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Spatial association as an indicator of the potential for future interactions between wind energy developments and golden eagles *Aquila chrysaetos* in Scotland

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ARTICLE INFO

Article history:
Received 12 September 2005
Received in revised form
12 January 2006
Accepted 24 February 2006
Available online 5 May 2006

Keywords:
Wind farm
Wind energy
Raptor
Bird of prey
Golden eagle
Displacement
Habitat loss
Collision
Scotland

ABSTRACT

Despite their environmental benefits in generating electricity without emission of 'greenhouse' gases, wind farms have attracted controversy with regard to their impacts on birds, especially golden eagles *Aquila chrysaetos*. Evidence from USA studies suggest eagle fatalities through collision with turbines may be the main potential impact whereas for breeding eagles in Scotland, displacement from wind farm areas (indirect habitat loss) may be the primary impact. In this study, we examined the co-occurrence potential for golden eagles and wind farms in Scotland by documenting the spatial association between wind farm proposals and breeding eagle territories and areas potentially suitable for non-breeding eagles. Although there were records for over 500 wind farm proposals at various stages of development, relatively few coincided with eagle territories (ca. 4% of territories had a proposal within 3 km of territory centre). Similarly, only 2% of habitat predicted to be suitable for non-breeding eagles overlapped with proposed or installed wind farm areas. Moreover, estimates of the potential for electricity generation from all wind farm proposals, with respect to government targets for renewable energy supplies, suggested most proposals were unlikely to be constructed. We conclude that in comparison with other constraints on Scotland's golden eagles, notably persecution, wind farms should not represent a serious concern if best practice in planning their location and minimising their impact are maintained. Potential future regional pressures on breeding eagles from wind farms are highlighted, however, and uncertainty of impact with respect to displacement or collision fatalities requires continued scrutiny.

1. Introduction

Increasing numbers of wind farms are being constructed in many parts of the world as a response to concern over the climatic effects of 'greenhouse' gases, because increasing the contribution of renewable sources of energy supplies is seen as a means of reducing outputs of greenhouse gases. Despite the environmental benefits driving their construction, considerable controversy has accompanied wind farms and their effects on birds. Wind farms may have at least three potentially adverse impacts on birds (e.g., Gill et al., 1996; NWCC, 2000; Bern Convention, 2003):

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doi:10.1016/j.biocon.2006.02.011

- Fatality through collision with wind turbine blades and associated power lines (although the latter is a potential factor for most forms of electricity generation).
- Displacement of birds around turbines or the wind farm site, including so-called 'barrier effects', as a result of disturbance (effectively indirect habitat loss).
- Direct habitat loss through the construction of the wind farm and ancillary structures (not considered influential at most wind farms as the scale of habitat loss is usually negligible, e.g., Bern Convention, 2003).

Much of the current controversy surrounding wind farm impacts have been prompted by the findings from one of the earliest large wind farms (several thousand turbines) at the Altamont Wind Resource Area (WRA) in California where many birds of prey have been found killed by strikes with turbine blades (e.g., Smallwood and Thelander, 2004). Particular concern has been expressed over fatality rates of golden eagles *Aquila chrysaetos* due to its legal status (e.g., Hunt, 2002). In the only study of a wind farm on the population of any bird, results suggested sufficient eagles were being killed at Altamont WRA to have an effect on local population abundance, but the lack of any observed change in population abundance may have been because many sub-adults killed came from migratory populations to the north (Hunt et al., 1997, 1999; Hunt, 2002). Studies at other sites in the USA, however, have not recorded comparable golden eagle fatalities (Erickson et al., 2001), and detectable impacts on populations were highly unlikely. Many of the fatality differences may be accounted for by site differences in eagle activity levels (Smallwood and Thelander, 2004), suggesting improved wind farm site selection following the installation of Altamont WRA (Johnson et al., 2000; Young et al., 2003).

Due to the antagonistic nature of displacement and turbine collision risk (Band et al., in press) collision risk declines if displacement occurs. At Altamont WRA there were no pre-construction studies of golden eagle activity levels, so definitive conclusions on the occurrence of displacement are not possible (Smallwood and Thelander, 2004). The available post-construction evidence, however, suggested that neither non-breeding sub-adults (which are the majority age class within the WRA) nor breeding adults were obviously displaced (Hunt et al., 1997, 1999; Hunt, 2002). Initial studies following construction of the Foote Creek Rim wind energy facility in Wyoming, USA indicated activity levels of golden eagles were similar to pre-construction observations: both non-breeding subadults and breeding birds were present (Johnson et al., 2000). Most other studies at USA wind farms on golden eagles and other birds of prey also suggest that displacement is not an influential factor (Madders and Whitfield, 2006).

By contrast, studies at a smaller Scottish wind farm within a golden eagle breeding territory indicated that the resident pair probably avoided the wind farm (Walker et al., 2005). The difference between Scotland and the USA may lie in a prolonged history of human persecution and greater use of remote areas away from human influence for eagles in Scotland (Whitfield and Coupar, in press) or that because turbines at Scottish sites typically are not arranged in 'strings' there are no obvious gaps where birds could 'feel safe' in entering the wind turbine arrays. If the latter argument is correct, future wind farms with larger turbines (and hence larger separation distances) may not be avoided in Scotland. As yet there are no studies in Scotland to indicate the reaction of non-breeding eagles to wind farms.

There were an estimated 443 occupied golden eagle territories in Scotland during 2003 (Whitfield et al., 2006; Eaton et al., in press) with territory occupancy, breeding productivity and survival rates varying regionally (Whitfield et al., 2004a,b, 2006; Eaton et al., in press). Conservation status also varies regionally, with only some sub-populations in regions of the western Highlands and Islands in favourable condition (Whitfield et al., 2006). Watson and Whitfield (2002), in deriving the concept of a conservation framework for Scottish golden eagles, noted several constraints (negative influences on abundance, distribution and demography) which act on golden eagles in Scotland, including afforestation, persecution by humans, grazing and recreation. The influence of these constraints varies regionally, so that, for example, grazing by sheep and/or red deer *Cervus elaphus* likely causes reduced productivity and jeopardises occupation of several territories in some western Highland regions through its effect on herbivorous prey of eagles (Watson, 1997; Watson and Whitfield, 2002; Whitfield et al., 2006). Historically, habitat loss through commercial conifer afforestation has also caused reduced productivity and territory abandonment in western Scotland (Watson, 1997; Watson and Whitfield, 2002) although this appears to be much less influential in recent years (Whitfield et al., 2006, in press). The most serious constraint, however, is the effect of persecution on some moorlands managed for shooting red grouse *Lagopus lagopus scoticus* in the central and eastern Highlands (and, likely, south of the Highlands) through its influence on eagle demography (Watson, 1997; Watson and Whitfield, 2002; Whitfield et al., 2003, 2004a,b, 2006, submitted). Persecution is strongly implicated in the vacancy of numerous otherwise suitable territories and in placing the national population at risk of decline (Whitfield et al., 2004a,b, 2006, submitted).

Watson and Whitfield (2002) indicated that wind farms may present a potential future constraint for the golden eagle and recommended their consideration within a national conservation framework. If resident eagle pairs are displaced by wind farms then indirect habitat loss could lead to range abandonment, reduced productivity or have little effect (Whitfield et al., 2001, in press). The impact of habitat loss on eagles is difficult to predict at the territory level (Whitfield et al., 2001, in press) and thus practically impossible to predict nationally (moreover, mitigation measures may often accompany installation, e.g., Madders and Walker, 2002). If displacement does not occur, national scale of analyses, uncertainty over the precise effects of wind farms on eagles generically and site-specifically, and that precise details of most wind farm schemes are currently unknown, precludes prediction of any population effects of any collision fatalities for resident pairs.

For non-breeding eagles, as for resident pairs, wind farms may effectively cause habitat loss or collision fatality. Previous analyses had suggested that subadult non-breeding eagles may move from areas where persecution does not oc-