iForest
Biogeosciences and Forestry

Research Article
doi: 10.3832/ifor5146-019
vol. 19, pp. 195-200

Wildfire incidence in Spanish Natura 2000 sites is largely explained by forest land cover

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The relationship between wildfires and protected areas remains controversial in Mediterranean regions, where several studies have reported a disproportionate incidence of fires within protected sites. Using data from the European Forest Fire Information System, 8,241 wildfires recorded in Spain between 2008 and 2025 were analyzed to assess whether wildfire incidence in Natura 2000 sites is primarily associated with protection status or with land-use structure, particularly forest land cover. Indicators of burnt area for total land and forest land at the national level and within the Natura 2000 network were calculated by aggregating wildfire perimeters and their distribution across forest land and Natura 2000 areas, and expressed as proportional indicators to enable direct comparison between spatial units. Additionally, correlation analyses between burnt area variables and Mann-Kendall tests to assess temporal trends in burnt area were applied. Natura 2000 sites accounted for 38.6% of the burnt area in Spain and 40.6% of the burnt forest land. Although the proportion of burnt area relative to total territory was higher within Natura 2000 than nationally (4.9% *vs*. 3.5%), this difference was largely explained by the higher share of forest land in protected sites (80.9% *vs*. 54.4%). When considering forest land only, the proportion of burnt area in Natura 2000 was slightly lower than the national average (5.4% *vs*. 5.9%). Significantly increasing trends in burnt area were detected in both protected and non-protected areas using the Mann-Kendall test. These results suggest that apparent differences in wildfire incidence between protected and non-protected areas are largely attributable to land-use composition rather than to protection status itself, highlighting the importance of explicitly accounting for landscape structure when interpreting wildfire statistics.

Keywords: Wildfires, Natura 2000, Forest Land, Land-use Structure, Protected Areas, Spain

Introduction

Wildfires pose a major ecological and socio-economic challenge in southern Europe, particularly in Mediterranean regions, where hot, dry summers favor recurrent fire activity (Fernández-García et al. 2021, Ma et al. 2021). Fire is a natural component of many Mediterranean ecosystems and has shaped vegetation traits and dynamics over evolutionary time (Keeley et al. 2011). However, in recent decades, increasing human pressures, rural abandonment, fuel accumulation, and climate change have contributed to higher wildfire risk and extreme fire seasons (Dupuy et al. 2020, Plana et al. 2016). Whether these broad-scale drivers translate into different wildfire incidence patterns inside and outside the Natura 2000 (N2000) network remains an open question, particularly when differences in land-use structure are not explicitly considered, given that land-use and land-cover dynamics, especially those affecting forest areas and transitions between forest and non-forest categories, play a key role in shaping ecosystem structure and function (Aksoy 2024, Aksoy et al. 2024).

Spain is among the European Union countries most affected by wildfires in terms of burnt area, with high interannual variability and recurrent extreme years (MMA 2007, EFFIS 2025). Exceptionally severe fire years, such as 2012, 2022, and 2025, have intensified public and political concern and have reinforced debates on wildfire prevention and land management policies. In this context, protected areas have received increasing attention because they concentrate high levels of biodiversity and a large proportion of forest land.

The relationship between wildfires and protected areas remains controversial. Several studies have reported a disproportionate concentration of burnt area within protected sites at global and regional scales (Rodrigues et al. 2023, Moustakas 2025, Resco et al. 2025a, 2025b), suggesting higher wildfire incidence in these areas. Institutional Spanish reports have expressed similar concerns (OCTCD 2023). Arellano-Del-Verbo et al. (2023) associated higher wildfire risk in protected areas with more

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Received: Jan 30, 2026 - Accepted: May 08, 2026

Citation: Enríquez-de-Salamanca Á (2026). Wildfire incidence in Spanish Natura 2000 sites is largely explained by forest land cover. iForest 19: 195-200. - doi: 10.3832/ifor5146-019 [online 2026-06-04]

Communicated by: Rafael Da Silveira Bueno

hazardous landscape characteristics. Some authors linked this pattern to regulatory constraints on fire prevention (Pereira et al. 2012, Artemisan 2022), but an institutional report indicated that current regulations do not restrict the integration of wildfire prevention (OCTCD 2023). In contrast, other studies and reports have found lower fire occurrence in protected areas (Greenpeace 2024, Kirkland et al. 2024). This divergence reflects two main explanatory frameworks. Studies reporting higher wildfire incidence in protected areas attribute this pattern either to more hazardous landscape characteristics or to constraints on preventive management, whereas others report lower incidence, not supporting a systematic effect of management constraints. However, these interpretations are based on heterogeneous datasets, spatial scales, and methodological approaches, which limit the comparability of results and, in some cases, introduce potential biases in their assessment, with some explanations not being consistently supported by empirical evidence.

The Spanish N2000 network covers most of the protected terrestrial area (97.5% – MITECO 2024) and is characterized by a markedly higher proportion of forest land than the national average (80.9% compared to 54.4% – MITECO 2007, 2024). This difference may strongly affect fire incidence, but is not explicitly considered when assessing wildfire occurrence in protected areas.

The present study addresses this gap by analyzing wildfire data from the European Forest Fire Information System for the period 2008-2025 (EFFIS 2025). Specifically, it examines whether differences in wildfire incidence between N2000 sites and the rest of Spain persist after accounting for forest land cover. This is assessed by explicitly comparing the burnt area and the proportion of forest land within and outside the N2000 network. It is hypothesized that these differences become non-significant once forest land cover is taken into account.

Material and methods

Data acquisition

To assess wildfire incidence in Spain, we used data from the European Forest Fire Information System (EFFIS), which provides information on fires larger than 30 ha across the European Union. This implies that smaller fires are not included, which may lead to an underestimation of total fire occurrence and a bias towards larger wildfire events. However, as large fires account for the majority of burnt area, the dataset is considered suitable for analyzing patterns of wildfire incidence at the national scale.

Data were requested in September 2025 and supplied in GIS format as a single layer containing 8,241 wildfire polygons for the period 2008-2025 (EFFIS 2025). The dataset consists of vector fire perimeters provided in the ETRS89 / LAEA Europe coordinate reference system (EPSG:3035). EFFIS is part of the EU Copernicus Emergency Management Service and compiles wildfire information from a network of national experts, supported by satellite-based observations. As a vector dataset, there is no fixed spatial resolution; instead, spatial detail depends on the delineation of each recorded fire event. In addition to fire perimeters, the dataset included information on burnt area, land-use proportions, and the proportion of each polygon located within the N2000 network.

EFFIS provides data on wildfire extent within N2000 sites. According to official data (MITECO 2024), the total terrestrial protected area in Spain is 14,227,005 ha, of which 13,870,813 ha are included in the N2000 network, corresponding to 97.5% of the protected area; therefore, this network is representative of the national protected areas system.

Forest land, part of the EFFIS dataset, was used to quantify burnt area separately within and outside forest land, and inside and outside the N2000 network. The total extent of forest land in Spain and within the N2000 network was obtained from MITECO (2007, 2024). Although these data sources correspond to different reference years, they represent aggregated land-cover and administrative statistics that change slowly over time at the national scale; therefore, their combined use is not expected to introduce any significant bias in the analysis. The variables used in the study are presented in Tab. 1. These variables include total and disaggregated burnt area (overall, within N2000, and within forest land), as well as the corresponding total areas, allowing comparisons between protected and non-protected areas and between forest and non-forest land. Total values were obtained by aggregating fire-level data across the study period.

Indicators

Nine indicators were defined and grouped into four categories: I1, proportion of burnt area within the N2000 network; I2, proportion of burnt area; I3, proportion of forest land; and I4, proportion of burnt forest land. Each indicator is calculated as a ratio between a specific burnt or land-use area and its corresponding reference area (*e.g.*, total burnt area in Spain or total forest land), allowing direct comparison between N2000 sites and the national territory. The first category relates the total and forest-burnt areas within the N2000 network to the corresponding values for Spain. The other three categories quantify the proportion of forest land, total burnt area, and burnt forest land in Spain and within the N2000 network. Thus, the indicators are designed to distinguish between absolute differences in burnt area and differences attributable to land-use composition.

To characterize wildfire patterns, both cumulative values for the entire study period (2008-2025) and annual statistics were used. Cumulative values quantify the overall magnitude and proportional distribution of burnt area, while annual statistics capture interannual variability, which is typically high in wildfire regimes due to extreme years. Indicators are expressed as cumulative values for the period 2008-2025 and, when based on annual data, also as mean and standard deviation; all results are reported as percentages.

Tab. 1 - Data used in the study. (Abbr): abbreviation.

	Variable			Abbr.	Unit	Observations	Source
-	Year			y_i	year	-	EFFIS (2025)
Spain	Total territory	Area	-	A	ha	-	MITECO (2007)
		Burnt	Per fire	b_i	ha	-	EFFIS (2025)
			Annual	B_{yi}	ha	$\Sigma\ b_i$ (year y_i)	Calculated
			Period	B	ha	$\Sigma\ b_i$ (2008-2025)	Calculated
	Forest land	Area	-	A_F	ha	-	MITECO (2007)
		Burnt	Per fire	b_{Fi}	ha	-	EFFIS (2025)
			Annual	B_{Fyi}	ha	$\Sigma\ b_{Fi}$ (year y_i)	Calculated
			Period	B_F	ha	$\Sigma\ b_{Fi}$ (2008-2025)	Calculated
N2000	Total territory	Area	-	A_N	ha	-	MITECO (2024)
		Burnt	Per fire	b_{Ni}	ha	-	EFFIS (2025)
			Annual	B_{Nyi}	ha	$\Sigma\ b_{Ni}$ (year y_i)	Calculated
			Period	B_N	ha	$\Sigma\ b_{Ni}$ (2008-2025)	Calculated
	Forest land	Area	-	A_{FN}	ha	-	MITECO (2024)
		Burnt	Per fire	b_{FNi}	ha	-	EFFIS (2025)
			Annual	B_{FNyi}	ha	$\Sigma\ b_{Ni}$ (year y_i)	Calculated
			Period	B_{FN}	ha	$\Sigma\ b_{Ni}$ (2008-2025)	Calculated

Inferential statistics

Correlation analyses were conducted among the variables considered, excluding year, using both pairwise and multiple correlation approaches. These analyses aimed to assess the strength and direction of the relationships between total burnt area and its components, particularly forest land and burnt area within N2000 sites, in order to evaluate the extent to which wildfire incidence is associated with land-use composition. For each analysis, the Pearson's correlation coefficient (r), the coefficient of determination (R^2), the adjusted coefficient of determination (adjusted R^2) for multiple correlations, and the corresponding p-values were calculated. Pearson's correlation was selected as the standard measure of linear association between continuous variables, given the data's aggregated nature. Correlations were considered statistically significant at the 95% confidence level when p-values were below 0.05. As the analysis is based on aggregated variables and aims to identify general relationships rather than to perform strict parametric inference, formal tests of statistical assumptions (including normality and homoscedasticity) were not applied. Consequently, the reported correlations should be interpreted as indicative of general associations rather than as precise estimates of statistical relationships.

Temporal trends in total burnt area and burnt forest land across Spain and in the N2000 network were assessed using the non-parametric Mann-Kendall test. This test was chosen as it does not assume normality and is robust to non-linear and non-normally distributed time series, making it suitable for analyzing environmental data. This test evaluates whether a variable exhibits a monotonic increase or decrease over time. Trends were considered statistically significant when p-values were below 0.05, and the sign of the Z statistic was used to determine the direction of change.

Tab. 2 - Results of the analysis of the EFFIS data over the period 2008-2025. Areas are expressed in hectares. Parameters abbreviations are reported in Tab. 1.

Year (y_i)	B_{yi}	B_{Fyi}	B_{Nyi}	B_{FNyi}
2008	10,073	7,687	4,304	3,229
2009	88,894	75,791	37,631	33,968
2010	19,913	19,276	7,028	6,791
2011	60,427	55,967	26,382	24,176
2012	189,747	168,538	79,603	77,154
2013	37,273	29,463	9,636	9,031
2014	22,056	19,499	8,295	7,772
2015	63,636	47,456	9,365	8,579
2016	52,730	45,728	17,937	16,478
2017	131,050	121,329	43,165	39,200
2018	12,789	11,482	5,276	4,827
2019	66,408	58,262	20,567	19,155
2020	64,286	56,720	20,571	19,022
2021	90,159	84,191	43,888	42,310
2022	316,853	270,627	121,314	112,683
2023	101,184	97,699	42,665	42,083
2024	47,607	39,783	17,982	13,264
2025	383,865	311,392	163,299	145,062
	B	B_F	B_N	B_{FN}
Σ	1,758,950	1,520,889	678,908	624,788
	A	A_F	A_N	A_{FN}
	50,592,567	27,525,708	13,870,813	11,525,678

Results and discussion

During 2008-2025, a total of 1,758,950 ha were burnt in Spain (B – Tab. 2), of which 678,908 ha occurred within the N2000 network (38.6% – B_N). Of the total burnt area, 1,520,889 ha corresponded to forest land (B_F), including 624,788 ha within N2000 sites (B_{FN}), equivalent to 41.08% of the total forest burnt area (I1a, I1b – Tab. 2, Tab. 3).

Cumulative values are reported to characterize the overall distribution of burnt area over the study period, as they are less affected by strong interannual variability typical of wildfire regimes. Annual means and standard deviations are provided to describe temporal variability. This distinction is particularly relevant given the occurrence of extreme fire years (*e.g.*, 2012, 2022, 2025), which can disproportionately influence mean values.

These values fall within the range reported in previous studies, which document proportions of burnt area in protected lands of around 28.5% at the global scale, 41.7% in the EU, 31-47% in Southern Europe, and 13.6-23.8% in Spain (OCTCD 2023, Rodrigues et al. 2023, Greenpeace 2024, San-Miguel et al. 2024, Moustakas 2025, Resco et al. 2025a). However, these studies differ substantially in spatial scope, definitions of protected areas, and methodological approaches, particularly regarding land-use composition and spatial aggregation of fire data. Therefore, the reported values are not directly comparable and are provided only as a general contextual reference.

In relative terms, the proportion of land

Tab. 3 - List of the indicators used in the analysis.

Indicator	Abbr.	Description	Cumulative proportion 2008-2025		Annual mean		Standard deviation
I1 - Proportion of N2000 territory burnt	I1a	Referred to total burnt land	$100 \cdot B_N/B$	38.60%	$100 \cdot B_{Nyi}/B_{yi}$	36.93%	7.88%
	I1b	Referred to forest land burnt	$100 \cdot B_{FN}/B_F$	41.08%	$100 \cdot B_{Nyi}/B_{yi}$	38.41%	7.64%
I2 - Proportion of burnt territory	I2a	in Spain	$100 \cdot B/A$	3.48%	$100 \cdot B_{yi}/A$	0.19%	0.20%
	I2b	in N2000	$100 \cdot B_N/A_N$	4.89%	$100 \cdot B_{Nyi}/A_N$	0.27%	0.31%
I3 - Proportion of existing forest land	I3a	in Spain	$100 \cdot A_F/A$	54.41%	-	-	-
	I3b	in N2000	$100 \cdot A_{FN}/A_N$	80.92%	-	-	-
I4 - Proportion of forest land burnt	I4a	Referred to Spanish forest land	$100 \cdot B_F/A_F$	5.53%	$100 \cdot B_{Fyi}/A_F$	0.31%	0.31%
	I4b	Referred to N2000 forest land	$100 \cdot B_{FN}/A_{FN}$	5.42%	$100 \cdot B_{FNyi}/A_{FN}$	0.30%	0.34%
	I4c	Referred to total burnt area	$100 \cdot B_F/B$	86.47%	$100 \cdot B_{Fyi}/B_{yi}$	87.05%	6.37%

Tab. 4 – Results of the correlation (parametric) analysis between the variables analyzed. Parameters abbreviations are reported in Tab. 1.

Stat	Correlation pairs		
	b_i-b_{Ni}	b_i-b_{Fi}	b_{Ni}-b_{FNi}
p	0.432	<0.001	<0.001
r	-0.009	0.928	0.932
R^2	0.008%	96.505%	86.763%

burnt within N2000 sites (I2b = 4.89% – Tab. 3), is 40.5% higher than the national mean (I2a = 3.48% – Tab. 3), a pattern often interpreted as evidence of higher wildfire incidence in protected areas. However, this comparison does not account for differences in land-use composition, particularly the distribution of forest land, where most burnt area occurs (I4c = 86.5% – Tab. 3).

Forest land represents 54.41% of Spain's territory, compared with 80.92% within the N2000 network (I3a, I3b – Tab. 3), indicating a substantially higher availability of burnable vegetation within protected areas.

The higher proportion of burnt area within N2000 sites is consistent with their greater forest cover, indicating that land-use composition plays a key role in the observed patterns.

Strong and statistically significant correlations were found between burnt area (b_i) and burnt forest land (b_{Fi}) in both Spain and the Natura 2000 network ($r \approx 0.93$, $p < 0.001$ – Tab. 4). In contrast, no significant correlation was observed between burnt area in Spain (b_i) and within the Natura 2000 network (b_{Ni}). These relationships reflect the distribution of burnt area across land-use types and do not imply causality.

Some studies report contrasting results regarding wildfire incidence in protected areas, with some documenting higher burnt area in protected sites (Rodrigues et al. 2023, Moustakas 2025, Resco et al. 2025a, 2025b), whereas others report lower fire occurrence (Greenpeace 2024, Kirkland et al. 2024). These contrasting results highlight a lack of consensus regarding wildfire incidence in protected areas. The cited studies include both scientific publications and institutional reports, most of which rely on official datasets, similar to those used in this study. Differences in reported findings may therefore arise from the analytical approach and interpretation of the data rather than from differences in the underlying data sources. While some of these sources are not peer-reviewed, this should be taken into account when interpreting their results.

Tab. 5 - Results of the Mann-Kendall tests (non-parametric). Parameter abbreviations are reported in Tab. 1 and Tab. 2.

Parameter	Z statistic	p-value
B_{yi}	2.121	0.034
B_{Nyi}	2.121	0.034
B_{Fyi}	2.045	0.041
B_{FNyi}	2.045	0.041
I1a	-0.076	0.94
I1b	0.227	0.82
I2a	2.121	0.034
I2b	2.121	0.034
I4a	2.045	0.041
I4b	2.045	0.041
I4c	1	0

The concentration of wildfires on forest land is statistically significant, and the higher proportion of forest land within N2000 sites (I3) is evident (Tab. 3). These two parameters, jointly, largely explain the observed difference in burnt area between N2000 sites and Spain as a whole. Moreover, when forest land is analyzed separately, the proportion of burnt forest land within N2000 (I4a = 5.4%) is nearly the same as the national mean (I4b = 5.5%), and even slightly lower (Tab. 3). Similarly, the annual mean values of burnt forest land are marginally higher at the national level than within the N2000 network. Consequently, when forest land is considered, the data do not support a higher incidence of wildfires in the Natura 2000 network. Taken together, these results indicate that the apparent differences in wildfire incidence between N2000 sites and Spain as a whole are largely explained by land-use composition rather than by protection status.

Several authors have argued that higher wildfire incidence in protected areas results from difficulties in implementing preventive treatments due to restrictive regulations or excessive protection (Pereira et al. 2012, Artemisan 2022, Rodrigues et al. 2023). This reasoning would mainly apply to forest land, where such treatments are implemented. However, the lower wildfire incidence observed in forest land within N2000 sites compared with the national mean does not provide empirical support for these claims at the national scale. Accordingly, the hypothesis that higher wildfire incidence in protected areas is primarily driven by management restrictions is not supported by our results.

Although forest transition processes and management regimes may influence wildfire risk at local scales, the present analysis does not capture these processes; however, at the national scale, forest land within the N2000 network does not exhibit higher wildfire incidence than the Spanish mean.

The present analysis does not distinguish ignition points or fire spread direction across N2000 boundaries, which would be necessary to assess management effectiveness or site-level processes. It is based on aggregated national-scale data and aims to identify general patterns rather than individual case studies. In addition, the use of large-fire data (>30 ha) and the lack of information on ignition causes limit the interpretation of wildfire drivers, preventing clear attribution of observed patterns to differences in ignition sources, fire spread, or other underlying processes. Although spatial datasets provide valuable information for analyzing wildfire patterns at large scales, their accuracy may be limited for certain variables and spatial resolutions (Kaptan et al. 2022), a limitation that should be considered when interpreting aggregated wildfire indicators across different spatial units.

The national-scale approach also masks spatial heterogeneity, as wildfire dynamics vary across regions, so the patterns identified in this study represent national averages rather than spatially homogeneous dynamics across the territory. Accordingly, the results should be interpreted as a national-scale assessment of wildfire incidence associated with land use and protection status, rather than as an evaluation of local management practices, with conclusions restricted to the spatial scale and variables considered and not intended to infer local processes or specific causal mechanisms.

Climatic conditions are a well-established background driver of wildfire activity in Mediterranean regions. However, at the national level considered here, climatic variability operates at broader spatial scales and affects both protected and non-protected areas, so it does not differentiate between N2000 sites and Spain as a whole.

A significant global increase in wildfires in protected areas between 2001 and 2024 has been reported, particularly in fire-prone biomes such as Mediterranean forests (Resco et al. 2025a). The Mann-Kendall tests (Tab. 5) indicate statistically significant increasing trends in burnt area between 2008 and 2025, both for Spain as a whole and for N2000 sites, in both total and forest land, as indicated by positive *Z*-values and *p*-values < 0.05. In contrast, non-significant results for indicators I1a, I1b, and I4c indicate the absence of a consistent temporal trend in these ratios (Tab. 5). These results indicate a general increasing trend rather than one specifically associated with protected areas. However, the present analysis does not allow identification of the underlying causes of this increase, as the dataset lacks variables related to ignition sources, climatic variability, or other potential drivers of wildfire activity.

Wildfire ignition causes are relevant for interpreting incidence patterns, but such information is not available in the EFFIS database. Consequently, this study focuses on patterns of wildfire incidence and burnt area rather than on the social or institutional drivers of ignitions. Assessing the

role of these factors would require integrating wildfire data with additional socio-economic information, which is beyond the scope of this study. As a result, the analysis cannot attribute the observed patterns to specific underlying mechanisms. However, the absence of higher wildfire incidence in forest land within the N2000 network does not provide empirical support for the hypothesis that these mechanisms increase wildfire occurrence in protected areas at the national scale.

The lack of information on ignition causes primarily affects the interpretation of potential drivers rather than the identification of observed patterns. Accordingly, the results provide a robust assessment of wildfire incidence patterns and their relationship with land-use composition at the national scale.

The use of aggregated national-scale data further constrains the generalizability of the results, as it does not capture regional variability or local processes. These limitations affect the interpretation of wildfire drivers rather than the identification of consistent large-scale patterns, which the analysis robustly captures.

Therefore, the main limitations of this study include the use of aggregated national-scale data, the absence of information on ignition causes and socio-economic drivers, and the lack of spatial detail regarding fire spread and site-level processes. However, the study also has important strengths, particularly the ability to assess wildfire incidence at the national scale over a long temporal period, which is essential for informing broad-scale policy discussions. While local-scale factors and management differences undoubtedly exist, the results indicate that these do not translate into a consistent general pattern at the national level.

Conclusions

Our results indicate that the higher incidence of wildfires within the N2000 network is largely associated with its higher proportion of forest land. When land-use composition is explicitly considered, differences in burnt area between N2000 sites and Spain as a whole are substantially reduced, and the proportion of burnt forest land within N2000 is slightly lower than the national mean.

Temporal analyses reveal a statistically significant increasing trend in burnt area within N2000 sites over the study period, closely mirroring the national trend. This indicates that recent increases in wildfire activity reflect a general pattern rather than a process specific to protected areas. Therefore, the hypothesis that higher wildfire incidence in protected areas is primarily driven by management restrictions limiting preventive treatments is not supported by the present national-scale evidence.

Overall, the results show that wildfire incidence patterns at the national scale are strongly influenced by the spatial distribution of forest land, highlighting how the analytical scale and the variables considered shape the observed results. Consequently, differences in fire incidence cannot be attributed solely to protection status, and wildfire risk assessments and related policy discussions should explicitly account for land-use composition. Otherwise, aggregated burnt area indicators may lead to misleading interpretations of wildfire incidence in protected areas. Claims linking higher wildfire incidence in protected areas to insufficient management would require stronger, more consistent empirical evidence, given the implications for environmental policy.

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