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PERSPECTIVE

Bird on the wire: Landscape planning considering costs and benefits for bird populations coexisting with power lines

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Abstract Power-line grids are increasingly expanding worldwide, as well as their negative impacts on avifauna, namely the direct mortality through collision and electrocution, the reduction of breeding performance, and the barrier effect. On the other hand, some bird species can apparently benefit from the presence of power lines, for example perching for hunting purposes or nesting on electricity towers. In this perspective essay, we reviewed the scientific literature on both costs and benefits for avifauna coexisting with power lines. Overall, we detected a generalized lack of studies focusing on these costs or benefits at a population level. We suggest that a switch in research approach to a larger spatio-temporal scale would greatly improve our knowledge about the actual effects of power lines on bird populations. This research approach would facilitate suitable landscape planning encompassing both mitigation of costs and promotion of benefits for bird populations coexisting with power lines. For example, the strategic route planning of electricity infrastructures would limit collision risk or barrier effects for threatened bird populations. Concurrently, this strategic route planning would promote the range expansion of threatened populations of other bird species, by providing nesting structures in treeless but potentially suitable landscapes. We suggest establishing a collaborative dialogue among the scientific community, governments, and electricity companies, with the aim to produce a win–win scenario in which both biodiversity conservation and infrastructure development are integrated in a common strategy.

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Keywords Barrier effect · Collision · Electrocution · Nesting platforms · Route planning · Win–win scenario

INTRODUCTION

Human population growth has led to the global increase of power lines during the last century. These infrastructures are used for electricity transmission (i.e., bulk movements of high voltage from generating sites to transformer substations) and distribution (i.e., delivery movements of medium and low voltage among transformer substations and then to customers). Only considering high- and medium-voltage infrastructures, over 65 million km of power lines are currently in use around the world, and this grid is increasing at a rate of about 5% annually (ABS Energy Research 2008; Jenkins et al. 2010). While these infrastructures have largely negative impacts on avifauna, some species are able to take advantage of them. In this perspective essay, we briefly review both costs and benefits for avifauna coexisting with power lines (see Appendix S1 for bibliographic search methods and the whole list of considered literature), discussing the implications for suitable landscape planning of electricity infrastructures.

COSTS FOR BIRDS COEXISTING WITH POWER LINES

The most recognized impact of power lines on birds is direct mortality through collision and electrocution. Collision occurs mainly with overhead wires, whereas the so-called electrocuting trap is triggered when a bird spans the distance between two wires or a wire and a grounding device (Bevanger 1994, 1998; Janss 2000). Most studies list the affected species along given power-line sections or calculate collision/electrocution rates at a local scale (e.g. Savereno et al. 1996; Harness and Wilson 2001; Rubolini et al. 2005). Overall, there are relatively few studies estimating collision or electrocution rates at a landscape or national scale (cf. Ferrer et al. 1991; Bevanger 1995; Loss et al. 2014). More importantly, there has been little research on the demographic impact of collisions and electrocution, which would ultimately define the real impacts of electricity infrastructures on bird populations. Most population-impact studies have focused on endangered birds, such as two globally vulnerable species: the blue crane *Anthropoides paradisea* in the Overberg region of South Africa (12% of annual collision mortality; Shaw et al. 2010) and the Iberian imperial eagle *Aquila adalberti* in Doñana Biosphere Reserve, in Spain (approximately 15% of annual electrocution mortality; Janss and Ferrer 2001). This evidence suggests that collisions and electrocutions can actually represent relevant threats for endangered bird populations. For this reason, several studies have investigated both intrinsic and extrinsic factors increasing collision and electrocution risk, although only a few have experimentally tested the actual relevance of these factors. Overall, the available literature suggests that intrinsic factors are mainly related to species morphology (see below in *1A* and also in Table S1) and behavior (*1B*), whereas extrinsic factors concern weather (*2A*), landscape (*2B*), and technical features of the power lines (*2C*).

(1) Intrinsic factors increasing collision and electrocution risk. (1A) Species morphology. The most relevant morphologic feature increasing collision risk has been suggested to be the combination of a heavy body and relatively small wings, for instance in bustards and grouses (Bevanger 1994, 1998; Janss 2000). Birds with narrow visual fields, such as storks and cranes, are also heavily affected by collisions (Martin and Shaw 2010; Martin 2011). Long legs or wings, such as for example in storks or eagles, can easily trigger the electrocuting trap (Bevanger 1998; Janss 2000). *(1B) Species behavior.* Behavioral susceptibility to collisions may be related to nocturnal activity, migratory habits and gregariousness. Overhead wires are less visible at night, and consequently nocturnal birds such as owls are often affected by collision mortality (Bevanger 1998; Rubolini et al. 2001). Collision risk has been suggested to possibly increase during migration across changing landscapes with recently built power lines (Bevanger 1994), especially for nocturnal migrants (Arnold and Zink 2011). On the other hand, the exposure to collision risk is lower for migratory species wintering or breeding in countries without well-developed electricity grids (Janss and Ferrer 2000). Furthermore, some species are more gregarious during migrations, potentially increasing collision hazard, as those birds at the rear of the flock can be relatively unaware of obstacles (Janss 2000; Jenkins et al. 2010). Finally, behavioral susceptibility to electrocution is mainly related to birds using electricity infrastructures for hunting or nesting (see below in Benefits), as for example raptors or storks (Gilmer and Wiehe 1977; Infante and Peris 2003).

(2) Extrinsic factors increasing collision and electrocution risk. (2A) Weather. Both mist and fog can increase collision risk by limiting visibility (Drewitt and Langston 2008; Jenkins et al. 2010). Wind and rain can produce similar effects by directly impairing flight (Bevanger 1994; Henderson et al. 1996). Meteorological factors can also affect the probability of electrocution, which has been estimated to increase tenfold during rainy days in raptors, due to feather wetting (Lehman et al. 2007). *(2B) Landscape*. Coastlines and valleys (but also lesser landscape features such as forest edges) are used by birds as directional cues during migrations and local movements (see below in Benefits), and may result in high numbers of collisions when associated with power lines (Bevanger 1994; Shobrak 2012). Topography and habitat structure are also among the key drivers of avian electrocution. For instance, electricity towers on hilltops are electrocution hotspots for raptors, because they provide a wider field of view for hunting than lowland towers (Boeker and Nickerson 1975; Prather and Messmer 2010), especially in open landscapes without alternative perches such as trees (Lehman et al. 2007). *(2C) Technical features of the power lines.* The diameter of the overhead wires and their installation at different heights of the same power-line span can possibly increase collision risk for birds (Bevanger 1994). A suitable example is the ground wire, which is usually thinner (i.e., less visible) and installed on top of transmission lines, and for this reason is often suggested to cause most collisions (Alonso et al. 1994; Jenkins et al. 2010). Technical features related to the distance between wire and tower, such as the presence and position of insulators, are the most relevant factors triggering the electrocuting trap (Ferrer et al. 1991; Bevanger 1994; Janss and Ferrer 2001).

A less recognized impact of power lines on birds is the reduction of breeding performance. Some species, such as raptors and storks, can breed on electricity towers and poles (see below in Benefits), but these infrastructures are intrinsically more exposed than trees to heavy rains, severe solar radiation and storm winds, with possible negative impacts on hatching success and nestling survival (Gilmer and Wiehe 1977; Janiszewski et al. 2015). Furthermore, electromagnetic pollution related to power lines has been suggested to decrease reproductive success in several species, from small passerines to storks (Doherty and Grubb 1998; Vaitkuvienė and Dagys 2014). American kestrels *Falco sparverius* have been observed to be more active during courtship and incubation when exposed to electromagnetic fields, potentially increasing the probability of egg breakage (Fernie and Reynolds 2005). Other negative effects have been associated with electromagnetic fields, such as for example abnormal embryogenesis in domestic chickens *Gallus gallus domesticus* (Berman et al. 1990; Fernie and Reynolds 2005) and reduced growth rates in American kestrels (Fernie and Bird 2005). The demographic consequences of this potential impact on bird populations are virtually unknown.

Finally, there is another, even less recognized, impact of power lines on avifauna: the barrier effect due to avoidance behavior, which has been described to extend from dozens of meters up to about 1 km to overhead wires (as estimated by Benítez-López et al. 2010 considering 200 bird species). For example, transmission power lines are significantly avoided by little bustards *Tetrax tetrax* in Portugal (Silva et al. 2010) and pink-footed geese *Anser brachyrhynchus* in Denmark (Larsen and Madsen 2000). Considering that in most cases overhead wires are neither a physical barrier nor associated with human presence, this avoidance might be related to the ability of birds to detect ultraviolet discharges on power lines, occurring both as standing coronas along wires and irregular flashes on insulators (Tyler et al. 2014). Furthermore, this kind of avoidance behavior can be also related to the habitat loss determined by vegetation management (mowing, cutting, or application of herbicides) along power-line easements (Andrews 1990; Baker et al. 1998; Strevens et al. 2008). Indeed, the regular removal of vegetation along power-line rights-of-way can create an abrupt discontinuity with adjacent natural habitats, inhibiting the movements of forest birds (Andrews 1990; Strevens et al. 2008), increasing their rates of nest predation and brood parasitism (Askins 1994; Rich et al. 1994) and ultimately affecting species richness and abundance (Baker et al. 1998).

BENEFITS FOR BIRDS COEXISTING WITH POWER LINES

The most obvious case of birds taking potential advantage of power lines concerns their use for perching and hunting, which has been widely described in scientific literature (Prather and Messmer 2010; Morelli et al. 2014), but virtually never estimating its demographic implications. Both solitary resting and communal roosting on power lines are frequently observed in several bird species, from small passerines to storks (Janss 1998; Donázar et al. 2002; Morelli et al. 2014). Resting and roosting on elevated perches have been traditionally interpreted as anti-predator behaviors (Blumstein et al. 2004; Møller et al. 2006). Perching behavior on electricity towers, poles, and wires also relates to hunting purposes, as already described for raptors (Kmetova et al. 2012), corvids (Prather and Messmer 2010), rollers (Catry et al. 2017), and shrikes (Morelli et al. 2016). These vertical infrastructures provide a wide field of view, enhancing predation efficiency (Boeker and Nickerson 1975; Prather and Messmer 2010). For this reason, perching behavior for hunting purposes often occurs on electricity towers located on hilltops (Boeker and Nickerson 1975), and generally in open landscapes affording a wide field of view (Lehman et al. 2007). Furthermore, where power lines are associated with roads, perching behavior to scavenge road-killed animals has been described for raptors and corvids (Meunier et al. 2000; Dean et al. 2006). In fact, the use of perching sites for scavenging is a less energy-demanding foraging strategy than searching flights (Meunier et al. 2000; Morelli et al. 2014). Perch availability can influence bird movement at both local and landscape scales. For example, the presence of foraging European rollers *Coracias garrulus* can be predicted to gradually increase according to the availability of power lines (Catry et al. 2017).

The most emblematic case of species taking potential advantage of power lines is the use of electricity towers and poles for nesting purposes. Most studies on this topic list the species nesting on electricity infrastructures or detail nest-site location at a local scale (e.g., Gilmer and Wiehe 1977; Janss and Sánchez 1997). Only a few studies have assessed bird-nesting on power lines at a landscape or national scale. One of them shows that the historical development of Portuguese very-high-voltage grid (from ca 1000 towers in 1958 to ca 11 000 in 2014) facilitated the increase of white storks *Ciconia ciconia* nesting on transmission towers (from 1 to 25% of breeding population; Moreira et al. 2017). Overall, there has been little research on the demographic consequences of nesting on power lines. In some cases, power lines have facilitated range expansions by providing nesting substrate in treeless but potentially suitable landscapes, as is the case of pied crows *Corvus albus* in the arid shrublands of South African Karoo (Cunningham et al. 2016). However, several species also select electricity infrastructures for nesting in wooded landscapes, e.g., white storks in Poland and Eurasian kestrels *Falco tinnunculus* in Spain (Fargallo et al. 2001; Tryjanowski et al. 2009). Electricity towers and poles are, indeed, less affected by nest predation than trees and buildings, as observed for Eurasian kestrels, because these infrastructures are less accessible to mammalian predators (Fargallo et al. 2001).

Finally, there are few studies suggesting that linear infrastructures can also affect bird movement. Levant sparrowhawks *Accipiter brevipes* and domestic pigeons *Columba livia domestica* have been reported to recognize and actively select highways as migration and homing paths, respectively (Lipp et al. 2004; Yosef 2009), similarly to other species using landforms, such as coastlines and rivers, as directional cues during migrations (Mueller and Berger 1967; Vardanis et al. 2011). Potential effects of power lines on bird movement, especially at a landscape scale, should be investigated in the future.

LANDSCAPE PLANNING: MITIGATING COSTS AND PROMOTING BENEFITS FOR BIRD POPULATIONS COEXISTING WITH POWER LINES

According to the short but exhaustive review we have performed in this perspective essay, there is a large and growing scientific literature concerning the interactions between birds and power lines. The overall purpose of power-line research is to quantify the ecological effects of electricity infrastructures, with the ultimate aim of mitigating costs and promoting benefits for bird populations. Nevertheless, we have found that most studies are only describing these costs and benefits at a local scale. In our opinion, this is a priceless starting point to understand the impacts of power lines on bird populations, but nowadays there is a compelling need for applied research focusing on the demographic consequences of these costs and benefits. Merely counting the number of dead birds along a given power-line section will not inform whether these infrastructures are threatening the population persistence of a given target species. Similarly, recording nest occupancy on a given amount of electricity towers is not sufficient to report whether power lines are increasing the population recruitment of the recipient species. This is especially true for species like the white stork, that are both negatively and positively affected by power lines (e.g., Infante and Peris 2003; Moreira et al. 2017).

This perspective essay is a call for more comprehensive studies, quantifying the demographic consequences of cost-benefit trade-offs along whole power-line grids. In our opinion, the essential step to achieve this goal should be a switch in research approach to a larger spatio-temporal scale, focused on suitable landscape planning entailing both mitigation of costs and promotion of benefits for bird populations coexisting with power lines (see Fig. S1 for a conceptual diagram). Concerning the mitigation of costs, the implementation of anti-collision devices such as wire markers (Barrientos et al. 2011, 2012) should be prioritized where conflictive power lines are associated with coastlines, valleys, and other landscape features that potentially produce collision hotspots, thereby threatening the population persistence of any given species. In case of collision hotspots affecting endangered species, the undergrounding of conflictive power-line spans should be seriously considered (Bevanger and Brøseth 2001; Jenkins et al. 2010). Routing of new power lines should be carefully planned, avoiding potential collision hotspots that probably coincide with protected areas and migratory corridors (Morkill and Anderson 1991; Bagli et al. 2011). A possible solution, already implemented in some cases, may be routing new power lines following already existing linear infrastructures (Bagli et al. 2011).

Electrocution, contrarily to collision, is not only affecting bird populations, but is also producing considerable failures in power transmission, with logistical and economic implications for electricity companies (Burgio et al. 2014; Maricato et al. 2016). As a consequence, the implementation of cost-effective mitigation measures (e.g., elevated perches, perching/nesting deterrents, and nest relocation) by electricity companies is already widespread in many developed countries (Tryjanowski et al. 2009; Kaługa et al. 2011; Maricato et al. 2016). These win–win measures should spread in the future, hopefully including developing countries.

Avoidance behaviors and the consequent barrier effects related to habitat loss along power-line easements are other impacts with potential implications for bird populations, but they are relatively difficult to mitigate. Removal of vegetation along power-line rights-of-way is an unavoidable management measure, as it protects power supply by preventing contact between vegetation and overhead wires, and reduces the probability of wildfires reaching the electricity infrastructures (Clarke et al. 2006). However, vegetation hand-cutting is a more selective form of management that avoids the complete removal of threatened plant species, and, whenever possible, should be preferred to mechanical mowing and especially to application of herbicides. Furthermore, in case of power-line easements causing habitat loss and consequently affecting the population persistence of endangered species, the route planning of electricity infrastructures should be modified. On the other hand, well-managed power-line rights-of-way can constitute a reservoir of shrubland habitat in heavily forested landscapes (King and Byers 2002) or intensive farmlands (Tryjanowski et al. 2009). This habitat is mostly suitable for shrubland birds (King and Byers 2002; King et al. 2009), including, for instance, declining species such as the near threatened golden-winged warbler *Vermivora chrysoptera* and painted bunting *Passerina ciris* (Askins 1994). Planning power-line easements with native shrubland along forest plantations or intensive farmlands can be an example of potential promotion of benefits for threatened bird populations coexisting with electricity infrastructures.

Finally, the implementation of safe perches, nesting platforms or nest-boxes on electricity towers may also generate benefits for bird populations coexisting with power lines. The provision of safe perches should be prioritized in open landscapes inhabited by endangered bird species that select electricity towers for hunting purposes. More importantly, the range expansion of threatened bird populations might be facilitated by providing nesting platforms or nest-boxes in treeless but potentially suitable landscapes.

Unfortunately, considering the worldwide scenario of economic crisis, it is difficult to obtain the long-term funding essential for investigating how to mitigate costs and promote benefits for bird populations coexisting with power lines. However, a promising strategy to develop the switch we suggest in research approach is to establish a collaborative dialogue among scientific community, governments and electricity companies, entailing an improvement in knowledge transference between research and policy. This dialogue would produce a potential win–win scenario in which biodiversity conservation would coincide with several benefits for electricity companies, as for example the optimization of their costs related to avifauna (e.g., Burgio et al. 2014; Maricato et al. 2016) and the promotion of their biodiversity-friendly attitude (Mainwaring 2015; Moreira et al. 2017). This win–win scenario would entail relevant repercussions on landscape planning, with considerable implications for the conservation of bird populations coexisting with power lines.

CONCLUDING REMARKS

- There is a large body of scientific literature describing costs and benefits for birds coexisting with power lines. Collision and electrocution are the most recognized costs, but both reduction of breeding performance and barrier effect have also been described. Perching, hunting, and nesting on electricity infrastructures are the most recognized benefits.
- Most research on birds and power lines has only described costs and benefits at a local scale. There is need for applied research focusing on the demographic consequences of cost-benefit trade-offs along whole power-line grids. This research would produce suitable landscape planning entailing both mitigation of costs and promotion of benefits for bird populations coexisting with power lines.
- Establishing a collaborative dialogue among the scientific community, governments and electricity companies can provide a win–win scenario in which both biodiversity conservation and infrastructure development are integrated in a common strategy.

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