Chapter 23
Conflicts Between Birds and On-Shore Wind Farms

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Background

Wind power is an important source of renewable energy, providing around 2.1 % of electricity worldwide during 2011 (Table 23.1). This figure may rise to 20 % by 2050, according to some projections (IPCC 2012). The use of on-shore wind farms has increased dramatically over the last decade (GWEC 2013) (Fig. 23.1). While the exploitation of renewable energy sources will be fundamental to combating climate change, this rapid expansion of wind farm development has raised issues about potential harmful effects on wildlife. Birds are one of the key groups of concern (IPCC 2012) and may be affected by wind farms both through direct collision with turbines and through habitat and ecosystem modifications associated with wind farm developments (Drewitt and Langston 2006). In this chapter, we will first review these effects and the mechanisms by which they may occur. We will then outline possible mitigation strategies against any potential adverse effects on wildlife.

Current Evidence on the Effects of Wind Farms on Birds

Wind turbines can affect bird populations in two main ways—directly, via mortality after collision with wind farm infrastructure, or indirectly, via disturbance and/or displacement effects caused by the presence or operation of turbines. First, we will focus on collision effects and then look into disturbance effects in a later section.

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Table 23.1 Electricity generation by wind power contributing to total electricity generated from all sources and from renewable sources

Compared to	Region	% Contribution 2007	2008	2009	2010	2011
All sources	North America	0.75	1.19	1.69	2.12	2.82
	Central and South America	0.11	0.13	0.20	0.32	0.43
	Europe	2.94	3.34	3.91	4.22	5.11
	Eurasia	0.02	0.03	0.03	0.04	0.08
	Middle East	0.02	0.03	0.03	0.02	0.03
	Africa	0.21	0.22	0.29	0.37	0.42
	Asia and Oceania	0.37	0.54	0.78	1.00	1.36
	World	0.90	1.15	1.45	1.69	2.12
Renewable sources	North America	4.85	7.21	9.59	12.35	14.55
	Central and South America	0.17	0.19	0.29	0.47	0.63
	Europe	13.80	14.81	15.95	16.11	19.47
	Eurasia	0.12	0.16	0.19	0.25	0.50
	Middle East	0.56	1.76	1.81	0.98	1.38
	Africa	1.22	1.31	1.63	2.05	2.41
	Asia and Oceania	2.64	3.53	5.07	6.11	8.54
	World	4.82	5.90	7.13	8.18	10.14

Data from U.S. Energy Information Administration (2014)
This table shows the percentage contribution of wind power to total electricity generated (*top*) and to renewable electricity generated (*bottom*) for eight international regions for the years 2007–2011

Collision

Every year, hundreds of millions of birds are killed due to collisions with a variety of human-made structures, for example vehicles, building and windows, power lines, communication towers, and wind turbines (Erickson et al. 2001). Some authors suggest that bird fatalities due to collisions with wind turbines or associated structures are low compared with other causes of mortality (e. g. Erickson et al. 2001). However, the potential effect that mortality caused by collisions with wind turbines may have on certain bird populations should not be underestimated (Hunt 2002; Madders and Whitfield 2006). High mortality rates have been reported at some wind farms, for example at the Altamont Pass in California, a large wind farm with 5400 turbines, where an estimated 1127 raptors are killed each year (Smallwood and Thelander 2008); an estimated mortality rate of 0.21 raptor/turbine/year. At Tarifa in Southern Spain, the estimated mortality rate was 0.15 birds/turbine/year for griffon vulture (*Gyps fulvus*) and 0.19 birds/turbine/year for common kestrel (*Falco tinnunculus*) (Barrios and Rodríguez 2004). It is not only raptors that have been reported to collide with wind turbines as an estimated seven little terns (*Sterna albifrons*), 238 common terns (*Sterna hirundo*), and 84 sandwich terns (*Sterna sandvicensis*) are thought to have collided at a wind farm in Zeebrugge,

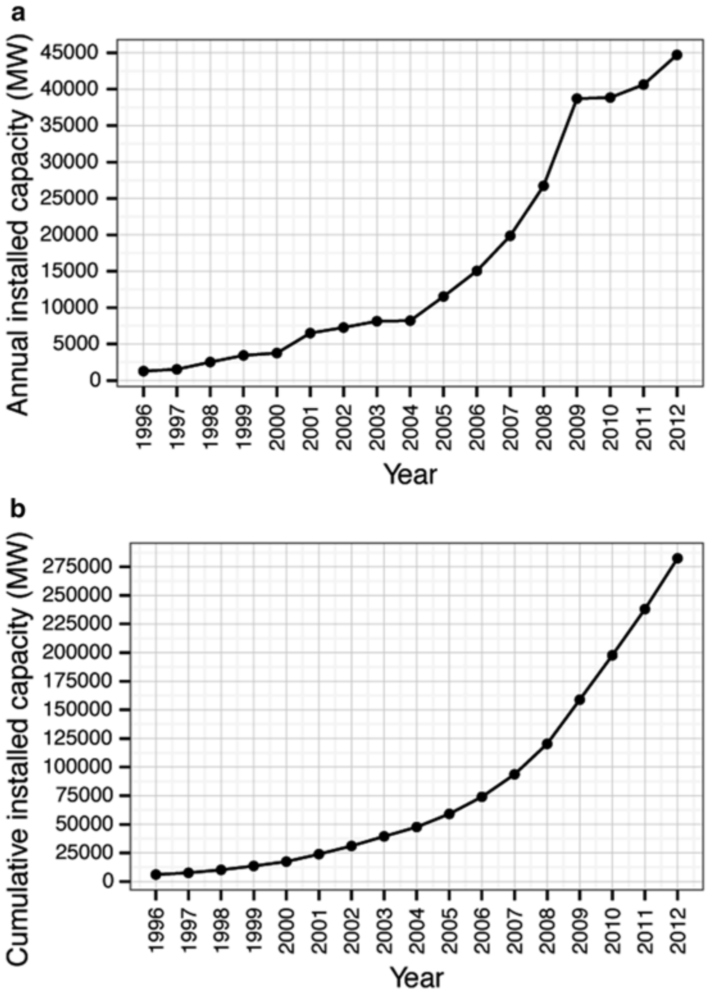

Fig. 23.1 Global-installed wind capacity from 1996 to 2012. (**a**) Global annual installed wind capacity in MW and (**b**) Cumulative global-installed wind capacity in MW. Data from GWEC (2013)

Belgium, during two breeding seasons (Everaert and Stienen 2006). By contrast, at a wind farm in Malaga in Southern Spain, only one collision of a common kestrel was recorded during the study period of two years and no collisions were identified for any other species, which included raptors, passerines, and non-passerines (Farfán et al. 2009). Furthermore, Rothery et al. (2009) reported that possibly two gannets (*Morus bassanus*) had collided at a wind farm at Blyth in England over a post-construction study period of 3 years and no collisions were reported for eight other seabird species. Thus, it is clear that collision mortality varies in time and space and it is important to understand and predict what factors affect collision probability.

The probability of bird collisions depends on factors associated both with the location of the wind farm and the species' flight behaviour. These are discussed in the following sections.

1. Site-Specific Factors

   The abundance of a species in the wind farm area has repeatedly been identified as one of the major factors affecting bird collision risk (Barrios and Rodríguez 2004; Carrete et al. 2012). However, collision risk cannot be predicted from abundance alone: some studies found no relationship between species abundance and collision rate (Fernley et al. 2006; Whitfield and Madders 2006; de Lucas et al. 2008). It is clear that other factors must be involved in modulating collision risk (Orloff and Flannery 1992; Orloff and Flannery 1996; de Lucas et al. 2008).

   One factor that influences avian collision risk is the type of turbine used. For example, some studies have found that lattice towers could provide perches for birds and their attraction could increase collision risk (Orloff and Flannery 1992; Percival 2005), while others have not supported this theory (Barrios and Rodríguez 2004; de Lucas et al. 2008). Turbines may also differ in height, for example at Altamont Pass the hub height differed from 12 m for the smallest turbine to 46 m for the tallest turbine. However, this was not reported as a factor that correlates with collision risk (Orloff and Flannery 1992; Orloff and Flannery 1996), and in an independent meta-analysis, Hötker et al. (2006) found only a weak relationship between height and collision risk.

   Another factor influencing avian collision risk is the number of turbines and their layout (Langston and Pullan 2003). A wind farm consisting of a large number of turbines (e.g. over 5000 turbines at Altamont Pass) may be associated with a large number of fatalities overall even if the collision risk per turbine is low (Langston and Pullan 2003; Percival 2003). In addition, a wind farm where turbines are positioned close to one another may allow less space for birds to successfully manoeuvre between them (Hunt 2002; Percival 2005). Furthermore, turbines located at the end of a row were reported to have higher collision rates at Altamont Pass (Orloff and Flannery 1992; Orloff and Flannery 1996; Smallwood and Thelander 2004), but the underlying causes for this difference are unknown and similar differences were not reported at Tarifa (de Lucas et al. 2008).

   Topographical features have also been suggested to influence collision risk in birds. Vultures, for example, require more lift to successfully evade turbines at higher altitudes, which might not always be available. Furthermore, many raptors use updrafts to aid their flight and thus areas with weaker updrafts can have higher mortality rates (de Lucas et al. 2008). For example, at a site in Spain, vulture mortality per turbine was higher in areas with gentle slopes producing weaker updrafts (de Lucas et al. 2008). In addition, wind farms located near features such as a sharp change in relief (e.g. plateau edges) and/or on mountain ridges resulted in higher raptor mortality (Percival 2005; Hötker et al. 2006).

Hunt (2002), in contrast, found that slope was not related to the number of fatalities, but the authors suggested that this may be because other factors (such as turbine spacing) were more important in this instance.

Finally, some studies showed correlations between prey availability and golden eagle (*Aquila chrysaetos*) collision mortality (Hunt 2002; Smallwood and Thelander 2004), suggesting that hunting raptors may not notice the turbines as they search for potential prey (Martin 2011).

2. Species-Specific Factors

   In addition to the site-specific factors discussed above, collision risk can also be affected by interspecific variation in behaviour and physiology. While birds in flight tend to focus their attention on what is below them to allow for effective detection of foraging opportunities, they also focus on conspecifics or roost sites (Martin 2011). They may have learnt to expect the open airspace above vegetation to be highly predictable and largely free of hazards (Martin 2011). In addition, the visual system of birds provides high resolution vision in the lateral fields but not in the frontal field. As a result, birds (particularly in flight) may have limited awareness of what is in front of them (Martin 2011), increasing collision risk with 'unexpected' objects such as wind turbines.

   Variation in flight maneuverability, which depends largely on morphology (Drewitt and Langston 2008), is another factor affecting collision risk. Although it is unknown which morphology factors influence collision risk, some suggestions have been made. For example, larger, relatively heavier species tend to have lower flight maneuverability and are thus less able to avoid wind turbines when necessary (Garthe and Hüppop 2004). In addition, many soaring birds are also less maneuverable as they have a weak-powered flight and use updrafts or thermals to power their flight (Tucker 1971; Pennycuick 1975; de Lucas et al. 2008). The number of flights, their duration, and height also influence collision risk (Garthe and Hüppop 2004; Drewitt and Langston 2008). For example, many passerines making local movements, as opposed to those during migration, tend to fly lower than the rotor swept area of larger turbines reducing the risk of collision (Hötker et al. 2006).

3. Other Factors

   A number of additional factors affecting bird collision risk that are not directly related either to the properties of the wind farm or bird biology and ecology have been identified. Certain weather conditions can influence flight ability. For example, heavy winds will affect flight maneuverability (Langston and Pullan 2003). Furthermore, fog and heavy rain will impede vision and thus also affect collision risk (Larsen and Guillemette 2007).

   It has been shown that collision risk changes with different seasons. In winter, lower temperatures mean that thermal updrafts are less common, affecting the flight ability of soaring birds. Indeed, de Lucas et al. (2008) found higher collision rates during winter than other seasons. Another study concerning little, common, and sandwich terns showed that collision risk was higher during chick provisioning (Everaert and Stienen 2006).

Disturbance

Substantial amounts of infrastructure (e.g. access tracks) are created during construction of wind farms. This, combined with the 'footprint' of the turbines themselves, causes a certain amount of direct habitat loss and/or fragmentation. While this loss of habitat is negligible for smaller wind farms, when the development consists of hundreds or even thousands of turbines, this loss can be considerable. Furthermore, birds may also avoid the area surrounding the wind farm, causing indirect habitat loss. This has been reported for different species in different seasons, primarily raptors, geese, ducks, and waders (Hötker et al. 2006) (Table 23.2).

However, birds do not always avoid turbine sites. For example, no disturbance effects have been found for most passerine species (Devereux et al. 2008; Farfán et al. 2009), or a range of other species, e.g. willow ptarmigan (*Lagopus lagopus*) (Bevanger et al. 2010; Douglas et al. 2011). Thus, disturbance behaviour appears to be species-specific, and it is unclear why certain species are affected while others are not. In addition, avoidance behaviour can be season-specific as a recent study found that black grouse (*Tetrao tetrix*) were avoiding wind farms during the breeding season, but there was no indication of avoidance during the winter (Zwart et al. 2015a). While we do not understand all the mechanisms driving avoidance behaviour, a range of contributing factors have been identified which we will outline below.

Firstly, noise produced by turbines could affect bird communication or foraging efficiency and birds might therefore perceive areas close to wind farms as of lower habitat quality. Most noise studies on animals have focused on the effects of urban or traffic noise. For example, great tits (*Parus major*) adjust the pitch of their song in response to urban noise (Slabbekoorn and Peet 2003) and traffic noise is correlated with a reduction in reproductive performance (Reijnen et al. 1996; Halfwerk et al. 2011). In another study, noise lowered foraging efficiency in chaffinches (*Fringilla coelebs*) (Quinn et al. 2006). There is limited information currently published on the impacts of wind turbine noise. Recent work has suggested that anti-predator behaviour in ground squirrels (*Spermophilus beecheyi*) and territorial behaviour in European robins (*Erithacus rubecula*) are affected by wind turbine noise (Rabin et al. 2006 Zwart et al. 2015b), but whether such effects can be generalized to other species is currently unclear. Zeiler and Grünschachner-Berger (2009) suggested that black grouse (*Tetrao tetrix*) may have left a wind farm site because of song disruption. However, the impacts of wind farm noise on bird distribution have not been directly addressed.

Secondly, increased human activity associated with wind farms could affect bird populations (Langston and Pullan 2003; Madders and Whitfield 2006; Zeiler and Grünschachner-Berger 2009). Such an increase would most likely be due to wind farm maintenance, but could also result from increases in tourism. After the construction of a wind farm in Norway, hiker activity increased as access to the area was improved through the newly created tracks that accompanied the wind farm development (Bevanger et al. 2010). Human disturbance is known to affect birds in a number of ways including reduced intake rates (de Boer and Longamane 1996;

Table 23.2 List of examples of disturbance effects by wind farms

Species	Scientific name	Country	Disturbance	Season	Reference
American Kestrel	*Falco sparverius*	US	Yes	Summer	Garvin et al. (2011)
Bewick's Swan	*Cygnus bewickii*	Netherlands	Yes	Winter	Fijn et al. (2007)
Black Grouse	*Tetrao tetrix*	Austria	Yes	Breeding	Zeiler and Grünschachner-Berger (2009)
Common Eider	*Somateria mollissima*	Denmark	Yes	Winter	Larsen and Guillemette (2007)
Cormorant	*Phalacrocorax carbo*	UK	Yes	Breeding	Rothery et al. (2009)
Corvids	*Corvidae*	UK	No	Winter	Devereux et al. (2008)
Dunlin	*Caldris alpina*	Norway	Yes	Breeding	Bevanger et al. (2010)
Eurasian skylark	*Alauda arvensis*	UK	No	Winter	Devereux et al. (2008)
Gamebirds		UK	No	Winter	Devereux et al. (2008)
Golden Plover	*Pluvialis apricaria*	UK	Yes		Pearce-Higgins et al. (2009)
Golden Plover	*Pluvialis apricaria*	Norway	Yes	Breeding	Bevanger et al. (2010)
Golden Plover	*Pluvialis apricaria*	UK	No	Breeding	Douglas et al. (2011)
Granivores		UK	No	Winter	Devereux et al. (2008)
Great Black-backed Gull	*Larus marinus*	UK	No	Breeding	Rothery et al. (2009)
Northern Harrier	*Circus cyaneus*	US	Yes	Summer	Garvin et al. (2011)
Pheasant	*Phasianus colchicus*	UK	Yes	Winter	Devereux et al. (2008)
Pink-footed Goose	*Anser brachyrhynchus*	Denmark	Yes		Larsen and Madsen (2000), Madsen and Boertmann (2008)
Red-tailed Hawk	*Buteo jamaicensis*	US	Yes	Summer	Garvin et al. (2011)
Sandwich Tern	*Sterna sandvicensis*	UK	No	Breeding	Rothery et al. (2009)
Tundra Bean Goose	*Anser serrirostris*	Netherlands	Yes	Winter	Fijn et al. (2007)
Turkey Vulture	*Cathartes aura*	US	Yes	Summer	Garvin et al. (2011)
Wheatear	*Oenanthe oenanthe*	Norway	Yes	Breeding	Bevanger et al. (2010)

(continued)

Table 23.2 (continued)

Species	Scientific name	Country	Disturbance	Season	Reference
White tailed eagles	*Haliaeetus albicilla*	Norway	Yes	Breeding	Bevanger et al. (2010), Dahl et al. (2012)
Willow Ptarmigan	*Lagopus lagopus*	Norway	No	Breeding	Bevanger et al. (2010)
Willow Ptarmigan	*Lagopus lagopus scotica*	UK	No	Breeding	Douglas et al. (2011)

This list was constructed via a literature search using “wind farms” AND “disturbance” AND “birds” OR “wind farms” AND “avoidance” AND “birds” as key words at the Web of Science™. This is not an exhaustive list

Goss-Custard et al. 2006) and increased nest predation (Lord et al. 2001) when they flee their foraging or nesting grounds due to an approaching person.

Third, physical properties of the wind farm such as turbine size and layout may alter bird distributions. Larger turbines can have a greater effect on nesting birds than smaller turbines (Hötker et al. 2006; Madsen and Boertmann 2008), which could be because larger turbines are more spaced out and thus cover a larger area. For example, birds were found not to actively avoid small wind turbines (micro-turbines or domestic turbines, 6–18 m hub height and often installed singly) (Minderman et al. 2012). In contrast, breeding birds, particularly songbirds, have been shown to be less affected by larger turbines (Hötker et al. 2006). Within wind farms, turbines can be positioned in a number of layouts, for example in clusters or rows. One study suggested that clusters might lead to a greater disturbance of pink-footed geese (*Anser brachyrhynchus*), as a cluster layout often coincides with their preferred habitat of open landscape (Larsen and Madsen 2000).

Finally, the construction of the wind farm might in fact cause more of an effect than the operational state (Douglas et al. 2011; Pearce-Higgins et al. 2012). If this is the case, it would be expected that the birds will return to the site over time after construction is completed. This has only been reported in a few cases (e.g. Madsen and Boertmann 2008) and some studies have reported that there is no habituation (Hötker et al. 2006; Stewart et al. 2007; de Lucas et al. 2008), but further longer-term studies are necessary to test this hypothesis.

In addition to indirect habitat loss, avoidance may lead to habitat fragmentation—the turbines lowering habitat quality in the surrounding area and thus breaking up a single patch of habitat into several smaller patches.

In conclusion, further studies are needed to fully understand the disturbance effects of wind farms on birds. In particular, while raptors are a key group that have been shown to be at risk of collision, studying population-level impacts of turbines is challenging due to the low breeding densities of these species (Newton 1979). It is worth adding one final note of caution: some of the effects of turbines on birds may have gone unnoticed as studies might not have been long enough for an effect to be detected (Garvin et al. 2011) or due to a lack of Before-After Control-Impact

(BACI) studies (Madders and Whitfield 2006). The before-after design involves data collection at a wind farm site prior to construction and compares it with data after construction. Collecting data before and after construction from a wind farm site *and* a control site is known as a BACI design.

Population-Level Effects

Both direct collision mortality and disturbance effects may have population-level consequences. These effects are likely to be highly species-specific and we discuss the potential impacts at a population-level below.

Consequences of Direct Collision Mortality

In contrast to disturbance effects, population-level consequences of collision mortality are thought to be more direct. Mortality from collisions could have a major impact on the population level of a species (Langston and Pullan 2003), particularly for long-lived species with low productivity (Langston and Pullan 2003; Hötker et al. 2006). Species with a small global range or population size might be particularly vulnerable. It is therefore important to consider the status of the birds that are using the proposed wind farm site in order to determine the potential effects. It is important to note that population effects may not be immediately apparent; for example, recruitment from other populations can replace the local nesting population, despite the number of birds being killed by the wind farm. The area would thus have become an ecological sink as more adults are coming into the area than leaving it (Smallwood and Thelander 2008).

Consequence of Disturbance Effects

The population-level consequences of disturbance effects are difficult to quantify and few studies have done so (Pearce-Higgins et al. 2012). Habitat loss caused by turbines is expected to cause a decrease in the overall quality of remaining habitat (Larsen and Madsen 2000; Madders and Whitfield 2006). The population-level response to this decrease in habitat quality depends on whether alternative habitat is available (Langston and Pullan 2003). For example, geese and swans moved from control areas to the wind farm area only when food availability in the control area was depleted (Fijn et al. 2007). Furthermore, birds might be displaced into less suitable habitat because optimal habitat might already support the maximum number of that species (e.g. insufficient availability of nesting locations or food resources), which may reduce their ability to survive and reproduce (Madders and Whitfield 2006; Dahl et al. 2012). This drop in productivity affects long-lived species with low annual productivity and slow maturation more than short-lived species with higher annual productivity (Langston and Pullan 2003; Hötker et al. 2006).

Alternatively, avoidance of turbine development areas may cause flights (e.g. between breeding and foraging grounds or migration flights) to be altered: the so-called barrier effect. Changes in flight paths may incur extra energy costs as travelling distances are increased. These increased energy costs could adversely affect survival or breeding success. For example, while flight lines of breeding little, common, and sandwich terns feeding young passed through a wind farm area, the same site was avoided during the non-breeding season, suggesting that they could not afford the extra flight time during the breeding season (Everaert and Stienen 2006). Migrating common eiders (*Somateria mollissima*) and geese have been reported to fly around an offshore wind farm in Denmark (Desholm and Kahlert 2005) and in England (Plonczkier and Simms 2012). The population-level consequences of the barrier effect for migratory populations are unclear, although they are expected to be limited if increases in flight time are relatively small (Desholm 2003).

Prevention and Mitigation

From looking at the factors that affect disturbance or collision caused by wind farms, it is clear that the impact on birds can be minimised by careful wind farm placement. Wind farm construction on sites where particularly sensitive species are present or where collision risk is high, as predicted from factors discussed above, should be avoided.

Therefore, the following is recommended:

1. Wind farms should avoid areas that are highly used by species sensitive to collision or disturbance. These include areas that are important to raptors, such as mountain ridges, and important foraging sites. Furthermore, wind farms should not be built in areas where there are large numbers of flights of sensitive species, such as migration crossing points or between nesting and feeding areas (Langston and Pullan 2003; Percival 2005; Hötker et al. 2006).
2. Wind farms should avoid areas that are designated as, or qualify for, sites of international or national nature conservation (Langston and Pullan 2003).
3. Wind farms should be placed so that they are parallel to the main flight direction (Hötker et al. 2006). For example, they could be placed parallel to migration route or flights between roosting and feeding areas.
4. Wind farms should have corridors so that birds can fly easily between them (Hötker et al. 2006).
5. Wind turbines should not have perching opportunities or other features that could attract birds (Hötker et al. 2006).
6. The height of the mast should be chosen so that the collision risk is low and/or any disturbance is minimal (Hötker et al. 2006).

In Europe, Competent Authorities require Environmental Impact Assessments (EIAs) to be carried out prior to any wind farm developments taking place.

These aim to ensure that the development is placed in a suitable location which minimises adverse impacts on wildlife (Directive 2011/92/EU). In brief, EIAs require a range of ecological surveys to be carried out, including those to determine which bird populations might be affected by any development. In addition, the sensitivity of those populations to any impact is determined and the scale of any potential effects is assessed. Finally, recommendations are made as to the acceptability of the predicted effects of the proposed development (Percival 2003). Outside Europe, there is little information on requirements that is easily accessible. Canada (Kingsley and Whittam 2005) and Mexico (Martínez 2008) have similar guidelines in place to those in Europe. In the United States, survey requirements vary extensively by state; some states have very detailed guidelines regarding the placement of wind farms, while others do not have any (Jodi Stemler Consulting 2007).

Given the possibility of bird mortality as outlined in the previous section, a key element of many EIAs is the estimation of likely bird mortality due to collision. To this end, numerical models are constructed that predict the number of bird fatalities per turbine per unit time, given the characteristics of the proposed turbines and bird activity in the area. The most widely used collision risk model was developed by Band et al. (2007) (Fig. 23.2). In this model, the collision rate is a product of a range of variables, including: (1) the size (wingspan and length) and flight speed of the given bird species; (2) the dimensions of the rotors and the speed of rotation; and (3) the avoidance rate of given species. The number of birds flying through this danger zone is calculated from vantage point surveys (Fig. 23.2) and is then multiplied by the collision risk rate to predict the number of collisions. One weakness of this model, among others, lies in the difficulty of estimating avoidance rate. The authors of the Band model tentatively suggest the use of a 95 % avoidance rate when data

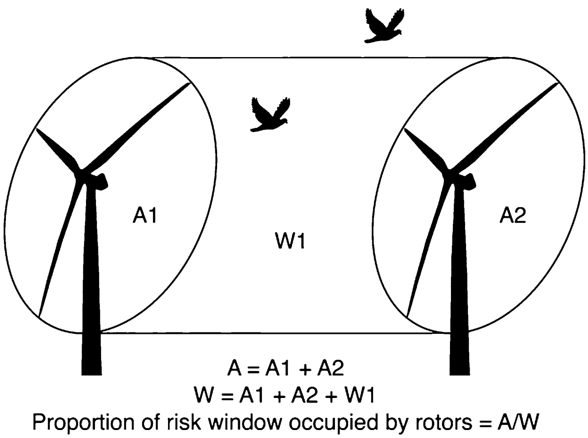

Fig. 23.2 An illustration of how to calculate the number of birds flying through the collision risk window (referred to as 'W' in (Band et al. 2007)). W is the sum of all birds observed flying through the areas A1, A2, and W1 during a period of time, e.g. 1 month, divided by the number of hours recording in that period (to calculate an hourly collision risk estimate). Thus, the lower bird would be classed as passing through the risk window, whereas the upper bird would not

are lacking, but recognise that this figure is somewhat arbitrary and advise against using it (Band et al. 2007). Despite this, the model remains the most used model in the UK. However, many studies have taken this avoidance rate figure as an absolute value for which it was never designed. Other studies suggest that avoidance rates may be a considerably higher than the original figure proposed by Band et al. (Desholm and Kahlert 2005; Chamberlain et al. 2006), suggesting that the Band model, when the 95 % avoidance rate is assumed, may overestimate collision rates. Conversely, a recent study by Ferrer et al. (2011) found that actual collision rates were in fact considerably higher than those predicted using the Band model, further highlighting the shortcomings of current collision risk modelling. Crucially, these risk models do not take into account many of the factors that were discussed earlier in this chapter, and no other models that do are currently used in practice (at least in Europe). It will be interesting to investigate, as the field develops, what effect the incorporation of these additional factors has on model performance.

Sensitivity maps can be used to visualise the suitability of potential sites for wind farm development. To date, maps have been created for Scotland (Bright et al. 2008) and the national waters of Germany (Garthe and Hüppop 2004). The map for Scotland is based on Special Protected Areas and the distribution of 16 bird species, although some sensitive species have not been taken into account (Bright et al. 2008), while the German map is based on densities of bird species occurring in the area and their sensitivity to wind farm development (Garthe and Hüppop 2004).

Tools like collision risk modelling and sensitivity mapping provide an additional tool for use in the assessment of the effects of wind farms on birds. Although there remain many unknowns in the interactions between birds and wind farms, we should make use of all available tools and use them with the best data available to date, in order to minimise the effect of wind farms to the best of our ability. However, we must do so carefully, acknowledging all the necessary caveats.

Effects of wind farms on bird populations are only possible to measure post-construction. There are some striking examples of significant impacts of wind farms on birds, as in the cases of Altamont and Tarifa (for details see above) (Smallwood and Thelander 2004; Barrios and Rodríguez 2004). Although no EIAs were performed before Altamont and Tarifa were constructed, it is important to recognise that not all effects can be successfully predicted (Ferrer et al. 2012), at least with our current level of knowledge. For example, some of the highest mortality rates have been reported at sites where collision risk was estimated to be sufficiently low during risk assessment studies conducted before construction (Ferrer et al. 2012). Alternative mitigation measures are required in such case. Repowering wind farms, by replacing old turbines with modern ones, can reduce bird mortality by avoiding areas which are known to have high mortality rates. Smallwood et al. (2009) suggested repowering could reduce by 70 % the mortality caused by the wind farm. In addition to repowering, turbines could be stopped at times when collision risk is highest. For example, in a recent case study, mortality was halved when turbines were stopped when griffon vultures were observed near them, while only 0.07 % of energy production was lost (de Lucas et al. 2012).

Conclusion

In many cases, effects of wind farms on bird populations are limited to species on the site, although substantial problems have been reported at some sites. Factors that contribute to collision risk include flight behaviour and the topography surrounding the wind farm. The studies reviewed in this chapter suggest that some adverse effects maybe prevented by appropriate placement of wind farms, and EIAs and sensitivity maps provide vital means to do so. Unexpected effects post-construction may be mitigated in variety of ways, including shutting down turbines during times of high collision risk or repowering of old turbines.

Currently, we do not fully understand the interaction between birds and wind farms and thus our predictions of potential effects may be inaccurate. Further research is therefore needed to improve understanding of both causes and consequences of collision mortality and displacement effects, and additional data are needed to more accurately estimate model parameters (e.g. avoidance rates). As some studies lack pre-monitoring data and could therefore have missed some disturbance effects, data from both pre- and post-construction EIA surveys could benefit new research. However, many of these are not publicly available due to commercial client confidentiality. In spite of such issues, collaborative studies between academics, consultants and NGO partners will be most likely to make genuine contributions to improving our understanding of conflicts between birds and wind turbines.

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