Birds and windfarms:

what are the real issues?

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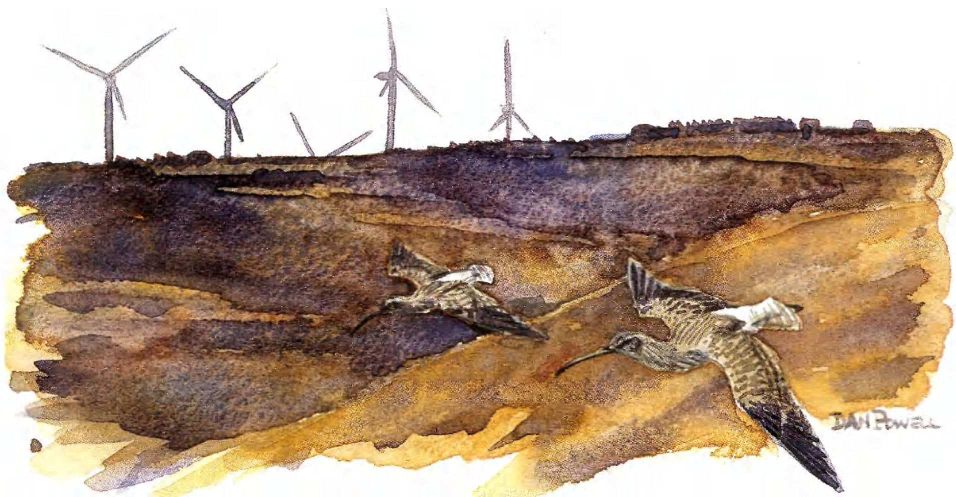

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ABSTRACT Windfarms are becoming increasingly common in Britain, and concerns about their possible effects on birds are increasing too. There are two main ways in which windfarms can affect birds: by collision with the turbines themselves, and through disturbance from a zone around them. Although no significant ornithological problems have yet been recorded at existing windfarms in the UK, there have been serious problems at windfarms in other countries, notably with birds of prey, and these are discussed. The evidence shows that birds and windfarms can coexist if the windfarm site is located appropriately. In particular, windfarm development should avoid areas: (i) with high-density raptor populations, where collisions could be significant; (ii) with high densities of other species vulnerable to a low level of additional mortality, and whose susceptibility to collision may be high; and (iii) where disturbance could potentially displace birds from important feeding or nesting habitats. It is vital to consider the potential problems of collisions and disturbance at windfarms on a case-by-case basis.

Windfarms are becoming increasingly common in the British countryside and many more are likely to be constructed during the next few years if the Government's renewable energy targets are to be met. At the time of writing, there are some 94 wind-energy projects connected to the UK national grid, comprising some 1,186 turbines with a capacity of 890 MW (www.bwea.com). Another 18 projects are under construction, and many more are presently being assessed by the planning system. The increase in the deployment of wind turbines is a global phenomenon; for example, Germany now has an operating wind-power capacity of over 15,000 MW, that in Spain is 6,600 MW and that in the USA is 6,400 MW (Milborrow & Tishler 2004). It is widely acknowledged by the Government, national nature conservation agencies and the RSPB that wind energy can make a positive contribution to combating climate change.

One of the main aims of the wind-power industry is to deliver less environmentally damaging energy. It is, therefore, in the interests of both windfarm developers and those seeking to protect bird populations that windfarms should be located away from areas where such developments may have a deleterious impact. Furthermore, the windfarm industry has legal obligations, via the European Directives on Habitats and Birds, to the network of protected sites and associated designated species. At the same time, given the environmental benefits that wind energy can deliver, it is also important that bird issues should not constrain wind-energy development unnecessarily in those areas where it is unlikely to cause significant problems.

All the projects in the UK have been, and will continue to be, subject to comprehensive environmental assessment, but, with the proposed expansion in windfarm capacity, might we be looking at a conflict between the industry and British bird populations in the near future? In the UK, there have been no significant ornithological problems reported at windfarms to date, mainly as a result of their location in areas away from important bird populations (SGS 1996; Langston & Pullan 2003). A range of sites have been developed, in coastal, upland and farmland habitats, with farms ranging in size from one to 100+ turbines.

This paper focuses chiefly on onshore windfarms, as it is at these that most of the research into the effects on birds has been carried out. Nonetheless, offshore windfarms are becoming a particularly important issue in the UK, as there are plans for several much larger-scale developments than have been constructed onshore (for details, see www.crownestate.co.uk).

This currently positive situation in Britain is, unfortunately, not always replicated elsewhere. Two windfarm areas in particular have become synonymous with ornithological problems: Altamont Pass, in California, and Tarifa, in southern Spain. Large numbers of raptors in particular have collided with wind turbines at these sites, including substantial numbers of Golden Eagles *Aquila chrysaetos* at Altamont (Orloff & Flannery 1992; Hunt *et al.* 1998; Thelander *et al.* 2003) and Griffon Vultures *Gyps fulvus* at Tarifa (SEO/BirdLife 1995; Janss 2000; Barrios & Rodriguez 2004). Large, long-lived species such as these are often susceptible to even small increases in mortality, so there is potential here for significant population effects. In both these areas, the scale of the windfarm development has clearly been inappropriate given the local bird populations. It is important that such mistakes are not repeated elsewhere, and that we understand the fundamental char-

Box 1. Information on birds and windfarms.

There is a range of sources of information on how birds have been affected by windfarms, including several reviews of the topic dating back more than a decade. These all provide useful information about the state of knowledge at the time that they were compiled. The following make a good start for anyone looking further into the potential effects of wind turbines on birds:

- Crockford (1992) – a review carried out for JNCC;
- Gill *et al.* (1996) – a review carried out for Scottish Natural Heritage;
- SGS Environment (1996) – a review carried out for the UK Department of Trade and Industry (DTI) Energy Technology Support Unit;
- Percival (2000) – a review for *British Wildlife*;
- Erickson *et al.* (2001) – a review of the collision rates at windfarms in the USA for the US National Renewable Energy Laboratory;
- Percival (2001) – a review of the potential ornithological impacts of offshore windfarms for the DTI Energy Technology Support Unit;
- Kingsley & Whittam (2003) – compiled by Bird Studies Canada for Environment Canada (Canadian Wildlife Service);
- Langston & Pullan (2003) – a review compiled by RSPB and its BirdLife partners for the Bern Convention.

acteristics of the bird populations in such locations and how potential problem sites can be identified (and avoided) in the future.

There are two main ways in which a windfarm might potentially affect bird populations. The first of these, often intuitively assumed to be the major risk, is that birds may fly into the turbines, principally the rotating blades, and be killed. Secondly (but potentially at least equally important in an ecological context), birds can be displaced from an area around the wind turbines through disturbance, resulting in effective habitat loss. Direct habitat loss from windfarm construction is usually small-scale and unlikely to be significant, although this might happen if a particularly scarce and important habitat was affected, or if there was potential to affect a wider area (e.g. through disrupting the hydrology of a peatland system).

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104. Tarifa, in southern Spain, is one of the windfarms which has become infamous for the number of bird collisions, notably of Griffon Vultures *Gyps fulvus* and other raptors. The scale and nature of windfarm development here (700 turbines, packed close together, and of an old design with latticework towers, and high-speed rotors close to the ground) was clearly inappropriate given the characteristics of the local bird populations.

Collision risk

What are the characteristics of Altamont Pass and Tarifa, where there have been major bird collision incidents, and why have they caused such problems? The number of collisions per turbine in these areas was actually quite low (considerably less than one bird per turbine per year; table 1), but taking each area as a whole, the number of collisions, particularly of protected species, was significant. Both of these windfarm areas are characterised by large numbers of turbines (c. 7,000 at Altamont, c. 700 at Tarifa), which are predominantly of an old design (small turbines, with high-speed rotors relatively close to the ground, and with the turbines often packed close together). Many also have lattice towers, which provide many perches, thus attracting birds, particularly raptors, into the collision-risk zone. Both areas support high densities of birds which are susceptible to collisions with turbines, and species for which a small increase in mortality has the potential to have an impact at the population level. Finally, but of particular importance, both sites support important food resources for key bird species. For example, at Altamont, the bases of the turbines have proved ideal for small burrowing mammals such as gophers (Geomyidae), attracting raptors to feed within the collision-risk zone (Thelander *et al.* 2003).

How widespread is the problem of collision? In table 1, a range of studies of bird collisions are summarised (focusing particularly on sites where problems have occurred, but also including sites where they have not) giving, where possible, information on the size and type of wind turbines, the birds' exposure to collision risk (numbers flying through at rotor height), the incidence of collision, and an assessment of whether this might result in any population impact. These have been summarised into broad classes to illustrate the main overall patterns.

A recent study in Navarre, in northern Spain, has highlighted the susceptibility to collision of Griffon Vultures in that area too (Lekuona 2001). Collisions between large raptors and wind turbines have also been reported from other regions, though not in such high numbers; for example, two White-tailed Eagles *Haliaeetus albicilla* collided with wind turbines in northern Germany recently (Krone & Scharnweber 2003). No other 'Altamont-type' problems have been reported else-

Table 1. Bird-windfarm collision studies: summary of findings.

Species group	Sites studied	Windfarm size	Turbine type	Exposure to collision risk	Incidence of collision	Population effect
Divers	Burgar Hill [1,2]	S	S/M	M	Nil	No
Cormorants	Buffalo Ridge [3]	VL	M	L	Nil	No
	Blyth [4,5]	S	S	L	VS	No
Swans	Yukon [6]	S	S	S	Nil	No
	Urk [7]	M	S	M/L	VS	No
Geese	Buffalo Ridge [3]	VL	M	L	Nil	No
	Klondike [9]	M	M	M	S	No
	Kreekrak [12]	S	S	M	S	No
	Gotland [10]	L	M	L	Nil	No
	Urk [7]	M	S	M	Nil	No
Ducks	Blyth [4,5]	S	S	L	S	No
	Buffalo Ridge [3]	VL	M	L	VS	No
	San Gorgonio [11]	VL	S	-	VS	No
	Kreekrak [12]	S	S	L	M	No
Eagles, vultures, hawks	Altamont [11,13]	VL	S	L	S	Likely
	Tehachapi [11]	VL	S	-	VS	Possible
	San Gorgonio [11]	VL	S	-	VS	No
	Tarifa [14,16]	VL	S	L	VS	Possible
	Navarre [15]	VL	M	L	S	Possible
Harriers	Buffalo Ridge [3]	VL	M	M	Nil	No
	Altamont [11,13]	VL	S	L	VS	No
	Foot Creek Rim [8]	L	M	-	VS	No
Falcons	Altamont [11,13]	VL	S	L	S	Possible
	Burgar Hill [1]	S	S	S	VS	No
	Novar [17]	M	M	M	VS	No
	Tehachapi [11]	VL	S	-	VS	No
	Tarifa [14, 16]	VL	S	L	VS	Possible
Upland gamebirds	Buffalo Ridge [3]	VL	M	S	VS	No
	Novar [17]	M	M	S	VS	No
	Tehachapi [11]	VL	S	-	VS	No
Owls	Altamont [11,13]	VL	S	L	VS	Possible
	San Gorgonio [11]	VL	S	-	VS	No
	Tehachapi [11]	VL	S	-	VS	Possible
Waders	Kreekrak [12]	S	S	L	S	No
	Gotland [21]	L	M	L	VS	No
	Blyth [4,5]	S	S	M/L	VS	No
	Oosterbierum [18]	M	S	M/L	VS	No
	Ovenden Moor [19]	M	S	L	VS	No
	Buffalo Ridge [3]	VL	M	L	VS	No
Gulls	Blyth [4,5]	S	S	L	M	No
	Kreekrak [12]	S	S	L	M	No
	Zeebrugge [20]	M	S/M	L	L	Possible
	Buffalo Ridge [3]	VL	M	L	Nil	No
Terns	Zeebrugge [20]	M	S/M	L	M	Possible
	Blyth [4,5]	S	S	M	Nil	No
Passerines	Blyth [4,5]	S	S	M/L	Nil	No
	Buffalo Ridge [3]	VL	M	L	M	No
	Oosterbierum [18]	M	S	L	L	No

KEY

Sources: 1. Meek *et al.* 1993; 2. Haworth 2002; 3. Johnson *et al.* 2000; 4. Still *et al.* 1995; 5. Painter *et al.* 1999; 6. Mossop 1998; 7. Winkelman 1989; 8. Young *et al.* 2003; 9. Johnson *et al.* 2003; 10. Percival 1998b; 11. Erickson *et al.* 2001; 12. Musters *et al.* 1995, 1996; 13. Thelander *et al.* 2003; 14. SEO/BirdLife 1995; 15. Lekuona 2001; 16. Janss 2000; 17. Bioscan 2001; 18. Winkelman 1992a; 19. EAS 1997; 20. Everaert *et al.* 2002; 21. Percival 2000.

Windfarm size: VL = very large (>200 turbines); L = large (50-200 turbines); M = medium (10-50 turbines); S = small (<10 turbines).

Turbine type: L = large (>1.5 MW); M = medium (500 KW-1.5 MW); S = small (<500 KW).

Exposure to collision risk (based on number of flights at rotor height/in proximity to turbines per year: L = large (>10,000); M = medium (1,000-10,000); S = small (<1,000).

Incidence of collision: L = large (>10/turbine/yr); M = medium (1-10/turbine/yr); S = small (0.1-1/turbine/yr); VS = very small (<0.1/turbine/yr).

Population effect: determined on the basis of the total numbers killed in relation to the population dynamics.

where in North America, even at other large windfarms or where large numbers of birds have been passing through the windfarm area (Erickson *et al.* 2001; Kingsley & Whittam 2003). Furthermore, studies at upland sites in the UK have generally reported extremely low collision rates, with some finding no collisions at all (Meek *et al.* 1993; Tyler 1995; EAS 1997; Bioscan 2001). This probably reflects the generally low bird densities present in these areas, though it should be noted that, so far, little work has been published from those UK upland windfarm sites that may pose a significant risk to larger raptors such as Golden Eagle or Hen Harrier *Circus cyaneus*, so possible impacts on species such as these are not yet well understood in Britain.

Studies of bird collisions at coastal windfarms have generally reported rather higher numbers of collisions than in upland areas, which probably reflects generally higher bird densities on the coast. Studies at Blyth Harbour, Northumberland (Still *et al.* 1995; Painter *et al.* 1999), and at Zeebrugge harbour, Belgium (Everaert *et al.* 2002), revealed collision rates in excess of one bird per turbine per year, with most casualties at both sites being gulls (Laridae). The number of collisions estimated in the Zeebrugge study were particularly high (an average of 23 birds per turbine per year at one of the three windfarms studied; rate per turbine varied within and among sites, from 0 to 125 birds per turbine per year, which highlights the high variability within and among windfarms).

Care is needed when interpreting quoted collision rates. Collisions are intrinsically rare events, and are difficult to measure accurately. Scavengers may remove collision victims before they are detected, and observers may miss some of the corpses, particularly of smaller birds. It is important that any study should be designed to take into account the local scavenger populations, and attempt to quantify scavenger removal and observer efficiency. Studies without such calibration can provide useful information, as long as it is appreciated that collision rates in such circumstances are minimum values and may underestimate true values. Similarly, quoted collision rates obtained by extrapolation and using large correction factors, such as in the Zeebrugge and Navarre studies (where only a low percentage of the estimated collisions were actually detected), also

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105. Blyth Harbour windfarm, Northumberland, where collision rates in excess of one bird per turbine per year have been documented, with most of the casualties being gulls (Laridae). See text and table 1.

need to be treated with caution. Ideally, it is preferable to adjust the methodology to take into account more rapid scavenger removal or low observer efficiency rather than applying a large correction factor. Caution is also needed when interpreting extrapolations of results; for example, if a study has been carried out over a few weeks, the observed collision rate could not justifiably be extrapolated to a whole year.

Collision risk depends on species, circumstances and any impediments to flight control. For example, a key factor in many collisions involving Griffon Vultures at Tarifa was the location of some turbines on ridges critical for lift by the vultures, which were unable to gain sufficient flight control to avoid the turbines (Barrios & Rodriguez 2004). Overall, however, studies using radar-tracking have shown that birds are generally able to avoid collisions with wind turbines and do not simply fly into them blindly. Dirksen *et al.* (1998) found that Common Pochards *Aythya ferina* and Tufted Ducks *A. fuligula* regularly flew through a windfarm in The Netherlands at night under moonlight, but flew around the turbines at a greater distance from them when dark and foggy. Reported collision rates are typically in the range of 1 in 1,000-10,000 bird flights through a windfarm, even in studies such as that at Zeebrugge, where relatively high numbers of collisions have been reported. In some cases, they are considerably lower, such as at the offshore windfarm at Utgrunden, Sweden, where over 500,000 Common Eider *Somateria mollissima* flights through the windfarm study area have been observed without a single collision being seen (Pettersson & Stalin 2003). Studies by Winkelman (1992a), however, indicated that most collisions occurred during periods of poor flight and sight conditions, which hamper studies of bird behaviour in relation to turbines.

It has been suggested that birds at windfarms may be susceptible to catastrophic collision events, as has been found with nocturnal landbird migrants at some large communication towers in the USA (Manville 2001). So far, however, there are no documented events on such a scale from any windfarm and there have been only occasional records of more than a handful of collisions occurring over a short time, almost all referring to nocturnal passerine migrants. For example, Kingsley & Whittam (2003) cite just four examples in their review: 28 night migrants at the 44-turbine site at Mountaineer, West Virginia (Kerlinger 2003); 14 collisions with two turbines at Buffalo Ridge (Johnson *et al.* 2002); an estimated 170 collisions with 18 turbines at Oosterbierum during seven nights of peak migration; and 43 birds at one turbine on Gotland (Karlsson 1983). All figures refer to a single night unless stated.

One potentially major problem in assessing the possible effects of new windfarm developments is a lack of information about the particular species which occur at that site. An approach using the precautionary principle, which has been used in some cases, is to look at the relative susceptibility of those species to other structures, such as power lines. Any risk assessment can usefully draw on relevant available information, such as that from collision with other structures, particularly so in the absence of good, quantitative data from windfarms. Such comparisons may, however, be of limited value where studies are not directly comparable; for example, geese are vulnerable to power-line collisions, but the few quantitative studies of goose collisions at windfarms suggest that such events are rare indeed, even when large numbers are potentially at risk (table 1). A better approach may be to consider the ecological characteristics of the species involved, comparing the species with those which *have* been studied, and in particular those for which problems have occurred. The best available data could then be used to establish a worst-case analysis and, in particular, gauge the likelihood of any population impact. An impact at the population level would require a combination of a sufficient number of flights at rotor height, and species which are both susceptible to collision and ecologically sensitive to additional mortality.

In considering the potential impact of windfarms, it is useful to set the resulting mortality into the overall context of bird-collision rates with other man-made structures. Erickson *et al.* (2001) produced the following estimates of bird-collision mortality in the USA:

- Vehicles: 60-80 million
- Buildings and windows: 98-980 million
- Power lines: from tens of thousands to 174 million
- Communication towers: 4-50 million
- Wind generation facilities: 10,000-40,000

Erickson *et al.* (2001) concluded that, even if the number of wind turbines in the USA increased by two orders of magnitude (to over one million turbines), they would still be likely to cause no more than a few per cent of all collision deaths related to human structures. As highlighted above, however, it is a few sensitive species which cause most of the concern, those for which even a small additional mortality attributable to collision with wind turbines may be significant.

Disturbance

The second potentially important effect of windfarms on birds is disturbance, since windfarm construction can bring a range of potentially disruptive activities. While the site is under construction, there is likely to be an increase in human presence, vehicle movements on site and noise levels. The same is true of the decommissioning phase (wind turbines are typically given planning permission for 20-25 years, after which they should be dismantled and removed from the site). During the operational phase, the physical presence of new structures may make some species reluctant to use the ground around them, while there is noise generated by the turbines and human presence (albeit usually low) through maintenance activities. Any or all of these could potentially contribute to displacement of birds from a zone around the turbines, effectively resulting in habitat loss.

There have been numerous studies of bird

Table 2. Bird-windfarm disturbance studies: summary of findings.

Species group	Sites studied	Habitat	Windfarm size	Turbine type	Disturbance distance
Cormorant	Blyth [1]	Coastal	S	S	None *
Swans	Urk [3]	Farmland and coastal	M	S	None (Bewick's), 300 m (Whooper)
Geese	Germany [4,5]	Farmland	M	S/M	Up to 600 m
	Urk [3]	Farmland and coastal	M	S	None
	Denmark [6]	Farmland	L	M	1-200 m
	Gotland [7]	Coastal marsh	L	M	0-25 m
	Toronto [8]	Parkland	S	M	None
Ducks	Tunø Knob [9]	Offshore	M	M	None
	Utgrunden [10]	Offshore	S	L	None
	Urk [3]	Coastal	M	S	Up to 300 m
Raptors	Bryn Tytli [16]	Upland moor	M	S	None
	Altamont [17]	Grassland	VL	S	None
Waders:	Ovenden Moor [11]	Upland moor	M	S	None
breeding	Various UK sites [12]	Upland	S/M	S/M	None
	Gotland [22]	Coastal and farmland	L	M	None
	Oosterbierum [15]	Lowland farmland	S	S	Up to 300 m
	Germany [13]	Lowland farmland	S/M	S/M	Up to 200 m
Waders:	Blyth [1]	Coastal	S	S	None
non-breeding	Tjaereborg [2]	Farmland	S	M	800 m
	Zeebrugge [14]	Coastal	M	S/M	Up to 250 m
	Oosterbierum [15]	Farmland	M	S	500 m
Gulls	Tjaereborg [2]	Farmland	S	M	800 m
	Blyth [1]	Coastal	S	S	None
Terns	Zeebrugge [14]	Coastal	M	S/M	None
	Blyth [1]	Coastal	S	S	None
Passerines	Various UK sites [12]	Upland	S/M	S/M	None
	Buffalo Ridge [18]	Grassland	VL	M	1-200 m
	Bryn Tytli [19]	Upland moor	M	S	None
	Burgar Hill [20]	Upland moor	S	S	None
	Novar [21,23]	Upland moor	M	M	None

KEY

Sources: 1. Still *et al.* 1995; 2. Pedersen and Poulsen 1991; 3. Winkelman 1989; 4. Kowallik & Borbach-Jaene 2001; 5. Kruckenberg & Jaene 1999; 6. Larsen & Madsen 2000; 7. Percival 1998a; 8. James 2003; 9. Guillemette *et al.* 1998, 1999; 10. Pettersson & Stalin 2003; 11. Bullen Consultants 2002; 12. Thomas 1999; 13. Ketzenberg *et al.* 2002; 14. Everaert *et al.* 2002; 15. Winkelman 1992b; 16. Green 1995; 17. Thelander *et al.* 2003; 18. Leddy *et al.* 1999; 19. Phillips 1994; 20. Meek *et al.* 1993; 21. Bioscan 2001; 22. Percival & Percival 1998; 23. Percival 2002.

Windfarm size: VL = very large (>200 turbines); L = large (50-200 turbines); M = medium (10-50 turbines); S = small (<10 turbines).

Turbine type: L = large (>1.5 MW); M = medium (500 KW-1.5 MW); S = small (<500 KW).

Disturbance distance: 'None' indicates no significant disturbance effect; * disturbance noted during construction but not operation.

disturbance at windfarms, one of the more comprehensive being that by Larsen & Madsen (2000) in Denmark. They looked at the effects of a large number of wind turbines (61) on the feeding distribution of wintering Pink-footed Geese *Anser brachyrhynchus*. They found that the geese maintained a distance of about 100 m from single turbines or rows of turbines, and a distance of about 200 m from clusters of turbines. This disturbance effect was of a similar magnitude to that of the other landscape features in the area, such as hedgerows, roads and buildings. This landscape-scale approach could be useful in planning other windfarms in similar situations, and in particular for locating turbines in areas which are already disturbed, to reduce their potential impact.

In many cases, including studies at upland, coastal and offshore windfarms, no significant disturbance effect has been detected (table 2). In other studies, however, a reduction in bird numbers has been reported as far as 800 m from turbines outside the breeding season, and up to 300 m from turbines for breeding birds. As for the impact of collision, care needs to be taken when interpreting the results. In cases where no significant effect is found, the sample size and power of the statistics used need to be considered carefully. In addition, several studies have unwittingly incorporated confounding factors such as increased human disturbance, a lack of proper habitat data to determine the birds' preferences in relation to windfarm location, and a lack of proper statistical testing or experimental design. The variability in results is exemplified by two studies on the Russian Barnacle Goose *Branta leucopsis* population. One was carried out on the birds' spring staging grounds in Gotland, Sweden, where they fed in close proximity to wind turbines (to within 25 m) with no significant disturbance effect (Percival 1998a). A study of the same population on their wintering grounds in Germany, however, found that few geese fed within 350 m of wind turbines, and a reduction in numbers up to 600 m from the turbines was evident (Kowallik & Borbach-Jaene 2001). The most likely explanation for such different results is that geese avoid wind turbines when there is easy access to alternative feeding habitat, but will be less selective when resources are limited. On Gotland, the geese fed primarily on saltmarsh, which had a restricted distribution within the study area, mostly in close proximity to the wind turbines. In contrast, the birds in Germany were feeding on farmland, where alternatives would have been more freely available. Similar results, where birds become more tolerant of disturbance as resources become scarcer, have been found in other studies of disturbance of wintering waterfowl (e.g. Percival 1993). Other results have suggested, however, that disturbance can lead to reduced breeding productivity (e.g. Madsen 1995), reduced survival, or a reduction in available habitat, so it remains possible that disturbance may be significant for some species in certain situations (see Woodfield & Langston 2004 for review). Overall, in terms of the ecological consequences of potential disturbance effects, these results suggest that birds may either move to nearby alternative food sources, if available, or be more tolerant of the presence of the wind turbines if not. In existing studies, substantial displacement by wind turbines seems to have occurred primarily in farmland habitats, where there would typically be alternative feeding areas within easy reach.

Studies at upland windfarms have not shown any major disturbance impact on waders, grouse or passerines (although, as emphasised above, survey results may be incon-

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106. The construction phase at Bowbeat windfarm in the Scottish Borders.

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107. Studies of Barnacle Geese *Branta leucopsis* on their wintering and spring staging grounds suggest that feeding birds will avoid wind turbines if there are easily accessible alternative food resources, but will be less selective if those resources are more limited.

clusive or limited by small sample size). The effects on raptors in upland habitats are less well known. Several species (including Golden Eagle and Hen Harrier) forage in high densities in windfarm areas in the USA, even hunting in close proximity (<50 m) to wind turbines at Altamont (Thelander *et al.* 2003), which suggests that disturbance during the operational phase is not such a problem as collision risk for these species.

The maximum distance over which birds have been reportedly affected by disturbance from an operational windfarm is 800 m (Pedersen & Poulsen 1991), although this single, large experimental turbine at Tjaereborg, Denmark, was operating in an atypically intermittent way and sited in less attractive habitat relative to the rest of the study area (which the study did not take into account). Two studies in Germany have reported goose disturbance up to 600 m from windfarms (Kruckenberg & Jaene 1999; Kowallik & Borbach-Jaene 2001). Though the results from these studies would not necessarily be generally applicable (even to the same goose population in other circumstances – see above), 600 m would perhaps make a more appropriate worst-case disturbance scenario (given that it is based on more reliable studies), at least for onshore windfarms. With rather less information available from offshore sites, a more cautious approach may be appropriate, given the (generally) different species involved and the often much larger proposed scale of development.

Wind turbines also have the potential to disrupt bird flight-lines. Several studies have shown that some species alter their route to avoid flying through windfarms, for example Tufted Duck and Common Pochard at Lely in The Netherlands (Dirksen *et al.* 1998), Common Eiders at Tunø Knob in the Danish Baltic (Tulp *et al.* 1999), and Common Eiders at Utgrunden in the Swedish Baltic (Pettersson & Stalin 2003). While this may reduce collision risk, it could also result in the windfarm acting as a barrier to bird movements. Such effects are not, however, universal and, for example, at Zeebrugge, large numbers of birds regularly fly through the windfarm without diverting around it (Everaert *et al.* 2002). For a small windfarm, the ecological consequences of such a barrier are unlikely to be a problem, with minimal diversion distances involved. For larger sites, however, particularly some of the offshore sites currently being proposed, this does have the potential to be more important, for example by increasing energy expenditure or disrupting ecological links between feeding and roosting/loafing areas.

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108. Offshore wind turbines at Tunø Knob, in the Danish Baltic Sea.

In summary, there are circumstances when the presence of a windfarm can cause disturbance, and circumstances when this has the potential to be ecologically significant. Displacement distances are clearly variable, even within the same bird population, but tend to be related to the availability of alternative resources nearby. An increased tolerance to disturbance when resources are scarce may reduce the potential for significant, long-term impacts, though further research is needed to confirm this. It is still necessary to consider new windfarm proposals on a case-by-case basis, and to assess the patterns of resource availability and the potential loss through disturbance for each.

Conclusions

Clearly, windfarms have the potential to cause significant problems for bird populations. Furthermore, every windfarm situation is different and, with the industry still at a relatively early stage of development, situations where previous research does not provide clear guidance as to whether a particular development will cause problems for local bird populations are commonplace. Nonetheless, problems have so far occurred at only a small number of sites, outwith the UK, and are highly site- and species-specific. To avoid problems with birds, the key factor when developing future sites should be the location, and it is clear from the evidence available that birds and windfarms *can* coexist where windfarms are sited appropriately. In particular, it is important to avoid developing windfarms at sites (a) with high-density raptor populations, where collisions could be significant; (b) with high densities of other species vulnerable to a low level of additional mortality, where their susceptibility to wind-turbine collision may be high; and (c) where disturbance could potentially displace birds from important habitats/sites (e.g. within 600 m of important feeding/roosting areas unless there is good evidence that the species would not be affected).

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