FIRE-RES

Innovative technologies & socio-ecological-economic solutions for fire resilient territories in Europe

D1.7 SPATIAL AND TEMPORAL CONDITIONS FOR EXTREME WILDFIRE EVENTS AT THE EUROPEAN SCALE

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Abstract: This report aims to identify pre-fire landscape composition, dynamics and configuration associated with the occurrence of Extreme Wildfire Events (EWE) in Europe in 2000-2022. A set of 137 EWE were compiled into a database, using literature revision and statistical analyses. Corine Land Cover (CLC) data was used to analyze landscape composition, configuration and dynamics of selected EWE and corresponding unburned buffers, divided into distinct EWE categories: outliers in fire size at European scale (≥ 7400 ha), fires with reported extreme behavior and operationality (< 7400 ha), and historical anomalies in fire size/impacts at the national scale (< 7400 ha). There is an increasing temporal trend in EWE in Europe in 2000-2022. Pre-fire landscape characteristics showed consistent patterns associated with EWE occurrence such as: lower agricultural land area (for most countries), higher scrubland area (for southern countries), and higher peatland area (for northern countries). Unburned perimeters presented higher land cover diversity and larger patches (on average) of agricultural lands for most countries, in comparison to burned perimeters. Wildland-urban interface was higher in burned perimeters than in surrounding unburned buffers in southern countries, while absent in northern countries. Future landscape composition in 2018-2102 shows an increasing area occupied by scrub/herbaceous vegetation for the Mediterranean region, representing an increasing fire risk. This report provides information to promote EWE resistant/resilient landscapes and improve modelling projections and decision support systems.

Key words: extreme wildfire events (EWE), landscape dynamics, landscape composition and configuration, LULC

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List of acronyms

CLC – Corine Land Cover
EFFIS – European Forest Fire Information System
EWE – Extreme Wildfire Events
LULC – Land Use / Land Cover
NUTS- Nomenclature of Territorial Units for Statistics
WUI – Wildland Urban Interface

INTRODUCTION

European context

Wildfires occur in most regions across Europe, but fire regimes and fire behaviour have been changing in the last two decades, with an increased threat to societies and the natural environment (Fernandez-Anez et al. 2021). Overall, there was a stagnating trend in burned area in Europe in 1986-2020, although with interannual and regional variability (Silva et al. 2011; de Rigo et al. 2017; Grünig et al. 2023). However, wildfire seasons are becoming longer and with a trend to be more severe (Duane et al. 2021; Fernandez-Anez et al. 2021; San-Miguel-Ayanz et al. 2022).

Fire regimes also seem to be changing spatially in terms of burned area. In the last 30 years, the Mediterranean region encompassed the largest burned area in Europe (79% of the total area burned in 1986-2020, Grünig et al. 2023), due to favourable conditions of fuel availability and low moisture (San-Miguel-Ayanz et al. 2013). However, in recent years, there has been an increasing burned area in temperate and boreal forests, which accounted for more than half of burned area in Europe in 2018 and 2020 (Grünig et al. 2023).

The occurrence of extreme wildfire events (EWE) has increased dramatically in Europe (European Environment Agency 2017; Artés et al. 2022), particularly in the Mediterranean region (Fernandez-Anez et al. 2021). EWE are usually defined as wildfires with fast, intense and unpredictable behaviour, with overwhelming suppression capabilities and great impacts, despite the different terms and definition criteria found in the literature (Tedim et al. 2018; Rego et al. 2021). Within FIRE-RES project, the term "EWE" was discussed and defined in Deliverable D1.1. as wildfires with large-scale complex interactions between fire and atmosphere generating pyroconvective behaviour, coupling processes, which results in fast, intense, uncertain, and fast-paced changing fire behaviour (Castellnou et al. 2022).

For example, in 2017, Portugal witnessed one of the most severe fire behaviours in Europe (Pedrógão Grande wildfire), with an increase of burnt area larger than 20 thousand hectares in one day (Comissão Técnica Independente 2022), and in 2018, a single fire in Greece (East Attica) registered 102 human fatalities (Kartsios et al. 2021). The year 2017 was also the worst year in Europe in terms of burnt areas, followed by 2022 and 2021 (San-Miguel-Ayanz et al. 2023). In 2021, fire season was particularly extreme in eastern Europe (with one of the worst fires ever recorded in Cyprus and several EWE registered in Greece) (San-Miguel-Ayanz et al. 2022). In 2022, burnt areas mapped within the Natura2000 network of protected sites corresponded to about 44% of the total burnt areas in the EU (365 308 ha), with significant impacts on endangered plant and animal species, and monetary losses estimated in about 2.5 billion euros (San-Miguel-Ayanz et al. 2023). The 2022 fire season was particularly extreme in southwest Europe (Portugal, Spain and France), with burned area about 3 times higher than the 2006–2021 annual mean, coupled with extreme weather conditions (Rodrigues et al. 2023). In 2023, Greece witnessed the worst fire season in terms of intensity and estimated carbon emissions of the last 20 years for the month of July, coinciding with its longest heatwave on record and the largest fire ever recorded in Europe (European Commission, Copernicus, Programme, https://climate.copernicus.eu/european-heatwave-july-2023-longer-term-context).

Changes in fire regimes and increased occurrence of EWE in Europe in recent years result from a complex interplay of changes in climate, land use, and landscape structure (Lloret et al. 2002; Moreira et al. 2011, 2020; Pausas and Paula 2012; Duane et al. 2021; Rego et al. 2021). In the Mediterranean region, rural land abandonment and increased wildland urban interface (WUI), coupled with extreme droughts, seem to be promoting more catastrophic fires (Nunes 2012; Pausas and Fernández-Muñoz 2012; San-Miguel-Ayanz et al. 2013; Fernandez-Anez et al. 2021). In Northern Europe, extensive fires have occurred in recent years, as shown by the large fires requiring international assistance across Sweden in 2018, following anomalously dry and warm spring and summer (Krikken et al. 2019; Fernandez-Anez et al. 2021). In 2021 in Estonia, for the first time in history, the access restrictions to forests and other vegetated areas and sites with peat ground were imposed in 6 counties (out of 15) from the middle of July. In Iceland, fire history in 1943-2012 shows that most wildfires occur in spring but in recent years, wildland fires started occurring also in summer months, which coincide with increased biomass due to global warming and reduced grazing, and increased WUI with higher risk of ignitions (Thorsteinsson et al. 2008). In most countries in Central and Western Europe, there is also concern about increasing urban sprawl into forested regions (Fernandez-Anez et al. 2021). In Eastern Europe, a shift of forest management from production to recreation could lead to more fuel accumulation and more ignitions, which may interact with climate change and increase fire occurrence (Fernandez-Anez et al. 2021).

Although EWE have been primarily associated with extreme weather conditions, EWE may also be influenced by landscape-level characteristics (e.g., composition and configuration of different land use/land cover classes) (Fernandes 2019; Rego et al. 2021). For example, land cover such as Mediterranean shrublands have been associated with higher flammability and fire hazard, while the presence of agricultural land in the landscape seems to effectively buffer increased wildfire risk (Moreira et al. 2011; Nunes 2012).

The homogenization of landscape composition and configuration seems to be related with the occurrence of large wildfires, sometimes with extreme behaviour (Loepfe et al. 2010; Duane et al. 2021; Rego et al. 2021). Patch size distribution may also determine the resilience of landscapes to future fires (Hessburg et al. 2007). Conversely, other studies have shown that landscape structure seems to have little effect on fire spread and size, which are primarily determined by weather conditions (Moritz et al., 2010; Moreira et al., 2020; Cruz et al., 2022).

However, few studies have addressed the effects of pre-fire landscape composition, dynamics, and configuration on the occurrence of EWE in Europe, which will likely be distinct among regions (Duane et al. 2021).

Aims of the deliverable

We acknowledge that weather and climate drivers are very important to explain EWE occurrence but we are trying to find landscape patterns that can help us to guide future landscape management towards more fire-resistant landscapes.

In this regard, the aims of the present Deliverable are to compile a database of EWE in Europe in 2000-2022, in order to analyze landscape composition, dynamics and configuration of selected EWE in pre-fire conditions, and identify landscape patterns associated with the occurrence of EWE. Observed dynamics is also used to predict and discuss future composition of European landscapes within distinct biogeographical regions, and associated conditions for the occurrence of extreme wildfire events. Finally, results of the Deliverable will feed other work packages (e.g., WP1, WP2 and WP5), by contributing to the development of fire regime models, landscape management models, simulations of fire resilient landscapes and decision support systems.

COMPILATION OF A DATABASE OF EWE ACROSS EUROPE IN 2000-2022

Criteria for inclusion in the EWE database

Extreme Wildfire Events (EWE) are defined as wildfires with large-scale complex interactions between fire and atmosphere generating pyroconvective behaviour, coupling processes, that results in fast, intense, uncertain, and fast-paced changing fire behaviour (see Deliverable 1.1, Castellnou et al. 2022). EWE might be wildfire disasters or not, but they are usually associated with each other.

Nevertheless, there might not be a unique factor that is accountable for the definition of extremeness (Castellnou et al. 2022).

The classification of a wildfire as an Extreme Event depends on different aspects (Tedim et al. 2020; Rego et al. 2021; Castellnou et al. 2022), which can be divided into four main categories:

- **Fire behaviour characteristics**: exceeding the technical limits of control, with high rate of spread, prolific crowning and/or spotting (fire line intensity ≥ 10.000 kW/m; rate of spread >50 m/min; spotting distance >1 km, according to Tedim et al. 2018), presence of fire whirls, and strong convection column, erratic and unpredictable fire behaviour and spread, and extreme growth of rate (surface per hour, ha/h values);
- **Operationality**: unpredictable fire behaviour that exceeds the general capacity of suppression and overwhelms the decision-making capabilities from the emergency system (firefighter crews and emergency managers, infrastructure managers and civilian population); collapse of the capacity of emergency organizations to extinguish a wildfire (Tedim et al. 2018); this category is usually associated with fire behaviour characteristics; it can also be associated with simultaneous emergencies (e.g., other EWE or earthquakes);
- **Outliers and anomalies in historical data**: context depending on space and time (e.g., expressed as percentiles of a specific fire characteristic such as fire size, rate of spread, among others); EWE are rare events and are socially perceived as an extreme wildfire event from a local perspective (also linked to media coverage);
- **Magnitude of impacts:** heightened threat to crews, population, assets, and natural values, as well as relevant negative socioeconomic and environmental impacts (Tedim et al. 2018).

A fire was included in the EWE database if it comprised at least one of the four criteria below:

(i) extreme fire behavior characteristics;
(ii) extreme operationality;
(iii) outlier in historical data at the European scale or at the national scale, in terms of fire size;
(iv) magnitude of impacts.

In order to identify outliers in historical data at the European scale, a fire was considered extreme (very large size) when fire size presented a probability of less than 0.001 (0.1%) based on the European Forest Fire Information System (EFFIS) database in 2000-2022 (including a total of 66 549 wildfires) (San-Miguel-Ayanz et al. 2012). This analysis is shown in section 2.3.

In addition, we also considered fires as EWE when they represented an anomaly in historical data in terms of fire size or impacts (e.g., the largest ever recorded) at regional or national scales based on literature revision; these fires were analyzed separately from the statistical outliers with very large fire size.

Collection and structuring of information

We compiled a database on EWE occurring in 2000-2022 in Europe. Information for the database was collected from annual fire reports published by EFFIS in 2000-2022 (https://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports; San-Miguel-Ayanz et al. 2023), and completed with scientific and grey literature. Each EFFIS report contains a description of the yearly fire season and fire information per country. Although the list of countries varies over time and among reports, southern European countries have been included in all the reports (namely, France, Greece, Italy, Portugal and Spain).

Collected data (from literature revision and statistical identification of outliers) was compiled into an Excel file, with the following information:

- country;
- fire start and end date;
- fire size (ha);
- NUTS2, NUTS3 and municipality of fire start;
- EFFIS ID (the identification number of the shapefile of fire size from EFFIS spatial database);
- coordinates (x,y) of the fire size center (polygon);
- criteria fulfilled to be classified as EWE (fire characteristics, operationality, outlier at EU scale, outlier at national scale, magnitude of impacts);
- cause of fire ignition;
- sources of information (references).

Under the scope of the present deliverable, the database was used to select a list of EWE in Europe for analysis. Nevertheless, this database is an ongoing process: it was already revised by some project partners and will continue to be completed and revised during project development, in order to be used for other tasks/deliverables and with distinct objectives, as a whole consortium product.

Selection of outliers in fire size at the European scale

The frequency distribution of the EFFIS dataset of 66549 wildfires (San-Miguel-Ayanz et al. 2012; Camia et al. 2014) recorded in 2000-2022 followed a general lognormal pattern that was well described by a normal distribution after a logarithmic transformation. This distribution can be used for countries with small number of fire events and for comparison among countries. In this case, we used a log10 transformation in order to allow for a better interpretation of the graphs. A value of 1 represents a wildfire of 10 hectares, a value of 2 represents 100 hectares, a value of 3 corresponds to 1000 hectares, and a value of 4 represents 10000 hectares, which is very rarely observed (Figure 1).

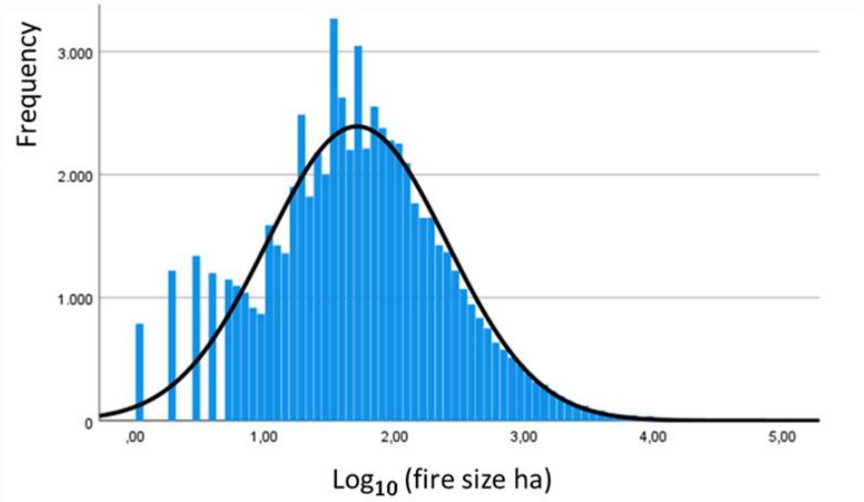


Figure 1. Histogram representing the frequency distribution of fire size (transformed by log10) for the whole EFFIS data set (2000-2022). A normal distribution shows a good fit to the frequencies of the log-transformed data, with an overall average of 1.710 (corresponding to 51.28 hectares) and a standard deviation of 0.694.

This frequency distribution allows for the selection of the most extreme wildfires in terms of fire size at the EU level. One possibility is to select a certain percentile, for example the percentile 99, and select the 1% largest wildfires, which correspond to those 666 fires above 2700 hectares in size. Equivalently, we may use the fitted distribution to select the extreme wildfires. In this case, we can compute the z – statistic for each fire:

$Z = \frac{[log_{10}(Fire\ size) - 1.710]}{0.694}$ or $Fire\ size = 51.28\ \times\ 10^{0.694\ .Z}$ Equation 1

The z value corresponding to the 2700 hectares is 2.48. All values above 2.48 would be considered as extreme with the 99-percentile rule.

However, for simplicity, we can use directly the different z values associated with the probabilities of a wildfire to overcome some thresholds. For example, the probabilities of 1%, 0.5% or 0.1% of a z value to be exceeded correspond to a z value of 2.33, 2.58, or 3.10, respectively.

For the inclusion in the database, wildfires were considered as extreme when wildfire size presented a probability of less than 0.001 (0.1%). This probability corresponded to a threshold of 7400 hectares (based on the fitted distribution of 66549 fires), resulting in 109 wildfires considered as extreme in terms of fire size at the European scale in 2000-2022, listed in Annex 1. From these, 44 fires occurred in Portugal, 35 in Spain, 18 in

Greece, 6 in Italy, 3 in France, 2 in Romania, and 1 in Sweden, being the Iberian Peninsula by far the region in Europe with the highest number of extreme wildfires in terms of fire size statistical anomalies at the European scale.

A graphical display of the lognormal distribution parameters (mean and standard deviation) for the European countries is shown in Figure 2. This figure allows for interesting comparisons. The countries with higher values in both mean and standard deviation in fire size distributions are Greece, Portugal and Spain, indicating that there is a great possibility of very large fires. Sweden and the Netherlands have small means but very large standard deviations, indicating a large variation in recorded fire sizes in these countries. Very large fires may occur but much less frequently than in other regions. Some countries, as Croatia, Cyprus, Slovenia and Belgium have high mean values but variation is relatively small, showing that when fires occur, they are significant in size but a low probability of being extreme. At the lower end, Denmark, Germany and Finland have the lower mean fire sizes, and Slovakia and Switzerland some of the lower variations with average fire sizes indicating that, in both cases, very large fires are statistically almost impossible to occur. A table with the distribution parameters per country is shown in Annex 2.

The seasonal distribution of all fires in EFFIS database (N = 66549) and outliers in fire size is shown in Figure 3. This distribution has a peak in March (20%) and a second peak in July (15%) and August (20%). On the other hand, outliers in fire size (≥ 7400 ha) show a much stronger concentration on July (30%) and August (40%), twice as much as the global percentage, and a very small percentage (2%) in March.

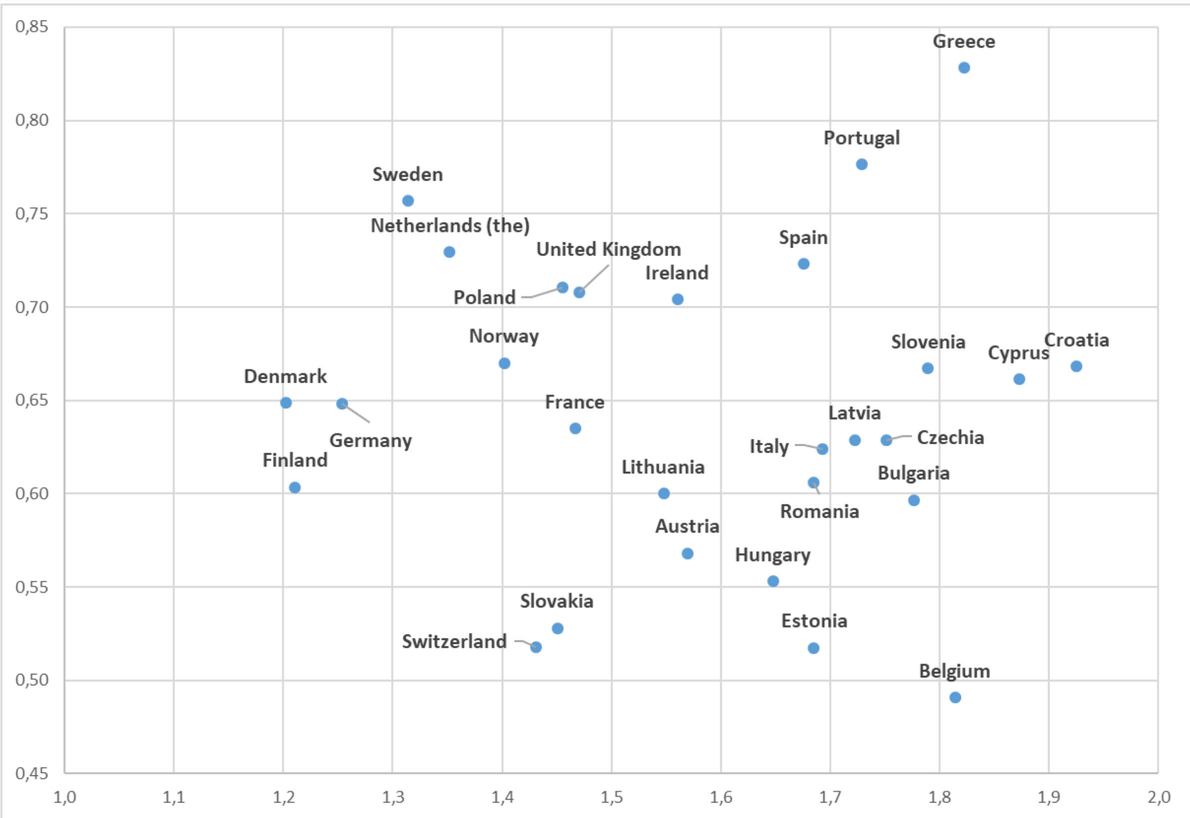


Figure 2. Graphic of the parameters of the lognormal distributions of fire size fitted for the various countries analyzed, with the parameter a (mean) in the x axis and the parameter b (standard deviation) in the y axis.

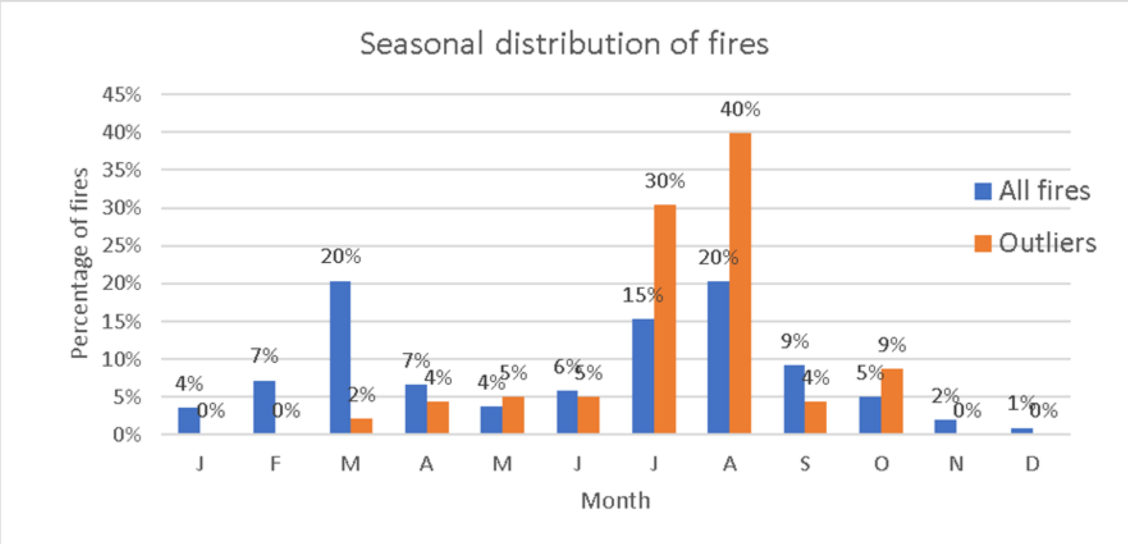


Figure 3. Seasonal distribution of outliers in fire size and all fires in EFFIS database in 2000-2022.

Fires included in the Database of EWE in Europe

A total of 137 fires occurring in Europe in 2000-2022 were included in the EWE database, based on the four criteria previously described. Table 1 summarizes those fires by country and selection criteria. Although extreme operationality was included as a separate criterion in the EWE database (allowing for separate analyses within the project or future studies), it was not analyzed as a separate group in the present deliverable. Extreme operationality is often a consequence of fire characteristics, such as extreme behavior, size or local/national contexts (Tedim et al. 2020) and was not considered as a criterion *per se* for the landscape assessment here presented.

A total of 109 fires were classified as outliers in fire size at the European scale (≥7400 ha), with 22 of these also reported as fires with extreme behaviour. Outliers in fire size occurred mostly in southern European countries, being Portugal and Spain the countries with the highest number (44 and 35, respectively), followed by Greece (18). Nevertheless, three outliers in fire size occurred in Romania (2) and Sweden (1), the latter with extreme behaviour.

When considering the selected fires based on extreme fire behaviour (independently of fire size, including 22 fires ≥ 7400 ha and 9 fires < 7400 ha), Portugal and Greece stand out as the countries with the highest number (13 in Portugal and 7 in Greece).

The last column of Table 1 shows EWE that were neither outliers in fire size at European scale nor presented extreme fire behaviour, but were considered as extreme due to unusual fire size in country historical records and/or impacts of great magnitude, based on the revised literature. This set of EWE includes several countries without a traditional fire season, namely, Austria (1), Czech Republic (1), Ireland (3), Latvia (1), Netherlands (1), Norway (1), Slovenia (1) and Sweden (4). Hence, it shows a large variation in fire size since it is context dependent, ranging from 109 ha in Austria to about 7000 ha in Spain, France and Romania (EWE database).

Table 1. Number of fires included in the EWE database by country and selection criteria.

Country	Outlier Fire size at EU scale with reported extreme behaviour (≥ 7400 ha)[1]	Outlier Fire size at EU scale (≥ 7400 ha)[2]	Extreme fire behaviour (< 7400 ha)[3]	Historical anomaly in fire size and/or impacts at national scale (< 7400 ha)[4]	Total
Austria				1	1
Croatia			1		1
Cyprus			2		2
Czech Republic				1	1
France		3	2	2	7
Greece	6	12	1		19
Ireland				3	3
Italy	1	5	1	1	8
Latvia				1	1
Netherlands				1	1
Norway				1	1
Portugal	11	33	2		46
Romania		2		2	4
Slovenia				1	1
Spain	3	32		1	36
Sweden	1			4	5
Total	22	87	9	19	137

The temporal distribution of selected fires (Table 1 and EWE database) shows an increasing trend in 2000-2022, for all classification categories considered (Figure 4).

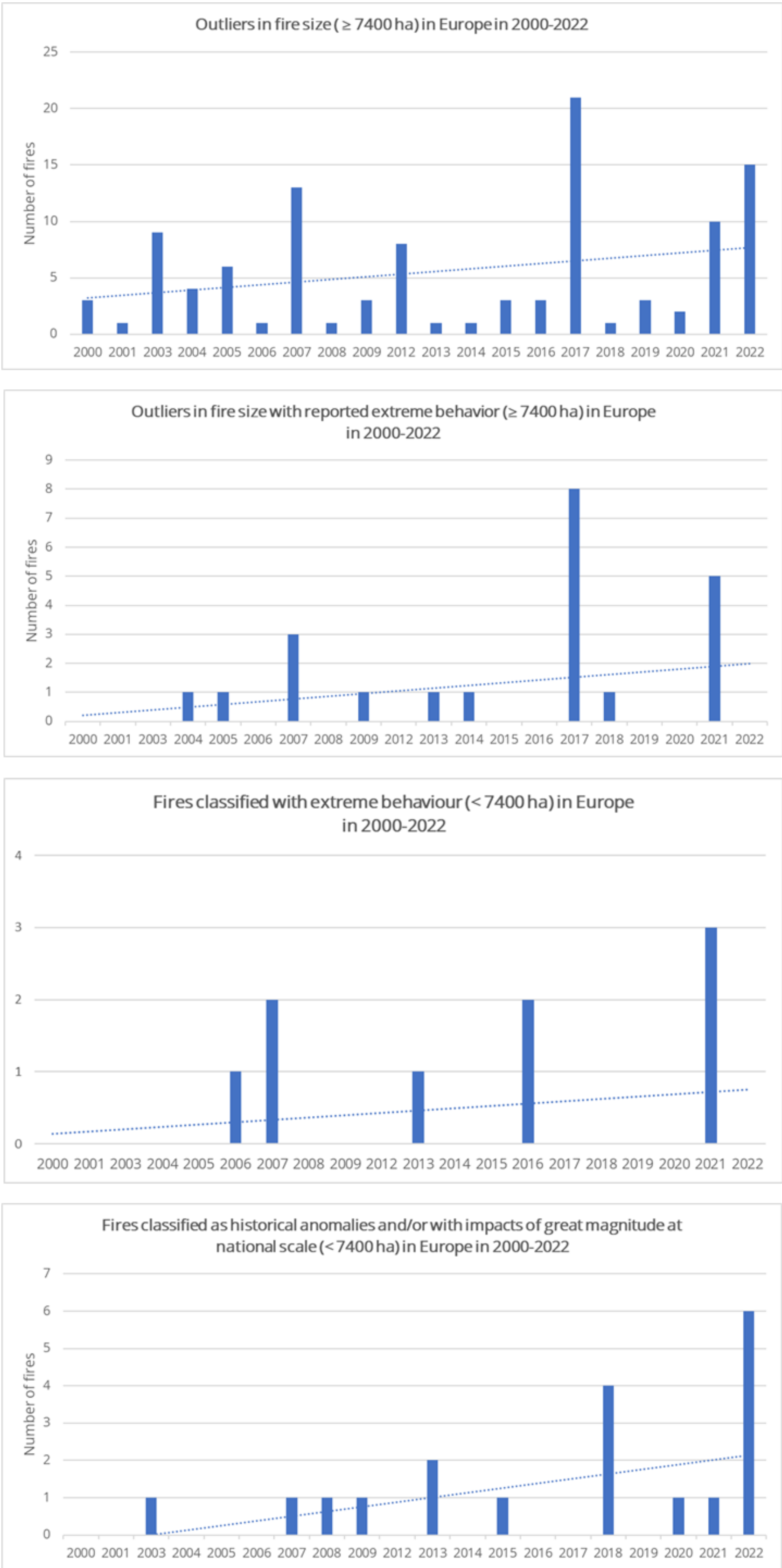


Figure 4. Number of selected fires per classification category and year in Europe in 2000-2022 with trend line.

LANDSCAPE COMPOSITION, DYNAMICS AND CONFIGURATION OF THE AREAS WHERE EWE OCCURRED IN EUROPE

Land Use/Land cover (LULC) data collection and analysis

We used LULC (land use / land cover) spatial data from Corine Land Cover (CLC, a pan-European land cover inventory) to quantify pre-fire LULC composition and LULC changes for all the selected EWE in Europe (n = 137). CLC data is produced with the same criteria for the whole EU region and allows for a consistent comparison among EU countries and regions (vector format: minimum mapping unit of 25 hectares for areal phenomena and a minimum width of 100 m for linear phenomena, raster format: 100 m resolution). More information on CLC data can be found at https://land.copernicus.eu/en/products/corine-land-cover).

LULC composition was quantified for the year with available LULC data prior to fire occurrence. Changes in LULC were quantified with transition matrices using 1990 as initial year and the year with available LULC data prior to fire occurrence as final year. Data used and periods analyzed are shown in Table 2.

Table 2. CLC nomenclature, data and periods used for the analysis of selected EWE per country (N = 137).

CLC Name	CLC Temporal extent	EWE period selected for the analysis	LULC composition	LULC transitions	AU	CR	CY*	CZ	FR	GR	IR	IT	LV	NE	NO*	PT	RO	SL	SP	SW*	Total
1990	1986-1998	2000-2001	CLC 1990	NA						3						1					4
2000	1999-2001	2002-2007	CLC 2000	1990-2001		1			2	7		5				13			10		38
2006	2005-2007	2008-2012	CLC 2006	1990-2007						3		1			1	2			7		14
2012	2011-2012	2013-2018	CLC 2012	1990-2012			1		1		3					24			6	5	40
2018	2017-2018	2019-2022	CLC 2018	1990-2018	1		1	1	4	6		2	1	1		6	4	1	13		41
				Total	1	1	2	1	7	19	3	8	1	1	1	46	4	1	36	5	137

* the initial year to quantify LULC transitions was based on CLC2000 for Cyprus, Norway and Sweden since these countries are not included in CLC1990
Country codes: AU – Austria, CR – Croatia, CY – Cyprus, CZ – Czech Republic, FR – France, GR – Greece, IR – Ireland, IT – Italy, LV – Latvia, NE – Netherlands, NO – Norway, PT – Portugal, RO – Romania, SL – Slovenia, SP – Spain, SW – Sweden.

Considering the aim of the present analysis, we used 9 LULC classes (of different levels) from CLC nomenclature (see European Environment Agency (2019) for a detailed explanation of each class), namely:

1. **Artificial surfaces** (Level 1, which includes urban, industrial, mines and other artificial areas);
2. **Agricultural areas** (Level 1, which includes arable land, permanent crops, pastures and heterogenous agricultural areas);
3. **Broad-leaved forest** (Level 3, which includes a predomination of broad-leaved species such as the ones belonging to the genus *Fagus*, *Quercus*, *Populus,* among others; riparian woodlands; *Eucalyptus* plantations)

4. **Coniferous forest** (Level 3, which includes a predomination of coniferous species such as the ones belonging to the genus *Pinus*, *Abies*, *Cedrus*, among others; young plantations of coniferous trees);
5. **Mixed forest** (Level 3, which includes a mixture of broad-leaved and coniferous species without predomination)
6. **Scrub and/or herbaceous vegetation associations** (Level 2, which includes natural grassland, moors and heathland, sclerophyllous vegetation, and transitional woodland/shrub);
7. **Open spaces with little or no vegetation** (Level 1, which includes beaches and dunes, bare rock, sparsely vegetated areas);
8. **Burnt areas** (Level 3);
9. **Wetlands and Water bodies** (Level 1, two joint classes, which include inland and coastal wetlands, and inland and marine waters).

To quantify pre-fire LULC composition, we clipped each individual EWE perimeter with the respective CLC (according to Table 2). To quantify pre-fire LULC transitions, we intersected pre-fire landscape composition with CLC1990 (used as initial year since this is the oldest CLC data available). CLC2000 was used as initial year for 8 EWEs that occurred in Cyprus, Norway and Sweden since these countries are not included in CLC1990. Transitions were not quantified for 4 EWEs that occurred in 2000-2001 (in Greece and Portugal) because there is only one CLC available to analyse this period (CLC1990) and therefore it is not possible to quantify transitions (i.e., changes in time) (see Table 2).

In addition, we produced an unburned buffer around each selected EWE, with proportional area (similar size), in order to compare results on pre-fire LULC composition and transitions between burned and unburned areas. The comparison of burned perimeters with adjacent unburned areas ("control areas") allows distinguishing and identifying the pre-fire landscape conditions associated with the area that burned (or did not burn) and is a common methodology to evaluate the relation between landscape dynamics and fire (Lloret et al. 2002; Viedma et al. 2006; Silva et al. 2011). Spatial analyses were performed with ArcGIS Pro 3.0.3 (Esri 2022).

Results were exported into Excel, and LULC transition matrices (absolute and relative) were produced for each fire polygon and corresponding unburned buffer. LULC transitions were classified into 10 types according to Table 3, to facilitate analysis and interpretation of results. For example, although an increase in scrub/herbaceous associations might result from distinct transitions (e.g., from agricultural land or forests changing into scrub/herbaceous), it shows that there is an increase in shrub biomass (understory fuel) in the landscape. In addition, we can use the matrices to identify the changes that originated a specific transition.

We quantified LULC composition and transitions in fire perimeters and corresponding unburned buffers, and calculated the differences in LULC (percentage points) between unburned and fire perimeters. Results are shown in the next section.

Table 3. Classification of transition types (LULC changes) from 1990 to pre-fire year (2000, 2006, 2012 or 2018 depending on the year of fire occurrence).

FROM \ TO	Artificial surfaces	Agricultural areas	Broad-leaved forest	Coniferous forest	Mixed forest	Scrub and/or herbaceous vegetation associations	Burnt areas	Open spaces with little or no vegetation	Wetlands and water bodies
Artificial surfaces	NC	Agricultural increase	Broad-leaved forest increase	Coniferous forest increase	Mixed forest increase	Scrub and herbaceous increase	Burnt areas increase	Open spaces increase	Wetlands and water bodies increase
Agricultural areas	Urbanization	NC	Broad-leaved forest increase	Coniferous forest increase	Mixed forest increase	Scrub and herbaceous increase	Burnt areas increase	Open spaces increase	Wetlands and water bodies increase
Broad-leaved forest	Urbanization	Agricultural increase	NC	Coniferous forest increase	Mixed forest increase	Scrub and herbaceous increase	Burnt areas increase	Open spaces increase	Wetlands and water bodies increase
Coniferous forest	Urbanization	Agricultural increase	Broad-leaved forest increase	NC	Mixed forest increase	Scrub and herbaceous increase	Burnt areas increase	Open spaces increase	Wetlands and water bodies increase
Mixed forest	Urbanization	Agricultural increase	Broad-leaved forest increase	Coniferous forest increase	NC	Scrub and herbaceous increase	Burnt areas increase	Open spaces increase	Wetlands and water bodies increase
Scrub and/or herbaceous vegetation associations	Urbanization	Agricultural increase	Broad-leaved forest increase	Coniferous forest increase	Mixed forest increase	NC	Burnt areas increase	Open spaces increase	Wetlands and water bodies increase

Burnt areas	Urbanization	Agricultural increase	Broad-leaved forest increase	Coniferous forest increase	Mixed forest increase	Scrub and herbaceous increase	NC	Open spaces increase	Wetlands and water bodies increase
Open spaces with little or no vegetation	Urbanization	Agricultural increase	Broad-leaved forest increase	Coniferous forest increase	Mixed forest increase	Scrub and herbaceous increase	Burnt areas increase	NC	Wetlands and water bodies increase
Wetlands and water bodies	Urbanization	Agricultural increase	Broad-leaved forest increase	Coniferous forest increase	Mixed forest increase	Scrub and herbaceous increase	Burnt areas increase	Open spaces increase	NC

NC – No Change

Pre-fire LULC composition of outliers in fire size at the European scale (≥ 7400 ha) and unburned buffers

Pre-fire LULC composition of outliers in fire size (≥ 7400 ha) was dominated by scrub/herbaceous associations in Portugal, Spain, Greece and France, by scrub/herbaceous associations and agricultural land in Italy, by coniferous forests in Sweden, and by wetlands (inland marshes) in Romania (Annex 3).

Figures 5 to 11 below show the differences in pre-fire LULC area of occupation between the unburned and burned perimeters (in percentage points, averaged per country and CLC year). Differences show consistent patterns across countries and over time for four classes: agricultural areas, artificial surfaces, scrub/herbaceous associations, and wetlands.

The area occupied by agricultural land in the pre-fire landscape was consistently higher within unburned buffers than within fire perimeters for Portugal, Spain, Greece, France and Sweden (Figures 5, 6, 7, 9 and 11). The highest difference in area occupied by agricultural land was observed for Portugal, which shows on average, about 12% more area occupied by agricultural land in unburned buffers, in comparison to burned areas (Figure 5). Recall that Portugal is also the country with the highest number of outliers in fire size (including outliers with extreme fire behaviour). Nevertheless, Sweden also showed a large difference of agricultural land area between unburned/burned perimeters in the pre-fire landscape of a single outlier in fire size registered in this country in 2014: the unburned buffer presented 10% more agricultural area than the burned perimeter, which showed no agricultural land at all (Figure 10 and Annex 3). In contrast, Italy did not show consistent differences in agricultural land between unburned and burned perimeters (Figure 8), which may be the result of specific characteristics of selected fire events. In fact, only one fire event was selected regarding pre-fire conditions in 2006 in Italy, which occurred in 2009 in Sardinia where most of the burned land was arable land mixed with agroforestry and natural vegetation, but that reached a large size due to strong winds (according to CLC classification and the EWE database built).

The second consistent pattern found in the pre-fire landscape was the larger area occupied by scrub/herbaceous associations in fire perimeters, in comparison to unburned buffers, for most outliers in fire size (Figures 5 to 11) analysed, except for Sweden (with a similar and small area occupied by this LULC in both unburned and burned areas, about 4%, Figure 10). In addition, France and Portugal showed the largest difference in area occupied by scrub/herbaceous associations between unburned and burned perimeters, with about 19% and 13% more area in burned perimeters, on average and respectively (Figures 9 and 5; see also Annex 3 for LULC composition in burned and unburned perimeters).

The area occupied by artificial surfaces and wetlands in the pre-fire landscape was larger within unburned buffers than within fire perimeters for most outliers in fire size analysed, but differences were smaller than the ones observed for agricultural areas and scrub/herbaceous associations (except for Greece with a larger difference, likely related with this country geography, Figure 7).

Within each country, there were also consistent patterns in pre-fire landscape composition, indicating distinct national forest contexts.

Portugal was the only country where the area occupied by broadleaved forests in pre-fire conditions was larger within fire perimeters than within unburned buffers (despite small differences), likely related to the dominance of eucalypt plantations in the

Portuguese regions where the 44 outliers in fire size occurred (central and northern regions) (Figure 5). Note that the larger difference (> 5%) of conifer forest area between unburned and burned perimeters observed in 1990 (with more conifer area in unburned perimeters) is related to a single fire that occurred in 2001 in Portugal (Figure 5).

In Italy, the area occupied by broadleaved forests in pre-fire conditions was slightly higher (from 1 to 5% difference depending on the years) within unburned buffers than within fire perimeters (Figure 8). Nevertheless, broadleaved forests (dominated by deciduous oaks and ash species) were a stable class in both burned and unburned perimeters, with small changes to other LULC classes over the analysed periods.

Spain and Greece showed a similar and consistent pattern over time regarding coniferous forests, with this forest type occupying a larger area within fire perimeters than within unburned buffers, in pre-fire conditions (Figures 6 and 7).

In Romania, most of the pre-fire landscape was occupied by wetlands (inland marshes) in both unburned and burned areas (about 95%, Annex 3), with a very small difference between the two (-0.8%, Figure 11).

In Sweden, pre-fire landscape composition of the large wildfire event of 2014 (15000 ha) was dominated by coniferous forests (almost 90%). Although the landscape of the surrounding unburned buffer was also dominated by coniferous forests (72%), it also contained 10% of agricultural areas, which might have mitigated fire progression. Conversely, agricultural areas were nearly absent from the pre-fire landscape of the burned area (0.2%), as already described (Figure 10).

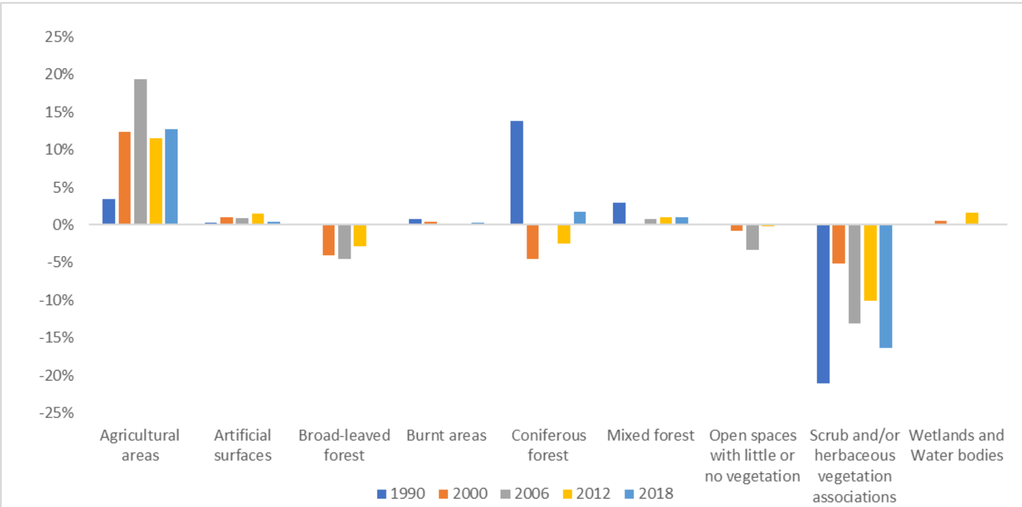


Figure 5. Pre-fire LULC difference (% points) in 1990, 2000, 2006, 2012 and 2018 between unburned buffers and outliers in fire size in Portugal (N = 44 outliers in fire size, ≥ 7400 ha; of these, 11 were reported with extreme fire behaviour).

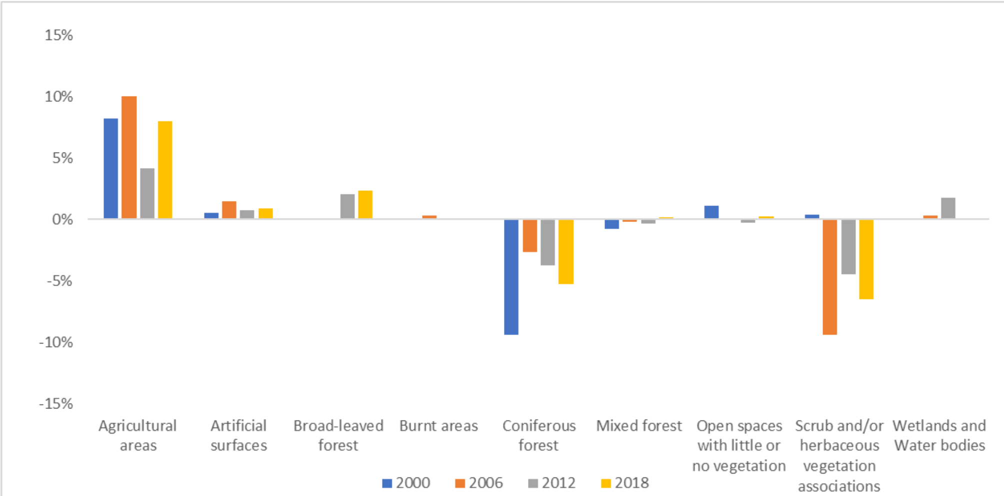


Figure 6. Pre-fire LULC difference (% points) in 2000, 2006, 2012 and 2018 between unburned buffers and outliers in fire size in Spain (N = 35 outliers in fire size, ≥ 7400 ha; of these, 3 were reported with extreme fire behaviour).

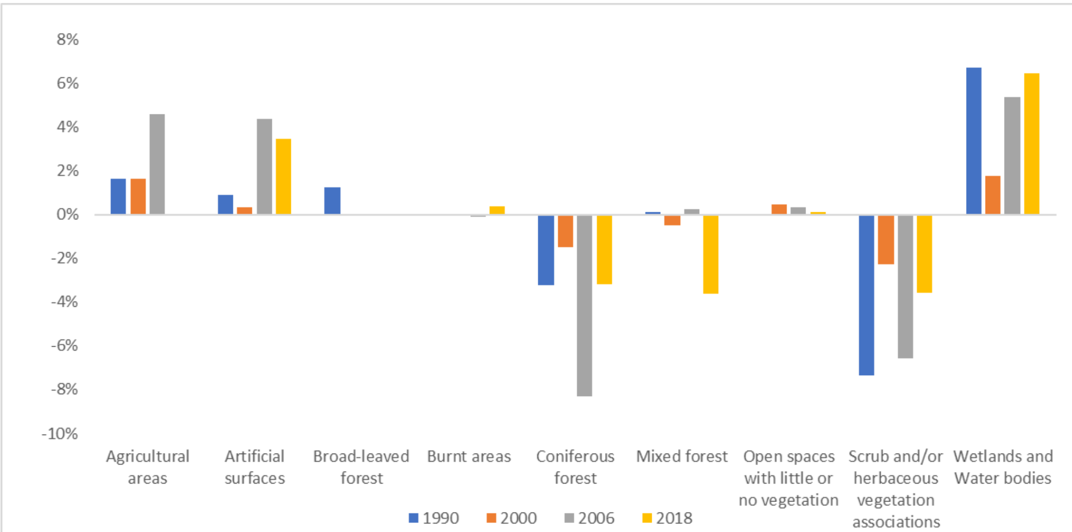


Figure 7. Pre-fire LULC difference (% points) in 1990, 2000, 2006 and 2018 between unburned buffers and outliers in fire size in Greece (N = 18 outliers in fire size, ≥ 7400 ha; of these, 6 were reported with extreme fire behaviour).

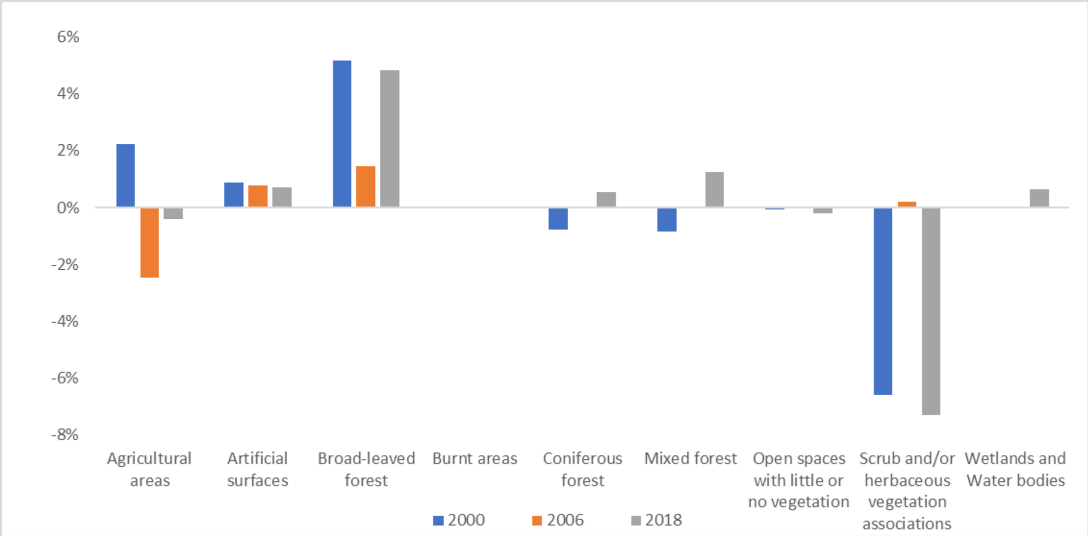


Figure 8. Pre-fire LULC difference in 2000, 2006 and 2018 (% points) between unburned buffers and outliers in fire size in Italy (N = 6, ≥ 7400 ha; of these, 1 was reported with extreme fire behaviour).

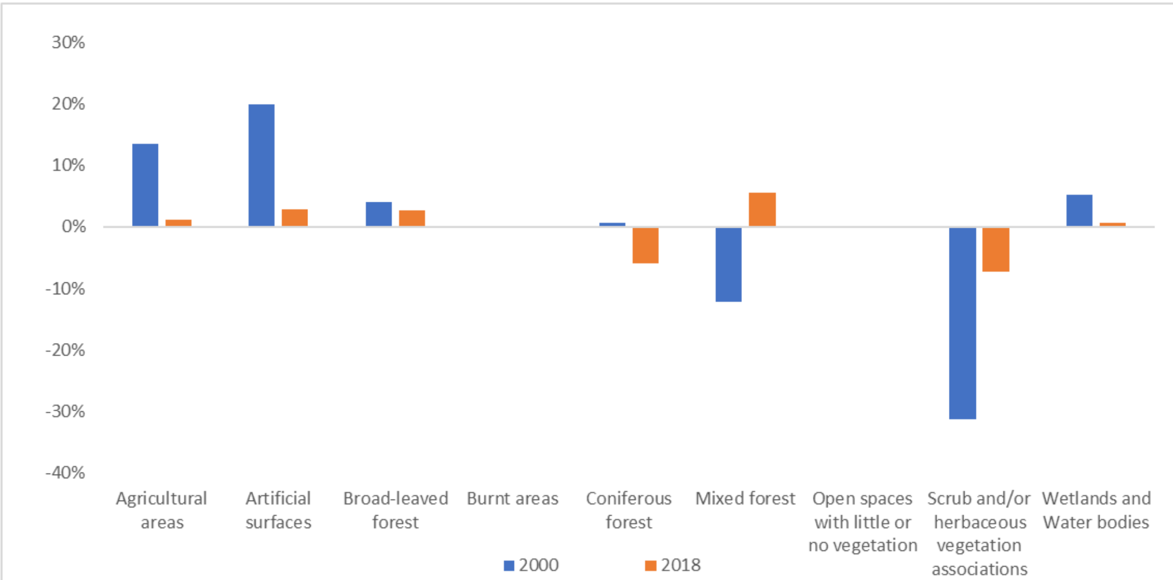


Figure 9. Pre-fire LULC difference (% points) in 2000 and 2018 between unburned buffers and outliers in fire size in France (N = 3, ≥ 7400 ha).

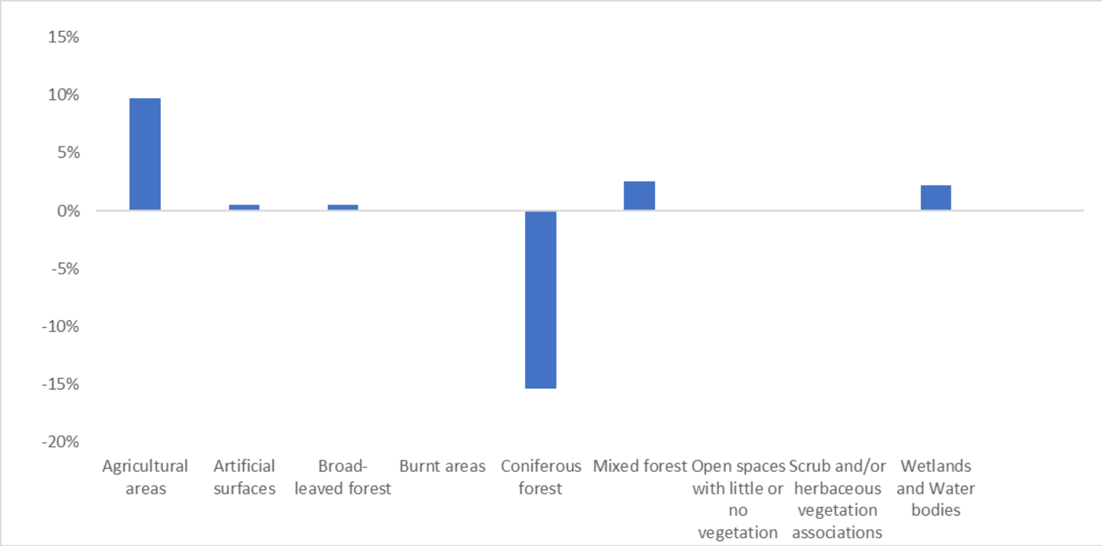


Figure 10. Pre-fire LULC difference (% points) in 2012 between the unburned buffer and outlier in fire size (reported with extreme fire behaviour) in Sweden (N = 1, ≥ 7400 ha).

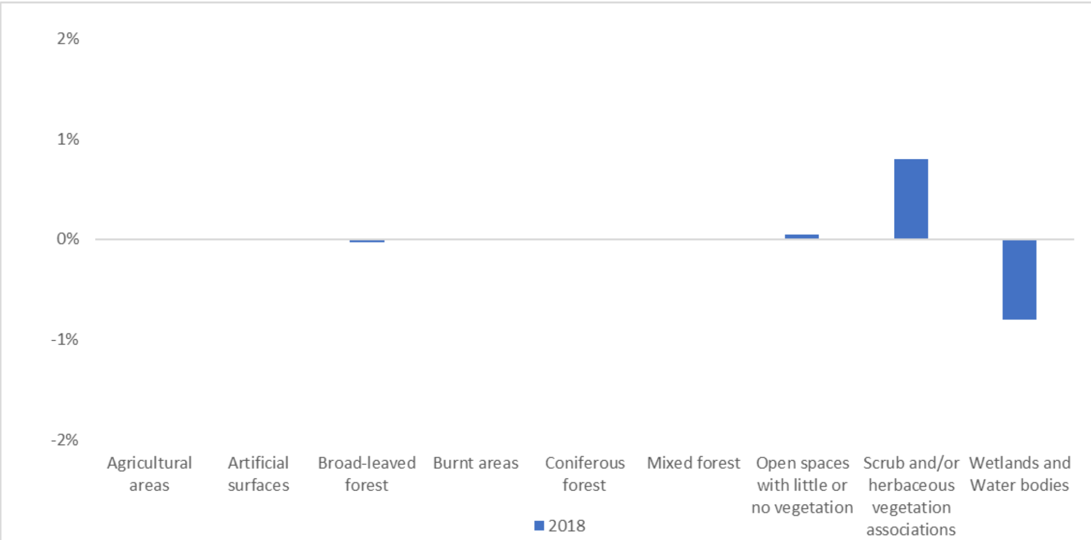


Figure 11. Pre-fire LULC difference (% points) in 2018 between unburned buffers and outliers in fire size in Romania (N = 2, ≥ 7400 ha).

Pre-fire LULC composition for fires with reported extreme behavior (< 7400 ha) and unburned buffers

Pre-fire LULC composition of the nine fire events with less than 7400 ha and extreme behaviour (as reported in the literature) was dominated by scrub/herbaceous associations in Portugal, Greece, France and Croatia, by agricultural land in Italy, and by coniferous forests in Cyprus (Annex 4).

Table 4 shows the differences in LULC composition of the pre-fire landscape between unburned buffers and fire perimeters with extreme behaviour (< 7400 ha) (shown in percentage points, averaged per country and CLC year). This dataset shows a high variability in fire size, ranging from 465 ha in Portugal to 6832 ha in France. Nevertheless, it follows patterns already observed for outliers in fire size (see previous section), namely: a larger area occupied by scrub/herbaceous associations and a smaller area occupied by agricultural land within burned areas than within surrounding unburned buffers, for the pre-fire landscape (Table 4). In addition, fires with larger size (> 6000 ha) showed the largest differences in area occupied by agricultural land in the pre-fire landscape, with the exception of Cyprus (Table 4).

The area occupied by artificial surfaces in the pre-fire landscape was always higher within unburned buffers than within the fire perimeters, for all fires with extreme behavior analyzed, but magnitude of differences was variable among and within countries.

Table 4. Pre-fire LULC difference (% points) between unburned buffers and fires reported with extreme behaviour (< 7400 ha), per country and year of LULC classification (N = 9).

		Croatia (N =1)	Cyprus (N = 2)		France (N = 2)		Greece (N = 1)	Italy (N = 1)	Portugal (N = 2)	
	LULC Year (CLC)	2000	2012	2018	2012	2018	2018	2000	2000	2012
	Fire event (Year and Size)	2007 (1062 ha)	2016 (1886 ha)	2021 (4450 ha)	2016 (2663 ha)	2021 (6832 ha)	2021 (4688 ha)	2007 (535 ha)	2006 (465 ha)	2013 (6548 ha)
LULC Class	**Agricultural areas**	4.4%	4.5%	-7.26%	-0.2%	10.4%	6.2%	2.0%	-0.5%	9.2%
	Artificial surfaces	0.7%	2.6%	0.09%	19%	2.3%	0.6%	0.5%	0.0%	1.0%
	Broad-leaved forest	0.0%	0.0%	0.26%	0.0%	-0.4%	1.9%	-1.6%	0.5%	1.4%
	Burnt areas	0.0%	0.0%	0.00%	0.0%	0.0%	-0.2%	0.0%	0.0%	0.0%
	Coniferous forest	8.8%	-7.0%	0.98%	-4%	-0.1%	0.0%	0.4%	-4.0%	-11.2%
	Mixed forest	0.0%	0.0%	0.00%	0.0%	0.1%	3.3%	0.9%	0.0%	7.4%
	Open spaces with little or no vegetation	-4.5%	0.0%	0.00%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Scrub and/or herbaceous vegetation associations	-11.9%	-0.1%	5.93%	-14.8%	-12.3%	-11.9%	-2.1%	4.0%	-7.7%
	Wetlands and Water bodies	2.6%	0.0%	0.00%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Pre-fire LULC composition for fires classified as historical anomalies and magnitude of impacts at the national scale (< 7400 ha) and unburned buffers

Pre-fire landscape composition of selected fire events classified as historical anomalies and magnitude of impacts at the national scale (< 7400 ha) was dominated by coniferous forests in Norway, Sweden, Austria and Czech Republic, by scrublands in Spain and France, by broadleaved forests in Italy and Slovenia, by wetlands (peatbogs) in Latvia, Netherlands and Ireland, and by wetlands (inland marshes) in Romania (Annex 5).

Table 5 shows the differences in area occupied by LULC classes in the pre-fire landscape between unburned and burned areas classified as historical anomalies/impacts at the national scale (shown as percentage points, averaged per country and CLC year).

This category of selected fires is the one with the highest variability in composition since it encompasses fires considered extreme at the national scale and thus reflecting very distinct conditions of biogeography and forests across northern and central European countries without a traditional fire season (e.g., Netherlands, Austria, Slovenia and Latvia), and Mediterranean countries (e.g., Spain and France). As a consequence, pre-fire landscape differences between burned and unburned areas show a large variation in magnitude and reflect country variability.

Nevertheless, observed pre-fire LULC differences for these national fire anomalies also follow some patterns already observed in the previous sections. In this regard, the area occupied by agricultural areas in the pre-fire landscape was higher in unburned buffers than in burned perimeters, for all fires classified as historical anomalies at the national scale, with the largest difference found for the Netherlands (20% difference, 2020-fire with 710 ha of size). Moreover, the area occupied by scrub/herbaceous associations in the pre-fire landscape was higher in fire perimeters than in the surrounding unburned buffers for most countries, with a very high difference for France (-58% scrublands in the unburned buffer for a fire event in 2003 with 5646 ha, classified as an anomaly in terms of impacts and not size) (Table 5).

Another interesting pattern observed in countries without a traditional fire history (including The Netherlands, Ireland, Latvia and Norway) is that the area occupied by peatbogs (included in the wetlands LULC class) in the pre-fire landscape was higher within fire perimeters than within unburned buffers, indicating that peatbogs represent a landscape with an increasing wildfire risk in northern Europe.

Table 5. Pre-fire LULC difference (% points) between unburned buffers and fires classified as historical anomalies and/or magnitude of impacts at the national scale, per country and year of LULC classification (N = 19).

		Austria (N = 1)	Czech Republic (N = 1)	France (N = 2)		Ireland (N = 3) *	Italy* (N = 1)	Latvia (N = 1)	Netherlands (N = 1)	Norway (N = 1)	Romania (N = 2)	Slovenia (N =1)	Spain (N = 1)	Sweden (N = 4)
	LULC Year (CLC)	2018	2018	2000	2018	2012	2000	2018	2018	2006	2018	2018	2006	2012
	Fire event (Year and Size)	2021 (109 ha)	2022 (1436 ha)	2003* (5646 ha)	2022 (7000 ha)	2013 (2215 and 3404 ha); 2015 (1500 ha)	2007 (2856 ha)	2022 (113 ha)	2020 (710 ha)	2008 (2751 ha)	2022 (7191 and 6700 ha)	2022 (3988 ha)	2009 (7289 ha)	2018 (2175, 2854, 3744 and 3825 ha)
LULC Class	**Agricultural areas**	0.0%	8.7%	-2.2%	0.0%	2.6%	-15.9%	0.0%	21.0%	1.3%	3.2%	10.7%	5.1%	0.2%
	Artificial surfaces	3.4%	0.4%	1.2%	5.4%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%
	Broad-leaved forest	0.0%	5.7%	-4.2%	0.0%	0.0%	-50.9%	0.0%	6.4%	0.0%	2.5%	-0.8%	1.7%	0.0%
	Burnt areas	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Coniferous forest	-11.2%	-11.3%	0.0%	-27.9%	1.5%	-1.7%	0.0%	0.0%	4.8%	0.0%	-3.7%	-11.7%	-1.8%
	Mixed forest	0.6%	-4.5%	86.5%	0.1%	1.5%	83.8%	0.0%	0.0%	0.0%	0.0%	-2.2%	1.2%	0.0%
	Open spaces with little or no vegetation	7.2%	0.0%	-23.7%	4.4%	-0.2%	0.0%	9.3%	0.0%	0.0%	0.5%	0.4%	0.4%	0.0%
	Scrub and/or herbaceous vegetation associations	0.0%	0.0%	-57.9%	0.4%	0.9%	-16.2%	0.0%	0.0%	-0.5%	-2.0%	-5.7%	3.4%	-4.0%
	Wetlands and Water bodies	0.0%	1.1%	0.3%	17.5%	-6.3%	0.0%	-9.3%	-27.4%	-5.6%	-4.2%	0.0%	0.0%	5.6%

* historical anomaly based on magnitude of impacts at the national scale.

Pre-fire LULC transitions for outliers in fire size (≥ 7400 ha) and unburned buffers

Figures 12 to 18 show the pre-fire transitions in LULC for outliers in fire size (≥ 7400 ha) and surrounding unburned buffers, by country and period of analysis. The number of selected fires and which were reported with extreme behavior per period is also shown in the figure’s legend. We do not show results for the period 1990-2001 (which includes 33 fires in total, for Portugal, Spain, Greece, Italy and France) due to the short time interval (11 years). We also do not show the category “No change” to better illustrate LULC transitions in the figures. Nevertheless, we discuss this category throughout the text.

In Portugal, the dynamism of the pre-fire landscape for these very large fires and unburned buffers increased in time, as the LULC area classified as “no changes” decreased from 1990-2007 to 1990-2018 (from about 80% to 60%). Furthermore, the pre-fire landscape was always more dynamic within burned areas than within unburned buffers. The dominant pre-fire landscape change in the three analyzed periods, for both burned and unburned areas, was the increase of scrub/herbaceous vegetation associations (Figure 12). Results also show that the longer the period of analysis, the higher this change, and the larger the difference of gains in scrub/herbaceous associations between fire perimeters and unburned buffers (2.1% in 1990-2007, 2.9% in 1990-2012 and 10% in 1990-2018). Gains in area of scrub/herbaceous associations originated mostly from coniferous forests (which are dominated by maritime pine in Portugal), as shown by the transition matrices quantified, indicating pine forest loss and increasing land abandonment, with shrub encroachment over time in areas formerly occupied by pines, in pre-fire conditions, particularly in burned areas. The decline of maritime pine forests in Portugal in the last twenty years results from the spread of the pinewood nematode that has decimated these forests since 1999, especially in areas with homogeneous pine landscapes and in drier and hotter locations (Calvão et al. 2019).

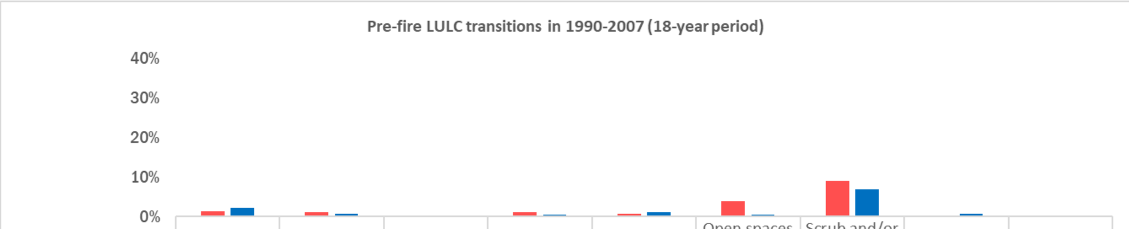
In Spain, the dominant pre-fire landscape transition in the three analyzed periods, for both burned and unburned perimeters, is also the increase of scrub/herbaceous vegetation, but differences in gains between burned and unburned areas do not increase in time, as was observed for Portugal (Figure 13). Gains in area of scrub/herbaceous associations originated mostly from agricultural land, coniferous and broadleaved forests over the analyzed periods, as shown by the transition matrices quantified. A second dominant pre-fire landscape transition observed is the increase in coniferous forest, which was higher in burned perimeters (Figure 13). Coniferous forest increased at the expense of agricultural land and scrub/herbaceous vegetation, indicating afforestation, reforestation or natural regeneration (as shown by transition matrices). Unchanged landscape in Spain in both burned and unburned areas (without transitions between LULC classes considered) was around 60% across periods analyzed.

In Greece and Italy, the pre-fire landscape was less dynamic than in Portugal and Spain (between 87-83% and 93-71% of unchanged landscape in Greece and Italy, respectively). Dominant LULC transitions in the Greek pre-fire landscape of both burned and unburned perimeters are the increase in scrub/herbaceous associations at the expense of coniferous forest in 1990-2007 and the increase in mixed forests in 1990-2018 at the expense of scrub/herbaceous vegetation associations (Figure 14). As for Italy, dominant pre-fire LULC transitions in 1990-2007, which correspond to one wildfire that occurred in 2009 in Sardinia, are the increase in scrub/herbaceous associations at the expense of agricultural areas in burned perimeters (indicating abandonment of land management), and the increase of agricultural lands originating from scrub/herbaceous vegetation in unburned buffers. In 1990-2018, the dominant pre-fire transition is the increase in agricultural land at the expense of scrub/herbaceous vegetation (Figure 15).

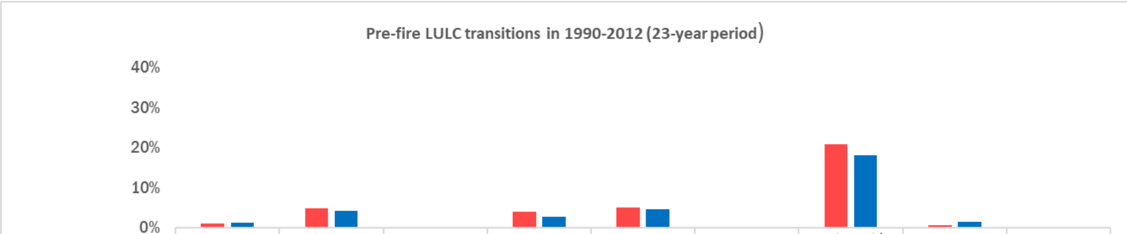
France was the most dynamic pre-fire landscape of all outliers in fire size analyzed in 1990-2018, with about 49% and 51% of "no changes" for burned and unburned areas, respectively. Dominant pre-fire LULC changes were scrub/herbaceous associations increase at the expense of coniferous forest, followed by coniferous forest increase at the expense of scrub/herbaceous associations (Figure 16), as shown by transition matrices. Such dominant transitions suggest a dynamics of coniferous forest regeneration and shrub encroachment within the pre-fire landscape of the two outliers in fire size selected for France, which occurred in 2021 (municipality of Gonfaron, Var, region of Provence-Alpes-Côte d'Azur) and 2022 (municipality of La Teste-de-Buch Gironde, region of Nouvelle-Aquitaine) (EWE database). Nevertheless, this result might also be due to misclassification of coniferous forest, which can be mistaken with tall scrublands when pine trees are young.

In Sweden, the single outlier in fire size at the European scale shows a more dynamic landscape than the surrounding unburned buffer (78% and 90% of "no changes" in LULC for burned and unburned areas, respectively). The dominant transitions in both burned and unburned areas were the increase in coniferous forests and the increase in scrub/herbaceous associations, which were higher within burned areas (Figure 17). As observed for France, such transitions result from exchanges between coniferous forest and scrub/herbaceous vegetation classes.

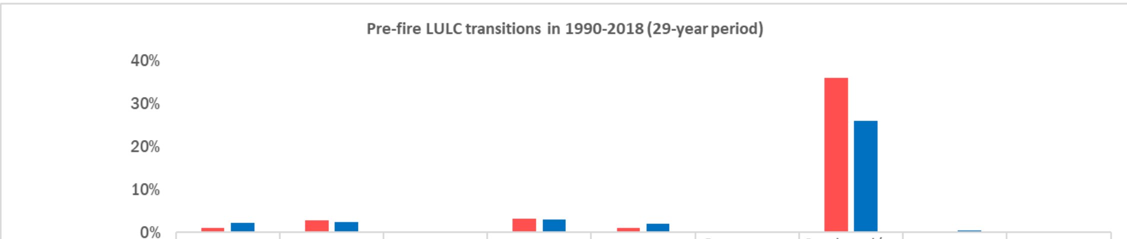
Romania shows the most static landscape for the two outliers in fire size analyzed, with almost null changes in 1990-2018 (29-year period). Recall that the pre-fire landscape of these two fire events was predominantly covered by wetlands (about 96% of inland marshes, Annex 3), which did not change in time (Figure 18).



	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	1.4%	1.1%	0.0%	1.0%	0.7%	3.8%	8.9%	0.0%	0.0%
Unburned Buffer	2.2%	0.6%	0.0%	0.4%	1.1%	0.5%	6.8%	0.7%	0.0%

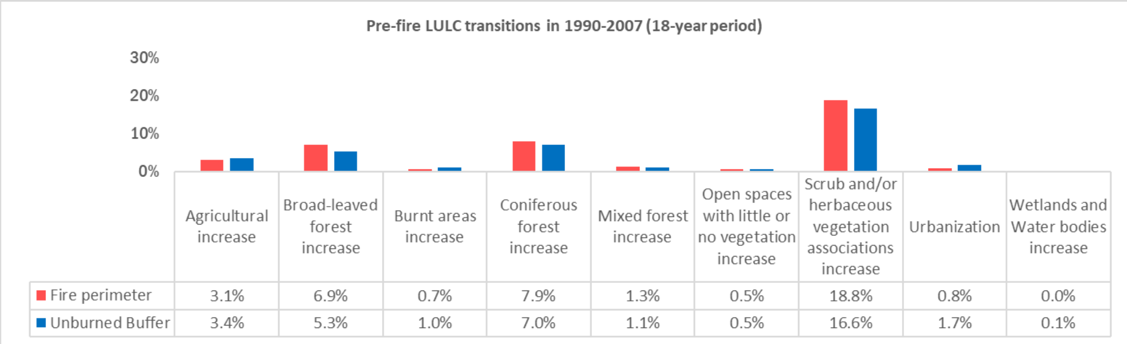


	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	1.0%	4.9%	0.1%	3.9%	5.0%	0.1%	20.9%	0.6%	0.1%
Unburned Buffer	1.3%	4.1%	0.1%	2.8%	4.5%	0.1%	18.0%	1.5%	0.2%

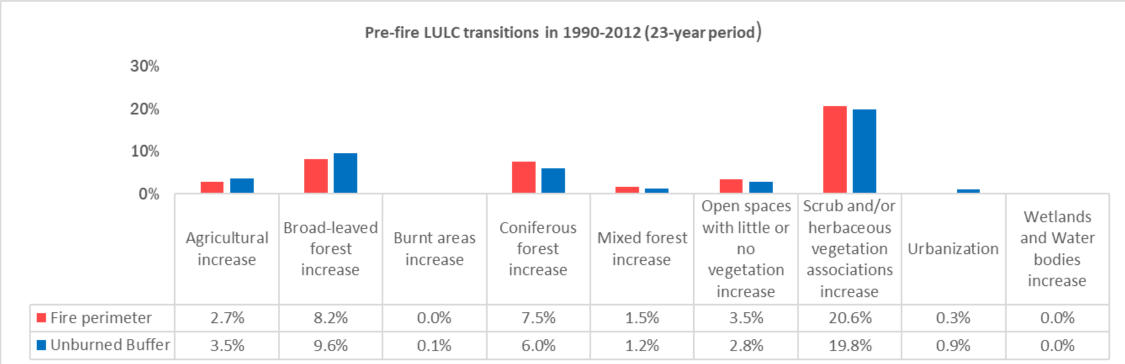


	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	1.00%	2.74%	0.03%	3.25%	1.11%	0.02%	36.02%	0.24%	0.00%
Unburned Buffer	2.24%	2.38%	0.32%	3.00%	2.01%	0.07%	25.91%	0.48%	0.00%

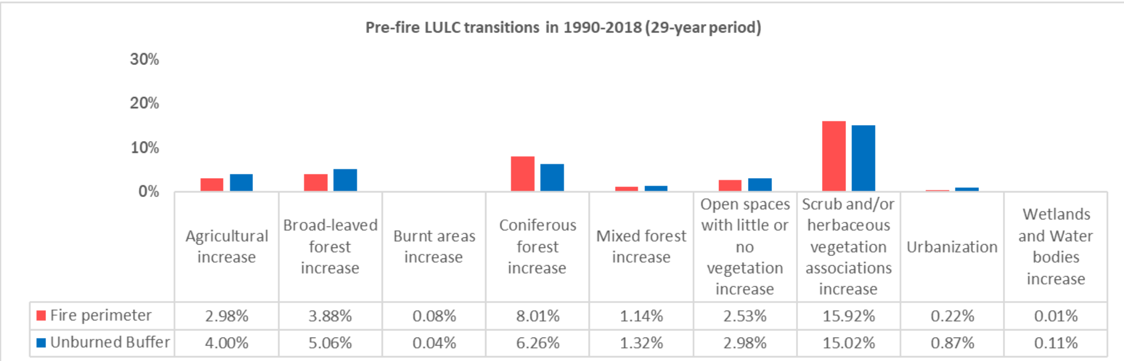
Figure 12. Pre-fire LULC transitions in Portugal for outliers in fire size and unburned buffers in 1990-2007 (N=2), 1990-2012 (N=23, ten of which were reported with extreme behaviour) and 1990-2018 (N=6).



	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	3.1%	6.9%	0.7%	7.9%	1.3%	0.5%	18.8%	0.8%	0.0%
Unburned Buffer	3.4%	5.3%	1.0%	7.0%	1.1%	0.5%	16.6%	1.7%	0.1%

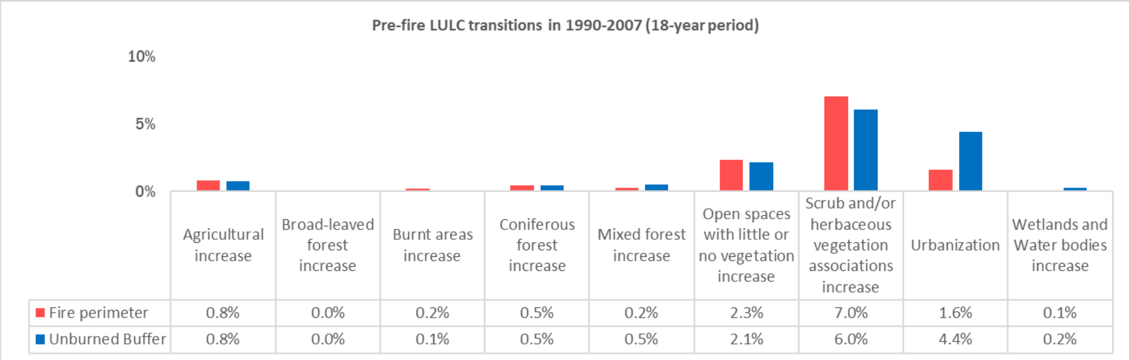


	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	2.7%	8.2%	0.0%	7.5%	1.5%	3.5%	20.6%	0.3%	0.0%
Unburned Buffer	3.5%	9.6%	0.1%	6.0%	1.2%	2.8%	19.8%	0.9%	0.0%

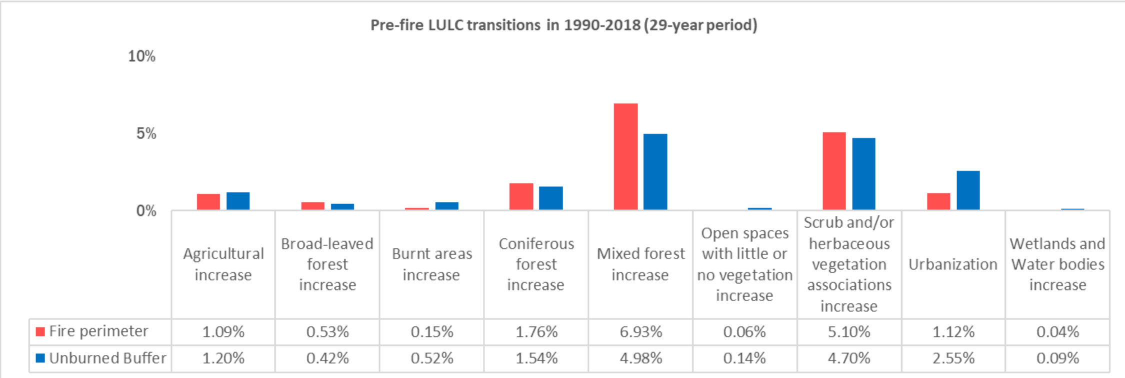


	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	2.98%	3.88%	0.08%	8.01%	1.14%	2.53%	15.92%	0.22%	0.01%
Unburned Buffer	4.00%	5.06%	0.04%	6.26%	1.32%	2.98%	15.02%	0.87%	0.11%

Figure 13. Pre-fire LULC transitions in Spain for outliers in fire size and unburned buffers in 1990-2007 (N =6), 1990-2012 (N=6) and 1990-2018 (N=13, one of which was reported with extreme behaviour).

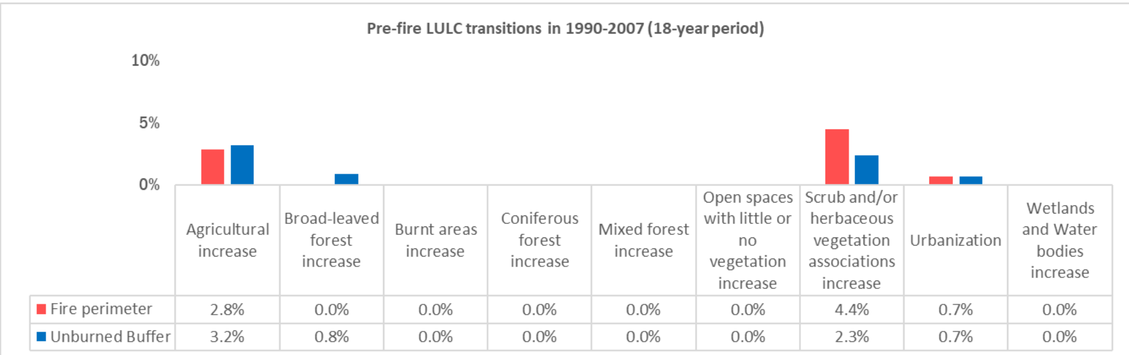


	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	0.8%	0.0%	0.2%	0.5%	0.2%	2.3%	7.0%	1.6%	0.1%
Unburned Buffer	0.8%	0.0%	0.1%	0.5%	0.5%	2.1%	6.0%	4.4%	0.2%

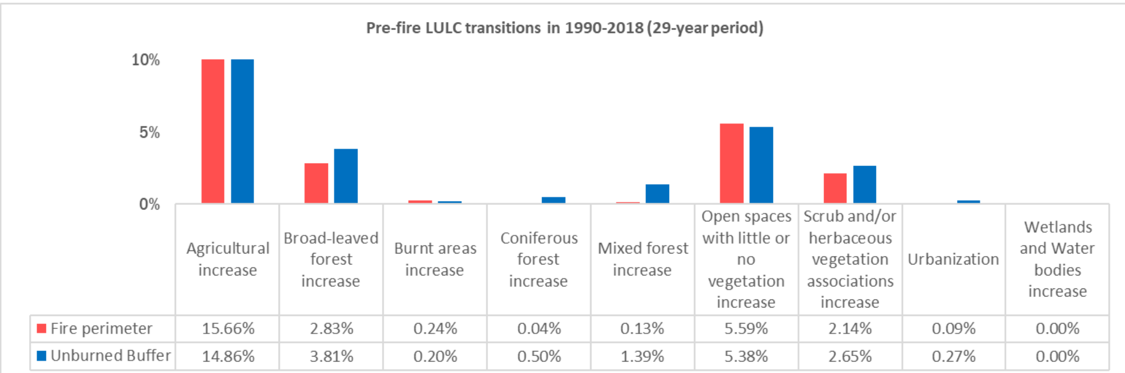


	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	1.09%	0.53%	0.15%	1.76%	6.93%	0.06%	5.10%	1.12%	0.04%
Unburned Buffer	1.20%	0.42%	0.52%	1.54%	4.98%	0.14%	4.70%	2.55%	0.09%

Figure 14. Pre-fire LULC transitions in Greece for outliers in fire size and unburned buffers in 1990-2007 (N = 3) and 1990-2018 (N=5, four of which were reported with extreme behaviour).

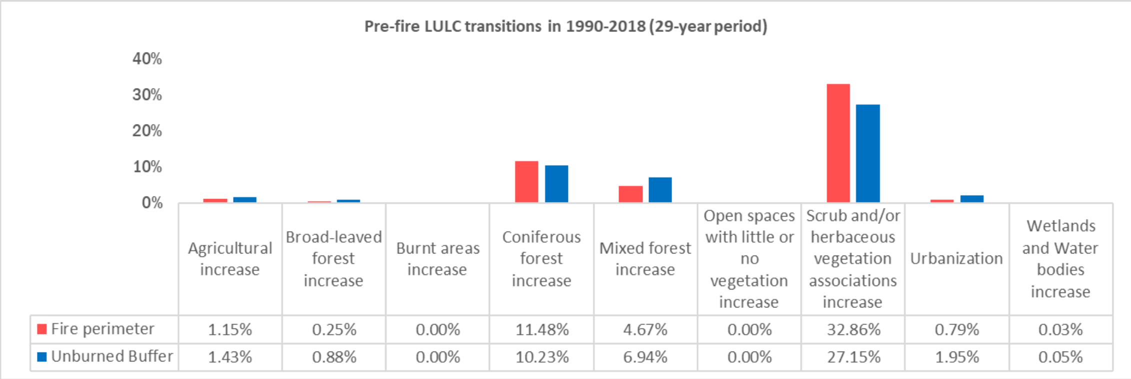


	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%	4.4%	0.7%	0.0%
Unburned Buffer	3.2%	0.8%	0.0%	0.0%	0.0%	0.0%	2.3%	0.7%	0.0%



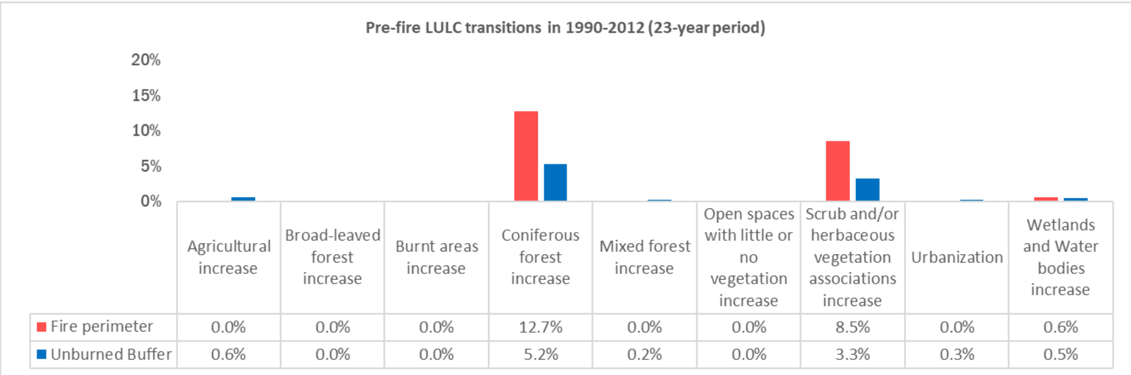
	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	15.66%	2.83%	0.24%	0.04%	0.13%	5.59%	2.14%	0.09%	0.00%
Unburned Buffer	14.86%	3.81%	0.20%	0.50%	1.39%	5.38%	2.65%	0.27%	0.00%

Figure 15. Pre-fire LULC transitions in Italy for outliers in fire size and unburned buffers in 1990-2007 (N =1, reported with extreme behaviour) and 1990-2018 (N=2).



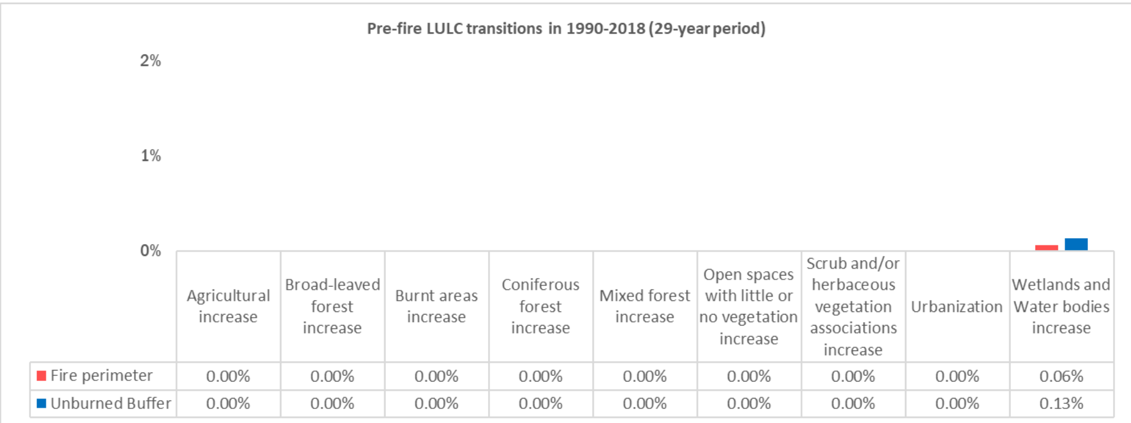
	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	1.15%	0.25%	0.00%	11.48%	4.67%	0.00%	32.86%	0.79%	0.03%
Unburned Buffer	1.43%	0.88%	0.00%	10.23%	6.94%	0.00%	27.15%	1.95%	0.05%

Figure 16. Pre-fire LULC transitions in France for outliers in fire size and unburned buffers in 1990-2018 (N = 2).



	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	0.0%	0.0%	0.0%	12.7%	0.0%	0.0%	8.5%	0.0%	0.6%
Unburned Buffer	0.6%	0.0%	0.0%	5.2%	0.2%	0.0%	3.3%	0.3%	0.5%

Figure 17. Pre-fire LULC transitions in Sweden for outliers in fire size and unburned buffers in 1990-2012 (N = 1).



	Agricultural increase	Broad-leaved forest increase	Burnt areas increase	Coniferous forest increase	Mixed forest increase	Open spaces with little or no vegetation increase	Scrub and/or herbaceous vegetation associations increase	Urbanization	Wetlands and Water bodies increase
Fire perimeter	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.06%
Unburned Buffer	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.13%

Figure 18. Pre-fire LULC transitions in Romania for outliers in fire size and unburned buffers in 1990-2018 (N = 2).

Pre-fire landscape configuration of EWE and unburned buffers

We clipped Corine Land Cover data (in vector format) with the 137 EWE perimeters (shapefiles) selected and compiled into the database. Afterwards, we used the Plugin V-LATE 2.0 (Vector-based landscape analysis tools) for ArcGis to calculate pre-fire landscape metrics for EWE perimeters and corresponding unburned buffers, as shown in Table 6. V-LATE was developed within the SPIN project (Contract No. EVG2-2000-0512, founded by the 5th EU Framework Program (Lang and Tiede 2003).

Table 6. Pre-fire landscape metrics quantified for burned (EWE) and unburned perimeters.

Metrics used		Description
Land cover diversity	Shannon diversity index	A measure of the diversity of land cover classes. The index value increases with the number of land cover types
	Richness (number)	A count of the number of distinct land cover classes
Patch size distribution	Mean patch size (ha)	The average size of all patches for each land cover class
Edge metrics	Edge density between wildland areas and urban areas (Wildland-Urban interface) (m/ha)	The edge-to-area ratio for selected land cover classes (Wildland areas include the classes: "Broad-leaved forest, Coniferous forest, Mixed forest, and Scrub and/or herbaceous vegetation associations"; Urban areas include the class "Artificial surfaces")

Table 7 shows the land cover diversity of the pre-fire landscape for burned perimeters (EWE) and surrounding unburned buffers, per period of analysis (CLC) and country. Results are very consistent across periods and among countries and show that land cover diversity is always higher in unburned areas, in agreement with several studies that show that landscape heterogeneity and land cover diversity hinder fire propagation and promote fire-resilient territories (Viedma et al. 2009; Loepfe et al. 2010; Duane et al. 2021; Rego et al. 2021).

Table 8 shows the mean patch size for each LULC class considered, for burned perimeters (EWE) and surrounding unburned buffers, per period of analysis (CLC) and country. Minimum and maximum patch size values are shown in Annex 6. A very consistent result is that the mean patch size of agricultural land is larger within unburned buffers than within burned perimeters, for all countries and EWE selected, indicating that larger areas of agricultural land promote fire resistant landscapes. The only exception is the large wildfire with extreme fire behaviour that occurred in 2009 in Italy (Sardinia, Bonorva´s fire), which burned 9500 ha of wooded and herbaceous pastures, in association with strong winds and hot temperatures (Salis et al. 2012). Minimum patch size of agricultural land in the pre-fire landscape of unburned perimeters was about 30 ha (Annex 6).

Results also show smaller patches (on average) of artificial surfaces (e.g., houses) in the pre-fire landscape of burned perimeters, consistently across southern European countries (Portugal, Spain, Greece, France and Italy), with few exceptions, which indicates higher fragmentation of artificial cover and higher wildland-urban interface (see also comments regarding Table 9).

Considering the mean patch size of coniferous forest areas, results are variable among countries. On the other hand, the mean patch size of broadleaved and mixed forests is larger within unburned perimeters than burned ones, for most countries and EWE, although with some exceptions. Note that CLC groups broadleaved forests as a unique class, which includes not only native species such as oaks but also exotic species such as eucalypts, which hinders the discussion of results. Nevertheless, in general, broadleaved species seem to promote fire resistant landscapes across Europe.

As for scrub/herbaceous vegetation, results are also variable across countries and EWE analysed. Burnt areas are usually larger within unburned perimeters, particularly in southern European countries (e.g., Portugal, Spain and Greece), indicating a lower likelihood of these areas to burn again.

Wetlands mean patch size was always smaller within burned perimeters, for all countries. This result is particularly interesting regarding northern countries (Netherlands, Ireland, Latvia and Norway) where the area occupied by peatbogs in the pre-fire landscape was higher within fire perimeters (see section 3.4.). Hence, smaller patches of peatbogs (on average) within burned perimeters in comparison to surrounding unburned buffers, indicate that peatbogs were more fragmented where fires developed.

Table 9 shows the Wildland-Urban interface (WUI) quantified as the edge density (m/ha) between wildland areas (forest/scrub LULC classes) and urban areas (artificial surfaces) of the pre-fire landscape, for fire perimeters (EWE) and corresponding unburned buffers in 1990-2018. Note that there is no WUI in most northern and central European countries due to the absence of artificial surfaces in the pre-fire landscape of burned perimeters.

On the other hand, WUI is common in the rural and forest landscapes of southern European countries, where it has been often associated with wildfire development and magnitude of impacts (Bento-Gonçalves and Vieira 2019). Indeed, our results for these countries show that maximum WUI values are higher in burned perimeters than in unburned ones, indicating a higher edge density between artificial and forest/scrubland areas in the pre-fire landscape of EWE analysed, in comparison to unburned buffers, although observed differences were small. Median WUI values did not show a pattern as consistent as for maximum WUI values, with differences between burned and unburned perimeters varying among southern countries

Table 7. Land cover diversity (Shannon diversity index and number of classes) of the pre-fire landscape of fire perimeters (EWE) and corresponding unburned buffers in 1990-2018 (values are shown as minimum, maximum and median per country and CLC year; N = number of fires selected and considered in the analysis).

			EWE						Unburned Buffer					
		N	Shannon diversity index			Richness (number of classes)			Shannon diversity index			Richness (number of classes)		
CLC	Country		Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median
1990	GR	3	0.68	1.34	1.13	4.00	7.00	7.00	0.98	1.57	1.25	6.00	8.00	8.00
	PT	1	0.88	0.88	-	6.00	6.00	-	1.05	1.05	-	6.00	6.00	-
2000	CR	1	0.90	0.90	-	4.00	4.00	-	1.24	1.24	-	6.00	6.00	-
	FR	2	0.97	1.06	1.01	6.00	6.00	6.00	1.43	1.46	1.44	7.00	7.00	7.00
	GR	7	0.71	1.35	1.26	4.00	8.00	6.00	0.89	1.42	1.28	6.00	8.00	7.00
	IT	5	0.54	1.33	1.12	4.00	7.00	5.00	0.54	1.42	1.15	4.00	7.00	6.00
	PT	13	0.71	1.54	1.03	3.00	8.00	7.00	0.78	1.64	1.13	4.00	9.00	7.00
	SP	10	0.56	1.13	0.89	3.00	7.00	5.00	0.77	1.42	1.06	4.00	7.00	6.00
2006	GR	3	1.00	1.18	1.03	4.00	8.00	6.00	1.23	1.48	1.33	6.00	8.00	6.00
	IT	1	0.31	0.31	-	3.00	3.00	-	0.42	0.42	-	4.00	4.00	-
	NO	1	0.64	0.64	-	4.00	4.00	-	0.59	0.59	-	4.00	4.00	-
	PT	2	1.06	1.12	1.09	6.00	7.00	6.50	1.10	1.16	1.13	6.00	7.00	6.50
	SP	7	0.62	1.45	0.98	4.00	8.00	6.00	0.89	1.55	1.25	5.00	9.00	7.00
2012	CY	1	0.38	0.38	-	3.00	3.00	-	0.64	0.64	-	4.00	4.00	-
	FR	1	1.18	1.18	-	5.00	5.00	-	1.27	1.27	-	5.00	5.00	-
	IR	3	0.33	0.45	0.41	3.00	4.00	4.00	0.57	0.68	0.64	4.00	5.00	4.00
	PT	24	0.78	1.69	1.13	5.00	8.00	7.00	0.87	1.70	1.36	6.00	9.00	7.00
	SP	6	0.76	1.43	1.04	4.00	8.00	7.00	0.90	1.50	1.23	5.00	9.00	8.00
	SW	5	0.47	0.98	0.69	3.00	5.00	3.00	0.72	0.99	0.85	3.00	7.00	3.00
2018	AU	1	0.99	0.99	-	3.00	3.00	-	1.16	1.16	-	5.00	5.00	-
	CZ	1	0.63	0.63	-	4.00	4.00	-	1.07	1.07	-	6.00	6.00	-
	CY	1	1.11	1.11	-	5.00	5.00	-	1.15	1.15	-	5.00	5.00	-
	FR	4	0.49	1.11	1.08	6.00	7.00	6.50	1.20	1.46	1.31	6.00	7.00	6.50
	GR	6	0.97	1.68	1.07	4.00	8.00	6.00	1.07	1.72	1.19	6.00	9.00	8.00
	IT	2	1.07	1.16	1.12	6.00	7.00	6.50	1.25	1.32	1.29	7.00	9.00	8.00
	LV	1	0.28	0.28	-	2.00	2.00	-	0.47	0.47	-	2.00	2.00	-
	NL	1	0.59	0.59	-	3.00	3.00	-	1.03	1.03	-	3.00	3.00	-
	PT	6	0.69	1.36	0.88	4.00	7.00	5.00	0.86	1.38	0.96	6.00	9.00	6.50
	RO	4	0.00	0.58	0.17	1.00	3.00	2.50	0.18	0.74	0.28	3.00	4.00	4.00
	SL	1	1.34	1.34	-	5.00	5.00	-	1.47	1.47	-	7.00	7.00	-
	SP	13	0.83	1.29	1.13	5.00	9.00	7.00	1.03	1.47	1.23	6.00	9.00	7.00
	Total	137												

Country codes: AU – Austria, CR – Croatia, CY – Cyprus, CZ – Czech Republic, FR – France, GR – Greece, IR – Ireland, IT – Italy, LV – Latvia, NL – Netherlands, NO – Norway, PT – Portugal, RO – Romania, SL – Slovenia, SP – Spain, SW – Sweden.

Table 8. Mean patch size (hectares) of pre-fire LULC classes for EWE and corresponding unburned buffers in 1990-2018 (shown as median values per country and CLC year) (N = number of fires selected and considered in the analysis; NA: the LULC class is absent)

			EWE								Unburned Buffer							
CLC	**Country**	**N**	**Agric. lands**	**Artif. surf.**	**Conif. forest**	**Broadl. forest**	**Mixed forest**	**Scrub/ Herb**	**Burnt areas**	**Wetl.**	**Agric. lands**	**Artif. surf.**	**Conif. forest**	**Broadl. forest**	**Mixed forest**	**Scrub/ Herb**	**Burnt areas**	**Wetl.**
1990	**GR**	**3**	97.45	20.92	317.22	84.10	41.68	118.38	NA	0.17	132.18	42.18	130.78	105.73	61.75	111.75	NA	2804.43
	PT	**1**	17.87	2.60	264.89	NA	97.48	404.26	NA	NA	34.64	30.86	422.88	NA	150.58	408.03	80.60	NA
2000	**CR**	**1**	49.91	NA	6.84	NA	NA	100.69	NA	NA	70.29	14.10	100.54	NA	NA	144.49	NA	55.29
	FR	**2**	38.27	25.93	38.23	59.30	786.09	286.53	NA	0.91	80.24	96.85	40.03	119.77	671.03	304.28	77.27	492.95
	GR	**7**	182.73	99.20	155.41	196.19	123.25	274.07	5.45	67.83	214.79	49.75	138.23	137.70	145.18	249.93	64.30	561.53
	IT	**5**	156.18	5.35	46.33	79.99	69.87	134.92	NA	NA	157.57	21.69	29.79	146.67	95.37	150.99	NA	NA
	PT	**13**	32.06	4.75	144.08	119.69	83.99	174.48	70.56	56.76	66.53	37.28	130.97	172.44	130.92	211.47	118.38	166.37
	SP	**10**	56.73	5.78	621.58	36.44	171.37	273.39	32.68	2.70	148.81	28.22	440.82	86.94	184.20	338.41	68.21	32.93
2006	**GR**	**3**	70.71	0.86	135.09	NA	67.42	170.30	111.45	26.80	105.81	47.23	182.15	NA	149.17	268.16	111.45	1051.12
	IT	**1**	409.34	19.78	NA	NA	NA	98.62	NA	NA	369.70	40.18	NA	52.99	NA	125.91	NA	NA
	NO	**1**	4.29	NA	2153.45	NA	NA	113.42	NA	68.60	26.13	NA	4572.96	NA	NA	40.16	NA	81.31
	PT	**2**	99.11	0.45	52.22	169.85	207.77	286.14	0.004	NA	145.28	42.06	50.47	175.66	214.02	298.83	0.004	NA
	SP	**7**	44.17	26.06	249.21	93.72	58.29	204.13	201.35	56.73	75.47	25.79	212.50	90.53	70.35	188.41	608.92	171.03
2012	**CY**	**1**	7.76	NA	854.63	NA	NA	221.63	NA	NA	56.93	33.49	1584.93	NA	NA	109.05	NA	NA
	FR	**1**	36.70	40.64	87.73	NA	45.56	350.64	NA	NA	40.89	112.11	77.12	NA	90.89	331.22	NA	NA
	IR	**3**	9.70	NA	8.46	NA	26.79	67.65	NA	1902.66	32.29	NA	21.76	NA	87.03	101.29	NA	3534.44
	PT	**24**	43.36	26.18	145.28	89.25	104.72	253.02	38.94	49.38	76.55	44.23	165.61	93.59	134.58	251.94	42.74	347.52
	SP	**6**	32.20	9.60	117.50	142.77	55.42	134.58	26.44	14.81	74.63	39.24	140.69	112.14	35.03	136.45	25.02	115.64
	SW	**5**	5.03	NA	2721.42	NA	4.54	53.52	NA	58.14	59.17	31.16	2579.93	26.27	43.05	52.23	NA	72.17
2018	**AU**	**1**	NA	NA	38.82	NA	21.41	NA	NA	NA	0.03	3.60	62.61	NA	43.31	NA	NA	NA
	CZ	**1**	0.45	NA	532.30	19.34	87.79	NA	NA	NA	32.00	11.76	907.27	92.14	96.40	NA	NA	28.00
	CY	**1**	128.24	11.32	390.69	4.49	NA	222.76	NA	NA	166.67	26.78	798.50	33.42	NA	350.87	NA	NA
	FR	**4**	29.30	20.06	272.02	55.69	49.41	177.35	NA	10.64	56.79	90.07	316.03	108.68	86.56	146.83	NA	57.78
	GR	**6**	125.44	37.64	224.86	155.18	233.92	176.96	61.20	17.96	155.96	54.38	254.64	179.91	234.90	208.46	72.58	336.00
	IT	**2**	360.26	7.62	43.14	215.57	15.08	314.12	32.47	NA	419.49	41.69	112.12	346.56	238.03	360.33	54.36	299.66
	LV	**1**	NA	NA	NA	NA	NA	NA	NA	104.15	NA	NA	NA	NA	NA	NA	NA	186.19
	NL	**1**	5.04	NA	NA	44.97	NA	NA	NA	252.11	95.18	NA	NA	87.06	NA	NA	NA	332.33
	PT	**6**	46.28	6.39	84.62	67.64	92.11	288.29	11.63	NA	74.73	24.14	122.51	114.79	120.77	262.81	38.83	0.51
	RO	**4**	NA	NA	NA	54.18	NA	78.93	NA	1454.21	984.98	NA	NA	47.43	NA	126.96	NA	1549.97
	SL	**1**	21.25	NA	78.73	464.76	92.90	125.97	NA	NA	55.49	21.60	54.60	601.43	90.50	85.72	NA	NA
	SP	**13**	59.94	10.95	176.38	78.84	56.53	198.60	55.40	9.79	100.96	30.56	202.93	143.73	68.00	221.47	58.84	128.74
	Total	137																

Country codes: AU – Austria, CR – Croatia, CY – Cyprus, CZ – Czech Republic, FR – France, GR – Greece, IR – Ireland, IT – Italy, LV – Latvia, NL – Netherlands, NO – Norway, PT – Portugal, RO – Romania, SL – Slovenia, SP – Spain, SW – Sweden.

Table 9. Wildland-Urban interface: edge density between wildland areas (forest/scrub LULC classes) and urban areas (artificial surfaces) (m/ha) of the pre-fire landscape, for fire perimeters (EWE) and corresponding unburned buffers in 1990-2018 (values are shown as minimum, maximum and median per country and CLC year; N = number of fires selected and considered in the analysis).

			EWE			Unburned Buffer		
			Edge Density (m/ha)			Edge Density (m/ha)		
CLC	**Country**	**N**	**Min**	**Max**	**Median**	**Min**	**Max**	**Median**
1990	**GR**	**3**	0.00	96.92	0.00	46.65	88.19	59.74
	PT	**1**	44.61	44.61	NA	35.55	35.55	NA
2000	**CR**	**1**	0.00	0.00	NA	54.68	54.68	NA
	FR	**2**	34.06	56.70	45.38	35.40	50.28	42.84
	GR	**7**	0.00	74.54	41.15	27.17	68.30	46.66
	IT	**5**	32.13	86.27	64.62	33.52	78.41	55.30
	PT	**13**	0.00	50.27	38.44	0.00	46.04	34.76
	SP	**10**	0.00	50.24	0.00	0.00	50.91	19.98
2006	**GR**	**3**	36.32	56.05	54.15	38.30	51.86	50.16
	IT	**1**	61.21	61.21	NA	61.67	61.67	NA
	NO	**1**	0.00	0.00	NA	0.00	0.00	NA
	PT	**2**	37.39	44.10	40.75	37.72	46.07	41.90
	SP	**7**	0.00	107.42	39.28	48.52	111.55	64.93
2012	**CY**	**1**	0.00	0.00	NA	21.48	21.48	NA
	FR	**1**	50.23	50.23	NA	50.73	50.73	NA
	IR	**3**	0.00	0.00	0.00	0.00	0.00	0.00
	PT	**24**	0.00	56.75	35.54	0.00	50.52	39.26
	SP	**6**	0.00	131.93	64.19	0.00	120.94	58.12
	SW	**5**	0.00	0.00	0.00	0.00	29.26	0.00
2018	**AU**	**1**	0.00	0.00	NA	98.92	98.92	NA
	CZ	**1**	0.00	0.00	NA	49.28	49.28	NA
	CY	**1**	42.43	42.43	NA	28.43	28.43	NA
	FR	**4**	21.52	67.66	58.76	22.99	65.39	51.38
	GR	**6**	0.00	80.47	52.27	39.37	73.90	46.33
	IT	**2**	33.43	53.79	43.61	30.48	44.61	37.55
	LV	**1**	0.00	0.00	NA	0.00	0.00	NA
	NL	**1**	0.00	0.00	NA	0.00	0.00	NA
	PT	**6**	0.00	53.87	20.31	25.64	49.73	40.76
	RO	**4**	0.00	0.00	0.00	0.00	0.00	0.00
	SL	**1**	0.00	0.00	NA	59.28	59.28	NA
	SP	**13**	0.00	84.50	56.79	42.47	79.96	61.71
	Total	137						

Country codes: AU – Austria, CR – Croatia, CY – Cyprus, CZ – Czech Republic, FR – France, GR – Greece, IR – Ireland, IT – Italy, LV – Latvia, NL – Netherlands, NO – Norway, PT – Portugal, RO – Romania, SL – Slovenia, SP – Spain, SW – Sweden.

EUROPEAN BIOGEOGRAPHICAL REGIONS: LANDSCAPE CHANGES IN 1990-2018 AND FUTURE LANDSCAPE COMPOSITION

We selected EWE that occurred in 2019-2022 from the EWE database. Selected fire perimeters were clipped with European biogeographical regions (EEA (European Environment Agency 2016, https://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-2) (shapefile formats) with ArcGIS Pro 3.0.3. Biogeographical regions in Europe are shown in Figure 19.

We built absolute and relative transition matrices with LULC changes in 1990-2018 (pre-fire) within selected fire perimeters, separately for each biogeographical region, using CLC data and the transition categories described in section 3.1. (Table 3). The elements (cells) of these matrices contain the proportions of change of each LULC class for another class, which were observed in a 29-year period (1990-2018). We can then use the observed proportions of change (probabilities) to project transitions into the future in one or more time steps of 29-years, assuming that transition probabilities are maintained over time as in a Markov chain model. A Markov chain model is a stochastic process model that describes the likelihood of one state to change to another state and uses this as the basis to project future changes (Baker 1989; Kumar et al. 2014; Keshtkar and Voigt 2016). For example, we can multiply the probabilities of the relative transition matrix by the areas (ha) of each LULC class in 2018 to obtain the areas of these classes in 2046 (t = 29), and so on into the future. We projected future LULC composition for each region for three time periods of 29-years: 2018-2046, 2046-2074 and 2074-2102.

We only considered regions where EWE perimeters occupied more than 500 ha, resulting in 5 regions, namely: Atlantic, Continental, Macaronesia, Mediterranean, and Steppic. We did not consider the region of Black Sea (which included 3 fire events in Romania that occurred after 2018) because the landscape was mostly static (dominated by wetlands, see section 3.2.) and simulations did not show any changes in time.

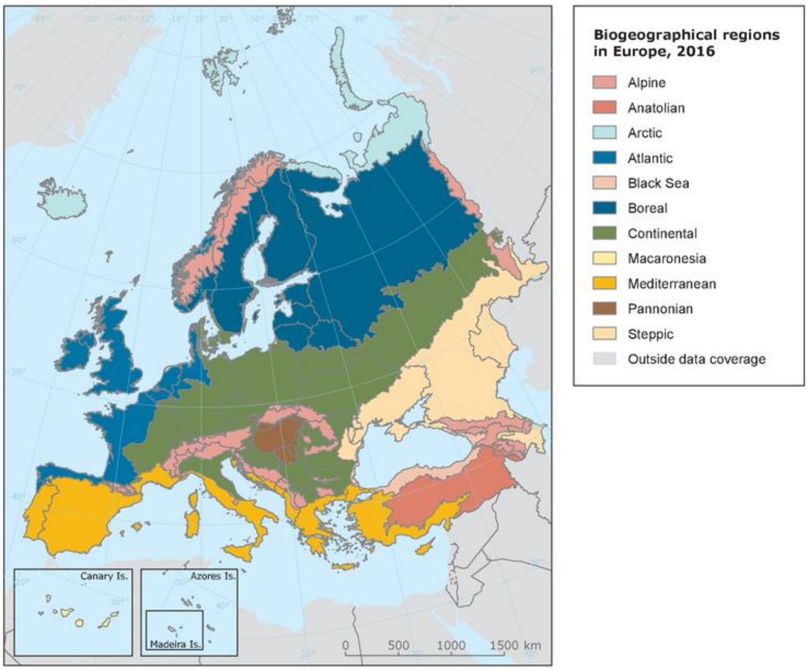


Figure 19. Biogeographical regions in Europe (European Environment Agency 2017).

Simulations are shown in Figures 20 to 24. Annex 7 shows the LULC absolute and relative transition matrices in 1990-2018 for the biogeographical regions analyzed.

Landscape changes and simulations for the Atlantic region are based on 3 fire events in France in 2022 and 1 in the Netherlands in 2020 (Figure 20). In this region, there is a sharp decrease of coniferous forests, with a large area (35%) changing into scrub/herbaceous associations in 1990-2018. Coniferous forests continue decreasing in time but with a smaller magnitude, while scrub/herbaceous associations show an initial increase in 1990-2018 (due to gains from coniferous forest area), followed by a small temporal decrease. On the contrary, agricultural land, artificial surfaces and mixed forests increase throughout the analyzed time periods.

The Continental region (based on two fire events in 2022, one in Czech Republic and one in Slovenia, Figure 21) shows an increase in area of broad-leaved forest, gained from scrub/herbaceous associations in 1990-2018 (30% change, Annex 7). Scrub/herbaceous associations show an initial increase in area originated from burned areas in 1990-2018 (69%, Annex 7), but after that they decrease, while the area of broad-leaved and mixed forests increases throughout the whole period, showing a recovery of these forests over time.

Regarding the Macaronesia region (based on one fire event in 2019 in Canary Islands, Spain, Figure 22), there is an initial increase in scrub/herbaceous associations in 1990-2018, which gained area mostly from agricultural land, and in a lesser extent from coniferous and broad-leaved forests, indicating agricultural abandonment (Annex 7). From 2018 onwards, scrub/herbaceous associations decrease, while open spaces with little or no vegetation increase, indicating a loss of vegetation cover in this region. Moreover, coniferous forests decrease and broad-leaved forest practically disappear over the observation period. Agricultural areas also decrease.

Landscape changes and simulations for the Mediterranean region are based on 28 fire events in 2019-2022 in Portugal, Spain, Greece, Italy, France and Cyprus (Figure 23). The largest landscape changes in the Mediterranean region in 1990-2018 are changes from coniferous forests, agricultural land and broad-leaved forest to scrub/herbaceous associations, indicating abandonment of forest management (especially coniferous) and of agricultural land. Forest recovery is also observed, with changes from scrub/herbaceous associations into forests, but gains in scrub/herbaceous area are higher than losses. Hence, the simulation of the future landscape in this region for 2022-2102 shows a decrease in coniferous forests and agricultural areas, with an increase in scrub/herbaceous associations, which represents an increasing fire risk in the future Mediterranean landscape. Recall that the analyzes of previous sections (3.2 and 3.3) consistently show a larger area occupied by scrub/herbaceous associations in fire perimeters than in unburned buffers, observed for the pre-fire landscape of Mediterranean countries.

Finally, landscape changes and simulation of the future landscape for the Steppic region (based on 2 fire events in Romania in 2022, Figure 24) show an increase in scrub/herbaceous associations and a decrease in wetlands (inland marshes) over time, suggesting increasing dryness.

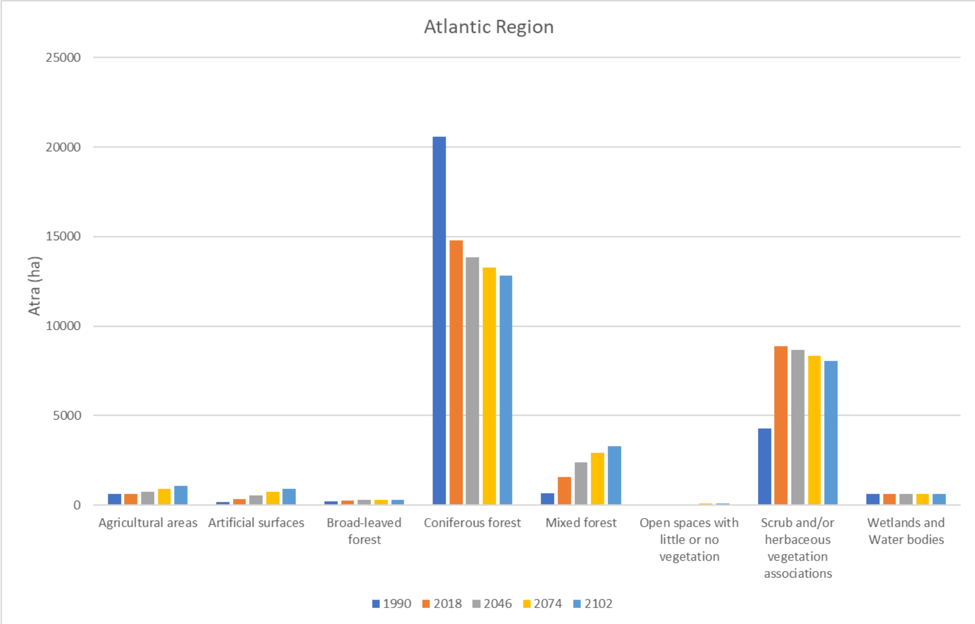


Figure 20. Simulation of future LULC composition for the Atlantic biogeographical region in Europe in 1990-2102 (based on 3 EWE in France in 2022 and 1 EWE in the Netherlands in 2020).

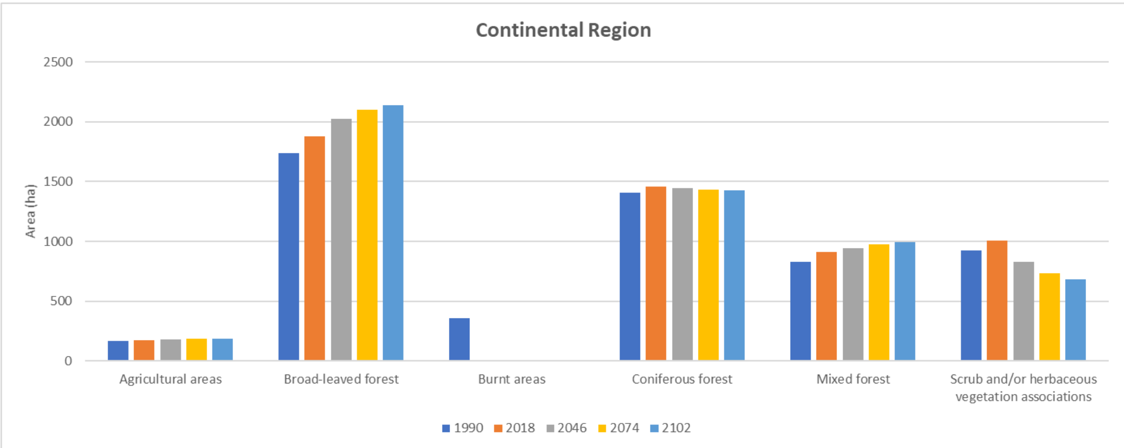


Figure 21. Simulation of future LULC composition for the Continental biogeographical region in Europe in 1990-2102 (based on 2 EWE in 2022 in Czech Republic and Slovenia).

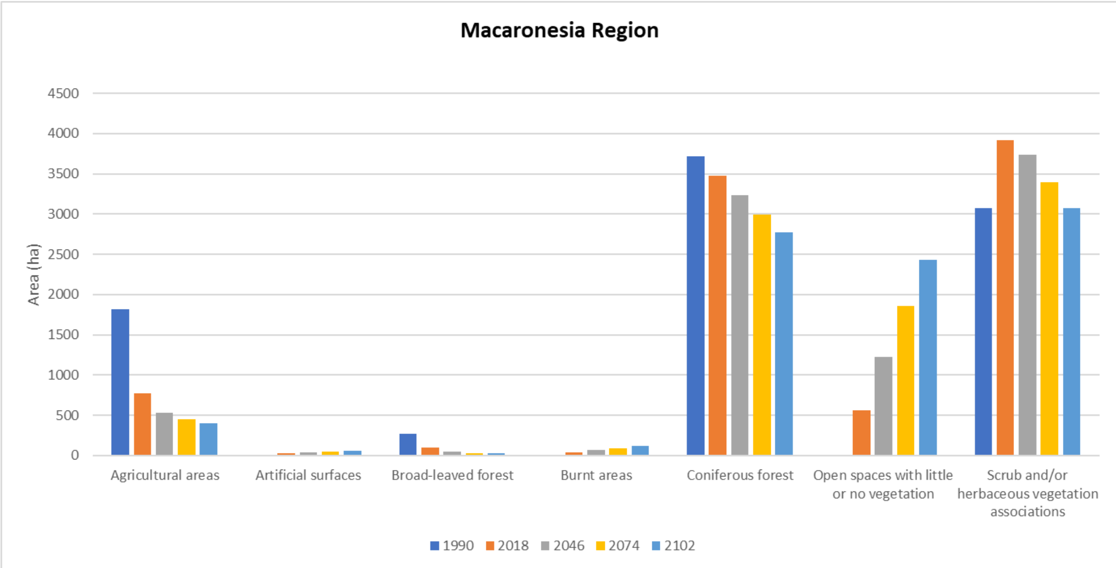


Figure 22. Simulation of future LULC composition for the Macaronesia biogeographical region in Europe in 1990-2102 (based on 1 EWE in 2019 in Spain).

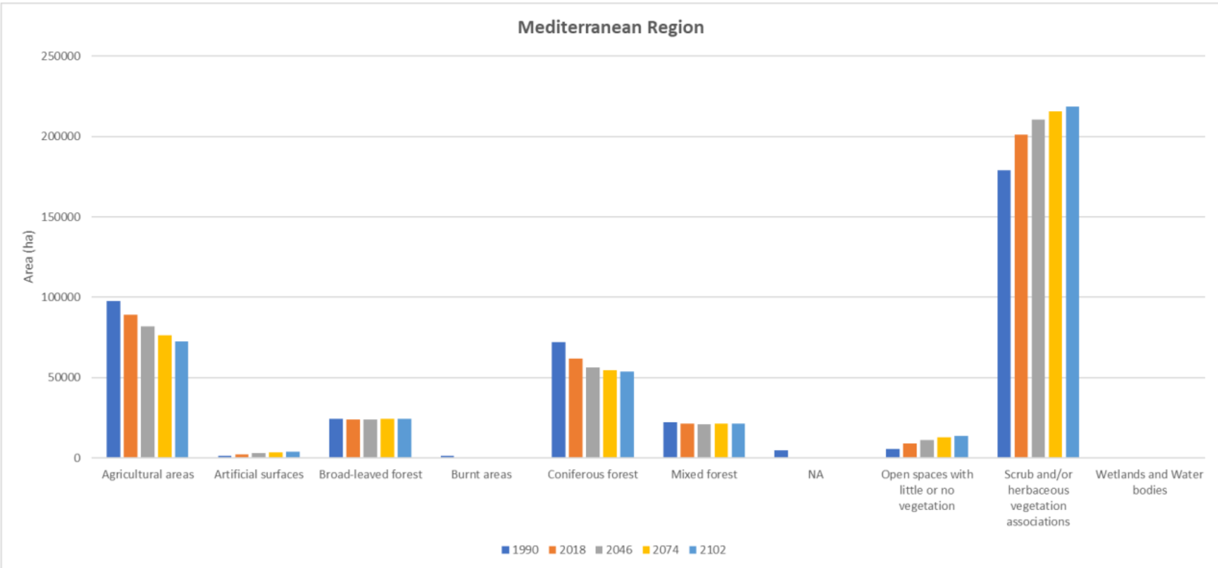


Figure 23. Simulation of future LULC composition for the Mediterranean biogeographical region in Europe in 1990-2102 (based on 28 EWE in 2019-2022 in Portugal, Spain, Greece, Italy, France and Cyprus).

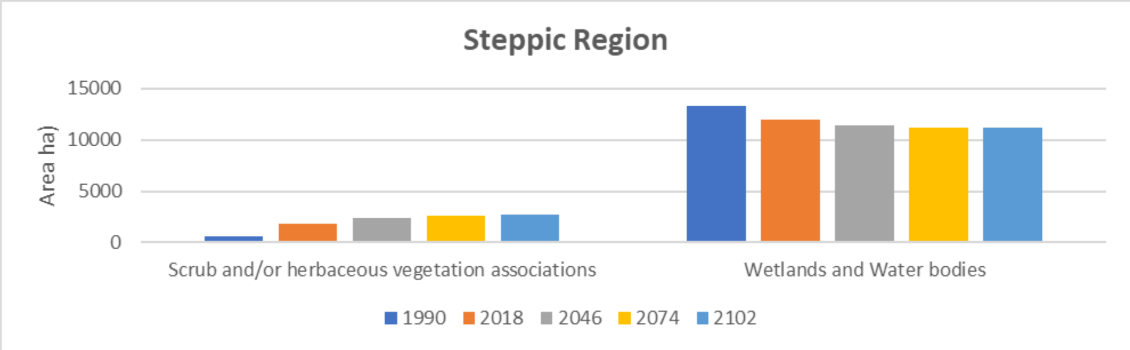


Figure 24. Simulation of future LULC composition for the Steppic biogeographical region in Europe in 1990-2102 (based on 2 EWE in 2022 in Romania).

DISCUSSION

In this report we compiled a database of 137 EWE in Europe in 2000-2022. This EWE dataset shows an increasing temporal trend, independently of the criteria used for EWE classification. As expected, EWE were more frequent in southern European countries throughout the analysed period, with the Iberian Peninsula showing the highest number of EWE classified as statistical anomalies in terms of fire size at the European scale. Nevertheless, EWE classified as historical anomalies at the national scale started to occur in the most recent years in northern and central European regions, which lacked a traditional fire history. This database shows that the occurrence of extreme wildfires has increased in time and is expanding northwards in Europe. The database will continue to be completed and revised along the project development and will serve as a work basis for the construction of fire regime models, landscape management models and decision support systems.

We found consistent patterns across countries and EWE selected regarding pre-fire landscape composition and configuration. In most of the cases, unburned perimeters presented a larger area occupied by agricultural land, artificial surfaces and wetlands (except peatbogs), in comparison to burned perimeters, with the largest differences for agricultural land. In addition, unburned perimeters presented larger patches (on average) of agricultural areas, for all countries and EWE selected. Indeed, the development of mosaic-landscapes with patches of agricultural land has been pointed out as an important strategy to promote fire-resistant and resilient landscapes, particularly in Mediterranean regions (Moreira and Pe'er 2018; Lecina-Diaz et al. 2023).

On the other hand, pre-fire landscape composition of burned perimeters presented a larger area of scrub/herbaceous vegetation than surrounding unburned buffers for southern European regions, especially for France and Portugal. In addition, the increase of scrub/herbaceous vegetation was the greatest LULC change in the pre-fire landscape of burned perimeters for Portugal, Spain and France. Thus, along with the development of mosaic-landscapes with agricultural land, management of understory fuel at the landscape-scale is clearly an important EWE prevention strategy in Mediterranean conditions, as shown by our results and by numerous studies (Fernandes 2013; Alcasena et al. 2019; Moreira et al. 2020), and described by Deliverable 1.11 of FIRE-RES project (Valor et al. 2023). However, in marginal areas of southern Europe, fuel management is often limited by economic sustainability, and "fire-smart" solutions for fuel management should be studied and developed, particularly under the EU Green Deal (www.consilium.europa.eu/en/policies/green-deal/) (Ascoli et al. 2023; Lecina-Diaz et al. 2023).

Our results also indicate a higher wildland-urban interface in the pre-fire landscape of most burned perimeters in comparison to surrounding unburned areas (despite small differences) for southern European countries (Portugal, Spain, Greece, France and Italy), while this interface was generally absent in burned areas of northern and central European countries. The interface of wildland and urban areas has been often associated with the development of large and extreme fires, sometimes with great human impacts, not only in southern Europe, but also in other regions with Mediterranean climate (e.g., Chile and California) (Radeloff et al. 2018; Bento-Gonçalves and Vieira 2019; Ganteaume et al. 2021), where numerous houses are exposed to extreme wildfire conditions, overwhelming firefighting resources and reducing fire protection effectiveness (Cohen 2008).

Interestingly, in northern European countries including The Netherlands, Ireland, Latvia and Norway, burned perimeters presented a larger area occupied by peatbogs than surrounding unburned buffers. This result clearly shows that peatbogs are becoming a landscape with increasing wildfire risk in northern Europe, due to the high flammability of dry peat soils, as peatbogs dry out from climate change (Flannigan et al. 2009; Wilkinson et al. 2018). Climate change may extend fire activity to areas that were historically weather limited and EWE may progressively shift to fuel-rich areas, if climate limitations to fire cease to exist (Duane et al. 2021). Furthermore, peatbogs were more fragmented in the pre-fire landscape of burned perimeters than in surrounding unburned areas. Peatbog fragmentation as a result of human activities (e.g. agriculture, forestry, peat harvesting and road construction) has been associated with its drainage and degradation, which can exacerbate the occurrence of large wildfires, in agreement with studies for northern European and Canadian peatlands (Turetsky et al. 2015; Granath et al. 2016; Wilkinson et al. 2018).

Analysis of landscape configuration clearly shows that land cover diversity was higher in unburned perimeters than in burned areas, consistently for the 137 EWE analysed, indicating that higher landscape diversity may enhance landscape resistance to EWE, in agreement with other studies (Viedma et al. 2009; Loepfe et al. 2010; Duane et al. 2021; Rego et al. 2021). Nevertheless, land cover diversity may also result from other natural factors (e.g., topography) that play a major role in fire propagation, but that were not considered in our analyses.

Projections of future landscapes show an increase of mixed and broadleaved forests in the Atlantic and Continental regions. On the other hand, in the Macaronesia region, projections show loss of forests and an increase of open spaces with little or no vegetation. In the Mediterranean region, future projections show an increase of scrub/herbaceous associations in the landscape, which represents an increasing fire risk considering that scrub formations were associated with EWE occurrence in the Mediterranean landscape. The Steppic region also shows an increase in scrub/herbaceous associations and a decrease in wetlands (inland marshes), suggesting increasing dryness. In agreement with our results, several studies predict scrubland expansion (particularly of pyrophytic species) and forest loss for the Mediterranean region due to a decrease in fuel moisture levels and increased aridity, as a result of climate change (Fernandes 2013; de Rigo et al. 2017; Peñuelas et al. 2017), which will enhance the risk of EWE in this region. Landscape-scale fuel management and fire-smart silviculture will therefore become critical components of forest management (Fernandes 2013). Moreover, under climate change, areas exhibiting low moisture are predicted to extend further northwards from the Mediterranean, which may enhance peatbog drying and increase the risk of EWE in temperate and boreal forests (Grünig et al. 2023).

The present deliverable shows that LULC structure is associated with EWE occurrence, beyond the major role of weather and climate drivers. Nonetheless, it is necessary to improve understanding on the interactions between LULC patterns, weather conditions, and other landscape physical attributes for EWE occurrence, particularly under climate change scenarios (de Rigo et al. 2017). In this regard, the present deliverable is a stepping stone for future studies.

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ANNEXES

Annex 1. Outliers in fire size at the European scale in 2000-2022 based on the probability of fire size being less than 0.001 (0.1%), listed by decreasing global z value.

Fire ID (EFFIS spatial database)	Fire date*	Country	Province**	Fire size (ha)	Global z value
10170	14-Oct-2017	PT	Viseu Dão Lafões	67521	4.5
10293	15-Oct-2017	PT	Região de Coimbra	64321	4.47
32245	2003	PT	Beira Baixa	59156	4.41
32349	2003	PT	Médio Tejo	53568	4.35
32825	2003	PT	Algarve	52233	4.34
213578	3-Aug-2021	EL	NA	51881	4.33
37655	24-Aug-2007	EL	NA	45809	4.25
36821	24-Aug-2007	EL	NA	42652	4.21
38429	24-Aug-2007	EL	NA	42350	4.2
12120	23-Jul-2017	PT	Médio Tejo	35575	4.1
10165	15-Oct-2017	PT	Região de Coimbra	34844	4.08
33173	2004	ES	Huelva	33179	4.05
3320	28-Jun-2012	ES	Valencia	32424	4.04
206474	17-Jul-2022	ES	Zamora	32528	4.04
585	17-Jun-2017	PT	Região de Leiria	29819	3.98
203513	16-Jun-2022	ES	Zamora	28046	3.95
14031	3-Aug-2018	PT	Algarve	27635	3.94
32941	2004	PT	Algarve	27802	3.94
888	8-Aug-2016	PT	Área Metropolitana do Porto	26593	3.91
7012	18-07-2012	PT	Algarve	26442	3.91
11818	15-Oct-2017	PT	Região de Coimbra	24183	3.85
52448	14-Aug-2021	ES	Ávila	23078	3.82
7353	30-Jun-2012	ES	Valencia	21762	3.79
36885	24-Aug-2007	EL	NA	20681	3.76
2583	22-Aug-2009	EL	NA	20521	3.75

209196	15-Aug-2022	ES	Castellón	19362	3.71
11041	15-Oct-2017	PT	Região de Leiria	18900	3.7
35215	2005	PT	Beiras e Serra da Estrela	18730	3.69
52249	4-Aug-2021	EL	NA	18400	3.68
35327	2005	PT	Região de Coimbra	17527	3.65
11033	18-Jun-2017	PT	Região de Coimbra	16950	3.63
42771	27-Aug-2020	ES	Huelva	16758	3.62
27429	2000	EL	NA	16488	3.61
36845	25-Aug-2007	EL	NA	16450	3.61
43873	13-Sep-2020	PT	Beira Baixa	15536	3.58
37355	28-07-2007	ES	Gran Canaria	15362	3.57
5736	08-Jul-2013	PT	Terras de Trás-os-Montes	15015	3.56
6802	22-Jul-2012	ES	Girona	15026	3.56
8783	18-Aug-2012	EL	NA	15201	3.56
13131	16-Aug-2017	PT	Médio Tejo	15023	3.56
33447	2004	PT	Algarve	15178	3.56
209050	6-Aug-2022	PT	Beiras e Serra da Estrela	15134	3.56
34867	2005	PT	Área Metropolitana do Porto	14984	3.55
707	04-Jul-2015	ES	Zaragoza	14615	3.54
37415	29-Jul-2007	ES	Tenerife	14648	3.54
206784	18-Jul-2022	ES	Zaragoza	14159	3.52
36713	25-Jul-2007	EL	NA	13500	3.49
206702	14-Jul-2022	ES	Lugo	13612	3.49
34991	2005	ES	Guadalajara	13401	3.48
50908	24-Jul-2021	IT	Bonarcado	13278	3.48
39291	22-Jul-2008	EL	NA	13117	3.47
206257	07-Jul-2022	FR	Gironde	13116	3.47
205334	11-Jul-2022	ES	Cáceres	12687	3.45
206648	15-Jul-2022	ES	Ourense	12735	3.45
466	31-Jul-2014	SE	VÃ¤stmanlands lÃ¤n	12484	3.44
32705	2003	ES	Cáceres	12428	3.44
27727	2000	EL	NA	12303	3.43
31931	2003	FR	Var	12273	3.43
209382	13-Aug-2022	ES	Alicante	12111	3.42
6377	19-Aug-2012	ES	León	11954	3.41
32603	2003	ES	Cáceres	11986	3.41

1618	23-Jul-2009	IT	Mores	11550	3.39
36887	24-Aug-2007	EL	NA	11357	3.38
51932	3-Aug-2021	EL	NA	11209	3.37
10941	21-Aug-2017	ES	León	10927	3.36
11573	15-Oct-2017	PT	Beiras e Serra da Estrela	10701	3.34
11942	25-Jun-2017	ES	Huelva	10375	3.32
12221	13-Aug-2017	PT	Médio Tejo	10282	3.32
16093	10-Mar-2019	RO	Tulcea	10216	3.31
54081	16-Aug-2021	EL	NA	10175	3.31
209560	15-Aug-2022	PT	Beiras e Serra da Estrela	10126	3.31
18351	20-Jul-2019	PT	Médio Tejo	9924	3.3
246	06-Jul-2015	ES	Jaén	9876	3.29
2273	30-Aug-2009	PT	Beiras e Serra da Estrela	9841	3.29
11511	15-Oct-2017	PT	Viseu DÃ£o LafÃµes	9881	3.29
32395	2003	PT	Beiras e Serra da Estrela	9898	3.29
52155	4-Aug-2021	IT	Palermo	9778	3.29
35351	2005	PT	Alto Minho	9613	3.28
13580	13-Oct-2017	PT	Viseu Dão Lafões	9436	3.26
28097	2001	PT	Região de Coimbra	9330	3.26
55350	8-Sep-2021	ES	Málaga	9296	3.26
1277	8-Aug-2016	PT	Alto Minho	9224	3.25
27855	2000	EL	NA	9156	3.25
209082	14-Aug-2022	ES	Zaragoza	9195	3.25
34517	2005	PT	Região de Leiria	9075	3.24
37331	24-Jul-2007	IT	Nuoro	9062	3.24
171027	1-Aug-2003	ES	Ávila	9008	3.24
6581	30-Aug-2012	ES	Málaga	8983	3.23
11411	17-Jul-2017	PT	Beiras e Serra da Estrela	8991	3.23
16531	17-Aug-2019	ES	Gran Canaria	8867	3.23
11472	15-Oct-2017	ES	Pontevedra	8722	3.22
36255	4-Aug-2006	ES	Pontevedra	8817	3.22
183657	18-Mar-2022	RO	Tulcea	8683	3.21
11831	23-Aug-2017	PT	Beira Baixa	8478	3.2
51943	3-Aug-2021	EL	NA	8454	3.2

12302	8-Oct-2017	PT	Região de Coimbra	8372	3.19
12587	15-Oct-2017	PT	Beiras e Serra da Estrela	8424	3.19
9098	5-Aug-2015	ES	Cáceres	8237	3.18
13334	15-Oct-2017	PT	TÃ¢mega e Sousa	8253	3.18
33797	2004	ES	Jaén	8117	3.17
36981	27-Aug-2007	IT	Sindia	8049	3.17
38315	29-Aug-2007	ES	Castellón	8126	3.17
8255	8-Aug-2016	PT	Região de Aveiro	7926	3.16
37561	23-Jul-2007	IT	L´Aquila	7919	3.15
5639	23-Sep-2012	ES	Valencia	7706	3.14
206106	17-Jul-2022	PT	Alto Tâmega	7641	3.13
208962	9-Aug-2022	FR	Gironde	7566	3.13
32569	2003	PT	Lezíria do Tejo	7466	3.12
52517	16-Aug-2021	PT	Algarve	7414	3.11

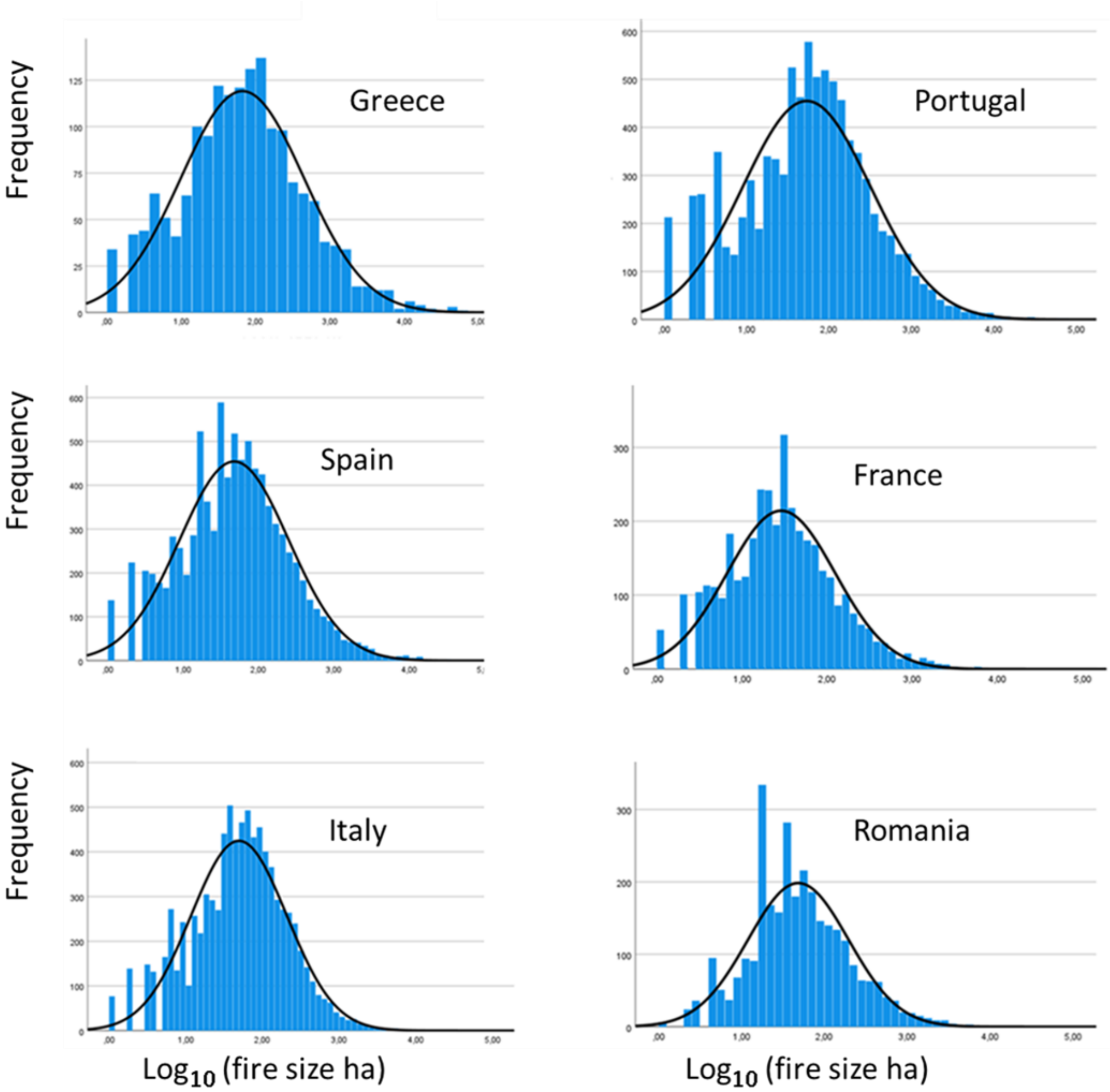
Country codes: EL – Greece, ES - Spain, FR – France, IT – Italy, PT – Portugal, RO – Romania, SE – Sweden
* Complete fire date is not available for fires before 2007 in EFFIS database
NA corresponds to names in Greek that appear as ?? in EFFIS database

Annex 2. Parameters and histograms of the lognormal distribution of fire size in 2000-2022 in European countries

Parameters of the lognormal distribution fitted for fire size in 2000-2022, per country

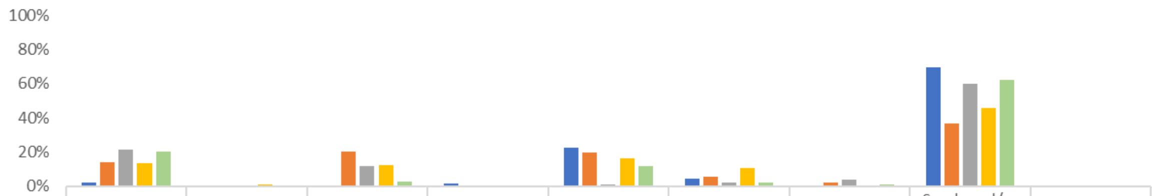
Country	Number of wildfires in the record (2000-2022)	Lognormal parameter a (mean)	Lognormal parameter b (standard deviation)
Austria	41	1.570	0.568
Belgium	29	1.814	0.491
Bulgaria	1510	1.777	0.597
Croatia	1003	1.925	0.668
Cyprus	169	1.873	0.661
Czechia	24	1.752	0.629
Denmark	84	1.202	0.649
Estonia	104	1.685	0.518
Finland	209	1.211	0.604
France	3752	1.467	0.635
Germany	255	1.253	0.648
Greece	1731	1.822	0.828
Hungary	238	1.648	0.553
Ireland	422	1.561	0.704
Italy	8636	1.693	0.624
Latvia	184	1.722	0.629
Lithuania	93	1.548	0.600
Netherlands	27	1.352	0.729
Norway	225	1.402	0.670
Poland	231	1.455	0.710
Portugal	8855	1.729	0.776
Romania	3013	1.685	0.606
Slovakia	25	1.451	0.528
Slovenia	27	1.790	0.667
Spain	9058	1.676	0.723
Sweden	290	1.314	0.757
Switzerland	9	1.431	0.518
United Kingdom	1365	1.470	0.708
Total EFFIS database	66549	1.710	0.694

Histograms representing the frequency distribution of fire size (transformed by log10) for Greece, Portugal, Spain, France, Italy and Romania (the 6 countries with higher number of wildfires recorded in 2000-2022). We can observe a general reasonable fit of the lognormal distributions



Annex 3. Pre-fire LULC composition of outliers in fire size (≥ 7400 ha) and unburned buffers by country in 1990-2018 (some with extreme behaviour, see section 3.2)

Prefire landscape composition of outliers in fire size in Portugal in 1990-2018 (N = 44, ≥ 7400 ha)



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
1990	1.9%	0.0%	0.0%	1.8%	22.7%	4.2%	0.0%	69.3%	0.0%
2000	14.0%	0.0%	20.3%	0.7%	20.0%	5.7%	2.4%	36.6%	0.4%
2006	21.2%	0.0%	11.5%	0.0%	1.0%	2.4%	3.8%	60.0%	0.0%
2012	13.2%	0.9%	12.1%	0.1%	16.4%	10.5%	0.7%	45.6%	0.6%
2018	20.1%	0.2%	2.8%	0.0%	11.6%	2.2%	1.0%	62.0%	0.0%

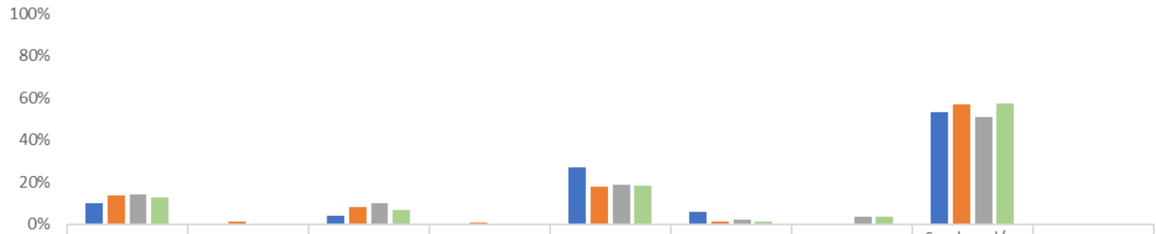
1990 2000 2006 2012 2018

Pre-fire landscape composition of unburned buffers around outliers in fire size in Portugal in 1990-2018 (N = 44, ≥ 7400 ha)

	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
1990	5.3%	0.3%	0.0%	2.6%	36.5%	7.1%	0.0%	48.2%	0.0%
2000	26.3%	1.0%	16.2%	1.2%	15.5%	5.8%	1.6%	31.5%	0.9%
2006	40.6%	0.9%	7.0%	0.0%	1.0%	3.2%	0.5%	46.9%	0.0%
2012	24.7%	2.3%	9.2%	0.1%	13.9%	11.5%	0.5%	35.5%	2.2%
2018	32.8%	0.7%	2.9%	0.3%	13.3%	3.2%	1.2%	45.6%	0.0%

1990 2000 2006 2012 2018

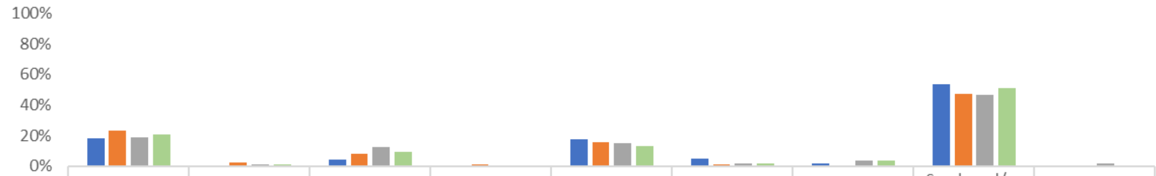
Prefire landscape composition of outliers in fire size in Spain in 2000-2018
(N = 35, ≥ 7400 ha)



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	9.8%	0.0%	3.9%	0.0%	26.8%	5.6%	0.3%	53.4%	0.0%
2006	13.4%	1.1%	8.2%	0.7%	18.0%	1.3%	0.5%	56.8%	0.1%
2012	14.3%	0.3%	10.0%	0.0%	18.9%	2.0%	3.5%	50.9%	0.0%
2018	12.8%	0.3%	6.6%	0.1%	18.4%	1.3%	3.3%	57.1%	0.1%

2000 2006 2012 2018

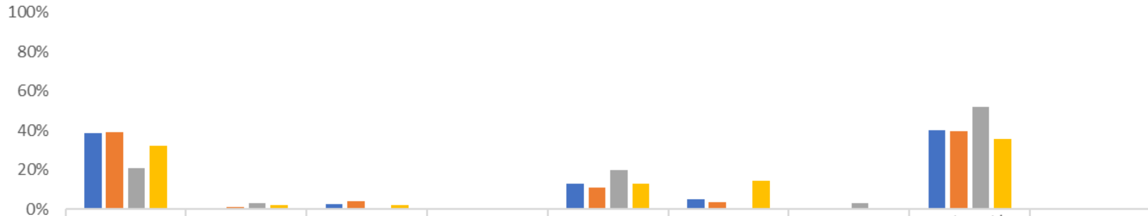
Pre-fire landscape composition of unburned buffers around outliers in fire size in Spain in 2000-2018
(N = 35, ≥ 7400 ha)



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	18.0%	0.6%	3.9%	0.0%	17.4%	4.8%	1.4%	53.8%	0.1%
2006	23.4%	2.5%	8.2%	1.0%	15.3%	1.2%	0.5%	47.5%	0.4%
2012	18.5%	1.1%	12.1%	0.1%	15.1%	1.7%	3.3%	46.4%	1.8%
2018	20.87%	1.16%	8.93%	0.04%	13.12%	1.45%	3.53%	50.68%	0.20%

2000 2006 2012 2018

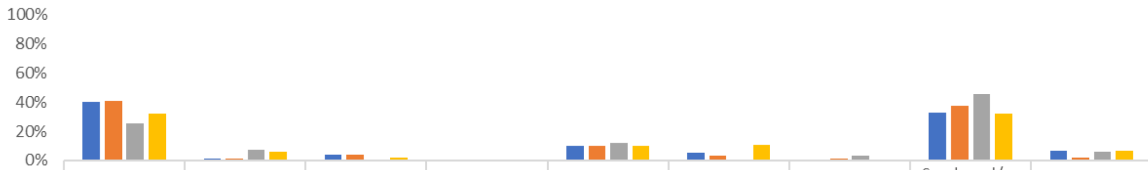
Prefire landscape composition of outliers in fire size in Greece in 1990-2018
(N = 18, ≥ 7400 ha)



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
1990	38.7%	0.3%	2.6%	0.0%	12.9%	5.0%	0.3%	40.2%	0.0%
2000	39.2%	1.1%	4.2%	0.0%	11.3%	3.7%	0.5%	39.9%	0.1%
2006	21.0%	3.2%	0.0%	0.2%	20.0%	0.2%	3.0%	52.1%	0.3%
2018	32.3%	2.3%	2.1%	0.2%	12.8%	14.5%	0.1%	35.6%	0.1%

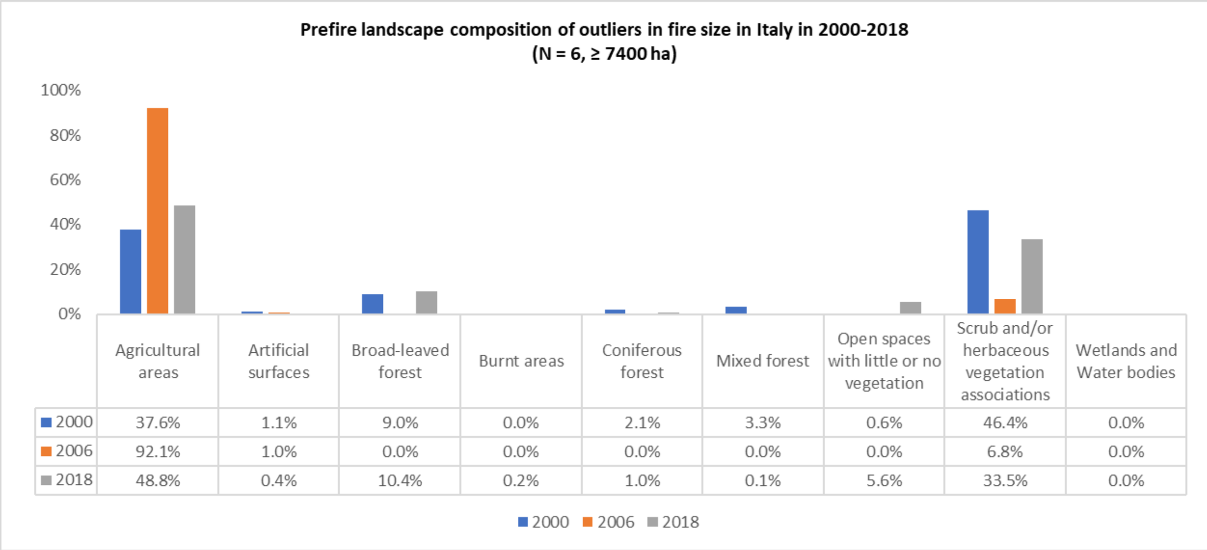
1990 2000 2006 2018

Pre-fire landscape composition of unburned buffers around outliers in fire size in Greece in 1990-2018
(N = 18, ≥ 7400 ha)

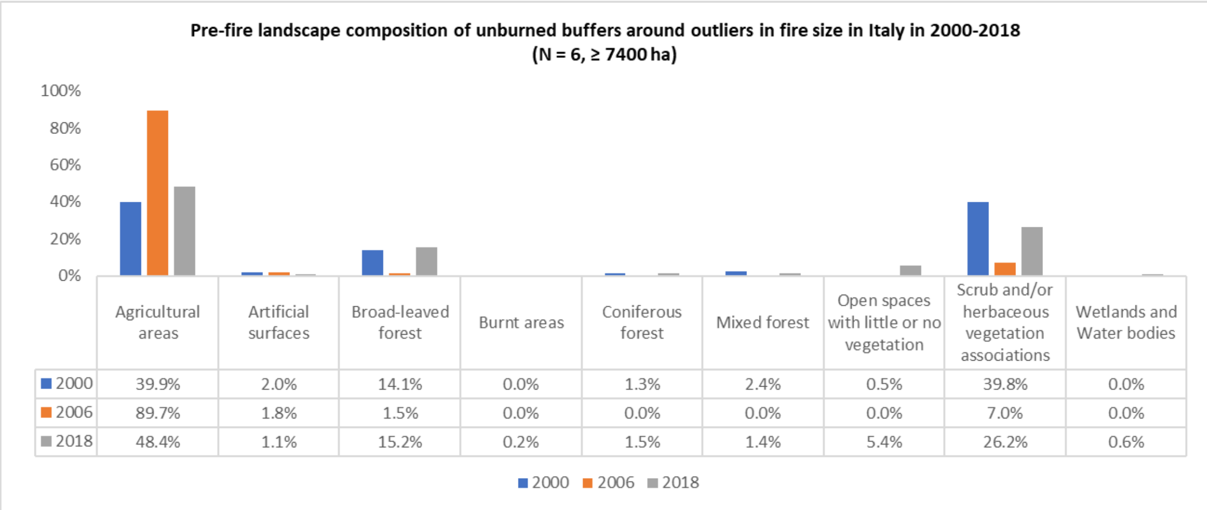


	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
1990	40.3%	1.2%	3.9%	0.0%	9.6%	5.1%	0.3%	32.8%	6.7%
2000	40.9%	1.5%	4.2%	0.0%	9.8%	3.2%	0.9%	37.6%	1.9%
2006	25.6%	7.6%	0.0%	0.1%	11.7%	0.5%	3.3%	45.5%	5.7%
2018	32.3%	5.8%	2.1%	0.5%	9.7%	10.9%	0.2%	32.0%	6.5%

1990 2000 2006 2018

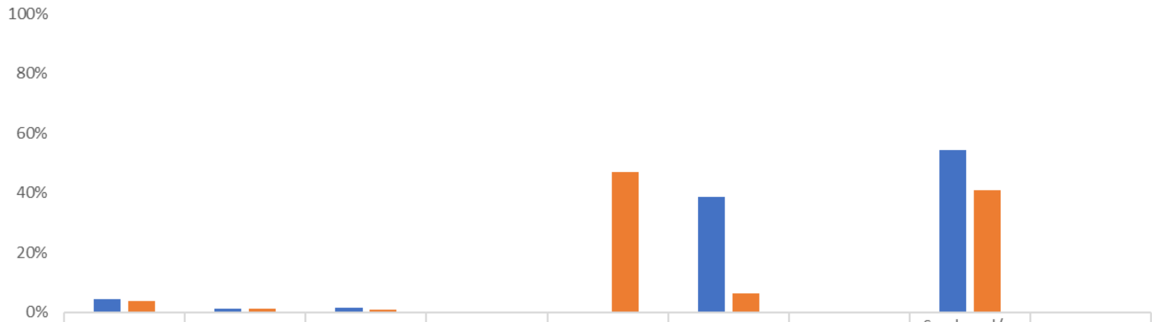


	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	37.6%	1.1%	9.0%	0.0%	2.1%	3.3%	0.6%	46.4%	0.0%
2006	92.1%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.8%	0.0%
2018	48.8%	0.4%	10.4%	0.2%	1.0%	0.1%	5.6%	33.5%	0.0%



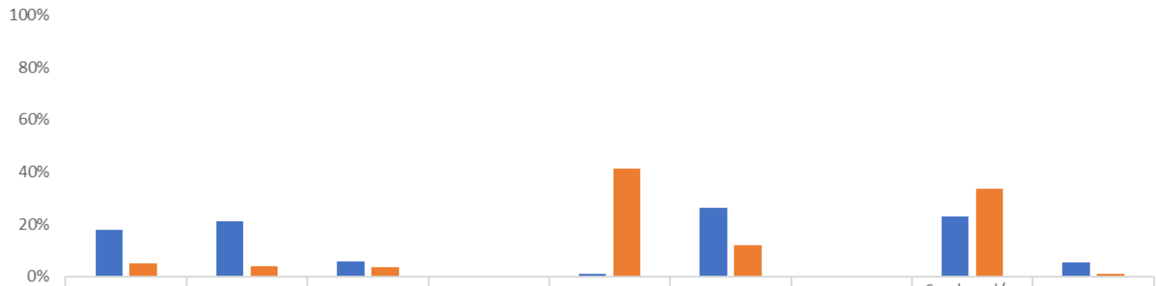
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	39.9%	2.0%	14.1%	0.0%	1.3%	2.4%	0.5%	39.8%	0.0%
2006	89.7%	1.8%	1.5%	0.0%	0.0%	0.0%	0.0%	7.0%	0.0%
2018	48.4%	1.1%	15.2%	0.2%	1.5%	1.4%	5.4%	26.2%	0.6%

Prefire landscape composition of outliers in fire size in France in 2000 and 2018 (N = 3, ≥ 7400 ha)

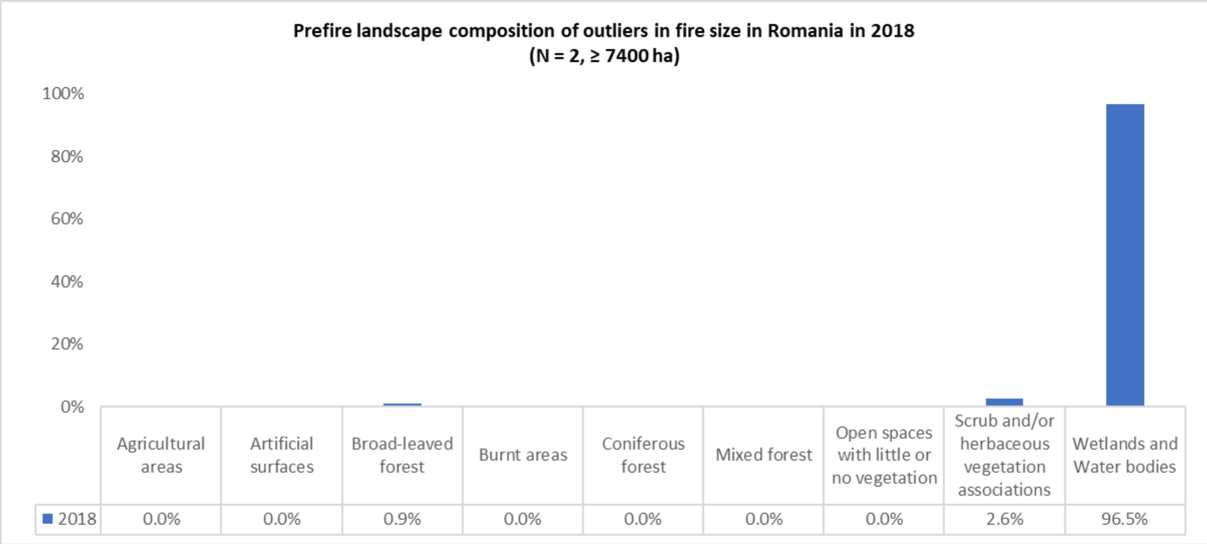


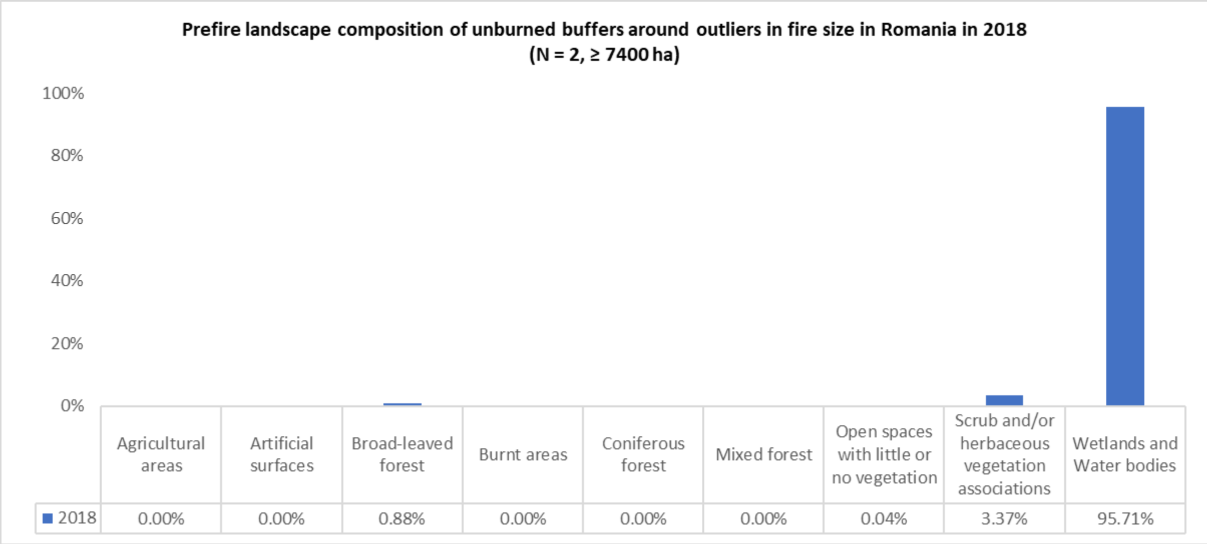
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	4.3%	1.1%	1.6%	0.0%	0.3%	38.4%	0.0%	54.3%	0.0%
2018	3.6%	1.1%	0.8%	0.0%	47.0%	6.3%	0.0%	40.9%	0.3%

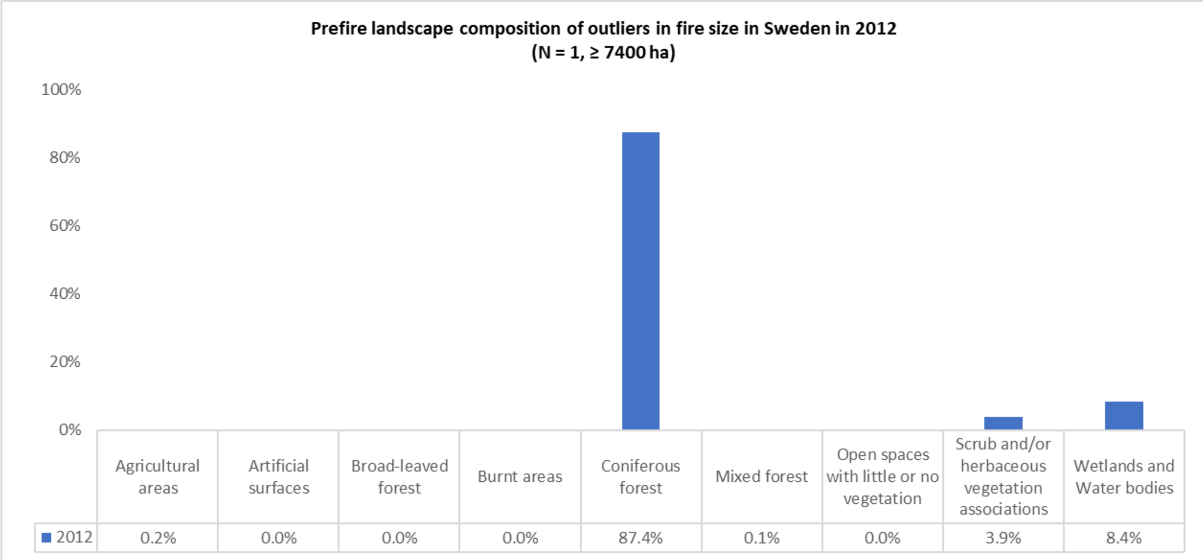
Pre-fire landscape composition of unburned buffers around outliers in fire size in France in 2000 and 2018 (N = 3, ≥ 7400 ha)

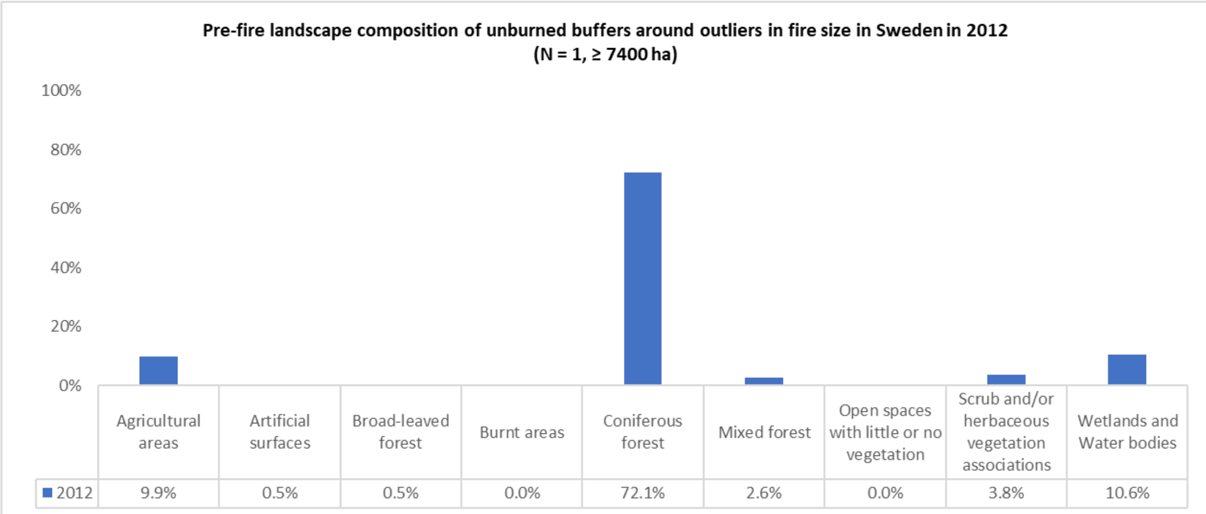


	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	17.9%	21.1%	5.6%	0.0%	0.9%	26.3%	0.0%	23.0%	5.2%
2018	4.80%	3.98%	3.55%	0.00%	41.16%	11.91%	0.00%	33.66%	0.94%

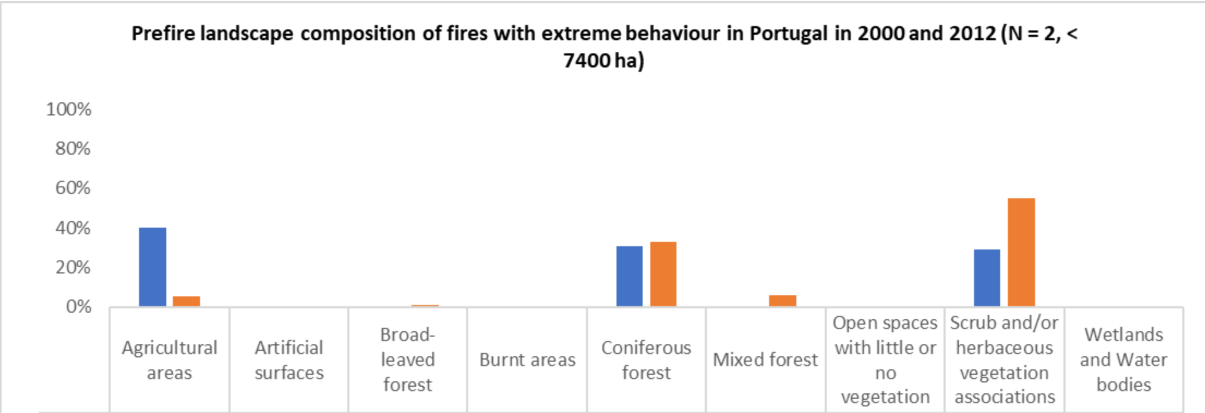

Prefire landscape composition of outliers in fire size in Romania in 2018
(N = 2, ≥ 7400 ha)
100%
80%
60%
40%
20%
0%
Agricultural areas
Artificial surfaces
Broad-leaved forest
Burnt areas
Coniferous forest
Mixed forest
Open spaces with little or no vegetation
Scrub and/or herbaceous vegetation associations
Wetlands and Water bodies
2018
0.0%
0.0%
0.9%
0.0%
0.0%
0.0%
0.0%
2.6%
96.5%


Prefire landscape composition of unburned buffers around outliers in fire size in Romania in 2018
(N = 2, ≥ 7400 ha)
100%
80%
60%
40%
20%
0%
Agricultural areas
Artificial surfaces
Broad-leaved forest
Burnt areas
Coniferous forest
Mixed forest
Open spaces with little or no vegetation
Scrub and/or herbaceous vegetation associations
Wetlands and Water bodies
2018
0.00%
0.00%
0.88%
0.00%
0.00%
0.00%
0.04%
3.37%
95.71%

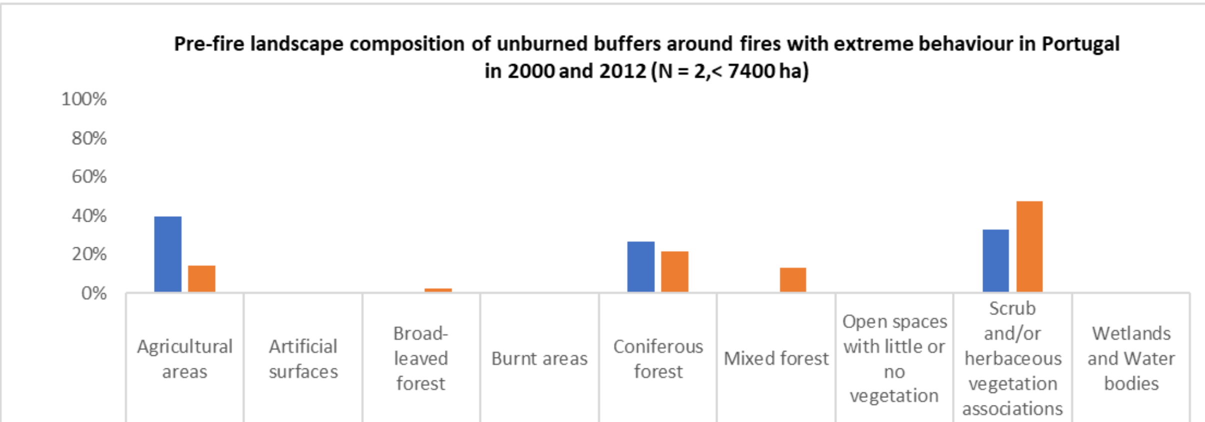

Prefire landscape composition of outliers in fire size in Sweden in 2012
(N = 1, ≥ 7400 ha)
100%
80%
60%
40%
20%
0%
Agricultural areas
Artificial surfaces
Broad-leaved forest
Burnt areas
Coniferous forest
Mixed forest
Open spaces with little or no vegetation
Scrub and/or herbaceous vegetation associations
Wetlands and Water bodies
2012
0.2%
0.0%
0.0%
0.0%
87.4%
0.1%
0.0%
3.9%
8.4%


Pre-fire landscape composition of unburned buffers around outliers in fire size in Sweden in 2012
(N = 1, ≥ 7400 ha)
100%
80%
60%
40%
20%
0%
Agricultural areas
Artificial surfaces
Broad-leaved forest
Burnt areas
Coniferous forest
Mixed forest
Open spaces with little or no vegetation
Scrub and/or herbaceous vegetation associations
Wetlands and Water bodies
2012
9.9%
0.5%
0.5%
0.0%
72.1%
2.6%
0.0%
3.8%
10.6%

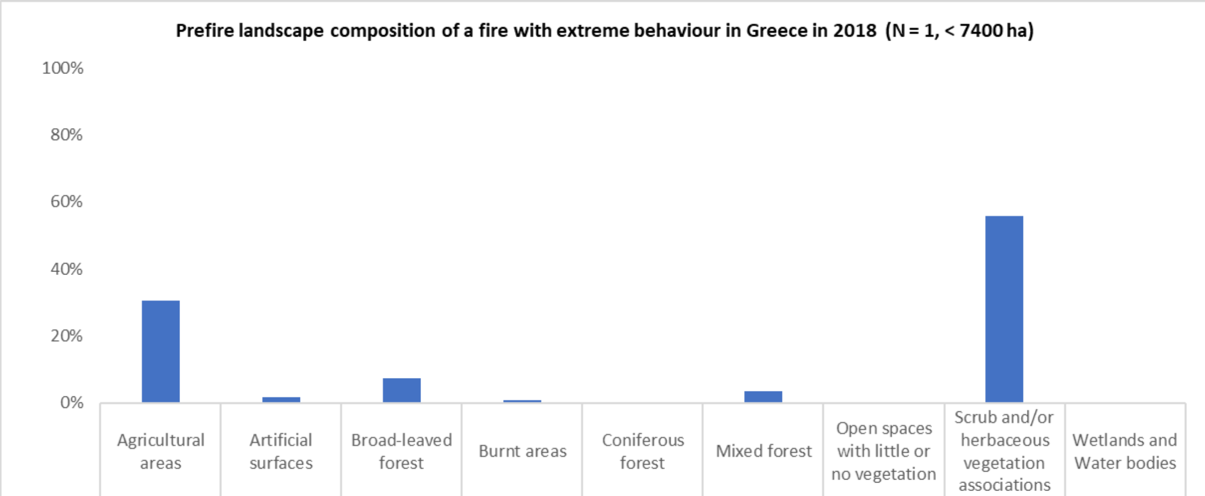
Annex 4. Pre-fire LULC composition of fires wit reported extreme behaviour (< 7400 ha) and unburned buffers by country in 2000-2018



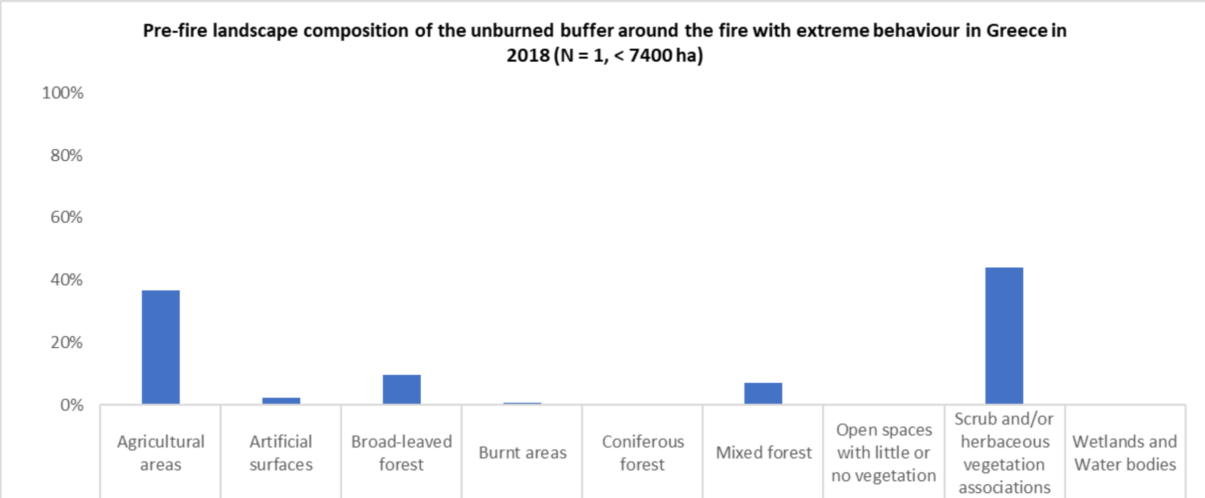
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	39.9%	0.0%	0.0%	0.0%	30.9%	0.0%	0.0%	29.2%	0.0%
2012	5.3%	0.0%	0.8%	0.0%	32.8%	6.0%	0.0%	55.1%	0.0%



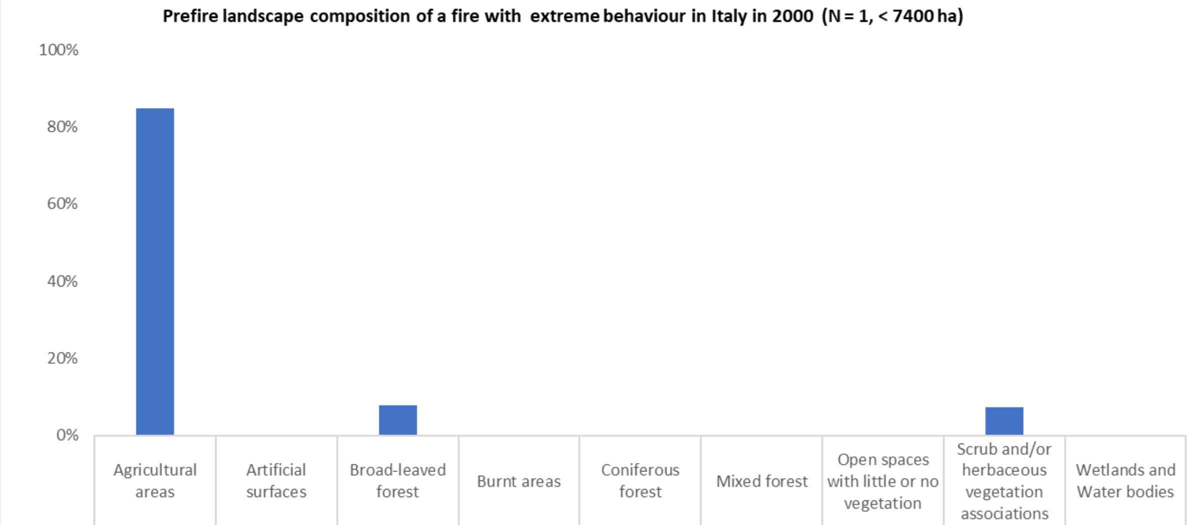
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	39.4%	0.0%	0.5%	0.0%	26.9%	0.0%	0.0%	33.1%	0.0%
2012	14.5%	1.0%	2.2%	0.0%	21.5%	13.4%	0.0%	47.3%	0.0%



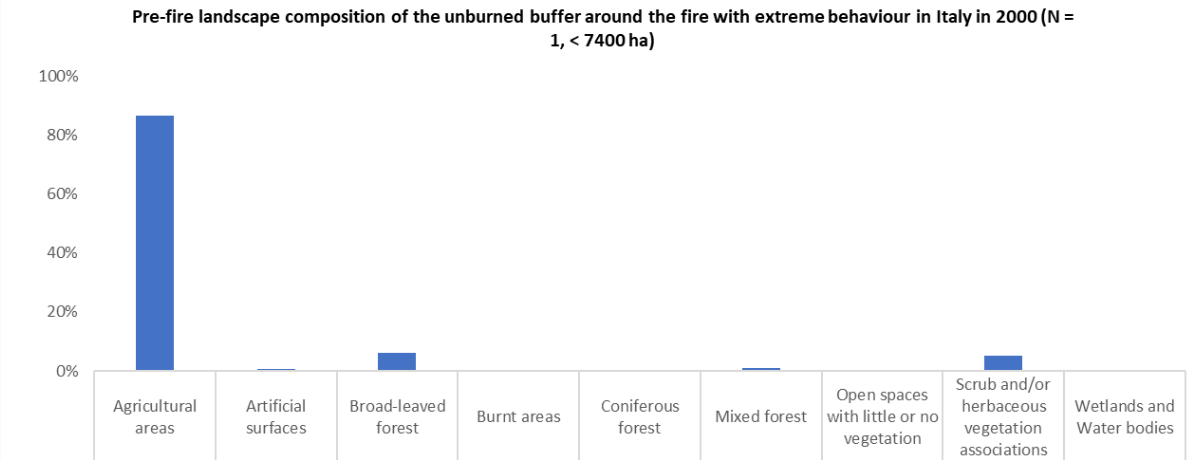
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2018	30.5%	1.7%	7.5%	0.9%	0.0%	3.5%	0.0%	55.8%	0.0%



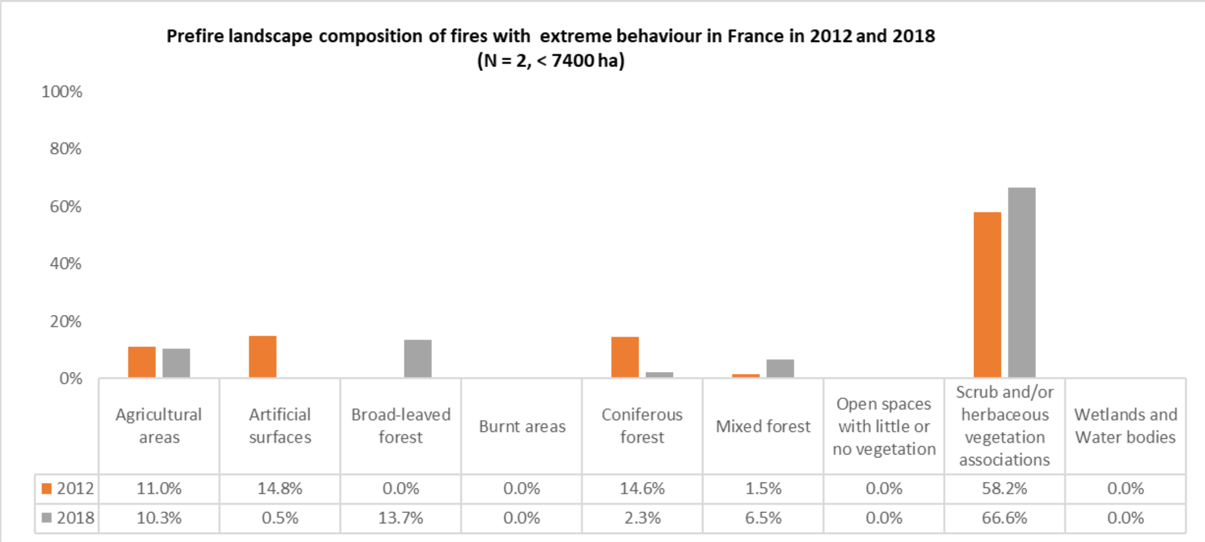
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2018	36.72%	2.30%	9.43%	0.77%	0.00%	6.88%	0.00%	43.89%	0.00%



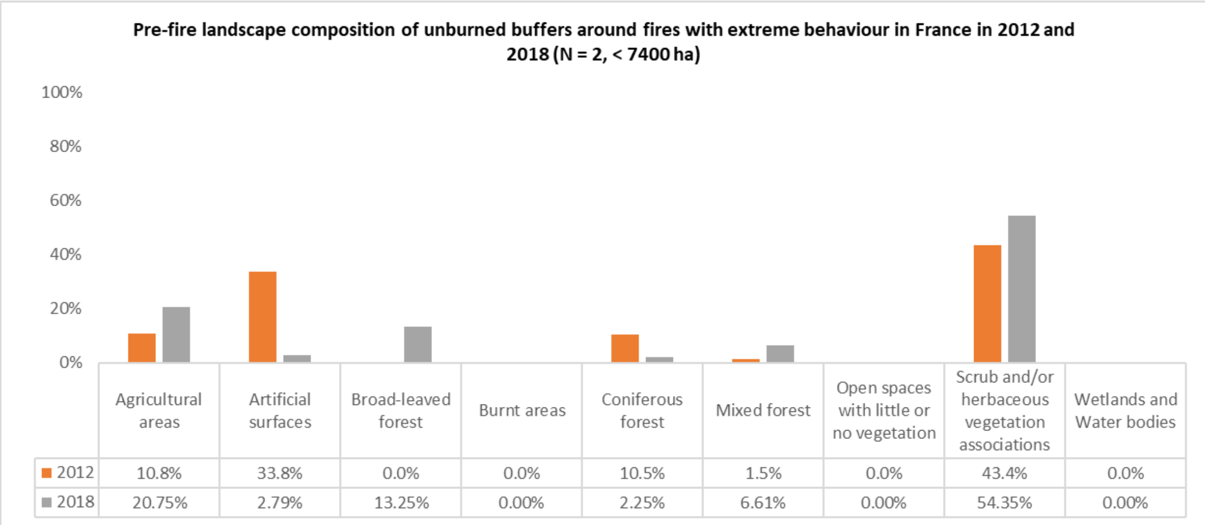
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	84.8%	0.0%	7.7%	0.0%	0.0%	0.0%	0.0%	7.4%	0.0%



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	86.8%	0.5%	6.1%	0.0%	0.4%	0.9%	0.0%	5.2%	0.0%



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2012	11.0%	14.8%	0.0%	0.0%	14.6%	1.5%	0.0%	58.2%	0.0%
2018	10.3%	0.5%	13.7%	0.0%	2.3%	6.5%	0.0%	66.6%	0.0%

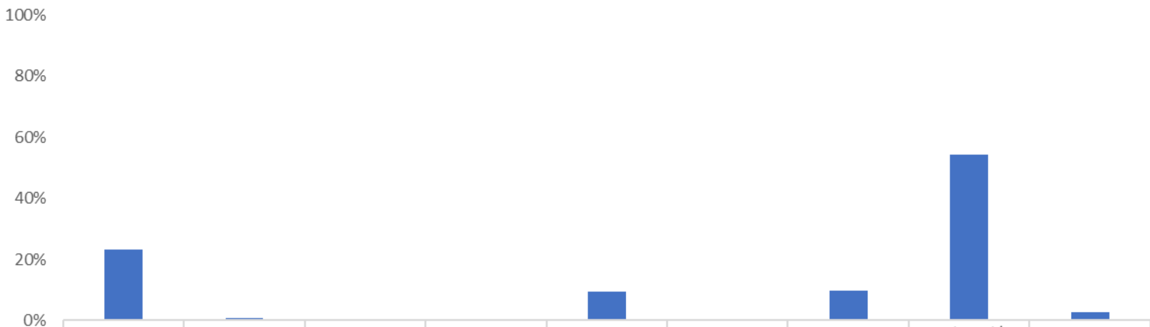


	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2012	10.8%	33.8%	0.0%	0.0%	10.5%	1.5%	0.0%	43.4%	0.0%
2018	20.75%	2.79%	13.25%	0.00%	2.25%	6.61%	0.00%	54.35%	0.00%

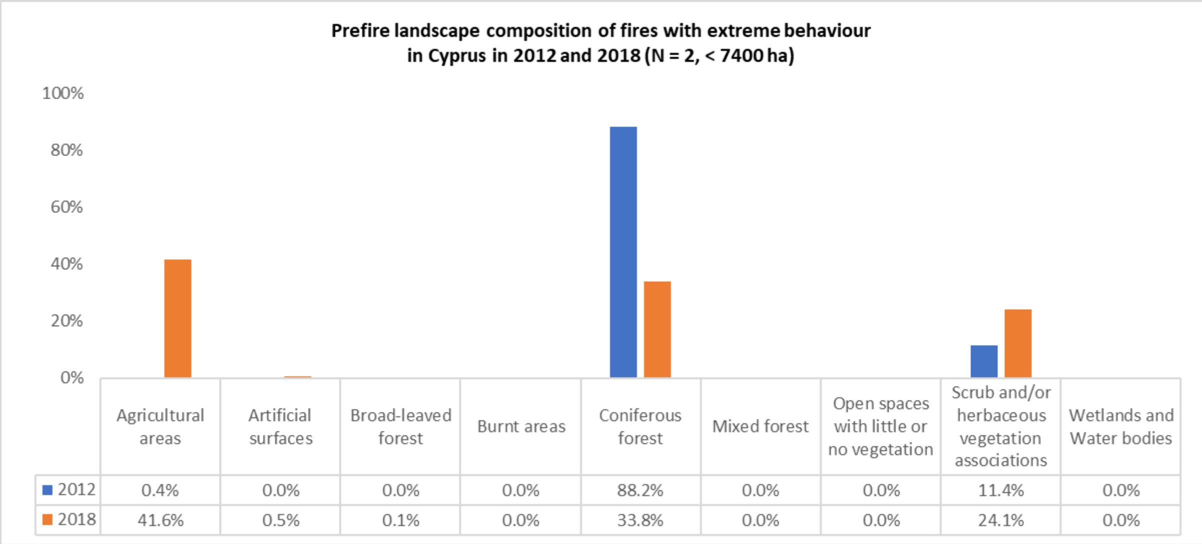
Prefire landscape composition of a fire with extreme behaviour in Croatia in 2000 (N = 1, < 7400 ha)

	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	18.8%	0.0%	0.0%	0.0%	0.6%	0.0%	14.2%	66.4%	0.0%

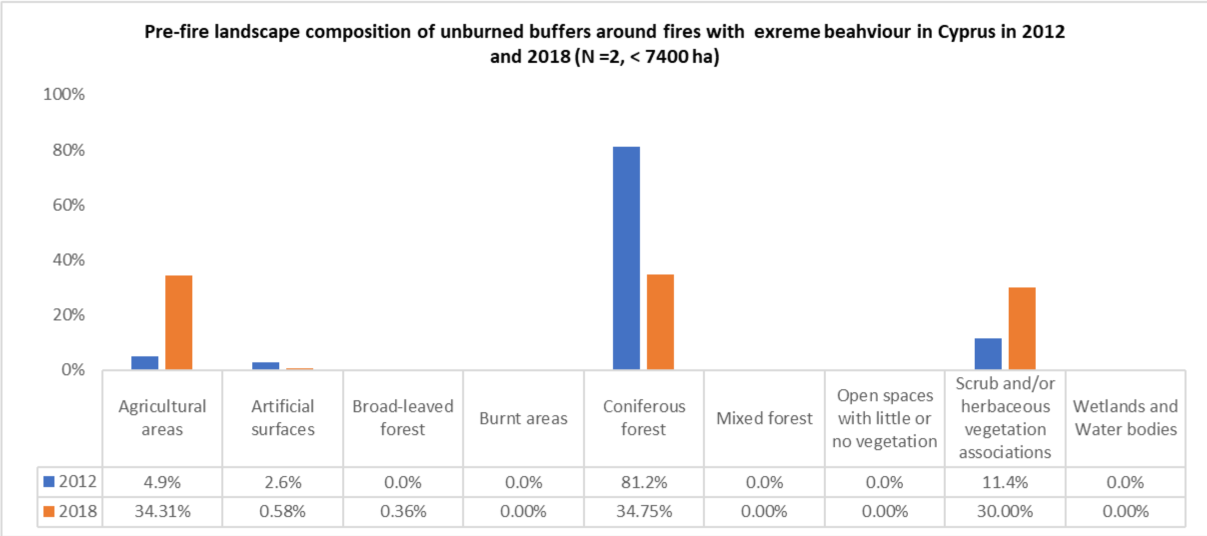
Pre-fire landscape composition of the unburned buffer around the fire with exreme beahviour in Croatia in 2000 (N = 1, < 7400 ha)



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	23.2%	0.7%	0.0%	0.0%	9.5%	0.0%	9.7%	54.4%	2.6%

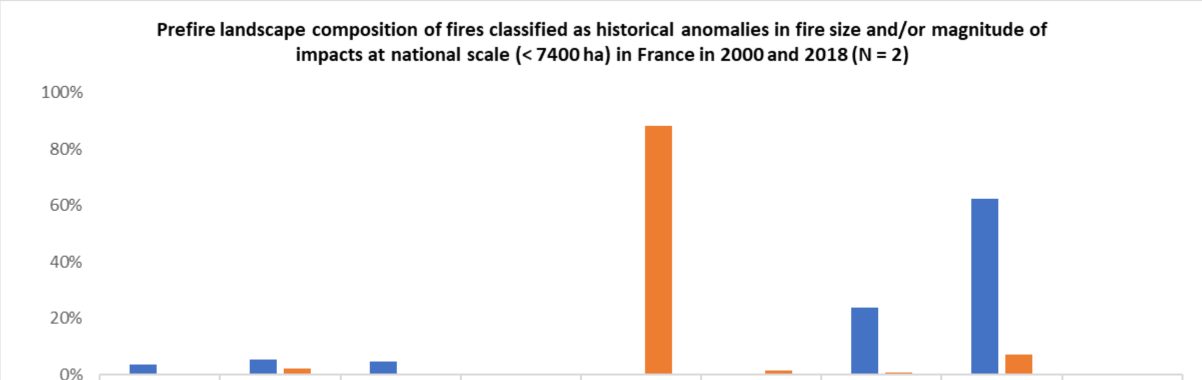


	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2012	0.4%	0.0%	0.0%	0.0%	88.2%	0.0%	0.0%	11.4%	0.0%
2018	41.6%	0.5%	0.1%	0.0%	33.8%	0.0%	0.0%	24.1%	0.0%

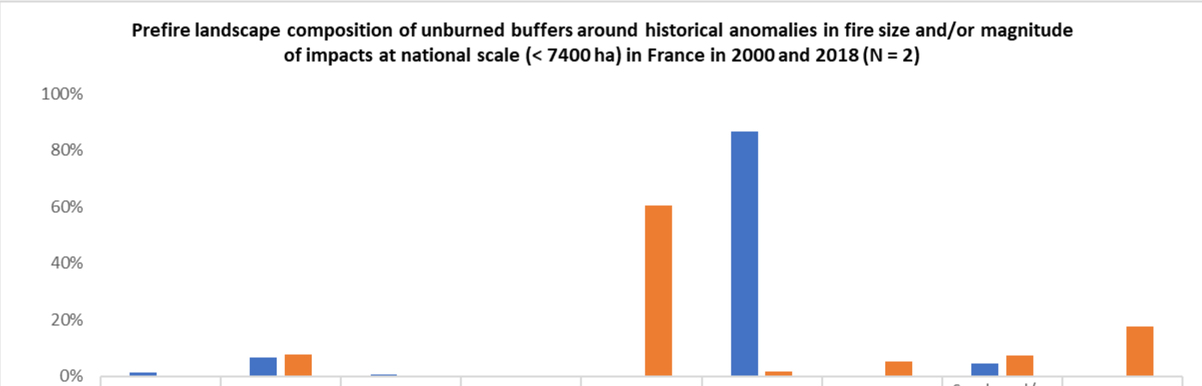


	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2012	4.9%	2.6%	0.0%	0.0%	81.2%	0.0%	0.0%	11.4%	0.0%
2018	34.31%	0.58%	0.36%	0.00%	34.75%	0.00%	0.00%	30.00%	0.00%

Annex 5. Pre-fire LULC composition of fires classified as historical anomalies in fire size and/or magnitude of impacts at the national scale (< 7400 ha) and unburned buffers by country in 2000-2018

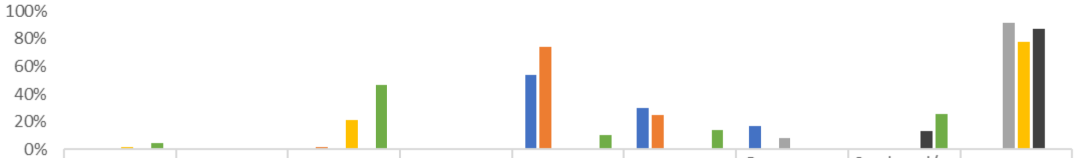


	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	3.7%	5.3%	4.9%	0.0%	0.0%	0.0%	23.7%	62.4%	0.0%
2018	0.0%	2.2%	0.0%	0.0%	88.3%	1.4%	0.7%	7.1%	0.2%



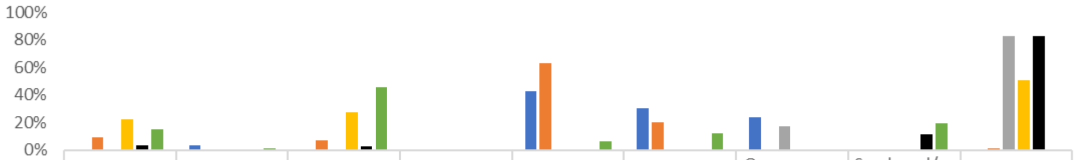
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
2000	1.5%	6.5%	0.7%	0.0%	0.0%	86.5%	0.0%	4.5%	0.3%
2018	0.00%	7.59%	0.00%	0.00%	60.45%	1.57%	5.17%	7.56%	17.66%

Prefire landscape composition of fires classified as historical anomalies in fire size and/or magnitude of impacts at national scale (< 7400 ha) in Austria, Czech Republic, Latvia, Netherlands, Slovenia (N =1) and Romania (N = 2) in 2018



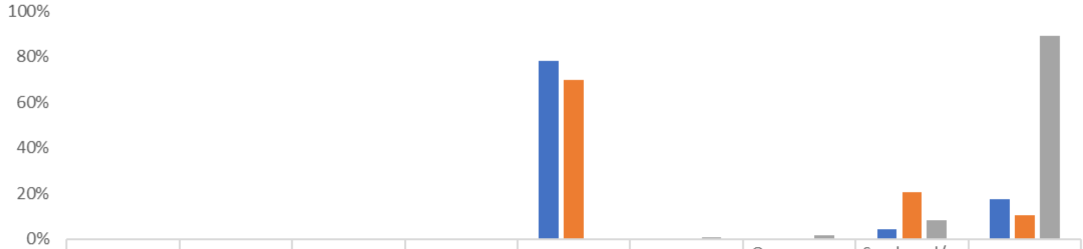
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Austria	0.0%	0.0%	0.0%	0.0%	53.9%	29.7%	16.4%	0.0%	0.0%
Czech Republic	0.1%	0.0%	1.3%	0.0%	74.1%	24.4%	0.0%	0.0%	0.0%
Latvia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.1%	0.0%	91.9%
Netherlands	1.6%	0.0%	20.8%	0.0%	0.0%	0.0%	0.0%	0.0%	77.7%
Romania	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	13.1%	86.9%
Slovenia	4%	0%	47%	0%	10%	14%	0%	25%	0%

Prefire landscape composition of unburned buffers around historical anomalies in fire size and/or magnitude of impacts at national scale (< 7400 ha) in Austria, Czech Republic, Latvia, Netherlands, Slovenia (N =1) and Romania (N = 2) in 2018



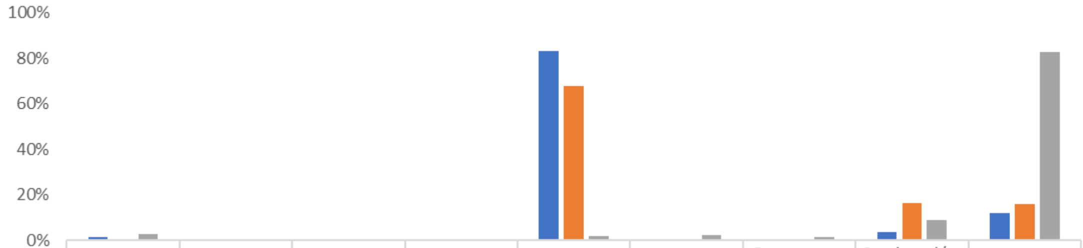
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Austria	0.00%	3.35%	0.00%	0.00%	42.69%	30.38%	23.58%	0.00%	0.00%
Czech Republic	8.77%	0.38%	7.01%	0.00%	62.78%	19.96%	0.00%	0.00%	1.09%
Latvia	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	17.42%	0.00%	82.58%
Netherlands	22.55%	0.00%	27.15%	0.00%	0.00%	0.00%	0.00%	0.00%	50.29%
Romania	3.24%	0.00%	2.51%	0.00%	0.00%	0.00%	0.47%	11.13%	82.64%
Slovenia	14.91%	1.41%	45.77%	0.00%	6.17%	11.79%	0.42%	19.52%	0.00%

Prefire landscape composition of fires classified as historical anomalies in fire size and/or magnitude of impacts at national scale (< 7400 ha) in Norway in 2006 (N = 1), Sweden in 2012 (N =4) and Ireland in 2012 (N = 3)



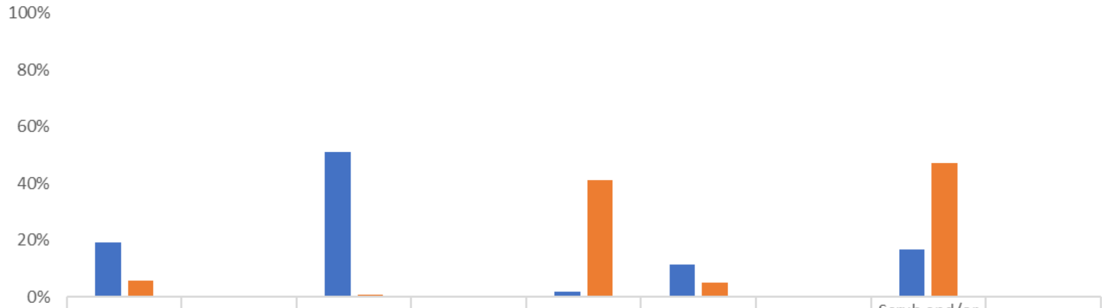
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Norway_2006	0.2%	0.0%	0.0%	0.0%	78.3%	0.0%	0.0%	4.1%	17.5%
Sweden_2012	0.0%	0.0%	0.0%	0.0%	69.5%	0.0%	0.0%	20.3%	10.2%
Ireland_2012	0.1%	0.0%	0.0%	0.0%	0.4%	0.7%	1.7%	8.1%	89.1%

Prefire landscape composition of unburned buffers around historical anomalies in fire size and/or magnitude of impacts at national scale (< 7400 ha) in Norway in 2006 (N = 1), Sweden in 2012 (N = 4) and Ireland in 2012 (N = 3)



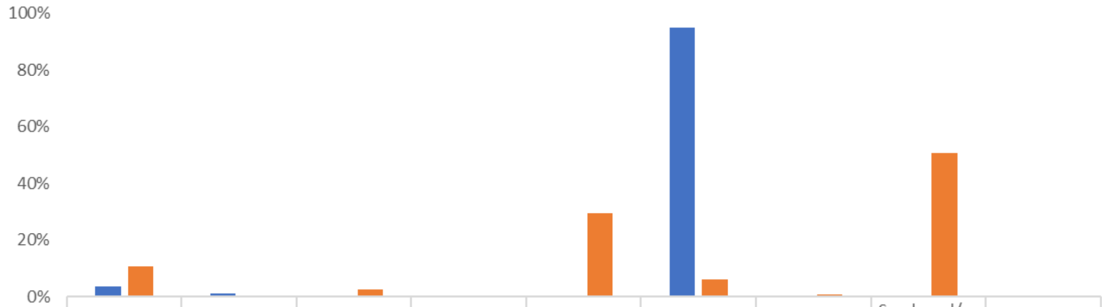
	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Norway_2006	1.4%	0.0%	0.0%	0.0%	83.1%	0.0%	0.0%	3.6%	11.8%
Sweden_2012	0.2%	0.0%	0.0%	0.0%	67.8%	0.0%	0.0%	16.3%	15.8%
Ireland_2012	2.7%	0.0%	0.0%	0.0%	1.9%	2.2%	1.5%	8.9%	82.8%

Prefire landscape composition of fires classified as historical anomalies in fire size and/or magnitude of impacts at national scale (< 7400 ha) in Italy in 2000 (N =1) and Spain in 2006 (N =1)



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Italy_2000	19.3%	0.2%	50.9%	0.0%	1.7%	11.2%	0.0%	16.5%	0.0%
Spain_2006	5.7%	0.0%	0.8%	0.0%	41.0%	4.9%	0.4%	47.2%	0.0%

Prefire landscape composition of unburned buffers around historical anomalies in fire size and/or magnitude of impacts at national scale (< 7400 ha) in Italy in 2000 (N = 1) and Spain in 2006 (N =1)



	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Italy_2000	3.4%	1.0%	0.0%	0.1%	0.1%	95.0%	0.0%	0.3%	0.0%
Spain_2006	10.8%	0.0%	2.5%	0.0%	29.3%	6.1%	0.7%	50.5%	0.0%

Annex 6. Mean patch size for pre-fire LULC classes, per country and CLC year

Mean patch size for pre-fire LULC classes, for burned perimeters, per country and CLC year (minimum, median and maximum values, hectares)

CLC	Country	N	Agricultural areas			Artificial surfaces			Broad-leaved forest			Burnt areas			Coniferous Forest			Mixed forest			Open spaces with little or no vegetation			Scrub and/or herbaceous vegetation asociations			Wetlands and water bodies		
			Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median
1990	GR	3	63.20	190.72	97.45	20.92	20.92	20.92	34.52	88.36	84.10	0.00	0.00	0.00	127.68	506.77	317.22	28.86	183.35	41.68	24.23	25.39	24.81	82.32	255.63	118.38	0.17	0.17	0.17
	PT	1	17.87	17.87	NA	2.60	2.60	NA	0.00	0.00	NA	85.89	85.89	NA	264.89	264.89	NA	97.48	97.48	NA	0.00	0.00	NA	404.26	404.26	NA	0.00	0.00	NA
2000	CR	1	49.91	49.91	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	6.84	6.84	NA	0.00	0.00	NA	75.36	75.36	NA	100.69	100.69	NA	0.00	0.00	NA
	FR	2	35.23	41.32	38.27	17.48	34.39	25.93	55.07	63.53	59.30	0.00	0.00	NA	38.23	38.23	38.23	786.09	786.09	786.09	153.31	153.31	153.31	156.81	416.24	286.53	0.91	0.91	0.91
	GR	7	60.17	261.47	182.73	3.57	233.11	99.20	45.83	364.54	196.19	5.45	5.45	5.45	30.28	608.60	155.41	92.78	318.75	123.25	23.56	187.58	32.89	102.59	862.06	274.07	26.24	109.42	67.83
	IT	5	28.48	480.33	156.18	0.07	85.08	5.35	45.11	637.70	79.99	0.00	0.00	NA	21.85	70.81	46.33	1.56	133.57	69.87	44.24	44.24	44.24	34.53	604.43	134.92	0.00	0.00	NA
	PT	13	10.93	311.28	32.06	2.37	28.40	4.75	20.73	2706.28	119.69	1.34	864.88	70.56	30.01	4485.68	144.08	32.07	271.00	83.99	177.46	370.43	274.62	42.20	587.13	174.48	0.35	108.90	56.76
	SP	10	19.27	157.77	56.73	0.27	33.74	5.78	15.92	259.10	36.44	32.68	32.68	32.68	30.18	8814.43	621.58	0.07	982.69	171.37	0.00	93.11	30.56	98.53	7633.03	273.39	2.06	51.75	2.70
2006	GR	3	69.84	132.59	70.71	0.03	131.71	0.86	0.00	0.00	NA	111.45	111.45	111.45	91.01	640.39	135.09	67.42	67.42	67.42	63.25	320.19	191.72	143.65	540.53	170.30	0.10	53.51	26.80
	IT	1	409.34	409.34	NA	19.78	19.78	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	98.62	98.62	NA	0.00	0.00	NA
	NO	1	4.29	4.29	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	2153.45	2153.45	NA	0.00	0.00	NA	0.00	0.00	NA	113.42	113.42	NA	68.60	68.60	NA
	PT	2	47.58	150.64	99.11	0.45	0.46	0.45	101.85	237.86	169.85	0.00	0.00	0.00	32.13	72.31	52.22	49.97	365.58	207.77	148.81	148.81	148.81	204.75	367.53	286.14	0.00	0.00	NA
	SP	7	26.93	77.80	44.17	16.87	36.64	26.06	56.66	435.40	93.72	187.00	215.70	201.35	51.65	2525.87	249.21	20.76	104.69	58.29	24.29	70.93	32.71	111.30	589.72	204.13	0.02	113.44	56.73
2012	CP	1	7.76	7.76	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	854.63	854.63	NA	0.00	0.00	NA	0.00	0.00	NA	221.63	221.63	NA	0.00	0.00	NA
	FR	1	36.70	36.70	NA	40.64	40.64	NA	0.00	0.00	NA	0.00	0.00	NA	87.73	87.73	NA	45.56	45.56	NA	0.00	0.00	NA	350.64	350.64	NA	0.00	0.00	NA
	IR	3	9.70	9.70	9.70	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	1.89	15.04	8.46	26.79	26.79	26.79	87.80	87.80	87.80	27.98	103.55	67.65	1243.73	3015.98	1902.66
	PT	24	15.40	92.95	43.36	1.13	144.48	26.18	13.64	2985.37	89.25	24.47	310.83	38.94	38.78	2182.16	145.28	17.02	415.94	104.72	6.27	349.93	48.43	54.15	1018.22	253.02	0.13	686.09	49.38
	SP	6	13.63	211.07	32.20	5.28	28.76	9.60	17.12	284.03	142.77	26.44	26.44	26.44	52.35	3101.03	117.50	1.57	96.70	55.42	0.56	346.43	71.14	87.69	311.28	134.58	14.81	14.81	14.81
	SW	5	0.41	9.65	5.03	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	308.51	10911.68	2721.42	4.54	4.54	4.54	0.00	0.00	NA	30.47	79.89	53.52	18.10	113.30	58.14
2018	AU	1	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	38.82	38.82	NA	21.41	21.41	NA	11.78	11.78	NA	0.00	0.00	NA	0.00	0.00	NA
	CH	1	0.45	0.45	NA	0.00	0.00	NA	19.34	19.34	NA	0.00	0.00	NA	532.30	532.30	NA	87.79	87.79	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA
	CP	1	128.24	128.24	NA	11.32	11.32	NA	4.49	4.49	NA	0.00	0.00	NA	390.69	390.69	NA	0.00	0.00	NA	0.00	0.00	NA	222.76	222.76	NA	0.00	0.00	NA
	FR	4	13.52	43.03	29.30	8.15	64.62	20.06	10.14	68.38	55.69	0.00	0.00	NA	50.58	5128.02	272.02	41.22	97.27	49.41	42.93	42.93	42.93	68.83	867.59	177.35	3.35	20.40	10.64
	GR	6	54.08	285.78	125.44	7.21	80.95	37.64	37.85	350.69	155.18	44.15	78.26	61.20	135.61	322.79	224.86	55.22	582.60	233.92	19.38	29.18	24.28	114.52	345.96	176.96	8.64	27.27	17.96
	IT	2	137.96	582.56	360.26	0.80	14.43	7.62	87.28	343.85	215.57	32.47	32.47	32.47	43.14	43.14	43.14	10.34	19.83	15.08	218.55	218.55	218.55	211.35	416.89	314.12	0.00	0.00	NA
	LT	1	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	9.16	9.16	NA	0.00	0.00	NA	104.15	104.15	NA
	NE	1	5.04	5.04	NA	0.00	0.00	NA	44.97	44.97	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	252.11	252.11	NA
	PT	6	26.83	152.04	46.28	2.32	105.14	6.39	16.84	636.89	67.64	8.08	15.18	11.63	31.42	463.66	84.62	5.51	106.18	92.11	229.13	229.13	229.13	198.26	1345.88	288.29	0.00	0.00	NA
	RO	4	0.00	0.00	NA	0.00	0.00	NA	36.28	72.07	54.18	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	59.49	628.65	78.93	530.51	2822.88	1454.21
	SL	1	21.25	21.25	NA	0.00	0.00	NA	464.76	464.76	NA	0.00	0.00	NA	78.73	78.73	NA	92.90	92.90	NA	0.00	0.00	NA	125.97	125.97	NA	0.00	0.00	NA
	SP	13	6.81	105.27	59.94	3.56	25.12	10.95	27.97	218.77	78.84	33.63	77.17	55.40	17.49	694.44	176.38	13.45	121.07	56.53	22.50	557.92	62.33	101.15	312.45	198.60	0.01	226.43	9.79

Mean patch size for pre-fire LULC classes, for unburned perimeters, per country and CLC year (minimum, median and maximum values, hectares)

CLC	Country	N	Agricultural areas			Artificial surfaces			Broad-leaved forest			Burnt areas			Coniferous Forest			Mixed forest			Open spaces with little or no vegetation			Scrub and/or herbaceous vegetation asociations			Wetlands and water bodies		
			Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median
1990	GR	3	89.38	228.13	132.18	24.05	47.67	42.18	90.73	192.50	105.73	0.00	0.00	0.00	17.53	529.71	130.78	46.42	192.88	61.75	32.37	36.00	34.19	110.09	253.11	111.75	1803.50	3805.37	2804.43
	PT	1	34.64	34.64	NA	30.86	30.86	NA	0.00	0.00	NA	80.60	80.60	NA	422.88	422.88	NA	150.58	150.58	NA	0.00	0.00	NA	408.03	408.03	NA	0.00	0.00	NA
2000	CR	1	70.29	70.29	NA	14.10	14.10	NA	0.00	0.00	NA	0.00	0.00	NA	100.54	100.54	NA	0.00	0.00	NA	102.79	102.79	NA	144.49	144.49	NA	55.29	55.29	NA
	FR	2	76.57	83.91	80.24	53.07	140.63	96.85	106.63	132.91	119.77	77.27	77.27	77.27	40.03	40.03	40.03	671.03	671.03	671.03	146.18	146.18	146.18	156.43	452.14	304.28	181.91	803.98	492.95
	GR	7	84.94	329.79	214.79	27.25	205.75	49.75	19.18	514.44	137.70	64.30	64.30	64.30	33.78	864.66	138.23	65.85	467.11	145.18	32.64	833.51	103.66	147.02	688.91	249.93	80.01	2555.22	561.53
	IT	5	32.56	764.75	157.57	13.20	124.12	21.69	80.88	909.84	146.67	0.00	0.00	NA	28.50	68.69	29.79	74.72	194.08	95.37	58.11	58.11	58.11	35.08	526.55	150.99	0.00	0.00	NA
	PT	13	38.61	351.22	66.53	1.68	65.77	37.28	4.80	1452.83	172.44	30.73	4000.62	118.38	22.66	3030.40	130.97	34.92	304.26	130.92	205.19	1246.99	509.93	63.40	636.94	211.47	41.67	515.97	166.37
	SP	10	55.17	321.06	148.81	9.12	344.63	28.22	48.10	235.70	86.94	64.45	71.97	68.21	47.35	5771.88	440.82	33.01	482.40	184.20	22.47	865.13	79.96	198.81	21459.81	338.41	17.66	136.21	32.93
2006	GR	3	105.63	213.96	105.81	22.97	224.30	47.23	0.00	0.00	NA	111.45	111.45	111.45	99.06	629.03	182.15	149.17	149.17	149.17	74.93	626.58	151.17	206.97	454.12	268.16	406.24	1314.39	1051.12
	IT	1	369.70	369.70	NA	40.18	40.18	NA	52.99	52.99	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	125.91	125.91	NA	0.00	0.00	NA
	NO	1	26.13	26.13	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	4572.96	4572.96	NA	0.00	0.00	NA	0.00	0.00	NA	40.16	40.16	NA	81.31	81.31	NA
	PT	2	81.73	208.82	145.28	16.73	67.39	42.06	67.86	283.47	175.66	0.00	0.00	0.00	28.63	72.31	50.47	58.43	369.60	214.02	118.43	118.43	118.43	232.22	365.43	298.83	0.00	0.00	NA
	SP	7	57.72	187.56	75.47	0.11	106.41	25.79	33.89	566.05	90.53	578.49	639.36	608.92	57.53	613.84	212.50	30.45	154.28	70.35	19.01	70.93	29.92	112.57	434.97	188.41	148.39	232.70	171.03
2012	CP	1	56.93	56.93	NA	33.49	33.49	NA	0.00	0.00	NA	0.00	0.00	NA	1584.93	1584.93	NA	0.00	0.00	NA	0.00	0.00	NA	109.05	109.05	NA	0.00	0.00	NA
	FR	1	40.89	40.89	NA	112.11	112.11	NA	0.00	0.00	NA	0.00	0.00	NA	77.12	77.12	NA	90.89	90.89	NA	0.00	0.00	NA	331.22	331.22	NA	0.00	0.00	NA
	IR	3	5.14	91.96	32.29	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	18.30	25.21	21.76	87.03	87.03	87.03	107.93	107.93	107.93	62.16	144.03	101.29	1114.04	5835.76	3534.44
	PT	24	32.57	124.50	76.55	16.37	87.71	44.23	20.11	2495.63	93.59	5.87	310.26	42.74	18.43	2163.79	165.61	29.07	371.50	134.58	26.23	351.02	87.07	59.97	1179.31	251.94	34.55	1365.75	347.52
	SP	6	50.93	220.71	74.63	29.71	60.76	39.24	31.20	455.64	112.14	0.58	49.45	25.02	54.62	2156.84	140.69	25.82	114.39	35.03	35.69	555.15	89.04	91.35	412.01	136.45	8.17	1048.34	115.64
	SW	5	48.81	69.53	59.17	31.16	31.16	31.16	26.27	26.27	26.27	0.00	0.00	NA	388.87	5194.18	2579.93	43.05	43.05	43.05	0.00	0.00	NA	39.99	80.32	52.23	56.91	267.61	72.17
2018	AU	1	0.03	0.03	NA	3.60	3.60	NA	0.00	0.00	NA	0.00	0.00	NA	62.61	62.61	NA	43.31	43.31	NA	34.45	34.45	NA	0.00	0.00	NA	0.00	0.00	NA
	CH	1	32.00	32.00	NA	11.76	11.76	NA	92.14	92.14	NA	0.00	0.00	NA	907.27	907.27	NA	96.40	96.40	NA	0.00	0.00	NA	0.00	0.00	NA	28.00	28.00	NA
	CP	1	166.67	166.67	NA	26.78	26.78	NA	33.42	33.42	NA	0.00	0.00	NA	798.50	798.50	NA	0.00	0.00	NA	0.00	0.00	NA	350.87	350.87	NA	0.00	0.00	NA
	FR	4	33.22	76.76	56.79	53.91	111.83	90.07	60.63	301.93	108.68	0.00	0.00	NA	50.46	7145.51	316.03	61.82	204.33	86.56	295.63	295.63	295.63	74.27	1416.55	146.83	51.64	663.85	57.78
	GR	6	76.47	268.66	155.96	37.74	175.40	54.38	42.35	511.77	179.91	27.40	166.41	72.58	46.90	352.15	254.64	218.27	829.37	234.90	4.00	60.41	35.54	151.15	443.09	208.46	107.56	15224.26	336.00
	IT	2	205.65	633.33	419.49	41.11	42.28	41.69	208.71	484.41	346.56	54.36	54.36	54.36	103.13	121.12	112.12	50.23	425.83	238.03	33.11	308.54	170.83	244.59	476.06	360.33	299.66	299.66	299.66
	LT	1	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	40.45	40.45	NA	0.00	0.00	NA	186.19	186.19	NA
	NE	1	95.18	95.18	NA	0.00	0.00	NA	87.06	87.06	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	332.33	332.33	NA
	PT	6	41.07	169.39	74.73	4.41	73.05	24.14	57.43	204.01	114.79	9.64	91.74	38.83	25.41	485.43	122.51	54.75	129.29	120.77	40.62	478.14	259.38	185.32	1632.60	262.81	0.03	0.99	0.51
	RO	4	984.98	984.98	984.98	0.00	0.00	NA	9.21	201.69	47.43	0.00	0.00	NA	0.00	0.00	NA	0.00	0.00	NA	15.04	75.61	45.33	82.20	951.78	126.96	658.35	2810.37	1549.97
	SL	1	55.49	55.49	NA	21.60	21.60	NA	601.43	601.43	NA	0.00	0.00	NA	54.60	54.60	NA	90.50	90.50	NA	21.78	21.78	NA	85.72	85.72	NA	0.00	0.00	NA
	SP	13	31.84	174.79	100.96	23.88	107.19	30.56	22.76	690.58	143.73	40.52	77.17	58.84	65.96	712.86	202.93	34.57	764.07	68.00	2.53	2781.62	68.87	121.22	395.23	221.47	40.38	242.66	128.74

Annex 7. LULC transition matrices in 1990-2018 for biogeographical regions in Europe

Absolute (ha) and relative (%) transition matrices in 1990-2018 for EWE in the Atlantic Region (based on 3 EWE in France in 2022 and 1 EWE in the Netherlands in 2020)

TO / FROM	Agricultural areas	Artificial surfaces	Broad-leaved forest	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Agricultural areas	423.76	43.55	0.00	112.89	5.88		36.35	0.00
Artificial surfaces	0.46	157.12		15.02	1.74	5.16	0.08	
Broad-leaved forest	3.56		218.56	3.25			0.19	0.03
Coniferous forest	86.22	80.66	37.68	12388.11	770.00	7.19	7190.02	7.12
Mixed forest	57.10	10.66		62.48	476.15		44.35	0.03
Open spaces with little or no vegetation		0.06		0.18		30.57		
Scrub and/or herbaceous vegetation associations	58.58	54.31		2214.01	321.37		1614.80	
Wetlands and Water bodies	0.00	1.30	0.20	3.62			0.23	592.64

TO / FROM	Agricultural areas	Artificial surfaces	Broad-leaved forest	Coniferous forest	Mixed forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Agricultural areas	68.08%	7.00%	0.00%	18.14%	0.94%	0.00%	5.84%	0.00%
Artificial surfaces	0.26%	87.49%	0.00%	8.36%	0.97%	2.88%	0.05%	0.00%
Broad-leaved forest	1.58%	0.00%	96.88%	1.44%	0.00%	0.00%	0.09%	0.01%
Coniferous forest	0.42%	0.39%	0.18%	60.23%	3.74%	0.03%	34.96%	0.03%
Mixed forest	8.77%	1.64%	0.00%	9.60%	73.17%	0.00%	6.81%	0.00%
Open spaces with little or no vegetation	0.00%	0.18%	0.00%	0.60%	0.00%	99.22%	0.00%	0.00%
Scrub and/or herbaceous vegetation associations	1.37%	1.27%	0.00%	51.93%	7.54%	0.00%	37.88%	0.00%
Wetlands and Water bodies	0.00%	0.22%	0.03%	0.61%	0.00%	0.00%	0.04%	99.11%

Absolute (ha) and relative (%) transition matrices in 1990-2018 for EWE in the Continental Region (based on 2 EWE in 2022 in Czech Republic and Slovenia)

FROM \ TO	Agricultural areas	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Scrub and/or herbaceous vegetation associations
Agricultural areas	147.51	9.48	0.00	0.09	0.05	8.87
Broad-leaved forest	13.25	1557.01	0.00	0.79	0.92	165.88
Burnt areas		5.13	0.00	61.12	46.16	247.18
Coniferous forest	0.01	1.72	0.00	1389.64	0.97	16.02
Mixed forest	0.01	1.13	0.00	2.95	821.00	4.80
Scrub and/or herbaceous vegetation associations	10.59	303.90	0.00	3.65	39.47	565.02

FROM \ TO	Agricultural areas	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	Scrub and/or herbaceous vegetation associations
Agricultural areas	88.86%	5.71%	0.00%	0.06%	0.03%	5.34%
Broad-leaved forest	0.76%	89.59%	0.00%	0.05%	0.05%	9.55%
Burnt areas	0.00%	1.43%	0.00%	17.00%	12.84%	68.74%
Coniferous forest	0.00%	0.12%	0.00%	98.67%	0.07%	1.14%
Mixed forest	0.00%	0.14%	0.00%	0.35%	98.93%	0.58%
Scrub and/or herbaceous vegetation associations	1.15%	32.94%	0.00%	0.40%	4.28%	61.24%

Absolute (ha) and relative (%) transition matrices in 1990-2018 for EWE in the Macaronesia Region (based on 1 EWE in 2019 in Spain)

FROM \ TO	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations
Agricultural areas	521.78	23.49	8.49	3.77	185.83	1.26	1070.54
Artificial surfaces	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Broad-leaved forest	1.03	0.60	67.75	0.00	4.97	0.00	193.24
Burnt areas	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coniferous forest	13.82	0.00	17.38	28.07	3037.42	128.30	486.77
Open spaces with little or no vegetation	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scrub and/or herbaceous vegetation associations	231.68	2.11	0.08	1.80	243.97	428.36	2164.31

FROM \ TO	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations
Agricultural areas	28.75%	1.29%	0.47%	0.21%	10.24%	0.07%	58.98%
Artificial surfaces		100.00%					
Broad-leaved forest	0.38%	0.22%	25.32%	0.00%	1.86%	0.00%	72.22%
Burnt areas				100.00%			
Coniferous forest	0.37%	0.00%	0.47%	0.76%	81.83%	3.46%	13.11%
Open spaces with little or no vegetation						100.00%	
Scrub and/or herbaceous vegetation associations	7.54%	0.07%	0.00%	0.06%	7.94%	13.94%	70.45%

Note: the value of 100% in some diagonal cells was inserted for mathematical reasons

Absolute (ha) and relative (%) transition matrices in 1990-2018 for EWE in the Mediterranean Region (based on 28 EWE in 2019-2022 in Portugal, Spain, Greece, Italy, France and Cyprus)

TO / FROM	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	NA	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Agricultural areas	75986.70	560.85	2581.31	46.08	2188.73	1192.70	0.00	243.50	14887.94	20.17
Artificial surfaces	5.97	885.72	3.58		40.22	34.93	0.00	0.93	163.59	
Broad-leaved forest	997.16	29.72	11185.71	24.68	680.60	1012.91	0.00	39.10	10215.63	15.79
Burnt areas	19.34	0.00			92.88		0.00		1346.12	
Coniferous forest	527.53	136.41	1644.76	22.95	37963.40	1340.06	0.00	67.40	30471.16	5.43
Mixed forest	274.16	43.63	740.84	0.23	3035.49	11356.62	0.00	52.82	6597.39	1.31
NA	1923.64	22.64	4.49		1562.78		0.00		1113.82	
Open spaces with little or no vegetation	0.76		2.82		27.40	3.09		3115.77	2564.38	
Scrub and/or herbaceous vegetation associations	9412.30	431.20	7562.83	193.84	16216.33	6170.45	0.00	5358.32	133528.33	15.60
Wetlands and Water bodies	3.29		0.78		5.15			0.40	56.44	259.54

TO / FROM	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	NA	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Agricultural areas	77.77%	0.57%	2.64%	0.05%	2.24%	1.22%	0.00%	0.25%	15.24%	0.02%
Artificial surfaces	0.53%	78.04%	0.32%	0.00%	3.54%	3.08%	0.00%	0.08%	14.41%	0.00%
Broad-leaved forest	4.12%	0.12%	46.22%	0.10%	2.81%	4.19%	0.00%	0.16%	42.21%	0.07%
Burnt areas	1.33%	0.00%	0.00%	0.00%	6.37%	0.00%	0.00%	0.00%	92.31%	0.00%
Coniferous forest	0.73%	0.19%	2.28%	0.03%	52.60%	1.86%	0.00%	0.09%	42.22%	0.01%
Mixed forest	1.24%	0.20%	3.35%	0.00%	13.73%	51.38%	0.00%	0.24%	29.85%	0.01%
NA	41.57%	0.49%	0.10%	0.00%	33.77%	0.00%	0.00%	0.00%	24.07%	0.00%
Open spaces with little or no vegetation	0.01%	0.00%	0.05%	0.00%	0.48%	0.05%	0.00%	54.53%	44.88%	0.00%
Scrub and/or herbaceous	5.26%	0.24%	4.23%	0.11%	9.07%	3.45%	0.00%	3.00%	74.64%	0.01%

TO / FROM	Agricultural areas	Artificial surfaces	Broad-leaved forest	Burnt areas	Coniferous forest	Mixed forest	NA	Open spaces with little or no vegetation	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
vegetation associations										
Wetlands and Water bodies	1.01%	0.00%	0.24%	0.00%	1.58%	0.00%	0.00 %	0.12%	17.34%	79.71%

Absolute (ha) and relative (%) transition matrices in 1990-2018 for EWE in the Steppic Region (based on 2 EWE in 2022 in Romania)

FROM \ TO	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Scrub and/or herbaceous vegetation associations	296.0	264.1
Wetlands and Water bodies	1590.0	11741.5

FROM \ TO	Scrub and/or herbaceous vegetation associations	Wetlands and Water bodies
Scrub and/or herbaceous vegetation associations	0.5	0.5
Wetlands and Water bodies	0.1	0.9