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# Conserving outside protected areas: edge effects and avian electrocutions on the periphery of Special Protection Areas

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## Summary

Electrocution on power lines is one of the principal problems facing raptors and other medium- and large-sized birds at the global scale. The recent European-based Spanish state legislation on avian electrocutions has focused on Special Protection Areas (SPA). Here we evaluate whether this policy has been successful, using the Community of Valencia, Spain, as a regional model. We compiled a database of 400 electrocution events from information on electrocuted birds taken into Wildlife Recovery Centres and incidents registered by the main local power company during the last decade. A small proportion (c.18%) of electrocution casualties occurred within SPA boundaries but the 5 km wide belt immediately surrounding the SPAs produced more than three times the number of avian electrocutions (c.60% of the total recorded). This was probably caused by higher densities of both power lines and susceptible birds, and higher use of the pylons for perching and roosting in the areas surrounding the SPAs. We therefore conclude that the focus on preventative measures being applied within SPAs is inefficient and that action should be targeted in these peripheral areas. Our results illustrate a classic problem of an edge effect associated with a protected area, where external human influences directly affect the persistence of protected species within reserves. Equally, they support the idea that management strategies within parks cannot be independent of the human activities surrounding them.

## Introduction

In 1979, the "Birds Directive" (79/409/CEE) was adopted by the European Community (EC) and it urged member states to declare Special Protection Areas for birds (SPAs), primarily aimed at the conservation of rare and vulnerable species. In 1992, the "Habitats Directive" (92/43/CEE) consolidated the Birds Directive, using among other tools, the integration of SPAs within a network of protected areas coordinated at international level (Natura 2000 Network). As a result, the European network of SPAs has absorbed a large proportion of the economic, legislative and conservation resources.

Collision with and electrocution on power lines, poles and other large objects such as wind turbines are one of the greatest threats to large, soaring birds worldwide (Ferrer and Janss 1999, APLIC 2006, Lehman *et al.* 2007, Telleira 2009, Rollan *et al.* 2010, Raab *et al.* 2011, Boshoff in press), seriously affecting large raptors (Ferrer *et al.* 1991, Janss and Ferrer 1999, Ledger and Hobbs 1999, Janss and Ferrer 2001, Sergio *et al.* 2004, González *et al.* 2007, Moleón *et al.* 2007, Tintó *et al.* 2010, Jenkins 2010), a faunal group threatened at both the European (BirdLife International 2004) and the global scales (del Hoyo *et al.* 1994). Spain is one of the countries leading applied research and management work in relation to the impact of electrocution on birds (see reviews in Ferrer and Janss 1999, Lehman *et al.* 2007) but the relevant legislation has been weak and it was not until 2008 that a specific national law (RD 1432/2008) concerning the protection of birds against electrocution was adopted. According to the European tradition of reserves-based conservation, the recent Spanish rules designated SPAs as the main priority areas for correcting power infrastructures, thus reducing the emphasis on areas outside this network. SPAs are not the only targets mentioned in the national regulations and other priority areas include those covered by action plans for threatened species as well as other important areas for breeding, feeding, dispersal and roosting of these species. However, SPAs are the only areas explicitly defined and protected by law and the delimitation of areas for the other two criteria depends entirely on the very variable uptake and implementation by regional governments. Although SPAs are undoubtedly important, it is unknown as to whether these are in fact the best areas in which to direct preventative action (i.e. in terms of conservation resource investment *vs* reduction in number of electrocution casualties). Unfortunately, and surprisingly, no evaluation of the effectiveness of the current regulations to combat electrocutions exists.

In this paper we therefore explore at the regional scale the incidence of bird electrocutions by power lines inside and outside SPAs, with the final, primary objective of assessing whether targeting these sites within the new European-based Spanish State legislation against electrocutions is optimal.

## Methods

The study area covered the Community of Valencia (hereafter CV; 23,655 km$^2$), situated on the East coast of the Iberian Peninsula. The SPA network within the community comprises 43 reserves occupying 31% of CV.

The identity and number of birds killed or injured by electrocution was compiled from (a) records of birds taken into Wildlife Recovery Centres (hereafter WRC) in the Community of Valencia (b) birds recorded by Iberdrola S.A. electric company (hereafter EC), from January 2000 to April 2010.

The causes of injury or death of birds taken into the WRS were certified by visual inspection or necropsy. Iberdrola S.A. is the largest power company in the region, with c.90% of the medium and low voltage power lines. When a bird is electrocuted, and the intensity of the electric shock is medium-high and lasts $>$ 2 seconds, it usually produces a fault in the power supply that is registered by the company. Subsequently, a field team from the company visits the site to determine the cause and record the details of each incident, including species identification in the case of bird-caused outages. Thus, the EC data can be considered spatially unbiased. For both data sources, we only used those records that were properly georeferenced. Records were grouped into two classes: "raptors" (both diurnal and nocturnal) and "non-raptors" (all other species). Each record was listed as either inside or outside an SPA and nearest distance from the edge of the closest SPA was calculated for both cases using GIS software (ArcGIS 9). Before data analyses were performed, we checked for duplication between the WRC and EC data sets. Duplicated data were then deleted from the WRC set (*a priori* the set being subject to more spatial biases; although see Results).

Chi-squared tests ($\alpha = 0.05$; using Yates' continuity correction where appropriate) were used to explore the differences in frequency of electrocution between (a) taxonomic groups, raptors *vs* non-raptors, irrespective of geographical origin, (b) inside *vs* outside SPAs without distinguishing taxonomic groups and (c) inside *vs* outside SPAs, distinguishing between taxonomic groups. After grouping records into 2.5 km spatial bands from the edge, both inside and outside of the nearest SPA, comparisons were also made of d) the distribution frequency observed *vs* that expected for the electrocuted birds. For comparisons (b) and (c), the total number of electrocutions was standardised against the area occupied by each of the two areas considered (inside *vs* outside SPAs). For (d), the expected frequency was calculated depending (1) on the surface area of each 2.5 km interval and (2) on the length of the network of high voltage power lines of second (30–66 kV) and third category ($<$ 30 kV) – those of greatest electrocution threat (Ferrer and Janss 1999) – in each of the spatial intervals considered. All the analyses were performed jointly and separately for each of the two data sources (WRC and EC; although see Results).

## Results

A total of 400 records of electrocuted birds were compiled, 286 (71.5%) from WRC and 114 (28.5%) from the EC (Table 1). Raptors were the taxonomic group significantly most affected, such that 82.5% of the total corresponded to this group compared to 16.0% non-raptors (principally storks, gulls and pigeons; $\chi^2_1 = 25.7$, $P < 0.01$); 1.5% of the individuals could not be specifically identified. However, differences were found between the two data sources; raptor incidents in the EC register made up less than 60% of records, whereas, in the WRC data, this

Table 1. Number of avian electrocution casualties in the Community of Valencia (Spain) inside and outside Special Protection Area (SPA) boundaries, as compiled from data provided by the regional network of Wildlife Recovery Centres (WRC) and Iberdrola S.A. electric company (EC) 2000-2010 (see text for more details). Species included in Annex I of the Birds Directive (09/147/CE) are indicated.

| Species | Annex I | Outside SPA | | | Inside SPA | | | Total $_{1+2}$ |
|---|---|---|---|---|---|---|---|---|
| | | WRC | EC | Total$_1$ | WRC | EC | Total$_2$ | |
| Osprey *Pandion haliaetus* | yes | 1 | - | 1 | - | - | - | 1 |
| Eurasian Griffon Vulture *Gyps fulvus* | yes | 10 | 4 | 14 | 2 | 4 | 6 | 20 |
| Short-toed Eagle *Circaetus gallicus* | yes | 6 | 4 | 10 | - | - | - | 10 |
| Montagu's Harrier *Circus pygargus* | yes | - | 1 | 1 | - | - | - | 1 |
| Golden Eagle *Aquila chrysaetos* | yes | 7 | 1 | 8 | 1 | - | 1 | 9 |
| Bonelli's Eagle *Hieraaetus fasciatus* | yes | 7 | 2 | 9 | 7 | 1 | 8 | 17 |
| Booted Eagle *Hieraaetus pennatus* | yes | 15 | 1 | 16 | 6 | 1 | 7 | 23 |
| Common Buzzard *Buteo buteo* | no | 22 | 4 | 26 | 4 | 1 | 5 | 31 |
| Eurasian Sparrowhawk *Accipiter nisus* | no | 1 | - | 1 | - | - | - | 1 |
| Northern Goshawk *Accipiter gentilis* | yes | 1 | - | 1 | - | - | - | 1 |
| Peregrine Falcon *Falco peregrinus* | yes | 1 | - | 1 | - | - | - | 1 |
| Common Kestrel *Falco tinnunculus* | no | 41 | 6 | 47 | 5 | - | 5 | 52 |
| Eurasian Eagle Owl *Bubo bubo* | yes | 94 | 31 | 125 | 17 | 4 | 21 | 146 |
| Little Owl *Athene noctua* | no | 1 | 1 | 2 | - | - | - | 2 |
| Tawny Owl *Strix aluco* | no | - | - | - | 1 | - | 1 | 1 |
| Barn Owl *Tyto alba* | no | 1 | 1 | 2 | 1 | - | 1 | 3 |
| Unidentified raptor | - | 1 | - | 1 | 2 | 1 | 3 | 4 |
| **Total raptors** | | **209** | **56** | **265** | **46** | **12** | **58** | **323** |
| Little Egret *Egretta garzetta* | yes | - | 1 | 1 | - | - | - | 1 |
| Grey Heron *Ardea cinerea* | no | 1 | 1 | 2 | 1 | - | 1 | 3 |
| Unidentified Heron *Ardea* sp. | - | 1 | - | 1 | - | 1 | 1 | 2 |
| White Stork *Ciconia ciconia* | yes | 3 | 10 | 13 | 4 | - | 4 | 17 |
| Black Stork *Ciconia nigra* | yes | 1 | - | 1 | - | - | - | 1 |
| Peacock *Pavo cristatus* | no | - | 1 | 1 | - | - | - | 1 |
| Unidentified Gull *Larus* sp. | - | - | 2 | 2 | - | - | - | 2 |
| Rock Dove *Columba livia* | no | 1 | 12 | 13 | - | 1 | 1 | 14 |
| Unidentified Pigeon *Columba* sp. | - | 1 | - | 1 | - | - | - | 1 |
| Eurasian Collared Dove *Streptopelia decaocto* | no | - | 1 | 1 | 3 | - | 3 | 4 |
| Hoopoe *Upupa epops* | no | - | 1 | 1 | - | - | - | 1 |
| Common Raven *Corvus corax* | no | 5 | 4 | 9 | 1 | - | 1 | 10 |
| Jackdaw *Corvus monedula* | no | - | 1 | 1 | - | - | - | 1 |
| European Magpie *Pica pica* | no | 2 | - | 2 | - | - | - | 2 |
| Chough *Pyrrhocorax Pyrrhocorax* | yes | - | - | - | 1 | - | 1 | 1 |
| House Sparrow *Passer domesticus* | no | - | 1 | 1 | - | - | - | 1 |
| Blackcap *Sylvia atricapilla* | no | 1 | - | 1 | - | - | - | 1 |
| Unidentified Thrush *Turdus* sp. | no | - | 3 | 3 | - | - | - | 3 |
| Unidentified Starling *Sturnus* sp. | no | 3 | - | 3 | - | 1 | 1 | 4 |
| **Total non-raptors** | | **19** | **38** | **57** | **10** | **3** | **13** | **70** |
| **Unidentified species** | | **2** | **4** | **6** | **-** | **1** | **1** | **7** |
| **Total** | | **230** | **98** | **328** | **56** | **16** | **72** | **400** |

increased to 91.3% ($\chi^2_1 = 49.60$, $P < 0.01$). This discrepancy is likely due to the fact that WRC information is biased towards species of higher conservation interest (e.g. raptors).

Electrocutions were more frequent outside than inside SPAs, for both data sources combined (82.5% *vs* 17.5%; $\chi^2_1 = 18.22$, $P < 0.001$), for WRC data only (80.4% *vs* 19.6%; $\chi^2_1 = 9.86$, $P < 0.01$) and for EC data only (86.0% *vs* 14.0%; $\chi^2_1 = 9.40$, $P < 0.01$). Differences were also found in the electrocution rate by taxonomic group comparing inside *vs* outside SPAs, either for both data sources joined (raptors: $\chi^2_1 = 14.86$, $P < 0.001$; non-raptors: $\chi^2_1 = 2.90$, $P = 0.08$), for WRC data only (only for raptors: $\chi^2_1 = 11.57$, $P < 0.001$; non-raptors: $\chi^2_1 = 0.08$, $P = 0.77$) or for EC data only (raptors: $\chi^2_1 = 3.29$, $P = 0.07$; non-raptors: $\chi^2_1 = 7.42$, $P < 0.01$).

There were no differences in the spatial distribution (distance bands from the SPAs) of the electrocutions between each data source ($\chi^2_6 = 7.45$, $P = 0.3$), suggesting that there was no bias in the collection of birds entering WRC and allowing combination of data from both sources in spatial analyses. Controlling for area, important differences between the observed and expected electrocution rates in the different spatial bands from the edges of the SPAs were observed ($\chi^2_6 = 44.75$, $P < 0.01$). In particular, there were increasingly fewer bird electrocutions than those expected with increasing distance inside the SPA boundary (> 2.5–2.5 km interval: $\chi^2_1 = 28.60$, $P = 0.001$), and more were found than those expected in the band 2.5–5 km outside the SPAs ($\chi^2_1 = 18.29$, $P < 0.001$; Figure 1).

Differences were also observed between electrocution frequency distribution in each of the bands and the length of power lines present ($\chi^2_6 = 75.47$, $P < 0.001$). Once again, the 2.5–5 km interval outside the SPAs accumulated a particularly high electrocution frequency ($\chi^2_1 = 18.29$, $P < 0.001$); additionally, the band 2.5–0 km inside the SPAs also showed higher than expected electrocution rates ($\chi^2_1 = 12.69$, $P = 0.001$), while in contrast, in the 5–7.5 km and 7.5–10 km intervals outside the SPAs the electrocutions reduced to below those expected (5–7.5 km interval: $\chi^2_1 = 7.89$, $P = 0.005$; 7.5–10 km interval: $\chi^2_1 = 6.08$, $P = 0.01$; Figure 1).

## Discussion

The management efforts promoted by the recently approved, SPA network-based Spanish legislation against electrocutions are clearly shown to be deficient in eliminating the problem at the large scale, given that only a small minority of casualties (17.5%) occur within SPAs. The number of species suffering electrocution was also higher outside ($n = 31$) than inside SPAs ($n =$

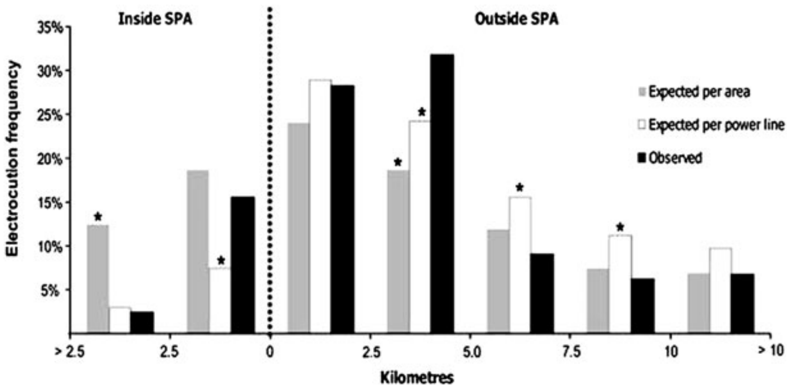


Figure 1. Comparison between observed and expected frequencies (based on a function of both area and length of power line; see text for more details) of electrocuted birds entering Wildlife Recovery Centres and recorded from Iberdrola S.A. electric company in the Community of Valencia (Spain), with respect to the distance from the border of the closest SPA. Significant differences ($P < 0.05$) between observed and expected frequencies are marked with an asterisk.

16; see Table 1). To be effective, the Spanish regulations for protection against electrocution need to be spatially refocused. The electrocutions outside SPAs are not randomly distributed, but tend to concentrate close to their boundaries and this allows for a practical targeting of effort. In this case, management activities focused on SPAs would produce a maximum reduction of c.18% in bird electrocutions, the same effort (in spatial terms) could reduce up to c.60% of electrocutions if it was directed in the 5 km band adjacent to each SPA, which in the CV occupies a similar area to that covered by the SPAs themselves (42% compared to 31%, respectively of the total area of CV). This case study indicates that national anti-electrocution strategies should be based on detailed and systematic studies of electrocution occurrence in all the country. In a recent study conducted in an area of Catalonia (NE Spain), Tintó *et al.* (2010) also found more electrocuted birds in the surroundings of protected reserves than inside them, supporting the hypothesis that this is not only a regional problem or pattern.

One of the factors determining the spatial imbalance in electrocution frequency could be the greater relative presence of power lines outside compared to inside the SPAs ($\chi^2_{10} = 5699.33$, $P < 0.001$), which is probably due to the conservation policies inside SPAs. However, the spatial distribution of power lines does not fully explain the pattern of electrocutions observed, such that there was a higher than expected frequency in the immediate surroundings of the SPAs. This pattern may be the compound result of two fundamental factors: (1) higher presence of birds and (2) a higher use of the pylons as perching sites in the bordering areas (Janss and Ferrer 1999, Mañosa 2001, APLIC 2006, Tintó *et al.* 2010). The majority of the SPAs were delimited using criteria regarding nesting sites for Annex I species in the Birds Directive. Traditionally, the breeding habitats of these species have been associated with relatively natural areas with low human influence, such that the inclusion of areas such as mountains or forests in the SPA selection process was favoured over others such as agricultural areas. However, raptor studies in the Mediterranean have shown that even the most forest-dwelling species show nesting selection at the landscape level for ecotones between natural and agricultural areas (Sánchez-Zapata and Calvo 1999), where their prey are more abundant. In addition, it has also been shown how those raptors breeding within the SPAs frequently use hunting areas outside them (e.g. Martínez *et al.* 2007). Thus, the areas bordering SPAs constitute ecotone areas between the natural habitat inside, and the more anthropogenically-modified (principally agricultural) habitats outside the protected areas, and these are highly favourable for many bird species. The relative scarcity of natural perching sites outside SPAs (due to the habitat usually being flatter and less forested) leads to a greater use of artificial perches (e.g. power pylons), thus increasing the risk of mortality through electrocution and converting these areas into ecological traps (Gates and Gysel 1978).

Various factors could bias our results (Ferrer and Janss 1999, Lehman *et al.* 2007), e.g. the existence of previous power line correction programmes or the presence of relatively low risk power lines inside SPAs (particularly in comparison to those in the immediately surrounding area). However, to date there have been no power line correction programmes in the CV (but for a few exceptions of small magnitude), and although not studied, there is no suggestion that the crossarm configuration (one of the most important determinants of the risk of a pylon; e.g. Mañosa 2001, Tintó *et al.* 2010) is on average different between those pylons inside and outside the SPAs, given that the use of one design or another (at least during the period studied, and before entry of the new anti-electrocution rules) depended on criteria unrelated to the conservation policies in protected areas, that is, strictly technical or economic ones. The concept that Spanish SPAs might traditionally have been associated with low levels of bird electrocutions and our suggestion that additional correction efforts linked to the new national regulation would be more effective while applied in their surroundings instead of inside them are non-mutually exclusive.

A bias in the recovery of birds could also invalidate our conclusions. However, data from WRC were not spatially different than those from the EC, which were considered to be unbiased in spatial terms (see Methods). For its part, the fact that a large proportion of the electrocuted individuals entering WRC were relatively fresh (41% alive) when located and that the birds causing outages and registered by the EC (those considered in this study) were rapidly found by company personnel minimised the potential biases due to the differential disappearance of corpses by scavengers (e.g. due to contrasting scavenger densities among areas). Bias is also minimised as the detection rate of medium- and large-sized birds (such as raptors), those more prone to suffer electrocutions, is subject to less bias from scavengers removing carcasses than that of small birds (APLIC 2006, Ponce *et al.* 2010).

In conclusion, our results seem to illustrate the classic problem of an edge effect associated with a protected area (Janzen 1986), where external human influences may directly affect the persistence of protected species within reserves (Loveridge *et al.* 2007). Equally, they support the idea that management strategies within reserves cannot be independent of the human activities surrounding them (Wells and Brandon 1992). In the case of power lines with risk of electrocution for birds, it even appears more worthwhile (in conservation terms) to invest in correction work outside rather than inside the reserves (SPAs) themselves. We strongly recommend that biodiversity conservation strategies are adopted based on prior evaluation of their effectiveness, so that management interventions are evidence-based (Sutherland *et al.* 2004).

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