ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by

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Characterization of Ecological Vulnerability to Wildfires based on the Fire patterns on a global scale

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Keywords

Vulnerability, Wildfires, Ecological Vulnerability to Fire, Global, GIS

Abstract

Fire is a natural phenomenon that has played a critical role in transforming the environment and maintaining biodiversity at a global scale. However, the plants in some habitats have not developed strategies for recovery from fire or have not adapted to the changes taking place in their fire regimes. Maps showing ecological vulnerability to fires could contribute to environmental management policies in the face of global change scenarios. The main objective of this work is to characterize the ecological vulnerability to fires based on how fires occur on a global scale. For this purpose, we are going to create zonal statistics by biome and by vulnerability category, finding out the average data of the different fire variables. For this, we have taken two spatial databases previously developed by us, Ecological Vulnerability to Wildfires and Wildfires Characteristics. Ecological Vulnerability to Wildfires is a global database that categorizes spatial vulnerability by ecoregion. Wildfire Characteristics collects global spatial mean data on recurrence, seasonality, patch size, and interannual variability. The results show that in areas with High/Very High vulnerability of tropical and subtropical biomes, fires are not very intense, with a small patch size and low interannual variability, but are highly recurrent and with extensive seasonality. The most vulnerable areas of the Mediterranean biome have more intense fires, with a considerable patch size and, in addition, they present considerable interannual variability, little recurrence and limited seasonality. Temperate forest biomes present their most vulnerable areas with moderate intensity, patch size and recurrence fires, but with high interannual variability. The most vulnerable areas of the montane grasslands biome show highly recurrent fires, with extensive seasonality, with moderate patch size, intensity, and interannual variability

1. Introduction

Fire is a natural phenomenon that has played an important role in the transformation of the environment and the maintenance of biodiversity on a global scale. It can have numerous positive and negative impacts. Most of the world's terrestrial habitats where fires occur depend on them for ecological sustainability. (Kirkman et al., 2001; Midgley & Bond, 2015). Fire can affect the distribution of habitats, carbon and nutrient fluxes, and the water holding properties of soils (Bowman et al., 2009). In habitats that are adapted to and even dependent on fire exclusion policies, this can result in a decrease in biodiversity (Guyette et al., 2002). In addition, the absence of fire results in increases in fuel loads (Bond et al., 2005), which frequently augment the risk of catastrophic fires over time. Fire has also been and continues to be used by humans as a crucial tool for managing terrestrial ecosystems, producing cultural landscapes that also benefit ecological health (Caprio & Graber, 2000; Guyette et al., 2002).

On the other hand, there are some habitats, such as moist tropical forests, that have never adapted to fires. The introduction of fire by humans can lead to an irreparable loss of their structure and composition (Cochrane & Laurance, 2002). Even in fire-adapted areas such as the Mediterranean ecosystems, recent human and climate related changes in fire regimes are having negative impacts on the functioning of ecosystems (Bajocco et al., 2011; Midgley & Bond, 2015). The increasing frequency and intensity of fires can have negative impacts on forest masses and landscapes, human life, infrastructures and ecosystem services and wildlife; and can cause changes in regeneration dynamics, hydrological regimes and air quality, among other environmental consequences on a global scale (Alcasena et al., 2016; Barrio et al., 2011; Buhk et al., 2007; Díaz-Delgado et al., 2002; Flannigan et al., 2009; Hobson & Schieck, 1999; Moreira et al., 2011; Scott & Van Wyk, 1990). As a result of this process of change, forest fires have become one of the main environmental problems today at both global and local levels.

This means that fires must be included in global and regional assessments of vulnerability to global change (Houghton et al., 2001; Lindner et al., 2010). Furthermore, fire risk assessment should be carried out spatially in order to design and implement prevention strategies that enable the conservation of the ecological value of ecosystems and landscapes. When fires happen, assessments of this kind can also be useful for implementing post fire strategies to bring about the recovery of pre-fire ecological values and cultural and socioeconomic assets (Aretano et al., 2015; Chuvieco et al., 2010). In terms of natural hazards terminology, spatially measured fire risk is a combination of ‘danger’ and ‘vulnerability’. ‘Danger’ is defined as the probability of fire occurring in a given place and time, while vulnerability refers to the potential damage that fire could cause to this place (Chuvieco et al., 2007). Vulnerability must include two parts: social and ecological.

There are few attempts to estimate the ecological vulnerability to fire locally or regionally, almost none globally, and none that show how fire occurs in ecosystems that are more or less vulnerable to fires in the world (Turner et al., 2003, Duguy et al., 2012, Aretano et al., 2015, Chuvieco et al., 2010, González, Kolehmainen, & Pukkala, 2007, Duguy & Vallejo, 2008, Giovannini & Lucchesi, 1997, Chuvieco et al. 2014).

In this paper, the main objective of this work is to characterize the ecological vulnerability to fires based on how fires occur on a global scale. This study will be carried out on a global scale so as to enable us to tackle the planetary ecosystem as a whole, unrestricted by governmental or geographic borders. In this way, this research could become an essential tool for decision-making about resource management and nature conservation across the globe.

2. Material and methods

2.1. Study Area

2.1.1.Section 1.1.1

The spatial units used in this study were the terrestrial ecoregions proposed by the World Wildlife Fund (WWF), as corrected in 2017 (Olson et al., 2001). The terrestrial ecoregion concept refers to a land unit large enough to house a set of natural communities composed of different species, dynamics and similar environmental conditions. Thus, ecoregions are a good way to structure ecological and fire information on a global scale, since they are relatively homogeneous in terms of climate and vegetation (Pausas & Ribeiro, 2017). The number of ecorregions and terrestrial biomes were reduced to 554 and 9 (figure 1)in order to exclude lack of data and zones in which forest fire were impossible to occur.

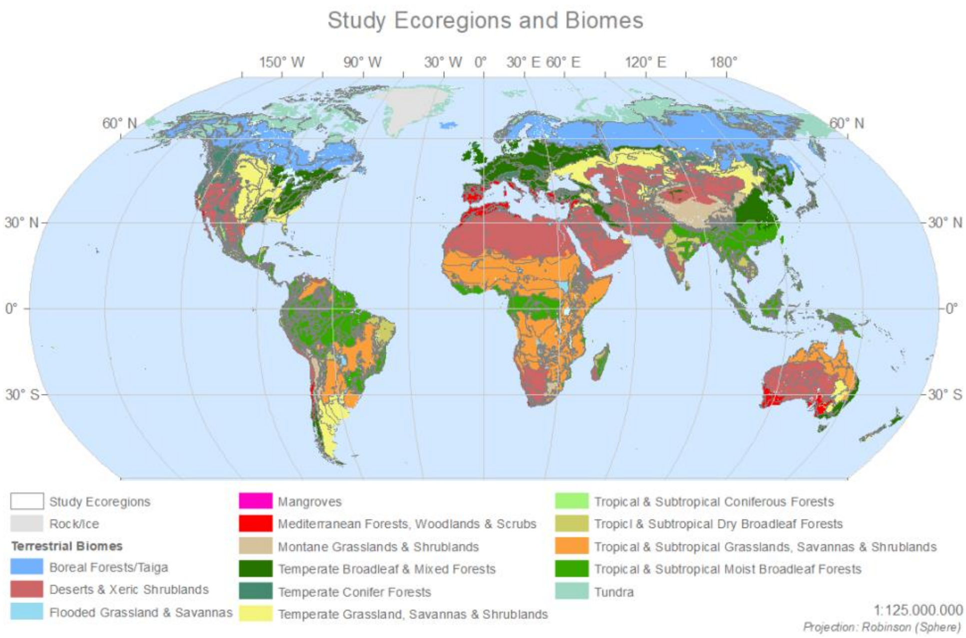

Figure 1. Terrestrial ecorregions within their biome for this study. (Source: The authors).

2.2. Ecological Vulnerability to Wildfires data

Ecological Vulnerability to Wildfire (figure 2) is a categorical spatial database at global scale in which each ecoregion contains a vulnerability category (Arrogante-Funes, F., Aguado, I., & Chuvieco, E. 2021). The categories of ecological vulnerability to fires are: Very High, High, Moderate and Low.

This database keeps in mind two ecological value indices: biological distinction and conservation status. Moreover, for the post-fire regeneration delay index, various factors were taken into account, including the type of fire regime, the increase in the frequency and intensity of forest fires and the potential soil erosion they can cause. These indices were combined by means of a qualitative cross-tabulation to create a new index evaluating Ecological Vulnerability to Wildfire.

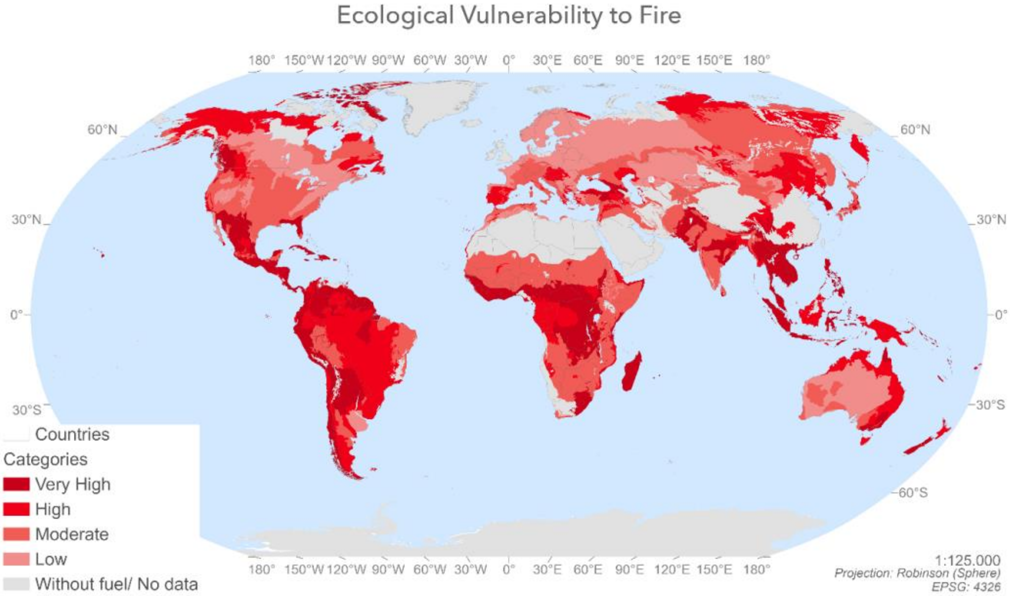

Figure 2- Spatial distribution of the Ecological Vulnerability to Fire.

2.3. Wildfire Characteristics data

Wildfire Characteristic data contain raster information at 0.25 grid for seasonality, recurrence, intensity, interannual variability and patch size, among others (García et al., 2022). This database was developed through the estimation of the mean data for each pixel from the information of remote sensing time series data of the last 20 years.

Seasonality is related to the numbers of months in which there are fire activity. Recurrence variable is the times burn each pixel in wherever part of it. Intensity is relative to the FRP which was estimated in MW through a patch method. Interannual variability measured the variance between patch size for the same zone during the years. Finally, patch size is related to the burned area estimated in km^2. All these variables contain a numeric data base on the mean data for all the time serie.

2.4. Zonal Statistics

Zonal Statistics is an analytical tool specifically for raster datasets used in a several works from different part of the knowledge (Jacox & Samet, 2007). Summarizes the values of a raster within the zones of another dataset and reports the results in a table. It can calculate the mean, median, sum, minimum, maximum, or range in each zone (Theobald, 2005).

Since we wanted to find the fire pattern for each vulnerability category by biome, we were able to use a zonal operation like this one. By using a Wildfire Characteristics raster as its value field, we were able to zone the Ecological Vulnerability to Wildfires categories by biome with the mean function. This process was computed by each fire variables previously cited.

3. Results

The Table 1 shows the results of the tool Zonal Statistics as a table with the mean data of each fire variable by ecological vulnerability to wildfires by biome. Red to green shows from lowest to highest values per column.

The results show that in areas with High/Very High vulnerability of tropical and subtropical biomes, fires have a high recurrence in addition to having an extensive seasonality. On the contrary, in this area the fires present low intensity, patch size and interannual variability.

The most vulnerable areas of the Mediterranean biome have more intense fires, with a considerable patch size and, in addition, they present considerable interannual variability, little recurrence and limited seasonality.

Temperate forest biomes present their most vulnerable areas with moderate intensity, patch size and recurrence fires, but with high interannual variability.

The most vulnerable areas of the montane grasslands biome show highly recurrent fires, with extensive seasonality, with moderate patch size, intensity, and interannual variability.

Table 1. Zonal Statistics as a Table with the mean function by each variables of fire inside the vulnerability categories belong per biome.

Biome	Vulnerability	Intensity (MW)	Patch Size (km2)	Recurence	Seasonality	Interannual Variability
Tropical & Subtropical Moist Broadleaf Forests	Very High	16.75	3981296.70	12	2.28	1.50
	High	21.05	3361362.99	12	2.46	1.44
	Moderate	20.85	4013734.70	11	2.36	1.55
	Low	12.08	4200226.87	14	2.51	1.14
Tropical & Subtropical Dry Broadleaf Forests	Very High	15.43	4522950.77	14	2.56	1.20
	High	22.34	4871753.71	14	2.81	1.35
	Moderate	21.11	4782870.58	11	2.20	1.66
	Low	8.19	2383960.00	8	1.75	1.89
Temperate Broadleaf & Mixed Forests	Very High	29.02	3723493.83	9	1.94	1.91
	High	22.31	5856315.89	10	2.15	1.86
	Moderate	24.29	3611295.52	10	2.12	1.69
	Low	19.09	2723740.31	12	2.43	1.54
Boreal Forests/Taiga	High	40.89	6166993.93	4	1.21	2.83
	Moderate	28.75	6147535.21	7	1.50	2.57
	Low	33.42	4210554.66	6	1.46	2.39
Tropical & Subtropical Grasslands, Savannas & Shrublands	Very High	20.15	8465814.33	17	2.87	0.61
	High	26.91	17008916.42	15	2.90	1.14
	Moderate	20.74	14132522.44	16	2.81	0.85
	Low	34.90	53263661.98	13	2.75	1.42
Temperate Grasslands, Savannas & Shrublands	Very High	34.72	3725854.74	11	2.30	1.56
	High	28.05	11980557.07	11	2.03	1.70
	Moderate	31.01	7567717.30	13	2.45	1.43
	Low	33.02	13497352.38	12	2.60	1.57
Montane Grasslands & Shrublands	Very High	26.73	5511734.67	13	2.82	1.36
	High	21.70	5547367.75	7	1.50	2.35
	Moderate	22.56	6219529.26	12	2.27	1.40
	Low	19.34	5042101.76	13	2.53	1.08
Mediterranean Forests, Woodlands & Scrub	Very High	41.08	5853423.54	11	2.19	1.66
	High	49.90	8364480.94	8	1.78	2.14
	Moderate	32.38	5039767.41	10	2.26	1.74
	Low	39.60	6076207.53	8	1.69	2.08
Deserts & Xeric Shrublands	Very High	21.91	6648254.38	10	2.29	1.67
	High	48.13	29316209.02	9	1.98	1.97
	Moderate	42.79	31419710.55	8	1.82	2.07
	Low	53.21	40374872.73	9	2.09	1.99

4. Discussion

Tropical & Subtropical Dry Broadleaf Forests and Moist Broadleaf Forest are biomes in which the origin of the fire may be due to the human being due to the low values of intensity, patch size and interannual variability, and due to the high values of recurrence and seasonality as in the case of Tropical & Subtropical Grasslands, Savannas & Shrublands (Crochane & Laurance, 2002). In addition, all the categories of ecological vulnerability to fires present similar values.

With Xeric Shrublands, the opposite of the previous case occurs since its origin could be natural and therefore said vegetation coexisted with fire, developing a vegetation with greater adaptation to fire (Moreira et al., 2011).

In the case of the Mediterranean forests, the fires are motivated by the periods of summer drought due to the highest values of intensity and interannual variability of the fire, while it presents lower values in the variables of recurrence and seasonality (Alcasena et al., 2016; Barrio et al., 2011; Bhuk et al., 2007)). In addition, it is more notable in the high and very high categories of the ecological vulnerability index, for which this biome could see its most outstanding ecological values affected (Diaz-Delgado et al., 2002).

In the case of biomes belonging to temperate zones, broadleaf and mixed forests are related to lower values of intensity, patch size, recurrence and seasonality, unlike what occurs in their grasslands, savannas and shrublands zones. This is generalized for all categories of ecological vulnerability to forest fires.

5. Conclusions

This is a first exploratory analysis of fire variables and ecological fire vulnerability categories.

Zonal statistics is a good tool for the spatial data of this work.

There are slight differences between the vulnerability categories within the biome for the various fire variables. The values are homogeneous within the biome.

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