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Short communication

The effect of avoidance rates on bird mortality predictions made by wind turbine collision risk models

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The model of Band *et al.* (2005) used data describing the structure and operation of the turbines: number of blades; maximum chord width and pitch angle of blades; rotor diameter; and rotation speed; and of bird size and flight: body length; wingspan; flight speed; flapping; or gliding flight, to derive a probability of collision. This approach was found to be generally sound mathematically (Chamberlain *et al.* 2005). Sensitivity analysis suggested that key parameters in determining collision risk were bird speed, rotor diameter and rotation speed, although variation in collision risk was still small within the likely range of these variables. Mortality is estimated by multiplying the collision probability by the number of birds passing through the area at risk height, determined from survey data. Crucially, however, the model assumes that an individual bird takes no avoiding action when encountering a turbine, so an adjustment must also be made for avoidance behaviour.

In this paper, we examine critically the estimation and use of avoidance rates in conjunction with the collision risk model (CRM). The sensitivity of predicted mortality to errors in estimated avoidance rates is assessed in three studies that have used the CRM. It should be noted that we consider only direct mortality caused by wind turbine collisions, but we accept that there may be other indirect effects on bird populations such as disturbance, displacement and loss of habitat (Langston & Pullan 2003, Percival 2005, Fox *et al.* 2006) that are outside the scope of this paper.

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CASE STUDIES

In the following case studies, we term the probability of a bird being hit as it passes through the rotors as 'collision risk'; the probability of a bird taking avoiding action when encountering a turbine as 'avoidance rate'; and its converse (1-avoidance rate), i.e. not taking avoidance action (Band *et al.* 2005) as 'non-avoidance rate'. The number of birds struck per unit time (as a product of collision risk; the number flying at risk height; and avoidance rates) is termed 'mortality rate' (assuming that each bird hit dies). Key parameters used in the first two case studies below are given in Table 1.

Case Study 1. Bewick Swans at Little Cheyne Court, southern England

An estimated 109 Bewick's Swans *Cygnus columbianus* flew at risk height through the Little Cheyne Court site over 180 days (Percival 2004). The study used an avoidance rate of 0.9962 (based on Painter *et al.* 1999, mainly for gulls which have different flight characteristics), giving a final predicted mortality rate of 0.145 (collision risk) × 109 (number of birds at risk) × 0.0038 (non-avoidance rate) = 0.06 birds over 180 days. A doubling of the non-avoidance rate from 0.0038 to 0.0076 doubles the mortality rate. A 10% decrease in avoidance rate increases the non-avoidance rate and therefore the mortality rate over 27 times to 1.64 birds (i.e. 0.145 × 109 × (1–0.8962)) over the same period.

Case Study 2. Golden Eagles at Ben Aketil and Edinbane, Skye, western Scotland

Estimated collision risks for Golden Eagle *Aquila chrysaetos* at potential wind farm sites at Ben Aketil and Edinbane were 0.112 and 0.133, respectively, with an avoidance rate of 0.995 drawn from work on Golden Eagles in the USA (Madders 2004). Again, if we assume an example of a 10% decrease in avoidance rate (i.e. fewer birds take avoidance action), then there are substantial effects on predicted mortality rate. At Ben Aketil, annual mortality would increase from 0.12 to 2.51 individuals per year. At Edinbane,

Table 1. Key parameters used in determining mortality rates at potential wind farm sites. Collision risk is derived from the collision risk model (CRM).

Case Study	1. Percival (2004)	2. Madders (2004)	
Species	Bewick's Swan	Golden Eagle (Ben Aketil)	Golden Eagle (Edinbane)
Time span	180 days	1 year	1 year
Collision risk	0.145	0.112	0.133
Avoidance rate	0.9962	0.995	0.995
Mortality rate	0.06	0.12	0.55

respective figures would be 0.55 and 11.55. Clearly, if avoidance rates really were so low, then there would be serious impacts on local Golden Eagle populations. However, the sensitivity of estimated collisions to avoidance rates is such that a reduction from this value of only 0.005 (i.e. doubling the non-avoidance rate from 0.005 to 0.010) would double the mortality rate. A further issue in interpretation here is that mortality rates were based on the number of passes by birds, rather than the number of individual birds, representing repeated sampling of the same individual. There is therefore an implicit assumption that any bird killed would be immediately replaced. An assessment of the validity of this assumption is outside the scope of this paper.

Case Study 3. Seabirds at Kentish Flats, southern England

Using survey data and an avoidance rate of 0.9998 taken from Winkelman (1992), Gill *et al.* (2002) estimated mortality rates derived from the CRM for four groups of seabirds (terns, divers, Gannets *Morus bassana* and Black-headed Gull *Larus ridibundus*) at Kentish Flats, UK. The estimated avoidance rate was used for all of the above groups by Gill *et al.* (2002), even though it was derived for passerines only (Winkelman 1992). It seems inappropriate to use the avoidance rate for passerines when all species considered at Kentish Flats were considerably larger and have very different flight characteristics from passerines. Furthermore, despite the authors' statement that the avoidance rate used is 'the worst case scenario', it is in fact one of the lowest rates presented in the source reference (see Table 12 in Winkelman 1992). For example, the maximum estimated nocturnal mortality for gulls is 0.18%, giving an avoidance rate of 0.9982. Application of this rate to the data resulted in over an eight-fold increase in mortality rates. This Kentish Flats study would have been a good candidate for presenting a range of avoidance rates, rather than a single (and arguably inappropriate) rate.

DISCUSSION

The original CRM was developed assuming birds showed no avoidance behaviour when encountering a wind turbine. Avoidance behaviour was incorporated by multiplying predicted collision risk by non-avoidance rate. Estimates of avoidance are typically very high (> 0.95 in most case studies). Hence, they heavily and linearly influence predicted collision rates. Small variations in avoidance rates result in relatively large changes in predicted collisions, so errors in avoidance rate estimation can have large impacts on estimated mortality rates.

Bird surveys at wind farm sites are typically carried out in good weather conditions and in daylight. Avoidance behaviour, however, is likely to vary according to conditions: it is reasonable to expect that avoidance rates would be much reduced at times of poor visibility, in poor weather (themselves depending in part on season) and at night (e.g. Winkelman 1992, Still *et al.* 1996). Furthermore, in conditions of poor visibility, birds tend to be drawn towards, and circle in the vicinity of, continuous lights, which may represent an attraction and therefore substantially affect avoidance rates (e.g. Gauthreaux & Belser 1999, Manville 2000). Birds may also be drawn to the vicinity of turbine structures for other reasons. Offshore, gulls and Cormorants *Phalacrocorax carbo* use them as perches, as do birds of prey on land, and where the presence of turbines increase feeding opportunities, birds may be further drawn into their vicinity elevating collision risk (Fox *et al.* 2006).

Avoidance rates have been calculated by dividing the estimated actual mortality rate by the number of birds 'at risk' (e.g. flying through the area at turbine height). Since both sources are subject to considerable observer, stochastic and systematic error, avoidance rates suffer from compounded error, both in accuracy and precision. Potential improvements to bird survey methods, particularly at night and in poor visibility could include remote sensing survey technologies (see below). Calculation of post-construction mortality rates has typically relied on corpse searches (Langston & Pullan 2003), using tideline searches for off-shore and coastal wind farms (e.g. Winkelman 1992, Still *et al.* 1996, Painter *et al.* 1999). There are potential biases in estimating mortality in this way due to searching efficiency, corpse removal by scavengers, injured birds leaving the area before death, 'obliteration' of birds struck by turbines (especially smaller species) and, for coastal locations, corpses being washed out to sea. Adjustments to mortality rates have been made to try and compensate for these factors by some authors (e.g. Winkelman 1992, Painter *et al.* 1999). Nevertheless, there is likely to be much local variation: scavenger communities are likely to differ locally; search efficiency depends on bird size and the vegetation in the surrounding area (Winkelman 1992); and at coastal sites, local tide, currents and weather conditions will affect recovery rates (Painter *et al.* 1999). Furthermore, postmortem examination has been used to assess mortality caused by turbine collision and compared to background mortality (where major physical injury has been taken as evidence of collision). However, birds may be driven to the ground by vortices associated with turbines rather than as a result of a collision (Winkelman 1992). Given these factors, it is probably unwise to use mortality rates (and therefore avoidance rates) derived from studies in locations that differ greatly from the potential site under consideration (in terms of habitat and topography for example), or indeed from different species (see Case Study 3 above). Rather, avoidance rates should be derived from the same species and from localities as similar as possible to the location under consideration.

Given the above caveats, avoidance behaviour of birds should ideally be studied *in situ* rather than be inferred

Table 2. Effects of 10% variation in input parameters on predicted mortality rates of Bewick's Swans at Little Cheyne Court (Percival 2004).

Input variable	Baseline′	Baseline ± 10%	Collision risk	Revised collisions	% increase
Max. chord (m)	5.00	5.50	0.153	0.063	5.62
Pitch angle (°)	30.00	33.00	0.150	0.062	3.55
Bird length (m)	1.21	1.33	0.151	0.063	4.24
Wingspan (m)	1.96	2.16	0.147	0.061	1.48
Bird speed (m/s)	20.00	18.00	0.158	0.065	9.07
Rotor diameter (m)	92.00	82.80	0.150	0.062	3.55
Rotation speed (/s)	3.00	2.70	0.158	0.065	9.07
Bird count	109.00	120.00	0.145	0.066	10.20
Avoidance rate	0.9962	0.897	0.145	1.628	2613.19

Variables were changed by 10% (increased or decreased) so that mortality rates increased. The original collision risk was 0.145 and the original number of predicted collisions was 0.06 (Table 1).

from two variables (mortality rates and bird counts at different heights) both of which can be subject to (sometimes considerable) error (Chamberlain *et al.* 2005). This error, even when small, can have relatively large effects on predicted mortality. This is illustrated by the example in Table 2 using data from Case Study 1. Table 2 lists all variables used in the calculation of mortality rates, including those used in the CRM, bird survey data and avoidance rates. By varying each parameter in turn by 10% (in the direction that leads to an increase in the predicted mortality rate), the effect that error in each parameter can have on the predicted mortality rate becomes obvious. Clearly, the effect of variation in avoidance rate is far higher than any other variable in the CRM. Even when all other parameters were changed simultaneously by 10%, the predicted mortality was estimated only at 0.091 per 180 days (a 52% increase from the original 0.06), compared to 1.63 per 180 days for a change in avoidance rate (a 2613% increase).

Small changes in avoidance rates can lead to large percentage changes in mortality rates. However, actual mortality rate increases in terms of numbers of birds killed may still be small. In a species such as Golden Eagle with a low reproductive rate (Whitfield *et al.* 2004), such an increase is likely to have much greater impacts on populations than it would in a passerine species. This raises a more general issue; species that exhibit low natural mortality rates with low reproductive potential (K-selected) are likely to suffer rapid declines in absolute numbers when subject to additive mortality (Fox *et al.* 2006). These species are typically rarer (and hence of disproportional nature conservation value) than short-lived species with high reproductive potential (r-selected). Where r-selected species are abundant and widespread, the effect in proportional terms (though not necessarily to local populations) is likely to be less. Whilst outside the scope of this paper, further research into the wider population impacts of increased mortality due to wind turbine collisions, especially on K-selected species such as Golden Eagle, is to be recommended.

Spatially explicit patterns of avoidance shown by birds can be generated under a range of meteorological, light, diurnal and seasonal conditions using relatively crude surveillance azimuth radar (e.g. conventional marine radar, Kahlert *et al.* 2004). This has been successful in measuring the level of avoidance at large spatial scales shown by migrating waterbirds (mainly ducks) to an extant offshore wind farm in Denmark (Desholm & Kahlert 2005). Furthermore, statically mounted thermal infra red imagery can be used to view rotating turbines in a way that could potentially directly record actual collision rates and mortal wounding events associated with air vortices, as well as flight avoidance of the rotor swept area by birds (Desholm 2003). This provides real time collision rates offshore (where collections of corpses is not practical) and onshore (to verify estimates from corpse collections), potentially generating data at the species or species group level (Desholm 2003). Archived imagery from such devices can also show the specific avoidance behaviour of individuals of particular species in close proximity to turbines that can further inform the development of meaningful parameterization of avoidance behaviour (Desholm *et al.* 2006). Use of such remote technologies is essential if we are to be able to provide useful precision on estimates of a parameter that makes such a huge difference to predicted collision risk.

CONCLUSIONS

Whilst the ultimate collision probabilities generated from the CRM approach are theoretically robust, their modification by the probability of avoidance shown by different species of bird is specifically ignored by the present formulation and ill-served with available real data at the present time (Band *et al*. 2005). We suggest that the value of the current model in estimating actual mortality rates is questionable until such time as species-specific and state-specific (i.e. different bird activities and behaviours under a range of conditions, for example breeding birds, recently fledged or moulting birds) avoidance probabilities can be better established. The CRM may be useful for comparative purposes, but this is dependent on sound evidence that potential sites being compared can be assumed to have equal avoidance rates. Avoidance rate studies should be carried out as a matter of urgency. Currently, inferring avoidance rates from survey sample data on bird occurrence and estimated mortality (themselves subject to error) is inadequate. Even small errors can have large effects on predicted mortality rates, such that no matter how robust the estimates of collision risk in the absence of avoiding action, the final predicted mortality is meaningless. We cannot therefore recommend the use of CRM without further research into avoidance rates. Indeed, Band *et al*. (2005), who developed the CRM, concur with this, in stating 'For the CRM to predict accurately measures of collision mortality, it is essential that more information is collected on avoidance'. Potential methodologies to obtain data on species and state specific avoidance rates include the use of surveillance azimuth radar and thermal infra red imagery (Desholm *et al*. 2006).

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