identified, using the words "ignis" in Latin, and "fire", "burn" and "extensive burn" in their Portuguese and Spanish variations (i.e., fogo, incêndio, queima, queimada, fuego, incendio, quema and quemada). Then, the pertinent data was thoroughly analysed and integrated using worksheets and geographic information systems and resorting to content analysis. First, the references to geographical locations throughout legislation were plotted to understand the geographical distribution over the country. Secondly, the following categories were defined as a result of the content analysis for identifying what wildfire topic is the focus of the legislation at each of the four periods: damage, fire use limitation, management, firefighting and prevention. Handwritten sources were not included in the study because they do not allow a keyword search, and none of the authors have knowledge of palaeography.

We divided the historical analysis into four periods, according to the changes in history we have identified and related to possible triggers of change in fire legislation. The four periods are as follows: (1) Common Law in the Kingdoms of the Iberian Peninsula: from the pre-Roman period to the Foundation of the Portuguese Kingdom; (2) Portuguese Law: from Portugal's Foundation (1143) to the mid-nineteenth century; (3) Forest Regime: from the late nineteenth century to the late twentieth century; and (4) Large fires: the twenty-first century (until 2021).

1.3 RESULTS AND DISCUSSION

We consulted and retrieved 205 legal and historical documents related to the use of fire between the fifth and twenty-first centuries. The Alfonsine Ordinances (fifteenth century), one of the first collections of laws of the Modern Era, omitted the use of fire.

Until the nineteenth century, 26 legislative documents were published on fire-use limitations and penalties for damaging fires. In contrast, fifteen legislative documents were published on the same subject in the twentieth century. Furthermore, the twenty-first century stands out in the entire historical legislative path for producing, in about two decades, the most significant number of documents in such a short period (nineteen documents), surpassing the twentieth century in the number of publications and even exceeding the entire period since the Foundation of Portugal (1143) until the end of the nineteenth century when fire was widely used throughout the country (Figure 1). Concerning the territorial application level, 45 were national, two were regional and five were municipal/local.

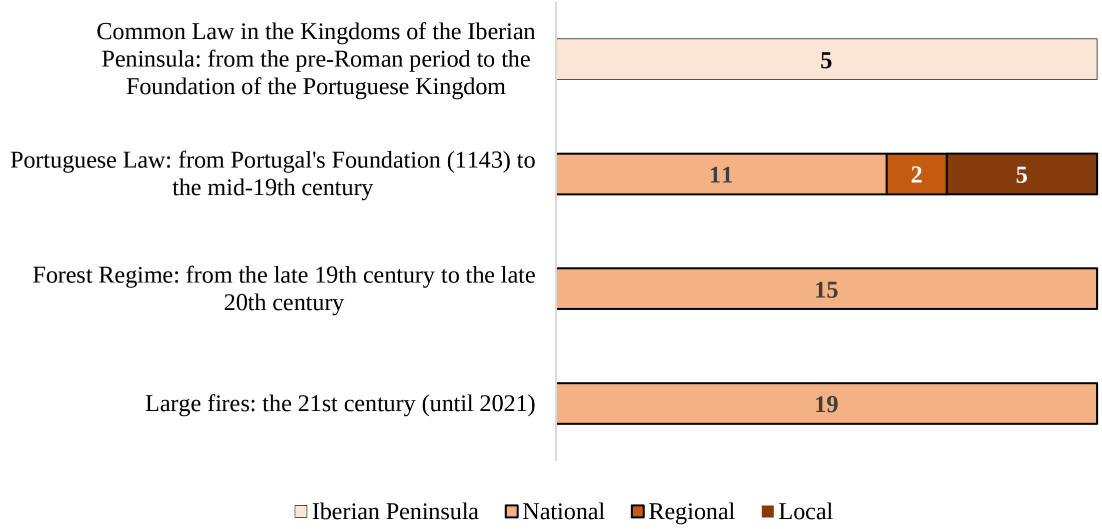


Figure 1. Number of legal documents compiled and consulted on the use of fire between the fifth and twenty-first centuries ce. This graphic did not consider pardon letters because they are not legal documents. Source: Elaborated by the authors.

Across all periods, the legislation focused not only on a specific use of fire but on several uses of fire instead. Moreover, these different uses of fire are associated with numerous practices characteristic of rural societies' agro-silvopastoral systems, particularly those of the Iberian Peninsula, where fire use has always been intrinsically cultural. Furthermore, the legislation limiting fire use over the centuries has maintained a sanctioning regime to reduce the damage caused by fire and hold perpetrators accountable. In this context of fire use as a cause of wildfires, the legislation published for several centuries should not be viewed as directly reactive to large wildfires, at least until 2004, as defended by Fernandes et al.[16], rejecting what Mourão et al.[15] had previously suggested. Before the large fires period (the twenty-first century), the published legislation was in the frame of the coexistence of fire and society over time. Significant changes were implemented during the large fires period in response to the devastating wildfires of 2003, 2005 and 2017, which burned four to five per cent of the country each time. These changes included establishing the first national system of forest defence against wildfires in 2004,[30] developing the first forest national strategy process in 2006,[31] and publishing several pieces of legislation to support these efforts.

---

[30] Portuguese Government (Ministério da Agricultura, Desenvolvimento Rural e Pescas), Decreto-Lei n.o 156/2004, de 30 de Junho, Diário da República n.º 152/2004, Série I-A, pp. 3968-3975, Sistema Nacional de Prevenção e Proteção da Floresta contra Incêndios (Portugal: Imprensa Nacional da Casa da Moeda, 2004). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2542&tabela=leis&so_miolo (accessed 13 Mar, 2023).

[31] Portuguese Government (Presidência do Conselho de Ministros), Resolução do Conselho de Ministros n.o 114/2006 - Estratégia Nacional para as florestas. Diário da República, 1ª série, Nr 179, 15 de Setembro, pp. 6730-6809 (Portugal: Imprensa Nacional da Casa da Moeda, 2006). https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/114-2006-539852 (accessed 10 Mar, 2023).

1.3.1 Common Law in the Kingdoms of the Iberian Peninsula: from the pre-Roman period to the Foundation of the Portuguese Kingdom

As expected, no specific written documents on limiting fire use were found until the thirteenth century bce. For that reason, this first period was reconstructed based on literature. One of the first worldwide descriptions of the penalty applied to support the costs of the damages caused by a fire spreading to cultivated fields can be found in the Mosaic Law. The Mosaic Law is associated with the Torah and is composed of a code of laws formed by Orders and Prohibitions, which were allegedly implemented in Mesopotamia around the thirteenth century bce ([32] and Book of Exodus, Psalm 22:6 [33]). Given its temporal and spatial context, this record shows the conflicts generated by using fire and agricultural activities at the time. However, we did not find any historical document recording it, as no written documents legitimised these sanctions, and the community generally punished the perpetrator.

During the Romanisation and its so-called Roman Law, the Iberian Peninsula peoples integrated part of the Mosaic Law into their daily lives through the influence of the empire's religion.[34] In the fifth century bce, the implemented Laws of the Twelve Tables (*Lex Duodecim Tabularum*) stood at the Foundation of Roman Law. In the Seventh Table (*De Delictis*), it is understood that the origin of conflicts derived from rural activities that are closely interconnected, such as grazing, fire and agriculture, which overlaps with the first reference found in the Mosaic Law.[35] However, the penalties seem harsher than in the Mosaic Law. Whether the fire was caused by arson or negligence, the perpetrator was sentenced to be beaten with rods and thrown into the fire.[36] Roman society was generally ruled by several nature conservation norms and regulations, especially about trees, livestock, crops and the severity of fire-caused damage.[37] Still, in the Roman period, likely around 286 bce, conflicts in the use of fire, grazing and agriculture were subjected to the principle of reparation of damage, i.e., the plebiscite *lex Aquilia*. This principle stated that in the event of damage caused, the respondent must pay the owner the corresponding value within thirty days. Later, it merged with the vast legislative compilation of the Justinian Code of the first half of the sixth century bce at the end of the Roman Empire.[37]

The former Western Roman Empire, i.e., the Iberian territory under Visigoth domination, established the first written laws and instituted Euric's Code in 476 ce, followed by Leovigildo's Code (580 ce) and the Visigoth Code (654 ce), all built over the previous, assimilating conceptions of Roman Law and bringing together the norms and laws of common Law.[38] The Visigoth Code intended to regulate the local practices and customs of the Hispano-Roman and Visigoth communities. This Code references the penalty applied to arsonists, set to be arrested and subjected to 100 or 150 lashes, in case the recipient was the master or the servant, respectively. According to experts' evaluation, the arsonist would repay the amount due for what was burned. Negligent fires were also considered, and the damage was reimbursed, with

---

[32] F.L. Castro, História do Direito Geral e Brasil (Rio de Janeiro: Livraria e Editora Lumen Juris Lda Rio, 2010).
[33] B.S. Childs, The Book of Exodus: A Critical, Theological Commentary (Kentucky: Westminster John Knox Press, 1974).
[34] E. Carrasco Jiménez, 'Derechos humanos y Régimen de garantías en la legislación Mosaica', POLIS, Revista Latinoamericana **6** (17) (2007): online.
[35] A. Santos Justo, 'As actiones do daño aquiliano', in A.D-B. Cremades and J.G. Sánchez (eds.), Fundamentos Romanísticos del Derecho Contemporáneo. Volume VI (Spain: Asociación Iberoamericana de Derecho Romano, Boletín Oficial del Estado, 2021), pp. 571–605.
[36] E.M.A. Madeira, 'A Lei das XII Tábuas', Revista da Faculdade de Direito de São Bernardo do Campo **136** (2007): 125-138.
[37] R. Aramburu Córdoba, La evolución de la Lex Aquilia: desde la Lex de las XII Tablas hasta el Digesto de Justiniano. First edition (La Plata: Editorial de la Universidad Nacional de La Plata, 2021).
[38] L. Dal Ri, 'A Tradição Romanística em Período Medieval: entre práxis e esquecimento - Roman Legal Tradition in Medieval Period: between oblivion and praxis', Seqüência: Estudos Jurídicos e Políticos **74** (2016): 269-294.

particular reference to the most relevant assets of the time (cereal crops, stubble, vineyards, houses, or orchards).[39]

1.3.2 Portuguese Law: from Portugal's Foundation (1143) to the mid-nineteenth century

During the first three centuries of the Kingdom of Portugal, the country followed the Visigoth Code until the publication of the Alfonsine Ordinances in 1446. Therefore, until that moment, the sources of Portuguese Law were mainly Charter Letters, "general laws", municipal customs or *fori*, and Canon Law.[3] The Ordinances of King Edward I of Portugal (1433-1438), likely published in 1436,[40] gives powerful insights from the past as it compiles legislation back to King Alfonso II of Portugal (1211-1223). Furthermore, a reference to King Denis I of Portugal and the Algarves (1279-1325) was found in cases where the Church should not intervene if the perpetrator seeks protection, namely, arsonists that destroy vineyards, trees, grainfields and roads.[40] This request from the King to the Church is a symptom of the conflicts between the Crown and the religious orders about land ownership and their power to protect perpetrators in the Church's lands, sheltering them.[41]

Moreover, the Royal Chancelleries of King Denis I of Portugal contains a Charter of Barter, dated June 3, 1300, between King Denis and Infante Alfonso of Portugal. This charter refers to not damaging vineyards or trees, not starting fires in his lands, nor demanding to do so unless Infante Alfonso of Portugal starts a war with King Denis, and a fire could start as a weapon to destroy the land.[40] The limitation of not using fire unless there is a war shows the importance of protecting vineyards and trees from fire.

In the fourteenth century, personal conflicts and their settlement started to be recorded in written documents, indicating that they became more relevant within communities. The first record found is from 1373 and reports on an agreement between inhabitants of Redondo to pay off a debt related to a fire that damaged the vineyards of a private owner (Casa de Abrantes, box 88, document 4920, Portuguese Digital Archive of Torre do Tombo).

Despite previous legislative records on limiting, sanctioning and sentencing regarding the use of fire, burned areas continue to be usual in hunting areas belonging to the Crown.[28,42] For instance, according to records of King John I (1415-1433) of Portugal' *Livro de Montaria*/Book of Wild Boar Hunting, all hunting dogs should be trained to prey for wild boars outside of burned areas.[43] Therefore, it is pretty surprising that the Alfonsine Ordinances, published ten years later (1446), did not reference fire uses and restrictions, considering the eight records in King Alfonso V of Portugal's Letters of Pardon about fire damage between 1440 and 1471, i.e., during his reign (1438-1477). In addition, there is also a Charter of Privilege by King Alfonso V, dated 1464, limiting the use of fire on the banks of the Mondego River, and a Letter of Pardon, dated 1473, mentioning a personal pardon for destroying some vineyards in Évora.[44]

---

[39] Fuero Juzgo en Latin y Castellano cotejado con los mas antiguos y preciosos Códices. Por La Real Academia Española (Madrid: Ibarra, Impresor de Cámara de S. M., 1815).

[40] M. Albuquerque and E.B. Nunes, Ordenações Del-Rei Dom Duarte. First edition (Lisboa: Fundação Calouste Gulbenkian, 1988).

[41] J. Pais and F. Reboredo, 'A construção naval e a destruição do coberto florestal em Portugal - Do Século XII ao Século XX', Ecologi@ **4** (2012): 31–42.

[42] C. Baeta Neves, *Alguns documentos do Arquivo Nacional da Torre do Tombo sobre Monteiros-mores, Caçadores-mores e Caçadores e Couteiros de perdizes* (Lisboa: Sociedade Astória, Lda., 1965).

[43] F. Pereira, *Livro da Montaria, feito por D. João I, Rei de Portugal* (Coimbra: Academia das Sciências de Lisboa, 1918).

[44] L. Duarte, Justiça e criminalidade no Portugal medievo 1459-1481. (PhD Thesis, Universidade do Porto, 1993).

Therefore, we assume that the punitive Visigoth Code, or local customs, was still applied at the time to solve fire-related conflicts and not that there were no more fire-related conflicts to solve. In effect, King John II of Portugal's Royal Charter, dated 1491, designated a kind of guard (*monteiro*) to monitor the banks of the Mondego as far as Linhares at the request of the inhabitants of Coimbra, indicating the continuity of conflicts over the use of fire and the several fires starting in the woods and banks of the river.

Moreover, there are 39 registers of Pardon letters compiled in the Chancelleries of King Manuel I of Portugal (1495-1521), dated between 1496 and 1517, referring to damage caused by using fire, mainly agricultural damage, of which 32 registers report to the year 1501 (Figure 2). It was impossible to identify the Law by which the use of fire was regulated at that time, but it is evident from the Kings Manuel I Ordinance descriptions that there would be a license requirement. Additionally, the severity of the penalty for causing a fire would depend on whether there was a license and the extent of damage. According to Freitas do Amaral,[45] this more significant effort to comply with legislation can be due to the reformist impulse of King Manuel I's reign in the justice field.

The records of the Pardon letters of the Chancelleries of King Alfonso V and King Manuel I show a geographical distribution more concentrated in the south of the country (79 per cent), followed by the Centre region (15 per cent), and lastly, northern Portugal (6 per cent) (Figure 2).

[45] D. Freitas do Amaral, ‘As reformas jurídicas, administrativas e financeiras de D. Manuel I e a construção do Estado Moderno em Portugal’, in CMGuimarães (ed.), *Livro de Atas de Conferência Internacional - III Congresso Histórico de Guimarães. D. Manuel e a sua época. 1a Secção: Administração, Justiça e Direito* (Guimarães: Câmara Municipal de Guimarães, 2001), pp. 50-60.

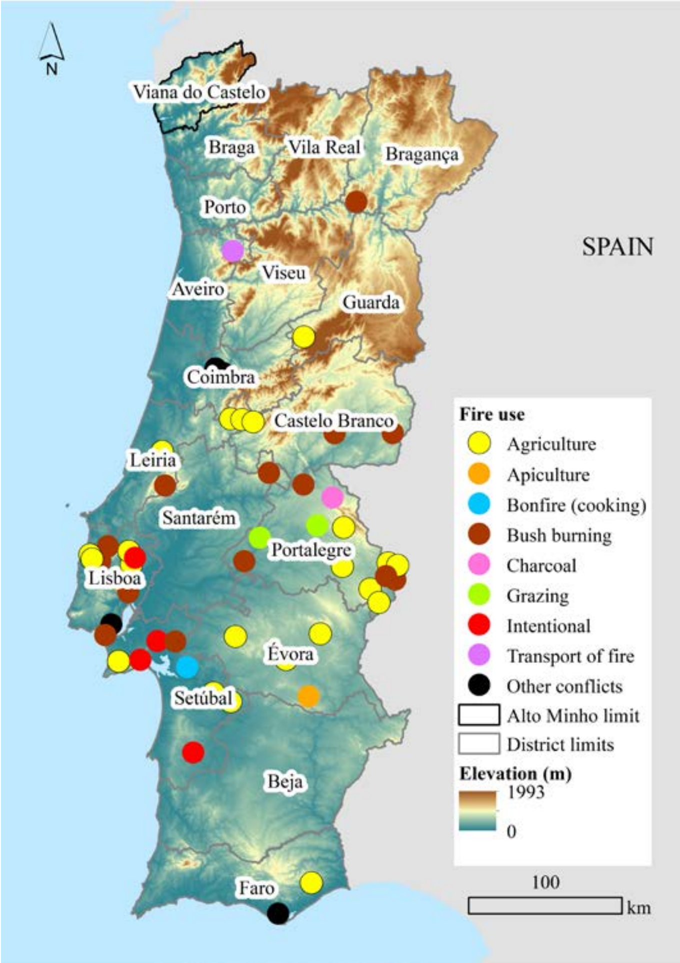


Figure 2. Geographical distribution of the Pardon letters related to the use of fire, granted during the reigns of King Alfonso V of Portugal (1438-1481) and King Manuel I of Portugal (1495-1521), and geographical locations of other conflicts found in legislation. Sources: District limits of Portugal 2022, DGT, http://id.igeo.pt/cdg/198497815bf647ecaa990c34c42e932e; Elevation Coverage map 2019, ESRI. Elaborated by the authors.

On the one hand, this geographic distribution may be related to the beginning of the Montados in the Alentejo through shrubland clearings. Oliveira Marques[46] describes the excessive use of fire in the extensive, uninhabited southern Portugal to clear shrubland, expand farmland and create/maintain hunting areas. On the other hand, there is no reference in the Chancelleries to sentences related to fire use in northwestern Portugal (Alto Minho), despite mid-sixteenth century local descriptions of a traditional system where fire use would be present.[7,47] The local practices and customs of the Alto Minho common lands might explain this lack of fire-related sentences: the rights were shared among the rural communities and allowed the use of fire for pasture renewal, hunting and the opening and fertilisation of land for cereal crops, in particular rye,[46] making the use of fire acceptable even today.

---

[46] A. Oliveira Marques, Introdução à história da agricultura em Portugal: a questão cerealífera durante a idade média. Third edition (Lisboa: Edições Cosmos, 1978).

[47] J. Lencar, *Geographia d'Entre Douro e Minho e Trás-os-Montes por João de Barros* (Porto: Câmara Municipal do Porto, 2019).

The Manueline Ordinances published in 1521 already included specific chapters about fire, such as LXXXIII, "*Penalties for those who set fires*",[48] dedicated exclusively to the improper use of fire. It must have been considered so relevant that it was again inserted in the Ordinances of 1533 and 1565. The Manueline Ordinances maintained the sanctioning and punitive regime for arson fires that would damage crops and rangelands in common lands, imposing that no person was allowed to set fire anywhere. Simultaneously, if the author of the fire could not be identified, hunting, grazing, and charcoal production activities would be temporarily restricted in the burned area. Likewise, it is mentioned for the first time the need for a municipal license to use fire and the obligation of the population to extinguish fire when it could cause damage. Later, in the Royal regulations and charters of the following centuries, the municipalities maintained their role in regulating these fire uses. However, municipalities also took part in mediating conflicts, as can be understood by the record of a Charter of Juiz de Fora of Tavira (Algarve), detailing the community needs for using fire for agriculture (with shipbuilding activities compromised), the imposed end of the use of fire and the subsequent outcome of conflicts.[49] The same group of documents included the Extravagant Laws of 1578, which mentioned a Pardon when there was a license and restitution for the damage. The amounts due depended on social class, location and the damage caused, with no pardon for the use of intentional fire.

The legislation follows societal changes, and fire use in Portugal is historically associated with different land uses. The Philippine Ordinances of 1603 is an example because of the distinction between the uses of fire for rangeland management, stubble-burning, weed-burning for crops and soil fertilisation, hunting and charcoal production. These Ordinances, like the previous references, disclose the relationship between fire and other traditional practices and how these, as a whole, were subject to regulation by the Crown. The reference to the significant lack of wood for shipbuilding stands out in the introduction of the Ordinances. For this reason, the regulation was extended to well-identified private forests.[50,51] The regulations also restricted charcoal production, which fed several industries, to protect the woodlands from deforestation.[41]

One of the first records on the need for fire prevention appears in the Regiment of *Verdes e Montados do Campo de Ourique*, 1699, establishing the need for fuel management and the determination of fire-use days by municipal councils, either to burn heaps and stubbles or in broadcast burning for crops or pastures. In 1751, an institutional reference to using fire to decrease fuel hazard in maritime pine stands was displayed in the Royal forest management book ordered by the King, likely the first reference to a proto-prescribed burning practice in Europe.[52]

At the beginning of the nineteenth century, when the Portuguese forest reached its minimum extent,[41] municipal councils' had to supervise fire prevention performed by

[48] Codigo Philippino, ou, Ordenações e leis do Reino de Portugal: recopiladas por mandado d'El-Rey D. Philippe I, *'Título LXXXVI – Dos que poem fogos. Quinto Livro das Ordenações'*, Volume V, Fourteen edition (Rio de Janeiro: Typographia do Instituto Philomathico, 1870), pp. 1233–1235.

[49] Portuguese Digital Archive of Torre do Tombo, *Corpo Cronológico, Part I, file 104, nr. 68*. https://digitarq.arquivos.pt/details?id=3767258 (accessed 13 Nov 2019).

[50] H. Vilela, 'Ordenações Filipinas e Código Criminal do Império do Brasil (1830) – Revisitando e Reescrevendo a História', *Revista Jurídica Luso-Brasileira* **3**(4) (2017): 767–780.

[51] A. Silva (ed.), 'Carta de Regimento para as Matas, Montarias e Coutadas Reais de 20 de março de 1605', *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1603 a 1612* (Lisboa: Typografia Maigrense, 1854), pp. 109–124.

[52] A. Silva (ed.), 'Regimento do Guarda Mór do Pinhal de Leiria de 25 de julho de 1751', in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1750 a 1762* (Lisboa: Typografia Maigrense, 1830), pp. 68–75.

landowners around villages and the forestry facilities along the road network and made them responsible for the damage caused by fires. The legislative documents focused on southern Portugal, showing the impact of fires and the conflicts generated, and the substantially lower tolerance and acceptance of fire compared to the northern and central regions.[53] Such difference may partially arise from the relative vicinity of these southern areas to Lisbon, a city demanding a huge amount of wood for reconstruction after the 1755 earthquake.[17] Despite all these legislative measures and diplomas, the references to wildfires increase, and the need for means to avoid them, particularly in pine forests and vineyards, is repeated throughout the years.[54] It led to increased restrictions on fire use, postfire land use (including the prohibition of using ashes from fires), and increased fuel management, namely the increase in the size of mandatory fuel breaks and heavy penalties for non-compliance. The ordinance also establishes workers' obligation to fight fires within a 5-6.6 kilometre radius. The Penal Code of King Manuel and King Philip's Ordinances, characterised by penalties reflecting oppression of the Crown and clergy towards populations,[50] was finally replaced in 1886 after the Liberal Revolution (1820) and the end of the Manorial Regime.[55] The 1886 Penal Code maintained the exile penalty in all cases but did not clarify the fire cause behind the damage.[56]

1.3.3 Forest Regime: from the late nineteenth century to the late twentieth century

During the Constitutional Monarchy (1820-1910) that followed the Liberal Revolution, the courts and the Parliament urged the need to implement a forest reform that would enable greater control by the State to ensure forest protection. Nevertheless, the records of the late nineteenth century parliamentary debates, referring to the need for legislative forest reforms and a Forest Code, show that delays in their implementation and the continuous degradation of national forests were still issues of concern.[57,58]

The more complex and diversified the use of fire, the more significant conflicts arose. Likewise, these conflicts worsened and were more important wherever private properties border common lands ruled by traditional local practices and customs. For example, it was only in the twentieth century that the limitation of fire use was generalised for all rural activities, mainly because burning agricultural and forest residues had led to wildfires. In 1901, legislation on the use of fire became conditioned by the legislation on the Forest Regime,[59] whose Decree defined the conditions for the use of fire and grazing, target inspection and Forest Police.[59] From then on, the State Forest Service took control over the common lands traditionally managed and

[53] A. Silva (ed.), ‘Portaria ocorrendo com providências ás queimadas que se frequentão ao Sul do Tejo, 2 de Outubro de 1813’, de 2 de julho de 1816’, in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1811 a 1820* (Lisboa: Typografia Maigrense, 1825), pp. 280.

[54] A. Silva (ed.), ‘Portaria, providenciando ácerca de incêndios’, de 2 de julho de 1816’, in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1811 a 1820* (Lisboa: Typografia Maigrense, 1825), pp. 516-519.

[55] A. Silva (ed.), ‘Decreto n.º 49 de 7 de abril de 1821’, in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1821 a 1823* (Lisboa: Typografia Maigrense, 1825), pp. 57-29.

[56] J. Rebello (ed.), ‘Capítulo IV – Do incêndio e damnos. Secção I – Fogo pôsto’, in *Codigo Penal Annotado* (Porto: Typographia Gutenberg, 1895), pp. 184–187.

[57] Portuguese Government, *Sessão 28 de abril de 1887 - As legislações Florestais* (Portugal: Imprensa Nacional da Casa da Moeda, 1887). https://debates.parlamento.pt/catalogo/mc/cd (accessed 8 Nov 2020).

[58] Portuguese Government, *Sessão N.o 12 de 26 de janeiro de 1900 - Propostas de lei apresentadas pelo Sr. Ministro das Obras Públicas. Proposta de lei n.o 1-L, 1900* (Portugal: Imprensa Nacional da Casa da Moeda, 1900). https://debates.parlamento.pt/catalogo/mc/cd (accessed 8 Nov 2020).

[59] Portuguese Government (Ministério do Reino), *Decreto de 24 de Dezembro de 1901, do Estabelecimento do Regime Florestal, pp. 1312-1355* (Portugal: Imprensa Nacional da Casa da Moeda, 1901). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?artigo_id=2799A0002&nid=2799&tabela=leis&ficha=1&nversao (accessed 17 Jan 2023).

headed by rural communities, even conditioning grazing and cereal rotation, thus imperilling livelihoods. Control was then centralised in the public administration and reinforced through a sanction regime in the forest common lands at the beginning of *Estado Novo* (1933-1974). Such sanction regime and policing withdrew and limited the rights based on local uses and customs that took place since before Portugal's Foundation.[60]

During the twentieth century, as afforestation progressed, so did the conflicts between the communities, the State Forest Service and other authorities. Simultaneously, the legislation on fire and grazing became increasingly limiting. The Law of Forest Settlement[61] gave room to the afforestation of common lands, and over the following twenty years (1940-1960), approximately 370,000 hectares of common lands were subjected to the Forest Regime.[14] Such increase in area under the Forest Regime (mainly in northern and central Portugal) and the State Forest Service's excessive authority resulted in local resistance, partly due to the restrictions imposed on the use of fire, particularly on silvopastoral activities.[62,63] Restrictions could imply heavy penalties, increased minimum distance from forest perimeters to burn without a permit, and new Forest Police reinforcements.[64] In that context, the difficulty of maintaining traditional practices, the need for industrial labour, the Portuguese Colonial War (1961-1974) effect, and the consequent emigration fostered the progressive abandonment of rural areas. In 1970, a new diploma was published, where, for the first time, the need for fire prevention education campaigns and wildfire risk assessment was recognised as an outcome of the increase in forest areas extent,[29,65,66] difficulties in hiring rural labour, increased wildfire activity in the sixties, and the death of 25 soldiers while fighting the 1966 Sintra wildfire.

On the one hand, there was again a return to local authorities' involvement. On the other hand, fines and sanctions for the widespread use of fire were increased. The referred diploma advocated innovation and flagged the European Year of Nature Conservation of 1970, but it maintained the vision of a "forest without fire" as in a typical fire suppression policy that was in force at the time and that has been mostly applied for decades until today.[67]

After April 25, 1974, the common lands were returned to rural communities,[68] remaining under the Forest Regime. The consequences of this long process were that common lands became more vulnerable to wildfire, mainly because of the rural population reduction, the abandonment of traditional land management, the existence of vast maritime pine stands,[14] and

---

[60] Comando Geral da Guarda Nacional Republicana, *Reorganização dos Serviços de Polícia Florestal. Decretos n.os 12625, e 12793, respectivamente de 3 e 30 de Novembro de 1926* (Lisboa: Tipografia da G.N.R, 1926).

[61] Portuguese Government (Ministério da Agricultura), *Lei n.o 1971 de 15 de junho de 1938, Lei do Povoamento Florestal. Diário da República, 1ª série, Nr 136, 15 de Junho* (Portugal: Imprensa Nacional da Casa da Moeda, 1938). https://files.dre.pt/1s/1938/06/13600/09710974.pdf (accessed 17 Jan 2023).

[62] A. Arala Pinto, 'Fogos', in Direção Geral dos Serviços Florestais e Aquícolas, *Separata das Publicações da Direcção Geral dos Serviços Florestais e Aquícolas*. Volume X, Tomo II, (Portugal: DGSFA, 1943), pp. 355–372.

[63] I. Skulska, C. Montiel-Molina and F. C. Rego, 'The role of forest policy in Mediterranean mountain community lands: A review of the decentralization processes in European countries', *Journal of Rural Studies* **80** (2020): 490–502.

[64] Portuguese Government (Ministério da Economia - Direcção-Geral dos Serviços Florestais e Aquícolas), *Decreto-Lei n.o 39 931, de 24 de novembro de 1954. Diário do Governo n.º 263/1954, Série I de 1954-11-24, pp. 1400–1405* (Portugal: Imprensa Nacional da Casa da Moeda, 1954). https://diariodarepublica.pt/dr/detalhe/decreto-lei/39931-1954-680793 (accessed 17 Jan 2023).

[65] F. Ferreira-Leite, A. Gonçalves and L. Lourenço, 'Grandes incêndios florestais na decáda de 60 do século XX, em Portugal Continental', *Territorium* **21** (2014): 189–195.

[66] Portuguese Government (Ministério Ministério das Finanças e da Economia), *Decreto-Lei n.o 488/70, de 21 de Outubro. Diário do Governo n.º 244/1970, Série I,. pp. 1508–1511* (Portugal: Imprensa Nacional da Casa da Moeda, 1970). https://files.dre.pt/1s/1970/10/24400/15081511.pdf (accessed 17 Jan 2023).

[67] M.C. Colaço, Bases para uma educação ambiental orientada para a diminuição do risco e aumento da resiliência das comunidades aos incêndios florestais em Portugal. (PhD Thesis, Universidade de Santiago de Compostela, 2017).

[68] Portuguese Government (Ministério da Agricultura e Pescas), *Decreto-Lei n.o 39/76, de 19 de janeiro, Diário do Governo n.º 15/1976, Série I, pp. 89-91*. (Portugal: Imprensa Nacional da Casa da Moeda, 1976). https://portal.oa.pt/upl/%7Bb7108909-3a78-4b47-ac93-d7cdbd838729%7D.pdf (accessed 17 Jan 2023).

the materialisation of conflicts through arson, resulting in the onset of a new fire regime in the mid-1970s.[69]

In the last decades of the twentieth century, numerous legal diplomas focused mainly on the following topics: organisation of fire management agencies; spatial and temporal restrictions to the use of fire; mandatory fuel treatments and inspection; creation of fuel breaks around buildings and infrastructures; and a continuous increase in restrictions, sanctions and fines applied to the improper use of fire, expected to discourage it further and reduce the number of wildfires.[70,71,72,73,74,75,76,77,78,79,80,81,82] Prescribed burning as a fuel-reduction technique by the State Forest Service personnel or accredited by them was instated in 1981.[72] Finally, fire use, namely bonfires, burning of heaps and broadcast pastoral burnings, was, from then on, faced as an activity of essentially urban nature, therefore subject to the same type of licensing and punishments for infractions.[82]

---

[69] P. M. Fernandes, C. Loureiro, N. Guiomar, G. Pezzatti, F. Manso and L. Lopes, 'The dynamics and drivers of fuel and fire in the Portuguese public forest', *Journal of Environmental Management* **146** (2015): 373–82.

[70] Portuguese Government (Presidência do Conselho de Ministros e Ministério da Agricultura e Pescas), *Decreto-Lei n.o 327/80, de 26 de Agosto. Diário do Governo n.º 196/1980, Série I, pp. 2375-2377* (Portugal: Imprensa Nacional da Casa da Moeda, 1980). https://dre.pt/dre/home (accessed 12 Nov 2020).

[71] Portuguese Government (Assembleia da República), *Lei n.o 10/81, de 10 de Julho. Diário da República n.º 156/1981, Série I, pp. 1649-1651* (Portugal: Imprensa Nacional da Casa da Moeda, 1981). https://files.dre.pt/1s/1981/07/15600/16491651.pdf (accessed 11 Nov 2020).

[72] Portuguese Government (Ministérios da Defesa Nacional, da Administração Interna e da Agricultura, Comércio e Pescas), *Decreto Regulamentar n.o 55, de 18 de Dezembro. Diário da República n.º 290/1981, Série I, pp. 3299-3307* (Portugal: Imprensa Nacional da Casa da Moeda, 1981). https://dre.pt/dre/home (accessed 31 Oct 2020).

[73] Portuguese Government (Ministério da Justiça), *Decreto-Lei n.o 400/82 de 23 de Setembro. Diário da República n.º 221/1982, 1º Suplemento, Série I, pp. 3006-(2)-3006-(64)* (Portugal: Imprensa Nacional da Casa da Moeda, 1982). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=101&tabela=lei_velhas&nversao=1&so_miolo (accessed 12 Nov 2020).

[74] Portuguese Government (Ministério da Administração Interna), *Decreto Regulamentar n.o 67/85 de 22 de Outubro, Diário da República n.º 243/1985, Série I, pp. 3480* (Portugal: Imprensa Nacional da Casa da Moeda, 1985). https://dre.pt/dre/home (accessed 11 Nov 2020).

[75] Portuguese Government (Assembleia da República), *Lei n.o 19/86, de 19 de julho. Diário da República n.º 164/1986, Série I, pp. 1775-1777* (Portugal: Imprensa Nacional da Casa da Moeda, 1986). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=232&tabela=leis&so_miolo (accessed 11 Nov 2020).

[76] Portuguese Government (Ministério da Administração Interna), *Decreto Regulamentar n.o 36/88, de 17 de Outubro, Diário da República n.º 240/1988, Série I, pp. 4238-(2)* (Portugal: Imprensa Nacional da Casa da Moeda, 1988). https://dre.pt/dre/home (accessed 11 Nov 2020).

[77] Portuguese Government (Ministérios do Planeamento e da Administração do Território, da Administração Interna, da Agricultura, Pescas e Alimentação e do Ambiente e Recursos Naturais), *Portaria n.o 341/90, de 7 de Maio, Diário da República n.º 104/1990, Série I, pp. 2115-2117* (Portugal: Imprensa Nacional da Casa da Moeda, 1990). https://diariodarepublica.pt/dr/detalhe/decreto-lei/341-1990-565861 (accessed 11 Nov 2020).

[78] Portuguese Government (Ministério do Planeamento e da Administração do Território), *Decreto-Lei no 334/90, de 29 de Outubro, Diário da República n.º 334/1990, Série I, pp. 4456-4457* (Portugal: Imprensa Nacional da Casa da Moeda, 1990). https://dre.pt/dre/home (accessed 11 Nov 2020).

[79] Portuguese Government (Ministério do Planeamento e da Administração do Território), *Decreto-Lei n.o 423/93, de 31 de dezembro, Diário da República n.º 304/1993, Série I, pp. 7242-7244* (Portugal: Imprensa Nacional da Casa da Moeda, 1993). https://dre.pt/dre/home (accessed 11 Nov 2020).

[80] Portuguese Government (Ministério das Cidades, Ordenamento do Território e Ambiente), *Decreto-Lei n.o 310/2002 de 18 de Dezembro, Diário da República n.º 292/2002, Série I-A, pp. 7896-7903* (Portugal: Imprensa Nacional da Casa da Moeda, 2002). https://diariodarepublica.pt/dr/detalhe/decreto-lei/310-2002-405693 (accessed 12 Mar 2019).

[81] Portuguese Government (Ministério da Administração Interna), *Decreto-Lei n.o 252/92, de 19 de Novembro. Diário da República n.º 268/1992, Série I-A, pp. 5334-5338* (Portugal: Imprensa Nacional da Casa da Moeda, 1992). https://www.igf.gov.pt/leggeraldocs/DL_252_92.htm (accessed 11 Nov 2020).

[82]. Portuguese Government (Ministério da Administração Interna), *Decreto-Lei n.o 316/95 de 28 de Novembro, Diário da República n.º 275/1995, Série I-A, pp. 7375-7382* (Portugal: Imprensa Nacional da Casa da Moeda, 1995). https://www.igf.gov.pt/leggeraldocs/DL_316_95.htm (accessed 2 Feb 2019).

1.3.4 Large fires: the twenty-first century (until 2021)

Fire legislation significantly changed in the first decade of the twenty-first century. In 2002, administrative decentralisation was reinforced for the benefit of the population, as the licensing powers of Civil Governments were transferred to Municipal Councils,[80] which meant that licensing the use of fire returned to local authorities, as it was until the mid-nineteenth century.

In the awakening from Portugal's devastating 2003 fire season, the measures and actions defined within the scope of the National Forest Fire Defense System were implemented in 2004, determining a set of rules to prevent wildfires.[83] For the first time, concepts related to the different uses of fire were defined. Again, fire use limitations were reinforced, expanding the limitations to the whole rural land, i.e., not just in forest areas, limiting its use according to fire danger and banning it during the so-called "critical period" that replaces the previous "normal fire season". In truth, it is not a matter of regulating fire use but restraining it. Finally, this decree-law establishes the use of technical fire with its implementation ensured by the State Forest Service (Chapter IV, "Preventive Measures"). The first Prescribed Burning Regulation was published in that context, focusing mainly on defining the accreditation and planning processes.[84]

In 2006, a diploma was published establishing the National Forest Fire Defense Plan (PNDFCI),[85] and the corresponding National Forest Fires Defense System (SNDFCI) was implemented.[86] After several amendments, it was republished in 2017,[87] maintaining limitations to the widespread use of fire. Furthermore, it introduced more technical monitoring and support for communities, e.g., it made technicians, firefighters or forest hand crews compulsory to assist in the use of fire within traditional activities. Likewise, the value of fines for infractions increased once more, again seeking a restrictive effect on the use of fire.

The concepts, definitions and rules for technical fire use were established in one of the amendments in 2009 when the legislation considered the use of suppression fire (backfire and counterfire).[88] In the meantime, the Fire Analysis and Use Group (GAUF) was established within the State Forest Service to use technical fire for land management goals and wildfire

---

[83] Portuguese Government (Ministério da Agricultura, Desenvolvimento Rural e Pescas), *Decreto-Lei n.o 156/2004 de 30 de Junho, Diário da República n.º 152/2004, Série I-A, pp. 3968-3975* (Portugal: Imprensa Nacional da Casa da Moeda, 2004). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2542&tabela=leis&so_miolo (accessed 17 Mar 2023).

[84] Portuguese Government (Ministério da Agricultura, Desenvolvimento Rural e Pescas), *Portaria n.o 1061/2004 de 21 de Agosto, Diário da República n.º 197/2004, Série I-B, pp. 5604-5605* (Portugal: Imprensa Nacional da Casa da Moeda, 2004). https://dre.pt/dre/home (accessed 17 Feb 2019).

[85] Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 65/2006 de 25 de Maio, Diário da República n.º 102/2006, Série I-B, pp. 3511-3559* (Portugal: Imprensa Nacional da Casa da Moeda, 2006). https://dre.pt/dre/home (accessed 17 Mar 2023).

[86] Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Decreto-Lei n.o 124/2006, de 28 de junho, Diário da República n.º 123/2006, Série I-A* (Portugal: Imprensa Nacional da Casa da Moeda, 2006). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=1931&tabela=leis (accessed 30 Dec 2020).

[87] Portuguese Government (Assembleia da República), *Lei n.o 76/2017, de 17 de agosto, Diário da República n.º 158/2017, Série I, pp. 4734-4762* (Portugal: Imprensa Nacional da Casa da Moeda, 2017). https://dre.pt/dre/home (accessed 27 Aug 2019).

[88] Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Decreto-Lei n.o 17/2009, de 14 de Janeiro, Diário da República n.º 9/2009, Série I, pp. 273-295* (Portugal: Imprensa Nacional da Casa da Moeda, 2009). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?tabela=leis&nid=1933&pagina=1&ficha=1 (accessed 17 Feb 2019).

suppression.[88,89,90] The competencies for using technical fire were published in 2014 and introduced the National Civil Protection Authority to the context of using fire in firefighting.[91]

At the end of the 2017 fire season (which resulted in 114 fatalities), a conceptual review of the principles of wildfire defence moved the terminology "forest fire" to "rural fire".[92] This change led to the replacement in 2021 of the SNDFCI by the Integrated Rural Fire-Management System (SGIFR).[93] Between 2017 and 2021, some other diplomas have been published on administrative decentralisation and local authorities' autonomy in rural fire prevention and licensing fire use, fuel management and inspection. Moreover, the broadcast burning concept was revised.[94,95,96] The new definition of broadcast burning conditioned the use of technical fire for habitat management objectives other than rangeland,[97] further limiting a more immediate response to the management needs.

The SGIFR reinforces the restrictions to all uses of fire by rural communities, maintaining the fire ban period and the mandatory municipal license, as in the Middle Ages.[93] Instead, using fire without a license is subject to the provisions of the 2011 amendment to the Penal Code, i.e., punishable with a prison sentence of one to eight years.[98] The focus seems to be on increasing the restrictions on traditional fire use to reduce the number of ignitions and the resulting impacts. Limitations to burn heaps and stubble have become more flexible but depend on municipal licensing. However, the use of fire is discouraged, and its replacement by biomass shredding is recommended.[96]

---

[89] Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Decreto-Lei n.o 159/2008, de 8 de agosto, Diário da República n.º 153/2008, Série I, pp. 5355-5359* (Portugal: Imprensa Nacional da Casa da Moeda, 2008). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=1054&tabela=leis (accessed 17 Feb 2019).

[90] Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Portaria n.o 35/2009, de 16 de Janeiro, Diário da República n.º 11/2009, Série I, pp. 386-388* (Portugal: Imprensa Nacional da Casa da Moeda, 2009). https://diariodarepublica.pt/dr/detalhe/portaria/35-2009-789382 (accessed 17 Feb 2019).

[91] Portuguese Government (Ministério da Agricultura e do Mar), *Decreto-Lei n.o 83/2014, de 23 de maio, Diário da República n.º 99/2014, Série I, pp. 2946-2947* (Portugal: Imprensa Nacional da Casa da Moeda, 2014). https://diariodarepublica.pt/dr/detalhe/decreto-lei/83-2014-25345886 (accessed 17 Feb 2019).

[92] Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 157-A/2017, Diário da República n.º 208/2017, Série I, pp. 5818-(2)-5818-(3)* (Portugal: Imprensa Nacional da Casa da Moeda, 2017). https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/157-a-2017-114109966 (accessed 22 Nov 2020).

[93] Portuguese Government (Presidência do Conselho de Ministros), *Decreto-Lei n.o 82/2021, de 13 de outubro, Diário da República n.º 199/2021, Série I, pp. 2-47* (Portugal: Imprensa Nacional da Casa da Moeda, 2017). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=3453&tabela=leis&so_miolo (accessed 12 Mar 2022).

[94] Portuguese Government (Assembleia da República), *Lei n.o 50/2018, de 16 de agosto, Diário da República n.º 15/2018, Série I, pp. 4102-4108* (Portugal: Imprensa Nacional da Casa da Moeda, 2018). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2932&tabela=leis&ficha=1 (accessed 26 Sep 2019).

[95] Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 20/2018 de 1 de março, Diário da República n.º 43/2018, Série I, pp. 1132-1141* (Portugal: Imprensa Nacional da Casa da Moeda, 2018). https://dre.pt/dre/home (accessed 17 Feb 2019).

[96] Portuguese Government (Presidência do Conselho de Ministros), *Decreto-Lei no 14/2019, de 21 de janeiro, Diário da República n.º 14/2019, Série I, pp. 443-446* (Portugal: Imprensa Nacional da Casa da Moeda, 2019). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2992&tabela=leis&ficha=1&pagina=1&so_miolo (accessed 26 Mar 2019).

[97] Portuguese Government (Ministério da Agricultura e do Mar - Gabinete do Secretário de Estado das Florestas e do Desenvolvimento Rural), *Despacho n.o 7511/2014, de 9 de junho, Diário da República n.º 110/2014, Série II, pp. 443-446* (Portugal: Imprensa Nacional da Casa da Moeda, 2014). https://diariodarepublica.pt/dr/detalhe/despacho/7511-2014-25696052 (accessed 26 Mar 2019).

[98] Portuguese Government (Assembleia da República), *Lei n.o 56/2011, de 15 de Novembro, Diário da República n.º 219/2011, Série I, pp. 4862-4863* (Portugal: Imprensa Nacional da Casa da Moeda, 2011). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=1540&tabela=leis&ficha=1&pagina=1&so_miolo=S (accessed 31 Out 2020).

In 2020, a new plan that will be in force until 2030 was approved, the Integrated Rural Fire-Management Plan.[99] The plan implies a follow-up on the restriction to the use of fire and describes non-technical fire uses as the primary sources of ignition originating rural fires. It also identifies the need to replace fire as an ancestral rural tool with other fuel treatments, indicating that techniques used to manage residual biomass from agricultural and forestry activities are no longer suitable.

1.3.5 The approach of legislation to using fire through all four periods

The use of fire was regulated throughout the four defined periods. However, the type of approach taken has changed over time. Results showed that, initially, i.e., in the first period (Common Law in Kingdoms of the Iberian Peninsula), the focus was to monetarily compensate for the damages inflicted by fires that unintentionally affected farmlands (Figure 3). Then, from the second period (Portuguese Law) on, legislation became broader in its approach to fire use, adding four other categories: prevention, firefighting, management and limitations. The distribution of all five categories over the last three periods has not been even as well. The focus on damage and restrictions was overall slightly reduced in the fourth period (large fires), as the focus on prevention, firefighting and management has increased. Legally imposed restrictions on the use of fire had a big share since the foundation of Portugal (Figure 3). Fire and land management were present in the legislation of the last three periods. In the second period, it aimed to protect trees and forests due to the heavy deforestation and high demand for wood by the different industries. In the fourth period, it referred mostly to using technical fire to manage the land and to assist in wildfire suppression.

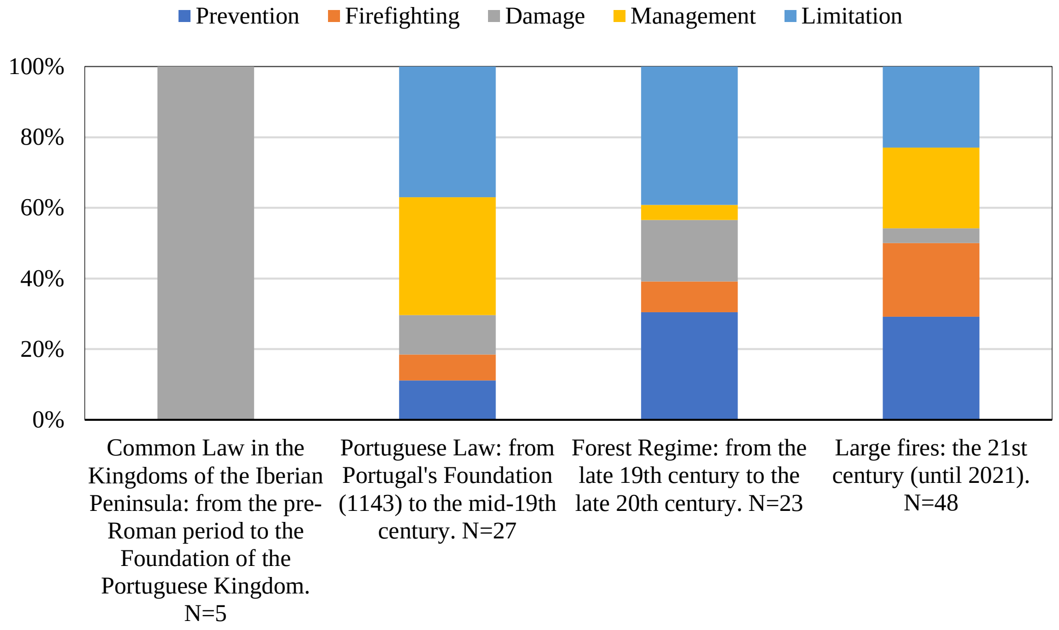


Figure 3. Type of approach in legislation about using fire, by period, with identification of the number of legal documents considered by period. Source: Elaborated by the authors.

[99] Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 45-A/2020, Diário da República n.º 115/2020, 1º Suplemento, Série I* (Portugal: Imprensa Nacional da Casa da Moeda, 2011). https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/45-2020-135844796 (accessed 19 Nov 2020).

The different uses of fire, including for management purposes, are generalised throughout the Portuguese legislation, and the corresponding penalties are the same as those applied to set wildfires (accidental and negligent) intentionally or to arsonism. The legal requirements and harsh penalties imposed over time (such as lashing or exile), increased prison sentences, fines, the bureaucracy volume and decreased temporal and spatial windows of opportunity for responsible burning practices. Such measures, plus the recent awareness campaigns for using shredders, did little to discourage the use of fire within agro-silvopastoral systems still active nationwide. Suppressing all fires from the landscape and legally eliminating the use of fire by rural communities, through the heavy limitations imposed, can foster the illegal use of fire, particularly under weather conditions leading to large and damaging fires, rather than empowering and holding the population accountable. Moving away from traditional community-led fire use and imposing strict punitive measures while simultaneously promoting institutional fire use may result in communities that do not fully understand the natural context of fire, making it more difficult to accept it as a natural process.[13]

Worldwide, there are examples of countries or regions that already acknowledged traditional ecological knowledge and burn practices as crucial to building more fire-resilient landscapes and, thus, are currently applying fewer restrictions to the use of fire. [13] Some examples are in Australia[100,101] and France (which allows pastoral burning),[102] Canada,[103,104,105] California in the United States of America,[106,107] and Aragón,[108] Cantabria[109] and Catalonia in Spain.[110] In 2010, European researchers in the Fire Paradox project policy brief advocated that Integrated Fire management should include central aspects of fire use regulation. It included traditional burning management, among other technical and professional uses of fire for prevention, nature conservation and suppression.[111]

[100] J. Russell-Smith, G.D. Cook, P.M. Cooke, A.C. Edwards, M. Lendrum, C.P. Meyer and P.J. Whitehead, 'Managing fire regimes in north Australian savannas: Applying Aboriginal approaches to contemporary global problems', *Frontiers in Ecology and the Environment* **11**(Online issue 1) (2013): e55-e63.

[101] A. Atkinson and C. Montiel-Molina, 'Reconnecting Fire Culture of Aboriginal Communities with Contemporary Wildfire Risk Management', *Fire* **6**(8) (2023): 296.

[102] P.M. Fernandes, G.M. Davies, D. Ascoli, C. Fernández, F. Moreira, E. Rigolot, C.R. Stoof, J.A. Vega and D. Molina, 'Prescribed burning in southern Europe:developing fire management in a dynamic landscape', *Frontiers in Ecology and the Environment* **11**(Online issue 1) (2013): e4-e14.

[103] Canadian Government, *Canadian Environmental Protection Act - An Act respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development* (Canada: Canadian Minister of Justice, 1999). https://laws-lois.justice.gc.ca/PDF/C-15.31.pdf (accessed 16 Mar 2023).

[104] C.C.S.M., *c E125, The Environment Act* (Manitoba: C.C.S.M., 1987), www.gov.mb.ca (accessed 16 Mar 2023).

[105] C.C.S.M., *Man. Reg. 77/93, Burning of Crop Residue and Non-Crop Herbage Regulation* (Manitoba: C.C.S.M., 1993), www.gov.mb.ca (accessed 16 Mar 2023).

[106] US Government (Senate), *Bill No. 332, SB-332 Civil liability: prescribed burning operations: gross negligence* (California: Legislative Counsel, 2021), https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB332 (accessed 16 Mar 2023).

[107] US Government (Assembly), *Bill No. 642, AB-642 Wildfires* (California: Legislative Counsel, 2021), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB642 (accessed 16 Mar 2023).

[108] Spanish Government (Departamento de Agricultura, Ganadería y Medio Ambiente), *Orden de 20 de febrero de 2015, sobre prevención y lucha contra los incendios forestales en la Comunidad Autónoma de Aragón para la campaña 2015/2016, Boletín Oficial de Aragón n.o 50, pp. 8619-8632* (Spain: B.O.A, 2015), https://www.boa.aragon.es/cgi-bin/EBOA/BRSCGI?CMD=VEROBJ&MLKOB=842831924646 (accessed 16 Mar 2023).

[109] Spanish Government (Consejería de Desarrollo Rural, Ganadería, Pesca, Alimentación y Medio Ambiente), *Orden MED/3/2021, de 09 marzo, por la que se regulan las quemas controladas y prescritas en la Comunidad Autónoma de Cantabria, Boletín Oficial de Aragón n.o 52, pp. 5617-5623* (Spain: B.O.C., 2021), https://boc.cantabria.es/boces/verAnuncioAction.do?idAnuBlob=359395 (accessed 16 Mar 2023).

[110] Catalonia Government (Conselh Generau d'Aran), *Plan Estrategic de Gestion Sostenibla Regim de Huec Val D'Aran - Oritzon 2030* (Aran: Conselh Generau d'Aran, 2015), https://www.seu-e.cat/web/conselhgeneraudaran/govern-obert- (accessed 16 Mar 2023).

[111] F. Rego, E. Rigolot, P. Fernandes, C. Montiel and J.S. Silva, *European Forest Institute Policy Brief 4 – Towards Integrated Fire Management* (Finland: EFI, 2010).

1.4 CONCLUSION

The retrieval and analysis of historical legal documents in Portugal have allowed us to validate the hypothesis that imposing constraints and regulations on the use of agro-silvopastoral fire throughout the centuries did not discourage its traditional use by communities over time. Since Portugal's Foundation, the legislation on the use of fire has been consistent in restrictions and constraints and continuous sanctions, fines and penalties. Moreover, the legislation on the use of fire over the last two centuries did not consider the different needs, timings and purposes of fire use, not relating the uses of fire with traditional practices and the need to maintain them. The legislation type of approach to the uses of fire became broader over time. Additionally, the legislation was not consistently enforced throughout the country. Nevertheless, fire was, and still is, an essential tool in traditional agro-silvopastoral systems.

Several countries are adopting less restrictive legislative regulations regarding fire's traditional and cultural uses. In this context of change, it is essential to rethink the old and current paradigm, especially since the beginning of the twentieth century, by elaborating an adequate legal framework for the different uses of fire, training communities and increasing their accountability.

CAPÍTULO II - REMAINS OF THE TRADITIONAL FIRE USE IN PORTUGAL: A HISTORICAL ANALYSIS

Abstract. Traditional, rural, native, or indigenous fire has coexisted with lightning-caused fire since the origin of Humanity. In Portugal, several uses of fire played an essential role in supporting communities from the settlement of the Portuguese territory within complex agrosilvo-pastoral systems. Previous studies approached traditional fire knowledge from different perspectives, but none comprehensively described the concept. Resorting to histori-cal documentary sources, this paper identifies and describes the traditional practices involving the different fire uses in Portuguese rural communities from the foundation of Portugal until the end of the 19th century. The approach showed a general abandonment and progressive loss of many of those traditional uses of fire at the end of the 19th century. It led to the breakdown of the conventional traditional agrosilvo-pastoral system and the disarticulation of the interdependence of Human and Nature processes. Due to legal conditionings and prohibi-tions, the current traditional uses of fire are only remains of the past. As a result, academia is essential to pro-mote and revive traditional fire knowledge in the country.

Keywords: broadcast burning; cultural burning; traditional fire knowledge; native fire, wildfire.

Resumen. *Vestigios del uso tradicional del fuego en Portugal: un análisis histórico*

El fuego tradicional, rural, nativo o indígena ha coexistido con el fuego provocado por el rayo desde el origen de la Humanidad. En Portugal, diversos usos del fuego desempeñaron un papel esencial en el sustento de las comunidades desde el poblamiento del territorio portugués dentro de complejos sistemas agrosilvo-pastorales. Estudios anteriores abordaron el conocimiento tradicional del fuego desde diferentes perspectivas, pero ninguno describió el concepto de forma exhaustiva. Recurriendo a fuentes documentales de carácter historico, este trabajo identifica y describe las prácticas tradicionales relacionadas con los diferentes usos del fuego en las comunidades rurales portuguesas desde la fundación de Portugal hasta finales del siglo XIX. El análisis muestra un abandono general y una pérdida progresiva de muchos de esos usos tradicionales del fuego a finales del siglo XIX. Esto llevó a la ruptura del sistema agrosilvo-pastoral tradicional convencional y a la desarticulación de la interdependencia de los procesos Humanos y de la Naturaleza. Debido a los condicionamientos legales y a las prohibiciones, los actuales usos tradicionales del fuego son sólo vestigios del pasado. En consecuencia, la academia es esencial para promover y revivir el conocimiento tradicional del fuego en el país.

Palabras clave: quemas extensivas; quemas culturales; conocimiento tradicional del fuego; fuego nativo, incendios forestales.

Resumo. *Vestixios do uso tradicional do lume en Portugal: unha análise histórica*

O lume tradicional, rural, nativo ou indíxena coexistiu co lume provocado polo raio desde a orixe da Humanidade. En Portugal, diversos usos do lume desempeñaron un papel esencial no sustento das comunidades desde o poblamiento do territorio portugués dentro de complexos sistemas agrosilvo-pastorais. Estudos anteriores abordaron o coñecemento tradicional do lume desde diferentes perspectivas, pero ningún describiu o concepto de forma exhaustiva. Recorrendo a fontes documentais de carácter historico, este traballo identifica e describe as prácticas tradicionais relacionadas cos diferentes usos do lume nas comunidades rurais portuguesas desde a fundación de Portugal ata finais do século XIX. A análise mostra un abandono xeral e unha perda progresiva de moitos deses usos tradicionais do lume a finais do século XIX. Isto levou á ruptura do sistema agrosilvo-pastoral tradicional convencional e á desarticulación da interdependencia dos procesos Humanos e da Natureza. Debido aos condicionamentos legais e ás prohibicións, os actuais usos tradicionais do lume son só vestixios do pasado. En consecuencia, a academia é esencial para promover e revivir o coñecemento tradicional do lume no país.

Palabras chave: queimas extensivas; queimas culturais; coñecemento tradicional do lume; lume nativo, incendios forestais.

2.1 INTRODUCTION

The abilities to make, control, and use fire have been determining skills in the evolution of the human species since the dawn of Humanity. The first energy Era began more than 300,000 years ago when Humanity started to use fire energy by burning biomass (Smil, 2004). With the control of this powerful energy, humans shaped their territory and themselves as individuals on physical, cognitive, and social levels (Bowman et al., 2011; Shimelmitz et al., 2014). The use of fire changed landscapes, allowing hunter-gatherer societies to emerge and develop. It was a determining factor in creating and expanding pastoral societies during the Neolithic (Bird & Cali, 1998; Jones, 1968; Monteiro Alves et al., 2006; S. Pyne & Goldammer, 1997).

In the context of this paper, traditional, rural, native, or indigenous fire uses are synonyms (Huffman, 2013) and refer to fire uses that have coexisted with lightning ignitions since the origin of Humanity and that have been passed down through generations by cultural transmission, i.e., the process through which cultural elements are passed down from one generation to the next (Liacos, 2015; S. Pyne & Goldammer, 1997). In other words, traditional fire use is the use of fire by rural communities for land and resource management purposes based on traditional know-how (Silva et al., 2010). In addition, traditional knowledge of fire has evolved as a branch or dimension of traditional ecological knowledge (Berkes et al., 2000; Vázquez-Varela et al., 2022). “Tradition” is from an anthropological point of view related to culture in its basics, i.e., something conventional (Vázquez-Varela et al., 2022).

Traditional fire uses are often associated with grazing, pruning, planting, harvesting, hunting, and beekeeping (Williams, 2003). Therefore, traditional fire, in its many forms, has shaped our landscapes beyond its use in cooking and advances in agriculture (Berkes et al., 2000). In Portugal, for e.g., before the plow introduction, the first crops were grown in clearings opened on burned native forest, and the soil was easily mobilized with a simple sharpened stick (Caldas, 1998). Traditional fire uses provided enough energy to supply the local communities, and also defined until the mid-19th century, a traditional agrosilvo-pastoral system that shaped the Portuguese landscape. After that, agriculture intensification with increased motorization, use of fossil fuels, and reduced rural labor left behind millennia-old traditional practices like manure, burning for soil fertilization, fallow, and fire as a working tool in general. A sharp decrease in the use of fire within the agrosilvo-pastoral systems accompanied the reduction of these activities. An exceptional accumulation of vegetation fuels in landscapes followed these processes that likely had never existed in the Mediterranean basin (Díaz-Fierros, 2019; Meira Castro et al., 2020; Moreira et al., 2023; Pyne & Goldammer, 1997; Vélez, 2005).

Nowadays, the purposes of traditional fire use are variable. Pasture renewal, creation of new pastures by forest clearing, crop installation, facilitating hunting, biomass management and fuel reduction, increasing fruit production, pest and disease control, wildlife management, biodiversity conservation, or cultural and ceremonial purposes are some to be mentioned (Eriksen, 2007; Garde, 2009; Mistry et al., 2016; Moura et al., 2019; Shaffer, 2010). Currently, the use of fire by communities in Portugal is often disconnected from the agrosilvo-pastoral systems practices (Meira Castro et al., 2020). Over the last century, the abandonment of traditional practices and the constraints and regulations on the uses of fire have blurred traditional knowledge, making it difficult to understand its traditional roots. Currently, the concept of fire use is generic, therefore, contemporary legislation in Southern Europe focused on decreasing the number of ignitions (Agência para a Gestão Integrada de Fogos Rurais (AGIF), 2020; D’Amelio, 2022). The linkage between traditional fire uses (e.g., pasture renewal), traditional practices (e.g., grazing) and the need to maintain them is currently underrated and overlooked. Several studies use the concept of traditional fire knowledge when referring to burning for pasture renewal, burning of heaps, fuel management, or for hunting purposes (de Oliveira et al., 2022; Mateus & Fernandes, 2014; Meira Castro et al., 2020; Tedim et al., 2019, 2022). However, none of them comprehensively describes the concept.

This paper identifies and describes the traditional practices involved in the different fire uses by Portuguese rural communities. We analyzed the historical documentation on the uses of fire, investigated its links with other traditional practices, and compared it with the current uses of fire. The temporal scale considered was from the foundation of Portugal (12th century) until the end of the 19th century. We aim to (1) assess the traditional Portuguese fire uses before implementing policies and measures to regulate them (late 19th century CE) and (2) to know what remains of traditional fire practices in Portugal.

2.2 MATERIALS AND METHODS

This study was based on the research, compilation, and analysis of historical documentary sources such as manuscripts, manuals, reports, chronicles, treatises, essays, and scientific journals produced from the 12th century to the late 19th century in Portugal, aiming to collect historical data and information about the techniques and purposes of fire use in Portuguese rural communities in that period.

The criterion used for the data gathered for this study was to be freely accessible and available online, and written in Portuguese or Spanish. Accordingly, the historical documentary sources used in this study were retrieved from 11 online libraries, covering the period from the 1st century to the 19th century (Table 1). The search string used for each library search was *fogo, fuego* (fire, in Portuguese and Spanish respectively), *queimas, queimadas,* and *quemas* (burns and broadcast burns, in Portuguese and Spanish), and no filter for date was considered. To the best of our knowledge, there are no regionalisms in archaic Portuguese, and the same keywords are still used in contemporary Portuguese. Spanish (Castilian) was a common language in Portugal until the middle of the 17th century CE, but was banned after 1640. However, the search string chosen can constitute a limitation of our research. This analysis followed a qualitative methodology with the exploratory–descriptive approach using the content analysis technique (Bardin, 1995). The results were thoroughly analyzed and selected by the title, followed by the reading part of the document. The data in each document describing fire uses was selected and put together by transcribing the selected quotes into a table and properly categorizing it with the use of fire identified (e.g., pasture renewal, stubble burning for fertilization, or charcoal production). The season/month for each use of fire was also retrieved. Some of the most relevant quotes were transcribed in the results section. The two aims of this paper were addressed by designing a calendar of traditional fire use and a diagram to illustrate the traditional fire regime with the information gathered during this study. The monthly calendar was based on the documentary descriptions analyzed. The monthly detail is also described in the crops, livestock, or charcoal production documents found.

Table 2. Historical documentary sources consulted.

Source	Available at
Portuguese National Digital Library	https://bndigital.bnportugal.gov.pt
Bank of Portugal	https://www.bportugal.pt/
Digital Library of the University of Coimbra	http://webopac.sib.uc.pt/
Almamater - Digital Library of Botany of the University of Coimbra	https://am.uc.pt/
Repository of the University of Lisbon	https://www.repository.utl.pt/
Centre for Historical Studies of the Nova University of Lisbon	https://ceh.fcsh.unl.pt
Royal Botanic Gardens Digital Library (Spain)	https://bibdigital.rjb.csic.es/
Non-profit Digital Library Internet Archive	https://archive.org
National Digital Library of Brazil	https://bndigital.bn.gov.br/
Guita and José Mindlin Brasiliana Library	https://digital.bbm.usp.br/
Google Books	https://books.google.pt

Our initial search returned 250 documents that were thoroughly reviewed. 135 of them referred to the use of fire and were considered for the study. The remaining 115 were rejected because they did not meet our aim of assessing the traditional Portuguese fire uses before implementing policies and measures to regulate them. From the final sample of 135 documents, we finally extracted 124 relevant quotes. They were categorized according to the topics in Table 2. Each quote can be related to more than one topic.

Table 2. Number of quotes by category of fire use.

Categories of fire use	Topics used in categorization	Number of quotes	Quotes time span
War (defense)	Burn of shrubland to facilitate troops movement Put out enemy fire Fire as a war method	3	1440–1868
Hunting	No training of dogs on burned land Use fire to control hunting prey that affects crops Use fire to keep away wild animals that destroy crops Use fire to burn forest and shrubland that served as hunting grounds	3	1415–1872
Soil fertilization	Ash from fires as soil fertilizer Ovens to incorporate fertilizers Burn of brushwood in sandy soils to improve fertility Burn of potato branches, vineyard prunings, or dry peat for fertilization	34	1513–1886
Pasture renewals	Pastoral burns Losses caused by burns Using fire to open up grazing areas Prohibitions of burning and grazing Negligent fire use by shepherds	26	1513–1886
Beekeeping	Precautions when using fire in beekeeping	2	1483–1513
Importance for livelihood	Fire as a key element for the origin and conservation of life	4	1610–1789
Plowing	Use fire in weed control Use fire to increase soil porosity Use fire before sowing wheat and rye	34	1513–1821
Charcoal production	Charcoal production (coal pits) Firewood for industry Charcoal certification Burn heathlands for farming and to obtain charcoal	12	1789–1886
Crop pests and disease control	Gather of leaves to burn Burning cereal straw, corn canes, rye, and pine forest to fight pests and diseases	7	1513–1868
Wildlife control	Use fire to keep wolves, wild boars and bears away Use fire to keep the game away Use fire to favor heath growth	5	1790–1868
Against frosting	Bonfires to produce smoke to protect crops against frost	1	1860
Firefighting (use of suppression fire)	Fighting wildfire using fire	1	1837
Fuel management (wildfire prevention)	Fuel- and fire-breaks Prescribed burning	3	1751–1859
Break rocks	Bonfires to break rocks	1	1513

Concerning the characteristics of the documents found, there were different issues to consider, as follows.

Until the second half of the 18th century, few Portuguese publications on agrarian themes documented fire's full integration into the agrosilvo-pastoral system. Difficulties in finding these types of documents are acknowledged in the preface of *Catálogo das Obras de Agricultura entre os séculos XVII e XIX* (Catalogue of Works on Agriculture, 17th and 19th centuries" (Simões, 1937), referring that no work on agriculture had been published in the 15th-century. Instead, all knowledge was passed down by the friars, who developed practices based on the Roman classics. Simões (1937) also states that in the 17th century, technical literature was limited to the translation of the so-called *Éclogas e Geórgicas de Vergílio* (Vergil's Eclogues and Georgics, Agricultural topics, from the 29 BCE, translated by Leonel Costa Lusitano in 1626 (Felix Pereira, 1875). In the 18th century, the book *De re Rustica*, originally from the 6th century BCE (Varron, 1773), also stands out among the republished Roman classics accessed for this study. Fire was a widely used tool, particularly in Portugal and Spain. There were writings about it only if incidents arose from its use, putting private property and crops at risk (Montiel-Molina et al., 2013).

Given the cultural similarities between the different Iberian peoples, we considered the outputs translated into Spanish by authors from the Iberian Peninsula, such as *Os Doze Livros de Agricultura* (The Twelve Books on Agriculture, (Columela, 1824) originally from Lucio Junio Moderato Columela (60 to 70 AD), born in Cádiz, and *Livro de Agricultura* (El Awam, 1802) originally by Ebn El Awan, a 12th-century Muslim writer from the city of Seville. In addition to these two books describing the uses of fire, we included the 16th-century book *Obra de Agricultura Compilada de Diversos Auctores* (Agricultura General de Gabriel Alonso Herrera, 1818) by the Spanish author Gabriel Alonso de Herrera, which is an agricultural treatise with the collaboration of several authors of the time and containing interesting descriptions of the uses of fire.

From the 18th century on, several technical and scientific outputs were published disseminating agricultural practices, following the new rationalist and Newtonian science introduced and driven by the Marquis of Pombal (Nunes, 2001). During this century, several works on agriculture covering the uses of fire were gathered in the *Jornal Encyclopedico Dedicado á Rainha; N. Senhora, e Destinado para Instrucção Geral com a Noticia dos Novos Descobrimentos em todas as Sciencias, e Artes* (Ordem de Cister. Mosteiro de Santa Maria (Alcobaça), n.d.) and in the *Memorias Economicas da Academia Real das Sciencias de Lisboa, para o adiantamento da Agricultura, das Artes, e da Industria em Portugal* (Academia Real das Sciencias de Lisboa, n.d.), and both were included in the present study.

For the 19th century, when several agronomy works were published, we included the relevant *O Archivo Rural - Jornal de Agricultura, Artes e Sciencias Correlativas*.

We plotted the Portuguese Regions to locate the places addressed in the paper (Figure 1).

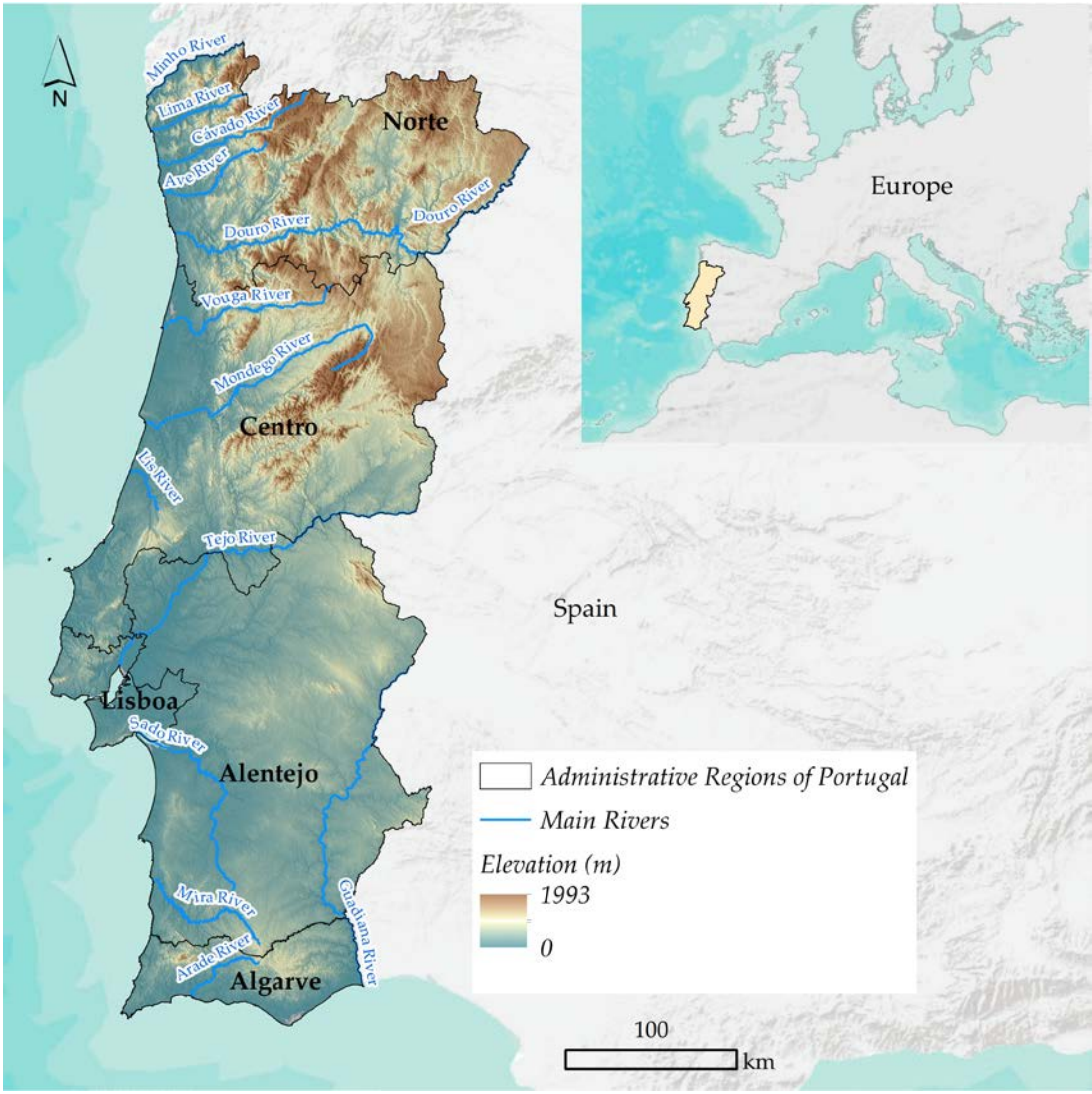


Figure 1. Regions of Portugal (Level 2 of the Nomenclature of Territorial Units for Statistics).

2.3 RESULTS

Results from documentary sources from the 12th century until the end of the 17th century showed that several uses of fire were essential for establishing the Portuguese nation. Rebelo da Silva (1868) described the establishment of Portuguese settlements and the use of fire and plowing to open up the first arable land during the Foundation period (12th century). The author also mentioned that agriculture was nearly a nomadic and itinerant activity because of the instability created by war. As a result, fire followed the same path, being applied every time the peasants of the newly founded Portuguese nation moved to new lands.

From the 13th century until the first half of the 14th century, farming in the mainly mountainous territory of what was the Portuguese nation at the time was a difficult process, having favored the pastoral system (Rebelo da Silva, 1868). Furthermore, as early as the 1st century BCE, the Iberian Roman author Columela said that lands with few trees should be converted by cutting them from the base, burning them, and incorporating them into the land through tillage (Columella, 1773).

In the 15th century, pastoral communities started the first conflicts with clergy and nobility as they became deprived of enough arable land due to the increase and expansion of these social classes' agricultural and Royal hunting properties. In response, regulations and punishments for those who set fire to the woods within hunting properties and forests in south Portugal (Santarém, Alentejo) were promulgated by Order of May 23, 1474, limiting grazing activities and the inherent use of fire to October, November and December (Rebelo da Silva, 1868).

In the first centuries of Portugal's foundation (until the 15th century), farming techniques were disseminated directly from the classic authors to the friars, who implemented the techniques and improved them with the peasants (Columella, 1773; El Awam, 1802). *Geórgicas de Vergílio* (70 BCE) compiled the agricultural techniques of the time in poems, which were widely disseminated in Romanised territories until the 18th century. This book described the need to use fire for soil fertilization and the associated constraints and risks. It also mentioned that neither legislation nor religion forbade critical agricultural practices during holidays, such as using fire for pasture renewals and plowing (free translation from the original)**:**

> "It is often convenient to throw the fire
> Into the barren ground, where it blazes
> Stubble, the flames crackling;
> Or because the soil, thus hidden, is vigorous
> Receive its nourishment most gracious;"

Agriculture practices in the Middle Ages (5th century to 15th century) employed very few amounts of manure on the soil and overstated burning for plowing (Campos, 1913; Oliveira Marques, 1978). The use of fire was diverse and followed ancient Roman knowledge. Such knowledge included using fire in stonemasonry, fertilizer production, increased pasture productivity for goat production, sterilizing manure, cattle disease control, and weed control in crops (Agricultura General de Gabriel Alonso Herrera, 1818). The 16th century author Alonso Herrera highlighted the need to burn the hills in September, as the renewal by sprouting and herbs made better pastures for goats, improving the fattening of the animals and preventing diseases.

Fire was fundamental to agricultural development based on the agrosilvo-pastoral system until the 19th century. The need to share fire among the community led to selecting a house to keep the fire lit to supply other houses when they ran out of fire, a widespread custom in Portuguese villages (Caldas, 1998). This practice still occurred in the 16th century, named

Tocheiro (man with a torch), according to a record dated March 14, 1500, of the Chancellery of King Manuel I (Arquivo Nacional da Torre do Tombo, 2008).

The 18th century Europe witnessed the stimulation and spread of the scientific, political, and philosophical discourse within the Enlightenment. In Portugal, one of the first agricultural publications was written by the Spaniard João António Garrido in 1749. In one of the chapters ("Farming in the fields"), the author describes the advantages of using fire over using manure, highlighting the burning in August of plants of the genus *Cistus* (rockrose) for cereal production (Garrido, 1749, p. 37) (free translation from the original):

> "In the absence of manure, it is very useful and advantageous to burn in August, which opens the soil's pores to receive more heat, together with the water when it rains in autumn. Experience has shown that more grain (bread, the original version) is produced from burned rockrose lands than from soil with manure, and so in the absence of rockroses, straw, stubble and shrubs brought from elsewhere should be laid on the land, to burn, and fertilize the lands (…)"

Several scientific journals focused on agricultural activity were launched in Portugal in the second half of the 18th century (Gomes Dias, 2014). *Jornal Encyclopedico* (1779─1793) and *Memorias Economicas da Academia Real das Sciencias de Lisboa* (1779─1820) are among these publications (Nunes, 2001). At the apogee of natural philosophy, the Portuguese Academy of the time sought to develop applied Portuguese studies and promote the so-called New Agriculture. It encouraged a model of an educated farmer with enough economic units of farmland and whose practices should be based on techniques derived from scientific knowledge, testing, and innovation, as opposed to conventional and traditional practices (Nunes, 2001). Such a mindset would be reinforced in the following century by liberal reforms and emerging interests for the common lands. The first written documents proposing changes to the conventional agrosilvo-pastoral system and replacing traditional practices, such as the use of traditional fire, with a new scholarly-based agrarian system, were published in the middle of the 18th century (Nunes, 2001). Foreign authors' knowledge deeply influenced the proposed new practices without considering the different countries' landscapes and realities. The first criticism of the use of fire and the instruction for what were believed to be better practices with the same aim came under the influence of foreign authors such as Duhamel du Monceau, Rozier, and Fourcroy (Nunes, 2001). Instead, Portuguese authors described the importance of traditional practices, including the benefits of using fire, such as using fire in soil fertilization and the importance of livelihood (Ferber, 1788; Lisboa, 1789; Paiva, 1788). A clear divergence existed between the authors who rejected the use of fire based on the practices performed in the Alentejo Region and those who advocated the conservation of these uses based on the practices carried out north of the Tejo River. E.g., Baptista (1789, pp. 287–288) described the importance of burnings and of burning cereal crops (free translation from the original):

> "Some renowned agriculture engineers order small furnaces of clods to be made around some paves of shrubs, and on the eve of the rain, they order a fire to be light in them, so that by burning the shrubland the clods are toasted, and turn black with the smoke, so that these same clods fertilized by the fire, and spread over the land make it all equally fertile."

The practice described is called *forneiros* in the rural communities of Paredes de Coura in Alto Minho (Norte Region), which is still active. However, it is currently associated with a simple slash-and-burn, not connected with the crop field fertilization practice that was previously widely used in several regions (Lacerda Lobo, 1790; Lasteyrie, 1827; Miret I Mestre, 2014). In contrast with the latter quote, in the same book, Silveira (1789, p. 59) criticizes the agricultural practices and the use of fire in the Alentejo Region (free translation from the original):

> "The farmers of Alentejo cultivate this ineffectively: they cleared them, set fire in August, and sow wheat on the ashes. (…) To perform a clearing, eight years must pass, all this time being necessary for the shrubland to grow and be able to be cut again. (...) they should set the fire in calm weather and have many men to extinguish the fire if it escapes, but to avoid the expense of so many workers, they order to set the fire, not having in the land more than two or three men, and for this reason, the fire escapes them repeatedly, without being able to stop it; because if pastures are dry, it runs with incredible speed, burning woodlands, destroying pastures many times in the extent of leagues (…)"

Additionally, the same author questioned the municipal management of common lands (lands characterized by traditional collective use, carried out and controlled by rural communities) in the Alentejo Region, which is based on *sortes* (lots) as an annual exploitation method and the inherent practice of itinerant agriculture, bringing the uses of fire with it. The concept goes back to pre-Roman times when communities divided the common land into *sortes*. Then, they distributed plots for cultivation every year and specified the crop to be cultivated according to the drawing of lots (Dias, 1984). Common lands provided pasture for livestock production until the mid-20th century, and fire was used for their renewal and improvement (Sá, 1791). In some locations where land for cereal crops was in shortage, particularly rye, common lands were plowed by clearing and burning (Estêvão, 1983). Fire was also used in long fallows within the crop rotation system (Monteiro Alves et al., 2006), soil fertilization and sanitization (Anónimo, 1791; P. F. Sequeira, 1790; Villa Nova Portugal, 1790) and for hunting and crop protection. However, recurrent fire was believed to be linked to negative effects, e.g., wolf extinction and a significant decrease in the wild boar population in Setúbal District, particularly in Serra da Arrábida, near Lisbon (Gomes de Oliveira, 1791). Gomes de Oliveira (1791) shed light on the decreasing pine forest due to the high demand for wood and charcoal for the cotton factory of Setúbal and the increasing population of Lisbon. Wood and charcoal were crucial energy resources for ceramics, glass, iron, steel, and food (bakeries) production in Lisbon and Setúbal districts at the end of the 18th century. The need to provide these fuels had contributed to cork and holm oaks logging in Alentejo and Middle Tejo (Centro Region) (M. A. P. de Almeida, 2002; Rocha, 1998), as stated in the Order of March 29, 1792, from the Court of the Senate of the Council. The increasing population of urban Lisbon at the end of the 18th century triggered a socioeconomic process of increased demand in the construction sector, energy supply, and food resources. It ultimately led to the overexploitation of rural resources, particularly in the surrounding regions, i.e., the Alentejo and Middle Tejo (Centro Region), by forcing the plowing of new lands for cereal and olive crop installation. Large areas of pine forests were logged for wood for the reconstruction of Lisbon after the earthquake of 1755 and for establishing new extensive livestock production areas using fire for clearing and pasture renewal.

The existence of vast common lands allowed the use of fire in the pastures that annually received transhumant cattle. In the second half of the 18th century, the extensive areas of common lands in the Alentejo became of great economic interest, i.e., implying privatization, to some of the influential layers of Portuguese society (Fonseca, 1996). The pressure on common lands and the objections against traditional practices, such as the use of fire, as a barrier to economic and agricultural progress was reinforced from the beginning of the 19th century (Estêvão, 1983).

In the first half of the 19th century, Portugal's agricultural modernization was still behind compared to other European countries, such as the UK, France and Germany, which had already introduced the steam engine created at the end of the 17th century (Broadberry et al., 2008). Initially developed for agriculture, the steam engine was soon applied to industry, giving rise to the first phase of the Industrial Revolution (Custódio, 2020). In 1742, Portugal bought two steam engines. The press published an article describing some of the advantages of adopting the new technology, highlighting the country's abundant availability of wood to feed the machines (Mascarenhas, 1742). Their industrial application in Portugal would only occur in 1820. Until then, Portuguese agriculture maintained its millenary and sustainable agrosilvo-pastoral system covering the whole country and using the common lands. Plowing and processing agricultural products were powered by human force, animal traction, and hydraulic and windpower machines of the pre-industrial age. In this context, fire was still the main tool supporting resource management.

Throughout the 19th century, the different perspectives on the positives and negatives of fire uses continued (Aguiar, 1869; Andrada e Silva, 1815; Anónimo, 1872; da Matta, 1859; Ferreira Lapa, 1859; Lima, 1867, 1868; Maria, 1849; Menezes, 1860; J. F. Pereira, 1868; Visconde de Vilarinho de S. Romão, 1857). Despite this controversy about traditional fire use, we found the first documented reference at the professional level of firefighting to the use of suppression fire in *Pinus pinaster* stands, published in 1837 by Joaquim Luiz da Cruz (J. L. da Cruz, 1837).

From the end of the 19th century, plenty of publications refer to pasture renewals and charcoal production as the causes of wildfires, which assisted in disbelieving traditional practices and eliminate fire from the landscape, particularly in the Ribatejo (Centro Region) and Alentejo Regions. The poor and less educated rural society was blamed for damaging and destroying the landscape. However, such dynamics were likely associated with processes of large urban centers' population growth and new industrialization, not by pressure from rural communities. Matos (2002, p. 134) described the concern of the Civil Governor of Portalegre district (Alentejo) in 1850 with the high demand for charcoal by the country's capital and its impacts on rural areas (free translation from the original):

> "The interest generated by the sale of charcoal in Lisbon, where many loads are taken, has destroyed an incalculable number of trees on the Alentejo farmsteads. It would be convenient to establish limits for such devastation."

One of the greatest problems of the end of the 19th century was Portugal's general deforestation because of the growing demand for charcoal for domestic consumption and industry and the appropriation of common lands to increase agriculture (Abel, 1988). However, these facts seem to have been overlooked by several authors whose articles solely focus on blaming the rural population, e.g., the historian Alexandre Herculano (1898), in Abel (1988), considered that the common lands were constraining the agricultural progress in the country and thus were an obstacle to the interests of the liberal reformists during the 19th century.

After the civil war of 1832-1834, due to the reforms led by Mouzinho da Silveira (a deputy elected for the Alentejo Region), property ownership was transferred and land redistributed, in particular, the disentailment of common lands. The south of the country, particularly the Alentejo Region, would suffer the effects of the prevailing liberalism, with the individual appropriation of common lands, consolidating large rural properties, and giving rise to the *latifundio* (large estate) (Abel, 1988; Hespanha, 1983). According to several scholarly authors implicated in the Royal Courts of the time and often strangers to the rural reality, fire was one of the main excuses used for stating that common lands were mismanaged, and that eventually led to their privatization (A. M. Cruz, 1865; Lima, 1865; Mendes, 1980; A. Pereira, 1862). Manuscripts from the end of the 19th century showed differences between Portugal's southern and northern regions concerning the use of common lands and the use of fire, which was better tolerated by the northern population. Augusto Vieira (1886, p. 365) described in his book *O Minho Pitoresco* his experience in a burn carried out in Serra Amarela (currently Peneda-Gerês National Park, Northwestern Portugal), highlighting the use of fire by the rural community for charcoal production by burning heathland (free translation from the original):

> "It is not, therefore, a broad vault that exists with any economic organization; it is the need of the moment that produces the association of wills directed by the same intention.
> The mayor says it is necessary to pay, and then those from Germil, to get rid of the burden, say to each other -let us do this- and so they agree to carry out the burning. These burnings sometimes last hours and days, and it is from the heather charcoal that the mountain people take the most advantage of for their small businesses. Whoever spends the night at some distance from the burnings enjoys a magnificent and beautiful show, watching the fire plowing through the extent of the rockroses, wide and vast, like the high flux of a beautiful aurora borealis."

The end of the 19th century marked the beginning of deep socioeconomic changes imposed by liberal reforms to keep up with other European countries. This approach took decades and continued through the following century until Portugal entered the European Economic Community (EEC) in 1986. In this context of reforms, 19th century Portugal was able to modernize various sectors such as agriculture, industry, transportation and communications, education, and the rule of law of the population. However, agriculture, mainly cereal-based, and the emerging steam engine-based industry, strived for forest resources, and common lands were a barrier to the growth of both sectors of activity because of their shared pastoralism activities and subsistence agriculture using frequent fire.

Akin to the industrialization process at the end of the century, Portuguese agriculture also started a process of great changes that broke with the conventional system that shaped and maintained landscape diversity for centuries. The new motorized agriculture started in the country's southern regions in 1855, particularly in the newly established *latifundios* in the Alentejo and Ribatejo (Centro Region) (Custódio, 2020). Inorganic fertilizers were introduced at the end of the second half of the 19th century to meet soil fertility decrease. Inorganic fertilizers, motorized agriculture, and land tenure changes gave rise to an irrevocable breakdown of the traditional agrosilvo-pastoral system, disarticulating the interdependence of agricultural, livestock, and livestock and forest productions. Thus, these three activities went from benefiting from each other to being unconnected, losing the balance and spending more resources. These changes heavily impacted rural communities' landscape and social structure, as well as soil fertility and structure (Carmo, 2018). Changes were faster in southern Portugal, particularly in Alentejo and Ribatejo (Centro Region), which had a greater extent of cereal crops on larger farms and whose geomorphological and edaphic characteristics helped agricultural motorization and the application of fertilizers to supply greater needs for nutrients. Previously mentioned land tenure changes and agriculture expansion have conditioned grazing activities and fire use due to conflicts generated by new land uses and land covers. In the following decades, the changes that happened at the end of the 19th century progressively spread to the whole country, with different degrees of impact and speed of change according to the characteristics of each region. As new technologies and techniques were being implemented and improved with time, and as the agrosilvo-pastoral system was being broken down, the different uses of fire were progressively abandoned, replaced, conditioned, or even forbidden by law (Carmo, 2018).

2.4 DISCUSSION

2.4.1 The traditional Portuguese fire uses before implementing policies and regulatory measures (late 19th century CE)

The human presence in the Portuguese territory has always implied a continuous use of fire to manage the landscape (Sweeney et al., 2022). The Portuguese landscape was shaped by fire associated with traditional practices within a deep-rooted and complex agrosilvo-pastoral system, developed and improved from generation to generation (Fábregas Valcarce et al., 1997; Jorge, 2000; Sanches, 2003; Sweeney et al., 2022). From the Neolithic until the 19th century, fire kept up with the initially itinerant and later rotational agriculture and transhumant grazing, generating cultural landscapes. Cultural landscapes are, thus, the outcome of different societies' resource management activities, and the evolution of the Portuguese landscape was led by the societies that became dominant in the different periods (Davidson-Hunt, 2003; Miller & Davidson-Hunt, 2010). As a result, the importance and perceptions of usefulness and benefits that the leading society had about fire uses impacted and changed the uses of fire in Portugal over time.

The historical documentary sources reviewed on the uses of fire allowed us to identify its various purposes in managing resources by rural communities in Portugal and the techniques and uses of fire throughout the centuries until it was conditioned. It was also possible to understand the difference between traditional fire knowledge transfer and traditional fire knowledge transmission. The first assumes the generational transfer of knowledge, i.e., with the inherent applicability of practices and techniques for sustainable resource management and environment for the inhabitant communities. The second does not imply practice and can be theoretical (Armatas et al., 2016; Berkes, 2012; S. J. Pyne, 2006).

Currently, there is a reductive view of the traditional use of fire, but the records found showed the existence of several uses in the past (Figure 2). Therefore, traditional fire knowledge is much broader and as diverse in a community as the complexity of managing the various resources to support the different activities (Vázquez-Varela et al., 2022).

Figure 2. Calendar of the traditional use of fire in Portugal based on literature and historical records.

The data retrieved in this study enabled the characterization of the several traditional uses of fire, going from an energy source useful for resource management at an individual level to a tool for supporting the whole community. Within traditional communities, subsistence depends on the phenology of food crops or wild plants, the breeding seasons and the type of farm animals, the hunting and protection periods for the juveniles of hunting species, the sanitary needs, pest control, protection against wildlife, beekeeping areas and charcoal production. As traditional rural communities depend on seasonality to obtain provisions, fire uses should be adapted to immediate or post-fire needs, i.e., the traditional fire regime should be considered (Figure 3).

The traditional fire regime should apply fire according to specific seasonality, severity, intensity, and recurrence criteria to achieve the different purposes. First, fire for pasture renewal should be low intensity to promote the sprouting of shrubs and grasses and the germination of certain herbaceous plants for livestock feeding in summer. Such fire occurs mainly during winter and usually allows easy control and self-extinguishing. Second, fires associated with plowing are carried out after grazing and cutting and demand higher intensity to facilitate the breaking up of the soil by the plow using animal traction and seeking the maximum quantity of ash for its fertilization. In this case, August is the appropriate month for this challenging task. Finally, fire recurrence is a condition that varies according to the exploitation regime and the associated crop.

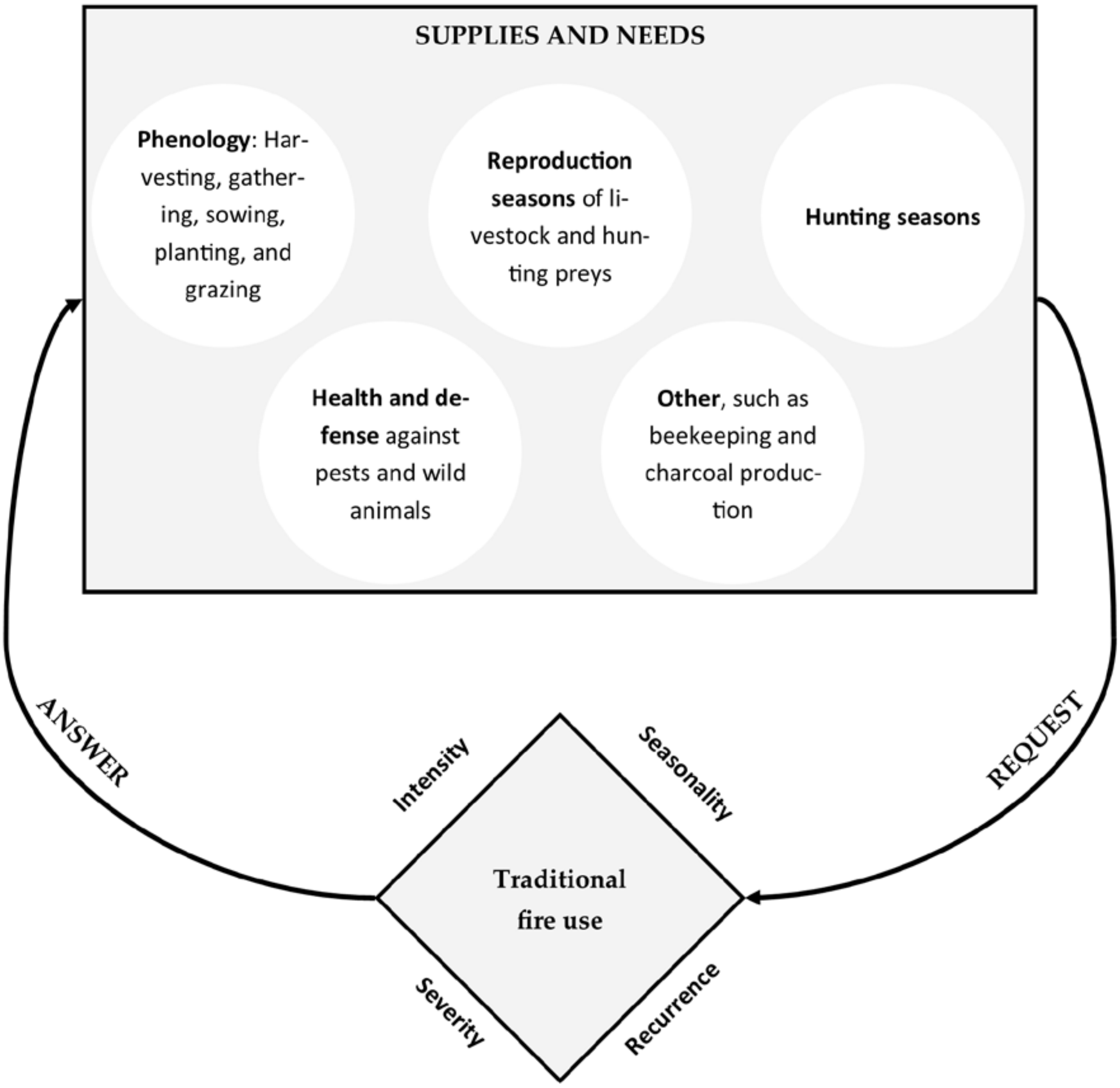


Figure 3. Fire use within a traditional fire regime

Until the second half of the 19th century, the diversified role of Portuguese communities' use of fire was part of a balanced system. Then, the liberal reforms and the country's industrialization brought powerful interests that would forever break with the conventional agrosilvo-pastoral system. The disentailment of common lands, the mandatory agriculture intensification of mainly cereal crops, and the charcoal demand for the emerging industry supported by steam engines and domestic uses strongly contributed to deforestation (Abel, 1988; Graça, 1999; Matos, 2002). At that time, fire was used for land management practices of converting the new properties from disentailment into cereal crops, meeting the high demand for charcoal for industry and domestic uses (Henriques, 2006). Old practices were kept in territories where pastoralism used common lands and agriculture based on *sortes* prevailed. Nevertheless, according to our findings, rural society was blamed as the main perpetrator of the country's deforestation for practices such as pastoralism and the use of fire.

2.4.2 The remains of the traditional fire in Portugal

In the late 19th to mid-20th century, cereal agriculture and industry sectors competed for forest resources, supported by legislation that constrained pastoralism and the use of fire (M. A. Almeida, 2020; Graça, 1999). This conditioning and prohibition over more than 150 years, together with other factors such as agricultural motorization and intensification, inorganic fertilization, and forestry based on monocultures, led to a decrease in most rural uses and to the abandonment of most uses of fire, which broke the generational transfer of knowledge (Huffman, 2013; Meira Castro et al., 2020). This loss resulted in a generalization and reduction of diversified uses to a generic and simplistic definition of the use of fire associated with rural practices that remain. Several European authors refer to this use of fire as traditional, associating it with the current practices of rural communities, such as the slash-and-burn of agricultural, forest heaps, and pastoral burning (de Diego et al., 2023; Ganteaume et al., 2013; Tedim et al., 2022; Torres-Manso et al., 2014).

Current fire use practices by rural communities represent only remains of past fire uses, essentially slash-and-burn, and agricultural, forest heaps, and pastoral burning, which were associated with many of the causes of wildfires in Portugal (Lourenço et al., 2013; Meira Castro et al., 2020; OTI et al., 2020; Parente et al., 2018; J. M. C. Pereira et al., 2006; M. G. Pereira et al., 2011). The slash-and-burn lost its purpose of obtaining agricultural fertilizer and is now only about pruning and crop residue removal through fire. The use of fire in pasture renewals became illegal, but the communities in the north of the Iberian Peninsula maintain extensive livestock and shared land management and still use fire. It brings together some of the knowledge and applicability of the past (seasonality, low-intensity nature, recurrence period), but legal impositions and constraints have eliminated the possibility of its implementation by pastoralist communities and changed the traditional practices of the past (Oliveira et al., 2023; Oliveira & Fernandes, 2023).

The Portuguese process of conditioning the use of fire by traditional communities is quite similar to what settlers imposed on American and Australian natives (Domínguez & Luoma, 2020; Hoffman et al., 2022; Marks-Block & Tripp, 2021; L. E. C. Pereira et al., 2018). For native communities, fire is the way to control and manage an important energy source and natural resources, thus very important for traditional communities' empowerment. Therefore, limiting and forbidding its use meant removing power from communities, thus impacting its sustainability (Domínguez & Luoma, 2020; Hoffman et al., 2022; Marks-Block & Tripp, 2021; Seijo, 2005).

Fire in Portugal is no longer a community-shared activity because of the legislation in force. Users choose to set and not "shepherd" the fire to avoid criminal charges, sometimes leading to wildfires, particularly between autumn and spring (Celaya et al., 2022; de Diego et al., 2021; González-Hidalgo, 2023; López-Rodríguez et al., 2021; Marey-Pérez et al., 2015; Seijo, 2005; A. C. Sequeira, 2020; C. R. Sequeira et al., 2019). It is impossible to refer to the current most commonly used fire practices by rural communities in Portugal as traditional fire, as it is just a remnant of the past. It is now a traditional fire use because of its local application.

However, it does not derive from traditional fire knowledge generational transfer anymore, as it still is in some traditional and native communities in other regions worldwide, such as in East Africa, Australia, Brazil, and the Basque Country in France (Butz, 2009; Coughlan, 2013; Eriksen, 2007; Lake et al., 2017; Moura et al., 2019; Myers, 2006).

Restoring fire to traditional rural communities is imperative. It must be carried out by creating mechanisms for training and responsibility for its use. It is especially important in the rural communities of the Iberian Peninsula because of the loss of traditional fire knowledge. It also implies that prescribed fire managers should receive broader training beyond the weather prescription designed to control fire and its direct on-site impacts. The training should replicate traditional fire knowledge to suit fire uses to local ecosystems and the local community needs. All the practices should comply with a wildfire risk analysis to protect the landscape from severe wildfires and enhance the positive role of fire instead of its negative impact.

2.5 Conclusion

Fire in traditional rural systems is connected and integrated into all components and processes that form these socioecological systems. In this context, traditional fire regimes are characterized by specific frequency, intensity, severity, and seasonality. Based on historical sources, our research identified and described the traditional practices involving the different fire uses in Portuguese rural communities by designing a calendar of the traditional use of fire in Portugal and detailing the characteristics of the traditional fire regime. It was possible to understand that the gradual loss of traditional fire uses and disruption in the traditional fire-knowledge transfer were derived from the changes, mainly in land tenure, inorganic fertilization and agriculture motorization, introduced at the end of the 19^{th} century. The breakdown of the conventional traditional system has disjointed the interdependence of human processes with nature. Moreover, the cultural landscape has changed because of leading societal changes, such as depopulation and population aging, traditional activities and land abandonment, and land use policies. New societies influencing rural areas fostered fire exclusion from the landscape, misleading the importance of anthropogenic fire in ecological processes in fire-adapted and fire-dependent ecosystems. Currently, fire is no longer connected with the landscape, and fire uses are dealt with from a simplistic and reductive perspective mirrored in the legislation. In the research, development, training, and designing of regulatory proposals for political decision-makers, much effort from academia will be needed to recover ancestral knowledge, restore traditional fire knowledge, and empower rural communities again, considering the new challenges climate change poses.

CAPÍTULO III - INCIDENT ANALYSIS OF TRADITIONAL BURNS IN PORTUGAL

Abstract. In Portugal, each year, the news typically report one or two cases of elderly farmer fatalities or injuries. However, in 2018, a startling 20 incidents were documented. This study aims to analyse the various factors that may account for this unusual surge in the numbers.

To gather comprehensive and organized data on the incidents, a meticulous review of both regional and national news sources was conducted from 2008 to 2021. This enabled the collection of various variables, including date, location, gender, age, and other pertinent information. Additionally, meteorological data related to wildfire risk, sociodemographic indices, and the legislative context were also incorporated to provide a more complete understanding of the incidents.

Between 2008 and 2021, a total of 54 incidents were recorded, with fatalities accounting for 78% of cases. The exceptional rise in incidents in 2018 constituted 37% of the total incidents. The majority of incidents involved elderly individuals (82%) and were primarily males (80%). March and October were the months when most incidents occurred. After conducting meteorological, social, and legislative analyses, it was found that the primary driver behind the unusual increase in incidents in 2018 was most probably the intense pressure to manage the vegetation, due to an impending deadline for fuel reductions, along with stricter inspections and law enforcement that doubled the fines for non-compliance.

Keywords: Fire use; Traditional fire; Wildfire prevention; Fatalities; Injuries; Rural population; Legislative pressure; Slash-burn; Huddled agriculture and forestry leftovers.

Resumen. *Análisis de incidentes en quemas tradicionales en Portugal*

En Portugal, cada año, las noticias suelen informar de uno o dos casos de agricultores ancianos muertos o heridos. Sin embargo, en 2018, se han registrado 20 incidentes. Este estudio pretende analizar los diversos factores que pueden explicar este inusitado aumento del número de casos.

Para recopilar datos completos y organizados sobre los incidentes, se llevó a cabo una revisión meticulosa de las fuentes de noticias tanto regionales como nacionales desde 2008 hasta 2021. Esto permitió recopilar diversas variables, como la fecha, la ubicación, el sexo, la edad y otros datos pertinentes. Además, también se incorporaron datos meteorológicos relacionados con el riesgo de incendios forestales, índices sociodemográficos y el contexto legislativo para proporcionar una comprensión más completa de los incidentes.

Entre 2008 y 2021 se registraron un total de 54 incidentes, con un 78% de víctimas mortales. El aumento excepcional de los incidentes en 2018 constituyó el 37% del total de incidentes. La mayoría de los incidentes afectaron a personas mayores (82%) y fueron principalmente hombres (80%). Marzo y octubre fueron los meses en los que se produjeron más incidentes. Después de realizar análisis meteorológicos, sociales y legislativos, se constató que el principal impulsor detrás del inusual aumento de incidentes en 2018 fue, muy probablemente, la intensa presión para gestionar la vegetación, debido a un plazo cada vez más limitado para reducir el combustible, junto con inspecciones más estrictas y una aplicación de la ley que duplicó las multas por incumplimiento.

Palabras clave: Uso del fuego; Fuego tradicional; Prevención de incendios forestales; Víctimas mortales; Heridos; Población rural; Presión legislativa; Quema de amontonados Restos agrícolas y forestales amontonados.

Resumo. *Análise de incidentes en queimas tradicionais en Portugal*

En Portugal, cada ano, as noticias adoitan informar dun ou dous casos de agricultores anciáns mortos ou feridos. Con todo, en 2018, rexistráronse 20 incidentes. Este estudo pretende analizar os diversos factores que poden explicar este inusitado aumento do número de casos.

Para recompilar datos completos e organizados sobre os incidentes, levou a cabo unha revisión meticulosa das fontes de noticias tanto rexionais como nacionais desde 2008 ata 2021. Isto permitiu recompilar diversas variables, como a data, a localización, o sexo, a idade e outros datos pertinentes. Ademais, tamén se incorporaron datos meteorolóxicos relacionados co risco de incendios forestais, índices sociodemográficos e o contexto lexislativo para proporcionar unha comprensión máis completa dos incidentes.

Entre 2008 e 2021 rexistráronse un total de 54 incidentes, cun 78% de vítimas mortais. O aumento excepcional dos incidentes en 2018 constituíu o 37% do total de incidentes. A maioría dos incidentes afectaron a persoas maiores (82%) e foron principalmente homes (80%).

Marzo e outubro foron os meses nos que se produciron máis incidentes. Despois de realizar análises meteorolóxicas, sociais e lexislativos, constatouse que o principal impulsor detrás do inusual aumento de incidentes en 2018 foi, moi probablemente, a intensa presión para xestionar a vexetación, debido a un prazo cada vez máis limitado para reducir o combustible, xunto con inspeccións máis estritas e unha aplicación da lei que duplicou as multas por incumprimento.

Palabras chave: Uso do lume; Lume tradicional; Prevención de incendios forestais; Vítimas mortais; Feridos; Poboación rural; Presión lexislativa; Queima de amoreados; Restos agrícolas e forestais amoreados.

3.1 INTRODUCTION

Portugal has a long history and numerous legislative references related to the use of fire in rural regions [1,2]. The practice of utilizing fire for managing huddled agriculture and forestry leftovers with small burns (slash-burns) and for the renewal of pastures has been widely employed in rural areas and is still used today. However, these areas are becoming depopulated, remaining aged and often isolated populations [3–5]. In the 1950s, the rural areas in Portugal were characterized by a network of agricultural and woodland patches maintained by local farmers. However, due to land abandonment, this is no longer the case. As a result, biomass accumulates in unused areas, increasing fuel loads and creating a high risk of wildfires[6–8]. Despite this, the remaining population in rural areas continues to use fire for land management [9], although not always with the necessary control [10,11]. The use of fire use in agricultural and pastoral practices is considered traditional burn, and it includes the practice of slash-burns and the use of fire for pasture renewal. These practices have played a significant role in shaping the landscape, creating a rich mosaic for biodiversity [12,13]. Additionally, prescribed burning - an institutional and professional fire technique, performed by fire managers, with both fuel reduction and ecological objectives - is also employed in land management [14,15] In recent decades, fire policies have encouraged the use of prescribed burning [8,16], while also restricting and controlling traditional fire use [17,18]. According to official data from the Portuguese Institute of Nature and Forest Conservation (ICNF), traditional burns, which are included in the negligent category, are a common cause of wildfires. For example, in 2020, fires caused by rural burns accounted for 27% of the total of 9,619 fires in Portugal's mainland [20].However, the fires caused by these burns occurred with very low meteorological severity and only accounted for 2% of the burned area [9]. This finding is consistent with the study by Parente *et al.* (2018) [21], which found that intentional fires have a much larger average size than negligent fires.

Nevertheless, as mentioned in the report of WWF [22]:

> "(…) the traditional use of fire in the maintenance of pasture and agricultural land can have disastrous effects when the flames spread onto abandoned plots and turn into uncontrollable wildfires".

Traditional burns can not only be a starting point for wildfires but also pose a risk of injuries or even fatalities. Each year, there are records in the media about incidents in Europe, particularly in the Mediterranean basin, mostly involving elderly people who use fire in the landscape. In 2018, the number of incidents in Portugal was much higher than the usual one or two records per year. While wildfire fatalities worldwide are often attributed to factors such as fire weather, slope, and vegetation type [23–25], no explanations are found in the literature regarding the incidents related to traditional burns. The present study aims to investigate the injuries and fatalities caused by slash-burns in mainland Portugal from 2008 to 2021, as reported in national and regional newspapers, and determine the factors (social, meteorological, legislative) that contributed to the significant increase in incidents in 2018. The incidents were classified into three periods: before 2018 (2008-2017), during 2018, and after 2018 (2019-2021), with a particular focus on the year 2018 due to the high number of incidents reported. The findings of this study can help the rural population to burn safely by providing valuable information about the drivers that lead to these incidents and initiate a research line related to the use of fire outside the critical wildfire period defined by law, a topic that has not been explored in previous research. Although incidents related to fire use in Portugal are prevalent and worsened after 2017, they have not been adequately addressed by academia or policymakers. Similar situations may also occur in other European countries, indicating a need to study the trend of such incidents in the context of rural change.

3.2 MATERIALS AND METHODS

3.2.1 Data collection

A comprehensive review of national and regional newspapers, both in print and online, from 2008 to 2021 was conducted to gather systematic data on incidents related to traditional burns. Search terms such as “incidents”, “death”, “fatalities”, “injury,” combined with “fire“, “agricultural burns”, “traditional burn”, “slash-burn”, “farmer” and “elderly population” were used for the online search. The data collected from the media sources included variables such as date, place, gender, age and whether the person was burning alone. To avoid potential duplication, each reported incident was cross-checked in multiple media sources (different magazines, online and print), and the collected information for each incident was thoroughly reviewed for completeness. The location of each incident was approximately geo-referenced using the parish or municipality centroid of the Official Administrative Map of Portugal of 2022.

Newspapers were used as a data source due to the absence of official data regarding slash-burn incidents. For instance, incidents data that do not result in wildfires are not included in the official database (Forest Fire Information Management System (SGIF), [20]). The majority of incidents are classified as accidents and are recorded in a separate information system related to relief and emergency services of the Portuguese Institute of Medical Emergency (INEM) and of the Portuguese Authority of Emergency and Civil Protection (ANEPC). However, access to these data is restricted. Moreover, the emergency recording system relies on toponymical location, not allowing for rigorous geo-referencing. The study utilized data from various sources to supplement the information gathered from newspapers. Meteorological data associated with wildfire risk provided by the SGIF [20], namely, Temperature (ºC), Relative Humidity (%), Wind Speed (km h^{-1}), Fine Fuel Moisture Code (FFMC), Initial Spread Index (ISI) and Daily Severity Rating (DSR). Sociodemographic indices were obtained from the National Statistics Institute [26], and the legislative context from the Electronic Republic Gazette (DR) [27]. To monitor public interest, a Google Trends proxy was used to track the popularity of the term, in Portuguese, "Limpeza de terrenos" (land clearing).

Only incidents from mainland Portugal were included in the study, as the climate and, consequently, the fire triggers in Portuguese islands are not comparable to those on the mainland.

3.2.2 Sociodemographic indices

The study considered two sociodemographic indices at the municipality level: population density (number of inhabitants per km^2) and the ageing index (the ratio of people above 65 years by people below 15 years old x 100). Previous studies [5,10,28–30], have indicated that these indices are directly related to social vulnerability to natural hazards.

Each sociodemographic index was grouped into three classes (Table 1). As the incident data covered only the 2011 national census and the study ran until 2021, the middle interval was set to reflect the national average from the 2011 census and the national statistics projection for 2020. The statistical data refers only to mainland Portugal.

Table 1. Class intervals for the sociodemographic variables.

Class	Low	Medium	High
Ageing Index	< 130.5	130.5 - 169.6	> 169.6
Population density	< 110.0	110 112.6	> 112.6

Source: National Institute of Statistics [26]

3.2.3 Meteorological indices

The Fire Weather Index (FWI) is used in Portugal to assess the meteorological risk of wildfires and to regulate certain practices such as the use of fire. The FWI is based on daily measurements of air temperature, relative humidity, wind speed, and previous 24-h precipitation at noon. For this study, two FWI sub-indices were used: the Fine Fuel Moisture Code (FFMC), which indicates the relative ease of ignition, and the Initial Spread Index (ISI), which indicates the potential spread of fire in its early stages shortly after ignition. Additionally, the Daily Severity Rating (DSR), which is calculated as a function of FWI, will also be analysed as it indicates the difficulty of controlling wildfires and the expected effort required for their suppression [19,31,32].

3.2.4. Legislation

The legislation related to the use of fire and fuel management in the wildland-urban interface (WUI) was examined before and after 2018.

3.2.5. Statistical analysis

To determine whether there was a statistically significant difference between the incidents' expected frequencies and the observed frequencies in the categorical variables (period vs. month, day of the week, ageing index or population density classes), the Pearson's chi-squared test was performed. For continuous variables, a one-way analysis of variance (ANOVA) was performed to test for significant differences between periods (before, during, and after 2018, respectively, 2008-2017, 2018, 2019-2021). When statistically significant differences were found, post hoc Tukey HSD test was used for multiple comparisons of period means. Statistical analyses were conducted with IBM SPSS Statistics 26 (IBM Corporation, USA). All statistical relationships were considered significant at $p < 0.05$. For continuous variables, results are presented by mean ± standard error of the mean (SE).

3.3 RESULTS

3.3.1 Temporal trends

Between 2008 and 2021, there were 54 reported incidents in the media relating to huddled agriculture and forestry leftovers burning (slash-burns). Of these incidents, 78% resulted in fatalities. From 2016 onwards, there was an increase in the number of incidents, mostly resulting in fatalities (Fig. 1 and Fig. 2a). As seen in fig. 1, the incidents occurred all over the country from the North to the South, with some predominance in the central part of Portugal. In 2018, a significant surge in reported incidents occurred, accounting for 37% of the cases. Following 2018, the number of incidents decreased, returning to values identical to 2017. The average incidents (Fig. 2b) by year before 2018 (2008-2017) was 1.7±0.5, which was much lower than in 2018 (20) or after 2018 (2019-2021), during which period an average of 6.3±0.9 incidents per year were reported (Fig. 2b). When the anomalous year of 2018 is excluded, a statistically significant increase in the incidents before and after 2018 was observed ($p < 0.05$)

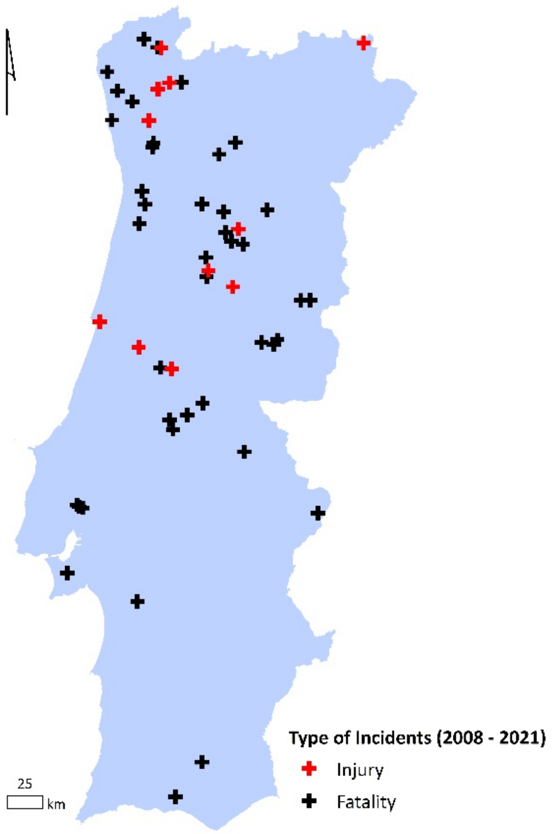


Fig. 1. Geographical distribution of incidents (fatalities and injuries) during 2008-2021 in Portugal.

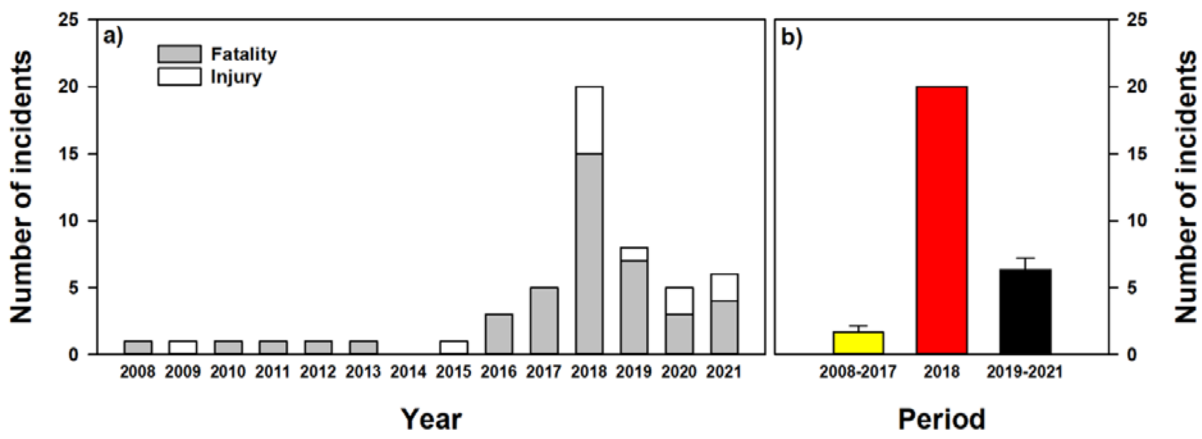


Fig. 2. (a) Number of incidents (fatality and injury) during 2008-2021 in Portugal. **(b)** Mean number of incidents by year before, during, and after 2018, respectively, 2008-2017, 2018, and 2019-2021. Error bars represent the standard error of the mean (SE).

Overall, the incidents occurred predominantly in October and March, representing 28% and 17% of the total cases, respectively (Fig. 3a). Only 7% of the incidents were reported during the summer months, without any occurrence in July and August. However, when comparing the different periods, i.e., before, during, and after 2018 (Fig. 3b), a shift in the primary occurrence of incidents can be observed from the last months of the year (September-December) to the first months of the year (January-June), although this change is not statistically significant ($p > 0.05$). Before 2018, the majority of incidents were reported between September and November (67 % of the incidents in the 2008-2017 period). After 2018, most incidents occurred between January and March (58% of the incidents in the 2019-2021 period).

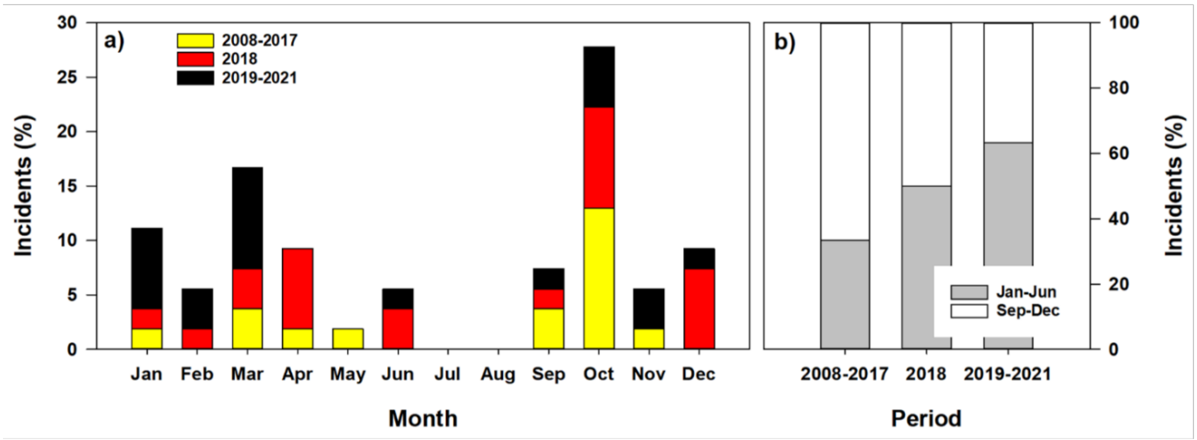


Fig. 3. (a) Percentage of incidents summed by month for the three periods considered: 2008-2017, 2018, and 2019-2021. **(b)** Percentage of incidents occurring in the first and second half of the year (in July and August, no incidents were reported), before, during, and after 2018.

Regarding the day of the week on which the incidents occurred, weekdays accounted for 85% of the total data. The beginning of the week, i.e., Monday (28%) and Tuesday (22%), were the most frequent days of incidents (Fig. 4a). The number of incidents was approximately the same on Wednesday through Saturday, (around 11% each day), with some variability between periods. There was no noticeable or significant ($p > 0.05$) change on the days of incidents occurrence before, during, or after 2018 (Fig. 4b). Nevertheless, it is worth noting that two fatalities occurred on Sundays in 2018.

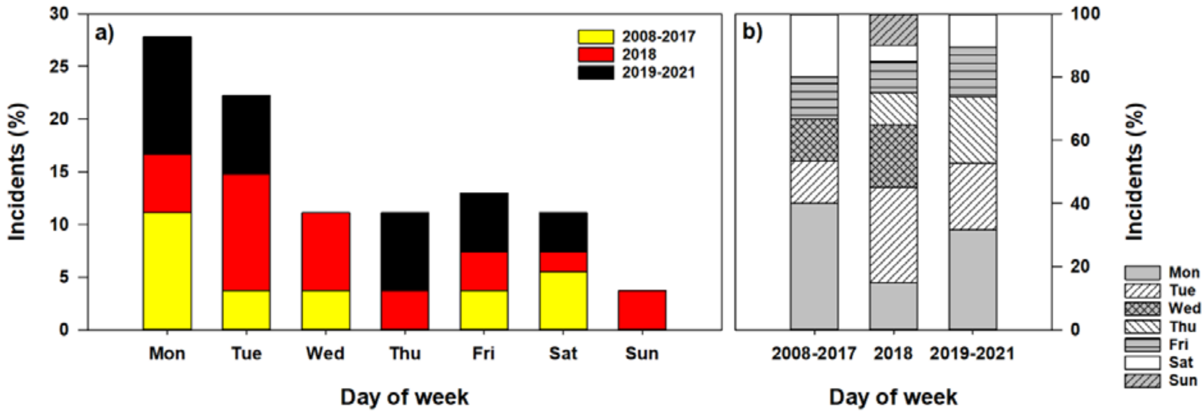


Fig. 4. (a) Percentage of incidents summed by day of the week for the three periods considered: 2008-2017, 2018, and 2019-2021. **(b)** Percentage of incidents occurring by day of the week, before, during, and after 2018.

3.3.2 Sociodemographic trends

Most of the victims were male (83%) and aged 65 years or older (80%). All the female victims were over 70 years old. The age of the victims ranged from 35 to 99 years old, with 2018 reporting the youngest and oldest victims. All fatalities under 60 years old and the oldest fatality victim (99 years old) were reported in 2018. However, there was no significant difference in the age of victims between periods ($p > 0.05$). Information on whether the victims were alone or accompanied during burning is incomplete, as 72% of media reports did not mention this context. However, available data showed that 60% of incidents occurred when victims were burning alone. The sparse data did not allow for the inference of whether being accompanied reduced the number of fatalities.The incidents reported were scattered throughout the country, with a higher concentration in central and northern mainland Portugal (Fig. 5a). They were not related to population density ($p > 0.05$, Fig. 5b) or ageing index ($p > 0.05$, Fig. 5c). However, most incidents occurred in low-population areas (57 % in municipalities with less than 110 inhabitants/km2) and/or high ageing index (65% > 169.6).

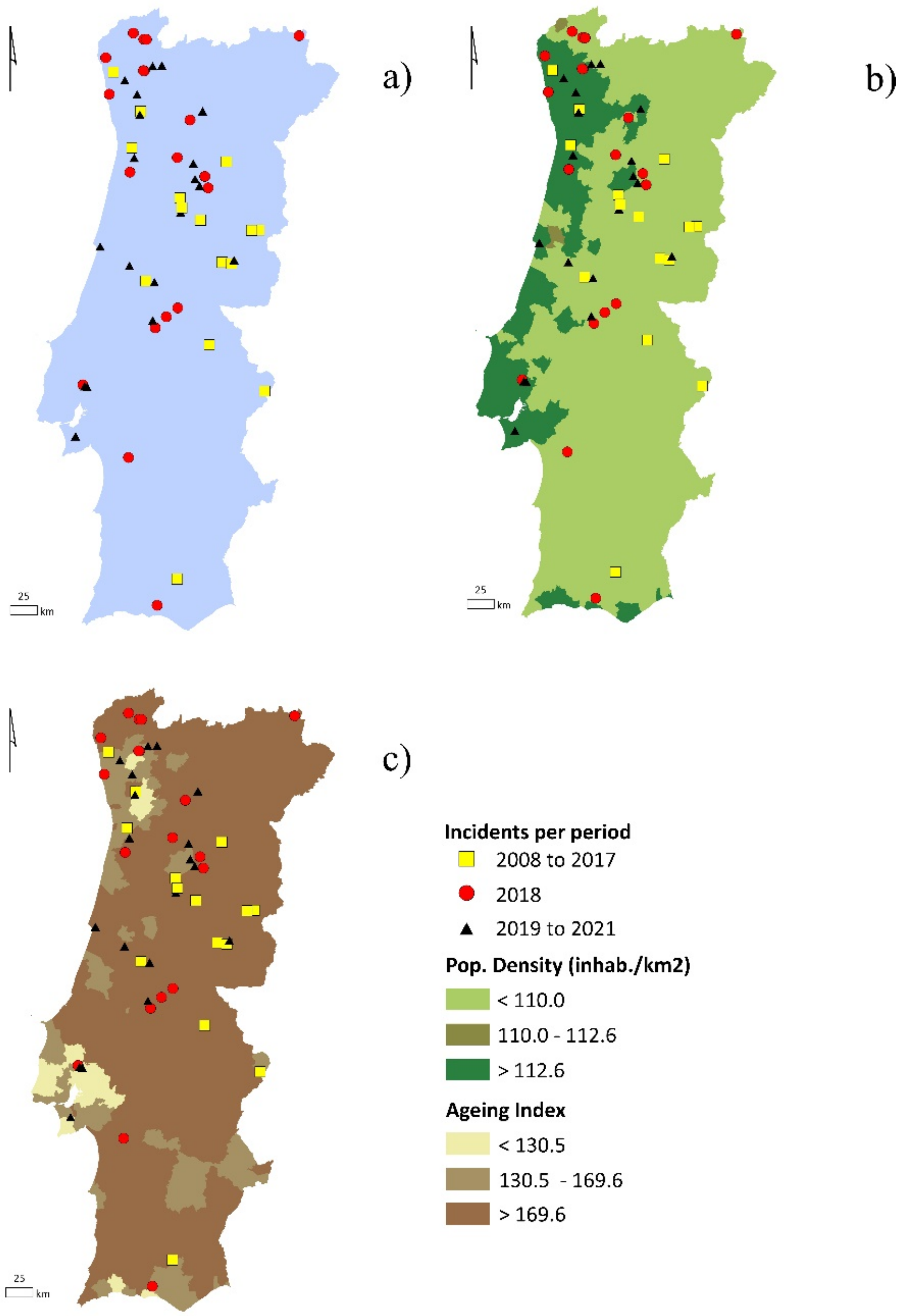


Fig. 5. **(a)** Mainland Portugal with the location of the incidents per period 2008-2017; 2018; 2019-2021; **(b)** Mainland Portugal with the incidents per period and sociodemographic variables, namely population density **(c)** and ageing index.

3.3.3 Meteorological conditions when incidents occurred

The incidents occurred under a variety of meteorological conditions, but seldom in extreme situations, as evidenced by Fig. 6. In fact, a trend over time can be observed towards better meteorological conditions with a lower temperature and DSR. Still, no statistically significant differences between periods were found for any meteorological variable or fire weather indices, namely FFMC, ISI and DSR ($p > 0.05$ for all considered variables).

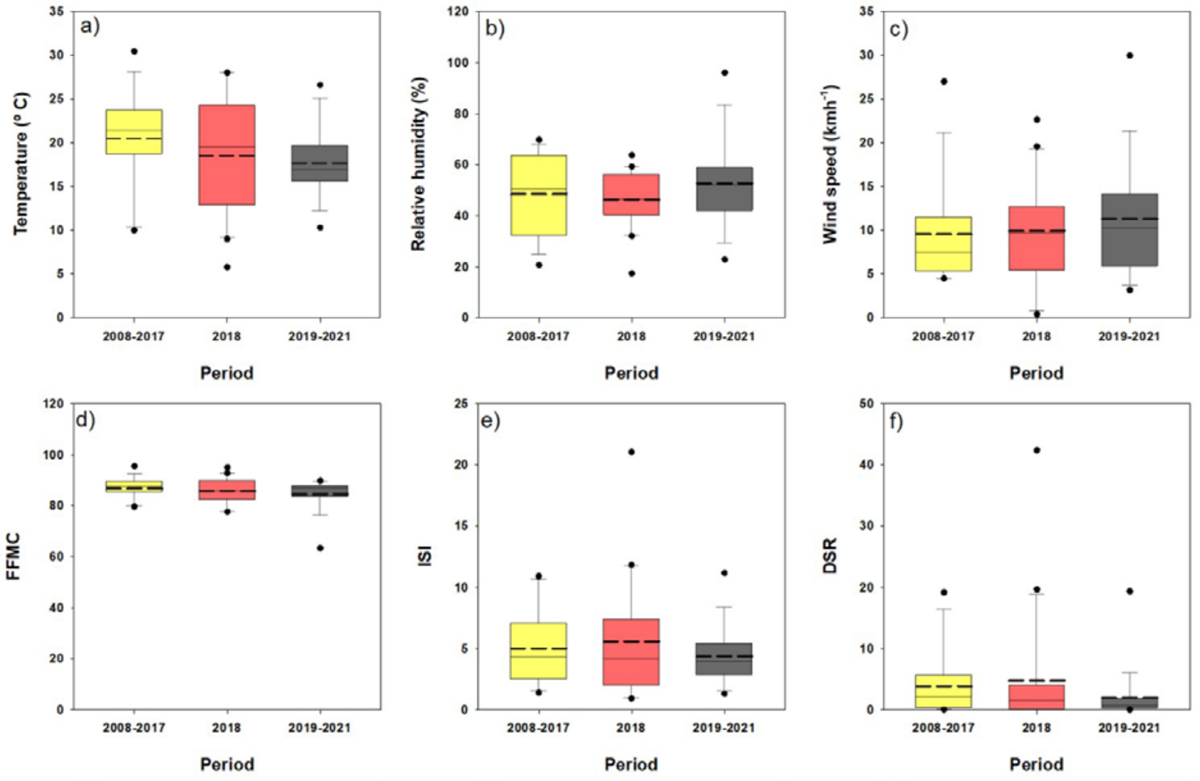


Fig. 6. Meteorological conditions and related fire indices. **(a)** Air temperature (º C). **(b)** Relative humidity (%). **(c)** Wind speed (km h-1). **(d)** Fine Fuel Moisture Code (FFMC). **(e)** Initial Spread Index (ISI). **(f)** Daily Severity Rating (DSR). The horizontal solid lines indicate the median, the horizontal dashed lines indicate the mean for each period. The dots indicate the outliers.

3.3.4 Legislation context

Following the devastating wildfires that caused a dramatic number of fatalities (117) in Portugal in 2017, with 92% of the victims being in the wildland-urban interface [10,11], wildfire prevention and fuel management became a top priority. Specifically, there was a greater emphasis on areas around isolated houses, the WUI, and roads, with increased demands from both the government and the authorities responsible for their management. Although legislation existed since 2006, [17] in 2018, the authorities increased public announcements, the inspection by police forces was intensified and doubled the fines for non-compliance. Table 2 illustrates the legislation that was in place before the fire season of 2017 (generally from July to September) and the subsequent changes that were implemented following the catastrophic event.

Table 2. Portuguese legislation before and after the 2017 fire season in relation to fuel management on the wildland-urban interface (WUI).

Timeline	Legislation	Short description
Before 2017 fire season	Decree-Law nr.124/2006 April 4th.	Art 15º 2 - Fuel management is mandatory for landowners with properties in the WUI (50 m or 100 m buffer) 3 – Fuel management is performed every year until April 15th. Art 38º 1 - Fines from 140€ to 5.000€ for individual landowners in case of non-compliance.
During the 2017 fire season	Law nr. 76/2017 August 17th	Art 15º 3 - Fuel management is mandatory for landowners with properties in the WUI (50m or 100m buffer) until April 30th.
After the 2017 Fire Season – Extraordinary laws were to be implemented only in 2018.	Law nr. 114/2017 December 29th	Art 153º 1 – Fuel management is mandatory until March 15th. 2 – Fines double in case of non-compliance.
	Order nr. 1913/2018, February 22nd	2 – Increase inspection from March 16th to April 30th
	Decree-Law nr. 19-A/2018, March 15th	Art 2º Extension of the fuel management deadline until May 15th. Inspections and fines after May 15th.
In 2019	Decree-Law nr. 14/2019, January 21st	New rules about the use of fire where it is mandatory to ask permission from the municipality or parish. If consent is not requested, the use of fire is considered arson.

Between 2019 and the end of this study (2021), the deadline for fuel management remained to be March 15th. However, due to weather restrictions or the COVID-19 pandemic, extensions were granted until May 31st in 2020 and May 15th in 2021.

As a result of the 2018 regulations, there was a rush to comply with the law, leading to price speculation for hiring qualified personnel to perform the necessary cleaning operations, as seen on the cover of several newspapers. This resulted in high costs that were unaffordable for many, particularly the elderly, who had meagre retirement pensions. According to the Portuguese Statistics Institute (INE), in 2018, the annual mean value for retirement pensions was 5,436 euros.

The concern shown by the citizens to perform fuel management operations around the houses is well expressed in Fig. 7, with Google Trends displaying increased interest in this subject.

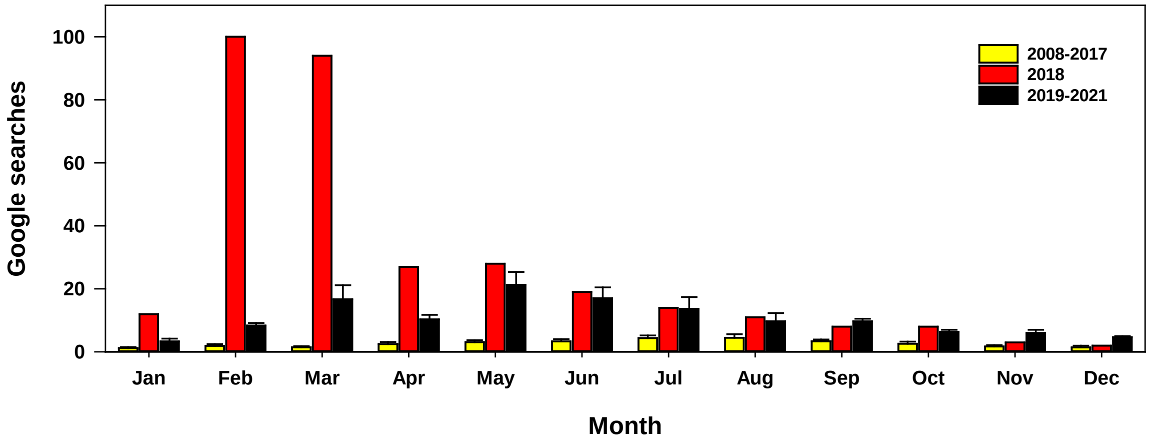


Fig.7. Number of searches retrieved from the Google Trends tool for the three periods considered: before (2008-2017), during 2018, and after 2018 (2019-2021). Values are mean ± SE.

3.4 DISCUSSION

In 14 years, between 2008 and 2021, there were 54 reported incidents due to slash-burns. In 2018 occurred 37% of the incidents. The results showed that the victims were mostly male and above 65 years old. The incidents reported were scattered throughout the country, and occurred in low-population areas and with high ageing index. They occurred predominantly in March and October. The first period coincides with the legal deadline for the fuel management before the fire season (Table 2), while the second period in October corresponds to the preparation of fields for new agricultural crops and the lifting of fire season restrictions [2]. Incidents that occurred in September were still within the period of fire use restrictions and can be classified as illegal fires.

While the statistical comparison between different periods was not significant (Fig. 2b), there seems to be a shift from a more traditional use of fire in agriculture (Sept-Dec) before 2018 to a greater focus on fuel reduction mandated by wildfire prevention legislation (Jan-Jun) after 2018. In 2018, incidents were reported in almost all the months, with no significant difference in the monthly distribution. The transition from agricultural fire use to fuel reduction practices can have several implications, not only social but also ecological. A traditional fire use encompasses knowledge concerning not only production but also ecology. When burning during spring for fuel reduction purposes, ecological concerns such as the nesting period, or plant cycle renewal are not safeguarded. Furthermore, individuals who are new to burning for fuel reduction purposes may lack knowledge regarding safe burning practices.

Age can be considered a critical factor since all the female victims were over 70 years old, and 80% of the male victims were over 65. Despite all the safety recommendations from the Portuguese Authorities about the use of fire, including the request to perform burning accompanied, there is not enough data to confirm if burning alone was one of the drivers of the incidents in all the periods. Burning practices in the Iberian Peninsula have traditionally been gendered, with men usually responsible for field burning while women mostly tended to small fires for cooking and heating homes. However, this gender "rule" was often disregarded, especially when women lived alone and needed to do the job themselves. Data from the incidents indicate that burning is still predominantly a male occupation. Nevertheless, the relatively small number of incidents involving women can also be attributed to their greater caution when using fire, as reported in previous studies [10,33].

3.4.1 Could an ageing territory explain the incidents with a low-density population?

The vulnerability to wildfires and fire use is increased by a high ageing index and low population density. Initially, it was hypothesized that a more isolated population without the resources to control a potential fire escape may have been the cause of the incidents. However, there was no statistically significant evidence to support this hypothesis, explain the increase in incidents in 2018 or the occurrence of all 54 incidents.

Nevertheless, only 22% of the incidents occurred in areas or regions with very high ageing index (above 300), and 39% occurred in sparsely populated areas (below 50 inhab/km^2). These findings highlight the risk associated with the use of fire by elderly populations, who are isolated and lack population renewal. This renewal would enable the continuation of traditional practices, with increased safety in rural areas where fire use is a common tool. Nonetheless, these factors constitute only a minor portion of the overall number of incidents and do not provide a statistical explanation for the rise in incidents observed in 2018.

3.4.2 Could the incidents be explained by meteorological severity that creates hazardous burning conditions?

Meteorological variables are crucial in determining fire behavior and controlling it. Temperature, relative humidity, and wind influence fuel moisture, affecting the ignition and spread of wildfires [34,35]. These variables were below the safe burning thresholds. Among other meteorological data, an analysis of the DSR, FFMC, and ISI of the day and area where the incident occurred was performed. DSR index indicates the difficulty in fire extinguishing operations, reflecting the amount of effort required to its deletion [29]. Thus, the higher the DSR value, the more complex and challenging will be fire control and extinction. The analysis showed that 89% of the incidents occurred on days with very low to moderate values of DSR, indicating that there was no relationship between the difficulty of controlling burning and the subsquent incidents. Other FWI sub-indices are related to the moisture of the fine fuel (FFMC) and the easiness of spreading the fire (ISI). The percentage of incidents that occurred in high, very high, and extreme danger classes (FFMC above 88 and ISI above 5) represented 33% and 37% respectively. While they cannot explain the increase in 2018, since there were no significant differences between periods, they can, to some extent, explain the incidents, showing that in some of them, the radiant heat, the intensity, and velocity of spread [36] was more substantial than what the elderly victims could manage. The implementation in 2018 of the new rule and platform requiring slash-burn permit requests may aid in enhancing burn safety. However, it remains uncertain whether agencies such as firefighters and forest sappers can offer assistance to farmers requesting permits, as this varies across the country. Nonetheless, these factors constitute only a minor portion of the overall number of incidents and do not provide a statistical explanation for the rise in incidents observed in 2018 .

3.4.3 Could the incidents be explained by a change of legislation and an increase in law enforcement?

Extreme wildfires often trigger national fire policy changes [32]. For Portugal, this was demonstrated by Mateus and Fernandes (2014) [8] and Fernandes *et al.,* (2017) [37], who analyzed the extreme fire seasons of 2003 and 2005. In 2017, Portugal experienced its most severe wildfire season on record, with the highest number of fatalities, damages, and burned areas in the country's history [38]. More than 100 people lost their lives, over 500,000 hectares were burned and several emblematic forests were affected. The impact of this fire season on society led to increased awareness of the dangers of wildfires, with people becoming more fearful of being in forest areas, particularly during summer. This is reflected in Google Trends (Figure 6), which show a sustained increase in interest in wildfires after 2018, particularly in what concerns land clearing, due to a more restrictive and punitive legislation.

The significant increase in incidents in 2018 can be attributed to several factors. The extension of the deadline twice for fuel reduction, along with the increase in fines' value and the intensification of police inspections, may have pressured the elderly population to become careless about safe burning practices and disregard safety guidelines from authorities like municipalities, ICNF, and ANEPC. Most incidents occurred due to the victims' physical condition, which resulted from their advanced age, causing them to neglect safety measures like creating fuel breaks or a mineral soil strip. These factors ultimately compromised the success of suppression and control, even though there were no significant differences in meteorological conditions between periods, as discussed earlier.

The pressure to reduce fuel decreased after 2019, despite maintaining the fines and deadlines. The requirement for burn permits from municipalities and parishes also became mandatory, potentially contributing to a reduction in the number of incidents, although not returning to the pre-2018 levels of one incident per year. The decrease in incidents in 2019 and 2020 may be linked to the COVID-19 pandemic, which resulted in a higher population presence in rural areas, allowing for more time for rural work and relaxation of enforcement.

3.5 CONCLUSION

Based on the legislative, social, and meteorological analysis, the increase in incidents can be attributed to the extreme pressure placed on managing vegetation, with strict enforcement measures in place, including fines for non-compliance. In response, the forest authorities have taken several actions to monitor and support slash-burn activities, particularly for elderly individuals in high fire-risk areas who may require assistance from fire teams in the field. It may also be helpful to include a field in the slash-burn request platform [39] for birth date and whether the person intends to burn alone or accompanied. However, it is important to note that mandatory laws enforced with high pressure must be complemented with pedagogical and supportive measures, or it can lead to unsafe practices and potential injuries or fatalities.

CAPÍTULO IV - UMA CARTOGRAFIA APERFEIÇOADA DAS ÁREAS ARDIDAS NO ALTO MINHO (NOROESTE DE PORTUGAL) ENTRE 2001 E 2020

Resumo. O Alto Minho é uma região do Norte de Portugal, situada no noroeste da Península Ibérica que é uma das regiões da Europa onde a recorrência do fogo é maior. A cartografia histórica das áreas ardidas tem sido fundamental para caraterizar o regime de fogo e na determinação de políticas de prevenção contra incêndios e de medidas de ordenamento urbanístico. Ao longo das últimas décadas, inúmeros estudos caraterizaram o impacto do fogo no território, baseando-se nesta fonte cartográfica oficial, disponibilizada pelo Instituto de Conservação da Natureza e das Florestas – ICNF. Neste estudo desenvolveu-se uma cartografia detalhada e rigorosa das áreas afetadas por fogos nas últimas duas décadas (2001 a 2020) no território do Alto Minho. Estas áreas foram apuradas com base na análise de 400 imagens dos satélites Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager - OLI) e Sentinel-2 (Multispectral Instrument – MSI), cujos perímetros resultaram da digitalização de forma manual apoiada em séries históricas de ortofotos. Foram digitalizados 12 692 perímetros de fogos que correspondem a 235 060 hectares ardidos no território do Alto Minho. Os resultados obtidos divergem substancialmente da informação cartográfica oficial, em relação ao rigor cartográfico, número de perímetros de incêndio (3873) e área ardida (179 283 hectares).

Palavras-chave: Fogos; incêndios florestais; mapeamento; deteção remota.

Abstract. An improved mapping of burned areas in Alto Minho (northwest Portugal) between 2001 and 2020.

Alto Minho is a region of northern Portugal, located in the northwest of the Iberian Peninsula, which is one of the regions in Europe where the recurrence of fire is higher. The historical mapping of burned areas has been fundamental to characterize the fire regime and to determine wildfire prevention policies and urban planning measures. Over the last decades, several studies have been published seeking to characterize the impact of fire on the territory, its frequency and recurrence, based on the official cartographic, provided by the Instituto de Conservação da Natureza e das Florestas – ICNF. In this study developed a detailed and rigorous cartography of the areas affected by fires in the last two decades (2001 to 2020) in the territory of Alto Minho. These areas were determined based on the analysis of 400 images from Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager - OLI) and Sentinel-2 (Multispectral Instrument - MSI) satellites, whose perimeters resulted from manual digitizing supported by historical series of orthophotos. Were digitalized 12,692 fire perimeters corresponding to 235 060 hectares burnt in the territory of Alto Minho. These results substantially differ from the official cartographic information, in terms of cartographic accuracy, number of fire perimeters (3,873) and burnt area (179,283 hectares).

Keywords: fires, wildfires, mapping, remote sensing

Resumen. Una cartografía mejorada de las superficies quemadas en el Alto Minho (Noroeste de Portugal) entre 2001 y 2020.

El Alto Minho es una región del norte de Portugal, localizada en el noroeste de la Península Ibérica, que constituye una de las regiones de Europa donde la recurrencia de los incendios es más elevada. La cartografía histórica de las zonas quemadas ha sido fundamental para caracterizar el régimen de fuego y determinar las políticas de prevención de incendios y las medidas de planificación urbana. A lo largo de las últimas décadas, numerosos estudios publicados han tratado de caracterizar el impacto del fuego en el territorio, basándose en esta fuente cartográfica oficial, proporcionada por el Instituto de Conservação da Natureza e das Florestas – ICNF. En este estudio se desarrolló una cartografía detallada y rigurosa de las superficies afectadas por los fuegos en las dos últimas décadas (2001 a 2020) en el territorio del Alto Minho. Estas superficies se calcularon a partir del análisis de 400 imágenes de los satélites Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager - OLI) y Sentinel-2 (Multispectral Instrument - MSI), cuyos perímetros resultaron de la digitalización manual apoyada en series históricas de ortofotos. Se digitalizaron 12 692 perímetros de fuegos, correspondientes a 235 060 hectáreas quemadas en el territorio del Alto Minho. Los resultados obtenidos difieren sustancialmente de la información cartográfica oficial, en lo que respecta a la precisión cartográfica, el número de perímetros de incendio (3873) y la superficie quemada (179 283 hectáreas).

Palavras clave: Fuegos; incendios forestales; cartografía; teledetección.

Resumo. *Unha cartografía mellorada das superficies queimadas no Alto Minho (Noroeste de Portugal) entre 2001 e 2020.*

O Alto Minho é unha rexión do norte de Portugal, localizada no noroeste da Península Ibérica, que constitúe unha das rexións de Europa onde a recorrencia dos incendios é máis elevada. A cartografía histórica das zonas queimadas foi fundamental para caracterizar o réxime de lume e determinar as políticas de prevención de incendios e as medidas de planificación urbana. Ao longo das últimas décadas, numerosos estudos publicados trataron de caracterizar o impacto do lume no territorio, baseándose nesta fonte cartográfica oficial, proporcionada polo Instituto de Conservação da Natureza e dás Forestas – ICNF. Neste estudo desenvolveuse unha cartografía detallada e rigorosa das superficies afectadas polos lumes nas dúas últimas décadas (2001 a 2020) no territorio do Alto Minho. Estas superficies calculáronse a partir da análise de 400 imaxes dos satélites Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager - OLI) e Sentinel-2 (Multispectral Instrument - MSI), cuxos perímetros resultaron da dixitalización manual apoiada en series históricas de ortofotos. Dixitalizáronse 12 692 perímetros de lumes, correspondentes a 235 060 hectáreas queimadas no territorio do Alto

Minho. Os resultados obtidos difiren substancialmente da información cartográfica oficial, no que respecta a a precisión cartográfica, o número de perímetros de incendio (3873) e a superficie queimada (179 283 hectáreas).

Palavras clave: Lumes; incendios forestais; cartografía; teledetección.

4.1 INTRODUÇÃO

Segundo dados oficiais do ICNF (Instituto de Conservação da Natureza e das Florestas), Portugal registou entre 2001 e 2020 uma área ardida total acumulada de cerca de 2,7 milhões de hectares, resultante de aproximadamente 400 mil ocorrências de incêndios. Estes números demonstram o impacto dos incêndios no território, quer a nível ambiental como a nível socioeconómico. O Alto Minho, situado no Norte de Portugal, em conjunto com as demais regiões do noroeste da Península Ibérica, concentram a maior percentagem de ocorrências de fogos florestais da Europa (Pereira *et al.*, 2006; Trigo *et al.*, 2013).

A produção cartográfica das áreas ardidas, tal como os dados estatísticos relacionados com as ocorrências, é de vital importância para a análise dos processos derivados do impacto dos fogos num dado território e num determinado período de tempo (Ferreira-Leite *et al.*, 2012).

Os dados estatísticos anuais sobre incêndios florestais apenas foram disponibilizados a partir da década de 80 do século XX, permitindo, com algumas limitações, uma análise desde a escala nacional à escala local. Desde então, as bases estatísticas relacionadas com as ocorrências de incêndios melhoraram ao longo dos anos com a introdução de dados úteis para a caraterização de cada incêndio. No ano 2000 é criado o Sistema de Gestão de Informação de Fogos Florestais (SGIF), o qual constitui uma robusta base de dados que centraliza até aos dias de hoje a informação relacionada com cada ocorrência, proveniente de três organismos (APIF & ISA, 2005) com competências na gestão e prevenção florestal (Instituto da Conservação da Natureza e das Florestas - ICNF), na investigação de causas (Guarda Nacional Republicana - GNR) e na gestão da emergência e socorro (Autoridade Nacional de Emergência e Proteção Civil - ANEPC). Desde 2002 passou a integrar a informação meteorológica proveniente do Instituto Português do Mar e da Atmosfera (IPMA) referente aos valores observados nas estações meteorológicas mais próximas do local de cada ocorrência, recentemente substituída pelos dados de reanálise ERA5-Land do European Centre for Medium-Range Weather Forecasts.

A informação cartográfica em formato vetorial (*shapefile*) apenas começa a ser produzida anualmente no início da década de 90. Entre 1990 e 1992 o processo de produção cartográfica foi elaborado por aquisição de serviços a uma empresa e a partir de 1993 até 2004, a cartografia foi elaborada mediante um protocolo de colaboração entre a Direção Geral das Florestas e o Departamento de Engenharia Florestal do Instituto Superior de Agronomia (ISA) (Ferreira-Leite *et al.*, 2012). A partir de 2006 a elaboração do registo cartográfico das áreas ardidas é assegurada pela então Direcção-Geral dos Recursos Florestais (atualmente ICNF) enquanto autoridade florestal nacional. Desde então, a produção cartográfica resulta do mapeamento com recurso a imagens satélite complementado pelo levantamento no terreno das áreas ardidas iguais ou superiores a um hectare, executado pela GNR e técnicos dos Gabinetes Técnicos Florestais dos municípios.

Tal como refere Ferreira-Leite *et al.* (2012) foram detetadas algumas incoerências nas bases de dados estatísticas das ocorrências de incêndios, o que levou a um processo de reformulação do SGIF em 2010. O mesmo ocorre com a série histórica cartográfica das áreas ardidas, devido à metodologia adotada (Oliveira *et al.*, 2012), limitações no tratamento das imagens de satélite e carência de validação da informação no terreno (Ferreira-Leite *et al.*, 2012).

Atualmente, a base histórica cartográfica disponibiliza informações de 1975 até à presente data, sendo que a informação do período de 1975 a 2005 resulta do atlas anual de incêndios (Pereira & Santos, 2003). Segundo Oliveira et al. (2012), o atlas anual resulta da obtenção das áreas ardidas a partir de imagens dos satélites Landsat do final do período verão-outono de cada ano, permitindo o mapeamento através de classificação semi-automática das áreas com dimensão mínima de 35ha no período de 1975 a 1983 (imagens Landsat MultiSpectral Scanner - MMS). A partir de 1984 até 2005, a área mínima cartografada através do mesmo procedimento foi de cinco hectares, dada a melhoria da resolução espacial das imagens satélite Landsat (Thematic Mapper - TM e Enhanced Thematic Mapper - ETM+).

De 2006 até ao momento atual, a cartografia oficial das áreas ardidas resulta de diversas fontes, quer de levantamentos no terreno realizados pela GNR, maioritariamente com recurso a desenho sobre ortoimagens, quer por mapeamento através de imagens de satélite com diversas escalas de resolução e diferentes métodos de obtenção (MODIS, Landsat, Sentinel-2). A partir desse ano até ao presente, a cartografia oficial passou a integrar áreas mínimas de incêndios rurais inferiores a cinco hectares.

A cartografia oficial integra parte da informação produzida pelo European Forest Fire Information System (EFFIS) desde 2017, embora não seja identificado o modo de obtenção das áreas ardidas. A informação produzida pelo EFFIS a partir de imagens do satélite MODIS com uma resolução espacial de 250m, permitia cartografar uma área igual ou superior a 30ha no período de 2008 a 2017. A partir de 2018, com recurso às imagens do satélite Sentinel-2, o EFFIS tem mapeado áreas ardidas com dimensão inferior a 30ha, sendo estas corrigidas por meio da interpretação visual das imagens (EFFIS, 2021).

Em termos gerais, as fontes estatísticas e cartográficas produzidas no país ao longo de décadas são suficientemente robustas e completas para comparar à escala nacional os impactos dos fogos, tornando Portugal o país que dispõe de melhor informação pública e acessível, quando comparado com outros países da Europa (Pereira et al., 2006). Contudo, a análise das tendências históricas frequentemente ignora as alterações de metodologia e de critério que ocorreram ao longo do tempo (Fernandes et al., 2017).

Independentemente da escala espacial, vários autores têm como base de investigação a informação cartográfica oficial para caracterizarem o regime de fogo (Marques et al., 2011; Pereira et al., 2022), a sua distribuição espácio-temporal (Silva et al., 2019), a frequência e recorrência dos fogos (Fernandes et al., 2012; Ferreira-Leite et al., 2011; Oliveira et al., 2012), os seus impactos (Fernandes & Guiomar, 2017; Ferreira-Leite et al., 2013; Scotto et al., 2014; Silva & Catry, 2006; Tedim et al., 2015), o risco e a suscetibilidade do território (Bergonse et al., 2021; Verde, 2008; Verde et al., 2010) e a gestão do risco (Tedim et al., 2013).

No entanto, para uma escala regional de âmbito distrital ou para uma escala espacial menor, a cartografia das áreas ardidas tem uma função fundamental no condicionamento da edificabilidade e na instalação de projetos agrícolas e florestais. Baseada nesta cartografia, a classificação da perigosidade de incêndio rural do território (ICNF, 2020; Oliveira et al., 2020), são aplicadas medidas de prevenção (planeamento da defesa da floresta contra incêndios). Nestas escalas, a informação cartográfica deverá ter o máximo rigor no mapeamento das áreas ardidas e sua classificação quanto à origem do fogo (OTI, 2019). Neste contexto, face à variação temporal nas metodologias utilizadas, este trabalho tem por objetivo reconstruir as séries históricas das áreas ardidas do período de 2001 a 2020 no território do Alto Minho e comparar os resultados obtidos com os dados históricos oficiais.

4.2 MATERIAL E MÉTODOS

4.2.1 Região de estudo

A região de estudo abrange todo o território do Alto Minho (Nomenclatura das Unidades Territoriais para Fins Estatísticos - NUTS III), situado no extremo Noroeste de Portugal, na unidade territorial NUTS II - Norte de Portugal (fig. 1). A Norte e Este faz fronteira com a Comunidade Autónoma da Galiza (Espanha) através do rio Minho e do Planalto de Castro Laboreiro e rio Laboreiro e Serra Amarela, respetivamente. Ao sul faz fronteira com o distrito de Braga e a Oeste o território é limitado com o oceano Atlântico. A região do Alto Minho corresponde à totalidade do território do distrito administrativo de Viana do Castelo, ocupando cerca de 2219km^2 e encontra-se distribuído por dez municípios. Em Portugal, os municípios encontram-se ainda subdivididos em unidades administrativas mais pequenas – as freguesias. O Alto Minho é constituído por 208 freguesias, o que confere elevada dispersão populacional e fragmentação administrativa do território.

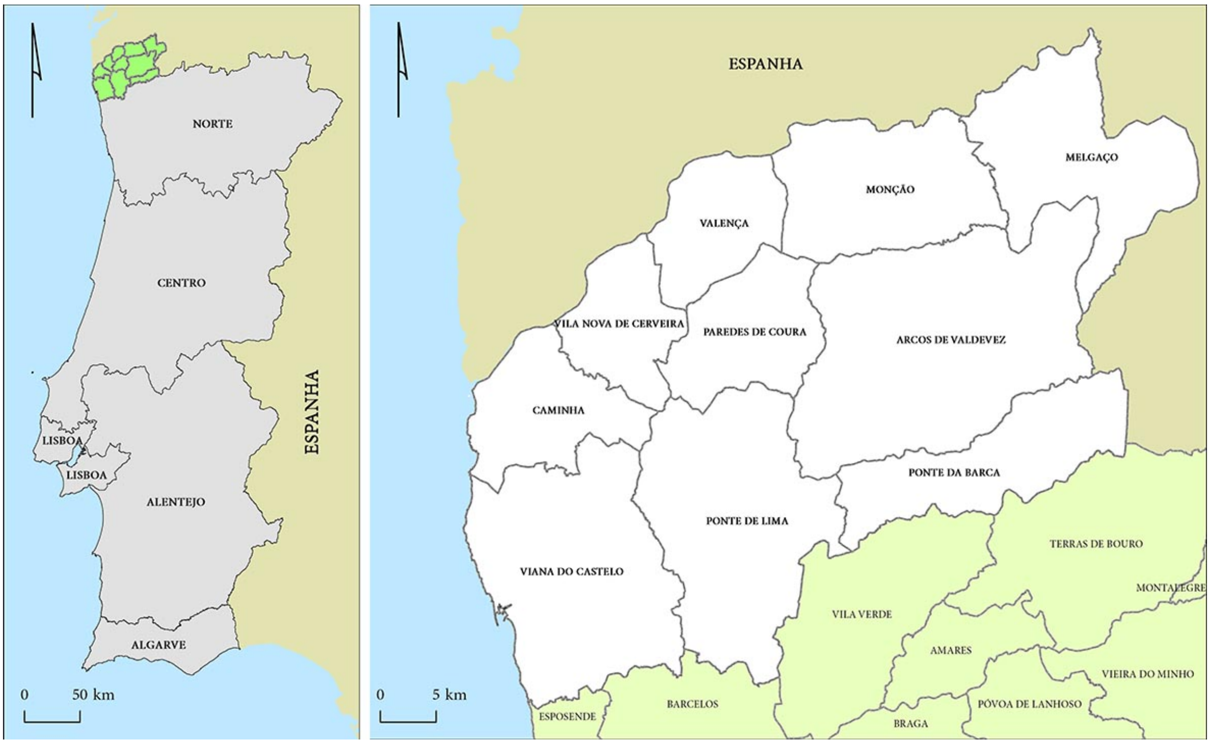


Fig. 1 – Enquadramento geográfico da região de estudo, Alto Minho. Figura a cores disponível online.
Fig. 1 *– Geographical context of the study region, Alto Minho. Colour figure available online.*
Fonte: Carta Administrativa Oficial de Portugal (DGT, 2020a); Limites Administrativos de Espanha (IGN, 2019)

O território é essencialmente ocupado por espaços florestais (72%) com uma importante atividade pecuária em regime extensivo e com ocupação agrícola em 18% (DGT, 2020b). À exceção da estreita faixa costeira e dos principais vales dos rios Minho e Lima, o relevo é predominantemente montanhoso, com altitudes superiores a 400 metros e, aproximadamente a 50 km do litoral, os cumes mais elevados excedem os 1000 metros de altitude (Monteiro *et al.*, 2005).

Quanto ao clima, o território apresenta duas regiões climáticas tipificadas por uma estação invernal moderada em toda a fachada atlântica (Ribeiro *et al.*,1988). Por outro lado, a época estival é moderada junto à costa, frequentemente afetada por ventos que sopram forte do Norte e por neblinas matinais de advecção e fresco nos lugares mais elevados das montanhas. Em alguns fundos de vales abrigados e expostos à radiação solar o verão costuma ser quente ou muito quente. Segundo o Plano Intermunicipal de Adaptação as Alterações Climáticas (CIM Alto Minho & IPVC, 2017) a generalidade do território tem baixa amplitude térmica anual, com temperatura média anual predominantemente entre 14ºC e 16ºC. Quanto à precipitação, o território apresenta uma grande variação do litoral para o interior, registando, em termos médios anuais, precipitações superiores a 1100mm, podendo atingir médias em zonas mais interiores na ordem dos 2400 a 2800mm.

O relevo, a ocupação e uso dos solos e o clima são fatores determinantes no regime de incêndios rurais. Por outro lado, as comunidades rurais do Alto Minho, à semelhança de outras comunidades do Noroeste Ibérico, usam o fogo há várias gerações dentro de um sistema tradicional agrário, desde o arroteamento, fertilização dos solos, renovação de pastagens e queima de sobrantes agrícolas e florestais (Díaz-Fierros, 2019). Este uso do fogo, associado às condições físicas do território, é também uma das muitas causas de incêndios rurais.

4.2.2 Metodologia

Analisou-se um conjunto de imagens dos satélites Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager - OLI) e Sentinel-2 (Multispectral Instrument – MSI) para o período 2001-2020. Estas imagens foram extraídas do Semi-Automatic Classification Plugin (SCP) desenvolvido por Congedo (2016; 2020; 2021) para o software QGIS e diretamente por via da plataforma da U.S. Geological Survey – Earth Explorer.

Foram selecionadas 400 imagens dos diversos satélites, preferencialmente sem nuvens ou com uma cobertura mínima, permitindo cobrir o máximo de meses do ano, com o fim de identificar padrões estacionais das áreas ardidas no Alto Minho. Através do SCP para QGis, foi realizado o pré-processamento de todas as imagens para correção atmosférica. Posteriormente, as áreas ardidas foram identificadas através do índice *Normalized Burn Ratio* (NBR) e pela composição de Falsa Cor RGB (Congedo, 2016; 2020; 2021). Identificaram-se também as áreas ardidas no ano 2000, de modo a evitar que estas áreas fossem erradamente somadas ao ano seguinte.

A determinação do índice NBR foi efetuada para todas as imagens de satélite. O NBR é um índice amplamente usado na identificação de áreas ardidas, a partir da diferença normalizada entre o pico de refletância no infra-vermelho próximo (NIR - *near-infrared*) e do infravermelho de ondas curtas (SWIR - *short-wave-infrared*) do espetro eletromagnético (Key & Benson, 2006; Lopez-Garcia & Caselles, 1991), com base na seguinte fórmula:

$$NBR = (NIR - SWIR) / (NIR + SWIR) \quad \text{(Eq.1)}$$

Esta fórmula foi aplicada às diferentes imagens obtidas a partir dos diversos satélites conforme o quadro I.

Quadro I – Caraterísticas das fontes de imagens satélite usadas na obtenção das áreas percorridas por fogos entre 2001 e 2020.

***Table I** – Characteristics of the satellite imagery sources used to obtain the areas affected by fires between 2001 and 2020.*

	LANDSAT 5	**LANDSAT 7**	**LANDSAT 8**	**SENTINEL-2**
Instituições	NASA (National Aeronautics and Space Administration) e USGS (U.S. Geological Survey)			ESA (European Space Program)
País/Região	EUA			UE
Lançamento	01/03/1984	15/04/1999	11/02/2013	23/06/2015
Situação Atual	Inativo (22/11/2011)	Ativo	Ativo	Ativo
Altitude (km)	705	705	705	786
Tempo de Duração da Órbita (min)	99	98,9	99	97,2
Período de Revisita (dias)	16	16	16	5
Instrumentos Sensores	MSS e TM	ETM+	OLI e TIRS	SAR e MSI
Nº de Imagens Utilizadas	75	84	41	193
Período das Imagens	2000 - 2011	2000 - 2014	2013 - 2020	2015 -2020
NBR - Bandas Utilizadas	NBR = (B4 – B7) / (B4 + B7)	NBR = (B4 – B7) / (B4 + B7)	NBR = (B5 – B7) / (B5 + B7)	NBR = (B8 - B12) / (B8 + B12)
Composição de Falsa Cor (Bandas Utilizadas)	4-3-2	4-3-2	5-4-3	8-4-3
Área Mínima cartografada	0,4ha	0,4ha	0,4ha	0,04ha
Resolução Espacial (m)	30	30	30	10

Fonte: Embrapa (2021)

Para facilitar a interpretação de dados e permitir uma identificação mais imediata das áreas ardidas, e complementar o produto NBR para cada uma das imagens, recorreu-se à composição de Falsa Cor (RGB). Esta composição de bandas é muito usual, pois permite observar alterações na vegetação (Riebeek & Simmon, 2014), através das bandas do infravermelho próximo (vermelho), verde (azul) e vermelho (verde).

4.2.2.1 Mapeamento das áreas ardidas

Uma vez obtidas as imagens (NBR e RGB falsa cor) com a diferenciação das áreas ardidas, os perímetros foram digitalizados. Alguns autores sugerem que o processo de digitalização destas áreas seja executado de forma manual e supervisionada apoiada em informação auxiliar com o fim de evitar erros de interpretação derivados da ocorrência de mudanças na cobertura do solo (Chuvieco & Congalton; 1988; Ruiz-Gallardo, 2007; Tanaka *et al.*, 1983). Para reduzir estes erros e aumentar o rigor no delineamento dos perímetros das áreas ardidas entre 2001 e 2020, procedeu-se à digitalização manual com base na série histórica de imagens obtidas e apoiada em ortofotos dos anos 2003 e 2004[i], 2007 (DGT, 2022) e 2018[ii].

No processo de digitalização manual, dada a necessidade de um maior detalhe, foi considerada a escala de acordo com a resolução das imagens dos diferentes satélites, entre 1:25 000 e 1:3 000. Este processo, apoiado em ortofotos de diferentes anos permitiu diferenciar os objetos, evitando que áreas de rocha, campos agrícolas ou pequenos planos de água, entre outros, fossem confundidos com superfícies atingidas pelo fogo. Para o efeito foram consideradas alterações num conjunto mínimo de 4 pixéis, ou seja, uma área correspondente a 0,4ha (Landsat 5, 7 e 8), a 0,03ha (Sentinel-2) e 0,1ha (ortofotos com uma resolução de 0,3 a 0,5m). Através dos ortofotos também foi possível identificar e corrigir com maior rigor os perímetros das áreas afetadas por fogos, reduzindo assim a área mínima cartografada (fig. 2).

Fig. 2 - Perímetro de incêndio delineado manualmente com base em imagem de satélite (Landsat 5) para posterior correção pela sobreposição sobre ortoimagem de 2004.
Fig. 2 - *Wildfire perimeter manually delineated based on a satellite image (Landsat 5) for subsequent correction by overlaying on an orthoimagery from 2004.*

O delineamento dos perímetros com base em imagens de satélite foi executado sem se ajustar excessivamente aos pixéis queimados e não sendo incluídas as áreas sem dano observável (Key & Benson, 2006). De igual modo, as ilhas interiores não ardidas também foram delimitadas e excluídas dos perímetros das áreas ardidas para não serem agregadas incorretamente como áreas afetadas pelo fogo. De modo a evitar a perda de informação, foram também delineados e incluídos os perímetros de áreas queimadas localizadas no limite da área de estudo até 500 metros, bem como delimitados na totalidade os perímetros associados a uma mesma ocorrência e que cruzaram o limite da área de estudo.

Por último, os dados cartográficos anuais de fonte oficial foram obtidos em formato vetorial (*shapefile*) a partir da página oficial do ICNF (2021). As manchas ardidas que não puderam ser aferidas por via das imagens tratadas por respeitarem a áreas muito reduzidas ou a povoamentos florestais densos, foram integradas na base de dados deste estudo. A informação cartográfica oficial foi comparada com a informação cartográfica obtida no presente estudo através da sobreposição dos perímetros. Do mesmo modo, com base na informação cartográfica referente ao fogo controlado (ICNF, 2021) foi possível identificar e classificar o tipo de fogo que está na origem da área ardida. Finalmente, a cartografia resultante deste estudo permitiu comparações com a cartografia oficial em termos do posicionamento e dimensão das áreas ardidas, bem como em termos de sazonalidade da ocorrência dos fogos (incêndios rurais e outros).

4.2.2.2 Relação entre as áreas percorridas por fogos e as ocorrências da base estatística e os focos de calor dos sensores MODIS e VIIRS

Após a fase de digitalização de cada perímetro procedeu-se à sua datação e classificação do tipo de fogo, através da importação e georreferenciação dos dados estatísticos anuais do Sistema de Gestão de Informação de Fogos Florestais (SGIF) do período de 2001 a 2020, disponibilizados pelo ICNF (2021) e dos focos de calor georreferenciados provenientes dos sensores MODIS e VIIRS. Os focos de calor foram obtidos a partir do arquivo na página *web* do Fire Information for Resource Management System (FIRMS, 2021) da NASA, em formato vetorial (ponto). Em relação aos dados oficiais do SGIF, não é possível a georreferenciação correta da larga maioria das ocorrências, pois a localização adotada é toponímica e a coordenada atribuída a cada ocorrência é o centroide do polígono referente ao limite administrativo da freguesia. Apenas nos últimos anos do período de análise é que a localização está mais próxima da realidade da origem da ocorrência, já que os equipamentos de comunicação usados pelas equipas de primeira intervenção nas operações de extinção permitem a sua geolocalização. Apesar desta fragilidade é possível relacionar a ocorrência com o perímetro da área ardida resultante de incêndio, através das datas das ocorrências com a interpolação das imagens satélite e dos dados dos sensores MODIS e VIIRS.

Os dados do sensor MODIS (*Moderate Resolution Imaging Spectroradiometer*) estão disponíveis desde novembro de 2000 (sensor Terra) e de julho de 2002 (sensor Aqua) até ao presente, detetando com fiabilidade focos de calor com chama ou chama latente com uma resolução espacial superior a 1000 metros. Enquanto que os dados do sensor VIIRS (*Visible Infrared Imager Radiometer Suite*) S-NPP estão disponíveis desde janeiro de 2012 até o presente, os dados do VIIRS NOAA-20 estão disponíveis a partir de janeiro de 2020, ambos possuem uma resolução espacial muito maior que o MODIS, de 375 metros (Giglio, 2015; Nieman *et al.*, 2021; Schroeder & Giglio, 2018).

Neste estudo foi considerado o conjunto de dados referente a focos de calor detetados pelos sensores MODIS e VIIRS no território do Alto Minho para o período de análise de 2001 a 2020. Através dos focos de calor e a sobreposição destes com os perímetros mapeados, segundo as datas de obtenção das imagens de satélite, foi possível atribuir uma data aos perímetros das áreas ardidas e classificá-los quanto à origem. Classificaram-se os perímetros como incêndio rural quando associado a uma ocorrência registada na base de dados do SGIF, ou seja, fogos que implicaram o despacho de meios de extinção e foram combatidos. Os demais perímetros, identificados a partir da sequência cronológica das imagens satélite e das datas dos focos de calor, para os quais não existe um registo de ocorrência associada no SGIF, portanto sem intervenção na extinção por equipas do dispositivo de supressão, foram classificados como “outros fogos”, tendo ocorrido exclusivamente nas estações de outono, inverno e primavera (fogos de outono-inverno-primavera e fogos controlados).

A datação obtida a partir da informação dos focos de calor, em complementaridade com as datas das diferentes imagens de satélite e com a informação dos dados oficiais do SGIF, permitiu ainda identificar a distribuição estacional dos diferentes tipos de fogos.

RESULTADOS

4.3.1 Comparação de áreas ardidas

Os resultados obtidos neste estudo indicam valores muito díspares quando comparados com os dados cartográficos oficiais. A fig. 3 apresenta exemplos de discrepâncias entre a cartografia oficial e das imagens utilizadas neste estudo. Os dados resultantes da reconstrução sistemática e precisa das áreas percorridas por fogos nos últimos 20 anos que afetaram o território do Alto Minho (fig. 4) totalizam 12 692 perímetros, correspondendo a uma área total afetada de 235 060 hectares (quadro II).

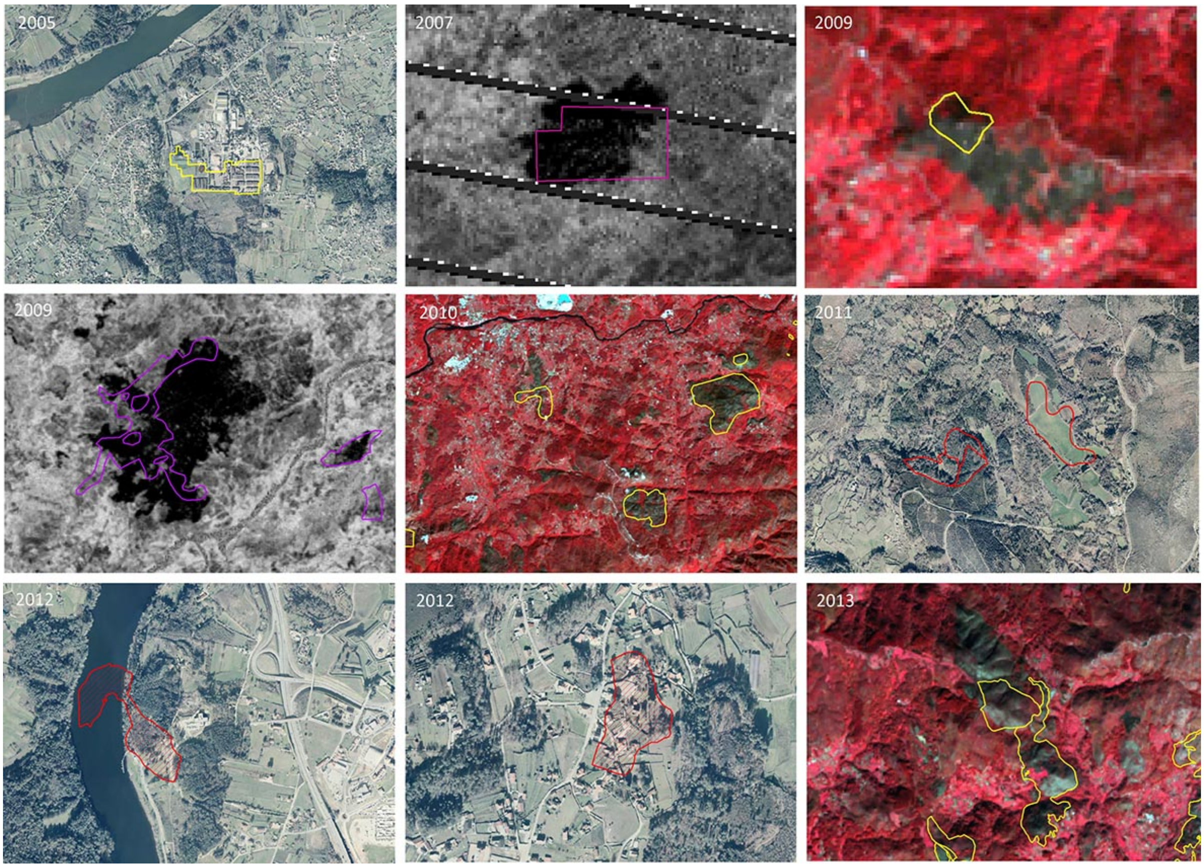


Fig. 3 – Exemplos de erros cartográficos presentes na informação oficial (ICNF, 2021).
***Fig. 3** – Examples of cartographic errors present in the official information (ICNF, 2021).*

Comparando os dados oficiais estatísticos (SGIF) e cartográficos (quadros II e III), verificam-se diferenças consideráveis. O número de perímetros incluídos na cartografia oficial (3873) apenas representa 13,7% do total de ocorrências registadas no SGIF (28 223) e cerca de 49% do universo de ocorrências registadas com área superior a um hectare (7888). Em comparação com o número de perímetros resultantes do estudo, o número de perímetros da cartografia oficial apenas representa 30,5% do total obtido (12 692). Os perímetros obtidos no estudo representam 45% do total das ocorrências de incêndio registadas no SGIF. Quanto ao total da área ardida no período, a cartografia oficial regista mais 7318ha em relação ao total registado na base de dados estatísticos (171 964ha). A cartografia das áreas ardidas referente aos anos 2003, 2004, 2008 e 2016 apresenta valores inferiores aos dados registados, apresentando uma diferença superior a 500 hectares.

Quadro II – Área ardida acumulada anualmente na região do Alto Minho, de acordo com os registos oficiais cartográficos e estatísticos e os resultados deste estudo.

Table II – *Burned area annually accumulated in the Alto Minho region, according to official cartographic and statistical records and the results of this study.*

	Dados Oficiais				Dados do Estudo	
	Dados Cartográficos		Dados Estatísticos			
	Polígonos	Área Ardida	Ocorrências	Área Ardida	Polígonos	Área Ardida
Ano	Nº	ha	Nº	ha	Nº	ha
2001	139	5998	1688	4601	1005	13 101
2002	156	10 587	2101	10 006	657	13 063
2003	26	713	1008	1506	89	1216
2004	55	2908	1657	3462	1052	7540
2005	124	28245	2597	27 091	822	33 069
2006	88	15 325	1116	15 721	323	18 247
2007	83	3407	1366	1985	348	5078
2008	16	193	691	811	158	1114
2009	232	5765	2059	5864	579	9011
2010	333	24 775	2269	23 899	562	29 704
2011	373	6209	2428	4822	732	9282
2012	282	4207	1331	2743	490	5426
2013	251	12 767	1882	12 262	571	15 612
2014	31	864	382	883	222	2359
2015	151	10 208	1321	9100	757	13 154
2016	287	30 477	1109	31 324	1018	32 912
2017	278	9276	1163	8927	1496	12 866
2018	125	1657	893	1522	586	2666
2019	472	2012	556	2007	762	4585
2020	371	3690	606	3428	463	5055
Totais	3873	179 283	28 223	171 964	12 692	235 060

Quadro III – Comparação dos dados cartográficos referentes à área ardida anualmente na região do Alto Minho, de acordo com os registos oficiais cartográficos e os resultados deste estudo.

Table III *– Comparison of the mapping data regarding the* annual area burned in the *Alto Minho region, according to official cartography and the results of this study.*

	Dados Cartográficos Oficiais			Dados do Estudo			Variação entre Dados Oficiais e Dados do Estudo			
	Polígonos	Área Ardida Total	Área Ardida Média	Polígonos	Área Ardida Total	Área Ardida Média	Polígonos		Área Ardida	
Ano	Nº	ha	ha	Nº	ha	ha	Nº	%	ha	%
2001	139	5998	43,2	1005	13 101	13,0	-866	-623	-7103	-118
2002	156	10 587	67,9	657	13 063	19,9	-501	-321	-2475	-23
2003	26	713	27,4	89	1216	13,7	-63	-242	-503	-71
2004	55	2908	52,9	1052	7540	7,2	-997	-1813	-4632	-159
2005	124	28 245	227,8	822	33 069	40,2	-698	-563	-4824	-17
2006	88	15 325	174,1	323	18 247	56,5	-235	-267	-2922	-19
2007	83	3407	41,0	348	5078	14,6	-265	-319	-1671	-49
2008	16	193	12,0	158	1114	7,1	-142	-888	-921	-478
2009	232	5765	24,9	579	9011	15,6	-347	-150	-3246	-56
2010	333	24 775	74,4	562	29 704	52,9	-229	-69	-4928	-20
2011	373	6209	16,6	732	9282	12,7	-359	-96	-3073	-49
2012	282	4207	14,9	490	5426	11,1	-208	-74	-1219	-29
2013	251	12 767	50,9	571	15 612	27,3	-320	-127	-2845	-22
2014	31	864	27,9	222	2359	10,6	-191	-616	-1495	-173
2015	151	10 208	67,6	757	13 154	17,4	-606	-401	-2946	-29
2016	287	30 477	106,2	1018	32 912	32,3	-731	-255	-2436	-8
2017	278	9276	33,4	1496	12 866	8,6	-1218	-438	-3590	-39
2018	125	1657	13,3	586	2666	4,5	-461	-369	-1009	-61
2019	472	2012	4,3	762	4585	6,0	-290	-61	-2573	-128
2020	371	3690	9,9	463	5055	10,9	-92	-25	-1366	-37
Totais	3873	179 283	54,5	12 692	235 060	19,1	-8819	-228	-55 777	-31

Por outro lado, comparando ambas as cartografias é possível comprovar que a cartografia oficial agrega, por diversas vezes, em apenas um perímetro, os perímetros resultantes de diversos incêndios e, em todos os anos do período de estudo, apresenta valores inferiores de área ardida.

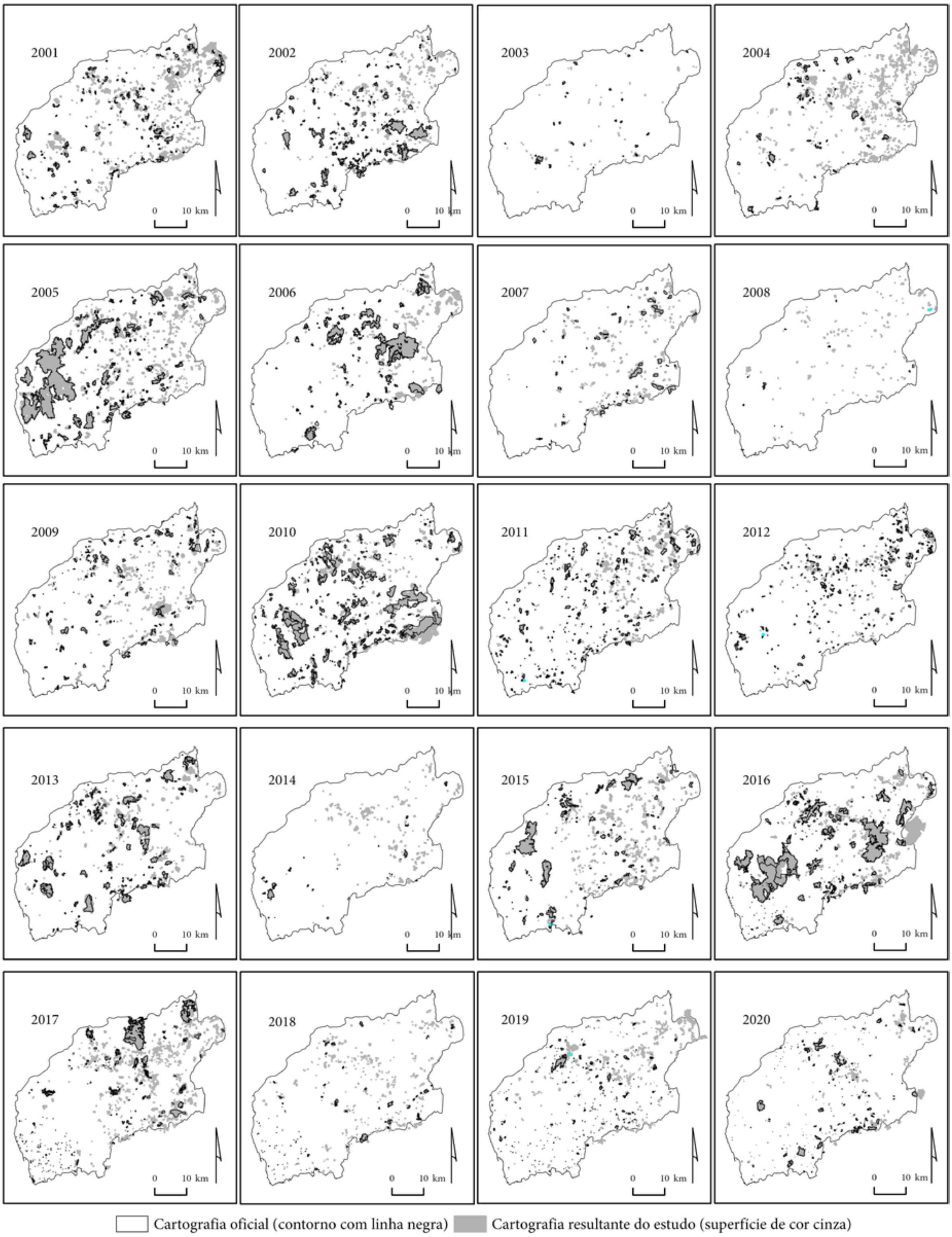


Fig. 4 – Análise comparativa da área ardida entre a cartografia oficial (linha negra) e a cartografia resultante do estudo (cor cinza).

Fig. 4 *– Comparative analysis of the burned area between the official cartography (black line) and this study cartography (grey colour).*

Entre 2001 e 2020, os anos que apresentam menores registos são 2003 e 2008, com valores totais inferiores a dois mil hectares. No que se refere a 2003, estes valores tão baixos devem-se sobretudo ao número reduzido de imagens de satélite (seis) e ao período de cobertura, pois apenas se obteve uma imagem referente ao período de inverno e as restantes cinco imagens referem-se ao período de verão. Contudo, é o único ano em que os resultados da área ardida são inferiores aos dados registados no SGIF, correspondendo a uma diferença negativa de 291 hectares, porém superior aos dados da versão cartográfica oficial. Nos restantes anos, os valores obtidos da área ardida acumulada anualmente são sempre superiores, totalizando cerca de 37% (63 095 hectares) acima do valor total registado no período. Em média, a diferença anual é de 3155ha em relação aos dados registados no SGIF.

Comparando ambos os produtos cartográficos, verifica-se que o presente estudo obteve valores muito superiores aos registados na fonte oficial, quer anualmente quer acumulados no período (fig. 5). Comprova-se a existência de mais 8819 perímetros acima do valor apresentado na cartografia oficial (3873), que correspondem a um valor superior em 55 777 hectares.

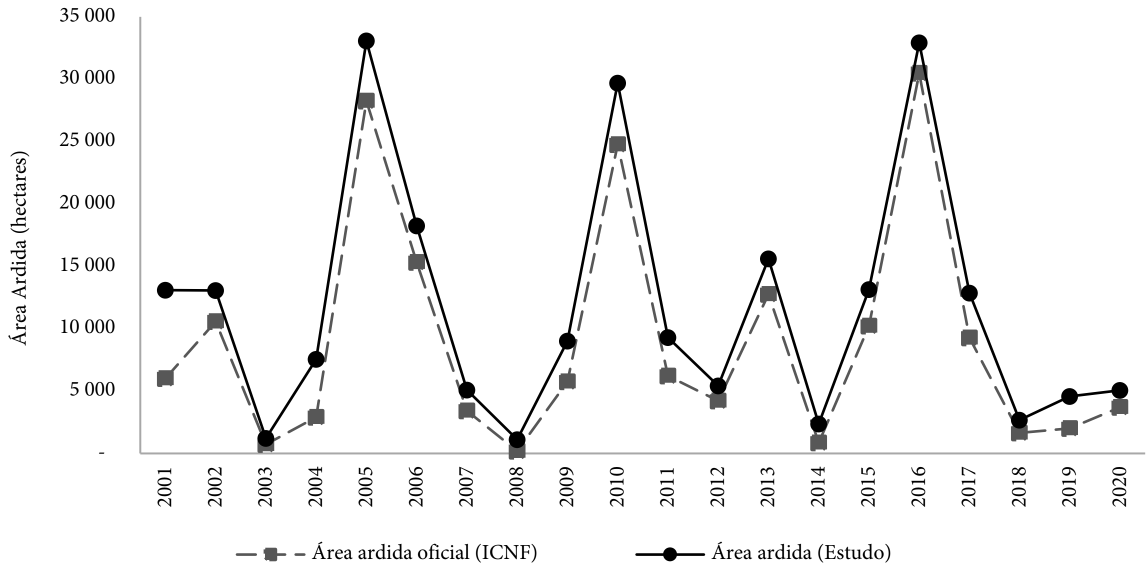


Fig. 5 – Comparação da área ardida anual obtida pela cartografia oficial e pelo presente estudo.
***Fig. 5** – Comparison of the annual burned area obtained by official cartography and by the present study.*

Do processo de classificação das áreas ardidas quanto à tipologia do fogo, resultaram um total de 5176 perímetros associados a incêndios rurais que ocorreram entre 2001 e 2020 (fig. 6), o que corresponde a uma área total ardida de 191 402 hectares. O número de perímetros classificados como "outros fogos" totalizou 7516 no mesmo período, cerca de 59% do total de perímetros obtidos neste estudo, correspondendo a 43 658 hectares de área ardida.

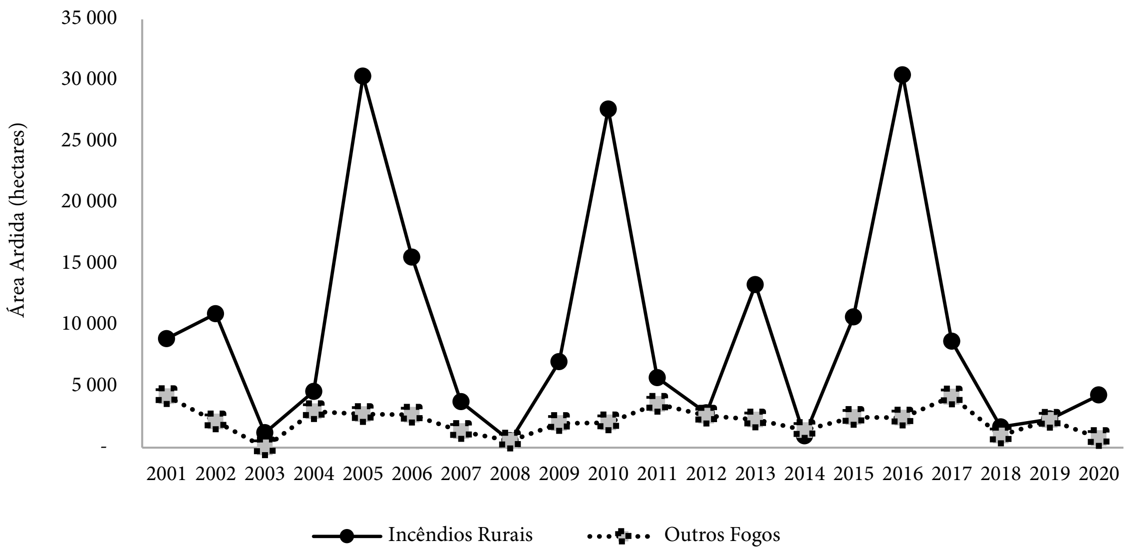


Fig. 6 – Área ardida anual resultante de fogos classificados como incêndios rurais e outros fogos (outono-inverno-primavera).
Fig. 6 *– Annual burned area resulting from fires classified as wildfires and other fires (autumn-winter-spring).*

Quanto à distribuição estacional da área ardida ao longo de 20 anos verifica-se que 79% dos perímetros concentram-se no outono, inverno e primavera e representam cerca de 39% da área ardida total (fig. 7). A média da área ardida por perímetro mapeado no conjunto destas três estações é de 9,1ha. A estação do verão concentra apenas 21,3% dos perímetros identificados e representa 61% do total de área ardida acumulada. A média da área ardida por perímetro no período estival é de 53,2ha.

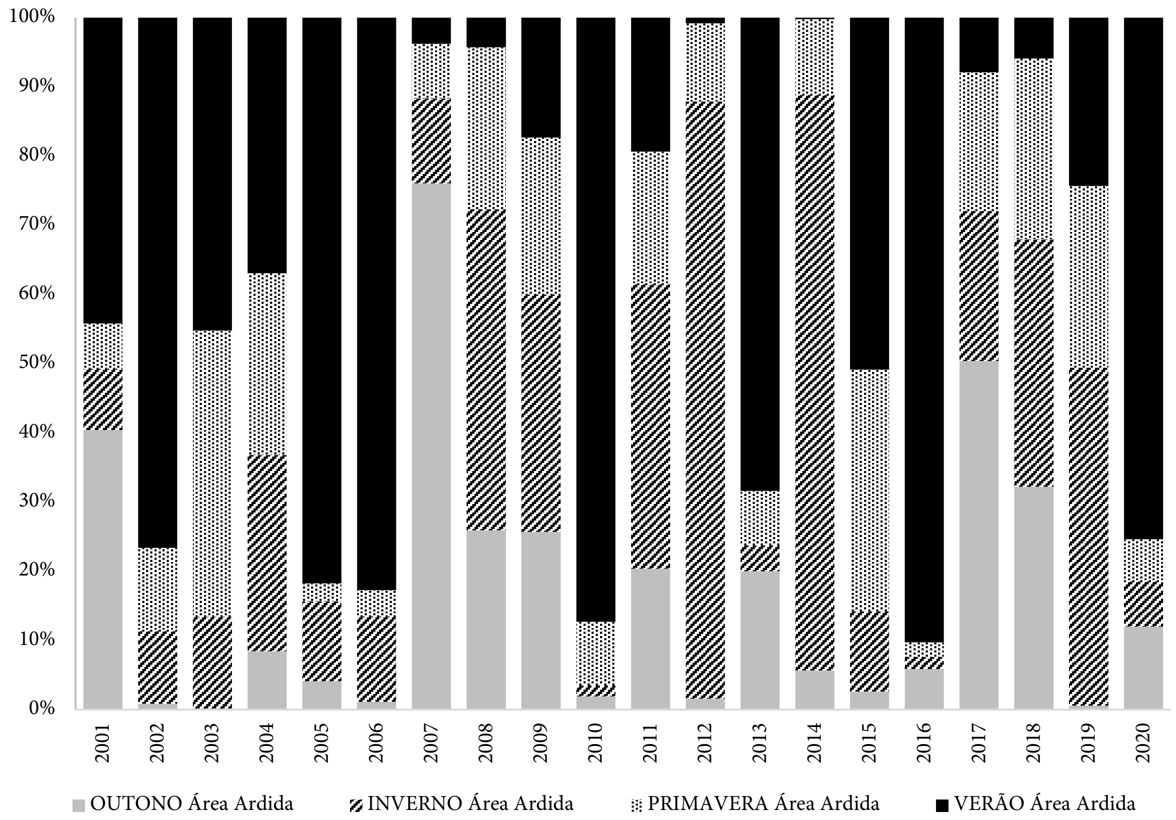


Fig. 7 – Distribuição estacional da área ardida obtida através da reconstrução da série histórica entre 2001 e 2020.

Fig. 7 *– Seasonal distribution of burned area obtained by reconstructing the historical series between 2001 and 2020.*

Analisando a frequência com que o território do Alto Minho sofre a perturbação do fogo nos últimos 20 anos, verifica-se que 46,1% do total do espaço foi alguma vez afetado. O quadro IV permite a comparação da frequência do fogo no território de estudo, considerando os produtos cartográficos produzidos no âmbito do estudo e da fonte oficial (ICNF). Os resultados do estudo identificam maior frequência e mais área ardida por fogo recorrente, quando comparados com a cartografia oficial. Esta discrepância é muito superior nas áreas afetadas por fogos que se repetem mais de 4 vezes. Verifica-se que em 20 anos 28,4% território foi percorrido por fogos mais do que uma vez e apenas 39 260 hectares arderam uma única vez, o que corresponde a 17,7% do território. Neste período, uma pequena área de cerca de seis hectares ardeu nove vezes.

Quadro IV – Análise comparativa da frequência dos fogos entre 2001 e 2020 no território do Alto Minho com base na cartografia elaborada no presente estudo e na cartografia oficial.

***Table IV** – Comparative analysis of the fire frequency between 2001 and 2020 in the territory of Alto Minho based on the cartography developed in this study and on official cartography.*

Estudo			Cartografia Oficial		
Nº de vezes que ardeu	Área (ha)	%	Nº de vezes que ardeu	Área (ha)	%
0	119 571	53,900	0	127 861	57,700
1	39 260	17,700	1	46 522	21,000
2	29 326	13,200	2	27 330	12,300
3	18 443	8,300	3	13 594	6,100
4	9437	4,300	4	4684	2,100
5	3688	1,700	5	1120	0,500
6	1619	0,700	6	447	0,200
7	288	0,100	7	150	0,100
8	74	0,030	8	2	0,001
9	6	0,003			

As figs. 8 e 9 permitem identificar as zonas da área de estudo onde o fogo é mais frequente.

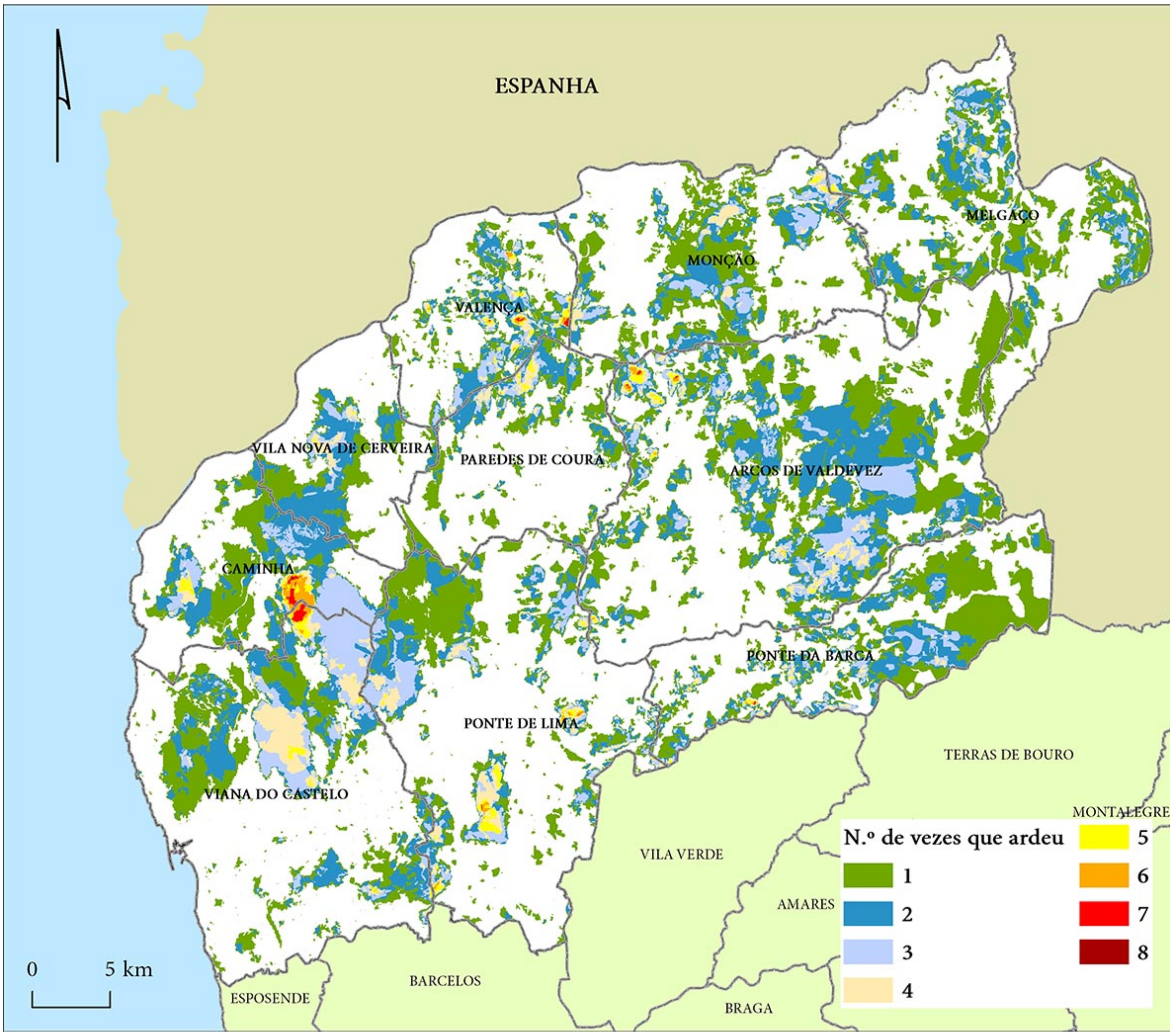


Fig. 8 – Frequência do fogo entre 2001 e 2020 com base na cartografia oficial (ICNF, 2021). Figura a cores disponível online.

Fig. 8 *– Fire frequency between 2001 and 2020 based on official cartography (ICNF, 2021). Colour figure available online.*

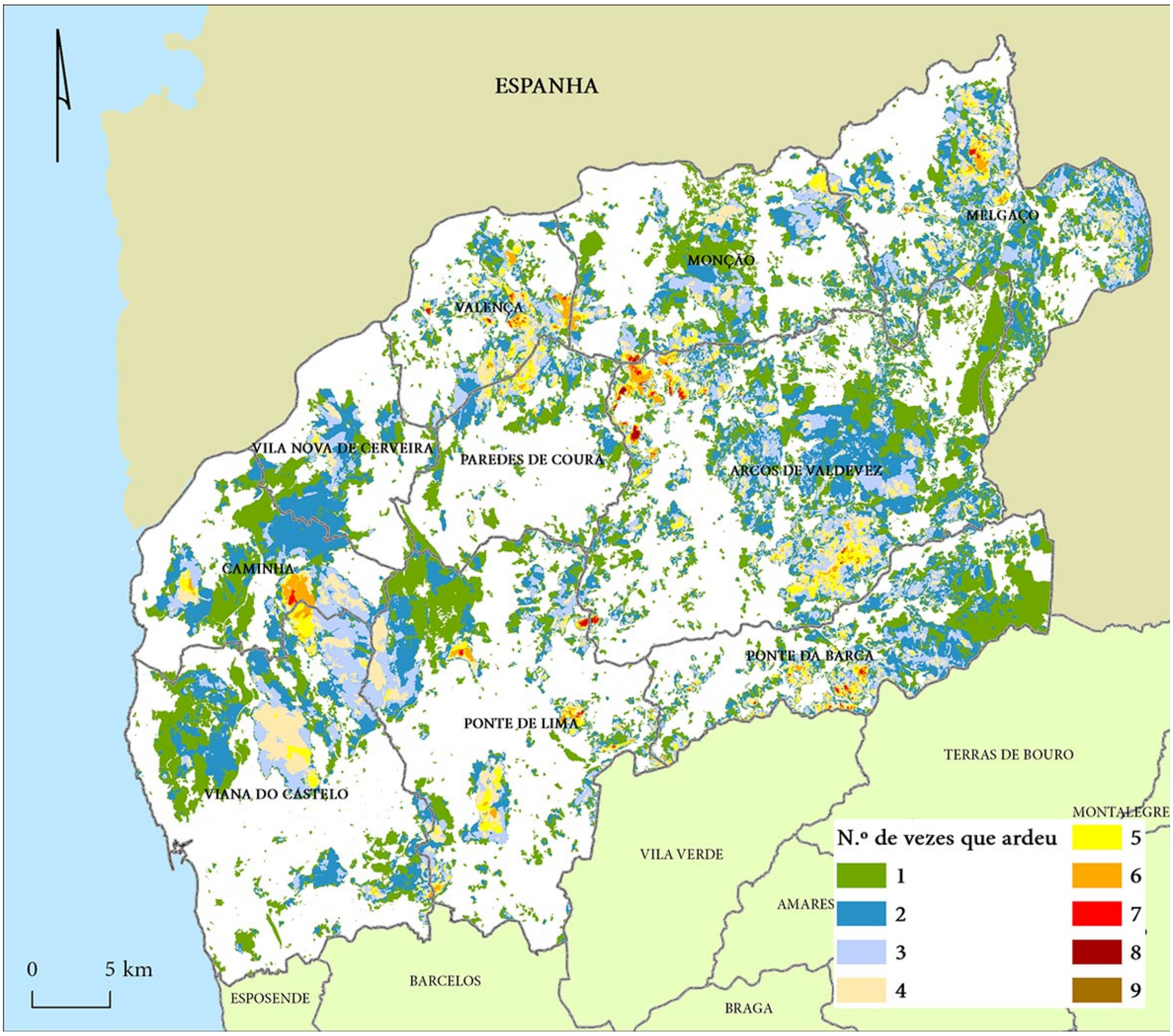


Fig. 9 – Frequência do fogo entre 2001 e 2020 com base na cartografia elaborada no presente estudo. Figura a cores disponível online.

Fig. 9 *– Fire frequency between 2001 and 2020 based on the cartography elaborated in this study. Colour figure available online.*

Ao examinar a diferença dos resultados da frequência do fogo entre a cartografia elaborada neste estudo e a cartografia oficial, verificam-se divergências nas áreas percorridas pelo fogo, bem como no número de vezes em que se repete esta perturbação no território. Na fig. 10 as divergências são assinaladas por valores diferentes de zero (0), sendo que os valores negativos da frequência correspondem às áreas resultantes da cartografia oficial e os valores positivos da frequência correspondem às áreas resultantes do processo de mapeamento do estudo. Os resultados obtidos no estudo permitiram identificar uma maior frequência do fogo nas regiões do interior da região do Alto Minho, correspondente às zonas mais montanhosas. Por outro lado, a cartografia oficial identifica maior frequência do fogo nas serras próximas ao litoral da região (com maior incidência nos territórios coincidentes com os municípios de Vila Nova de Cerveira, Caminha, Viana do Castelo e Ponte de Lima). As divergências identificadas derivam do rigor e das metodologias utilizadas na elaboração de ambos os processos cartográficos.

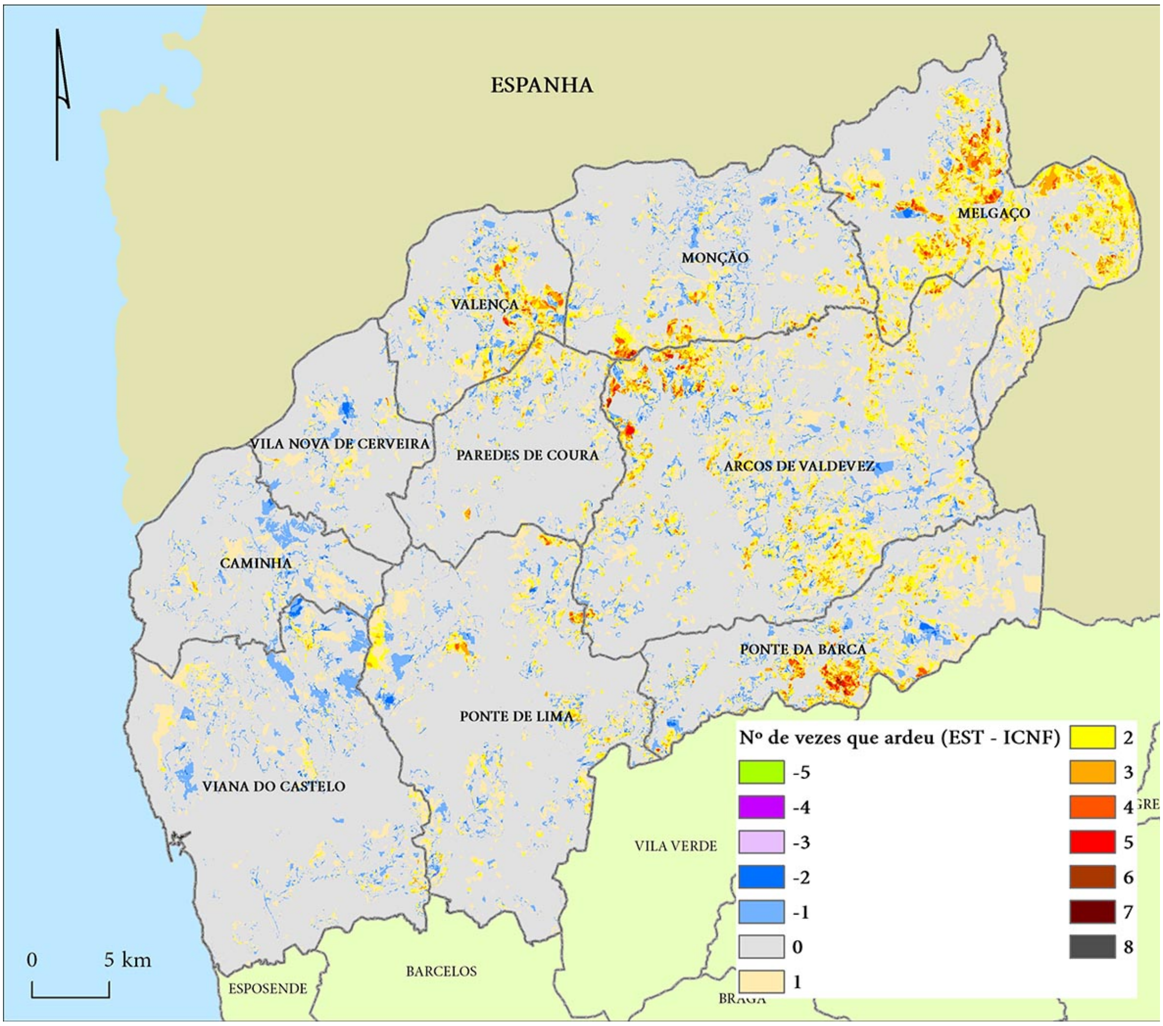


Fig. 10 – Diferença da frequência do fogo entre as duas fontes cartográficas (cartografia elaborada neste estudo menos a cartografia oficial). Figuras a cores disponível online.

***Fig. 10** – Difference in fire frequency between the two cartographic sources (cartography elaborated in this study minus official cartography). Colour figure available online.*

4.4 DISCUSSÃO E CONCLUSÕES

Tendo em consideração as evidências do impacte dos fogos registadas por via das séries históricas das imagens de satélite, ao longo das diversas estações do ano, verifica-se quer pelos perímetros quer pela área ardida acumulada que a área percorrida por fogos no território do Alto Minho é bastante superior à registada na cartografia oficial. Se por um lado a cartografia oficial não integrou áreas percorridas por fogos, por outro, inclui áreas que de acordo com as imagens de satélite e ortofotos utilizados neste estudo não aparentam ter ardido. Uma parte dos perímetros detetados neste estudo e ausentes da cartografia oficial poderá resultar de fogos que não implicaram a intervenção de equipas do dispositivo de extinção, pelo que também não estão registados no SGIF. Noutros casos, a omissão resulta dos processos de mapeamento, os quais por vezes ocorrem semanas ou meses após o fogo. Note-se que a cartografia oficial das áreas ardidas era otimizada para os incêndios de verão, baseando-se numa única imagem de satélite obtida após o suposto findar da época de incêndios (Oliveira *et al.*, 2012), enquanto no presente estudo se procuraram analisar todas as imagens de satélite de cada ano. No que se refere aos perímetros que na cartografia oficial delimitam áreas ardidas, mas que neste estudo não foram identificadas como tal, a explicação poderá resultar de erros de deteção e de interpretação resultante de processos de mapeamento automático e sem supervisão, ou de levantamentos no terreno com base em cartografia. Outro fator que poderá ter contribuído para as grandes diferenças de resultados cartográficos será a limitada acessibilidade das imagens de satélite no passado, principalmente na primeira década, ao contrário do que acontece atualmente. Adicionalmente, a complementaridade pela sobreposição de outras fontes cartográficas, como os focos de calor dos sensores MODIS e VIIRS e a produção periódica de ortofotos, permitiram apoiar o trabalho na identificação mais precisa das áreas ardidas e a sua datação, bem como a identificação dos perímetros dos incêndios rurais registados no SGIF.

A utilização de dados oficiais para fins de ordenamento e de gestão do fogo no território à escala distrital e municipal, ou para fins de investigação, recomenda uma prévia validação e correção, com o objetivo de reduzir eventuais erros de interpretação. Os principais erros identificados na cartografia oficial encontram-se sobretudo no insuficiente rigor na delimitação dos perímetros dos fogos, na ausência de áreas ardidas, na falta de critérios de integração das diversas áreas percorridas por incêndios (com a alocação de meios de extinção) e por outros fogos (queimadas e fogos controlados) e na ausência de dados integrados com os registos de base estatística (SGIF) de cada perímetro de incêndio (por exemplo: a data, o código de ocorrência, hora de alerta, ocupação do solo afetado e variáveis meteorológicas).

O aumento do número de satélites e melhoria dos sensores radiométricos na última década, destacando-se a missão do Sentinel-2, com uma recorrência temporal alta para uma mesma região (intervalos de cinco dias), assim como o incremento de voos para obtenção de ortoimagens, permite um trabalho sistemático e cada vez mais rigoroso das áreas percorridas pelos fogos, a uma escala maior e adequada ao ordenamento do território (Navarro *et al.*, 2017). O rigor cartográfico é fundamental, não só para identificar e caraterizar o regime de fogos, mas também pelas implicações e condicionamentos para o comum cidadão, uma vez que o histórico cartográfico determina a carta de perigosidade de um espaço, condicionando o seu uso e ocupação.

A sobreposição da cartografia com os focos de calor dos sensores MODIS e VIIRS é essencial para a datação daqueles fogos que não implicaram a atuação de meios de extinção e para os quais não existe registo, ocorrendo nas estações de outono, inverno e primavera. Estes fogos constituem uma importante fração da área ardida na região de estudo e com efeitos na estrutura da paisagem e na acumulação e heterogeneidade espacial dos combustíveis florestais e, consequentemente, assumem um papel na propagação dos incêndios de verão, merecendo um futuro estudo mais detalhado, nomeadamente comparando a sua influência com aquela exercida pelo fogo controlado (Davim *et al.*, 2021; 2022). É de salientar que, de acordo com a metodologia oficial para o cálculo da perigosidade espacial de incêndios, os perímetros dos fogos que a cartografia oficial omite não são contabilizados no processo, do que resulta uma subestimação da perigosidade.

É provável que a ordem de grandeza das diferenças entre a cartografia oficial de áreas queimadas e aquela produzida por este estudo seja extensível a outros territórios de Portugal, nomeadamente àqueles caraterizados por regimes de fogo influenciados pela atividade pastoril e, portanto, com uma componente relevante de ocorrências no outono-primavera (Pereira *et al.*, 2022). É importante melhorar a informação cartográfica de todas as áreas percorridas por fogos e daquelas que, dada a sua natureza, têm implicações no condicionamento do uso e ocupação do solo, em particular na classificação da perigosidade de incêndios rurais no território (OTI, 2019), bem como a criação de normas técnicas para o processo de mapeamento e classificação.

CAPÍTULO V - PASTORAL BURNING AND ITS CONTRIBUTION TO THE FIRE REGIME OF ALTO MINHO, PORTUGAL

Abstract. Alto Minho (in north-western Iberia) is one of the European regions most affected by fires. Many of these fires originate from rangeland management of Atlantic heathlands, and while being illegal, often are not actively suppressed. Pastoral fires (autumn to spring fires unrecorded by authorities), spring wildfires, and summer wildfires were independently mapped and dated from remote sensing. Alto Minho burned at a mean annual rate of 5.0% of the territory between 2001 and 2020. Pastoral burning totalled 40,788 hectares during the period, accounting for 20% of the total burned area. Rangeland burning occurs mostly from December to April, the rainiest months that guar-antee the conditions for pasture renewal and fire self-extinction. The mean fire return interval of pastoral burning is slightly higher than that of wildfires (13 years versus 11 years), except in part of the inner mountains where it dominates fire activity. Pastoral fires are more frequent and largely prevail over wildfires in the parishes with higher livestock quantities. Conversely, the largest wildfires and higher summer burned areas correspond with very low livestock and nearly non-existing pastoral fires. Traditional fire knowledge should not be overlooked by fire management, as it contributes to more sustainable fire regimes and ecosystems.

Keywords: fire use, fire frequency, rangeland management, traditional fire knowledge

Resumen. *Las quemas pastorales y su contribución al régimen de fuegos del Alto Minho, Portugal*

El Alto Miño (en el noroeste de Iberia) es una de las regiones europeas más afectadas por los incendios. Muchos de estos incendios tienen su origen en la gestión de los matorrales atlánticos y, aunque son ilegales, a menudo no se extinguen de forma activa. Los fuegos pastorales (incendios de otoño a primavera no registrados por las autoridades), los incendios forestales de primavera y los incendios forestales de verano se cartografiaron y dataron de forma independiente a partir de teledetección. El Alto Minho ha ardido a una tasa media anual del 5,0% del territorio entre 2001 y 2020. Las quemas pastorales totalizaron 40.788 hectáreas durante el período, lo que representa el 20% de la superficie total quemada. Las quemas de pastos se producen sobre todo de diciembre a abril, los meses más lluviosos que garantizan las condiciones para la renovación de los pastos y la autoextinción del fuego. El intervalo medio de retorno del fuego de las quemas pastorales es ligeramente superior al de los incendios forestales (13 años frente a 11 años), excepto en una parte del interior de las zonas de montaña, donde domina la actividad del fuego. Los fuegos pastorales son más frecuentes y prevalecen ampliamente sobre los incendios forestales en las parroquias con mayor cabaña ganadera. Por el contrario, los mayores incendios forestales y las mayores superficies quemadas en verano corresponden a una ganadería muy escasa y a fuegos pastorales casi inexistentes. El conocimiento tradicional del fuego no debe ser ignorado por la gestión de incendios, ya que contribuye a regímenes de fuegos y ecosistemas más sostenibles.

Palabras clave: uso del fuego, frecuencia de los fuegos, gestión de pastos, conocimiento tradicional del fuego

Resumo. *As queimas pastorais e a súa contribución ao réxime de lumes do Alto Minho, Portugal*

O Alto Miño (no noroeste de Iberia) é unha das rexións europeas máis afectadas polos incendios. Moitos destes incendios teñen a súa orixe na xestión das matogueiras atlánticas e, aínda que son ilegais, a miúdo non se extinguen de forma activa. Os lumes pastorais (incendios de outono a primavera non rexistrados polas autoridades), os incendios forestais de primavera e os incendios forestais de verán cartografáronse e dataron de forma independente a partir de teledetección. O Alto Minho ardeu a unha taxa media anual do 5,0% do territorio entre 2001 e 2020. As queimas pastorais totalizaron 40.788 hectáreas durante o período, o que representa o 20% da superficie total queimada. As queimas de pastos prodúcense sobre todo de decembro a abril, os meses máis chuviosos que garanten as condicións para a renovación dos pastos e a autoextinción do lume. O intervalo medio de retorno do lume das queimas pastorais é lixeiramente superior ao dos incendios forestais (13 anos fronte a 11 anos), excepto nunha parte do interior das zonas de montaña, onde domina a actividade do lume. Os lumes pastorais son máis frecuentes e prevalecen amplamente sobre os incendios forestais nas parroquias con maior cabana gandeira. Pola contra, os maiores incendios forestais e as maiores superficies queimadas no verán corresponden a unha gandería moi escasa e a lumes pastorais case inexistentes. O coñecemento tradicional do lume non debe ser ignorado pola xestión de incendios, xa que contribúe a réximes de lumes e ecosistemas máis sostibles.

Palabras chave: *uso do lume, frecuencia dos lumes, xestión de pastos, coñecemento tradicional do lume*

5.1 INTRODUCTION

Alto Minho, located in the northwest of the Iberian Peninsula, is one of the regions in Portugal that has been more affected by fires in recent decades [1,2]. While Holocene fire expansion in southern Europe was initially conditioned by high climatic seasonality, the use of fire by the first agrarian societies in the Neolithic promptly shaped the fire regime [3]. The frequency of fires increased with population increase, as new agricultural areas, areas for grazing, and new settlements were established [4–6] . As in other regions of southern Europe, fire has marked the structure and functioning of ecosystems that have adapted over thousands of years to a human-shaped fire regime, as the primary causes of fires in the territory are anthropogenic [6,7].

The Atlantic heathlands of NW Iberia have been traditionally maintained by a combination of grazing, shrub cutting and burning [8] . The use of fire, rather than an isolated practice, was integrated into the ancestral agro-silvo-pastoral system that lasted until the mechanization of agriculture and the introduction of inorganic fertilisation in the second half of the 19th century [9,10] . The abandonment of agricultural activity in NW Portugal contributed to increased fire occurrence and burned area [11]. Traditional pastoral fires, mainly in shrubland, contribute to create and maintain mosaic-structured landscapes [12]. The abandonment of small-scale farming and traditional practices such as grazing dissolves the traditional mosaic and reinforces the connectivity between homogenous and extensive high fuel-load patches derived from contemporary afforestation and rewilding [6]. However, a number of studies point to a relationship between wildfires and the traditional use of fire, particularly for range management purposes [13–15]. This type of fire use may constitute a negligent or intentional cause of wildfire, depending on each country legislation [16]. Other studies associate the replacement of agriculture by extensive livestock production and the need to use fire as a tool for pasture maintenance as the origin of the increase in frequent wildfires [17,18].

The impact of large wildfires in the Mediterranean Basin, including Portugal, fostered studies linking components of the fire regime to weather and climate [19–21], and examining how fire incidence relates with land use and biophysical variables [22–25] and anthropogenic causes [13,26,27], including social conflicts and recreational and leisure activities [10]. A global study showed that farmlands are prone to recurrent fire, which given the human agency involved is less affected by weather variability than in other land cover types [28]. In Portugal, fire density is maximum in densely populated regions but it also increases with elevation, in part because of pastoral burning of shrubland [22]. Recently, the first classification and mapping of fire regimes in mainland Portugal was published [27], covering the period from 1980 to 2017 at parish scale, and highlighting the existence in northern and central Portugal of frequent fire regimes with a marked autumn-to-spring component revealing of pastoral burning activity.

Wildfire causality studies in Portugal have relied to date on official data from the Institute for Nature Conservation and Forests (ICNF), which has inconsistencies because of variation in mapping methods, database completeness, limitations in satellite image processing, and insufficient field validation [2,29,30]. Here we seek to understand the relationship between extensive livestock production and the use of fire, whose practice is currently a remnant of the agro-silvo-pastoral system that has modelled Alto Minho and other European Atlantic landscapes over the centuries, e.g. [31]. Based on rigorous and detailed fire mapping using several cartographic sources and historical series of satellite images and orthoimagery, we examine (i) the contribution of pastoral burning to fire activity in the Alto Minho, and (ii) whether there is a relationship between pastoral burning and livestock in the region.

5.2 MATERIALS AND METHODS

5.2.1 Study region

The study region is the entire Alto Minho, located in the extreme northwest of Portugal (Figure 1). To the North and East, it is bordered by the Autonomous Community of Galicia (Spain), to the South by the district of Braga and to the West by the Atlantic Ocean. Alto Minho coincides with the Viana do Castelo district, occupying an area of approximately 2217 km^2 and is divided into ten municipalities. These municipalities are further subdivided into smaller administrative units, parishes, which were our sample units (n=208).

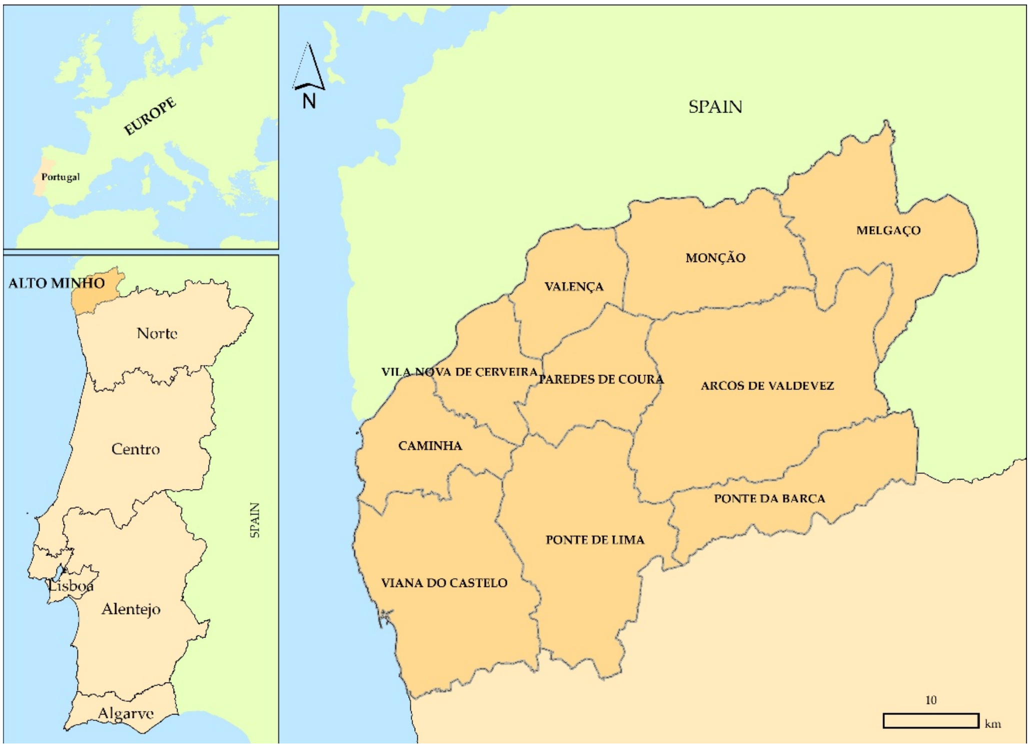


Figure 1. Geographic context of the study region, Alto Minho. Source: Official Administrative Map of Portugal, Directorate General of Territory - DGT (2020), Administrative Limits of Spain, National Geographic Institute of Spain - IGN (2019)

Approximately 18% of Alto Minho is occupied by agriculture and 72% corresponds to forests and shrublands, of which 52% are common lands (DGT, 2020). Portuguese common lands were extensively afforested with pine in the 20th century, only to subsequently revert to Atlantic heathland through fire [32]. Terrain is predominantly mountainous, with elevations exceeding 400 meters, up to over 1000 meters, with the exception of the coastal zone and the main valleys of the Minho and Lima rivers [33]. Annual temperature range is generally low, with average annual temperature between 14ºC and 16ºC [34]. Mean annual precipitation exceeds 1000 mm and varies markedly from the coast to the interior, where it can reach 2400 to 2800 mm at higher elevations. Similarly to other northwest Iberia regions, the use of fire in the Atlantic heathlands of Alto Minho is intrinsic to the ancestral agro-silvo-pastoral system, both in ploughing, soil fertilisation, renewal of pastures and the burning of heaps and stubbles [35], and is also thought to be a relevant wildfire cause.

5.2.2 Methodology

5.2.2.1 Obtaining and processing satellite images

Images were acquired from Landsat 5 (TM), Landsat 7 (ETM+), Landsat 8 (Operational Land Imager - OLI) and Sentinel-2 (Multispectral Instrument - MSI) satellites for the 2001-2020 period. These images were obtained from the Semi-Automatic Classification Plugin (SCP) application developed by Congedo [36] for the QGIS software and directly via the U.S. Geological Survey platform - Earth Explorer. Approximately 400 images cloud-free or with minimum cloud cover spanning from 2001 to 2020 were collected from the satellites to identify seasonal patterns of burnt areas in Alto Minho. This allowed for maximum coverage of each year and accurate analysis of fire patterns.

All images were pre-processed for atmospheric correction using the SCP for QGis. Burned areas were subsequently identified using the NBR index and the RGB false colour composition [36]. The year 2000 fire scars were identified to avoid their potential inclusion in the burned areas of the following year.

5.2.2.2 Obtaining the burnt areas perimeters

The fire perimeters were digitised from the NBR and RGB false colour images. The process was entirely manual and supervised, supported by ancillary information such as high-resolution orthophotos, to avoid interpretation errors resulting from changes in land cover that might alter the final result [37–39].

The manual digitisation process considered the resolution of the images from different satellites, ranging from a scale of 1:25,000 to 1:3000. The use of historical orthophoto series also allowed the identification and correction of the fire perimeters, increasing the accuracy and detail of mapping.

5.2.2.3 Dating and classifying fire perimeters

Once the digitisation phase was concluded, the fires were dated and classified. To do so, the georeferenced hotspots from the MODIS and VIIRS sensors were overlaid, after download from the archive on the NASA Fire Information for Resource Management System (FIRMS) website (https://firms.modaps.eosdis.nasa.gov/) in vector format (point).

Annual data on individual fire occurrences from 2001 to 2020, provided by ICNF, was imported and georeferenced. Temporal and spatial cross-referencing between ICNF data and remotely-sensed information enabled to match fire records and fire perimeters. Similarly, institutional cartographic information in vector format (polygon) respecting to prescribed fire was overlaid. The overlay of the different sources related to the fires allowed dating the perimeters and classifying them according to their origin.

The fire perimeters were classified as "wildfire" when matching an official database record, i.e. fires that involved the dispatch of suppression resources. We distinguished between summer season fires, classifying them as "summer wildfire" (WFSUM), and fires occurring in other seasons, classifying them as "autumn-winter-spring wildfire" (WFAWS). The remaining fire perimeters were either classified as "autumn-winter-spring fires" (FAWS) or "prescribed burning" (PB). The former were identified from the chronological sequence of satellite images and hotspots dates, and correspond to fires absent from the official database, therefore indicating that suppression operations were not undertaken. The reasons for such no-response may vary, from no detection or lack of suppression resources to awareness and acceptance of the land management goals of those fires. Fires transmitted from outside the study region were included in the burned area estimates but were not typified.

5.2.2.4 Other data

The agrarian nature or motivation of autumn to spring fires in Alto Minho recommends an analysis of the evolution and distribution of livestock. Livestock data concerning extensive and semi-extensive production at parish level, in particular ruminants and horses, was sourced from the decennial Agricultural Censuses of 1999, 2009 and 2019 (National Statistical Institute - INE) and adapted to the Official Administrative Map of Portugal (DGT, 2020).

Additional context for the fire-livestock analyses was given by retrieving the area occupied by forest and shrubland in each parish.

5.2.2.5 Data analyses

Burned areas per fire type (FAWS, WFAWS, WFSUM) were summed for each year and globally for the study period and month of the year. Fire frequency (or the mean annual burn probability of each pixel) was calculated and mapped for each fire type as the number of times it burned in the 2001-2020 period divided by 20. Five fire frequency classes (and their corresponding fire return intervals, see Results) were considered to summarize cumulative burned area distribution across the three fire types. Similar statistics were separately calculated for the Union of Parishes of Castro Laboreiro and Lamas de Mouro, Melgaço, where the frequency of pastoral burning is the highest in Alto Minho.

In order to detect relationships between fire and livestock production, burned area was summed and distributed by fire type for several groups of parishes, defined by the mean number of extant animals across the study period, respectively 0-250, 250-500, 500-1000, 1000-1500 and >1500 animals. Finally, a K-means cluster analysis was carried out to identify groups of parishes with similar livestock amounts and fire frequencies per fire type, as well as similar territorial contexts in terms of shrubland fraction. For this purpose, the reference to calculate fire frequency was the area of forest and shrubland in the parish.

5.3 RESULTS

5.3.1 Fire in Alto Minho

The cumulative burnt area resulting from all types of fires during the 2001 – 2020 period was 221,854 hectares (Table 1), or 5.0% of the Alto Minho region as an annual average. Fire type distribution shows that 60.8% of the cumulative area is the result of summer wildfires. Autumn to spring wildfires and autumn to spring fires have similar shares, respectively 19.9% and 18.6% of the total burnt area in the period. Prescribed fire accounts for a very minor component of the fire regime, comprising just 0.7% of the total burned area (Table 1). However, interannual seasonal variation is high: summer wildfire can be almost absent, and autumn to spring fire activity can account for more than 80% of the annual burned area, like in 2009, 2011, 2017 and 2018, with FAWS comprising a maximum of 57.2% of the burned area in the mild fire weather year of 2014.

Table 1. Annual burned area (ha) distribution by fire type in Alto Minho (2001-2020), respectively autumn to spring fire (FAWS), autumn to spring wildfire (WFAWS), summer wildfire (WFSUM), and prescribed fire.

Year	FAWS	WFAWS	WFSUM	Prescribed fire	Total burnt area
2001	4371	1824	5724	-	11,920
2002	2098	856	9505	-	12,459
2003	10	653	549	-	1212
2004	2890	1489	2708	-	7086
2005	2685	3299	26,578	-	32,562
2006	2631	367	14,701	-	17,699
2007	1266	3006	193	-	4464
2008	548	510	48	-	1105
2009	1946	4831	1525	52	8354
2010	1587	1723	23,570	444	27,324
2011	3432	3938	1747	43	9160
2012	2512	2978	65	67	5622
2013	2128	2642	10,111	103	14,984
2014	1322	916	11	63	2312
2015	2302	3903	6636	113	12,955
2016	2308	696	26,051	108	29,163
2017	3952	7607	1017	137	12,713
2018	895	1361	148	53	2457
2019	1603	1090	942	364	3999
2020	757	371	3164	10	4302
Total	41,244	44,060	134,994	1557	221,854
Mean	2062	2203	6750	130	11,093

The monthly distribution of precipitation based on the climatological normal of 1981 to 2010 (Portuguese Institute of Sea and Atmosphere - IPMA, 2022) reveals June to August to be the driest months of the year, corresponding to a drought period lengthy enough to result in a distinct wildfire activity peak in August but also implying that the window for significant fire activity is short in the oceanic climate of Alto Minho (Figure 2). FAWS are more prevalent from December to April and during these months their extent is higher than that of wildfire.

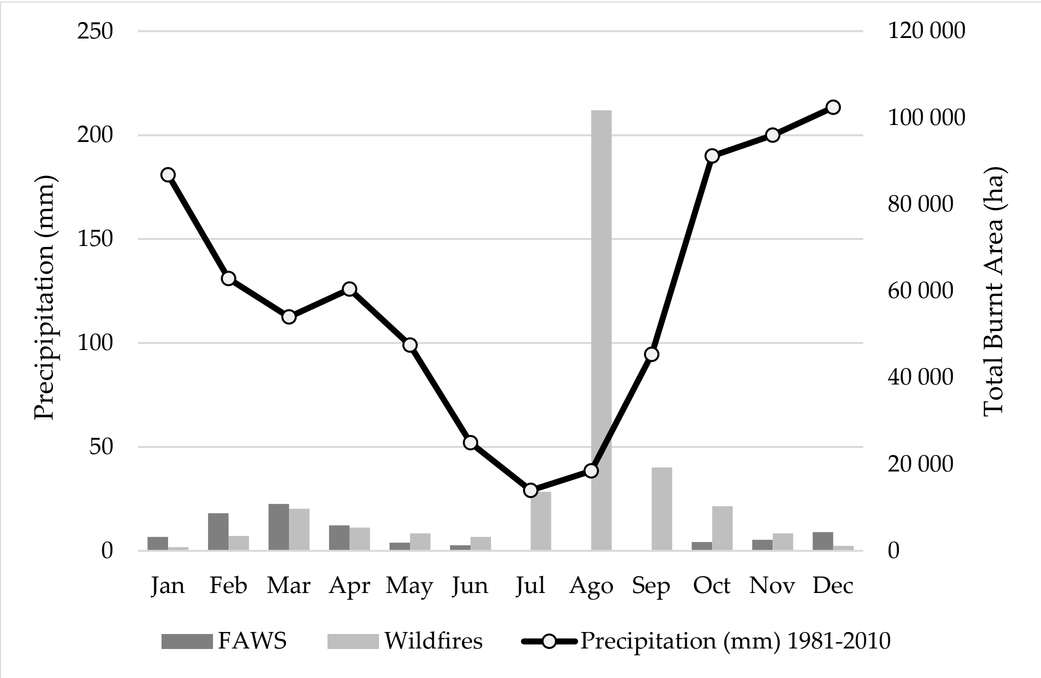


Figure 2. Total monthly burned area (2001-2020) by autumn to spring fires (FAWS) and by wildfires in Alto Minho, and precipitation (mm) according to the 1981 – 2010 climatological normal from the weather station of Viana do Castelo (Meadela)

Autumn to spring fire activity is dominated by fire return intervals greater than 10 years and, especially, greater than 20 years (Table 2). However, fire frequencies higher than 0.05 year^{-1} are more represented in summer wildfires, where the 0.1 – 0.2 fire frequency class is only slightly less represented than the two lower frequency classes, implying that summer fires are more frequent over much larger areas. Autumn to spring wildfires have lower burnt area in the higher frequency classes and a much higher accumulated area in the lower frequency class when compared with pastoral fires. Overall, the approximate mean fire return intervals for the WFSUM, FAWS and WFAWS fire types are respectively 11, 13 and 20 years, and 13 years on the whole.

The spatial patterns of fire extent and recurrence also vary by fire type (Figure 3). Pastoral burning is mostly located in the inner mountain region, with greater relevance in the Melgaço municipality, where rural communities still use fire as a tool for pasture renewal. Conversely, coastal mountains in Caminha, Viana do Castelo and Ponte de Lima are more affected by large summer fires, including relatively large high-frequency patches. It is also clear that autumn to spring wildfires (Fig. 3b) are generically smaller than summer fires (Fig. 3c) and larger than pastoral fires (Fig. 3a), which also feature substantially higher dispersion.

Table 2. Absolute (relative, %) burned area (2001 – 2020) by fire frequency / fire return interval class and fire type in the Alto Minho, respectively autumn to spring fire (FAWS), autumn to spring wildfire (WFAWS) and summer wildfire (WFSUM).

Fire frequency ($year^{-1}$)	Fire return interval (years)	FAWS	WFAWS	WFSUM
0 – 0.05	>20	17,090 (41.9)	28,075 (63.7)	44,137 (32.7)
0.05 – 0.1	10 – 20	12,098 (29.7)	11,722 (26.6)	43,564 (32.3)
0.1 – 0.2	5 – 10	10,864 (26.6)	3964 (9.0)	41,429 (30.7)
0.2 – 0.3	3 – 5	691 (1.7)	277 (0.6)	5653 (4.2)
0.3 – 0.4	2 – 3	45 (0.1)	24 (<0.1)	237 (0.2)
Total Burnt Area		40,788	44,061	135,019

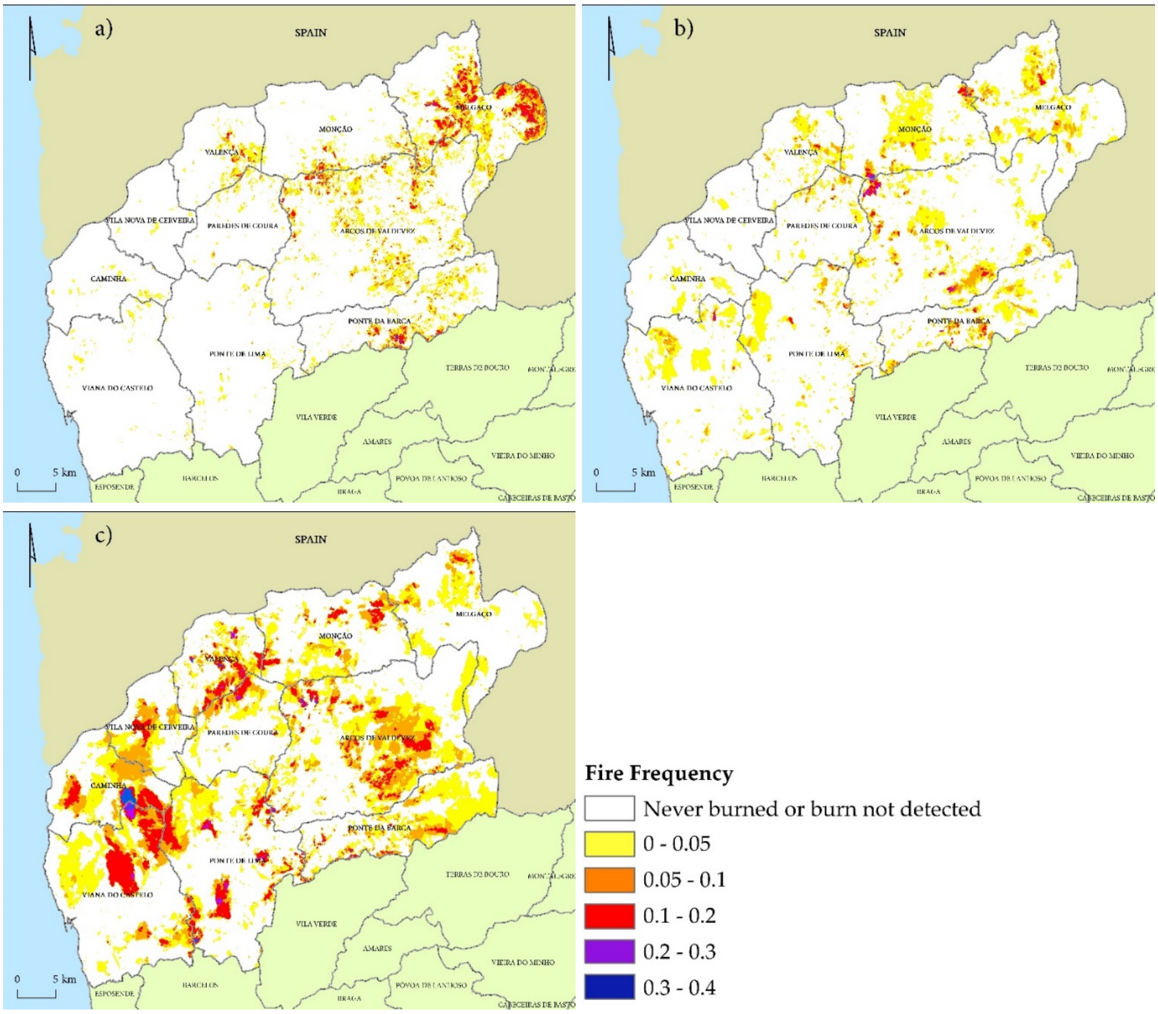


Figure 3. Map of fire frequency in the Alto Minho: **a)** autumn to spring fires (FAWS); **b)** autumn to spring wildfires (WFAWS); **c)** summer wildfires (WFSUM)

5.3.2 The particular case of Castro Laboreiro and Lamas de Mouro

The Union of Parishes of Castro Laboreiro and Lamas de Mouro, Melgaço, occupies 10,602 ha within the Peneda-Gerês National Park. Resident population was 874 inhabitants in 2001 (Census 2001, INE), but is now around 503 people (INE, 2022). Approximately 95.5% of the parish is under communal land tenure, with shrubland predominating (78.5% of the parish); forest occupies little more than 17% of the territory. It is one of the six parishes of Alto Minho with more than 1500 livestock animals. According to the Agricultural Census of 2019 (INE, 2021), 2001 animals were present, respectively cattle (48.8%), sheep (36.3%), goats (9.4%) and horses (5.4%). Livestock is mostly kept in an extensive regime in heathlands of *Erica* sp., *Pterospartum tridentatum*, *Ulex* sp. and *Cytisus* sp.

Approximately 81% of the Union of Parishes of Castro Laboreiro and Lamas de Mouro parish did burn at least once between 2001 and 2020, as manifest in Figures 4 and 6. Cumulative burned area from 2001 to 2020 reached 13,980 ha, of which 74.2% were FAWS, and these fires occurred mostly (68% of the cumulative area) from December to March. Autumn to spring wildfires, summer wildfires and prescribed burning amounted respectively to 16.1, 9.5 and 0.3% of the total burned area. The temporal patterns of the three non-institutional fire types are quite distinct: while pastoral burning mostly occupies the 5-20 years fire return interval range, wildfires predominantly (autumn to spring) or almost totally (summer) recur at intervals >20 years (Table 3). Approximate mean fire return intervals for the FAWS, WFAWS and WFSUM fires are respectively 11, 23 and 38 years.

Table 3. Absolute (relative, %) burned area (2001 – 2020) by fire frequency / fire return interval class and fire type in the Union of Parishes of Castro Laboreiro and Lamas de Mouro, respectively autumn to spring fire (FAWS), autumn to spring wildfire (WFAWS) and summer wildfire (WFSUM).

Fire frequency ($year^{-1}$)	Fire return interval (years)	FAWS	WFAWS	WFSUM
0 – 0.05	>20	2485 (24.7)	1462 (65.0)	1289 (97.6)
0.05 – 0.1	10 – 20	3249 (32.3)	751 (33.3)	32 (2.4)
0.1 – 0.2	5 – 10	4074 (40.6)	35 (1.6)	
0.2 – 0.3	3 – 5	234 (2.3)		
Total Burnt Area		10,042	2249	1321

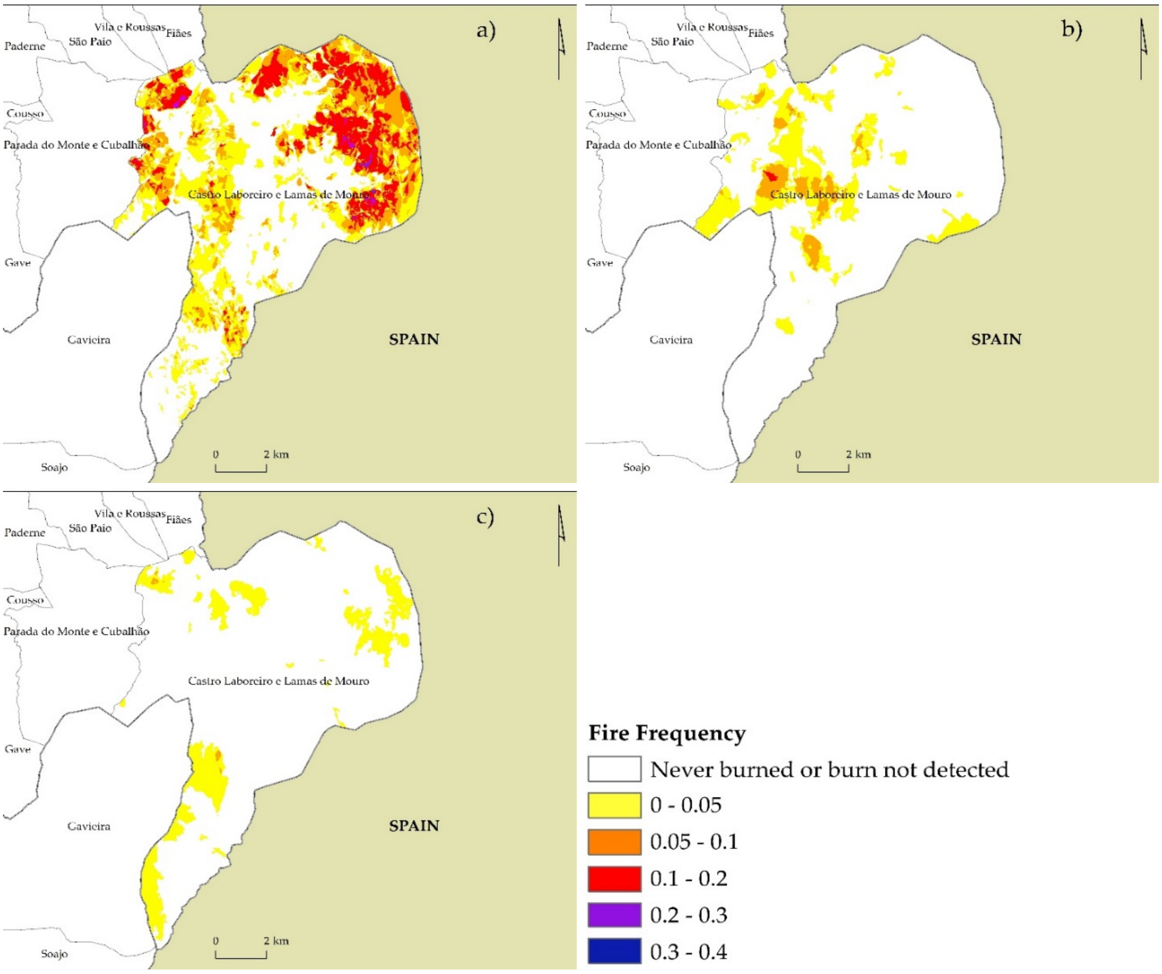


Figure 4. Fire frequency map for the different types of fires in the Union of Parishes of Castro Laboreiro and Lamas de Mouro between 2001 and 2020; **a)** autumn to spring fires (FAWS); **b)** autumn to spring wildfires (WFAWS); **c)** summer wildfires (WFSUM)

5.3.3 Livestock and fire

Livestock under an extensive exploitation regime is a relevant feature of Alto Minho. However, a generalized loss of livestock occurred from 1999 to 2019 in all Alto Minho municipalities, with an overall reduction of 43% in the number of animals (Table 4). Only 20 parishes have more than 1000 animals each, concentrating 30.5% of the total mean livestock (1999-2019) in about 26% of Alto Minho.

Table 4. Evolution and distribution of livestock in the municipalities of Alto Minho between 1999 and 2019

Municipality	Municipality area (ha)	Common lands (%)	No. of animals			% Variation 2019-1999
			1999	2009	2019	
Arcos de Valdevez	44,727	50.8	20,326	18,665	19,918	-2.0
Caminha	13,640	41.6	3660	2861	1847	-98.2
Melgaço	23,808	62.0	8683	7867	6437	-34.9
Monção	21,115	28.3	16,752	14,448	8933	-87.5
Paredes de Coura	13,808	23.7	12,308	12,444	8074	-52.4
Ponte da Barca	18,198	52.9	5745	4873	3437	-67.2
Ponte de Lima	32,000	21.2	18,797	16,946	14,398	-30.6
Valença	11,703	30.0	6220	6031	3243	-91.8
Viana do Castelo	31,875	16.4	12,460	9220	8323	-49.7
Vila Nova de Cerveira	10,838	47.7	3573	3099	1444	-147.4
Total	221,711	37.3	108,524	96,454	76,054	-42.7

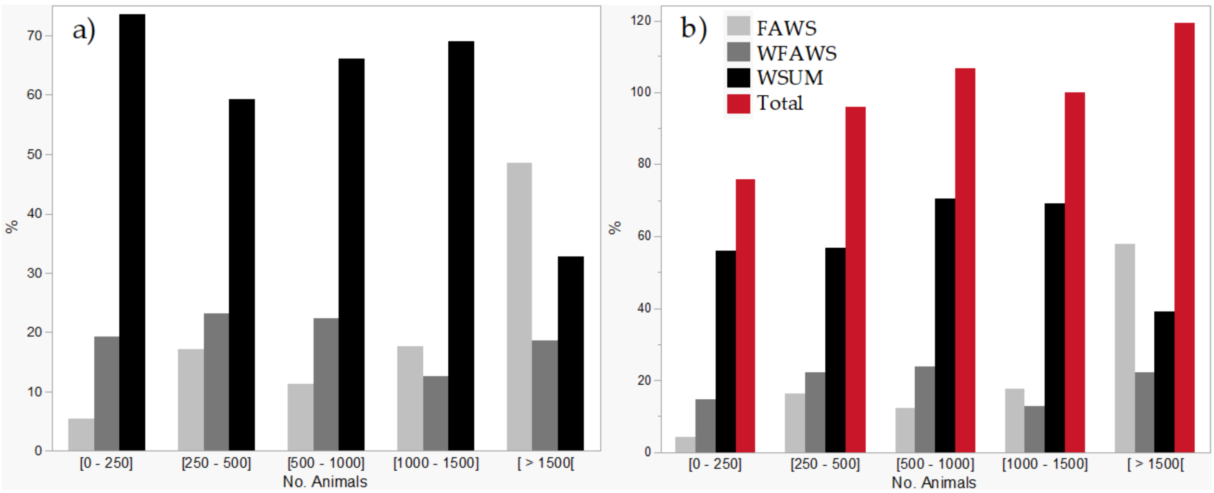


Figure 5. Cumulative burned area in Alto Minho (2001-2020) distribution (%) in each class of number of ruminants and horses, respectively by fire type (a) and by fire type as a percentage of parishes area (b).

The parishes at the extremes of livestock quantity are distinct regarding the relevance of the different fire types. Lower animal numbers (<250) correspond with residual pastoral burning and more than 70% of the fire extent occurring in summer (Figure 5a). In contrast, nearly half of the burned area is of type FAWS in the parishes with the highest livestock quantity (>1500), exceeding summer wildfire area. Figure 6 juxtaposes livestock quantity and FAWS frequency, indicating that the largest patches of pastoral burning (and at higher recurrence), coincide with the highest livestock quantities. The three intermediate livestock classes have similar fire types distribution. Autumn to spring wildfires account for similar shares of burned area across the livestock quantity range, suggesting (as we assumed) that these fires are unrelated to pastoral activity. Patterns of burned area as a land fraction (Figure 5b) are similar, except that low livestock quantity does not amount to the highest share of summer fire. Overall, the amount of fire in the landscape as a fraction of parish area has an increasing trend with increased livestock.

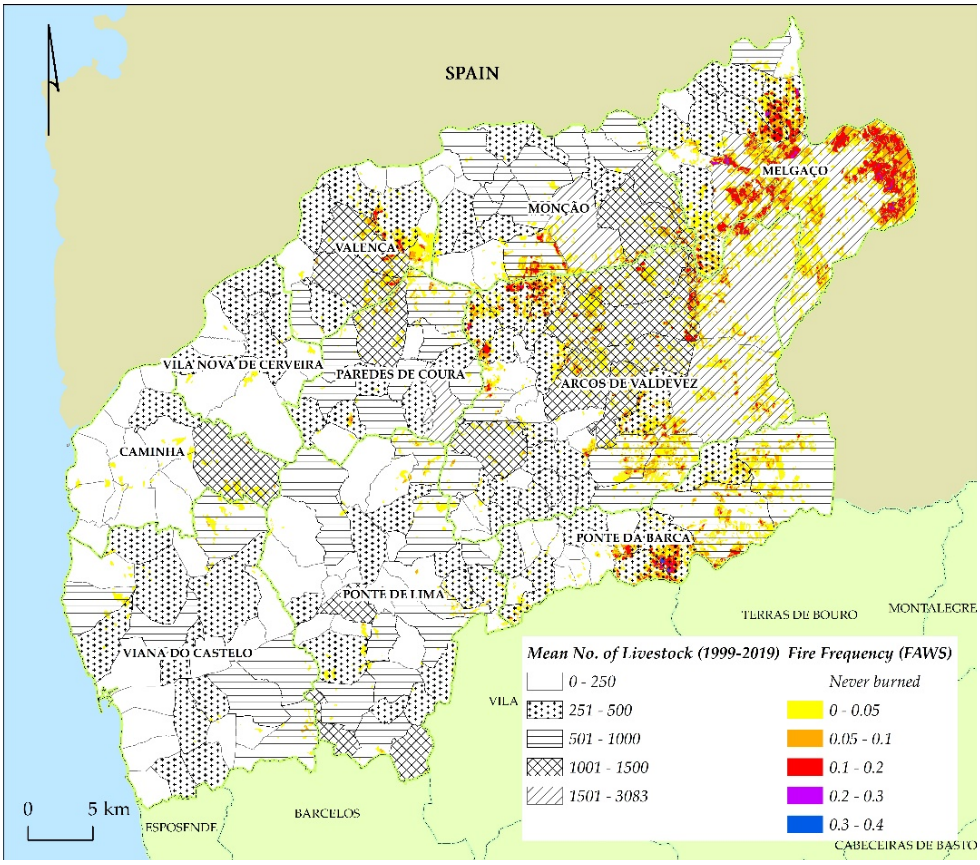


Figure 6. Mean fire frequency of autumn to spring fires (FAWS) in Alto Minho (2001-2020) and mean total livestock by parish (1999-2019).

Table 5. Mean characteristics of the Alto Minho parishes forming groups of distinct fire-livestock relationships as identified by K-means cluster analysis.

Cluster no. (Parishes no.)	Livestock no.	Shrubland fraction	Fire frequency (year^{-1})		
			FAWS	WFAWS	WFSUM
1 (95)	341	0.061	0.001	0.005	0.018
2 (2)	2305	0.218	0.004	0.021	0.023
3 (16)	366	0.434	0.035	0.034	0.048
4 (22)	1041	0.422	0.010	0.013	0.054
6 (3)	1934	0.688	0.041	0.011	0.010
7 (20)	358	0.172	0.006	0.035	0.031
8 (47)	303	0.191	0.002	0.009	0.072

Further systematization of the understanding of fire-livestock relationships through cluster analysis produced 8 groups of parishes, of which one (cluster 5) is excluded from Table 5 as it comprised a single outlier parish with an abnormal burn likelihood as a result of fire exported by neighbour parishes. As expected, the lowest frequency of pastoral burning occurs at low livestock levels, combined with low fractions of shrubland, corresponding to four clusters (1, 4, 7 and 8) that include 89% of the total number of parishes, including the two clusters with the highest rates of summer wildfire. Cluster 2 has the maximum livestock but low fraction of shrubland and minimal pastoral burning. Cluster 3 is characterized by a moderately high shrubland fraction and its pastoral burning frequency is the second highest (but it is lower than summer wildfire) even if livestock quantity is low. Finally, cluster 6, which includes the Castro Laboreiro and Lamas de Mouro parish, has very high livestock, the highest fraction of shrubland and the maximum and minimum frequencies of pastoral burning and summer wildfire, respectively. The clusters are not spatially coherent, i.e. are disperse, except for cluster 6 and, to a lesser degree, clusters 1 and 4 (Figure 7).

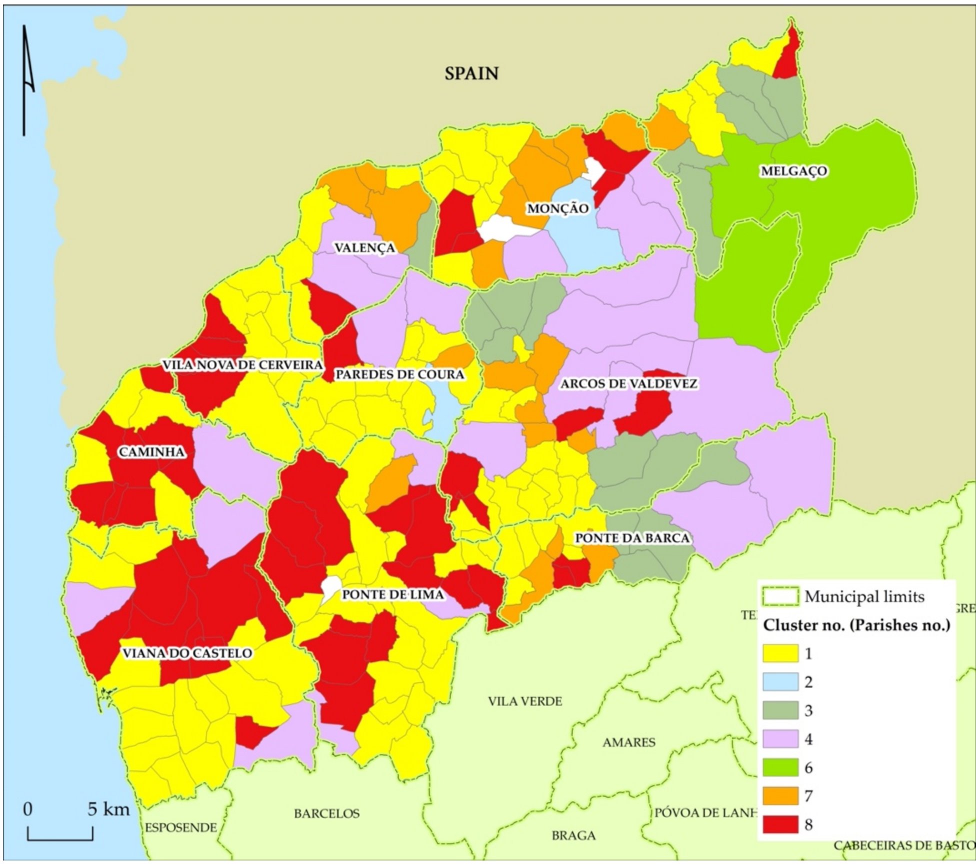


Figure 7. Classification of Alto Minho parishes by fire-livestock relationship cluster (Table 5). Clusters 3 and 6 correspond to substantial pastoral burning. Parishes in white denote either outliers or no fire activity.

5.4 DISCUSSION

The historical reconstruction by manually delineating perimeters and overlapping different fire-related data sources allowed classifying and quantifying the annually burnt areas in Alto Minho between 2001 and 2020 and identify their seasonality. Besides wildfires (WFAWS and WFSUM), actively suppressed by definition, we were able to identify and map autumn to spring fires (FAWS) that were not the subject of firefighting actions. The official Portuguese fire atlas allows a general analysis of pyrogeography, but omissions and variable detail in delineating and classifying each burn patch decreases the rigour and accuracy of fire regime characterization in relation to metrics of frequency, extent, seasonality and size distribution, especially where out-of-summer fires are a relevant feature and at more local scales. This was particularly well illustrated in this study by the case of Castro Laboreiro and Lamas de Mouro, with a fire regime distinct from most of the rest of Alto Minho but that it is not portrayed by the official fire atlas.

Annual mean burned area in Alto Minho during 2001-2020 doubled what a previous study had quantified [2] for the 1975-2005 period, probably indicating a change in the fire regime but also reflecting our increased detection and mapping of autumn to spring fire activity. Note that 20% of all burned area quantified in this study putatively corresponds to pastoral burning and that the fire return interval of 13 years estimated for the region is substantially lower than in previous studies, respectively 22 years [2] and 17 years 23]. FAWS thus dominates the fire regime in certain Alto Minho landscapes, expressing the persistence of traditional fire use practices for rangeland management, particularly where extensive livestock exists in higher quantity.

Contrary to what could be expected, we found that pastoral burning generically conforms to a longer cycle than summer wildfire, with respective return intervals of 13 and 11 years. However, the frequency of the former is higher in landscapes where pastoral burning is prevalent and summer wildfire is scarce, namely every 11 years in the Castro Laboreiro and Lamas de Mouro parish. Still, and considering the needs of rangeland renewal, this reflects a conservative and parsimonious practice, as the increase in nutritional quality of postfire shrub regeneration is short lived [40].

Livestock quantity decreased substantially over much of Alto Minho between 1999 and 2019, continuing long-term trends starting in the 1940s [32,41]. Loss of livestock and the increasingly repressive legal restrictions to the use of fire by local communities might have reduced pastoral burning, mostly of low intensity and low severity [42], potentially contributing to increase the area disturbed by large and severe wildfires, as in the coastal and western parishes of the region. Pyrodiversity, the memory of antecedent fire creating more heterogeneous and finely grained spatial patterns in vegetation, has been shown to limit the development of large fires where pastoral burning is common in Portugal [43].

Fires associated with extensive livestock production, i.e., autumn to spring fires, were expected to be more frequent where animal load is higher, given the need to use fire to renew pastures of interest for animal fodder. The general trends observed in this study were that (i) less livestock equalled more summer wildfire and less autumn to spring fire, but the trend was mostly determined by the upper and lower extremes of livestock quantity, and (ii) that more livestock increased the overall burned area. In fact, fire-livestock relationships were more complex and nuanced than this, as shown by the cluster analysis. While pastoral burning is more prevalent where heathland occupies a higher fraction of the landscape, more heathland in the landscape does not imply more livestock and more pastoral burning. Likewise, high burn probability by summer wildfire is restricted to low to intermediate livestock levels but can coincide with high pastoral burning levels.

The common perception of pastoral burning as the main cause for the increase in severe summer fires is unfounded. Pastoral fires occur in winter or precede the rainy season in early autumn, when fire spreads more effectively in shrublands dominated by species poor in elevated dead fuel, namely *Cytisus* sp. (pers. observ.). Maintenance of FAWS is conditional on maintaining extensive livestock production and both have a considerable role in conserving the landscape, shaping the heathland mosaic and the distribution of species and habitats of pastoral or conservation interest, such as the Iberian wolf [44–47].

Despite the high loss of population between 2001 and 2021, traditional fire practices persist in Castro Laboreiro and Lamas de Mouro, indicating that the maintenance of agro-silvo-pastoral practices and in particular extensive livestock production, associated with traditional fire use, continues to be relevant in the conservation of the mosaic landscape. Institutional prescribed burning could replace pastoral burning, but its extent is irrelevant and is far from responding to the local communities needs. Limitations to the use of prescribed burning in the parish may be related in part to the constraints resulting from the area belonging to the National Park of Peneda-Gerês. However, prohibiting the use of fire for pastures renewal by the community does not prevent it from being used illegally, as examples from other regions of the world show, e.g. [48]. The communities of Castro Laboreiro and Lamas de Mouro were forced to adapt their use of fire, having abandoned the practice of "shepherding" (as they say locally) and monitoring the fire. Instead, they chose days with weather and fuel moisture conditions conducive to fire self-extinction. But pastoral fires can become significant wildfires under more fire-prone weather and the clandestine conditions under which they are carried out by the force of law and bureaucracy. Nonetheless, as remarked in relation to pastoral fires in the Pyrenees [31], this does not imply that such escapes are environmentally detrimental, as long as the fire burns only the "right" type of vegetation.

5.5 CONCLUSION

The detailed reconstruction of burned areas and the classification of the various types of fires are fundamental to develop a robust database allowing accurate fire regime characterization at scales meaningful for fire and land management. It is also essential to review the process of assigning the causes of wildfires, especially those related to the use of fire to renew pastures. E.g., season should be considered, because summer does not coincide with the period traditionally selected for pastoral burning. Legal instruments should be guaranteed that enable traditional communities to burn responsibly in autumn to spring, without the constraints they are currently subjected to and that lead to the use of "proscribed fire" that sometimes escapes and demands suppression action. In a time where fire management is increasingly challenged by global change, traditional fire users should be actively engaged and their knowledge taken advantage of rather than being marginalized by land management and emergency response agencies [49], namely in southern Europe mountains where traditional fire practices are deemed sophisticated [50].

Finally, it is important to acknowledge that eradicating fire from landscapes is not only impossible, but it is also not desirable. Policies that advocate for total fire exclusion are actually selecting for the largest and most damaging wildfires, instead of managing low-intensity fires that fulfil land management goals and are part of sustainable ecosystems. Furthermore, the current minimum expression of institutional (prescribed) fire is not suitable for the needs of local communities. Given these compounded factors, it is the responsibility of decision-makers with technical expertise or political functions to carefully consider which type of fire should be maintained to conserve rural landscapes, reduce territorial vulnerability to climate change, and minimize the associated risks.

CAPÍTULO VI - UNRAVELING THE EFFECT OF FIRE SEASONALITY ON FIRE-PREFERRED FUEL TYPES AND DYNAMICS IN ALTO MINHO, PORTUGAL (2000–2018)

Abstract. Socio-demographic changes in recent decades and fire policies centered on fire suppression have substantially diminished the ability to maintain low fuel loads at the landscape scale in marginal lands. Currently, shepherds face many barriers to the use of fire for restoring pastures in shrub-encroached communities. The restrictions imposed are based on the lack of knowledge of their impacts on the landscape. We aim to contribute to this clarification. Therefore, we used a dataset of burned areas in the Alto Minho region for seasonal and unseasonal (pastoral) fires. We conducted statistical and spatial analyses to characterize the fire regime (2001–2018), the distribution of fuel types and their dynamics, and the effects of fire on such changes. Unseasonal fires are smaller and spread in different spatial contexts. Fuel types characteristic of maritime pine and eucalypts are selected by seasonal fires and avoided by unseasonal fires which, in turn, showed high preference for heterogeneous mosaics of herbaceous and shrub vegetation. The area covered by fuel types of broadleaved and eucalypt forest stands increased between 2000 and 2018 at the expense of the fuel type corresponding to maritime pine stands. Results emphasize the role of seasonal fires and fire recurrence in these changes, and the weak effect of unseasonal fires. An increase in the maritime pine fuel type was observed only in areas burned by unseasonal fires, after excluding the areas overlapping with seasonal fires.

Keywords: wildfires; fuel types; landscape; traditional use of fire; seasonality; fire regime; fire recurrence

Resumen. *Desvelando el efecto de la estacionalidad de los fuegos sobre los tipos de combustible más afectados y la dinámica de los fuegos en Alto Minho, Portugal (2000-2018)*

Los cambios sociodemográficos de las últimas décadas y las políticas contra incendios centradas en su supresión han disminuido sustancialmente la capacidad de mantener bajas cargas de combustible a escala de paisaje en las tierras marginales. En la actualidad, los pastores se enfrentan a numerosas barreras a la hora de utilizar el fuego para restaurar los pastos en comunidades afectadas por el matorral. Las restricciones impuestas se basan en el desconocimiento de sus impactos en el paisaje. Nuestro objetivo es contribuir a este esclarecimiento. Para ello, utilizamos un conjunto de datos de superficies quemadas en la región del Alto Minho por incendios estacionales y no estacionales (pastoreo). Realizamos análisis

estadísticos y espaciales para caracterizar el régimen de incendios (2001-2018), la distribución de los tipos de combustible y su dinámica, y los efectos del fuego en dichos cambios. Los incendios no estacionales son más pequeños y se propagan en diferentes contextos espaciales. Los tipos de combustible característicos del pino marítimo y los eucaliptos son seleccionados por los incendios estacionales y evitados por los incendios no estacionales que, a su vez, mostraron una alta preferencia por los mosaicos heterogéneos de vegetación herbácea y arbustiva. La superficie cubierta por los tipos de combustible de las masas forestales de frondosas y eucaliptos aumentó entre 2000 y 2018 a costa del tipo de combustible correspondiente a las masas de pino marítimo. Los resultados destacan el papel de los incendios estacionales y la recurrencia de incendios en estos cambios, y el escaso efecto de los incendios no estacionales. Solo se observó un aumento del tipo de combustible de pino marítimo en las zonas quemadas por incendios no estacionales, tras excluir las zonas coincidentes con incendios estacionales.

Palabras clave: incendios forestales; tipos de combustible; paisaje; uso tradicional del fuego; estacionalidad; régimen de incendios; recurrencia de incendios

Resumo. *Desvelando o efecto da estacionalidade dos lumes sobre os tipos de combustible máis afectados e a dinámica dos lumes no Alto Minho, Portugal (2000-2018)*

Os cambios sociodemográficos das últimas décadas e as políticas contra incendios centradas na súa supresión diminuíron substancialmente a capacidade de manter baixas cargas de combustible a escala de paisaxe nas terras marxinais. Na actualidade, os pastores enfróntanse a numerosas barreiras á hora de utilizar o lume para restaurar os pastos en comunidades afectadas pola matogueira. As restricións impostas baséanse no descoñecemento dos seus impactos na paisaxe. O noso obxectivo é contribuír a este esclarecemento. Para iso, utilizamos un conxunto de datos de superficies queimadas na rexión do Alto Minho por incendios estacionais e non estacionais (pastoreo). Realizamos análises estatísticas e espaciais para caracterizar o réxime de incendios (2001-2018), a distribución dos tipos de combustible e a súa dinámica, e os efectos do lume nos devanditos cambios. Os incendios non estacionais son máis pequenos e propáganse en diferentes contextos espaciais. Os tipos de combustible característicos do piñeiro marítimo e os eucaliptos son seleccionados polos incendios estacionais e evitados polos incendios non estacionais que, á súa vez, mostraron unha alta preferencia polos mosaicos heteroxéneos de vexetación herbácea e arbustiva. A superficie cuberta polos tipos de combustible das masas forestais de frondosas e eucaliptos aumentou entre 2000 e 2018 á conta do tipo de combustible correspondente ás masas de piñeiro marítimo. Os resultados destacan o papel dos incendios estacionais e a recorrencia de incendios nestes cambios, e o escaso efecto dos incendios non estacionais. Só observouse un aumento do tipo de combustible de piñeiro marítimo nas zonas queimadas por incendios non estacionais, tras excluír as zonas coincidentes con incendios estacionais.

Palabras chave: incendios forestais; tipos de combustible; paisaxe; uso tradicional do lume; estacionalidade; réxime de incendios; recorrencia de incendios

6.1 INTRODUCTION

Fire is an ecological process that has not only co-evolved with and shaped the structure and composition of a wide range of ecosystems since the advent of land plants, but also played a critical role in regulating vegetation feedbacks in atmospheric oxygen [1–4]. Although doubts remain about the moment from which humans started to control and regularly use fire, there is evidence that in Europe fire began to be used as a technological tool between 300,000 to 400,000 years ago [5,6]. However, Daniau et al. [7] did not find evidence of extensive use of fire for managing ecosystems in western Europe until 10,000 years ago. According to Connor et al. [8], changes in fire regime in the Iberian Peninsula started 7,500 years ago, but the most pronounced fire-induced landscape changes only become evident from 5500-5000 cal. years BP onwards, and have become more intense and persistent in the last two millennia. In the Iberian regions, fire as a landscape management tool, was used by humans to expand pasture areas and soils for cereal production [9–12], showing additional effects of increasing soil fertility by recycling nutrients (ash-fertilization) and promoting healthy crops by controlling soil pathogens [13].

Currently, in the Mediterranean region, about 95% of rural fires are of human origin (negligence, accidents, or arson) [14]. In the cultural landscapes of the Iberian Peninsula, natural fires represent a small fraction of the total number of fires larger than 0.01 ha [15]: 4.1% in Spain and 1.1% in Portugal. Among the registered anthropogenic fire causes, 34.05% of the ignitions in Portugal [16,17] and 35.96% in Spain [18] are closely related to land management activities (accounting for 16.27% and 36.17% of the total registered burned area, respectively), such as slash-pile and agricultural stubble burnings, and pastoral fires to improve or restore grasslands. These rural fire-use practices emerged from ancestral practical knowledge of landscape management [19] and are the result of cumulative and dynamic processes of learning by practice, generational knowledge transfer and adaptation to changes over a long period [20]. Such cultural practices determine fire regimes at the local level and have contributed, since ancient times, to landscape heterogeneity, and to ecosystems and biodiversity conservation [21–23]. Fire, for the traditional pastoral communities of the Iberian Peninsula, continues to be a critical tool for woody vegetation management and to promote and restore an herbaceous layer rich in palatable species to livestock [24–27], as in other regions across the Mediterranean basin [28–30].

However, European landscapes have been changing significantly in recent decades [31–33]. In southern Europe, except for some regions where land use intensification was possible or encouraged (e.g., [34]), the most frequent processes of land use change are related to agricultural abandonment, decrease in livestock production and in forestry intensity [35–39]. De-intensification processes have often been identified as the factors driving changes in the fire regimes in the Iberian Peninsula as they result in wildland fuels accumulation and connectivity at the local (vertical) and landscape (horizontal) scales [40–43]. Contributing to this fuel accumulation, the effect of fire exclusion policies is not insignificant, which is translated in the scientific literature into a series of paradoxes [44–46]: 'wildfire paradox', 'firefighting trap', and 'safe development paradox'. In general, the system is a victim of its own success. By managing to reduce the progression of ignitions that occur within meteorological thresholds favorable to fire suppression and, in the absence of other landscape management mechanisms that allow reducing the fuel load, it reduces pyrodiversity and increases the spatial connectivity of fuels, creating conditions conducive for increasingly larger [47] and extreme fires, such the ones observed in Southern Europe in last 6 years [48–52].

Silvo-pastoral communities that traditionally use fire have been particularly affected by these fire suppression policies [53]. The disruption of these cultural burnings, resulting from the successive constraints or prohibitions inscribed in the legislation that converted the traditional use of fire into "proscribed fires" or "proscribed burnings", has multiple effects that contribute to the occurrence of more complex fires: a) it allows the encroachment of more flammable fuels [54]; b) the marginalization of these cultural practices enhances the increase of illegal burnings that are not properly monitored [55]; and c) although fire is considered as "(…) *an element of our farming culture*", as stated by Coutinho ([56], p. 35), the knowledge that guided its correct use is progressively lost [57].

The landscape-fire interactions are very complex and in face of extreme fire weather conditions, fire spread is not very sensitive to the types of land cover [58–60] and, therefore, the role that these traditional fires play in maintaining a pyrodiverse mosaic in the landscape cannot be overlooked. Moreover, the operationalization of the paradigm shift identified by Moreira et al. [61], in the sense of measuring the effectiveness of fire management policies in terms of damage and losses in socio-ecological systems instead of the annual variation in the burned area, implies distinguishing the regimes and effects of different types of fires. Considering that the resilience of individuals, populations and communities is determined by the fire regime [62], and not by the simple presence of the disturbance factor, the above-mentioned changes in fire regimes can catalyze dynamics in landscape structure and composition [63,64].

The need to apply "let it burn" approaches and adaptive prescribed burns is growing and urgent considering not only the most expected climate change scenarios [65], but also the current and future landscape trajectories strongly driven by rural abandonment [66] and respective effects in reducing the fire regulation capacity [43]. However, little is known about the fire regime associated with the unseasonal fires, and what effects they have on landscape and fuel dynamics. Fire seasonality is a critical component of the fire regime that, in cultural landscapes, reflects the combined effects of human activity, the use of fire for landscape management and local biophysical conditions, and whose understanding allows defining effective strategies to reduce the prevalence of extreme fires during the fire season [67–69].

In this way, this paper intends to contribute to the consolidation of scientific knowledge about the fire regime in an area of northwest mainland Portugal, Alto Minho, where the traditional use of fire still has a strong presence, the fuel types affected by seasonal and unseasonal fires, and their role in fuel types' changes. To accomplish the overall objective, we compared the burned areas between 2001 and 2018 by seasonal (summer fires) and unseasonal fires to assess variability in: a) fire metrics and regime *sensu stricto* (following Krebs et al. [70]definition); b) the types of fuels affected through the Jacobs' Index [71]; and c) the dynamics between fuel types in the period considered using transition matrices and applying logistic regression.

6.2 MATERIALS AND METHODS

6.2.1 Study area

The study area is located in the extreme northwest of mainland Portugal, comprising the entire sub-region of Alto Minho (NUTS III level) and covering 10 municipalities (221,884 hectares; Figure 1).

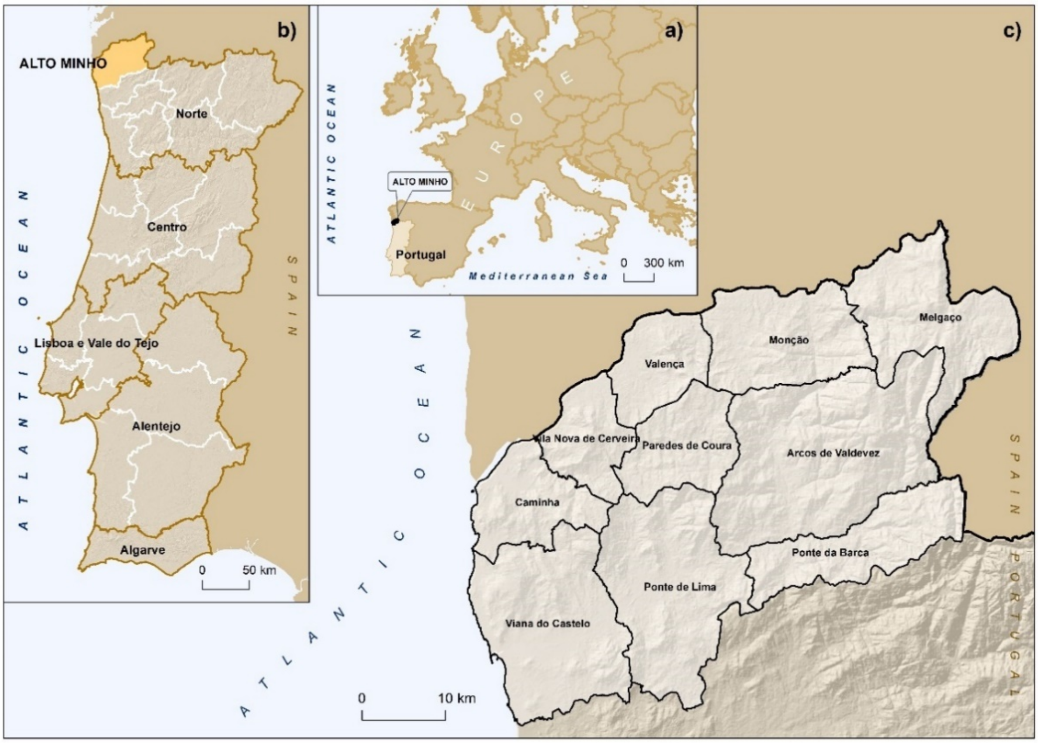


Figure 1. Geographical context of the study area, Alto Minho: a) Location of the study region in western Europe; b) Administrative regions of mainland Portugal (NUTS II); c) Distribution of the limits of the municipalities in the study region. Source: Official Administrative Map of Portugal, Direção-Geral do Território - DGT 2020.

The study region is predominantly mountainous, and the average altitudes exceed 400 m, attaining elevations higher than 1000 m, except in the coastal area and the floodplain of the main valleys of the Minho and Lima rivers [72]. According to the Intermunicipal Plan for Adaptation to Climate Change [73], the annual mean temperatures vary between 14ºC and 16ºC in most of the region but can be substantially lower at higher elevations (≤ 9.5ºC). The mean annual rainfall is above 1100 mm, but the distribution of precipitation shows high variability between the coastal strip and the most continental and mountainous areas of the study region, reaching in the latter values between 2400 and 2800 mm [73]. The dominant soils are Regosols (51.6%), followed by Anthrosols (24.1%) and Leptosols associated with rocky outcrops (13.8%) [74]. Regosols and Leptosols are poorly developed soils and are common in mountain areas and Anthrosols are highly modified soils through long-term human land use [75].

The cultural landscapes of Alto Minho, as other rural areas of the Iberian Peninsula, were the result of a long process of deforestation that began in the Neolithic for establishing agricultural areas for cereal production and pastures for livestock [76,77]. Agricultural expansion reached its peak at the beginning of the 20th century (according to the 1910 agricultural and forestry map, arable crops covered 33.2% of the study region), resulting from the cereal protectionist policies ('Hunger Law' between 1889 and 1914 and 'Wheat Campaign' between 1928 and 1938) that started in the second half of the 19th century [78,79]. In the middle of the 20th century, afforestation of common lands with maritime pine (*Pinus pinaster*) was intensified (the common lands currently cover 37.8% of the study region), as a response of public policies to soil degradation in marginal areas [80]. Afforestation of common lands, that were critical to mountain agriculture and livestock production in the multifunctional landscapes of Alto Minho, was imposed by the state forest service [81] and implied grazing and fire exclusion [82]. Currently, shrubland and forest stands dominate the Alto Minho landscapes, covering ~72% of the study region, followed by agriculture, ~18% [83].

The biophysical characteristics of the Alto Minho region and public policies with an impact on rural landscapes management determined not only the spatial pattern of land cover types but also the land systems and respective temporal dynamics, in close connection with the fire regime. Fire was the preferred instrument in the land systems that shaped these landscapes over time, having been used for multiple functions within an ancestral agro-silvo-pastoral system that defines the territories of northwest Iberia [84].

6.2.2 Burned area maps

We used the dataset of burned areas in Alto Minho between 2001 and 2018 produced by Oliveira and Fernandes [85]. The burned areas were obtained from images captured by the *Landsat 5* (TM), *Landsat 7* (ETM+), *Landsat 8* (*Operational Land Imager* - OLI) and Sentinel-2 (*Multispectral Instrument – MSI*) satellites. These images (about 400) were extracted and pre-processed from the Semi-Automatic Classification Plugin (SCP) application developed by Congedo [86] for the QGIS software [87]. Oliveira and Fernandes [85] selected images without clouds or with a minimum cloud cover, to cover the maximum number of months of each year, allowing the identification of seasonal patterns in the burned areas in Alto Minho. The authors produced false-color RGB compositions and the Normalized Burn Ratio [88] and edited the burned areas manually and supervised, with the support of auxiliary data, such as high-resolution orthophotos, to avoid errors resulting from the other types of land cover changes that could compromise the final results [89,90]. The resulting burned areas, with a minimum map unit of 0.04 ha for burned areas mapped through Sentinel-2 images and of 0.4 ha for burned areas mapped through Landsat images, were classified according to the period in which they occurred, whether in the "fire season", i.e. during the summer months, or "non-fire season", for fires that spread during the period between autumn and spring. To establish this classification, Oliveira and Fernandes [85] used the national rural fire database (from the Portuguese Institute for Nature Conservation and Forests), which brings together a set of relevant data such as the date the fire started and pairs of coordinates with its location, and also the hotspots from the MODIS and VIIRS sensors, available since November 2000 and since January 2012, respectively, and obtained through the NASA's Fire Information for Resource Management System (FIRMS) web archive (https://firms.modaps.eosdis.nasa.gov/).

6.2.3 Spatial distribution of fuel models

We used the fuel types based on the fuel models of Fernandes et al. [91], built by combining published and field inventories data and also from the National Forest Inventory [92] that describes the composition and vertical structure of vegetation. The fuel types are divided into three groups based on the structure and relative importance of the different components of the fuel complexes in fire behavior (Table 1, where only the fuel types identified in the study region are listed): i) litter (F), referring to forest stands in which fire behavior is dominated by the litter layer; ii) litter and understory vegetation (M), referring to forest stands in which fire behavior results from the combined effect of litter and understory layers; iii) and other vegetation (V), which involves plant communities, with or without a tree canopy, in which fire behavior is determined by the shrub or herbaceous layers.

Table 1. Fuel types identified in the study region according with the classification of Fernandes et al. [91], respective distribution in 2000 and 2018 (%), and percentage change (%C)

Fuel types	Short description of the fuel types	% area in 2000	% area in 2018	%C
F-RAC	Short-needle conifers (*Pseudotsuga, Cedrus, Cupressus, Pinus sylvestris, P. nigra*) (litter)	0.75	0.62	-17.84
F-PIN	Medium-long needle pines (*P. pinaster, P. pinea, P. halepensis, P. radiata*) (litter)	0.01	0.01	12.34
F-FOL	Broadleaved forest stands (litter)	6.64	8.05	21.21
M-PIN	Medium-long needle pines (litter + understory vegetation)	19.36	15.33	-20.85
M-EUC	Eucalyptus stands (litter + understory vegetation)	7.71	12.01	55.60
M-CAD	Broadleaved forest stands, including marcescent and deciduous oaks and *Castanea sativa* (litter + understory vegetation)	6.14	6.38	3.87
M-ESC	Sclerophyllous hardwood stands (cork oak, holm oak, strawberry tree) (litter + understory vegetation)	≤ 0.01	≤ 0.01	-50.05
V-MAa	Tall shrublands (> 1 m) (heather, gorse)	28.36	26.38	-7.05
V-MMb	Short shrublands (< 1 m) (cistus, broom)	2.29	2.08	-9.49
V-Hb	Short herbs, including agricultural areas	17.63	16.70	-5.35
V-Ha	Tall herbs	0.36	≤ 0.01	-98.61
V-MH	Mosaics of young shrublands and herbs	2.38	2.38	-0.10

Areas without vegetation covered 10.07% and 19.99% of the area of the study region in 2000 and 2018, respectively.

The combination of structural and vegetation type criteria that defines the fuel types of Fernandes et al. [91] allows its easy recognition in the field as well as its association with land cover classes. Therefore, the construction of the fuel types maps referring to the years 2000 and 2018 was based on the official Land Cover Maps produced by the Portuguese General Directorate of the Territory at 1:25,000 scale. This map series has thematic, spatial and temporal consistency allowing comparative analyzes between different periods [93,94], including Land Cover Maps for the years 1995, 2007, 2010, 2015 and 2018. The classification system, comprising 83 thematic classes, allows establishing the relationships between these and the fuel types based on their generic description included in Table 1. This relationship was established directly for the 2018 land cover map (FC2018), but for the starting point of our fire data series we do not have the same temporal congruency. To build the fuel map in 2000 (FC2000), we established the relationships between land cover classes and fuel types for the years 1995 and

2007 (FC1995 and FC2007, respectively) following the same procedure used to define the FC2018. We then carried out a bi-temporal analysis combining FC1995 and FC2007 to extract patches that showed changes in fuel types over that period to reclassify in accordance with the procedure set out below. We used the land cover data from CORINE Land Cover 2000 (CLC2000) [95,96], at 1:100,000 scale and 44 thematic classes, as auxiliary data to identify divergences and convergences in the land cover classes between 1995 and 2000. The lower thematic and geometric resolution of the CLC2000 does not allow its direct use for comparison with the layers mentioned in the previous paragraphs, but it proved to be useful in adjusting the land cover classes to the year 2000 of the patches that showed changes between 1995 and 2007. We assumed that divergences between the FC1995 and CLC2000 patch classes were indicative of changes occurring between 1995 and 2000, implying the attribution of the 2007 fuel type to these ones, and that their convergence was indicative that changes would have occurred between 2000 and 2007, keeping the 1995 fuel type in these cases.

6.2.4 Data analysis

All statistical analyzes were performed using R software [97]. We analyzed the annual distribution of fire patches and burned area. In addition to annual global values, we also evaluated their distribution in the fire season and non-fire season. We extracted the main descriptive statistics (e.g., mean, coefficient of variation) and tested the time series for temporal trends through the R package *funtimes* [98]. We inspected the existence of linear and monotonic trends by enhanced versions of the *t*-test [99] and Mann-Kendall test [100] through sieve bootstrap approaches for time series [101,102]. The Mann-Kendall tau and *t*-values were extracted, and respective significance, and also the coefficient p of the autoregressive model ($AR_{(p)}$) obtained through the robust difference-based estimator proposed by Hall and van Keleigom [103].

Violin plots [104] built through the R software package *ggplot2* [105] were used to compare the distribution of fire sizes of individual fires occurred during and outside the fire season, and differences between the distributions were tested through the Mann-Whitney U test [106]. Raincloud plots [107] were also produced to analyze the distribution of burned area and number of fire patches by fire size classes considering all events, and also those that occur during and outside the fire season. To build the raincloud plots, the following R software packages were used: *ggplot2* [105], *tidyverse* [108], *tidyquant* [109], *ggdist* [110] and *ggthemes* [111]. We fitted the Weibull distribution [112] using the mean intervals between successive fires from the recurrence maps (censored plus complete intervals), to assess fuel-age dependency [113,114], using the R software package *fitdistrplus* [115]. We fitted the parameters b, representing the fire intervals that will not be exceeded 63.2% of the time, and c, which describes the change in burn probability through time.

Fire preference or avoidance was assessed through the Jacobs Index [71], considering all burned areas, and also the affected areas by seasonal and unseasonal fires (total and excluding the overlapped areas between the burned areas during and outside the fire season). The spatial overlay of the fuel type maps (FC2000 and FC2018), and of these with the burned areas layers (2001-2018) allowed the identification of the incidence of the fire season and non-seasonal fires in the different fuel complexes and to quantify the contribution of these fires to the fuel types changes observed in the Alto Minho landscapes. Sankey diagrams were suggested by Cuba [116] to compare categorical maps and to identify and represent the main flows between land cover classes. We have computed the Sankey diagrams showing changes across the study region, and also for the burned areas by seasonal and non-seasonal fires, through the R software packages *raster* [117], *networkD3* [118] and *dplyr* [119,120]. Additionally, cross-tabulation matrices (provided in the Supplementary Material) were constructed to improve the description of the observed changes. We also carried out a logistic regression [121] to determine the role of different fire (recurrence, fire size, seasonality) and landscape (composition of the patch in 2000, patch area) metrics to assess the effects of fire on fuel types changes. In this analysis we focused on the transitions involving the typical fuel types of forest stands with higher representativity in the study region (F-RAC, F-FOL, M-CAD, M-EUC, M-PIN, see Table 1 for a general description of each one). F-FOL fuel type was established as reference category. The transitions from the mentioned models were all considered and classified as 1 (*n*=7267) and the areas that showed stability as 0 (*n*=7221), the latter being randomly distributed by burned and unburned areas, conditioning the distribution of two points in the same patch. In the group of independent variables, in addition to the tree species already mentioned, we considered patch size of pre-fire fuel types ($FC2000_{PS}$), since smaller fragments may be more prone to change. Regarding fire metrics, we considered fire recurrence ($FIRE_{rec}$), fire seasonality ($FIRE_{fs}$ for fire-season fires and $FIRE_{nfs}$ for non-seasonal fires), and the size of the largest fire that affected each burned patch ($FIRE_{fslf}$). We used the R software package *rcompanion* [122] to compute the Efron, McFadden, Cox and Snell and Nagelkerke/Cragg and Ubler pseudo-R^2 measures [123–125] to assess the performance of the model.

6.3 RESULTS

6.3.1 Fire regime in Alto Minho

The dataset of burned areas developed by Oliveira and Fernandes [85] contains 10,784 perimeters in the period between 2001 and 2018, representing a cumulative area of 211,942.44 ha.

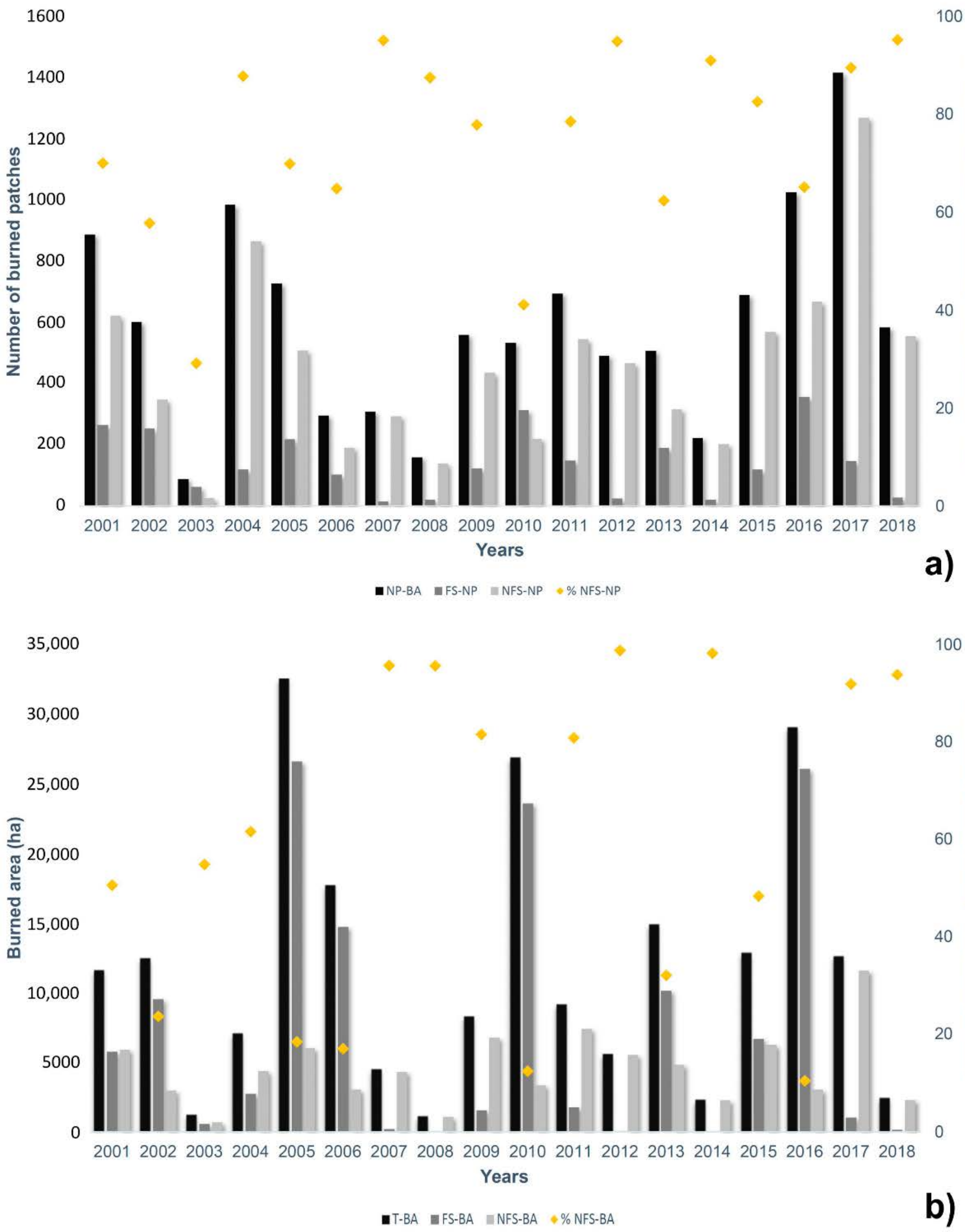


Figure 2. Annual distribution of the fire patches a) and the burned area b). The yellow dots represent the percentage of the fire patches and the burned area by non-seasonal fires. NP-BA: total number of fire patches; FS-NP: number of patches of seasonal fires; NFS-NP: number of patches of non-seasonal fires; T-BA: burned area by all fires; FS-BA: burned area by seasonal fires; NFS-BA: burned area by non-seasonal fires

However, only 23.5% of the identified polygons belong to fires that started in the fire season, but which represent 61.8% of the burned area. The mean annual burned area is 11,774.58 ha, and the mean annual number of fire patches is 599. The annual variability in both indicators (Figure 2) is high, with coefficients of variation of 54.39% and 78.64%, for the number of fire patches and burned area, respectively. The number of seasonal fire patches exceeded those of non-seasonal fires only in the exceptional years of 2003 and 2010 (Figure 2a). The area burned by non-seasonal fires is higher than the area burned by seasonal fires in 61.1% of the years, but only in those that have an annual area burned below the annual mean value (Figure 2b).

All the trend tests carried out allowed to eliminate the 'no trend' null hypothesis (Table 2). However, the *p*-values of the tests are high and, therefore, the evidence is not robust enough to reject the hypothesis of no trend. The coefficients of the autoregressive model, all with a value of 0, suggesting purely random processes, not capturing any type of trend in the annual distribution of our fire data (Table 2).

Table 2. Statistics obtained through the Mann-Kendall's test and Student's t-test enhanced by Sieve-bootstrap procedures for monotonic and linear trends, respectively.

	Sieve-bootstrap Mann-Kendall's test				Sieve-bootstrap Student's t-test			
	MK tau	p-value	H0: no trend	AR p	t-value	p-value	H0: no trend	AR p
T-NP	0.11	0.51	Rejected	0	1.05	0.32	Rejected	0
T-BA	0.03	1.00	Rejected	0	0.06	0.96	Rejected	0
FS-NP	-0.07	0.75	Rejected	0	-0.49	0.63	Rejected	0
FS-BA	-0.14	0.44	Rejected	0	-0.22	0.83	Rejected	0
NFS-NP	0.23	0.20	Rejected	0	1.41	0.18	Rejected	0
NFS-BA	0.12	0.51	Rejected	0	1.04	0.33	Rejected	0

T-NP: total number of fire patches; FS-NP: number of patches of seasonal fires; NFS-NP: number of patches of non-seasonal fires; T-BA: burned area by all fires; FS-BA: burned area by seasonal fires; NFS-BA: burned area by non-seasonal fires.

Approximately 45.6% of the study region burned at least once between 2001 and 2018. The difference between the accumulated value (211,942.4 ha) and the surface effectively burned (110,735.3 ha) shows the relevance of fire recurrence in certain locations (Figure 3a). Of the total burned area, 39.8% burned once, 29.7% burned twice, and 30.5% burned three or more times between 2001 and 2018. The fires that occurred in the fire season affected 35.7% of the study region, representing 78.3% of the total burned area. Approximately 16.0% of the area affected by fire-season fires burned three or more times, 27.7% twice, and 56.3% only once (Figure 3b). Fires spreading outside the fire season affected a smaller area, about 23.22% of the study region representing 50.9% of the total area burned between 2001 and 2018. Recurrence is also lower when compared to fire-season fires, considering that only 14.0% burned three or more times (23.4% burned twice, and 62.6% only once) (Figure 3c). There is still a relevant aspect to point out, since the burned area by seasonal and unseasonal fires intersect in 29.2% (29,555.9 ha) of the total burned area, that may lead with potential confounding effects of their individual impacts.

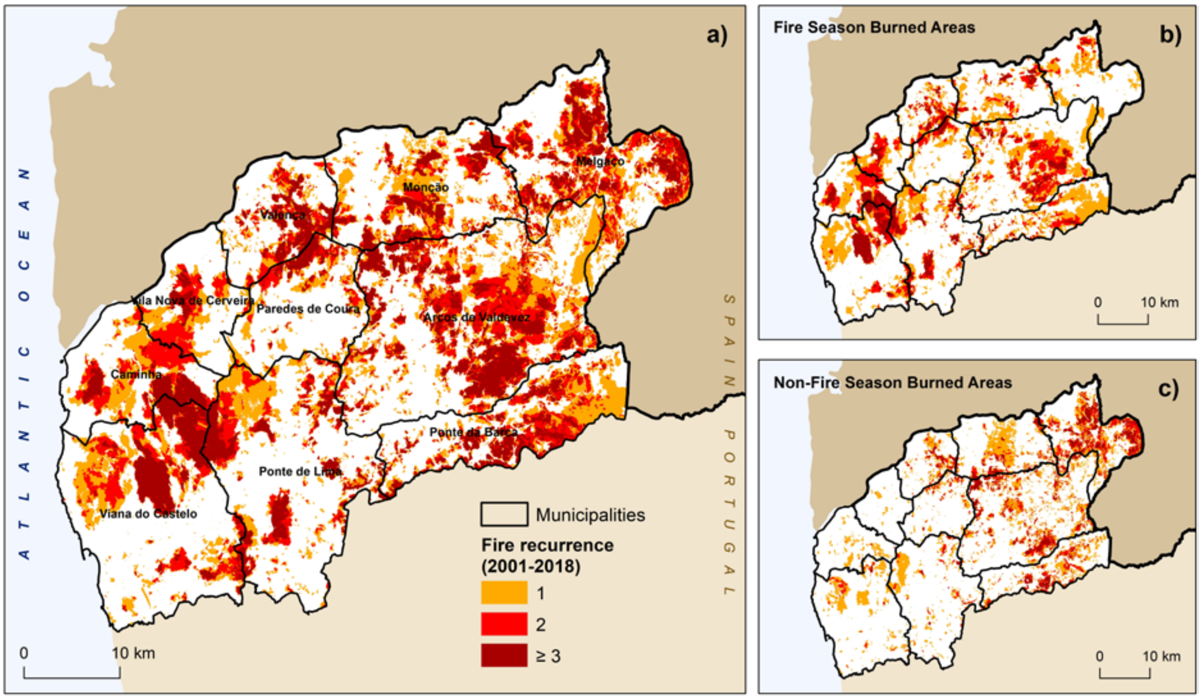


Figure 3. Spatial distribution of fire recurrence between 2001 and 2018 considering all fires **(a)**, and the areas burned during the fire season **(b)** and outside the fire season **(c)**

The Weibull distribution fit allowed estimating the parameters *b* and *c*, which correspond to the scale and shape of the distribution, respectively. For the complete dataset of fires, the estimated value of the parameter *b* was 12.9 (σ_μ=0.02), for unseasonal fires was 15.4 (σ_μ=0.55) and for fire season fires is 15.0 (σ_μ=0.55). The dimensionless parameter *c*, which defines the shape of the distribution, is always higher than 1 and, therefore, indicating that fire hazard increases over time and is fuel-age dependent: 2.20 for all fires (σ_μ=0.01), 2.90 for non-seasonal fires (σ_μ=0.26), and 2.83 for the fire-season events (σ_μ=0.24).

The distribution of individual fire sizes during and outside the fire-season (Figure 4) shows relevant differences, in particular the lowest fire size of non-seasonal fires and the higher flattening of the base of its violin plot which highlights a lower probability of large fires, and the lower fire size of the outliers (larger fires). The Mann-Whitney U Test performed indicates that the distributions are statistically different (U = 9101548, *p*-value < $2.2e^{-16}$).

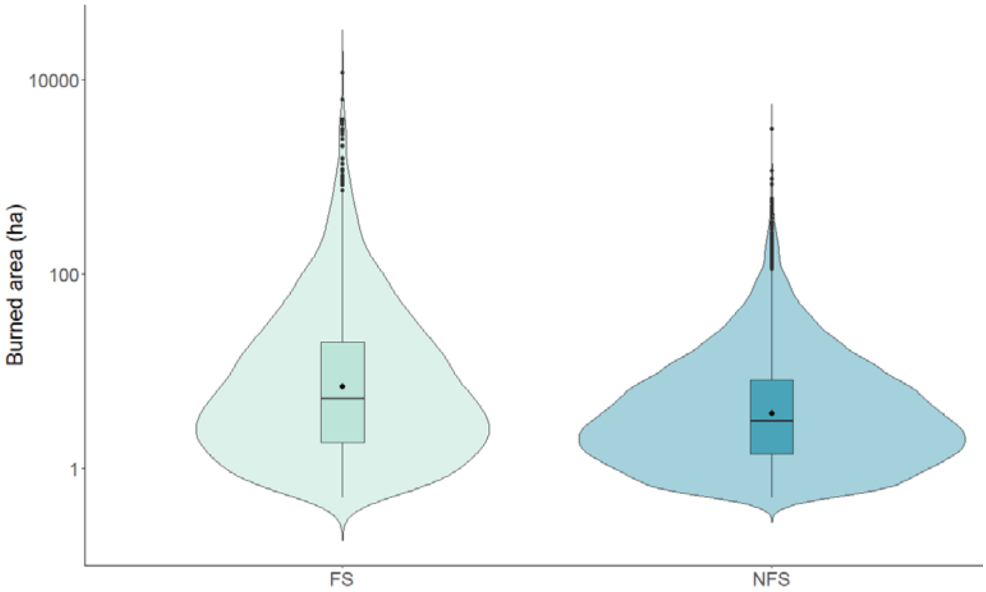


Figure 4. Violin plots with the distribution of fire size by individual fires between 2001 and 2018 during the fire season (FS) and outside the fire season (NFS) (burned area by individual fires is represented in log scale on the y-axis)

According with the distribution of fire patches and area burned by fire size class (Figure 5a) the fire patches smaller than 10 ha represent ~75% of the total fire patches, but their contribution to the burned area is less than ~15%. Larger fire patches (> 100 ha) represent less than 5% of the total, but their contribution to burned area shows high variability, and may exceed 75%. However, the same analysis conducted on the seasonally disaggregated data shows differences between the two distributions, mainly in the fire patches higher than 10 ha and in their contribution to the burned area. While the number of fire patches decreases with increasing fire size in both distributions, their contribution to the burned area is completely different: during the fire-season increases with fire size (Figure 5b) and outside the fire-season decreases with fire size (Figure 5c).

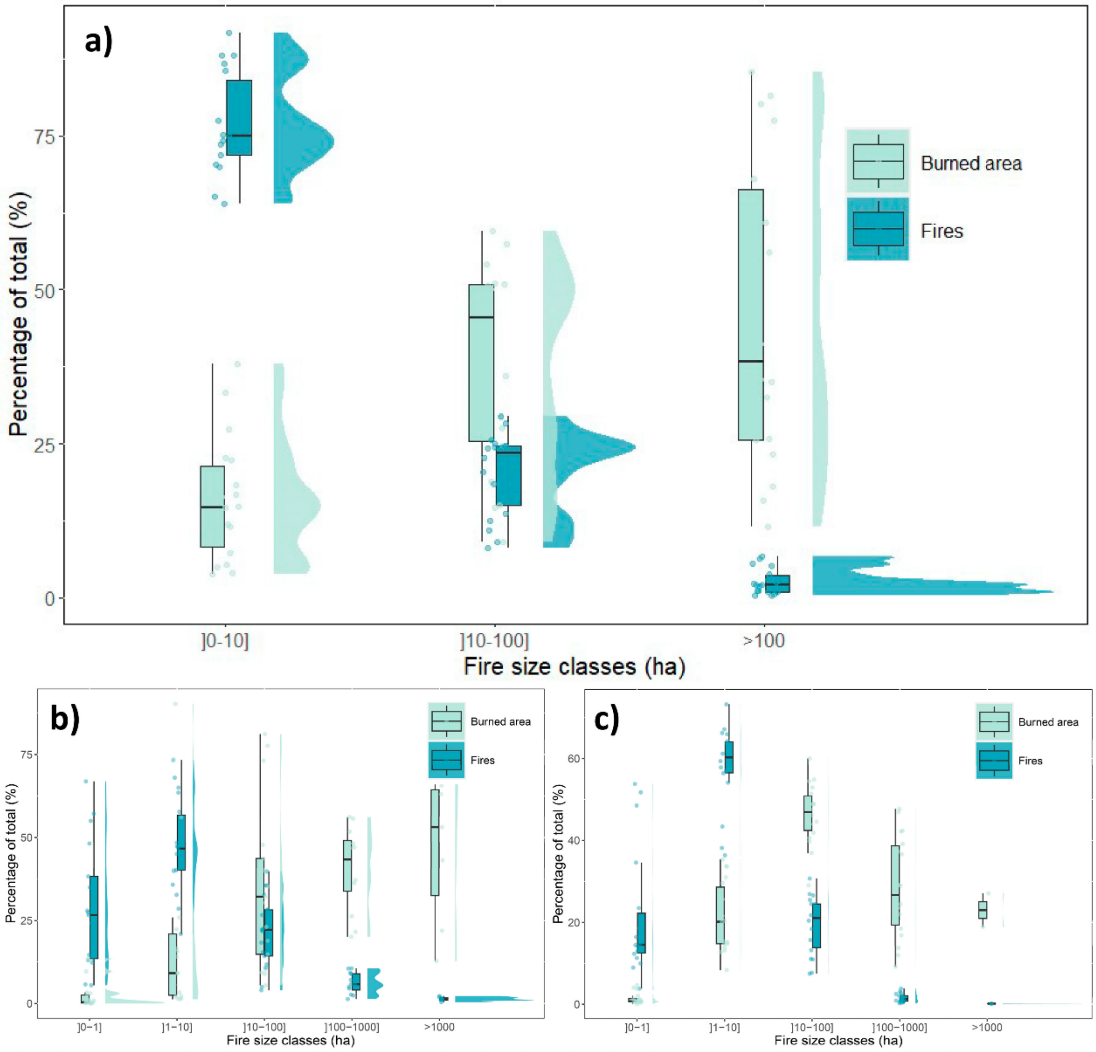


Figure 5. Raincloud plots showing the distribution of fire patches and burned area by fire size classes considering the total number of events **(a)**, the fire-season fires **(b)** and the non-seasonal fires **(c)**

6.3.2 Changes in fuel models between 2000 and 2018

The fuel type maps (Figure 6a,b) allowed comparing their dynamics between 2000 and 2018 in the Alto Minho region (Table 1). In 2000, the 3 dominant fuel types covered 65.4% of the study region: tall shrublands (V-MAa; 28.4%), fuel complexes including litter and woody understory in forest stands of medium-long needle pines (M-PIN; 19.4%) and short grasslands or pastures (V-Hb; 17.6%). Between 2000 and 2018 there was a considerable reduction (-20.9%) in the area covered by the M-PIN type, essentially dominated by maritime pine. V-MAa and V-Hb fuel types also lost area, showing smaller percentage decreases than M-PIN, but still -7.1% and -5.4%, respectively. In the opposite direction, we observed considerable increases in 2018 referring to fuel types typical of eucalyptus (M-EUC) and broadleaved (F-FOL) forest stands, with percentage increases of 55.6% and 21.1%, respectively.

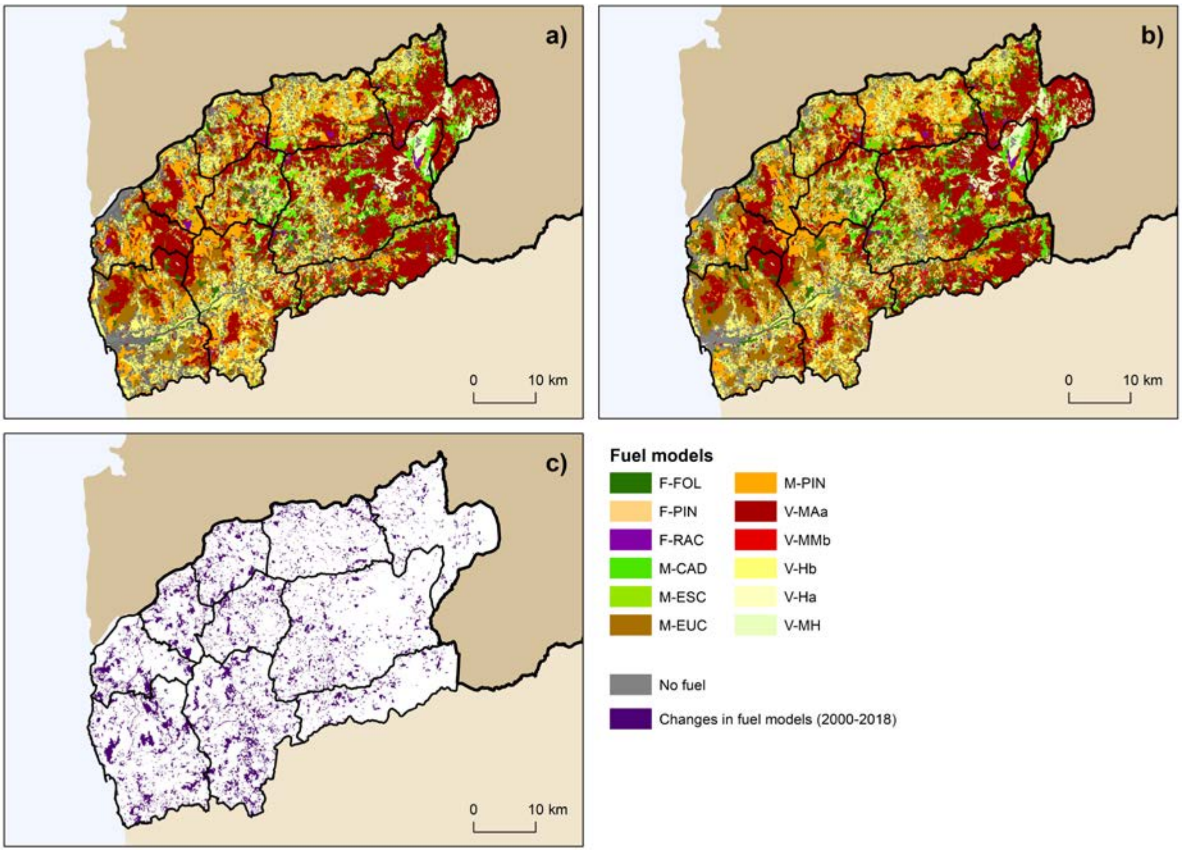


Figure 3. Spatial distribution of fuel types in 2000 **(a)** and in 2018 **(b)**, and changes between 2000 and 2018 **(c)**.

The spatial distribution of changes in fuel types is showed in the Figure 6c. We detected changes in 25,695.02 ha of the study region (11.58% of the total area) between 2000 and 2018. The Sankey diagram of Figure 7 shows the main flows between fuel types, in which the thickness of the lines is shown proportionally to the flow quantity.

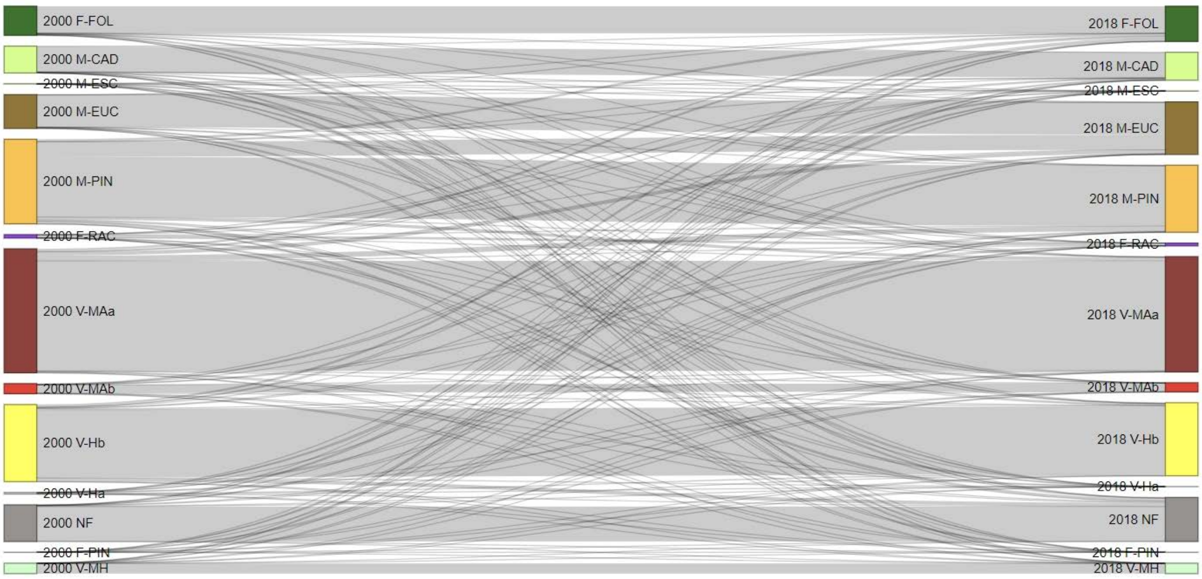


Figure 4. Sankey diagram showing the main flows between 2000 and 2018 in the fuel types in the study region (see Table 1 for a briefly description of the fuel types).

An analysis of the diagram clearly highlights the increase in typical fuels of eucalyptus forest stands (M-EUC) because of the loss of fuel types related to maritime pine stands (M-PIN), flowing 7644.7 ha from M-PIN to M-EUC (see cross-tabulation matrices in Supplementary Material), corresponding to 17.8% of M-PIN area in 2000. The fuel type M-PIN still lost considerable areas that flowed to shrubland fuel types (V-MAa), and to fuels of broadleaved forest stands (F-FOL), giving to these fuel types 1374.6 ha and 1100.0 ha, respectively. Of the most representative fuel types in the study region, V-MAa also presents some dynamics having flowed to M-PIN about 2524.2 ha (4.0%), and 1833.2 to M-EUC (2.9%) and 1039.9 ha to F-FOL (1.7%).

It should also be noted the sharp increase of typical fuel types of broadleaved forests (F-FOL) which, in addition to the area transferred by the aforementioned M-PIN and V-MAa fuel types, also gained area (963.9 ha) from V-Hb (short grassland communities).

6.3.3 Fires and fuels in Alto Minho: identifying ‘winners’ and ‘losers’

Between 2001 and 2018, more than half of the burned area (52.8%) in Alto Minho resulted from fires that spread on tall shrublands and post-fire pine regeneration (V-MAa), followed by maritime pine (M-PIN; 20.0%) and eucalyptus forest stands (M-EUC; 11.7%). The Jacobs index *D* shows that fuel types V-Hb and V-MMb are strongly avoided by fire (*D*=-0.9 and *D*=-0.7, respectively), and fuel types F-FOL and M-CAD are only moderately avoided (*D*=-0.3 and *D*=-0.1, respectively), while fuel types M-EUC and V-MH are moderately preferred by fire (*D*=0.2) and V-MAa is strongly fire-selected (*D*=0.5) (Table 3). Although the M-PIN burned in proportion to its availability in the landscape (*D*-value near 0), its vulnerability to fire is high. About 32.5% of the burned M-PIN changed to another fuel type, representing more than half of all observed changes in fire-affected landscapes (see Table A2 in Supplementary Material). M-PIN present the most significant negative balance in the burned area (-4934.2 ha), having lost area to M-EUC (-4462.7 ha) and to V-MAa (-1285.9 ha). V-MAa is, in turn, another of the most significant losers in fire-affected areas, showing a negative balance of -2646.6 ha. The typical fuel types of eucalypts (M-EUC) and broadleaved (F-FOL) forest stands were the ones that gained the most area in the fire-affected landscapes, with positive balances of 6035.3 ha and 1160.1 ha, respectively. In addition to the area gained from the M-PIN fuel type, M-EUC also received 1522.1 ha from the V-MAa. In turn, the F-FOL type gained area from V-MAa (712.0 ha) and M-PIN (440.5 ha) fuel types (see cross-tabulation matrices in Supplementary Material). In general, the balance between gains and losses that determine the 'winners' and 'losers' is similar to what was described in the previous section.

Table 3. Fire selectivity for fuel types through the Jacobs Index.

	Jacobs Index					
Fuel types	TBA	FS_{tBA}	NFS_{tBA}	$FS_{tBA} \cap NFS_{tBA}$	FS_o	NFS_o
F-FOL	-0.25	-0.22	-0.40	-0.44	-0.12	-0.35
F-PIN	-0.43	-0.33	-1.00	-1.00	-0.11	-1.00
F-RAC	0.08	0.11	-0.06	-0.11	0.20	-0.01
M-CAD	-0.10	-0.15	-0.20	-0.46	-0.01	0.05
M-ESC	0.04	0.17	0.22	0.46	-0.24	-1.00
M-EUC	0.22	0.32	-0.07	0.09	0.41	-0.37
M-PIN	0.02	0.05	-0.18	-0.23	0.18	-0.12
V-MAa	0.48	0.45	0.65	0.71	0.25	0.56
V-MMb	-0.74	-0.75	-0.81	-0.89	-0.68	-0.72
V-MH	0.19	-0.04	0.29	-0.29	0.07	0.57
V-Ha	-0.61	-0.65	-0.62	-0.75	-0.59	-0.48
V-Hb	-0.89	-0.92	-0.89	-0.98	-0.88	-0.78
NF	-0.92	-0.92	-0.95	-0.96	-0.89	-0.94

TBA: Total burned area; FS_{tBA}: fire-season burned area; NFS_{tBA}: unseasonal burned area; FS_o: fire-season burned area only (excluding the overlapped area between FS_{tBA} and NFS_{tBA}); NFS_o: unseasonal burned area only (excluding the overlapped area between FS_{tBA} and NFS_{tBA})

We have found, however, differences, both in the affected area and in the flow between fuel types when we separate the fires according to the period in which they occurred, as can be observed in Figures 8 and 9 (and Tables A3 and A4 in Supplementary Material). The distribution of the fire-season burned area by fuel types is similar to that determined through the analysis conducted on the global burned areas. Around 51.3% of the fire-season burned area was covered by V-MAa, 21.1% by M-PIN and 13.9% by M-EUC. However, in this case the V-MH fuel type is not preferred by fire, as above mentioned, being proportionally affected in relation to its availability in the study region (*D*-value near 0), such as M-PIN. Regarding the fuel types affected by unseasonal fires, about 65.2% of their area was covered by shrublands in 2000, represented by the V-MAa fuel type, while the percentage of area of fuel types M-PIN and M-EUC is lower (14.3% and 6.7%, respectively) than the one observed for the fires occurred during the fire-season. Regarding the Jacobs Index, the major differences, when compared with the results obtained for the area affected by fires during the fire-season, are in the fuel types M-PIN and M-EUC, which are moderately avoided by these fires (*D*=-0.2 and *D*=-0.1), and in the V-MH fuel type which is moderately selected by fire (*D*=0.3) (Table 3).

By removing the effect of the area that was cumulatively affected by seasonal and unseasonal fires (29.2% of the total burned area), the ranking of fuel types affected by seasonal fires did not change substantially, but the percentages between the three types of most affected fuel became more balanced. In this way, and considering the area affected by fire-season fires only, about 40.0% was covered by V-MAa, 25.8% by M-PIN and 16.8% by M-EUC. Estimates in areas affected by unseasonal fires only showed larger differences, dominating areas covered by V-MAa (58.4%), followed by M-PIN (15.9%), V-MH (8.1%), and M-CAD (6.7 %). According to the Jacobs Index, while M-EUC and M-PIN are moderately selected by fire during the fire season (*D*=0.4 and *D*=0.2, respectively), they are moderately avoided outside this period (*D*=-0.4 and *D*=-0.1, respectively). M-CAD burns proportionally to its availability during the fire-season (*D*-value near 0), while it is moderately selected by unseasonal fires. In turn, V-MH is moderately selected by fire-season fires, and strongly selected by unseasonal fires (*D*=0.6) (Table 3).

Regarding the total area burned during the fire season, about 24.3% (4066.1 ha) of the M-PIN affected by these fires changed to M-EUC (Figure 8), which in turn also gained 3.5% (1412.2 ha) of the V-MAa burned area. M-EUC is the main 'winner' in the burned areas resulting from fire-season fires, showing an increase of 5697.0 ha (overall balance of 5523.5

ha). F-FOL also present a significant positive balance of 933.8 ha, gaining 571.8 ha from V-MAa and 376.6 ha to M-PIN. V-MAa also gained 1235.2 ha from M-PIN, but lost 1412.2 ha to M-EUC, and showed a negative balance of -1723.3 ha. However, the main 'loser' during the fire-season is M-PIN, showing a negative balance of -4998.4 ha (58.8% of the overall losses in the fuel types affected by fire-season fires).

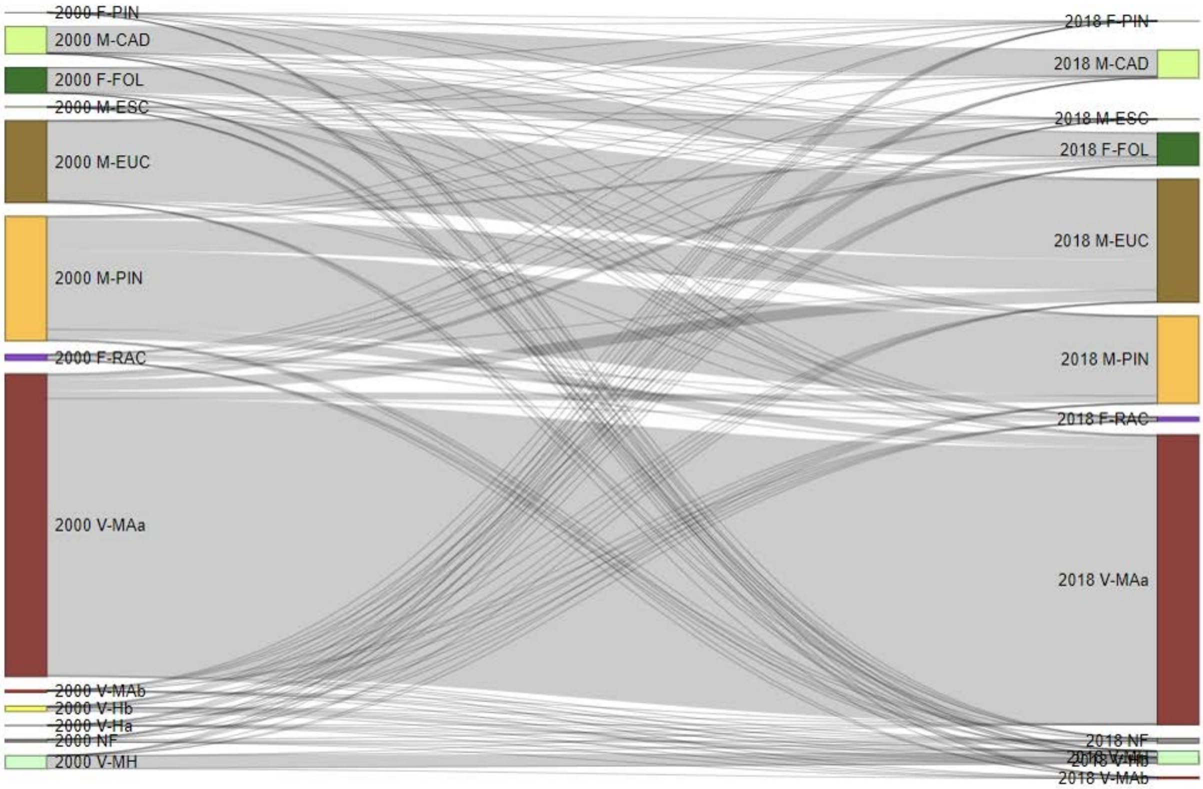


Figure 5. Sankey diagram showing the main flows between 2000 and 2018 in the fuel types affected by fires during the fire season (see Table 1 for a briefly description of the fuel types).

Concerning all the area affected by the non-seasonal fires, the results showed a similar pattern (Figure 9), highlighting the same 'winners' and 'losers', but exhibiting much less pronounced balances between gains and losses: M-EUC: +1622.3 ha; F-FOL: +409.2 ha; M-PIN: -1094.4 ha; V-MAa: -1101.2 ha). However, removing the areas that represent the cumulative effect of fires that occurred in both periods (see Table A5 in Supplementary Material), differences between them are highlighted. While M-PIN losses represent 59.0% of all losses in fuel types mapped in 2000 in the affected areas during the fire season, the unseasonal fires exert more expressive successional dynamics in the fuel type V-MAa, which represents 57.7% of all losses in this period. The 'winners' and 'losers' remain the same in the areas affected during the fire-season, highlighting positive balances in fuel types M-EUC (+4412.9 ha) and F-FOL (+750.9 ha), and negative balances in fuel types M-PIN (-3839.8 ha) and V-MAa (-1545.4 ha) (see Table A6 in Supplementary Material). However, in the areas affected by unseasonal fires, the only relevant 'loser' is V-MAa (-923.3 ha), showing positive balances in M-EUC (+511.7 ha), F-FOL (226.3 ha), and also in M-PIN (+64.2 ha) (see Table A7 in Supplementary Material). The cumulative effect between areas burned by seasonal and unseasonal events is relevant and contrary to most fuel type transitions, part of the M-PIN losses in these burned areas by unseasonal fires overlap burned areas during the fire-season, and thus only 416,4 ha are exclusive of the non-seasonal fires, which were compensated by gains of 636.5 ha.

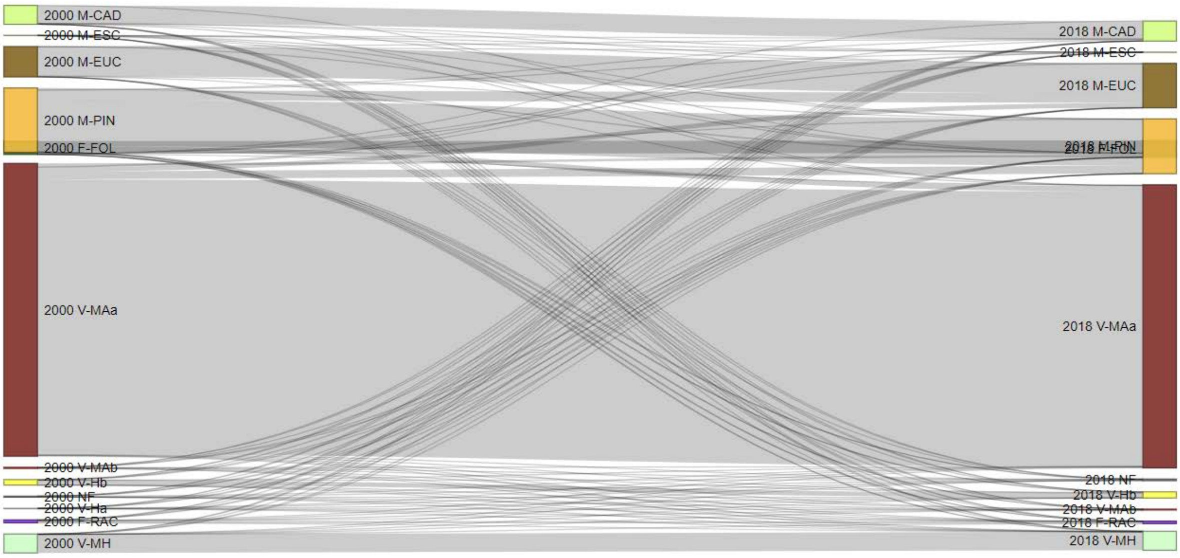


Figure 6. Sankey diagram showing the main flows between 2000 and 2018 in the fuel types affected by non-seasonal fires (see Table 1 for a briefly description of the fuel types).

Figure 10 represents the percentage of the area covered by each fuel type that changed in burned areas (total, seasonal and unseasonal) as a function of their overall losses (transitions to other fuel types) in the study region.

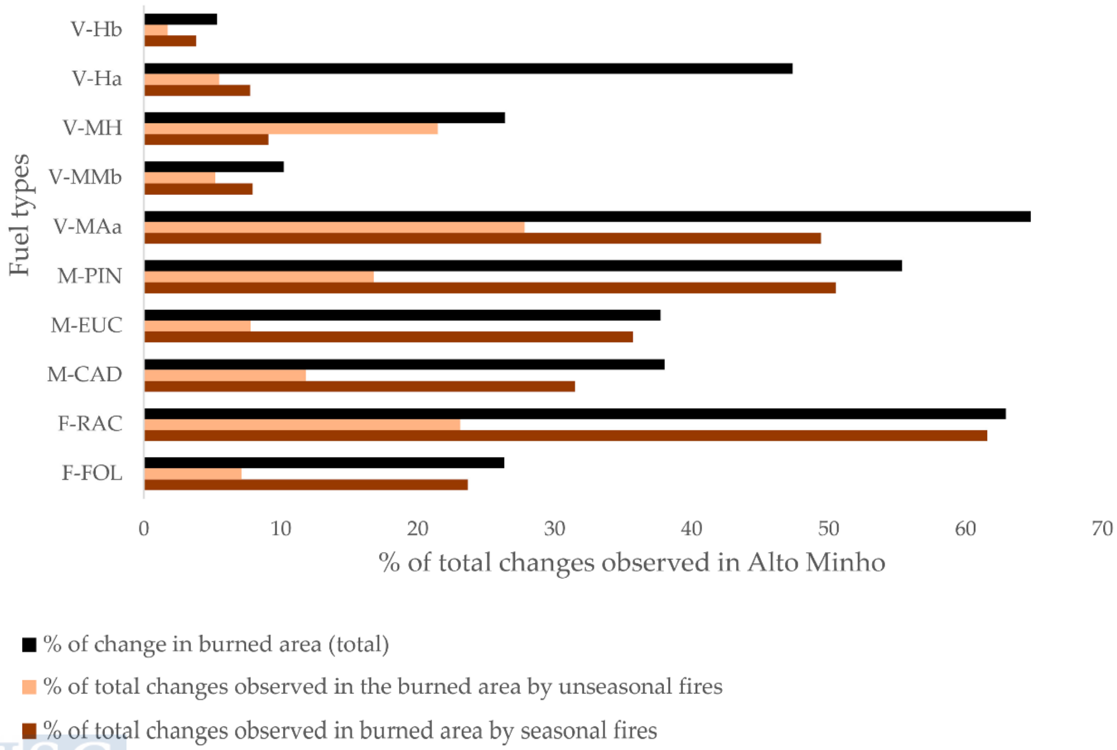


Figure 7. Contribution of the seasonal and non-seasonal fires to changes in fuel types in the burned areas between 2000 and 2018 in Alto Minho.

Approximately 64.8%, 55.4% and 5.3% of the areas that changed in the three fuel types with the highest losses in absolute terms (V-MAa, M-PIN and V-Hb, respectively) were affected by fires between 2001 and 2018. While most of the V-MAa transitions seem to be driven by fire, any changes that occur in communities typical of early stages of ecological succession, such as V-Hb (short grasslands), to other fuel types result from the prolonged absence of disturbance factors. In the case of M-PIN, the contribution of fire to the distribution of areas that changed to other fuel types is very relevant, but it reveals the existence of other factors explaining its overall loss in the study region. Figure 10 also highlights that the contribution of unseasonal fires to fuel type transitions is much lower than that observed in areas burned during the fire-season, except for the V-MH fuel type, which represents mosaics of herbaceous and scattered low shrubs, characteristic of recently burned areas.

The results obtained through logistic regression (Table 4) help clarify the effect of different fires on fuel types changes. Pseudo-R^2's values are not too high because we only wanted to assess the effects of fire and pre-fire fuel types on fuel types transitions, excluding the effects of other drivers that boost changes in vegetation structure and composition. Of all variables, only $FIRE_{nfs}$ was not statistically significant (*z*-value <2; *p*-value = 0.35), evidencing its low contribution in the transitions between fuel types affected by fire. According to the logistic regression results, fires that spread in the fire-season ($FIRE_{fs}$) and higher fire recurrence ($FIRE_{rec}$) are critical in explaining the transitions observed in the study region. $FIRE_{fs}$ and $FIRE_{rec}$ multiply by 1.75 and 1.62 (odds ratios), respectively, the probability of observing transitions in fuel types, when compared to other areas. Despite the statistical significance, the contribution of fire size ($FIRE_{fslf}$) to the distribution of transitions is low. Considering the effect of the fuel types affected by fires, it is relevant to highlight the weaker level of statistical significance of M-CAD when compared to the ones obtained for the remaining variables. Considering that these are moderately selected by unseasonal fires, and moderately avoided by fire-season fires, it is expected that the transition probability or its contribution to the distribution of transitions is not very effective. The results highlight the higher probability of post-fire transition in fuel types characteristic of forest stands dominated by conifers (M-PIN and F-RAC). These values substantially reinforce the 'loser' character of the M-PIN highlighted in the previous analyses and its higher vulnerability to fires. In contrast, the transition probability is reduced by 41.1% when the fuel type affected by fire is M-EUC, the most prominent 'winner' among the forest stands in the previous analyses (the same can be applied to F-FOL fuel type, which was established as reference category in the logistic regression). We did not find a relevant effect of the patch size of forest stands on the probability of transitioning to other fuel types after fire.

Table 4. Results from the logistic regression to assess the factors explaining transitions between fuel types between 2000 and 2018

	Estimate	Std. Error	*z*-value	*p*-value
Intercept	-2.25	0.06	-36.86	< 0.001
$FIRE_{rec}$	0.48	0.04	10.64	< 0.001
$FIRE_{fs}$	0.56	0.08	7.18	< 0.001
$FIRE_{nfs}$	0.06	0.07	0.92	0.35
$FIRE_{fslf}$	0.00	0.00	-5.29	< 0.001
$FC2000_{F-RAC}$	1.72	0.12	14.59	< 0.001
$FC2000_{M-CAD}$	0.19	0.08	2.31	0.02
$FC2000_{M-EUC}$	-0.53	0.08	-6.39	< 0.001
$FC2000_{M-PIN}$	2.70	0.06	41.66	< 0.001
$FC2000_{PS}$	0.00	0.00	5.57	< 0.001
Efron's pseudo-R^2	0.42			
McFadden pseudo-R^2	0.34			
Cox and Snell pseudo-R^2	0.37			
Nagelkerke pseudo R^2	0.50			
Null deviance	20084 (14487 d.f.)			
Residual deviance	13314 (14478 d.f.)			
AIC	13334			

$FIRE_{rec}$: fire recurrence; $FIRE_{fs}$: fire-season fires; $FIRE_{nfs}$: unseasonal fires; $FIRE_{fslf}$: fire size of the largest fire that affected each burned patch; $FC2000_{F-RAC}$: area covered by fuel type F-RAC in 2000; $FC2000_{M-CAD}$: area covered by fuel type M-CAD in 2000; $FC2000_{M-EUC}$: area covered by fuel type M-EUC in 2000; $FC2000_{M-PIN}$: area covered by fuel type M-PIN in 2000; $FC2000_{PS}$: patch size of pre-fire fuel types

6.4 DISCUSSION

6.4.1 Fire Regime

Alto Minho is one of the European regions with the highest number and recurrence of rural fires [84,114,126,127]. However, our results show high annual variability both in burned area and fire patches. Fire-weather is the main factor in explaining the annual variability of burned area in mainland Portugal [128] and the determining fire-driver in fire-prone areas with high primary productivity, such our study region, and drought-driven fire regimes [40,129]. Both the number of unseasonal fires and their burned area exceed, in most years, the observed values of seasonal fires. However, this fact only occurs in years with burned area below the annual average for the period considered. This observation was used by Barreiro & Rodrigues [130] to state that the empowerment of traditional communities allowing them to use fire for landscape management must be eradicated to avoid the costs of wildfires. However, disconnecting the percentage distribution from the absolute variation in a wider universe of years generates erroneous conclusions, as the one stated by the authors, and motivates policy options that not only will have detrimental impacts on the fire regime, but may in the medium-term lead to opposite effect, contributing to the fuel accumulation and increasing the probability of large and/or extreme fires. The fire return period is between 13 and 15 years, and is similar to those obtained by other authors [113,114,131] using different timeframes and fire data. The results achieved through the Weibull parameter estimation also pointed out that fire hazard increases over time and is fuel-age dependent [113,114]. Fire size increased with high fuel connectivity and low pyrodiversity [47], and exclude unseasonal fires from the landscape will contribute to fuel buildup and increase spatial homogeneity of the wildland fuels, as observed elsewhere [132–134]. Less heterogeneous cultural landscapes due to the disruption of cultural burnings leads to the encroachment of more flammable fuels [13,135,136], mainly where fire supporting cultural practices has been banned. The distinctive character of the land mosaics of the cultural landscapes of the Alto Minho region is gradually changing, with the exception of the mountain areas where ancestral agro-silvopastoral practices are still maintained. This is indicative not only of the importance that fire as a management tool still has in the region [131], considering also the lower potential damage caused by these unseasonal fires, when compared with fires spreading during the fire-season, which is supported by the positive relation between fire size and high fire severity established by Fernández-Guisuraga et al. [137].

The distribution of fire patches and area burned by fire size classes shows a typical pattern already observed and discussed in other geographical contexts [138–140]. Most of the fire affected area (in some years may exceed 75%) result from the contribution of less than 5% of the total number of fires (fires > 100 ha). However, the unseasonal fires showed a different pattern, since their contribution to the annual burned area decreases with fire size. This difference reflects the number of events, but also the lower suppression capacity in the summer months when fire-weather conditions exceed the typical thresholds that allows fast growth of the burned area in this geographic context [141], reinforcing the need to maintain a landscape with sufficient heterogeneity in the fuel structure that guarantees a set of potential opportunities that can be used by the resources committed to fire suppression when the fire-weather carry back the suppression capacity.

6.4.2 Effects of fire seasonality on fire preferences of fuel types

The assessment of fire selectivity by land cover types has already been addressed in different geographic contexts and scales (e.g., [59,60,142–149]). However, there are not many studies addressing the effect of fire seasonality on fire preferences. Bajocco et al. [69] analysed seasonal patterns of fire occurrence in Sardinia (Italy) to identify land cover types where wildfires occur earlier or later than expected in a random model, and concluded that fires in agricultural areas occur earlier, while ignitions in forest stands, shrublands and pastures occur later than expected. V-MAa fuel type (tall shrublands) is preferred by fire regardless of the period in which fires occur. This fire selection of shrublands is highlighted by different studies carried out in Europe at different scales and using different methodological approaches (e.g., [59,60,142,146,147]). According to Bergonse et al. [150] the area covered by shrublands control the extent of burned area. The representative fuel types of herbaceous communities (V-Ha and V-Hb), where agricultural areas are included, are clearly avoided by fire, also corroborating other studies [59,60,147]. Still, Oliveira et al. [142], in a comparative study among southern European countries, determined that grasslands are among the most preferred types of fuel. Our results reveal an interesting difference in the shrubland fuel types, since V-MMb fuel type (short shrublands) burned less than expected, regardless of the period in which the fires occur, and contrary to the observed for V-MAa fuel type. This difference may be result from the easier fire suppression in fuel complexes with less fuel load, thus limiting the burned area in that fuel complex (1-h fuel load of 9.5 $t.ha^{-1}$ for V-MAa and 4.0 $t.ha^{-1}$ for V-MMb [91]). The V-MH fuel type, which represents heterogeneous mosaics of herbaceous and shrub species and is typical of recently burned or affected by other disturbance factors [91], burns proportionally to its availability in the landscape during the fire season, but is strongly selected by unseasonal fires. The results of Bajocco et al. [68] show that, in Central Italy, a proportion of the vegetation communities is affected by fires during the winter-spring rainy season and that this bimodal fire regime is strongly determined by humans fire use for landscape management. At the global scale Benali et al. [67] pointed out that in regions showing bimodal fire regimes the fraction of fires occurring especially in crops and pastures are closely related with the use of fire as a land management tool. These cultural fires are started by humans to clear land and renew pastures, to obtain fresh and nutritious herbaceous vegetation for cattle grazing [25,151]. The difference in fire selectivity highlighted in V-MH between seasonal and unseasonal fires is indicative of the importance that fire as a management tool still has in the region [131]. According to Oliveira & Fernandes [131] pastoral fires accounted for 20% of the total area burned between 2000 and 2020 in our study region, are more frequent and mostly prevail over seasonal fires in parishes with a higher livestock density, and occur mainly between december and april, the rainiest months that guarantee the conditions for the renewal of pastures and the self-extinction of fire. The concentration of the area burned by non-seasonal fires in V-MAa is not surprising, as most of these fires are intended to increase the availability of livestock forage through shrubland burning [25,26,131,152,153].

Concerning the fuel types typical of forest stands, we found relevant differences resulting from fire seasonality and also contrasts with findings from other studies. Our results show that the F-FOL fuel type (typical of broadleaved forest stands) is moderately avoided by fire, being independent of fire seasonality. The results obtained by Moreira et al. [147] for the study region are coincident with ours - F-FOL fuel types also burned less than expected - while Silva et al. [145] showed the opposite since, in their findings, unspecified broadleaved forests were among the most forest types preferred by fire. These differences may be due to the fact that this heterogeneous group of forest stands encompasses high diversity of vegetation communities, from less fire-prone riparian galleries to areas covered by invasive species such as *Acacia* spp. [63] high susceptible to fire. Barros & Pereira [60] highlight the greater land cover proneness of the maritime pine, similar to what we obtained for M-PIN for the fires that spread during the fire season. However, our findings indicate that the M-PIN fuel type is avoided by unseasonal fires. The same pattern was observed in the type of fuel M-EUC (typical of eucalyptus forest stands).

6.4.3 The role of fire in changing fuel types

According to our results, the 'loser' that stands out in our study region is M-PIN fuel type. This result is supported not only by the analyses carried out from the transition matrices, but also by the logistic regression results. In logistic regression, fire metrics emerge that can explain this greater vulnerability of M-PIN to fire. The effect of fire recurrence is very high, since *Pinus pinaster* needs fire intervals higher than 14 years to guarantee the sexual maturity of the individuals [154], whose effect was observed in other pine species, such as *Pinus attenuata* which is also an obligatory post-fire seeder with serotinous cones [155]. The logistic regression also highlighted the effect of seasonal fires on the transitions from M-PIN. Post-fire regeneration of maritime pine is also extremely affected by fire severity [156–159]. Considering the positive relation established by Fernández-Guisuraga et al. [137] between fire size and the proportion of high fire severity, it is expected that larger seasonal fires have a negative impact on the survival of individuals, as observed in other land systems [64]. Moreover, large-scale disturbances are associated with high uncertainty in the succession pathways, which increase with the destruction of biological legacies required for post-fire response and the need of colonization from unburned edges [160]. Maritime pine, like other conifers (e.g., [158,161–164]), has regeneration mechanisms allowing its survival and regeneration after surface fires of low to moderate severity. Although unseasonal fires did not have significant effects on the probability of change, it is relevant to note that the only positive balance between losses and gains (Table A7 in Supplementary Material) in M-PIN was registered in areas affected by unseasonal fires only (excluding the overlapped areas with seasonal fires). Moreover, the lower Pseudo-R^2‘s values indicate that there are other factors driving the observed changes in fuel types. In the case of the M-PIN fuel type, ~55% of its overall gains and losses occurred in fire affected areas. Outside the burned area, gains may result from colonization and growth in areas burned before 2001, while losses may be related to the development of pine wilt disease that has spread across the country in recent decades [165].

Other relevant 'loser' in the study region was V-MAa fuel type, which lost area to M-PIN and M-EUC. Despite the negative balance verified in this time period, the V-MAa fuel type is the one whose dynamics are most determined by fire, since 73.8% of its global gains and 64.7% of its global losses occurred in areas affected by fires. The V-MAa-M-PIN transition may correspond to pine development in previously burned areas, since V-MAa also includes dense natural pine regeneration up to a certain growth stage. M-EUC, which was the main ‘winner’ between 2000 and 2018 gained area to M-PIN and M-EUC. Despite the low mortality rate and the natural establishment of eucalypts in burned areas [166,167], this increase of M-EUC (62.1% of global gains occurred in the burned areas) seems to be due to changes promoted by land owners or managers as a result of opportunities provided by fire. These replacement of forest species, allowing eucalypts (mainly *Eucalyptus globulus*) expansion had already been highlighted by Moreira et al. [58]. F-FOL fuel type, characteristic of broadleaved forest stands, also showed positive balance between gains and losses in the burned areas. However, it should be noted that the broadleaved land cover classes re-classified as fuel types also include alien invaders such as *Acacia* spp. [63], whose expansion essentially results from the effect of ecological and management-induced disturbances, including wildfires [168]. However, only 35.5% of the global gains were observed in burned areas. The overall increase in the F-FOL model may also be related to colonization processes of natural vegetation, including trees, after abandonment of the previous agricultural activity, in particular where the transitions observed arise from the V-Hb model associated with herbaceous plant communities. Agriculture abandonment and decreased grazing intensity had also been emphasized by Moreira et al. [58] as a driver of change in fire regimes, since result in shrub encroachment and/or tree expansion (e.g., [169–172]), and consequently in fuel accumulation and fuel structure homogenization.

6.5 CONCLUSIONS

Our results showed, at the landscape scale, relevant dynamics in the distribution of the fuel types most representative in Alto Minho between 2000 and 2018, due to the high burned area in the same period. The fuels types representing the typical maritime pine stands are being replaced by fuel complexes related to eucalypt plantations. This change is the result of the loss of income in burned pine forest stands and rural landowners' recognition of an opportunity for change. Another significant change that occurs in parallel with the gain of eucalypts fuel types at the expense of in pine fuel types, stems from the expansion of broadleaved trees fuel types, which partially result from the post-fire expansion of invasive species; this process has not yet been addressed on a spatial scale allowing accurate assessment of the global effects of fire on the current expansion of alien species. However, these processes mainly occur in areas that were affected by fire-season fires. Unseasonal fires are more selective, are smaller, and induce less perceptible changes at this scale of analysis. Furthermore, the spatial distribution of seasonal and unseasonal fires is substantially different, despite the spatial overlap in ~29% of the global burned area that cannot be neglected. This overlap may be due to the increased marginalization of cultural fires that starts to have unintended consequences; on the one hand related to unattended ignitions occurring closer to the fire-season, and on the other hand with the increased fuel load resulting from the de-intensification of land use. In the past, fire was used in northwest Iberia as an instrument for clearing soil for the first crop fields, for soil fertilization, for pastures restoration and for burning agricultural and forest residues. Currently, the presence of such use of fire, which emerges from ancestral traditional practices of land use, is also one of the main causes of rural fires, as a result of fire suppression policies. However, the simple fact that they constitute one of the main causes of ignition does not directly imply that the damage caused by these fires is high. To avoid large fires, with the potential to induce changes in the landscape and threaten people and property, fire management policies will have to meet the shepherd's needs, making them allies in the pursuit of landscape management objectives.

6.6 SUPPLEMENTARY MATERIALS

Table A1. Matrix of changes in fuel types (in hectares) in the study region between 2000 and 2018.

	F-FOL	F-PIN	F-RAC	M-CAD	M-ESC	M-EUC	M-PIN	V-MAa	V-MMb	V-MH	V-Ha	V-Hb	NF	TOTAL	*Losses*
F-FOL	14,193.1	0.0	7.7	7.5	0.0	168.4	45.4	22.2	9.6	0.0	0.0	125.3	141.5	**14,720.7**	*527.6*
F-PIN	0.0	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**18.8**	*0.0*
F-RAC	4.3	0.0	1211.9	0.0	0.0	77.5	155.6	208.4	0.0	0.0	0.0	1.5	0.0	**1659.3**	*447.4*
M-CAD	81.0	0.0	3.2	13,347.2	0.0	66.4	42.5	15.5	3.2	0.0	0.0	25.2	32.7	**13,616.8**	*269.6*
M-ESC	0.0	0.0	0.0	0.0	1.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.2**	*1.6*
M-EUC	63.9	0.0	0.6	7.3	0.0	16,619.0	17.7	48.7	0.4	0.0	0.0	49.6	297.8	**17,104.9**	*485.9*
M-PIN	1100.0	0.0	36.9	62.1	0.0	7644.7	31,079.2	1374.6	30.8	2.2	0.0	450.3	1156.3	**42,937.1**	*11,857.9*
V-MAa	1039.0	0.0	100.6	293.3	0.0	1833.2	2524.2	56,328.9	15.9	40.8	0.0	209.2	536.8	**62,922.0**	*6593.1*
V-MMb	287.9	0.0	1.6	172.6	0.0	18.8	23.6	48.8	4215.6	0.0	0.0	115.4	200.7	**5085.1**	*869.4*
V-MH	0.4	0.0	0.0	0.0	0.0	0.3	12.8	0.0	0.0	5228.6	0.0	0.0	30.9	**5272.9**	*44.3*
V-Ha	36.0	0.0	0.6	39.1	0.0	6.9	1.7	41.3	20.4	0.0	11.1	609.7	27.2	**794.0**	*783.0*
V-Hb	963.9	2.3	1.3	224.6	0.0	190.4	97.1	403.1	309.1	0.0	0.0	35,444.1	1467.6	**39,103.5**	*3659.4*
NF	87.5	0.0	0.0	0.0	0.0	9.2	12.8	36.4	1.1	0.0	0.0	8.8	18,437.1	**18,592.9**	*155.8*
TOTAL	**17,857.0**	**21.1**	**1364.4**	**14,153.9**	**1.6**	**26,636.3**	**34,012.5**	**58,528.1**	**4606.2**	**5271.5**	**11.1**	**37,039.1**	**22,328.6**		
Gains	*3663.9*	*2.3*	*152.5*	*806.7*	*0.0*	*10,017.3*	*2933.3*	*2199.1*	*390.6*	*42.9*	*0.0*	*1595.0*	*3891.5*		
Balance	3136.3	2.3	-294.9	537.1	-1.6	9531.3	-8924.6	-4394.0	-478.9	-1.3	-783.0	-2064.4	3735.7		

Table A2. Matrix of changes in fuel types (in hectares) between 2000 and 2018 in the burned area

	F-FOL	F-PIN	F-RAC	M-CAD	M-ESC	M-EUC	M-PIN	V-MAa	V-MMb	V-MH	V-Ha	V-Hb	NF	TOTAL	*Losses*
F-FOL	4004.8	0.0	4.0	5.2	0.0	83.3	24.0	9.5	1.1	0.0	0.0	9.4	2.5	**4143.7**	*138.9*
F-PIN	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.4**	*0.0*
F-RAC	2.5	0.0	615.0	0.0	0.0	69.7	2.2	207.0	0.0	0.0	0.0	0.2	0.0	**896.6**	*281.6*
M-CAD	22.5	0.0	0.1	5040.8	0.0	39.1	26.3	10.5	1.3	0.0	0.0	1.6	1.1	**5143.3**	*102.5*
M-ESC	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1.6**	*0.0*
M-EUC	27.2	0.0	0.0	7.0	0.0	11,619.9	12.2	40.4	0.1	0.0	0.0	18.2	78.3	**11,803.3**	*183.3*
M-PIN	440.5	0.0	8.9	57.7	0.0	4462.7	13,655.7	1285.9	2.8	2.2	0.0	150.6	151.9	**20,218.9**	*6563.2*
V-MAa	712.0	0.0	65.2	154.7	0.0	1522.1	1539.9	49,206.9	2.6	33.6	0.0	112.1	126.6	**53,475.8**	*4268.9*
V-MMb	39.6	0.0	0.5	11.6	0.0	1.6	15.6	18.8	251.9	0.0	0.0	5.9	1.6	**347.1**	*345.5*
V-MH	0.2	0.0	0.0	0.0	0.0	0.3	1.6	0.0	0.0	3514.4	0.0	0.0	9.7	**3526.1**	*11.7*
V-Ha	0.3	0.0	0.2	3.2	0.0	3.9	0.0	7.3	0.1	0.0	0.0	73.7	0.1	**88.8**	*88.7*
V-Hb	44.9	0.0	0.0	32.0	0.0	35.3	6.1	40.9	23.2	0.0	0.0	1068.8	12.7	**1263.8**	*195.0*
NF	9.3	0.0	0.0	0.0	0.0	0.7	1.3	2.0	0.0	0.0	0.0	0.0	359.6	**372.9**	*370.9*
TOTAL	**5303.8**	**3.4**	**694.0**	**5312.1**	**1.6**	**17,838.5**	**15,284.7**	**50,829.2**	**283.1**	**3550.2**	**0.0**	**1440.5**	**744.1**		
Gains	*1299.0*	*0.0*	*79.0*	*271.4*	*0.0*	*6218.6*	*1629.1*	*1622.3*	*31.2*	*35.8*	*0.0*	*371.7*	*384.5*		
Balance	*1160.1*	*0.0*	*-202.6*	*168.9*	*0.0*	*6035.2*	*-4934.2*	*-2646.6*	*-314.3*	*24.1*	*-88.7*	*176.7*	*13.6*		

Table A3. Matrix of changes in fuel types (in hectares) between 2000 and 2018 in the burned area by fire-season fires

	F-FOL	F-PIN	F-RAC	M-CAD	M-ESC	M-EUC	M-PIN	V-MAa	V-MMb	V-MH	V-Ha	V-Hb	NF	TOTAL	*Losses*
F-FOL	3293.5	0.0	3.4	5.1	0.0	74.2	21.3	9.5	1.1	0.0	0.0	8.5	1.7	**3418.2**	*124.7*
F-PIN	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.4**	*0.0*
F-RAC	2.5	0.0	459.7	0.0	0.0	69.0	1.3	202.6	0.0	0.0	0.0	0.2	0.0	**735.2**	*275.5*
M-CAD	14.1	0.0	0.0	3584.6	0.0	36.2	25.6	6.9	0.0	0.0	0.0	0.8	1.1	**3669.5**	*84.9*
M-ESC	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1.6**	*0.0*
M-EUC	23.6	0.0	0.0	7.0	0.0	10,821.3	10.4	40.3	0.1	0.0	0.0	17.4	74.7	**10,994.8**	*173.4*
M-PIN	376.6	0.0	8.9	53.3	0.0	4066.1	10,739.5	1235.2	2.7	2.2	0.0	106.4	139.4	**16,730.4**	*5990.9*
V-MAa	571.8	0.0	44.3	82.6	0.0	1412.2	915.0	37,369.7	1.4	27.8	0.0	97.9	106.6	**40,629.3**	*3259.6*
V-MMb	28.6	0.0	0.5	8.5	0.0	1.4	13.8	10.9	194.6	0.0	0.0	3.8	1.6	**263.6**	*69.0*
V-MH	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1743.6	0.0	0.0	3.8	**1747.6**	*4.0*
V-Ha	0.3	0.0	0.2	2.5	0.0	3.8	0.0	7.1	0.1	0.0	0.0	46.7	0.1	**60.7**	*60.7*
V-Hb	31.6	0.0	0.0	23.1	0.0	33.2	3.9	22.1	13.8	0.0	0.0	562.1	11.1	**700.9**	*138.9*
NF	9.3	0.0	0.0	0.0	0.0	0.7	1.3	1.8	0.0	0.0	0.0	0.0	301.6	**314.6**	*13.1*
TOTAL	**4352.0**	**3.4**	**517.1**	**3766.7**	**1.6**	**16,518.3**	**11,732.1**	**38,906.0**	**213.9**	**1773.6**	**0.0**	**843.8**	**641.6**		
Gains	*1058.4*	*0.0*	*57.4*	*182.1*	*0.0*	*5697.0*	*992.5*	*1536.3*	*19.2*	*30.0*	*0.0*	*281.7*	*340.0*		
Balance	933.8	0.0	-218.1	97.2	0.0	5523.5	-4998.4	-1723.3	-49.8	26.0	-60.7	142.8	327.0		

Table A4. Matrix of changes in fuel types (in hectares) between 2000 and 2018 in the burned area by unseasonal fires

	F-FOL	F-PIN	F-RAC	M-CAD	M-ESC	M-EUC	M-PIN	V-MAa	V-MMb	V-MH	V-Ha	V-Hb	NF	TOTAL	*Losses*
F-FOL	1491.0	0.0	2.0	2.5	0.0	23.0	6.7	1.4	0.0	0.0	0.0	1.0	0.9	**1528.5**	*37.6*
F-PIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	*0.0*
F-RAC	0.0	0.0	236.0	0.0	0.0	4.9	1.9	96.5	0.0	0.0	0.0	0.0	0.0	**339.3**	*103.3*
M-CAD	11.0	0.0	0.1	2135.2	0.0	11.2	1.3	6.1	1.3	0.0	0.0	0.9	0.0	**2167.1**	*31.9*
M-ESC	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1.2**	*0.0*
M-EUC	6.7	0.0	0.0	0.0	0.0	3435.3	4.7	11.9	0.0	0.0	0.0	7.8	6.7	**3473.1**	*37.8*
M-PIN	162.5	0.0	2.6	55.8	0.0	1118.8	5394.2	583.1	0.1	0.0	0.0	48.7	17.2	**7383.1**	*1988.9*
V-MAa	238.2	0.0	50.7	87.5	0.0	497.2	861.3	31,774.6	1.3	18.0	0.0	43.5	35.3	**33,607.5**	*1832.9*
V-MMb	12.9	0.0	0.0	4.2	0.0	0.2	14.5	11.1	80.2	0.0	0.0	2.1	0.0	**125.4**	*45.2*
V-MH	0.2	0.0	0.0	0.0	0.0	0.2	1.6	0.0	0.0	2161.2	0.0	0.0	7.6	**2170.7**	*9.5*
V-Ha	0.0	0.0	0.0	0.7	0.0	1.5	0.0	2.5	0.0	0.0	0.0	38.4	0.0	**43.1**	*43.1*
V-Hb	15.2	0.0	0.0	11.9	0.0	3.1	2.4	18.9	10.4	0.0	0.0	557.9	1.7	**621.5**	*63.6*
NF	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	110.5	**110.8**	*0.3*
TOTAL	**1937.7**	**0.0**	**291.4**	**2297.8**	**1.2**	**5095.5**	**6288.8**	**32,506.4**	**93.2**	**2179.2**	**0.0**	**700.3**	**180.0**		
Gains	*446.8*	*0.0*	*55.4*	*162.6*	*0.0*	*1660.2*	*894.5*	*731.8*	*13.0*	*18.0*	*0.0*	*142.4*	*69.4*		
Balance	409.2	0.0	-47.9	130.7	0.0	1622.3	-1094.4	-1101.2	-32.2	8.5	-43.1	78.8	69.2		

Table A5. Matrix of changes in fuel types (in hectares) between 2000 and 2018 in the burned area resulting from the spatial intersection between seasonal and unseasonal fires

	F-FOL	F-PIN	F-RAC	M-CAD	M-ESC	M-EUC	M-PIN	V-MAa	V-MMb	V-MH	V-Ha	V-Hb	NF	TOTAL	*Losses*
F-FOL	779.7	0.0	1.4	2.4	0.0	13.9	4.0	1.4	0.0	0.0	0.0	0.2	0.1	**803.1**	*23.4*
F-PIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	*0.0*
F-RAC	0.0	0.0	80.6	0.0	0.0	4.2	1.0	92.0	0.0	0.0	0.0	0.0	0.0	**177.9**	*97.2*
M-CAD	2.6	0.0	0.0	679.0	0.0	8.4	0.6	2.5	0.0	0.0	0.0	0.2	0.0	**693.3**	*14.3*
M-ESC	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**1.2**	*0.0*
M-EUC	3.1	0.0	0.0	0.0	0.0	2636.7	2.9	11.8	0.0	0.0	0.0	7.0	3.1	**2664.6**	*27.9*
M-PIN	98.7	0.0	2.6	51.4	0.0	722.2	2478.1	532.5	0.0	0.0	0.0	4.5	4.7	**3894.7**	*1416.6*
V-MAa	98.0	0.0	29.8	15.4	0.0	387.3	236.5	19,937.3	0.0	12.2	0.0	29.2	15.2	**20,761.0**	*823.7*
V-MMb	1.9	0.0	0.0	1.1	0.0	0.0	12.7	3.2	23.0	0.0	0.0	0.0	0.0	**41.9**	*18.9*
V-MH	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	390.4	0.0	0.0	1.7	**392.2**	*1.9*
V-Ha	0.0	0.0	0.0	0.0	0.0	1.4	0.0	2.2	0.0	0.0	0.0	11.3	0.0	**15.0**	*15.0*
V-Hb	1.9	0.0	0.0	3.0	0.0	1.0	0.3	0.1	1.0	0.0	0.0	51.2	0.1	**58.6**	*7.4*
NF	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.5	**52.5**	*0.1*
TOTAL	**985.9**	**0.0**	**114.5**	**752.3**	**1.2**	**3775.3**	**2736.1**	**20,583.2**	**24.0**	**402.6**	**0.0**	**103.5**	**77.4**		
Gains	*206.2*	*0.0*	*33.8*	*73.3*	*0.0*	*1138.6*	*258.0*	*645.8*	*1.1*	*12.2*	*0.0*	*52.4*	*25.0*		
Balance	182.8	0.0	-63.4	59.0	0.0	1110.6	-1158.6	-177.8	-17.9	10.3	-15.0	44.9	-27.5		

Table A6. Matrix of changes in fuel types (in hectares) between 2000 and 2018 in the burned area by fire-season fires only

	F-FOL	F-PIN	F-RAC	M-CAD	M-ESC	M-EUC	M-PIN	V-MAa	V-MMb	V-MH	V-Ha	V-Hb	NF	TOTAL	*Losses*
F-FOL	2513.8	0.0	2.0	2.7	0.0	60.3	17.3	8.1	1.1	0.0	0.0	8.3	1.6	**2615.1**	*101.3*
F-PIN	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**3.4**	*0.0*
F-RAC	2.5	0.0	379.0	0.0	0.0	64.8	0.3	110.6	0.0	0.0	0.0	0.2	0.0	**557.4**	*178.3*
M-CAD	11.6	0.0	0.0	2905.6	0.0	27.9	25.0	4.4	0.0	0.0	0.0	0.7	1.1	**2976.2**	*70.6*
M-ESC	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.4**	*0.0*
M-EUC	20.5	0.0	0.0	7.0	0.0	8184.6	7.5	28.5	0.1	0.0	0.0	10.4	71.6	**8330.1**	*145.5*
M-PIN	277.9	0.0	6.3	1.9	0.0	3343.9	8261.4	702.7	2.7	2.2	0.0	101.9	134.7	**12,835.8**	*4574.3*
V-MAa	473.8	0.0	14.6	67.2	0.0	1024.9	678.5	17,432.3	1.4	15.6	0.0	68.7	91.3	**19,868.3**	*2435.9*
V-MMb	26.7	0.0	0.5	7.4	0.0	1.4	1.1	7.7	171.7	0.0	0.0	3.7	1.6	**221.7**	*50.1*
V-MH	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1353.2	0.0	0.0	2.1	**1355.4**	*2.2*
V-Ha	0.3	0.0	0.2	2.5	0.0	2.4	0.0	4.8	0.1	0.0	0.0	35.4	0.1	**45.8**	*45.8*
V-Hb	29.7	0.0	0.0	20.2	0.0	32.2	3.6	21.9	12.8	0.0	0.0	510.9	11.0	**642.4**	*131.5*
NF	9.3	0.0	0.0	0.0	0.0	0.7	1.3	1.8	0.0	0.0	0.0	0.0	249.1	**262.1**	*13.0*
TOTAL	**3366.0**	**3.4**	**402.6**	**3014.4**	**0.4**	**12,743.0**	**8996.0**	**18,322.8**	**189.8**	**1371.0**	**0.0**	**740.3**	**564.2**		
Gains	*852.2*	*0.0*	*23.6*	*108.8*	*0.0*	*4558.4*	*734.5*	*890.5*	*18.2*	*17.8*	*0.0*	*229.3*	*315.1*		
Balance	750.9	0.0	-154.7	38.2	0.0	4412.9	-3839.8	-1545.4	-31.9	15.6	-45.8	97.9	302.0		

Table A7. Matrix of changes in fuel types (in hectares) between 2000 and 2018 in the burned area by unseasonal fires only

	F-FOL	F-PIN	F-RAC	M-CAD	M-ESC	M-EUC	M-PIN	V-MAa	V-MMb	V-MH	V-Ha	V-Hb	NF	TOTAL	*Losses*
F-FOL	711.2	0.0	0.6	0.1	0.0	9.2	2.8	0.0	0.0	0.0	0.0	0.9	0.8	**725.5**	*14.2*
F-PIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	*0.0*
F-RAC	0.0	0.0	155.3	0.0	0.0	0.7	1.0	4.5	0.0	0.0	0.0	0.0	0.0	**161.4**	*6.1*
M-CAD	8.4	0.0	0.1	1456.2	0.0	2.8	0.7	3.6	1.3	0.0	0.0	0.7	0.0	**1473.8**	*17.6*
M-ESC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	*0.0*
M-EUC	3.6	0.0	0.0	0.0	0.0	798.6	1.7	0.1	0.0	0.0	0.0	0.8	3.6	**808.5**	*9.9*
M-PIN	63.9	0.0	0.0	4.5	0.0	396.6	2916.1	50.6	0.0	0.0	0.0	44.2	12.5	**3488.4**	*572.3*
V-MAa	140.2	0.0	20.9	72.0	0.0	109.9	624.8	11,837.3	1.3	5.8	0.0	14.2	20.1	**12,846.5**	*1009.3*
V-MMb	11.0	0.0	0.0	3.1	0.0	0.2	1.8	7.9	57.2	0.0	0.0	2.1	0.0	**83.5**	*26.2*
V-MH	0.2	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	1770.8	0.0	0.0	5.9	**1778.5**	*7.6*
V-Ha	0.0	0.0	0.0	0.7	0.0	0.1	0.0	0.3	0.0	0.0	0.0	27.0	0.0	**28.1**	*28.1*
V-Hb	13.3	0.0	0.0	8.9	0.0	2.1	2.1	18.8	9.4	0.0	0.0	506.7	1.6	**562.9**	*56.2*
NF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	58.1	**58.3**	*0.2*
TOTAL	**951.8**	**0.0**	**176.9**	**1545.5**	**0.0**	**1320.2**	**3552.7**	**11,923.2**	**69.2**	**1776.6**	**0.0**	**596.7**	**102.5**		
Gains	*240.6*	*0.0*	*21.6*	*89.3*	*0.0*	*521.6*	*636.5*	*85.9*	*11.9*	*5.8*	*0.0*	*90.0*	*44.5*		
Balance	226.3	0.0	15.5	71.7	0.0	511.7	64.2	-923.3	-14.3	-1.8	-28.1	33.8	44.3		

DISCUSIÓN

En Portugal los incendios forestales constituyen en la actualidad uno de los riesgos más mediatizados y de mayor impacto en la sociedad, con elevados daños y pérdidas medioambientales y económicas que se repiten con elevada frecuencia. Como se ha descrito en los capítulos anteriores, diversos estudios han tenido como objetivo principal evaluar las causas, los factores determinantes en la propagación y comportamiento del fuego y las consecuencias e impactos de los incendios forestales. Aunque el punto de partida de esta tesis, han sido los incendios forestales, los trabajos de investigación desarrollados y aquí presentados, buscan comprender el impacto del uso del fuego por parte de las comunidades rurales. En consecuencia, la elaboración de esta tesis implicó un enfoque más amplio, buscando respuestas del pasado y partiendo de un contexto general, transversal al territorio de Portugal a un contexto más local, a la escala de la región del Alto Minho.

El fuego es el resultado de las relaciones entre el ser humano, como individuo y como ser en sociedad, y el paisaje. Esta relación tiene por objeto la gestión de los recursos. La evolución de esta relación Hombre-Fuego-Paisaje obligó desde el principio a crear normas, que fueron evolucionando a medida que se desarrollaba la sociedad. El fuego fue y sigue siendo utilizado como herramienta de gestión de los recursos compartidos por una comunidad. Esta relación también puede percibirse a través del estudio y análisis de los documentos legislativos que permitieron identificar la evolución de los conflictos en el territorio portugués a lo largo de los siglos hasta la actualidad. Sin duda, el fuego ha sido esencial para el desarrollo de las sociedades a lo largo del tiempo.

El uso del fuego, sus limitaciones y conflictos, y las consecuencias derivadas de su uso pueden reconstruirse a partir de un análisis histórico legislativo y normativo (Molina et al., 2013; Sequeira et al., 2019). Sin embargo, ninguno de los estudios publicados hasta la fecha aborda específicamente cuáles eran las limitaciones impuestas por la legislación que regula el uso del fuego en Portugal.

Al analizar la legislación sobre el uso del fuego en Portugal, ésta ha acompañado los cambios de la sociedad en relación con el espacio, cómo se utiliza y cómo se ocupa. Los usos del fuego en Portugal están históricamente asociados a los diferentes usos y ocupación del espacio y al régimen de propiedad.

En el siglo XV, la publicación de Las Ordenanzas Alfonsinas, una de las primeras recopilaciones de leyes de la Edad Moderna en Portugal, omitían el uso del fuego. Aunque, el paisaje rural portugués es principalmente un producto de la Edad Media, caracterizada por un fuerte fomento y expansión de la agricultura, por lo que el fuego fue un instrumento ampliamente usado en la roturación de nuevas tierras de cultivo y en la expansión de las actividades agrosilvopastoriles. En las Ordenanzas Filipinas, de 1603, se destacan la reglamentación sobre los diferentes usos o utilidades del fuego, para la gestión de los pastos, la quema de rastrojos agrícolas, la quema de arbustos para la labranza y fertilización del suelo, la caza y para la producción de carbón vegetal.

Hasta el siglo XIX, se publicaron 26 documentos legislativos sobre las limitaciones del uso del fuego y las sanciones por incendios perjudiciales. Por el contrario, en el siglo XX se publicaron 15 documentos legislativos sobre el mismo tema. Además, el siglo XXI destaca en toda la trayectoria legislativa histórica por producir, alrededor de dos décadas, el número más significativo de documentos normativos en un período tan corto (19 documentos), superando al siglo XX en el número de publicaciones e incluso superando todo el período desde la Fundación de Portugal (1143) hasta el final del siglo XIX, cuando el fuego era ampliamente utilizado en todo el país.

Cuanto más complejos y diversificados son sus usos, mayores son los conflictos que surgen. Asimismo, estos conflictos se agravan y tienen mayor repercusión allí donde la propiedad privada prima sobre los espacios comunales regidos por usos y costumbres ancestrales. El análisis de la documentación histórica legislativa permitió identificar que el uso diversificado del fuego por parte de las comunidades portuguesas formaba parte de un sistema equilibrado hasta la segunda mitad del siglo XIX. La legislación no se centraba únicamente en un uso específico del fuego, sino en varios usos del fuego. Por otra parte, estos diferentes usos del fuego están asociados a numerosas prácticas características de los sistemas agrosilvopastorales de las sociedades rurales, en particular las de la Península Ibérica, donde el uso del fuego ha sido siempre intrínsecamente cultural. Asimismo, la legislación que ha limitado el uso del fuego a lo largo de los siglos ha mantenido un régimen sancionador para reducir los daños causados por el fuego y responsabilizar a los autores. Sólo en el siglo XX se generalizó el concepto legislativo del uso del fuego, sobre todo en lo que respecta a la quema de restos agrícolas y forestales y quemas pastorales y su relación con los incendios forestales.

Actualmente, el uso del fuego por las comunidades en Portugal está, en la mayoría de los casos, desconectado de las prácticas de los sistemas agrosilvopastoriles que lo generaron en primer lugar (Meira Castro et al., 2020). A lo largo del último siglo, el abandono de las prácticas tradicionales y las limitaciones y regulaciones sobre los usos del fuego han desdibujado el conocimiento tradicional, dificultando la comprensión de sus raíces tradicionales. En la actualidad, existe un concepto genérico y algo simplista del uso del fuego, reflejado, por ejemplo, en la legislación publicada en el sur de Europa que impone restricciones y reglamentos sobre el uso del fuego, para reducir el número de igniciones (AGIF, 2020; D’Amelio, 2022). La relación entre los usos tradicionales del fuego, las prácticas tradicionales y la necesidad de mantenerlas está actualmente infravalorada y pasada por alto. Varios estudios utilizan el concepto de conocimiento tradicional del fuego cuando se refieren a la quema para la renovación de pastos, la quema de montones, la gestión del combustible o con fines cinegéticos (Oliveira et al., 2022; Mateus and Fernandes, 2014; Meira Castro et al., 2020; Tedim et al., 2019, 2022). Sin embargo, ninguno de ellos describe exhaustivamente el concepto. La revisión de la documentación histórica relativa a los registros sobre los usos del fuego permitió identificar sus diversas finalidades en la gestión de los recursos por parte de las comunidades rurales, así como las técnicas y aplicaciones del fuego a lo largo de los siglos en Portugal, hasta su acondicionamiento. El uso tradicional del fuego supone la transferencia generacional de conocimientos y la aplicabilidad de prácticas y técnicas, en una gestión continua de los recursos para su sostenibilidad y del medio ambiente del que depende (Armatas et al., 2016; Berkes, 2012; Pyne, 2006). Si en la actualidad, hay una generalización del uso tradicional del fuego, como atestan los actuales diplomas legislativos y normativos, los registros históricos anteriores al siglo XX, muestran en el pasado la existencia de diversos usos a lo largo del año. El conocimiento tradicional del fuego es, por tanto, mucho más amplio y diverso en una comunidad como la complejidad de la gestión de los distintos recursos para apoyar las diversas actividades (Vázquez-Varela et al., 2022). La bibliografía histórica nos permite desvelar y caracterizar los diversos usos tradicionales del fuego, siendo éste la fuente de energía necesaria para gestionar los recursos con el fin de satisfacer las necesidades individuales de sustento o de mantener a toda una comunidad.

Como ya se ha mencionado, hasta el siglo XIX el uso del fuego estaba ampliamente aceptado como herramienta de gestión en diversas actividades. Sin embargo, durante este siglo surgió una nueva sociedad portuguesa como consecuencia del proceso de industrialización del país, similar al de otros países de Europa, que también produjo profundos cambios a nivel político, socioeconómico, en la gestión de los recursos y en el régimen de la propiedad de la tierra. Con las reformas liberales y la industrialización del país, surgieron intereses que rompieron irreversiblemente con el ancestral sistema agrosilvopastoral. El desmantelamiento de las tierras comunales y la imposición de la intensificación de la agricultura, esencialmente cerealista, así como el consumo de carbón vegetal para la incipiente industria apoyada en las máquinas de vapor, fueron factores que contribuyeron considerablemente a la deforestación (Abel, 1988; Graça, 1999; Matos, 2002). El fuego se utilizó entonces, para roturar las nuevas propiedades resultantes de la desamortización y convertirlas en campos de cereal y para satisfacer la gran demanda de carbón, tanto para la industria como para uso doméstico (Henriques, 2006). Sin embargo, los autores de la época culpaban a los campesinos de prácticas como el pastoreo y el uso del fuego como principales responsables de la deforestación del país. Desde finales del siglo XIX hasta mediados del XX, los sectores cerealista e industrial competirían por los recursos forestales, apoyados por una legislación que limitaría el pastoreo y el uso del fuego (Almeida, 2020; Graça, 1999).

Este condicionamiento y prohibición a lo largo de más de 150 años, unido a otros factores como la motorización e intensificación agrícola, la fertilización inorgánica y la selvicultura productiva, han provocado la pérdida de los usos del fuego que, a su vez, han roto la transferencia generacional del conocimiento y dominio de su aplicación (Huffman, 2013; Meira Castro et al., 2020).

Esta pérdida ha dado lugar a una generalización y reducción de usos diversificados, y se ha mudado a una definición genérica y simplista de un uso del fuego asociado a prácticas rurales que aún se mantienen. Varios autores europeos se refieren a este uso del fuego como tradicional, asociándolo a las prácticas actuales de las comunidades rurales, como la quema de excedentes agrícolas y forestales y la quema pastoral (de Diego et al., 2023; Ganteaume et al., 2013; Tedim et al., 2022; Torres-Manso et al., 2014). Sin embargo, las prácticas actuales de uso del fuego por parte de las comunidades rurales representan sólo vestigios de los usos del pasado, consistiendo esencialmente en la quema de restos agrícolas y forestales amontonados y en la quema para la renovación de pastos, estando estos usos asociados a un número considerable de causas de incendios forestales en Portugal. Aunque de forma diferente, ambos usos difieren de las aplicaciones del pasado. La quema de restos agrícolas y forestales amontonados han perdido su finalidad de obtención de fertilizantes para la agricultura y hoy en día, sólo se quema para eliminar restos de poda y de cultivos.

El uso del fuego para renovar los pastos ha pasado a estar proscrito, aunque sigue siendo usado de forma ilegal en las regiones montañosas, sobre todo en el norte de la Península Ibérica, donde las comunidades mantienen prácticas ganaderas extensivas y donde predominan las tierras gestionadas colectivamente. Aunque conserva parte de los conocimientos y aplicabilidad del pasado, manteniendo su carácter estacional, de baja intensidad y obedeciendo a un determinado periodo de recurrencia; las imposiciones y condicionamientos legales han eliminado la posibilidad de su implantación por parte de las comunidades pastoriles. El fuego dejó de estar acompañado, por lo que sus usuarios optan por encenderlo y abandonarlo. Esta práctica da lugar en ocasiones a incendios forestales, sobre todo entre las estaciones de otoño y primavera (Celaya et al., 2022; de Diego et al., 2021; Gonzalez-Hidalgo, 2023; Lopez-Rodriguez et al., 2021; Marey-Perez et al., 2015; Seijo, 2005). Por lo tanto, no se puede referir al fuego actual en Portugal, más comúnmente utilizado por las comunidades rurales, como fuego tradicional. Aunque se trate de un uso del fuego nativo, dada su naturaleza local, sólo presenta en su aplicabilidad vestigios del pasado, ya que no procede de la transferencia de un pleno conocimiento tradicional del fuego, transferido y practicado de generación en generación, como aún se conserva en algunas comunidades tradicionales e indígenas de otras regiones del mundo, como en África Oriental, Australia, Brasil y el País Vasco en Francia (Butz, 2009; Coughlan, 2013; Eriksen, 2007; Lake et al., 2017; Moura et al., 2019; Myers, 2006).

Los cambios socioeconómicos que afectaron los territorios rurales portugueses en las últimas décadas, caracterizados por la despoblación, el envejecimiento y aislamiento de la población, la pérdida de usos y prácticas tradicionales, han alterado profundamente el paisaje (Colaço, 2017; Oliveira and Zêzere, 2020; Pardellas et al., 2018). En la década de 1950, las zonas rurales de Portugal se caracterizaban por una red de parcelas agrícolas y forestales mantenidas por los agricultores locales. Sin embargo, debido al abandono de la agricultura, hoy esto ya no es así. Como resultado, la biomasa se acumula en las zonas no gestionadas, aumentando la carga de combustible y creando un alto riesgo de incendios forestales (Mateus and Fernandes, 2014; Moreira et al., 2011; Moreira and Russo, 2007). A pesar de ello, el resto de la población de las zonas rurales sigue utilizando el fuego para la gestión del territorio (Nunes et al., 2021), aunque no siempre con el control necesario (Colaço, 2019; Rodrigues et al., 2022).

Según datos oficiales del Instituto de Conservação da Natureza e das Florestas (ICNF), las quemas asociadas al denominado “uso tradicional del fuego”, que se incluyen en la categoría de negligencia, son una causa frecuente de incendios forestales. Por ejemplo, en 2020, los incendios causados por quemas rurales supusieron el 27% del total de 9 619 incendios en Portugal continental (Instituto da Conservação da Natureza e das Florestas, 2022). Sin embargo, los incendios provocados por estas quemas se produjeron con una gravedad meteorológica muy baja y sólo representaron el 2% de la superficie quemada (Nunes et al., 2021). Este resultado coincide con el estudio de Parente et al. (2018), que constató que los incendios intencionados tienen un tamaño medio mucho mayor que los incendios por negligencia.

Las quemas tradicionales no sólo pueden ser un foco de incendios forestales, sino que también suponen un riesgo de lesiones o incluso de muerte. Cada año, aparecen en los medios de comunicación registros sobre incidentes en Europa, especialmente en la cuenca mediterránea, en su mayoría protagonizados por personas mayores que utilizan el fuego para la gestión de los combustibles. En 2018, el número de incidentes en Portugal fue muy superior a lo que es habitual, uno o dos registros anuales. Mientras que las muertes por incendios forestales en todo el mundo suelen atribuirse a factores como las condiciones meteorológicas, la pendiente y el tipo de vegetación (Coogan et al., 2019; Molina-Terrén et al., 2019; Zong et al., 2022), no se encuentran explicaciones en la literatura sobre los incidentes relacionados con las quemas tradicionales.

La pérdida de conocimientos sobre el uso del fuego, especialmente condicionada por las referidas limitaciones legales y las sanciones, conduce a un uso proscrito del fuego. Mientras que la presión legislativa en materia de lucha contra los incendios forestales crea también una presión sobre las comunidades rurales portuguesas. Por otro lado, el cruce de datos oficiales y la integración de información recogida a partir de fuentes de noticias, permitieron identificar que entre 2008 y 2021 se registraron 54 incidentes debidos a quemas de restos y solo en 2018 se produjeron el 37% del total incidentes. La investigación permitió identificar un cambio de un uso más tradicional del fuego en la agricultura (septiembre-diciembre) antes de 2018 a un mayor enfoque en la reducción de combustible ordenada por la legislación de prevención de incendios forestales (enero-junio) después de 2018. En 2018, las noticias evidenciaron incidentes en casi todos los meses, sin diferencias significativas en la distribución mensual. Cabe señalar que en 2017, Portugal vivió la temporada de incendios forestales más grave de la que se tiene constancia, con el mayor número de víctimas mortales, daños y zonas quemadas de la historia del país (Turco et al., 2019). Más de 100 personas perdieron la vida, se quemaron más de 500.000 hectáreas y varios bosques emblemáticos se vieron afectados. El impacto de esta temporada de incendios en la sociedad hizo que aumentara la concienciación sobre los peligros de los incendios forestales, y que la gente tuviera más miedo de estar en zonas forestales, sobre todo en verano. Los datos de la investigación indican que el significativo aumento de los incidentes (con heridos y muertos) en 2018 puede atribuirse al endurecimiento de la legislación, junto con el aumento del valor de las multas y la intensificación y presión de las inspecciones policiales, principalmente sobre una población rural envejecida y más vulnerable. Se constata así lo que parece constituir un nuevo cambio en el uso del fuego por las comunidades rurales que, por una nueva presión normativa en materia de lucha contra incendios, se verifica una transición del uso agrícola del fuego a prácticas asociadas a la reducción y gestión del combustible, en particular en zonas de interfaz urbano-forestal; apartándose así del ancestral uso tradicional del fuego.

El Alto Minho, situado en el norte de Portugal, se ha seleccionado como zona piloto para un estudio de caso, el cual, junto con otras regiones del noroeste de la Península Ibérica, concentra el mayor porcentaje de incendios forestales de Europa (Díaz-Fierros, 2019; Pereira et al., 2006). Mientras que la expansión del fuego en el Holoceno en el sur de Europa estuvo inicialmente condicionada por la alta estacionalidad climática, el uso del fuego por parte de las primeras sociedades agrarias en el Neolítico configuró rápidamente el régimen de incendios (Connor et al., 2019). En este trabajo también se ha constatado que la frecuencia de los incendios forestales aumentó con el aumento de la población, al establecerse nuevas zonas agrícolas, zonas de pastoreo y nuevos asentamientos (Ganteaume et al., 2013; Pinto et al., 2010; Vannière et al., 2008). Por otro lado, al igual que en otras regiones del sur de Europa, el fuego ha marcado la estructura y el funcionamiento de unos ecosistemas que se han adaptado durante miles de años a un régimen de fuego de origen humano, ya que las principales causas de los incendios en el territorio son antropogénicas (Ganteaume et al., 2013; Vázquez and Moreno, 1993).

Los matorrales atlánticos del noroeste de Iberia se han mantenido tradicionalmente mediante una combinación de pastoreo, desbroce y quema (Honrado et al., 2017). El uso del fuego, más que una práctica aislada, se integró en el ancestral sistema agrosilvopastoral que perduró cómo ya mencionado hasta los finales del siglo XIX. El abandono de la actividad agrícola en el noroeste de Portugal contribuyó al aumento de los incendios y de la superficie quemada (Moreira et al., 2001). Los fuegos pastorales tradicionales, principalmente en matorrales, contribuyen a crear y mantener paisajes con estructura de mosaico (Pyne, 2006). El abandono de la agricultura a pequeña escala y de prácticas tradicionales como el pastoreo disuelve el mosaico tradicional y refuerza la conectividad entre manchas homogéneas y extensas de alta carga de combustible derivadas de las actuales repoblaciones forestales y de *rewilding* (Ganteaume et al., 2013). Sin embargo, varios estudios apuntan a una relación entre los incendios forestales y el uso tradicional del fuego, en particular con fines de gestión de pastos (Casau et al., 2022; Parente et al., 2018; Sequeira et al., 2019). Este tipo de uso del fuego puede constituir una causa negligente o intencionada de incendio forestal, dependiendo de la legislación de cada país (Tedim et al., 2022). Otros estudios asocian la sustitución de la agricultura por la ganadería extensiva y la necesidad de utilizar el fuego como herramienta para el mantenimiento de los pastos como origen del aumento de los incendios forestales frecuentes (Bassi and Kettunen, 2008; Pereira et al., 2004).

Al igual que en otras regiones del noroeste de la Península Ibérica, el uso del fuego en los matorrales atlánticos del Alto Miño es intrínseco al sistema agrosilvopastoral ancestral, tanto en el roturación, como en la fertilización del suelo, la renovación de los pastos y la quema de montones y rastrojos (Díaz-Fierros, 2019), y también se cree que es una causa relevante de incendios forestales.

Los estudios sobre la causalidad, impactos, riesgo y regímenes de los incendios forestales en Portugal se han basado hasta la fecha en los datos oficiales del Instituto de Conservação da Natureza e das Florestas (ICNF), que presenta incoherencias debidas a la variación de los métodos cartográficos, la exhaustividad de la base de datos, las limitaciones del tratamiento de imágenes por satélite y la insuficiente validación sobre el terreno (Ferreira-Leite et al., 2012; Oliveira et al., 2012; OTI et al., 2019).

Para obtener datos más precisos que puedan contribuir a rigurosa caracterización del régimen de fuego que afecta al territorio del Alto Minho, se consideró esencial la reconstrucción histórica y la clasificación de todos los perímetros de fuego que se propagaron en el paisaje. Por ello, todos los datos relacionados con esta tesis fueron desarrollados a partir de cartografía producida y clasificada en el ámbito de la investigación según la metodología descrita en el Capítulo IV. Teniendo en cuenta las evidencias del impacto de los incendios registrados a través de la serie histórica de imágenes de satélite a lo largo de las diversas estaciones del año, se verifican grandes diferencias entre los datos de esta investigación y los datos oficiales. En este estudio, se digitalizaron 12 692 perímetros de incendios, correspondientes a 235 060 hectáreas quemadas en el territorio del Alto Minho. Los resultados obtenidos difieren sustancialmente de la información cartográfica oficial, en lo que respecta a la precisión cartográfica, el número de perímetros de incendio (3 873) y la superficie quemada (179 283 hectáreas). Si por un lado la cartografía oficial no incluía zonas afectadas por fuegos, por otro incluye zonas que según las imágenes de satélite y ortofotos utilizadas en este estudio no parecen haber ardido. Parte de los perímetros detectados en este estudio y ausentes de la cartografía oficial pueden ser el resultado de incendios que no supusieron la intervención de los equipos de extinción, por lo que no están registrados en la base de datos de incendios forestales. En otros casos, la omisión se debe a los procesos cartográficos, que a veces tienen lugar semanas o meses después del fuego. Hay que señalar que la cartografía oficial de las zonas quemadas se optimizó para los incendios estivales, basándose en una única imagen de satélite obtenida tras el supuesto final de la temporada de incendios (Oliveira et al., 2012); en cambio en la presente investigación se analizaron todas las imágenes de satélite de cada año.

En cuanto a los perímetros que delimitan zonas quemadas en la cartografía oficial, pero que no fueron identificados como tales en este estudio, la explicación puede deberse a errores de detección e interpretación derivados de procesos cartográficos automáticos y no supervisados, o de levantamientos de campo basados en interpretación cartográfica (a partir de ortofotos y mapas militares). Otro factor que puede haber contribuido a las grandes diferencias en los resultados cartográficos es la limitada accesibilidad de las imágenes de satélite en el pasado, especialmente en la primera década, en comparación con la actualidad. Además, la complementariedad mediante la superposición de otras fuentes cartográficas, como los focos de calor de los sensores de satélite MODIS y VIIRS y la producción periódica de ortofotos, permitió apoyar el trabajo en la identificación más precisa de las superficies quemadas y su datación, así como la identificación de los perímetros de los incendios rurales registrados en la base de datos oficial. La utilización de estos datos oficiales con fines de planificación y gestión de incendios en el territorio a escala comarcal y municipal, o con fines de investigación, recomienda su validación y corrección previa para reducir posibles errores de interpretación.

Los principales errores identificados en la cartografía oficial se deben principalmente a la insuficiente precisión en la delimitación de los perímetros de los incendios, la ausencia de superficies quemadas, la falta de criterios para integrar las distintas superficies afectadas por el incendios (con la asignación de medios de extinción) y por otros fuegos (quemas pastorales y quemas prescritas) y la ausencia de datos integrados con los registros de base estadística de incendios forestales de cada perímetro de incendio. El aumento del número de satélites y la mejora de los sensores radiométricos en la última década, en particular la misión Sentinel-2, con una elevada recurrencia temporal para una misma región (intervalos de cinco días), así como el incremento de vuelos para la obtención de ortoimágenes, permiten realizar trabajos sistemáticos y cada vez más rigurosos sobre las zonas afectadas por los incendios a una escala mayor y adecuada para la ordenación del territorio (Navarro et al., 2017). La precisión cartográfica es fundamental, no sólo para identificar y caracterizar el régimen de fuego, sino también por las implicaciones y limitaciones para cualquier ciudadano, ya que el histórico cartográfico determina el mapa de peligrosidad de una zona, condicionando su uso y ocupación. La superposición de la cartografía con las fuentes de calor de los sensores MODIS y VIIRS es fundamental para la datación de aquellos fuegos que no implicaron la acción de medios de extinción y de los que no se tiene registro, ocurridos en las estaciones de otoño, invierno y primavera. Estos fuegos constituyen una fracción importante de la superficie quemada en la región de estudio y con efectos sobre la estructura del paisaje y sobre la acumulación y heterogeneidad espacial de los combustibles forestales y, en consecuencia, asumen un papel en la propagación de los incendios estivales.

Esta reconstrucción histórica, mediante la delineación manual de perímetros y la superposición de diferentes fuentes de datos relacionados con los fuegos, permitió clasificar y cuantificar las superficies quemadas anualmente en el Alto Minho entre 2001 y 2020 e identificar su estacionalidad, bien como su relación con el uso del fuego en la renovación de pastos asociado a la producción ganadera.

Además de los incendios forestales, clasificados en esta investigación como incendios forestales no estacionales y estacionales (de otoño a primavera y de verano, respectivamente), suprimidos activamente por definición, se identificaron y se cartografiaron los fuegos de otoño a primavera que no fueron objeto de acciones de extinción. El atlas oficial de incendios portugués permite un análisis general de la pirogeografía, pero las omisiones y el detalle variable en la delimitación y clasificación de cada mancha quemada disminuyen el rigor y la precisión de la caracterización del régimen de incendios. Esta condición será determinante en relación con las métricas de frecuencia, extensión, estacionalidad y distribución del tamaño, especialmente cuando los incendios fuera del verano son una característica relevante y a escalas más locales. Esto fue particularmente bien ilustrado en este estudio de caso, a la escala de la parroquia de Castro Laboreiro y Lamas de Mouro, dentro del territorio del Parque Nacional de Peneda-Gerês, con un régimen de fuego distinto de la mayor parte del resto del Alto Minho pero que no está retratado por el atlas oficial de incendios.

La superficie media anual quemada en el territorio del Alto Minho durante 2001-2020 es el doble del cuantificado en un estudio anterior (Oliveira et al., 2012) para el periodo 1975-2005, lo que probablemente indica un cambio en el régimen de fuego pero también refleja una mayor detección y detalle cartográfico en este trabajo de investigación sobre la actividad del fuego de otoño a primavera. Es importante destacar que el 20% de toda la superficie quemada cuantificada en este estudio corresponde supuestamente a quemas pastorales y que el intervalo de retorno del fuego de 13 años, estimado para la región, es sustancialmente menor que en estudios anteriores, respectivamente 22 años (Oliveira et al., 2012) y 17 años (Fernandes et al., 2012). Así, los fuegos asociados a las quemas pastorales dominan el régimen de fuego en ciertos paisajes del Alto Minho, expresando la persistencia de prácticas dichas tradicionales de uso del fuego para la gestión de los pastos, particularmente donde existe ganadería extensiva en mayor cantidad. Contrariamente a lo que cabría esperar, se ha observado que las quemas pastorales tienen, en general, un ciclo más largo que los incendios estivales, con intervalos de retorno respectivos de 13 y 11 años. Sin embargo, la frecuencia de la primera es mayor en los paisajes donde prevalece la quema pastoral y escasean los incendios forestales estivales. Por otro lado, teniendo en cuenta las necesidades de renovación de los pastizales, esto refleja una práctica conservadora y parsimoniosa, ya que el aumento de la calidad nutricional de la regeneración de arbustos tras el incendio es de corta duración (Rego et al., 1988).

La cantidad de ganado disminuyó sustancialmente en gran parte del Alto Minho entre 1999 y 2019, continuando las tendencias a largo plazo que comenzaron en la década de 1940 (Fernandes et al., 2014; Torres-Manso et al., 2014). La pérdida de ganado y las restricciones legales cada vez más represivas sobre el uso del fuego por parte de las comunidades locales pueden haber reducido las quemas pastorales, principalmente de baja intensidad y poca gravedad (Manso et al., 2010), contribuyendo potencialmente al aumento de la superficie perturbada por incendios grandes y graves, como en las parroquias costeras y occidentales de la región. Se ha demostrado que la pirodiversidad, es decir, la memoria del fuego precedente que crea patrones espaciales más heterogéneos y de grano más fino en la vegetación, limita el desarrollo de grandes incendios en los lugares donde las quemas pastorales son comunes en Portugal (Fernandes et al., 2016). Se esperaba que los fuegos asociados a la ganadería extensiva, esto es, los fuegos de otoño a primavera, fueran más frecuentes allí donde la carga animal es mayor, dada la necesidad de utilizar el fuego para renovar los pastos de interés para el forraje de los animales. Las tendencias generales observadas en esta investigación fueron que (i) menos ganado equivalía a más incendios forestales estivales y menos incendios desde el otoño hasta la primavera, pero la tendencia venía determinada sobre todo por los extremos superior e inferior de la cantidad de ganado, y (ii) que la presencia de más ganado aumentaba la superficie total quemada. De hecho, las relaciones entre el fuego y el ganado respondían a patrones todavía más complejos. A partir del análisis de los datos obtenidos se verificó que aunque las quemas pastorales son más frecuentes cuando los brezales ocupan una mayor fracción del paisaje, el hecho de que haya más brezales en el paisaje no implica que haya más ganado y más quemas pastorales.. Del mismo modo, la alta probabilidad de quema por incendios forestales de verano se limita a niveles de ganadería bajos o intermedios, pero puede coincidir con altos niveles de quema pastoral.

Así, en esta investigación se ha podido constatar que, la percepción común de que las quemas pastorales son la causa principal del aumento de los graves incendios estivales carece de fundamento. Los incendios pastorales se producen en invierno o preceden a la estación de lluvias a principios de otoño, cuando el fuego se propaga con mayor eficacia en matorrales dominados por especies pobres en combustible muerto, a saber *Cytisus sp.* (*pers. observ.*). El mantenimiento de los fuegos de otoño a primavera está condicionado al sistema productivo de la ganadería extensiva y ambas tienen un papel considerable en la conservación del paisaje, modelando el mosaico de brezales y la distribución de especies y hábitats de interés pastoril o de conservación, como el lobo ibérico (González et al., 2022; Izco et al., 2006; Lino et al., 2019; Pastro et al., 2014).

La prohibición del uso del fuego para la renovación de los pastos por parte de la comunidad no impide que se utilice ilegalmente, como demuestran ejemplos de otras regiones del mundo, por ejemplo Coughlan (2016). Las comunidades, como de la parroquia de Castro Laboreiro y Lamas de Mouro se vieron obligadas a adaptar el uso del fuego, abandonando la práctica de "pastorear el fuego" (como se dice localmente) y de vigilar el fuego. En su lugar, eligieron días con condiciones meteorológicas y de humedad del combustible propicias para la autoextinción del fuego. Pero estos fuegos pueden convertirse en importantes incendios forestales en condiciones meteorológicas más propensas al fuego y a las condiciones clandestinas en las que se llevan a cabo tratando de huir de la ley y de la burocracia.

Poco se sabe sobre el régimen de fuego asociado al uso tradicional del mismo, y qué efectos tiene sobre el paisaje y la dinámica de los combustibles. Considerando los cambios en el paisaje del Alto Minho entre 2000 y 2018 (con base en las cartas oficiales de ocupación del suelo), esta investigación también permitió contribuir a la consolidación del conocimiento científico sobre el régimen de fuegos considerando el uso del fuego por las comunidades pastorales. De los datos obtenidos y tratados se destaca que sólo el 23,5% de los polígonos identificados pertenecen a fuegos iniciados en la época de incendios, pero que representan el 61,8% de la superficie quemada. Esta disparidad entre periodos es indicativa no sólo de la importancia que el fuego como herramienta de gestión sigue teniendo en el territorio, sino también de los menores daños potenciales provocados por los incendios no estacionales. Por otro lado, la superficie quemada por incendios no estacionales es superior a la quemada por incendios estacionales en el 61,1% de los años estudiados, pero sólo en aquellos que tienen una superficie anual quemada inferior al valor medio anual. Esta observación fue utilizada cómo argumento por Barreiro y Rodrigues (2022) para afirmar que el empoderamiento de las comunidades tradicionales que les permite utilizar el fuego para la gestión del paisaje debe erradicarse para evitar los costes de los incendios forestales. Sin embargo, desconectar la distribución porcentual de la variación absoluta en un universo más amplio de años genera conclusiones erróneas, como la expuesta por los autores, y motiva opciones políticas que no sólo tendrán impactos perjudiciales sobre el régimen de fuego, sino que a medio plazo pueden conducir al efecto contrario. Basado en datos de la base EFFIS, Rodrigues et al. (2013) encontraron un aumento significativo del número de incendios forestales en el Alto Minho, pero no en superficie quemada. Turco et al. (2016) no encontró tendencias significativas en el número de incendios en los meses de verano, basándose en datos oficiales de Portugal, pero sí incrementos en el resto de meses del año.

Los fuegos ocurridos en la época de incendios, entre 2000 y 2018, afectaron más de un tercio del territorio, representando poco más del 78% de la superficie total quemada. Igualmente, presentan una superficie más grande afectada por estos fuegos de forma recurrente, originando grandes incendios forestales. Por el contrario, los fuegos no estacionales, que se propagan entre otoño y primavera, afectan superficies más pequeñas, siendo mucho menores y con menor recurrencia. Los datos obtenidos en este estudio, demuestran que, a la escala regional, se verifica un alto nivel de estabilidad en la distribución de los tipos de combustibles más representativos en el Alto Minho entre 2000 y 2018, a pesar de la elevada superficie quemada en el mismo período. Sin embargo, es de destacar que más de la mitad de la superficie quemada afectó los tipos de combustible típicos asociados a las masas de pino marítimo, seguidos de matorrales altos. Por el contrario, los tipos de combustible asociados a las masas forestales de eucalipto y frondosas fueron los que más superficie ganaron en los paisajes afectados por el fuego. Según el periodo en el que ocurrieron los fuegos, también se encontraron diferencias, tanto en superficie como en el flujo entre tipos de combustible. La distribución de la superficie quemada durante la temporada de incendios por tipos de combustible es más heterogénea que la determinada mediante el análisis realizado sobre las superficies quemadas globales. Al contrario, los fuegos no estacionales mostraron un patrón completamente distinto, propagándose sobre todo en tipos de combustible asociados a matorrales.

La concentración de la superficie quemada por incendios no estacionales en este tipo de combustible no es sorprendente, ya que la mayoría de estos incendios tienen por objeto aumentar la disponibilidad de forraje para el ganado mediante la quema de matorrales (Coughlan, 2015; Múgica et al., 2021; Ruiz-Mirazo et al., 2012; San Emeterio et al., 2016). De hecho, la contribución de los fuegos no estacionales a los cambios entre los tipos de combustible es mucho menor que la observada en las superficies quemadas durante la temporada de incendios, excepto en el tipo de combustible que representa mosaicos de herbáceas y arbustos bajos dispersos, característicos de las superficies quemadas regularmente por fuegos de baja intensidad.

Cabe aún señalar que la clase de ocupación del suelo asociada a frondosas reclasificada como tipo de combustible (F-FOL) también incluye invasoras exóticas como *Acacia spp*. (Silva et al., 2011), cuya expansión se debe esencialmente al efecto de perturbaciones ecológicas e inducidas por la gestión, incluyéndose los incendios forestales (Moreira et al., 2013). Este aumento en el tipo asociado a las frondosas también puede estar relacionado con procesos de colonización de la vegetación natural, incluidos los árboles, tras el abandono de la actividad agrícola anterior, en particular cuando las transiciones observadas surgen del tipo asociado a comunidades vegetales herbáceas. El abandono de la agricultura y la disminución de la intensidad del pastoreo provocan la invasión de arbustos y/o la expansión de los árboles (Komac et al., 2013; Palombo et al., 2013; Romero-Calcerrada and Perry, 2004; Sanjuán et al., 2018), dando lugar a la acumulación de combustible y a la homogeneización de la estructura del combustible a escala local y regional. Además, el efecto de excluir el fuego del paisaje está contribuyendo a la homogeneidad espacial del territorio y a la acumulación de combustible, como se ha observado en otros lugares (Airey-Lauvaux et al., 2022; Iglesias et al., 2022; Mori and Lertzman, 2011). Los paisajes culturales menos heterogéneos debido a la interrupción de las quemas culturales conducen a la invasión de combustibles más inflamables (Christianson et al., 2022; Johansson et al., 2012; Moreira et al., 2023), principalmente allí donde se ha prohibido el fuego como apoyo a las prácticas culturales. El carácter distintivo de los mosaicos de los paisajes culturales de la región del Alto Minho está cambiando gradualmente, con la excepción de las zonas montañosas donde aún se mantienen prácticas agro-silvopastoriles ancestrales. El paisaje de esta región, semejante a muchos otros territorios del noroeste Ibérico, ha convivido y convive con el fuego desde hace miles de años. El paisaje es resultado de esa perturbación recurrente pero no aislada de otras prácticas y usos tradicionales tan importantes para el mantenimiento de los hábitats y de los ecosistemas dependientes. Por último, la perdida del uso del fuego por las comunidades rurales, resultante de las sucesivas limitaciones o prohibiciones determinadas por la legislación, ha desvirtuado el ancestral uso tradicional del fuego y lo convirtió en "fuego proscrito", con múltiples efectos que contribuyen a la ocurrencia de incendios cada vez más complejos: (i) permite la invasión de tipos de combustibles más inflamables (Mariani et al., 2022); (ii) la marginación de estas prácticas culturales favorece el aumento de las quemas ilegales que no se controlan adecuadamente (Souza et al., 2022); y (iii) aunque el fuego se considera *"(...) un elemento de nuestra cultura agrícola*", como afirma Coutinho (2009, p.35), los conocimientos que guiaban su uso correcto se pierden progresivamente (Salgueiro, 2010). Perder el uso tradicional del fuego sobre el paisaje, es también perder el paisaje al albur de los grandes incendios forestales.

CONCLUSIONES DE LA TESIS Y FUTURAS LÍNEAS DE INVESTIGACIÓN

Este último apartado se obtiene a partir de los resultados más relevantes y de la discusión de los mismos y del aprendizaje alcanzado en las fases anteriores. Finalmente se identifican futuras líneas de investigación.

CONCLUSIONES

Diecisiete siglos de aplicación de toda la suerte de restricciones y regulaciones sobre el uso del fuego agrosilvopastoril no han disuadido a las comunidades sobre el uso tradicional del fuego. Por otro lado, también se ha constatado que, en los últimos dos siglos, la legislación sobre el uso del fuego no consideró sus diferentes necesidades, períodos y fines, ignorando las relaciones del uso del fuego con las prácticas tradicionales y la necesidad de mantenerlas. Por ello, y siguiendo el ejemplo de varios países, es importante revisar el marco legal sobre el uso del fuego por parte de las comunidades tradicionales, fomentando la formación, integrando los conocimientos tradicionales y responsabilizando su uso. Aunque existían conflictos derivados de los diferentes usos del fuego, estas prácticas coexistieron en un ambiente de tolerancia hasta la segunda mitad del siglo XIX. Con las reformas liberales que condujeron a la desamortización de las tierras comunales y a la imposición de una agricultura basada en el cereal, los conflictos sobre el uso del fuego no hicieron sino aumentar. Varios autores de finales de ese siglo culparon las comunidades tradicionales por la deforestación y por el uso abusivo del fuego. Sin embargo, los registros históricos apuntan a la creciente demanda de carbón vegetal para las máquinas de vapor de la industria emergente y para el consumo doméstico en las grandes ciudades, así como a la expansión de la agricultura cerealista, por lo que constituyeron condiciones determinantes en el cambio de los usos y ocupación de los paisajes y, el fuego, sólo ha sido una herramienta de trabajo para responder a las nuevas solicitudes. Todos estos factores provocaron cambios en el ancestral sistema agrosilvopastoril, que permaneció prácticamente inalterado durante siglos y cuyos cambios tendrán consecuencias futuras en los paisajes portugueses.

El siglo XIX estuvo marcado por una nueva sociedad burguesa, influyente en los gobiernos y con intereses en la apropiación de las tierras comunales para sus propios fines, como se materializó con la creación del latifundio y la desamortización de los montes comunales. Como ha ocurrido en otros países (EEUU, Australia, Canadá), la forma de desempoderar a las comunidades tradicionales o indígenas fue condicionar y prohibir sus prácticas, siendo el uso del fuego el principal objetivo. De este modo, se cortó su fuente de energía y se prohibió su herramienta de trabajo. La ilegalización del uso del fuego por parte de las comunidades tradicionales portuguesas comenzó en el siglo XIX, de modo que los conocimientos ancestrales se disolvieron en el siglo siguiente, por lo que hoy sólo nos restan vestigios del fuego del pasado.

El despoblamiento, aislamiento y envejecimiento de la población rural no es más que el resultado de los cambios de la sociedad, de forma más contundente a partir de la segunda mitad del siglo XX, con el agravamiento en las últimas décadas. Las políticas actuales de prevención de incendios, en particular después del año 2017, insisten sobre todo en medidas a la escala del ciudadano, especialmente en la gestión de los combustibles en las zonas de interfaz urbano-forestal. Esta obligación es responsabilidad de los propietarios rurales, siendo fiscalizados continuamente por las autoridades policiales, lo que genera una gran presión sobre una población envejecida y con escasos recursos económicos. El fuego sigue siendo la herramienta más accesible para esta población a la hora de gestionar los combustibles y los residuos resultantes de las acciones de prevención. El número de incidentes registrados por el uso del fuego acompaña esta presión legislativa y de fiscalización. El mayor número de incidentes se produce en el sector de la población rural más envejecido, y por tanto más vulnerable a los riesgos. Este uso emerge de prácticas tradicionales en la gestión de residuos agrícolas y forestales. Por lo tanto, es esencial que una mayor presión legislativa y de fiscalización vaya acompañada también de más actividades pedagógicas y de un mayor apoyo en la prevención de riesgos, sobre todo entre las poblaciones más vulnerables.

Si bien la cartografía oficial de Portugal permite un análisis global a escala nacional, el trabajo a escala regional y municipal requiere una cartografía más detallada y rigurosa. Actualmente, el fácil acceso a las más diversas fuentes de satélites e a series históricas de ortoimágenes permite asegurar una cartografía sistemática y cada vez más rigurosa de las superficies quemadas. La precisión cartográfica es esencial en la identificación del régimen de fuego, en la evaluación de sus impactos y también en las implicaciones y limitaciones para la ciudadanía, ya que condiciona el uso y ocupación del suelo, en el ámbito de los instrumentos de planificación y gestión del territorio. Por lo tanto, es esencial proceder, para todo el territorio nacional, a una reconstrucción histórica detallada de todas las superficies afectadas por fuegos, lo que implica la creación de normas técnicas para el proceso de cartografía y su clasificación. Esta reconstrucción rigurosa y su clasificación permite una caracterización precisa del régimen de incendios a una escala suficiente para la gestión del fuego y del territorio.

Los fuegos de otoño a primavera, integrados en la producción ganadera y en la gestión cinegética, desempeñan un papel importante en la conservación del paisaje mosaico. Estos incendios, asociados sobre todo a la renovación de los pastos, son fuegos de baja intensidad y severidad que se autoextinguen. Dadas las limitaciones legales, estos fuegos son “fuegos proscritos”, por lo que, si no se vigilan, pueden convertirse en incendios forestales y exigir la intervención de los equipos de extinción. Esto impone la necesidad de regular legalmente los fuegos pastorales, garantizando su responsabilidad, preservando los conocimientos tradicionales y manteniendo el paisaje mosaico. Cabe destacar que erradicar el fuego de los paisajes no sólo es imposible, sino también indeseable. En las últimas décadas, las políticas de exclusión total del fuego sólo han contribuido a una selección de incendios cada vez más grandes y destructivos, en lugar de garantizar la gestión de fuegos de baja intensidad que cumplan los objetivos de gestión del territorio y sostenibilidad de los ecosistemas.

Los incendios asociados a las denominadas prácticas tradicionales, como la renovación de pastos, especialmente los que se producen en las estaciones de otoño a primavera, son de menor tamaño, son más selectivos en cuanto a los tipos de combustible, predominando en zonas de tipos asociados al matorral, e inducen cambios menos perceptibles en el paisaje. Por otro lado, los incendios de la estación estival son menos selectivos, son de grandes dimensiones y tienen un destacado papel en la homogeneización de los tipos de combustible. El resultado de estos grandes incendios, más recurrentes, es la ampliación de los tipos de combustible que incluyen especies invasoras, así como la pérdida considerable de tipos asociados a las masas de pino marítimo. A su vez, se observa un notable aumento de los tipos asociados a las masas de eucalipto en las zonas afectadas por los incendios estivales. Este cambio se debe principalmente a la oportunidad de sustitución post-incendio de las masas de pino marítimo por eucalipto por parte de los propietarios rurales. El paisaje, como consecuencia de la pérdida de los usos tradicionales, incluyendo el uso del fuego y, de los cambios de ocupación del suelo, se está volviendo más homogéneo y más susceptible a los incendios. Por otro lado, la presencia de este uso del fuego, es también una de las principales causas de los incendios rurales. Sin embargo, cómo se pudo constatar, el simple hecho de que constituya una de las principales causas de ignición no implica directamente que los daños causados por estos incendios sean elevados. Para evitar grandes incendios, con el potencial de inducir cambios en el paisaje y amenazar a personas y propiedades, las políticas de gestión de incendios tendrán que satisfacer las necesidades de los pastores y ganaderos, convirtiéndolos en aliados en la consecución de los objetivos de gestión de paisajes más resilientes a los cambios climáticos y los grandes incendios forestales.

En resumen, interesa destacar que no se debe analizar la evolución de los grandes incendios en un determinado paisaje sin considerar el impacto o el papel de todos los fuegos que afectan a ese territorio. Del mismo modo, hay que tener en cuenta los impactos a lo largo del tiempo de las políticas que condicionan las dinámicas de ocupación y usos del suelo, así como la pérdida de los usos del fuego tradicional.

FUTURAS LÍNEAS DE INVESTIGACIÓN

Las futuras líneas de investigación que se abren tras la realización de esta tesis son muy amplias, debido al propio ámbito de la investigación. Sin embargo, la propuesta principal, como base para todos los estudios futuros que impliquen la caracterización del régimen de incendios y sus impactos, debe basarse en la reconstrucción y clasificación histórica de todas las superficies afectadas por el fuego en todo el territorio nacional. Por lo tanto, la metodología presentada en esta tesis puede ser implementada para asegurar la precisión deseable, tanto en términos de investigación como en términos de instrumentos de planificación y gestión del territorio.

En particular, se proponen líneas de investigación que pueden incluso ser objeto de futuras tesis, bien utilizando la información producida, bien mediante la metodología presentada en esta tesis:

- Evaluar la severidad y la recuperación post-fuego resultantes de las quemas pastorales y compararlas con los incendios forestales.

- Evaluar los incidentes con víctimas en el uso del fuego por parte de la población rural en la gestión del combustible a nivel de otros países europeos. Asimismo, investigar el impacto de las detenciones y sanciones aplicadas a la población por el uso del fuego cuando provoca negligentemente incendios forestales o agrícolas.

- Identificar y analizar el efecto de las infraestructuras en la evolución de la lucha contra los grandes incendios forestales, así como evaluar el condicionamiento humano en la propagación de los grandes incendios forestales.

- Evaluar el estado fenológico del paisaje a una escala más fina y su correlación con los tipos de combustible y los diferentes fuegos que manifiestan el paisaje.

REFERENCIAS

REFERENCIAS GENÉRICAS (TESIS)

Abel, M. (1988). Os baldios portugueses em período de transição (1820 - 1910). *Revista de História. Centro de História Da Universidade Do Porto*, *VIII*, 339–343. https://ler.letras.up.pt/uploads/ficheiros/6459.pdf

Agência para a Gestão Integrada de Fogos Rurais (AGIF). (2020). 20-30 National Plan for Integrated Rural Fire Management (EN). In *Resolution of the Council of Ministers nº 45-A/2020, of June 16th*. https://www.agif.pt/app/uploads/2020/12/20-30_NPIRFM_littledoc.pdf

Aira Rodríguez, M., & Ramil Rego, P. (1995). Datos paleobotánicos del norte de Portugal (Baixo Minho) estudio polínico y paleocarpológico. *Lagascalia*, *18*(1), 25–38. http://hdl.handle.net/11441/62159

Airey-Lauvaux, C., Pierce, A. D., Skinner, C. N., & Taylor, A. H. (2022). Changes in fire behavior caused by fire exclusion and fuel build-up vary with topography in California montane forests, USA. *Journal of Environmental Management*, *304*. https://doi.org/10.1016/j.jenvman.2021.114255

Almeida, M. A. (2020). The use of rural areas in Portugal: Historical perspective and the new trends. *Revista Galega de Economia*, *29*(2 Special issue), 1–17. https://doi.org/10.15304/rge.29.2.6750

Armatas, C. A., Venn, T. J., McBride, B. B., Watson, A. E., & Carver, S. J. (2016). Opportunities to utilize traditional phenological knowledge to support adaptive management of social-ecological systems vulnerable to changes in climate and fire regimes. *Ecology and Society*, *21*(1). https://doi.org/10.5751/ES-07905-210116

Bardin, L. (1995). *Análise de conteúdo*. Edições 70.

Barreiro, P., & Rodrigues, P. (2022). COST MANAGEMENT: THE USE OF FIRE FOR PASTURE RENEWAL IN ALTO MINHO. *Revista Floresta*, *53*(1), 46–55. https://doi.org/10.5380/rf.v53

Bassi, S., & Kettunen, M. (2008). *FOREST FIRES: causes and contributing factors in Europe*.

Berkes, F. (2012). *Sacred Ecology Third Edition* (3rd ed.). Routledge.

Bettencourt, A. M. S. (2008). *Lições de Pré-História Peninsular*. Universidade do Minho. https://hdl.handle.net/1822/45270

Bowman, D. M. J. S., Balch, J., Artaxo, P., Bond, W. J., Cochrane, M. A., D'Antonio, C. M., Defries, R., Johnston, F. H., Keeley, J. E., Krawchuk, M. A., Kull, C. A., Mack, M., Moritz, M. A., Pyne, S., Roos, C. I., Scott, A. C., Sodhi, N. S., & Swetnam, T. W. (2011). The human dimension of fire regimes on Earth. In *Journal of Biogeography* (Vol. 38, Issue 12, pp. 2223–2236). https://doi.org/10.1111/j.1365-2699.2011.02595.x

Bowman, D. M. J. S., Balch, J. K., Artaxo, P., Bond, W. J., Carlson, J. M., Cochrane, M. A., Antonio, C. M. D', Defries, R. S., Doyle, J. C., Harrison, S. P., Johnston, F. H., Keeley, J. E., Krawchuk, M. A., Kull, C. A., Marston, J. B., Moritz, M. A., Prentice, I. C., Roos, C. I., Scott, A. C., … Pyne, S. J. (2009). Fire in the Earth System. *Science*, *324*, 481–484. www.sciencemag.org

Butz, R. J. (2009). Traditional fire management: historical fire regimes and land use change in pastoral East Africa. *International Journal of Wildland Fire*, *18*(4), 442. https://doi.org/10.1071/wf07067

Caetano, M., Igreja, C., & Marcelino, F. (2018). *Especificações técnicas da Carta de Uso e Ocupação do Solo (COS) de Portugal Continental para 1995, 2007, 2010 e 2015*.

Casau, M., Ferreira Dias, M., Teixeira, L., Matias, J. C. O., & Nunes, L. J. R. (2022). Reducing Rural Fire Risk through the Development of a Sustainable Supply Chain Model for Residual Agroforestry Biomass Supported in a Web Platform: A Case Study in Portugal Central Region with the Project BioAgroFloRes. *Fire*, *5*(3). https://doi.org/10.3390/fire5030061

Celaya, R., Ferreira, L. M. M., Lorenzo, J. M., Echegaray, N., Crecente, S., Serrano, E., & Busqué, J. (2022). Livestock Management for the Delivery of Ecosystem Services in Fire-Prone Shrublands of Atlantic Iberia. In *Sustainability (Switzerland)* (Vol. 14, Issue 5). MDPI. https://doi.org/10.3390/su14052775

Christianson, A. C., Sutherland, C. R., Moola, F., Gonzalez Bautista, N., Young, D., & MacDonald, H. (2022). Centering Indigenous Voices: The Role of Fire in the Boreal Forest of North America. In *Current Forestry Reports* (Vol. 8, Issue 3, pp. 257–276). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s40725-022-00168-9

Chuvieco, E., & Congalton, R. G. (1988). Mapping and inventory of forest fires from digital processing of tm data. *Geocarto International*, *3*(4), 41–53. https://doi.org/10.1080/10106048809354180

Colaço, M. C. (2017). *Bases para uma educação ambiental orientada para a diminuição do risco e aumento da resiliência das comunidades aos incêndios florestais em Portugal* [PhD Thesis]. Universidade de Santiago de Compostela.

Colaço, M. C. (2019). Reaprender a vivir cos incendios forestais nun contexto de cambio climático. In Proxecto Batefogo - Coord. (Ed.), *Arbores que non arden: As mulleres na prevención de incendios forestais* (pp. 127–146). Editora Catro Ventos.

Congedo, L. (2016). *Semi-Automatic Classification Plugin Documentation. Release 6.0.1.1*. . (2016). Semi-Automatic Classification Plugin Documentation. Release 6.0.1.1. https://doi.org/10.13140/RG.2.2.29474.02242/1

Connor, S. E., Vannière, B., Colombaroli, D., Anderson, R. S., Carrión, J. S., Ejarque, A., Gil Romera, G., González-Sampériz, P., Hoefer, D., Morales-Molino, C., Revelles, J., Schneider, H., van der Knaap, W. O., van Leeuwen, J. F., & Woodbridge, J. (2019). Humans take control of fire-driven diversity changes in Mediterranean Iberia's vegetation during the mid–late Holocene. *The Holocene*, *29*(5), 886–901. https://doi.org/https://doi.org/10.1177/0959683619826652

Coogan, S. C. P., Robinne, F. N., Jain, P., & Flannigan, M. D. (2019). Scientists' warning on wildfire — a canadian perspective. In *Canadian Journal of Forest Research* (Vol. 49, Issue 9). https://doi.org/10.1139/cjfr-2019-0094

Coughlan, M. R. (2013). Errakina: Pastoral fire use and landscape memory in the Basque region of the French Western Pyrenees. *Journal of Ethnobiology*, *33*(1), 86–104. https://doi.org/10.2993/0278-0771-33.1.86

Coughlan, M. R. (2015). Traditional fire-use, landscape transition, and the legacies of social theory past. *Ambio*. https://doi.org/10.1007/s13280-015-0643-y

Coughlan, M. R. (2016). Wildland Arson as Clandestine Resource Management: A Space–Time Permutation Analysis and Classification of Informal Fire Management Regimes in Georgia, USA. *Environmental Management*, *57*(5), 1077–1087. https://doi.org/10.1007/s00267-016-0669-3

Coutinho, J. M. P. (2009). *Incêndios florestais: causas e atitudes*. Númena.

D'Amelio, J. (2022). *Current status of Prescribed Burning Laws in Italy, Spain, and Portugal: A Comparative Study* [Dissertation to obtain a master's degree in Mediterranean Forestry and Natural Resources Management]. Instituto Superior Agronomia.

Davidson-Hunt, I. J. (2003). Indigenous Lands Management, Cultural Landscapes and Anishinaabe People of Shoal Lake, Northwestern Ontario, Canada. *Environments*, *31*(1), 21–41.

de Diego, J., Fernández, M., Rúa, A., & Kline, J. D. (2023). Examining socioeconomic factors associated with wildfire occurrence and burned area in Galicia (Spain) using spatial and temporal data. *Fire Ecology*, *19*(1), 18. https://doi.org/10.1186/s42408-023-00173-8

de Diego, J., Rúa, A., & Fernández, M. (2021). Vulnerability variables and their effect on wildfires in Galicia (Spain). a panel data analysis. *Land*, *10*(10). https://doi.org/10.3390/land10101004

de Oliveira, E., Lobo-do-Vale, R., & Colaço, C. (2022). The last landscape gardeners: Incident analysis of traditional burns in Portugal. *Advances in Forest Fire Research 2022*, 792–795. https://doi.org/10.14195/978-989-26-2298-9_120

DGF. (2001). *Inventário Florestal Nacional, Portugal Continental. 3ª Revisão, 1995-1998.*

DGT. (2019). *Especificações técnicas da Carta de Uso e Ocupação do Solo (COS) de Portugal Continental para 2018*. http://www.ghbook.ir/index.php?name=فرهنگ و رسانه های نوین&option=com_dbook&task=readonline&book_id=13650&page=73&chkhashk=ED9C9491B4&Itemid=218&lang=fa&tmpl=component

Díaz-Fierros, F. (2019). Forest fires in Galicia and Portugal: an historical overview. *Territorium: Revista Portuguesa de Riscos, Prevenção e Segurança*, *26 (I)*, 97–114. https://doi.org/10.14195/1647-7723_26-1_7

Eriksen, C. (2007). Why do they burn the "bush"? Fire, rural livelihoods, and conservation in Zambia. In *The Geographical Journal* (Vol. 173, Issue 3).

Fábregas Valcarce, R. (1988). Cronología y periodización del megalitismo en Galicia y Portugal. *Espacio, Tiempo y Forma, Serie I, Prehistoria*, *I*, 279–291.

Fábregas Valcarce, R., Fernández-Rodríguez, C., & Ramil-Rego, P. (1997). La adopción de la economía productora en el Noroeste Ibérico. In A. Rodríguez Casal (Ed.), *O Neolítico Atlántico e as Orixes do Megalitismo* (pp. 463–484). Universidad de Santiago de Compostela. https://www.researchgate.net/publication/269910826

Fábregas Valcarce, R., & Otero, J. S. (1999). El proceso de neolitización en Galicia. *Saguntum: Papeles Del Laboratorio de Arqueología de Valencia*, *Nº Extra 2*, 541–548. http://hdl.handle.net/10347/24607

Fernandes, P., Gonçalves, H., Loureiro, C., Fernandes, M., Costa, T., Cruz, M. G., & Botelho, H. (2009). Modelos de Combustível Florestal para Portugal. In *Poster* (pp. 348–354). https://www.researchgate.net/publication/261708410

Fernandes, P. M., Davies, G. M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C. R., Vega, J. A., & Molina, D. (2013). Prescribed burning in southern Europe: Developing fire management in a dynamic landscape. In *Frontiers in Ecology and the Environment* (Vol. 11, Issue SUPPL. 1). https://doi.org/10.1890/120298

Fernandes, P. M., Loureiro, C., Guiomar, N., Pezzatti, G. B., Manso, F. T., & Lopes, L. (2014). The dynamics and drivers of fuel and fire in the Portuguese public forest. *Journal of Environmental Management*, *146*, 373–382. https://doi.org/10.1016/j.jenvman.2014.07.049

Fernandes, P. M., Loureiro, C., Magalhes, M., Ferreira, P., & Fernandes, M. (2012). Fuel age, weather and burn probability in Portugal. *International Journal of Wildland Fire*, *21*(4), 380–384. https://doi.org/10.1071/WF10063

Fernandes, P. M., Monteiro-Henriques, T., Guiomar, N., Loureiro, C., & Barros, A. M. G. (2016). Bottom-Up Variables Govern Large-Fire Size in Portugal. *Ecosystems*, *19*(8), 1362–1375. https://doi.org/10.1007/s10021-016-0010-2

Ferreira-Leite, F., Bento-Gonçalves, A., Lourenço, L., & Úbeda, X. (2012). Problemas Metodológicos no estudo dos incêndios florestais em Portugal Continental. O Caso dos Grandes Incêndios Florestais. In Dominic Royé, José Antonio Aldrey Vázquez, Marcos Valcárcel Díaz, Miguel Pazos Otón, & María José Piñeira Mantiñán (Eds.), *XIII Coloquio Ibérico de Geografia* (pp. 848–857).

Ganteaume, A., Camia, A., Jappiot, M., San-Miguel-Ayanz, J., Long-Fournel, M., & Lampin, C. (2013). A review of the main driving factors of forest fire ignition over Europe. *Environmental Management*, *51*(3), 651–662. https://doi.org/10.1007/s00267-012-9961-z

González, T. M., González-Trujillo, J. D., Muñoz, A., & Armenteras, D. (2022). Effects of fire history on animal communities: a systematic review. In *Ecological Processes* (Vol. 11, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s13717-021-00357-7

González-Hidalgo, M. (2023). Affected by and affecting forest fires in Sweden and Spain: A critical feminist analysis of vulnerability to fire. *Sociologia Ruralis*. https://doi.org/10.1111/soru.12432

Graça, L. L. (1999). *Propriedade e agricultura: evolução do modelo dominante de sindicalismo agrário em Portugal*.

Henriques, S. de S. T. (2006). *Os consumos domésticos de energia em Portugal* [Master]. Universidade Técnica de Lisboa.

Honrado, J. P., Lomba, A., Alves, P., Aguiar, C., Monteiro-Henriques, T., Cerqueira, Y., Monteiro, P., & Barreto Caldas, F. (2017). Conservation Management of EU Priority Habitats after Collapse of Traditional Pastoralism: Navigating Socioecological Transitions in Mountain Rangeland. *Rural Sociology*, *82*(1), 101–128. https://doi.org/10.1111/ruso.12111

Huffman, M. R. (2013). The many elements of traditional fire knowledge: Synthesis, classification, and aids to cross-cultural problem solving in firedependent systems around the world. *Ecology and Society*, *18*(4). https://doi.org/10.5751/ES-05843-180403

Iglesias, M. C., Hermoso, V., Campos, J. C., Carvalho-Santos, C., Fernandes, P. M., Freitas, T. R., Honrado, J. P., Santos, J. A., Sil, Â., Regos, A., & Azevedo, J. C. (2022). Climate- and fire-smart landscape scenarios call for redesigning protection regimes to achieve multiple management goals. *Journal of Environmental Management*, *322*. https://doi.org/10.1016/j.jenvman.2022.116045

Instituto da Conservação da Natureza e das Florestas. (2022). *Sistema de Gestão Informação de Incêndios Florestais*. ICNF. https://fogos.icnf.pt/sgif2010/login.asp

Izco, J., Amigo, J., Ramil-Rego, P., & Díaz, R. (2006). Brezales: biodiversidad, usos y conservación. *Recursos Rurais*, *(2)*, *2*, 5–24. https://doi.org/https://doi.org/10.15304/rr.id5327

Johansson, M. U., Fetene, M., Malmer, A., & Granström, A. (2012). Tending for cattle: Traditional fire management in ethiopian montane heathlands. *Ecology and Society*, *17*(3). https://doi.org/10.5751/ES-04881-170319

Komac, B., Kefi, S., Nuche, P., Escós, J., & Alados, C. L. (2013). Modeling shrub encroachment in subalpine grasslands under different environmental and management scenarios. *Journal of Environmental Management*, *121*, 160–169. https://doi.org/10.1016/j.jenvman.2013.01.038

Lake, F. K., Wright, V., Morgan, P., McFadzen, M., McWethy, D., & Stevens-Rumann, C. (2017). Returning fire to the land: Celebrating traditional knowledge and fire. In *Journal of Forestry* (Vol. 115, Issue 5, pp. 343–353). Society of American Foresters. https://doi.org/10.5849/jof.2016-043R2

Lino, S., Sillero, N., Torres, J., Santos, X., & Álvares, F. (2019). The role of fire on wolf distribution and breeding-site selection: Insights from a generalist carnivore occurring in a fire-prone landscape. *Landscape and Urban Planning*, *183*, 111–121. https://doi.org/10.1016/j.landurbplan.2018.12.003

López-Rodríguez, G., Rodríguez-Vicente, V., & Marey-Pérez, M. F. (2021). Study of forest productivity in the occurrence of forest fires in Galicia (Spain). *Sustainability (Switzerland)*, *13*(15). https://doi.org/10.3390/su13158472

MacDonald, K. (2018). Fire-Free Hominin Strategies for Coping with Cool Winter Temperatures in North-Western Europe from Before 800,000 to Circa 400,000 Years Ago. *Paleo Anthropology*, *16*, 7–26. https://doi.org/10.4207/PA.2018.ART109

Manso, F. T., Bento, J., Botelho, H., Pinto, R., Ferreira, P., Magalhães, M., & Gomes, M. (2010). Avaliação de Características Regionais e Sazonais Inerentes ao Regime de Fogo e ao Pastoreio. *Silva Lusitana*, *18*(1), 27–45.

Marey-Pérez, M. F., Díaz-Varela, E., & Calvo-González, A. (2015). Does higher owner participation increase conflicts over common land? An analysis of communal forests in Galicia (Spain). *IForest*, *8*(AUG2015), 533–543. https://doi.org/10.3832/ifor1060-008

Mariani, M., Connor, S. E., Theuerkauf, M., Herbert, A., Kuneš, P., Bowman, D., Fletcher, M. S., Head, L., Kershaw, A. P., Haberle, S. G., Stevenson, J., Adeleye, M., Cadd, H., Hopf, F., & Briles, C. (2022). Disruption of cultural burning promotes shrub encroachment and unprecedented wildfires. In *Frontiers in Ecology and the Environment* (Vol. 20, Issue 5, pp. 292–300). John Wiley and Sons Inc. https://doi.org/10.1002/fee.2395

Mateus, P., & Fernandes, P. M. (2014). *Forest Fires in Portugal: Dynamics, Causes and Policies*. https://doi.org/10.1007/978-3-319-08455-8_4

Matos, A. C. de. (2002). Indústria e ambiente no século XIX. *Ler História*, *42*, 119–152. http://hdl.handle.net/10174/21480

Meira Castro, A. C., Nunes, A., Sousa, A., & Lourenço, L. (2020). Mapping the causes of forest fires in Portugal by clustering analysis. *Geosciences (Switzerland)*, *10*(2). https://doi.org/10.3390/geosciences10020053

Miller, A. M., & Davidson-Hunt, I. (2010). Fire, agency and scale in the creation of aboriginal cultural landscapes. *Human Ecology*, *38*(3), 401–414. https://doi.org/10.1007/s10745-010-9325-3

Molina, C. M., Álamo, R. G. del, Villar, E. A., García, L. M., Lijarcio, J. J. V., Benito, M. M.-P. y, Jiménez, E. A., García, A. L., Estremera, T. P., Lomana, G. M. G. de, & Martínez, L. E. (2013). *Presencia histórica del fuego forestal en el territorio* (A. y M. A. Ministerio de Agricultura, Ed.).

Molina-Terrén, D. M., Xanthopoulos, G., Diakakis, M., Ribeiro, L., Caballero, D., Delogu, G. M., Viegas, D. X., Silva, C. A., & Cardil, A. (2019). Analysis of forest fire fatalities in Southern Europe: Spain, Portugal, Greece and Sardinia (Italy). *International Journal of Wildland Fire*, *28*(2). https://doi.org/10.1071/WF18004

Moreira, F., Ferreira, A., Abrantes, N., Catry, F., Fernandes, P., Roxo, L., Keizer, J. J., & Silva, J. (2013). Occurrence of native and exotic invasive trees in burned pine and eucalypt plantations: implications for post-fire forest conversion. *Ecological Engineering*, *58*, 296–302. https://doi.org/10.1016/j.ecoleng.2013.07.014

Moreira, F., Leal, M., Bergonse, R., Canadas, M. J., Novais, A., Oliveira, S., Ribeiro, P. F., Zêzere, J. L., & Santos, J. L. (2023). Recent Trends in Fire Regimes and Associated Territorial Features in a Fire-Prone Mediterranean Region. *Fire*, *6*(2), 60. https://doi.org/10.3390/fire6020060

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. In *Landscape Ecology* (Vol. 16).

Moreira, F., & Russo, D. (2007). Modelling the impact of agricultural abandonment and wildfires on vertebrate diversity in Mediterranean Europe. *Landscape Ecology*, *22*(10), 1461–1476. https://doi.org/10.1007/s10980-007-9125-3

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Barbati, A., Corona, P., Vaz, P., Xanthopoulos, G., Mouillot, F., & Bilgili, E. (2011). Landscape - wildfire interactions in southern Europe: Implications for landscape management. In *Journal of Environmental Management* (Vol. 92, Issue 10, pp. 2389–2402). https://doi.org/10.1016/j.jenvman.2011.06.028

Mori, A. S., & Lertzman, K. P. (2011). Historic variability in fire-generated landscape heterogeneity of subalpine forests in the Canadian Rockies. *Journal of Vegetation Science*, *22*(1), 45–58. https://doi.org/10.1111/j.1654-1103.2010.01230.x

Moura, L. C., Scariot, A. O., Schmidt, I. B., Beatty, R., & Russell-Smith, J. (2019). The legacy of colonial fire management policies on traditional livelihoods and ecological sustainability in savannas: Impacts, consequences, new directions. *Journal of Environmental Management*, *232*, 600–606. https://doi.org/10.1016/j.jenvman.2018.11.057

Múgica, L., Canals, R. M., San Emeterio, L., & Peralta, J. (2021). Decoupling of traditional burnings and grazing regimes alters plant diversity and dominant species competition in high-mountain grasslands. *Science of the Total Environment*, *790*. https://doi.org/10.1016/j.scitotenv.2021.147917

Myers, R. L. (2006). *Convivir con el fuego-Manteniendo los ecosistemas y los medios de subsistencia mediante el Manejo Integral del Fuego Iniciativa Global para el Manejo del Fuego Junio de 2006*. http://tncfuego.org

Navarro, G., Caballero, I., Silva, G., Parra, P. C., Vázquez, Á., & Caldeira, R. (2017). Evaluation of forest fire on Madeira Island using Sentinel-2A MSI imagery. *International Journal of Applied Earth Observation and Geoinformation*, *58*, 97–106. https://doi.org/10.1016/j.jag.2017.02.003

Nunes, L. J. R., Raposo, M. A. M., & Pinto Gomes, C. J. (2021). A historical perspective of landscape and human population dynamics in guimarães (Northern Portugal): Possible implications of rural fire risk in a changing environment. *Fire*, *4*(3). https://doi.org/10.3390/fire4030049

Oliveira, S. L. J., Pereira, J. M. C., & Carreiras, J. M. B. (2012a). Fire frequency analysis in Portugal (1975-2005), using Landsat-based burnt area maps. In *International Journal of Wildland Fire* (Vol. 21, Issue 1, pp. 48–60). https://doi.org/10.1071/WF10131

Oliveira, S., & Zêzere, J. L. (2020). Assessing the biophysical and social drivers of burned area distribution at the local scale. *Journal of Environmental Management*, *264*. https://doi.org/10.1016/j.jenvman.2020.110449

OTI, O. T. I., Castro Rego, F., Fernandes, P., Sande Silva, J., Azevedo, J., Moura, J. M., Oliveira, E., Cortes, R., Viegas, D. X., Caldeira, D., & Duarte Santos, F. (2019). *O planeamento da Defesa da Floresta Contra Incêndios (DFCI)*. https://www.parlamento.pt/Documents/2019/dezembro/20191205-Estudo-Tecnico-Planeamento-DFCI.pdf

Palombo, C., Chirici, G., Marchetti, M., & Tognetti, R. (2013). Is land abandonment affecting forest dynamics at high elevation in Mediterranean mountains more than climate change? *Plant Biosystems*, *147*(1), 1–11. https://doi.org/10.1080/11263504.2013.772081

Pardellas, M., Colaço, C., Rego, F., & Meira, P. (2018). El reto educativo de los incendios forestales: De la percepcion social del riesgo a la accion comunitaria. In F. Días-Fierros (Ed.), *Incendios Forestales: Reflexiones desde Galicia*. Hercules de Ediciones. https://www.researchgate.net/publication/344140953

Parente, J., Pereira, M. G., Amraoui, M., & Tedim, F. (2018). Negligent and intentional fires in Portugal: Spatial distribution characterization. *Science of the Total Environment*, *624*, 424–437. https://doi.org/10.1016/j.scitotenv.2017.12.013

Pastro, L. A., Dickman, C. R., & Letnic, M. (2014). Fire type and hemisphere determine the effects of fire on the alpha and beta diversity of vertebrates: A global meta-analysis. *Global Ecology and Biogeography*, *23*(10), 1146–1156. https://doi.org/10.1111/geb.12195

Pereira, H. M., Domingos, T., & Vicente, L. (2004). *Portugal Millennium Ecosystem Assessment: State of the Assessment Report*. http://ecossistemas.org.

Pereira, J. M. C., Carreiras, J., Silva, J. M. N., & Vasconcelos, M. J. P. (2006). Alguns Conceitos Básicos sobre os Fogos Rurais em Portugal. In *Incêndios Florestais em Portugal - Caracterização, Impactes e Prevenção* (pp. 133–158). https://www.researchgate.net/publication/236734596

Pinto, B., Aguiar, C., & Partidário, M. (2010). Brief historical ecology of northern Portugal during the Holocene. In *Environment and History* (Vol. 16, Issue 1, pp. 3–42). https://doi.org/10.3197/096734010X485283

Pyne, S., & Goldammer, J. G. (1997). The Culture of Fire: An Introduction to Anthropogenic Fire History. In J. S. Clark, H. Cachier, J. G. Goldammer, & B. Stocks (Eds.), *Sediment Records of Biomass Burning and Global Change. NATO ASI Series* (Vol. 51, pp. 71–114). Springer, Berlin, Heidelberg. https://doi.org/https://doi.org/10.1007/978-3-642-59171-6_5

Pyne, S. J. (1999). Fuego sobre la tierra. Introducción a su historia. In E. Araque Jiménez (Ed.), *Incendios históricos. Una aproximación multidisciplinar* (pp. 365–382). Universidad Internacional de Andalucia - España.

Pyne, S. J. (2006). Fogo no Jardim: Compreensão do Contexto dos Incêndios em Portugal. In J. S. Pereira, J. M. C. Pereira, F. C. Rego, J. M. N. Silva, & T. P. da Silva (Eds.), *Incêndios florestais* *em Portugal : caracterização, impactes e prevenção* (ISA Press, pp. 115–131). Instituto Superior de Agronomia.

Rego, F. C., Bunting, S. C., & Barreira, M. G. (1988). Effects of Prescribed Fire on Chamaespartium tridentatum ((L.)P. Gibbs) in Pinus pinaster (Aiton) Forests. *Journal of Range Management*, *41*(5), 410. https://doi.org/10.2307/3899579

Rodrigues, A., Santiago, A., Laím, L., Viegas, D. X., & Zêzere, J. L. (2022). Rural Fires—Causes of Human Losses in the 2017 Fires in Portugal. *Applied Sciences (Switzerland)*, *12*(24). https://doi.org/10.3390/app122412561

Rodrigues, M., Miguel, J. S., Oliveira, S., Moreira, F., & Camia, A. (2013). An insight into spatial-temporal trends of fire ignitions and burned areas in the European Mediterranean countries. *Journal of Earth Science and Engineering*, *3*, 497–505. https://doi.org/10.17265/2159-581X/2013.07.006

Roebroeks, W., & Villa, P. (2011). On the earliest evidence for habitual use of fire in Europe. *Proceedings of the National Academy of Sciences*, *108*(13), 5209–5214. https://doi.org/10.1073/pnas.1018116108

Romero-Calcerrada, R., & Perry, G. L. W. (2004). The role of land abandonment in landscape dynamics in the SPA 'Encinares del río Alberche y Cofio, Central Spain, 1984–1999. *Landscape and Urban Planning*, *66*, 217–232. https://doi.org/10.1016/S0169-2046(03)00112-9

Ruiz Gallardo, J. R. (2007). *Teledetección y SIG en la asistencia de la actuación forestal postincendio* [PhD, Universidad de Castilla-La Mancha]. http://hdl.handle.net/10578/968

Ruiz-Mirazo, J., Martínez-Fernández, J., & Vega-García, C. (2012). Pastoral wildfires in the Mediterranean: understanding their linkages to land cover patterns in managed landscapes. *Journal of Environmental Management*, *98*, 43–50. https://doi.org/10.1016/j.jenvman.2011.12.017

Salgueiro, A. (2010). The Portuguese national programme on suppression fire: GAUF team actions. In C. Montiel & D. Kraus (Eds.), *Best practices of fire use – Prescribed burning and suppression fire programmes in selected case-study regions in Europe-* (pp. 123–136). European Forest Institute.

San Emeterio, L., Múgica, L., Ugarte, M. D., Goicoa, T., & Canals, R. M. (2016). Sustainability of traditional pastoral fires in highlands under global change: effects on soil function and nutrient cycling. *Agriculture, Ecosystems and Environment*, *235*, 155–163. https://doi.org/10.1016/j.agee.2016.10.009

Sanches, M. de J. (2003). Sobre a ocupação do Neolítico inicial no Norte de Portugal. *Muita Gente, Poucas Antas? Origens, Espaços e Contextos Do Megalitismo. Artigo Em Livro de Atas de Conferência Internacional*, 155–179. https://hdl.handle.net/10216/111573

Sanjuán, Y., Arnáez, J., Beguería, S., Lana-Renault, N., Lasanta, T., Gómez-Villar, A., Álvarez-Martínez, J., Coba-Pérez, P., & García-Ruiz, J. M. (2018). Woody plant encroachment following grazing abandonment in the subalpine belt: a case study in northern Spain. *Regional Environmental Change*, *18*(4), 1103–1115. https://doi.org/10.1007/s10113-017-1245-y

Seijo, F. (2005). The politics of fire: Spanish forest policy and ritual resistance in Galicia, Spain. *Environmental Politics*, *14*(3), 380–402. https://doi.org/10.1080/09644010500087665

Sequeira, R., Rego, C., Romão Sequeira anaca, C., Montiel-Molina crismont, C., & Castro Rego, F. (2019b). Historical fire records at the two ends of Iberian Central Mountain System: Estrela massif and Ayllón massif. *Investigaciones Geográficas (Esp)*, *72*.

Shimelmitz, R., Kuhn, S. L., Jelinek, A. J., Ronen, A., Clark, A. E., & Weinstein-Evron, M. (2014). “Fire at will”: The emergence of habitual fire use 350,000 years ago. *Journal of Human Evolution*, *77*, 196–203. https://doi.org/10.1016/j.jhevol.2014.07.005

Silva, J. S., Vaz, P., Moreira, F., Catry, F., & Rego, F. C. (2011). Wildfires as a major driver of landscape dynamics in three fire-prone areas of Portugal. *Landscape and Urban Planning*, *101*, 349–358. https://doi.org/10.1016/j.landurbplan.2011.03.001

Smil, V. (2004). World History and Energy. *Encyclopedia of Energy*, *6*, 549–561.

Souza, M. E. B., Pacheco, A. P., & Teixeira, J. G. (2022). Systematizing experts’ risk perception on rural fires resulting from traditional burnings in Portugal: A Mental Model approach. In *Advances in Forest Fire Research 2022* (pp. 1520–1525). Imprensa da Universidade de Coimbra. https://doi.org/10.14195/978-989-26-2298-9_232

Tanaka, S., Kimura, H., & Suga, Y. (1983). Preparation of a 1:25000 landsat map for assessment of burnt area on etajima island. *International Journal of Remote Sensing*, *4*(1), 17–31. https://doi.org/10.1080/01431168308948528

Tarín-Carrasco, P., Augusto, S., Palacios-Penã, L., Ratola, N., & Jiménez-Guerrero, P. (2021). Impact of large wildfires on PM10 levels and human mortality in Portugal. *Natural Hazards and Earth System Sciences*, *21*(9), 2867–2880. https://doi.org/10.5194/nhess-21-2867-2021

Tedim, F., Leone, V., Gutierres, F., Correia, F., & Magalhães, C. G. (2019). Evidences about causes of wildfires in the Northern Region of Portugal. In L. Lourenço, F. Tedim, & C. Ferreira (Eds.), *Os Incêndios Florestais. Em busca de um novo paradigma. II Diálogo entre Ciência e Utilizadores* (pp. 59–92). NICIF - Núcleo de Investigação Científica de Incêndios Florestais Faculdade de Letras da Universidade de Coimbra. https://doi.org/http://dx.doi.org/10.34037/978-972-8330-25-5_2_4

Tedim, F., Leone, V., Lovreglio, R., Xanthopoulos, G., Chas-amil, M. L., Ganteaume, A., Efe, R., Royé, D., Fuerst-bjeliš, B., Nikolov, N., Musa, S., Milenković, M., Correia, F., Conedera, M., & Pezzatti, G. B. (2022a). Forest Fire Causes and Motivations in Southern and South-Eastern Europe through the Perception of Experts: Contribution to Enhance the Current Policies. *Forests*, *13*(4). https://doi.org/10.3390/f13040562

Tedim, F., Remelgado, R., Carvalho, S., & Martins, J. (2015). The largest forest fires in Portugal: the constraints of burned area size on the comprehension of fire severity. *Journal of Environmental Biology*, *36*, 133–143. https://repositorio-aberto.up.pt/bitstream/10216/79926/2/77377.pdf

Torres-Manso, F., Fernandes, P., Pinto, R., Botelho, H., & Monzon, A. (2014). Regional livestock grazing, human demography and fire incidence in the Portuguese landscape. *Forest Systems*, *23*(1), 15–21. https://doi.org/10.5424/fs/2014231-02758

Turco, M., Bedia, J., di Liberto, F., Fiorucci, P., von Hardenberg, J., Koutsias, N., Llasat, M.-C., Xystrakis, F., & Provenzale, A. (2016). Decreasing fires in mediterranean Europe. *PLoS ONE*, *11*(3), e0150663. https://doi.org/10.1371/journal.pone.0150663

Turco, M., Jerez, S., Augusto, S., Tarín-Carrasco, P., Ratola, N., Jiménez-Guerrero, P., & Trigo, R. M. (2019). Climate drivers of the 2017 devastating fires in Portugal. *Scientific Reports*, *9*(1). https://doi.org/10.1038/s41598-019-50281-2

Vannière, B., Colombaroli, D., Chapron, E., Leroux, A., Tinner, W., & Magny, M. (2008). Climate versus human-driven fire regimes in Mediterranean landscapes: the Holocene record of Lago dell'Accesa (Tuscany, Italy). *Quaternary Science Reviews*, *27*(11–12), 1181–1196. https://doi.org/10.1016/j.quascirev.2008.02.011

Vázquez, A., & Moreno, J. M. (1993). Sensitivity of fire occurrence to meteorological variables in Mediterranean and Atlantic areas of Spain. *Landscape and Urban Planning*, *24*, 129–142.

Vázquez-Varela, C., Martínez-Navarro, J. M., & Abad-González, L. (2022). Traditional Fire Knowledge: A Thematic Synthesis Approach. In *Fire* (Vol. 5, Issue 2). MDPI. https://doi.org/10.3390/fire5020047

Zong, X., Tian, X., Yao, Q., & Brown, P. M. (2022). An analysis of fatalities from forest fires in China, 1951-2018. *International Journal of Wildland Fire*, *31*(5). https://doi.org/10.1071/WF21137

REFERENCIAS: CAPÍTULO I

1. C. Montiel (ed.), *Presencia histórica del fuego en el territorio* (Madrid: Ministerio de Agricultura, Alimentación y Medio Ambiente, 2013).
2. C.R. Sequeira, C. Montiel-Molina and F.C. Rego, 'Historical fire records at the two ends of Iberian Central Mountain System: Estrela massif and Ayllón massif', *Investigaciones Geograficas* ***72*** (2019): 31–52.
3. E. Fernandes and A. Rêgo, *História do Direito Português. Súmula das lições proferidas pelo Ex.mo Prof. Doutor Marcelo Caetano ao Curso do 1o Ano Jurídico de 1940-41 na Faculdade de Direito de Lisboa* (Lisboa: Faculdade de Direito de Lisboa, 1941).
4. M. Lobo da Costa, 'A Revogação da Sentença no Direito Lusitano (Perfil Histórico)'. *Revista da Faculdade de Direito* **78** (1983): 110–140.
5. J.A.G. Cortázar, Organización social del espacio en la España medieval. La Corona de Castilla en los siglos VIII a XV, Working paper (Barcelona: Ariel, 1985).
6. C. Fabião, 'O Passado Proto-Histórico e Romano', in J. Mattoso (ed.), *História de Portugal, Volume I: Antes de Portugal* (Lisboa: Círculo de Leitores, 1992), pp. 79-299.
7. C. Barros, 'La humanización de la naturaleza en la Edad Media', *Edad Media: Revista de historia* **2** (1999): 169–194.
8. J.J.A. Dias, *Ordenações Manuelinas: Livros I a V. Reprodução em fac-símile da edição de Valentim Fernandes (Lisboa, 1512-1513)*, Volume V, First edition (Lisboa: Universidade Nova de Lisboa. Centro de Estudos Históricos, 2002).
9. É. Carra, As Sesmarias do Reino à Colónia. (MsC Thesis, Universidade de Coimbra, 2020).
10. E.C. Pereira, Concelhos e Ordens Militares na Idade Média. Relações de dependência e de confronto dos séculos XII a XIV. (MsC Thesis, Universidade do Porto, 2013).
11. A.M. Pinto, O Lavrador de Forais - Estudo dos forais outorgados por D. Dinis. (Msc Thesis, Universidade de Coimbra, 2008).
12. E.V. de Oliveira, F. Galhano and B. Pereira, *Alfaia agrícola portuguesa* (Lisboa: Etnográfica Press, 1995).
13. C. Montiel-Molina, 'Comparative assessment of wildland fire legislation and policies in the European Union: towards a Fire Framework Directive', *Forest Policy and Economics* **29** (2013): 1–6.
14. F. Rego and I. Skulska, 'Evolução Histórica do Regime Florestal em Portugal', in M.J. Antunes and D. Lopes (eds.), *Florestas e Legislação: Que Futuro?*, (Coimbra: Faculdade de Direito da Universidade de Coimbra, Instituto Juridíco, 2019), pp. 75-82.
15. P.R. Mourao and V.D. Martinho, 'Discussing structural breaks in the Portuguese regulation on forest fires- An economic approach', *Land Use Policy* **54** (2016): 460–478.
16. P.M. Fernandes, N. Guiomar, P. Mateus and T. Oliveira, 'On the reactive nature of forest fire-related legislation in Portugal: A comment on Mourão and Martinho (2016)', *Land Use Policy* **60** (2017): 12–15.
17. N. Devy-Vareta and A.A.M. Alves, 'Os avanços e os recuos da floresta em Portugal - da Idade Média ao Liberalismo' in J.S. Silva (ed.), *Floresta e sociedade, uma história em comum*, (Lisboa: Público SA e Fundação Luso-Americana, 2007), pp. 55–75.
18. K. Trápaga Monchet, 'El estudio de los bosques reales de Portugal a través de la legislación forestal en las dinastías Avis, Habsburgo y Braganza (ca. 1435-1650)', *Philostrato. Revista de Historia y Arte* 1 (1987): 5–27.
19. K.Trápaga Monchet and F.L. Arroyo, 'Políticas forestales y deforestación en Portugal, 1580-1640: realidad o mito?', *Ler História* **75** (2019): 133–156.
20. F. Labrador Arroyo, *La Casa Real en Portugal (1580–1621)* (Madrid: Polifemo, 2009).

21. M.C. Radich and A.A.M. Alves, *Dois Séculos da Floresta em Portugal* (Lisboa: CELPA, 2000).
22. C.J. de Melo, 'Guerra, impérios e Corte Joanina nas Coutadas de Caça: Alavancas de Regeneração Florestal em Portugal, em Meados do século XVIII', *Manuscrits* **42** (2020): 199–220.
23. C.J. de Melo, 'Menos coutadas melhores pinhais: império, inundações, fisiocracia, guerra e especialização das matas reais em Portugal (1777-1824)', *Tiempos Modernos* **39** (2019): 456-487.
24. C.J. de Melo, *An Analysis of the Royal Preserves in Portugal: issues of privilege, power, management and conflict* (Sheffield: Wildtrack Publishing, 2015).
25. C.J. de Melo, *Coutadas reais (1777-1824): privilégio, poder, gestão e conflito* (Lisboa: Montepio Geral, 2000).
26. A. Costa Lobo, *História da Sociedade em Portugal no Seculo XV - Secção I: População; Aspecto Geral do Paiz e do seu Estado social; Pesos e Medidas; Moeda; Os Haveres Individuais* (Lisboa: Imprensa Nacional, 1903).
27. E.C. Caldas, *A Agricultura na História de Portugal* (Lisboa: Empresa de Publicações Nacionais, Lda., 1995).
28. A.A. Monteiro Alves, N. Devy-Vareta, Â.C. Oliveira and J. Santos Pereira, 'A floresta e o fogo através dos tempos', in J. Santos Pereira, J.M. Cardoso Pereira, F. Castro Rego, J.M. Neves Silva and T. Pereira da Silva (eds.), *Incêndios Florestais em Portugal. Caracterização, Impactes e Prevenção* (Lisboa: ISAPress, 2006), pp. 15–40.
29. J. Pinho and P. Mateus, 'Retrato a carvão: A gestão do fogo no âmbito da Administração Florestal e do Ordenamento Florestal do Território. Subsídios para uma perspectiva histórica e de futuro', *Territorium* **26** (2019): 61–88.
30. Portuguese Government (Ministério da Agricultura, Desenvolvimento Rural e Pescas), *Decreto-Lei n.o 156/2004, de 30 de Junho, Diário da República n.º 152/2004, Série I-A, pp. 3968-3975, Sistema Nacional de Prevenção e Proteção da Floresta contra Incêndios* (Portugal: Imprensa Nacional da Casa da Moeda, 2004). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2542&tabela=leis&so_miolo (accessed 13 Mar, 2023).
31. Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 114/2006 - Estratégia Nacional para as florestas. Diário da República, 1ª série, Nr 179, 15 de Setembro, pp. 6730-6809* (Portugal: Imprensa Nacional da Casa da Moeda, 2006). https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/114-2006-539852 (accessed 10 Mar, 2023).
32. F.L. Castro, *História do Direito Geral e Brasil* (Rio de Janeiro: Livraria e Editora Lumen Juris Lda Rio, 2010).
33. B.S. Childs, *The Book of Exodus: A Critical, Theological Commentary* (Kentucky: Westminster John Knox Press, 1974).
34. E. Carrasco Jiménez, 'Derechos humanos y Régimen de garantías en la legislación Mosaica', *POLIS, Revista Latinoamericana* **6** (17) (2007): online.
35. A. Santos Justo, 'As actiones do daño aquiliano', in A.D-B. Cremades and J.G. Sánchez (eds.), *Fundamentos Romanísticos del Derecho Contemporáneo.* Volume VI (Spain: Asociación Iberoamericana de Derecho Romano, Boletín Oficial del Estado, 2021), pp. 571–605.
36. E.M.A. Madeira, 'A Lei das XII Tábuas', *Revista da Faculdade de Direito de São Bernardo do Campo* **136** (2007): 125-138.
37. R. Aramburu Córdoba, *La evolución de la Lex Aquilia: desde la Lex de las XII Tablas hasta el Digesto de Justiniano.* First edition (La Plata: Editorial de la Universidad Nacional de La Plata, 2021).

38. L. Dal Ri, 'A Tradição Romanística em Período Medieval: entre práxis e esquecimento - Roman Legal Tradition in Medieval Period: between oblivion and praxis', *Seqüência: Estudos Jurídicos e Políticos* **74** (2016): 269-294.
39. *Fuero Juzgo en Latin y Castellano cotejado con los mas antiguos y preciosos Códices. Por La Real Academia Española* (Madrid: Ibarra, Impresor de Cámara de S. M., 1815).
40. M. Albuquerque and E.B. Nunes, *Ordenações Del-Rei Dom Duarte*. First edition (Lisboa: Fundação Calouste Gulbenkian, 1988).
41. J. Pais and F. Reboredo, 'A construção naval e a destruição do coberto florestal em Portugal - Do Século XII ao Século XX', *Ecologi@* **4** (2012): 31–42.
42. C. Baeta Neves, *Alguns documentos do Arquivo Nacional da Torre do Tombo sobre Monteiros-mores, Caçadores-mores e Caçadores e Couteiros de perdizes* (Lisboa: Sociedade Astória, Lda., 1965).
43. F. Pereira, *Livro da Montaria, feito por D. João I, Rei de Portugal* (Coimbra: Academia das Sciências de Lisboa, 1918).
44. L. Duarte, Justiça e criminalidade no Portugal medievo 1459-1481. (PhD Thesis, Universidade do Porto, 1993).
45. D. Freitas do Amaral, 'As reformas jurídicas, administrativas e financeiras de D. Manuel I e a construção do Estado Moderno em Portugal', in CMGuimarães (ed.), *Livro de Atas de Conferência Internacional - III Congresso Histórico de Guimarães. D. Manuel e a sua época. 1a Secção: Administração, Justiça e Direito* (Guimarães: Câmara Municipal de Guimarães, 2001), pp. 50-60.
46. A. Oliveira Marques, *Introdução à história da agricultura em Portugal: a questão cerealífera durante a idade média*. Third edition (Lisboa: Edições Cosmos, 1978).
47. J. Lencar, *Geographia d'Entre Douro e Minho e Trás-os-Montes por João de Barros* (Porto: Câmara Municipal do Porto, 2019).
48. Codigo Philippino, ou, Ordenações e leis do Reino de Portugal: recopiladas por mandado d'El-Rey D. Philippe I, *'Título LXXXVI – Dos que poem fogos. Quinto Livro das Ordenações'*, Volume V, Fourteen edition (Rio de Janeiro: Typographia do Instituto Philomathico, 1870), pp. 1233–1235.
49. Portuguese Digital Archive of Torre do Tombo, *Corpo Cronológico, Part I, file 104, nr. 68*. https://digitarq.arquivos.pt/details?id=3767258 (accessed 13 Nov 2019).
50. H. Vilela, 'Ordenações Filipinas e Código Criminal do Império do Brasil (1830) – Revisitando e Reescrevendo a História', *Revista Jurídica Luso-Brasileira* **3**(4) (2017): 767–780.
51. A. Silva (ed.), 'Carta de Regimento para as Matas, Montarias e Coutadas Reais de 20 de março de 1605', *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1603 a 1612* (Lisboa: Typografia Maigrense, 1854), pp. 109–124.
52. A. Silva (ed.), 'Regimento do Guarda Mór do Pinhal de Leiria de 25 de julho de 1751', in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1750 a 1762* (Lisboa: Typografia Maigrense, 1830), pp. 68–75.
53. A. Silva (ed.), 'Portaria ocorrendo com providências ás queimadas que se frequentão ao Sul do Tejo, 2 de Outubro de 1813', de 2 de julho de 1816', in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1811 a 1820* (Lisboa: Typografia Maigrense, 1825), pp. 280.
54. A. Silva (ed.), 'Portaria, providenciando ácerca de incêndios', de 2 de julho de 1816', in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1811 a 1820* (Lisboa: Typografia Maigrense, 1825), pp. 516-519.

55. A. Silva (ed.), 'Decreto n.º 49 de 7 de abril de 1821', in *Collecção da Legislação Portugueza desde a ultima compilação das Ordenações. Legislação de 1821 a 1823* (Lisboa: Typografia Maigrense, 1825), pp. 57-29.
56. J. Rebello (ed.), 'Capítulo IV – Do incêndio e damnos. Secção I – Fogo pôsto', in *Codigo Penal Annotado* (Porto: Typographia Gutenberg, 1895), pp. 184–187.
57. Portuguese Government, *Sessão 28 de abril de 1887 - As legislações Florestais* (Portugal: Imprensa Nacional da Casa da Moeda, 1887). https://debates.parlamento.pt/catalogo/mc/cd (accessed 8 Nov 2020).
58. Portuguese Government, *Sessão N.o 12 de 26 de janeiro de 1900 - Propostas de lei apresentadas pelo Sr. Ministro das Obras Públicas. Proposta de lei n.o 1-L, 1900* (Portugal: Imprensa Nacional da Casa da Moeda, 1900). https://debates.parlamento.pt/catalogo/mc/cd (accessed 8 Nov 2020).
59. Portuguese Government (Ministério do Reino), *Decreto de 24 de Dezembro de 1901, do Estabelecimento do Regime Florestal, pp. 1312-1355* (Portugal: Imprensa Nacional da Casa da Moeda, 1901). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?artigo_id=2799A0002&nid=2799&tabela=leis&ficha=1&nversao (accessed 17 Jan 2023).
60. Comando Geral da Guarda Nacional Republicana, *Reorganização dos Serviços de Polícia Florestal. Decretos n.os 12625, e 12793, respectivamente de 3 e 30 de Novembro de 1926* (Lisboa: Tipografia da G.N.R, 1926).
61. Portuguese Government (Ministério da Agricultura), *Lei n.o 1971 de 15 de junho de 1938, Lei do Povoamento Florestal. Diário da República, 1ª série, Nr 136, 15 de Junho* (Portugal: Imprensa Nacional da Casa da Moeda, 1938). https://files.dre.pt/1s/1938/06/13600/09710974.pdf (accessed 17 Jan 2023).
62. A. Arala Pinto, 'Fogos', in Direção Geral dos Serviços Florestais e Aquícolas, *Separata das Publicações da Direcção Geral dos Serviços Florestais e Aquícolas*. Volume X, Tomo II, (Portugal: DGSFA, 1943), pp. 355–372.
63. I. Skulska, C. Montiel-Molina and F. C. Rego, 'The role of forest policy in Mediterranean mountain community lands: A review of the decentralization processes in European countries', *Journal of Rural Studies* **80** (2020): 490–502.
64. Portuguese Government (Ministério da Economia - Direcção-Geral dos Serviços Florestais e Aquícolas), *Decreto-Lei n.o 39 931, de 24 de novembro de 1954. Diário do Governo n.º 263/1954, Série I de 1954-11-24, pp. 1400–1405* (Portugal: Imprensa Nacional da Casa da Moeda, 1954). https://diariodarepublica.pt/dr/detalhe/decreto-lei/39931-1954-680793 (accessed 17 Jan 2023).
65. F. Ferreira-Leite, A. Gonçalves and L. Lourenço, 'Grandes incêndios florestais na decáda de 60 do século XX, em Portugal Continental', *Territorium* **21** (2014): 189–195.
66. Portuguese Government (Ministério Ministério das Finanças e da Economia), *Decreto-Lei n.o 488/70, de 21 de Outubro. Diário do Governo n.º 244/1970, Série I,. pp. 1508–1511* (Portugal: Imprensa Nacional da Casa da Moeda, 1970). https://files.dre.pt/1s/1970/10/24400/15081511.pdf (accessed 17 Jan 2023).
67. M.C. Colaço, Bases para uma educação ambiental orientada para a diminuição do risco e aumento da resiliência das comunidades aos incêndios florestais em Portugal. (PhD Thesis, Universidade de Santiago de Compostela, 2017).
68. Portuguese Government (Ministério da Agricultura e Pescas), *Decreto-Lei n.o 39/76, de 19 de janeiro, Diário do Governo n.º 15/1976, Série I, pp. 89-91*. (Portugal: Imprensa Nacional da Casa da Moeda, 1976). https://portal.oa.pt/upl/%7Bb7108909-3a78-4b47-ac93-d7cdbd838729%7D.pdf (accessed 17 Jan 2023).
69. P. M. Fernandes, C. Loureiro, N. Guiomar, G. Pezzatti, F. Manso and L. Lopes, 'The dynamics and drivers of fuel and fire in the Portuguese public forest', *Journal of Environmental Management* **146** (2015): 373–82.

70. Portuguese Government (Presidência do Conselho de Ministros e Ministério da Agricultura e Pescas), *Decreto-Lei n.o 327/80, de 26 de Agosto. Diário do Governo n.º 196/1980, Série I, pp. 2375-2377* (Portugal: Imprensa Nacional da Casa da Moeda, 1980). https://dre.pt/dre/home (accessed 12 Nov 2020).

71. Portuguese Government (Assembleia da República), *Lei n.o 10/81, de 10 de Julho. Diário da República n.º 156/1981, Série I, pp. 1649-1651* (Portugal: Imprensa Nacional da Casa da Moeda, 1981). https://files.dre.pt/1s/1981/07/15600/16491651.pdf (accessed 11 Nov 2020).

72. Portuguese Government (Ministérios da Defesa Nacional, da Administração Interna e da Agricultura, Comércio e Pescas), *Decreto Regulamentar n.o 55, de 18 de Dezembro. Diário da República n.º 290/1981, Série I, pp. 3299-3307* (Portugal: Imprensa Nacional da Casa da Moeda, 1981). https://dre.pt/dre/home (accessed 31 Oct 2020).

73. Portuguese Government (Ministério da Justiça), *Decreto-Lei n.o 400/82 de 23 de Setembro. Diário da República n.º 221/1982, 1º Suplemento, Série I, pp. 3006-(2)-3006-(64)* (Portugal: Imprensa Nacional da Casa da Moeda, 1982). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=101&tabela=lei_velhas&nversao=1&so_miolo (accessed 12 Nov 2020).

74. Portuguese Government (Ministério da Administração Interna), *Decreto Regulamentar n.o 67/85 de 22 de Outubro, Diário da República n.º 243/1985, Série I, pp. 3480* (Portugal: Imprensa Nacional da Casa da Moeda, 1985). https://dre.pt/dre/home (accessed 11 Nov 2020).

75. Portuguese Government (Assembleia da República), *Lei n.o 19/86, de 19 de julho. Diário da República n.º 164/1986, Série I, pp. 1775-1777* (Portugal: Imprensa Nacional da Casa da Moeda, 1986). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=232&tabela=leis&so_miolo (accessed 11 Nov 2020).

76. Portuguese Government (Ministério da Administração Interna), *Decreto Regulamentar n.o 36/88, de 17 de Outubro, Diário da República n.º 240/1988, Série I, pp. 4238-(2)* (Portugal: Imprensa Nacional da Casa da Moeda, 1988). https://dre.pt/dre/home (accessed 11 Nov 2020).

77. Portuguese Government (Ministérios do Planeamento e da Administração do Território, da Administração Interna, da Agricultura, Pescas e Alimentação e do Ambiente e Recursos Naturais), *Portaria n.o 341/90, de 7 de Maio, Diário da República n.º 104/1990, Série I, pp. 2115-2117* (Portugal: Imprensa Nacional da Casa da Moeda, 1990). https://diariodarepublica.pt/dr/detalhe/decreto-lei/341-1990-565861 (accessed 11 Nov 2020).

78. Portuguese Government (Ministério do Planeamento e da Administração do Território), *Decreto-Lei no 334/90, de 29 de Outubro, Diário da República n.º 334/1990, Série I, pp. 4456-4457* (Portugal: Imprensa Nacional da Casa da Moeda, 1990). https://dre.pt/dre/home (accessed 11 Nov 2020).

79. Portuguese Government (Ministério do Planeamento e da Administração do Território), *Decreto-Lei n.o 423/93, de 31 de dezembro, Diário da República n.º 304/1993, Série I, pp. 7242-7244* (Portugal: Imprensa Nacional da Casa da Moeda, 1993). https://dre.pt/dre/home (accessed 11 Nov 2020).

80. Portuguese Government (Ministério das Cidades, Ordenamento do Território e Ambiente), *Decreto-Lei n.o 310/2002 de 18 de Dezembro, Diário da República n.º 292/2002, Série I-A, pp. 7896-7903* (Portugal: Imprensa Nacional da Casa da Moeda, 2002). https://diariodarepublica.pt/dr/detalhe/decreto-lei/310-2002-405693 (accessed 12 Mar 2019).

81. Portuguese Government (Ministério da Administração Interna), *Decreto-Lei n.o 252/92, de 19 de Novembro. Diário da República n.º 268/1992, Série I-A, pp. 5334-5338* (Portugal: Imprensa Nacional da Casa da Moeda, 1992). https://www.igf.gov.pt/leggeraldocs/DL_252_92.htm (accessed 11 Nov 2020).

82. Portuguese Government (Ministério da Administração Interna), *Decreto-Lei n.o 316/95 de 28 de Novembro, Diário da República n.º 275/1995, Série I-A, pp. 7375-7382* (Portugal: Imprensa

Nacional da Casa da Moeda, 1995). https://www.igf.gov.pt/leggeraldocs/DL_316_95.htm (accessed 2 Feb 2019).

83. Portuguese Government (Ministério da Agricultura, Desenvolvimento Rural e Pescas), *Decreto-Lei n.o 156/2004 de 30 de Junho, Diário da República n.º 152/2004, Série I-A, pp. 3968-3975* (Portugal: Imprensa Nacional da Casa da Moeda, 2004). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2542&tabela=leis&so_miolo (accessed 17 Mar 2023).
84. Portuguese Government (Ministério da Agricultura, Desenvolvimento Rural e Pescas), *Portaria n.o 1061/2004 de 21 de Agosto, Diário da República n.º 197/2004, Série I-B, pp. 5604-5605* (Portugal: Imprensa Nacional da Casa da Moeda, 2004). https://dre.pt/dre/home (accessed 17 Feb 2019).
85. Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 65/2006 de 25 de Maio, Diário da República n.º 102/2006, Série I-B, pp. 3511-3559* (Portugal: Imprensa Nacional da Casa da Moeda, 2006). https://dre.pt/dre/home (accessed 17 Mar 2023).
86. Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Decreto-Lei n.o 124/2006, de 28 de junho, Diário da República n.º 123/2006, Série I-A* (Portugal: Imprensa Nacional da Casa da Moeda, 2006). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=1931&tabela=leis (accessed 30 Dec 2020).
87. Portuguese Government (Assembleia da República), *Lei n.o 76/2017, de 17 de agosto, Diário da República n.º 158/2017, Série I, pp. 4734-4762* (Portugal: Imprensa Nacional da Casa da Moeda, 2017). https://dre.pt/dre/home (accessed 27 Aug 2019).
88. Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Decreto-Lei n.o 17/2009, de 14 de Janeiro, Diário da República n.º 9/2009, Série I, pp. 273-295* (Portugal: Imprensa Nacional da Casa da Moeda, 2009). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?tabela=leis&nid=1933&pagina=1&ficha=1 (accessed 17 Feb 2019).
89. Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Decreto-Lei n.o 159/2008, de 8 de agosto, Diário da República n.º 153/2008, Série I, pp. 5355-5359* (Portugal: Imprensa Nacional da Casa da Moeda, 2008). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=1054&tabela=leis (accessed 17 Feb 2019).
90. Portuguese Government (Ministério da Agricultura, do Desenvolvimento Rural e das Pescas), *Portaria n.o 35/2009, de 16 de Janeiro, Diário da República n.º 11/2009, Série I, pp. 386-388* (Portugal: Imprensa Nacional da Casa da Moeda, 2009). https://diariodarepublica.pt/dr/detalhe/portaria/35-2009-789382 (accessed 17 Feb 2019).
91. Portuguese Government (Ministério da Agricultura e do Mar), *Decreto-Lei n.o 83/2014, de 23 de maio, Diário da República n.º 99/2014, Série I, pp. 2946-2947* (Portugal: Imprensa Nacional da Casa da Moeda, 2014). https://diariodarepublica.pt/dr/detalhe/decreto-lei/83-2014-25345886 (accessed 17 Feb 2019).
92. Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 157-A/2017, Diário da República n.º 208/2017, Série I, pp. 5818-(2)-5818-(3)* (Portugal: Imprensa Nacional da Casa da Moeda, 2017). https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/157-a-2017-114109966 (accessed 22 Nov 2020).
93. Portuguese Government (Presidência do Conselho de Ministros), *Decreto-Lei n.o 82/2021, de 13 de outubro, Diário da República n.º 199/2021, Série I, pp. 2-47* (Portugal: Imprensa Nacional da Casa da Moeda, 2017).

https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=3453&tabela=leis&so_miolo (accessed 12 Mar 2022).

94. Portuguese Government (Assembleia da República), *Lei n.o 50/2018, de 16 de agosto, Diário da República n.º 15/2018, Série I, pp. 4102-4108* (Portugal: Imprensa Nacional da Casa da Moeda, 2018). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2932&tabela=leis&ficha=1 (accessed 26 Sep 2019).
95. Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 20/2018 de 1 de março, Diário da República n.º 43/2018, Série I, pp. 1132-1141* (Portugal: Imprensa Nacional da Casa da Moeda, 2018). https://dre.pt/dre/home (accessed 17 Feb 2019).
96. Portuguese Government (Presidência do Conselho de Ministros), *Decreto-Lei no 14/2019, de 21 de janeiro, Diário da República n.º 14/2019, Série I, pp. 443-446* (Portugal: Imprensa Nacional da Casa da Moeda, 2019). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=2992&tabela=leis&ficha=1&pagina=1&so_miolo (accessed 26 Mar 2019).
97. Portuguese Government (Ministério da Agricultura e do Mar - Gabinete do Secretário de Estado das Florestas e do Desenvolvimento Rural), *Despacho n.o 7511/2014, de 9 de junho, Diário da República n.º 110/2014, Série II, pp. 443-446* (Portugal: Imprensa Nacional da Casa da Moeda, 2014). https://diariodarepublica.pt/dr/detalhe/despacho/7511-2014-25696052 (accessed 26 Mar 2019).
98. Portuguese Government (Assembleia da República), *Lei n.o 56/2011, de 15 de Novembro, Diário da República n.º 219/2011, Série I, pp. 4862-4863* (Portugal: Imprensa Nacional da Casa da Moeda, 2011). https://www.pgdlisboa.pt/leis/lei_mostra_articulado.php?nid=1540&tabela=leis&ficha=1&pagina=1&so_miolo=S (accessed 31 Out 2020).
99. Portuguese Government (Presidência do Conselho de Ministros), *Resolução do Conselho de Ministros n.o 45-A/2020, Diário da República n.º 115/2020, 1º Suplemento, Série I* (Portugal: Imprensa Nacional da Casa da Moeda, 2011). https://diariodarepublica.pt/dr/detalhe/resolucao-conselho-ministros/45-2020-135844796 (accessed 19 Nov 2020).
100. J. Russell-Smith, G.D. Cook, P.M. Cooke, A.C. Edwards, M. Lendrum, C.P. Meyer and P.J. Whitehead, ‘Managing fire regimes in north Australian savannas: Applying Aboriginal approaches to contemporary global problems’, *Frontiers in Ecology and the Environment* **11**(Online issue 1) (2013): e55-e63.
101. A. Atkinson and C. Montiel-Molina, ‘Reconnecting Fire Culture of Aboriginal Communities with Contemporary Wildfire Risk Management’, *Fire* **6**(8) (2023): 296.
102. P.M. Fernandes, G.M. Davies, D. Ascoli, C. Fernández, F. Moreira, E. Rigolot, C.R. Stoof, J.A. Vega and D. Molina, ‘Prescribed burning in southern Europe:developing fire management in a dynamic landscape’, *Frontiers in Ecology and the Environment* **11**(Online issue 1) (2013): e4-e14.
103. Canadian Government, *Canadian Environmental Protection Act - An Act respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development* (Canada: Canadian Minister of Justice, 1999). https://laws-lois.justice.gc.ca/PDF/C-15.31.pdf (accessed 16 Mar 2023).
104. C.C.S.M., *c E125, The Environment Act* (Manitoba: C.C.S.M., 1987), www.gov.mb.ca (accessed 16 Mar 2023).
105. C.C.S.M., *Man. Reg. 77/93, Burning of Crop Residue and Non-Crop Herbage Regulation* (Manitoba: C.C.S.M., 1993), www.gov.mb.ca (accessed 16 Mar 2023).
106. US Government (Senate), *Bill No. 332, SB-332 Civil liability: prescribed burning operations: gross negligence* (California: Legislative Counsel, 2021),

https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB332 (accessed 16 Mar 2023).

107. US Government (Assembly), *Bill No. 642, AB-642 Wildfires* (California: Legislative Counsel, 2021), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB642 (accessed 16 Mar 2023).

108. Spanish Government (Departamento de Agricultura, Ganadería y Medio Ambiente), *Orden de 20 de febrero de 2015, sobre prevención y lucha contra los incendios forestales en la Comunidad Autónoma de Aragón para la campaña 2015/2016, Boletín Oficial de Aragón n.o 50, pp. 8619-8632* (Spain: B.O.A, 2015), https://www.boa.aragon.es/cgi-bin/EBOA/BRSCGI?CMD=VEROBJ&MLKOB=842831924646 (accessed 16 Mar 2023).

109. Spanish Government (Consejería de Desarrollo Rural, Ganadería, Pesca, Alimentación y Medio Ambiente), *Orden MED/3/2021, de 09 marzo, por la que se regulan las quemas controladas y prescritas en la Comunidad Autónoma de Cantabria, Boletín Oficial de Aragón n.o 52, pp. 5617-5623* (Spain: B.O.C., 2021), https://boc.cantabria.es/boces/verAnuncioAction.do?idAnuBlob=359395 (accessed 16 Mar 2023).

110. Catalonia Government (Conselh Generau d'Aran), *Plan Estrategic de Gestion Sostenibla Regim de Huec Val D'Aran - Oritzon 2030* (Aran: Conselh Generau d'Aran, 2015), https://www.seu-e.cat/web/conselhgeneraudaran/govern-obert- (accessed 16 Mar 2023).

111. F. Rego, E. Rigolot, P. Fernandes, C. Montiel and J.S. Silva, *European Forest Institute Policy Brief 4 – Towards Integrated Fire Management* (Finland: EFI, 2010).

REFERENCIAS: CAPÍTULO II

Abel, M. (1988). Os baldios portugueses em período de transição (1820 - 1910). *Revista de História. Centro de História Da Universidade Do Porto, VIII*, 339–343. https://ler.letras.up.pt/uploads/ficheiros/6459.pdf

Academia Real das Sciencias de Lisboa. (n.d.). *Memorias economicas da Academia Real das Sciencias de Lisboa para o adiantamento da agricultura, das artes, e da industria em Portugal, e suas conquistas. 1789 - 1815*. Officina da Academia Real das Sciencias.

Agência para a Gestão Integrada de Fogos Rurais (AGIF). (2020). 20-30 National Plan for Integrated Rural Fire Management (EN). In *Resolution of the Council of Ministers nº 45-A/2020, of June 16th*. https://www.agif.pt/app/uploads/2020/12/20-30_NPIRFM_littledoc.pdf

Agricultura General de Gabriel Alonso Herrera, corregida segun testo original de la primera edicion publicada en 1513 por el mismo autor. (1818). *Agricultura General de Gabriel Alonso Herrera, corregida segun testo original de la primera edicion publicada en 1513 por el mismo autor. Tomo I - V*. Real Sociedad Economica Matritense.

Aguiar, A. A. de. (1869). Visita ás principaes comarcas vinhateiras do centro do reino no anno de 1867. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. XII* (pp. 344–345). Typographia Universal de Thomaz Quintino Antunes.

Almeida, M. A. P. de. (2002). Carvoeiro. In N. L. Madureira, C. A. Martins, & G. N. Monteiro (Eds.), *História do trabalho e das ocupações: Vol. Vol. III* (pp. 300–301). Celta Editora.

Almeida, M. A. (2020). The use of rural areas in Portugal: Historical perspective and the new trends. *Revista Galega de Economia*, *29*(2 Special issue), 1–17. https://doi.org/10.15304/rge.29.2.6750

Andrada e Silva, J. B. (1815). *Memória sobre a necessidade e utilidades do plantio de novos bosques em Portugal, particularmente de pinhaes nos areaes de beiramar; seu methodo de sementeira , costeamento, e administração*. Typografia da Academia Real das Sciencias.

Anónimo. (1791). Memoria Sobre o estado da Agricultura , e Commercio do Alto-Douro. In *Memorias economicas da Academia real das ciencias de Lisboa, para o adiantamento da agricultura, das artes, e da industria em Portugal, e suas conquistas.: Vol. III* (p. 73). Academia Real das Ciências.

Anónimo. (1872). Partes Veterinarias. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. XIV* (p. 139). ypographia Universal de Thomaz Quintino Antunes.

Armatas, C. A., Venn, T. J., McBride, B. B., Watson, A. E., & Carver, S. J. (2016). Opportunities to utilize traditional phenological knowledge to support adaptive management of social-ecological systems vulnerable to changes in climate and fire regimes. *Ecology and Society, 21*(1). https://doi.org/10.5751/ES-07905-210116

Arquivo Nacional da Torre do Tombo. (2008, February 1). *Chancelaria de D. Manuel I, liv. 46, fl. 29*. PORTUGAL, Fernando - Índice Geográfico Das Cartas de Perdão Da Chancelaria D. Manuel [Policopiado] / Fernando Portugal. - [s.l.: S.n., s.d.]. - P.m. ; 30 Cm . Disponível Na Torre Do Tombo, Biblioteca 930.255(469.411. https://digitarq.arquivos.pt/details?id=3859357

Baptista, M. D. (1789). Ensaio de huma descripçaõ, fizica, e economica de Coimbra , e seus arredores. In *Memorias economicas da Academia real das ciencias de Lisboa, para o adiantamento da agricultura, das artes, e da industria em Portugal, e suas conquistas.: Vol. I* (pp. 287–288). Academia Real das Ciências.

Bardin, L. (1995). *Análise de conteúdo*. Edições 70.

Berkes, F. (2012). *Sacred Ecology Third Edition* (3rd ed.). Routledge.

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications*, *10*(5), 1251–1262.

Bird, M. I., & Cali, J. A. (1998). *A million-year record of fire in sub-Saharan Africa*.

Bowman, D. M. J. S., Balch, J., Artaxo, P., Bond, W. J., Cochrane, M. A., D'Antonio, C. M., Defries, R., Johnston, F. H., Keeley, J. E., Krawchuk, M. A., Kull, C. A., Mack, M., Moritz, M. A., Pyne, S., Roos, C. I., Scott, A. C., Sodhi, N. S., & Swetnam, T. W. (2011). The human dimension of fire regimes on Earth. In *Journal of Biogeography* (Vol. 38, Issue 12, pp. 2223–2236). https://doi.org/10.1111/j.1365-2699.2011.02595.x

Broadberry, S., Fremdling, R., & Solar, P. (2008). *European Industry, 1700 - 1870*. Groningen Growth and Development Centre, University of Groningen, GGDC Research Memoran-dum.

Butz, R. J. (2009). Traditional fire management: historical fire regimes and land use change in pastoral East Africa. *International Journal of Wildland Fire*, *18*(4), 442. https://doi.org/10.1071/wf07067

Caldas, E. de C. (1998). *A Agricultura na História de Portugal*. E.P.N. - Empresa de Publicações Nacionais, Lda.

Campos, E. de. (1913). *A Comservação da Riqueza Nacional. A frei. Os minerais. A Terra. As Matas. Os rios.*

Carmo, M. C. (2018). *Solo e Agricultura no Século XX Português. Um problema ambiental , histórico e epistemológico.* [ISA]. https://www.repository.utl.pt/handle/10400.5/17510

Celaya, R., Ferreira, L. M. M., Lorenzo, J. M., Echegaray, N., Crecente, S., Serrano, E., & Busqué, J. (2022). Livestock Management for the Delivery of Ecosystem Services in Fire-Prone Shrublands of Atlantic Iberia. In *Sustainability (Switzerland)* (Vol. 14, Issue 5). MDPI. https://doi.org/10.3390/su14052775

Columela, L. J. M. (1824). *Los Doce Libros de Agricultura que escribió en latin Lucio Junio Moderato Columela. Traducidos al catellano por D. Juan Maria Alvarez de Sotomayor y Rubio.: Vol. I* (J. M. A. Sotomayor y Rubio, Ed.). Imprenta de D. Miguel de Burgos.

Columella, L. J. M. (1773). *Traduction d'anciens ouvrages latins relatifs a l'agriculture et a la médecine vétérinaire, / Avec des notes : par M. Saboureux de la Bonnetrie, Ecuyer, Avocat au Parlament, & Docteur Aggrégé de la Faculté des Droits en l'Université de Paris. ; Tome troisieme, contenant l'économie rurale de Columelle: Vol. III* (C.-F. Saboureux de la Bonneterie, Ed.). Libraire de la Faculté de Médecine.

Coughlan, M. R. (2013). Errakina: Pastoral fire use and landscape memory in the Basque region of the French Western Pyrenees. *Journal of Ethnobiology*, *33*(1), 86–104. https://doi.org/10.2993/0278-0771-33.1.86

Cruz, A. M. (1865). Partes Veterinarias. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. VIII* (p. 293). Typographia Universal.

Cruz, J. L. da. (1837). Memoria sobre a cultura dos pinheiros , e extracção de sua matéria resinosa, oferece Joaquim Luiz da Cruz. In *Memorias da Academia Real das Sciencias de Lisboa: Vols. XII-Parte I* (p. 82). Academia Real das Ciências.

Custódio, J. (2020). A Era da Energia a Vapor em Portugal: o caso agrícola. In *Al-Madan Online. Almada: Centro de Arqueologia de Almada: Vol. 23 (2)* (pp. 107–128).

da Matta, J. N. (1859). Correspondencia; José Nunes da Matta, Bailão, 3 de novembro de 1859. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas* (Vols. 1-2.º Ano, p. 354). Typograghia Universal.

D'Amelio, J. (2022). *Current status of Prescribed Burning Laws in Italy, Spain, and Portugal: A Comparative Study* [Dissertation to obtain a master's degree in Mediterranean Forestry and Natural Resources Management]. Instituto Superior Agronomia.

Davidson-Hunt, I. J. (2003). Indigenous Lands Management, Cultural Landscapes and Anishinaabe People of Shoal Lake, Northwestern Ontario, Canada. *Environments*, *31*(1), 21–41.

de Diego, J., Fernández, M., Rúa, A., & Kline, J. D. (2023). Examining socioeconomic factors associated with wildfire occurrence and burned area in Galicia (Spain) using spatial and temporal data. *Fire Ecology*, *19*(1), 18. https://doi.org/10.1186/s42408-023-00173-8

de Diego, J., Rúa, A., & Fernández, M. (2021). Vulnerability variables and their effect on wildfires in Galicia (Spain). a panel data analysis. *Land*, *10*(10). https://doi.org/10.3390/land10101004

de Oliveira, E., Lobo-do-Vale, R., & Colaço, C. (2022). The last landscape gardeners: Incident analysis of traditional burns in Portugal. *Advances in Forest Fire Research 2022*, 792–795. https://doi.org/10.14195/978-989-26-2298-9_120

Dias, J. (1984). *Rio de Onor – Comunitarismo Agro-Pastoril*. Editorial Presença.

Díaz-Fierros, F. (2019). Forest fires in Galicia and Portugal: an historical overview. *Territorium: Revista Portuguesa de Riscos, Prevenção e Segurança*, *26 (I)*, 97–114. https://doi.org/10.14195/1647-7723_26-1_7

Domínguez, L., & Luoma, C. (2020). Decolonising Conservation Policy: How Colonial Land and Conservation Ideologies Persist and Perpetuate Indigenous Injustices at the Expense of the Environment. *Land*, *9*(3), 65. https://doi.org/10.3390/land9030065

El Awam, E. (1802). *Libro de Agricultura. Su Autor El Doctor Excelente Abu Zacaria Iahia Aben Mohamed Ben Ahmed El Awam, Sevillano. TRaducido al castellano y anotado por Don Josef Antonio Banqueri: Vol. I* (J. A. Banqueri, Ed.). Imprenta Real.

Eriksen, C. (2007). Why do they burn the “bush”? Fire, rural livelihoods, and conservation in Zambia. *The Geographical Journal*, *173*(3), 242–256. https://doi.org/10.1111/j.1475-4959.2007.00239.x

Estêvão, J. A. (1983). A florestação dos baldios. *Análise Social*, *XIX (77-78-79)*(3.º, 4.º, 5.º), 1157–1260.

Fábregas Valcarce, R., Fernández-Rodríguez, C., & Ramil-Rego, P. (1997). La adopción de la economía productora en el Noroeste Ibérico. In A. Rodríguez Casal (Ed.), *O Neolítico Atlántico e as Orixes do Megalitismo* (pp. 463–484). Universidad de Santiago de Compostela. https://www.researchgate.net/publication/269910826

Felix Pereira, J. (1875). *As Georgicas de Virgilio. Traduzidas do original em verso endecasyllabo, com anootações exclusivamente agronomicas e zootechnicas*. Typographia Universal.

Ferber, M. J. (1788). Continuação da primeira secção das Reflexões sobre a antiguidade relativa das montanhas , e das camadas ou bancos terrestres, que formam a côdea do Globo terreal, extrahidas das Reflexôes sobre o mesmo assumpto de M. J. Ferber. In *Jornal Encyclopedico dedicado á Rainha; N. Senhora, e destinado para instruccão geral com a noticia dos novos descobrimentos em todas as sciencias, e artes.* (p. 334).

Ferreira Lapa, J. I. (1859). Chronica Agricola. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas* (Vols. 1-2.º Ano, pp. 158–159). Typograghia Universal.

Fonseca, H. A. (1996). As elites económicas alentejanas, 1850-1870:anatomia social e empresarial. *Análise Social*, *XXXI*(2.º-3.º), 711–748.

Ganteaume, A., Camia, A., Jappiot, M., San-Miguel-Ayanz, J., Long-Fournel, M., & Lampin, C. (2013). A review of the main driving factors of forest fire ignition over Europe. *Environmental Management*, *51*(3), 651–662. https://doi.org/10.1007/s00267-012-9961-z

Garde, M. (2009). *The language of fire: seasonality, resources and landscape burning on the Arnhem Land Plateau. Culture, Ecology and Economy of Fire Management in North Australian Savannas: Rekindling the Wurrk Tradition*. http://ebookcentral.proquest.com/lib/anu/detail.action?docID=474353.

Garrido, J. A. (1749). *Livro de agricultura em que se trata com clareza, e distinçaõ do modo, e tempo de cultivar as terras de paõ, vinho, azeite, hortaliças, flores dos jardins, e pumares de fruta, como também da criaçaõ dos animais domesticos, e da cassa dos bravos. Com obras* *confidenciais, e importantes avizos, para que os homens do campo coletaõ mais copiozo fruto do trabalho nas muitos da agricultura.* .

Gomes de Oliveira, J. P. (1791). N.° II. Extracto das Posturas da Villa de Azeitaõ, Comarca de Setubal. In *Memorias economicas da Academia real das ciencias de Lisboa, para o adiantamento da agricultura, das artes, e da industria em Portugal, e suas conquistas.: Vol. III* (p. 313). Academia Real das Ciências.

Gomes Dias, E. (2014). «O esplendor do Jornal Encyclopedico na imprensa periódica portuguesa entre os séculos XVIII-XIX». In *Mátria Digital* (Vol. 2, pp. 210–215). CIJVS.

González-Hidalgo, M. (2023). Affected by and affecting forest fires in Sweden and Spain: A critical feminist analysis of vulnerability to fire. *Sociologia Ruralis*. https://doi.org/10.1111/soru.12432

Graça, L. L. (1999). *Propriedade e agricultura: evolução do modelo dominante de sindicalismo agrário em Portugal*.

Henriques, S. de S. T. (2006). *Os consumos domésticos de energia em Portugal* [Master]. Universidade Técnica de Lisboa.

Herculano, A. (1898). *Opúsculos por Alexandre Herculano - Tomo VII* (Tavares Cardoso & Irmão, Ed.; 1ª). Typ. da Empreza Litteraria e Typographica.

Hespanha, P. (1983). Através dos campos dos senhores da terra. Notas para o estudo da grande lavoura alentejana oitocentista. *Revista Crítica de Ciências Sociais*, *11*, 61–80. http://hdl.handle.net/10316/10853

Hoffman, K. M., Christianson, A. C., Dickson-Hoyle, S., Copes-Gerbitz, K., Nikolakis, W., Diabo, D. A., McLeod, R., Michell, H. J., Mamun, A. Al, Zahara, A., Mauro, N., Gilchrist, J., Ross, R. M., & Daniels, L. D. (2022). The right to burn: barriers and opportunities for Indigenous-led fire stewardship in Canada. *FACETS*, *7*, 464–481. https://doi.org/10.1139/facets-2021-0062

Huffman, M. R. (2013). The many elements of traditional fire knowledge: Synthesis, classification, and aids to cross-cultural problem solving in firedependent systems around the world. *Ecology and Society*, *18*(4). https://doi.org/10.5751/ES-05843-180403

Jones, R. (1968). The geographical background to the arrival of man in Australia and Tasmania. In *Reprinted from Archaeology & physical anthropology in Oceania186: Vol. III, no. 3* (pp. 186–215). Australasian Medical Publishing Co.

Jorge, S. O. (2000). Domestication the land: the first agricultural communities in Portugal. *Journal of Iberian Archaeology*, *2*, 43–98.

Lacerda Lobo, C. B. (1790). Continuaçaõ da Memoria Sobre a cultura das Vinhas (a). In *Memorias economicas da Academia real das ciencias de Lisboa, para o adiantamento da agricultura, das artes, e da industria em Portugal, e suas conquistas.: Vol. II* (pp. 201–241). Academia Real das Ciências.

Lake, F. K., Wright, V., Morgan, P., McFadzen, M., McWethy, D., & Stevens-Rumann, C. (2017). Returning fire to the land: Celebrating traditional knowledge and fire. In *Journal of Forestry* (Vol. 115, Issue 5, pp. 343–353). Society of American Foresters. https://doi.org/10.5849/jof.2016-043R2

Lasteyrie, C. de. (1827). Agriculture. De l' Écobuage, ou de la combustion du sol fréquemment réitérée comme un puissant moyen de fertiliser la terre, et de remplacer les engrais. In *Journal des connaissances usuelles et pratiques: Vol. V* (pp. 36–89).

Liacos, L. G. (2015). Present studies and history of burning in Greece. *Fire Ecology*, *11*(3), 3–13. https://doi.org/10.1007/BF03400631

Lima, S. B. (1865). Chronica Agrícola, Lisboa, 20 de setembro 20. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. VIII* (p. 164). Typographia Universal.

Lima, S. B. (1867). Chronica Agricola. Lisboa, 25 de Setembro de 1867. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. X* (pp. 164–165). ypographia Universal de Thomaz Quintino Antunes.

Lima, S. B. (1868). Chronica Agricola. Lisboa, 25 de Outubro de 1868. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. XI* (pp. 214–215). Typographia Universal de Thomaz Quintino Antunes.

Lisboa, B. da S. (1789). Continuação da viagem mineralógico botanica, &c. de Coimbra a Coja publicada nos Jornaes de Agosto e Setembro passados. PROSSEGUI depois para Fajão, huma antiga vilIa (…). In *Jornal Encyclopedico dedicado á Rainha; N. Senhora, e destinado para instruccão geral com a noticia dos novos descobrimentos em todas as sciencias, e artes.* (pp. 126–131).

López-Rodríguez, G., Rodríguez-Vicente, V., & Marey-Pérez, M. F. (2021). Study of forest productivity in the occurrence of forest fires in Galicia (Spain). *Sustainability (Switzerland)*, *13*(15). https://doi.org/10.3390/su13158472

Lourenço, L., Fernandes, S., Nunes, A., Bento-Gonçalves, A., & Vieira, A. (2013). Determination of forest fire causes in Portugal. In *FLAMMA* | (Vol. 4, Issue 3).

Marey-Pérez, M. F., Díaz-Varela, E., & Calvo-González, A. (2015). Does higher owner participation increase conflicts over common land? An analysis of communal forests in Galicia (Spain). *IForest*, *8*(AUG2015), 533–543. https://doi.org/10.3832/ifor1060-008

Maria, D. J. (1849). *Guia e manual do cultivador ou elementos de agricultura: Vol. I*.

Marks-Block, T., & Tripp, W. (2021). Facilitating Prescribed Fire in Northern California through Indigenous Governance and Interagency Partnerships. *Fire*, *4*(3), 37. https://doi.org/10.3390/fire4030037

Mascarenhas, J. F. de M. (1742). *Gazeta de Lisboa* (Vol. 6). https://hemerotecadigital.cm-lisboa.pt/periodicos/gazetadelisboa/gazetadelisboa.htm

Mateus, P., & Fernandes, P. M. (2014). *Forest Fires in Portugal: Dynamics, Causes and Policies*. https://doi.org/10.1007/978-3-319-08455-8_4

Matos, A. C. de. (2002). Indústria e ambiente no século XIX. *Ler História*, *42*, 119–152. http://hdl.handle.net/10174/21480

Meira Castro, A. C., Nunes, A., Sousa, A., & Lourenço, L. (2020). Mapping the causes of forest fires in Portugal by clustering analysis. *Geosciences (Switzerland)*, *10*(2). https://doi.org/10.3390/geosciences10020053

Mendes, J. M. A. (1980). (1980). Memoria sobre o estado da agricultura da provincia do Minho, principalmente tocante á parte florestal, e ideas geraes sobre o estado das suas manufacturas, commercio e pesca, pelo Visconde de Balsemão. In *Memória sobre a província do Minho pelo 2.° Visconde de Balsemão (Introdução, Transcrição e Notas): Vol. XVIII* (p. 76). Revista Portuguesa de História.

Menezes, A. C. de. (1860). Estadistica da Agricultura ao Norte e Sul do Tejo pelo Desembargador Alberto Carlos de Menezes, Superintendente da Agricultura nas Comarcas de Santarem Evora e Setuba. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. III* (p. 14). Typographia da Sociedade Typographica Franco – Portugueza.

Miller, A. M., & Davidson-Hunt, I. (2010). Fire, agency and scale in the creation of aboriginal cultural landscapes. *Human Ecology*, *38*(3), 401–414. https://doi.org/10.1007/s10745-010-9325-3

Miret I Mestre, J. (2014). Las rozas en la Península Ibérica. Apuntes de tecnología agraria tradicional. *Historia Agraria*, *34,* 165–193. https://www.historiaagraria.com/en/issues/josep-miret-i-mestre-las-rozas-en-la-peninsula-iberica-apuntes-de-tecnologia-agraria-tradicional

Mistry, J., Bilbao, B. A., & Berardi, A. (2016). Community owned solutions for fire management in tropical ecosystems: Case studies from Indigenous communities of South America. In

Philosophical Transactions of the Royal Society B: Biological Sciences (Vol. 371, Issue 1696). Royal Society of London. https://doi.org/10.1098/rstb.2015.0174

Monteiro Alves, A. A., Devy-Vareta, N., Oliveira, Â. C., & Santos Pereira, J. (2006). A floresta e o fogo através dos tempos. In J. Santos Pereira, J. M. Cardoso Pereira, F. Castro Rego, J. M. Neves Silva, & T. Pereira da Silva (Eds.), *Incêndios Florestais em Portugal. Caracterização, Impactes e Prevenção* (pp. 15–40). ISAPress.

Montiel-Molina, C., Álamo, R. G. del, Villar, E. A., García, L. M., Lijarcio, J. J. V., Benito, M. M.-P. y, Jiménez, E. A., García, A. L., Estremera, T. P., Lomana, G. M. G. de, Martínez, L. E., & Montiel-Molina, C. (2013). Presencia histórica del fuego forestal en el territorio. In *Cuadernos de la Sociedad Española de Ciencias Forestales* (Vol. 38).

Moreira, F., Leal, M., Bergonse, R., Canadas, M. J., Novais, A., Oliveira, S., Ribeiro, P. F., Zêzere, J. L., & Santos, J. L. (2023). Recent Trends in Fire Regimes and Associated Territorial Features in a Fire-Prone Mediterranean Region. *Fire*, *6*(2), 60. https://doi.org/10.3390/fire6020060

Moura, L. C., Scariot, A. O., Schmidt, I. B., Beatty, R., & Russell-Smith, J. (2019). The legacy of colonial fire management policies on traditional livelihoods and ecological sustainability in savannas: Impacts, consequences, new directions. *Journal of Environmental Management*, *232*, 600–606. https://doi.org/10.1016/j.jenvman.2018.11.057

Myers, R. L. (2006). *Convivir con el fuego-Manteniendo los ecosistemas y los medios de subsistencia mediante el Manejo Integral del Fuego Iniciativa Global para el Manejo del Fuego Junio de 2006*. http://tncfuego.org

Nunes, M. de F. (2001). *Imprensa Periódica Científica (1772-1852). Leituras de «sciencia agricola» em Portugal* (J. M. Rodrigues Ferreira, Ed.; Colecção Thesis). ESTAR EDITORA LDA. http://hdl.handle.net/10174/5057

Oliveira, E., & Fernandes, P. M. (2023). Pastoral Burning and Its Contribution to the Fire Regime of Alto Minho, Portugal. *Fire*, *6*(5), 210. https://doi.org/10.3390/fire6050210

Oliveira, E., Fernandes, P. M., Barros, D., & Guiomar, N. (2023). Unraveling the Effect of Fire Seasonality on Fire-Preferred Fuel Types and Dynamics in Alto Minho, Portugal (2000–2018). *Fire*, *6*(7), 267. https://doi.org/10.3390/fire6070267

Oliveira Marques, A. H. de. (1978). *Introdução à história da agricultura em Portugal: a questão cerealífera durante a idade média* (3ª). Edições Cosmos.

Ordem de Cister. Mosteiro de Santa Maria (Alcobaça). (n.d.). *Jornal Encyclopédico dedicado á Rainha N. Senhora, e destinado para instrucção geral com a notícia dos novos descobrimentos em todas as sciencias, e artes. Julho 1779 - Maio 1793*. Offic. de Antonio Rodrigues Galhardo. Retrieved April 16, 2022, from https://purl.pt/33878

OTI, O. T. I., Castro Rego, F., Fernandes, P., Sande Silva, J., Azevedo, J., Moura, J. M., Oliveira, E., Cortes, R., Viegas, D. X., Caldeira, D., & Duarte Santos, F. (2020). *O Uso do Fogo em Portugal – tradição e técnica*. https://www.parlamento.pt/Parlamento/Documents/oti/Uso-do-Fogo-Portugal.pdf

Paiva, M. J. H. (1788). Idee sopra la vegetazione Scc., isto he, Ideas sobre a vegetação , lidas n' Academia publica das Sciencias, e d' Agricultura de Bresse por João Baptista Corniani, hum dos presidentes. Bresse 1787. cm 8.°. In *Jornal Encyclopedico dedicado á Rainha; N. Senhora, e destinado para instruccão geral com a noticia dos novos descobrimentos em todas as sciencias, e artes.* (p. 129).

Parente, J., Pereira, M. G., Amraoui, M., & Tedim, F. (2018). Negligent and intentional fires in Portugal: Spatial distribution characterization. *Science of the Total Environment, 624*, 424–437. https://doi.org/10.1016/j.scitotenv.2017.12.013

Pereira, A. (1862). Ligeiras considerações sobre o estado actual da agricultura em Azambuja maneira de o modificar, causas economicas e administrativas que se oppõem a estas modificações. In

O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. V (pp. 547–609). Typographia Universal.

Pereira, J. F. (1868). Compendio de Principios Geraes de Economia e Legislação Rural. In *O Archivo Rural – Jornal de Agricultura, Artes e Sciencias Correlativas: Vol. XI* (pp. 429–431). Typographia Universal de Thomaz Quintino Antunes.

Pereira, J. M. C., Carreiras, J., Silva, J. M. N., & Vasconcelos, M. J. P. (2006). Alguns Conceitos Básicos sobre os Fogos Rurais em Portugal. In *Incêndios Florestais em Portugal - Caracterização, Impactes e Prevenção* (pp. 133–158). https://www.researchgate.net/publication/236734596

Pereira, L. E. C., Bilbao, B., Mistry, J., & Schmidt, I. B. (2018). From fire suppression to fire management: advances and resistances to changes in fire policy in the savannas of Brazil and Venezuela. *The Geographical Journal*, *185*(1). https://doi.org/10.1111/geoj.12245

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. *Natural Hazards and Earth System Science*, *11*(12), 3343–3358. https://doi.org/10.5194/nhess-11-3343-2011

Pyne, S., & Goldammer, J. G. (1997). The Culture of Fire: An Introduction to Anthropogenic Fire History. In J. S. Clark, H. Cachier, J. G. Goldammer, & B. Stocks (Eds.), *Sediment Records of Biomass Burning and Global Change. NATO ASI Series* (Vol. 51, pp. 71–114). Springer, Berlin, Heidelberg. https://doi.org/https://doi.org/10.1007/978-3-642-59171-6_5

Pyne, S. J. (2006). Fogo no Jardim: Compreensão do Contexto dos Incêndios em Portugal. In J. S. Pereira, J. M. C. Pereira, F. C. Rego, J. M. N. Silva, & T. P. da Silva (Eds.), *Incêndios florestais em Portugal : caracterização, impactes e prevenção* (ISA Press, pp. 115–131). Instituto Superior de Agronomia.

Rebelo da Silva, L. A. (1868). *Memória sobre a População e a Agricultura de Portugal desde a Fundação da Monarchia até 1865. Parte I (de 1097 – 1640)*. Imprensa Nacional.

Rocha, I. V. da. (1998). O carvão na industrialização portuguesa. *A Indústria Portuense Em Perspectiva Histórica : Actas Do Colóquio*, 117–139.

Sá, J. A. (1791). Descripçaõ Economica da Torre de Moncorvo. In *Memorias economicas da Academia real das ciencias de Lisboa, para o adiantamento da agricultura, das artes, e da industria em Portugal, e suas conquistas.: Vol. III* (p. 260). Academia Real das Ciências.

Sanches, M. de J. (2003). Sobre a ocupação do Neolítico inicial no Norte de Portugal. *Muita Gente, Poucas Antas? Origens, Espaços e Contextos Do Megalitismo. Artigo Em Livro de Atas de Conferência Internacional*, 155–179. https://hdl.handle.net/10216/111573

Seijo, F. (2005). The Politics of Fire: Spanish Forest Policy and Ritual Resistance in Galicia, Spain. *Environmental Politics*, *14*(3), 380–402. https://doi.org/10.1080/09644010500087665

Sequeira, A. C. (2020). *Regímenes del fuego y dinámica del paisaje rural en el Sistema Central: Serra da Estrela y Sierra de Ayllón* [PhD Thesis in Geography]. Universidad Complutense de Madrid.

Sequeira, C. R., Montiel-Molina, C., & Rego, F. C. (2019). Historical fire records at the two ends of Iberian Central Mountain System: Estrela massif and Ayllón massif. *Investigaciones Geograficas*, *72*, 31–52. https://doi.org/10.14198/INGEO2019.72.02

Sequeira, P. F. (1790). Memoria Sobre as Azinheiras, Sovereiras, e Carvalhos da Provincia do Além-Téjo, onde se trata de sua cultura , e usos , e dos milhoramentos , que no estado actual podem ter. In *Memorias economicas da Academia real das ciencias de Lisboa, para o adiantamento da agricultura, das artes, e da industria em Portugal, e suas conquistas.: Vol. II* (pp. 357–360). Academia Real das Ciências.

Shaffer, L. J. (2010). Indigenous fire use to manage savanna landscapes in southern mozambique. *Fire Ecology*, *6*(2), 43–59. https://doi.org/10.4996/fireecology.0602043

Shimelmitz, R., Kuhn, S. L., Jelinek, A. J., Ronen, A., Clark, A. E., & Weinstein-Evron, M. (2014). “Fire at will”: The emergence of habitual fire use 350,000 years ago. *Journal of Human Evolution*, *77*, 196–203. https://doi.org/10.1016/j.jhevol.2014.07.005

Silva, J. S., Rego, F., Fernandes, P., & Rigolot, E. (2010). *Towards Integrated Fire Management - Outcomes of the European Project Fire Paradox*.

Silveira, A. H. (1789). RACIONAL DISCURSO. Sobre a Agricultura , e Populaçaõ da Província de Alem-Tejo. *Memorias Economicas Da Academia Real Das Ciencias de Lisboa, Para o Adiantamento Da Agricultura, Das Artes, e Da Industria Em Portugal, e Suas Conquistas.*, *I*, 59–77.

Simões, C. (1937). *Obras de Agricultura e Ciências Subsidiárias, dos Séculos XVII, XVIII e Meado do Século XIX, em Português e Latim, Originais e Traduções, Existentes na Biblioteca do Instituto Superior de Agronomia*. Instituto Superior de Agronomia.

Smil, V. (2004). World History and Energy. *Encyclopedia of Energy*, *6*, 549–561.

Sweeney, L., Harrison, S. P., & Linden, M. Vander. (2022). Assessing anthropogenic influence on fire history during the Holocene in the Iberian Peninsula. *Quaternary Science Reviews*, *287*, 107562. https://doi.org/10.1016/J.QUASCIREV.2022.107562

Tedim, F., Leone, V., Gutierres, F., Correia, F., & Magalhães, C. G. (2019). Evidences about causes of wildfires in the Northern Region of Portugal. In L. Lourenço, F. Tedim, & C. Ferreira (Eds.), *Os Incêndios Florestais. Em busca de um novo paradigma. II Diálogo entre Ciência e Utilizadores* (pp. 59–92). NICIF - Núcleo de Investigação Científica de Incêndios Florestais Faculdade de Letras da Universidade de Coimbra. https://doi.org/http://dx.doi.org/10.34037/978-972-8330-25-5_2_4

Tedim, F., Leone, V., Lovreglio, R., Xanthopoulos, G., Chas-amil, M. L., Ganteaume, A., Efe, R., Royé, D., Fuerst-bjeliš, B., Nikolov, N., Musa, S., Milenković, M., Correia, F., Conedera, M., & Pezzatti, G. B. (2022). Forest Fire Causes and Motivations in Southern and South-Eastern Europe through the Perception of Experts: Contribution to Enhance the Current Policies. *Forests*, *13*(4). https://doi.org/10.3390/f13040562

Torres-Manso, F., Fernandes, P., Pinto, R., Botelho, H., & Monzon, A. (2014). Regional livestock grazing, human demography and fire incidence in the Portuguese landscape. *Forest Systems*, *23*(1), 15–21. https://doi.org/10.5424/fs/2014231-02758

Varron, M. T. (1773). *Traduction d’anciens ouvrages latins relatifs a l’agriculture et a la médecine vétérinaire, / Avec des notes : par M. Saboureux de la Bonnetrie, Ecuyer, Avocat au Parlament, & Docteur Aggrégé de la Faculté des Droits en l’Université de Paris. ; Tome second, contenant l’économie rurale de Varron: Vol. II* (C.-F. Saboureux de la Bonneterie, Ed.). Libraire de la Faculté de Médecine.

Vázquez-Varela, C., Martínez-Navarro, J. M., & Abad-González, L. (2022). Traditional Fire Knowledge: A Thematic Synthesis Approach. In *Fire* (Vol. 5, Issue 2). MDPI. https://doi.org/10.3390/fire5020047

Vélez, R. (2005). *Community Based Fire Management in Spain. Forest Protection Working Papers* (Forest Protection Working Papers, Working Paper FFM/4/E. Forest Resources Development Service, Forest Resources Division.). www.fao.org/forestry

Vieira, J. A. (1886). *O Minho Pitoresco: Vol. I*. Livraria de Antonio Maria Pereira .

Villa Nova Portugal, T. A. (1790). Memoria Sobre a Cultura dos terrenos Baldios que ha no Termo da Villa de Ourem. Por Thomaz Antonio de Villa Nova Portugal. In *Jornal Encyclopedico dedicado á Rainha; N. Senhora, e destinado para instrucção geral com a noticia dos novos descobrimentos em todas as sciencias, e artes.: Vol. II* (p. 415). Academia Real das Ciências.

Visconde de Vilarinho de S. Romão. (1857). Memoria sobre a epicenonia ou moléstia geral das videiras. In *Memorias da Academia Real das Sciencias de Lisboa. Classe de Sciencias Matematicas, Physicas e Naruraes. Nova Serie: Vols. II-Parte I* (pp. 52–53).

Williams, G. (2003). *References on the American Indian Use of Fire in Ecosystems*.

REFERENCIAS: CAPÍTULO III

[1] C.M.L.B. Neves, O Ano Europeu da Conservação da Natureza e o seu eco em Portugal, Estudos e Divulgação Técnica. Lisboa: Secretaria de Estado da Agricultura. Direcção-Geral dos Serviços Florestais e Aquícolas., Lisboa, 1972.

[2] O.T.I. OTI, F. Castro Rego, P. Fernandes, J. Sande Silva, J. Azevedo, J.M. Moura, E. Oliveira, R. Cortes, D.X. Viegas, D. Caldeira, F. Duarte Santos, O Uso do Fogo em Portugal – tradição e técnica, Lisboa, 2020. https://www.parlamento.pt/Parlamento/Documents/oti/Uso-do-Fogo-Portugal.pdf (accessed March 10, 2023).

[3] M.C. Colaço, Bases para uma educação ambiental orientada para a diminuição do risco e aumento da resiliência das comunidades aos incêndios florestais em Portugal, PhD Thesis, Universidade de Santiago de Compostela, 2017.

[4] M. Pardellas, C. Colaço, F. Rego, P. Meira, El reto educativo de los incendios forestales: De la percepcion social del riesgo a la accion comunitaria, in: F. Días-Fierros (Ed.), Incendios Forestales: Reflexiones Desde Galicia, Hercules de Ediciones, 2018. https://www.researchgate.net/publication/344140953.

[5] S. Oliveira, J.L. Zêzere, Assessing the biophysical and social drivers of burned area distribution at the local scale, J Environ Manage. 264 (2020). https://doi.org/10.1016/j.jenvman.2020.110449.

[6] F. Moreira, D. Russo, Modelling the impact of agricultural abandonment and wildfires on vertebrate diversity in Mediterranean Europe, Landsc Ecol. 22 (2007) 1461–1476. https://doi.org/10.1007/s10980-007-9125-3.

[7] F. Moreira, O. Viedma, M. Arianoutsou, T. Curt, N. Koutsias, E. Rigolot, A. Barbati, P. Corona, P. Vaz, G. Xanthopoulos, F. Mouillot, E. Bilgili, Landscape - wildfire interactions in southern Europe: Implications for landscape management, J Environ Manage. 92 (2011) 2389–2402. https://doi.org/10.1016/j.jenvman.2011.06.028.

[8] P. Mateus, P.M. Fernandes, Forest Fires in Portugal: Dynamics, Causes and Policies, in: 2014. https://doi.org/10.1007/978-3-319-08455-8_4.

[9] L.J.R. Nunes, M.A.M. Raposo, C.J. Pinto Gomes, A historical perspective of landscape and human population dynamics in guimarães (Northern Portugal): Possible implications of rural fire risk in a changing environment, Fire. 4 (2021). https://doi.org/10.3390/fire4030049.

[10] M.C. Colaço, Reaprender a vivir cos incendios forestais nun contexto de cambio climático, in: Proxecto Batefogo - Coord. (Ed.), Arbores Que Non Arden: As Mulleres Na Prevención de Incendios Forestais, Editora Catro Ventos, Vigo, España, 2019: pp. 127–146.

[11] A. Rodrigues, A. Santiago, L. Laím, D.X. Viegas, J.L. Zêzere, Rural Fires—Causes of Human Losses in the 2017 Fires in Portugal, Applied Sciences (Switzerland). 12 (2022). https://doi.org/10.3390/app122412561.

[12] S. Moreno, R. Villafuerte, Traditional management of scrubland for the conservation of rabbits Oryctolagus cuniculus and their predators in Doñana National Park, Spain, Biol Conserv. 73 (1995). https://doi.org/10.1016/0006-3207(95)90069-1.

[13] S. Guadilla-Sáez, M. Pardo-de-Santayana, V. Reyes-García, The role of traditional management practices in shaping a diverse habitat mosaic in a mountain region of Northern Spain, Land Use Policy. 89 (2019). https://doi.org/10.1016/j.landusepol.2019.104235.

[14] P.M. Fernandes, H.S. Botelho, A review of prescribed burning effectiveness in fire hazard reduction, Int J Wildland Fire. 12 (2003). https://doi.org/10.1071/WF02042.

[15] T.D. Penman, F.J. Christie, A.N. Andersen, R.A. Bradstock, G.J. Cary, M.K. Henderson, O. Price, C. Tran, G.M. Wardle, R.J. Williams, A. York, Prescribed burning: How can it work to conserve the things we value?, Int J Wildland Fire. 20 (2011). https://doi.org/10.1071/WF09131.

[16] Resolução do Conselho de Ministros n.º 45-A/2020, Portugal, 2020. https://dre.pt/dre/home (accessed November 19, 2020).

[17] Decreto-Lei n.º 124/2006, de 28 de junho, Portugal, 2006. https://dre.pt/dre/home (accessed December 30, 2020).

[18] Decreto-Lei n.º 82/2021, de 13 de outubro, da Presidência do Conselho de Ministros, Portugal, 2021. https://dre.pt/dre/home (accessed March 12, 2022).

[19] C.E. Van Wagner, Development and structure of the Canadian forest fire weather index system, 1987.

[20] Instituto da Conservação da Natureza e das Florestas, Sistema de Gestão Informação de Incêndios Florestais, ICNF. (2022). https://fogos.icnf.pt/sgif2010/login.asp (accessed October 17, 2022).

[21] J. Parente, M.G. Pereira, M. Amraoui, F. Tedim, Negligent and intentional fires in Portugal: Spatial distribution characterization, Science of the Total Environment. 624 (2018) 424–437. https://doi.org/10.1016/j.scitotenv.2017.12.013.

[22] W.W.F., Forests ablaze. Causes and effects of global forest fires. Study D., 2017.

[23] S.C.P. Coogan, F.N. Robinne, P. Jain, M.D. Flannigan, Scientists' warning on wildfire — a canadian perspective, Canadian Journal of Forest Research. 49 (2019). https://doi.org/10.1139/cjfr-2019-0094.

[24] D.M. Molina-Terrén, G. Xanthopoulos, M. Diakakis, L. Ribeiro, D. Caballero, G.M. Delogu, D.X. Viegas, C.A. Silva, A. Cardil, Analysis of forest fire fatalities in Southern Europe: Spain, Portugal, Greece and Sardinia (Italy), Int J Wildland Fire. 28 (2019). https://doi.org/10.1071/WF18004.

[25] X. Zong, X. Tian, Q. Yao, P.M. Brown, An analysis of fatalities from forest fires in China, 1951-2018, Int J Wildland Fire. 31 (2022). https://doi.org/10.1071/WF21137.

[26] Instituto Nacional de Estatística, Censos, INE. (2021). https://censos.ine.pt/ (accessed May 3, 2021).

[27] Diário da República Electrónico, (n.d.). https://dre.pt/dre/home (accessed October 10, 2022).

[28] W.N. Adger, Social and ecological resilience: Are they related?, Prog Hum Geogr. 24 (2000). https://doi.org/10.1191/030913200701540465.

[29] F.C. Rego, M.C. Colaço, Wildfire Risk Analysis, in: Abdel H. El-Shaarawi, Walter P. Piegorsch (Eds.), Encyclopedia of Environmetrics, 2nd ed., John Wiley & Sons, Ltd, United Kingdom, 2013. https://doi.org/10.1002/9780470057339.vnn023.

[30] P.A. Champ, H. Brenkert-Smith, J.P. Riley, J.R. Meldrum, C.M. Barth, C. Donovan, C.J. Wagner, Actionable social science can guide community level wildfire solutions. An illustration from North Central Washington, US, International Journal of Disaster Risk Reduction. 82 (2022). https://doi.org/10.1016/j.ijdrr.2022.103388.

[31] C. Vitolo, F. Di Giuseppe, B. Krzeminski, J. San-Miguel-ayanz, Data descriptor: A 1980–2018 global fire danger re-analysis dataset for the Canadian fire weather indices, Sci Data. 6 (2019). https://doi.org/10.1038/sdata.2019.32.

[32] F. Castro Rego, P. Morgan, P.M. Fernandes, C. Hoffman, Fire Science. From Chemistry to Landscape Management, 2021.

[33] A.C. Iglesias, Os incendios forestais e a variable xénero: estereotipos de ida e volta, in: Proxecto Batefogo - Coord. (Ed.), Árbores Que Non Arden. As Mulleres Na Prevención de Incendios Forestais, Editora Catro Ventos, Vigo, Espanha, 2019: pp. 16–28.

[34] R.M. Trigo, J.M.C. Pereira, M.G. Pereira, B. Mota, T.J. Calado, C.C. Dacamara, F.E. Santo, Atmospheric conditions associated with the exceptional fire season of 2003 in Portugal, International Journal of Climatology. 26 (2006). https://doi.org/10.1002/joc.1333.

[35] A. Carvalho, M.D. Flannigan, K. Logan, A.I. Miranda, C. Borrego, Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System, Int J Wildland Fire. 17 (2008) 328–338. https://doi.org/10.1071/WF07014.

[36] P. Fernandes, P. Palheiro, Interpretação dos índices do Sistema Canadiano de Indexação do Perigo de Incêndio Florestal, 2015. https://doi.org/10.13140/RG.2.1.3683.8568.

[37] P.M. Fernandes, N. Guiomar, P. Mateus, T. Oliveira, On the reactive nature of forest fire-related legislation in Portugal: A comment on Mourão and Martinho (2016), Land Use Policy. 60 (2017). https://doi.org/10.1016/j.landusepol.2016.10.008.

[38] M. Turco, S. Jerez, S. Augusto, P. Tarín-Carrasco, N. Ratola, P. Jiménez-Guerrero, R.M. Trigo, Climate drivers of the 2017 devastating fires in Portugal, Sci Rep. 9 (2019). https://doi.org/10.1038/s41598-019-50281-2.

[39] Instituto da Conservação da Natureza e das Florestas, Plataforma de registo de queimas e queimadas, ICNF. (n.d.).

REFERENCIAS: CAPÍTULO IV

APIF - Agência para a Prevenção de Incêndios Florestais & ISA - Instituto Superior de Agronomia (2005): Plano Nacional de Defesa da Floresta Contra Incêndios – Proposta Técnica [National Forest Fire Fighting Plan - Technical Proposal]. Lisboa

Bergonse, R., Oliveira, S., Gonçalves, A., Nunes, S., DaCamara, C. & Zêzere, J. L. (2021). Predicting burnt areas during the summer season in Portugal by combining wildfire susceptibility and spring meteorological conditions. *Geomatics, Natural Hazards and Risk*, 12(1), 1039-1057. https://doi.org/10.1080/19475705.2021.1909664.

Chuvieco, E. & Congalton, R. G. (1988) Mapping and inventory of forest fires from digital processing of tm data, *Geocarto International*, 3(4), 41-53. https://doi.org/10.1080/10106048809354180.

CIM Alto Minho - Comunidade Intermunicipal do Alto Minho & Instituto Politécnico de Viana do Castelo (2017). PIAAC - Plano Intermunicipal de Adaptação às Alterações Climáticas do Alto Minho - Contextualização e cenarização climática [Intermunicipal Climate Change Adaptation Plan of Alto Minho - Contextualization and climate scenario]. http://www.cim-altominho.pt/fotos/editor2/5piaac2020_cimaltominho.pdf

Congedo, L. (2016). Semi-Automatic Classification Plugin Documentation. Release 6.0.1.1. 10.13140/RG.2.2.29474.02242/1.

Congedo, L. (2020). Semi-Automatic Classification Plugin Documentation Release 7.9.7.1.

Congedo, L. (2021). Semi-Automatic Classification Plugin: A Python tool for the download and processing of remote sensing images in QGIS. *The Journal of Open Source Software*, 6, 3172. https://doi.org/10.21105/joss.03172.

Davim, D. A., Rossa, C. G. & Fernandes, P. M. (2021). Survival of prescribed burning treatments to wildfire in Portugal. *Forest Ecology and Management*, 493, 119250. https://doi.org/10.1016/j.foreco.2021.119250

Davim, D.A., Rossa, C. G., Pereira, J. M. C. & Fernandes, P. M. (2022). Evaluating the effect of prescribed burning on the reduction of wildfire extent in Portugal. *Forest Ecology and Management*, 519, 120302. https://doi.org/10.1016/j.foreco.2022.120302

DGT – Direção Geral do Território (2020). Carta de Uso e Ocupação do Solo para 2018 [Land Use and Cover Map 2018]. Consulta: 10/01/2020. https://www.dgterritorio.gov.pt/Carta-de-Uso-e-Ocupacao-do-Solo-para-2018

DGT - Direção Geral do Território (2022). Fotografia aérea e imagens de satélite [Aerial photography and satellite images]. Consulta: 04/02/2022. https://www.dgterritorio.gov.pt/cartografia/fotografia-aerea#fichatecnica

Díaz-Fierros Viqueira, F. (2019). Incêndios florestais na Galiza e Portugal: uma perspectiva histórica [Wildfires in Galicia and Portugal: na historical perspective]. *Territorium*, 26(I), 97-114. https://doi.org/10.14195/1647-772326-17

EFFIS - European Forest Fire Information System - Joint Research Centre (JRC) of the European Commission (2022). Rapid Damage Assessment. Consulta: 07/01/2021. https://effis.jrc.ec.europa.eu/about-effis/technical-background/rapid-damage-assessment

Embrapa - Empresa Brasileira de Pesquisa Agropecuária (2021). LANDSAT - Land Remote Sensing Satellite. Consulta: 07/01/2021. https://www.embrapa.br/satelites-de-monitoramento/missoes/landsat

Embrapa - Empresa Brasileira de Pesquisa Agropecuária (2021). SENTINEL - Missão Sentinel [SENTINEL - Sentinel Mission]. Consulta: 07/01/2021. https://www.embrapa.br/satelites-de-monitoramento/missoes/landsat

Fernandes, P. M. & Guiomar, N. (2017). Os incêndios como causa de desarborização em Portugal [Wildfires as a cause of deforestation in Portugal]. *AGROTEC*, 22, 28-32.

Fernandes, P. M., Guiomar, N., Mateus, P., & Oliveira, T. (2017). On the reactive nature of forest fire-related legislation in Portugal: A comment on Mourão and Martinho (2016). *Land Use Policy*, 60, 12-15. https://doi.org/10.1016/j.landusepol.2016.10.008

Fernandes, P.M., Loureiro, C., Magalhães, M., Ferreira, P. & Fernandes, M. (2012). Fuel age, weather and burn probability in Portugal. *International Journal of Wildland Fire*, 21(4), 380-384. https://doi.org/10.1071/WF10063

Ferreira-Leite, F., Bento-Gonçalves, A. & Vieira, A. (2011). The recurrence interval of forest fires in Cabeço da Vaca (Cabreira Mountain-northwest of Portugal). *Environmental Research*, 111, 215-21. https://doi.org/10.1016/j.envres.2010.05.007

Ferreira-Leite, F., Bento-Gonçalves, A.; Lourenço, L; & Úbeda, X. (2012). Problemas metodológicos no estudo dos incêndios florestais em Portugal Continental. O Caso dos Grandes Incêndios Florestais [Methodological Problems in the Study of Wildfires in Mainland Portugal. The Case of the Large Forest Fires]. XIII Coloquio Ibérico de Geografia. Santiago de Compostela. p. 848-857.

Ferreira-Leite, F., Lourenço, L. & Bento-Gonçalves, A. (2013). Large forest fires in mainland Portugal, brief characterization. *Méditerranée*, 121, 53-65.

Fioravante, P., Luti, T., Cavalli, A., Giuliani, C., Dichicco, P., Marchetti, M., … Munafò, M. (2021). Multispectral Sentinel-2 and SAR Sentinel-1 Integration for Automatic Land Cover Classification. *Land*, 10(6), 611. https://doi.org/10.611.10.3390/land10060611

GEOGLOBAL (2007). Execução de cartografia numérica vetorial e ortofotomapas à escala 1:10000 para a região do Vale do Lima – Relatório Final [Execution of numerical vectorial cartography and orthophoto maps at a scale of 1:10000 for the Lima Valley region - Final Report]. VALIMAR Comunidade Urbana do Vale do Lima

Giglio, L. (2015). MODIS Collection 6 Active Fire Product User's Guide. Department of Geographical Sciences - University of Maryland. URL: http://modisfire.umd.edu/files/MODIS_C6_Fire_User_Guide_A.pdf

Hudak, A. T. & Brockett, B. H. (2004). Mapping fire scars in a southern African savannah using Landsat imagery. *International Journal of Remote Sensing*, 25(16), 3231-3243. https://doi.org/10.1080/01431160310001632666

ICNF – Instituto da Conservação da Natureza e das Florestas (2020). Metodologia para a produção da Carta de Perigosidade de Incêndio Rural de cariz estrutural [Methodology for the production of the Rural Fire Danger Chart of structural nature. Definitive Report]. Relatório Definitivo. 03 de abril de 2020. PAHL Consulting; Instituto de Geografia e Ordenamento do Território) IGOT) – Universidade de Lisboa. https://www.icnf.pt/api/file/doc/96bb210ebf341cda

Key, C. H. & Benson, N. C. (2006). Landscape assessment: Ground measure of severity the Composite burn index, and remote sensing of severity, the Normalized Burn index. USDA Forest Service. RMRSGTR-164-CD: LA1-51(Ogden, UT)

López García, M. J. & Caselles, V. (1991). Mapping burns and natural reforestation using Thematic Mapper data. *Geocarto International*, 6, 31-37. https://doi.org/10.1080/10106049109354290

Marques, S., Borges, J., Garcia-Gonzalo, J., Moreira, F., Carreiras, J., Oliveira, M., …Pereira, J. (2011). Characterization of wildfires in Portugal. *European Journal of Forest Research*, 130, 775-784. https://doi.org/10.1007/s10342-010-0470-4

Monteiro, A., Ferreira, C. & Madureira, H. (2005). Atlas Agroclimatológico do Entre Douro e Minho (2005). Relatório Final [Agroclimatological Atlas of Entre Douro e Minho (2005). Final Report]. Projecto POCTI/GEO/14260/1998

Navarro, G., Caballero, I., Silva, G., Parra, P. C., Vázquez, A. & Caldeira, R. (2017). Evaluation of forest fire on Madeira Island using Sentinel-2A MSI imagery. *International Journal of Applied Earth Observation and Geoinformation*, 58, 97-106. https://doi.org/10.1016/j.jag.2017.02.003

Nieman, W. A., van Wilgen, B.W. & Leslie, A. J. (2021). Correction to: A reconstruction of the recent fire regimes of Majete Wildlife Reserve, Malawi, using remote sensing. *Fire Ecology*, 17, 36. https://doi.org/10.1186/s42408-021-00122-3

Oliveira, S., Gonçalves, A., & Zêzere, J. L. (2020). Reassessing wildfire susceptibility and hazard for mainland Portugal. *Science of the Total Environment*, 762, 143121. https://doi.org/10.1016/j.scitotenv.2020.143121

Oliveira, S., Pereira, J. & Carreiras, J. (2012). Fire frequency analysis in Portugal (1975–2005), using Landsat-based burnt area maps. *International Journal of Wildland Fire*, 21, https://doi.org/48-60.10.1071/WF10131

OTI - Observatório Técnico Independente: Rego, F., Fernandes, P., Silva, J., Azevedo, J., Moura, J. M., Oliveira, E., … Santos, F. D. (2019). O planeamento da Defesa da Floresta Contra Incêndios (DFCI) [Forest Fire Defence Planning (FDFCI)] Assembleia da República. Lisboa. 53 pp.

https://www.parlamento.pt/Documents/2019/dezembro/20191205-Estudo-Tecnico-Planeamento-DFCI.pdf

Pereira, J. M. C. & Santos, M. T. (2003). Cartografia das Áreas Queimadas e do Risco de Incêndio em Portugal Continental (1990-1999) [Mapping Burnt Areas and Fire Risk in Mainland Portugal (1990-1999)]. Lisboa, Portugal: Direcção-Geral das Florestas.

Pereira, J. M. C., Carreiras, J. M. B., Silva, J. M. N. & Vasconcelos, M. J. (2006). Alguns Conceitos Básicos sobre os Fogos Rurais em Portugal. Capítulo 6; Incêndios Florestais em Portugal - Caracterização, Impactes e Prevenção [Some Basic Concepts about Rural Fires in Portugal. Chapter 6; Wildfires in Portugal - Characterization, Impacts and Prevention]. ISA Press, Lisboa. p. 133- 158

Pereira, J. M. C., Silva, P. C., Melo, I., Oom, D., Baldassarre, G. & Pereira, M. G. (2022). Cartografia de Regimes de Fogo à Escala da Freguesia (1980-2017) [Mapping Fire Regimes at the Parish Level (1980-2017)]. ForestWISE (Coord.) - Projetos AGIF 2021 (P32100231), Vila Real, 29 pp

Ribeiro, O., Lautensach, H. & Daveau, S. (1988). Geografia de Portugal 2. O Ritmo Climático e a Paisagem [Geography of Portugal 2. The Climate Rhythm and the Landscape]. Edições João Sá da Costa, Lisboa,1988.

Riebeek, H. & Simmon, R. (2014). Why is that Forest Red and that Cloud Blue? How to Interpret a False-Color Satellite Image. The Earth Observatory - NASA. https://earthobservatory.nasa.gov/features/FalseColor

Ruiz-Gallardo, J. R. (2007.) Teledetecção e GIS na assistência de atuação florestal pós-incêndio. [Tese de doutoramento]. Universidad de Castilla la Mancha. http://hdl. handle.net/10578/968

Schroeder, W. & Giglio, L. (2018). NASA VIIRS Land Science Investigator Processing System (SIPS). Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m & 750 m Active Fire Products Product. User's Guide Version 1.4. NASA. https://lpdaac.usgs.gov/documents/427/VNP14_User_Guide_V1.pdf

Scotto, M. G., Gouveia, S., Carvalho, A., Monteiro, A., Martins, V., Flannigan, M. D., … Borrego, C. (2014). Area burned in Portugal over recent decades: an extreme value analysis. *International Journal of Wildland Fire*, 23(6), 812-824. https://doi.org/10.1071/WF13104

Silva, J, & Catry, F. (2006). Forest Fires in cork oak (*Quercus suber* L.) stands in Portugal. *International Journal of Environmental Studies*, 63(3), 235-257. https://doi.org/10.1080/00207230600720829

Silva, J. M. N., Moreno, M. V, Le Page, Y., Oom, D., Bistinas, I. & Pereira, J. M. C. (2019). Spatio-temporal trends of area burnt in the Iberian Peninsula, 1975 - 2013. *Regional Environmental Change*, 19, 515–527. https://doi.org/10.1007/s10113-018-1415-6

Tanaka, S., Kimura, H. & Suga, Y. (1983) Preparation of a 1:25000 Landsat map for assessment of burnt area on Etajima Island. *International Journal of Remote Sensing*, 4,1, 17-31. https://doi.org/10.1080/01431168308948528

Tedim, F., Remelgado, R., Martins, J., & Carvalho, S. (2013). Os grandes incêndios florestais em Portugal. Desafios para a gestão do risco. Grandes Incêndios Florestais, Erosão, Degradação e Medidas de Recuperação dos Solos. Edição: Universidade do Minho, Guimarães, Portugal; Editora: NIGP – Núcleo de Investigação em Geografia e Planeamento Universidade do Minho; RISCOS; CEGOT Editores: António Bento Gonçalves, António Vieira. p. 75-86

Tedim, F., Remelgado, R., Martins, J., & Carvalho, S. (2015). The largest forest fires in Portugal: the constraints of burned area size on the comprehension of fire severity. *Journal of Environmental Biology*, 36, 133-143.

Trigo, R., Sousa, P., Pereira, M., Rasilla, D. & Gouveia, C. (2013). Modelling wildfire activity in Iberia with different Atmospheric Circulation WTs. International Journal of Climatology, 36, 3149. https://doi.org/10.1002/joc.3749

Verde, J. & Zêzere, J. (2010). Assessment and validation of wildfire susceptibility and hazard in Portugal. *Natural Hazards and Earth System Sciences*, 10, 485-497. https://doi.org/10.5194/nhess-10-485-2010

Verde, J. (2008). Avaliação da perigosidade de incêndio florestal [Forest fire hazard assessment]. [Dissertação de Mestrado, Universidade de Lisboa]. Repositório da Universidade de Lisboa. https://repositorio.ul.pt/bitstream/10451/502/1/17981_Tese_Mestrado_Geografia_Fisica_JOAOVERDE.pdf

[i] *Execução de cartografia numérica vetorial e ortofotomapas à escala 1:10000 para a região do Vale do Lima – Relatório Final. Documento cedido por VALIMAR Comunidade Urbana do Vale do Lima.*
[ii] *Ortoimagens do território do Alto Minho – voo de 2018. Documentos cedidos pela Comunidade Intermunicipal do Alto Minho.*

REFERENCIAS: CAPÍTULO V

1. Pereira, J.M.C.; Carreiras, J.; Silva, J.M.N.; Vasconcelos, M.J.P. Alguns conceitos básicos sobre os fogos rurais em Portugal. In *Incêndios Florestais em Portugal - Caracterização, Impactes e Prevenção*; Lisboa, **2006**; pp. 133–158.

2. Oliveira, S.L.J.; Pereira, J.M.C.; Carreiras, J.M.B. Fire frequency analysis in Portugal (1975-2005), using Landsat-based burnt area maps. *Int J Wildland Fire* **2012**, *21*, 48–60.

3. Connor, S.E.; Vannière, B.; Colombaroli, D.; Anderson, R.S.; Carrión, J.S.; Ejarque, A.; Gil Romera, G.; González-Sampériz, P.; Hoefer, D.; Morales-Molino, C.; et al. Humans take control of fire-driven diversity changes in Mediterranean Iberia's vegetation during the Mid–Late Holocene. *Holocene* **2019**, *29*, 886–901, doi:10.1177/0959683619826652.

4. Vannière, B.; Colombaroli, D.; Chapron, E.; Leroux, A.; Tinner, W.; Magny, M. Climate versus Human-Driven Fire Regimes in Mediterranean Landscapes: The Holocene record of Lago Dell'Accesa (Tuscany, Italy). *Quat Sci Rev* **2008**, *27*, 1181–1196, doi:10.1016/j.quascirev.2008.02.011.

5. Pinto, B.; Aguiar, C.; Partidário, M. Brief historical ecology of Northern Portugal during the Holocene. *Environ Hist Camb* **2010**, *16*, 3–42.

6. Ganteaume, A.; Camia, A.; Jappiot, M.; San Miguel-Ayanz, J.; Long-Fournel, M.; Lampin, C.; Ganteaume, A.; Camia B, A.; Jappiot, M.; San-Miguel-Ayanz B, J.; et al. A Review of the main driving factors of forest fire ignition over Europe. *Environ Manage* **2013**, *51*, 651–662, doi:10.1007/s00267-012-9961-zï.

7. Vázquez, A.; Moreno, J.M. Sensitivity of fire occurrence to meteorological variables in Mediterranean and Atlantic areas of Spain. *Landsc Urban Plan* **1993**, *24*, 129–142.

8. Honrado, J.P.; Lomba, A.; Alves, P.; Aguiar, C.; Monteiro-Henriques, T.; Cerqueira, Y.; Monteiro, P.; Barreto Caldas, F. Conservation Management of EU priority habitats after collapse of traditional pastoralism: navigating socioecological transitions in mountain rangeland. *Rural Sociol* **2017**, *82*, 101–128, doi:10.1111/ruso.12111.

9. Carmo, M.C. Solo e agricultura no século XX Português. Um problema ambiental, histórico e epistemológico. Ph.D. Dissertation, Universidade de Lisboa: Lisboa, **2018**.

10. Meira Castro, A.C.; Nunes, A.; Sousa, A.; Lourenço, L. Mapping the causes of forest fires in Portugal by Clustering Analysis. *Geosciences (Switzerland)* **2020**, *10*, doi:10.3390/geosciences10020053.

11. Moreira, F.; Rego, F.C.; Ferreira, P.G. Temporal (1958-1995) pattern of change in a cultural landscape of Northwestern Portugal: implications for fire occurrence. *Landscape Ecol* 2001, *16*, 557–567.

12. Pyne, S.J. Fogo no jardim: compreensão contexto dos incêndios em Portugal. In *Incêndios florestais em Portugal : caracterização, impactes e prevenção*; Pereira, J.S., Pereira, J.M.C., Rego, F.C., Silva, J.M.N., Silva, T.P. da, Eds.; Instituto Superior de Agronomia: Lisboa, **2006**; pp. 115–131.

13. Parente, J.; Pereira, M.G.; Amraoui, M.; Tedim, F. Negligent and intentional fires in Portugal: spatial distribution characterization. *Science of the Total Environment* **2018**, *624*, 424–437, doi:10.1016/j.scitotenv.2017.12.013.

14. Sequeira, C.R.; Rego, F.C.; Montiel-Molina, C. Historical fire records at the two ends of Iberian Central Mountain System: Estrela Massif and Ayllón Massif. *Investigaciones Geográficas* **2019**, *72*, 31–52.

15. Casau, M.; Ferreira Dias, M.; Teixeira, L.; Matias, J.C.O.; Nunes, L.J.R. Reducing rural fire risk through the development of a sustainable supply chain model for residual agroforestry biomass supported in a web platform: a case study in Portugal Central Region with the Project BioAgroFloRes. *Fire* **2022**, *5*, 61, doi:10.3390/fire5030061.

16. Tedim, F.; Leone, V.; Lovreglio, R.; Xanthopoulos, G.; Chas-amil, M.L.; Ganteaume, A.; Efe, R.; Royé, D.; Fuerst-Bjeliš, B.; Nikolov, N.; et al. Forest Fire causes and motivations in Southern and South-Eastern Europe through the perception of experts: contribution to enhance the current policies. *Forests* **2022**, *13*, doi:10.3390/f13040562.

17. Pereira, H.M.; Domingos, T.; Vicente, L. *Portugal Millennium Ecosystem: State of the Assessment Report*; **2004**;

18. Bassi, S.; Kettunen, M. *Forest Fires: causes and contributing factors in Europe*; London, **2008**;

19. Carvalho, A.; Flannigan, M.D.; Logan, K.; Miranda, A.I.; Borrego, C. Fire activity in Portugal and its relationship to weather and the Canadian Fire Weather Index System. *Int J Wildland Fire* **2008**, *17*, 328–338, doi:10.1071/WF07014.

20. Carmo, M.; Ferreira, J.; Mendes, M.; Silva, Á.; Silva, P.; Alves, D.; Reis, L.; Novo, I.; Xavier Viegas, D. The climatology of extreme wildfires in Portugal, 1980–2018: Contributions to forecasting and preparedness. *Int J Climatol* **2022**, *42*, 3123–3146, doi:10.1002/joc.7411.

21. Silva, P.; Carmo, M.; Rio, J.; Novo, I. Changes in the seasonality of fire activity and fire weather in Portugal: is the wildfire season really longer? *Meteorology* **2023**, *2*, 74–86, doi:10.3390/meteorology2010006.

22. Catry, F.X.; Damasceno, P.; Silva, J.S.; Galante, M.; Moreira, F. Spatial distribution patterns of wildfire ignitions in Portugal. In Proceedings of Wildfire 2007; Sevilla, Spain, **2007**.

23. Fernandes, P.M.; Loureiro, C.; Magalhes, M.; Ferreira, P.; Fernandes, M. Fuel age, weather and burn probability in Portugal. *Int J Wildland Fire* **2012**, *21*, 380–384, doi:10.1071/WF10063.

24. Nunes, L.J.R.; Raposo, M.A.M.; Pinto Gomes, C.J. A Historical perspective of landscape and human population dynamics in Guimarães (Northern Portugal): Possible implications of rural fire risk in a changing environment. *Fire* **2021**, *4*, doi:10.3390/fire4030049.

25. Bergonse, R.; Oliveira, S.; Zêzere, J.L.; Moreira, F.; Ribeiro, P.F.; Leal, M.; Lima e Santos, J.M. Biophysical controls over fire regime properties in Central Portugal. *Science of the Total Environment* **2022**, *810*, doi:10.1016/j.scitotenv.2021.152314.

26. Ribeiro, C.; Valente, S.; Coelho, C.; Figueiredo, E. A Look at forest fires in Portugal: technical, institutional, and social perceptions. *Scand J For Res* **2015**, *30*, 317–325, doi:10.1080/02827581.2014.987160.

27. Pereira J.M.C., S.P.C., M.I., O.D., B.G. e P.M.G. *Cartografia de regimes de fogo à escala da freguesia (1980-2017)*; Vila Real, 2022;

28. Chuvieco, E.; Justice, C. Relations between human factors and global fire activity. In *Advances in Earth Observation of Global Change*; Springer Netherlands, 2010; pp. 187–199 ISBN 9789048190843.

29. Ferreira-Leite, F.; Bento-Gonçalves, A.; Lourenço, L.; Úbeda, X. Problemas metodológicos no estudo dos incêndios florestais em Portugal Continental. O caso dos grandes incêndios florestais. In Proceedings of the XIII Coloquio Ibérico de Geografia; Dominic Royé, José Antonio Aldrey Vázquez, Marcos Valcárcel Díaz, Miguel Pazos Otón, María José Piñeira Mantiñán, Eds.; XIII Coloquio Ibérico de Geografia. Santiago de Compostela, October 2012; pp. 848–857.

30. O.T.I. (Observatório Técnico Independente: Castro Rego, F.; Fernandes, P.; Sande Silva, J.; Azevedo, J.; Moura, J.M.; Oliveira, E.; Cortes, R.; Viegas, D.X.; Caldeira, D.; et al. *O planeamento da defesa da floresta contra incêndios (DFCI)*; Lisboa, 2019;

31. Coughlan, M.R. Errakina: Pastoral fire use and landscape memory in the Basque Region of the French Western Pyrenees. *J Ethnobiol* **2013**, *33*, 86–104, doi:10.2993/0278-0771-33.1.86.

32. Fernandes, P.M.; Loureiro, C.; Guiomar, N.; Pezzatti, G.B.; Manso, F.T.; Lopes, L. The dynamics and drivers of fuel and fire in the Portuguese public forest. *J Environ Manage* **2014**, *146*, 373–382, doi:10.1016/j.jenvman.2014.07.049.

33. Monteiro, A.; Ferreira, C.; Madureira, H. *Atlas Agroclimatológico do Entre Douro e Minho (2005). Relatório Final*; 2005;

34. CIM Alto Minho - Comunidade Intermunicipal do Alto Minho & Instituto Politécnico de Viana do Castelo *PIAAC - Plano Intermunicipal de Adaptação às Alterações Climáticas do Alto Minho - Contextualização e Cenarização Climática*; Viana do Castelo, 2017;

35. Díaz-Fierros, F. Forest fires in Galicia and Portugal: an historical overview. *Territorium: Revista Portuguesa de riscos, prevenção e segurança* **2019**, 97–114, doi:10.14195/1647-7723_26-1_7.

36. Congedo, L. *Semi-Automatic Classification Plugin Documentation. Release 6.0.1.1*; 2016;

37. Tanaka, S.; Kimura, H.; Suga, Y. Preparation of a 1:25000 Landsat map for assessment of burnt area on Etajima Island. *Int J Remote Sens* **1983**, *4*, 17–31, doi:10.1080/01431168308948528.

38. Chuvieco, E.; Congalton, R.G. Mapping and inventory of forest fires from digital processing of TM Data. *Geocarto Int* **1988**, *3*, 41–53, doi:10.1080/10106048809354180.

39. Ruiz Gallardo, J.R. Teledetección y SIG en la asistencia de la actuación forestal postincendio. Ph.D. Dissertation, Universidad de Castilla-La Mancha: Cuenca, 2007.

40. Rego, F.C.; Bunting, S.C.; Barreira, M.G. Effects of prescribed fire on *Chamaespartium tridentatum* ((L.)P. Gibbs) in *Pinus pinaster* (Aiton) Forests. *Journal of Range Management* **1988**, *41*, 410, doi:10.2307/3899579.

41. Torres-Manso, F.; Fernandes, P.; Pinto, R.; Botelho, H.; Monzon, A. Regional livestock grazing, human demography and fire incidence in the Portuguese landscape. *For Syst* **2014**, *23*, 15–21, doi:10.5424/fs/2014231-02758.

42. Manso, F.T.; Bento, J.; Botelho, H.; Pinto, R.; Ferreira, P.; Magalhães, M.; Gomes, M. Avaliação de características regionais e sazonais inerentes ao regime de fogo e ao pastoreio. *Silva Lusit* **2010**, *18*, 27–45.

43. Fernandes, P.M.; Monteiro-Henriques, T.; Guiomar, N.; Loureiro, C.; Barros, A.M.G. Bottom-up variables govern large-fire size in Portugal. *Ecosystems* **2016**, *19*, 1362–1375, doi:10.1007/s10021-016-0010-2.

44. Izco, J.; Amigo, J.; Ramil-Rego, P.; Díaz, R. Brezales: biodiversidad, usos y conservación. *Recursos Rurais, (2)* **2006**, *2*, 5–24, doi: https://doi.org/10.15304/rr.id5327.

45. Pastro, L.A.; Dickman, C.R.; Letnic, M. Fire type and hemisphere determine the effects of fire on the alpha and beta diversity of vertebrates: a global meta-analysis. *Global Ecology and Biogeography* **2014**, *23*, 1146–1156, doi:10.1111/geb.12195.

46. Lino, S.; Sillero, N.; Torres, J.; Santos, X.; Álvares, F. The role of fire on wolf distribution and breeding-site selection: insights from a generalist carnivore occurring in a fire-prone landscape. *Landsc Urban Plan* **2019**, *183*, 111–121, doi:10.1016/j.landurbplan.2018.12.003.

47. González, T.M.; González-Trujillo, J.D.; Muñoz, A.; Armenteras, D. Effects of fire history on animal communities: a systematic review. *Ecol Process* 2022, *11*.

48. Coughlan, M.R. Wildland arson as clandestine resource management: a space–time permutation analysis and classification of informal fire management regimes in Georgia, USA. *Environ Manage* **2016**, *57*, 1077–1087, doi:10.1007/s00267-016-0669-3.

49. Huffman, M.R. The many elements of Traditional Fire Knowledge: Synthesis, classification, and aids to cross-cultural problem solving in fire dependent systems around the world. *Ecology and Society* **2013**, *18*, doi:10.5751/ES-05843-180403.

50. Vázquez-Varela, C.; Martínez-Navarro, J.M.; Abad-González, L. Traditional Fire Knowledge: a thematic synthesis approach. *Fire* **2022**, *5*.

REFERENCIAS: CAPÍTULO VI

1. He, T.; Lamont, B.B. Baptism by Fire: The Pivotal Role of Ancient Conflagrations in Evolution of the Earth's Flora. *Natl Sci Rev* **2018**, *5*, 237–254, doi:10.1093/nsr/nwx041.

2. Pausas, J.G.; Keeley, J.E. A Burning Story: The Role of Fire in the History of Life. *Bioscience* **2009**, *59*, 593–601, doi:10.1525/bio.2009.59.7.10.

3. Belcher, C.M.; Mills, B.J.W.; Vitali, R.; Baker, S.J.; Lenton, T.M.; Watson, A.J. The Rise of Angiosperms Strengthened Fire Feedbacks and Improved the Regulation of Atmospheric Oxygen. *Nat Commun* **2021**, *12*, doi:10.1038/s41467-020-20772-2.

4. McLauchlan, K.K.; Higuera, P.E.; Miesel, J.; Rogers, B.M.; Schweitzer, J.; Shuman, J.K.; Tepley, A.J.; Varner, J.M.; Veblen, T.T.; Adalsteinsson, S.A.; et al. Fire as a Fundamental Ecological Process: Research Advances and Frontiers. *Journal of Ecology* 2020, *108*, 2047–2069.

5. MacDonald, K. Fire-Free Hominin Strategies for Coping with Cool Winter Temperatures in North-Western Europe from Before 800,000 to Circa 400,000 Years Ago. *Paleo Anthropology* **2018**, *16*, 7–26, doi:10.4207/PA.2018.ART109.

6. Roebroeks, W.; Villa, P. On the Earliest Evidence for Habitual Use of Fire in Europe. *Proceedings of the National Academy of Sciences* **2011**, *108*, 5209–5214, doi:10.1073/pnas.1018116108.

7. Daniau, A.L.; D'Errico, F.; Goñi, M.F.S. Testing the Hypothesis of Fire Use for Ecosystem Management by Neanderthal and Upper Palaeolithic Modern Human Populations. *PLoS One* **2010**, *5*, doi:10.1371/journal.pone.0009157.

8. Connor, S.E.; Vannière, B.; Colombaroli, D.; Anderson, R.S.; Carrión, J.S.; Ejarque, A.; Gil Romera, G.; González-Sampériz, P.; Hoefer, D.; Morales-Molino, C.; et al. Humans Take Control of Fire-Driven Diversity Changes in Mediterranean Iberia's Vegetation during the Mid–Late Holocene. *Holocene* **2019**, *29*, 886–901, doi:10.1177/0959683619826652.

9. Abel-Schaad, D.; López-Sáez, J.A. Vegetation Changes in Relation to Fire History and Human Activities at the Peña Negra Mire (Bejar Range, Iberian Central Mountain System, Spain) during the Past 4,000 Years. *Veg Hist Archaeobot* **2013**, *22*, 199–214, doi:10.1007/s00334-012-0368-9.

10. Bal, M.C.; Pelachs, A.; Perez-Obiol, R.; Julia, R.; Cunill, R. Fire History and Human Activities during the Last 3300cal Yr BP in Spain's Central Pyrenees: The Case of the Estany de Burg. *Palaeogeogr Palaeoclimatol Palaeoecol* **2011**, *300*, 179–190, doi:10.1016/j.palaeo.2010.12.023.

11. Santos, L.; Romani, J.R. V; Jalut, G. History of Vegetation during the Holocene in the Courel and Queixa Sierras, Galicia, Northwest Iberian Peninsula. *J Quat Sci* **2000**, *15*, 621–632.

12. Carrión, J.S.; Sánchez-Gómez, P.; Mota, J.F.; Yll, R.; Chaín, C. Holocene Vegetation Dynamics, Fire and Grazing in the Sierra de Gádor, Southern Spain. *Holocene* **2003**, *13*, 839–849, doi:10.1191/0959683603hl662rp.

13. Johansson, M.U.; Fetene, M.; Malmer, A.; Granström, A. Tending for Cattle: Traditional Fire Management in Ethiopian Montane Heathlands. *Ecology and Society* **2012**, *17*, doi:10.5751/ES-04881-170319.

14. Leone, V.; Lovreglio, R.; Martín, M.P.; Martínez, J.; Vilar, L. Human Factors of Fire Occurrence in the Mediterranean. In *Earth Observation of Wildland Fires in Mediterranean Ecosystems*; Springer Berlin Heidelberg: Berlin, Heidelberg, 2009; pp. 149–170.

15. Fernandes, P.M.; Santos, J.A.; Castedo-dorado, F.; Almeida, R. Fire from the Sky in the Anthropocene. *Fire* **2021**, *4*, doi:10.3390/fire4010013.

16. ICNF Sistema de Gestão de Incêndios Florestais.

17. Pereira, M.G.; Malamud, B.D.; Trigo, R.M.; Alves, P.I. The History and Characteristics of the 1980-2005 Portuguese Rural Fire Database. *Natural Hazards and Earth System Science* **2011**, *11*, 3343–3358, doi:10.5194/nhess-11-3343-2011.

18. Santalla, A.L.; García, M.L. *Los Incendios Forestales En España - Decenio 2006-2015*; Madrid, 2019;

19. Rego, F.; Rigolot, E.; Fernandes, P.; Joaquim, C.M.; Silva, S. *Hacia La Gestión Integrada Del Fuego EFI-Informe de Políticas Nº 4*; 2010;

20. Reyes-García, V. Conocimiento Ecológico Tradicional Para La Conservación: Dinámicas y Conflictos. *Papeles* 2009, *107*, 39–55.

21. Welch, J.R.; Coimbra, C.E.A. Indigenous Fire Ecologies, Restoration, and Territorial Sovereignty in the Brazilian Cerrado: The Case of Two Xavante Reserves. *Land use policy* **2021**, *104*, doi:10.1016/j.landusepol.2019.104055.

22. Fernandes, P.M.; Davies, G.M.; Ascoli, D.; Fernández, C.; Moreira, F.; Rigolot, E.; Stoof, C.R.; Vega, J.A.; Molina, D. Prescribed Burning in Southern Europe: Developing Fire Management in a Dynamic Landscape. *Front Ecol Environ* 2013, *11*.

23. Mistry, J.; Bilbao, B.A.; Berardi, A. Community Owned Solutions for Fire Management in Tropical Ecosystems: Case Studies from Indigenous Communities of South America. *Philosophical Transactions of the Royal Society B: Biological Sciences* **2016**, *371*, doi:10.1098/rstb.2015.0174.

24. Lasanta, T.; Cortijos-López, M.; Errea, M.P.; Khorchani, M.; Nadal-Romero, E. An Environmental Management Experience to Control Wildfires in the Mid-Mountain Mediterranean Area: Shrub Clearing to Generate Mosaic Landscapes. *Land use policy* **2022**, *118*, doi:10.1016/j.landusepol.2022.106147.

25. Ruiz-Mirazo, J.; Martínez-Fernández, J.; Vega-García, C. Pastoral Wildfires in the Mediterranean: Understanding Their Linkages to Land Cover Patterns in Managed Landscapes. *J Environ Manage* **2012**, *98*, 43–50, doi:10.1016/j.jenvman.2011.12.017.

26. San Emeterio, L.; Múgica, L.; Ugarte, M.D.; Goicoa, T.; Canals, R.M. Sustainability of Traditional Pastoral Fires in Highlands under Global Change: Effects on Soil Function and Nutrient Cycling. *Agric Ecosyst Environ* **2016**, *235*, 155–163, doi:10.1016/j.agee.2016.10.009.

27. Coughlan, M.R. Errakina : Pastoral Fire Use and Landscape Memory In the Basque Region of the French Western Pyrenees. *J Ethnobiol* **2013**, *33*, 86–104, doi:10.2993/0278-0771-33.1.86.

28. Ascoli, D.; Bovio, G. Prescribed Burning in Italy: Issues, Advances and Challenges. *IForest* 2013, *6*, 79–89.

29. Meddour-Sahar, O.; Lovreglio, R.; Meddour, R.; Leone, V.; Derridj, A. Fire and People in Three Rural Communities in Kabylia (Algeria): Results of a Survey. *Open J For* **2013**, *03*, 30–40, doi:10.4236/ojf.2013.31006.

30. Castoldi, E.; Quintana, J.R.; Mata, R.G.; Molina, J.A. Early Post-Fire Plant Succession in Slash-Pile Prescribed Burns of a Sub-Mediterranean Managed Forest. *Plant Ecol Evol* **2013**, *146*, 272–278, doi:10.5091/plecevo.2013.848.

31. van Vliet, J.; de Groot, H.L.F.; Rietveld, P.; Verburg, P.H. Manifestations and Underlying Drivers of Agricultural Change in Europe. *Landsc Urban Plan* **2015**, *133*, 24–36.

32. Plieninger, T.; Draux, H.; Fagerholm, N.; Bieling, C.; Bürgi, M.; Kizos, T.; Kuemmerle, T.; Primdahl, J.; Verburg, P.H. The Driving Forces of Landscape Change in Europe: A Systematic Review of the Evidence. *Land use policy* **2016**, *57*, 204–214, doi:10.1016/j.landusepol.2016.04.040.

33. Schulp, C.J.E.; Levers, C.; Kuemmerle, T.; Tieskens, K.F.; Verburg, P.H. Mapping and Modelling Past and Future Land Use Change in Europe's Cultural Landscapes. *Land use policy* **2019**, *80*, 332–344, doi:10.1016/j.landusepol.2018.04.030.

34. Weissteiner, C.J.; Strobl, P.; Sommer, S. Assessment of Status and Trends of Olive Farming Intensity in EU-Mediterranean Countries Using Remote Sensing Time Series and Land Cover Data. *Ecol Indic* **2011**, *11*, 601–610, doi:10.1016/j.ecolind.2010.08.006.

35. Kuemmerle, A.T.; Levers, C.; Erb, K.; Estel, S.; Martin, R. Hotspots of Land Use Change in Europe. *Environmental Research Letters* **2016**, *11*, 1–48, doi:10.1088/1748-9326/11/6/064020.

36. Levers, C.; Müller, D.; Erb, K.; Haberl, H.; Jepsen, M.R.; Metzger, M.J.; Meyfroidt, P.; Plieninger, T.; Plutzar, C.; Stürck, J.; et al. Archetypical Patterns and Trajectories of Land Systems in Europe. *Reg Environ Change* **2018**, *18*, 715–732, doi:10.1007/s10113-015-0907-x.

37. Plutzar, C.; Kroisleitner, C.; Haberl, H.; Fetzel, T.; Bulgheroni, C.; Beringer, T.; Hostert, P.; Kastner, T.; Kuemmerle, T.; Lauk, C.; et al. Changes in the Spatial Patterns of Human Appropriation of Net Primary Production (HANPP) in Europe 1990–2006. *Reg Environ Change* **2016**, *16*, 1225–1238, doi:10.1007/s10113-015-0820-3.

38. Weissteiner, C.J.; Boschetti, M.; Böttcher, K.; Carrara, P.; Bordogna, G.; Brivio, P.A. Spatial Explicit Assessment of Rural Land Abandonment in the Mediterranean Area. *Glob Planet Change* **2011**, *79*, 20–36, doi:10.1016/j.gloplacha.2011.07.009.

39. Debolini, M.; Marraccini, E.; Dubeuf, J.P.; Geijzendorffer, I.R.; Guerra, C.; Simon, M.; Targetti, S.; Napoléone, C. Land and Farming System Dynamics and Their Drivers in the Mediterranean Basin. *Land use policy* **2018**, *75*, 702–710, doi:10.1016/j.landusepol.2017.07.010.

40. Fernandes, P.M.; Loureiro, C.; Guiomar, N.; Pezzatti, G.B.; Manso, F.T.; Lopes, L. The Dynamics and Drivers of Fuel and Fire in the Portuguese Public Forest. *J Environ Manage* **2014**, *146*, 373–382, doi:10.1016/j.jenvman.2014.07.049.

41. Viedma, O.; Moity, N.; Moreno, J.M. Changes in Landscape Fire-Hazard during the Second Half of the 20th Century: Agriculture Abandonment and the Changing Role of Driving Factors. *Agric Ecosyst Environ* **2015**, *207*, 126–140, doi:10.1016/j.agee.2015.04.011.

42. Azevedo, J.C.; Moreira, C.; Castro, J.P.; Loureiro, C. Agriculture Abandonment, Land- Use Change and Fire Hazard in Mountain Landscapes in Northeastern Portugal. In *Landscape ecology in forest management and conservation: challenges and solutions for global change*; Li, C., Lafortezza, R., Chen, J., Eds.; Springer: Berlin, 2011; pp. 329–351.

43. Sil, Â.; Fernandes, P.M.; Paula, A.; Alonso, J.M.; Honrado, J.P.; Perera, A.; Azevedo, J.C. Farmland Abandonment Decreases the Fire Regulation Capacity and the Fire Protection Ecosystem Service in Mountain Landscapes. *Ecosyst Serv* **2019**, *36*, 100908, doi:10.1016/j.ecoser.2019.100908.

44. Collins, R.D.; de Neufville, R.; Claro, J.; Oliveira, T.; Pacheco, A.P. Forest Fire Management to Avoid Unintended Consequences: A Case Study of Portugal Using System Dynamics. *J Environ Manage* **2013**, *130*, 1–9, doi:10.1016/j.jenvman.2013.08.033.

45. Ingalsbee, T. Whither the Paradigm Shift? Large Wildland Fires and the Wildfire Paradox Offer Opportunities for a New Paradigm of Ecological Fire Management. *Int J Wildland Fire* **2017**, *26*, 557–561, doi:10.1071/WF17062.

46. Leone, V.; Tedim, F.; Xanthopoulos, G. Fire Smart Territory as an Innovative Approach to Wildfire Risk Reduction. In *Extreme Wildfire Events and Disasters: Root Causes and New Management Strategies*; Elsevier, 2020; pp. 201–215 ISBN 9780128157213.

47. Fernandes, P.M.; Monteiro-Henriques, T.; Guiomar, N.; Loureiro, C.; Barros, A.M.G. Bottom-up Variables Govern Large-Fire Size in Portugal. *Ecosystems* **2016**, *19*, 1362–1375, doi:10.1007/s10021-016-0010-2.

48. Castellnou, M.; Guiomar, N.; Rego, F.; Fernandes, P.M. Fire Growth Patterns in the 2017 Mega Fire Episode of October 15 , Central Portugal. **2018**, 447–453.

49. Rodrigues, M.; Cunill Camprubí, À.; Balaguer-Romano, R.; Coco Megía, C.J.; Castañares, F.; Ruffault, J.; Fernandes, P.M.; Resco de Dios, V. Drivers and Implications of the Extreme 2022 Wildfire Season in Southwest Europe. *Science of the Total Environment* **2023**, *859*, doi:10.1016/j.scitotenv.2022.160320.

50. Dossi, S.; Messerschmidt, B.; Ribeiro, L.M.; Almeida, M.; Rein, G. Relationships between Building Features and Wildfire Damage in California, USA and Pedrógão Grande, Portugal. *Int J Wildland Fire* **2022**, doi:10.1071/WF22095.

51. Pinto, P.; Silva, Á.P.; Viegas, D.X.; Almeida, M.; Raposo, J.; Ribeiro, L.M. Influence of Convectively Driven Flows in the Course of a Large Fire in Portugal: The Case of Pedrógão Grande. *Atmosphere (Basel)* **2022**, *13*, doi:10.3390/atmos13030414.

52. Giannaros, T.M.; Papavasileiou, G.; Lagouvardos, K.; Kotroni, V.; Dafis, S.; Karagiannidis, A.; Dragozi, E. Meteorological Analysis of the 2021 Extreme Wildfires in Greece: Lessons Learned and Implications for Early Warning of the Potential for Pyroconvection. *Atmosphere (Basel)* **2022**, *13*, doi:10.3390/atmos13030475.

53. Seijo, F.; Cespedes, B.; Zavala, G. Traditional Fire Use Impact in the Aboveground Carbon Stock of the Chestnut Forests of Central Spain and Its Implications for Prescribed Burning. *Science of the Total Environment* **2018**, *625*, 1405–1414, doi:10.1016/j.scitotenv.2017.12.079.

54. Mariani, M.; Connor, S.E.; Theuerkauf, M.; Herbert, A.; Kuneš, P.; Bowman, D.; Fletcher, M.S.; Head, L.; Kershaw, A.P.; Haberle, S.G.; et al. Disruption of Cultural Burning Promotes Shrub Encroachment and Unprecedented Wildfires. *Front Ecol Environ* 2022, *20*, 292–300.

55. Souza, M.E.B.; Pacheco, A.P.; Teixeira, J.G. Systematizing Experts' Risk Perception on Rural Fires Resulting from Traditional Burnings in Portugal: A Mental Model Approach. In *Advances in Forest Fire Research 2022*; Imprensa da Universidade de Coimbra, 2022; pp. 1520–1525.

56. Coutinho, J.M.P. *Incêndios Florestais: Causas e Atitudes*; Númena: Porto Salvo, 2009;

57. Salgueiro, A. The Portuguese National Programme on Suppression Fire: GAUF Team Actions. In *Best practices of fire use – Prescribed burning and suppression fire programmes in selected case-study regions in Europe*-; Montiel, C., Kraus, D., Eds.; European Forest Institute: Joensuu, 2010; pp. 123–136.

58. Moreira, F.; Viedma, O.; Arianoutsou, M.; Curt, T.; Koutsias, N.; Rigolot, E.; Barbati, A.; Corona, P.; Vaz, P.; Xanthopoulos, G.; et al. Landscape-Wildfire Interactions in Southern Europe: Implications for Landscape Management. *J Environ Manage* **2011**, *92*, 2389–2402, doi:10.1016/j.jenvman.2011.06.028.

59. Nunes, M.C.S.; Vasconcelos, M.J.; Pereira, J.M.C.; Dasgupta, N.; Alldredge, R.J.; Rego, F.C. Land Cover Type and Fire in Portugal: Do Fires Burn Land Cover Selectively? *Landsc Ecol* **2005**, *20*, 661–673, doi:10.1007/s10980-005-0070-8.

60. Barros, A.M.G.; Pereira, J.M.C. Wildfire Selectivity for Land Cover Type: Does Size Matter? *PLoS One* **2014**, *9*, e84760, doi:10.1371/journal.pone.0084760.

61. Moreira, F.; Ascoli, D.; Safford, H.; Adams, M.A.; Moreno, J.M.; Pereira, J.M.C.; Catry, F.X.; Armesto, J.; Bond, W.; González, M.E.; et al. Wildfire Management in Mediterranean-Type Regions: Paradigm Change Needed. *Environmental Research Letters* **2020**, *15*, doi:10.1088/1748-9326/ab541e.

62. Keeley, J.E.; Pausas, J.G.; Rundel, P.W.; Bond, W.J.; Bradstock, R.A. Fire as an Evolutionary Pressure Shaping Plant Traits. *Trends Plant Sci* **2011**, *16*, 406–411, doi:10.1016/j.tplants.2011.04.002.

63. Silva, J.S.; Vaz, P.; Moreira, F.; Catry, F.; Rego, F.C. Wildfires as a Major Driver of Landscape Dynamics in Three Fire-Prone Areas of Portugal. *Landsc Urban Plan* **2011**, *101*, 349–358, doi:10.1016/j.landurbplan.2011.03.001.

64. Guiomar, N.; Godinho, S.; Fernandes, P.M.; Machado, R.; Neves, N.; Fernandes, J.P. Wildfire Patterns and Landscape Changes in Mediterranean Oak Woodlands. *Science of the Total Environment* **2015**, *536*, 338–352, doi:10.1016/j.scitotenv.2015.07.087.

65. Duane, A.; Aquilué, N.; Canelles, Q.; Morán-Ordoñez, A.; De Cáceres, M.; Brotons, L. Adapting Prescribed Burns to Future Climate Change in Mediterranean Landscapes. *Science of the Total Environment* **2019**, *677*, 68–83, doi:10.1016/j.scitotenv.2019.04.348.

66. Perpiña Castillo, C.; Jacobs-Crisioni, C.; Diogo, V.; Lavalle, C. Modelling Agricultural Land Abandonment in a Fine Spatial Resolution Multi-Level Land-Use Model: An Application for the EU. *Environmental Modelling and Software* **2021**, *136*, doi:10.1016/j.envsoft.2020.104946.

67. Sil, Â.; Fernandes, P.M.; Rodrigues, A.P.; Alonso, J.M.; Honrado, J.P.; Perera, A.; Azevedo, J.C. Farmland Abandonment Decreases the Fire Regulation Capacity and the Fire Protection Ecosystem Service in Mountain Landscapes. *Ecosyst Serv* **2019**, *36*, doi:10.1016/j.ecoser.2019.100908.

68. Benali, A.; Mota, B.; Carvalhais, N.; Oom, D.; Miller, L.M.; Campagnolo, M.L.; Pereira, J.M.C. Bimodal Fire Regimes Unveil a Global-Scale Anthropogenic Fingerprint. *Global Ecology and Biogeography* **2017**, *26*, 799–811, doi:10.1111/geb.12586.

69. Bajocco, S.; Ferrara, C.; Guglietta, D.; Ricotta, C. Easy-to-Interpret Procedure to Analyze Fire Seasonality and the Influence of Land Use in Fire Occurrence: A Case Study in Central Italy. *Fire* 2020, *3*, 1–11.

70. Bajocco, S.; Pezzatti, G.B.; Mazzoleni, S.; Ricotta, C. Wildfire Seasonality and Land Use: When Do Wildfires Prefer to Burn? *Environ Monit Assess* **2010**, *164*, 445–452, doi:10.1007/s10661-009-0905-x.

71. Krebs, P.; Pezzatti, G.B.; Mazzoleni, S.; Talbot, L.M.; Conedera, M. Fire Regime: History and Definition of a Key Concept in Disturbance Ecology. *Theory in Biosciences* **2010**, *129*, 53–69, doi:10.1007/s12064-010-0082-z.

72. Jacobs, J. *Quantitative Measurement of Food Selection A Modification of the Forage Ratio and Ivlev's Electivity Index*; Springer-Verlag, 1974; Vol. 14;.

73. Monteiro, A.; Ferreira, C.; Madureira, H. *Atlas Agroclimatológico Do Entre Douro e Minho (2005). Relatório Final*; 2005;

74. CIM Alto Minho - Comunidade Intermunicipal do Alto Minho & Instituto Politécnico de Viana do Castelo *PIAAC - Plano Intermunicipal de Adaptação Às Alterações Climáticas Do Alto Minho - Contextualização e Cenarização Climática*; Viana do Castelo, 2017;

75. LEAF EPIC WebGIS Portugal .

76. FAO *World Reference Base for Soil Resources 2014: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; Food and Agriculture Organization of the United Nations: Rome, 2015; ISBN 9789251083697.

77. Sweeney, L.; Harrison, S.P.; Linden, M. Vander Assessing Anthropogenic Influence on Fire History during the Holocene in the Iberian Peninsula. *Quat Sci Rev* 2022, *287*.

78. Martínez-Cortizas, A.; Costa-Casais, M.; López-Sáez, J.A. Environmental Change in NW Iberia between 7000 and 500 Cal BC. *Quaternary International* **2009**, *200*, 77–89, doi:10.1016/j.quaint.2008.07.012.

79. Reis, J. A «Lei Da Fome»: As Origens Do Proteccionismo Cerealífero (1889-1914). *Anal Soc* **1979**, *15*, 745–793.

80. Pais, J.M.; Valadas de Lima, A.M.; Baptista, J.F.; Marques de Jesus, M.F.; Gameiro. M.M. Elementos Para a História Do Fascismo Nos Campos: A «Campanha Do Trigo»: 1928-38 (Ii). *Anal Soc* **1978**, *14*, 321–389.

81. Mendonça, J.C. *75 Anos de Actividade Na Arborização de Serras*; Direcção-Geral dos Serviços Florestais e Aquícolas: Lisboa, 1961;

82. Brouwer, R. Between Policy and Politics: The Forestry Services and the Commons in Portugal. *Forest & Conservation History* **1993**, *37*, 160–168, doi:10.2307/3983554.

83. Brouwer, R. Planting Power - The Afforestation of the Commons and State Formation in Portugal, 1995.

84. DGT Carta de Uso e Ocupação Do Solo Para 2018.

85. Díaz-Fierros, F. Forest Fires in Galicia and Portugal: An Historical Overview. *Territorium: Revista Portuguesa de riscos, prevenção e segurança* **2019**, 97–114, doi:10.14195/1647-7723_26-1_7.

86. Oliveira, E.; Fernandes, P. UMA CARTOGRAFIA APERFEIÇOADA DAS ÁREAS ARDIDAS NO ALTO MINHO (NOROESTE DE PORTUGAL) ENTRE 2001 E 2020. **2023**, 430–5027, doi:10.18055/Finis28546.

87. Congedo, L. Semi-Automatic Classification Plugin: A Python Tool for the Download and Processing of Remote Sensing Images in QGIS. *J Open Source Softw* **2021**, *6*, 3172, doi:10.21105/joss.03172.

88. QGIS Development Team QGIS Geographic Information System.

89. Key, C.H.; Benson, N.C. Landscape Assessment (LA): Sampling Analysis and Methods. In *FIREMON: fire effects monitoring and inventory system*; Lutes, D.C., Keane, R.E., Caratti, J.F., Key, C.H., Benson, N.C., Sutherland, S., Gangi, L.J., Eds.; USDA Forest Service: Ogden, 2006; p. LA-1-LA-51.

90. Chuvieco, E.; Congalton, R.G. Mapping and Inventory of Forest Fires from Digital Processing of Tm Data. *Geocarto Int* **1988**, *3*, 41–53, doi:10.1080/10106048809354180.

91. Tanaka, S.; Kimura, H.; Suga, Y. Preparation of a 1:25000 Landsat Map for Assessment of Burnt Area on Etajima Island. *Int J Remote Sens* **1983**, *4*, 17–31, doi:10.1080/01431168308948528.

92. Fernandes, P.; Gonçalves, H.; Loureiro, C.; Fernandes, M.; Costa, T.; Cruz, M.G.; Botelho, H. Modelos de Combustível Florestal Para Portugal. *Poster* 2009, 348–354.

93. DGF *Inventário Florestal Nacional, Portugal Continental. 3ª Revisão, 1995-1998*; Lisboa, 2001;

94. Caetano, M.; Igreja, C.; Marcelino, F. *Especificações Técnicas Da Carta de Uso e Ocupação Do Solo (COS) de Portugal Continental Para 1995, 2007, 2010 e 2015*; Lisboa, 2018;

95. DGT *Especificações Técnicas Da Carta de Uso e Ocupação Do Solo (COS) de Portugal Continental Para 2018*; Lisboa, 2019;

96. Büttner, J.; Feranec, J.; Jaffrain, G. *Corine Land Cover Update 2000: Technical Guidelines. EEA Technical Report n.º 89*; Copenhagen, 2002;

97. Caetano, M.; Marcelino, F. *CORINE Land Cover de Portugal Continental 1990-2000-2006-2012*; Lisboa, 2017;

98. R Core Team R: A Language and Environment for Statistical Computing 2023.

99. Lyubchich, V.; Gel, Y.R.; Brenning, A.; Chu, C.; Huang, X.; Islambekov, U.; Niamkova, P.; Ofori-Boateng, D.; Schaeffer, E.D.; Vishwakarma, S.; et al. Package ‘Funtimes’ - Functions for Time Series Analysis Available online: https://cran.r-project.org/web/packages/funtimes/funtimes.pdf (accessed on 30 April 2023).

100. Noguchi, K.; Gel, Y.R.; Duguay, C.R. Bootstrap-Based Tests for Trends in Hydrological Time Series, with Application to Ice Phenology Data. *J Hydrol (Amst)* **2011**, *410*, 150–161, doi:10.1016/j.jhydrol.2011.09.008.

101. Lyubchich, V.; Gel, Y.R.; El-Shaarawi, A. On Detecting Non-Monotonic Trends in Environmental Time Series: A Fusion of Local Regression and Bootstrap. *Environmetrics* **2013**, *24*, 209–226, doi:10.1002/env.2212.

102. Kreiss, J.P.; Lahiri, S.N. Bootstrap Methods for Time Series. In *Handbook of Statistics*; Elsevier B.V., 2012; Vol. 30, pp. 3–26.

103. Bühlmann, P.; Buhlmann, P. *Sieve Bootstrap for Time Series*; 1997; Vol. 3;.

104. Hall, P.; van Keilegom, I. *Using Difference-Based Methods for Inference in Nonparametric Regression with Time Series Errors*; 2003; Vol. 65;.

105. Hintze, J.L.; Nelson, R.D. Violin Plots: A Box Plot-Density Trace Synergism. *American Statistician* **1998**, *52*, 181–184, doi:10.1080/00031305.1998.10480559.

106. Wickham, H. *Ggplot2 - Elegant Graphics for Data Analysis*; Springer New York, 2009;

107. Mann, H.B.; Whitney, D.R. On a Test of Whether One of Two Random Variables Is Stochastically Larger than the Other. *Annals of Mathematical Statistics* **1947**, *18*, 50–60, doi:10.1214/aoms/1177730491.

108. Allen, M.; Poggiali, D.; Whitaker, K.; Marshall, T.R.; Kievit, R.A. Raincloud Plots: A Multi-Platform Tool for Robust Data Visualization [Version 1; Peer Review: 2 Approved]. *Wellcome Open Res* **2019**, *4*, doi:10.12688/wellcomeopenres.15191.1.

109. Wickham, H.; Averick, M.; Bryan, J.; Chang, W.; McGowan, L.; François, R.; Grolemund, G.; Hayes, A.; Henry, L.; Hester, J.; et al. Welcome to the Tidyverse. *J Open Source Softw* **2019**, *4*, 1686, doi:10.21105/joss.01686.

110. Dancho, M.; Vaughan, D. Package "tidyquant" - Tidy Quantitative Financial Analysis Available online: https://github.com/business-science/tidyquant/issues.

111. Kay, M.; Wiernik, B.M. Package 'Ggdist' - Visualizations of Distributions and Uncertainty Available online: https://github.com/mjskay/ggdist/ (accessed on 30 April 2023).

112. Arnold, J.B.; Daroczi, G.; Werth, B.; Weitzner, B.; Kunst, J.; Auguie, B.; Rudis, B.; Talbot, J. Package "ggthemes" - Extra Themes, Scales and Geoms for "Ggplot2" Available online: http://github.com/jrnold/ggthemes (accessed on 30 April 2023).

113. Weibull, W. A Statistical Distribution Function of Wide Applicability. *J Appl Mech* **1951**, *18*, 297–293, doi:10.1115/1.4010337.

114. Fernandes, P.M.; Loureiro, C.; Magalhães, M.; Ferreira, P.; Fernandes, M. Fuel Age, Weather and Burn Probability in Portugal. *Int J Wildland Fire* **2012**, *21*, 380–384, doi:10.1071/WF10063.

115. Oliveira, S.L.J.; Pereira, J.M.C.; Carreiras, J.M.B. Fire Frequency Analysis in Portugal (1975-2005), Using Landsat-Based Burnt Area Maps. *Int J Wildland Fire* **2012**, *21*, 48–60, doi:10.1071/WF10131.

116. Delignette-Muller, M.L.; Dutang, C. Fitdistrplus: An R Package for Fitting Distributions. *Journal of Statistical Software* **2015**, *64*, doi:10.18637/jss.v064.i04.

117. Cuba, N. Research Note: Sankey Diagrams for Visualizing Land Cover Dynamics. *Landsc Urban Plan* **2015**, *139*, 163–167, doi:10.1016/j.landurbplan.2015.03.010.

118. Hijmans, R.J.; van Etten, J.; Sumner, M.; Cheng, J.; Baston, D.; Bevan, A.; Bivand, R.; Busetto, L.; Canty, M.; Fasoli, B.; et al. Package "raster" - Geographic Data Analysis and Modeling Available online: https://github.com/rspatial/raster/issues/.

119. Allaire, J.J.; Ellis, P.; Gandrud, C.; Kuo, K.; Lewis, B.W.; Owen, J.; Russell, K.; Rogers, J.; Sese, C.; Yetman, C.J.; et al. Package "networkD3" - D3 JavaScript Network Graphs from R Available online: https://github.com/christophergandrud/networkD3/issues.

120. Jockers, M.L.; Thalken, R. Introduction to Dplyr. In; 2020; pp. 121–132.

121. Mailund, T. Manipulating Data Frames: Dplyr. In *R Data Science Quick Reference*; Apress: Berkeley, CA, 2019; pp. 109–160.

122. Hosmer, D.W.; Lemeshow, S. *Applied Logistic Regression*; 2nd ed.; John Wiley & Sons: New York, 2000;

123. Mangiafico, M. Package "rcompanion" - Functions to Support Extension Education Program Evaluation Available online: http://rcompanion.org.

124. Cox, D.R.; Snell, E.J. *A General Definition of Residuals*; 1968; Vol. 30;.

125. Smith, T.J.; Mckenna, C.M. *A Comparison of Logistic Regression Pseudo R 2 Indices*; 2013; Vol. 39;.

126. Mcfadden, D. *REGRESSION-BASED SPECIFICATION TESTS FOR THE MULTINOMIAL LOGIT MODEL*; 1987; Vol. 34;.

127. Pereira, J.M.C.; Carreiras, J.; Silva, J.M.N.; Vasconcelos, M.J.P. Alguns Conceitos Básicos Sobre Os Fogos Rurais Em Portugal. In *Incêndios Florestais em Portugal - Caracterização, Impactes e Prevenção*; Lisboa, 2006; pp. 133–158.

128. Trigo, R.M.; Sousa, P.M.; Pereira, M.G.; Rasilla, D.; Gouveia, C.M. Modelling Wildfire Activity in Iberia with Different Atmospheric Circulation Weather Types. *International Journal of Climatology* **2016**, *36*, 2761–2778, doi:10.1002/joc.3749.

129. Fernandes, P.M.; Guiomar, N.; Rossa, C.G. Analysing Eucalypt Expansion in Portugal as a Fire-Regime Modifier. *Science of the Total Environment* **2019**, *666*, 79–88, doi:10.1016/j.scitotenv.2019.02.237.

130. Pausas, J.G.; Fernández-Muñoz, S. Fire Regime Changes in the Western Mediterranean Basin: From Fuel-Limited to Drought-Driven Fire Regime. *Clim Change* **2012**, *110*, 215–226, doi:10.1007/s10584-011-0060-6.

131. Barreiro, P.; Rodrigues, P. COST MANAGEMENT: THE USE OF FIRE FOR PASTURE RENEWAL IN ALTO MINHO. *Revista Floresta* **2022**, *53*, 46–55, doi:10.5380/rf.v53.

132. Oliveira, E.; Fernandes, P.M. Pastoral Burning and Its Contribution to the Fire Regime of Alto Minho, Portugal. *Fire* **2023**, *6*, doi:10.3390/fire6050210.

133. Iglesias, M.C.; Hermoso, V.; Campos, J.C.; Carvalho-Santos, C.; Fernandes, P.M.; Freitas, T.R.; Honrado, J.P.; Santos, J.A.; Sil, Â.; Regos, A.; et al. Climate- and Fire-Smart Landscape Scenarios Call for Redesigning Protection Regimes to Achieve Multiple Management Goals. *J Environ Manage* **2022**, *322*, doi:10.1016/j.jenvman.2022.116045.

134. Mori, A.S.; Lertzman, K.P. Historic Variability in Fire-Generated Landscape Heterogeneity of Subalpine Forests in the Canadian Rockies. *Journal of Vegetation Science* **2011**, *22*, 45–58, doi:10.1111/j.1654-1103.2010.01230.x.

135. Airey-Lauvaux, C.; Pierce, A.D.; Skinner, C.N.; Taylor, A.H. Changes in Fire Behavior Caused by Fire Exclusion and Fuel Build-up Vary with Topography in California Montane Forests, USA. *J Environ Manage* **2022**, *304*, doi:10.1016/j.jenvman.2021.114255.

136. Christianson, A.C.; Sutherland, C.R.; Moola, F.; Gonzalez Bautista, N.; Young, D.; MacDonald, H. Centering Indigenous Voices: The Role of Fire in the Boreal Forest of North America. *Current Forestry Reports* 2022, *8*, 257–276.

137. Moreira, F.; Leal, M.; Bergonse, R.; Canadas, M.J.; Novais, A.; Oliveira, S.; Ribeiro, P.F.; Zêzere, J.L.; Santos, J.L. Recent Trends in Fire Regimes and Associated Territorial Features in a Fire-Prone Mediterranean Region. *Fire* **2023**, *6*, 60, doi:10.3390/fire6020060.

138. Fernández-Guisuraga, J.M.; Martins, S.; Fernandes, P.M. Characterization of Biophysical Contexts Leading to Severe Wildfires in Portugal and Their Environmental Controls. *Science of the Total Environment* **2023**, *875*, doi:10.1016/j.scitotenv.2023.162575.

139. Strauss, D.; Bednar, L.; Mees, R. Do One Percent of Forest Fires Cause Ninety-Nine Percent of the Damage? *Forest Science* **1989**, *35*, 319–328.

140. Malamud, B.D.; Millington, J.D.A.; Perry, G.L.W. Characterizing Wildfire Regimes in the United States. *Proc Natl Acad Sci U S A* **2005**, *102*, 4694–4699.

141. Hantson, S.; Pueyo, S.; Chuvieco, E. Global Fire Size Distribution: From Power Law to Log-Normal. *Int J Wildland Fire* **2016**, *24*, 589–596, doi:10.1071/WF15108.

142. Fernandes, P.M. Variation in the Canadian Fire Weather Index Thresholds for Increasingly Larger Fires in Portugal. *Forests* **2019**, *10*, 838, doi:10.3390/f10100838.

143. Oliveira, S.; Moreira, F.; Boca, R.; San-Miguel-Ayanz, J.; Pereira, J.M.C. Assessment of Fire Selectivity in Relation to Land Cover and Topography: A Comparison between Southern European Countries. *Int J Wildland Fire* **2014**, *23*, 620–630, doi:10.1071/WF12053.

144. Bajocco, S.; Ricotta, C. Evidence of Selective Burning in Sardinia (Italy): Which Land-Cover Classes Do Wildfires Prefer? *Landsc Ecol* **2008**, *23*, 241–248, doi:10.1007/s10980-007-9176-5.

145. Mermoz, M.; Kitzberger, T.; Veblen, T.T. Landscape Influences on Occurrence and Spread of Wildfires in Patagonian Forests and Shrublands. *Ecology* **2005**, *86*, 2705–2715, doi:10.1890/04-1850.

146. Silva, J.S.; Moreira, F.; Vaz, P.; Catry, F.; Godinho-Ferreira, P. Assessing the Relative Fire Proneness of Different Forest Types in Portugal. *Plant Biosyst* **2009**, *143*, 597–608, doi:10.1080/11263500903233250.

147. Pereira, M.G.; Aranha, J.; Amraoui, M. Land Cover Fire Proneness in Europe. *For Syst* **2014**, *23*, 598–610, doi:10.5424/fs/2014233-06115.

148. Moreira, F.; Vaz, P.; Catry, F.X.; Silva, J.S. Regional Variations in Wildfire Susceptibility of Land-Cover Types in Portugal: Implications for Landscape Management to Minimize Fire Hazard. *Int J Wildland Fire* **2009**, *18*, 563–574, doi:10.1071/WF07098.

149. Pezzatti, G.B.; Bajocco, S.; Torriani, D.; Conedera, M. Selective Burning of Forest Vegetation in Canton Ticino (Southern Switzerland). *Plant Biosyst* **2009**, *143*, 609–620, doi:10.1080/11263500903233292.

150. Cumming, S.G. Forest Type and Wildfire in the Alberta Boreal Mixedwood: What Do Fires Burn? *Ecological Applications* **2001**, *11*, 97–110, doi:10.1890/1051-0761(2001)011[0097:FTAWIT]2.0.CO;2.

151. Bergonse, R.; Oliveira, S.; Zêzere, J.L.; Moreira, F.; Ribeiro, P.F.; Leal, M.; Lima e Santos, J.M. Biophysical Controls over Fire Regime Properties in Central Portugal. *Science of the Total Environment* **2022**, *810*, doi:10.1016/j.scitotenv.2021.152314.

152. Coughlan, M.R. Farmers, Flames, and Forests: Historical Ecology of Pastoral Fire Use and Landscape Change in the French Western Pyrenees, 1830-2011. *For Ecol Manage* **2014**, *312*, 55–66, doi:10.1016/j.foreco.2013.10.021.

153. Coughlan, M.R. Traditional Fire-Use, Landscape Transition, and the Legacies of Social Theory Past. *Ambio* **2015**, doi:10.1007/s13280-015-0643-y.

154. Múgica, L.; Canals, R.M.; San Emeterio, L.; Peralta, J. Decoupling of Traditional Burnings and Grazing Regimes Alters Plant Diversity and Dominant Species Competition in High-Mountain Grasslands. *Science of the Total Environment* **2021**, *790*, doi:10.1016/j.scitotenv.2021.147917.

155. Fernandes, P.M.; Rigolot, E. The Fire Ecology and Management of Maritime Pine (Pinus Pinaster Ait.). *For Ecol Manage* **2007**, *241*, 1–13, doi:10.1016/j.foreco.2007.01.010.

156. Keeley, J.E.; Ne'eman, G.; Fotheringham, C.J. Immaturity Risk in a Fire-Dependent Pine. *Journal of Mediterranean Ecology* 1999, *1*, 41–48.

157. Maia, P.; Pausas, J.G.; Arcenegui, V.; Guerrero, C.; Pérez-Bejarano, A.; Mataix-Solera, J.; Varela, M.E.T.; Fernandes, I.; Pedrosa, E.T.; Keizer, J.J. Wildfire Effects on the Soil Seed Bank of a Maritime Pine Stand - The Importance of Fire Severity. *Geoderma* **2012**, *191*, 80–88, doi:10.1016/j.geoderma.2012.02.001.

158. Maia, P.; Pausas, J.G.; Vasques, A.; Keizer, J.J. Fire Severity as a Key Factor in Post-Fire Regeneration of Pinus Pinaster (Ait.) in Central Portugal. *Ann For Sci* **2012**, *69*, 489–498, doi:10.1007/s13595-012-0203-6.

159. Cruz, O.; García-Duro, J.; Casal, M.; Reyes, O. Role of Serotiny on Pinus Pinaster Aiton Germination and Its Relation to Mother Plant Age and Fire Severity. *IForest* **2019**, *12*, 491–497, doi:10.3832/ifor2968-012.

160. Fernandes, P.M.; Guiomar, N. Os Incêndios Como Causa de Desarborização Em Portugal. *AGROTEC* **2017**, *3*, 28–32.

161. Turner, M.G.; Baker, W.L.; Peterson, C.J.; Peet, R.K. Factors Influencing Succession: Lessons from Large, Infrequent Natural Disturbances. *Ecosystems* **1998**, *1*, 511–523, doi:10.1007/s100219900047.

162. Hernández-Serrano, A.; Verdú, M.; González-Martínez, S.C.; Pausas, J.G. Fire Structures Pine Serotiny at Different Scales. *Am J Bot* **2013**, *100*, 2349–2356, doi:10.3732/ajb.1300182.

163. Pausas, J.G. Evolutionary Fire Ecology: Lessons Learned from Pines. *Trends Plant Sci* 2015, *20*, 318–324.

164. Pausas, J.G. Bark Thickness and Fire Regime. *Funct Ecol* 2015, *29*, 315–327.

165. Guiote, C.; Pausas, J.G. Fire Favors Sexual Precocity in a Mediterranean Pine. *Oikos* **2023**, *2023*, doi:10.1111/oik.09373.

166. Mota, M.M.; Vieira, P.C. Pine Wilt Disease in Portugal. In *Pine Wilt Disease*; Springer Japan: Tokyo, 2008; pp. 33–38.

167. Águas, A.; Ferreira, A.; Maia, P.; Fernandes, P.M.; Roxo, L.; Keizer, J.; Silva, J.S.; Rego, F.C.; Moreira, F. Natural Establishment of Eucalyptus Globulus Labill. in Burnt Stands in Portugal. *For Ecol Manage* **2014**, *323*, 47–56, doi:10.1016/j.foreco.2014.03.012.

168. Catry, F.X.; Moreira, F.; Tujeira, R.; Silva, J.S. Post-Fire Survival and Regeneration of Eucalyptus Globulus in Forest Plantations in Portugal. *For Ecol Manage* **2013**, *310*, 194–203, doi:10.1016/j.foreco.2013.08.036.

169. Moreira, F.; Ferreira, A.; Abrantes, N.; Catry, F.; Fernandes, P.; Roxo, L.; Keizer, J.J.; Silva, J. Occurrence of Native and Exotic Invasive Trees in Burned Pine and Eucalypt Plantations: Implications for Post-Fire Forest Conversion. *Ecol Eng* **2013**, *58*, 296–302, doi:10.1016/j.ecoleng.2013.07.014.

170. Sanjuán, Y.; Arnáez, J.; Beguería, S.; Lana-Renault, N.; Lasanta, T.; Gómez-Villar, A.; Álvarez-Martínez, J.; Coba-Pérez, P.; García-Ruiz, J.M. Woody Plant Encroachment Following Grazing Abandonment in the Subalpine Belt: A Case Study in Northern Spain. *Reg Environ Change* **2018**, *18*, 1103–1115, doi:10.1007/s10113-017-1245-y.

171. Komac, B.; Kefi, S.; Nuche, P.; Escós, J.; Alados, C.L. Modeling Shrub Encroachment in Subalpine Grasslands under Different Environmental and Management Scenarios. *J Environ Manage* **2013**, *121*, 160–169, doi:10.1016/j.jenvman.2013.01.038.

172. Palombo, C.; Chirici, G.; Marchetti, M.; Tognetti, R. Is Land Abandonment Affecting Forest Dynamics at High Elevation in Mediterranean Mountains More than Climate Change? *Plant Biosyst* **2013**, *147*, 1–11, doi:10.1080/11263504.2013.772081.

173. Romero-Calcerrada, R.; Perry, G.L.W. The Role of Land Abandonment in Landscape Dynamics in the SPA ‘Encinares Del Río Alberche y Cofio, Central Spain, 1984–1999. *Landsc Urban Plan* **2004**, *66*, 217–232, doi:10.1016/S0169-2046(03)00112-9.

ÍNDICES DE FIGURAS

ÍNDICES DE FIGURAS: CAPÍTULO I

ÍNDICES DE FIGURAS: CAPÍTULO II

ÍNDICES DE FIGURAS: CAPÍTULO III

ÍNDICES DE FIGURAS: CAPÍTULO IV

ÍNDICES DE FIGURAS: CAPÍTULO V

ÍNDICES DE FIGURAS: CAPÍTULO VI

ÍNDICES DE TABLAS

ÍNDICES DE TABLAS: CAPÍTULO I

ÍNDICES DE TABLAS: CAPÍTULO II

ÍNDICES DE TABLAS: CAPÍTULO III

ÍNDICES DE TABLAS: CAPÍTULO IV

ÍNDICES DE TABLAS: CAPÍTULO V

ÍNDICES DE TABLAS: CAPÍTULO VI

ANEXO - ESTADO DE LAS PUBLICACIONES

Capítulo I - The use of vegetation fire in Portugal: historical legislative and normative analysis

Emanuel de Oliveira [1], Ana Catarina Sequeira [2], Paulo M. Fernandes [3], and M. Conceição Colaço [4]

[1] International PhD School (EDIUS), Department of Agroforestry Engineering, University of Santiago de Compostela. Rúa Benigno Ledo, 27002 Lugo, Spain;

[2] Centro de Ecologia Aplicada Baeta Neves (CEABN-InBIO), Instituto Superior de Agronomia, Universidade de Lisboa. Portugal; Tapada da Ajuda, 1349 - 017 Lisboa, Portugal

[3] Centro de Investigação e de Tecnologias Agro-Ambientais e Biológicas, Universidade de Trás-os-Montes e Alto Douro. Portugal; Quinta de Prados, Edifício Reitoria. 5000-801 Vila Real, Portugal

[4] Centro de Ecologia Aplicada Baeta Neves (CEABN-InBIO), Instituto Superior de Agronomia, Universidade de Lisboa. Portugal; Tapada da Ajuda, 1349 - 017 Lisboa, Portugal

En el Capítulo I se reproduce la publicación sometida a la Revista “Environment and History” (E-ISSN: 1752-7023)

Estado: Aceptado y En prensa

Índices de Calidad de la Revista

Es una revista incluida en la base de datos JCR y Scopus, incluida en el apartado:

- History: Segundo cuartil (Q2)

Presenta los siguientes índices de calidad:

- Impact Factor: 1.1
- CiteScore: 1.2

Contribución del Autor

Conceptualización, Metodología, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

Autorización de la Revista

Todas las publicaciones realizadas en la editorial The White Horse Press pueden ser utilizadas sin consentimiento expreso. Más información al respecto en la siguiente página web: https://www.whpress.co.uk/publications/free-to-read/

The White Horse Press

The Old Vicarage, Main Street, Winwick, Cambridgeshire PE28 5PN
Partners: Andrew Johnson, Alison Johnson, Sarah Johnson, James Rice
www.whpress.co.uk

29 September 2023

To Whom it May Concern:

I hereby declare that the paper entitled **'The use of vegetation fire in Portugal: Historical legislative and normative analysis'**, by Emanuel de Oliveira, Catarina Sequeira, P.M. Fernandes and M.C. Colaço

has been accepted for publication in *Environment and History.*

Yours faithfully,

Dr Sarah Johnson
Partner, The White Horse Press

USC
UNIVERSIDADE
DE SANTIAGO
DE COMPOSTELA

Capítulo II - Remains of the traditional fire use in Portugal: a historical analysis

Emanuel de Oliveira [1], M. Conceição Colaço [2], Paulo M. Fernandes [3], and Ana Catarina Sequeira [4]

[1] International PhD School (EDIUS), Department of Agroforestry Engineering, University of Santiago de Compostela. Rúa Benigno Ledo, 27002 Lugo, Spain;

[2] Centro de Ecologia Aplicada Baeta Neves (CEABN-InBIO), Instituto Superior de Agronomia, Universidade de Lisboa. Portugal; Tapada da Ajuda, 1349 - 017 Lisboa, Portugal

[3] Centro de Investigação e de Tecnologias Agro-Ambientais e Biológicas, Universidade de Trás-os-Montes e Alto Douro. Portugal; Quinta de Prados, Edifício Reitoria. 5000-801 Vila Real, Portugal

[4] Centro de Ecologia Aplicada Baeta Neves (CEABN-InBIO), Instituto Superior de Agronomia, Universidade de Lisboa. Portugal; Tapada da Ajuda, 1349 - 017 Lisboa, Portugal

En el Capítulo II se reproduce la publicación sometida a la Revista “Trees, Forests and People” (E-ISSN: 2666-7193)

Estado: Aceptado y En Prensa

Índices de Calidad de la Revista

Es una revista incluida en la base de datos Scopus, incluida en el apartado:

- Forestry: Primer cuartil (Q1); Management, Monitoring, Policy and Law (Q2)

Presenta los siguientes índices de calidad:

- Impact Factor: 2.7
- CiteScore: 2.3

Contribución del Autor

Conceptualización, Metodología, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

Autorización de la Revista

Todas las publicaciones realizadas en la editorial Elsevier pueden ser utilizadas sin consentimiento expreso. Más información al respecto en la siguiente página web: https://www.elsevier.com/open-access

ELSEVIER

My Tracked Articles emanuel1973 Help

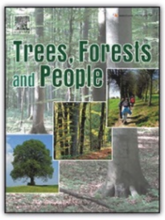
← Back to My Tracked Articles

Track Your Accepted Article

The easiest way to check the publication status of your accepted article

Remains of traditional fire use in Portugal: a historical analysis

Article reference	TFP_100458
Journal	Trees, Forests and People
Corresponding author	Ana Catarina Sequeira
First author	Emanuel de Oliveira
Received at Editorial Office	27 Jun 2023
Article revised	28 Sep 2023
Article accepted for publication	3 Nov 2023



ISSN 2666-7193

Last update: 3 Nov 2023

Share via email

Status comment

- Your article has been received for production.

Production events

3 Nov 2023 Received for production

Complimentary items

- You are entitled to a Share Link for your article free of charge. The Share Link will be sent you as soon as the final article is published in an issue.

Track another article >

Bibliographic information

Volume/Issue
Will appear soon

Full bibliographic details
Will appear soon

Article available online
Will appear soon

Track another article

Capítulo III - Incident analysis of traditional burns in Portugal

Emanuel de Oliveira[1]; Raquel Lobo-do-Vale [2]; Maria Conceição Colaço [3]

[1] International PhD School (EDIUS), Department of Agro-forestry Engineering, University of Santiago de Compostela, Rúa Benigno Ledo, 27002 Lugo, Spain;

[2] Forest Research Centre, Associate Laboratory TERRA, School of Agriculture, University of Lisbon, Tapada da Ajuda, 1349-017 Lisbon, Portugal

[3] Centre for Applied Ecology 'Prof. Baeta Neves' (CEABN-InBIO), School of Agriculture, University of Lisbon, Tapada da Ajuda, 1349-017 Lisbon, Portugal

En el Capítulo III se reproduce la publicación sometida a la Revista "International Journal of Disaster Risk Reduction" (E-ISSN: 2212-4209)

Estado: Publicado (https://doi.org/10.3390/fire6050210)

Índices de Calidad de la Revista

Es una revista incluida en la base de datos Scopus, incluida en el apartado:

- Safety Research: Primer cuartil (Q1)

Presenta los siguientes índices de calidad:

- Impact Factor: 5
- CiteScore: 7.4

Contribución del Autor

Conceptualización, Metodología, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

Autorización de la Revista

Todas las publicaciones realizadas en la editorial Elsevier pueden ser utilizadas sin consentimiento expreso. Más información al respecto en la siguiente página web: https://www.elsevier.com/open-access

Capítulo IV- Uma cartografia aperfeiçoada das áreas ardidas no Alto Minho (Noroeste de Portugal) entre 2001 e 2020

Emanuel Oliveira[1], Paulo M. Fernandes[2]

[1] International PhD School (EDIUS), Department of Agro-forestry Engineering, University of Santiago de Compostela, Rúa Benigno Ledo, 27002 Lugo, Spain;

[2] Centre for the Research and Technology of Agro-Environmental and Biological Sciences, CITAB, University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801 Vila Real, Portugal.

En el Capítulo IV se reproduce la publicación sometida a la Revista “Finisterra” (0430-5027)

Estado: Publicado (https://doi.org/10.18055/Finis28546)

Índices de Calidad de la Revista

Es una revista incluida en la base de datos Scopus, incluida en el apartado:

- Geography, Planning and Development: Tercer cuartil (Q3)

Presenta los siguientes índices de calidad:

- Impact Factor: 0.647
- CiteScore: 1.5 (2022)

Contribución del Autor

Conceptualización, Metodología, Software, Validación, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

Autorización de la Revista

Todas las publicaciones realizadas en la editorial FINISTERRA pueden ser utilizadas sin consentimiento expreso. Más información al respecto en la siguiente página web: https://revistas.rcaap.pt/finisterra/estatutoeditoral

Capítulo V- Pastoral burning and its contribution to the fire regime of Alto Minho, Portugal

Emanuel Oliveira[1], Paulo M. Fernandes[2]

[1] International PhD School (EDIUS), Department of Agro-forestry Engineering, University of Santiago de Compostela, Rúa Benigno Ledo, 27002 Lugo, Spain;

[2] Centre for the Research and Technology of Agro-Environmental and Biological Sciences, CITAB, University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801 Vila Real, Portugal.

En el Capítulo V se reproduce la publicación sometida a la Revista "Fire - MDPI" (ISSN: 2571-6255)

Estado: Publicado (https://doi.org/10.3390/fire6050210)

Índices de Calidad de la Revista

Es una revista incluida en la base de datos JCR, incluida en el apartado:

- Forestry: Primer cuartil (Q1)

Presenta los siguientes índices de calidad:

- Impact Factor: 3.2 (2022); 5-Year Impact Factor: 4.0 (2022)
- CiteScore: 3.5

Contribución del Autor

Conceptualización, Metodología, Análisis formal, Investigación, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

Autorización de la Revista

Todas las publicaciones realizadas en la editorial MDPI pueden ser utilizadas sin consentimiento expreso. Más información al respecto en la siguiente página web: https://www.mdpi.com/openaccess

Capítulo VI - Unraveling the Effect of Fire Seasonality on Fire-Preferred Fuel Types and Dynamics in Alto Minho, Portugal (2000–2018)

Emanuel Oliveira[1], Paulo M. Fernandes[2], David Barros[3] and Nuno Guiomar[4]

[1] International PhD School (EDIUS), Department of Agro-forestry Engineering, University of Santiago de Compostela, Rúa Benigno Ledo, 27002 Lugo, Spain;

[2] Centre for the Research and Technology of Agro-Environmental and Biological Sciences, CITAB, University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801 Vila Real, Portugal. E-mail:

[3] Department of Agro-forestry Engineering, University of Santiago de Compostela, Rúa Benigno Ledo, 27002 Lugo, Spain;

[4,] MED - Mediterranean Institute for Agriculture, Environment and Development; CHANGE - Global Change and Sustainability; EaRSLab - Earth Remote Sensing Laboratory Institute; IIFA - Institute for Advanced Studies and Research, University of Évora, 7006-554, Évora, Portugal.

En el Capítulo VI se reproduce la publicación sometida a la Revista “Fire - MDPI” (ISSN: 2571-6255)

Estado: Publicado (https://doi.org/10.3390/fire6070267)

Índices de Calidad de la Revista

Es una revista incluida en la base de datos JCR, incluida en el apartado:

- Forestry: Primer cuartil (Q1)

Presenta los siguientes índices de calidad:

- Impact Factor: 3.2 (2022); 5-Year Impact Factor: 4.0 (2022)
- CiteScore: 3.5

Contribución del Autor

Conceptualización, Metodología, Análisis formal, Investigación, Curación de datos, Redacción - preparación del borrador original, Redacción - revisión y edición, Visualización.

Autorización de la Revista

Todas las publicaciones realizadas en la editorial MDPI pueden ser utilizadas sin consentimiento expreso. Más información al respecto en la siguiente página web: https://www.mdpi.com/openaccess

USC
UNIVERSIDADE
DE SANTIAGO
DE COMPOSTELA

El paisaje del Alto Minho es resultado de una íntima y larga relación con el fuego. Los grandes incendios forestales son una de las consecuencias de la pérdida de prácticas tradicionales, formas de uso de la tierra y de la pérdida del propio conocimiento y uso tradicional del fuego. El objetivo de esta tesis es identificar los impactos de los diferentes fuegos en el paisaje y comprender el papel del fuego pastoral en el régimen de fuego. A partir de una profunda revisión documental histórica, los tres primeros capítulos pretenden encuadrar, definir y aclarar el uso tradicional del fuego y su evolución hasta nuestros días, bien como sus riesgos. Mientras que los tres últimos son el resultado de la reconstrucción cartográfica, que permitió identificar y caracterizar el régimen de fuego en el Alto Minho.