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Assessing the impacts of wind farms on birds

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The potential effects of the proposed increase in wind energy developments on birds are explored using information from studies of existing wind farms. Evidence of the four main effects, collision, displacement due to disturbance, barrier effects and habitat loss, is presented and discussed. The consequences of such effects may be direct mortality or more subtle changes to condition and breeding success. The requirements for assessing the impact of future developments are summarized, including relevant environmental legislation and appropriate methods for undertaking baseline surveys and post-construction monitoring, with particular emphasis on the rapidly developing area of offshore wind farm assessments. Mitigation measures which have the potential to minimize impacts are also summarized. Finally, recent developments in the monitoring and research of wind energy impacts on birds are outlined and some areas for future work are described.

INTRODUCTION

The UK, in common with many other EU member states, is set to see a rapid increase in the number of wind farms. The UK government's target is to derive 10% of energy from renewables by 2010, of which 7–8% would be from wind energy (8–10 GW in total). It is estimated that, using the latest turbine technology, the installation of 2000 turbines onshore and approximately 1500 offshore would be sufficient to meet this target (www.bwea.com). Although it is widely accepted that greenhouse gas emission is the primary cause of anthropogenically driven global climate change (Huntley *et al*. 2006), and that moving to renewable energy sources will play a vital role in reducing emissions, the unprecedented rate and scale of development of wind farms raises questions about impacts on wildlife. Unfortunately, understanding of the potential implications of large-scale wind energy developments, especially offshore, has not kept pace with the recent rise in the number of development proposals.

This paper explores the potential effects of the proposed increase in wind energy developments on birds, summarizing information collected from studies of existing wind farms and identifying possible impacts resulting from the larger scale wind farms currently proposed and under development. It outlines how impact assessments for proposed developments should be made, and what mitigation measures might be available to minimize those impacts. Finally, it explores recent developments in the monitoring and research of wind energy impacts on birds and describes some important areas for future work.

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WIND ENERGY IN THE UK

The UK has one of the largest wind resources in Europe, with 40% of Europe's total potential resource for wind-generated power, the equivalent to three times the UK's current electricity usage (Troen & Petersen 1989). There are currently 101 wind farms in the UK, consisting of 1234 turbines, which produce 979 MW of generating capacity (www.bwea.com). No significant impacts on birds have been recorded at any of these wind farms to date. The majority of developments in the UK are relatively small, consisting of 1–20 turbines and less than 10 MW output. This is in contrast to recent and proposed developments, especially offshore, which are of a much larger scale in terms of number of turbines, turbine size and wind farm extent. For example, the recently constructed wind farms at North Hoyle in Liverpool Bay and Scroby Sands off the East Anglian coast both comprise 30 turbines with each having a 2 MW output. These developments are dwarfed by the latest offshore proposals, with the proposed London Array in the Thames estuary comprising up to 300 turbines, each having an output of 3 MW or more, and extending over 200 km^2. Onshore developments, although generally not approaching the scale of the latest offshore proposals, are also exploiting technological advances and now tend to use larger turbines. These developments could have different implications for birds than the earlier, smaller wind farms and turbines.

The potential vulnerability of wildlife to large-scale wind energy developments has been recognized in the latest round of offshore development proposals in the Greater Wash, the Thames Estuary and off north-west England. Developments are currently excluded from a coastal strip of a minimum width of 8 km from the shoreline and extending to 13 km in areas of particular landscape sensitivity. Additionally, in north-west England, wind farm development is excluded from waters 10 m deep or less. This is in recognition of the potentially high sensitivity of shallow coastal waters to wind farm developments, especially with regard to displacement of seaducks that dive to feed on shallow subtidal habitats, visual impacts from the shore and the possible impacts on inshore fishing and recreational activities.

Wind farms comprise the wind turbines themselves, interconnecting cables, transformer stations, meteorological masts and ancillary infrastructure including onshore access roads and visitor centres. The components of the individual turbines comprise a tapering mast, the nacelle or hub, foundations and rotor blades. The proportions of the turbine are determined by the rotor blade length and tower height. The largest 2 MW machines onshore can have a tower height of 80 m and a rotor diameter of 90 m, resulting in an overall height of 125 m (over 400 feet). By comparison, a normal electricity transmission pylon is 52 m tall. In the case of these large turbines, the height of the rotor sweep above ground can be as much as 35 m. Turbine design for offshore wind farms is currently similar to that for terrestrial use, although the economics of offshore development will tend to result in turbines which are significantly larger than those deployed onshore. Offshore machines with a generating capacity of at least 5 MW are already anticipated.

POTENTIAL EFFECTS ON BIRDS

To be effective, wind farms must be sited in open, exposed areas where there are high average wind speeds. This means that they are often proposed in upland, coastal and offshore areas, thus potentially affecting important habitats for breeding, wintering and migrating birds. The effects of a wind farm on birds are highly variable and depend on a wide range of factors including the specification of the development, the topography of the surrounding land, the habitats affected and the number and species of birds present. With so many variables involved, the impacts of each wind farm must be assessed individually. The principal areas of concern with regard to effects on birds are described below. Each of these potential effects can interact, either increasing the overall impact on birds or, in some cases, reducing a particular impact (for example where habitat loss causes a reduction in birds using an area which might then reduce the risk of collision).

COLLISION

Collision mortality

Direct mortality or lethal injury of birds can result not only from collisions with rotors, but also with towers, nacelles and associated structures such as guy cables, power lines and meteorological masts. There is also evidence of birds being forced to the ground as a result of being drawn into the vortex created by moving rotors (Winkelman 1992b). The majority of studies of collisions caused by wind turbines have recorded relatively low levels of mortality (e.g. Winkelman 1992a, 1992b, Painter *et al.* 1999, Erickson *et al.* 2001). This is perhaps largely a reflection of the fact that many of the studied wind farms are located away from large concentrations of birds. It is also important to note that many records are based only on finding corpses, with no correction for corpses that are overlooked or removed by scavengers (Langston & Pullan 2003).

Accepting that many wind farms result in only low levels of mortality, even these levels of additional mortality may be significant for long-lived species with low productivity and slow maturation rates, especially when rarer species of conservation concern are affected. In such cases there could be significant effects at the population level (locally, regionally or, in the case of rare and restricted species, nationally), particularly in situations where cumulative mortality takes place as a result of multiple installations.

Collision risk

Collision risk depends on a range of factors related to bird species, numbers and behaviour, weather conditions and topography and the nature of the wind farm itself, including the use of lighting. Clearly, the risk is likely to be greater on or near areas regularly used by large numbers of feeding or roosting birds, or on migratory flyways or local flight paths, especially where these are intercepted by the turbines. Large birds with poor manoeuvrability (such as swans and geese) are generally at greater risk of collision with structures (Brown *et al.* 1992) and species that habitually fly at dawn and dusk or at night are perhaps less likely to detect and avoid turbines (Larsen & Clausen 2002). Collision risk may also vary for a particular species, depending on age, behaviour and stage of annual cycle. For example, work on terns has shown that birds making regular foraging flights to provision chicks are more susceptible to collision with overhead wires because they tend to fly closer to the structures at this time (Henderson *et al.* 1996).

Risk also changes with weather conditions, with evidence from some studies showing that more birds collide with structures when visibility is poor due to fog or rain (e.g. Karlsson 1983, Erickson *et al.* 2001), although this effect may be to some extent offset by lower levels of flight activity in such conditions. Birds that are already on migration, however, cannot avoid poor weather conditions, and will be more vulnerable if forced by low cloud to descend to a lower altitude or land. Strong headwinds also affect collision rates and migrating birds in particular tend to fly lower when flying into the wind (Winkelman 1992b, Richardson 2000). Collision risk in coastal and offshore areas is also likely to vary as birds move around in response to the state of tide and offshore currents.

The precise location of a wind farm site can be critical. Particular topographic features may be used for lift by soaring species (e.g. Alerstam 1990) or can result in large numbers of birds being funnelled through an area of turbines. Birds also lower their flight height in some locations, for example when following the coastline or crossing a ridge (Alerstam 1990, Richardson 2000), which might place them at greater risk of collision with rotors.

Features of wind turbines associated with collision risk

The size and alignment of turbines and rotor speed are likely to influence collision risk (Winkelman 1992c, Thelander *et al.* 2003) as are aviation and shipping warning lights on turbines, which may increase the risk of collision by attracting and disorientating birds. The effects of lights in these circumstances are poorly known, though collisions of large numbers of migrants with illuminated structures, especially during overcast nights with drizzle or fog, are well documented (Hill 1990, Erickson *et al.* 2001). The current advice is to use the minimum number of intermittent flashing white lights of lowest effective intensity (Hüppop *et al.* 2006). It is not known if the use of lights on the outer turbines alone, which would perhaps result in more diffuse lighting, would be less likely to disorientate birds than a single bright point source.

Recorded collision rates

A review of the available literature indicates that, where collisions have been recorded, the rates per turbine are very variable with averages ranging from 0.01 to 23 bird collisions annually (the highest figure is the value, following correction for scavenger removal, for a coastal site in Belgium and relates to gulls, terns and ducks amongst other species (Everaert *et al.* 2001)). Although providing a helpful and standardized indication of collision rates, average rates per turbine must be viewed with some caution as they are often cited without variance and can mask significantly higher rates for individual turbines or groups of turbines (as Everaert *et al.* (2001) demonstrate).

Some of the highest levels of mortality have been for raptors at Altamont Pass in California (Howell & DiDonato 1991, Orloff & Flannery 1992) and at Tarifa and Navarre in Spain (Barrios & Rodriguez unpublished data). These cases are of particular concern because they affect relatively rare and long-lived species such as Griffon Vulture *Gyps fulvus* and Golden Eagle *Aquila chrysaetos* which have low reproductive rates and are vulnerable to additive mortality. At Altamont, Golden Eagles congregate to feed on super-abundant prey which supports very high densities of breeding birds. In the Spanish cases, extensive wind farms were built in topographical bottlenecks where large numbers of migrating and local birds fly through a relatively confined area due to the nature of the surrounding landscape, for example through mountain passes, or use rising winds to gain lift over ridges (Barrios & Rodriguez 2004). Although the average numbers of fatalities annually per turbine were generally low at Altamont Pass and Tarifa, ranging from 0.02 to 0.15 collisions/turbine, overall collision rates were high because of the large numbers of turbines involved (over 7000 at Altamont). At Navarre, corrected annual estimates ranging from 3.6 to 64.3 mortalities/turbine were obtained for birds and bats (unpublished data).

Thus, a minimum of 75 Golden Eagles are killed annually at Altamont and over 400 Griffon Vultures are estimated (following the application of correction factors) to have collided with turbines at Navarre. Work on Golden Eagles at Altamont Pass indicated that the population was declining in this area, thought to be at least in part due to collision mortality (Hunt *et al.* 1999, Hunt 2001).

Examples from coastal sites in north-west Europe provide corrected yearly average collision rates ranging from 0.01 to 1.2 birds/turbine (wintering waterfowl, gulls, passerines) in the Netherlands (Winkelman 1989, 1992a,1992b,1992c, 1995), 6 birds/turbine (Common Eider *Somateria mollissima* and gulls) at Blyth in Northumberland (Painter *et al.* 1999), and 4–23 birds/turbine (ducks, gulls, terns – observed range 0–125) at three study sites in Flanders, Belgium (Everaert *et al.* 2001). Nearly all these cases involve small turbines of 300–600 kW capacity in relatively small clusters. At Blyth, there was an initial additional mortality of 0.5–1.5% for Common Eider but collision rates dropped substantially in subsequent years. None of these examples have been associated with significant population declines. Often, the highest levels of mortality occurred at specific times of the year and, in some cases, were caused by particular turbines or groups of turbines (e.g. Everaert *et al.* 2001).

Information relating to collision mortality attributable to offshore wind farms is currently very limited, largely as a consequence of the difficulties of detecting collisions at sea. Improved methods to measure collisions and flight avoidance at offshore wind farms are urgently needed and techniques currently under development include radar, thermal imagery and acoustic detection (Desholm 2003, 2005, Desholm *et al.* 2005, 2006). Radar studies at Nysted offshore wind farm, Denmark, show that most birds start to divert their flight paths up to 3 km away in daytime and within 1 km at night, showing marked flight deviations to fly around the turbine cluster (Kahlert *et al.* 2004a, 2004b, Desholm 2005). In addition, thermal imagery indicates that Common Eiders are probably subject to only relatively low levels of collision mortality (M. Desholm, NERI, Denmark, *pers comm*). Similarly, visual observations of Common Eider movements in response to two small, relatively near-shore wind farms (seven 1.5 MW and five 2 MW turbines) in the Kalmar Sound, Sweden, recorded only one collision event during observations of 1.5 million migrating waterfowl (Pettersson 2005). However, it is not known what impact larger wind farms or multiple installations may have in the longer term, or on different species.

Displacement due to disturbance

The displacement of birds from areas within and surrounding wind farms due to visual intrusion and disturbance can amount effectively to habitat loss. Displacement may occur during both the construction and operational phases of wind farms, and may be caused by the presence of the turbines themselves through visual, noise and vibration impacts, or as a result of vehicle/vessel and personnel movements related to site maintenance. The scale and degree of disturbance will vary according to site- and species-specific factors and must be assessed on a site-by-site basis.

Unfortunately, few studies of displacement due to disturbance are conclusive, often because of the lack of before-and-after and control-impact (BACI) assessments. Onshore, disturbance distances (in other words the distance from wind farms up to which birds are absent or less abundant than expected) up to 800 m (including zero) have been recorded for wintering waterfowl (Pedersen & Poulsen 1991), though 600 m is widely accepted as the maximum reliably recorded distance. The variability of displacement distances is illustrated by one study which found lower post-construction densities of feeding European White-fronted Geese *Anser albifrons* within 600 m of the turbines at a wind farm in Rheiderland, Germany (Kruckenberg & Jaene 1999), while another showed displacement of Pink-footed Geese *Anser brachyrhynchus* up to only 100–200 m from turbines at a wind farm in Denmark (Larsen & Madsen 2000).

Studies of breeding birds are also largely inconclusive or suggest lower disturbance distances (Winkelman 1992d, Ketzenberg *et al.* 2002), though this apparent lack of effect may be due to the high site fidelity and long life-span of the breeding species studied. This might mean that the true impacts of disturbance on breeding birds will only be evident in the longer term, when new recruits replace existing breeding birds. Few studies have considered the possibility of displacement for short-lived passerines, although Leddy *et al.* (1999) found increased densities of breeding grassland passerines with increased distance from wind turbines, and higher densities in the reference area than within 80 m of the turbines, indicating that displacement did occur at least in this case. The consequences of displacement for breeding productivity and survival are crucial to whether or not there is likely to be a significant impact on population size. In the absence of any reliable information on the effects of displacement on birds, it is precautionary to assume that significant displacement will lead to a population reduction.

Looking at effects offshore, studies of two Danish wind farms at Tunø Knob and Horns Rev are helpful (Guillemette *et al.* 1998, 1999, Petersen *et al.* 2004). At the former site a decrease in the number of Common Eiders and Common Scoters *Melanitta nigra* was observed in the development site in the 2 years following construction. Although Common Eider numbers subsequently increased, supporting the view that the decline following construction was not due to the wind farm, there was only a partial recovery for Common Scoter. It is also possible that the increase in Common Eider numbers post-construction may have occurred as a result of changes in the abundance of Mussels *Mytilus edulis* or due to birds habituating to the wind farm. This work is subject to a number of caveats regarding its application to other developments, in particular relating to the small size of the wind farm (ten 500 kW turbines) and the small size of the flocks studied.

More recent studies at Horns Rev (80 2 MW turbines) found that divers, Northern Gannets *Morus bassanus*, Common Scoters and Common Guillemots *Uria aalge*/Razorbills *Alca torda* occurred in lower numbers than expected in the wind farm area, and the zones within 2 and 4 km of it, following construction (Petersen *et al.* 2004). Conversely, gulls and terns showed a preference for the wind farm area following construction. However, the causes of changes in distribution are unknown, and could be due to any one or a combination of the presence of wind turbines, increased human and boat activity due to maintenance visits and changes in food distribution.

These studies show that the scale of disturbance caused by wind farms varies greatly. This variation is likely to depend on a wide range of factors including seasonal and diurnal patterns of use by birds, location with respect to important habitats, availability of alternative habitats and perhaps also turbine and wind farm specifications. Behavioural responses vary not only between different species, but between individuals of the same species, depending on such factors as stage of life cycle (wintering, moulting, breeding), flock size and degree of habituation. The possibility that wintering birds in particular might habituate to the presence of turbines has been raised (Langston & Pullan 2003), though it is acknowledged that there is little evidence and few studies of long enough duration to show this. A recent systematic review of the effects of wind turbines on bird abundance has shown that increasing time since operation resulted in greater declines in bird abundance (Stewart *et al.* 2004). This evidence that impacts are likely to persist or worsen with time suggests that habituation is unlikely, at least in some cases.

Barrier effect

The effect of birds altering their migration flyways or local flight paths to avoid a wind farm is also a form of displacement. This effect is of concern because of the possibility of increased energy expenditure when birds have to fly further, as a result of avoiding a large array of turbines, and the potential disruption of linkages between distant feeding, roosting, moulting and breeding areas otherwise unaffected by the wind farm. The effect depends on species, type of bird movement, flight height, distance to turbines, the layout and operational status of turbines, time of day and wind force and direction, and can be highly variable, ranging from a slight 'check' in flight direction, height or speed, through to significant diversions which may reduce the numbers of birds using areas beyond the wind farm.

Studies of bird movements in response to offshore developments have recorded wildfowl taking avoiding action between 100 and 3000 m from turbines (Winkelman 1992c, Christensen *et al.* 2004, Kahlert *et al.* 2004b). There is limited evidence to show that nocturnally migrating waterfowl are able to detect and avoid turbines, at least in some circumstances, and that avoidance distances can be greater during darker nights (Winkelman 1992a, Dirksen *et al.* 1998, 2000). At Horns Rev and Nysted (72 2.3 MW turbines), there were strong indications that Common Scoters on migratory flights avoided the wind farm and its immediate vicinity, though changes in their distribution were not solely influenced by the presence of the wind farm (Christensen *et al.* 2004, Kahlert *et al.* 2004a, Petersen *et al.* 2004). Depending on the distance between turbines some birds will fly between turbine rows, for example in the case of Common Eider at Nysted, where the turbines are 480 m apart. Although evidence of this type of response is limited (Christensen *et al.* 2004, Kahlert *et al.* 2004a) these observations clearly have implications for wind farm design – see *Mitigation measures* below.

A review of the literature suggests that none of the barrier effects identified so far have significant impacts on populations. However, there are circumstances where the barrier effect might lead indirectly to population level impacts; for example where a wind farm effectively blocks a regularly used flight line between nesting and foraging areas, or where several wind farms interact cumulatively to create an extensive barrier which could lead to diversions of many tens of kilometres, thereby incurring increased energy costs.

Habitat change and loss

The scale of direct habitat loss resulting from the construction of a wind farm and associated infrastructure depends on the size of the project but, generally speaking, is likely to be small per turbine base. Typically, actual habitat loss amounts to 2–5% of the total development area (Fox *et al*. 2006), though effects could be more widespread where developments interfere with hydrological patterns or flows on wetland or peatland sites (unpublished data), or where they disrupt geomorphological processes offshore resulting in changes including increased erosion. Habitat changes as a result of alterations in land-use, or use of the seabed, might also occur. There is much uncertainty about the scale and nature of such changes and whether they could be significant, notably offshore, and there is ongoing research on marine geomorphology in response to placement of wind turbines (P. Leonard, DEFRA, *pers. comm*.). Some changes could also be beneficial. For example, habitat changes following the development of the Altamont Pass wind farm in California led to increased mammal prey availability for some species of raptor (for example through greater availability of burrows for Pocket Gophers *Thomomys bottae* around turbine bases), though this may also have increased collision risk (Thelander *et al*. 2003).

Offshore developments could cause the loss of habitats in terrestrial areas (transformer stations) as well as marine habitats due to the construction of turbine foundations and the use of scour protection materials. The scale of offshore developments, especially in the context of relatively limited areas of shallow sandbanks supporting large aggregations of feeding seabirds, might be significant in this context. Other related effects include turbidity (as a result of increased scour of the seabed due to interactions between the turbine bases and tidal currents) and vibration from the turbines, both of which might influence fish distribution and have effects on piscivorous birds. More beneficially, turbine structures can act as artificial reefs, perhaps increasing structural diversity and creating a local abundance of prey species. Of course this is only of net benefit to birds if they are not displaced by the presence of the turbines themselves and if there is no significant mortality due to collisions.

ASSESSING POTENTIAL IMPACTS

Legislation and consents

In the UK, there is a range of national and international environmental legislation relevant to wind farm development. In relation to environmental assessment, there are two key pieces of legislation that apply in the EU, the Environmental Impact Assessment (EIA) Directive 85/337/EEC on Assessment of certain public and private projects on the environment (as amended by Directive 97/11/EC), and the Strategic Environmental Assessment (SEA) Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment. The EIA Directive requires an impact assessment to be carried out in support of an application for development consent for certain types of project, including 'installations for the harnessing of wind power for energy production (wind farms)'. Under UK legislation, an EIA may be (and invariably is) required if there are potentially significant environmental impacts as a result of the development, and would normally be required where a Ramsar site, a potential or classified Special Protection Area (SPA), or a candidate, agreed or designated Special Area of Conservation (SAC) could be affected.

The SEA Directive aims to integrate environmental considerations into the preparation of plans and programmes, building on the project-level EIA by considering environmental issues much earlier in the decision-making process. To assist decision-making on the design and terms of the competition for offshore sites leases, the UK government has commissioned a SEA in line with the requirements of the Directive. Three strategic areas for competition for leases have been identified: Liverpool Bay, the Thames Estuary and the Greater Wash. Phase 1 of this SEA resulted in the preparation of an *Environmental Report* which suggests a strategic approach is adopted which will, amongst other things, avoid development in shallow water where Common Scoter, Red-throated Diver *Gavia stellata* and other species are known to congregate, and address the uncertainties of cumulative impacts (BMT Cordah Ltd. 2003). It is intended that follow-on work to be carried out at the strategic area level will address cumulative impacts, not only as a result of the interaction of wind farm developments, but also in combination with other offshore developments and activities.

Where proposals are likely to significantly affect Ramsar sites, potential or classified SPAs or candidate or designated SACs (known collectively as Natura 2000 sites) there are additional obligations for assessment under Article 6 of the Habitats Directive 92/43/EEC on The conservation of natural habitats and of wild fauna and flora and under the UK Habitats Regulations 1994. Under the Habitats Regulations, and in accordance with the Directive, a plan or project can only be consented if it can be ascertained that there will be no adverse effect on the integrity of the site (the coherence of its ecological structure and function which supports the habitats and/or species for which it has been designated). If it cannot be ascertained that no adverse effect will result, the plan or project can only be carried out if there are no alternative solutions and if there are imperative reasons of overriding public interest (which may be of a social or economic nature). Where such a plan or project is consented, the UK Secretary of State must secure any necessary compensatory measures to ensure the overall coherence of Natura (2000). However, especially offshore, compensatory measures will be particularly difficult to achieve.

Wind farms onshore are consented by local planning authorities or the relevant Government department (Department of Trade & Industry (DTI), Scottish Executive or the National Assembly for Wales). A range of consents are relevant to offshore wind farms, including: a consent from the Department of Environment, Food and Rural Affairs (DEFRA) (or the Scottish Executive Rural Affairs Department (SERAD) or the Welsh Assembly) under the Coast Protection Act 1949 for the construction of works below mean high water springs if they are likely to cause an obstruction to navigation; a licence from Defra (or SERAD or the Welsh Assembly) under the Food & Environment Protection Act 1985 for the placing of structures below mean high water springs to ensure protection of the marine environment; in England and Wales, a consent from the DTI under the Electricity Act 1989 for an offshore wind farm which will have an export capacity of more than 1 MW; and planning permission for cables and grid connections above mean low water.

Method and scope of assessment

In the majority of cases nature conservation impacts could be minimized, to the level where they are of no significant concern, by careful siting. At the preliminary stages of a development proposal it is clearly important to use existing information to determine the likelihood of impacts. Ideally this would be undertaken in a pre-emptive, strategic way, collating information to identify those areas where there are unlikely to be significant impacts on birds (or other nature conservation interests) and prioritizing them for development. Unfortunately, many onshore wind farms were already constructed or in the planning process before the SEA Directive, which would have provided the necessary lever to trigger this approach, came into force in July 2004. Consequently, onshore wind farms in the UK have so far been dealt with on a case-by-case basis.

Where at all possible, developers should avoid areas supporting the following:

(1) a high density of wintering or migratory waterfowl and waders where important habitats might be affected by disturbance or where there is potential for significant collision mortality;

(2) areas with a high level of raptor activity, especially core areas of individual breeding ranges and in cases where local topography focuses flight activity which would cause a large number of flights to pass through the wind farm; and

(3) breeding, wintering or migrating populations of less abundant species, particularly those of conservation concern, which may be sensitive to increased mortality as a result of collision.

Developments potentially affecting one or more of these features are likely to require detailed assessments. The nature of an assessment will depend on site-specific factors such as the scale of the development and species vulnerability related to behaviour, habitat requirements and productivity.

Onshore Assessments

An assessment should include a minimum 12-month field survey to determine the baseline numbers of birds present during an annual cycle (Scottish Natural Heritage 2005). This survey should provide data on bird distribution and movements, including observations of bird numbers, intensity of movements, altitude and orientation of flight during different weather conditions and tidal cycles. Nocturnal surveys, minimally using image-enhancing equipment with an infra-red spotlight for near observations, and perhaps radar, should also be undertaken when important numbers of nocturnally active species such as the European Golden Plover *Pluvialis apricaria* are likely to be affected. For species that show significant annual variation in numbers and distribution it may be necessary to undertake at least 2 years' baseline survey. In order to assess the potential for collisions it is clearly important to collect as much information as possible on the numbers of birds using or moving through the area and the proportion occurring at rotor height. Studies should include an area around the wind farm which might be subject to displacement and barrier effects (up to at least 600 m from the outer turbines).

Many recent assessments have employed a collision risk model (e.g. Band *et al.* 2005) to predict the rate of bird collisions following the construction of a wind farm. Such models are potentially useful but, in order to be effective, require sufficient data on bird movements (numbers, intensity, flight height and angle of approach), both throughout the annual cycle and across a range of conditions, including different weather conditions, state of the tide at coastal sites, at day and night. Collision risk models enable a standardized approach to be taken to the measurement of the likelihood of collisions where birds take no avoiding action. However, a significant limitation of these models is that their accuracy in determining actual collision risk depends greatly on the application of reliable flight avoidance rates obtained from monitoring of existing wind farms (Chamberlain *et al.* 2006, Madders Whitfield 2006, Band *et al.* 2005). Unfortunately, very few studies of existing developments allow the calculation of reliable avoidance rates and, at present, these only exist for a limited range of species under a restricted range of circumstances. This has led to some environmental assessments utilizing available estimates of collision risk, even though they have been derived for different species in different habitats, and without the necessary testing of their relevance. In future it is essential that avoidance rates applied to a particular development are derived from the same or similar species in response to similar structures in a similar situation to that being assessed. In the absence of reliable collision avoidance rates for the relevant species, and until such models have been adequately validated by follow-up monitoring, particular care is needed in their application and the interpretation of their outputs.

Any potentially significant harmful effect on wild birds identified by an assessment must be addressed. If an impact can be avoided or mitigated by suitable measures then the assessment should identify them (see *Mitigation measures* below). In addition, in the event that the wind farm is consented, the assessment should include measures to compensate for any residual damage not covered by the mitigation measures. Often, both onshore and offshore, several wind farms can be proposed in relatively close proximity to each other. If there are any other projects (including non-wind energy developments) which have been developed or are being proposed in an area where affects on an SPA or SAC are likely, then it is required that the assessment should take into account any cumulative effects that may arise from the wind farm development in combination with these other projects.

For those developments which are consented, it is essential that appropriate monitoring is made a condition of the consent. Pre- and postdevelopment monitoring should be carried out using the BACI approach and details of the monitoring programme must be set out in the assessment. This monitoring is needed to indicate whether further remedial measures are required in the event of additional, unpredicted impacts occurring. It is also needed to help increase the understanding of actual impacts, which can then be used to improve future assessments. Post-construction monitoring must continue long enough to identify both short- and long-term effects and to enable these to be satisfactorily addressed. It is important that all monitoring work is carried out to an adequate level, using standardized and repeatable methods appropriate for the key issues and species, enabling comparison across sites. Post-construction monitoring and research are urgently needed on all aspects of avian response to wind turbines, particularly displacement as a result of both the presence of turbines and related maintenance activities and collision avoidance rates across a range of different wind farm specifications, locations and weather conditions. In order to obtain results that can be applied more generally, site-based monitoring should, where feasible, be both compatible and integrated with targeted research on key species and issues. It is also essential that the results of monitoring and research are communicated widely and as quickly as possible.

Offshore assessments

In offshore areas, the species groups of most concern are seabirds, grebes, seaducks, and migrating waterfowl and passerines. Unfortunately, information on the distribution of concentrations of these birds, their variability in numbers between and within years, and the underlying determinants of their occurrence in a given location, is often unavailable or at too broad a scale to be useful. Food supply is clearly an important factor influencing bird distribution and more information is needed on food availability and changes in its distribution offshore and how it is exploited by birds. As a consequence, it is currently only possible to give broad indications of the locations of important areas for birds offshore. A recently developed programme of aerial surveys in the Irish Sea and off the east coast of England, jointly funded by government and the wind energy industry, should improve the level of information on the location of feeding birds in the strategic areas identified for offshore wind farm development in the UK (www.dti.gov.uk/renewables/renew_2.1.3.7.htm).

Collecting information on the movements of birds at sea is more problematic. Knowledge of local, inshore movements as well as observations of long distance migrants as they approach land (including movements and flight heights in different weather conditions and at night) is essential for assessing the potential impacts of collision and barriers to movements (Hüppop *et al.* 2006). Some broad information on the timing of bird movements is available from bird observatories and recent work on the distances travelled by breeding seabirds on foraging trips is useful (Allcorn *et al.* 2003, Perrow *et al.* 2006). However, for the vast majority of the birds that fly in near shore and offshore areas, very little is known. This lack of data is of particular concern, given the large scale of proposed offshore wind farms, and the probability of cumulative effects.

The BACI principles outlined above are equally applicable to offshore developments, although the scope for developers to share responsibility for control or reference areas might be greater offshore. A recent review of ship-based and aerial surveys for wind farm studies concluded that the use of the two platforms is complementary, with each fulfilling different objectives (Camphuysen *et al.* 2004). Aerial survey provides simultaneous coverage of extensive, offshore areas and reliable 'snapshot' information on distribution and numbers. Ship-based survey is better for detailed observations of behaviour (perhaps in relation to oceanographic data collected at the same time), for determining age and sex of birds, and for discriminating between similar species.

This account gives a brief summary of the requirements of wind farm impact assessments. Although methodologies are still, to a large extent, under development, more detailed guidance on current approaches and recommendations is available in Camphuysen *et al.* (2004), DEFRA (2005), Cranswick (2002), Komdeur *et al.* (1992) Scottish Natural Heritage (2005), and Desholm *et al.* (2005).

MITIGATION MEASURES

Mitigation measures fall into two broad categories: best-practice measures which could be adopted by any wind farm development and should be adopted as an industry standard, and additional measures which are aimed at reducing an impact specific to a particular development.

Examples of best practice measures are:

(1) ensuring that key areas of conservation importance and sensitivity are avoided;

(2) implementing appropriate working practices to protect sensitive habitats;

(3) providing adequate briefing for site personnel and, in particularly sensitive locations, employing an on-site ecologist during construction;

(4) implementing an agreed postdevelopment monitoring programme through planning or licence conditions;

(5) siting turbines close together to minimize the development footprint (subject to technical constraints such as the need for greater separation between larger turbines);

(6) grouping turbines to avoid alignment perpendicular to main flight paths and to provide corridors between clusters, aligned with main flight trajectories, within large wind farms;

(7) increasing the visibility of rotor blades – research indicates that high contrast patterns might help reduce collision risk (at least in conditions of good visibility (McIsaac 2001)), although this may not always be acceptable on landscape grounds. Another suggested, but untested possibility is to paint blades with UV paint, which may enhance their visibility to birds;

(8) where possible, installing transmission cables underground (subject to habitat sensitivities and in accordance with existing best practice guidelines for underground cable installation);

(9) marking overhead cables using deflectors and avoiding use over areas of high bird concentrations, especially for species vulnerable to collision;
(10) timing construction to avoid sensitive periods;
(11) implementing habitat enhancement for species using the site; and
(12) offshore, carefully timing and routing maintenance trips to reduce disturbance from boats, helicopters and personnel.

Turning to more site-specific mitigation, it may be necessary to prepare a site management plan designed to reduce or prevent harmful habitat changes following construction, and to provide habitat enhancement as appropriate. Other measures which may be suitable in some circumstances include the relocation of proposed or actual turbines responsible for particular problems, halting operation during peak migration periods, or reducing rotor speed. Again, post-construction monitoring is essential in order to test the effectiveness of such mitigation measures and research is needed to provide more information on specific impacts and novel mitigation measures that might reduce impacts.

RECENT DEVELOPMENTS AND PRIORITIES FOR FUTURE WORK

There have been a number of recent developments in the assessment and monitoring of the effects of wind farms on birds. In particular, there has been much work in Denmark using remote sensing technologies to measure potential and actual collision mortality (Desholm & Kahlert 2005, Desholm *et al.* 2005, 2006, Desholm 2005, Fox *et al.* 2006).

Radar

The most important advantage of radar over visual observations is that it allows continuous and simultaneous sampling of bird movements over a large area, regardless of time of day and visibility conditions (although limited in high moisture, radar extends the range of observations considerably beyond that possible for visual observations). Clearly, continuous sampling is desirable for monitoring bird movements, especially at sea, as such movements are often complex and fluctuate greatly. A combination of horizontal and vertical radar can provide information on flight direction and flight heights.

The technology is not without limitations, however. Marine radar, the technology most often used for tracking bird movements, is impaired by rain and fog, and has a relatively short effective range (up to 11 km for radar equipment used for bird studies in the UK), which can be reduced further by topography. Large-scale surveillance radar has a longer range and tracking radar can be used to provide detailed information on the movements of individual flocks, though these systems are more expensive and difficult to use than marine radar. Although radar records a range of signal characteristics such as reflectivity, size and speed, which have been used in some studies to separate signals into species groups, verification of species identification still requires complementary visual and/or acoustic survey effort, which may be a severe limitation in practice. Furthermore, because of 'shadow' caused by the turbines and moving rotors, radar cannot be used to detect collisions. Another drawback is the need to place offshore radar on a fixed platform or a boat. Although not a technical constraint, keeping a boat at sea for several days or weeks, or the construction of a platform (for example, met mast, wind turbine, or jack-up barge) is costly.

Radar has been used to monitor bird movements and flight responses to several offshore and near shore wind farms in Sweden and Denmark (Christensen *et al.* 2004, Kahlert *et al.* 2004a,2004b, Pettersson 2005). Most recently radar observations have been made from offshore transformer stations at the Horns Rev and Nysted wind farms off the coast of Denmark. Although subject to various limitations, including effectiveness over only a relatively short distance and usage under a limited range of weather conditions, this work has provided some extremely useful insights to birds' responses to wind farms at sea (as described earlier under *Barrier effects*).

In the UK there has, until recently, been little deployment of radar to assist wind farm environmental assessments, partly because of the lack of available equipment and expertise. This situation should be remedied with the recent development of radar specifically for bird monitoring (Allan *et al.* 2004). This equipment detects bird movements in both the horizontal and vertical planes and analyses and summarizes radar data using GIS tools and statistical techniques.

Thermal Animal Detection Systems (TADS)

Researchers in Denmark (NERI) have been developing the use of remote Thermal Animal Detection Systems (TADS) using an infra-red video camera in an attempt to record birds flying in close proximity to wind turbines (Desholm 2003). TADS can be set to detect and film birds of a particular size and up to a given distance. Provisional assessments indicate that it is possible to distinguish species type from silhouette, flight behaviour and approximate size. This system has been piloted most recently at the Nysted offshore wind farm, with a camera attached to a turbine, directed up at the rotors and controlled remotely using computer software (Desholm & Kahlert 2005, Desholm 2005, Desholm *et al.* 2006).

TADS can provide valuable information on flight behaviour, avoidance and collisions, especially in offshore areas where visual observations and the collection of corpses is not feasible, thus providing essential data to populate collision avoidance models. TADS can also function in conditions of poor visibility and at night. However, the work at Nysted has shown that there is, under normal circumstances, a very low probability of an individual camera recording a collision event (Desholm 2003). This is, in part, due to the narrow field of view provided by the camera, with only a third of the rotor-swept area observed, and because of the very limited number of birds passing the visible area. Although the system clearly has potential, and at Nysted has given an indication of the magnitude of collisions experienced by Common Eider, in order for it to provide more precise data on collision rates it would be necessary to install many cameras on turbines throughout a wind farm. The camera at Nysted has also helped verify radar data which indicate that Common Eiders fly between turbine rows at that development (M. Desholm, NERI, Denmark, *pers comm.*).

Other remote techniques are being investigated, including the use of pressure/vibration sensors within turbine blades to detect bird strikes (Desholm *et al.* 2005) and acoustic detection to monitor bird movements from their calls (Evans 2000). The COWRIE (Collaborative Offshore Wind Research into the Environment) Steering Group has commissioned a project to develop best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore wind farms (Desholm *et al.* 2005).

Population modelling

As well as improving remote technology for observing behavioural reactions of birds including collisions and displacement, the development of demographic and distributional (or spatial) models is also important to predict, and subsequently test predictions, of population-level impacts attributable to the wind farm, as distinct from other factors. Spatial models are especially valuable for studies of displacement of birds in the offshore environment, where the data on abundance and distribution are usually based on particularly small samples and are themselves subject to wide confidence limits. As well as predicting the impacts of a single wind farm, spatial modelling is essential for predicting the possible cumulative displacement of bird populations on a wider scale resulting from the combined impacts of several wind farms.

Demographic models were developed to evaluate the effects of collision mortality on the population dynamics of Golden Eagles at Altamont Pass (Hunt *et al.* 1999, Hunt 2001). Such research requires long timescales to verify model predictions and is therefore a costly and long-term process which will not be appropriate for all species nor for all wind farm proposals. Modelling is also needed to predict population level impacts as a result of changes in survival and breeding productivity following reduced intake rates and increased energy consumption due to displacement and barrier effects. An example of this approach is the development of a predictive model in the UK to determine the potential impacts of offshore wind farms, including displacement from feeding areas, on Common Scoter (COWRIE, www.offshorewindfarms.co.uk; Kaiser *et al.* 2006, West & Caldow 2006).

CONCLUSIONS

The development of wind-energy is a vital component of the Europe-wide objective to increase the proportion of energy derived from renewable sources, thus helping to reduce the emission of greenhouse gases. However, wind energy developments are themselves not without impacts on the environment, and the current pace and scale of development proposals, combined with a poor understanding of their impacts, is a cause for concern.

One of the main areas of concern is the potential impact of wind farms on birds. Although many of the studies carried out on collision mortality, displacement, barrier effects and direct habitat loss caused by wind farms are either inconclusive, due in part to inadequate study methods, or indicate effects that are not significant for a given species, site and season, this should not be used as justification for poor or inadequate assessments of future developments. Indeed, the relatively few studies that do indicate a significant impact are a clear warning that the inappropriate location of wind farms can adversely affect wild bird populations. The potential implications of wind farms for birds are of even greater concern when considering the scale of current proposals, and the possibility of the effects of individual wind farms interacting to produce much larger cumulative impacts on bird populations.

Developers should avoid, wherever possible, concentrations of vulnerable bird species. In cases where this is not possible, or where information on birds is not available (as is often the case offshore), then detailed and sometimes long-term environmental assessments are likely to be necessary. Although existing information on birds may help to design these assessments, it will, in almost every case, be necessary to collect data on bird numbers, distribution and movements in order to predict impacts. The methods and technology available to carry out these assessments are, broadly speaking, well developed onshore, though further verification and refinements are necessary for some techniques (for example, collision risk models).

The current challenge is to develop suitable techniques for offshore assessments. The application and further development of ship-based and aerial survey techniques have been invaluable in carrying out assessments. The next step is to develop and successfully apply remote data-gathering equipment such as radar and infra-red cameras to provide information on bird distribution and movements. These techniques are needed now, particularly in the UK where environmental assessments of offshore wind farms are underway and the collection of information on bird movements is a high priority.

As this overview has shown, there is a pressing need for more information on the range of potential impacts of wind farms on birds, both onshore and offshore. It is essential that detailed monitoring and research is carried out on avian responses to wind farms, and that developers, consenting authorities and their advisors gather and communicate such information as a matter of the most urgent priority. Further research is required in particular to develop spatial and demographic models which can help predict the effects of individual wind farms and groups of developments which have cumulative effects across extensive areas. Increasing understanding of the implications of wind farms for birds, in common with other environmental impacts, will depend on the close collaboration of industry, governments and researchers. A central element to this work is the design and implementation of detailed post-construction monitoring of the actual effects of existing wind farms (of the type being undertaken at Horns Rev and Nysted for example), which will not only help to assess the effectiveness of mitigation of any harmful impacts resulting from these developments but will also provide valuable information for future assessments.

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