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Mitigating wind-turbine induced avian mortality: Sensory, aerodynamic and cognitive constraints and options

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ABSTRACT

Because of the fast rate of wind-energy development it will become a challenge to verify impacts on birdlife and construe ways to minimise these. Birds colliding with wind turbines are generally perceived as one of the major conflict issues for wind-energy development. Development of effective and practical measures to reduce bird mortality related to offshore and onshore wind energy is therefore paramount to avoid any delay in consenting processes. The expected efficacy of post-construction mitigation measures for wind-turbine induced avian mortality can be expected to be species-specific with regard to audible, optical and biomechanical constraints and options. Species-specific sensory faculties limit the ability to observe a wind turbine in a given circumstance. Their consequent cognitive perception may depend on the possibilities for associating wind turbines with risk, and discriminating these from other sources. Last but not least, perceived risks may only be evaded when their aerodynamic, locomotive physiology enables them to do so in due time. In order to be able to identify and construe functional mitigation measures these aspects need to be taken into account. Measures eliciting a series of intermittent strong stimuli that are variable in frequency may limit habituation effects; these should only be elicited specifically to mitigate imminent collision. Thus measures either adjusting turbine operation or warning/deterring birds approaching turbines are expected to be most functional. Warning signals may either be based on optical or audible stimuli; however, birds' hearing is inferior to humans while their visual acuity and temporal resolution is higher, but with great differences among species. Implementing effective mitigation measures could reduce the general level of conflicts with birdlife and thus enable both the development at new sites, at sites that have been declared having too high conflict levels, and utilise the wind resources better at specific sites without increasing the conflict levels.

Contents

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1. Introduction

Reducing emission of greenhouse gases to prevent anthropogenic climate change has boosted the innovation, development and application of renewable energy sources like wind. Unfortunately the ecological and societal footprints may be substantial [1]. Successful development and implementation of wind energy depends on the technological advances and the ability to address environmental challenges. Energy systems for the future must acknowledge simultaneously the challenges of climate change and biodiversity loss.

Focus on unintended bird mortality has become increasingly important recognising that the cumulative effect of mortality from anthropogenic sources may be detrimental to some species. Several reviews have summarised different bird mortality sources and have identified structures posing the highest risk [2–5]. Recent reviews have assessed the extent of annual bird mortality caused by anthropogenic causes to be in the magnitude of 500 million to possibly over 1 billion individuals in the United States alone [6,7]. It is now recognised that for some red-listed species with dwindling populations, human-induced mortality could be fatal [8]. Thus, identifying the causes of mortality and species-specific vulnerability to man-made structures is vital to enable functional design of mitigating measures. Regarding bird mortality due to collision with power lines this was recognised several years ago, in particular the importance of species-specific biomechanical and optical characteristics [9–11]. In a review on bird mortality caused by wind-turbines [12], a main conclusion was that these two aspects should be addressed in particular.

The step from documenting the extent of the mortality caused by anthropogenic factors to successful mitigation is normally a very long one [13]. Mitigating wind-turbine induced bird mortality is particularly complicated due the fact that birds are exposed to collisions with the static structure, as well as being hit by the rotating turbine blades. Thus, it is vital to identify proximate and ultimate factors causing different bird species (or groups) to become wind turbine victims. Targeting these factors is vital to tailor effective mitigating measures for the target species and bird groups [12,14–18]. Still there are reasons to believe that some bird species or groups might be "no-cure species".

Here we review the literature on post-construction mitigating measures to reduce bird mortality due to collisions with wind-turbines and wind-power plants, and evaluate their efficacy from an avian sensory, aerodynamic and cognitive perspective. Mitigation options for other man-made structures were included only where relevant also to mitigation of wind-turbine induced collisions. Pre-construction mitigation measures (e.g. wind-power plant siting) and compensatory measures are not included. We use the term wind turbine for the whole structure that produces energy, including the base (tower), the turbine housing (nacelle) and the rotating rotor blades. A wind-power plant includes several wind turbines and the accompanying infrastructure (e.g. buildings, roads and boat routes, and possible power lines). We also restrict the review to tubular towers, which was early recommended as an important measure for bird survival due to the lack of perches for raptors [19]. Therefore, this review includes (1) minimising impacts by limiting the degree or magnitude of the action (wind-energy production) and its implementation, (2) rectifying the impact by repairing, rehabilitating, or restoring the affected environment, and (3) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action [15]. The main focus is collision mitigation related to birds. Mitigation options for bats and marine mammals were only included where relevant to birds as well.

2. The sensory and aerodynamic ecology of birds

2.1. Bird vision

Vision is the dominant sense of most birds; crucial while flying, finding food, recognising mates or conspecifics, and evading predators. However, behaviour and life-history strategies differ, and birds being e.g. active in periods with poor light at high latitudes, twilight at dawn and dusk as well as nocturnal species, are expected to be vulnerable to crashing into artificial obstacles [20,21]. Activity patterns when the light is poor are a major and complex aspect of bird behaviour, and flight under such conditions does not take place without risks, and "nocturnal behaviour in birds requires an unobstructed habitat" [20].

Regarding vision acuity there is a great variety of adaptations among birds [22,23], a majority being classified as central monofoveal [24], having a single fovea (an area on the retina of very good acuity or resolution due to the high visual cell density) located near the centre of the retina. However, typical predators or hunters (e.g. hawks, bitterns and swallows), have two areas (bifoveal retina) [22,24]. A bifoveal retina and frontal eyes of a falcon allow about 60° binocular or three-dimensional perception but at an expense of a 200° blind zone [22]. An extensive blind zone may help to explain why even some raptors with highly binocular vision e.g. fly into power lines [9,25]. Some birds, like gallinaceous species, are afoveal [24], i.e. they lack or have a poorly developed fovea. This is interesting since tetraonids seem particularly vulnerable to collide with power lines [26]. Birds have a restricted range of flight speeds to adjust information gain when visibility is reduced [27], and e.g. fast-moving object at close distance may escape notice due to "motion smear" (also known as "motion transparency" or "motion blur") [28,29].

Birds are tetra- and pentachromatic (being able to differentiate between two different wavelengths of UV), compared to the human eye, which is trichromatic. This is a common ability of diurnal birds and is due to their special UV-sensitive rods. This ability plays an important role in inter- and intraspecific communication based on plumage UV-reflection, and the ability to, e.g., identify and assess fruit ripeness based on varying UV-reflection of fruit wax layers. As such it is an important factor in understanding bird behaviour [30–34]. Birds probably employ lateral vision for the detection of conspecifics, foraging opportunities and predators, which is normally more important to them than looking ahead during flight in the open airspace [25].

2.2. Hearing in birds

The general anatomy of the bird ear has evolved in a similar way as in mammals, including human [35–38]. However, the auditory pathway is different and more complex, especially in birds most dependent on sounds [39]. Avian ears are located behind and below the eyes, and the openings are protected by feathers. The bird ear, the shape of the head and the location of the two ears enable the bird to determine sound direction and distance [35,40]. This may be of relevance to acoustically alert birds in the vicinity of wind turbines. Directional sensitivity has evolved to a state of great precision in nocturnal hunters as owls listening for small noises made by their prey [38,41], and asymmetry in the outer ear enables some owls to localise sound in the vertical plane [42]. The ears are funnel-shaped to focus sound, and consist of three parts, external, middle and inner ear. The length of the *cochlea* in the inner ear is an index for a bird's sensitivity of sounds [43,44], which is especially long in several wader, pigeon and passerine species, but short in e.g. sea eagle and geese [45,46]. Birds are most sensitive to sounds at 1–5 kHz, with an upper hearing limit at about 10 kHz, but in general have a smaller frequency range and lower sensitivity compared to humans [37,46,47]. Large birds are especially sensitive to low frequency sounds, small birds to high frequency sounds [45]. Hereby, acoustic mitigation measures may be attuned to the specific species at risk. Birds are sensitive to pitch, tone and rhythm changes, and able to recognize other individual birds, even in noisy flocks [35]. As part of their social life, species have specific songs, calls and alerts for different situations; and some species even use sound to echolocate [38,40]. Birds are able to hear details in a sound, and have acute sound recognition skills. Thus they are able to recognize if a call is from predator or conspecific, indicate warning, advertise territory or render information about food [40,48]. This means that also conspecific warning or predator-specific calls may be effective in alerting birds to wind turbines.

2.3. Other senses

Olfaction is a chemical sense (chemoreception) and exploits information encoded in molecules moving through air or water [38]. The main characteristics of olfaction are the possibilities to receive information from a stimulus at a greater distance, and the duration of the stimulus may be for a longer time than other sense modalities. The importance of olfaction is direction-dependent. The olfaction in birds has generally lower sensitivity than in human, and has received less research interest than birds' vision and hearing [49]. However, there is evidence that birds may navigate using olfactory cues [50], and have been important in early birds [51]. Information received through olfaction also may become more important as ambient light levels decrease [52]. Olfaction seems to be more important in some bird groups, including several marine bird groups, as fulmars, shearwaters and storm petrels [49]. Several ultimate questions about olfaction are still unanswered, i.e. how birds use their olfactory system. Olfaction is known to play an important role in both foraging and predation risk in some bird species [53,54]. Olfactory cues may thereby both attract or repel birds to/from an area. Magnetoreception, the ability to receive and exploit information about magnetic fields, is documented as important in navigation and orientation in birds [55–58]. This sense makes it possible for the birds to extract information from the Earth's magnetic field, and it has been found in all major groups of birds, both in long-distance migrating and non-migrating groups [56,58]. However, the involved mechanisms at all levels are yet poorly understood, but seem to involve several different mechanisms, even in the same bird [59]. Ruminants have been shown to be disrupted in their body alignment by the extremely low-frequency magnetic fields generated by high-voltage power lines [60]. Thus also man-made electromagnetic fields may affect orientation in magnetic-sensitive species such as birds.

2.4. Bird flight performance

Most bird species are able to fly; however, there are major differences among bird taxa with respect to how they master the aerosphere. A species' susceptibility to collisions with e.g. wind turbines may be due to their biomechanical abilities, i.e. their manoeuvrability and agility. Manoeuvrability has been defined as the minimum radius of turn attained by a flying animal and agility as the maximum roll acceleration during the turn initiation, i.e. how fast can the bird change its flight path [61]. Theoretical models for bird flight are reviewed by several authors [27,62–65]. Applying principal component analysis to wing morphology [66] derived statistically independent measures of size and wing proportions. He grouped the major bird taxa within six main categories, determined by differences in aerodynamic performance: "poor" flyers, water birds, diving birds, marine soarers, aerial predators and thermal soarers. Rayner [66] emphasised that species categorised as "poor" flyers probably never had experienced strong evolutionary pressure to enhance their flight efficiency. In a review Bevanger [67] related Rayner's six categories to data derived from the literature on bird species frequently colliding with overhead wires like power lines and found that gallinaceous birds, rails, coots and cranes ("poor flyers") are among the species most commonly and numerously recorded as victims in America and Europe. "Aerial predators" like several raptor species possess excellent flying abilities (and binocular vision). However, they spend a major part of their life in the air and the probability of crossing power lines (and colliding) is higher compared to ground-dwelling species, which may explain why aerial predators are regularly recorded as collision victims, although in seemingly small numbers [68]. How susceptible "thermal soarers", i.e. birds with large and broad wings and a decreased wing loading, are to collision is difficult to predict. In short, it seems to be empirical evidence to say that species with high wing loading and low aspect, i.e. the "poor flyers" [66], should be classified in a high risk group as regards collisions with utility structures. The "poor flyers" are characterised by rapid flight and the combination of heavy body and small wings obviously restricting swift reactions to unexpected obstacles. As Rayner [66] emphasised, there are significant variations within some bird groups regarding wing load and aspect ratio, underlining the importance of making accurate analyses among species in the same family to predict the species-specific collision hazard.

3. Cognition and behaviour in birds with respect to disturbance

Species-specific sensory faculties (e.g. vision, hearing), physiological considerations (e.g. body condition, aerodynamics, age, breeding status), behavioural aspects (e.g. motion, response to external stimuli, flight and feeding behaviour), and the surroundings (e.g. food availability, light conditions) limits the birds ability to perceive and respond to wind turbines and wind-power plants. Cognitive perception of wind turbines as risk factors might depend on individual and species-specific possibilities for associating them with risk, and the ability to discriminate from other sources of risk and disturbance [69–71]. Other impulses acting upon the bird simultaneously through its behaviour (e.g. foraging, displaying) may affect detection/perception of wind turbines. In general, continuous exposure to a certain risk may lead to increased discrimination (latent inhibition), but decreased associability (habituation). The spatial cognitive abilities of a species simultaneously enable it to build up a cognitive map of its surroundings where wind turbines may function as landmarks [70,72]. These spatial cues may be processed cognitively either unconsciously (i.e.

the acquisition of knowledge through experience, without awareness of the knowledge thus acquired) or consciously [70]. Thus, the individual's perception may consequently result in either a “passive” or a more stress-related “active” response.

3.1. Perception of disturbance risk

In order to evaluate the possible efficiency of post-construction mitigation measures to reduce bird collisions with wind turbines it might be useful to adopt the hypothesis that nonlethal disturbance stimuli caused by humans are analogous to predation risk [69,71]. However contrary to the framework discussed by Frid and Dill [69] the disturbance stimuli (i.e. wind turbines) are stationary, albeit with moving rotor blades, and the animal is approaching the stimuli instead of being approached. The perceived risk of a wind turbine can only then be evaded when (1) it is being associated with fear by the approaching individual which is generally amplified by increased distance to refuge and prior experience with the risk [69,71], and (2) its locomotive morphology (e.g. wing load, wing aspect) and aerodynamic capability enables the bird to do so in due time [9,63,66]. The efficacy of post-construction measures for mitigating avian collisions with wind turbines therefore depends on the interplay of a species' sensory faculties, behaviour, consequent cognitive perceptions and aerodynamic capabilities for evasion. Many impulses that affect vigilance may act simultaneously upon the bird through its behaviour (e.g. foraging, courtship or territorial defence), and limit the detection and/or perception of wind turbines as potential dangers [73]. Social learning about predators (i.e. a wind turbine), and increased vigilance, may be faster and more robust in species in which alarm behaviour reliably predicts high risk [74]. Blumstein [75] reviewed flight initiation distance (FID), as a metric of awareness, in 150 species of birds. His findings strongly suggest that an important first step in implementing mitigation measures based on FIDs should be to evaluate the potential, site-specific, species at risk, and their life-history strategies. FID is measured in relation to an approaching moving object (a human walking towards the bird in focus) so it might not be directly related to bird's behaviour against a stationary object such as a wind turbine. However, it might be regarded as important in order to be able to judge the prospects of mitigation measures where information on species-specific FIDs can be used to develop mechanisms that might prevent birds from colliding with wind turbines by increasing their FIDs. In that aspect one should, however, strongly consider the possibilities that distracting elements (sounds, flashing lights etc.) could reduce FIDs rather than increase them [76] or increase vulnerability to predation [77]. In order to use bird vigilance as a tool for developing mitigation measures two factors should be considered: (1) the stimuli presented should, as far as possible, resemble a predation situation or a situation that the target species recognises as a potential danger that should be avoided, and (2) it should be presented in a way that minimises the risk of habituation – i.e. it has to be strongly correlated with the probability of colliding with the wind turbine if the stimuli is absent.

3.2. Habituation and learning

Continuous exposure to either the actual wind turbine or a proposed post-construction measure for mitigating avian collisions with wind turbines are subject to learning in birds, and may lead to decreased associability with disturbance, and also increased habituation. If it is possible to introduce a mitigation measure increasing the birds' awareness of the dangerous turbine blade or tower, and maintain this awareness over time, this measure will be more effective. Depending on the measure proposed, its efficacy may deteriorate over time when birds habituate to them or learn by association their harmlessness [78–81]. Stimuli that are only elicited with increased collision risk, enables birds to habituate to this specific stimulus while leaving it responsive to other stimuli (i.e. stimulus specificity) [78]. In relation to post-construction measure for mitigating avian collisions with wind turbines, their efficacy over time may be maintained by taking into account aspects enhancing dis-habituation such as eliciting multiple stimuli and repetitions of these. According to behavioural characteristics of habituation [78], mitigation measures should elicit a series of intermittent strong stimuli that are variable in frequency. The stimulus should, however, not become too repetitive, and specifically be elicited to mitigate collision only. There seem to be no mitigation study at wind turbines examining factors and stimuli leading to learning by association, habituation or other learning mechanisms in birds [81,82], although several proposals have mentioned the problem, especially when using auditory measures. In this review we use the term habituation, the simplest form of learning [79,81,82], to represent and including all mechanisms of learning, because there have been no mitigation study revealing the relative importance of habituation (waning of responsiveness), associative (classical and operational conditioning) or social learning mechanisms. Birds may learn by association [81–83], both to perceive the danger of the turbines and the harmlessness of a specific mitigation stimulus. Birds also use social learning e.g. in recognition of predators and disturbances [81,84], and this may be used by birds also near wind turbines, i.e. when birds perceive a collision by other individuals, and may be important also at several mitigation measures.

4. Assessment of measures mitigating avian collisions with wind turbines

4.1. Methodology

The overview of possible post-construction mitigation measures is based on existing reviews on the topic [12,15,18,19,85–89], keyword searches in ISI Web of Science, Google Scholar and Internet sites (see Table 1 for keywords used), and by contacting experts internationally (researchers, and representatives from industry and government agencies) directly. This broad approach was deemed appropriate to retrieve as much information as possible both from scientific (peer-reviewed journals, books) and grey literature (reports, articles, commercial patents/products, brochures, web sites). In total 77 references to 26 possible mitigation measures to reduce bird collisions with wind turbines were collected (Supplementary appendix). Possible mitigation options to reduce collisions between birds and wind turbines in existing wind-power plants can be categorised as either turbine-based or bird-based. Mitigation options on turbines encompass

Table 1
Keywords used literature databases (ISI Web of Knowledge) and on Internet search browsers (Google, Google Scholar).

General searches were combined with “wind turbine*” AND bird*:
mitigation/mitigate/mitigating/mitigate*
mitigation experiment*
temporary shutdown
bird collision*
bird mortality
avian collision*
avian mortality
deterrent/deterrence*
Including different combinations of these keywords

wind-power plant design, micro-siting of turbines, repowering and operation. Such measures have small or only indirect effects on bird behaviour, but may have high effects on bird mortality. The other approach is to directly affect bird behaviour. The mitigation options affecting bird behaviour encompass turbine design, deterrence/harassment and habitat alterations. The latter may be either inside (decreasing the attractiveness of the area), or outside the wind-power plant area (increasing the attractiveness of other areas).

To evaluate the efficacy of the proposed measures to mitigate wind-turbine induced bird mortality we employed a set of six qualitative criteria; partially divided into (1) turbine-specific or (2) bird-specific aspects. Criteria I–III focus on the expected efficacy of the stressor-exposure-response gradient used in ecological risk assessments [90]. Criteria IV and V assess the potential for ensuring effectiveness over time [78]. Criterion VI assesses the costs involved from an operational, economic and societal perspective. The six criteria are defined as follows:

Criterion I – Stressor: The proposed measure elicits a weak/medium/strong stimulus with regard to the (1) turbine-specific event (e.g. operational, design), or (2) bird-specific intensity (e.g. luminance, decibel) and/or spectral/auditory sensitivity (e.g. visibility, wavelength range).
Criterion II – Exposure: The stressor of the proposed measure results in low/medium/high detection with regard to (1) turbine-specific event regime (e.g. schedule, trigger distance), or (2) bird-specific perceptual range and exposure regime (e.g. exposure time, repetition).
Criterion III – Response: The exposure to the stressor of the proposed measure elicits a weak/medium/strong (1) turbine-specific risk reduction, or (2) bird-specific evasive response.
Criterion IV – Habituation: The proposed mitigation measure results in high/medium/low levels of habituation or other forms of learning in birds, reducing its efficacy.
Criterion V – Specificity: The proposed mitigation measure has a low/medium/high specificity to mitigate collision only, and/or repetitive levels.
Criterion VI – Implementation: The proposed mitigation measure comes at a high/medium/low cost for installation, maintenance and/or energy production; or may result in societal conflict (e.g. annoying lights or noise).

The assessment builds on the expected or – when available – observed, estimated or tested efficacy of the proposed mitigation measure. For each mitigation measure the six criteria were scored from one to three with three as most preferable (Table 2).

4.2. Turbine-specific mitigation options

Measures to mitigate collision risk through adjustments in turbine design and/or operation do not directly affect the sensory faculties, but rather aim at reducing the risk by reducing the birds' exposure to the hazard (i.e. the potential for collision irrespective of events; risk = hazard × exposure). The stressor (Criterion I) may here be interpreted as a form for incentive, rather than a negative stimulus.

Table 2
Evaluation of the efficacy of measures to mitigate turbine-induced mortality in birds.

Mitigation measures		**Criterion I: stressor**	**Criterion II: exposure**	**Criterion III: response**	**Criterion IV: habituation**	**Criterion V: specificity**	**Criterion VI: implementation**	**Total score**
Turbine-specific								
Wind-power plant design		1	2	2	1	1	1	1.33
Repowering/larger turbines		1	3	2	2	1	2	1.83
Removing selected turbines		2	2	2	2	3	1	2.00
Relocating selected turbines		2	1	2	2	2	1	1.67
Altering turbine speed		3	3	3	2	3	3	**2.83**
Temporary shutdown		3	3	3	2	3	2	**2.67**
Bird-specific								
Visual cues								
Marking/painting	☼	2	3	1	1	1	2	1.67
Visibility: reducing motion smear	☼	1	2	2	2	2	3	2.00
UV-coating	☼	2	2	2	2	2	3	2.17
Reflectors	☼	2	3	3	2	2	3	**2.50**
Minimal turbine lighting	☽	1	1	1	3	1	3	1.67
Turbine lighting regime	☽	2	2	2	3	2	3	2.33
Visual deterrence	☽	3	3	3	3	3	1	**2.67**
Laser	☽	3	3	2	3	3	2	**2.67**
Acoustic cues								
Acoustic harassment		3	1	2	1	2	2	1.83
Audible deterrence		2	3	3	3	3	2	**2.67**
Other sensory cues								
Electromagnetism		1	1	1	3	1	2	1.50
Olfaction		3	3	2	2	1	2	2.17
Habitat alterations								
On-site								
Habitat quality		2	1	2	2	1	2	1.67
Food availability		1	1	1	2	1	3	1.50
Off-site								
Habitat quality		2	3	2	2	1	2	2.00
Food availability		2	3	2	2	2	3	2.33
Breeding habitat		2	2	2	2	2	2	2.00
Roosting places		2	2	2	3	2	3	2.33
Other measures								
Funding wildlife research		NA	NA	NA	NA	NA	NA	NA
Monitoring fatalities		NA	NA	NA	NA	NA	NA	NA

Recently, movement models have shown to be able to provide insight into and identify possible impacts of offshore wind power plants at the planning state [91]. Changing the design of a wind-power plant by placing turbines in tight clusters was assessed to have limited efficacy. Although the total impact area is reduced by clustering turbines; at the same time the entire area will become inaccessibly to the birds due to reduced openness. Tighter placed turbines may be perceived as a single landmark (versus several turbines within natural habitat) to be avoided. However, it remains as yet unclear to which extent this results in possible adjustments in their spatial cognitive map [72] and how this affects a species' behaviour and spatial ecology [73]. Also, implementation costs in a post-construction situation are high; both with regard to relocating turbines and due to reduced wind capture. In general, fewer and larger turbines are thought to be preferred over many small turbines with regard to minimising collision risk to birds. Primarily in wind-power plants in the USA, older turbines with lattice towers and/or smaller turbines were replaced by larger tubular towered turbines. Repowering may result in dramatic changes with regard to exposure; and has been observed to lead to clearly reduced mortality in the Altamont Pass Wind Resource Area [18,92–95]. Other studies have however shown little [96,97] or even opposite effects [98] on fatality rates. However, birds may habituate to these larger structures, especially because repowering does not involve any specificity towards collision-reduction. Also, any benefit may only occur in old-generation wind-power plant facilities, such as was the case in the Altamont Pass Wind Resource Area. The implementation costs are lower relative to changing wind-power plant design because repowered turbines are likely more efficient in generating energy.

Micro-siting options (i.e. removing or relocating turbines) aim at identifying locations with increased risk for collisions. In wind-power plants where turbines were placed at more hazardous locations to bird collisions, these were either removed or relocated. Micro-siting has been proposed in agricultural areas [99], wetlands [100] and along ridges with many soaring raptors [14,18,93,94,101]. Removing "problem" turbines will specifically reduce mortality at that location, but may possibly lead to a shift of the problem to other turbines. Relocation of "problem" turbines instead may create increased collision risk elsewhere; and has therefore a lower expected efficacy. It has for example been suggested that outer turbines and turbines at the end of each row may experience higher risk of collision [14,102]. If this is the case, removing outer turbines will not remedy, only shift, the problem. Unless "problem" turbines were placed at specific hazardous locations, such as breeding sites [103], migration bottlenecks [12,104] or topography creating thermals [104,105], the collision risk may be expected to be reduced when such turbines are removed or relocated. The efficacy of micro-siting options is likely very site-specific and should preferably be done prior to the construction of the wind-power plant.

Most proposed mitigation measures focus on adjusted operation; either through altering turbine speed (cut-in speed, feathering) or temporary shutdown of turbines. These measures may only mitigate mortality due to collisions with rotor blades, and not for birds colliding with the turbine structure. Several studies have shown the highest activity of bats or birds at low wind speed [104,106–111]. To minimise collisions at low wind speeds, when energy output may be marginal, the cut-in wind speed at which the turbines start to produce energy was increased. For bats this usually happened around 6 m/s [106–109,111], for raptors collision risk declined at wind speed over 8 m/s [104]. Whether changing the cut-in speed at lower wind speeds, possibly at specific turbines, may be an effective way of reducing mortality depends on the species' flight behaviour. For birds that are mainly active at lower wind speeds, such as large soaring birds (e.g. raptors, herons and storks) that use thermal updrafts [112–114], the measure may specifically reduce the risk in such situations. Such a reduction of the risk window may come at relatively low costs because energy generation at low wind speed is limited (annual power loss $\leq 1\%$ of total annual output) [106,108]. Temporary shutdown has been tested in periods with high bird activity, or when birds moved too close to the turbines [93,115–119]. Methods used to assess when birds flew too close to turbines were either through visual observations [116,118] or avian radar [119,120]. An effective use of this measure, however, depends on a good monitoring scheme to limit unnecessary shutdown and thereby loss of energy generation. Especially when shutdown is restricted to specific events of near-collisions, the efficacy will likely improve as this will limit possible habituation effects. Too large shutdown periods may cause birds to adjust to this new situation, leading to reduced avoidance of the turbines [121,122]. However, other studies indicated that birds may primarily be affected by the actual turbine structures [123].

4.3. Bird-specific mitigation options

Another option for mitigation of collisions is to alert birds to the turbines or affecting bird behaviour. Alerting birds to the turbine structure may encompass making the rotor blades more visible, where reduction of motion smear [29] has been the major incentive. Alternatively mitigation measures have been proposed to dissuade birds from coming too close to the turbines through sensory cues. The efficacy of such measures is dependent on the birds' perception and response to the sensory cues (i.e. stressors). It is therefore crucial to take into account the sensory constraints placed upon the species of focus [124]. Mitigation options include passive and active visual cues (e.g. painting or lighting), audible deterrence/harassment, and to a lesser extent other sensory cues (e.g. olfaction, microwaves). In addition, habitat alterations either within or outside of the wind-power plant area may affect the birds' behaviour. Although great differences exist among species, generally birds' hearing is inferior to humans while their visual acuity and temporal resolution is higher [29,37]. Consequently, most measures are based on visual cues.

Mitigation measures based on passive visual cues include use of marking, reducing motion smear, reflectors or UV-coating. Marking patterns that have been proposed include scarecrows, conspecific/raptor models or displaying conspecific corpses. Stimuli placed on the ground have been suggested be most visible to birds due to the higher resolution of their lateral fields of view [25]. However, due to the lack of movement habituation may be more pronounced [125]. Because of this, and the lack of specificity towards reduction of collisions the efficacy of marking patterns is deemed limited. As a result of the work by Hodos [29], reduction of motion smear have been proposed as a measure to increase the conspicuity of the rotor blades enabling birds to take evasive action in due time. The ex-situ experiments by Hodos [29] indicated that painting one of three blades black reduced motion smear most. This measure has not been tested in-situ and merits further investigation [88,126]. Depending on whether decreased visibility of rotor blade tips is the cause of collisions, reducing motion smear may enhance the exposure potential. Especially when the motion smear pattern appears to be "moving" this may benefit its efficacy, and reduce habituation, as the frontal vision in birds may be more tuned for the detection of movement [25]. However, this measure does not directly reduce collision risk, but rather alerts birds to the presence of the rotor blades. As for all measures based on passive visual cues, UV-coating only works during daytime. UV-coating on rotor blades to increase their visibility has been proposed and tested in the USA with unclear conclusions on its efficacy [127,128]. This measure is expected to have similar effects as for reducing motion smear, although we scored it higher on the stressor criterion because the UV-coating lies within a, for birds, sensitive spectral wavelength [129]. Reflectors in the form of mirrors and aluminium/silvered objects – one could even think of holograms – may also provide to be an effective way of scaring birds [125]. However, reflectors will only be effective when they reflect (sun)light and lose their efficacy between sunset and sunrise, they were recommended in combination with other methods of scaring [125]. At daytime, when also most birds are active, they may create an ever-moving myriad of lights reflecting off the blades. Due to these changing reflections, the blades may become more visible and may attract attention to them resulting in increased responsiveness in the birds. However, as this measure is not specifically minimising collisions, but rather aims at increasing the conspicuity of the blades and alerting birds to their presence, habituation may occur. Implementation costs should be relatively low, although reflectors on the blades may require regular cleaning.

Mitigation measures based on active visual cues include minimal use of turbine lighting, adjustment of turbine lighting regimes, visual deterrence or laser. Minimal use of turbine lighting has been proposed especially for bats and nocturnal migrating birds. However, observations showed no differences in fatality rates between lit and unlit turbines [130–132]. Even though nocturnal (migrating) birds may be attracted to the (red) flashing or steady-burning safety lights [87,133]. Although the implementation costs – air traffic safety implications aside – should be limited, minimal use of lighting may have limited impact for reducing collisions. Although nocturnal birds may be prevented being attracted to the turbine lights, they are also not alerted their presence.

Adjustment of turbine lighting regime on the other hand has given more promising results. Using pulsating lights instead of steady-burning lights reduced bird fatalities at guyed communication towers significantly [134]. White strobe lights have also been proposed instead of the standard red lights [88,126]. However, experiments have shown that nocturnal migrating birds were least attracted and disoriented by blue and green lights especially on overcast nights [135]. Adjustment of turbine lighting regime therefore scores higher on the stressor-exposure-response scale, compared to minimal use of turbine lighting. Although this still has to be implemented and tested in-situ, this measure aims at alerting birds to the turbines while minimising detrimental attraction and disorientation.

Visual deterrence includes the use of strobing, flashing, revolving lights causing a temporary blinding and thereby confusion effect [136]. This measure will be most effective at low light levels, and may therefore mainly help mitigate collisions of nocturnal birds. Habituation may be reduced through randomized selection of at least two strobe frequencies; however use of bright lights may cause visual nuisance for local residents [125]. Also, its efficacy will be enhanced greatly when the visual deterrents are emitted only in situations when birds are in close vicinity of a turbine. This requires a functional, e.g. based on video [137] or avian radar [119,120], system to continuously monitor bird flight behaviour. Depending on the exact wavelength, luminance and exposure regime used this will likely result in high levels of evasive responses. For example, aircraft mounted with lights led to quicker evasive responses in Canada geese *Branta canadensis*, and was suggested to be most effective – given their spectral sensitivity – when the lights peak in the ultraviolet/violet range (380–400 nm) [138]. However, the implementation may be more challenging as such deterrence systems should be installed on all ("problem") turbines and require trustworthy triggering of the deterring stimulus (i.e. both with regard to Type I and Type II errors). Using laser renders similar efficacy as for visual deterrence. The difference being that laser may be directed more accurately at an approaching bird [125,136]. However this accuracy may also be its limitation as it assumes that it will be possible to pinpoint a flying bird. The visual nuisance of laser may however be less pronounced than for lights. Lasers also work best under low light levels. Something that has not been proposed is to utilise UV lasers that sweep upwards during night time encircling the rotor swept zone. UV lasers are invisible to the human eye but may deter nocturnal birds from entering the rotor swept zone.

Acoustic-based mitigation measures can either be in the form of audible harassment or deterrence. Audible harassment has been implemented especially at airports, agriculture and aquaculture [139–142]. It involves emitting hard sounds to scare away birds from an area. Methods used include: gas cannons, shooting, pyrotechnics, and ultrasound [125,143]. Most of these sounds will have to be emitted at high intensity and will therefore create audible nuisance for local residents. Ultrasound should largely be inaudible to humans, but has shown varying results in deterring birds [142,143]. Also, auditory harassment is subject to habituation and may therefore only have short-term benefit [19,37,125,136,142]. Effectiveness may be enhanced by varying firing frequency and direction, and/or using a combination of methods [136,142]. Dooling [37] suggested, based on his review on birds' hearing and options for mitigation, that an acoustic "whistling" cue in the region of best hearing for birds (2–4 kHz) help birds hear the blades while adding almost nothing to overall noise level. Instead of using artificial sounds, also bio-acoustic sounds may be used, such as bird alarm and distress calls [125,144]. Because of their biological meaning, these are thought to be more resistant to habituation. Although the response to bio-acoustic sounds likely is very species-specific, it may also evoke responses in other species [145]. Whereas acoustic harassment aims at scaring birds irrespective of where they are, audible deterrence warns/dissuades birds when approaching a turbine. Similar to visual deterrence, this requires functional monitoring systems to record hazardous bird flights [137]. What remains as yet unclear is at what wavelength and decibels sound should be emitted to evoke the most urgent response and be most effective [146,147]. Also the exposure regime (i.e. schedule, trigger distance) when replaying e.g. distress calls to deter birds, and variety in these parameters, affect its efficacy [136]. This may limit habituation effects, especially when in multiple-stressor set-up.

Other sensory cues that have been proposed as deterrence measures are electromagnetism and olfaction. Magnets and especially microwaves can create magnetic fields that are thought to disorient birds. Although this seemed effective for bats [148,149], it is expected to be of limited effect to deter birds from an area [140,150]. A behavioural evasive response may only occur when electromagnetic radiation is so intense to pose a potential health hazard to the birds but also humans [140]. Olfaction is known to play an important role in both foraging and predation risk in some bird species [53,54]. At airports, distributing toxicants in sub-lethal doses may cause disorientation and erratic behaviour and birds [125]. Applying behavioural repellents, however, has little specificity to reduce collision risk, its spatio-temporal permanence may depend on terrain and weather conditions (e.g. wind direction and speed, precipitation) and habituation may occur. Also, when too high doses are applied this may present a hazard to (non-targeted) birds [140].

4.4. Habitat alterations for mitigation

Finally, birds may be discouraged either by making areas near the turbines less attractive, or to enhance the habitat quality outside the wind-power plant. On-site habitat alterations (i.e. inside the wind-power plant area) which have been proposed include clear-cutting forests [131,151] or making open vegetation near turbines less attractive for either birds or their prey [87,99]. The efficacy of on-site habitat alterations likely depends on the importance of the habitat for the given species. When a wind-power plant is located in prime habitat for a species, this area may function as an ecological trap [152]. Still, unless the preferred habitat is altered dramatically (i. e. non-habitat), the area may still be frequented. Also, habitat alterations will result in habitat loss, or gain, for other non-targeted species (previously) not affected by the turbines. The loss of e.g. foraging or breeding habitat may lead to shifts in range use; however it does not preclude moving through the wind-power plant. The specificity is therefore limited, and the extent of habituation may depend on e.g. population density, territoriality and the availability of quality habitat in the surrounding landscape. Alternatively, the prey availability may be reduced inside the wind-power plant. This has mainly been proposed for e.g. eagles [153,154], vultures [155,156] and owls [115]. Obligatory scavengers aside, removal of carcasses or live prey (e.g. through rodent control) may have limited efficacy to reduce collisions within a wind-power plant. Only in specific situations when birds of prey or scavengers are attracted to the turbine bases to forage for prey using the rocky foundations as (burrowing) habitat or for collision fatalities [14,18,94] may localised rodent control or removal of fatalities show any effect. Better, however would be to alter the rocky substrate at the tower base to less attractive habitat for prey.

Off-site habitat alteration measures aim to increase the attractiveness of other areas outside the wind-power plant. These include the creation of novel habitats, breeding sites, food availability, and roosting sites or perches for birds. Although attraction of birds to improved or novel habitats outside the wind-power plant may present the birds with a stronger stimulus to shift their habitat preferences spatially, this has so far not been documented [99,157,158]. Simultaneously altering habitat quality both on- and off-site may, considering habitat alteration options alone, maximise its efficacy. However, the lack of specificity of this measure with regard to the species which are targeted may make this of less interest from a conservation point of view. Some success has been observed when presenting birds of prey with alternative feeding opportunities outside a wind-power plant [155,159]. However, this assumes the possibility for off-site prey base improvements relative to the on-site foraging quality [160]. Specifically protecting existing or creating artificial breeding sites has been proposed for raptors [19,153]. Another option is to erect perching towers outside a wind-power plant, which was suggested to have potential for offshore birds [88,126]. Although this may indirectly enhance breeding success or survival in a local population affected by increased turbine-induced mortality, it does not preclude these birds moving through and utilising the wind-power plant to forage. Any reduced exposure therefore influences only part of their ecology. Removal of existing breeding sites in the vicinity of a wind-power plant has so far not been proposed as a possible mitigation option due to the fact that this will lead to an additional impact on an already vulnerable population. Increased perching opportunities previously not available to the birds (e.g. offshore) may also attract them to the turbines, reducing its efficacy. Much of the same conditions as for habitat alterations will apply also for breeding sites and roosts/perches; the location of the turbines with regard to available quality habitat in the surrounding landscape greatly affects its expected efficacy.

4.5. Other measures for mitigation

Finally, some mitigation options have been proposed which may benefit the species indirectly. When mitigation may not be possible or did not have its desired effect on the species at risk, funding research may render new insights into the species' ecology for long-term conservation [87]. In many cases, the knowledge base on which mitigation measures are proposed is insufficient. An improved understanding on why, when and where a species may be expected to be most at risk can be assessed by studying e.g. flight behaviour, habitat and food preferences and causes of mortality. This may offer novel options for offsets at biological appropriate locations. Employing appropriate fatality monitoring programmes [17,161] does not directly reduce collisions, but may render increased insight into where and when which species are most at risk. This may then in the future direct possible operational – or other – mitigation measures. However, such a monitoring scheme only sets focus on possible spatial and temporal correlates in fatality patterns; it does not include other biologically relevant aspects such as habitat preferences and flight behaviour.

5. Concluding remarks

Minimisation of impacts from wind-energy development should always be addressed in the consenting process through the "avoid – minimise – compensate" mitigation hierarchy [162]. Collision-reducing mitigation measures should therefore always be preceded by a thorough siting process. As becomes clear in this review, post-construction mitigation measures should be species-specific and directed towards the most collision-prone species. However fatalities may also be highly seasonal and site-specific. For instance, white-tailed eagle [163] and griffon vulture (*Gyps fulvus*) [116] mortalities have been demonstrated to be highly seasonal, and related to habitat structure; most fatalities were clustered to a limited number of turbines. This fact was used when implementing a programme where the wind turbines were stopped when griffon vultures were observed near them, reducing vulture mortality rates by 50% while the energy production was only reduced by 0.07% per year [116]. The choice of mitigation measures should therefore be tailored for the species-at-risk at each wind-power plant separately. For instance, at the Smøla wind-power plant in Norway impacts on white-tailed eagles are perceived to be significant [163–165]. Studies, however, indicate that this day-active species neither actively avoids nor is displaced by the turbines [103,166,167]. Collision risk reduction was therefore proposed to be done either through audible deterrence or enhancing the visibility of the rotor blades.

On-site mitigation measures proven to have been effective may also have an indirect effect on the overall habitat quality. As a result of visual or acoustic deterrence measures, birds may choose to move away from the wind-power plant area to other possibly suboptimal habitat. The effect of such measures on the entire population may therefore be larger than the effect of some birds colliding with wind turbines. Although there is a general preference for on-site mitigation over off-site mitigation, sometimes off-site mitigation may result in greater net benefits to affected species and their habitats [86]. Possibly development of wind energy and transmission line construction on disturbed lands may offer the potential to dramatically reduce associated wildlife impacts [1]. In addition, preclusion of construction activity near breeding territories and/or during the breeding season may be preferred [168].

Because sound intensity is reduced with square number of the distance, possibilities to use audible deterrence as mitigation measure will be best at small distances. Given the social importance of sound in birds, utilising sounds with a biological meaning (e.g. predator sounds or warning calls) may be useful in mitigation measures [46]. In general acoustic devices are effective only for a short time [37,47], and the most effective use of acoustic signals is when they are reinforced with activities that produce death or a painful experience to some members in a population [46]. Sound-level changes of only a few decibels and stimuli duration may e.g. be important to improve the use of acoustic devices to birds' responses [146]. Utilisation of multiple stressors may be more effective to minimise collision risk. For instance, with respect to visual cues combining passive measures (e.g. coating) with active measures (e.g. lighting) reduce collision risk both at high and low light levels, respectively. We would like to stress that some measures actually should be considered to become common practise in turbine design and construction, such as turbine lighting regimes and bird-friendly micro-siting of turbines.

Finally, a prerequisite for successful mitigation is to map baseline information, and doing research on the vulnerable species as a part of the mitigation project [14,17,87,88]. Monitoring of fatalities is especially important, employing a scientifically defensible monitoring method [14,18,86,88,97,169–171].

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Appendix A. Supplementary information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.rser.2014.10.002

References

[1] Kiesecker JM, Evans JS, Fargione J, Doherty K, Foresman KR, Kunz TH, et al. Win-win for wind and wildlife: a vision to facilitate sustainable development. Plos One 2011;6:e17566.
[2] Avery ML, Springer PF, Dailey NS. Avian mortality at man-made structures: an annotated bibliography. U.S. Fish and Wildlife Service, Biological Services Program, National Power Plant Team; 1978. p. 108.
[3] Hebert E, Reese E, Mark L. Avian collision and electrocution: an annotated bibliography. Staff Report P700-95-001. California Energy Commission; 1995. 114 p.
[4] Trapp JL. Bird kills at towers and other man-made structures: an annotated partial bibliography (1960–1998). U.S. Fish and Wildlife Service, Office of Migratory Bird Management. 〈http://www.fws.gov/r9mbmo/issues/tower.html〉; 1998.
[5] Klem D. Preventing bird–window collisions. Wilson J Ornithol 2009;121:314–21.
[6] Erickson WP, Johnson GD, Young DPJ. A summary and comparison of bird mortality from anthropogenic causes with an emphasis on collisions; 2005.
[7] Longcore T, Rich C, Mineau P, MacDonald B, Bert DG, Sullivan LM, et al. An estimate of avian mortality at communication towers in the United States and Canada. PloS One 2012;7:e34025.
[8] Temple SA. The problem of avian extinctions. In: Johnston RF, editor. Current ornithology. New York: Plenum Press; 1986. p. 453–85.
[9] Bevanger K. Bird interactions with utility structures: collision and electrocution, causes and mitigating measures. Ibis 1994;136:412–25.
[10] Savereno AJ, Savereno LA, Boettcher R, Haig SM. Avian behavior and mortality at power lines in coastal South Carolina. Wildlife Soc Bull 1996;24:636–48.
[11] Janss GFE. Avian mortality from power lines: a morphological approach of a species-specific mortality. Biol Conserv 2000;95:353–9.
[12] Drewitt AL, Langston RHW. Collision effects of wind-power generators and other obstacles on birds. Ann N Y Acad Sci 2008;1134:233–66.
[13] Lehman RN, Kennedy PL, Savidge JA. The state of the art in raptor electrocution research: a global review. Biol Conserv 2007;136:159–74.
[14] Smallwood KS, Thelander CG. Developing methods to reduce bird mortality in the Altamont Pass Wind Resource Area. California, USA: Final Report by BioResource Consultants to the California Energy Commission, Public Interest Energy Research-Environmental Area, Contract No. 500-01-019. Linda Spiegel, Program Manager; 2004. 363 p.+appendices.
[15] NWCC Mitigation Subgroup, Rechtenwald J. Mitigation Toolbox. National Wind Coordinating Collaborative (NWCC); 2007. 114 p.
[16] Bevanger K, Bartzke G, Brøseth H, Dahl EL, Gjershaug JO, Hanssen F, et al. Optimal design and routing of power lines; ecological, technical and economic perspectives (OPTIPOL). Progress Report 2010. NINA Report. Trondheim, Norway: Norwegian Institute for Nature Research; 2010. p. 51.
[17] Strickland MD, Arnett EB, Erickson WP, Johnson DH, Johnson GD, Morrison ML, et al. Comprehensive guide to studying wind energy/wildlife interactions. Prepared for the National Wind Coordinating Collaborative, Washington, DC, USA; 2011. 289 p.
[18] Smallwood KS. Wind power company compliance with mitigation plans in the Altamont Pass Resource Area. Environ Energy Law Policy J 2008;2:229–85.
[19] Johnson GD, Strickland MD, Erickson WP, Young jr DP. Use of data to develop mitigation measures for wind power development impacts to birds. In: de Lucas M, Janss GFE, Ferrer M, editors. Birds and wind farms risk assessment and mitigation. Madrid: Servicios Informativos Ambientales/Quercus; 2007. p. 241–57.
[20] Martin GR. Birds by night. London, UK: T&AD Poyser Ltd.; 1990.
[21] Elkins N. Weather and bird behaviour. Calton: T&AD Poyser; 1988.
[22] Schmidt-Morand D. Vision in the animal kingdom. Vet Int 1992;4:3–32.
[23] Martin GR. Eye. In: King AS, McLelland J, editors. Form and function in birds. London, UK: Academic Press; 1985. p. 311–73.
[24] Sillman AJ. Avian vision. In: Farner DS, King JR, editors. Avian biology. London, UK: Academic Press; 1973. p. 349–87.
[25] Martin GR. Understanding bird collisions with man-made objects: a sensory ecology approach. Ibis 2011;153:239–54.
[26] Bevanger K. Estimates and population consequences of tetraonid mortality caused by collisions with high tension power lines in Norway. J Appl Ecol 1995;32:745–53.
[27] Norberg UM. Vertebrate flight: mechanics, physiology, morphology, ecology and evolution. Berlin, Germany: Springer-Verlag; 1990.
[28] McIsaac HP. Raptor acuity and wind turbine blade conspicuity. In: S.S. Schwartz, editor. Proceedings of the national avian-wind power planning meeting IV. Carmel, California: Avian Subcommittee of the National Wind Coordinating Committee; 2001. p. 59–87.
[29] Hodos W. Minimization of motion smear: reducing avian collisions with wind turbines. Period of performance: July 12, 1999–August 31, 2002. Golden, Colorado: National Renewable Energy Laboratory; 2003 (35 p.).
[30] Bennett ATD, Cuthill I, Partridge JC, Maier EJ. Ultraviolet vision and mate choice in zebra finches. Nature 1996;380:433–5.
[31] Cuthill IC, Partridge JC, Bennett ATD, Church SC, Hart NS, Hunt S. Ultraviolet vision in birds. Adv Study Behav 2000;29:159–214.
[32] Cuthill IC, Stevens M, Sheppard J, Maddocks T, Párraga CA, Troscianko TS. Disruptive coloration and background pattern matching. Nature 2005;434:72–4.
[33] Siitari H, Huhta E. Behavioural evidence on ultraviolet vision in a tetraonid species – foraging experiments with black grouse (*Tetrao tetrix*). J Avian Biol 2002;33:199–202.
[34] Lendvai Á, Kis J, Székely T, Cuthill IC. An investigation of mate choice based on manipulation of multiple ornaments in Kentish plovers. Anim Behav 2004;67:703–9.
[35] Evans HE, Heiser JB. What's inside: anatomy and physiology. In: Podulka S, Rohrbaugh RWj, Bonney R, editors. Handbook of bird biology. 2nd ed.. Ithaca, New York: The Cornell Lab of Ornithology; 2001. p. 4.1–162.
[36] de Juana E. Class AVES (BIRDS). In: del Hoyo J, Elliott A, Sargatal J, editors. Handbook of the birds of the world, vol. 1: ostrich to ducks. Barcelona: Lynx Edicions; 1992. p. 35–73.
[37] Dooling R. Avian hearing and the avoidance of wind turbines. Golden, Colorado: National Renewable Energy Laboratory; 2002 (79 p.).
[38] C.U.M. Smith. Biology of sensory systems. 2nd ed. Chichester, West Sussex, UK: Wiley-Blackwell; 2008.
[39] Nagel K, Kim G, McLendon H, Doupe A. A bird brain's view of auditory processing and perception. Hearing Res 2011;273:123–33.
[40] Baptista LF, Kroodsma DE. Foreword: avian bioacoustics. In: del Hoyo J, Elliott A, Sargatal J, editors. Handbook of the birds of the world, volume 6: mousebirds to hornbills. Barcelona: Lynx Edicions; 2001. p. 11–52.
[41] Bye FN, Jacobsen BV, Sonerud GA. Auditory prey location in a pause-travel predator: search height, search time, and attack range of Tengmalm's owls (*Aegolius funereus*). Behav Ecol 1992;3:266–76.
[42] Norberg RÅ. Independent evolution of outer ear assymmetry among five owl lineages; morphology, function and selection. In: Newton I, Kavanagh R, Olsen J, Taylor I, editors. Ecology and conservation of owls. Collingwood, Victoria, Australia: Csiro Publishing; 2002. p. 329–42.
[43] Walsh SA, Barrett PM, Milner AC, Manley G, Witmer LM. Inner ear anatomy is a proxy for deducing auditory capability and behaviour in reptiles and birds. Proc R Soc B: Biol Sci 2009;276:1355–60.
[44] Walsh S, Milner A. Evolution of the avian brain and senses. In: Dyke G, Kaiser G, editors. Living dinosaurs: the evolutionary history of modern birds. Chichester, UK: John Wiley & Sons Ltd.; 2011. p. 282–305.
[45] Birkhead T. Bird sense: what it's like to be a bird. London, Berlin, New York, Sydney: Bloomsbury; 2012.
[46] Beason RC. What can birds hear? In: Timm RM, Gorenzel WP, editors. In: Proceedings of the 21st vertebrate pest conference. University of California; 2004. p. 92–6.
[47] Dooling RJ, Lohr B. The role of hearing in avian avoidance of wind turbines. In: SSe Schwartz, editor. Proceedings of the national avian-wind power planning meeting IV. Carmel, California: Avian Subcommittee of the National Wind Coordinating Committee; 2001. p. 115–27.

[48] Kroodsma DE. Vocal behavior. In: Podulka S, Rohrbaugh RWj, Bonney R, editors. Handbook of bird biology. 2nd ed.. Ithaca, New York: The Cornell Lab of Ornithology; 2001. p. 7.1–98.
[49] Wenzel BM. Avian olfaction: then and now. J Ornithol 2007;148:S191–4.
[50] Wallraff HG. Zur olfaktorischen Navigation der Vögel. (Olfactory navigation by birds). J Ornithol 2003;144:1–32.
[51] Zelenitsky DK, Therrien FO, Ridgely RC, McGee AR, Witmer LM. Evolution of olfaction in non-avian theropod dinosaurs and birds. Proc R Soc B: Biol Sci 2011;278:3625–34.
[52] Martin GR. Through birds' eyes: insights into avian sensory ecology. J Ornithol 2012;153:S23–48.
[53] Roth TC, Cox JG, Lima SL. Can foraging birds assess predation risk by scent? Anim Behav 2008;76:2021–7.
[54] Nevitt GA. Sensory ecology on the high seas: the odor world of the procellariiform seabirds. J Exp Biol 2008;211:1706–13.
[55] Wiltschko W, Wiltschko R. Magnetoreception in birds: two receptors for two different tasks. J Ornithol 2007;148:S61–76.
[56] Falkenberg G, Fleissner G, Schuchardt K, Kuehbacher M, Thalau P, Mouritsen H, et al. Avian magnetoreception: elaborate iron mineral containing dendrites in the upper beak seem to be a common feature of birds. Plos One 2010;5:e9231 (9pp.).
[57] Wiltschko W, Wiltschko R. Magnetic orientation and magnetoreception in birds and other animals. J Comp Physiol A 2005;191:675–93.
[58] Lohmann KJ. Magnetic-field perception. Nature 2010;464:1140–2.
[59] Rodgers CT, Hore PJ. Chemical magnetoreception in birds: the radical pair mechanism. Proc Natl Acad Sci USA 2009;106:353–60.
[60] Burda H, Begall S, Červený J, Neef J, Němec P. Extremely low-frequency electromagnetic fields disrupt magnetic alignment of ruminants. Proc Natl Acad Sci 2009;106:5708–13.
[61] Norberg UM, Rayner JMV. Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. Philos Trans R Soc Lond Ser B, Biol Sci, 316; 1987; 335–427.
[62] Pennycuick CJ. Bird flight performance. Oxford, UK: Oxford University Press; 1989.
[63] Pennycuick CJ. Modelling the flying bird. London, UK: Elsevier; 2008.
[64] Rayner JMV. Estimating power curves for flying vertebrates. J Exp Biol 1999;202:3449–61.
[65] Alerstam T. Bird migration performance on the basis of flight mechanics and trigonometry. In: Domenici P, Blake RW, editors. Biomechanics in animal behaviour. Oxford, UK: Bios; 2000. p. 105–24.
[66] Rayner JMV. Form and function in avian flight. In: Johnston RF, editor. Current ornithology. New York: Plenum Press; 1988. p. 1–66.
[67] Bevanger K. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. Biol Conserv 1998;86:67–76.
[68] Bevanger K, Overskaug K. Utility structures as a mortality factor for raptors and owls in Norway. In: Chancellor RD, Meyburg B-U, Ferrero JJ, editors. Holarctic birds of prey. Berlin, Germany: World Working Group on Birds of Prey and Owls; 1998. p. 381–92.
[69] Frid A, Dill L. Human-caused disturbance stimuli as a form of predation risk. Conserv Ecol 2002;6:11.
[70] Shettleworth SJ. Cognition, evolution and behaviour. 2nd ed. New York: Oxford University Press; 2010.
[71] Stankowich T, Blumstein DT. Fear in animals: a meta-analysis and review of risk assessment. Proc R Soc B: Biol Sci 2005;272:2627–34.
[72] Healy SD, Braithwaite VA. The role of landmarks in small- and large-scale navigation. In: Dolins FL, Mitchell RW, editors. Spatial cognition, spatial perception: mapping the self and space. New York: Cambridge University Press; 2010. p. 152–79.
[73] Stephens DW. Decision ecology: foraging and the ecology of animal decision making. Cognit Affect Behav Neurosci 2008;8:475–84.
[74] Griffin AS. Social learning about predators: a review and prospectus. Learn Behav 2004;32:131–40.
[75] Blumstein DT. Developing an evolutionary ecology of fear: how life history and natural history traits affect disturbance tolerance in birds. Anim Behav 2006;71:389–99.
[76] Chan AAY-H, Giraldo-Perez SS, Blumstein DT. Anthropogenic noise affects risk assessment and attention: the distracted prey hypothesis. Biol Lett 2010;6:458–61.
[77] Dukas R. Causes and consequences of limited attention. Brain Behav Evol 2004;63:197–210.
[78] Rankin CH, Abrams T, Barry RJ, Bhatnagar S, Clayton D, Colombo J, et al. Habiatuation revisited: an updated and revised description of the behavioural characteristics of habituation. Neurobiol Learn Mem 2009;92:135–8.
[79] Thorpe WH. Learning and instinct in animals. London: Methuen; 1963.
[80] Thompson RF, Spencer WA. Habituation: a model phenomenon for the study of neuronal substrates of behavior. Psychol Rev 1966;73:16–43.
[81] Reznikova Z. Animal intelligence. From individual to social cognition. Cambridge, UK: Cambridge University Press; 2007.
[82] Manning A, Dawkins MS. An introduction to animal behaviour. 5th ed.. Cambridge, UK: Cambridge University Press; .
[83] Kroodsma DE, Bateson PPG, Bischof H-J, Delius JD, Hearst E, Immelmann K, et al. Biology of learning in nonmammalian vertebrates. Group report. In: Marler P, Terrace HS, editors. The biology of learning. Berlin, Heidelberg, New York, Tokyo: Springer Verlag; 1984. p. 399–418.
[84] Slagsvold T, Wiebe KL. Social learning in birds and its role in shaping a foraging niche. Philos Trans R Soc B: Biol Sci 2011;366:969–77.
[85] May R, Bevanger K. Proceedings on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011; 140.
[86] U.S. Fish & Wildlife Service. U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines. Arlington, USA: U.S. Fish and Wildlife Service; 2012. p. 82.
[87] Arizona Game and Fish Department. Guidelines for reducing impacts to wildlife from wind energy development in Arizona. Revised November 23, 2009. Arizona Game and Fish Department; 2009. p. 68.
[88] Cook ASCP, Ross-Smith VH, Roos S, Burton NHK, Beale N, Coleman C, et al. Identifying a range of options to prevent or reduce avian collision with offshore wind farms using a UK-based case study. BTO Research Report. Thetford, Norfolk, UK: British Trust for Ornithology; 199.
[89] Northrup JM, Wittemyer G. Characterising the impacts of emerging energy development on wildlife, with an eye towards mitigation. Ecol Lett 2013;16:112–25.
[90] Environmental Protection Agency. Guidelines for ecological risk assessment. Washington, DC, USA; 1998.
[91] Masden EA, Reeve R, Desholm M, Fox AD, Furness RW, Haydon DT. Assessing the impact of marine wind farms on birds through movement modelling. J R Soc Interface 2012;9:2120–30.
[92] Smallwood KS. Biological effects of repowering a portion of the Altamont Pass Wind Resource Area, California: The Diablo Winds Energy Project; 2006. p. 34.
[93] Smallwood KS. Fatality rates in the Altamont Pass Wind Resource Area 1998–2009; 2010. 55 p.
[94] Smallwood KS, Karas B. Avian and bat fatality rates at old-generation and repowered wind turbines in California. J Wildlife Manag 2009;73:1062–71.
[95] Hunt G. Golden eagles in a perilous landscape: predicting the effects of mitigation for wind turbine blade-strike mortality. PIER Consultant Report. Santa Cruz: California Energy Commission; 2002; 52.
[96] Krijgsveld KL, Akershoek K, Schenk F, Dijk F, Dirksen S. Collision risk of birds with modern large wind turbines. Ardea 2009;97:357–66.
[97] Anderson R, Neumann N, Tom J, Erickson WP, Strickland MD, Bourassa M, et al. Avian monitoring and risk assessment at the Tehachapi Pass Wind Resource Area. Period of performance: October 2, 1996–May 27, 1998. Golden, Colorado: National Renewable Energy Laboratory; 2004 (102 p.).
[98] de Lucas M, Janss GFE, Whitfield DP, Ferrer M. Collision fatality of raptors in wind farms does not depend on raptor abundance. J Appl Ecol 2008;45: 1695–1703.
[99] Mammen U, Mammen K, Heinrichs N, Resetaritz A. Red Kite (*Milvus milvus*) fatalities at wind turbines – why do they occur and how they are to prevent? In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 108.
[100] Hill R, du Gueschlin P, Herring M, McCarthy M, Smales I. Managing cumulative wind farm impacts on the Brolga *Grus rubicunda* in Victoria, Australia. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 96.
[101] Thelander CG, Rugge L. Avian risk behavior and fatalities at the Altamont Wind Resource Area. March 1998 to February 1999: Report to National Renewable Energy Laboratory, Golden, Colorado. Work performed by Predatory Bird Research Group, University of California, Santa Cruz, California; 2000.
[102] Orloff S, Flannery A. Wind turbine effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County wind resource areas. Tiburon, California; 1992.
[103] Dahl EL, Bevanger K, Nygård T, Røskaft E, Stokke BG. Reduced breeding success in white-tailed eagles at Smøla windfarm, western Norway, is caused by mortality and displacement. Biol Conserv 2012;145:79–85.
[104] Barrios L, Rodriguez A. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. J Appl Ecol 2004;41:72–81.
[105] Bevanger K, Dahl EL, Gjershaug JO, Halley DJ, Hanssen F, Nygård T, et al. Ornitologisk etterundersøkelse og konsekvensutredning i tilknytning til planer for utvidelse av Hitra vindkraftverk. Trondheim, Norway: Norwegian Institute for Nature Research; 2010.
[106] Arnett EB, Huso MMP, Schirmacher MR, Hayes JP. Altering turbine speed reduces bat mortality at wind-energy facilities. Front Ecol Environ 2011;9:209–14.
[107] Rydell J, Bach L, Dubourg-Savage MJ, Green M, Rodrigues L, Hedenstrom A. Mortality of bats at wind turbines links to nocturnal insect migration? Eur J Wildlife Res 2010;56:823–7.
[108] Arnett EB, Schirmacher M, Huso MMP, Hayes JP. Effectiveness of changing wind turbine cut-in speed to reduce bat fatalities at wind facilities. A final report submitted to the Bats and Wind Energy Cooperative. Austin, Texas, USA: Bat Conservation International; 2010.
[109] Baerwald EF, Edworthy J, Holder M, Barclay RMR. A large-scale mitigation experiment to reduce bat fatalities at wind energy facilities. J Wildlife Manag 2009;73:1077–81.
[110] Obermeyer B, Manes R, Kiesecker J, Fargione J, Sochi K. Development by design: mitigating wind development's impacts on wildlife in Kansas. Plos One 2011;6:e26698.
[111] Lagrange H, Roussel E, Ughetto A-L, Melki F, Kerbiriou C. Chirotech – assessment of research programme 2006–2011. Vilnius 2011, Jerez 2012, Bourges 2012, 2011.
[112] Ákos Z, Nagy M, Vicsek T. Comparing bird and human soaring strategies. Proc Natl Acad Sci 2008;105:4139–43.

[113] Bohrer G, Brandes D, Mandel JT, Bildstein KL, Miller TA, Lanzone M, et al. Estimating updraft velocity components over large spatial scales: contrasting migration strategies of golden eagles and Turkey vultures. Ecol Lett 2012;15:96–103.
[114] Shamoun-Baranes J, Leshem Y, Yom-Tov Y, Liechti O. Differential use of thermal convection by soaring birds over Central Israel. The Condor 2003;105:208–18.
[115] Smallwood KS, Thelander CG, Morrison ML, Rugge LM. Burrowing owl mortality in the Altamont Pass Wind Resource Area. J Wildlife Manag 2007;71:1513–24.
[116] de Lucas M, Ferrer M, Bechard MJ, Munoz AR. Griffon vulture mortality at wind farms in southern Spain: Distribution of fatalities and active mitigation measures. Biol Conserv 2012;147:184–9.
[117] AWEA. With wind industry, conservation groups collaborating, study shows how to reduce bat fatalities. Wind Energy Weekly; 2009. p. 27.
[118] Muñoz A-R, Ferrer M, de Lucas M, Casado E. Raptor mortality in wind farms of southern Spain: mitigation measures on a major migration bottleneck area. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 42.
[119] Tomé R, Canário F, Leitão A, Pires N, Teixeira I, Cardoso P, et al. Radar detection and turbine stoppage: reducing soaring bird mortality at wind farms. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 131.
[120] Davenport J, Smith A, Kelly TA, Lewis J, Vidao J, Villar S. Implementation of avian radar–SCADA interface to mitigate avian mortality at windfarms. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 81.
[121] Winkelman JE De invloed van de Sep-proefwindcentrale te Oosterbierum (Friesland) op vogels, 1: Aanvaringsslachtoffers. Arnhem, the Netherlands: IBN-DLO; 1992.
[122] de Lucas M, Janss GFE, Ferrer M. The effects of a wind farm on birds in a migration point: the Strait of Gibraltar. Biodivers Conserv 2004;13:395–407.
[123] Larsen JK, Guillemette M. Effects of wind turbines on flight behaviour of wintering common eiders: implications for habitat use and collision risk. J Appl Ecol 2007;44:516–22.
[124] Martin GR. Through birds' eyes: insights into avian sensory ecology. J Ornithol 2012;153:23–48.
[125] Bishop J, McKay H, Parrott D, Allan J. Review of international research literature regarding the effectiveness of auditory bird scaring techniques and potential alternatives; 2003.
[126] Burton N, Cook A, Roos S, Ross-Smith V, Beale N, Coleman C, et al. Identifying options to prevent or reduce avian collisions with offshore windfarms. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 74.
[127] Young jr DP, Erickson WP, Strickland MD, Good RE, Sernka KJ. Comparison of avian responses to UV-light-reflective paint on wind turbines, Subcontract report July 1999–December 2000. Golden, Colorado: National Renewable Energy Laboratory; 2003 (61 p.).
[128] Curry RC, Kerlinger P. Avian mitigation plan: Kenetech model wind turbines, Altamont Pass WRA, California. In: Richardson WJ, Harris RE, editors. Proceedings of national avian – wind power planning meeting III. San Diego, California: Avian Subcommittee of the National Wind Coordinating Committee; 2000. p. 18–28.
[129] Blackwell BF, Bernhardt GE, Dolbeer RA. Lasers as nonlethal avian repellents. J Wildlife Manag 2002;66:250–8.
[130] Johnson GD, Erickson WP, Strickland MD, Shepherd MF, Shepherd DA, Sarappo SA. Mortality of bats at a large-scale wind power development at Buffalo Ridge, Minnesota. Am Midl Nat 2003;150:332–42.
[131] Johnson GD, Perlik MK, Erickson WIP, Strickland JD. Bat activity, composition, and collision mortality at a large wind plant in Minnesota. Wildlife Soc Bull 2004;32:1278–86.
[132] Erickson WP, Jeffrey J, Kronner K, Bay K. Stateline wind project wildlife monitoring final report, July 2001–December 2003; 2004. 105 p.
[133] Hötker H, Thomsen K-M, Jeromin H. Impacts on biodiversity of exploitation of renewable energy sources: the example of birds and bats – facts, gaps in knowledge, demands for further research, and ornithological guidelines for the development of renewable energy exploitation. Bergenhusen, Germany: Michael-Otto-Institut in NABU; 2006 (65 p.).
[134] Gehring J, Kerlinger P, Manville AM. Communication towers, lights, and birds: successful methods of reducing the frequency of avian collisions. Ecol Appl 2009;19:505–14.
[135] Poot H, Ens BJ, de Vries H, MAH Donners, Wernand MR, Marquenie JM. Green light for nocturnally migrating birds. Ecol Soc 2008;13:47 (online).
[136] Clarke TL. An autonomous bird deterrent system. [Dissertation]. University of Southern Queensland; 2004.
[137] Liquen. DTBird. A self-working system to reduce bird mortality at wind farms. Brochure June 2012. In: Liquen, editor. Madrid, Spain. ⟨www.dtbird.com⟩; 2012.
[138] Blackwell BF, DeVault TL, Seamans TW, Lima SL, Baumhardt P, Fernández-Juricic E. Exploiting avian vision with aircraft lighting to reduce bird strikes. J Appl Ecol 2012;49:758–66.
[139] Mott DF, Boyd FL. A review of techniques for preventing cormorant depredations at aquaculture facilities in the southeastern United States. Colonial Waterbirds 1995;18:176–80.
[140] Harris RE, Davis RA. Evaluation of the efficacy of products and techniques for airport bird control. King City, Ontario, Canada: LGL Limited; 1998.
[141] Belant JL, Martin JA. Bird harassment, repellent, and deterrent techniques for use on and near airports. A synthesis of airport practice. ACRP Synthesis. 23rd ed.. Washington DC: Transportation Research Board; 2011.
[142] Gilsdorf JM, Hygnstrom SE, VerCauteren KC. Use of frightening devices in wildlife damage management. Integr Pest Manag Rev 2002;7:29–45.
[143] Diederichs A, Brandt MJ, Höschle C, Betke K, Nehls G. Testing the effects of an acoustic harassment device on the behaviour of harbour porpoises (*Phocoena phocoena*). Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011; 24.
[144] Hüppop O, Hilgerloh G. Flight call rates of migrating thrushes: effects of wind conditions, humidity and time of day at an illuminated offshore platform. J Avian Biol 2012;43:85–90.
[145] Magrath RD, Pitcher BJ, Gardner JL. A mutual understanding? Interspecific responses by birds to each other's aerial alarm calls Behav Ecol 2007;18:944–51.
[146] Pater LL, Grubb TG, Delaney DK. Recommendations for improved assessment of noise impacts on wildlife. J Wildlife Manag 2009;73:788–95.
[147] Leavesley AJ, Magrath RD. Communicating about danger: urgency alarm calling in a bird. Anim Behav 2005;70:365–73.
[148] Nicholls B, Racey PA. The aversive effect of electromagnetic radiation on foraging bats – a possible means of discouraging bats from approaching wind turbines. Plos One 2009;4:e6246.
[149] Nicholls B, Racey PA. Bats avoid radar installations: could electromagnetic fields deter bats from colliding with wind turbines? Plos One 2007;2:e297.
[150] Kreithen ML. Development of a pulsed microwave warning system to reduce avian collisions with obstacles. In: Proceedings of the second international conference on raptors. Urbino, Italy; 1996.
[151] Walker D, McGrady M, McCluskie A, Madders M, McLeod DRA. Resident Golden Eagle ranging behaviour before and after construction of a windfarm in Argyll. Scottish Birds 2005;25:24–40.
[152] Battin J. When good animals love bad habitats: ecological traps and the conservation of animal populations. Conserv Biol 2004;18:1482–91.
[153] Allison TD. Eagles and wind energy: identifying research priorities. Washington, DC, USA: American Wind Wildlife Institute; 2012 (35 p.).
[154] BPA. Condon Blanco wind project: draft environmental impact statement. Portland: Oregon: Bonneville Power Administration; 2001.
[155] Camina A. The effect of wind farms on vultures in Northern Spain: fatalities, behaviour and correction measures. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 17.
[156] Martínez-Abraín A, Tavecchia G, Regan HM, Jiménez J, Surroca M, Oro D. Effects of wind farms and food scarcity on a large scavenging bird species following an epidemic of bovine spongiform encephalopathy. J Appl Ecol 2012;49:109–17.
[157] Robson P. Review of Hen Harrier breeding and flight activity near a windfarm in Argyll. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 123.
[158] Balcombe CK, Anderson JT, Fortney RH, Kordek WS. Wildlife use of mitigation and reference wetlands in West Virginia. Ecol Eng 2005;25:85–99.
[159] Paula A, Santos J, Cordeiro A, Costa H, Mascarenhas M, Reis C. Habitat management for prey recovery – an off-site mitigation tool for wind farms' impacts on top avian predators. In: May R, Bevanger K, editors. Proceedings conference on wind energy and wildlife impacts, 2–5 May 2011. Trondheim, Norway: Norwegian Institute for Nature Research; 2011. p. 44.
[160] Rasran L, Dürr T, Hötker H. Analysis of collision victims in Germany. In: Hötker H, editor. Birds of prey and wind farms: analysis of problems and possible Solutions. Berlin, Germany; 2008. p. 26–30.
[161] Bernardino J, Bispo R, Costa H, Mascarenhas M. Estimating bird and bat fatality at wind farms: a practical overview of estimators, their assumptions and limitations. N Z J Zool 2011;40:63–74.
[162] Langston RHW, Pullan JD. Windfarms and Birds: An analysis of the effects of windfarms on birds, and guidance on environmental assessment criteria and site selection issues. Secretariat Memorandum of the Standing Committee, Convention on the conservation of European wildlife and natural habitats. Strasbourg: BirdLife International, RSPB; 2003; 1–58.
[163] Bevanger K, Berntsen F, Clausen S, Dahl EL, Flagstad Ø, Follestad A, et al. Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway (BirdWind). Report on findings 2007–2010. Trondheim, Norway: Norwegian Institute for Nature Research; 2010.
[164] May R, Hoel PL, Langston R, Dahl EL, Bevanger K, Reitan O, et al. Collision risk in white-tailed eagles. Modelling collision risk using vantage point observations in Smøla wind-power plant. Trondheim, Norway: Norwegian Institute for Nature Research; 2010; 25.
[165] May R, Nygård T, Dahl EL, Reitan O, Bevanger K. Collision risk in white-tailed eagles. Modelling kernel-based collision risk using satellite telemetry data in Smøla wind-power plant. Trondheim, Norway: Norwegian Institute for Nature Research; 2011; 22.

[166] Dahl EL, May R, Hoel PL, Bevanger K, Pedersen HC, Røskaft E, et al. White-tailed eagles (*Haliaeetus albicilla*) at the Smøla wind-power plant, Central Norway, lack behavioral flight responses to wind turbines. Wildlife Soc Bull 2013;37:66–74.
[167] May R, Nygård T, Dahl EL, Bevanger K. Habitat utilization in white-tailed eagles (*Haliaeetus albicilla*) and the Displacement impact of the Smøla wind-power plant. Wildlife Soc Bull 2013;37:75–83.
[168] Pearce-Higgins JW, Stephen L, Douse A, Langston RHW. Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. J Appl Ecol 2012;49:386–94.
[169] NWCC Wildlife Workgroup. Wind & Wildlife Key Research Topics. National Wind Coordinating Collaborative (NWCC); 2008. p. 15.
[170] Sanders S, Spiegel L. A roadmap for PIER research on methods to assess and mitigate impacts of wind energy developments on birds and bats in California. California Energy Commission; 2008 (87 p.+appendix).
[171] U.S. Fish & Wildlife Service. Draft Land-Based Wind Energy Guidelines. Recommendations on measures to avoid, minimize, and compensate for effects to fish, wildlife, and their habitats: U.S. Fish and Wildlife Service; 2011. p. 83.