Biological Conservation 190 (2015) 179–187

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Review

A unifying framework for the underlying mechanisms of avian avoidance of wind turbines

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ARTICLE INFO

Article history:
Received 6 March 2015
Received in revised form 6 May 2015
Accepted 3 June 2015

Keywords:
Wind-turbine avoidance
Displacement
Disturbance
Predation risk
Habitat selection
Vigilance
Fleeing

ABSTRACT

The construction and operation of wind-power plants may affect birds through collision mortality, reduced habitat utilization due to disturbance, barriers to movement and habitat modifications, with the nature and magnitude of those effects being site- and species-specific. Birds may however manage these effects through fleeing, activity shifts or changed habitat utilization; usually termed avoidance. Given the important role avoidance plays in estimating the impact wind-power development has on birds, there is a pressing need to formalizing the avoidance process. Crucial in this context is to identify the underlying mechanisms of behavioural responses by birds to wind-power plants and individual turbines. To provide a better basis for and improved understanding of the underlying mechanisms for avoidance a conceptual framework for wind-turbine avoidance is presented decomposing various forms of avoidance at different spatial scales. Avoidance behaviour includes displacement (macro-avoidance), anticipatory and impulsive evasion (meso-avoidance), and escape (micro-avoidance). For understanding why particular responses occur with regard to wind-turbine disturbance this concept is applied to predation risk theory. The risk-disturbance hypothesis elucidates possible trade-offs between avoiding perceived risk and fitness-enhancing activities. The four behavioural responses are related to, respectively, habitat selection, vigilance and fleeing (twice); from which specific predictions can be derived. Formalizing the different forms of avoidance facilitates design of effects studies, enhances comparisons among sites studied, and guide siting and mitigation strategies.

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http://dx.doi.org/10.1016/j.biocon.2015.06.004

1. Introduction

The global potential for wind-power generation is enormous (Lu et al., 2009), and regarded by many as the most promising renewable energy source. All power generation, however, has environmental costs (IPCC, 2011). Bird mortality is generally perceived as a major conflict issue for wind-power development (Drewitt and Langston, 2006; Stewart et al., 2007). The construction and operation of wind-power plants may affect birds through collision mortality, reduced habitat utilization due to disturbance, barriers to movement and habitat modifications, with the nature and magnitude of those effects being site- and species-specific (Drewitt and Langston, 2006). Birds may however respond to these effects through fleeing, activity shifts or changed habitat utilization; usually termed avoidance. An increasing number of empirical studies have improved our understanding of avoidance, although significant knowledge gaps remain. However, comparison of studies are hampered by differences in definitions and methodology employed (cf. Furness et al., 2013); also the distinction between different forms of avoidance may in reality be challenging (Langston, 2013). Given the important role avoidance plays in estimating the effect wind-power development has on birds directly (risk of collision, energetic expenditure) or indirectly (e.g. reduced reproduction, resource exclusion), there is a pressing need to formalize the avoidance concept. Crucial in this context is to identify the underlying mechanisms of behavioural responses by birds to wind-power plants and individual turbines (Drewitt and Langston, 2008; Langston 2013). This may reveal species-, site- and state-specific factors enhancing avoidance (Chamberlain et al., 2006), improve impact estimates (Ferrer et al., 2012), and ultimately aid siting and mitigation strategies (Marques et al., 2014; May et al., 2014). Here I present a conceptual framework for wind-turbine avoidance and place this concept in the context of the movement ecology paradigm (Mueller and Fagan, 2008; Nathan et al., 2008) and the risk-disturbance hypothesis (Frid and Dill, 2002; Stankowich and Blumstein, 2005). The movement ecology paradigm facilitates understanding of the causes and mechanisms of avoidance responses and promotes hypothesis generation. Invoking the risk-disturbance hypothesis provides a better basis for predicting why particular avoidance responses may be expected to occur. This framework links behavioural and physiological theory to the reality of studying and interpreting avoidance by replacing often practical and intuitive definitions with a common playing field in terms of terminology and definitions to aid the study of bird avoidance of wind turbines.

2. Material and methods

I compiled studies, including both peer-reviewed articles, technical reports and conference proceedings relating to avian avoidance of wind turbines. Literature was collected through search engines (ISI Web of Knowledge and Google Scholar), databases (NREL's Wind-Wildlife Impacts Literature Database) as well as already compiled information derived from other reviews (e.g. Cook et al., 2014; Johnson et al., 2007; Marques et al., 2014; May et al., 2014). Information was searched for using the following key phrases: "avoid*", displace*" or "disturb*", coupled with "wind energy", "wind power" or "wind turbine". In addition, taking the reviews by Nathan et al. (2008), Mueller and Fagan (2008), Frid and Dill (2002) and Stankowich and Blumstein (2005) as a starting point, I further searched for peer-reviewed literature relating to the theoretical foundation for avoidance and predation risk. Appendix 1 summarizes the support for each formalized prediction for different forms of wind-turbine avoidance (Table A2), as derived from the original predictions of the risk-disturbance hypothesis (Table A1).

3. Decomposition of the avoidance process

In practise it may be difficult to tease apart different avoidance-related decisions as they may shift gradually into one another. To understand the mechanisms underlying specific avoidance-related decisions, however, require the decomposition of the concept of avoidance into distinct avoidance responses along this continuum. This distinction is important to be able to identify all factors influencing the proximate causes of avoidance responses. Avoidance may occur at varying intensities within multiple hierarchical spatial scales (Mueller and Fagan, 2008). Here three spatial scales may be distinguished: birds may avoid the wind-power plant area as a whole (i.e. 'forest'), turbine arrays or single wind turbines (i.e. 'trees') and last-second evasion of the rotor blades (i.e. 'branches'). (Cook et al., 2014) dubbed these scales 'macro-avoidance', 'meso-avoidance' and 'micro-avoidance' respectively. Although avoidance intuitively is defined based on the spatial scale it is likely to occur, this does not reveal specific behaviour causing avoidance responses. A behavioural response to the presence of a wind-power plant results in a reduced number of birds entering and possibly avoiding wind turbines (e.g. Desholm and Kahlert, 2005; Petersen et al., 2006). This apparent continuum means that wind turbine avoidance may for certain bird species involve a combination of reduced habitat utilization and consequent reduced flight activity close to wind turbines, hence reduced risk of collision (e.g. Dahl et al., 2012, 2013; Garvin et al., 2011; May et al., 2013; Pearce-Higgins et al., 2009). Alternatively, collision avoidance for birds commuting between areas of utilized habitat (e.g. foraging, resting, migration corridor) may depend only on active in-flight response to wind turbines intercepting their route (i.e. barrier effect) (e.g. Desholm and Kahlert, 2005; Larsen and Guillemette, 2007; Masden et al., 2009; Plonczkier and Simms, 2012). Birds may also reduce the risk of colliding with a wind turbine through changes in in-flight behaviour near turbines or last-second responses near the rotor blades (e.g. Krijgsveld et al., 2011). In-flight responses may also be influenced by external factors such as wind and topography (e.g. Barrios and Rodriguez, 2004; de Lucas et al., 2004; Farfán et al., 2009; Hull and Muir, 2013). These studied examples along that continuum may represent pronounced differences for some bird species, or more subtle distinctions for others, depending on a species' tolerance of disturbance and its behavioural plasticity in adapting to the perceived risk from wind turbines (Furness et al., 2013). To clarify the actual meaning of the term 'avoidance' in different circumstances, however, different terms for each form of avoidance should be reserved for the responses of birds to wind turbines at different spatial scales. The term 'avoidance' is here proposed to signify the entire conceptual process.

3.1. A movement framework for avoidance responses

To understand the concept of avoidance, we may place it in the context of the movement ecology paradigm (Nathan et al., 2008). This paradigm provides the framework facilitating the understanding of why, how and where animals move; and the ecological and evolutionary consequences of movement. The conceptual framework identifies four interacting mechanistic components central to movement: internal state (why move), motion (how to move) and navigation capacities (where to move), and external factors affecting movement. Navigation mechanisms may be further divided into (1) non-oriented (sensory stimuli), (2) oriented (perceptual cues) and (3) memory-based (cognitive maps) movements (Mueller and Fagan, 2008). The movement ecology paradigm unites fundamental paradigms central to movement of organisms (Fig. 1). With regard to avoidance, a bird's internal state (e.g. body