



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



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## ARTICLE INFO

### Article history:

Received 6 May 2013

Received in revised form

13 August 2014

Accepted 1 October 2014

Available online 24 October 2014

### Keywords:

Wind energy

Mitigation measures

Birds

Efficacy

Environmental impacts

## 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.

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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

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