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Wildfires as collateral effects of wildlife electrocution: An economic approach to the situation in Spain in recent years

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HIGHLIGHTS

- Fauna electrocution can be a cause of wildfire ignition Bird species that caused wildfires were similar to species killed by electrocution.
- For the period 2000–2012 fauna mediated wildfires has an economic cost of €7.6–12.4 M with an estimate of direct CO_2 emissions of 1.8×10^4 tons.
- Corrections of dangerous power lines would reduce the wildfire by electrocution.

GRAPHICAL ABSTRACT

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ABSTRACT

The interaction between wildlife and power lines has collateral effects that include wildfires and Carbon Dioxide (CO_2) emissions. However, currently available information is scarce and so new approaches are needed to increase our understanding of this issue. Here, we present the first analysis of wildfires and their incidence as a result of this interaction in Spain during the period 2000–2012. Amongst the 2788 Power-Line Mediated Wildfires (PLMW recorded) during this period, 30 records of Fauna Mediated Wildfires (FMW) were found, with an average affected vegetation cover of 9.06 ha. Our findings suggest that no significant differences were observed between the amount of affected surface area due to fauna mediated wildfires and power-line mediated wildfires. In both cases, a space-grouping trend was observed. In terms of changing trends over time, after the first incident detected in 2005, the number of incidents increased until 2008, year in which the percentage of wildfires caused by wildlife stabilized at approximately 2.4% of all power-line-induced wildfires. Population density and road abundance were variables that better explained PLMW whereas for FMW, the models that included land use and raptor abundance. In the multivariate model, FMW emergence was positively related with population density, percentage of grazing areas and Natura 2000 cover, and predatory abundance; and negatively with the percentage of forested area. No significant differences were observed between the species of birds that caused wildfires and the species of ringed birds killed by electrocution. The economic and environmental impact due to necessary repairs, the loss of biodiversity and CO_2 emissions represent an estimated net value of €7.6–12.4 M for the period 2000–2012, which indicates the importance of the economic and environmental costs associated with wildfires.

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1. Introduction

The interaction between wildlife and power lines has been extensively researched (Bevanger, 1998; Lehman et al., 2007; Jenkins et al., 2010). The most thoroughly studied aspect of this interaction are the negative impacts on bird population such as mortality due to collisions (Loss et al., 2014), electrocution (Lehman et al., 2007) and, to a lesser degree, forest fragmentation due to power-line corridors (e.g. Kroodsma, 1982; Andrews, 1990). Other affected animals include reindeer, whose migration patterns are disrupted by power lines (Reimers et al., 2007). On the other hand, the most studied positive effect of power lines is the use of pylons by birds as nesting sites (Infante and Peris, 2003; Mainwaring, 2015; Tryjanowski et al., 2014).

Other negative effects of power lines including their electromagnetic fields (Fernie and Reynolds, 2005; Balmori and Hallberg, 2007), changes in species interactions including increases in predator presence and/or prey visibility (Lammers and Collopy, 2007; Dinkins et al., 2012), and bird mortality due to entanglement (Gangoso and Palacios, 2002) have not been comprehensively studied.

Another negative effect that has only ever been poorly studied is the impact of the wildfires caused by electrocuted animals. Although power lines usually cause wildfires when there is electrical contact with nearby trees (Mitchell, 2013), wildfires can also occur when an electrocuted animal begins to burn and falls to the ground (Kagan, 2016). Despite significant negative consequences including the loss of human life in cases such as the 2014 Valparaíso wildfire in Chile (Vargas, 2016), fauna-mediated wildfires are very poorly documented in the literature.

Fire is a natural phenomenon that plays a major role in shaping the environment and maintaining worldwide biodiversity (Shlisky et al., 2007; Kelly and Brotons, 2017). The benefits and impacts of wildfires are far-reaching as the majority of the world's terrestrial habitats depend on fire for their ecological sustainability. Fire determines the distribution of habitats, carbon and nutrient fluxes, and soils properties (DeBano et al., 1998). However, >20% of all terrestrial ecoregions experience altered fire regimes due to direct fire suppression or human-caused ignitions that lie outside the range of natural variation (Shlisky et al., 2007). The human alteration of fire regimes can contribute to provide a pathway for harmful invasive species, change regional hydrology, accelerate ecosystem transformations caused by long-term climate change (Kershaw et al., 2002; Shlisky et al., 2007), and directly threaten biodiversity and human habitation and security (Bardsley et al., 2015).

The Mediterranean Basin is one of the world's richest places in terms of animal and plant biodiversity (Cuttelod et al., 2009) and fire has been one of the major drivers shaping its landscape for millennia (Blondel and Aronson, 1999; Fernandes et al., 2013; Moreno et al., 2014). Nevertheless, in the previous century the fire regime changed sharply and it is now regarded as one of the main threats to environmental conservation by some authors (Moreira and Russo, 2007; Syphard et al., 2009). Accordingly, major efforts have been devoted to prevention, management and extinction (Vélez, 2000; Parente et al., 2016). Over the past 35 years, >15.8 million ha have burned in the EU Mediterranean Member States (European Commission, 2015); in Spain alone, 2.3 million ha of forestlands burned in 1981–2013. This is particularly worrying given this country's populations of endemic species such as the Spanish imperial eagle (*Aquila adalberti*) and the Iberian lynx (*Lynx pardinus*), and of highly threatened species at global level such as the cinereous vulture (*Aegypius monachus*) and Bonelli's eagle (*Aquila fasciata*), all of which are affected directly or indirectly by power lines and wildfires (not necessarily in a negative way, i.e. López-López et al., 2006; Rollan and Real, 2011). At the same time, Spain is one of the countries where most studies of bird deaths due to electrocution (Lehman et al., 2007) and the causes of wildfires (ADCIF, 2002, 2012a) have been performed. This country is thus a good case study for investigating the interaction between wildfires caused by wildlife and power lines.

This study addresses the principal issues arising from the occurrence of wildfires caused by the interaction between wildlife and power lines in Spain (hereafter referred to as fauna-mediated wildfires; FMW). Our main goals are i) to explore this phenomenon by analyzing the characteristics of FMW, ii) to characterise the location of wildfires by type and the presence or absence of a space-grouping scheme; iii) to analyse the factors affecting the occurrence of wildfire types and address the timing of wildfires during the year; iv) to identify the species that cause these events; and v) to examine the economic impact in terms of both the costs of recovery and Carbon dioxide (CO_2) emissions.

2. Material and methods

The study was carried out in Spain (~500,000 km^2) using data for the period 2000–2012 obtained from *Defense Area Against Wildfires* (ADCIF) database, managed by the Spanish Ministry of the Environment (ADCIF, 2014) This database compiles wildfire statistics since 1968 (ADCIF, 2002). This dataset contains the causes of wildfires gathered in broad categories, including wildfires caused by power lines – belongs to the group *Negligence and accidental causes* (ADCIF, 2002). The database of the government administration does not specifically distinguish between fires provoked by electrocuted fauna within the fires caused by power lines. To determine which PLMWs are FMWs, we reviewed all additional information of PLMW considering as FMW those events which included any comment or reference to a bird/animal as the cause of the fire.

Finally, for this study, data from the Canary Islands were not included due to the low number of wildfires ($n = 10$) and absence of FMW in this archipelago.

2.1. Description of FMW and PLMW

We compared the characteristics of FMW and PLMW by taking into account two essential aspects: the total affected forest surface area and the potential for self-regeneration. These data were calculated on a regional basis by technical staff using a standardized methodology and then stored the database. For areas <50 ha, a palmtop GPS was used in the field to measure the affected surface area; for areas >50 ha PNOA orthoimages were used (Spanish National Orthoimage Plan). The potential for self-regeneration was assessed following the method described by ADCIF (2012b), which consists of a qualitative evaluation of the affected surface area capable of self-regeneration without any specific treatment. This assessment considers three levels depending on the recoverable surface area (without treatment): level 1: <30%of the affected surface area; level 2: 30–59%: and level 3: >60%.

2.2. Locations of wildfires by type

We used spatial UTM coordinates to study the spatial distribution of FMW and PLMW. First of all, the spatial coordinates corresponding to the fieldwork conducted regionally and incorporated into the database were checked to detect events (i) with incorrectly entered coordinates, (ii) that took place over 1 km from the Spanish border, or (iii) with multiple coordinates from different years; all such events were deleted.

Additionally, we analysed the percentage of wildfires caused by electrocution in Special Protection Areas (SPA hereafter) and drew an external buffer of 5 km around each such area (Pérez-García et al., 2011).

We investigated the spatial distribution of the FMW and PLMW and assessed their regularity and randomness. We used the G function at 96% (Baddeley et al., 2015) that measures the distance between a given point and the next nearest. If these distances are given by $d_i = \min_j\{d_{ij}, \forall j \neq i\}, i = 1, \ldots n$ then the G function can be estimated as $\hat{G}(r) = \frac{\#\{d_i : d_i \leq r, \forall i\}}{n}$. Using Complete Spatial Randomness (CSR), the value of the G function is $G(r) = 1 - \exp(-\lambda \pi r^2)$ where λ is the strength or average of the number of dots by surface unit. To determine the randomness of the FMW distribution in the PLMW, a complementary analysis was conducted for both FMW and PLMW. The goal of this analysis is to determine if FMW are randomly distributed within PLMW. We employed a dot-marked analysis (Baddeley et al., 2015) using function J and the existence of wildlife interaction or not in a wildfire as the mark. The analysis compares the spatial distribution of the marked points is similar to the unmarked ones, through a visual analysis of a simulated pattern.

2.3. Factors contributing to FMW and PLMW

To determine the factors contributing to the probability of FMW and PLMW occurrence, we used logistic regression models (detailed description of statistical analysis is included in Section 2.7). For each 10 × 10 km UTM cell in 2000–2012, we considered the occurrence of FMW and PLMW as binomial response variables. Number of 10 × 10 km UTM grids used for presence/absence variable was 1326/4079 for PLMW and 28/5377 for FMW. As explanatory variables, we selected 12 environmental variables considered relevant in other studies of wildfires such as human negligence (Bajocco et al., 2010; Bajocco and Ricotta, 2008; Boubeta et al., 2015) and wildlife electrocution on power lines (Mañosa, 2001; Guil et al., 2011; Pérez-García et al., 2017). We built six hypothetical models by grouping similar environmental predictors as a means of assigning a cause: i) topography (altitude), ii) land use, iii) breeding raptor richness, iv) power lines, v) protected area distribution, and vi) human population and roads. A detailed description of all variables is included in Table 1.

2.4. Timing of wildfires

The yearly FMW distribution was studied and compared to that of the PLMW. Relative yearly frequencies for each type of fire were studied using F from the Fisher-Snedecor variance test.

2.5. Prevalent species

The groups of species causing wildfires and those of ringed electrocuted birds were compared. We used the database of ringed electrocuted birds in Spain in 1990–2010 taken from data provided by Guil et al. (2015) with the following categories and families: diurnal raptors (*Accipitridae* and *Falconidae*), nocturnal raptors (*Strigidae* and *Tytonidae*), ravens (*Corvidae*), starlings (*Sturnidae*), herons and their allies (*Ardeidae*, *Phoenicopteridae* and *Threskiornithidae*), rollers and their allies (*Coraciiformes*), waders (*Charadriformes*) and woodpeckers (*Picidae*); mammals not considered in this study were excluded (Guil et al., 2015).

Table 1
List of landscape variables used to model fauna and power lines mediated wildfires distribution in Spain. Land used variables were obtained from the 2006 CORINE land cover (EEA, www.eea.europa.eu/es). Rest of variables was downloaded from the Spanish governmental spatial data web-repository (www.idee.es).

Variable	Explanation
WF_powerlines:	Total number of power lines mediated wildfires during 2000–2012.
Wf_fauna:	Total number of fauna mediated wildfires during 2000–2012.
Mean altitude	Mean altitude of each grid
Roughness	Roughness measure as standard deviation of mean altitude of each grid
Population density	Population according to 2014 census, proportional to each municipality surface in the grid, considering the population is uniformly allocated
Perc. forest	Percentage of forest cover according to CORINE-2006
Perc. scrub	Percentage of scrub cover according to CORINE-2006
Perc. grassland:	Percentage of grass cover according to CORINE-2006
HV power lines:	High-Voltage Power line length according to the National Cartographic database at 1:25.000 scale
Paths	Unpaved road length according to National Topographic Map with a scale of 1:200.000
Paved roads	Length of all type of paved roads according National Topographic Map with a scale of 1:200.000
Protected N2000	Percentage of protected area included in Natura 2000
Protected SPA	Percentage of Special Protected Area for birds
Raptor richness	Number of raptors species breeding in each grid

2.6. Economic and environmental impacts

The economic cost of recovery plus associated CO_2 emissions was evaluated. To assess the recovery costs we used an environmental responsibility model (Modelo de Oferta de Responsabilidad Ambiental; MORA; freely available at http://eportal.magrama.gob.es/mora/login.action). This software distinguishes between total primary repairs, which include the cost of returning all affected surfaces to their previous status, and total compensatory repairs for specific damage, including mature trees. The model also considers additional costs, associated with reparation projects and creating access to affected areas. A detailed explanation of this methodology and its software is included as supplementary material (Table S1).

To calculate the direct CO_2 emissions attributable to each wildfire, we used a characterisation of the plant cover of the affected area. If the wildfire did not originate in a forest, we considered the nearest vegetated area as the 'affected' area. (http://www.esri.com/) We have used two complementary maps of vegetation cover from two WMS official servers.

We calculated emissions as the direct CO_2 metric ton/burned ha using data provided by Valero et al. (2007). For vegetation without defined CO_2 emissions, we considered the emissions of the structurally nearest vegetation type. For vegetation potentially belonging to more than one category, mean emission values were used. We applied the Social Cost of Carbon (SCC; Interagency Working Group on Social Cost of Carbon, 2015) to evaluate the economic impact; the 2015 SCC was used with a discount rate of 3%, which was 36 2007 dollars per metric ton CO_2. In this case, the SCC was converted to 2016 dollars using the inflation between 2007 and 2015 (17.57%; World Bank Data, 2016). Finally, the results were converted to euros using the 2016 yearly average exchange rates for converting foreign currency to U.S. dollars (0.94; Internal Revenue Service, 2017). The cost of CO_2 emissions was calculated at 39.787 2016 euros per metric ton CO_2.

To assess the economic impact we chose mean annual amounts. We chose the net present value (NPV) as a useful concept for evaluating the impact of an investment, or, in this case, a permanent harm (Remer and Nieto, 1995). As fires were to occur permanently, the repayment time was considered as infinite. The discount rate used was 3%, a rate often used in studies of this type and the official Spanish legal interest of money in 2016 and 2017 (Costanza et al., 2006; Banco de España, 2017). To obtain the net present value we used the NPV formula for infinite repayment, $NPV = {}^{C}/_{i}$, where C is the value of the emissions (thus, 39.787 € per CO_2 metric ton) and i is the discount rate. In our case, the formula will be $NPV = {}^{39.787 \cdot YECO_2}/_{3\%}$, where $YECO_2$ represents the annual CO_2 emissions in metric tons.

2.7. Statistical analyses

We used Generalized Linear Models (GLMs; McCullagh and Searle, 2000) to relate the occurrence of FMW and PLMW to the environmental factors in 10 × 10 km UTM grids. All GLM were performed with a binomial error distribution and the link function logit. In each model we evaluated the over dispersion or lack of fit using the c-hat value. We used the corrected Akaike information criterion (AICc; Burnham and Anderson, 2002) to establish rankings, and we computed delta AICc to determine the strength of evidence and AICc weights to represent the relative likelihood of each model (Burnham and Anderson 2002). Multicollinearity can make comparing alternate models difficult. We considered two predictors to be collinear when the Spearman rank correlation coefficients were $> |0.7|$. If two strongly correlated predictors were included in the same model, we retained those with the clearest ecological meaning (Dormann et al., 2013).

To evaluate the influence of individual variables, we built a best model for both FMW and PLMW separately. A model with all variables was constructed and the best-saturated model was reached step-by-step using the AIC. The estimates, odds ratio (OR) and 95% confidence intervals for each variable retained in the best model were obtained. To compare differences between the 'best' models, we used an analysis of deviance by maximum likelihood ratio test.

To assess the spatial distribution of the FMW and PLMW and their regularity and randomness with the function G, we used the *spatstat* package (Baddeley and Turner, 2005; Baddeley et al., 2015) in R 3.2.3 (R Core Team, 2015). One hundred simulations and edge-effect corrections were applied. The Spanish National Geographical Institute shapefile of peninsular Spain and the Balearic Islands at 1:200,000 scale, imported to R using the *maptools* package (Bivand and Lewin-Koh, 2016), was used as the data framework.

We used the Wilcoxon rank-sum test to determine the differences between total affected areas and affected areas with potential self-regenerated surfaces for both FMW and PLMW. To compare the bird communities that caused the wildfire and the distributions of electrocuted ringed birds we used Kuiper's test. We considered a significance level of 5% for all these tests. All statistical procedures were performed using R 3.2.3 software (R Core Team, 2015) with the *MASS* (Venables and Ripley, 2002), *AICcmodavg* (Mazerolle, 2011) and *aod* (Lesnoff and Lancelot, 2012) packages.

3. Results

3.1. Description of FMW and PLMW

Amongst the 2788 PLMW recorded in 2000–2012, 30 records of FMW were found, with an average affected vegetation cover of 9.06 ha (±37.68 SD; max = 203.85 ha). PLMW represented 1.22% of the total 227,778 wildfires and a 0.17% of the total 1,614,855 burned forest hectares in the period 2000–2012. None of the remaining 2758 PLMW, with an average affected surface area of 9.84 ha (±76.7 SD; Max = 1890 ha), were reported as having been caused by wildlife. No significant differences were observed between burnt surfaces with and without wildlife interaction (W = 41,929.5, $p = 0.653$); similar results were found when we compared the self-regeneration levels (W = 41,553, $p = 0.935$).

3.2. Locations of wildfires by type

In total, 83,36% of the total PLMW ($n = 2788$) and, 96.67% of the total FMW ($n = 30$) had correct and useable coordinates (Fig. 1). Of these 29 wildfires, six took place inside a SPA (20.69%); however, if we take into account a buffer area of 5 km, the number of wildfires increased threefold to 19 (65.52%). Although the percentage of PLMW in SPA (21.56%) is similar to FMW, it's higher considering the buffer area of 5 km (81.68%).

The FMW formed distinct groupings. A subset of the values obtained was above the expected value for the G function, with a probability of 96% (Figs. 2 and. 3). Therefore, CSR can be ruled out. In addition, the FMW spatial distribution in the PLMW was not random, which indicates that was a degree of clustering (Fig. 4).

3.3. Factors contributing to FMW and PLMW

Population density and road abundance were the best competing models for describing PLMW (Table 2); for FMW, the best models included land use and raptor abundance. The difference between these two models was not statistically significant (analysis of deviance by maximum likelihood ratio test $p = 0.08$).

In the multivariate model, PLMW emergence was positively related with the percentage of forest areas, scrubland, grazing areas, predator abundance by area, total number of power lines, and total number of asphalt roads, but, conversely, was negatively related to the mean height above sea level (Table 3).

For the FMW, the best model only retained five variables: positively with population density, percentage of grazing areas and Natura 2000 cover, and predatory abundance; and negatively with the percentage of forested area (Table 2).

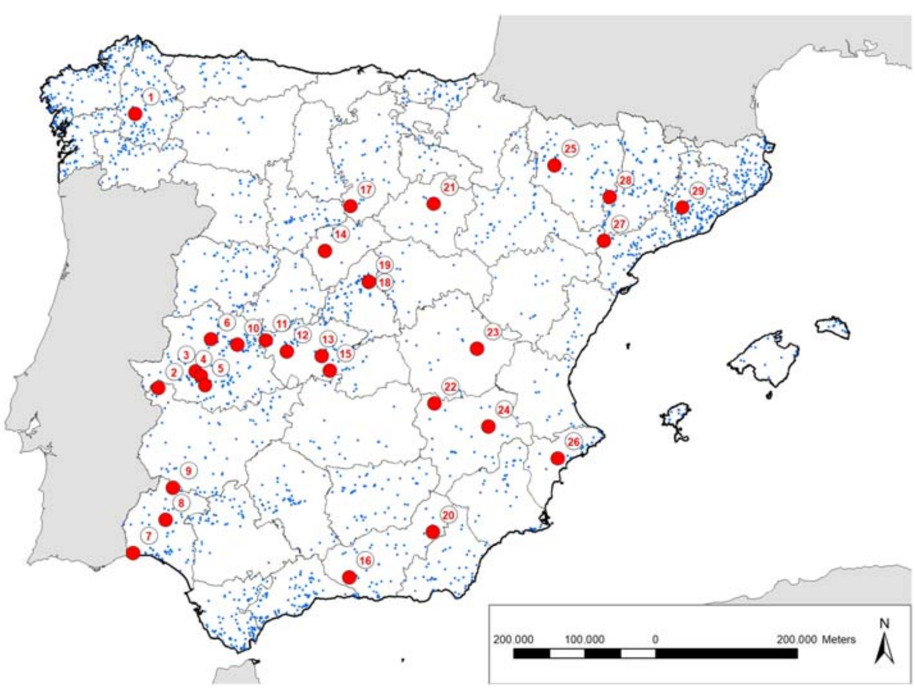

Fig. 1. Wildfires caused by power lines (blue dots) and by the interaction between fauna and power lines (red dots with numbers). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

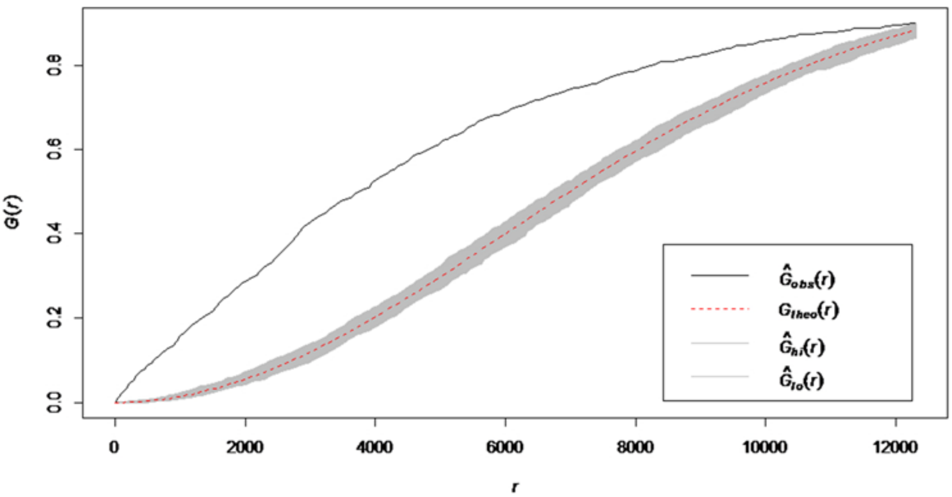

Fig. 2. G function for wildfires caused by power lines (black line) and a theoretical CSR value (red dotted line), and its simulation at 96% (grey area, with 100 simulations. The black line outside of the grey area shows the absence of a random spatial distribution. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.4. Timing of wildfires

For the whole study period, FMW supposed 1.07% of the PLMW. When compared to the PLMW, the FMW occurrence was statistically different ($F_{12} = 0.040$, $p < 0.0001$). Three distinct phases can be described: although no FMW were detected in phase one (2000–04), a significant increase was observed in phase two (2005–08) followed by a steady constant occurrence in phase three (Fig. 5). For the last period, about 2.4 ± 0.5% of PLMW were FMW.

3.5. Prevalent species

In 20 of the 30 cases of FMW, the taxonomic groups of species causing the wildfires could be determined. The most frequent species were diurnal raptors ($n = 8$), followed by *Corvidae* ($n = 5$) and nocturnal raptors ($n = 2$); the remaining categories were only responsible for one wildfire each (1 *Coraciiformes*: *Upupa epops*; 1 *Picidae*: *Picus viridis*; 1 *Starlings*, *Sturnus* sp.; 1 Storks: *Ciconia ciconia*; 1 mammal: *Martes foina*). Of the eight wildfires caused by raptors, vultures (non-identified species) caused three, a short-toed eagle (*Circaetus gallicus*) and lesser kestrel (*Falco naumanni*) caused one each, a non-specified eagle caused one, and the final one was caused by an unidentified raptor.

No significant differences were found between birds causing wildfires and electrocuted ringed birds in Spain ($V = 33$, $p = 0.236$) when compared to the data shown in Guil et al. (2015) (see Fig. 6).

3.6. Economic and environmental impacts

Between 2000 and 2012, the economic impact (both repair and additional costs) of FMW was €2.2×10^6 (see Table S2), which corresponds to €1.7×10^5 annually. It is estimated that in this period direct CO_2 emissions reached 1.8×10^4 tons (see Table S3), an average of 1.4×10^3 t CO_2/year.

However, only taking into account the period in which wildfires caused by birds were reported (2005–2012), the NPV due to FMW reached €9.3×10^6, with annual values of €2.8×10^5 and 2.3×10^3 t CO_2/year.

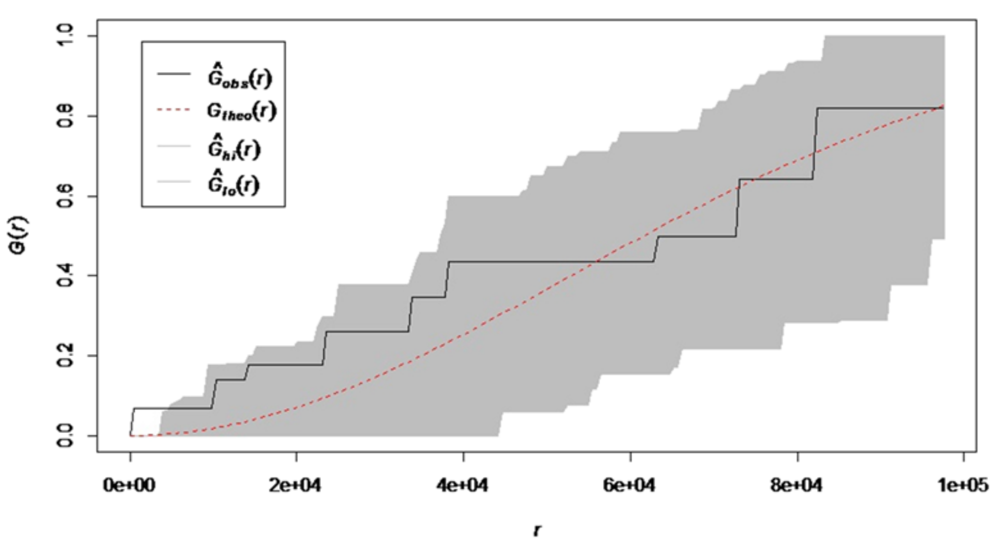

Fig. 3. G function comparison for wildfires caused by the interaction between fauna and power lines (FMW, black line) and a theoretical CSR value (red dotted line), and its simulation at 96% (grey area), with 100 simulations. The black line outside of the grey area shows the absence of a random spatial distribution. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

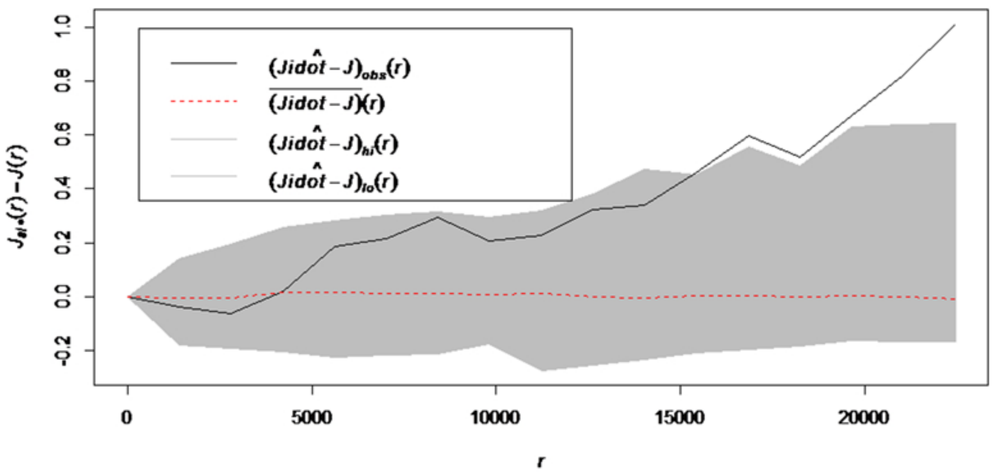

Fig. 4. J function comparison for wildfires caused by the interaction between fauna and power lines (FMW, black line) and theoretical value (red dotted line), and its simulation at 96% (grey area), with 100 simulations. The black line outside of the grey area shows the presence of a grouping of FMW within PLMW. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Finally, the total annual economic impact, both considering the economic impact and the CO_2 emissions, lies in the range €2.3 × 10^4–3.7 × 10^4, with an NPV of €7.6 × 10^6–12.4 × 10^6.

4. Discussion

To date, the issue of birds interacting with electric power lines has been addressed primarily from a standpoint either of bird conservation (Lehman et al., 2007) or of the indirect cost of a loss of electricity supply (McIvor et al., 2012). No published study has ever evaluated wildfires and their associated costs, which include CO_2 emissions and the recovery from biodiversity loss. This study addresses this subject for the first time and evaluates the main characteristics of interactions between fauna and power lines, events that are responsible for wildfires and their subsequent economic impact.

Results show that in Spain in 2000–2012 only a small percentage (1.22%) of all recorded wildfires were due to power lines. Of these, only 2.4% were attributable to bird or other animal electrocutions (according to the relation between FMW and PLMW during the most recent period). Although this percentage is a conservative estimate, from a global perspective its impact is low. However, this contrasts with the economic and environmental relevance of these events.

Although the general characteristics of FMW are similar to those of PLMW, the differences are not negligible. According to our findings, the spatial distribution of FMW is not random and is concentrated in certain areas. The origin of the tendency is likely to be the existence of areas that are more susceptible to wildfires (González-Olabarria et al., 2012; Serra et al., 2013) and/or areas with more breeding bird species that are susceptible to electrocution (Guil et al., 2011). These hypotheses are based on groupings in the PLMW areas. The spatial coincidence of wildfires in SPAs (20.69%) and in the surrounding 5-km buffer areas (65.52%) with bird electrocutions further supports this hypothesis (Pérez-García et al., 2011). Power lines are known to cause large destructive fires, as has occurred in southern California (Keeley et al., 2011) and Australia (e.g. Cruz et al., 2012). In the former case, this is important because power-line fires are concentrated in autumn and are associated with strong winds, which create situations of extreme fire behaviour (Mitchell, 2013; Syphard and Keeley, 2015).

Spatial patterns of the risk of wildfires have been widely studied, the Mediterranean region included (Martínez et al., 2009; Millington et al., 2009; Romero-Calcerrada et al., 2010; Juan et al., 2012; Ordóñez et al., 2012; Serra et al., 2013, 2014). Agricultural landscape patterns and abandonment, and development processes have been identified as the principal factors affecting human fire occurrence in Spain (Martínez et al., 2009). In addition, the proximity to urban areas may explain the incidence of fires in the *Intentional fires and arson* category and the lack of naturally caused fires (Serra et al., 2014). We also highlight this relationship between urban density and road proximity as one of the main

Table 2
Competing logistic regression models of wildfire occurrence caused by a) power lines (PLMW) and b) electrocuted wildlife (FMW) representing our hypotheses. Models with less AICc than the null model are not displayed. K = total number of parameters; AICc = corrected Akaike's Information Criterion; Δ AICc = difference between the AICc value for that model and the best model; and Akaike's weights W.

A) PLMW	K	AICc	Δ AICc	AICc Wt
Population	4	5584.68	0	1
Power line	2	5841.67	257	0
Topography	2	5980.7	396.02	0
Raptor	2	5999.01	414.33	0
Land uses	4	6001	416.33	0
Protected area	3	6017.1	432.42	0
Intercept	1	6024.73	440.05	0
B) FMW				
Land uses	4	350.37	0	0.37
Raptor	2	351.3	0.93	0.23
Null model	1	352.58	2.21	0.12

Table 3
Estimates, odds ratio (OR) and respective 95% confidence intervals (95% CI) of the regression parameters for the best logistic model of wildfire occurrence caused by a) power lines (PLMW) and b) electrocuted wildlife (FMW). Variables were ranked by odds ratio.

A) PLMW	Estimate (95% CI)	OR (95% CI)
Paved roads	1.55 (1.25–1.85)	4.7 (3.49–6.33)
HV Power lines	0.92 (0.57–1.28)	2.52 (1.77–3.59)
Population density (log)	0.22 (0.17–0.28)	1.25 (1.18–1.32)
Raptor richness	0.05 (0.03–0.08)	1.05 (1.03–1.08)
Perc. pastureland	0.02 (0.02–0.02)	1.02 (1.02–1.02)
Perc. scrubland	0.01 (0.01–0.02)	1.01 (1.01–1.02)
Perc. forest	0.01 (0–0.01)	1.01 (1–1.01)
Perc. protected natura 2000	0 (0–0)	1 (1–1)
Mean altitude (log)	−0.22 (−0.3 to −0.14)	0.8 (0.74–0.87)
Constant	−3.52 (−4.25 to −2.81)	0.03 (0.01–0.06)
B) FMW		
Population density (log)	0.22 (−0.03–0.47)	1.25 (0.97–1.59)
Raptor richness	0.13 (0.01–0.24)	1.13 (1.01–1.28)
Perc. grassland	0.02 (0–0.03)	1.02 (1–1.03)
Perc. forest	−0.02 (−0.05–0.01)	0.98 (0.95–1.01)
Constant	−8.17 (−10.77 to −5.71)	0 (0–0)

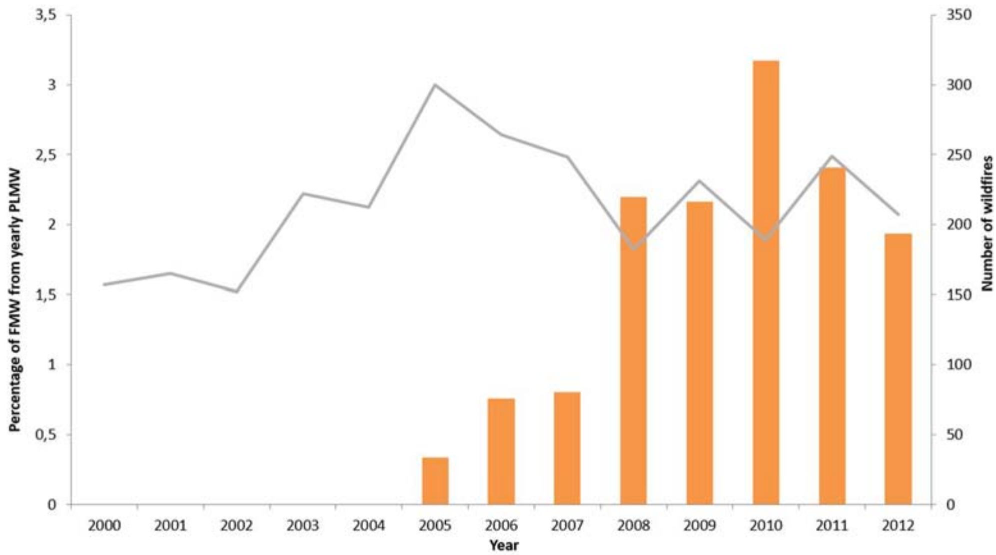

Fig. 5. Annual evolution of the number of wildfires caused by power lines (PLMW, grey line) and the percentage of fauna-mediated wildfires respect to PLMW (FMW, orange bars). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

factors that explain PLMW occurrence, as is the case of work performed in California (Syphard and Keeley, 2015). These factors are likely to be related to the distribution of medium and/or low voltage power lines in areas of high population density, and the existence of longer high-voltage power lines corresponding to longer roads (Dwyer et al., 2016). Therefore, our model might indicate a greater probability of wildfires due to large numbers of potential causes of ignition. In addition, the relationship with other factors such as pasture, forest and scrub cover may be linked to their ease of ignition, while raptor richness could be related to the presence of more natural areas. In the case of forests, although in Spain – as occurs in other countries – special regulations exist regarding vegetation clearing under power lines, there is still a greater potential for ignition since trees interact with power lines. In the particular case of FMW, the models are less robust, probably due the low sample size. Despite this limitation, the factors that explain the occurrence of FMW are related to human presence and urbanization, the presence of inflammable material, and the greater risk of bird electrocution. It is important to note that all of these variables were previously included in the PLMW risk models and also coincide with the environmental predictors included in the risk models for bird electrocution in Spain (Tintó et al., 2010; Pérez-García et al., 2017).

Likewise, no differences were found for the species causing wildfires, which agrees with findings obtained in previous studies of the prevalence of electrocution (Mañosa, 2001; Tintó et al., 2010; Guil et al., 2015). As suggested above, in nearly all cases large birds are the main cause of these interactions (Janss, 2000; Pérez-García et al., 2016). Nevertheless, smaller birds (e.g. *Upupa epops*, *Picus viridis* and *Sturnus* sp.) and even a medium-sized mammal (*Martes foina*) have also been found to cause fires, mainly on pylons with electric conductors above the crossarm. Despite the absence of significant differences, Fig. 6 points out differences, on the storks, the most relevant group in Guil et al. (2015) (68.9% of the total electrocutions, including mainly white *Ciconia ciconia*, but also black storks *Ciconia nigra*), and now only a 5% of the total groups. We should consider the white stork habitat use, more prone to open areas (Gilbert et al., 2016), where power lines are the main selected perch (Guil et al., 2011), also for nesting (Tryjanowski

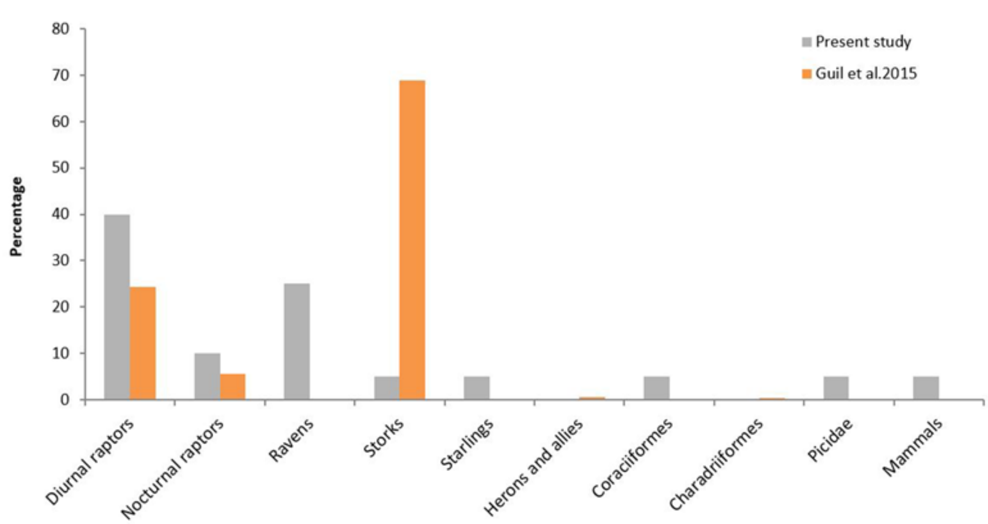

Fig. 6. Proportion of groups causing fauna-mediated wildfires (FMW, grey bars) and data from electrocuted ringed birds in 1990–2010 (Guil et al., 2015, orange bars). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

et al., 2014).Several interesting questions such as the identification of the main factors that cause the feathers or fur of an electrocuted animal to burn, or in what percentage of electrocutions ignition occurs, remain unanswered and are beyond the scope of this paper. Despite this, several factors could be related to the temporal probability of FMW occurrence, of which the most important could be that summer, characterised by drought and the highest temperatures, coincides with the fledging and independence of large nestlings, which are more likely to suffer electrocution (Janss, 2000; González et al., 2007). This means that in Spain the probability of occurrence of FMW is likely to be higher than in other European countries due to the coincidence between huge populations of large birds and periods of extreme hot and dry weather. Thus, breeding density and the patches frequented by the main affected species could explain this pattern since there is a greater frequency of bird mortality and FMW around SPA zones. Nevertheless, this effect should be checked more systematically with more detailed field studies.

During the final years of the study period, FMW increased. This trend may be due to more thorough investigations of the causes of wildfires (ADCIF, 2002, 2012a) since the incidence of bird electrocution decreased during the same period, probably as a consequence of the implementation of corrective measures (López-López et al., 2011; Guil et al., 2015). Accordingly, we consider the last period frequency (2.4%) as the most plausible one. The main cause to this asseveration is its stability. The economic impact of the wildfires caused by wildlife-power-line interaction is significant (€7.6 M–12.4 M NPV), despite the fact that the number of recorded wildfires fell. In all, 24% of this economic impact was related to CO_2 emissions, and the remaining 76% to recovery costs. This impact is relatively small, compared to the yearly cost of the forest fires in Spain (€1045.2 M; Ferreiro, 2014) that includes prevention, extinction and restoration. But it is an avoidable issue, which depends mainly on power line design (Guil et al., 2011) but also landscape factors and sensitivity species distribution (Pérez-García et al., 2017). And given the future land uses and its sensitivity to wildland fires (Lindner et al., 2010; Gallardo et al., 2016), this should be a priority, both for natural and economic impacts.

To date, the main tool used to reduce wildfires caused by power lines has been to control the vegetation growing under overhead conductors. However, for wildfires caused by the electrocution of an animal this type of control is ineffective, as electrocuted fauna might be several meters away from the pole (Mañosa, 2001; Tintó et al., 2010), and other alternatives should be considered. Measures such as wire insulation or structural corrections of power pylons help reduce electrocution events (Guil et al., 2011; Tintó et al., 2010) and therefore the number of fires caused by fauna. Yet, it is clear that measures such as the burial of power lines are the most effective for eliminating the fire risk due both to contact with power lines (Syphard and Keeley, 2015) and to wildlife interactions including electrocution and collisions (Dwyer et al., 2014; Pérez-García et al., 2017).

5. Conclusions

Spain is located in a region of the world blessed with great biodiversity (Cuttelod et al., 2009) but it is also one of the European countries that is most affected by fires, in terms of both their number and the surface area burned (European Commission, 2015). In 1981–2013, 2.3 million ha of forested land burned (roughly 5% of the country: ADCIF, 2002, 2012a, 2013, 2014). Fauna electrocution in an under-estimated cause of wildfire ignition, with a relevant environmental and economic impact. Although no large wildfire due to electrocuted wildlife was registered during the monitoring period in Spain, the risk is present and therefore the precautionary principle should be applied to avoid a major event with disastrous consequences such as occurred in Chile in 2014, where c. 1000 ha burned and 15 people died (Vargas, 2016). As population trend of large raptors is increasing, and land uses are more prone to wildland fires (Pereira and Navarro, 2015; Gallardo et al., 2016), corrections of existing power lines and a correct design should be priority management conservation actions to reduce the wildfire by electrocution.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2017.12.242.

References

ADCIF, 2002. Los incendios forestales en España Decenio 1991–2000. Ministerio de Medio Ambiente, Madrid (Available at). http://www.magrama.gob.es/es/desarrollo-rural/estadisticas/decenio_1991_2000_tcm7-349069.pdf.

ADCIF, 2012a. Los incendios forestales en España Decenio 2001-2010. Ministerio de Agricultura. Alimentación y Medio Ambiente, Madrid (Available at). http://www.magrama.gob.es/es/desarrollo-rural/estadisticas/INCENDIOS_FORESTALES_2001-2010_FINAL_mod.1_tcm7-349255.pdf.

ADCIF, 2012b. Metodología de la estadística general de incendios forestales. Ministerio de Agricultura. Medio Ambiente, Madrid, Alimentación y (Available at). http://www.magrama.gob.es/es/desarrollo-rural/estadisticas/Estad%C3%ADstica_General_de_Incendios_Forestales_METODOLOG%C3%8DA_tcm7-349131.pdf.

ADCIF, 2013. Los incendios forestales en España. Año 2011. Ministerio de Agricultura. Alimentación y Medio Ambiente, Madrid (Available at). http://www.mapama.gob.es/es/desarrollo-rural/estadisticas/los_incendios_forestales_en_espana_2013_tcm7-408988.pdf.

ADCIF, 2014. Los incendios forestales en España. Año 2012. Ministerio de Agricultura. Alimentación y Medio Ambiente, Madrid (Available at). http://www.mapama.gob.es/es/desarrollo-rural/estadisticas/Los_incendios_forestales_en_Espa%C3%B1a_2012_tcm7-349124.pdf.

Andrews, A., 1990. Fragmentation of habitat by roads and utility corridors: a review. Aust. Zoologist 26 (3–4), 130–141.

Baddeley, A., Turner, R., 2005. Spatstat: an R package for analyzing spatial point patterns. J. Stat. Softw. 12 (6), 1–42.

Baddeley, A., Rubak, E., Turner, R., 2015. Spatial Point Patterns: Methodology and Applications with R. Chapman and Hall/CRC Press, London.

Bajocco, S., Ricotta, C., 2008. Evidence of selective burning in Sardinia (Italy): which land-cover classes do wildfires prefer? Landsc. Ecol. 23 (2), 241–248.

Bajocco, S., Rosati, L., Ricotta, C., 2010. Knowing fire incidence through fuel phenology: a remotely sensed approach. Ecol. Model. 221 (1), 59–66.

Balmori, A., Hallberg, Ö., 2007. The urban decline of the house sparrow (*Passer domesticus*): a possible link with electromagnetic radiation. Electromagn. Biol. Med. 26 (2), 141–151.

Bardsley, D.K., Weber, D., Robinson, G.M., Moskwa, E., Bardsley, A.M., 2015. Wildfire risk, biodiversity and peri-urban planning in the Mt Lofty Ranges, South Australia. Appl. Geogr. 63, 155–165.

Bevanger, K., 1998. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biol. Conserv. 86, 67–76.

Bivand, R., Lewin-Koh, N., 2016. Maptools: Tools for Reading and Handling Spatial Objects. (R package version 0). pp. 8–39.

Blondel, J., Aronson, J., 1999. Biology and Wildlife of the Mediterranean Region. Oxford University Press, USA.

Boubeta, M., Lombardía, M.J., Marey-Pérez, M., Morales, D., 2015. Prediction of forest fires occurrences with area-level Poisson mixed models. J. Environ. Manag. 154, 151–158.

Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer, New York.

Costanza, R., Wilson, M., Troy, A., Voinov, A., Liu, S., D'Agostino, J., 2006. The Value of New Jersey's Ecosystem Services and Natural Capital. New Jersey Department of Environmental Protection (Available at). http://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1014&context=iss_pub.

Cruz, M.G., Sullivan, A.L., Gould, J.S., Sims, N.C., Bannister, A.J., Hollis, J.J., Hurley, R.J., 2012. Anatomy of a catastrophic wildfire: the Black Saturday Kilmore East fire in Victoria, Australia. Forest Ecol. Manag. 284, 269–285.

Cuttelod, A., García, N., Malak, D.A., Temple, H.J., Katariya, V., 2009. The Mediterranean: a biodiversity hotspot under threat. Wildlife in a Changing World–an analysis of the 2008 IUCN Red List of Threatened Species. p. 89.

de España, Banco, 2017. Tabla tipos de interés legal. (Available at). https://www.bde.es/clientebanca/es/areas/Tipos_de_Interes/Tipos_de_interes/Otros_tipos_de_i/otros-tipos/Tabla_tipos_de_interes_legal.html.

DeBano, L.F., Neary, D.G., Ffolliott, P.F., 1998. Fire Effects on Ecosystems. John Wiley, Sons, NYC-USA.

Dinkins, J.B., Conover, M.R., Kirol, C.P., Beck, J.L., 2012. Greater Sage-Grouse (*Centrocercus urophasianus*) select nest sites and brood sites away from avian predators. Auk 129 (4), 600–610.

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., García Marquéz, J.R., Gruber, B., Lafourcade, B., Leitão, P.J., Münkemüller, T., McClean, C., Osborne, P.E., Reineking, B., Schröder, B., Skidmore, A.K., Zurell, D., Lautenbach, S., 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36 (1), 27–46.

Dwyer, J.F., Harness, R.E., Donohue, K., 2014. Predictive model of avian electrocution risk on overhead power lines. Conserv. Biol. 28 (1):159–168. https://doi.org/10.1111/cobi.12145.

Dwyer, J.F., Harness, R.E., Gerber, B.D., Landon, M.A., Petersen, P., Austin, D.D., Woodbridge, B., Williams, G.E., Eccleston, D., 2016. Power pole density informs spatial prioritization for mitigating avian electrocution. J. Wildl. Manag. 80:634–642. https://doi.org/10.1002/jwmg.1048.

European Commission, 2015. Forest Fires in Europe, Middle East and North Africa 2014, EUR 27400 EN. Publications Office of the European Union, Luxembourg, p. 107.

Fernandes, P.M., Davies, G.M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C.R., Vega, J.A., Molina, D., 2013. Prescribed burning in southern Europe: developing fire management in a dynamic landscape. Front. Ecol. Environ. 11 (s1).

Fernie, K.J., Reynolds, S.J., 2005. The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: a review. J. Toxicol. Environ. Health A 8 (2), 127–140.

Ferreiro, M., 2014. Análisis socioeconómico de los incendios forestales españoles y propuesta de rediseño de la estrategia de prevención-concienciación. (Final Master Dissertation). University of Valencia (Available at). https://riunet.upv.es/bitstream/handle/10251/67963/TFM%20-%20Ferreiro%20G%C3%B3mez%2C%20A..pdf?sequence=1.

Gallardo, M., Gómez, I., Vilar, L., Martínez-Vega, J., Martín, M.P., 2016. Impacts of future land use/land cover on wildfire occurrence in the Madrid region (Spain). Reg. Environ. Chang. 16 (4), 1047–1061.

Gangoso, L., Palacios, C.J., 2002. Endangered Egyptian Vulture (*Neophron percnopterus*) entangled in a power line ground-wire stabilizer. J. Raptor Res. 36 (3), 238–239.

Gilbert, N.I., Correia, R.A., Silva, J.P., Pacheco, C., Catry, I., Atkinson, P.W., Gill, J.A., Franco, A.M., 2016. Are white storks addicted to junk food? Impacts of landfill use on the movement and behaviour of resident white storks (*Ciconia ciconia*) from a partially migratory population. Mov. Ecol. 4 (1):7. https://doi.org/10.1186/s40462-016-0070-0.

González, L.M., Margalida, A., Mañosa, S., Sánchez, R., Oria, J., Molina, J.I., Caldera, J., Aranda, A., Prada, L., 2007. Causes and spatio-temporal variations of non-natural mortality in the vulnerable Spanish imperial eagle *Aquila adalberti* during a recovery period. Oryx 41 (04), 495–502.

González-Olabarria, J.R., Brotons, L., Gritten, D., Tudela, A., Teres, J.A., 2012. Identifying location and causality of fire ignition hotspots in a Mediterranean region. Int. J. Wildland Fire 21 (7), 905–914.

Guil, F., Fernández-Olalla, M., Moreno-Opo, R., Mosqueda, I., Gómez, M.E., Aranda, A., Arredondo, A., Guzmán, J., González, L.M., Margalida, A., 2011. Minimising mortality in endangered raptors due to power lines: the importance of spatial aggregation to optimize the application of mitigation measures. PLoS One 6 (11), e28212.

Guil, F., Colomer, M.À., Moreno-Opo, R., Margalida, A., 2015. Space–time trends in Spanish bird electrocution rates from alternative information sources. Glob. Ecol. Conserv. 3, 379–388.

Infante, O., Peris, S., 2003. Bird nesting on electric power supports in northwestern Spain. Ecol. Eng. 20 (4), 321–326.

Interagency Working Group on Social Cost of Carbon, United States Government, 2015. Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. (Available at). https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.

Internal Revenue Service, 2017. Yearly average exchange rates for converting foreign currency into U.S. Dollars. (Available at). https://www.irs.gov/Individuals/International-Taxpayers/Yearly-Average-Currency-Exchange-Rates.

Janss, G.F., 2000. Avian mortality from power lines: a morphologic approach of a species-specific mortality. Biol. Conserv. 95 (3), 353–359.

Jenkins, A.R., Smallie, J.J., Diamond, M., 2010. Avian collisions with power lines: a global review of causes and mitigation with a South African perspective. Bird Conserv. Int. 20 (03), 263–278.

Juan, P., Mateu, J., Saez, M., 2012. Pinpointing spatio-temporal interactions in wildfire patterns. Stoch. Env. Res. Risk A. 26 (8), 1131–1150.

Kagan, R.A., 2016. Electrocution of raptors on power lines: a review of necropsy methods and findings. Vet. Pathol. 53 (5), 1030–1036.

Keeley, J.E., Bond, W.J., Bradstock, R.A., Pausas, J.G., Rundel, P.W., 2011. Fire in Mediterranean ecosystems: ecology, evolution and management. Cambridge University Press, Cambridge.

Kelly, L.T., Brotons, L., 2017. Using fire to promote biodiversity. Science 355 (6331), 1264–1265.

Kershaw, P., Clark, J.S., Gill, A.M., D'Costa, D.M., 2002. A History of Fire in Australia. In: Bradstock, R., Williams, J., Gill, M. (Eds.), Flammable Australia: The Fire Regimes and Biodiversity of a Continent. Cambridge University Press, pp. 3–25.

Kroodsma, R.L., 1982. Edge effect on breeding forest birds along a power-line corridor. J. Appl. Ecol. 361–370.

Lammers, W.M., Collopy, M.W., 2007. Effectiveness of avian predator perch deterrents on electric transmission lines. J. Wildl. Manag. 71 (8), 2752–2758.

Lehman, R.N., Kennedy, P.L., Savidge, J.A., 2007. The state of the art in raptor electrocution research: a global review. Biol. Conserv. 136 (2), 159–174.

Lesnoff, M., Lancelot, R., 2012. Aod: analysis of Overdispersed Data (R package version, 1).

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J., Marchetti, M., 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For. Ecol. Manag. 259 (4), 698–709.

López-López, P., García-Ripollés, C., Aguilar, J.M., Garcia-López, F., Verdejo, J., 2006. Modelling breeding habitat preferences of Bonelli's eagle (*Hieraaetus fasciatus*) in relation to topography, disturbance, climate and land use at different spatial scales. J. Ornithol. 147 (1), 97–106.

López-López, P., Ferrer, M., Madero, A., Casado, E., McGrady, M., 2011. Solving man-induced large-scale conservation problems: the Spanish imperial eagle and power lines. PLoS One 6 (3), e17196.

Loss, S.R., Will, T., Marra, P.P., 2014. Refining estimates of bird collision and electrocution mortality at power lines in the United States. PLoS One 9 (7), e101565.

Mainwaring, M.C., 2015. The use of man-made structures as nesting sites by birds: a review of the costs and benefits. J. Nat. Conserv. 25, 17–22.

Mañosa, S., 2001. Strategies to identify dangerous electricity pylons for birds. Biodivers. Conserv. 10 (11), 1997–2012.

Martínez, J., Vega-Garcia, C., Chuvieco, E., 2009. Human-caused wildfire risk rating for prevention planning in Spain. J. Environ. Manag. 90 (2), 1241–1252.

Mazerolle, M.J., 2011. AICcmodavg: model Selection and Multimodel Inference Based on (Q) AIC (c) (R package version, 1(1.15)).

McCullagh, P., Searle, S.R., 2000. Generalized Linear and Mixed Models. Wiley-Interscience, New York.

McIvor, G.E., Rowe, C., Healy, S.D., 2012. Deterring hooded crows from re-nesting on power poles. Wildl. Soc. Bull. 36 (4), 729–734.

Millington, J.D., Wainwright, J., Perry, G.L., Romero-Calcerrada, R., Malamud, B.D., 2009. Modelling Mediterranean landscape succession-disturbance dynamics: a landscape fire-succession model. Environ. Model. Softw. 24 (10), 1196–1208.

Mitchell, J.W., 2013. Power line failures and catastrophic wildfires under extreme weather conditions. Eng. Fail. Anal. 35, 726–735.

Moreira, F., Russo, D., 2007. Modelling the impact of agricultural abandonment and wildfires on vertebrate diversity in Mediterranean Europe. Landsc. Ecol. 22 (10), 1461–1476.

Moreno, M.V., Conedera, M., Chuvieco, E., Pezzatti, G.B., 2014. Fire regime changes and major driving forces in Spain from 1968 to 2010. Environ. Sci. Pol. 37, 11–22.

Ordóñez, C., Saavedra, A., Rodríguez-Pérez, J.R., Castedo-Dorado, F., Covián, E., 2012. Using model-based geostatistics to predict lightning-caused wildfires. Environ. Model. Softw. 29 (1), 44–50.

Parente, J., Pereira, M.G., Tonini, M., 2016. Space-time clustering analysis of wildfires: the influence of dataset characteristics, fire prevention policy decisions, weather and climate. Sci. Total Environ. 559, 151–165.

Pereira, H.M., Navarro, L.M. (Eds.), 2015. Rewilding European Landscapes. Springer, New York.

Pérez-García, J.M., Botella, F., Sánchez-Zapata, J.A., Moleón, M., 2011. Conserving outside protected areas: edge effects and avian electrocutions on the periphery of Special Protection Areas. Bird Conserv. Int. 21 (03), 296–302.

Pérez-García, J.M., Sebastián-González, E., Botella, F., Sánchez-Zapata, J.A., 2016. Selecting indicator species of infrastructure impacts using network analysis and biological traits: bird electrocution and power lines. Ecol. Indic. 60, 428–433.

Pérez-García, J.M., DeVault, T., Botella, F., Sánchez-Zapata, J.A., 2017. Using risk prediction models and species sensitiv4ity maps for large-scale identification of infrastructure-related wildlife protection areas: the case of bird electrocution. Biol. Conserv. 210 (A), 334–342.

R Core Team, 2015. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.

Reimers, E., Dahle, B., Eftestøl, S., Colman, J.E., Gaare, E., 2007. Effects of a power line on migration and range use of wild reindeer. Biol. Conserv. 134 (4), 484–494.

Remer, D.S., Nieto, A.P., 1995. A compendium and comparison of 25 project evaluation techniques. Part 1: net present value and rate of return methods. Int. J. Prod. Econ. 42 (1), 79–96.

Rollan, À., Real, J., 2011. Effect of wildfires and post-fire forest treatments on rabbit abundance. Eur. J. Wildl. Res. 57 (2), 201–209.

Romero-Calcerrada, R., Barrio-Parra, F., Millington, J.D.A., Novillo, C.J., 2010. Spatial modelling of socioeconomic data to understand patterns of human-caused wildfire ignition risk in the SW of Madrid (central Spain). Ecol. Model. 221 (1), 34–45.

Serra, L., Juan, P., Varga, D., Mateu, J., Saez, M., 2013. Spatial pattern modelling of wildfires in Catalonia, Spain 2004–2008. Environ. Model. Softw. 40, 235–244.

Serra, L., Saez, M., Juan, P., Varga, D., Mateu, J., 2014. A spatio-temporal Poisson hurdle point process to model wildfires. Stoch. Env. Res. Risk A. 28 (7), 1671–1684.

Shlisky, A., Waugh, J., Gonzalez, P., González, M.E., Manta, M., Santoso, H., Nuruddin, A.A., Rodríguez-Trejo, D.A., Swaty, R., Schmidt, D., Kaufmann, M., Myers, R., Alencar, A.,

Kearns, F., Johnson, D., Smith, J., Zollner, D., 2007. Fire, Ecosystems and People: Threats, and Strategies for Global Biodiversity Conservation – Report of the Global Fire Initiative. The Nature Conservancy, Boulder, CO.
Syphard, A.D., Keeley, J.E., 2015. Location, timing and extent of wildfire vary by cause of ignition. Int. J. Wildland Fire 24 (1), 37–47.
Syphard, A.D., Radeloff, V.C., Hawbaker, T.J., Stewart, S.I., 2009. Conservation threats due to human-caused increases in fire frequency in Mediterranean-climate ecosystems. Conserv. Biol. 23 (3), 758–769.
Tintó, A., Real, J., Mañosa, S., 2010. Predicting and correcting electrocution of birds in Mediterranean areas. J. Wildl. Manag. 74 (8), 1852–1862.
Tryjanowski, P., Sparks, T.H., Jerzak, L., Rosin, Z.M., Skórka, P., 2014. A paradox for conservation: electricity pylons may benefit avian diversity in intensive farmland. Conserv. Lett. 7 (1), 34–40.
Valero, E., Picos, J., Carracedo, M.H., 2007. Cálculo de las emisiones de CO_2 por los incendios de 2006 en la provincia de Pontevedra (Galicia). 4th International Wildland Fire Conference, Sevilla.
Vargas, S., 2016. Risk Communication in Chile: A Study of 2014 Valparaiso Wildfire. (Master Dissertation. Simon Fraser University (Available at). http://summit.sfu.ca/system/files/iritems1/16691/etd9621_SVargas.pdf.
Vélez, R., 2000. La defensa contra incendios forestales: fundamentos y experiencias. McGraw-Hill, Madrid.
Venables, W.N., Ripley, B.D., 2002. Random and Mixed Effects. Modern Applied Statistics with S. Springer, New York, pp. 271–300.
World Bank Data, 2016. Inflation, consumer prices (annual %). (Available at). http://data.worldbank.org/indicator/FP.CPI.TOTL.ZG.