Large scale eucalypt plantations associated to increased fire risk

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To satisfy the high timber demands of human society, forest plantations, especially with fast growing species like pines and eucalypts, are increasing worldwide. In some European countries, the number of wildfires has been augmenting since the second half of the XX century, in parallel with these tree plantations. The record for wildfires in Europe is paradoxically found in the NW of the Iberian Peninsula, a region where broadleaved *Quercus* forests are the potential climax vegetation, with a humid climate, unfavourable for fire occurrence. The ecological and forestry literature have analysed fire occurrence with complex models of fuel accumulation and vegetation structure, combined with no less complex climatic models to explain why this region has such a high fire occurrence. Economists have concentrated on the relationship between income and fire. Historians, sociologists and political scientists have long ago demonstrated that several conflicts over land use and property are behind most wildfires in this region, but there is little interaction between these fields. Here I use official statistics about fire frequency and wood production to test whether fire frequency is associated to the use of pyrophytic species. I found that fire frequency in NW Spain can be predicted by the amount of eucalypt biomass accumulated in forest plantations. I further explore the relationships between intensive sylviculture and fire risk at a regional scale (the North of the Iberian Peninsula) and a large scale, the Mediterranean countries. NW Iberia peasants have traditionally used fire to manage their common lands, and used the same techniques to oppose forest policies implemented by Franco's dictatorship, which continued until now with little changes. The use of highly pyrophytic species like eucalypts and some pines has exacerbated this problem, as suggested by the positive correlation between eucalypt plantations and fire frequency at the local, regional and Mediterranean scales.

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Abstract

To satisfy the high timber demands of human society, forest plantations, especially with fast growing species like pines and eucalypts, are increasing worldwide. In some European countries, the number of wildfires has been augmenting since the second half of the XX century, in parallel with these tree plantations. The record for wildfires in Europe is paradoxically found in the NW of the Iberian Peninsula, a region where broadleaved *Quercus* forests are the potential climax vegetation, with a humid climate, unfavourable for fire occurrence. The ecological and forestry literature have analysed fire occurrence with complex models of fuel accumulation and vegetation structure, combined with no less complex climatic models to explain why this region has such a high fire occurrence. Economists have concentrated on the relationship between income and fire. Historians, sociologists and political scientists have long ago demonstrated that several conflicts over land use and property are behind most wildfires in this region, but there is little interaction between these fields. Here I use official statistics about fire frequency and wood production to test whether fire frequency is associated to the use of pyrophytic species. I found that fire frequency in NW Spain can be predicted by the amount of eucalypt biomass accumulated in forest plantations. I further explore the relationships between intensive sylviculture and fire risk at a regional scale (the North of the Iberian Peninsula) and a large scale, the Mediterranean countries. NW Iberia peasants have traditionally used fire to manage their common lands, and used the same techniques to oppose forest policies implemented by Franco's dictatorship, which continued until now with little changes. The use of highly pyrophytic species like eucalypts and some pines has exacerbated this problem, as suggested by the positive correlation between eucalypt plantations and fire frequency at the local, regional and Mediterranean scales.

Keywords: wildfires, forest plantations, social conflicts, pyrophytic species, Iberian Peninsula, Mediterranean countries.

Introduction

Global wood harvesting in 2005 amounted to 3.4 billion m^3, of which about 60 percent was industrial roundwood and 40 percent fuelwood (FAO, 2006). To satisfy these timber needs, forest plantations, especially with fast growing species like pines and eucalypts, are intensively managed, and planted outside their native range. Exotic species account for about 25% of world tree plantations, amounting however to 77% in Oceania, over 80% in Central and South America and almost 100% in Eastern and Southern Africa (FAO, 2010). The ecological, social and economic impacts of these large and intensive plantations are not well understood (Spence, 2001), but industrial forestry has clear negative impacts on biodiversity (Hunter, 1990; Calviño-Cancela, Rubido-Bará & van Etten, 2012; Almeida et al., 2016), the water cycle (Jackson et al., 2005), forest-dependent human societies (Hammond, 1997) and ecosystem services (Cordero-Rivera, 2012). Nevertheless, tree plantations are able to produce large amounts of wood in short times, and are therefore justified in economic terms (Brockerhoff et al., 2013), and might reduce the pressure to obtain wood from forests. Careful design of multi-purpose plantations could provide some of the ecosystem services which monocultures do not provide (Paquette & Messier, 2010).

From a mechanistic point of view, fire risk is related to type of fuel and accumulation (biomass), dry, hot and windy weather and a source of ignition. Land managers are able to reduce the impact of wildfires by extinguishing them as soon as possible, and a large amount of funds are used for these activities. This reduces the area burned. Nevertheless, fire frequency is much more difficult to manage, particularly if climatic or social factors are prevalent.

In the Iberian Peninsula, many authors have shown that particular climatic conditions are clearly related to the severity of wildfires (Pereira et al., 2005; Carracedo Martín et al., 2009). Another approach to the problem highlights the sociological reasons behind fire ignition, associated to rural activities like pasture management (Carracedo Martín et al., 2009), conflicts over land property (Seijo, 2005; Cabana Iglesia, 2009), or between rural and urban interests (Balsa-Barreiro & Hermosilla, 2013). Over 90% of fires are human-provoked in some Iberian regions (Varela García, 2006). Yet research has also shown that not all vegetation types are equally likely to burn, and some like native *Quercus* forests of deciduous broadleaved species seem to be the least fire-prone (Moreira et al., 2009; Calviño-Cancela et al., 2016). Highly flammable tree species like some pines and eucalypts (Figure 2) have been associated to increased fire risk (Shakesby & Doerr, 2006; Taylor et al., 2017). Nevertheless, timber industries and their foresters strongly negate any relation between the species of tree planted and fire risk, arguing that, given that fires are provoked by peasants, industrial tree plantations do not increase fire risk or even decrease that risk because people do not burn profitable lands (ENCE, 2009). Analyses of fire frequency and vegetation types are therefore needed to identify causal factors and find possible solutions.

There are conspicuous differences in fire frequency between regions, even in cases where they share similar climate. In Europe, Spain and Portugal are the regions most devastated by wildfires in the last 30 years (Schmuck et al., 2015; Turco et al., 2016), and Galiza, the "Switzerland of Spain" (Meakin, 1909), a region under mild and humid Atlantic climate (NW of Iberia), holds surprisingly the record for wildfires in Europe, together with Northern Portugal (Pereira et al., 2005). In August 2006, widespread wildfires pushed the region into the headlines, and induced an European Parliament Resolution (European Parliament, 2006), highlighting that "by 14 August 2006, 88,473 hectares were affected, leading to 4 deaths, injuring 514 people, killing livestock and wildlife and causing considerable material and ecological damage, including 17 Sites of Community Importance (SCIs)". Figure 36 in the report "Forest fires in Europe 2006" shows dramatically how intense that fire episode was (Barbosa et al., 2007). The economic damages from these fires to Galician economy have been estimated in 300 million euro (Barrio, Loureiro & Luisa, 2007). Furthermore, in autumn 2006 very intense rains produced strong erosion and floods in the same previously burned areas, with extensive damage to several cities (Díaz-Fierros, 2006), which promoted social and political debates. More recently, severe wildfires have occurred in Chile in January 2017, killing 11 people and destroying one town (https://en.wikipedia.org/wiki/2017_Chile_wildfires), and in June 2017 in Central Portugal, producing at least 64 deaths and 204 injured people (https://en.wikipedia.org/wiki/2017_Portugal_wildfires). These three episodes have a common line: all these areas are dominated by intensive plantations of *Eucalyptus globulus* (sometimes accompanied by pines).

Here I use official statistics about fire frequency and wood production to test ecological hypotheses about fire risk and frequency, and show that fire frequency in NW Spain can be predicted by the amount of eucalypt biomass accumulated in woodlands. I further explore the relationships between intensive sylviculture and fire risk at a regional scale (the North of the Iberian Peninsula) and a large scale, the Mediterranean countries.

Methods

Official statistics on fire frequency and burned area are published in yearly reports by the Spanish Government since 1968, with some data available since 1961. The last report summarizes data from 2012 (Cubo María et al., 2014). Three scales of analyses are included in this study. First, at a local scale, I compiled the number of fires reported for Galiza (provinces of A Coruña, Lugo, Ourense and Pontevedra; see Figure 1). Second, at a regional scale further 19 provinces in the Northern third part of Spain were studied (Figure 1; Asturias, León, Zamora, Cantabria, Palencia, Valladolid, Burgos, Biscay, Gipuzkoa, Álava, La Rioja, Soria, Navarra, Zaragoza, Huesca, Barcelona, Girona, Lleida and Tarragona). The three Basque provinces (Biscay, Gipuzkoa and Álava) are here treated as a single province, given that individually they represent about one third of the area of the remaining provinces. The final number of units of analysis in the regional study is in total 21 provinces. From fire reports, I compiled data on burned area by species groups per province (eucalypts, coniferous and total woodland burned). The precipitation during winter has been shown to be –weakly– positively related to burned area in Northern Portugal, and spring and summer precipitation show negative correlations with burned area (Pereira et al., 2005). It is reasonable to expect that rainy weather reduce fire frequency. Therefore, to test for climatic effects on fire frequency at the local scale, data on annual rainfall, winter (January-April), May and summer rainfall (June-September) of one typical Galician locality (Lourizán; 42º 24' N, 8º 39' W, 60 m altitude) were compiled from the Galician meteorological information service (www.meteogalicia.es) for the period 1985-2012.

National Forest Inventories in Spain provide data on biomass per species and are available for 1972, 1986, 1998 and 2009 in the case of Galiza. I compiled the volume of eucalypt wood estimated in these inventories for Galician provinces and related these values to the number of wildfires recorded in the six years before each inventory. If pyrophytic species contribute to fire frequency, I expect a positive correlation between eucalypt biomass and fire frequency.

Data on wood removals were obtained from the yearly reports of the Spanish National Institute of Statistics (Anuario Estadístico de España, available at www.ine.es), for the period 1961-2013. I compiled the total amount of wood harvested, and how much was from eucalypts and coniferous species, per province and year. No data were available for the years 1977, 1987 and 1997.

For the large scale study, I compiled the number of wildfires for the decade 1991-2001 from FAO statistics (www.fao.org), available for European countries. Additionally, data for the same European countries and also Morocco and Algeria are available for the period 2011-2014 at European reports (Schmuck et al., 2015). The area of eucalypt plantations in Mediterranean countries was obtained from the compilation by Iglesias Trabado & Wilstermann (2008), ranging from zero in Albania, Bosnia & Herzegovina, the former Yugoslav Republic of Macedonia, Croatia, Cyprus, Greece, Romania and Slovenia to the maximum of 647,000 ha in Portugal.

Some authors indicate that the number of fires was under-recorded in the 1960s and 1970s in Spanish fire statistics (Cabana Iglesia, 2009; Gómez-Armisén & Úbeda, 2015), and similar claims have been made for Portuguese statistics (Pereira et al., 2005). Others indicate that criteria to report a fire have changed over time (Turco et al., 2016). These facts have to be taken into account when discussing temporal patterns.

The number of fires per year does not follow a normal distribution. The best way to approach a normal distribution proved to be a Box-Cox transformation, which was used for all statistical tests, although plots show the untransformed variables. I used regression analyses to test for possible relationships between variables. Proportions were converted using the angular transformation. Statistical analyses were done with xlStat 2016 (www.xlstat.com) and Genstat 18th edition (GenStat, 2015).

RESULTS

Local scale: wildfires and eucalypt plantations in Galiza (NW Iberian Peninsula)

Wildfires in Galiza have been increasing since the 1970's, when the mean was 1,700 fires/year, to 10,600 fires/year in 2000-2005, but recent years show a change in tendency to a lower number of fires, with an average of 4,300 fires/year in 2006-2012 (Figure 3A). This region has had the maximum fire frequency of Spain (and Europe): Fluctuations in the number of fires in Galiza explain the variability of fires per year in the whole Spain, even if Galiza only represents 10% of woodland of Spain ($r=0.95$, $p<0.001$), illustrating how relevant this region is over the total fire risk in Spain (Fig. 3A). Burned area does not show a clear temporal tendency (Fig. 3B), and the values have been greatly minimised by an increase in extinction costs since 1990, but again Galician and Spanish values are highly correlated ($r=0.64$, $p<0.001$).

In the last 50 years, the amount of wood harvested in Spanish woodlands has augmented by a factor of three (Carreras & Tafunell, 2005), which indicates that forests and plantations are increasing. All else being equal, an increase in biomass accumulation should be positively related to fire frequency. In agreement with this, the correlation between yearly wood removals and number of fires in Galicia for the period 1961-2012 is 0.68 ($p<0.001$). However, if eucalypt plantations contribute extra risks associated to fire frequency, then we expect a positive relationship between the proportion of eucalypt wood harvested and fire number, i.e. how much abundant are eucalypt plantations in the region. This relationship is positive for Galiza as a whole ($r=0.67$, $p<0.001$) and also in each of the three coastal provinces (A Coruña, Lugo and Pontevedra) where eucalypts now represent 40-80% of wood harvested (Table 1; Figure 4). In the province of Ourense, eucalypts are rare due to the cold winters (currently less than 5% of wood harvested), but even there the correlation is surprisingly high ($r=0.69$, $p<0.001$; Figure 4).

One can argue that the amount of eucalypt wood harvested each year is the consequence of fire and not the opposite. If that were the case, then there should be a positive relationship between the surface of woodland affected by fires and the amount of eucalypt wood harvested the same year. Nevertheless, this relationship is marginally negative ($r=-0.28$, $p=0.078$) and remains similar if one-year of delay is allowed for wood harvesting (r=-0.29, p=0.065). Therefore, eucalypt wood harvested does not increase with the surface of woodland burned.

To further test the strength of the putative causal relationship between eucalypt plantations and fire risk, I used the four direct estimations available of eucalypt biomass (mostly *Eucalyptus globulus*) in Galician plantations from National Forest Inventories, from 1972 to 2009. I related these values to the number of fires in the 6-year period ending at each inventory date, and found that eucalypt biomass explains 50% of variance in the number of wildfires (Figure 5). There is a positive relationship between the accumulated eucalypt biomass and number of wildfires, but a change of tendency appears in the last period analysed.

Climatic variables are expected to explain part of variability in fire number. The only marginally significant correlations are negative –as expected– between total land burned and May (r=-0.36, p=0.060) and summer precipitation (r=-0.36, p=0.063). All correlations between fire number and the precipitation of the year, spring or summer are not significant (all correlations <0.3, p-values ranging 0.165 to 0.762). A multiple regression analysis with the number of fires per year as the response variable and precipitation variables (May and summer) and the proportion of eucalypt and coniferous wood harvested as predictors (and first level interactions) confirms that climatic variables explain little variability in fire number. The only effect with a p-value lower than 0.05 included in the model is the interaction term between the proportion of eucalypt and coniferous wood (coefficient 1.321±0.566, p=0.033).

Regional scale: wildfires and eucalypt plantations in the North of Spain

Given the positive correlations between eucalypt abundance and fire frequency in Galiza, I predicted that the same relationship should be found in other provinces where eucalypts are being planted at a large scale. This is the case for Asturias and Cantabria (Figure 4). The number of wildfires per province and the proportion of eucalypts and coniferous wood is summarized in Table 1 for the period 1968-2012. There are clear differences among provinces, and those with higher proportion of eucalypt wood harvested are also among those with higher number of fires. All provinces where eucalypts are more than 20% show positive correlations between fire frequency and eucalypt wood. Provinces with higher than average fire frequency but no or few eucalypts show positive correlations between coniferous wood and fire frequency (León, Zamora and Navarra). A detailed analysis by decades indicates that the number of fires has increased with the proportion of eucalypt wood in all periods (data not shown). For the last period (2001-2012), Figure 6A shows that the number of fires is positively related to the proportion of eucalypt wood harvested (r=0.62, p=0.003). The relationship with the proportion of pyrophytic wood (eucalypts and coniferous) is positive but not significant (r=0.34, p=0.138; Figure 6B).

For the period 1990-2012, I analysed the number of fires per year with a linear mixed model, including the proportion of eucalypt and coniferous wood as predictors and year and province as random terms (to account for variability in time and space). Results indicate that only the proportion of eucalypt wood has a significant positive effect (coefficient= 0.515±0.198, p-value to enter in the model=0.004), whereas the proportion of coniferous wood has a negligible effect (coefficient= -0.066±0.079, p-value=0.406).

Large scale: wildfires and eucalypt plantations in the Mediterranean countries

There is a positive relationship between fire number per year and the surface of eucalypt plantations in the Mediterranean countries, both during 1991-2001 (r= 0.67, p=0.008) and 2011-2014 (r= 0.61, p=0.026; Figure 7). Examination of the plot in Figure 7 suggests that the correlation is mainly due to Spain and Portugal, whose yearly variation in fire frequency is completely different to the other large Southern European countries (France, Italy and Greece; Figure 8).

DISCUSSION

The results of my analyses indicate that large scale eucalypt plantations, and, to a lesser degree other pyrophytic species, are associated to an increase in fire frequency at the local, regional and Mediterranean scale. Given that this is a correlative study, cause-effect conclusions cannot be made. We should therefore ask, how could tree plantations promote fire? Three conditions are needed for a wildfire to occur: fuel (biomass accumulation), favourable weather (dry and windy)

(Pereira et al., 2005) and a source of ignition (usually, the human component). If pyrophytic tree species are planted over large areas, then fire frequency should be related to their extent, and this is what I found (Figures 5 and 7), but certainly other causes are acting jointly.

Galiza produces about 50% of the wood harvested in Spain, with an average of 6.5 million cubic metres in the period 2000-2013. About 40% is *Pinus pinaster* wood and 44% eucalypt wood (Xunta de Galicia, 2012), both highly pyrophytic species. Since 1972 to 2009, eucalypts have increased in the coastal provinces by a factor of six (Figure 5), and over the same period fire frequency in this region reached a maximum (Díaz-Fierros & Baamonde, 2006). To give an idea of the dimension of the problem we can consider that Galiza has 10% of the woodland area in Spain, but about 50% of fires occur there. Furthermore, this is one of the most humid areas in Spain, potentially covered by Atlantic *Quercus* forests, that now occupy less than 1% of their original surface (Fernández, 1994). This is consequently an area where "natural" wildfires should be extremely rare. Therefore, human intervention in the landscape has completely changed the vegetation, promoting large accumulations of pyrophytic fuel. Eucalypts are used almost exclusively by a paper industry, which was forcibly imposed by Franco's dictatorial regime in the 1950s in Pontevedra (Rico Boquete, 1999), the province that holds the record of fires (Table 1). The province of Ourense is a clear outlier at the local scale: it holds the second largest number of fires, but eucalypts represent there only 0.1% of wood (about 5% currently). Nevertheless this province has 93% of pines (mainly *Pinus pinaster* and *P. radiata*), which are as pyrophytic as eucalypts. The high fire frequency of all the region is mainly explained by conflicts over land property (Rico Boquete, 1995a; Seijo, 2005). Given the propensity of peasants to use fire to control vegetation, the use of pyrophytic species at a large scale by the forestry administration was certainly temerarious. This fact was clearly known to Ximénez de Embún and Ceballos, the two foresters who designed the plantation policy during Franco's dictatorship, which were absolutely contrary to the large scale plantation of pyrophytic species in Galiza, but were not given credit (Rico Boquete, 1995b).

The regional analysis confirms a relationship between pyrophytic plantations and fire risk (Table 1): all provinces where eucalypts have been planted at a large scale share high fire frequencies. The province of Cantabria, with the maximum of eucalypt wood, but ranking seventh by fire frequency, illustrates that fire frequency is explained by multiple causes. Cantabria shows positive trends in the period 1985-2011, in contrast to other Spanish regions, where fire number has recently decreased (Turco et al., 2016). This coastal province has a humid climate, unfavourable for fire outbreaks, except during periodic episodes of Southern winds ("suradas"), which occur during winter. In this province most of the fires take place from January to March, and are clearly related to these particular Southern winds and grassland management for livestock (Carracedo Martín et al., 2009). Furthermore, the seven provinces with the highest fire frequency (Table 1) are all in the Northwest of the Iberian Peninsula, and are contiguous to the regions of Portugal where fire frequency is maximum (Moreira, Rego & Ferreira, 2001). This suggests that they share similar sources of ignition (the human component of fire risk). It is interesting to note that the Mediterranean provinces of Catalonia, where fire is more likely, have maintained a similar fire frequency since medieval periods (Lloret & Marí, 2001), and have not been intensively planted with eucalypts.

Most of the wildfires in the Iberian Peninsula are human-induced, but the problem is not simple. Official statistics identify at least 24 motivations behind the fires (Gómez, 2005). Fire needs wood to spread, and therefore, many researchers have indicated that changes in rural life since 1950s, with a progressive ageing of the population and the increased amount of land set aside, are the social explanations for fire outbreaks, favoured by the large accumulation of wood biomass (Moreira, Rego & Ferreira, 2001). Some environmentalist groups have stressed that woodlands have been rapidly transformed into large-scale monocultures of pines and eucalypts, a process begun during Franco's dictatorship in Spain (Rico Boquete, 1995a), and have indicated that these trees are more susceptible to fire and are favoured by repeated wildfires. In fact, *Eucalyptus globulus* is more likely to stablish itself after fire in Portugal and Australia (Larcombe et al., 2013; Águas et al., 2014). Other pyrophytic species, like *Pinus contorta*, also show an increase after fire, and can create positive feedbacks (Taylor et al., 2017). In the case of Galiza, historians have shown that fire was employed as a way to oppose forest policies which usurped common lands, impeding livestock grazing (Cabana Iglesia, 2009), and that these policies were the main cause of a massive emigration and the destruction of rural life during the 1960s (Rico Boquete, 1995a). There is no doubt that forest policy during Franco's dictatorship created a social conflict in NW Spain, which "exploded" as wildfires (Seijo, 2005). The original idea of the afforestation policy was to recover native forests (Rico Boquete, 1995b), but the option of large scale cellulose production with exotic trees was finally implemented, provoking strong opposition by local people, and even deaths in confrontations with the police of the dictator (Rico Boquete, 1995a). If fire was used as a way to oppose afforestation plans, then the conflict should have been maximum in the 1960s and 1970s. Nevertheless, the maximum fire frequency occurred in the 1990s and early 2000s (Figure 3A), although early statistics may be unreliable (Cabana Iglesia, 2007). The decrease in fire number after 2005 might be explained by the disappearance of the generation who suffered the conflict, combined with a series of rainy summers, and a higher environmental sensitivity of the society, as well as increased efficiency in fire control (Rodrigues et al., 2013). If the social factor (conflicts) was preeminent, then we can predict that fire number should remain low in the future, as a consequence of the generational substitution. If climatic variables were the main driver, then fire frequency will be higher in a scenario of climatic change (Turco et al., 2016). Time will tell.

The high incidence of fire in other regions that shared similar forest policies (large scale pyrophytic plantations) and comparable climate and cultural traditions might be explained by the interaction mechanisms between fire frequency and pyrophytic species identified here. Some foresters strongly disagree with this interpretation and indicate that "trees do not burn spontaneously". They argue that species identity has no effect on fire frequency: causes are exclusively social. For instance, a recent analysis of wildfires in Spain does not even mention the fact that eucalypt species have been planted over large areas in Northern Spain, concentrating the discussion about fire causes on the human component (Gómez-Armisén & Úbeda, 2015). Nevertheless, forest ecology has long ago established that some species are adapted to fire, and eucalypts dominate the Australian landscape precisely because wildfires are very frequent there (Caldararo, 2002). In this context, my results confirm the risks associated to intensive forestry of pyrophytic species, especially in regions where fire has been traditionally used to manage land. The 2017 terrific wildfires in Chile and Portugal occurred in areas largely planted with eucalypts. The low number of fires in Italy and France (Figure 8) (Turco et al., 2016), two countries with large regions of Mediterranean climate, which have not planted eucalypts or pyrophytic pines at a large scale, suggests that, together with human culture, tree identity matters.

CONCLUSSION

Eucalypt monocultures have drastic negative effects on animal and plant biodiversity, not only of woodlands (Varela Díaz, 1990; Paiva, 1992; Calviño-Cancela, Rubido-Bará & van Etten, 2012; Calviño-Cancela, 2013), but also of rivers and streams (Graça et al., 2002; Cordero-Rivera, Martínez Álvarez & Álvarez, 2017). Their positive effects as Carbon sequesters are offset by their significant negative effect on the water cycle and water salinity (Jackson et al., 2005). Further, as they are very likely to burn, all Carbon is released in hours, so that they are unlikely to act as long-term Carbon sinks. The analyses presented here indicate that planting eucalypts and pyrophytic pines at a large scale would not only be inappropriate and ecologically unsustainable, it also would significantly increase extreme fire risk. Pyrophytic species are favoured by fires, and fires are also highly favoured by the accumulation of eucalypt and pine biomass, in a mutually promoting mechanism (Taylor et al., 2017). The Galician government has spent between 50 and 65 million euro in fire control each year in the period 2000-2006, which is about 20% of the value of the wood produced (Sineiro García, 2006). Therefore, the economic benefits of these plantations are for private owners, but the costs are shared by all Galicians, who pay for fire control efforts with taxes, and suffer the effects of fires, erosion and floods. This is unfair and seems economically unsustainable. Finally, the eucalypts themselves are unlikely to burn spontaneously: social causes are preeminent behind this high number of human-induced fires, which further suggests that these plantations are also socially unsustainable. Northern and Central Portugal suffer from similar high fire frequencies (Moreira, Rego & Ferreira, 2001; Rodrigues et al., 2013) and the "eucalyptization" of the landscape, with tragic consequences in the summer of 2017. The results presented here suggest that promoting diversification of forest plantations (Brockerhoff et al., 2013) would greatly reduce fire frequency and, presumably, extent. Such a forest policy would also contribute to the long-term conservation of biodiversity and forest ecosystem services (Cordero-Rivera, 2012).

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Years ago, I found myself in front of a wildfire, in a very hot day of summer, and I was able to extinguish it alone, paradoxically using a young eucalypt tree to smite the flames. Nobody was around and the fire was small enough to be controllable by one person. How could it have started? This question was behind this research. This paper is the result of a double frustration. Frustration due to the impotence against wildfires, which are part of my life since my childhood, and frustration because most of the little areas with recovering forests in my province were converted to eucalypt lands in the last decades. I thank María Calviño Cancela, Miguel Ángel de Zavala and Froilán Sevilla for their comments on the ms. Part of this research was funded by a grant from the Spanish Ministry with competences in science, including FEDER funds, whose main goal is to study the effect of tree plantations on streams (CGL2014-53140-P).

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Figure 1

Map of the Iberian Peninsula, with the provinces of Spain.

Galician provinces (sky blue) are the region where the frequency of fires is maximum in Spain. The yellow area indicates the other provinces analysed in this paper. A Coruña: C; Pontevedra: Po; Lugo: Lu; Ourense: Ou; Asturias: As; León: Le; Zamora: Za; Cantabria: Ca; Palencia: Pa; Valladolid: Va; Burgos: Ba; Basque Country: BC; La Rioja: R; Soria: So; Navarra: Na; Zaragoza: Z; Huesca: Hu; Lleida: Ll; Tarragona: Ta; Barcelona: B; Girona: Gi. Source of the map: Wikimedia Commons.

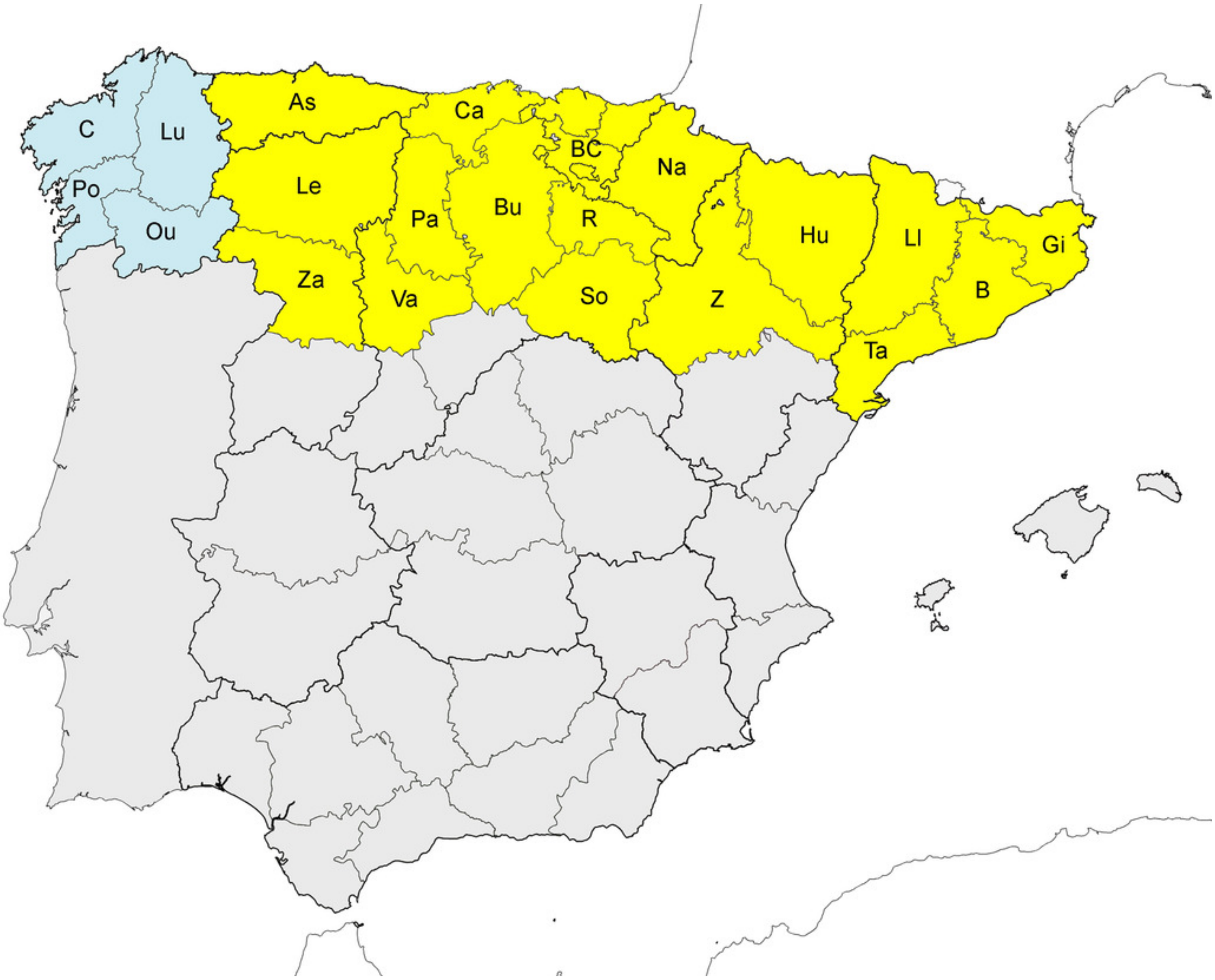


Figure 2

Eucalypt plantations.

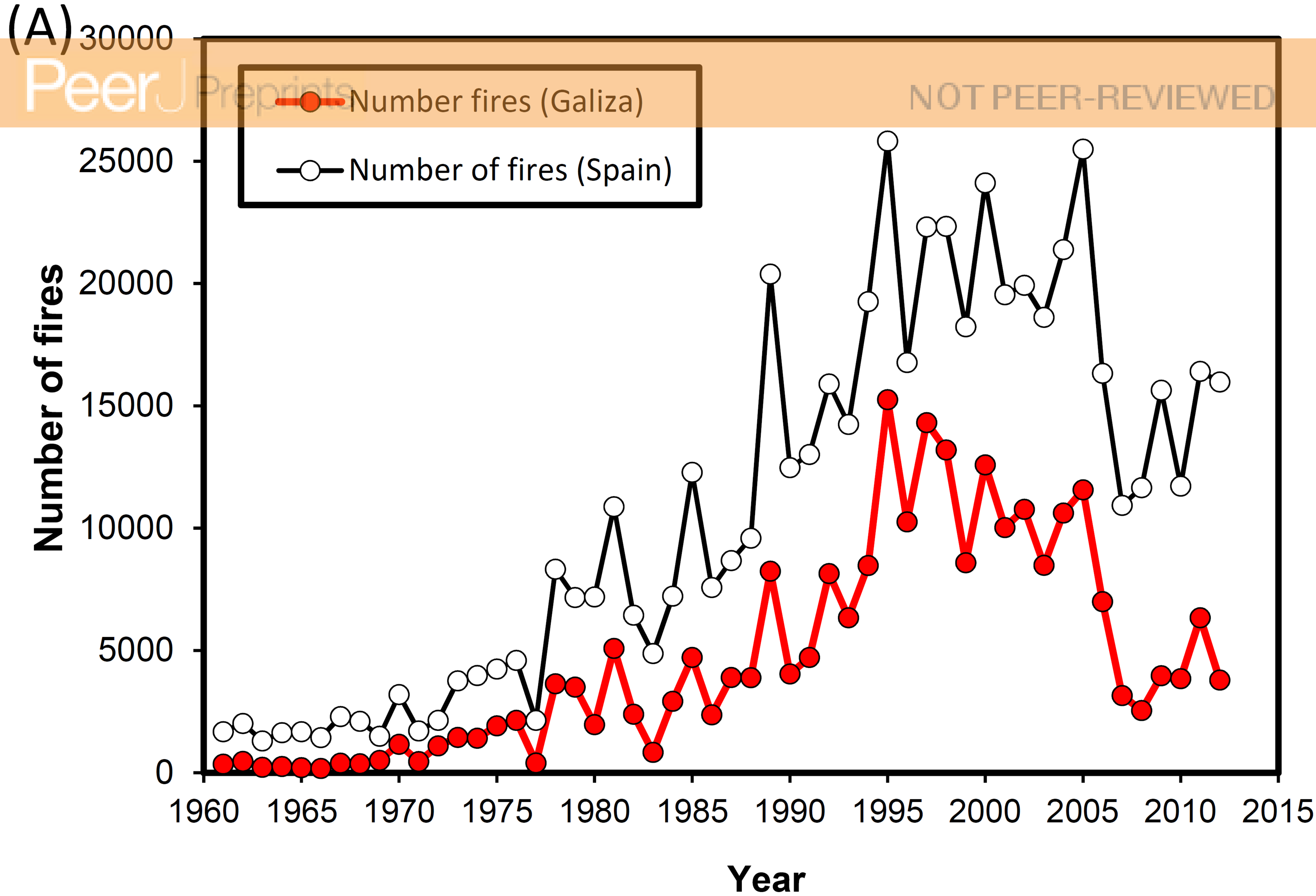
(A) Typical landscape of a Galician plantation of eucalypts (*Eucalyptus globulus*) and pines (*Pinus pinaster*), partially burned. (B) High density of fuel and very reduced diameter of trees is characteristic of most plantations of eucalypts in NW Spain, two facts likely related to fire risk. Pictures by the author.


A
B

Figure 3 (on next page)

Wildfires in Galiza and Spain.

(A) Temporal evolution of the number of wildfires and (B) burned area in Galiza and Spain, since 1961 to 2012


(A)
Number of fires
Number fires (Galiza)
Number of fires (Spain)
30000
25000
20000
15000
10000
5000
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year

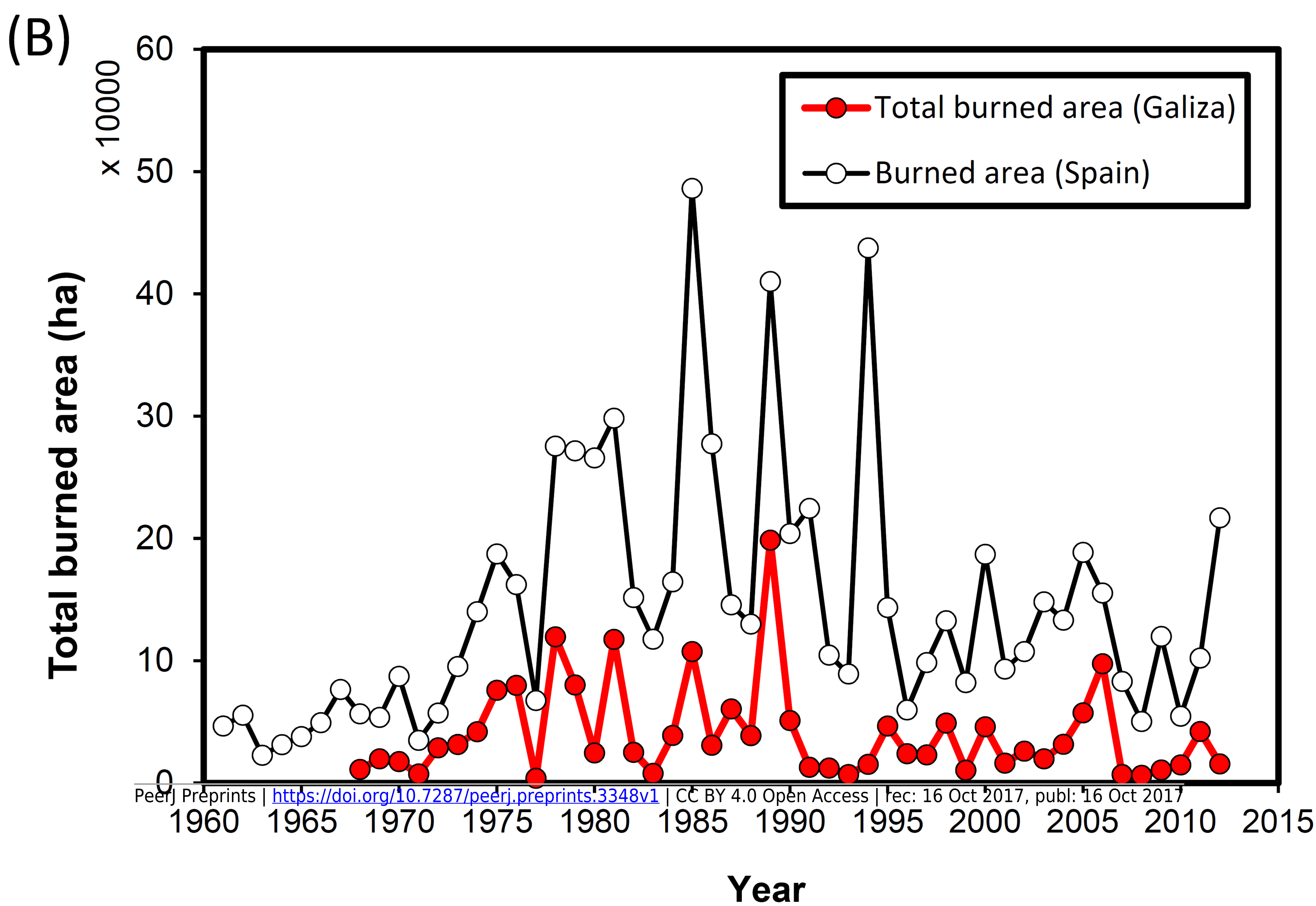

(B)
x 10000
Total burned area (ha)
Total burned area (Galiza)
Burned area (Spain)
60
50
40
30
20
10
0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure 4 (on next page)

The relationship between the proportion of eucalypts over the total wood harvested and the number of wildfires in the four provinces of Galiza, Asturias and Cantabria.

In all cases the correlation is positive.


y = 2989.5x - 30.342
R² = 0.3225
Number of fires per year (A Coruña)
Proportion of Eucalypt wood (m³)
y = 2153x + 147.67
R² = 0.1755
Number of fires per year (Lugo)
Proportion of Eucalypt wood (m³)
y = 90660x + 717.29
R² = 0.5341
Number of fires per year (Ourense)
Proportion of Eucalypt wood (m³)
y = 4606.8x - 90.9
R² = 0.4447
Number of fires per year (Pontevedra)
Proportion of Eucalypt wood (m³)
y = 4514.5x - 1660.7
R² = 0.5229
Number of fires per year (Asturias)
Proportion of Eucalypt wood (m³)
y = 906.44x - 449.45
R² = 0.1086
Number of fires per year (Cantabria)
Proportion of Eucalypt wood (m³)

Figure 5(on next page)

Eucalypts and fire in Galiza (NW Spain).

Temporal variation of eucalypt biomass available in Galician plantations (estimated by four National Forest Inventories) and the number of wildfires in the period of 6 years ending at each inventory. Vertical bars indicate SE.


Eucalypt biomass
Fires
6000
5000
4000
3000
2000
1000
0
14000
12000
10000
8000
6000
4000
2000
0
1970
1980
1990
2000
2010
Date
Eucalypt wood (m^3 with bark)
x 10000
Average number of wildfires

Figure 6 (on next page)

Eucalypts and fire in Northern Spain.

The relationship between (A) the proportion of eucalypts over the total wood harvested and (B) the proportion of pyrophytic species (eucalypts and coniferous) and the number of wildfires in 21 provinces of Northern Spain, for the period 2001-2012.

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(A)
y = 1347x + 365.63
R² = 0.2888
Ourense
Pontevedra
Asturias
A Coruña
Lugo
Cantabria
Number of fires
3000
2500
2000
1500
1000
500
0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of eucalypt wood harvested
(B)
y = 1584x - 660.99
R² = 0.1816
Ourense
Pontevedra
Asturias
A Coruña
Lugo
Cantabria
Number of fires
3000
2500
2000
1500
1000
500
0
0.0
0.2
0.4
0.6
0.8
1.0
Proportion of pyrophytic wood harvested

Figure 7(on next page)

Eucalypts and fire in the Mediterranean.

The relationship between the area planted with eucalypts in 13 Mediterranean countries and the average number of wildfires, for the period 2011-2014. Vertical bars indicate SE.

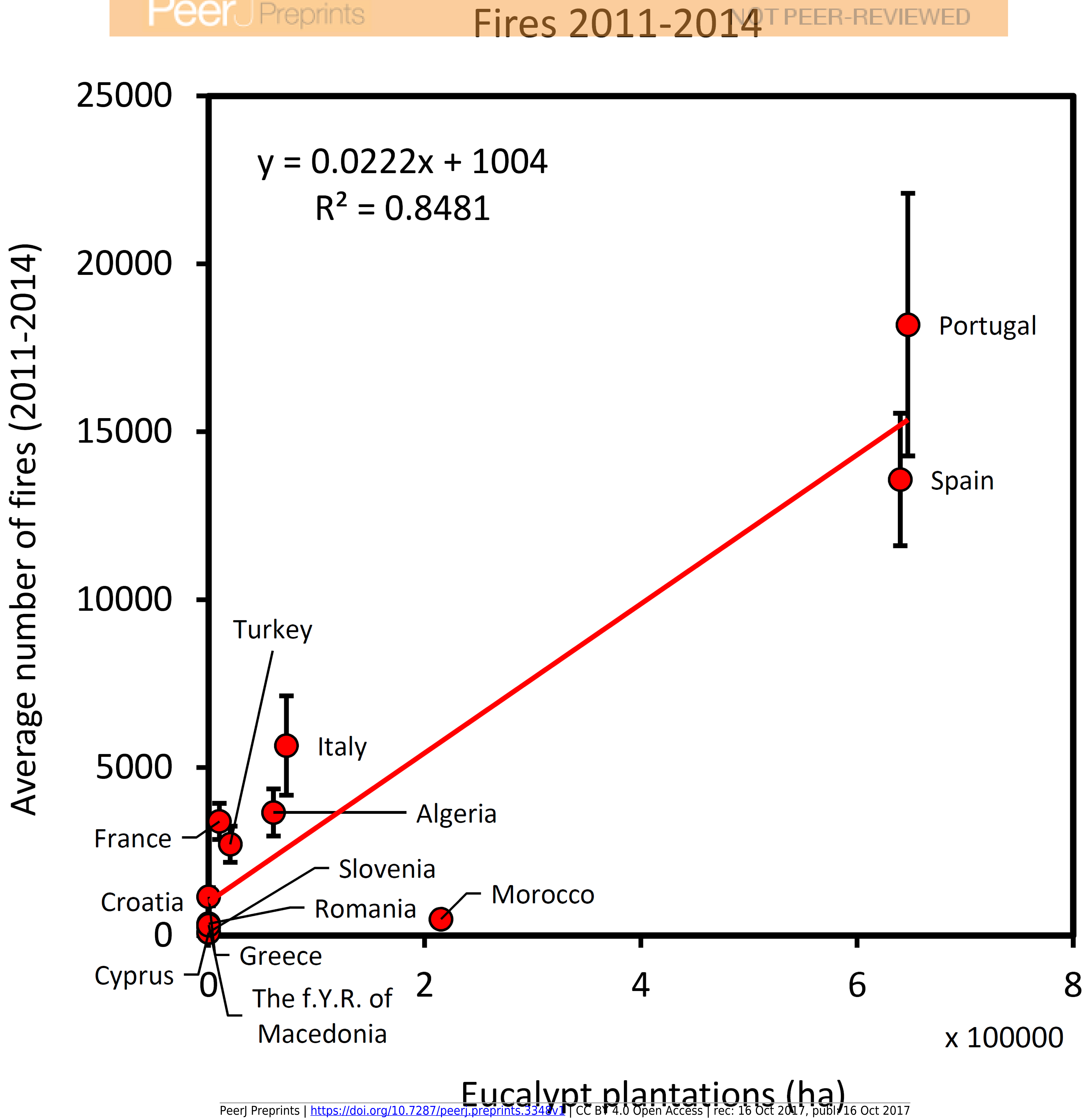
Fires 2011-2014
y = 0.0222x + 1004
R² = 0.8481
Average number of fires (2011-2014)
25000
20000
15000
10000
5000
0
Portugal
Spain
Turkey
Italy
Algeria
France
Slovenia
Morocco
Croatia
Romania
Greece
Cyprus
The f.Y.R. of
Macedonia
0
2
4
6
8
x 100000
Eucalypt plantations (ha)

Figure 8(on next page)

The evolution of fire number per year in five Mediterranean countries between 1980 and 2014.

Note that the two countries with the largest eucalypt plantations (Portugal and Spain) show disproportionate fire frequency, particularly compared to France, which is the largest country. Eucalypt plantations have increased dramatically since the early 1990s in Portugal and Spain.


Portugal
Spain
France
Italy
Greece
Number of wildfires
40000
35000
30000
25000
20000
15000
10000
5000
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014

Table 1(on next page)

Basic statistics of fires

The average number of wildfires per year, standard error (SE), number of years (N), minimum and maximum, the proportion of eucalypt and coniferous wood on wood year removals and coefficients of correlation between fires and those proportions (r). Values in bold are significant at $p<0.05$. Data for 21 provinces of the North of Spain for the period 1968-2012. Provinces are ordered by decreasing number of fires.

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Table 1. The average number of wildfires per year, standard error (SE), number of years (N), minimum and maximum, the proportion of eucalypt and coniferous wood on wood year removals and coefficients of correlation between fires and those proportions (r). Values in bold are significant at p<0.05. Data for 21 provinces of the North of Spain for the period 1968-2012. Provinces are ordered by decreasing number of fires.

Province	Number of fires	SE	N	Min	Max	Proportion Eucalypts	Eucalypts-fire (r)	Proportion Coniferous	Coniferous-fire (r)
Pontevedra	1683.3	175.9	45	154	4717	0.343	**0.673**	0.637	**-0.664**
Ourense	1642.8	220.3	45	78	5317	0.009	**0.694**	0.931	-0.117
A Coruña	1264.2	166.4	45	67	5009	0.372	**0.672**	0.606	**-0.651**
Asturias	897.2	109.7	45	56	2246	0.553	**0.613**	0.297	**-0.594**
Lugo	798.8	92.0	45	38	2465	0.267	**0.623**	0.637	**-0.339**
León	432.6	43.3	45	24	1075	0.000		0.398	**0.565**
Cantabria	318.1	35.0	45	72	1227	0.826	**0.497***	0.123	-0.114*
Zamora	315.4	32.8	45	5	835	0.000		0.396	**0.451**
Navarra	272.9	35.7	37	31	698	0.000		0.453	**0.581**
Barcelona	236.6	15.1	45	47	549	0.001	-0.007	0.898	0.017
Basque Country	189.4	35.6	34	63	1309	0.030	0.104	0.916	0.181
Burgos	145.6	11.6	45	22	400	0.000		0.702	-0.131
Girona	124.2	9.7	45	10	261	0.036	0.277	0.574	-0.106
Tarragona	117.6	8.5	45	19	268	0.000		0.955	-0.145
Zaragoza	99.3	11.7	45	2	276	0.000		0.443	-0.154
Lleida	83.4	7.0	45	6	198	0.000		0.932	**-0.442**
Palencia	81.4	9.6	45	9	323	0.000		0.227	0.294
Huesca	76.2	6.8	45	2	227	0.000		0.802	-0.304
La Rioja	73.7	6.9	45	7	197	0.000		0.273	**0.572**
Valladolid	70.0	5.3	45	15	142	0.000		0.872	-0.260
Soria	47.6	5.1	45	1	156	0.000		0.922	**-0.368**

* The value for 1989 was excluded for the estimation of correlation coefficient, because the number of fires was a clear outlier

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