Birds and offshore wind farms: a hot topic in marine ecology

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Wind generated electricity, the most advanced renewable technology, is promised to become an important source of energy in the near future. According to current plans, within about 10 years, wind farms with a combined output of thousands of megawatts will be installed in European seas. This means that offshore wind turbines may well become Europe's most extensive technical intervention in marine habitats. Though the saving in fossil fuels is to be welcomed, the advent of a major extension in the number of wind farms is likely to cause major problems for nature conservation, especially birds.

European seas are internationally important for a number of breeding and resting seabird populations that are subject to special protection status. Moreover, every year tens of millions of birds cross the North Sea and the Baltic Sea on migration. The erection of offshore wind turbines may affect birds as follows: (1) risk of collision, (2) short-term habitat loss during construction, (3) long-term habitat loss due to disturbance by turbines including disturbances from boating activities in connection with maintenance, (4) formation of barriers on migration routes, and (5) disconnection of ecological units, such as roosting and feeding sites. To date, it has only been possible to estimate the impact on birds from experiences with comparatively small onshore wind turbines. To assess the actual impact of these new wind farms, detailed studies on pilot offshore wind farms are essential. It is also vital that all potential construction sites are considered as part of an integral assessment framework, so that cumulative effects can be fully taken into account. A problem in making these assessments is that there is currently a lack of good data on migration routes and flight behaviour of many of the relevant bird species.

INTRODUCTION

At the beginning of the 21st century one of the most important issues in marine and coastal research, and probably also in marine conservation, is determining the likely impact of wind farms on the environment, especially on birds, which will probably be affected most. Within the framework of the United Nations Climate Convention, industrial nations agreed in the 1997 Kyoto Protocol to reduce their greenhouse gas emissions by an average of 5% (compared to 1990) by 2012. Member states of the European Union committed themselves to reduce emissions by 8%. The EU White Paper on Renewables aims at doubling the share of renewable energy by the year 2010, with a target of 40,000 MW from wind power (Duwind 2001). Suitable land locations have become very limited. Not surprisingly, major plans for the installation of offshore wind farms have been announced in several European countries (e.g. Denmark, Germany, Ireland, The Netherlands, Sweden, United Kingdom). It is expected that within 10 years, wind farms with a total capacity of thousands of megawatts will be installed in European seas. We illustrate the magnitude of this development with figures for Germany.

According to the current plans for the German parts of the North Sea and the Baltic Sea, marine wind farms alone will require an area of about 13,000 km^2, corresponding to 26.5% of the area of Germany's Exclusive Economic Zone (www.offshore-wind.de/de/projekte/pr_140.html). Moreover, there are plans to erect several wind farms near shore, e.g. in shallow waters north of the East Frisian Islands close to the Wadden Sea national park (www.niedersachsen.de/functions/downloadObjects/0,,c645558_s20,00.pdf). Offshore wind turbines as well as their number will be appreciably larger than those currently installed on land. Whereas the total height of land-based turbines seldom exceed 100 m, offshore wind machines will reach about 150 m. Moreover, existing land-based wind farms seldom consist of more than 30–40 turbines, single marine wind farms will consist of up to 1,000, taking up an area of some 100 km^2 each. Thus, offshore wind farms may become Europe's most extensive technical intrusion into marine habitats (Merck & von Northeim 2000).

Both the North and Baltic Seas support large concentrations of breeding, and wintering birds, and therefore are of international importance. Both seas are also part of a global flyway system and every year tens of millions of birds pass through on their way from breeding grounds to wintering areas and back. Hence, all European countries have obligations under national and international legislation (e.g. EU Bird Directive, EU Habitat Directive) as well as under international conventions (e.g. Ramsar Convention, AEWA under Bonn Convention, Bern Convention) (e.g. Adams 2000, Boye & Hüppop 2001, Mitschke *et al.* 2001), to protect and conserve habitats and bird populations. Moreover, in Germany the Sea Engineering Regulations permit governmental licensing authorities to refuse permission for the erection of wind farms, if threats to bird migration are anticipated (Sea Engineering Regulations 2002: 1193, § 3; see Dahlke 2002). On the basis of studies at land-based wind farms, it seems likely that resting and foraging birds as well as birds on migration will be put at risk by wind turbines.

Undoubtedly, our knowledge of the potential impact of wind farms has improved greatly over the past decade. However, this mainly relates to terrestrial species studied at onshore wind farms. These results can only be applied to coastal birds and seabirds or to birds crossing the sea during their migration to a limited extent. The aim of this paper is to outline this topic as an aid for future research and environmental impact assessments (for recent reviews and references see Langston & Pullan 2002, Exo *et al.* 2003). Because of the political pressure to build offshore wind farms as soon as possible, there is an urgent need to assess their actual impact on all birds, but particularly seabirds, waders and waterfowl as well as on migratory species. Already, two pilot offshore wind farms have been licensed in Germany, despite the fact that we know so little about their ecological impact. Other licences are likely to be granted very soon. Moreover, the construction of the first pilot wind farm in Germany's Exclusive Economic Zone will commence in 2004.

POTENTIAL THREATS FROM OFFSHORE WIND FACILITIES

Erection of wind farms in marine areas can affect (1) resting and/or foraging waterbirds and (2) terrestrial and/or waterbird species crossing the sea during migration. The main potential hazards are risk of collision with turbines and habitat loss caused by disturbance and barrier effects.

Collision risk

The collision risk at inland wind farms is generally considered to be low, except for facilities erected at migratory "bottlenecks", such as on the Altamont Pass in California, USA (Orloff & Flannery 1992) and at Tarifa, Spain (SEO/BirdLife 1995), and at sites with large, less manoeuvrable species, such as those that habitually soar in thermals. The impact of such losses can be particularly severe in large, long-lived species with low natural mortality rates and low productivity. For such, even a small increase in mortality may have a devastating effect on population levels. Most seabirds and waterfowl and many waders are long-lived species.

Although no collisions of Common Eiders *Somateria mollissima* were recorded at a small Danish offshore wind farm, the collision risk at sea is likely to be higher than on land. Offshore wind turbines will be considerably taller and rotor blades longer resulting in significantly higher tip-speeds and higher turbulence. Moreover, the birds' acoustic perception will be hampered by background noise from waves and wind. Additionally, nearly all seabirds and waterfowl fly low above the water surface – mostly <100 m, often <50 m –, especially during foraging trips or when moving between roosting or breeding sites and feeding areas, i.e. during short sea crossings (e.g. Dirksen *et al.* 1996, 1998a, van der Winden *et al.* 1999, Krüger & Garthe 2001). Many terrestrial species also tend to cross the sea at low altitudes. Recent radar surveys on the islands of Helgoland, Fehmarn and Rügen (all Germany) showed that 20–30% or more of all birds crossing the sea below an altitude of 2,000 m flew at 0–200 m (Hüppop & Wendeln, unpubl.), i.e. within the height span of the rotor blades. There are considerable differences in characteristic flight altitude between different taxonomic groups. Based on recent studies of visible migration during daytime at Helgoland covering the lowest 200–300 m above the sea, less than 10% of divers, grebes, ducks, mergansers, skuas, terns, gulls and auks were observed in flight at altitudes above 50 m, whereas 37% of the waders preferred to fly higher than 50 m (Dierschke & Daniels 2003). However, as high-flying waders are notoriously difficult to spot and low-flying waders are mainly seen in headwinds, when many sea and coastal birds fly in lower altitudes than in tailwinds, the real percentages of high-flying birds is probably much higher. In general, most migrating waders tend to fly at greater heights. But, when moving between high-tide roosts and low-tide feeding areas waders generally fly at altitudes below 100 m (Dirksen *et al.* 1996, 1998a, 1998b, van der Winden *et al.* 1999).

The greatest collision risk occurs at night, especially on moonless nights or in unfavourable weather conditions such as fog, rain, and strong wind. These conditions also tend to reduce the flight altitudes of migrating birds. Radar studies of behavioural responses to turbines on Lake Ijsselmeer, The Netherlands, indicate that some ducks will fly between turbines in moonlight, but around the outside of turbine clusters in conditions of poor visibility. This suggests that some, probably local, birds can adjust their behaviour to the presence of turbines (Spaans *et al.* 1998). Nevertheless behavioural observations have shown that most birds fly closer to rotor blades at night than during the day and that more birds collide with them at night than by day (Winkelman 1990).

Long-term habitat loss: disturbance and barrier effects

Disturbance by operating wind turbines can exclude birds from suitable breeding, roosting, and feeding habitats. Whereas direct loss of habitat due to the foundations of the turbines seems to be of no major concern for birds, numerous studies have shown that wind farms may indirectly affect a much larger area. In terrestrial habitats, numbers of roosting and/or feeding birds decreased around the turbines up to a radius of 800 m (depending on the species). In general, migrants, especially the larger species, seem to be more affected than local residents. Moreover, there are indications that wind farms may act as barriers: either between ecologically linked areas, such as roosting and feeding sites or to migrants. There are observations indicating, for example, that geese, waders and terns may react to the presence of turbines at distances of a few hundred meters. Either the birds flew higher or, more often, changed direction. Sometimes a consequence of flight adjustments to avoid collision is the disruption of flock formation.

Bird species that are considered to be especially sensitive to the presence of wind farms and which may suffer habitat loss as a result of their installation include, divers, scoters, geese, and waders, such as Eurasian Curlew *Numenius arquata* and Eurasian Golden Plover *Pluvialis apricaria*. Feeding and resting Curlews and Golden Plovers sometimes keep more than 500 m away from wind farms (Winkelman 1992, Schreiber 1993). Divers and scoters are particularly sensitive to disturbance, as exemplified by the fact that they will avoid ships by as much as a few kilometres. Consequently, they occur mainly in areas with light sea traffic (Mitschke *et al.* 2001). Besides species-specific differences, the degree of disturbance is presumably determined by a number of other factors, such as availability of suitable habitats, especially roosting and feeding areas, time of year, flock size and also the layout of the wind farm.

The farms will lead to a constant level of disturbance. Additional impacts will occur during the construction phase and maintenance. Disturbances during the construction phase of wind farms are temporary, but they can be expected to be considerable because of high levels of ship and/or helicopter activities and noise caused, for example, by ramming piles. Once the wind farms have been built, disturbances arising from increased boat traffic associated with maintenance are likely to be substantial. However, to our knowledge, such disturbances have never been assessed separately in any environmental impact assessment to date. According to current plans, most offshore wind farms will consist of a few hundred wind machines each. Assuming that each turbine has to be checked at least once a year plus one or two extra visits per turbine to deal with technical problems, there may be more or less daily boating activities within the wind farm area. Boating activities associated with the maintenance of the turbines may thus create more disturbance than the operating turbines themselves.

In conclusion, it seems likely that marine wind farms will cause greater problems for bird conservation than those on land. This is because offshore areas are rich in large bird species that are generally considered to be more sensitive to disturbance, and because offshore wind turbines will be substantially taller and wind farms generally larger than ones on land.

CURRENT DEFICITS AND RECOMMENDATIONS FOR FUTURE STUDIES

According to our current knowledge, the main deficits and recommendations for future research can be summarised as follows:

Based on experience gained from studies at inland wind facilities and at the few near-shore sites where environmental impact assessments are currently under way (in total 10 wind farms worldwide, British Wind Energy Association, BWEA 2002: www.offshorewindfarms.co.uk/else.html), we conclude that marine wind farms could have a significant adverse effect on resident seabirds and other coastal birds as well as migrants. Moreover, the potential impacts may be considerable higher offshore than onshore. Disturbance and barrier effects probably constitute the highest conflict potential. Whereas there are fairly complete data on the large-scale distribution of seabirds (e.g. Skov *et al.* 1995, 2000, Mitschke *et al.* 2001), detailed data on migration routes and flight behaviour, especially on flight altitudes above the sea are still quite scarce. Because of the political pressure to erect offshore wind farms quickly, there is an urgent need to fill these gaps.

Based on current knowledge of the spatio-temporal patterns in the distribution and abundance of seabirds, the most sensitive areas for them can already be identified and protected. Areas that fulfil the criteria for selection of Important Bird Areas (IBA) (see Skov *et al.* 1995, 2000, Heath & Evans 2000, Sudfeldt *et al.* 2002) have to be designated by national governments as marine protected areas as soon as possible. It is unacceptable to erect wind farms inside or close to IBAs or marine protected areas. The designation of protected areas will make the planning process easier.

To date, it has only been possible to estimate the impact of offshore wind farms on birds from experiences with comparatively small onshore and some near-shore wind facilities. The actual impact of offshore farms on roosting birds and on migrants cannot yet be fully assessed. Therefore, detailed studies on pilot wind farms are essential. Only these will allow us to assess actual conflict potential and, thus, answer the central question whether a low conflict between offshore wind farms and bird conservation is possible and how it can be achieved. Remote observation techniques, such as radar, and thermal imaging videocameras, including radio-linked online control have recently become available and will be of great value in these studies. In our opinion, it is essential to obtain results of bird-impact studies from a few pilot wind parks before any more offshore wind farms are licensed. However, there is no need to construct pilot parks at each proposed site.

It is to be hoped that studies on pilot wind parks will facilitate guidance on a bird-friendly technical design for wind farms. This should includes not only recommendations on the total number of turbines per cluster, but also on the arrangement of individual turbines within a farm, distances between neighbouring wind farms, as well as type amount of illumination.

Research projects are appropriate for providing a solid basis for a general assessment of proposed wind farm sites, but these will not enable the assessment of the actual impacts on birds at individual sites. Therefore specific assessments need to be made for each site by the applicants. The environmental impact assessments for individual sites need to include three major components (for details see Hüppop *et al.* 2002): (1) transect studies to analyse the distribution and density of seabirds; (2) radar studies; and (3) visual observations and flight call recordings to detect movements of passage migrants and foraging birds including avoidance behaviour in response to construction activities and turbines. The studies should include long-term comparative studies before and after installation of a wind farm as well as synchronous investigations in unaffected reference/control areas (the "Before–After Control–Impact approach"). Suitable standards and appropriate quality control regulations need to be implemented by national governments.

For a proper assessment of the impact of offshore wind farms on the marine environment, it is essential that all potential construction sites are considered not only individually, but as parts of an integral assessment framework, including their cable connections to the network on the mainland. Moreover, the environmental impact assessments must take into account any cumulative effects that may arise from other utilizations, such as transportation routes, oil and gas platforms, pipelines, cable connections, sand and gravel pits, military activities, fisheries, and established as well as proposed marine nature reserves. This means that in Europe national governmental licensing authorities must each undertake a Strategic Environmental Assessment as set out in EU Directive 2001/42/EC. Only integrated assessment and coordinated planning can provide both conservationists and developers with the essential requirements of a robust planning framework.

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