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Review of the impacts of wind farms and other aerial structures upon birds

J Paul Gill[1], Mike Townsley[1] & Greg P Mudge[2]

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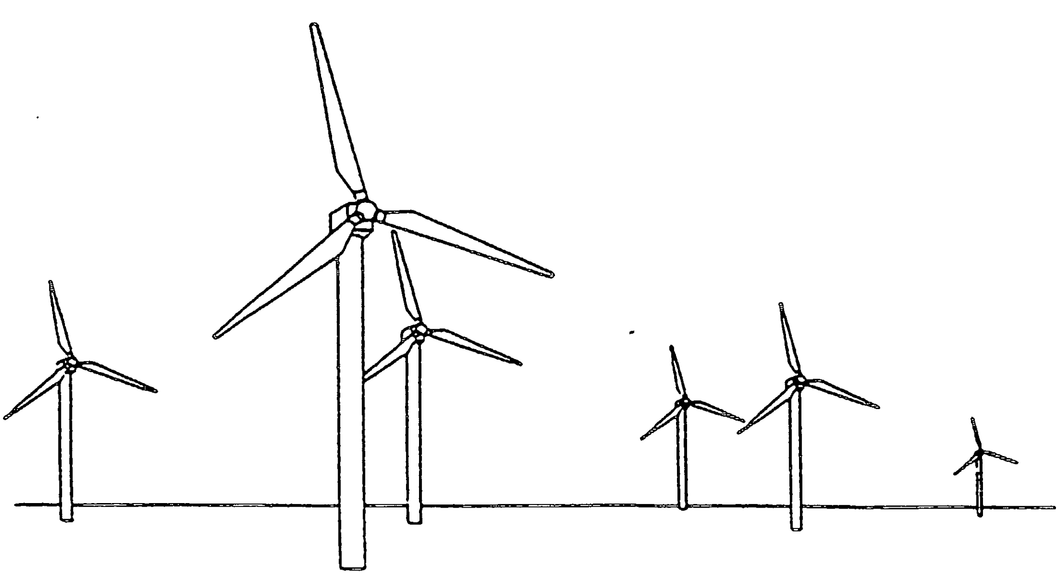

EXECUTIVE SUMMARY

Scotland is witnessing a massive increase in wind power activity. The enactment of the Scottish Renewables Order (SRO) to support the development of renewable energy sources has already led to proposals for eleven wind farms to be built throughout Scotland. This will inevitably lead to conflicts between nature conservation and natural heritage issues, and the need to develop renewable energy sources. Such energy sources are valued for their low level of environmental impact. However, while not contributing to the growing burden of globally pervasive pollutants, they can have significant local impacts and can potentially place extra strains on populations of sensitive species and birds in particular.

The purpose of this report is to conduct a critical review of available international literature on the impact of wind turbines and associated aerial structures on bird species, taking the 1992 Joint Nature Conservation Committee (JNCC) report by Crockford as a baseline. Where appropriate Crockford's main conclusions have been reiterated, expanded upon or added to. The report concludes with the identification of strategic approaches to mitigating and monitoring bird impacts, and a series of broad conclusions and comments drawn from the reviewed literature.

The extent of variations in wind farm size, dictated by turbine type and quantity, in addition to wide climatic and topographical differences, and the range of bird species present in different locations, makes the job of drawing concrete conclusions from the available literature extremely difficult. This problem is further exacerbated by flawed assumptions, methodological differences and the lack of adequate control or baseline data in most of the published work.

However, some general conclusions can be made, but they must be interpreted with due regard to the fact that each individual wind farm proposal presents unique environmental features which combine with bird species to create a range of issues which must be addressed individually.

If all other factors are equal, taller structures with rotors of greater diameters might be expected to cause more collisions, since a larger proportion of birds could fly within the range of the rotor sweep area. However, taller turbines are generally more powerful, so a given generation capacity can be achieved with fewer turbines, which in turn could result in a reduction in collision risk. Where taller turbines also have higher minimum rotor blade heights, the range of species potentially at risk may be different than where shorter turbines are deployed. Hen harriers may be less vulnerable to taller turbines, but the susceptibility of geese may be greater.

It is possible from the general literature on disturbance in birds to identify some key species which are likely to be sensitive to disturbance caused both by wind farm construction and operation, such as raptors, divers or loons, ducks, and waders. For the latter two groups, disturbance effects have been recorded up to 800m from turbines. The operation of Bryn Titli wind farm has deterred ravens, red kites and other raptors from using the site. Conversely, in spite of being known to be sensitive to recreational disturbance, there is as yet no firm evidence to suggest that breeding golden plover have been impacted by any wind developments. Roosting purple sandpipers and cormorants were tolerant of disturbance during both construction and operation of the Blyth harbour wind farm. Where studies have been undertaken, breeding success and bird energy budgets have been ignored in favour of censuses and observations of flight behaviour.

Most birds in flight usually take evasive action before encountering obstacles. Different species probably vary in their capacities to adjust flight patterns. Ducks and geese appear to react more often than waders, while reactions of ducks occur at greater distances from turbines than those of geese and waders. All these key species may avoid wind farms completely, or display characteristic panic responses when close to turbines.

European studies highlight the vulnerability to collisions of ducks and waders, while in California golden eagles were found to be more susceptible than hen harriers. Despite the large amount of work carried out in California on bird impacts, any evidence must be treated with caution as the context of very high densities and total turbine numbers, and the focus on higher density raptor populations, makes comparison with UK wind farms difficult. All of these studies probably underestimate the number of victims caused by wind turbines.

While susceptible or vulnerable species may be identified from particular studies these should not be used to make general predictions about risk since risk assessment must be undertaken on a species- and site-specific basis.

Most studies, to date, suffer from a lack of adequate control or baseline data, and in most mortality studies the age, sex and breeding status of casualties has not been reported. In the absence of such data it is very difficult to assess bird impacts, or their consequences.

Considerable work still remains be carried out in order to improve our understanding of the issues involved in promoting sites for wind turbines which do not cause unacceptable impacts to sensitive or vulnerable bird populations.

When considering the potential impact of a proposed wind farm, cumulative and additional sources of impact should also be taken into account. At a number of wind farms some of the recorded changes in bird activity could have been the result of changes in land use or agricultural practice, increased human disturbance created by the presence of a visitors centre or the frequency of site visits.

Careful siting studies should be used to direct wind farms away from critical habitats and topographical features which could cause birds to be concentrated in the area of a wind farm. Where there is uncertainty about the likely influence of poor visibility and inclement weather conditions precaution should be exercised.

Finally, in reviewing translated literature and the citation of such literature in other papers, a surprising degree of inaccuracy and misinterpretation seems to have occurred. This leads to the conclusion that translated documents should be approached with regard to the possibility of inconsistencies generated during translation. Many such translations exist only as brief summaries, which limits their usefulness in establishing wider inferences, including the influences of weather, topography and species present.

CHAPTER 1 - INTRODUCTION

This report describes the results of a review, commissioned by Scottish Natural Heritage (SNH) of evidence for the impact of wind farms and associated structures upon birds, with particular reference to geese, other waterfowl, waders and other moorland species in Scotland. In 1991-2 the Joint Nature Conservation Committee (JNCC) reviewed evidence on the possible impacts of wind farms on birds, and other wildlife (Crockford 1992). Since that time a number of studies, not reviewed by Crockford, have emerged, though few have been completed. During this period concern has been heightened over the potential impacts of wind farms upon birds primarily because in some locations in California and Spain significant mortalities have occurred through birds colliding with turbines. Together with a wider appreciation of the possible effects of disturbance upon birds (Hocken et al 1992), this raises fundamental species impact, planning and public relations issues which need to be fully addressed for the wind industry to safely achieve its full potential in the United Kingdom (UK).

The UK Government intends to work towards a figure of 1,500 megawatts (MW) renewable electricity generating capacity by the year 2000 (HMSO 1993a, HMSO 1994a). It has been estimated that 73% of areas suitable for wind development are in Scotland (Clarke 1989). It seems likely therefore that Scotland will experience a large scale exploitation of its wind energy resource. In response to announcement of government support for renewable energy in Scotland many wind energy developers drew up proposals for wind farms in Scotland.

Under Scottish Office Guidelines (NPPG 6) issued in 1994, the Environmental Assessment regulations for Scotland were amended so that an Environmental Impact Assessment (EIA), resulting in an Environmental Statement (ES) is required for all proposed wind schemes in environmentally designated areas in Scotland, and for all developments of more than ten turbines, or 5 MW Installed Capacity (IC) (Scottish Office 1994a). Under the revised Environmental Assessment (Scotland) Regulations 1988, EIA procedures require an assessment to be made of the risks presented by wind farms to any bird species (and other fauna and flora) likely to be affected by the development. This information should be presented in the ES and should relate to the particular site proposed, together with detailed information on bird distribution and movements.

Unfortunately for the natural heritage interest, the competitive bidding process has directed prospective developers towards the windiest sites, and there appears to be an association between such sites and some of the remaining areas supporting threatened bird species. These include geese, such as Greenland white-fronted geese, divers (*Gavidae*), golden plover, hen harrier and other moorland species. The Ramsar Convention on Wetlands of International Importance, especially as Waterfowl Habitat, and the European Community (EC) Directive (79/409/EEC) for the Conservation of Wild Birds impose certain obligations on the UK Government in terms of potential impacts of developments on birds and their habitats. These are detailed in Scottish Office Circular 6/1995 (Scottish Office 1995c). The need for nature conservation and landscape considerations to be carefully weighed up in the wind farm planning process is set out in Scottish Office (1994a).

SNH's statutory consultee role in relation to EAs for proposed wind farms requires it to have ready access to the most up-to-date and comprehensive information on the possible impacts of wind schemes upon the natural heritage, including birds. Crockford's 1992 review has, to date, provided most of SNH's information base on avian-wind power interactions. The current review was commissioned to update those parts of Crockford (1992) relevant to birds in wetlands and moorland areas.

Initially it was anticipated that the risk of birds colliding with turbines and associated aerial structures would be the focus of this review. It soon became clear that sub-lethal impacts of wind developments, such as disturbance, which may affect breeding success, roosting behaviour, food intake or flight behaviour may be more important in many European situations. Such impacts may in turn result in a deterioration in habitat quality, as evidenced by reduced usage by birds. Habitat may also be affected directly by the construction of wind farms, and during this period inevitable disturbance effects may be exacerbated by injudicious siting or clumsy site management.

Most monitoring studies in the UK have not been running for sufficient duration for conclusions to be drawn. Particular emphasis was therefore placed upon reviewing mortality studies in California, and several coastal wind farms in the Netherlands, where studies of disturbance impacts have also been undertaken.

This review sought to separate the contribution of different influences upon the likelihood of impact of wind farm and associated aerial structures upon birds. These include weather, topography and habitat, bird species present, and a variety of wind farm variables. Unfortunately, a number of factors conspired to confound this objective. In particular, most studies completed to date have suffered from imperfect design, changes in land use, farming practice or levels of human disturbance. An additional problem was that, apart from Kenetech Windpower, most US developers do not publish or release their in-house or commissioned research (Paul Gipe *pers. comm*).

It was hoped to examine the influences of wind, fog & mist and cloud conditions on the vulnerabilities of different bird groups to collision with turbines and associated structures, but limitations of the studies conducted to date limited this. The importance of topography and habitat were carefully considered, and general conclusions drawn. The differing responses to disturbance and capacities for avoidance manoeuvres and flight line adjustment of different species were examined. Particular attention was focussed on any particular vulnerability of waterfowl, waders and other moorland species, reflecting SNH's concern about potential interactions at a number of proposed developments in Scotland.

It was emphasized that because of the dual site- and species-specificity of risk of impact, all proposals should continue to be dealt with on a case-by-case basis. Much more work is needed in separating out the influence of weather in contributing to risk of impact. This gap in knowledge may become even more important as wind farms are developed offshore.

A variety of methods, including E-mail, fax or telephone were used to establish a world-wide contact list. These were approached for relevant publications, unpublished reports and other information. Sources of information received before February 1996 were systematically reviewed, while other sources and all relevant references known to the authors appear in the bibliography. Site visits were made to Hagshaw Hill and Blyth Harbour wind farms.

This report is a comprehensive review of all literature, relevant to its focus upon waterfowl, divers, waders and raptors, and made available to the authors up to 31st January 1996. In general it does not repeat ground covered by Crockford, but seeks to bring it up-to-date. Many of Crockford's sources available to the authors were re-examined in light of changes in the context of wind power in the UK, the key species focus (see 3.3), and concern about the influences of weather and topography. Where her conclusions now seem incorrect, or have been superceded by subsequent developments, studies reviewed by her were revisited and re-reviewed. Therefore this report should be read in conjunction with Crockford (1992).

Several other broad reviews have been produced (Benner, Berkhuisen, deGraaff & Postma 1992; Edley 1993a & B; Jacobs 1994; Winkelman 1995; Colson 1995; Bioscan 1995a; Clausager & Nohr 1995; SGS Environment in prep.). Winkelman (1995) sought to summarize much of the European work for an American audience, while Colson summarized and interpreted much of the US work. Clausager & Nohr (1995) spent nine months reviewing all Danish and other mainland European literature, unpublished results and information on wind turbines and birds available to the Danish national Environmental Research Institute (NERI) and Ornis consultancy. In a review which was not comprehensive, Bioscan (1995a) examined 20 studies (2 in the USA, 9 in the UK and 9 elsewhere in Europe) which were available to them, with a view to supporting the environmental assessment process for the Novar wind farm in Highland Region of Scotland (Bioscan 1995b). The SGS Environment review, funded by the Energy Technology Support Unit 9ETSU), extended from an initial focus upon monitoring studies on UK wind farms, to a broader review of such studies I other countries' studies. The current review has sought to avoid excessive duplication of work undertaken by others, by complementing these reviews. Short sections of Clausager & Nohr (1995) and SGS Environment (in prep.) were provided to the authors. Other important material not received before going to press includes a study (SEO 1994) of some of the Spanish wind farm developments at Tarifa, and the (considerable) mortality of raptors and other birds, which has been reported there (Luke 1995).

Chapter 2 describes the wind power generation industry in Scotland and the UK, in the context of government support, international experience and technology available. In Chapter 3 the impacts of wind farms upon birds are examined and assessed, with particular reference to species and habitats likely to experience wind farm development proposals. Impacts of other aerial structures commonly associated with wind farms are considered briefly in Chapter 4. Chapter 5 begins the conclusions with a consideration of a range of strategic issues, and a number of opportunities for further work are recommended. In Chapter 6 the main conclusions and relevant comments are set out.

CHAPTER 2 - THE WIND POWER GENERATION INDUSTRY IN SCOTLAND AND THE UK

2.1 UK Government Support For Wind Power

"The Government's policy is to stimulate the development of renewable energy sources, wherever they have prospects of being economically attractive and environmentally acceptable, in order to contribute to:-
- *diverse, secure and sustainable energy supplies;*
- *a reduction in the emission of pollutants;*
- *the encouragement of internationally competitive renewables industries."*

(Scottish Office 1995a)

The advantages of renewable energy sources from the view point of not contributing to the growing weight of globally pervasive pollutants are self evident. However, rather than having a global environmental impact, many renewables have a localised impact which can lead to considerable public opposition.

In March 1993, the Government announced its intention to work towards establishing 1,500 MW of new renewable electricity generating capacity, in the UK, by the year 2000 (HMSO 1993a). This is to be achieved by establishing a series of Orders, which will be made under Section 32 of the Electricity Act of 1989, obliging the public electricity supply companies (in Scotland, ScottishPower and Hydro-Electric) to buy specified amounts of new generating capacity from renewable sources.

Collectively, the Orders are known as the Non-Fossil Fuel Obligation (NFFO). A separate Obligation exists to subsidise electricity generated by nuclear power. In England and Wales two tranches of renewable supply have already been supported (NFFO-1 and NFFO-2) while the first Scottish Renewables Order (SRO) was established in December 1994. No target has been set for the Scottish wind contribution towards the Government's target of 1,500 MW, but the Scottish Office says the establishment of new generating capacity will be in proportion to the rest of the UK.

Under the SRO contracts for electricity supply will last 15 years, enabling wind developers to receive a guaranteed return on investment. Wind operators will be further paid a premium price for their electricity. "Obtaining a contract under the SRO does not imply any preferential treatment during the formal planning process" (Scottish Office 1995b).

In the wind technology band of SRO-1 some 100 MW of new Nameplate or Installed Capacity (IC) was contracted for (see Table 1).

A total of 139 separate projects with a total generating capacity of 331 MW made it through to the final round in bidding for inclusion in SRO-1. Wind power is one of the most developed of the renewable energy sources, and is considered to be on the verge of commercial viability. Wind farm capacities are often given as Declared Net Capacity (DNC) which is defined by the Scottish Office (1995) to be 43% of IC for wind power. IC is the maximum technically possible output of a wind farm, representing as it does the sum of the rated outputs of the turbines. An estimate of the likely contribution of a wind farm to the national grid is provided by DNC which is of lesser significance for bird impacts than IC. Throughout this report IC is used in preference to DNC.

Table 1: SRO-1 Wind Projects (compiled from various sources)

Company	Location	No. of Turbines	IC Cap (MW)
Micon	West Garty, Sutherland	30[2]	12
Renewable Energy Systems	Helmsdale, Sutherland	20	10
National Wind Power	Beinn Ghlas, Argyll	16	8
	Bendealt, Ross-shire	18	9
	Meall an Tuirc, Ross-shire	16	8
	Polwhat Rig[1], Kirkcudbrightshire	20	10
Gallow Rig	Gallow Rig[1], Kirkcudbrightshire	20	10
Trigen (Kintyre)	Largie, Kintyre	30[2]	15
	Hagshaw Hill, Lanarkshire	10	5
	Hagshaw Hill, Lanarkshire	20	10
Windcluster	Laggan, Islay	5	3
TOTAL			100

[1] These two wind farms are collectively known as Windy Standard, for which National Wind Power submitted a single environmental statement (NWP 1995).
[2] Micon have opted for 20 600 MW machines, rather than the 30 400 MW machines originally proposed. Trigen (Kintyre) have reduced the number of turbines proposed to 24, of larger capacity.

In November 1995, George Kynoch, the Minister for Industry at the Scottish Office, announced a second round of bidding for the SRO: "The first order led to 30 quality renewables projects with a total capacity of 76 MW (DNC) securing contracts with ScottishPower and Hydro-Electric. I am now minded to make a second Order under the SRO in 1996. I hope that this proposed second order will again attract technically sound and innovative projects which will be even more competitive on prices. If so, the second Order is likely to be about the same size as the first" (Scottish Office 1995a).

It is widely believed, by industry analysts, that wind schemes will account for a substantial part of the next phase of SRO but the Scottish Office has given no indication of this. SRO-2 will cover the period from early 1997 until early 2017, including five years set up time. A third, and possibly final, SRO will be launched sometime in 1998.

Scotland is unusually blessed with a vast wind potential. According to the Commission of the European Communities, the European Union's wind resources is over 4 million billion watt hours per year (GWh/year), some two and a half times its current electricity consumption. More than one third of this resource is to be found in the UK. Of the UK resource about 70-80% is in Scotland (Clarke 1989; Twidell 1988), well in excess of its total electricity demand (Twidell 1988).

The wind does not always blow, and because of the intermittent nature of wind power the technical maximum contribution it could make to our electricity supplies is likely to be restricted to about 20% (HMSO 1992).

Under the NFFO and SRO schemes developers are being forced to use areas with average annual wind speeds above 7.5 metres per second. Such areas occur in just 18% of the UK landmass and are likely to be in or adjacent to designated areas or those valued for their natural heritage interest. However, if the constraints of the supported schemes where to be relaxed slightly then areas with average speeds of 6.5 metres per second could be used, freeing up a further 30% of the UK landmass (FOE Cymru 1991).

Two companies dominate the wind technology band of SRO-1, Trigen and National Wind Power. Between them they account for eight of the 12 projects accepted by the Scottish Office for support under SRO-1 (see Table 1).

2.2 International Experience

Global wind energy generating capacity soared from just 15 MW in 1981 to 2,215 MW by 1991 (Ecogen 1994) with much of that capacity installed in the USA. By the end of 1994 equal amounts of generating capacity (approximately 1720 MW each) had been installed in Europe and the USA. Europe and India are now the focus of wind energy development, with 588 MW and 400 MW estimated new capacity in 1995 respectively. Together with 150 MW new capacity in the USA, global capacity should now approach 5,000 MW (Anon 1996).

2.2.1 US Experience

While many countries were still pondering the potential of wind power, hundreds of turbines were erected in California during the 1980s - a period known as the Californian Windrush - following the passing of tight air pollution laws and budgetary support for wind. This transformed the fledgling wind industry into big business. California currently has about 1,600 MW of wind capacity.

Despite many mistakes made during the Californian boom years, the US wind industry is now expanding across the country. Major new wind plants are in operation or under construction or advanced planning in Washington, Wyoming, Minnesota, Texas, Iowa, Maine, Vermont, New York and elsewhere (DeMeo 1995). Between 500 and 1,000 MW is under discussion in California, while elsewhere some 50 MW is already up and running and a further 750 MW are in the pipeline. US analysts put the investment under discussion at between $1-2 billion.

In the US the environmental debate over wind impacts has moved beyond the simple issue of visual intrusion or noise. Prominence appears to be being given to bird impacts. According to DeMeo (1995b) a National Wind Co-ordinating Committee (NWCC) has been established under US President Clinton's Climate Change Action Plan with the aim of identifying barriers to wind development and ensuring the responsible use of wind power in the US. Among the issues it will address are: the environmental objection to the running of transmission cable from windy sites which are distant from major population centres and often in environmentally sensitive areas, and concerns over reported collisions between birds and wind turbines. Following an Avian-Wind Power Planning meeting in 1994 (Resolve 1995) a special Avian Sub-Committee of the NWCC has been established.

2.2.2 European Experience

Despite having one of the best wind regimes in the world for generating electricity, wind power development in Scotland has lagged well behind many other European countries, including England and Wales.

The European mainland also has a more advanced wind industry than the UK. Most European governments now have programmes for encouraging the development of wind power. About 1,000 MW has already been installed and there are plans for about 4,000 MW by the end of the century (DeMeo 1995a).

Most European countries have a wind target for the turn of the century: Germany 2,000 MW; Greece 200 MW; Spain 800 MW; Italy 100 MW; Holland 500 MW, and Denmark 1,000 MW (Anon 1996).

Germany, witnessing a massive increase in wind activity, has now overtaken Denmark both in its achievements and ambitions to harness wind power. After initial investigations into multi-megawatt machines in the mid-1980s Germany now has begun to use machines rated at around 500 kW. In the early 1990s planning permission was easily obtained for wind farms from the provincial governments, however, recently as competition for and pressure on sites has begun to heat up its was widely recognised that their was a need for a co-ordinated approach to planning in order to take visual influence and regional planning issues into account (Holst 1995).

2.3 Technology

Technology for harnessing the wind is not new, for thousands of years the power of the wind has been used for a variety of industrial tasks. However, in the wake of the 1973 oil crisis, power generating companies began to seriously reconsider the possibilities of generating electricity from the wind. However, modern wind turbines owe more to the aerospace industry than to the windmills of yesterday.

A proportion of the solar radiation reaching the earth is absorbed by the atmosphere, resulting in an uneven heating of the air. This in turn causes air to move between areas of high and low pressure, creating wind. One of the most important concepts in the design of wind turbines is the fact that the power available increases with the cube of the wind speed, thus if the speed doubles then the available power increases eight fold.

There are two basic designs of modern wind turbine: horizontal (sometimes known as propeller turbines) and vertical axis machines, many of which bear a superficial resemblance to childrens' toy gyroscopes.

So far, no proposals have emerged under any of the UK renewable orders involving the vertical axis machines. They are still considered to be in the research stage. However, they do offer significant advantages over the propeller designs. They can harness wind from any direction and need considerably less structural support, as their gear boxes and generators can be placed on the ground. Ultimately it is believed that such machines offer the best prospect for exploiting the vast and powerful off-shore wind resource. (Twidell & Weir 1986). The UK offshore wind power potential has been estimated to be about 240 TWh/year, limited to areas no further than 5 kilometres (km) off the coast and less than 30 metres (m) deep (Walker 1988).

Propeller or horizontal axis wind turbines account for all of the projects coming through under the renewables obligation, and are likely to continue to dominate the exploitation of the UK's on-shore wind resource. Horizontal axis machines can, in theory, have any number of blades.

However, due to a combination of factors, both economic and technical, most wind turbines involve two or three bladed machines. A major disadvantage of such turbines is that to generate electricity effectively the blades must be facing into the wind. For turbines above 50 kW a motor is used to move the blades.

When the UK Government first began to express an interest in wind power, in the early 1980s, it was believed that the only way to produce a significant contribution was to pursue the development of large multi-megawatt machines. To this end the Department of Energy commissioned a 3 MW (enough to power 2,000 homes) experimental horizontal axis wind turbine on Burgar Hill, Orkney (Department of Energy 1988a & b). Now, however, such machines are seen to be too large for commercial exploitation. These include the 100m high 2.5 MW MOD-2 Californian turbine and the Danish 2 MW turbine at Tjaereberg.

Wind projects included in the English and Welsh NFFO incorporate a wide range of turbine types and overall project capacity. The minimum rating of machines is 15 kilowatts (kW) and the largest is 500 kW though smaller turbines proposed for SRO-1 are being replaced by larger ones (see Table 1). Some projects involve only a single turbine, while the largest project involves sixty 300 kW turbines. However, typically wind farms employ machines rated at between 200 kW and 450 kW, with less than 25 turbines. The current trend within the wind industry is towards using machines rated between 500 kW and 750 kW. This trend of increases in size of turbines will probably not exceed 750 kW turbines, in view of the earlier experiences of low efficiencies and poor reliability, together with technical problems and higher costs for turbines in excess of 1 MW (e.g. MOD-2, Tjaereborg and Burgar Hill).

There are a number of wind turbine manufacturers around the world, and each turbine design involves a variety of turbine heights and rotor diameters. For example, the Danish manufacturer Bonus currently produces two main turbines: a 300 kW Mk III and the 600 kW Mark II & Mark III models. Both the 600 MW machines have a hub height of either 40 or 50m. The Mark II has a rotor diameter of 44m which rotates at 27 revolutions per minute (rpm) and the Mark III is otherwise identical, but can rotate at 18 or 27 rpm. The introduction of variable speed models is also occurring in the US manufacturing scene with Kenetech Windpower replacing older models with its new 300 kW 33M-VS turbine.

Trigen's Hagshaw Hill wind farm, the first in Scotland, used 26 Bonus 600 kW Mark II turbines, but future developments will probably utilise the more efficient variable speed 600 kW Mark III model. The Bryn Titli wind farm developed by National Wind Power used 22 of the earlier Bonus 450 kW Mark III turbines, while Ecogen's Rhyd-y-Groes wind farm on Anglesey used 24 Bonus 300 MW turbines with rotors of diameter of 33m, rotating at 31 rpm. Such wind farms also typically comprise meterological masts, access tracks, a switching house and underground or overhead electrical power lines, normally 11 or 33 kilovolts (kV), but exceptionally, as at Llandinam and the proposed Humble Hill site, 132 kV.

While wind power development requires the premium prices and long term contracts guaranteed under the renewables orders to bridge the gap between the development stage and commercial viability, the Government believes that performance will increase and costs will decrease over time. The cost of producing power from the wind is expected to drop by about 25% of its current cost by 2005 (DTI 1994c).

CHAPTER 3 - IMPACTS OF WIND FARMS UPON BIRDS

3.1 Introduction

An earlier review of evidence of bird impacts at wind farms Crockford (1992) presented a great deal of information relevant to the current review. Much of this still holds and the two reviews should be read together.

Crockford considered the nature conservation importance of impacts of wind farms in terms of significant reductions in the local, regional, national or international population size and distribution through decreased survival or breeding success of individual bird populations. Crockford pointed out that for rare or vulnerable species, even low mortality rates may be significant. To Crockford's statement should also be added particular concern about:

1.) relatively low mortality rates in species of high annual survival and/or longevity,

2.) even low levels of disturbance affecting populations where rate of reproduction or recruitment is low,

3.) to species of known vulnerability to disturbance where population security is otherwise in question.

In view of the rapid expansion of the wind industry, any cumulative impacts of wind farms in the same vicinity may require special attention.

The sub-chapter structure of Crockford's Part B: "The impact of wind turbines on wildlife" has not been adhered to, partly because non-avian wildlife are not considered here, and the specific foci of this review are primarily species of waterfowl, but also waders and other moorland species (see 3.3). The sub-chapter structure adopted here aims to improve the biological basis of impact classification.

The impacts of wind turbines upon birds may be divided into three often mutually dependent classes:

(a) possible deterioration of bird habitats;

(b) effects of disturbance;

(c) collision impacts.

This structure is preferred to Crockford's separation of "direct" and "indirect" impacts. Thus, any possible positive impacts are considered first at 3.4. At 3.5.1 "disturbance" (divided into 3.5.1.1 "habitat deterioration" and 3.5.1.2 "effects upon behaviour") is distinguished from 3.5.2 "direct mortality".

3.2 Definition Of Terms

Several terms encountered in the literature appear to have caused some ambiguity. To help avoid some of the consequent problems a number of terms are defined in Table 2 below.

Table 2

seasonal migration	long-distance regular movement to exploit seasonal food supplies, along migratory routes or flyways, which may be different in spring and autumn. Such behaviour may be adaptive in increasing energy surplus, even allowing for increased energetic costs of flight, and therefore the likelihood of successful breeding.

diurnal migration	as above, occurring primarily during daylight hours, (especially applicable to larger birds such as raptors, geese and other waterfowl).
nocturnal migration	as above, occurring primarily during night (especially applicable to passerines).
daily movement	local movement, often between feeding and roosting areas and along regular flight lines (sometimes referred to as daily or local migration).
natural foraging	movement within home range in search of food.
certainly killed	proven by autopsy (Winkelman 1990a-c, 1992a-c, 1995).
very probably killed	obviously so but without autopsy (Winkelman 1995).
probably killed	fresh remnants implying collision (Winkelman 1995).
possibly killed	as above (Winkelman 1985, 1987, 1990a-c, 1992a-c).
positive impact	effect which enhances survival or breeding success.
negative impact	effect which diminishes survival or breeding success.
time budget	activity budget by which time is allocated by a bird to meeting basic needs such as feeding, resting and moving.
additive mortality	deaths that would not have occurred in the same time frame in the absence of the development, in this case a wind farm (Resolve 1995).
compensatory mortality	deaths that would have occurred for another reason if the wind farm had not been present.
PVA	Population Viability Analysis, assessing the likelihood of population decline or local extinction.
BACI	Before-After Control-Impact comparison or pre- and post-construction data, in relation to one control site nearby.
IC	Installed Capacity, or Nameplate Capacity, the total potential output of a wind farm, calculated by multiplying the maximum power output (i.e. rating) of the turbines by the number of turbines. This is used in preference to DNC in this report.
DNC	Declared Net Capacity, representing for wind power, 43% of the highest net generation of electricity (or Installed Capacity, IC). Since the use of DNC is no more biologically meaningful than IC, the latter is used in this report. Where discrepancies in the stated output of wind farms arise, these are generally caused by inappropriate use of DNC or IC.
end-row turbine	turbine at either end of a row or string.
rotor zone[1]	area swept by turbine rotor blades.

[1] The area around a wind turbine, from the point of view of a bird, may be classified into four or five spatial classes (Winkelman - 1984 Figure 4; 1985b - Figure 2; 1992c - Figure 7). In Figure 4 in Winkelman (1985b) the rotor zone is the area swept by the turbine rotor blades. Spatial classes 2, 3 and 4 extend up to the rotor blade diameter, 15m and 50m respectively from the base of the turbine.

3.3 Key Bird Species

Geese are often considered together as one group (especially where data are not specifically disaggregated in reports, summaries and their translations), while other waterfowl are divided into ducks (including moorhen & coot, following Winkelman 1992a), and waders. Large birds including swans, and sometimes geese, have been aggregated in much of the Dutch work (e.g. Winkelman 1992c). Moorland birds include raptors, divers and waders. All the above groups are regarded as focal groups in this review, reflecting their likely exposure to future wind farm proposals in the UK. Almost all US data concern effects on birds in California, where raptors have been the focus of attention. Other groups, including waterfowl and night-migrating passerines could be a larger concern in other parts of the US where wind farms are now being planned (Resolve 1995). Other groups considered together, especially in the Dutch literature include gulls, doves, and other passerines, sometimes divided into those larger or not, than starlings. Latin names are given in Appendix 1.

3.4 Positive Impacts

Long-term positive impacts for birds associated with wind farms include retention of semi-natural habitat and protection from persecution Colson (1995).

3.4.1 Habitat Protection and Enhancement

Since the land taken by wind farms is minimal, and because most land uses remain unaffected by wind development, wind power can protect semi-natural habitat from other development.

Off-site planning gain is often advocated in the USA as mitigation or (more correctly) compensation for unavoidable impacts. For example, available habitat for otherwise threatened species may be extended or improved, adjacent to the wind farm site, or elsewhere. In some cases developers have made donations to funds for the protection of such species in locations far removed from the wind farm development.

Opportunities for on-site habitat improvement at the proposed wind farm at Novar have been suggested and explored by Bioscan (1995b).

3.4.2 Provision of Perch and Nest Sites

In the USA, developers have, to date favoured grassland and desert habitats which generally lack bird perches. Over 50 references, of varying relevance to this project, are given in CEC (1995). Several species of raptor and passerine frequently perch upon turbine lattice towers, stationary rotor blades and associated aerial structures (see 3.7.3 & 3.7.4.). Red-tailed hawks, ravens and many passerine species will nest on turbine lattice towers, but nests are usually removed.

3.4.3 Protection from Disturbance and Harassment

This consideration may apply especially to moorland raptors still subject to persecution for their predation of gamebirds. By bringing rental revenue into rural estates, wind farms may reduce the economic incentives which favour the (illegal) killing of raptors.

3.5 Negative Impacts

3.5.1 Disturbance

While collision mortality has been the focus of most US studies, in Europe disturbance, especially that leading to habitat loss or deterioration, has caused greater concern. Some European birds, including waterfowl and waders, have altered their use of habitat and their behaviour to avoid wind turbines. These effects are best studied using a BACI (Before-After Control-Impact) design, which has been considered optimal for field investigations of environmental impact (Green 1979; Underwood 1992). Where control sites are not available, generalized linear regression analyses relative to distance from the wind farm have been used (Winkelman 1995). Other studies, such as Pedersen & Poulsen (1991), lacking full temporal control (i.e. no baseline set before impact) and often lacking spatial control sites, are less able to demonstrate cause and effect. At best such evidence of impact (or the lack of it) should be regarded as anecdotal and therefore suggestive of possible effect. It should be recognised that most of the evidence for disturbance impacts of wind farms comes from two Dutch coastal wind farms (18-300 kW turbines at Oosterbierum and 25-300 kW turbines at Urk) (Winkelman 1989; 1990a-c & 1992a-d) and in Denmark (Poulsen & Pedersen 1991) the very large single turbine of 2 MW capacity at Tjaereborg, much larger than any of those likely to be used in Britain, or elsewhere (see 1.3). While the Dutch data **may** provide an adequate basis for extrapolation to the UK situation, the Danish study probably does not, and some of its findings may be misleading.

Confounding variables such as land use change, adjustments to farming practice and alterations in levels of human disturbance are considered in detail by Bioscan (1995a). Some of these issues are discussed in this chapter.

None of the monitoring studies which are known to have been formally established in the UK, at Ovenden Moor (EAS 1992 & 1993b), Chelker Reservoir (EAS 1993a), Bryn Titli* (Green 1995a & 1995b; Phillips 1994), Cold Northcott* (McCartney 1990 & 1994), Blyth Harbour* (Still et al 1994 & Still, Little & Lawrence 1995), Mynydd y Cemmaes* Dulas (1995), Haverigg* (SGS Environment in prep.), Cold Clough (Econsult 1995) and Rigged Hill (Natural Environmental Consultants 1995) have not been running for sufficient time to draw any firm conclusions. SGS Environment (in prep.) discuss these and other sites where ESs have considered there to be potential bird impacts. They also provide in depth reviews of the monitoring studies marked *.

3.5.1.1 Habitat deterioration

Apart from direct habitat loss, which is generally minor or of restricted scale for most wind farms, some species may experience an indirect loss or deterioration of habitat. Such effects may arise either through an increase in disturbance from the wind farm itself or from human activity, or through changed land use. All may cause birds to leave the area in question but quantification of the effect of wind farms may be confounded by these other changes. If suitable unoccupied habitats are available nearby, such displacements of bird populations may not be of great concern or significance. The likelihood of such situations arising differs between breeding, feeding and migrating birds.

(a) *Nesting sites.* Winkelman, using a generalized linear regression model (1990b & 1992d), found no disturbance effect in terms of loss of habitat revealed by 1984-1991 census data for lapwing, black-tailed godwit, redshank or oystercatcher around the Oosterbierum wind farm (Winkelman 1990b). This wind farm consists of 18 300 kW turbines, and seven meteorological towers or anemometers. The site at Oosterbierum occupies 55 hectares or arable land and lies 3-4 km inland from the Wadden Sea, an inter-tidal area of international importance for waterfowl. Winkelman's continuing studies extended from 1989 to 1991 did not reveal any disturbance effects upon these species' use of habitat either. However for "species of high nest site fidelity and a long life span" (Winkelman 1992d) experiments lasting many years are necessary to prove negative impacts.

Breeding waders, especially lapwing, appeared to move away from the single large 2 MW wind turbine at Tjaereborg in Denmark between 1987 and 1989 during the construction and early operational phases (Pedersen & Poulsen 1991). Bioscan (1995a) regards this study as flawed because of the invalidity of its assumption that the study area of 45 hectares was of similar habitat quality. Apparently the area 300m around the turbines occupied 60% of the study area, but only held 30% of the lapwing population before the wind farm development. Thus in the area within 300m of the turbines the proportion of total lapwing numbers breeding within the overall study area declined from 30% in 1987 to 5% in 1989, but this area was already of poorer quality (Bioscan 1995a).

Howell & Noone (1991) found similar numbers of raptor nests before and after construction of Phase 1 of the Montezuma Hills in California wind development. Black-shouldered kites were not found nesting after construction, though this effect was attributed to land use change and altered farming practices, rather than disturbance.

An apparently well designed monitoring study (EAS 1992 & 1993b) has been established at the 23 Vesta 400 kW turbine Ovenden Moor wind farm, with a control site at Haworth Moor. After one year, changes in bird census data at both sites were considered to lie within the normal range of fluctuation, though the wind farm site held more golden plover in 1993 than 1992 and fewer curlew and snipe. Bird strike monitoring is apparently also being undertaken but no results, nor calibration efforts were presented in EAS (1993b). Monitoring apparently continues but further results were not available at the time of going to press.

Another monitoring study was established at the four WEG 300 kW turbine Chelker Reservoir wind farm in 1992, with further surveys by members of the Bradford Ornithological Group planned in 1993 and subsequently (EAS 1993a). Fourteen indicator species were identified, and a detailed recording programme was initiated. These species are non-breeding little grebe, breeding and non-breeding great-crested grebe and mallard, non-breeding tufted duck and goosander, breeding and non-breeding coot and lapwing, non-breeding golden plover, curlew, and 5 gull species. Most of these species were recorded in higher numbers over 41 visits in 1992 than over the period 1987-1991, probably reflecting slightly higher and more constant effort in 1992. As for Ovenden Moor, more recent results were not yet available.

The effects of the construction and initial year of operation of the 22 Bonus 450 kW turbines at Bryn Titli were investigated by Phillips (1994). He detected no significant changes in the breeding bird populations either before and after construction in the same area or, after construction between the wind farm site and an adjacent control site (Bioscan 1995a). The study was, like Ovenden Moor, fairly consistent with the Before-After Control-Impact (BACI) approach (see 3.5.1 above), but apparently lacked a pre-construction baseline at the control site.

Prior to construction of a wind farm consisting of 10 Nordtank 500 kW turbines at Rigged Hill, Limavady in Northern Ireland, a baseline survey as part of the EIA revealed three pairs of red grouse. Two years later the surveyors found no evidence of grouse present or having used the site, and a negative impact was concluded (Econsult 1995). Apparently grouse have since been recorded on the site (S. Lowther *pers. comm.*), reflecting the mobility of this species and the danger of drawing premature conclusions from monitoring studies.

(b) *Feeding and roosting birds.* Clausager & Nohr (1995) concluded that in some studies feeding and roosting birds were disturbed, and that **within a distance of 250m from the turbine up to 95% of the birds present may be affected**. The mechanism of disturbance was not specified in the English summary.

The construction and continued operation of a wind turbine could indirectly alter prey availability, particularly if changing economic flows consequent upon wind farm development result in land use change and/or altered farming practices. The effects of higher populations of predators hidden by landscape features (including windfarms, Masden 1985) could affect roosting birds such as geese. An untranslated German review of this issue (Schreiber 1993) which refers to both golden plover and curlew could reveal other effects (proven and possible) upon roosting birds. Winkelman's (1989) study at Urk was summarised by Crockford (1992).

In Winkelman's (1989) Before-After Control-Impact study of the 25 turbine Urk wind farm the temporal comparison was limited by weather differences between years: the winter of 1987 was colder than 1988 and 1989. Significantly smaller numbers of wintering waterfowl were found within 300m of the wind farm than on the control site plots. Data on geese and swans were inconclusive and were confounded by weather differences between years. Winkelman (1992d) found fewer birds feeding and resting close to the 18 turbine Oosterbierum wind farm than farther away. The fully operational wind farm was estimated to have had a disturbance effect up to a maximum of 500m beyond the outer row of turbines. Mallard, oystercatcher and common gull were significantly affected by the wind farm once it became fully operational, while tufted duck, coot, golden plover, lapwing, curlew were affected also during the construction phase. However, alterations in the levels of human disturbance may be responsible for some of these changes, since a visitor centre was constructed and the study area was used by a variety of research personnel.

Pedersen & Poulsen (1991) in Denmark reported significantly smaller numbers of golden plover and lapwing (and also starling, black-headed and common gulls), within 800m of the single large 2 MW wind turbine at Tjaereborg Polder, an internationally important wetland in the Wadden Sea. The displacement of golden plover resulted in the loss of two-thirds of the study area as potential feeding and roosting habitat. These trends in spatial distribution were detected between 1987 and 1989 by regular censuses of non-breeding birds. The authors' translated summary stated "that the wind turbine has caused a vacuum effect preventing birds from exploiting the areas close to the wind turbine" (Pederson & Poulsen 1991). Without a pre-construction baseline, and in the absence of control sites, firm conclusions cannot be drawn. It should be noted that this large turbine was mostly not in operation during the study period and the higher noise levels associated with its intermittent action, together with changes in land use or farming practices in the surrounding area during the course of the study, may have contributed to higher disturbance effects.

Green (1995a) detected a decline in the usage of the Bryn Titli wind farm site by buzzard and raven during the latter stages of construction and by red kite in the early stages. This study is flawed by the absence of a baseline before construction. Nevertheless, subsequent fieldwork (Green 1995b) confirmed the deterrent effect for these species, as well as peregrine and kestrel. The effect was particularly apparent with regard to red kite and raven.

(c) *Flight lines and flyways.* Benner (1993) concluded that "no data are available on the impact of wind turbines on local migration (i.e. daily movements) between areas for foraging and high water refuge areas". The current review has found no such data either. One study at Cold Northcott Wind Farm in Cornwall appeared to demonstrate a shift in starling flight lines (McCartney 1990 & 1994) but methodological problems exist with this study.

Flight lines may have been altered in response to the introduction of wind farms into habitats used by birds, but in the absence of adequate baseline data collected before development, any such effects cannot be demonstrated. By avoiding habitats in the vicinity of wind farms, birds could conceivably incur higher energetic costs, which might become critical during the breeding season in species such as common terns for example (Henderson et al 1995). Alternatively birds could approach the turbines more closely than they might at times of lower energetic demand, resulting in elevated collision risks. Of course the most likely effect of flight lines being altered is that birds may fly around the wind farm, thus steering clear of turbines.

To date the only European wind farms which have been located directly in the path of a major migration flyway are in southern Spain at Tarifa. Heavy collision mortality of migratory raptors including Griffon vultures have been reported (Luke 1995), but until the Spanish report (SEO 1994) is made available, the findings cannot be evalated.

3.5.1.2 Effects upon behaviour

Behavioural disturbance attributable to wind farms may affect breeding success, feeding activity or flight patterns. Most evidence of impacts upon breeding, feeding and roosting birds comes from census studies (see 3.5.1.1a above), rather than investigation of trends in breeding success or chànges in time budgets.

(a) *Breeding success.* Only one study has addressed impacts upon breeding success, as opposed to the spatial distribution of nests (see 3.5.1.1a above). In this study evidence for a 6% loss of unhatched lapwing eggs due to the impact of the large 2 MW Tjaereborg turbine was presented by Pedersen & Poulsen (1991). However, egg losses attributable to predation and farming activities varied from 10-43% and 7-42% respectively, suggesting that land use and/or farming practices may have changed during the study period. Unfortunately, like Crockford (1992), without access to a translation of the full report it is not possible to determine whether confounding variables were operating. Bioscan (1995a) suggested that, in this study, the 6% loss of unhatched eggs included all egg losses not attributable to a known cause. This emphasizes the need for control sites.

(b) *Feeding activity.* Foraging patterns of open-habitat raptors such as golden eagle and red-tailed hawk (and merlin) could be disrupted by large wind developments (Orloff & Flannery 1992). Prey availability may change, but not necessarily decline. During breeding attempts effects upon time budgets could become critical (Henderson et al 1994). Green (1995a) found that red kite and raven usage of the Bryn Titli wind farm (22 Bonus 450 kW turbines) declined while the wind farm was operating, and that changes in sheep numbers (which influence food availability) cannot account for the changes. No study considered has investigated time budgets to examine the influence of wind farms on feeding and resting behaviour.

(c) *Flight behaviour.* Most birds in flight usually take evasive action before encountering obstacles. Winkelman (1992c) found that about 75% of bird reactions she observed within 200 to 300m of turbines at the Oosterbierum wind farm, were started within 100m of the turbines, and about 50% between 51 and 100m. About 75% of all such reactions were gradual and calm, but 25% of reacting birds showed "panic" responses characterised by altering the angle of the body (especially ducks), accelerating wing beat, or making several passing attempts. The wind farm was completely avoided by 8% of all birds, (12% of ducks, 14% of waders and 17.5% of large birds, including geese - see Table 33). Fewer migrants were recorded close to the wind farm whether or not the turbines were operating (Winkelman 1992d). Mallard, snipe and curlew seemed to be the most sensitive. Local gulls appeared to be habituated to the turbines in that they displayed fewer panic-like and more calm responses than migrants (Winkelman 1992c). Only 2% of birds were observed to shift altitude to rise above turbine height as they crossed the wind farm. At a finer scale, 14% of all reacting birds showed a shift in the flight path in the vertical plane causing height loss, and 7% caused a gain in height. This appears to suggest that more birds will lose height and descend into wind farms, and therefore refute Spaans & van den Bergh's (1994a & 1995b) suggestion that white-fronted geese might be expected to "take height before crossing the wind turbines".

Whether or not the wind turbine was in operation (see 3.8.7) a 0-30° change in direction by birds passing the Tjaereborg turbine was reported by Pedersen & Poulsen (1991). To this it should be added that within 300m of the turbine 5% of these changes were greater than 30°, suggesting panic-like reactions. Further away from the turbine only 2% of such changes could be so regarded. Unfortunately the authors' English summary contains insufficient detail for detailed evaluation and does not disaggregate these data by species, although various citations of this work suggest that mallard and common gull were included. Definite alterations in flight direction as migrants passed over German wind farms were described by Vaux et al (1990), but details were not given in the brief English summary.

3.5.2 Direct Mortality

Bird mortality at wind farms is best studied through a combination of searches of corpses and observation of flight patterns (Winkelman 1987). Attention is increasingly focussing upon the population consequences of such mortality. However, from a planning, and often in the USA, a legal perspective, mortality of protected birds may be deemed to be unacceptable, whether or not there are (immediate) population consequences (Resolve 1995).

3.5.2.1 Study methods

Two approaches have been used to investigate collisions between birds and wind turbines, namely searches for corpses of dead birds and direct observation of collisions. To derive total site estimates of casualties, the former requires careful calibration to correct for search efficiency, scavenger activity, causes of death, area searched, and number of search-days. The latter is expensive in terms of equipment and time for analysis, but when used in conjunction with radar to estimate total numbers of birds passing particular wind turbines can also generate estimates of total numbers of bird collision victims. Estimated rates of collision are generally so low as to make observation of casualties relatively unlikely, except perhaps for nocturnal migrants at some sites (Winkelman 1990c & 1992b). Orloff & Flannery (1992) pointed out that the behaviours which place raptors at risk, such as stooping on prey, may be inhibited by the presence of people. Direct observation also permits an examination of avoidance manoevres and the determination of any species differences with respect to collision risk (see 3.7.2 & 3.7.3).

Winkelman (1990a) used a formula to calibrate numbers of birds found (Na) to generate an estimate of the total numbers of bird collision victims (N):

$N = (Na-Nb)/P*Z*O*D$

Na = numbers of birds found
Nb = numbers of birds that did not collide
P = scavenger activity (proportion of corpses not scavenged)
Z = search efficiency (proportion of corpses not overlooked)
O = proportion of area searched
D = proportion of days searched

This formula is still applicable (Winkelman 1992a), and a modified version was used in the Californian study of Orloff & Flannery (1992). In the case of coastal sites where corpses may fall into the water (Still et al 1995), correction factors for loss of buoyancy and drift of floating corpses away from search areas should be added to the denominator. Once further data are collected overall mortality for Blyth harbour wind farm shall be estimated using a modified version of this formula (D. Still *pers. comm.*).

Scavenger activity may be high for small birds, with up to 50% of small bird carcasses disappearing within the first 24 hours at Oosterbierum wind farm in the Netherlands (Winkelman 1992c). Orloff & Flannery (1992) found a similar association between size of corpse and scavenger activity, with no removal of golden eagle corpses detected in their study. This and other Californian studies may have overlooked small passerines (Howell & Noone 1992; Colson 1995).

The proportion of corpses placed in tall grassland found may be low, especially for small birds, even with careful searching. Estimates for dead birds up to the size of starlings placed around two Dutch wind farms ranged from 30 to 83% (Winkelman 1995), with means of 45% for Oosterbierum (Winkelman 1992a) and 73% for Urk (Winkelman 1990a).

In the USA, where the collision rate per turbine (see 3.5.2.2) is very low, some authors have attempted to draw inferences about how birds collide with turbine structures from studies of wire collisions. However, the usefulness of this extrapolation has been questioned by Bioscan (1995a) because such wires probably differ in their visibility to birds from turbine structures.

Because of difficulties of calibration, and since the small sample sizes may result in large statistical errors in estimates, any data derived from direct observation provides important supportive evidence of collision impacts. Byrne (1983) observed an American kestrel struck by a rotor on a third passing attempt. In many hours of observation at Altamont in California, Orloff & Flannery (1992) observed no collisions. Up until November 1994, Kenetech's Avian Research Program had evidence of only two observed collisions at Altamont. During one of several passes through a row or string of non-operating turbines, an American kestrel collided with the nacelle of one of the turbines. A red-tailed hawk was observed with its wings fully extended in the "stall position", attempting to cross the sweep of the rotor blades to land on the horizontal beam of a turbine tower, when the bird was struck by a blade and killed. In neither case was the bird observed to take evasive action in time to avoid striking the turbine (Kenetech 1994).

To date very few collision victims have been found at UK wind farms, and in the absence of adequate calibration, those studies which have reported dead birds (e.g. one snipe - Dulas 1995) are best regarded as anecdotal. Some studies (e.g. Tyler 1995) reveal high scavenger (fox, corvid and raptor) activity, suggesting that weekly visits will fail to detect evidence of collision victims before they are removed.

3.5.2.2 Mortality estimates

In the USA various mortality estimates have been derived by calibrating counts of collision victims (Orloff & Flannery 1992, Howell & Noone 1992, PBRG 1995). In a review of 108 European study sites, it was concluded that estimates of the total numbers of bird victims could only be made at 3 sites, because elsewhere data required for calibration had not been collected (Winkelman 1995). Most of the US data relates to raptors though there may have been a search bias (see 3.7.3) while European data relate primarily to waders, waterfowl, gulls and passerines.

In spite of these problems, a number of authors (e.g. Benner et al 1992 - reproduced as Table 3 in Colson 1995; Still et al 1995) have attempted to summarize such flawed mortality rates from published sources. Benner (1993) recognised that "all of these studies underestimate the number of victims caused by wind turbines".

Winkelman (1990a) described 35 dead birds found at Oosterbierum up until spring 1989, of which only 29% were certainly or very probably killed by collision. When two further spring and one additional autumn period of search are added (i.e. over the total of six spring and four autumn periods from 1986-1991), 642 search days yielded a total of 78 dead birds of 25 species, of which carcass examination suggested 36% were certainly or very probably killed through collisions with turbines, while 22% were "possibly" so. Other causes of death or unknown factors were considered responsible for the remainder (Winkelman 1992a). With correction, the overall estimates of total numbers of collision victims at Oosterbierum wind farm given by Crockford up until 1989 (Winkelman 1990a) have been reworked (Winkelman 1992a). The total of 107 birds (95% confidence limits 81 to 321) cited by Crockford as certainly and very probably killed by collision, changed to 100 (74-298) after re-analysis (Winkelman 1992a). For autumn 1990 and spring 1991, when the wind farm was fully operational the estimated total numbers of certain, very probable and possible collision casualties were 122 (84-284) and 146 (130-451) respectively. In spring 1991 the species group (see 3.7.3) with the greatest total casualties (excluding passerines for which search effort was not estimated) was waders, estimated to be 73 (65-226), followed by ducks and gulls with 37 (33-113) each (Winkelman 1992a - Tables 9b & 9c).

Orloff & Flannery (1992) estimated, using a variety of calibration factors, that over the whole Altamont wind development, with its 7,340 turbines, 403 raptors were killed by turbines in 1989-90 and 164 in 1990-91. Using conservative assumptions they concluded that 39 golden eagles were killed each year, and that this represented 69% of all golden eagle deaths in that area. A major research project investigating the population consequences of this mortality is currently being undertaken (PBRG 1995) with funding from Kenetech and the National Renewable Energy Laboratory (NREL).

Collision rates, mostly for raptors have been derived from a number of Californian studies (e.g. Orloff & Flannery 1992; Howell & Noone 1992), but these are very unlikely to be comparable to any UK situation. European collision rates are generally higher and involve waterfowl and passerines, often in migration. In the USA wetland areas where waterfowl and waders concentrate have been avoided to date (Colson 1995).

Orloff & Flannery (1992) estimated that during the period 1990-91 the **annual collision rate for raptors** was 0.0234 per turbine. Ignoring the absence of estimates of search efficiency or scavenger activity, the data of Howell & Noone (1992) suggest **annual mortality rates** of 0.0739 total birds per turbine and 0.0478 raptors per turbine 1988-89. These are much lower than the estimates of **daily collision rate** during autumn and spring at Urk and Oosterbierum in the Netherlands. For the former the estimates were 0.04 birds (95% confidence limits 0.03-0.14) in autumn and 0.05 (0.04-0.93) in spring (Winkelman 1995). The equivalent figures for Oosterbierum were 0.06 (0.04-0.13) and 0.09 (0.09-0.29). It appears that Dutch collision rates exceed those in Altamont by between two and three orders of magnitude.

Daily, seasonal or annual mortality rates per turbine do need to be estimated if comparisons between habitats (3.6.3), wind farm layout (3.8.1) and different turbine heights and designs (3.8.2), are to have any value. Unfortunately, because of the deficiency or absence of most attempts at calibration, most such comparisons are flawed and misleading, including those summarized by Still et al (1995), Benner et al 1992 (reproduced in Colson 1995) and SGS Environment (in prep.).

3.5.2.3 Catastrophic mortalities

Crockford cited Karlsson (1983) as having reported 49 dead birds near one turbine at Nasudden in Sweden. Apparently, it appears from various other citations, that 43 of these deaths occurred during one night of very poor weather conditions. That night the wind turbine was not operating and a lamp had been attached to the turbine tower at a height of 10m, probably fatally attracting the birds (Clausager & Nohr 1995, and see 3.8.6). Neither Winkelman (1990a & 1992a), nor any of the other European studies reviewed by Winkelman (1995) have recorded nights with such large kills, which are more characteristic of some high TV and radio masts (CEC 1995).

3.5.2.4 Non-fatal injuries

At Oosterbierum some birds were observed to recover from collisions and some from wake effects (Winkelman 1990c, 1992b). Winkelman saw 15 collisions of waterfowl, of which apparently four recovered after colliding and continued their flight. In six of the nocturnal "collisions" the birds, flying with tail winds were swept down through the wake behind the rotor. In half of these "wake" encounters the birds recovered, while the other half were fatal. Benner (1993) has pointed out that Winkelman's (1992a & c) estimates of mortality assume that emigration of wounded victims does not exceed immigration. Except in the Californian context such an assumption seems untenable, and mortality presented should be regarded as minimum estimates. Seventeen percent of the 78 (or 76? as given in the English translation) birds found in searches for corpses were not yet dead (Winkelman 1992a), though in such cases mortality seems inevitable, if only through subsequent predation. Ignoring mortality of injured birds which may contribute to a net emigration of such birds from the collision victim search area, may therefore lead to substantial underestimation.

3.6 Environmental Factors

Each wind farm site has unique environmental, biological and engineering characteristics that provide little opportunity for making general predictions of the probability and significance of impacts. This dual site- and species-specificity of risk estimation cannot be over-emphasized.

3.6.1 Weather

At Oosterbierum most collision victims were found after nights with poor visibility and flight conditions due to strong (head) winds, mist, rain and/or dark nights lacking moonlight (Winkelman 1992a). Strong winds, fog, dense cloud cover and rain can all reduce visibility, thereby reducing the range at which birds may see the rotating blades of turbines. Furthermore, if birds fly lower during inclement weather (as suggested by Winkelman 1992c and Colson 1995), they may place themselves at greater risk for collisions with turbines and other aerial structures. Weather patterns in Dutch and Danish coastal and Californian upland locations, where most studies have been undertaken, may be unsuitable for extrapolation to the types of habitats currently subject to wind development in the north and west of Scotland. The influences of weather are in any case far more likely to contribute to collision risk in Europe than in California, where inclement weather is probably not a critical factor.

At Urk Winkelman (1989) found "certainly" or "very probably" collided birds only after nights with poor visibility and more often so in combination with bad flight conditions. Although the data remains to be fully analysed, there is an impression that most collision victims at Blyth harbour were found after periods of poor visibility (D. Still *pers. comm.*).

During nocturnal observations Winkelman (1992c) found 87% of birds flying into head winds, approaching turbines with confident, strongly fluttering flight. However, on different nights only 29% did so when flying in tail winds. Flying upwind or across the wind direction past turbines may allow a bird more time to react, than when flying downwind. This is supported by observations that large birds, including geese, showed significantly more reactions with tail winds.

None of these studies provide evidence supporting the common belief that low cloud cover may cause birds to fly lower than otherwise, and thereby bringing them into closer proximity to turbine blades.

There is an indication (Orloff & Flannery 1987 cited in Colson 1995) that waterfowl flew above the fog line at the Howden wind farm at Solano County in California, and that raptors did not fly at all in fog. However this area is rarely subjected to fog during high wind, as may be experienced in Scotland. Colson (1995) observed that birds will generally avoid flying during periods of heavy precipitation or fog. However, when birds are caught away from roosts by sudden storms or fog, collisions with aerial structures may occur (Avery et al 1980). According to published data weather, including high winds, has not played a significant role in bird collisions with wind turbines in California.

3.6.2 Seasonal and Daily Timing

Winkelman (1990c & 1992) reported that one of 14 (7%) birds observed during daylight trying to cross the rotor area collided. The risk of collision appeared to be four times higher at night, with 14 out of 51 birds (28%) observed crossing the rotor at twilight and night, suffering collision. This study also suggests that peak risks of collision may occur in spring and autumn migration as well as during the dusk and dawn periods.

3.6.3 Topography and Habitat

Some general principles about the influence of topography upon the risk of bird collisions with turbines can be stated. Any habitat features or landforms which concentrate birds, **even temporarily** should be avoided (C.J. Pennycuick *pers. comm.*). Thus, many wind farm sites in the western United States have avoided waterfowl populations in wetland habitats but many are located close to natural valley passes (Colson 1995), where any bird movements may result in temporary concentrations. In Europe most wind farms have been placed in coastal areas where seasonal concentrations may also occur.

Guidelines in the literature frequently suggest that topographic features such as mountain passes, river valleys (including canyons) or depressions (including swales), shoulders of hills, high points of ridges, outcrops frequented by birds, resting or roosting sites and in general coastal flyways should be avoided. For example Orloff & Flannery (1992) found consistently higher raptor mortality rates in close proximity to canyons than those farther from canyons. It has been suggested that the most dangerous turbines at Tarifa in Southern Spain seem to be those on high points of ridges, near night roosts and frequented outcrops (Pennycuick 1994). Until a definitive study of the problem has been undertaken, and all raw data from existing studies (SEO 1994; Luke 1995) published, it is not possible to verify this suggestion.

Each site has unique features that combine with the species present to create a range of issues which should be addressed individually. Early attempts at typologies of wind farm sites by habitat (Benner 1993, Still et al 1994) are useful in making comparisons between habitat types, contributing to **indicative zonation** (see 5.3) and **buffer zone definition** (5.2). It is however, neither possible nor desirable to generate a **site-** nor a **specific-** index of probability of impact.

3.7 Species Differences

3.7.1 Tolerance of Disturbance

Species may display characteristics which make them especially susceptible or vulnerable to disturbance impacts. It should be borne in mind that these characteristics may become critical for survival or reproduction at some sites, but not others. Furthermore, depending upon how philopatric (site faithful) an individual bird is, response to disturbance may be delayed for some time.

At Urk wind farm, alongside Lake IJsselmeer in the Netherlands, Winkelman (1989) recorded a decrease in wintering mallard, pochard, tufted duck and goldeneye within 300m of the wind farm. Because of differences in numbers and distribution of geese recorded in different years it was not possible to determine the effect of the wind farm on geese including European white-fronted geese. This raises doubts over the conclusions drawn by Spaans & van den Bergh (1994a & 1995b) in a risk assessment for the Largie wind farm, located near Greenland white-fronted goose winter roosts in western Scotland.

From the general literature on disturbance in birds (Hocken et al 1992) it is possible to identify some key species likely to be sensitive to disturbance caused by construction and operation of wind farms: raptors (van Daele & van Daele 1982), divers or loons (*Gavidae*) (Andersson et al 1980), geese (Madsen 1985; Keller 1991) and waders (van der Zande et al 1980).

Species of known vulnerability to disturbance combined with high site fidelity, for example divers have been affected by insufficiently careful construction of one large turbine on Orkney (Meek et al 1993). During wind farm construction and operation at Blyth Harbour roosting purple sandpipers appeared to display high tolerances for disturbance, as did gulls and cormorants (Still et al 1995). In spite of being known to be vulnerable to recreational disturbance (Yalden & Yalden 1989 & 1990), there is, as yet, no firm evidence to suggest that breeding golden plover have been impacted by wind farms. Careful research is needed (see 3.11 & 5.5) to quantify any disturbance impacts of wind farms upon breeding performance and time budgets, and to define buffer zones (see 5.2).

Clausager & Nohr (1995) concluded that the degree of impact experienced by feeding and roosting birds subject to disturbance from wind farms depends upon the species, though disaggregated data are not presented in the English summary. For some species over 95% of the birds within 250m of turbines may be affected. Geese and waders appear to be more sensitive than other groups, with disturbance effects recorded at distances up to 800m.

3.7.2 Flight Adjustment

Birds of large body mass in relation to wing surface area (those with 'high wing loading', including ducks, geese, swans and grouse) are generally 'poor' flyers and relatively unmanoeverable in the air. This is confirmed by "hit wire" indices developed from recoveries of ringed birds in the UK (Rose & Baillie 1989).

Different species probably vary in their capacities to adjust flight patterns ahead of obstacles. Raptors were considered by McCrary et al (1987, cited in Orloff & Flannery 1992) to be less likely to display evasive avoidance behaviour in relation to wind turbines than any other group. This may in part account for the substantial numbers of dead raptors found in US studies.

During observations at ten small 10-30m high 50-99 kW turbines located at six coastal wind development sites, more flight reactions were recorded amongst ducks and geese (43% of total) than other groups, and waders accounted for less than 6% of reacting birds (Winkelman 1984). Disaggregated data for "panic" responses (see 3.5.1.2c) by different species, including accelerated wing beats and tilting of the body (Winkelman 1985b; 1992c) are not presented for observations at these sites (Winkelman 1984, 1985a & b) nor Oosterbierum wind farm (Winkelman 1992c). At Oosterbierum, ducks reacted at the greatest distance from turbines. Waders reacted in flight at intermediate distances, and small passerines reacted closest to turbines. Aggregated data for "other large birds" suggested that geese behaved similarly to waders (Winkelman 1992c). Both Winkelman (1992c) and Moller & Poulsen (1984) observed ducks to panic when close to turbines.

At Blyth wind farm in Northumberland, observations of flight reactions to a line of nine 300 kW turbines located along a harbour pier suggested that cormorants do not panic, displaying few diversionary manoeuvres, and rarely approach turbines closely, whereas eider ducks did.

3.7.3 Collision Vulnerability

Waders, and to a lesser extent ducks and gulls, were found by Winkelman (1992a) to be the species groups, apart from passerines, most represented in the mortalities at Oosterbierum wind farm. US studies reveal mostly raptor mortalities, though there are implications in the methodology sections of bias in search effort and efficiency between species groups. From April 1990 to April 1992 in study areas comprising 40% of Kenetech's phase 1 Montezuma Hills wind development, 22 dead birds of 11 species were found (Howell & Noone 1992). **White-fronted geese, mallard and pintail were present, as were dunlin, red-necked phalaropes, and an unknown diver species. No waterfowl mortalities were recorded, though waterfowl activity rates were lower during the mortality search periods than at other times during the study**. 50% of all mortalities were red-tailed hawks or American kestrels. In a similar study area comprising 14% of the Altamont wind development, 182 dead birds were found between 1989 and 1991 (Orloff & Flannery 1992). 119 of these were raptors (see 3.7.3), of which 45% were red-tailed hawks, 17% American kestrels, 14% were golden eagles, 7% owls (including barn and short-eared owls) and 2% ferruginous hawks. 55% of all raptor deaths were attributed to collisions with turbines, 8% to electrocutions and 11% to collisions with wires (see 4.2).

The habit of some species of flying in line-formation, with the leading bird negotiating a line of turbines, but followers and rear birds in particular, being more vulnerable, may make these groups more susceptible to collision. There is some evidence from observations of eiders at Blyth wind farm that rear birds flew critically closer to the sweep of the turbine rotors than leading birds (Still et al 1995).

Of 46 birds "certainly", "very probably" or "possibly" killed by collision with the Oosterbierum turbines, 5 were ducks, 6 were waders, 11 were gulls, 21 were passerines, plus two kestrels and a coot (Winkelman 1992a). **The vulnerability of waders and ducks was confirmed by calibrated estimates** (see 3.5.2.2). Vaux et al (1990) found 32 dead birds of 15 species, likely to have collided with turbines at several German wind farms. Neither the species nor details of calibration attempts were given in the English summary.

Radar studies apparently suggested that birds in general were able to detect and avoid the large single 2 MW turbine at the Tjaereborg Polder (Pedersen & Poulsen 1991). Mortality searches, together with tests for (negligible) scavenger activity suggested that only 7 (unspecified) birds had been killed by colliding with the turbine or 90m anemometer, between 1987-1990 (Pedersen & Poulsen 1991).

No other European studies are known to have corrected counts of collision victims using robust calibrations to yield overall estimates of mortality.

Orloff & Flannery (1992) defined susceptibility to collision in terms of perching behaviour, flight height and feeding habit. No dead hen harriers (*Circus cyaneus* - northern harriers in North America) were found, nor were ferruginous hawks. Raptors regularly perch on turbine structures in Californian wind farms where natural perches are generally few and far between. Northern harriers frequently hunt below the minimum height (30 feet) of Altamont turbine rotor blades. Ferruginous hawks perched on turbine structures less than the more susceptible red-tailed hawks. Ravens appear to have been less vulnerable than raptors such as golden eagles, red-tailed hawks and American kestrels, in spite of frequently being observed perching on turbines and flying below the maximum blade height. Ravens appeared in the mortality statistics less than their abundance might suggest. Their very low turbine collision mortality rates may be linked to their scavenging feeding habit in contrast to the stooping behaviour (see 3.7.4) of the apparently susceptible species (Orloff & Flannery 1992). A few long billed curlews and other waders were found but no conclusions about susceptibility were drawn from this study.

Colson (1995) pointed out that it remains unknown whether birds, and visually acute raptors in particular, can see high velocity neutral coloured turbine blades when in operation (the "visibility hypothesis"). This uncertainty remains since the experiment described by Howell, Noone & Wardner (1991) to test this hypothesis was inconclusive. Current research on visual perception in American kestrels and red-tailed hawks is further investigating this question. Field experiments using pigeons as surrogate subjects suggest that they can distinguish between individually rotating turbine blades (Kenetech 1994). The visual acuity of American kestrels has been determined in laboratory experiments to be lower than that previously reported in the literature: comparable but not quite as great as that of humans with regard to capacity to distinguish rotating turbine rotor blades (Kenetech 1994). It has been suggested that the extensive blind zone of falcons in combination with its excellent flight may cause them to be vulnerable to collision with power lines (Bevanger 1994).

The generally unremarkable hearing of raptors (Howell & DiDonato 1991) may prevent auditory warning of the proximity of turbines. This consideration may diminish opportunities for the exploitation of the scaring effect of noise to reduce collision risks- see 3.8.4). It was outwith the scope of this review to systematically evaluate knowledge in this area.

3.7.4 Habituation and Learning Capacity

Raptors are excellent flyers and are believed to possess excellent eyesight, so their high representation in Californian collision mortality statistics requires explanation. Colson (1995) pointed out that it remains unknown what aspects of the behaviour of raptors makes them more susceptible to turbine collisions than waterfowl. In the US waterfowl were felt to be more susceptible to power line collisions, but not often recorded as victims of turbine collisions, in contrast to the situation in Europe.

The evidence for differences in habituation and learning capacity is equivocal. Species differences in capacity for habituation and acclimation are discussed by Winkelman (1992d), Bioscan 1995a and Clausager & Nohr (1995). Habituation may be an important factor contributing to risk of collisions in California, where the most susceptible species perch on turbine towers and in some cases upon stationary rotor blades. Orloff & Flannery (1992) also frequently observed raptors flying very close to moving blades. Habituation, particularly of resident gulls was also described by Winkelman (1985, 1992d).

It is possible that raptors such as golden eagles, red-tailed hawks or American kestrels stooping on prey might be less aware of a rotating turbine, or may misjudge the distance to rotor blades, while concentrating upon foraging. Birds often hit wires while preoccupied with hunting (Bevanger 1994). If so, collision mortality may be higher in areas of high prey density. Although Orloff & Flannery (1992) found no statistically significant correlation between their measurements of ground squirrel density and collision mortalities of their raptor predators, they believe that, below a threshold of prey abundance, the presence of prey may, in fact contribute to mortality.

Comparisons of mortality rates for older as opposed to younger, or local as opposed to migrant birds, should reveal any role that learning may play in avoidance of turbine collisions. The age profile of victims has generally not been published in European studies. At Blyth nine out of 30 casualties of known age were immature or subadult, though only two of these were the eiders (see 6.2). Immature golden eagles and red-tailed hawks featured more (Orloff & Flannery 1992) in the mortality statistics (63 & 40% respectively) than would have been predicted from their abundance in the population (48 & 16% respectively). The preliminary findings of the Predatory Bird Research Group (PBRG) at the University of California Santa Cruz supports this observation and a higher concentration of immature or non-breeding eagles was recorded within the wind development area. They also reportedly found stockpiles of ground squirrel prey at nesting sites away from the wind development, suggesting that these eagles at least did not have to expose themselves to the hazards of wind turbines (Kenetech 1994).

3.8 Wind Farm Variables & Mitigation Measures

3.8.1 Wind Farm Layout

Where wind farms are placed near migration flyways, such as at Urk and Oosterbierum, Winkelman (1989 & 1992a) recommends either a dense cluster parallel to the main migration direction, or a open cluster. Supportive evidence comes from Winkelman's finding that fewer birds probably collided with the middle row of turbines at Oosterbierum (Winkelman 1992a-Table 6).

All other things equal, placing turbines perpendicular to flight lines, and perhaps migration flyways, may increase the bird collision risk. Since flight lines often follow prevailing wind directions, the placement of turbines in optimum position and orientation for wind energy capture may result in obstacles directly in the path of local and migratory birds. The influence of turbine orientation is currently under investigation at various sites (Kenetech 1993 & 1994).

Any investigation of the role of multiplicity of structures (including masts) in promoting mortality cannot be viewed in isolation from other factors. For example the trend towards larger capacity, and generally higher turbines, will lead to fewer turbines being required to provide a given generation capacity.

In the Californian context of very high densities and total numbers, which is a poor basis for considering the UK situation, Orloff & Flannery (1992) found significantly higher mortality rates of all species at relatively lower density turbine arrays. This could suggest that high-density arrays (above a critical density) may be more effective in excluding birds.

A debate has arisen in the Californian situation as to whether end-(of)-row turbines present greater or smaller collision risks to birds. Howell & Noone (1992-Table 7) did not find end-row turbines to be statistically more likely to contribute to mortality, since collisions appeared to be randomly distributed along rows. Conversely, the data of Orloff & Flannery (1992) indicated that raptor mortality was significantly higher at end-row than at in-row turbines. Locations within a wind farm are likely to vary in their risk of impacts. Mitigation opportunities may exist for developers to resite such turbines within the wind farm area at the planning stage.

It is questionable whether findings may be extrapolated from these situations where thousands of turbines are involved to the UK situation. Few UK wind farms will exceed 20 MW installed capacity (see 2.3), and therefore most wind farms will comprise less than 60 turbines (though two large wind farms in Wales have been treated together, as the 103 turbine Llandinam development, for administrative purposes). Similarly, much Californian research into turbine orientation and location in relation to mortalities is probably of limited relevance to the UK situation.

3.8.2 Turbine Height and Design

McCrary et al (1984, cited in Colson 1995) defines the design features which may influence the frequency of bird collisions, including turbine height, blade diameter, number of blades, maximum and minimum blade heights, blade velocity, and blade sweep area. Their suggestion that the most important factors in determining the frequency of bird collisions are blade diameter and corresponding sweep area, remains untested.

Current work by Kenetech (Kenetech 1993 & 1994) is investigating whether their new turbine, the 33M-VS model presented greater or reduced collision risk to raptors. The older 56-100 model, with 18m rotor blades, normally mounted upon a lattice tower (see below) which offers more perching opportunities, has smaller and much lighter blades. The 33M-VS has 33m blades normally mounted on a tubular steel tower, rotates variably at between 12.2 and 53.5 rpm (average 29 mph), depending upon wind speed. The 56-100 model rotates at a fixed rate of 72 rpm. This difference in angular velocity means that the tips of rotor blades of the 56-100 model are moving at 152 mph in winds of 16 mph, whereas the 33M-VS have a tip speed of 112 mph. In field experiments some pigeons have attempted to fly through the blade sweep of the new and larger 33M-VS, whereas none has attempted to cross the 56-100 model's smaller rotor swept area. It is possible that the slower individual blades of the 33M-VS are more visible, and that the variable speed facility of such turbines may reduce any disturbance effects related to elevated noise levels caused by the intermittent action of single speed systems. The lattice tower, with its open structure provides perch sites which may contribute to increased collision risk (Orloff & Flannery 1992, 1996 in press). The pitch of 33M-VS blades is also variable and may be less visible at higher speeds, when it is sharp to the wind.

All other factors equal, taller structures might be expected to cause more bird mortality, since a larger proportion of birds might fly within the range of turbine height. However, taller turbines are generally more powerful, so a given generation capacity may be achieved with fewer taller turbines.

3.8.3 Need for Mitigation

The simplest mitigation is for birds to fly around the turbines. This is best achieved by avoiding the construction of wind farms in areas of even temporary bird concentrations unless site specific analyses indicate otherwise. Careful siting studies should direct wind farm development away from critical habitat (see 5.3).

High priority concerns in the US relate to ways of preventing, reducing or mitigating mortalities at wind farms (Resolve 1995). This situation has arisen largely because very large scale wind developments have been allowed to proceed in locations where birds, mostly raptors, concentrate.

3.8.4 Scaring Devices

Some turbine designs emit low frequency sound, which may be audible to birds, although there is no evidence that birds can hear ultra-sound (Colson 1995). It is possible that noise inaudible to most humans (and therefore not noise pollution) could deter approaching birds (Colson 1995). However, the scaring effects of noise, whether deliberately, or incidentally from the normal operations of turbines have not been investigated systematically. Possible deliberate scaring noises include predator calls played back randomly near problem turbines, but such measures may become ineffective as a result of habituation in the medium term. There was some indication from the single very large Tjaereborg turbine that its intermittent action may have contributed to the disturbance impacts recorded there (see 3.5.1).

3.8.5 Painting Rotor Blades

Painted blade tips (whether red or green) did not appear to make a difference to mortality estimates, though sample sizes were too small for statistical analysis (Orloff & Flannery 1992). An experiment to investigate the so-called "visibility hypothesis" that raptors may be unable to see high velocity neutral coloured turbine blades, and attempt to reduce mortality by painting rotor blades, was inconclusive due to imperfect experimental design and insufficiently large sample sizes (Howell, Noone & Wardner 1991). Following suggestions from Howell, Noone & Wardner (1991) and Orloff & Flannery (1992) Kenetech are currently conducting research into the influence of colour, contrast and speed rotation on the value of painting turbines in deterring approach by pigeons (Colson 1995; Kenetech 1993 & 1994).

3.8.6 Lighting

Illuminating other (taller) aerial structures in the USA to make them more visible to aircraft has resulted in increased bird mortalities (CEC 1995; Colson 1995). Byrne (1983) pointed out that illumination of turbines might lead to elevated collision risk, especially in poor weather, as has occurred at TV & radio masts, lighthouses and other aerial structures. There was some indication from the work of Byrne (1983) that stroboscopic illumination might reduce bird activity in the vicinity of turbines, but this has not been tested since. Many lighting options which cause light pollution may be expected to diminish the likelihood of receiving planning permission. Insufficient attention seems to have been paid to that part of birds' visual spectra not shared with humans.

3.8.7 Shutting Down Temporarily

No monitoring study has yet specifically investigated the effect of shutting down turbines upon bird impacts. Winkelman (1992c) noted that fewer migrants were recorded close to Oosterbierum, whether or not the turbines were operating. However, at Oosterbierum most collision victims were found after the wind farm became fully operative (Winkelman 1992a) suggesting that shutting down turbines during periods of elevated risk might reduce any unacceptable mortalities which arise. At Tarifa it has been suggested that if further mortalities occur during spring migration, the only feasible response would be to shut down turbines which present the greatest hazard to birds, during high risk periods. These were assumed to be only at certain times of day, and in those wind conditions when most flocks come through during peak migration (Pennycuick 1994). However, it should be pointed out that such mitigation would, in all probability, be unacceptable to developers on economic grounds, unless restricted to brief periods of elevated risk such as dusk and dawn during peak migration.

3.8.8 Removing and Relocating

This is the ultimate fate of any turbine which is proven to cause unacceptable bird losses.

3.9 Ornithological Sections of Environmental Statements

Potential disturbance impacts have been largely ignored by Environmental Statements (ESs). It is worthwhile noting that the Bryn Titli ES (Nicholas Pearson Associates 1993) did not predict the deterrent effect upon habitat use by raptors and ravens (Green 1995a & b).

In the US, in the light of recent experience of raptor mortalities at some locations a major concern is for developers to develop the ability to predict avian mortality at new sites (Resolve 1995). In the UK this should be an integral part of the Environmental Statement (ES) process. Unfortunately many ESs examined to date have not really addressed this question in scientific terms. There are however good examples of the differing approaches from various developers (e.g. Yorkshire Windpower 1990; Trigen (Kintyre) 1995, Bioscan 1995b, Border Wind 1994b).

Bird surveys are directed towards the identification of all species which may be exposed to impacts as a result of wind farm construction and operation, and all environmental (weather and habitat) factors which might conspire to produce significant negative impacts. It is helpful to present these as a thorough Potential Environmental Impact Matrix (Yorkshire Windpower 1990 - Appendix 4, Table 1). Careful evaluation of the risks to key species associated with particular sites may be necessary (e.g. Spaans & van den Bergh 1994 & 1995).

The identities of all birds utilizing the site (and therefore potentially at risk) are sought from published information and local experts to determine the ornithological significance of the site. Ornithologically significant sites generally receive a ground survey. Several ESs have identified raptors such as peregrine, hen harrier, short-eared owl, merlin, buzzard, sparrowhawk and kestrel, as being at some risk from collision. Others have identified Greenland white-fronted geese as being potentially at risk from collision or disturbance (NGT (Scotland) 1994a & c; Border Wind 1994b; Trigen (Kintyre) 1994; Trigen (Hill of Forss) 1994; Woolerton Dodwell Associates (1995c). Some predicted that goose flight lines might be constrained, one suggested that there would be no effect (acknowledging that any additional mortality would be unacceptable), while others claimed that impacts upon this species would be insignificant. Trigen (Kintyre) commissioned a risk assessment (Spaans & van den Bergh 1994 & 1995) to support their application.

An adequate baseline of avian and land use data is essential for the Before-After Control-Impact (BACI) (Green 1979; Underwood 1992) approach to impact monitoring. Too few ESs have involved the collection of pre-construction data at control sites, and none have involved more than one control site, though such data are probably essential to effective monitoring.

Derived from the methods of Orloff & Flannery (1992) ten minute scan total bird counts have been used to quantify relative bird activity at various prospective UK wind farm sites (Lawrence 1995 a & c). They typically range from 0.1-1.7 birds/10 minute scan. An extreme upper point of 2500-3500 was recorded at Blyth harbour (Still et al 1995). Typical figures for California include 2.038 birds/10 minute scan (Howell & Noone 1992).

Attempts are often made to identify species potentially vulnerable to collision with turbines by estimating flight height range at the locations of proposed turbine strings and flight lines between feeding and roosting areas (Lawrence 1995a & c). Often such attempts at collision risk assessment suggest low or negligible risk. For example MANWEB (1994a) found no preferential flight paths for birds flying in the vicinity of the turbines and that the majority of birds were flying below the height of the turbines.

Bird movements are typically recorded as flight lines through ground survey, to determine the likelihood of any birds flying between feeding and roosting areas interacting with turbines. The possibility of feeding or roosting birds being disturbed by construction activities and turbine operation is usually assessed. The absence of firm evidence on the required size of buffer zones (see 5.2) make such prediction very difficult. The influence of unusual or inclement weather conditions should be assessed.

In some ESs the likelihood of some collision mortality is accepted, and the vulnerability of particular species may be highlighted. At the Hill of Forss site proposed by the Danish developer NGT there was "no doubt that some birds will be killed as a result of colliding with the rotors or the towers, but it is not possible to predict how many or which species will be affected." Laybourne (1992) felt it likely that groups of migratory swans and geese "would descend on approaching the coast and could be in danger of colliding with towers and rotating blades of the generators". The ES suggested that nocturnal migrants would be forced down to lower levels in fog, thereby increasing the risk of flying into turbines, but did not estimate risk nor numbers of birds that will be killed. Geese were felt to be at greater risk because they sometimes fly along the ridges and the higher ground (NGT (Scotland) 1994a).

To date, only one UK monitoring study (Still et al 1994 & 1995) has been running for sufficient time to permit the predictions of possible impacts contained in the ES to be tested against practice. At Blyth harbour wind farm the potential impacts identified in the ES (Regen 1991) included "interference with bird life especially waders", and the risk of disturbance to wintering purple sandpipers was highlighted. After three years of monitoring it was concluded that no direct or indirect adverse effects of the wind farm on this species was identified. However, the collisions recorded (Still et al 1995) and the apparent susceptibility of eider ducks were not predicted by the ES. The accuracy of predictions contained in ESs should be audited so as to improve environmental impact assessment at other sites (see 5.5.8).

3.10 Gaps in Knowledge

It is unknown whether larger turbines, with slower operation speeds, but required in fewer numbers, present greater or fewer hazards to birds.

The size of buffer zones within which disturbance effects may be detected remains in need of further work (see 5.2).

Bioscan (1995a) have pointed out that there have been no studies undertaken to investigate any special risks to birds whose **hunting** or **display** behaviour during breeding season might bring them into direct contact with rotating blades (e.g. hen harrier, merlin, short-eared owl, golden plover, lapwing, curlew, snipe and dunlin).

There are often insufficient data, on the sex and age of collision victims, or upon changes in breeding success to conduct Population Viability Analysis (PVA) as part of risk assessments.

3.11 Research Requirements

Given the paucity of field data in relation to operating wind farms it is difficult to obtain more than an anecdotal feel for likely impacts. The highest research priority should be the establishment of a series of carefully designed monitoring studies, while the wind industry is still in its infancy in the UK, so more substantial datasets can be provided for analysis. Given the current rapid expansion of the industry, **matched studies with control sites and adequate sample sizes should be possible to set up if sufficient co-ordination between developers occurs.** Furthermore, since both land use and human disturbance can be manipulated, well-designed research should be capable of disentangling wind farm impacts from confounding changes (Bioscan 1995a).

There are many pitfalls to statistical analysis and the authors of some of the reports reviewed have fallen into them. Lack of control sites has led to the influences of changes in land use and farming practices, disturbance from visitors and other researchers, confounding identification of wind farm impacts. Future monitoring studies should ensure that study findings accurately separate wind farm impacts from changes which occur naturally or as a consequence of other activities in the immediate vicinity (Bioscan 1995a).

Complete randomization is impossible to incorporate in the design of field environmental impact studies, so the Before-After Control-Impact (BACI) design (Green 1979; Underwood 1992) is recommended. The BACI approach to environmental impact assessment suffers to a certain extent from its advocacy of a single control site, and the possibility that baselines may be collected over an insufficient period to reveal statistically significant change. Where possible two or three control sites may be used for each wind farm site, and time-series data should be collected at replicate sampling locations within each control and wind farm site (Nudds 1995).

A carefully agreed standardized methodology for data gathering and reporting at a variety of matched sites might go some way towards reducing these problems. The problem of lack of replication in all environmental impact studies, even where the BACI model has been adopted, is a further problem. This may be addressed by Adaptive Resource Management (ARM) - an iterative approach in which policies are treated as hypotheses and management actions are treated as experiments (Walters 1986; Walters & Holling 1990). The ARM approach also offers some promise in research directed both towards mitigating impacts in pre-existing sites, and towards reducing uncertainty about the effects of new wind farms upon birds (Nudds 1995).

Confident predictions about the nature and scale of impacts at a prospective wind farm site can only be made on the basis of calibrated observations or carefully designed experiment. Standardized survey techniques for the collection of baselines as part of environmental assessment and the production of Environmental Statements, need to be defined.

In most studies examined, it is clear that **adequate resources for the collection of sufficient baseline data analysis of relevant data are essential for the identification of wind farm impacts**. This implies that funds for intensive monitoring may need to be targeted at particular sites.

Knowledge of bird behaviour can be used to identify factors which may predispose certain species to particular impacts at certain times. Such opinions may be useful for targeting future research and for scoping environmental impact assessment. Similarly evidence of impacts from other aerial structures can help identify species which might be vulnerable to collisions in general. However, the usefulness of extrapolation from such studies may be limited because the likelihood of impacts is highly connected with factors such as a structure's visibility (Bioscan 1995a).

The lack of information on impacts of disturbance on breeding birds in moorland habitats needs to be rectified. At any moorland site where monitoring of breeding bird impacts may be considered necessary, one approach might be to find, and study reproductive success at, all nests within a critical distance of the turbines. For a BACI study this should also be done at a control site nearby.

The nature, risk and extent of possible impacts of wind farms on birds in all habitats need to be evaluated. **Research is needed in habitats likely to be the subject of future proposals, but for which insufficient information is currently available such as grass, farmland and moorland habitats and wetland and offshore locations.**

CHAPTER 4 - IMPACTS OF OTHER AERIAL STRUCTURES UPON BIRDS

4.1 Introduction

Impacts upon birds are often considered to be greater and more extensive for other man-made obstacles in the environment than for wind farms (Winkelman 1984-1995, Ornis Consult 1989, Pedersen & Poulsen 1991, Still et al 1995). There appears to be a lack of comparative estimates of fatal mortality associated with different aerial structures. Some of those that have been attempted give such a wide range as to undermine their usefulness in comparative analysis. For example, in the USA, Klem (1990 cited in Colson 1995), has estimated 98-976 million annual bird deaths attributable to collisions with windows. After conducting an extensive review, incorporated into CEC (1995), Avery et al (1980) suggested that 200,000,000 birds are killed annually by flying into all man-made structures in the USA, out of 5,000,000,000,000 bird deaths per year attributable to all non-natural causes.

Winkelman has estimated that 21,000 to 46,000 extra bird deaths per year might be caused by the installation of 1,000 MW of wind generating capacity in the Netherlands (Winkelman 1995). This can be compared with current estimates of 1-2,000,000 bird deaths attributable to collisions with power lines in the Netherlands, and 2-8,000,000 deaths on Dutch roads.

It should be realised that aerial structures probably differ in their visibility to birds so it is not possible to quantify effects at wind farms by extrapolating from bird impact studies for such structures (Bioscan 1995a). This may be especially the case for weather induced mortalities at very tall TV and radio masts, where there are numerous reports of over 10,000 birds having died from collisions in single nights (CEC 1995). SGS Environment (in prep.) also conclude that it is not reasonable to make extrapolations regarding the likely ecological impacts of wind energy developments on the basis of studies undertaken at other tall man-made structures.

4.2 Meteorological Masts or Anemometers

There appears to be an absence of confirmed mortalities in the UK caused by birds colliding with anemometers or their guy wires. Considering California, Colson (1995) stated that it is known that birds have died by such collisions but Pedersen & Poulsen (1991) concluded that 7 out of 15 corpses found "had collided with the wind turbine or meteorological mast", but the two potential causes of collision mortality were not distinguished in the English summary.

Orloff & Flannery (1992) found no mortalities near 48 meteorological masts, most of which were supported by guy wires, at their Altamont sample sites. Two birds collided with guy wires or the masts they supported at the single Solano turbine in California (Byrne 1983). None of the 175 annotated references (see 4.3) to studies involving birds colliding with TV, radio and other masts (CEC 1995) related to meteorological masts.

In the USA it is recommended that guy wires are no longer used to support aerial structures at wind farms (Colson 1995 - 5-1 and 3-6) because it is felt that they may present effectively invisible hazards to birds. Whether such a guideline is necessary in the UK is not yet clear.

It would appear from the very limited data available that anemometers may cause fewer collision mortalities than wind turbines and other aerial structures.

4.3 Pylons & Power Lines

Collisions with overhead wires have been studied in the USA for at least 120 years (CEC 1995). Many of the current issues of concern are discussed in the proceedings of a conference of the Electric Power Research Institute (EPRI) and the Avian Powerline Interaction Committee (APLIC) held in Miami in December 1993 (EPRI 1993). The APLIC has apparently guided the Avian Wind Sub-committee of the NWCC (see 2.2.1) in establishing itself (Resolve 1995), and both fora now offer unrivalled opportunities for co-ordinated strategic monitoring (see 5.5).

In a wide ranging literature search of 468 references from 1876 to 1992 on avian collision and electrocution, the California Energy Commission (CEC) published 121 annotated references on power line impacts, and a further 50 references on other overhead wires (CEC 1995). Eighty-one of these references concern mitigation measures, but many are anecdotal. The annotated references include those previously collated by Avery et al (1980) who has extensive experience in this area, including investigations of the influence of scavenger activity and weather on mortality rates (Avery et al 1978 & 1980). CEC invite further unpublished sources, and maintain an archive in their Environmental Protection Office in Sacremento, California.

There is a suggestion in the literature (Scott, Roberts & Cadbury 1972) that orienting even low tension power lines parallel to flight lines and flyways may reduce collision and electrocution risk. In that study 21 mute swans out of a flock of 70 were electrocuted along 400m of power line in the two months following its erection. In an investigation of 128 swan mortalities at the Ouse washes (Owen & Cadbury 1975) found that 38% were due to collision with power lines. Orloff & Flannery (1992) attributed 11% of 119 raptor deaths they recorded in sample sites at Altamont to collisions with wires including power lines.

As part of an investigation into bird mortality associated with the Blyth wind farm (Still et al 1995) areas where 5 sets of power lines cross an estuary were checked for collision victims within an area of 3.5 ha. Twenty one collision victims were found but unquantified scavenging was detected and effort was not specified so the significance of this finding requires further investigation.

Risks of electrocution can now be avoided through improved design of pylons and other structures, and in the US mitigation measures introduced at older wind farms have substantially reduced incidence. Guidelines of the APLIC have been published (Colson 1995- Table 2) which aim to avoid bird electrocutions and reduce risk of wire collisions. Seventy four annotated references are given in CEC (1995).

It appears that higher collision rates for the thinner ground wires may be attributable to the greater visibility of the thicker conductive wires (Alonso et al 1994; Petty 1995). At Tarifa in Spain, Griffon vultures have reportedly been electrocuted, but until the definitive SEO (1994) report is translated, it is not possible to quantify the incidence.

Estimates of capercaillie and black grouse mortality caused by collisions with power lines in Norway have recently been reported and the population consequences were concluded to be comparable to the annual hunting harvest (Bevanger 1995). In a review of the influence of biological, topographical and meteorological aspects upon the risk of power line collisions, Bevanger (1995) highlit the vulnerability of "poor" flyers (see 3.7.2), some raptors and other "fast strong" flyers (see 3.7.3 & 3.7.4).

4.4 Fences and Buildings

Fences are sometimes introduced as part of wind farm construction or habitat enhancement schemes designed to compensate for impacts.

Catt et al (1995) estimated a fence collision mortality rate of 32% per year for male capercaillie, additional to 23% annual mortality from other causes. The population consequences are sufficient to warrant widespread mitigation attempts and the removal of unnecessary fences. This study of the impact of fences upon woodland grouse in the Cairngorms is being expanded within the Scottish Highlands and further results are described in Petty (1995). Data on red and black grouse suggest that these species may be a little less vulnerable to collision.

Eighteen references on bird-fence collisions, including 2 concerning mitigation are given in CEC (1995).

None of the buildings commonly associated with wind farms such as switching houses are likely to give rise to elevated bird impacts.

CHAPTER 5 - STRATEGIC APPROACHES

5.1 Introduction

With the volume of wind farm proposals arising in or near moorland, wetland and offshore locations it is clear that a strategic approach is needed (see 3.11).

5.2 Buffer Zone Definition

In any study of disturbance and other impacts of development, it is important to recognize the range of types and intensity of disturbance effects. It may be possible to draw on experience gained from studies of disturbance impacts of roads (van der Zande, Terkeurs & van der Weijden 1980; Keller 1991; Reijnen et al 1995). Management guidelines should be presented, for example, as a practicable range of buffer zone distances. Reijnen et al (1995) proved the effect, almost certainly, of traffic noise on birds up to 2.8 km away from busy roads.

This subject needs much more rigorous fieldwork and analysis. Although some data exist, they cannot yet be used as the basis of setting guidelines. It should be possible, with a co-ordinated research programme, to establish replicated wind farm and control sites and determine the required size of buffer zones.

Two areas are in particular need of work and should be regarded as a high priority for all those concerned about the disturbance impacts of wind farms upon birds:

5.2.1 Flight line avoidance

Depending upon topography (3.6.3) and species (3.7.2) birds may avoid wind farms or interact closely.

5.2.2 Disturbance to breeding, feeding and roosting birds

Clausager & Nohr (1995) recommended buffer zones of up to 800m in order to reduce possible disturbance impacts. In Denmark, planning constraints already prevent wind turbines being sited within 150m of large streams and lakes larger than 3 ha, and within 100m of the coast (Benner et al 1992 cited in Colson 1995).

5.3 Indicative Zonation

Recognizing that the need for mitigation may be avoided by careful siting studies, the American state of Wisconsin has developed a wind farm siting guidance (Ugoretz 1994) which emphasizes the need to avoid both designated and undesignated bird habitats.

Several Scottish local planning departments have produced indicative zonation plans which identify "preferred areas of search" for potential wind farm sites. These include Highland Regional Council (HRC 1995), Strathclyde Regional Council (SRC 1995), Clydesdale District Council (CDC 1995), Argyll & Bute District Council (ABDC 1995) and Borders Regional Council (BRC 1995b). All councils are expected to do so (Scottish Office 1994b).

Unfortunately the input of ornithological data has been variable to date, though close consultation with SNH may improve the situation.

5.4 Offshore Locations

Disturbance (mainly of ducks) by an offshore wind farm at lake IJsselmeer in the Netherlands is being studied by Dr. A. Spaans of the Dutch Institute for Forestry and Nature Research. Ornithological monitoring is also being undertaken by Ib Clausager of NERI at a Danish offshore wind farm comprising 10-12 turbines (Winkelman 1995). Following Danish and Dutch offshore experience, and proposals for facilities on the shallow submarine platforms between Sweden and Denmark.

Following early proposals for an offshore wind farm in the Wash, in Northumberland the first offshore UK plans have recently been formulated (D. Still *pers. comm.*).

5.5 Recommendations

5.5.1 A series of carefully designed monitoring studies involving several matched wind farm and control sites, selected to separate impacts solely attributable to wind farms from confounding influences (3.11).

5.5.2 In the UK ETSU have funded several pilot monitoring studies, reviewed by SGS Environment (in prep.). In the US a cost-sharing scheme between developers and government has part-subsidised the cost of ESs and bird monitoring schemes. To improve the co-ordination of UK studies it may be helpful to advocate a 'round table' forum in the UK, similar to the Avian Sub-committee of the NWCC (see 2.2.1).

5.5.3 With a 'round table' approach it may be possible for conservation agencies to direct developers' monitoring resources towards those sites which cause greatest concern. Sites selected for detailed and long-term monitoring should ideally include replicated wind farm and control sites, used by sufficiently large numbers of key species (see 3.3) for robust statistical analysis.

5.5.4 Sufficient resources for the collection of adequate baseline data, and analysis of relevant data are required, reinforcing the need for co-ordination and targeting upon particular sites (3.11).

5.5.5 It would appear that wind farm developments should avoid areas heavily used by red kites, and treat with caution the possibility of impacts upon peregrine and hen harrier (Green 1995b).

5.5.6 Future monitoring resources may need to be focused upon moorland, wetland and eventually, offshore locations.

5.5.7 Once a lead agency for avian-wind power issues has been identified or an individual come forward, like Tom Gray (tomgray@econet.org) of the American Wind Energy Association in the USA, a home page and points of access to information could be placed upon the World Wide Web on the Internet.

5.5.8 The accuracy of predictions contained in ESs should be audited so as to improve environmental impact assessment at other sites.

Chapter 6 - CONCLUSIONS

Assessment Of Impacts On Birds

This review has supported most of the conclusions drawn by Crockford in 1992. Most of the studies then available have been re-examined to permit more focused consideration of key species, and the influences of weather, topography and possible mitigation.

Perhaps, the main conclusion, drawn from a review of available literature, is that each prospective wind farm site has unique environmental and engineering features which combine with the bird species present to create a range of issues which should be addressed individually.

Early attempts at typologies of wind farm sites by habitat are useful in making comparisons between habitat types, contributing to indicative zonation and buffer zone definition. However, it is neither possible nor desirable to generate a site- nor a species-index of probability of impact.

Key species which are likely to be sensitive to disturbance, caused both by the construction and operation of wind farms, include **raptors, divers, geese and waders**. Conversely, in spite of being known to be sensitive to recreational disturbance, there is as yet no firm evidence to suggest that breeding golden plover have been impacted by any wind developments in the UK. Roosting purple sandpipers, gulls and cormorants appeared to display high tolerance to disturbance during both construction and operation of a coastal wind farm. However, there is now **evidence for the sensitivity of foraging raven and red kite, and to a lesser extent, other raptors, to disturbance from an operating moorland wind farm**.

Some authors have tried to draw inferences about turbine collisions by extrapolating from wire collision studies (e.g. Rose & Baillie 1989). The usefulness of this approach can been questioned, as such wires probably differ in their visibility to birds from wind turbines.

Despite the large amount of work carried out in Altamont Pass in California, primarily upon raptor collisions, any evidence must be treated with caution. The context of very high raptor and turbine densities, and total turbine numbers (7,340 turbines) makes comparison with the low density and relatively small number of turbines which comprise proposed UK wind farms difficult. It is also worth sounding the same note of caution in cases of evidence gathered at very large single turbines, for example, at Burgar Hill on Orkney and Tjaereborg in Denmark.

European collision mortality data relates much more to waders, wildfowl, gulls and passerines, and suggests much higher collision rates per turbine. However, despite the lack of comparable, properly calibrated estimates, some authors have attempted to summarise mortality rates from published sources. Such information should be treated with extreme caution, since **all such studies underestimate, to varying degrees the number of victims caused by wind turbines**.

In spite of the challenges of accurate calibration, daily, seasonal or annual mortality rates per turbine are useful to make comparisons between the likely effects of wind farms in the contexts of different weather conditions, landforms, species, turbine layout, height and design. The studies collected for review demonstrated an unfortunate lack of attempts at such calibration, therefore most such comparisons are both flawed and misleading.

The need to compare 'like with like' cannot be over stated. Of use in trying to gauge the likely impact on birds of proposed wind farms in Scotland are studies at the Urk and Oosterbierum wind farms in the Netherlands. However, the topographical and climatic differences complicate extrapolation from the Dutch situation.

At Urk wind farm on the Dutch coast, the only 'certain' or 'very probable' collision victims were found after nights of poor visibility and more often following a combination of poor visibility and bad flying conditions. The influences of weather may be even more likely to contribute to collision risk in northern and western Scotland.

A further note of caution has become apparent during the collation and interpretation of bird impact studies from around the world: reliance on translations of foreign language reports, which in many cases exist only as summaries, can lead to misinterpretation of results and can limit the possibility of drawing wider inferences from the given results.

Most studies, to date, suffer from a lack of adequate control or baseline data. In the absence of such data it is not possible to demonstrate cause and effect, and such evidence should be regarded as anecdotal and therefore only suggestive of possible effect. When considering the potential impact of a proposed wind farm possible additional sources of impact should also be taken into account. At Urk, for example, some of the recorded changes in bird activity could have been the result of increased human disturbance created by the presence of a visitors centre and the frequency of visits to the site by a variety of research personnel. Other potentially confounding variables include fluctuations in habitat usage by birds, land use change and adjustments to farming practice which may alter the amount of food available to birds.

The simplest mitigation is for birds to fly around turbines. This is best achieved by precluding the erection of wind farms in areas of even temporary bird concentrations, unless site-specific analysis indicates otherwise. Careful siting studies should be used to direct wind farms away from critical habitats. Due regard should also be given to topographical features such as ridges and valleys which could cause birds to be concentrated in the area of a wind farm. Here, the influence of unusual or inclement weather conditions should also be assessed.

Different species vary in their capacities to adjust flight patterns ahead of obstacles. Studies at Urk, Oosterbierum and Blyth harbour wind farms permit some specific conclusions relevant to the UK situation. These should not be used to make general predictions about risk. Again it must be stressed that risk assessment must be undertaken on a species- and site-specific basis.

Should significant disturbance or displacement take place, it is possible that populations may subsequently occupy nearby habitats, if available and suitable. Such a possibility should be considered in the context of the differing requirements of breeding, feeding, roosting and migrating birds.

However, it should be noted, that by avoiding habitats in the vicinity of wind farms, birds may incur higher energetic costs, which could become a critical factor in breeding success. Alternatively, the energetic constraints experienced by breeding birds could lead them to make closer approaches to turbines during the breeding season and thus result in higher mortality rates.

If all other factors are equal, taller structures might be expected to cause more collisions, since a larger proportion of birds might fly within the area swept by the turbine rotor. However, taller turbines are generally more powerful, so a required generation capacity can be achieved with fewer turbines, which in turn could result in a reduction in the likely number of bird collisions. The relative influences of other turbine design characteristics, including possible mitigation measures remain uncertain.

The significance of mortality and disturbance needs to be considered in both species impact and planning terms, as well as for good public relations and the maintenance of the high environmental credentials of the wind industry. In view of the rapid growth of the industry, cumulative impacts upon bird populations will need to be carefully assessed.

To accurately assess the biological significance of bird mortality at a wind farm it is necessary evaluate additional mortality against criteria such as risk of population decline or local extinction. This may require data on the genetics, sex and age structure, and temporal and spatial dynamics of the population concerned. If available, such data may be used to model the viability of the population under scenarios of additive (e.g. adult breeders in long-lived species, with high adult survival rates and low reproductive potential) or compensatory (e.g. juveniles or non-breeders in fecund species of high reproductive turnover) mortality.

Such Population Viability Analyses (PVA) permit an assessment of the likelihood of **population decline or local extinction** to be made. Unfortunately such data are only available for a handful of species for which PVA night be considered worthwhile in the context of potential wind farm impacts. In the absence of such data, evaluation will continue to be made against rigid and semi-subjective criteria, and precaution may prevent the proposed wind farm from receiving planning permission.

Data on the age, sex and breeding status of casualties not only improves risk assessment, but might also cast some light on the capacity of specific populations to learn to avoid obstacles such as wind turbines. Long term population census data could reveal any tendency towards size fluctuations, in the troughs of which additive mortality caused by farm collisions might be considered especially threatening.

Very little data of these types have been collected in wind farms studies to date. At Blyth harbour wind farm ten of the twelve eider collision victims found were adults: the additional adult mortality possibly representing a significant impact in this relatively long-lived species. The population consequences are probably less severe than those arising from deer fence collisions by capercaillie in pine forests or swans flying into power lines located near estuaries.

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APPENDIX

Species Referred To In Report Text

Red-throated Diver	*Gavia stellata*
Black-throated Diver	*Gavia arctica*
Great Northern Diver	*Gavia immer*
Cormorant	*Phalacrocorax carbo*
Mute Swan	*Cvgnus olor*
Bewick's Swan	*Cvgnus columbianus*
Whooper Swan	*Cvgnus cygnus*
Bean Goose	*Anser fabalis*
Pink-footed Goose	*Anser brachyrhynchus*
White-fronted Goose	*Anser albifrons*
Greylag Goose	*Anser anser*
Canada Goose	*Branta canadensis*
Barnacle Goose	*Branta leucopsis*
Brent Goose	*Branta bernicla*
Shelduck	*Tadorna tadorna*
Mandarin	*Aix galericulata*
Wigeon	*Anas penelope*
Gadwall	*Anas strepera*
Teal	*Anas crecca*
Mallard	*Anas platyrhynchos*
Pintail	*Anas acuta*
Garganey	*Anas querquedula*
Shoveler	*Anas clypeata*
Pochard	*Aythya ferina*
Ferruginous Duck	*Aythya nyroca*
Tufted Duck	*Aythya fuligula*
Eider	*Somateria mollissima*
Turkey Vulture	*Cathartes aura*
Honey Buzzard	*Pernis apivorus*
Red Kite	*Milvus milvus*
Black-shouldered Kite	*Elanus caeruleus*
White-tailed Sea Eagle	*Haliaeetus albicilla*
Hen or Northern Harrier	*Circus cyaneus*
Goshawk	*Accipiter gentilis*
Sparrowhawk	*Accipiter nisus*
Sharp-shinned Hawk	*Accipiter striatus*
Cooper's Hawk	*Accipiter cooperii*
Buzzard	*Buteo buteo*
Red-tailed Hawk	*Buteo jamaicensis*
Red-shouldered Hawk	*Buteo lineatus*
Broad-winged Hawk	*Buteo platypterus*
Fegguginous Hawk	*Buteo regalis*
Swainson's Hawk	*Buteo swainsonii*
Rough-legged Buzzard or Hawk	*Buteo lagopus*
Bald Eagle	*Haliaeetus leucocephalus*
Golden Eagle	*Aquila chrysaetos*

Osprey	*Pandion haliaetus*
Kestrel	*Falco tinnunculus*
Merlin	*Falco columbarius*
Eleonora's Falcon	*Falco eleonorae*
Peregrine	*Falco peregrinus*
Red Grouse	*Lagopus lagopus*
Ptarmigan	*Lagopus mutus*
Black Grouse	*Tetrao tetrix*
Capercaillie	*Tetrao urogallus*
Coot	*Fulica atra*
Golden Plover	*Pluvialis apricaria*
Lapwing	*Vanellus vanellus*
Dunlin	*Calidris alpina*
Purple sandpiper	*Calidris maritima*
Snipe	*Gallinago gallinago*
Curlew	*Numenius arquata*
Redshank	*Tringa totanus*
Red-necked Phalarope	*Phalaropus lobatus*
Black-headed Gull	*Larminus ridibundus*
Common Gull	*Larus canus*
Lesser Black-backed Gull	*Larus fuscus*
Herring Gull	*Larus argentatus*
Great Black-backed Gull	*Larus marinus*
Common Tern	*Sterna hirundo*
Barn Owl	*Tyto alba*
Short-eared Owl	*Asio flammeus*
Carrion/Hooded Crow	*Corvus corone*
Raven	*Corvus corax*
Fox	*Vulpes vulpes*

Scottish Natural Heritage

Scottish Natural Heritage is an independent body established by Parliament in 1992, responsible to the Secretary of State for Scotland.

Our task is to secure the conservation and enhancement of Scotland's unique and precious natural heritage - the wildlife, the habitats, the landscapes and the seascapes - which has evolved through the long partnership between people and nature.

We advise on policies and promote projects that aim to improve the natural heritage and support its sustainable use.

Our aim is to help people to enjoy Scotland's natural heritage responsibly, understand it more fully and use it wisely so that it can be sustained for future generations.