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A synthesis

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VINDVAL

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Preface

There is a great need for knowledge concerning the impact of wind power on humans and landscapes, the marine environment, birds, bats and other mammals. Previous studies regarding the environmental impacts from wind farms have lacked an overall view of the effects. This has led to deficiencies in the processes of establishing new wind farms. Vindval is a program of knowledge and a cooperation between Energimyndigheten (Swedish Energy Agency) and Naturvårdsverket (Environmental Protection Agency). The purpose of the program is to collect and provide scientific knowledge of wind power impacts on humans and nature. The commission of Vindval extends to 2013.

The program comprises about 30 individual projects and also four so called works of synthesis. Syntheses are prepared by experts which compile and assess the collected results of research and experience regarding the effects of wind power within four different areas – humans, birds/bats, marine life and terrestrial mammals. The results of research and synthesis work will provide a basis for environmental impact assessments and in the processes of planning and permits associated with wind power establishments.

Vindval requires high standards in the work of reviewing and decision making regarding research applications in order to guarantee high quality reports. These high standard works are also carried out during the reporting approval and publication of research results in the projects.

This report was written by Jens Rydell, Biology Department, Lund University. Henri Engström, The Swedish Ornithological Society and the Center of Evolutionary Biology, Uppsala University. Anders Hedenström, Biology Department, Lund University. Jesper Kyed Larsen, Vattenfall Wind Power, Fredericia, Denmark. Jan Pettersson, JP Fågelvind, Färjestaden and Martin Green, Biology Department, Lund University.

This report is a translation of the previous report in Swedish ”Vindkraftens effekter på fåglar och fladdermöss” (Naturvårdsverket report no 6467). The authors are responsible for the content.

Vindval in August 2012

Summary

- The wind power industry almost certainly faces a considerable expansion within the near future in Sweden and elsewhere, and it is probably unavoidable that birds and bats will be killed or otherwise affected negatively to some extent. However, we believe that an increase in wind power production according to the national plan (30 TWh until the year 2020) is compatible with the preservation of viable populations of all bird and bat species in Sweden. The risk of negative effects can be limited considerably by planning and cooperation and by using the available information. On the other hand, there are also considerable gaps in our knowledge and these should be filled in order to minimize the uncertainties during future projects.
- We have reviewed the existing (2010) literature on the effects on wind farming on birds and bats in Europe and North America. The information has been analyzed with respect to species and groups of species, their occurrence and behavior and also according to the location and size of wind farms and wind turbines. The identified effects may be either direct, when animals are killed, or indirect, when their habitats are changed as a consequence of the establishment or operation of wind energy facilities. The indirect effects are believed to be relatively small for bats but they are probably the most important for birds. We have not reviewed effects arising from construction of power lines, extraction of materials for construction, changed hydrology and the like.
- A wind turbine in Europe or North America kills on average 2.3 birds and 2.9 bats per year. These are median values, however, and the variation is large (0-60 birds and 0-70 bats) and the distribution uneven (bimodal). While most wind turbines actually kill none or very few birds and bats, some turbines kill many. The location of a wind farm in relation to the local topography and surrounding habitat is the primary determinant of the number of birds and bats that will be killed.
- By far the most important measure that can be taken to minimize the risk of negative effects on birds and bats is to identify the dangerous locations and avoid locating wind turbines there. Most accidents with birds occur in places where they concentrate, such as near wetlands and bodies of water, but sometimes also in elevated sites including peaks and ridges of hills and mountains. For bats the most dangerous locations include coastlines and the top of distinct hills, but linear landscape elements such as lake shores, rivers, motorways, and, on a smaller scale also tree-lines, hedgerows and the like should also be considered as potentially risky. In contrast, in areas of intensively managed forest or open farmland the effect of wind turbines on birds and bats are usually small, particularly in flat terrain.

- Most future wind farm establishments in Sweden will probably be allocated to elevated sites within any of the two major forest regions. Such locations are generally not considered dangerous for birds and bats, but recent evidence from Germany and USA suggests that wind turbines located in such places sometimes are very dangerous to bats. Unfortunately, there is no information on the reaction of bats to wind turbines at high elevation forest sites in Sweden. This requires investigation as soon as possible.
- All flying birds may potentially collide with wind turbines. However, raptors, grouse and their allies, and also gulls and terns tend to collide more often than expected from their occurrence and numbers. Birds that breed, stop over or overwinter in a particular area, and thus spend more time there, face a higher risk to collide with wind turbines, compared to birds that pass over during migration. The fatality rate at a certain wind farm generally does not decline with time, which indicates that birds do not learn to handle the problem.
- There is no evidence that present or planned (30 TWh until 2020) wind farming in Sweden will affect any bird population at the national level, although eagles and other large raptors, as well as some waders, could possibly be affected locally or regionally. Nevertheless, particular attention is needed in areas where raptors are concentrated and in places with higher densities of breeding waders such as coastal meadows, bird islets and some bogs and mountain locations.
- Birds, with the possible exception of swallows and swifts, are normally not attracted to wind turbines. Instead, they either avoid or ignore such installations, and this applies both to land based and off shore wind farms. During the breeding season the disturbance range is usually short or difficult to determine, but its presence is more obvious in waders than in other birds. Furthermore, it is more obvious at other times of the year, particularly in water birds that live in flocks, including divers, geese, ducks and waders. Disturbance reactions usually become obvious within 100-500 m from the turbine, but for some birds such as divers, the distance can be longer.
- Bird densities in areas used for wind farming may either decrease or increase with time. We have been unable to find any general trends in this respect, however, although many high quality studies have been reviewed. The same situation applies to habituation, which means that the behavioral disturbance effects may either increase or decrease with time. If the densities and behavioral effects increase, decrease or remain stable over time seems to depend on the bird species in question and the particular situation.
- Migrating seabirds usually avoid flying close to wind turbines both in daytime and at night. In daylight, obvious changes in the flight paths occur at 1-2 km (sometimes 5 km) from the turbines, but at night the reaction becomes obvious only at 0.5-1 km. The change in

flight direction may lead to barrier effects and hence longer flight paths around the wind farms. On the other hand, accidents with migrating seabirds at marine wind farms seem to be very rare.

- Bats are killed at wind turbines as they hunt for insects that accumulate around the turbine towers. The immediate causes of death may be either fractures resulting from collision with the rotor blades, or ruptures of blood vessels or lungs visible as internal hemorrhaging. In the latter case, the damage is caused by rapidly falling air pressure behind the rotor blades. The accidents usually (90%) occur during warm nights with slow wind speed in late summer and autumn (late July to September), but sometimes also in spring (May to early June). Very few bats are killed at wind farms in the middle of the summer and during the winter season. Like bats, swallows and swifts are also killed while feeding on insects at wind turbines, but the extent of this is unknown and needs to be investigated.
- Accidents with bats at wind farms are predictable with respect to the time of day and prevailing weather conditions and usually occur during a limited part of the year (late summer) as well. In contrast, accidents with birds at wind farms tend to occur throughout the year and without any obvious coupling to the season and prevailing weather conditions. This difference between birds and bats is fundamental and implies that the two groups of animals should be handled separately with respect to wind farming. The continued use of a wind turbine that proves to be dangerous for bats may perhaps be facilitated, providing a mitigation scheme is worked out. This seems to be more difficult to do for birds, because their contact with wind turbines is more unpredictable in general and also highly variable among species. Hence, careful consideration of the turbine location before construction is most important for birds.
- Bats occasionally hunt migrating or drifting insects that form local swarms at wind turbines far out at sea, but if this behavior results in bats being killed at marine wind farms has not been investigated. However, the behavior of bats at offshore wind turbines is similar to that observed at wind turbines on land, so until evidence is available we should expect that the risk of being killed is also similar.
- The risk that bats are killed at wind turbines varies strongly from species to species. For some species, fatalities are rare or occasional, while other species are much more vulnerable. The high-risk species are adapted to catch insects in the open air and include the common noctule, the parti-colored bat, the northern bat and the pygmy pipistrelle and also their rarer relatives Leisler´s bat and the common and Nathusius´ pipistrelles. These species together comprise as much as 98% of all fatalities of bats at north European wind farms. Other species, some of which are very common, seem to spend less time at heights where they are at risk to collide with turbine rotor blades. Nevertheless, there are a few species, notably the barbastelle, which

are hard to categorize. They occur in scarce or small populations, which in itself could be the main reason why they are rarely found dead at wind turbines.

- Taller turbines kill more bats compared to lower turbines, but this does not seem to apply to birds, perhaps with the exception of certain raptors. The modernization of older wind power facilities usually means that the turbines become higher and more efficient but possibly fewer. Hence modernization of older wind farms may result in lower risks for birds in general but at the same time, the risk for bats and possibly raptors probably increases. Otherwise, the fatality rate, defined as the number of fatal accidents per turbine and year, does not seem to be related to the construction or lighting of the turbines or to their internal location within the wind park. Likewise, we found no evidence that the fatality rate depends on the distance between the rotor and the ground or on the size of the wind farm (number of turbines).
- To evaluate the possible impact of future wind farming on bat populations in Sweden, we developed a simple mathematical model. Unfortunately, the necessary demographic information is not available for Swedish bat populations, so we had to use data from Germany. This means that the conclusions become less reliable. Nevertheless, our modelling suggests that we should not exclude the risk that the wind farm development along the national plan (30 TWh until 2020) could have a significant negative impact on some bat species at the national level.
- The risk that a bird or a bat is killed at a wind turbine is probably small compared to the risks faced from other human activities. However, the mortality at wind turbines is different from other mortality factors with respect to which species and age groups that are affected, and therefore the risk of potential long-term effects of wind farming on birds and bats should not be neglected.
- An already published model (Ahlén 2010a) may be used as a general guide for the handling process of wind farm applications. Suggested localizations of turbines may be considered as either a) “high-risk”, where negative effects on bats or birds can be expected, b) “uncertain”,where a qualified evaluation requires pre- or post-construction surveys, or both, or c) “low-risk”, where negative effects on birds or bats are considered unlikely.
- We present what we believe should be included in a wind farm EIA (Environmental Impact Assessment) with respect to birds and bats and also how the pre- and post-constructions surveys should be carried out. To maintain the quality of the surveys, it is essential that they are made generally available and open to discussion for extended periods. Hence, the survey methods and protocols should be standardized and the results should be published or otherwise made accessible in printed form or on the internet as early as possible.

Contents

A. General

1. Introduction

Wind farming is rapidly expanding in Sweden as in many other countries, as part of the move towards green energy in general and lowered emissions of CO_2. During 2010 the increase in production of wind energy was the fastest ever, and we have now (May 2011) 1661 wind turbines in operation and an installed effect of 2018 MW in total. The production of electricity was 3.5 TWh, which is an increase of 42% compared to the year before. At the same time the turbines are made larger and larger, and, therefore, the production of electricity increases much faster than the number of turbines. At present 2.4% of the net production of electricity in Sweden comes from wind power (www.energimyndigheten.se).

The distribution of wind power facilities across the country is uneven. Most wind turbines are found in the south and particularly in the regions of Skåne and Gotland. Recently, however, several wind farms have been built in the northern half of the country particularly in Jämtland and southern Lapland. The trend with increasing exploitation in the forested areas in the north seems to continue and wind turbines will almost certainly be constructed throughout the country in due course. Taken together, the evidence suggests that the proportion of the electricity that comes from wind power will increase rapidly in the near future (www.energimyndigheten.se).

Figure A1. Examples of wind turbines in a location with elevated collision risk to birds and bats, in this case, on the coast of Öland. At the time the picture was taken, carcasses of a mute swan and a big bat have been found. Photo Ingemar Ahlén.

Sweden as a country was by no means among the first to introduce wind energy at a large scale. Denmark and Spain, for example, started this business much earlier. On the other hand, the great majority of countries in the world still have to introduce wind power. Globally, we should therefore expect an increasing number of wind facilities for a long time to come and this also applies to the environmental effects that may result. Although wind farming generally may be considered environmentally friendly, particularly when compared to other kinds of energy production, the business will nevertheless result in various undesired effects on nature and the environment.

At the same time we should stress that most wind farms today are operated with little or no effect on birds and bats. Nevertheless, to make the wind power facilities as environmentally friendly as possible, there are several things that should be considered during the planning process. The localization of the wind turbines is of primary importance and this must be considered carefully. Localizations that result in dead birds and bats or loss of valuable natural habitats will almost certainly lead to conflicts with conservation interests and in the long run probably also to an increasing resistance from the general public. The problems, where they occur, may sometimes be the result of ignorance or missing information, but could nevertheless have been avoided by better planning and discussions between exploiters, decision makers and experts at an early stage. The work presented in this report has the aim of facilitating such cooperation. Our goal is to increase the knowledge among actors and decision makers at various levels, so that future decisions regarding wind farm establishments can be carefully evaluated.

This report is the result of a request from Vindval (SNV 20081105) to summarize and critically evaluate what currently (2010) is known about how birds and bats are affected by wind farming worldwide. For a long time there has been an obvious need for a scientifically based and practically useful publication that can be used by exploiters and decision makers as well as by non-governmental organizations and the general public during the various stages of wind farm establishment. We will try to clarify what is important and what is not with respect to birds, bats and wind turbines. Finally, we should also, if possible, evaluate the risk that present and future wind farming, including an expected rapid expansion and increase of the industry, will have a negative impact on bird and bat populations at a national level.

We planned to write a report where birds and bats were treated together as a unit. However, we rapidly realized that the problem is fundamentally different for the two groups. When birds and bats are killed at wind power facilities, it usually happens for entirely different reasons, which means that the approaches must be different. Therefore, we decided to present birds and bats separately. Basically, the difference is that bats deliberately come to wind turbines to feed on insects that sometimes swarm around the towers. Birds, with the possible exceptions of swallows and swifts, do not approach wind turbines for this reason. Instead they sometimes collide with the rotor blades or even the towers more randomly and probably because they do not appreciate the danger in time or because they tend to ignore it.

Figure A2. Examples of wind turbines that are located in a place with little risk of collision for bats and birds. They stand on level ground, well away from the height (Ålleberg) and outside the obvious hinge lines. The picture was taken near Falkirk in Västergötland. Photo by Jens Rydell.

2. Acknowledgments

Most of the initial literature search was made by Sara Henningsson and a summary of the bird part was compiled by Janne Dahlén. Thanks also to all those who helped us through the partly grey literature jungle, who shared their experiences and ideas with us or provided valuable suggestions and useful criticism; Hans Baagøe, Lothar Bach, Petra Bach, Robert Barclay, Henrick Blank, Per Carlsson, Marie-Jo Dubourg-Savage, Tobias Dürr, Johan Elmberg, Mats Gustafsson, Sofia Gylje Blank, Mikael Henriksson, Malin Hillström, Lars Hydén, Håkan Ignell, Gareth Jones, Nils Lagerkvist, Winston Lancaster, Krister Mild, Alexander Eriksson, Jonas Nordanstig, Torgeir Nygård, Hans Ohlsson, Stefan Pettersson, Luisa Rodrigues, Gustav Tibblin, Ingegärd Widerström and Peter Wredin. Finally massive thanks to Ingemar Ahlén, who has been engaged in the birds/bats and wind turbine problem in Sweden and internationally for more than a decade, and who has contributed considerably to the knowledge on this subject. He provided unvaluable support throughout this project.

B. Birds

1. Introduction

That birds sometimes are killed at wind turbines became obvious long ago (Rogers et al. 1976, 1977, Philips 1979), but the problem has received much more attention recently, as wind farming has become more and more prevalent in many countries. The principal purpose of the initial surveys was to estimate the number of birds that are killed at wind turbines. More recently, several other aspects have been investigated, such as possible disturbance effects caused by the construction or drift of wind turbines and changes in the densities of birds in surrounding areas. Several more or less comprehensive reviews of the birds and wind power problem have become available over the years. In particular, we recommend those by Erickson et al. (2001), Hötker et al. (2006) and Drewitt & Langston (2006, 2008).

Although investigations have been going on for several decades, many questions about birds and wind power remain to be investigated. This is partly because there still are relatively few habitat types in which wind farms have been established. Nevertheless, the knowledge about the effects on wind farms on birds increases rapidly at present and there are now several general points that may be used during planning of new facilities. In this report, we summarize the present (2011) situation. A shift towards production of more renewable energy is probably necessary, but at the same time, negative effects on the bird fauna must be minimized whenever possible. This review should be seen as a summary of the evidence and an attempt to evaluate the impact of wind power on birds based on this summary. Presumably, it will have to be updated in the near future.

2. Methods

2.1. Literature survey

This report is based on information that was available in 2009 and 2010 in published or unpublished written reports and articles but not in internal reports or in material that was unavailable to us. Nevertheless, a considerable part of the cited work consist of “grey literature”, reports and other pieces of work that have not been published in scientific journals, and, therefore usually have not gone through a so called peer review process. We have used information from Europe and North America almost exclusively. Although there are a few reports from other parts of the world as well, we have evaluated them as being of less significance in this case. The cited reports have been critically examined, and we believe that we have managed to synthesize the most relevant information, so that this report can be considered representative of the current situation.

Literature searches were made using electronic publication databases and the internet in general. The resulting literature compilation was then compared with an already published database from NINA (Norwegian Institute for Nature Research; Nygård et al. 2008). Some articles found only through references in other articles were also included in our literature list.

2.2. Literature search - Methods

To find relevant scientific and popular literature, and to some extent”grey” literature as well, we used electronic data bases and the internet. To find scientifically published articles, we used *Web of Knowledge* (*BIOSIS*; http://apps.isiknowledge.com/BIOSIS) and *Google Scholar* (www.scholar.google.com, Google) and for free search on the internet we used *Dogpile meta-search* (www.dogpile.com, InfoSpace).

The following search terms were used:

- bird* AND wind turbine*
- bird* AND windfarm*
- bird* AND wind park*
- bird* AND wind AND turbine*
- bird* AND wind AND farm*
- bird* AND wind AND park*
- bird* AND wind AND installation*
- raptor* AND wind*
- wader* AND wind*
- duck* AND wind*
- swan* AND wind*
- geese AND wind*
- goose AND wind*

In *BIOSIS* “bird* AND wind turbine*” and “bird* AND wind park*” generated the same result as “bird* AND wind AND turbine*” and “bird* AND wind AND park*”, but in *Google Scholar* and *Dogpile* these seach terms generated different results. To find Swedish articles we used the search term”fåglar AND vindkraft” in *Dogpile*. In *BIOSIS* and *Dogpile*, the number of hits for each search term was limited and all articles were examined. Only those that obviously concerned different subjects were rejected at this stage. All other literature was listed on an Excel-sheet for further evaluation. The searches in Google Scholar generated an uncomfortably high number of hits per search term, and, therefore, only the first 50 articles were evaluated. Articles found relevant for further work were included in the literature list. Articles published before 1995 were generally excluded because we considered them irrelevant for the present work. This limitation was only applied to searches in the NINA database, however.

2.3. Evaluation of articles

Following the listing of all articles and reports, we made a thorough evaluation of their relevance for the continued synthesis work. They were considered relevant only if they reported *effects* of wind power facilities or construction of such facilities on birds. The criteria were that the article or report in question should (1) deal with one or several species of birds, (2) refer to a field investigation of some kind, and (3) apply to a present wind power facility or to one in the process of being built. Various kinds of EIAs (Environmental Impact Assessments) and other reports made before establishment of a particular wind power facility, have generally been excluded. Nevertheless, literature summaries and reviews that do not include any primary data, but contains other information that we considered important for the present synthesis, were sometimes included.

The literature list resulting from the search in *BIOSIS*, *Google Scholar* and *Dogpile* initially contained 341 articles and reports that we found relevant. A comparison with the NINA data base added another 30 articles to the list, which means that we initially had 371 articles and reports. In these we found references to another 26 relevant articles, which ends up to 397 articles in total. During a first critical survey, 173 of these were excluded in the first step, and then another 26, which could not be found in full text, were also omitted. Of the 167 remaining articles and reports, 34 were reviews of some kind, whereas 39 largely concerned policies and methods used to study effects of wind power facilities on birds. The remaining 94 articles fulfilled our initial criteria for inclusion in this review.

2.4. Analysis

To provide estimates of the number of birds that are killed at wind turbines ("fatality rate"; tables 5.1. and 5.2), we have used all available studies where dead birds have been collected under wind turbines in a reasonably systematic way. The methods used sometimes differ considerably from study to study and those carried out more recently are usually of higher quality, because more stringent methods have been employed. In this review we have not accounted for this methodological variation, which means that the results are not always strictly comparable. On the other hand, we have been careful when making our conclusions, having this limitation in mind.

Regarding collisions of birds with wind turbines, we have only used results from surveys in which the most important biases have been controlled for one way or another. These biases are:

a. scavengers remove or eat dead birds under wind turbines before they are counted
b. all dead birds are not found by a searcher and the searching efficiency may differ between observers
c. the chance to detect a dead bird under a wind turbine strongly depends on the prevailing conditions at the site, including the vegetation and light.

This means that the number of birds that actually are killed at a site is higher than the number of carcasses found. Hence, the estimated fatality rates, as given in tables 5.1 and 5.2, have been adjusted upwards in order to account for these biases. The adjustments are specific for each locality or even for a single turbine, and could not have been made afterwards. Otherwise, the protocol used for bird collisions follows the one used for bats (see below).

With respect to changes in the density of birds near wind farms, we have not been able to account for the fact that different methods were used when the data were originally collected. Some of the surveys were carried out using a so called BACI-design (Before-After-Control-Impact). This means that the area in question is first surveyed before any wind turbines are constructed at the site, and then, using the same methods, after the facility is established. In addition, a comparison should be made with adjacent control areas which are not affected by any wind power facility. So far, very few studies have been carried out using such stringent protocols. In fact, the methods used vary considerably from study to study, from strict and long-term BACI-surveys to short and much simpler surveys sometimes without any controls. We are well aware of these differences. Nevertheless, we believe that the methodological differences do not affect the overall conclusions that emerge from this review.

2.5. Occurrence of birds in Sweden – Compilation of data

To describe the breeding bird fauna of Sweden in the best possible way, we used several different sources. One of these sources is a yet unpublished report that includes recent estimates of the numbers of breeding birds in each of the geographic and administrative regions in Sweden (Ottosson, Ottvall, m.fl. "Fåglarna i Sverige – utbredning och antal i län och landskap"). The authors of this report have affinities to Lund University, the Swedish Species Information centre (SLU, Uppsala), Svenska Jägarförbundet, Kristianstad University and the Swedish Ornithological Society. We have been given permission to use this material in order to describe the Swedish bird fauna (part 3) and to show how some species groups, that we believe are particularly sensitive to the effects of wind power facilities, are distributed across the country (part 9). The purpose of this is to supply information that may be used during the planning process, in order to predict the possible effects of wind farm establishments on national or regional bird populations.

For most common species, the population estimates presented by Ottosson et al. are based on counts from standard inventory routes (http://www.zoo.ekol.lu.se/birdmonitoring/), included in the national surveys that form part of the Environmental Monitoring Program of the Swedish Environmental Protection Agency. The routes are parts of a system with one route for every 25 km north-south and east-west throughout the country, along which birds are counted annually. There are 716 such standard routes in total. For less common species or for those with more limited distributions, the numbers given are based on other sources used exclusively or in combination with information based on the standard inventory routes.

In addition, we have compiled a list of the localities in Sweden that regularly harbor important concentrations of birds. This list may be used to identify areas of particular importance for birds. A concentration is in this case defined as a locality where at least 1% of the individual birds in a reference population have occurred during at least part of the year for at least two years over the last decade. The 1% figure is taken from the Ramsar Convention for the protection of wetlands (www.ramsar.org). It is generally accepted for the identification of areas of high conservation values. Within the global bird protection organization BirdLife International, a similar system is used to identify areas with important bird ocurrences (”Important Bird Areas”). As reference populations for breeding birds in Sweden we have normally used the estimated population sizes resulting from the present compilation. In cases where winter- or roosting concentrations consist mostly of birds from breeding areas outside Sweden (predominantly some geese, duck and waders), we have used the international populations for comparison, as provided in Wetlands International (2006). The search was restricted to species with breeding populations of more than 500 pairs in Sweden or species that occur in large numbers during the migration period in autumn or winter.

We also compiled reported observations of birds from the data base in Artportalen (*Svalan*, www.artportalen.se/birds). "Svalan" is a web-based report system for birds in Sweden. It is organized by the Swedish Species Information Centre (SLU, Uppsala) and funded by the Swedish Environmental Protection Agency, as requested by the Ornithological Society of Sweden.

The reports in "Svalan" are usually spontaneous observations from amateur otnithologists. The observations are normally made unsystematically and without any particular question in mind. For this reason, the information provided in "Svalan" alone is not always sufficient to describe the bird fauna at a particular locality. For localities that are frequently visited, or for bird species that periodically are concentrated to a limited number of sites, such as some waders, reports of good quality are usually available, and indeed, we are convinced that the great majority of localities that regularly harbor concentrations of birds have been adequately covered by reports to "Svalan". Exceptions may be sea banks and some minor archipelagos, which rarely if ever are visited by ornithologists.

3. Occurrence of birds in Sweden

The Swedish bird fauna is very well mapped with respect to distribution and numbers of species. This is a result of a long and continuous tradition of bird watching by amateur ornithologists, most of which are organized through the Swedish Ornithological Society (SOF). There are many publications about the distribution and occurrence of birds in Sweden, including, for example Svensson et al. (1999) and SOF (2002). Changes in the size and composition of the bird fauna is followed continuously through systematic inventories within national and international survey programmes (Ottvall et al. 2009, Lindström et al. 2011), programmes for specific species and through general observation reports to "Svalan". Here we present a general overview of the occurrence of birds in Sweden. More detailed information on certain birds, which may be of particular interest with respect to wind power, is provided in chapter 9.

The number of bird species that have so far been observed in Sweden is 486 (late 2008; SOF 2009). Of these, about 250 species breed annually in the country and a further 70 are regular visitors, that pass on migration between their summer and winter quarters (Tjernberg & Svensson 2007). Many of the annual migrants are abundant species that breed on the tundra or in the taiga of Russia and which are dependent on wetlands during migration. The rest are more or less occasional visitors that may not be considered members of the regular Swedish bird fauna. The number of breeding pairs of birds in the country is estimated to 70 million, which means that there are at least 140 million birds within the country at the start of each breeding season. Since there is also an unknown number of non-breeding individuals, the real number of birds is higher. Most individuals are present in late summer, after the young have fledged but before the start of the southern migration. In this period, an estimated 500 million birds may occur within the country. Among the regularly breeding species the numbers differ enormously. The rarest species may occur with a few breeding pairs only, while for the two commonest species, the common warbler and the chaffinch, population estimates are 13 and 8 million pairs, respectively.

Approximately 80% of the breeding bird species in Sweden are migratory and thus have a winter distribution mainly outside our country. These birds only spend part of the year in Sweden, in some cases only a few months. Slightly less than half of the migratory species spend the winter in west Europe and the Mediterranean countries, whereas a little more than 30% spend the winter in Africa. There are also a few species that breed in Sweden but spend the winter in Asia. An estimated 85% of the "Swedish" bird individuals leave the country for the winter.

The great majority of breeding birds in Sweden are passerines or generally "small birds" (Passeriformes). This group accounts for as much as 92% of the breeding bird individuals in the country. There are only four other groups which are abundant enough to account for more than one percent of the breeding birds, namely waders (2%), fowl (including grouse, quails, partridges and phesants, i.e. galliform birds; 1%), pigeons (1%) and ducks and allies (the anseriform birds; 1%). Remaining groups represent three percent of the breeding bird count in Sweden if taken together, but each group alone represents less than 0.5%.

The birds are far from evenly distributed across the country. Generally, the density declines from south to north. For example, the average density of breeding pairs of birds, all species included, is estimated as 266 per km^2 in the south (Götaland), 201 per km^2 in the central part (Svealand) and 123 per km^2 in the north (Norrland), which means that the average density of birds in the north is about half of that in the south. Obviously, there are also considerable differences in density between habitats within each region. Generally, the highest densities are found in broad-leaved woodlands in the south and the lowest densities in alpine areas in the north. Places at or near the coast usually have higher densities of birds than inland areas and coastal localities usually have more species as well.

A similar pattern is evident for resting or migrating birds, although more exact count are generally missing. The difference in density between the northern and southern parts of the country is probably even more pronounced in this case. Concentrations to coastal localities and biologically productive areas in the vicinity may be even more obvious for birds during the migration periods than during other seasons.

The Swedish red list includes 95 species of birds that are considered rare or that show an unfavorable population trend. The listing is based on an estimated risk of extinction within a certain time frame (Gärdenfors 2010). Most of the species listed breed within the country, but there are also a few examples of overwintering species or passing migrants that breed outside Sweden. Nine of the species on the red list are classified as *nationally extinct* (RE), although in some cases a few individuals may occasionally breed within the country. Six species are considered as *critically endangered* (CE), ten as *endangered* (EN) and 25 as *vulnerable* (VU). Together, these species are those considered as threatened in Sweden. However, it is important to understand that the same classification may not necessarily apply to other countries, and, in fact, a species may be endangered in Sweden and at the same time common and not threatened elsewhere. The Swedish population may be small or otherwise restricted for natural reasons. Remaining species included in the red list are considered near threatened (NT), which implies that there is a risk that the species will become threatened within the near future (Gärdenfors 2010). The bird species included in the Swedish red list can be found in appendix 3 of this report.

There are also 66 species or subspecies of birds that regularly occur in Sweden and which are included in list 1 of the EU Birds Directive with specified requirements of preservation (Directive 79/409/EEG on the protection of wild birds). The Bird and Habitats Directives are EU-directives and are legally binding commitments. The countries within the EU have mutually agreed to protect all populations of naturally occurring bird species as well as the habitats on which these species depend.

4. Potential effects of wind farming on birds

4.1. What may be expected?

Generally, there are three potential effects that wind power facilities may have on birds. These are (1) collisions, resulting in increased mortality, (2) habitat loss, which may be either direct through destroyed habitats, or indirect by causing disturbance and potentially lower population counts locally, and (3) barrier effects (Dierschke & Garthe 2006, Fox et al. 2006, Drewitt & Langston 2008).

4.2. Collisions

That birds sometimes collide with towers or the rotors of wind turbines has been known since the early days of wind farming (Erickson et al. 2001). Collisions usually lead to immediate death of the bird or to serious wounds from which it dies later. In addition, birds may collide with infrastructure associated with the wind turbines, such as meteorological towers, electrical power lines, buildings or traffic (Kuvlesky et al. 2007). The possible effect of such mortality is virtually unknown and hard to evaluate. We will focus on the effects of the wind turbines themselves but it should be remembered that a secondary mortality of unknown magnitude should be added to the reported estimates.

Surveys of birds killed at wind power facilities have been carried out for a long time, usually by applying systematic searches for dead birds under wind turbines and the immediate surroundings (part 2.4). Form these surveys collision frequencies or fatality rates have been estimated. *The fatality rate is defined as the number of dead birds per wind turbine and year or per unit of electricity (MW) produced per year.*

The risk for collision depends on the bird and its life habit and behavior, particularly its reaction to the presence of wind turbines. The characteristics of the wind turbines may also be of importance such as the height above the ground, the length of the rotor blades (sweep area) and presence of artificial light sources at or near the turbine. The location of the turbines in relation to the occurrence of birds may be of primary importance. Finally, the risk that birds will collide with a wind turbine could also be related to the time of the year and the prevailing weather (Drewitt & Langston 2008).

For obvious reasons, fatality rates of birds are much more difficult to estimate at off shore wind farms compared to those on shore. The chance to recover dead birds at sea is probably near zero. Consequently, most of what we know about collision frequencies of birds at marine wind farms is based on direct observations of collisions or on observed behavior of birds in such places, including their movement patterns and apparent reactions to the turbines. In practice, few if any estimates of fatality rates have been made for off shore wind farms. Hence, estimates based on surveys of dead birds under wind turbines always refer to wind facilities on land, most of them in the USA. The problem that birds are killed at wind turbines has not received the same attention in Europe as in the USA, and in Sweden only very few investigations on this subject have been carried out so far.

When evaluating the *consequences* of increased mortality from collisions with wind turbines at the population level, it may be important to know that a certain number of dead birds may be much more serious for long-lived species with slow reproduction and late maturity (usually large birds) than for species that mature early and reproduce rapidly (typically small birds). The effect on the population may be particularly serious for slowly reproducing species that also happen to be rare (Desholm 2009).

4.3. Habitat loss

The construction of a wind farm may affect the density of birds in the vicinity. A direct loss of habitat will certainly occur at the site of construction and perhaps also at a distance from the site. On top of this comes the area occupied by the surrounding infrastructure, which may vary in importance depending on the size and location of the facility. Areas may have to be cleared for trees, roads must be built and water may have to be drained. Nevertheless, we believe that the areas thus directly affected, probably are relatively small in most cases. On the other hand, if the wind farm is located in previously pristine areas, new roads may result in fragmentation of the entire area, which potentially could have effects that are worse than the direct effects of the presence or construction of the plant.

However, the most important kind of habitat loss is probably the indirect one. If birds avoid the immediate vicinity of a wind power facility, this area may lose its attraction to birds on a long term basis. To some extent, construction of a wind power facility means increased human activity in the area during and to some extent also after the construction phase (Kuvlesky et al. 2007) and the disturbance caused by this may be significant. Associated roads may provide access to previously relatively pristine areas and hence indirectly make them available to forestry and traffic. Such disturbance effects would probably appear during the early construction and may continue with varying intensity (Langston & Pullan 2003).

The effects of habitat loss are usually studied by comparing densities of birds a) at different distances from existing wind power facilities, b) in one site before and after the construction of a facility, and c) in areas with wind power facilities and those without, respectively. Although there may be considerable logistical problems, it should be possible to carry out such studies also at off shore wind farms as well, by using boats or aircraft. Habitat loss has not been studied for as long as collisions and it has generally recieved more attention in Europe than in North America. Few such investigations have been carried out in Sweden, but some have recently been initiated.

The consequences of disturbance may differ considerably depending on the value of a particular area for birds. In some cases the birds may move to adjacent areas without any noticeable effect on the population. More likely, however, the birds may have to use areas where conspecifics already occur, with increasing competition and lower survival as a likely result. In the longer run, this means that the population as a whole will become smaller. For a hypothetical example where the effect may be dramatic, imagine a species which only occurs in a highly particular habitat on which it is totally dependent, such as small offshore islands with a certain water depth nearby. If these islands are used for wind farming and the area potentially available to the birds decreases dramatically for this reason, there may be a risk that the birds disappear from the entire area (Petersen et al. 2006).

4.4. Barrier effects

A barrier effect means that an obstacle such as a wind power facility acts as a barrier to flying birds, so that they avoid the vicinity of the obstacle and take another flight course. This behavior obviously leads to a lower collision risk, but at the same time the birds would have to take a longer route, hence potentially increasing the energy consumption during transports between feeding-, breeding- and resting areas. The avoidance behavior may consist of a minor adjustment of the flight course with negligibly increased energy consumption, but it could also have the consequence that a larger area behind the obstacles is practically avoided. The extent of the area avoided depends on the size and construction of the facility and its location relative to the surrounding bird habitat.

Barrier effects have primarily been investigated for migrating seabirds near off shore wind farms. The birds have usually been observed with radar and their reaction to the presence of wind turbines have been quantified at various distances from the wind turbines. Such studies have been carried out at several sites in Swedish and Danish waters. The extra distance the birds have to fly to negotiate a wind farm at sea is probably negligible in most cases, but since birds sometimes fly very long distances and may pass many wind farms on their way, the cumulative effects on their energy consumption may perhaps become significant. If this will be the case, it will almost certainly result in lower long-term survival or breeding success. In order to evaluate the importance of cumulative effects, we obviously need to know the situation along entire migration routes.

5. The effect of wind farming on birds

5.1. Collisions

5.1.1. Fatality rates at wind facilities in Europe and North America

In tables 5.1 and 5.2 we have summarized all available estimates of fatality rates of birds at wind power facilities in Europe and North America. There are considerable differences in fatality rate from site to site. While some wind parks kill very few birds (Erickson et al. 2001), others may kill as much as 60 birds per turbine annually (Lekuona 2001). The localities where many birds are killed each year are relatively few, however, and the statistical distribution is skewed. We therefore use the median value rather than the mean to describe the average fataily rates. The median value across all wind power facilities reviewed here is *2.3 dead birds per turbine and year*.

The estimated fatality rates at wind turbines are generally much higher at the European wind farms (median 6.5 birds per turbine and year) than at the North American ones (median 1.6). This difference probably depends on differences in location of the wind farms on the two continents. For North America (table 5.2), most are located in various types of grassland usually at rather high elevation, while for Europe (table 5.1) most estimates refer to sites in agricultural areas near wetlands or at the coast. Such areas usually harbor higher densities of birds than uplands.

5.1.2. Effects of turbine and farm construction

The development of wind turbine technology has resulted in a rapid increase in general dimensions of the turbines. In particular, the towers have become much taller and the rotor blades have become longer and thus with larger sweep areas. This means that modern wind turbines reach the altitudes where birds regularly move in large numbers during migration (>100 m above the ground). It has therefore been suspected that higher wind turbines may be more dangerous to birds than smaller ones, but in contrast to the situation for bats, this does not seem to be the case for birds in general. An analysis of this problem, using data from North America, did not show any increase in collision frequency at taller turbines and not at those with longer rotor blades either (Barclay et al. 2007). Analyses of such data from the Netherlands, Belgium and Germany resulted in the same conclusion, namely that the danger to birds does not depend on the height or the sweep area of the turbines (Everaert & Kuijken 2007, Hötker et al. 2006). If we consider the collision frequency in relation to the installed energy (MW) of the turbine, we find that there is a negative relationship between the two. Hence, fewer birds are killed per MW of installed energy. This is as expected, because larger plants produce more electricity than smaller ones but still do not kill more birds (Hötker et al. 2006, Barclay et al. 2007).

Table 5.1. The number of birds killed annually at wind power facilities in Europe (fatality rate). Dead birds were collected regularly during one season or more. The numbers shown are adjusted for differences between observers and observing conditions and for carcasses that have been removed between the observations. Hence, the estimated numbers of dead birds are higher than the numbers of carcasses found.

Name of wind farm	Location	No. of turbines	Fatality rate	References
Belgium				
Oostdam	Wetland	25	21.0	Everaert & Kuijken 2007
Boudewijnkanal 1	Wetland	14	26.0	Everaert & Kuijken 2007
Boudewijnkanal 2	Wetland	7	43.0	Everaert & Kuijken 2007
Te Schelle	Wetland	3	12.0	Everaert & Kuijken 2007
Gent 1		11	7.0	Everaert & Kuijken 2007
Gent 2		2	2.0	Everaert & Kuijken 2007
Nieuwkapelle		2	1.0	Everaert & Kuijken 2007
The Netherlands				
Jaap Rodenburg	Fields*	10	20.0	Krijgsveld et al.2009
Waterkaapocht	Fields*	8	39.0	Krijgsveld et al.2009
Groettocht	Fields*	7	20.0	Krijgsveld et al.2009
Osterbierum	Grassland	18	1.8	Winkelman 1992a
Kreekraak sluice	Wetland	5	3.7	Musters et al. 1996
Urk	Wetland	25	1.7	Winkelman 1989
Great Britain				
Blyth harbour	Grassland	9	19.0	Newton & Little 2009
Bryn Tytli	Grassland	?	0.0	Philips 1994
Burgar Hill, Orkney	Grassland	?	0.2	Percival 2000
Haverigg Cumbria	Grassland	?	0.0	Percival 2000
Ovenden Moor	Grassland	?	0.04	Percival 2000
Cemmaes	Grassland	?	0.04	Percival 2000
Germany				
Bremerhaven	Wetlands	?	9.0	Scherner 1999b
Denmark				
Tjaereborg	Wetlands	?	3.0	Pedersen & Poulsen 1991
Sweden				
Näsudden	Forest		0.7	Percival 2000
Norway				
Smøla	Heath	68	0.4	Bevanger et al. 2009
Spain				
Salajones	Ridge	33	21.7	Leukona 2001
Izco-Albar	Ridge	75	22.6	Leukona 2001
Alaiz	Ridge	75	3.6	Leukona 2001
Guerinda	Ridge	145	8.5	Leukona 2001
El Perdon	Ridge	40	64.3	Leukona 2001
Basque Country		40	6.0	Onrubia et al. 2002
PESUR, Tarifa	Ridge	190	0.07**	de Lucas et al. 2008
E3, Tarifa	Ridge	66	0.04**	de Lucas et al. 2008

* large scale daily movements of birds from the fields to nearby wetlands occurred

** only large birds were sampled; this figure is not used to calculate averages

? the number of turbines in the park was not provided in the report

Table 5.2. The number of birds killed annually at wind power facilities in North America (fatality rate). Dead birds were collected regularly during one season or more. The numbers are adjusted for differences between observers and observing conditions and for carcasses that have been removed between the observations. Hence, they are higher than the actual numbers of carcasses found.

Name of wind farm	Location	No. of turbines	Fatality rate	References
Eastern USA				
Searsborg	Mountain	11	0.0	Kerlinger 2002
Maple Ridge 1	Grassland	120	3.9	Jain et al. 2007
Casselman	Mountain	23	4.7	Arnett et al. 2009
Meyersdale	Mountain	20	0.9	Kerns et al. 2005
Mountaineer	Mountain	44	2.6	Kerns & Kerlinger 2004
Buffalo Mountain 1	Mountain	18	1.8	Fiedler et al. 2007
Somerset County	Ridge	8	0.0	Kerlinger 2000
Central USA				
Buffalo Ridge 1	Grassland	733	0.9	Johnson et al. 2003a
Buffalo Ridge 2	Grassland	143	2.3	Johnson et al. 2004
Buffalo Ridge 3	Grassland	138	4.4	Johnson et al. 2004
Lincoln	Fields	31	1.3	Howe et al. 2002
Top of Iowa	Fields, wetland	98	0.6	Koford et al. 2004
IDGWP	Ridge	3	0.0	Erickson et al. 2001
Western USA				
Judith Gap	Pass, grassland	90	4.5	TRC 2008
Klondike	Fields	16	1.4	Johnson et al. 2003b
Vansycle	Grassland	38	0.6	Erickson et al. 2000
Stateline	Grassland	454	1.9	Erickson et al. 2003a
Foote Creek Rim	Grassland	69	1.5	Young et al. 2003
Nine Canyon	Grassland	37	3.6	Erickson et al. 2003b
High Winds	Grassland	90	2.3	Kerlinger et al. 2006
Altamont	Pass, grassland	1526	0.8	Smallwood et al. 2006
Diablo Winds		31	1.2	WEST Inc. 2006
San Gorgonio	Ridge	2947	2.3	Erickson et al. 2001
Canada				
McBride Lake	Fields, grassland	114	0.4	Brown & Hamilton 2004
Magrath		20	2.6	Brown, cited in Barclay 2007
Summerview	Fields	39	1.9	Brown & Hamilton 2006b
Cypress		16	1.4	NE Ltd. 2004
Pickering	Lake shore	1	4.0	James 2003

The lights fitted to wind turbines have also been suspected to attract birds and increase the risk for collisions. This is because birds sometimes die in big numbers when they collide with towers, bridges, light houses or other lit structures during misty night with poor visibility (Erickson et al. 2001, Drewitt & Langston 2008 and references therein). However, there are very few occasions where more than a few birds have collided with wind turbines at the same time, suggesting that large-scale mortality of birds at wind turbines is rare. Furthermore, very particular conditions prevailed on these occasions. For example, 42 dead birds were found under a wind turbine at Näsudden on the Swedish island of Gotland in 1982 during a period when the plant was not in operation but while it was lit (Karlsson 1983). Likewise, at a wind power facility in eastern USA, 27 dead birds were found on a night with poor weather. In this case as well, the facility was lit during a service operation (Kerns & Kerlinger 2004).

The presently used warning lights on wind turbines are either red or intensive and flashing white, with the type of light depending on the total height of the turbine. The flashing white light marks objects taller than 150 m (Transportstyrelsen 2010). Neither of these lights seem to increase the risk that birds are killed at wind turbines, however (Johnson et al. 2000, WEST 2004, Jain et al. 2007), although it has been suggested that the risk may be minimized if flashing light is used and if the time interval is then maximized (Hüppop et al. 2006) or if the light is made dimmer (Drewitt & Langston 2008).

There is no indication that larger wind farms, i.e. those with more turbines, kill more birds per turbines compared to smaller ones (tables 5. 1 and 5.2). Nevertheless, larger wind farms obviously may have greater impact than smaller parks, because more birds are killed in total. In some cases the number of birds killed depends on the location of the turbine within an installation. For example, in Altamont in California, USA, turbines located near a canyon kill more birds than those nearby (Orloff & Flannery 1992, 1996). Likewise, in Spain it has been observed that most vultures are killed at turbines located on mountain slopes or at its peak (de Lucas et al. 2008). In Zeebrugge in Belgium, some of the wind turbines comprising a wind park are located on a wave breaker with a large colony of breeding terns neaby, whereas other turbines are closer to land and further away from the normal flyway used by the terns. The turbines on the wave breaker kill 34.4 birds per turbine and year while those closer to land kill 3.9 (Everaert & Kuijken 2007). Although such specific differences may occur occasionally, the location of the turbines within the wind farm is normally of minor importance and do not seem to affect the fatality rate substantially (Brown & Hamilton 2006, de Lucas et al. 2008). In some cases, lower collisions frequencies of raptors and other birds have been observed at the turbines at the edge of a wind park (Anderson et al. 2004), but in other cases the opposite situation prevail (Orloff & Flannery 1992, Bevanger et al. 2009).

5.1.3. Importance of surrounding habitats

The kind of environment that surrounds the wind farm is the primary determinant of the collision frequency (fatality rate; tables 5.1 and 5.2). The frequencies are usually highest at turbines located near wetlands and in coastal localities (15.5 birds per turbine per year), but the collision risk may also be high on mountain tops and ridges as well as in other places with distinct topographical variation (4.0 per turbine and year). However, the absolute altitude does not seem to be of any importance for the collision frequency. In open agricultural landscapes and in other habitats the collision frequencies are usually relatively low; 1.4 and 1.8 per turbine and year, respectively. This generally agrees well with the conclusions from the study made by Hötker et al. (2006).

Many birds in an area generally mean that the risk that some will be killed is relatively high. Investigations have indicated that the density or activity of birds near wind farms and the risk for collisions are closely related (Musters et al. 1996, Barrios & Rodrigues 2004, Everaert & Kuijken 2007, Stienen et al. 2008), but there are also cases where this does not seem to be the case (de Lucas et al. 2008, Krijgsveld et al. 2009). The number of birds that are killed does not depend exclusively on the number of birds that are present in the area but also on which species, and to what extent these are exposed to the wind turbines (section 5.1.4).

Some particular wind farms regularly kill many birds. For example, at certain facilities in Belgium, at least 20 birds are killed per turbine and year (Everaert & Kuijken 2007), a figure which is nearly ten times higher than the average for all wind farms investigated. Likewise, in Altamont in California, dense populations of raptors co-occur with one of the worlds´ largest wind farms with 5400 turbines located within an area of 165 km^2. These facilities kill an estimated 1127 raptors annually, including 67 golden eagles (Smallwood & Thelander 2008). The park is located within a topographically varied area with mountain ridges and deep canyons and where high densities of animals preyed on by raptors also occur. To some extent this situation applies to Tarifa in southern Spain as well. In that area 151 raptorial birds have been found dead at wind turbines over a ten year period (de Lucas et al. 2008). Again, the wind farms are located within a topographically varied area that includes several mountain ridges and forms one of the most important flyways for migrating raptors in Europe. At the windward side of hills and ridges, hangwinds useful for raptors and other birds are often formed and the risk of fatalities increases if wind turbines are located in such places. However, the birds most frequently colliding with wind turbines in such places are *not* migrating specimens but rather members of local populations.

There is yet another wind farm showing a particularly high fatality rate, and which should be mentioned in this context, namely Smøla, an island off the coast of Norway. The island harbors a high density of breeding sea eagles. Since the establishment of the wind park in 2002, 39 sea eagles have been killed by the 68 wind turbines that exist at present (2010). The entire park has been systematically searched for dead animals using trained dogs since 2006 (Bevanger et al. 2010).

Petterson (2005) monitored two small offshore wind farms in Kalmarsund at the east coast of Sweden, using radar over the four consecutive years 2000-2003. He observed a single collision of a migrating bird. Based on the observed behavior of the passing birds and the single collision, he estimated that on average one sea bird (eider) is killed annually per turbine in this area.

Each year about 1.5 million birds pass over the area and in most cases the birds fly at approximately the height of the turbine rotors. However, it should be noted that the present wind farm occupies only a small part of the area used by eiders and that the situation may change with additional wind farms. Even lower collision rates have been recorded at the Danish off shore plant at Nysted. Petersen et al. (2006) estimated that 0.7 sea birds (eiders) are killed per turbine and year at this wind farm. The turbines at Nysted have been surveyed continously and systematically using a heat image camera, with the purpose to provide an estimate of fatality rate of sea birds. One collision (a song bird) was observed during almost a hundred days of observation in spring and autumn (Petersen et al. 2006). Based on these investigations it seems clear that collisions between birds and wind turbines at sea generally are very few.

5.1.4. Distribution of fatalities among species

The risk of being killed at a wind turbine is not the same for all species of birds. Instead, it differs considerably from species to species, which probably is a result of differences in their flight performance and maneuverability (Barrios & Rodrigues 2004, Drewitt & Langston 2006). Large and heavy birds that typically maneuver slowly may be expected to face a higher risk to collide with wind turbines and other obstacles in their flight path (Brown et al. 1992, de Lucas et al. 2008). Birds that often fly at night or at dusk and dawn may also be expected to show a lower ability to discover and avoid such obstacles (Larsen & Clausen 2002).

In Germany, data on birds found dead under wind turbines have been collected systematically since 1989 (table 5.3). The raptors constitute as much as 37% of the 1193 reported victims and most recorded fatalities are from this group. Following the raptors are the passerine group (27%), the gulls and terns (11%), the pigeons (7%), the ducks, geese and swans (5%) and the swifts (3%). Crows and allies (corvids) and swallows are also relatively frequently reported. The German data provides no evidence that nocturnally migrating species are more vulnerable at wind turbines than diurnal migrants. Of the dead migratory passerines registered, 30% belonged to nocturnally migrating species, while 48% were diurnal migrants. The remaining species were stationary in a broad sense, including those that show partially migratory behavior mostly in daytime. However, since the data have not been collected systematically, the compilation can only provide a rough indication off which birds are most frequently killed at wind turbines. It seems likely that large birds have been reported unproportionally often and, likewise, that small birds often have remained undetected.

The risk of collision seems to be related to the behavior of the bird when approaching a moving rotor blade of a turbine. Accordingly, birds that typically show strong avoidance responses also face a relatively low risk of collision (Hötker et al. 2006). Examples of such birds include sea birds such as geese and ducks and also most waders. Passerines are not found dead at wind turbines to the extent that may be expected (27% of the victims at German facilities, table 5.3), considering that they comprise the great majority of all birds. However, since most passerines are small and presumably relatively difficult to find on the ground, the real frequency may be considerably higher. In fact they are almost certainly the group of birds that most often are killed at wind turbines (Johnson et al. 2000, Jain et al. 2007). Nevertheless, passerines generally show strong avoidance reactions and also low fatality rates in relation to the large size of the populations (Hötker et al. 2006).

The grouse, quails and phesants (galliform birds) are relatively heavy and unmaneuverable birds and, accordingly, they collide with wind turbines relatively frequently. Poor maneuverability is a consequence of small wings in relation to the body weight of these birds. At Smøla in Norway 45 willow grouse have been found dead between 2003 and 2010 (Bevanger et al. 2010) and this species is the one most often found dead at this site. Many of the grouse victims showed no visible injuries, suggesting that they may not have been hit by a moving rotor. Instead thay may have collided with the turbine tower or been thrown to the ground by the turbulence near the rotor. This pattern is very different from that of other bird species at the site (Bevanger et al. 2010). Indeed, galliform birds relatively often collide with structures other than wind turbines such as power lines (Bevanger 1995).

Avoidance reactions at wind turbines are also shown by raptors as well as by gulls and terns, although their behavior may not be as obvious as in the cases already mentioned (Hötker et al. 2006). Nevertheless these birds are frequent victims at wind turbines despite their relatively small populations.

Tabell 5.3. Birds found dead under wind turbines in Germany 1989 – 2010 according to systematic affinity (from Dürr 2010).

Bird group	No. of dead birds
Raptors	447
Passerines excl. swallows	247
Gulls and terns	133
Pigeons	84
Ducks, geese and swans	65
Crows and allies	47
Swifts	40
Swallows	33
Waders	22
Owls	22
Storks	22
Grouse, quails and phesants	10
Rails	8
Cormorants and herons	4
Cranes	2
Woodpeckers	2
Cuckoos	2
Divers	1
Auks	1
Total	**1192**

With respect to collisions at wind turbines, the raptors have been the subject of most attention and worry. This is partly because these birds generally have low reproductive rate, which means that a relatively minor increase in mortality can have considerable consequences for the population. Four of the species most often reported as fatalities in Germany are raptors, namely common buzzard, red kite, sea eagle and kestrel, in decreasing order (Dürr 2010). These statistics show a predominance of large raptors as victims at wind turbines. The same picture applies internationally, even if we exclude some particular sites known to kill many raptors such as Altamont in California, for example. Hence it seems as if raptors are more at risk at wind turbines compared to birds in general (Langston & Pullan 2003, de Lucas et al. 2004, 2008, Hötker et al. 2006, Hötker 2009). This may be surprising at first sight, because raptors generally have sharp vision, good flight maneuverability and they usually avoid flying in poor light conditions. Therefore they would not be expected to have any problems detecting and avoiding wind turbine rotors (more of this in part 5.1.8).

There are some interesting similarities between raptors and gulls, the latter of which relatively often are killed at wind turbines at coastal sites and near wetlands (Everaert & Kuijken 2007, Dürr 2010). Like raptors, gulls have good visual capacity and maneuverability and they would not be expected to have any problems detecting and avoiding wind turbines. In contrast to raptors, however, gulls often fly in poor light conditions. In raptors and gulls, it could perhaps be that with the high visual capacity and good flight performance, these birds do not normally avoid objects at distances that are safe in the case of moving wind turbine rotors.

Passerines and other nocturnal migrants have been of major concern because they may be expected to be particularly at risk to collide with wind turbines, principally because they move in the dark. This concern is based on occasional observations of high numbers of song-birds colliding with high towers, light-houses and other tall buildings during nights when large scale migratory movements coincide with poor visibility (Erickson et al. 2001). However, this fear has not been verified at all (Kerlinger et al. 2011). Although most birds killed at wind power facilities may be passerines, the risk of being killed is probably low in relation to the numbers of these birds (Hötker et al. 2006, Krijgsveld et al. 2009, Dürr 2010). There are several possible reasons why this may be the case. First, during nocturnal migratory flights, birds generally fly at several hundred or even thousand meters altitude and hence high above any wind turbine (Alerstam 1990). Second, the warning lights on modern wind turbines apparently do not attract migrating birds. Third, each migrating passerine only passes a given wind power facility once (or perhaps twice) every year, which is in sharp contrast to those that may nest in the vicinity, for example, and hence spend more time near the turbines (Krijgsveld et al. 2009).

Other nocturnal birds such as owls and nightjars may perhaps also be expected to be at particular risk at wind turbines. However, there is no indication that this is really the case. In fact, there are only a few known fatalities involving owls and none involving nightjars. Like nightjars, swallows and swifts catch their insect prey in the air, which perhaps means that they are particularly vulnerable at wind turbines (Ahlén 2010a), and, if so they may be like bats in that they feed on insects that are attracted to the turbine towers. Of all *small* birds found dead at wind turbines in Germany, almost one fourth are swallows and swifts (table 5.3), which indeed is a much higher proportion than may be expected based on their numbers.

5.1.5. Seasonal variation

As discussed above, birds sometimes die in high numbers during migratory flights in poor weather, because they collide with various objects. Such mortality is generally thought to include many young individuals moving cohesively through largely unknown areas (Erickson et al. 2001). Initially, a similar pattern was expected at wind turbines, with increased collision frequency of birds during the migration periods. This has not been observed, however (Drewitt & Langston 2008). In contrast, the collision frequency varies between places and among bird species and it seems to be independent of any migratory movements. There is no clear evidence that the risk for birds at wind turbines changes according to the season in general terms. This is in sharp contrast to the pattern observed in bats (see below).

For some raptors an increased risk of collision during the breeding season has been observed (see 5.1.8) and this has also been found in terns. For sea-eagles at Smøla in Norway, it seems clear that the risk is highest in the beginning of the nesting season in spring (Bevanger et al. 2009, 2010). For terns at a coastal site in Belgium, an increased risk at wind turbines coincided with the period when the parents were feeding the young and therefore maintained a much shorter safety distance to obstacles along their flyway than than they do at other times (Everaert & Kuijken 2007). Presumably, the parent birds were under time pressure and therefore may have been prepared to take higher risks than usual.

5.1.6. Weather effects

Thre is no obvious effect of the prevailing weather conditions on the fatality risk for birds at wind turbines and, again, this is in contrast to the case observed for bats. Nevertheless, birds may fly near the ground but also at altitudes of several thousand meters. The flight altitude depends to some extent on the direction and speed of the wind, so that they fly much lower in headwind than in tailwind (Alerstam 1990). Hence, while birds migrating in tailwind fly high above any wind turbines, they may possibly encounter wind turbines in headwind. We are not aware of any surveys that have considered this, however.

In summary, there is no evidence of high mortality of migrating birds at wind turbines as far as we know. High mortality of migrating birds at other facilities, such as towers, bridges or other buildings, usually equipped with strong lights, have been results of rapid weather changes including poor visibility and sometimes also strong winds, conditions that have forced the birds towards lower altitudes, where the collisions subsequently occurred.

5.1.7. Change with time – habituation

Obvious signs that consistent changes in the behavior of birds have resulted in fewer collisions have only been observed at one place, namely at Blyth Harbour in England. Of fifteen observed collisions involving eiders during eleven years of observation, twelve occurred during the first three years. The eiders now swim passed the wind turbines rather than flying on their way to and from their nesting area (Newton & Little 2009). There is no evidence of a similar change in behavior from any other wind power facility studied (see for example de Lucas et al. 2008, Smallwood & Thelander 2008, Bevanger et al. 2010, and for raptors also part 5.1.8 in this report).

5.1.8. Fatality rates of raptors

Because some raptorial birds seem particularly vulnerable to collisions at wind turbines, we provide a more detailed picture of the situation for these. As for birds in general, the fatality rates for raptors differ considerably between places (habitats) and species. Using all collision data available, the fatality rates vary between none and eight individual raptors per wind turbine and year. The highest numbers refer to occasional sites and years. In cases where numbers are available from the same site during several successive years, the medians are lower, usually less than 0.3 individuals per year and with an overall median of 0.03. If we use only data from localities with high raptor densities and where the most thorough and long term studies have been carried out, the comparable median is 0.07 raptors per turbine and year.

Generally, the risk to be killed at a wind turbine seems to be higher for large and medium sized raptors that typically glide or soar, than for those that use flapping flight to a higher extent. The first group includes eagles, buzzards and kites and in southern Europe, vultures as well. The second group includes the marsh harrier and the sparrow- and goshawks. The falcons are more difficult to characterize. For most of them only few collisions have been recorded, but at the same time, the kestrel is one of the raptors most frequently found dead under wind turbines. Hence, the kestrel is unusual in this respect. It is a small raptor which collides with wind turbines relatively frequently.

In Germany 16 of the 18 raptor species present in the country have been found dead under wind turbines. The most frequent victims are those that breed within the country. Species that pass Germany during migration only, or that overwinter there, are strongly underrepresented and account for no more than 0.9% of the carcasses found (Dürr 2010). In Sweden seven species of raptors have so far been found under wind turbines. However, only a single brief survey has been carried out (Ahlén 2010b).

Collisions with wind turbines affect old and young birds alike. There is no evidence that older and more experienced individuals are less vulnerable in this case. For average sized raptors, such as buzzards and kites in Germany, 10% of the fatalities are young or subadult individuals, while the rest (90%) are mature (adult) birds (Rasran et al. 2009b). However, for sea eagles the corresponding figures are more even, 47% of the fatalities are young or subadults and 53% adults (Krone et al. 2009). At Smøla in Norway, 18% of the sea eagles killed at wind turbines were young birds (<1 year old), 28% were subadults (1-6 years) and 54% were old birds (Bevanger et al. 2010). Comparable figures for griffon vultures in southern Spain were 20% young, 51% subadults and 29% adults (Barrios & Rodriguez 2004). Kestrels found dead at wind turbines in southern Spain were consistently young individuals (Barrios & Rodriguez 2004). Most of the golden eagles found dead at Altamont in California were subadults, but young and adult birds have been found as well. In this case, the breeding areas are far from the wind farms and this means that the old and the young individuals use the area near the wind turbines to a lesser extent than the half grown, non-breeding birds, which typically use wider home ranges (Hunt 2002).

Although fatalities involving raptors have been registered throughout the year, the accidents are by no means evenly distributed seasonally. Most collisions occur when the flight activity is highest, usually during the breeding season, perhaps because the adult birds then spend much time within certain areas and at altitudes where they frequently come in contact with wind turbines. In Germany, for example, most accidents occur in spring (March-April) and again in late summer and early autumn (August-September), at least as long as all species of raptors are considered (Rasran et al. 2009b). The first peak coincides with the formation of breeding territories and involves aerial displays and disputes with other birds, while the second peak covers the period when the young birds leave the breeding territories and extend their home ranges. For red kites, the collisions risk is highest in the spring (March-May) and in late summer (July-August), which is in line with the general picture (Mammen et al. 2009). For sea eagles in Germany, most adult birds are killed at the onset of the nesting period in late winter and early spring but for younger individuals most fatalities occur in late winter (Krone et al. 2009). At Smøla in Norway most sea eagles are killed during spring and early summer (March-June), which represent the early part of the nesting season and the time when most eagles move around in this and nearby areas (Bevanger et al. 2010). In Spain, the highest fatality rates of larger raptors have been registered during the winter months (Barrios & Rodriguez 2004, de Lucas et al. 2008), but for kestrels most fatalities occurred in late summer, coinciding with the first flights of the young birds (Barrios & Rodriguez 2004).

As already mentioned (part 5.1.7), there is no evidence that the collision frequencies at wind farms decline with time. Real long-term studies are unusual, but in Altamont in California, large wind farms have existed since the 1980´s and there is yet no apparent decrease in the collision frequency (Smallwood & Thelander 2008). Likewise, in Tarifa in southern Spain the fatality rate did not change noticeably over the ten year monitoring period 1993-2003 (de Lucas et al. 2008). This also applies to the wind farm at Smøla in Norway, which has been monitored systematically between 2003 and 2010 (Bevanger et al. 2010). Hence, there is no evidence for a habituation process in raptors with respect to wind turbines.

Migrating raptors seem to avoid wind turbines to a lesser extent than other birds with the possible exception of gulls and terns. While most birds usually show some kind of avoidance behavior at a considerable distance from wind turbines (Hötker et al. 2006 and part 5.3 in this report), many raptors fly close to moving rotor blades apparently without any appreciation of the danger. Observations from Germany and Sweden show that red kites do not avoid the area next to wind turbines. On the contrary, they have been seen passing through the space between moving rotor blades (Mammen et al. 2009, Ahlén 2002). Old and young sea eagles have been observed to fly very close to wind turbines both in Germany and Norway (Krone et al. 2009, Hoel 2009, Bevanger et al. 2010). In the latter case it has even been demonstrated that the flight behavior of the eagles is the same within the wind farm as it is outside (Hoel 2009). Although harriers apparently seldom collide with wind turbines, they do not avoid flying near them. In the case of Montagu´s harrier, individuals have been observed to hunt regularly within 10 m from the turbines (Grajetzky et al. 2009, Joest et al. 2009) and the hen harrier seems to behave similarly (Whitfield & Madders 2006).

What we have said above does *not* mean that raptors (and also gulls and terns) do not possess any behavioral means to avoid wind turbines or other obstacles. In fact, if this was the case, they would probably regularly collide with other obstacles as well, which is clearly not the case. Instead, the likely explanation is that raptors (and gulls) are highly maneuverable flyers, and as such they do not avoid obstacles at sufficient distances to account for the fast speed of a moving wind turbine rotor blade. Moving obstacles must be avoided at longer distances than non-moving ones and this difference is apparently not accounted for by these birds (Martin 2011).

Most birds have their eyes on the side of the head, which gives them a wide field of view. However, this is not generally the case in raptors, which rather have their eyes directed forwards. This facilitates the ranging performance (estimate of distance), which is essential during attacks on prey. Furthermore, in flight raptors typically keep their head slightly downwards, which potentially makes it difficult to locate obstacles that may turn up in the direction of flight (Martin & Shaw 2011). In Tarifa in southern Spain, it was recorded that 71% of all soaring birds, including larger raptors and white storks, changed their flight direction as they approached wind turbines, with 28% showing a drastic change in the flight course (de Lucas et al. 2004). Walker et al. (2005) found that a stationary pair of golden eagles in Scotland avoided a wind farm, although the turbines were located within the eagles´ home range. The only exception was when other eagles were chased away from the territory.

Generally, the danger to raptorial birds increases as the wind turbines become taller and have larger rotors. This relationship has been observed in USA as well as in Spain and Germany (Thelander et al. 2003, de Lucas et al. 2008, Rasran et al. 2009), but it should be noted that this do not seem to apply to birds other than raptors (part 5.5.2). Since modern and more efficient turbines produce more electricity than older ones, the number of collisions per unit energy produced decreases as old turbines are replaced by a smaller number of modern ones (Smallwood & Karas 2009). The construction of the tower does not seem to be related to the number of raptors that are killed (Barrios & Rodriguez 2004, Smallwood & Karas 2009). This is in contrast to earlier worries that turbines that offer perches for raptors in the tower may be more dangerous (Erickson et al. 2001). In Germany, large wind farms kill more raptors than smaller farms, but the number of fatalities per turbine is lower (Rasran et al. 2009).

In Germany is has been recorded that wind turbines located on open farmland kill more raptors than turbines in other tree-less places. This may perhaps be an effect of differences in the availability of food or because prey animals may be easier to find or catch in such areas. In contrast, the occurrence of trees in the vicinity of the wind farm has no influence on the number of birds that are killed (Rasran et al. 2009). It has been speculated that raptors may be attracted to wind farms because there may be easily captured food in the form of dead birds or bats under the turbines, as is sometimes the case along highways or railways. However, we have not found any indication that this is really the case at wind turbines. Possibly, the number of carcasses found under wind turbines is generally too low to justify such behavior.

There is no indication that migratory raptors are particularly vulnerable at wind turbines. This problem has not been studied in detail, but there is some evidence that migrating raptors may even be at lower risk compared to stationary ones. For example, at the Tarifa wind farms in Spain, nearly all raptors found dead belong to stationary rather than migratory species. At the same time, most collisions occur during the winter months and not during the migration periods when many raptors pass through the area (de Lucas et al. 2008). The reason behind this pattern is most likely that birds migrating past Tarifa fly high above the wind farms. In this case the risk for collision is highest during take off and landling. Alternatively, the birds may have a stronger avoidance reaction during migration.

There is some conflicting evidence on how collisions between raptors and wind turbines may be influenced by the weather, and there is no general answer. For most species, collisions are most frequent during cold weather and low wind speed particularly in the winter months, when the upwinds usually are weak. This applies at least to vultures in Spain (de Lucas et al. 2008).

5.1.9. Fatality rates at wind farms in Sweden

According to two occasional reports from the 1980´s a small number of migratory passerines were found dead at wind turbines on the island of Gotland off the east coast of Sweden (Karlsson 1983). A brief compilation of the *species* found dead under wind turbines in Sweden was recently provided by Ahlén (2010b). The latter report was the result of visits to 160 wind turbines in Skåne and Blekinge and on the islands of Öland and Gotland in 2002 and to another 200 turbines in southernmost Sweden in 2008. To this material has also been added data from the Museum of Natural History in Stockholm and from several non-governmental organizations as well as from universities and regional authorities. In total, the list contains 53 species of birds (table 5.4). At least one dead bird was found in 25% of the wind turbines surveyed (Ahlén 2010b). The list includes seven species of raptors and for these the number of dead individuals are also provided; red kite 12, sea eagle 12, golden eagle 4, common buzzard 3, osprey 2, rough-legged buzzard 1 and goshawk 1 (Ahlén 2010b).

Table 5.4. Bird species found dead under wind turbines in Sweden until January 2010 (data from Ahlén 2010b).

English name	Latin name
Cormorant	*Phalacrocorax carbo*
Mute swan	*Cygnus olor*
Whooping swan	*Cygnus cygnus*
Greylag goose	*Anser anser*
Barnacle goose	*Branta leucopsis*
Mallard	*Anas palatyrhynchos*
Gadwall	*Anas strepera*
Pintail/shoveler	*Anas acuta/clypeata*
Teal	*Anas crecca*
Eider	*Somateria molissima*
Long-tailed duck	*Clangula hyemalis*
Sea eagle	*Haliaeetus albicilla*
Osprey	*Pandion haliaetus*
Golden eagle	*Aquila chrysaetus*
Red kite	*Milvus milvus*
Rough-legged buzzard	*Buteo lagopus*
Common buzzard	*Buteo buteo*
Goshawk	*Accipiter gentilis*
Pheasant	*Phasianus colchicus*
Oystercatcher	*Haematopus ostralegus*
Golden plover	*Pluvialis apricaria*
Lapwing	*Vanellus vanellus*
Redshank	*Tringa totanus*
Curlew	*Numenius arquata*
Woodcock	*Scolopax rusticola*
Snipe	*Gallinago gallinago*
Blach-headed gull	*Larus ridibundus*
Common gull	*Larus canus*
Herring gull	*Larus argentatus*
Lesser black-backed gull	*Larus fuscus*
Great black-backed gull	*Larus marinus*
Common tern	*Sterna hirundo*
Stock dove	*Columba oenas*
Wood pigeon	*Columba palumbus*
Tawny owl	*Strix aluco*
Great horned owl	*Bubo bubo*
Swift	*Apus apus*
Greater spotted woodpecker	*Dendrocopus major*
Skylark	*Alauda arvensis*
Barn swallow	*Hirundo rustica*
Sand martin	*Delichon urbica*
Dunnock	*Prunella modularis*
Robin	*Erithacus rubecula*
Fieldfare	*Turdus pilaris*
Song thrush	*Turdus philomelos*
Blackbird	*Turdus merula*
Willow warbler	*Phylloscopus trochilus*
Goldcrest	*Regulus regulus*
Rook	*Corvus frugilegus*
Crow	*Corvus corone*
Raven	*Corvus corax*
Chaffinch	*Fringilla coelebs*
Yellowhammer	*Emberiza citrinella*

5.2. Habitat loss – are birds disturbed by wind farms?

The direct habitat loss resulting from the construction of a wind power facility is probably quite limited in most cases, although this problem has not recieved much attention so far. The problem is certainly not unique for wind farm construction and should be handled in the same way as other kinds of exploitation.

However, there are many investigations of possible indirect effects such as disturbance from the construction and drift of wind turbines, but they are difficult to compare, because the methods used are usually different. Nearly all the data about the density of birds near wind farms have been collected in open landscapes, principally because this is where most wind turbines are found. The habitats studied include agricultural fields, coastal areas and the open sea, and the birds that occur there. There are no comparative studies from forests as far as we know. The summary presented below was largely taken from the review made by Hötket et al. (2006).

Table 5.5. The number of surveys during the breeding season showing either a similar or higher density or a lower density, respectively, of birds near the wind farm, following its construction and in comparison with an unaffected reference area.

Species group	Stable or higher density following construction	Lower density after construction
Ducks	6	5
Raptors	5	5
Grouse, quails and phesants	7	10
Waders	25	44
Song-birds	125	74
Total	**168**	**138**

Of the surveys made during the breeding season, 55% report densities of birds that are equal or higher near the wind power facilities, while 45% of the surveys show lower densities near the turbines. The pattern observed differs between species or groups of species, however. For example, lower densities near wind turbines have been reported particularly often for partridges and phesants (but not including grouse) and waders. It may be mentioned that the detailed study of willow grouse carried out at the Smøla wind farm in Norway does not indicate any difference in density of birds between the wind park and a reference site (Bevanger et al. 2010). Another study from the same place suggests that the brown-throated diver has disappeared entirely from the area near the wind farm, but the reason for this is not clear (Halley & Hopshaug 2007). For passerines, most studies indicate that the presence of a wind farm does not affect the density of birds (table 5.5).

Negative effects of wind farm establishments have been observed for all groups of birds studied and absence of effects have also been recorded for all groups. Waders and perhaps also partridges and phesants are two groups that seem to show negative responses to wind farm establishments during the breeding season. In total 58% of all surveys indicate negative effects of wind farm establishment on the density of birds. Geese, ducks and waders predominantly show negative responses, while in most other groups there is no obvious response in any direction. Apparently, disturbance effects are more obvious outside the breeding season and more so for birds that live in large groups such as geese, ducks and waders.

Results from surveys made in marine habitats show that divers in particular, but also some sea-birds, such as gannets, clearly avoid the area near wind turbines. A similar behavior is shown, although less explicitly, by some species of marine ducks and terns and perhaps also auks. This applies at least to the initial years following the construction of the wind farm. At the same time, gulls and cormorants may increase their use of the area following the construction, presumably because the turbine fundaments provide suitable perching sites (Petersen et al. 2006, Krijgveld et al. 2010, Leopold et al. 2010, Percival 2010).

Table 5.6. The number of surveys outside the breeding season showing either a similar or higher density or a lower density, respectively, of birds near the wind farm, following its construction and in comparison with an unaffected reference area.

Species group	Higher density or the same following construction	Lower density after construction
Geese	2	15
Ducks	2	22
Raptors	27	23
Grouse, quails and pheasants	1	1
Waders	35	72
Gulls and terns	19	15
Song-birds	34	19
Total	**120**	**167**

Specific disturbance ranges, the distances at which birds show avoidance reactions or within which lower densities of birds have been recorded, vary considerably within and between species as well as over the year and between different locations. Hence, again, it is difficult to draw any general conclusions. Nevertheless, disturbance ranges are usually less than 500 m and in most cases no more than 100-200 m (Hötker et al. 2006). A summary of disturbance ranges for some bird species groups is shown in table 5.7. The longest disturbance ranges are found among geese, ducks and waders, while the shortest are in raptors and passerines. At sea, disturbance ranges have not been measured using the same methods as in terrestrial habitats. Instead, bird densities have been measured within zones around some larger wind farms. For example, reduced densities of divers have been recorded up to 2 km from the wind parks (Petersen et al. 2006).

Birds often become habituated to frequent but generally harmless distubances and the effect of a particular type of disturbance therefore tend to decline with time. How this applies to wind turbines has been reviewed by Hötker et al. (2006). In tables 5.8 and 5.9 we have used their review and added some observations that have become available more recently. Again, the results are not consistent. Surveys suggesting a decreasing disturbance range are about as many as those where no change has been found. This applies both to the breeding season and the non-breeding season. For ducks as well as for fowl, shortened disturbance ranges have been recorded consistently. However, the studies have been carried out only a few years following the construction and the observed reactions have been small. Habituation at the individual level has not been observed.

Tabell 5.7. The disturbance ranges for different groups of bird species during and outside the breeding season as estimated in different studies. The variation shown is +/- one standard deviation.

Species group	Disturbance distance (m) Mean	Disturbance distance (m) Variation	Number of studies
Breeding season			
Ducks	103	47-159	8
Waders	203	30-376	32
Song-birds	65	0-190	105
Non-breeding season			
Herons	65	0-62	6
Swans	150	19-289	8
Geese	373	146-559	13
Ducks	230	89-371	30
Raptors	38	0-87	29
Waders	221	10-432	89
Gulls and terns	105	0-286	21
Pigeons and doves	160	0-355	5
Song-birds	40	0-112	38

Nevertheless, there are a few clear examples where the avoidance range has decreased with time. In foraging pink-footed geese it decreased from 200 m to 125 m and from 100 m to 25 m at two different wind farms in Belgium over 8 and 10 years, respectively (Madsen & Boertmann 2008). At Horns reef off western Danmark, the number of common scoters has increased over successive years, following the construction of a large wind farm in 2002 (Petersen & Fox 2007). However, it remains unclear if the increase in bird density was an effect of habituation to the wind turbines or of something else.

We could also imagine a situation where the disturbance range actually increases with time. This would be expected if older birds show a strong affinity to their breeding sites, while at the same time, young birds avoid the same area because of the wind turbines. As the older birds die off, the apparent disturbance range would become longer. A scenario like this was used to explain the gradually declining numbers of black grouse observed near a wind farm in the Alps (Zeiler & Grünschachner-Berger 2009).

Tabell 5.8. The number of surveys showing long term changes in the disturbance distance for different groups of bird species during the breeding season, following wind farm construction (data from Hötker et al. 2006).

Species group	Unchanged disturbance distance	Shorter disturbance distance
Ducks	0	2
Grouse, quails and pheasants	0	6
Waders	9	8
Pigeons and doves	1	0
Song-birds	31	22
Total	**41**	**38**

A meta-analysis including the results of surveys at 19 wind farms throughout Europe and North America, showed a clear relationship between the time since construction of the wind farm and the density of birds. Bird density consistently decreased with the time after construction (Stewart et al. 2007). This highlights the importance of long investigation periods whenever the effects of wind power facilities are being investigated.

It may be possible that the disturbance range to some extant depends on the size of the wind turbines. This question has been examined for 17 species during the breeding season and for 16 outside the breeding season. In one of studies cases, namely breeding lapwings, taller towers resulted in a longer disturbance range, but in the remaining studies there was no such effect (Hötker et al. 2006).

The disturbance range may depend on the availability of the preferred habitat, so that if a sparse but highly preferred habitat occurs near the turbines, this may result in a shorter range. This is believed to explain the observed differences in disturbance range of barnacle geese on the baltic island of Gotland and in Germany. On Gotland, the availablity of alternative feeding areas without wind turbines was low, and therefore the birds foraged as close as 25 m form the turbines (Percival 2003). In Germany, with abundant alternative fields, the geese rarely foraged closer than 350 m from the turbines and the density of foraging geese remained lower than expected within as much as 600 m from the turbines (Percival 2003).

Stewart et al. (2007) made a literature survey, using an evidence-based methodology of high scientific standard. Based on the 19 surveys included in the study, a negative effect on bird density was demonstrated. Ducks were most strongly affected, followed by waders, while smaller effects were found for raptors and passerines. There was no demonstated effect of the number of turbines in the wind park. The time since establishment of the park had a clear effect, however, so that the disturbance effects increased with time and the densities of birds near the wind turbines decreased. Finally, it was found that the disturbance effects increased with latitude, with stronger effects at northern localities.

Tabell 5.9. The number of surveys showing long term changes in the disturbance range for different groups of bird species outside the breeding season, following wind farm construction (data from Hötker et al. 2006).

Species group	Unchanged disturbance distance	Shorter disturbance distance
Geese	1	2
Ducks	0	7
Raptors	3	2
Waders	7	6
Gulls and terns	3	2
Pigeons	1	1
Passerines	2	2
Total	**17**	**21**

5.3. Barrier effects

Hötker et al. (2006) summarized 168 single observations and surveys of presence or absence of barrier effects at land based wind power faclilties. They did not include the magnitude of the observed barrier effects however, so it is difficult to use this material for any general conclusions. At the same time, the definition of a barrier effect was set at a low level, so that if at least 5% of the individuals of a certain species changed their flight direction or height on the encounter with a wind turbine, the behavior was classified as a barrier effect. With this classification, 104 of the 168 observations (62%) indicated that barrier effects occurred. These observations were spread across 91 bird species, 82 of which showed apparent barrier effects at least once. These effects were observed in all major groups of bird species.

The results from detailed off shore surveys carried out using radar and various visual observation methods in Sweden and Denmark are perhaps of more immediate interest for our purpose. Migrating seabirds, mainly eiders, changed their flight courses as they approached two small (5 and 7 turbines, respectively) wind farms in the Kalmarsund area off the Baltic coast of Sweden and clearly avoided the area near the turbines (Pettersson 2005). Obviously, this behavior prevented collisions with the turbines, but at the cost of a slightly longer flight route. In good weather conditions in daytime, the birds reacted at a distance of 1-2 km, and only 3% of the flocks flew closer than 500 m from the turbines. The behavior at night was genarally the same, although the change in the flight course occurred at shorter range, usually 0.5-1 km (Pettersson 2005). This behavior was also observed during nights with relatively poor visual conditions, although only few birds continued their migration flights on such nights (Pettersson 2009).

At the two major Danish wind farms at Horns reef (80 turbines) and Nysted (72 turbines), roughly 80% (71-86% and 78%, respectively) of all birds, mostly eiders and other seabirds, that headed towards the farms, avoided to fly through them (Petersen et al. 2006). In fact, the proportion of bird flocks that passed the area of the present wind farms decreased from 40% before the construction to 9% afterwards. The flight direction of approaching bird flocks sometimes changed as far as 5 km from the turbines, although the distance usually was 1-2 km. As in Kalmarsund, the behavior was the same at night, except that the avoidance reaction distances observed were shorter. Birds that nevertheless flew through the wind farms usually made use of corridors between the rows of turbines and hence to some extent still maximized the distance to the turbines (Desholm & Kahlert 2005, Petersen et al. 2006).

The extra flight distances that are consequences of avoidance behaviors are probably negligible for migrating seabirds and this presumably means that the associated energetic cost also are of minor importance. For example, based on data from Nysted, it was estimated that the total energetic cost of a migratory flight for an eider (1400 km) will be 0.5-0.7% higher because of the avoidance of this particlular wind farm (Petersen et al. 2006). Obviously the extra cost of avoiding one wing farm is negligible, but the cumulative effect of avoidance behavior at many wind farms along the way could potentially increase the risk for more important and long-term consequences (Masden et al. 2009).

Tabell 6.1. Causes of death for golden eagles in Sweden, as reported to the Natural History Museum in Stockholm and the National Institute of Vererinary Medicine in Stockholm 1993-2008 (data from Johansson 2009).

Cause of death	Number of individuals
Collision with train	79
Collision with power lines and accociated structures	45
External injuries of unknown origin	25
Collison with road traffic	14
Disease	11
Poaching	11
Starvation	9
Lead poisoning	8
Collison with wind turbine	4
Caught in trap	2
Killed by hunter following attack on dog	2
Rib bone stuck in throat or stomach	2
Killed by lynx	2
Killed during attack on human	1
Drowned for unknown reason	1
Frightened to death in chicken yard	1
Killed by another eagle	1
Total	**217**

6. Effects of wind farming on birds – Fatality rates in perspective

An estimated 100 000 birds are killed annually by oil spills in Sweden, while power lines and associated structures kill 200 000 and windows another 500 000. However, the most important sources of death for birds in Sweden are traffic and house cats, which kill an estimated 10 million and 6-7 million birds annually, respectively (Dahlfors 2006). The construction of 5 000 wind turbines in Sweden before the year 2020 may be a likely outcome according to the national plan. If the fatalilty rate remains at 2.3 birds per turbine per year (see part 6.1.1), a total of about 11 500 birds may be expected to die at wind turbines per year in 2020. In comparison with other causes of death this is not much, but the effect obviously depends on which species are affected and where this happens.

An important question is whether the mortality at wind turbines is additive or compansatory. If is is additive, it can have negative long term effects on some populations, particularly those that show stable or decreasing trends. In contrast, a population that shows a positive trend may have a better chance to compensate for increased mortality. If the new mortality is compensatory however, the birds that are killed should have died anyway, and in this case the added mortality from wind turbines would have no effect at all on the population size.

Even if wind farming does not seem to be a serious threat to birds in general, it could possibly affect some species or populations negatively. This is primarily of concern for large raptors (see sections 5.1.4 and 5.1.8). If a future expansion of wind farming will affect bird populations negatively will primarily depend on where the turbines are located and which species occur there. The golden eagle may be a particularly sensitive species. Above, we present a list of known causes of death for golden eagles in Sweden up to 2008 (table 6.1). However, it should be remembered that the causes reported probably differ from the real ones, since some types of mortality may be more easily detected than others. Most (77%) of the dead eagles reported had apparently died from causes related to human activities, but, most likely, other causes were strongly underrepresented in the sample. Nevertheless, trains seem to be of particular danger to golden eagles, representing as much as 48% of the fatalities recorded, while power lines and associated structures also kill many individuals (21%). Few golden eagles seem to die at wind turbines (4 individuals, 1.8%), although there are more turbines now compared to when the study was published (2009).

In the same way, causes of death have been compiled for sea eagles (table 6.2). Even in this case death causes related to human activities prevail, representing 86% of the records. The causes differ from those for the golden eagle, however. Lead poisoning is the most important human related cause of death in sea eagles, representing 36% of the cases. Sea eagles ingest lead when they feed on seabirds carrying lead after having been shot at (Helander & Bignert 2008). Wind power facilities were responsible for 4% of the fatalities, which is slightly more than for golden eagles. The difference probably reflects that more turbines are located in areas used by sea eagles, such as along the coast. Since the present summary (table 6.2) was made, a further 10 sea eagles have been reported killed at wind turbines (part 5.1.9). The part of the mortality of sea eagles caused by wind turbines most likely have increased recently, because more wind turbines have been built.

Table 6.2. Causes of death for sea eagles in Sweden, as reported to the Natural History Museum in Stockholm and the National Institute of Vererinary Medicine in Stockholm 2002-2007. Note that the table shows the record up to 2008. The number and presumably the fraction of birds killed at wind turbines have increased since then (data from Helander & Bignert 2008).

Cause of death	Number of individuals
Lead poisoning	17
Unknown reason	8
Collision with power lines and accociated structures	6
Killed by another eagle	4
Collision with train	2
External injuries of unknown origin	2
Collision with road traffic	2
Disease	2
Collison with wind turbine	2
Collision with aircraft	1
Drowned	1
Total	**47**

7. Sensitive bird occurrences – Help during planning

In part 3 we discussed the distribution of birds across the country in general terms. In the following chapter, we will provide a more detailed picture on the occurrence of bird species that are particularly vulnerable to collisions and habitat loss from wind farming. We also point out localities and areas that regularly harbor larger concentrations of birds. Together with general knowledge of habitat requirements of different bird species, this information can be used during the planning process at the county or community levels. In appendix 1 we summarize the regional distribution of breeding raptors, grouse and allies and waders across the country.

7.1. Breeding raptors

The raptors are the group most likely to be negatively affected through collisions with wind turbines (see 5.1.4 and 5.1.8). Hence, we will take a closer look at the distrubution of these birds across the country. The density of raptors decreases as we go north (fig. 7.1.), which is because the availability of food is generally lower at higher latitudes. This pattern follows that for birds in general. The higest density of raptors, 70 pairs per 100 km^2, is found in Skåne, the southernmost county, and this is primarily an effect of dense populations of red kites and common buzzards. Other counties with high raptor densities, 50 pairs or more per 100 km^2, are Blekinge, Västra Götaland, Södermanland, Stockholm and Uppsala. In the northern counties such as Jämtland, Västerbotten and Norrbotten, the densities are generally less than 15 pairs per km^2. This pattern applies to raptors in general, but for the individual species the picture may be more complicated.

Since the density of raptors is highest in the south, the risk for collision with wind turbines may also be expected to be highest in the south. This pattern seems to apply not only for raptors in general but also for the raptor species most often found dead at wind turbines. Even if we include only the six large and medium sized raptor species, namely red kite, sea- and golden eagles, common and rough-legged buzzards and osprey and the smaller kestrel, the pattern still holds. Particularly high densities of these species occur in Skåne (40 pairs per 100 km^2), but high densities are also found in Blekinge, Västra Götaland and the three counties near lake Mälaren (18-25 pairs). The lowest densities are found in the three northernmost counties and in Dalarna (< 5 pairs), although the densities are also quite low in Värmland and Västernorrland (< 10 pairs).

The peregrine falcon and the gyrfalcon should also be considered as vulnerable species, as suggested by several dead individuals (peregrines) found at German wind power facilities. These species occur within restricted areas and in small populations, compared to other raptors.

In figure 7.1, the densitiy and proportional distribution of breeding raptors are shown for each county in Sweden. It is evident that several of the northern counties have lower densities of raptors, but at the same time higher proportions of the total populations than the southern counties. This is obviously because the northern counties are much larger on average. Nevertheless, the densities of the different species are the most relevant measure with respect to the potential effects of wind turbines.

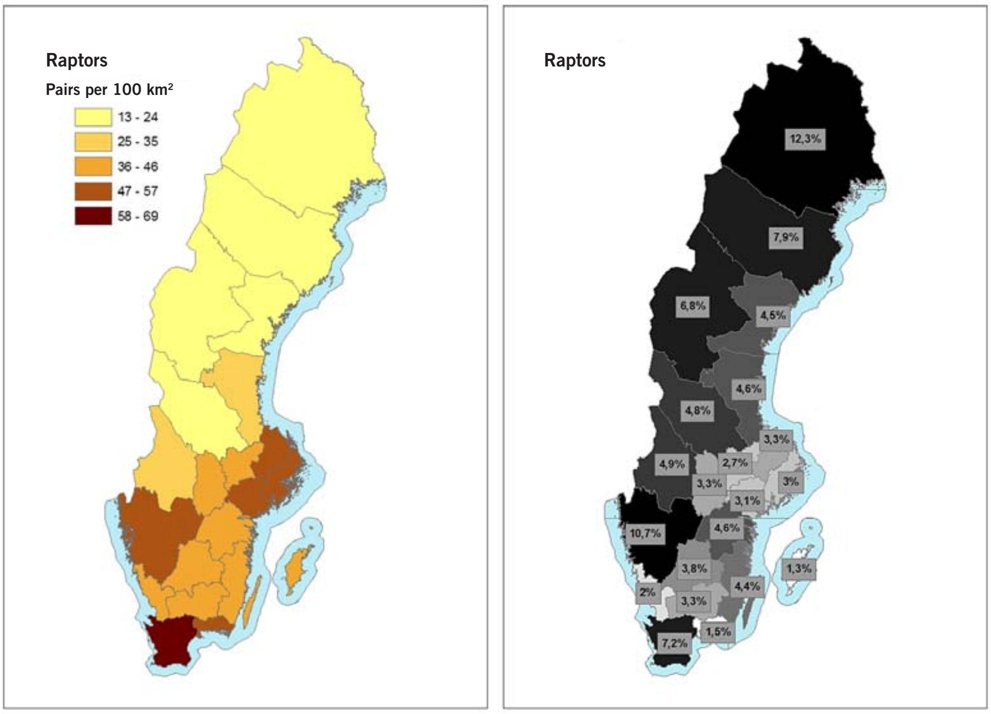

Figure 7.1. Raptors, pairs per 100 km^2. Densities of breeding raptors across the 21 counties of Sweden (left) and the fraction (%) that breed in each (right).

7.1.1. Red kite, sea eagle and golden eagle

In the following chapter we will take a closer look at the three bird species considered to be the most vulnerable at wind turbines and for which the need to minimize the risk is particularly important. The red kite is the species of raptor most frequently found dead under wind turbines in Germany and it has also been found under wind turbines in Sweden (Ahlén 2002). In the past this species was heavily affected by pesticides and illegal hunting and nearly disappeared from Sweden. Improved protection and fewer threats have resulted in strong population recovery, and therefore the red kite is no longer included in the national red list. Internationally, however, it is still included in the red list. It is classified as near threatened (NT) because the populations are still declining in some countries, and is included in Annex 1 of the EU Habitats Directive (http://www.birdlife.org/datazone/speciesfactsheet.php?id=3353).

The Swedish population of red kites represents as much as 10% of the world population of the species, the distribution of which is largely limited to Europe. Within Sweden the red kite is restricted to the southernmost counties, with 95% of the individuals in Skåne. The species is spreading slowly towards the north, however. The Swedish population of the red kite currently consists of more than 2 000 pairs. At present, with the great majority of the individuals within a single county (Skåne), this is obviously where the risk for collisions is highest.

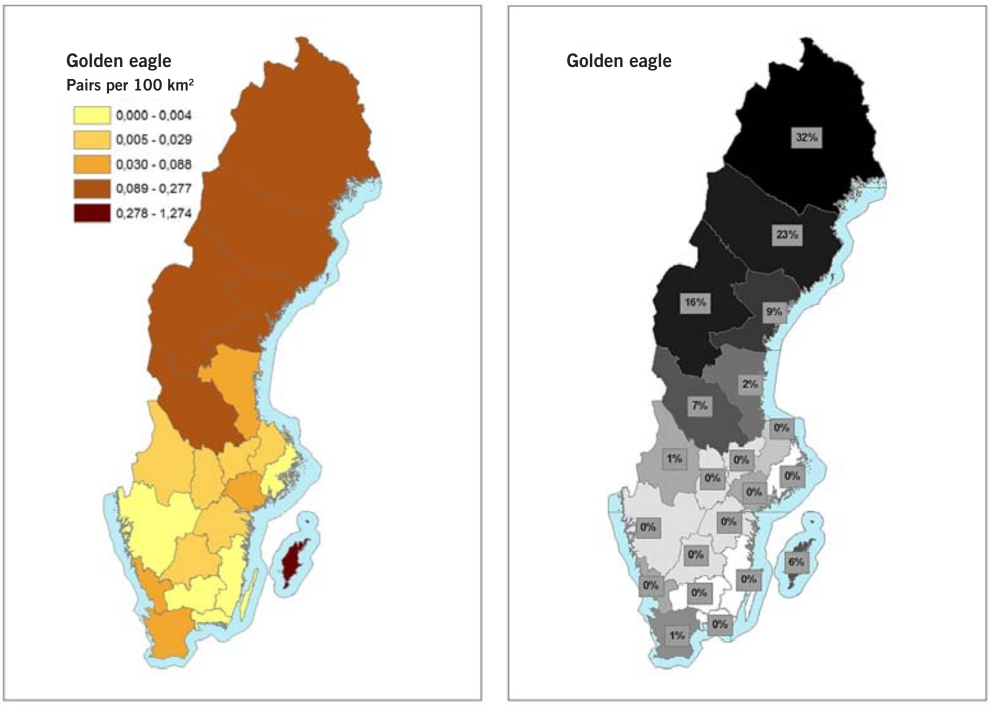

Figure 7.2. Golden eagle, pairs per 100 km². Densities of breeding golden eagles across the 21 counties of Sweden (left) and the fraction (%) that breed in each (right).

At present (2011) there are about 300 wind turbines in Skåne (www.lansstyrelsen.se/skane). To get an idea of how these turbines may affect the population of the red kite, we can make a simple calculation. First, we assume that the fatality rate observed in other areas with dense raptor populations, namely 0.1 raptors per turbine per year, applies to Skåne as well. We may also assume that one third of the raptors that are killed at wind turbines in Skåne are red kites. The latter assumption may be justified because one third of the breeding raptors in Skåne (of the high-risk category) are red kites. This means that about 10 red kites will be killed annually at wind turbines in Skåne (300 x 0.1 x1/3), which represents approximately 0.25% of the breeding population (10/4000). In fact, the figure may be lower than this in practice, because not only adults but also young and non-breeding individuals are killed. Hence, if our assumptions are reasonable, the effect of wind turbines on the population of red kites in Skåne is small.

The sea eagle is nationally red listed in the near threatened (NT) category and it is included in Annex 1 of the EU Birds Directive. In the past it was seriously threatened and the population size and distribution were severely constrained in Sweden and throughout Europe. Since the 1970´s the species has recovered and it is no longer on the international red list. The sea eagles in Sweden are now estimated to number 500 pairs, which is about 5% of the European population of the species (Helander 2009), and is still expanding in some areas. The highest densities of sea eagles are found along the east coast between the counties of Uppsala and Kalmar, an area that harbors almost 60% of the breeding individuals. The highest density occurs in the counties around Stockholm. However, the total number of sea eagles per province is highest in Norrbotten in the far north, although the density is only about 1/7 of the density further south along the east coast (Helander 2009).

Compared to the red kite, the sea eagle occurrence is more spread and the density is much lower, which means that it is more difficult to identify any particular area where the species faces an elevated risk. Rather than trying to identify particular regions, we should concentrate on habitats for this species, such as along the entire Baltic coast line and to some extent also the larger lakes in southern Sweden. At present the breeding populations are rather weak in Jämtland, Jönköping and Halland, but if the spreading continues, these areas will presumably become populated as well in due course (Helander 2009).

The third of the more vulnerable raptor species is the golden eagle. This species too have increased strongly in numbers and it has also resumed part of its previous distribution. Golden eagles are still relatively few in the south (Götaland), however, so a further increase of the population is expected. The golden eagle is nationally red listed in the category near threatened (NT) and it is included in Annex 1 of the EU Birds Directive. However, it is no longer on the international red list. There are about 500 pairs of golden eagles in Sweden, which corresponds to 5% of the European population (Hjernquist 2011). The number of breeding pairs of this species varies considerably from year to year, however, depending on the prevailing weather and the availability of food.

Although the golden eagle is found breeding throughout most of Sweden, the great majority (87%) of the nesting pairs occur in the four northernmost regions and in Dalarna. By far the densest population of golden eagles is found on the island of Gotland, however, although these individuals only represent 6% of the population in the country (figure 7.2). Nevertheless, the density of golden eagles on Gotland is between four and eight times higher than in the northern areas, where most of the breeding pairs are found, and therefore it is on Gotland that the risk of collision with wind turbines is highest. Until the year 2011, seven dead golden eagles have been found under some of the 150 wind turbines on Gotland (Hjernquist 2011). Systematic surveys are missing, however, so the real number is probably higher. Nevertheless, let us make the same calculations for the golden eagle on Gotland as for the red kite in Skåne. We assume that the total fatality rate for vulnerable raptors is 0.1 per turbine per year and that golden eagles represent 11% of the breeding raptors of the species (belonging to the high-risk category). Hence, we can expect that one or two golden eagles will be killed at wind turbines on Gotland each year (150 x 0.1 x 0.11 = 1.65), which represents 2.8% of the breeding population on the island (1.65/0.06 x 1000 = 0.028). As in the red kite, the real number is probably lower, because some of the killed birds are likely to be non-breeding individuals.

The golden eagle population predominantly occurs at low densities. In particular, this is the case along the east coast, where the sea eagle is relatively common. Most breeding sites for golden eagles in Sweden are found in forested areas of the northern regions, frequently often at or near heights. This is a habitat type which may be of interest for wind farm construction, and we can see a potential risk of conflict between wind farming and conservation of golden eagles in this region. We recommend contact with the non-governmental organization "Kungsörn Sverige" (http://kungsorn.org/), which is a cooperative effort of local and regional eagle groups.

In an ongoing project funded through Vindval (http://www.naturvardsverket.se/Vindval), the use of the breeding territory by golden eagles is investigated. We also need to know more about where golden eagles spend the winter, and particularly where they appear in high numbers. In the past, large scale winter feeding was used to increase the survival of the eagles, but as the populations have increased, many of these feeding sites are no longer in use. For both eagle species, there are designated action plans and ongoing research projects (Helander 2009, Hjernquist 2011).

7.2. Breeding grouse and ptarmigans

Grouse, ptarmigans and their allies (galliforms) ralatively often collide with wind turbines and other constructions (se 5.1.4). There is also a particular interest in these birds from hunters and those interested in conservation in general. However, it should be noticed that the risk that wind power facilities will affct populations of grouse and ptarmigans at the national level is probably negligible, although local effect may possibly occcur.

The density of forest grouse (capercaillie, black cock and hazelhen) and ptarmigan (willow grouse and rock ptarmigan) is highest in the north, from Norrbotten south to Värmland and Dalarna, and lowest in Skåne and on Gotland (figure 7.3). The difference in density is considerable, on average only one fifth in the south as compared to the north. This applies to the group in general but also for each species separately. Of the five species included, it is only the black cock that occurs in all regions. The rock ptarmigan has the most restricted distribution. It is found only at high elevation in the alpine western parts of the northernmost regions. The willow grouse occurs in Norrland south to Dalarna and Värmland. The capercaillie and hazelhen are found in all regions except the island of Gotland. All the species except the rock ptarmigan live in forests. None of the species are red listed in Sweden, but capercaillie, black cock and hazelhen are included in Annex 1 of the EU Birds Directive.

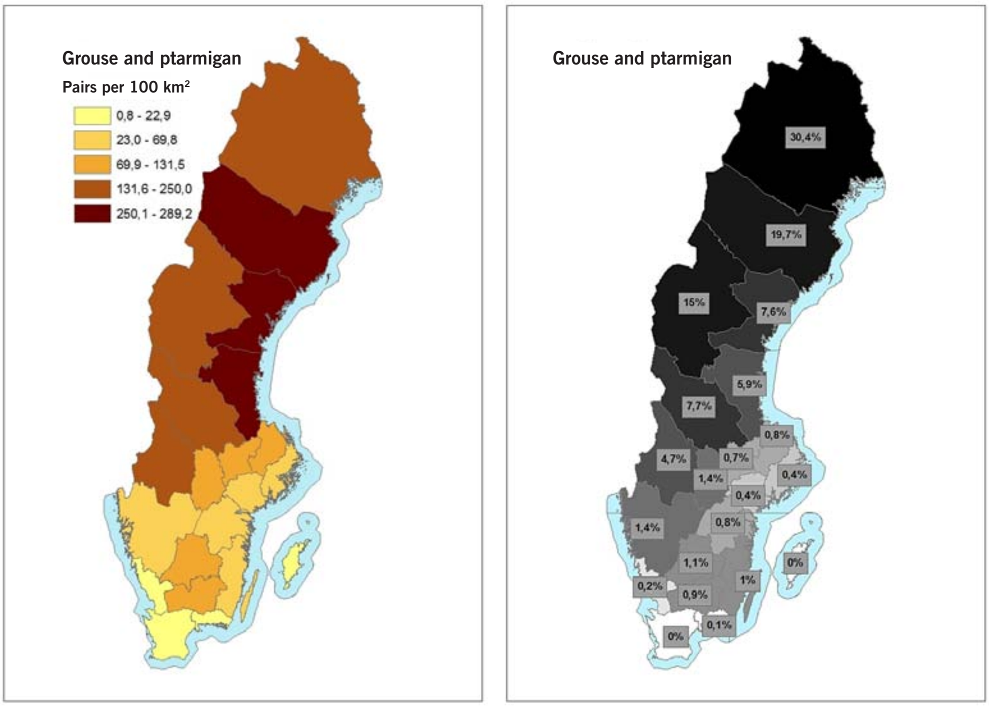

Figure 7.3. Grouse and ptarmigan, pairs per 100 km². Densities of breeding grouse and ptarmigan across the 21 counties of Sweden (left) and the fraction (%) that breed in each region (right).

The highest densities of grouse and ptarmigan are found in northern Sweden, in the same counties where the highest proportions of the individuals occur. In contrast to raptors, the populations of grouse and ptarmigan are large and dispersed throughout much of the country, which means that detrimental effects from wind farms are unlikely. Nevertheless, for the lekking species the display sites are to some extent traditional and they are usually located in particular habitats. Capercaillie leks are usually found in full grown forest and black cock leks most often occur on large open bogs. Generally, there is a need for better knowledge about how disturbance at leks may affect populations of these birds.

7.3. Breeding waders

Wading birds sometimes avoid nesting in the vicinity of wind turbines (5.2.2). They also appear in the collision statistics (tables 5.3 and 5.4), but as a group they do not seem to collide more often than other birds. Many waders are closely associated with particular habitat types. There are several examples of decreasing population trends in waders, which could make them particularly vulnerable and motivate a closer look at the situation. Below we review the geographical distribution of the 29 species of waders that regularly breed in Sweden.

The density of waders does not follow the general north-south gradients evident for most other birds. The highest densities occur in south-eastern Sweden, particularly on the Baltic islands of Gotland and Öland (the latter is part of the county of Kalmar). In both cases the high densities of waders is an effect of large areas of coastal meadows. The third highest density is found in Norrbotten in the far north. Generally, waders occur at reasonably high densities in all regions, so rather than focusing on the regions, it may be better to identify the habitats and localities that may be of particular importance. Together the three large counties in the north harbor more than half of the waders in Sweden, but Skåne as well as the islands of Öland and Gotland are also very important for waders.

Most waders are associated with wet habitats. In the agricultural landscape there are also important breeding areas, but perhaps more importantly, there are areas used for resting or overwintering as well. Coastal meadows usually harbor the highest densities of waders and are therefore of extraordinary importance. Mires and bogs, which are characteristic parts of the northern forest regions and mountains, are also important areas for waders, and this is the main reason behind the relatively high densities observed in Norrbotten and the other northern counties. In the north, the highest densities of waders are usually found on large open mires but mountain heaths may also be important. In addition, there are a few species that breed in forest.

Wetlands, coastal meadows and larger mires and bogs should generally be considered as important for waders and the risk of negative effects from wind farming in such places may be higher than in other habitats. Because disturbance ranges usually are relatively short for waders (see 5.2.2), negative effects could probably be minimized relatively easily by locating the wind turbines outside the wetland area. We suggest a safety distance of 500 m in this case. Vulnerable coastal meadows are usually narrow areas facing the water. Such areas occur more or less throughout the country, although they are particularly common on Öland and Gotland.

Eight waders that breed in Sweden are included in the national red list, namely southern dunlin (CR), ruff (VU), black-tailed godwit (VU), bar-tailed godwit (CR), curlew (VU), common sandpiper (NT) and turnstone (VU). The density of these species taken together is highest in the three large regions in the north and decreases towards the south. However, this information may be of limited value in comparison with information of the preferred habitat of the separate species. What has been said above about coastal meadows and bogs and mires in general also applies to the red listed species. However, the common sandpiper is usually found at lake shores inland, lesser water courses and sometimes on sea-shores, while the turnstone typically occurs in archipelagos and coastal meadows. The curlew occurs predominantly on peat bogs but also in open agricultural landscapes. The two waders that currently seem to face the highest danger and for which recent population declines have been most serious are the southern dunlin and the black-tailed godwit. In Sweden these two species are found exclusively on coastal meadows in the south and on some wet inland meadows near Kristianstad in Skåne.

Nine species of waders are included in Annex 1 of the EU Birds Directive. For these species the respective countries have agreed to guarantee the continued existence of the important habitats. This applies to the avocet, dotterel, golden plover, southern dunlin, ruff, great snipe, bar-tailed godwit, green sandpiper and red-necked phalarope. The protection of these species in relation to wind power facilities is best considered at the local level. The golden plover and the green sandpiper are the most common and well spread species, whereas the other species are more specific with respect to habitat. Two of the species, namely golden plover and dotterel, occur on dry alpine heaths or tundra-like habitats in the northern mountains.

7.4. Larger concentrations of birds

There are approximately 250 species of birds that breed in Sweden more or less regularly. For 59 of these, we found reports about local concentrations that included at least 1% of the total number of individuals (the methods used were described in part 2.5 and the 59 species are listed in Appendix 2). Of more than 35 000 reports of 1%-concentrations of birds in Sweden, 1510 represented unique localities. Slightly more than half of these (55%) consisted of protected areas such as nature reserves and national parks. Most of the larger concentrations occurred along the coasts or in wetlands further inland. Many of these sites are high-risk sites for birds with respect to wind farm establishment (see 5.1.3). All the important localities resulting from this compilation are listed in Appendix 3.

In this summary, we have included occasional observations reported spontaneously, which means that certain classic bird localities that regularly are visited by ornithologists most likely are overrepresented. This is less of a problem for localities on land, where most important areas are already well known. The situation is slightly different for localities at sea or on small coastal islands, which may be less well known with respect to birds. Some overwintering sites may regularly harbor thousands of sea birds, including divers, diving ducks, gulls and auks. Examples of such sites are the sand banks in the southern Baltic Sea, used by large numbers of birds in winter. Such localities are not included in this summary.

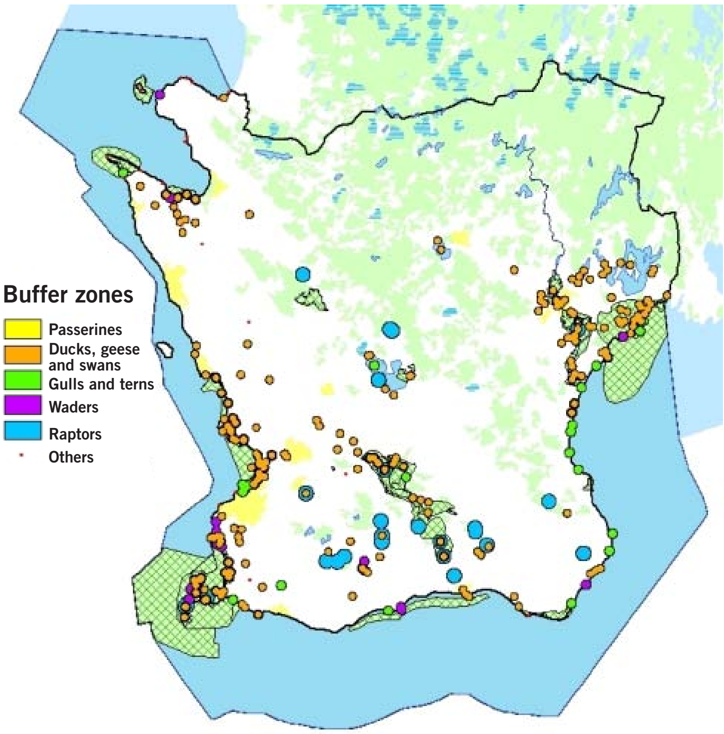

Figure 7.4. Areas and localities in Skåne that are considered important for different bird species groups. Larger dots indicate higher vulnerability; yellow = passerines, orange = ducks, geese and swans, green = gulls and terns, violet = waders, blue = raptors. National parks, SPA- IBA- and Ramsar sites are green-checked (see text for further explanation).

7.4.1. Maps of important bird concentrations

In the following section we provide examples on how larger concentrations of birds may be distributed within a county. The counties are selected to give a representative picture of the variation across the country. For each county, localities or areas with important concentrations of birds are shown by dots, where the size of the dot indicates the estimated vulnerability of the site with respect to wind farming and where different colors refer to the groups of bird species. Vulnerability in this case includes the risk for collisions and habitat loss (see sections 5.1 and 5.2 for further details). We have classified raptors as generally most vulnerable, followed by waders, gulls and terns, ducks and allies, passerines and other birds. The maps also show the extent of protected

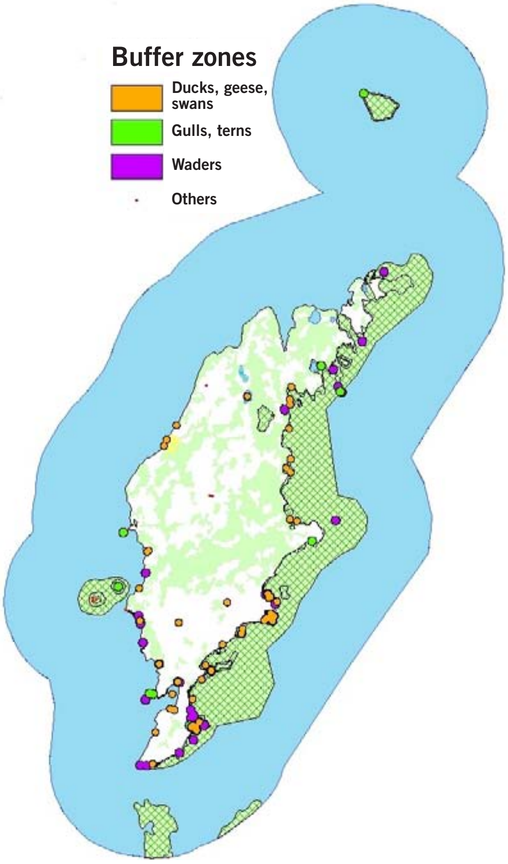

Figure 7.5. Areas and localities on Gotland that are considered important for different bird species groups. Explanations as in figure 7.4.

areas of particular value for birds (national parks and SPA-areas) as well as areas classified as particularly important for birds according to BirdLife International (IBA-areas) or the Ramsar convention (Ramsar areas).

In Skåne most of the larger concentrations of birds are found near the coast or at shallow lakes or wetlands further inland. Of extraordinary importance is the coast of Öresund southwards from Helsingborg, the southern part of the bay at Skälderviken, the valley at Klingavälsån and the wetland areas around Kristianstad in the northeast (fig. 7.4). In contrast there are only few larger concentrations of birds in the forested (northern) parts of the county. Although Skåne is one of the counties with most important concentrations of birds, the total area of these localities represents a comparatively small part.

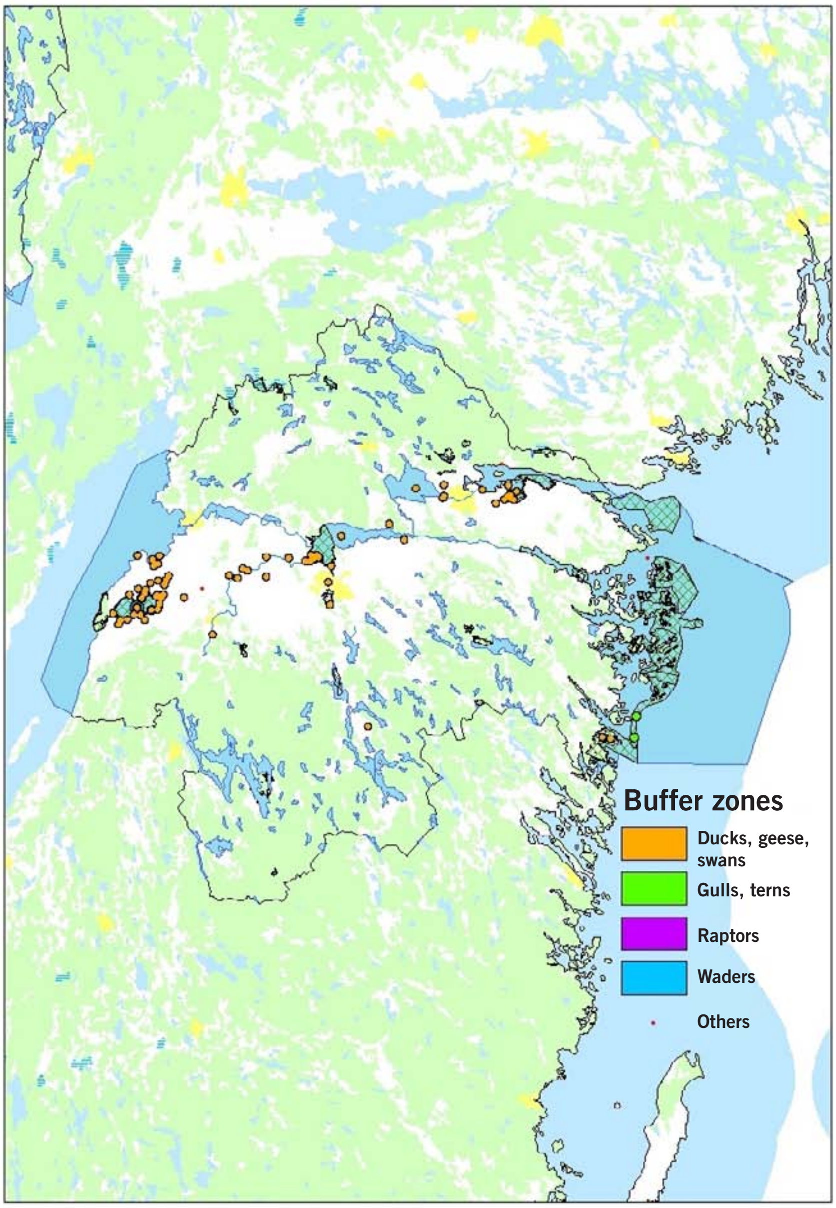

Figure 7.6. Areas and localities in Östergötland that are considered important for different bird species groups. Explanations as in figure 7.4.

Most of the important bird localities on Gotland are found at the coast (fig. 7.5) particularly in the south and southeast. Larger concentrations of birds are virtully missing from the central part of the island. We found no single localities with important concentrations of raptors despite the fact that Gotland has the highest density of golden eagles in the country (part 7.1). In the region of Östergötland the most important bird localities are found at well known bird lakes and surrounding farmlands. The lakes Tåkern, Roxen and Svensksundsviken at Bråviken are of particular importance in this county (fig. 7.6). No localities with concentrations of passerines were found.

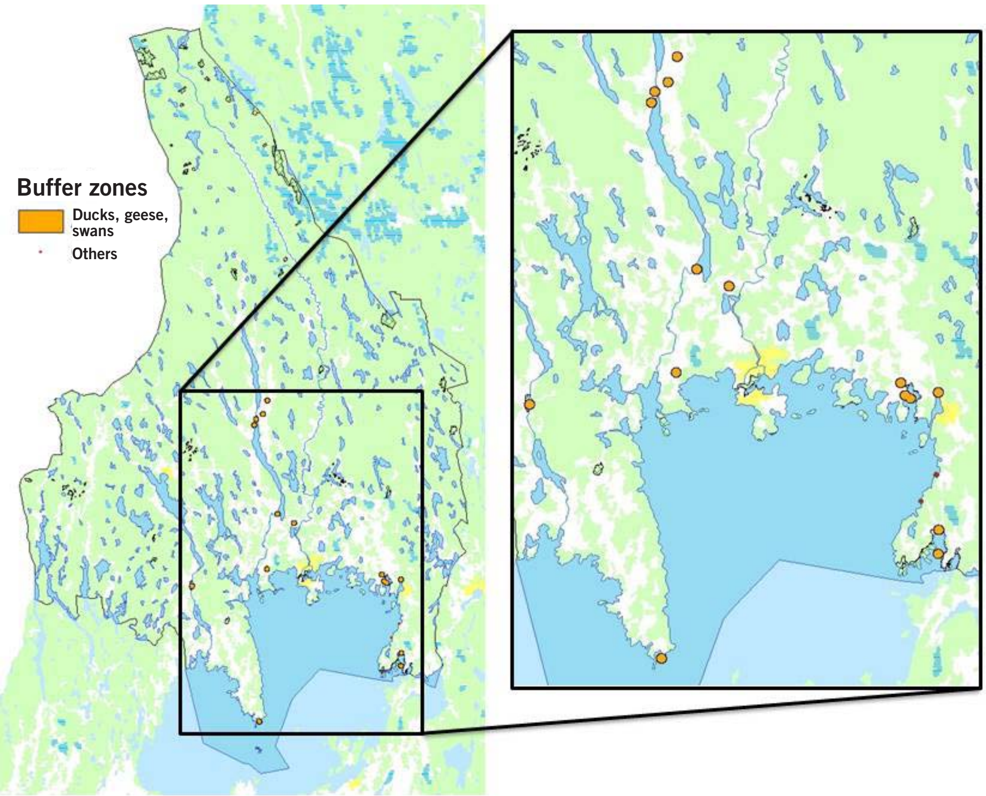

Figure 7.7. Areas and localities in Värmland that are considered important for different bird species groups. Explanations as in figure 7.4.

The forested parts of Östergötland are almost devoid of larger concentrations of birds. In the region of Värmland we only found localities with concentrations of ducks, geese and swans, and for obvious reasons these localities are located near lake Vänern or at small shallow lakes further inland (fig. 7.7). In the region of Norrbotten the important bird concentrations are found near the coast (fig. 7.8). The forests and the mountains in this county cover vast areas, but bird populations are generally sparse.

7.4.2. Concentrations of eagles

The distribution of breeding sea eagles and golden eagles in Sweden were covered in part 7.1.1. The nesting period is a particularly sensitive period for

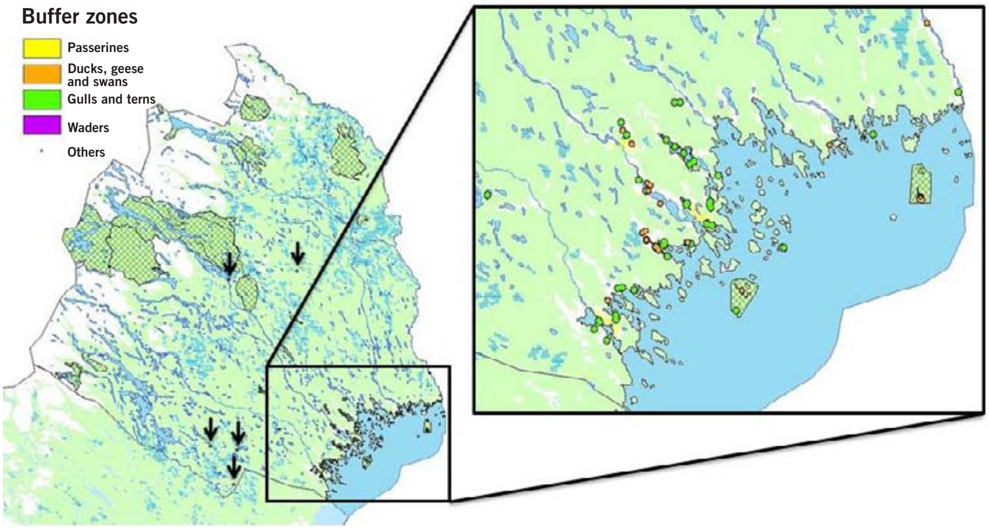

Figure 7.8. Areas and localities in Norrbotten that are considered important for different bird species groups. Explanations as in figure 7.4.

these birds and the territories then used cover large areas. This is necessary to provide sufficient amounts of food for the birds. Some older individuals may stay within these territories throughout the year, although the birds are generally more spaced out during the winter. Localities where eagles have been observed outside the breeding season are found at Artportalen (www.artportalen.se/birds). However, the maps published at Artportalen are not complete, due to the perceived risk of revealing some sensitive localities. Here we will only provide a brief summary of the subject. More information can be found in the action plans for sea- and golden eagle (Helander 2009, Hjernquist 2011).

Larger concentrations of eagles occur occasionally and this is particularly obvious for the sea eagle. Such concentrations are most frequent in winter but for sea eagles concentrations may also occur in summer. More than ten golden eagles at the same site are unusual, although many individuals may be seen at artificial feeding places. In contrast, several tens of sea eagles are sometimes found together. Concentrations of sea eagles may be found in areas rich in sea birds and at breeding sites for fish. For example, several of the localities identified as of particular importance for birds in the previous chapter (7.4.1.), may also periodically harbor concentrations of sea eagles.

Localities with many sea eagles may be found anywhere along the coastline, although the east coast appears to be particularly important. Localities with reports of at least five sea eagles at the same time are spread out along the central part of the Baltic cost and at the four larger lakes Vänern, Vättern, Hjälmaren and Mälaren. There are also occasional reports from other parts of southern Sweden. If we limit the selection to localities with at least 10 sea eagles, however, the importance of the coastal strip from Uppsala to Kalmar becomes obvious. This coincides with the area with the highest densities of sea eagles as identified previously. At the same time it seems clear that larger concentrations of sea eagles are absent from inland areas in the northern half of the country and also from the south-central part.

For golden eagles the distribution pattern is different. Localities from which at least five individuals have been reported are found throughout the country. A closer look at the reported observations shows that several of the observations from the northern coastland also include migrating individuals and in some cases the dots actually represent observations over a prolonged period. The present statistics include several sites in Skåne and on Gotland, regions which thus harbor many golden eagles even outside the breeding season. For both sea- and golden eagles the above information provides an idea about areas where concentrations may occur outside the breeding season. However, as mentioned earlier, the information provided is not always complete and it may be necessary to consider information from regional and local eagle groups as well.

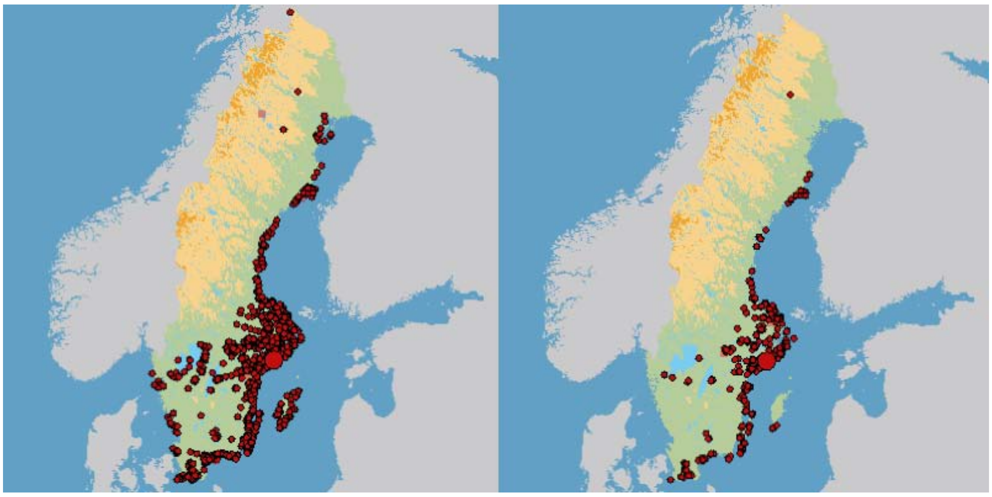

Figure 7.9. Localities at which at least five (left) or ten (right) sea eagles have been reported during the 2006-2010 period. Data from Artportalen (www.artportalen.se/birds).

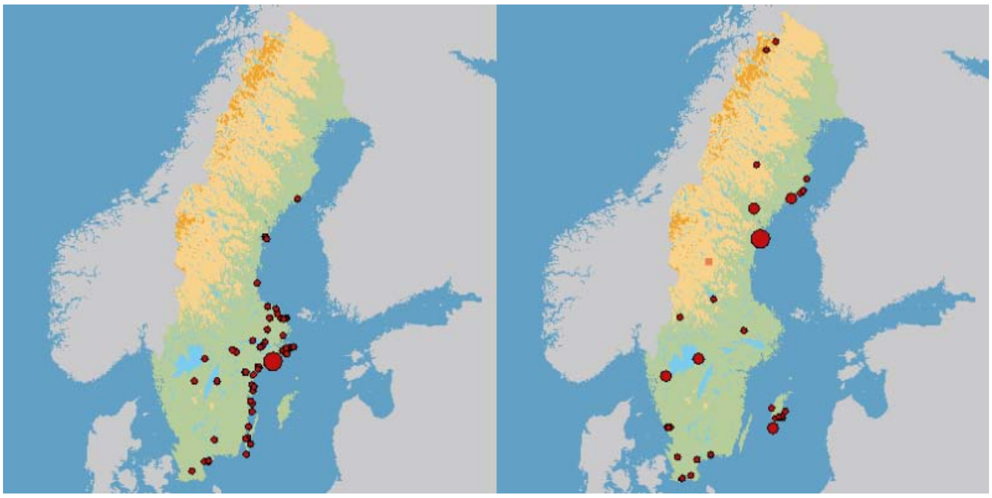

Figure 7.10. Localities at which at least 20 sea eagles (left) or at least five golden eagles (right) have been reported during the 2006-2010 period. Data from Artportalen (www.artportalen.se/birds).

8. Measures to minimize negative effects

In this section we will review what we think should be considered during planning and construction of wind energy facilities. The information presented here is an evaluated analysis of the results obtained within the framework of the present synthesis. It is not always easy to suggest biologically meaningful and reliable and appropriate limits for what may be considered acceptable effects on bird communities. For example, are we talking about local, regional, national or global effects? It must also be made clear what a "favorable conservation status" means in the actual case. Furthermore, the effect of one single factor, such as wind turbines, cannot easily be separated from other factors that also may be in operation. In fact, the effects of several risk factors may add up and the sum may be larger than if each factor operated separately. From this it follows that it is usually not possible to provide objective recommendations and suggest limits on what can be accepted. The framework for protection of birds and valuable nature in general is set by national and international regulations, but interpretations are required to make these regulations practically useful.

8.1. Pre-construction measures – The choice of location

The simplest and most efficient way to minimize the risk for birds at wind turbines is to *avoid building wind farms in areas or at sites where the risk is likely to be high*. At present there is not much we can do to substantially reduce the negative effects, once the turbines are built at a site. Proper planning and avoidance of high-risk sites are therefore prerequisites for effective minimization of negative effect of wind farming on birds.

As we have seen, the risk that birds are killed at wind turbines differs considerably between various environments and habitats. The risks are highest near wetlands and along the coast and also at hills and ridges. Therefore, if a wind farm is planned in or near any of these environments, a natural first step would be to survey the birds at the site. Next, the vulnerability of the bird species present with respect to wind farming should be assessed. We have shown that raptors, gulls and terns, grouse, quails and pheasants and perhaps also swifts and swallows are relatively often killed, while those particularly sensitive to disturbance include waders during the breeding-season, and also divers, ducks and allies and finally waders and auks outside the breeding-season. High density or numbers of any of these birds should motivate a closer investigation of the actual area and particularly how the area is utilized by the birds in question.

The easiest and most efficient way to minimize accidents involving raptors, is to avoid building wind turbines *near nesting sites or places with regular concentrations of raptors*. A similar reasoning is appropriate for gulls and terns. For grouse and their allies it is harder to give simple guidelines, although it may be reasonable to avoid areas near known lekking sites for forest grouse (black cock and capercaillie). To minimize the disturbance effects on breeding waders, sea meadows, bogs and rocky islets with high densities of these birds should not be used for wind turbines. This is particularly important in areas where threatened species of waders are found. For resting or overwintering divers, ducks, waders and auks, it is primarily a matter of how many of the actual species use the area in question. If the locality is found to be of higher significance, which means that it harbors at least 1% of the total population of a particular species, it is probably wise to avoid building wind turbines there.

8.2. Buffer Zones

Breeding sites or resting sites for threatened or otherwise vulnerable species have from time to time been provided with buffer zones, in order to minimize the expected negative effect of a certain type of disturbance. This is an effective and reasonable measure that has been used during the establishment of

Table 8.1. The extension of buffer zones for certain bird species and species groups, as suggested by the Swedish Ornithological Society. The zones indicate the minimum distance from nests, breeding colonies or other types of localities at which more detailed surveys and evaluations may be considered before construction.

Bird species or species group	Type of locality	Buffer Zone (km)
Sea eagle	Nesting sites	2-3
Sea eagle	Natural concentrations (>10 inds.)	2-3
Golden eagle	Nesting sites	2-3
Golden eagle	Natural concentrations (>5 inds.)	2-3
Gyrfalcon	Nesting sites	3
Peregrine falcon	Nesting sites	2
Other large and medium sized raptors	Nesting sites	1
Gulls	Nesting colonies	1
Terns	Nesting colonies	1
Eagle owl	Nesting sites	2
Waders	Breeding sites*	0.5
Waders	Resting localities**	0.5
Ducks, swans and geese	Resting localities***	0.5
Capercaillie	Lekking sites (> 5 cocks)	1
Black cock	Lekking sites (> 10 cocks)	1

* coastal meadows, bogs or bird islets with red listed species, species included in list 1 of the EU Birds Directive or with generally high density of waders.

** coastal- and coastal meadow localities where many waders occur regularly. Not including agricultural fields.

*** shallow lakes and coastal localities where many ducks, swans or geese occur regularly. Not including agricultural fields.

wind power facilities. Nevertheless, it is important to notice that the suggested buffer zones are no more than just suggestions or recommendations based on the best available information. Hence, they are usually not the result of scientific experiments and they are certainly not absolute in the sense that there is no risk to birds as long as they remain outside the buffer zone. Buffer zones are given as a radius distance from a nesting site, a breeding colony or any kind of important bird site. Normally, the risk would decrease with increasing distance from the nest, but this is complicated by the fact that birds do not use the various sectors of the circle to the same extent. Therefore, the size and shape of the buffer zones must always be adjusted according to the local conditions.

In table 8 we provide suggested extents of buffer zones for the species or species groups that we consider most vulnerable with respect to wind power facilities. We follow the recommendations from the Swedish Ornithological Society (http://sofnet.org). We include two species of forest grouse, for which buffer zones around lekking sites may be justified. In contrast, we do not include buffer zones for birds that rest or overwinter in marine areas, such as divers, marine ducks and auks. This is principally because we do not know how the idea could be applied to this situation.

8.3. Some general recommendations and suggestions

Breeding *raptors* and *owls* are usually sparsely distributed in the landscape and they often hunt over large areas. Some species, including sea- and golden eagles, often breed in trivial habitats, including production forests, for example. To protect the birds in such habitats may require specific measures. The peregrine falcon, gyrfalcon and eagle owl often nest in steep cliffs, which often have been used over long periods, sometimes decades or even centuries. Such places cannot easily be replaced once they are lost.

Several species of raptors have increased in numbers as a consequence of improved protection measures and less pressure from biocides and they now recolonize their previous breeding grounds. To facilitate the continued recolonization of new areas it is important to protect potential breeding sites or sites that have been used earlier, even if they are not used at present. Access to potential breeding sites that are unoccupied is obviously necessary for the continued spread of a species. For nesting site used by larger raptors buffer zones may be employed. Species included in the Swedish red list and list 1 in the EU Birds Directive should be given priority.

For *resting or overwintering divers, ducks and allies, waders and auks* particular concern is needed in areas with larger concentrations. This may apply to shallow areas at sea, lakes, open farmland and coastal habitats. Gulls, terns, cormorants and auks often breed in colonies and together with certain other bird species they may form so called sea bird colonies. The grey heron also nests in colonies. Areas with such bird colonies are usually protected one way or another and establishment of wind farms in the vicinity should be avoided.

Lekkig sites of *black cocks* are usually found on bogs and mires. This species has decreased drastically in the past but the population has now stabilized at a lower level. Lekking sites of *capercaillies* are usually found on more solid ground such as rocky outcrops with sparse pines. The capercaillie occurs in good populations throughout northern Sweden but it has declined in the south. It is found in old forest but also in younger managed forests. Both species are dependent on the surrounding forests for growth and survival of the chicks and for overwinter survival. Lekking sites including many cocks need to be protected. We cannot evaluate the potential effect of wind farm establishment on these species but we suggest that buffer zones are applied around larger lekking sites. It is important to notice that the populations of these bird species vary considerably from year to year for natural reasons, which means that evaluation of possible effects should be based on surveys extending over several years.

8.4. Post-construction measures

Various experiments with colors and color patters on wind turbines have been carried out in order to minimize the risk of collision. The results of such efforts have so far been quite limited (Smallwood 2009). The white or light grey coloration that wind turbines have today (Transportstyrelsen 2010) are probably near the optimal for their detection by birds (Ödeen & Håstad 2007). This has some relevance to recent suggestions that the wind turbines should preferably be painted red or purple in order to minimize their attractiveness to insects and bats (Long et al. 2010a). However, although the collision frequency for bats and perhaps also for swallows and swifts may decline if the turbines would be painted red, this may be of limited value if the risk for birds in general increases.

Various technical innovations have been tried in order to discourage birds from staying near wind turbines but these too have had very limited success. Solutions that imply that the turbines are switched off as flying birds are closing in on the turbines have been suggested, but there is no evidence that this idea may work in practice. In any case, it would be necessary to halt the rotors very rapidly. This may be technically possible, but it will almost certainly result in other undesired effects such as increased load on the turbines. In areas where vulnerable bird species occur during restricted periods, it may perhaps be possible to halt the turbines during the entire period when birds are present. However, this method is probably not feasible in practice if we talk about longer periods such as weeks or months, although it may perhaps work for brief periods or during particular weather conditions.

It has also been suggested that the areas surrounding wind farms could be made less attractive to birds. This may result in fewer birds near the turbines and then presumably to fewer collisions. However, there is little evidence that birds are attracted to wind turbines anyway, with the possible exception of swallows and swifts, so the effect of such measures is questionable. An alternative would be to entice the birds away from the wind turbines by suggesting alternative and preferably better habitats further away. This kind of habitat management has been tried on golden eagles (Walker et al. 2005). At a smaller scale, potential perching sites or hunting grounds in the immediate vicinity of the turbines may perhaps be eliminated, although it is not clear if this really leads to fewer collisions.

9. Some important considerations

9.1. The Species Protection Act

All species of birds that occur naturally in Sweden are covered by the Species Protection Act (2007:845a, se http://www.notisum.se/rnp/SLS/lag/20070845.htm), which is based on the EU Habitats Directive (92/43/EEC), the EU Birds Directive (79/409/EEG) in addition and national conservation regulations. According to § 4 in the Species Protection Act it is *illegal* to *deliberately* kill or injure wild birds. It is also illegal to deliberately disturb wild birds, particularly during the breeding season as well as during the migration- and owewintering periods. *Deliberately* includes not only cases where birds are killed, injured or harassed on purpose, but also cases when such effects can be predicted, based on the operation that is carried out. The hunting of certain species is regulated through the Hunting Law (1987/259) and Hunting Ordinance (1987/905), but otherwise, the Species Protection Act is valid and provides only limited possibilities of exemption. For more reading about the interpretation of the Species Protection Act we refer to Naturvårdsverket (2009) and http://naturvardsverket.se/sv/Artskyddsforordningen/Start/Lagtolkningar/.

The Species Protection Act should generally apply to wind power projects, because it is well documented that wind power facilities kill birds and also result in various disturbance effects (see part 5). In other words, effects on birds caused by the construction or drift of wind turbines must be considered deliberate, provided the locality harbors known occurrences of birds regardless of species. Obviously, this is nearly always the case. How should we handle the apparent conflict inherent in this situation? A strict interpretation of the regulation would probably mean that exploitation for wind power facilities, and also for many other human activities for that matter, would be nearly impossible, because we know already from the start that birds will be killed or disturbed by the activity. Comparable examples include large-scale agriculture and forestry as well as traffic. Hence, strict interpretations of the Species Protection Act in connection with the construction or drift of wind power facilities are practically unfeasible.

In “Handbok för Artskyddsförordningen“ (Naturvårdsverket 2009) it is suggested that bird species that are listed in the EU Birds Directive or in the national red list or which show negative population trends should be given priority. Artdatabanken, which is commissioned by the Swedish Environmental Protection Agency, compiled a list including 132 bird species that should be given priority under the Species Protection Act (annex 3 in this report, Naturvårdsverket 2009). As part of the present synthesis work, we have updated this list and present a new version, which we believe is a better representative of the current situation. The new version includes a) the 64 breeding species listed in the Birds Directive (35 of which are included in the national red list), b) another 50 species that are included in the national red list and which do not show a favorable conservation status, and c) a further

13 species which have decreased nationally by more than 50% in the 1975-2010 period. In addition the new version is updated according to the latest national red list (Gärdenfiors 2010) and according to recent evaluations of population trends (Ottvall et al. 2008, Lindström et al. 2011). Hence, the updated list includes 127 species altogether. To the list has been added our assessment of which species may be particularly vulnerable at wind turbine facilities. We consider 23-26 species as vulnerable to collisions with wind turbines and another 29 species as particularly sensitive to disturbance. For some nocturnal species, mostly owls, we have indicated that we have almost no information on how these species are affected by wind farming.

Obviously, it is not our mission to interpret the Species Protection Act or to suggest how it should be used in practice. Nevertheless, we assume that whenever vulnerable species occur in areas proposed for establishment of wind turbines, the feasibility of the localization will be carefully considered. For some of these species, construction of wind power plants *near* known nesting sites or important migratory- and overwintering sites may be strictly unsuitable.

Exemption from the Species Protection Act may be applied for, provided that the conservation status of the species is not compromised by the exemption. In cases of habitat destruction or disturbance, the exemption may be connected to a requirement for compensatory measures. However, it should be stressed that compensation cannot be used in cases where birds may be expected to be killed as a result of the activity. In "Handbok för Artskyddsförordningen" (Naturvårdsverket 2009), the following (translated) citation may be worth mentioning; "The protection of species should be considered at an early stage during infra-structure or other major projects, including roads, railways and wind power facilities. A species occurrence may result in changes or in a halt in the project if there are alternative ways to reach the end and if the resulting effect on the species compromises its continued favorable conservation status. Exemptions may only be granted if the preconditions are fulfilled for the species in question" (Naturvårdsverket 2009, pp. 45-46).

9.2. A model for handling of a wind turbine proposal

Ahlén, (2010a) suggested a model that can be used as a guideline during the planning of wind power establishments. The model was originally intended to be used for problems related to bat occurrences (see 9.1 in the bat part), but it is equally applicable to birds. The model includes a classification of the applied projects to either of three categories with respect to their estimated risk to birds. The classification below is made for birds exclusively and the details differ from that of bats.

1. **High-risk sites** where considerable negative effects on birds are likely through the loss of valuable habitats or a high risk of collision. In such areas the bird fauna is normally already well known. It may include localities where large natural concentrations of raptors or other birds occur permanently or occasionally. It may also apply to coastal meadows or wetlands with occurrences of threatened waders or bird islets with high concentrations of waders, gulls or terns.

2. **Uncertain sites** are those where the relevant information is missing or insufficient or where there is a perceived risk for collisions or disturbance, that needs to be investigated further. In this case a detailed pre-construction survey is normally required and sometimes also a post-construction survey. Initially, most applications, particularly those that consider wind farm construction in coniferous forest areas, will probably be allocated to this category.

3. **Low-risk sites** are those where the risk for birds is considered small or negligible. Examples include larger areas with intensive and uniform agriculture, other heavily exploited urban sites and deep sea areas far off-shore without any important concentrations of birds or valuable occurrences of vulnerable species.

As is the case for bats (below), the model suggests that it is only for projects in category 2 that more careful inventories and evaluations are necessary. Hence, the process of application and handling may therefore be faster and simpler as the knowledge accumulates. At present, most applications will probably be allocated to category 2, principally because the focus is on establishment of wind farms in coniferous forests, en environment for which the effect on birds is poorly known. As the experience about this habitat and the birds therein increase, more proposals will be allocated to other categories.

It is obviously important that the knowledge of the decision makers is maintained and that the decisions are made from a firm scientific basis. The regional authorities must therefore have access to the relevant competence, to ensure that the requirements are relevant and correct.

9.3. The pre-construction survey

Normally, a comprehensive and thorough evaluation of the importance of the area for birds and the expected consequences of the exploitation is usually required as part of an environmental impact assessment (EIA). It is important that the consultant possesses the necessary skills and expertise and that the survey is carried out correctly and at the right time. It is also important that the following analyses and evaluations are reliable and follow common scientific practice. There is a great need to standardize the surveys made for wind power establishments. This is necessary in order to facilitate repetitive sampling at the same site and for comparisons with different sites. The final evaluation should be of sufficient quality to be used without restrictions for decision making by the authorities in question.

For evaluation of the suitability of a site for wind farm establishment, it is usually necessary to collect both quantitative and qualitative information on the bird fauna. An assessment of its vulnerability with respect to the construction should also be provided. Whenever threatened or otherwise vulnerable species occur in the area, a more detailed description of the birds´ use of the area may also be required. In particular, the following aspects are of interest:

1. Which species nest in the area?
2. Is the site important for resting or overwintering birds?
3. Is the site a bottleneck where migrating birds may be concentrated?
4. Are any of the species found listed in the Birds Directive Annex 1 or the national red list?

An application for construction of a wind farm should normally include a compilation of already existing information such as, for example, maps and survey reports and perhaps also a list of important bird localities (according to Appendix 3 of this report) in the vicinity. Including general knowledge of the area, a preliminary evaluation of its quality as habitat for birds may then be made. The next step would be to use this evaluation to design a field inventory, which may cover the construction area or selected parts of it, depending on what has already become apparent. Existing information on bird occurrences may be gleaned from Artportalen (Svalan) and from local or regional ornithology journals or reports, but it may also consist of personal information from ornithologists active in the area at present or in the past.

For a survey of the breeding birds in an area inventories should normally be made at least three times. Surveys of common species in forest and in open areas should be based on line transects. For raptors, grouse and allies, woodpeckers, owls and other nocturnal species, more specific efforts are usually required, however, and the efforts should be designed according to the habitats available and the seasonal and daily timing of the activity patterns of the birds in question. To evaluate the importance of the area for birds, it is essential that consultations with local or regional ornithologists are made early in the process. If the area turns out to be of major importance for migrating species, specially designed efforts are probably necessary. In this case it is not possible to provide any general suggestions. Instead the inventory efforts must be based on the prevailing situation at the site.

Normally, inventories within a single season are usually sufficient for an EIA. However, extended effort may sometimes be necessary, particularly when present knowledge is scarce and there are potentially important bird occurrences in the area. This may apply to areas with known or suspected occurrence of threatened raptors, which may not necessarily breed annually, or to overwintering localities for sea birds species that may alternate between several areas.

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Appendix 1a. Densities of breeding raptors in each of the 21 counties in Sweden (pairs/100km^2). Numbers are for all raptors, for selected raptor species that have shown to be particularly sensitive to wind farming (including red kite, sea eagle, common buzzard, rough-legged buzzard, golden eagle, osprey and kestrel) and for three of the species separately.

County	All raptors	Selected raptors	Red kite	Sea eagle	Golden eagle
Skåne	68.56	39.67	13.60	0.05	0.07
Blekinge	54.74	24.65	0.95	0.17	0.00
Kalmar	40.92	12.70	0.03	0.41	0.00
Kronoberg	40.48	13.23	0.14	0.02	0.00
Jönköping	37.43	11.80	0.00	0.00	0.01
Halland	38.76	15.46	0.83	0.00	0.06
Västra Götaland	46.54	21.31	0.01	0.03	0.00
Östergötland	45.62	16.91	0.00	0.33	0.01
Gotland	42.26	11.94	0.06	0.41	1.27
Södermanland	52.76	18.73	0.00	0.53	0.05
Stockholm	48.52	18.31	0.00	1.12	0.00
Uppsala	49.41	18.63	0.00	0.86	0.03
Västmanland	44.81	14.82	0.00	0.13	0.02
Örebro	39.99	13.10	0.00	0.06	0.01
Värmland	28.93	7.85	0.00	0.02	0.02
Dalarna	17.85	4.91	0.00	0.00	0.16
Gävleborg	26.36	12.74	0.00	0.14	0.09
Jämtland	14.44	3.43	0.00	0.00	0.21
Västernorrland	21.79	8.96	0.00	0.01	0.28
Västerbotten	14.85	4.80	0.00	0.03	0.26
Norrbotten	12.97	4.10	0.00	0.09	0.21

Appendix 1b. Proportions of breeding raptors in the 21 counties in Sweden (percent of total). Numbers are for all raptors, for selected raptor species that have shown to be particularly sensitive to wind farming (including red kite, sea eagle, common buzzard, rough-legged buzzard, golden eagle, osprey and kestrel) and for three of the species separately.

County	All raptors	Selected raptors	Red kite	Sea eagle	Golden eagle
Skåne	7.24	11.48	94.16	1.41	1.25
Blekinge	1.54	1.90	1.76	1.17	0.00
Kalmar	4.38	3.73	0.19	10.80	0.00
Kronoberg	3.28	2.94	0.75	0.47	0.00
Jönköping	3.76	3.25	0.00	0.00	0.16
Halland	2.03	2.21	2.82	0.00	0.47
Västra Götaland	10.68	13.39	0.19	1.64	0.16
Östergötland	4.62	4.69	0.00	8.22	0.16
Gotland	1.27	0.98	0.13	3.05	6.24
Södermanland	3.06	2.98	0.00	7.51	0.47
Stockholm	3.02	3.12	0.00	17.14	0.00
Uppsala	3.31	3.42	0.00	14.08	0.31
Västmanland	2.71	2.45	0.00	1.88	0.16
Örebro	3.26	2.93	0.00	1.17	0.16
Värmland	4.87	3.63	0.00	0.70	0.62
Dalarna	4.82	3.64	0.00	0.23	7.02
Gävleborg	4.59	6.09	0.00	5.87	2.50
Jämtland	6.84	4.45	0.00	0.00	16.38
Västernorrland	4.53	5.10	0.00	0.47	9.36
Västerbotten	7.89	6.98	0.00	3.52	22.62
Norrbotten	12.30	10.64	0.00	20.66	31.98

Appendix 1c. Densities of breeding grouse in the 21 counties of Sweden (pairs/100km²). Numbers are for each species separately and for all species together.

County	Ptarmigan	Willow grouse	Hazelhen	Black grouse	Capercaillie	All species
Skåne	0.00	0.00	0.00	0.01	0.01	1.50
Blekinge	0.00	0.00	0.02	0.05	0.09	15.30
Kalmar	0.00	0.00	0.11	0.32	0.27	69.82
Kronoberg	0.00	0.00	0.17	0.39	0.35	91.04
Jönköping	0.00	0.00	0.14	0.33	0.38	85.92
Halland	0.00	0.00	0.08	0.06	0.09	22.92
Västra Götaland	0.00	0.00	0.10	0.28	0.09	46.78
Östergötland	0.00	0.00	0.13	0.28	0.24	65.33
Gotland	0.00	0.00	0.00	0.01	0.00	0.80
Södermanland	0.00	0.00	0.17	0.26	0.12	54.46
Stockholm	0.00	0.00	0.15	1.53	0.06	44.68
Uppsala	0.00	0.00	0.17	0.57	0.14	88.71
Västmanland	0.00	0.00	0.21	0.60	0.13	93.62
Örebro	0.00	0.00	0.22	0.68	0.41	131.50
Värmland	0.00	0.06	0.39	0.85	0.85	215.55
Dalarna	0.03	0.15	0.14	0.78	1.13	223.27
Gävleborg	0.00	0.01	0.82	0.93	0.88	264.86
Jämtland	0.17	0.34	0.26	0.59	1.11	246.34
Västernorrland	0.00	0.05	0.92	0.88	1.01	286.00
Västerbotten	0.08	0.94	0.52	0.34	1.01	289.28
Norrbotten	0.26	1.13	0.20	0.22	0.69	250.02

Appendix 1d. Proportions of breeding grouse in the 21 counties of Sweden (percent of total). Numbers are for each species separately and for all species together.

County	Ptarmigan	Willow grouse	Hazelhen	Black grouse	Capercaillie	All species
Skåne	0.00	0.00	0.02	0.04	0.02	0.02
Blekinge	0.00	0.00	0.04	0.08	0.09	0.06
Kalmar	0.00	0.00	0.98	2.00	1.05	0.96
Kronoberg	0.00	0.00	1.14	1.83	1.05	0.95
Jönköping	0.00	0.00	1.22	1.94	1.40	1.11
Halland	0.00	0.00	0.37	0.17	0.17	0.15
Västra Götaland	0.00	0.00	1.96	3.71	0.73	1.38
Östergötland	0.00	0.00	1.14	1.66	0.87	0.85
Gotland	0.00	0.00	0.00	0.01	0.00	0.00
Södermanland	0.00	0.00	0.81	0.89	0.24	0.41
Stockholm	0.00	0.00	0.81	0.83	0.14	0.36
Uppsala	0.00	0.00	0.98	2.22	0.35	0.76
Västmanland	0.00	0.00	1.06	2.11	0.28	0.72
Örebro	0.00	0.00	1.55	3.22	1.22	1.38
Värmland	0.00	0.54	5.62	8.32	5.25	4.65
Dalarna	1.94	2.25	3.26	12.20	11.20	7.73
Gävleborg	0.00	0.10	12.22	9.43	5.60	5.92
Jämtland	21.16	8.89	10.59	16.08	19.24	14.96
Västernorrland	0.00	0.54	16.30	10.54	7.70	7.61
Västerbotten	11.35	27.79	23.63	10,54	19.59	19.68
Norrbotten	65.55	59.91	16.30	12.20	23.79	30.37

Appendix 1e. Densities of breeding waders in the 21 counties of Sweden given as density (pairs/100km2) and proportion (%) of the total. Numbers are for all species taken together, species included in the national red list of threatened species (southern dunlin, ruff, great snipe, black-tailed godwit, curlew, common sandpiper, and turnstone) and the EU Birds Directive (avocet, dotterel, golden plover, southern dunlin, ruff, great snipe, black-tailed godwit, green sandpiper and red-necked phalarope).

County	All species (density)	Red listed (density)	EU BD (density)	All species (%)	Red listed (%)	EU BD (%)
Skåne	279.63	11.15	4.28	2.22	0.64	0.14
Blekinge	323.26	14.35	1.02	0.68	0.22	0.01
Kalmar	428.35	22.51	6.99	3.44	1.32	0.23
Kronoberg	349.61	15.49	1.89	2.13	0.69	0.05
Jönköping	317.31	16.04	4.77	2.39	0.88	0.15
Halland	299.50	19.22	2.60	1.18	0.55	0.04
Västra Götaland	309.21	16.39	3.45	5.33	2.06	0.25
Östergötland	272.23	17.59	0.15	2.07	0.97	0.00
Gotland	536.37	24.36	16.94	1.21	0.40	0.16
Södermanland	267.69	15.92	0.00	1.17	0.51	0.00
Stockholm	268.12	23.44	0.02	1.25	0.80	0.00
Uppsala	349.46	24.65	1.16	1.76	0.90	0.02
Västmanland	365.76	22.72	2.02	1.66	0.75	0.04
Örebro	396.14	24.81	3.09	2.43	1.11	0.08
Värmland	299.55	33.01	2.67	3.79	3.04	0.14
Dalarna	336.51	35.01	21.56	6.83	5.18	1.83
Gävleborg	343.92	38.43	11.71	4.50	3.67	0.64
Jämtland	302.53	50.52	97.28	10.77	13.10	14.45
Västernorrland	315.47	39.05	29.14	4.92	4.44	1.90
Västerbotten	271.99	51.16	84.66	10.85	14.87	14.09
Norrbotten	412.90	84.65	221.14	29.40	43.91	65.78

Appendix 2. The number of localities in Sweden with concentrations of birds. A concentration is defined as an area or locality where at least 1% of the Swedish population of the species is or has been found. Only species with more than 500 breeding pairs in Sweden are included. Asterisks (*) indicate that population data are from Wetlands International and not from the breeding bird count in Sweden (section 2.5).

English name	Latin name	Number of localities
Red-throated diver	*Gavia stellata*	30
Black-throated diver	*Gavia arctica*	2
Horned grebe	*Podiceps auritus*	24
Great crested grebe	*Podiceps cristatus*	12
Red-necked grebe	*Podiceps grisegena*	30
Grey heron	*Ardea cinerea*	9
Cormorant	*Phalacrocorax carbo*	44
Whooper swan*	*Cygnus cygnus*	28
Mute swan	*Cygnus olor*	101
Bean goose*	*Anser fabalis*	250
Greylag goose*	*Anser anser*	146
Canada goose	*Branta canadensis*	325
Barnacle goose	*Branta leucopsis*	34
Shelduck	*Tadorna tadorna*	49

English name	Latin name	Number of localities
Wigeon	*Anas penelope*	37
Gadwall	*Anas strepera*	162
Mallard	*Anas platyrhynchos*	5
Pintail	*Anas acuta*	166
Shoveler	*Anas clypeata*	72
Garganey	*Anas querquedula*	9
Tufted duck	*Aythya fuligula*	196
Pochard	*Aythya ferina*	68
Scaup *	*Aythya marila*	2
Velvet scoter	*Melanitta fusca*	8
Red-breasted merganser	*Mergus serrator*	4
Goosander	*Mergus merganser*	43
Red kite	*Milvus milvus*	27
Marsh harrier	*Circus aeruginosus*	4
Golden eagle	*Aquila chrysaetos*	1
Coot	*Fulica atra*	35
Crane	*Grus grus*	50
Avocet	*Recurvirostra avosetta*	148
Lapwing	*Vanellus vanellus*	24
Oystercatcher	*Haematopus ostralegus*	10
Golden plover	*Charadrius apricaria*	35
Dunlin	*Calidris alpina*	99
Purple sandpiper	*Calidris maritima*	53
Curlew	*Numenius arquata*	7
Turnstone	*Arenaria interpres*	1
Arctic skua	*Stercorarius parasiticus*	6
Little gull	*Larus minutus*	181
Black-headed gull	*Larus ridibundus*	35
Great black-backed gull	*Larus marinus*	5
Lesser black-backed gull	*Larus fuscus*	11
Common tern	*Sterna hirundo*	6
Arctic tern	*Sterna paradisaea*	1
Little tern	*Sterna albifrons*	48
Caspian tern	*Sterna caspia*	58
Black guillemot	*Cepphus grylle*	14
Razorbill	*Alca torda*	11
Guillemot	*Uria aalge*	10
Collared turtle dove	*Streptopelia decaocto*	8
Stock dove	*Columba oenas*	3
Red-throated pipit	*Anthus cervinus*	3
Rock pipit	*Anthus petrosus*	1
Jackdaw	*Corvus monedula*	6
Rook	*Corvus frugilegus*	2
Pine grosbeak	*Pinicola enucleator*	4
Snow bunting	*Plectrophenax nivalis*	1

Appendix 3. List of bird species included in Annex 1 of EU Birds Directive (BD), the national red list (R), or that have declined with at least 50% during the 1975-2010 period (-50%), according to Ottvall et al. (2008) and Lindström et al. (2011). We have also tried to evaluate if the species is at risk at wind energy facilities through collisions or disturbance. For ten nocturnal species, the impact is considered unknown (?), hence stressing that relevant information is almost entirely missing. The potential effects on swifts and swallows are also poorly known, although these may be expected to be more vulnerable at wind energy facilities, compared to other small birds (see text).

English name	Latin name	Listing	Suspected effects of windfarming
Red-throated diver	*Gavia stellata*	BD R	Disturbance
Black-throated diver	*Gavia arctica*	BD	Disturbance
Horned grebe	*Podiceps auritus*	BD R	
Black-necked grebe	*Podiceps nigricollis*	R	
Bittern	*Botaurus stellaris*	BD R	
Whooper swan	*Cygnus cygnus*	BD	Disturbance
Bean goose	*Anser fabalis*	R	Disturbance
Lesser white-fronted goose	*Anser erythropus*	BD R	Disturbance
Barnacle goose	*Branta leucopsis*	BD	Disturbance
Pintail	*Anas acuta*	R	Disturbance
Blue-winged teal	*Anas querquedula*	R	Disturbance
Pochard	*Aythya ferina*	R	Disturbance
Scaup	*Aythya marila*	R	Disturbance
Eider	*Somateria molissima*	R	Disturbance
Long-tailed duck	*Clangula hyemalis*	R	Disturbance
Velvet scoter	*Melanitta fusca*	R	Disturbance
Smew	*Mergus albellus*	BD R	Disturbance
Honey buzzard	*Pernis apivorus*	BD R	Collisions
Red kite	*Milvus milvus*	BD	Collisions
Sea eagle	*Haliaeetus albicilla*	BD R	Collisions
Marsh harrier	*Circus aeruginosus*	BD	
Hen harrier	*Circus cyaneus*	BD R	
Montagu´s harrier	*Circus pygargus*	BD R	
Rough-legged buzzard	*Buteo lagopus*	R	Collisions
Golden eagle	*Aquila chrysaetos*	BD R	Collisions
Osprey	*Pandion haliaetus*	BD	Collisions
Merlin	*Falco columbarius*	BD	
Gyrfalcon	*Falco rusticolus*	BD R	Collisions
Peregrine falcon	*Falco peregrinus*	BD R	Collisions
Hazelhen	*Tetrastes bonasia*	BD	Collisions
Black grouse	*Tetrao tetrix*	BD	Collisions
Capercaillie	*Tetrao urogallus*	BD	Collisions
Partridge	*Perdix perdix*	R	Collisions
Quail	*Coturnix coturnix*	R	Collisions
Spotted crake	*Porzana porzana*	BD R	
Corncrake	*Crex crex*	BD R	
Crane	*Grus grus*	BD	
Avocet	*Recurvirostra avosetta*	BD	Disturbance
Kentish plover	*Charadrius alexandrinus*	BD R	Disturbance
Dotterel	*Charadrius morinellus*	BD	Disturbance
Golden plover	*Charadrius apricaria*	BD	Disturbance

English name	**Latin name**	**Listing**	**Suspected effects of windfarming**
Dunlin (southern)	*Calidris alpina schinzii*	BD R	Disturbance
Ruff	*Philomachus pugnax*	BD R	Disturbance
Snipe	*Gallinago gallinago*	-50%	Disturbance
Great snipe	*Gallinago media*	BD R	Disturbance
Bar-tailed godwit	*Limosa lapponica*	BD R	Disturbance
Black-tailed godwit	*Limosa limosa*	R	Disturbance
Curlew	*Numenius arcuata*	R	Disturbance
Wood sandpiper	*Tringa glareola*	BD	Disturbance
Common sandpiper	*Actitis hypoleucos*	R	Disturbance
Turnstone	*Arenaria interpres*	R	Disturbance
Red-necked phalarope	*Phalaropus lobatus*	BD	Disturbance
Little gull	*Larus minutus*	BD	Collisions
Blach-headed gull	*Larus ridibundus*	-50%	Collisions
Herring gull	*Larus argentatus*	R	Collisions
Lesser black-backed gull	*Larus fuscus*	R	Collisions
Kittiwake	*Rissa tridactyla*	R	Collisions
Caspian tern	*Sterna caspia*	BD R	Collisions
Sandwich tern	*Sterna sandvicensis*	BD R	Collisions
Common tern	*Sterna hirundo*	BD	Collisions
Arctic tern	*Sterna paradisaea*	BD	Collisions
Little tern	*Sterna albifrons*	BD R	Collisions
Black tern	*Chlidonias niger*	BD R	Collisions
Black guillemot	*Cepphus grylle*	R	
Collared turtle dove	*Streptopelia decaocto*	R	
Cuckoo	*Cuculus canorus*	-50%	
Barn owl	*Tyto alba*	R	?
Eagle owl	*Bubo bubo*	BD R	?
Arctic owl	*Bubo scandiacus*	BD R	?
Hawk owl	*Surnia ulula*	BD	?
Pygmy owl	*Glaucidium passerinum*	BD	?
Great grey owl	*Strix nebulosa*	BD R	?
Ural owl	*Strix uralensis*	BD	?
Short-eared owl	*Asio flammeus*	BD R	?
Tengmalm´s owl	*Aegolius funereus*	BD	?
Nightjar	*Caprimulgus europaeus*	BD R	?
Swift	*Apus apus*	R	Collisions?
Hoopoe	*Upupa epops*	R	
Kingfisher	*Alcedo atthis*	BD R	
Wryneck	*Jynx torquilla*	R	
Grey-headed woodpecker	*Picus canus*	BD	
Green woodpecker	*Picus viridiis*	-50%	
Black woodpecker	*Dryocopus martius*	BD	
White-backed woodpecker	*Dendrocopus leucotos*	BD R	
Lesser spotted woodpecker	*Dendrocopus minor*	R	
Three-toed woodpecker	*Picoides tridactylus*	BD R	
Woodlark	*Lullula arborea*	BD	

English name	**Latin name**	**Listing**	**Suspected effects of windfarming**
Skylark	*Alauda arvensis*	R	
Shore lark	*Eremophila alpestris*	R	
Sand martin	*Riparia riparia*	R	Collisions?
House martin	*Delichon urbica*	-50%	Collisions?
Tawny pipit	*Anthus campestris*	BD R	
Red-throated pipit	*Anthus cervinus*	R	
Yellow wagtail (southern)	*Motacilla flava flava*	R	
Dunnock	*Prunella modularis*	-50%	
Nightingale	*Luscinia luscinia*	-50%	
Bluethroat	*Luscinia svecica*	BD	
Whinchat	*Saxicola rubetra*	-50%	
Grasshopper warbler	*Locustella naevia*	R	
River warbler	*Locustella fluviatilis*	R	
Great reed warbler	*Acrocephalus arundinaceus*	R	
Blyth´s reed warbler	*Acrocephalus dumetorum*	R	
Barred warbler	*Sylvia nisoria*	BD R	
Willow warbler	*Phylloscopus trochiloides*	R	
Arctic warbler	*Phylloscopus borealis*	R	
Chiffchaff	*Phylloscopus collybita abietinus*	-50%	
Firecrest	*Regulus ignicapilla*	R	
Red-breasted flycatcher	*Ficedula parva*	BD R	
Collared flycatcher	*Ficedula albicollis*	BD	
Marsh tit	*Parus palustris*	-50%	
Willow tit	*Parus montanus*	-50%	
Siberian tit	*Parus cinctus*	R	
Penduline tit	*Remiz pendulinus*	R	
Golden oriole	*Oriolus oriolus*	R	
Red-backed shrike	*Lanius collurio*	BD	
Siberian jay	*Perisoreus infaustus*	R	
Nutcracker	*Nucifraga caryocatactes*	R	
Starling	*Sturnus vulgaris*	-50%	
House sparrow	*Passer domesticus*	-50%	
Serin	*Serinus serinus*	R	
Linnet	*Carduelis cannabina*	R	
Twite	*Carduelis flavirostris*	R	
Scarlet grosbeak	*Carpodachus erythrinus*	R	
Pine grosbeak	*Pinicola enucleator*	R	
Ortolan bunting	*Emberiza hortulana*	BD R	
Little bunting	*Emberiza pusilla*	R	
Corn bunting	*Emberiza calandra*	R	

C. Bats

1. Introduction

Bats are sometimes killed at wind turbines. This is a growing problem because wind power is expected to increase considerably over the next few years. This applies to Sweden (www.energimyndigheten.se), Europe in general (EWEA 2008), North America and in the long run perhaps to most of the world. The problem that bats are sometimes killed at wind turbines has been known for more than a decade (Osborn et al. 1996, Bach et al. 1999, Ramel et al. 1999), but only during the last few years has it been considered a serious issue. The vulnerability of bats at wind farms is now regarded as important conservational and ethical issues at least in some countries. For example it has been suggested that, with the fatality rates observed in some places in North America, the long term survival of some bat populations is questionable. Bats reproduce slowly. They normally live long lives and suffer low mortality rates (Barclay & Harder 2003, Podlutsky et al. 2005). It therefore seems likely that if bats die in numbers at wind farms, it may have long term effects on populations. Along the Appalachian mountains in USA, for example, fatality rates as high as 30-40 bats per turbine and year have been recorded. Using this figure and the expected growth of wind farming in the Appalachians until the year 2020, it has been estimated that between 33 000 and 110 000 bats will be killed annually in this region (Kunz et al. 2007a, Arnett et al. 2008).

Fortunately the high fatality rates reported for the Appalachian Mountains does not seem to be a particularly common phenomenon throughout the rest of North America and Europe, at least as far as we know from available reports. Nevertheless, similar frequencies have been reported from several places in Europe, particularly along coastlines (Dulac 2008) and on top of forested mountains (Brinkmann et al. 2006). We will look at these cases in some detail later.

As will become apparent, the problem with bats and wind turbines is rather unusual. The species that are most affected by wind turbines are usually quite common and normally not particularly vulnerable in other respects. The national red list, which normally is an important conservation tool (Gärdenfors 2010), is not very useful in this particular case. This is because the bat species most often killed at wind turbines are usually not listed. We certainly have to expect occasional accidents with bats at wind turbines, but we may argue that there is certainly no reason to accept that bats are killed regularly or at a large scale. In fact, all our bats are protected through the Species Protection Act, the EU Habitats Directive and the EUROBATS agreement. We will return to this issue later (9.1).

Interestingly enough, the problems surrounding the wind turbines have recently resulted in investigations of several new aspects of bat biology, and this research have provided novel and exciting results. Some particularly interesting studies have involved the behavior of bats during migration flights and their feeding on insects over the open sea (Ahlén 1997, 2002, 2003, Ahlén et al. 2007, 2009) and at high altitudes (Ahlén et al. 2007, 2009, McCracken et al. 2008, Collins & Jones 2009). For those who may want a general insight into bat ecology and behavior, we recommend recent books by Kunz & Fenton (2003) and Dietz et al. (2007, 2009), respectively. Unfortunately, there is yet no comparable literature in the Swedish language.

2. Methods

2.1. Literature survey

This report is based on information available in 2009 and 2010 and includes published and unpublished written reports which are not kept secret. As will be evident from a look at the literature list, much of the information was found in so called "grey literature", which means that it is not published in scientific journals. This implies that the reports have not gone through a peer review process, and therefore they may not necessarily live up to the normal scientific standards, although many of them actually do. In addition there are also an unknown number of unpublished reports that have not been available to us, and this applies both to USA and Europe. We have not attempted to dig up these reports. Likewise, we have omitted all oral information which could not be confirmed in written reports. This means that we could have missed some information which has not been available. Nevertheless, we believe that we have managed to find most of the relevant information, and, therefore, what is presented here may be considered representative.

2.2. Search methods and evaluation of articles

To find the relevant scientific and popular literature we used electronic databases and the Internet. Published articles were found through *Web of Knowledge* (*BIOSIS*; http://apps.isiknowledge.com/BIOSIS) and *Google Scholar*, Google). For free search on the Internet we used *Dogpile meta-search* (www.dogpile.com, InfoSpace). The following search terms were used to find literature on bats and wind power:

- bat* AND wind turbine*
- bat* AND windfarm*
- bat* AND wind park*
- bat* AND wind AND turbine*
- bat* AND wind AND farm*
- bat* AND wind AND park*
- bat* AND wind AND installation*

The number of hits per term in BIOSIS and Dogpile were few and all articles could be evaluated at this stage. Only those which obviously were not relevant were rejected and the rest were entered into a literature list on an Excel-sheet for further evaluation. The Google Scholar searches generated an uncomfortably large number of hits, so we saved only the first 50 articles for each search term. At this stage we decided which articles and reports were relevant for the synthesis work. We rejected most of which did not consider *effects* of wind power on bats, such as pre-construction impact assessments (EIA) and the like.

An important part of the cited articles are unpublished or otherwise inaccessible. We found many of these only through the generous efforts of friends and colleagues around the world or in some cases in the libraries of certain departments and consultants. In particular we acknowledge Lothar and Petra Bach (Bremen, Germany), Bat Conservation International (Austin, Texas, USA), Gareth Jones (Bristol University, UK), Marie-Jo Dubourg-Savage (Muséum d'Histoire Naturelle de Bourges, France), Luisa Rodrigues (Instituto da Conservação da Natureza e da Biodiversidade, Lisbon, Portugal) and the EUROBATS Secretariat (Bonn, Germany).

2.3. Limitations in the literature

The American material in particular seems to be limited by the fact that researchers and conservation organizations have had access to wind power facilities in some particular areas only. Hence, many North American habitats are not represented in the available material. The American reports that we have seen refer to either of three regions; the Appalachian mountains in eastern USA, the prairie east of the Rocky Mountains in southern Canada and the highland prairie in northwestern USA. There areas are probably not very representative for the entire continent, although they are very different geographically and topographically and with respect to how wind farming affects bats (table 4.1). The regions of North America that are most diverse with respect to bats, namely the southwestern states (Texas, Arizona and California), are not represented in our material, despite the fact that large scale exploitation for wind power occurs there. This may also be the case for the Rocky Mountains in USA and to some extent also for the coniferous forest belt in Canada.

Most European reports are from Germany, which is the country where the effects of wind farming on bats was first studied and the only country in the northern half of the continent where studies of the problem has been carried out and published more than occasionally. The German information is supplemented by reports of occasional investigations from Austria, Switzerland, northern France, England and Sweden. There are several countries where wind farming occurs on a relatively large scale, but from which we have been unable to find any studies of how bats are affected. This applies to Holland and Belgium, for example. It is also true for much of Denmark, which was among the first countries to introduce wind power facilities on a larger scale. We have found two reports from Danish marine wind farms (in Öresund; Ahlén et al. 2007, 2009) but none from wind farms on land.

Recently, many investigations of bats and wind farms have been made in southern Europe, particularly from Spain, Portugal, Greece, Italy and southern France, which, however, were not included in this report. Most of the reports are unpublished and normally written in various languages, which are largely inaccessible to us, and of varying quality. We expect that this material will be compiled and summarized in the near future, so that it becomes generally available. Unfortunately, we have not been able to find any material at all on bats and wind turbines from the eastern part of Europe, including Poland, the Czech Republic, Slovakia, Hungary, Russia and the Baltic countries.

2.4. Analysis

We have used all available surveys in which dead bats under wind turbines have been searched in a reasonably systematic way (tables 4.1 and 4.2) and where a number of dead bats per turbine and year (fatality rate) have been calculated. In contrast, we have not analyzed data and information that could not be related to the wind turbines as such. For example, measures of variations in the number of individuals or species of bats in the vicinity of the turbines, or variation in insect abundance, have generally been excluded from our analysis, although observed effects may sometimes be suspected to be related to the presence of turbines. The reason that we have been restrictive in this case will be discussed later (4.9).

All investigations that we have used are from the last decade, but it is only during the last few years that the methods have become reasonably standardized so that the various reports are comparable in the strict sense (examples of reports where the development of the methodology can be followed include Grünkorn et al. 2005, Kunz et al. 2007b, Arnett et al. 2008, Rodrigues et al. 2009, Huso 2010). In our meta-analysis we have generally not considered that the methods sometimes have varied, and to be strict, the result should perhaps not have been compared directly. On the other hand, we have been aware of the differences, and therefore been careful with the interpretations. In the statistical analyses we only included results from surveys where the most important biases have been controlled for one way or another. These biases are:

a. Dead bats under wind turbines may be removed by scavengers before they can be counted
b. An observer may not find all dead bats present and the searching efficiency also varies between observers
c. The possibility to find a dead bat under a wind turbine strongly depends on the prevailing circumstances such as the light condition and the height and density of the vegetation.

Not surprisingly, is has become evident that the number of bats killed at a certain wind turbine usually is much higher than the number of carcasses actually found. The figures showing estimated fatality rates (tables 3.1 and 3.2) have at least to some extent been controlled for this, usually in the original reports. However, in a few cases we have made the adjustments, using figures provided by the authors.

There are also some other potential sources of bias that we have not been able to control for. For example, the time between observations has varied between studies from one to 24 days. Also, in some surveys the biases (a-c above) have been measured for each turbine separately, while in other studies a single turbine has been assumed to be representative for the entire wind farm or a major part of it. A dog has in some cases been used to recover carcasses, which has increased the efficiency considerably particularly in dense vegetation (Arnett 2006). For experimental controls for scavenger removals and search efficiency differences (a-c above) dead bats have sometimes been used, but in other cases dead bats were replaced by chicken, mice or home-made cloth or paper models. Finally, different statistical methods have been used to adjust for the biases and for estimates of the fatality rates shown in our tables (such as Winkelman 1989, Erickson et al. 2000, Huso 2010). However, we have not attempted to control for potential differences that may occurred for this reason, and, hopefully, the methods are now becoming more standardized (Huso 2010, Huso et al. 2011).

A potentially more serious methodological problem is that the fatality rate seems to vary considerably over the season and that some surveys have been of shorter duration than others. It was realized that most accidents with bats at wind farms occur in late summer. Therefore, in many studies the field surveys were concentrated to August and September, the period when accidents were most likely. To be able to compare at least roughly the full year studies with those that were made only during the late summer period, we adjusted the fatality estimates for the shorter studies upwards by dividing by 0.9. The available whole season studies, of which there are 2 from Europe and 7 from North America, show that on average 90% of the fatalities occur in August and September and the rest (10%) in May and early June. The apparent seasonality is discussed in some detail below (4.4).

For our meta-analyses we used the Internet (Google Maps) to obtain some additional information on the sites such as elevation, extent of the vegetation cover, distance to the nearest tree-line and distance to the sea. Information about particular wind turbines were found either at the manufacturers´ home pages or at www.thewindpower.net. Because of the differences in methodology, we have been careful when comparing fatality rates across regions, countries and continents and we have tried to concentrate on patterns rather than details. Each wind farm has been regarded as a statistically independent unit. The analyses were done using non-parametric methods, because of bimodal distribution of the data (Siegel 1956). For more detailed information on the methods used in the original reports and in our analysis, we refer to two recent articles in which we present the work in more detail (Rydell et al. 2010 a, b).

3. Occurrence of bats in Sweden

The occurrence and distribution of bats in Sweden have been reviewed by Nilsson (1847), Ryberg (1947), Ahlén and Gerell (1989) and more recently by Ahlén (2004, 2006, 2011). In this chapter, we will give a brief summary of the situation. Several systematic surveys have been made over the last few years, and much of the resulting data have been made accessible through reports from the various regional authorities (e.g. Blank et al. 2008). The distribution of bats in Sweden must now be considered good or even very good particularly in the south. This chapter is largely based on the distribution maps and other pieces of information from a recent article on the distribution of bats in Sweden (Ahlén 2011).

Nineteen species of bats have been observed in Sweden so far, but some of these are very rare and may have been observed only in Skåne, the southernmost province. For example the greater mouse-eared bat is known in Sweden only from a single observation in Skåne (Gerell & Lundberg 1985). The grey long-eared bat and Bechstein´s bat probably occur permanently within the country, but with very limited distributions restricted to Skåne. This group may also include the Alcathoe whiskered bat, a species which only very recently has been discovered in Skåne and Blekinge (Ahlén 2010b). All these species should obviously be treated as threatened wherever they are found although known accidents at wind turbines so far are very few (there are no cases in Sweden).

Among the remaining 15 species there are some which are more or less rare. For example the serotine was discovered in Skåne in 1983 (Gerell et al. 1983), but it has since been observed more or less regularly much further north in the provinces of Södermanland and Västergötland. Leisler´s bat and the pipistrelle are also rare species, which have so far only been found in the southern provinces. Nathusius´ pipistrelle, a species previously known only from Skåne (Ryberg 1947), has become relatively common in the eastern part of the country north to Uppland, although it still remains rather uncommon in the western part (Ahlén 2006). The pipistrelle has only recently been separated as a species from the pygmy pipistrelle (Ahlén & Baagøe 2001). In Sweden the former species was first discovered in the year 2000 on the island of Öland, but since then it has been found further north as far as Västergötland. These species all belong to a group of bats that relatively often are killed at wind turbines on the European continent, where they generally are more common than in Sweden (table 4.3).

The bat species most likely to be encountered near wind turbines in the southern part of Sweden are the common noctule, the parti-colored bat, the northern bat and the pygmy pipistrelle. The first two are probably the most vulnerable of the Swedish species with respect to wind power. Both regularly feed in the open air, usually higher above the ground than most other bats, and they are believed to be long-distance migrants (Hutterer et al. 2005).

Their distributions roughly cover the southern half of the country, although extending a bit further north along the Baltic coast. A similar distribution also applies to the very common pygmy pipistrelle bat. In contrast, the northern bat occurs throughout the country, except at high elevation in the northern mountains, but in the far north it is rare and seems to live on the margin (Rydell 1992a). The northern bat is probably the only bat species that has to be considered during establishments of wind farms in inland areas of the northernmost provinces.

The pygmy pipistrelle and the northern bat are among the most common bat species in Sweden, and even if they relatively often are killed at wind turbines, the risk that they will be noticeably affected at the population level seems small (see 7.1 below). Remaining species belong to the three genera *Myotis, Plecotus* and *Barbastella.* Some of these species are more or less rare and may also be included in the red list (table 3.1). This applies to the barbastelle, Natterer´s bat and the pond bat, for example. These species, possibly with the exception of the barbastelle (see 4.6), usually do not fly in the free air above the trees, where there is a risk for collision with wind turbine rotors, but normally stay close to vegetation or near the ground. Nevertheless, these species could still be affected negatively by habitat transformations or disturbance during the establishment of wind power facilities, and they should be regarded as threatened species.

Table 3.1. The northern distribution limits and national red listing of Swedish bats, according to Ahlén (2011) and Gärdenfors (2010). The species on the upper half of the table are those most frequently found dead under wind turbines in Europe (see also table 4.2).

English name	Latin name	Distribution limit	Swedish red list
Common noctule	*Nyctalus noctula*	S. Norrland (62°N)	
Leisler´s bat	*Nyctalus leisleri*	Götaland (55°N)	Endangered (EN)
Nathusius´ pipistrelle	*Pipistrellus nathusii*	Svealand (61°N)	
Common pipistrelle	*Pipistrellus pipistrellus*	Götaland (55°N)	Critically end. (CR)
Pygmy pipistrelle	*Pipistrellus pygmaeus*	Svealand (61°N)	
Parti-colored bat	*Vespertilio murinus*	Svealand (61°N)	
Northern bat	*Eptesicus nilssonii*	N. Norrland (68°N)	
Serotine	*Eptesicus serotinus*	Götaland (58°N)	Endangered (EN)
Alcathoe whiskered bat	*Myotis alcathoe*	Skåne, Blekinge (55°N)	
Gerater mouse-eared bat	*Myotis myotis*	Skåne (55°N)	
Pond bat	*Myotis dasycneme*	Svealand (61°N)	Endangered (EN)
Daubenton´s bat	*Myotis daubentonii*	M. Norrland (64°N)	
Brandt´s bat	*Myotis brandtii*	M. Norrland (64°N)	
Whiskered bat	*Myotis mystacinus*	S. Norrland (62°N)	
Natterer´s bat	*Myotis nattereri*	M. Norrland (63°N)	Vulnerable (VU)
Bechstein´s bat	*Myotis bechsteinii*	Skåne (55°N)	Critically end. (CR)
Grey long-eared bat	*Plecotus austriacus*	Skåne (55°N)	
Brown long-eared bat	*Plecotus auritus*	M. Norrland (63°N)	
Barbastelle	*Barbastella barbastellus*	Götaland (58°N)	Endangered (EN)

As mentioned previously, the problems related to wind turbine establishments and bats are rather special in the sense that the species most often killed are not considered particularly rare or threatened in other contexts. In this work we have tried to concentrate on what we believe are most relevant with respect to wind power. For the protection of bats in Sweden I general and the corresponding international agreements on protection of bats we refer to part 9.1 and Ahlén (2011). In some more detail, the national and international agreements and the red lists of threatened species are presented by Gärdenfors (2010) and Temple and Terry (2007), respectively. Updated fact sheets of the Swedish bat species can be found at www.artdata.slu.se.

4. Effects of wind power on bats

4.1 Fatality rates at wind farms in Europe and North America

We have compiled the results of European and North American post-construction surveys, in which fatality rate of bats has been quantified (tables 3.1 and 3.2). The results show great differences particularly with respect to where the wind farms were built in relation to topography and vegetation. Most bats are killed at wind farms located along coast lines or on tops of hills and mountains in forested areas, in the latter case apparently regardless of whether the forests are coniferous or broad-leaved. The primary North European example is the Black Forest in southern Germany, where there are many small wind farms and where on average 18 bats are killed annually per turbine. A survey from the Jura Mountains in Switzerland suggests that the situation there is similar. This also applies to wind farms located along ridges of the Appalachians in eastern USA, although even higher fatality rates have been recorded there.

The opposite situation may apply to intensively farmed lowlands and other flat and tree-less areas, including much of Schleswig-Holstein in north-western Germany, Cambridgeshire in England and the prairie in Alberta, Canada. In such places the fatality rate is usually low, on average less than three bats per turbine annually. Nevertheless, some wind farms located on open farmland, including Prellenkirchen in Austria and Summerview in Canada, show that the fatality rate may be raised locally even in such places, although the reason for this is not always apparent. In the case of Summerview, however, the elevated fatality rate is believed to be an effect of the proximity to a forest patch, which is frequently used as a roosting site by bats during their southward migration (Baerwald & Barclay 2009).

Generally, the fatality rate increases slightly in agricultural areas if there is more variation in topography and vegetation. One example of this is the state of Sachsen in eastern Germany, where the fatality rate is 1.8 bats per turbine annually. Although this is higher than that observed at wind farms in northern Germany, for example, it is still only one tenth of that recorded in the Black Mountains. Despite a great deal of variation in fatality rate as well as in vegetation and topography, we were unable to find any obvious relationships in the lowland samples. However, it seems clear that the number of accidents increases at turbines located within 100-200 m from a tree-row or forest edge, relative to turbines located further away (Endl et al. 2004, Seiche 2008). It also seems likely that fatality rate increases drastically at turbines located near the coast line. Unfortunately, we only have access to data from a single site of this kind, namely the wind farm Bouin at Vendée on the Atlantic coast of France. At this site, the fatality rate is as high as 19 bats per turbine annually, despite the fact that the area around the wind farm is completely flat and treeless. It also appears that the fatality rates are elevated at wind farms located at or near wetlands, although we have only found two examples of this situation. These are Pickering in Canada and the Top of Iowa in USA, where 10.7 and 7.8 bats are killed per turbine and year, respectively.

There is no obvious relationship between fatality rate and the size of the wind farm (the number of turbines). Turbines which are parts of larger wind farms do not kill more or fewer bats compared to those in smaller farms or single turbines. This applies at least to Europe, where the number of turbines per studied wind farm varies between 1 and 18. However, as shown in fig. 3, wind turbines with higher towers kill more bats than lower ones. This relationship seems to be exponential, which means that the risk to bats increases more rapidly at the tallest towers. The same relationships are observed in North America, as shown by Barclay et al. (2007).

Table 4.1. Estimated fatality rates (the numbers of bats killed annually per turbine) at wind farms in North America. In each study reviewed here, dead bats were collected regularly throughout most of a season or more. The numbers have been adjusted for differences between observers and observation conditions and also for the removal of carcasses by scavengers. For more details we refer to Kunz et al. (2007a), Arnett et al. (2008) and Rydell et al. (2010a).

Name of wind farm	Location	No. of turbines	Fatality rate	References
Eastern USA				
Searsborg	Mountain	11	0.0	Kerlinger 2002
Maple Ridge 1	Grassland, hill	120	24.5	Jain et al. 2007
Maple Ridge 2	Grassland, hill	195	12.3	Jain et al. 2009
Casselman	Mountain	23	32.3	Arnett et al. 2009
Meyersdale	Mountain	20	25.6	Kearns et al. 2005
Mountaineer	Mountain	44	47.5	Kerns & Kerlinger 2004
Buffalo Mountain 1	Mountain	3	28.0	Nicholson 2003
Buffalo Mountain 2	Mountain	15	69.6	Fiedler et al 2007
Central USA				
Buffalo Ridge 1	Grassland	73	0.1	Johnson et al. 2003a
Buffalo Ridge 2	Grassland	143	2.0	Johnson et al. 2004
Buffalo Ridge 3	Grassland	138	2.1	Johnson et al. 2004
Lincoln	Fields	31	4.3	Howe et al. 2002
Top of Iowa	Fields	98	7.8	Koford et al. 2004
Western USA				
Judit Gap	Grassland	90	13.4	TRC 2008
Klondike	Fields	16	1.2	Johnson et al. 2003b
Vansycle	Grassland	38	0.8	Erickson et al. 2000
Stateline	Grassland	454	1.1	Erickson et al. 2003a
Foote Creek Rim	Grassland	69	1.3	Young et al. 2003
Nine Canyon	Grassland	37	3.2	Erickson et al. 2003b
High Winds	Grassland	90	3.7	Kerlinger et al. 2006
Canada				
McBride Lake	Fields	114	0.5	Brown & Hamilton 2004
Castle River	Fields	60	0.6	Brown & Hamilton 2006a
Summerview	Fields	39	18.5	Brown & Hamilton 2006b
Pickering	Lake shore	1	10.7	James 2002

It should be stressed that bats and birds are different in this case. For birds, the height of the tower does not seem to have any major effect, contrary to the situation with bats. The number of bats that are killed at a wind turbine also depends on the sweep area of the rotor, so that larger rotors kill more bats. The distance between the rotor and the ground does not seem to affect the fatality rate, however (Barclay et al. 2007).

Table 4.2. Estimated fatality rates (the numbers of bats killed annually per turbine) at wind farms in northern and central Europe. In each study reviewed here, dead bats were collected regularly throughout most of a season or more. With the exception of three studies where the fatality rate is given in parenthesis, the numbers have been adjusted for differences between observers and observation conditions and also for the removal of carcasses by scavengers. For more details we refer to Rydell et al. (2010a).

Name of wind farm	Location	No. of turbines	Fatality rate	References
Northwestern Germany				
Blumendorf	Fields	2	(2.0)	Göbel & Göttsche 2005
Tralau	Fields	4	(2.0)	Göttsche & Göbel 2007
Friedrich-Wilhelm Lübke Koog	Fields	13	0.0	Grünkorn et al. 2005
Bosbüll	Fields	4	0.0	Grünkorn et al. 2005
Marienkoog	Fields	15	0.0	Grünkorn et al. 2005
Reussenköge	Fields	17	0.0	Grünkorn et al. 2005
Breklumer Koog	Fields	11	0.0	Grünkorn et al. 2005
Simonsberger Koog	Fields	13	0.0	Grünkorn et al. 2005
Uelvesbuller Koog	Fields	4	0.0	Grünkorn et al. 2005
Cappel-Neufeld	Fields	5	3.1	Bach & Bach 2010
Langwedel	Fields	5	3.0	Bach & Niermann 2011
Eastern Germany				
Puschwitz	Woodland	10	4.1	Endl et al. 2004
Wendischbora	Fields	17	3.6	Endl et al. 2004
Bayerhöhe	Hill, fields	5	4.0	Endl et al. 2004
Wachau	Fields	5	0.0	Endl et al. 2004
Bernsdorf	Woodland	3	0.0	Endl et al. 2004
Röhrsdorf	Fields	4	0.0	Endl et al. 2004
Ludwigsdorf	Fields	18	1.1	Endl et al. 2004
Thornberg	Fields	12	1.1	Endl et al. 2004
Kleinröhrsdorf	Fields	3	2.2	Endl et al. 2004
Melaune	Fields	7	2.6	Endl et al. 2004
Reichenbach	Fields	7	1.9	Endl et al. 2004
Eckardsberg	Fields	5	2.6	Endl et al. 2004
Southern Germany				
Lahr	Mountain	3	(0.6)	Behr & Helversen 2005
Ittenschwander Horn	Mountain	2	18.3	Behr et al. 2006
Rosskopf	Mountain	4	26.0	Brinkmann et al. 2006
Brudergarten	Mountain	3	15.0	Brinkmann et al. 2006
Hohe Eck	Mountain	1	41.1	Brinkmann et al. 2006

Name of wind farm	Location	No. of turbines	Fatality rate	References
Schillinger Berg	Mountain	2	31.6	Brinkmann et al. 2006
Holzschlägermatte	Mountain	2	13.3	Brinkmann et al. 2006
Plattenhöfe	Grassland, hill	4	3.9	Brinkmann et al. 2006
Fürstenberg	Grassland, hill	1	0.0	Brinkmann et al. 2006
Austria				
Oberdorf	Fields	5	0.0	Traxler et al. 2004
Prellenkirchen	Fields	8	8.8	Traxler et al. 2004
Steinberg	Fields	9	5.3	Traxler et al. 2004
Switzerland				
Mont Soleil	Grassland, hill	3	13.6	Leuzinger et al. 2008
Feldmos	Grassland, hill	1	0.0	Leuzinger et al. 2008
Tramelan	Grassland, hill	1	0.0	Leuzinger et al. 2008
England				
Coldham 1	Fields	8	1.2	Bioscan 2008
France				
Bouin	Coast, fields	8	19.0	Dulac 2008

4.2. Fatality rates at wind farms in Sweden

The problem of bats being killed at wind turbines in Sweden became apparent in 1999, when several carcasses were found under a group of wind turbines on the island of Gotland. Nevertheless, after more than a decade, there are still no figures indicating how many bats actually are killed at wind turbines in this country. However, there is a survey that may be used to make a rough comparison with the German figures cited above (Ahlén 2002). It indicates that fatality rates at wind turbines in Sweden and Germany are of the same order of magnitude. Ahlén surveyed 160 wind turbines in the southernmost provinces and the Baltic islands (Skåne, Blekinge, Öland and Gotland) and found 17 dead bats altogether (0.11 per turbine; each turbine was visited once). Of these, as many as 14 were found at turbines located within 500 m of the coast (0.20 per turbine). Only three bats were found at turbines further inland (0.03 per turbine). In Thüringen in southern Germany, Kusenbach (2004) made a similar study. She found 7 dead bats at 94 turbines, each of which was visited once, which means 0.06 bats per turbine. In a much larger study in Sachsen in eastern Germany, Seiche (2008) found 114 dead bats during 6987 visits at 145 turbines, which means 0.02 bats per turbine on average (in this case, each turbine was visited several times, however). In the two German studies, the surveyed wind farms were all located in more or less flat and open farmland far away from the coast. Hence, although only very few dead bats have yet been found under wind turbines in Sweden, it seems as if the fatality rate at wind turbines in Sweden is of a similar magnitude compared to similar areas (farmland) in Germany. Ahlén´s figures also suggest that the fatality rate increases drastically (about 6 times) at the coast, compared to inland sites.

Estimates of fatality rates at the European continent seem to agree reasonably well with the conditions in Sweden, so we may, because of the scarcity of data from Sweden, use figures from Germany. In an open agricultural landscape, fatalities are usually few and similar in all countries and regions of northern Europe (Sweden-Germany-Austria-England). Fatalities become more frequent (5-10 times) at the coast (Sweden-France) or on top of mountains or ridges (Germany-Switzerland). Nevertheless, the story is somewhat complicated by several examples where fatalities are common even on open farmland away from obvious high-risk areas (Traxler et al. 2004).

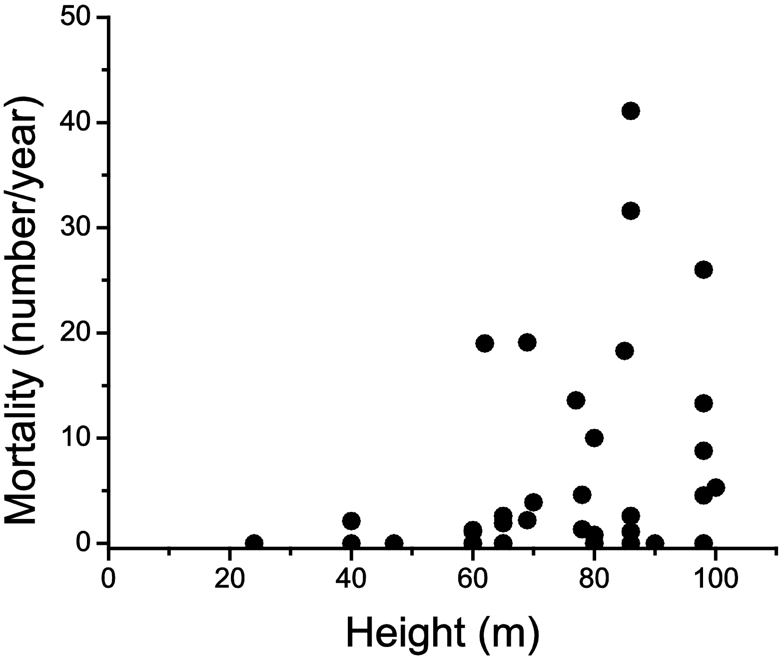

Figure 4.1. Estimated fatality rate (number of dead bats per turbine and year) in relation to the height of the turbine tower. The relationship shown above has not been controlled for the fact that higher turbines also have longer rotors on average, and therefore sweep over larger areas and kill more bats. Each point represents a wind farm in northern Europe. The fatality rates have been controlled for differences among observers and observation conditions and also for carcasses removed by scavengers.

Unfortunately, data on fatality rates at wind turbines located along other linear landscape elements, such as river banks and lakes shores, which frequently are used by bats (Limpens & Kapteyn 1991, Furmankiewicz & Kucharska 2009), are missing entirely. It also seems likely that bats follow major roads and motorways, particularly those lit by streetlamps (Rydell 1992a, 2005). If this means that motorways also should be regarded as high-risk with respect to wind turbine locations remains to be seen. Likewise we have no information on the number of bats that are killed at marine wind farms (Ahlén et al. 2007).

4.3. Distribution among species

Accidents with bats at wind turbines hit very unevenly depending on the species, and the difference is at least to some extent related to the species´ normal behavior. As much as 98% of the bats killed at wind turbines in northern Europe belong to one of eight high-risk species (our classification) in the genera *Nyctalus*, *Pipistrellus, Vespertilio* and to some extent also *Eptesicus* (table 4.3). The remaining 11 bat species that occur in Sweden comprise only 2% of the fatalities. This group includes all the species considered threatened at the European level or those listed in the Habitat Directive Annex II or IV. Much of this group consists of long-eared bats (*Plecotus* spp.) and mouse-eared bats (*Myotis* spp.). Some of these are among our commonest bats, while others are very rare. In either case, these bats usually fly near the ground or among vegetation, and they therefore seldom are at risk of colliding with rotor blades of wind turbines. However, some of the species, including the barbastelle and Bechstein´s bat, are so rare that it would be unlikely to find them dead under turbines in any case. How the latter two species behave with respect to wind turbines is not known as far as we know.

Observations with ultrasonic detectors (bat detectors) at wind turbines in Sweden and Europe in general have shown that the bats searching for food (flying insects) around the top of towers and rotor blades of wind turbines nearly always belong to any of the eight high-risk species (Ahlén 2002, Endl et al. 2004, Behr & Helversen 2005, Brinkmann et al. 2006, Ahlén et al. 2007, Behr et al. 2007, Grünwald & Schäfer 2007, Seiche 2008, Collins & Jones 2009, Bach & Bach 2010, Bach & Niermann 2011). Hence, the bat species most often killed at wind turbines are the same as those that feed in such places.

To characterize some species as "high-risk" is certainly to generalize. Bats show highly variable behavioral patterns and are sometimes found in rather unexpected places. The barbastelle, for example, seems to be particularly hard to characterize, and this species shows several different behavioral patterns. It has an unusual wing form with narrow wing tips and thereby uses a rather characteristic flight technique. Occasionally the barbastelle behaves similar to the northern bat, and particularly in late summer, it may turn up in entirely tree-less places. It has also been observed to hunt insects around street-lamps (Zingg 1994). How barbastelles will behave at wind turbines is difficult to predict, so we should be particularly careful and restrictive if exploitation for wind farming is considered in areas with regular occurrence of barbastelles. This should also apply to Bechstein´s bat, which occurs in the province of Skåne, of which we know even less.

Although the bats that suffer most seriously from accidents at wind turbines nearly always belong to the high-risk species group, the exact species composition varies geographically and in relation to topography and vegetation. As an example we may use Germany. In open agricultural lowland areas it is nearly always the same species that are killed regardless of location. In the states of Sachsen and Brandenburg, where this kind of landscape dominates, common noctules and Nathusius´ pipistrelles clearly dominate among the fatalities. In the high altitude and largely forested Black Forest in the state of Bayern, it is usually common pipistrelles and Leisler´s bats that are killed. The difference in which species are being killed simply reflects local or regional differences in the occurrence of high-risk species.

There is an idea prevalent in the American literature, namely that accidents with bats at wind turbines predominantly affect migratory species (Kunz et al. 2007a, Arnett et al. 2008, Cryan 2008, Horn et al. 2008). However, this view does not agree with what have been observed in Europe. Although the common noctule and Nathusius´ pipistrelle are typical long-distance migrants in Europe (Hutterer et al. 2005) this is not the case for the common pipistrelle, the species most often killed at wind turbines in the Black Forest in Germany (Behr & Helversen 2006) and at the wind farm at Bouin on the Atlantic coast of France (Dulac 2008). This species is believed to be more or less stationary in the respective areas. This also applies to the northern bat, the species most frequently killed at wind turbines in Sweden (Ahlén 2002). Therefore our conclusion is that wind turbines to a high extent kill migratory bats, but because stationary bats are also affected, the accidents probably occur independently of the migration as such. We have presented a hypothetical explanation which may account for this (Rydell et al. 2010b), and we will return briefly to this issue later (5.1).

Table 4.3. The distribution among species of bats found dead at wind turbines in Europe (data from Dürr 2009). Only species that occur in Sweden are included. Asterisks show the species that are considered threatened at the European level or listed in the EU Habitat Directive Annex II or IV (Temple & Terry 2007).

Species	Latin name	Number of dead bats			
		Sweden	Germany	Other	Total
High-risk species					
Common noctule	*Nyctalus noctula*	1	374	15	390
Leisler´s bat	*Nyctalus leisleri*	0	52	28	80
Nathusius´ pipistrelle	*Pipistrellus nathusii*	5	284	57	346
Common pipistrelle	*Pipistrellus pipistrellus*	1	230	139	370
Pygmy pipistrelle	*Pipistrellus pygmaeus*	1	21	14	36
Parti-colored bat	*Vespertilio murinus*	1	44	2	47
Northern bat	*Eptesicus nilssonii*	8	2	0	10
Serotine	*Eptesicus serotinus*	0	25	15	40
Other species					
Alcathoe whiskered bat	*Myotis alcathoe*	0	0	0	0
Greater mouse-eared bat	*Myotis myotis**	0	2	1	3
Pond bat	*Myotis dasycneme**	0	1	0	1
Daubenton´s bat	*Myotis daubentonii*	0	3	2	5
Brandt´s bat	*Myotis brandtii*	0	1	0	1
Whiskered bat	*Myotis mystacinus*	0	2	0	2
Natterer´s bat	*Myotis nattereri*	0	0	0	0
Bechstein´s bat	*Myotis bechsteinii**	0	0	1	1
Grey long-eared bat	*Plecotus austriacus*	0	6	1	7
Brown long-eared bat	*Plecotus auritus*	0	3	0	3
Barbastelle	*Barbastella barbastellus**	0	0	1	1
Unidentified		0	41	131	172
Total		**17**	**1091**	**407**	**1505**

The high-risk species (*Nyctalus*, *Pipistrellus, Vespertilio* and to some extent *Eptesicus*) are more or less adapted for insect hunting in the open air or at least several meters from trees and other obstacles. They normally fly relatively straight and fast, which is facilitated by their more or less long and narrow wings (Norberg 1990). They also use echolocation or sonar (SONAR = SOund Navigation and Ranging) systems suitable for this purpose, namely short but strong pulses with more or less narrow bandwidths and longer listening intervals in between. Short narrow band pulses give echoes that include amplitude- and frequency modulations that can be used by the bats to find and characterize fluttering insect wings in the air (Waters et al. 1995). The performance of such echolocation systems is usually poor in the immediate vicinity of structures that return unwanted echoes, so called "clutter", and cannot be used with any efficiency near the ground or among vegetation. Therefore other species of bats rather use very short broad-band pulses or frequency sweeps, which are much less sensitive to clutter, and so can be used efficiently even near the ground, within vegetation or close to water (Jones & Rydell 2003). Generally, species that use broad-band pulses also have relatively short and broad wings, which facilitate slow and maneuverable flight, which may be necessary to make use of confined spaces (Norberg 1990). On the other hand, the latter species are poorly equipped for the fast flight, that may be important for avoidance of avian predators, and they usually avoid open places (Baagøe 1987). In this chapter we have used examples from Europe, but the situation seems to be very similar in North America, although the genera and species involved are different.

In summary, we think we know relative well which species are affected and which are not by wind turbines in northern Europe, and we also believe that we understand the reason for the observed differences. This information is important whenever the potential effects wind farms on bats will be evaluated in future projects.

4.4. Distribution among sexes and age classes

We have only been able to find four European surveys where bats found dead at wind turbine have been sexed and aged. All are from Germany, namely form Sachsen (Endl et al. 2004, Seiche 2008) and the Black Forest (Behr & Helversen 2006, Brinkmann et al. 2006), respectively. This means that our data are very limited, and does not indicate that the risk of being killed depends on sex or age. This is not in agreement with most observations from North American wind farms, where adult males are killed more frequently than females and young in all areas that have been investigated (Arnett et al. 2008). We are cannot explain this apparent difference in any other way than that the European data probably is too limited for a meaningful comparison.

4.5. Distribution of fatalities over the year

To collect dead bats in a wind farm at short intervals throughout a season or more is very time and labor consuming. Therefore the searches have in many cases been concentrated to the time of the year when most (90%) fatalities at wind turbines occur, namely in late summer and early autumn. We have compiled the results of two studies from Germany (Trapp et al. 2002, Endl et al. 2004) and one from France (Dulac 2008). These three are among the few European studies where wind farms have been searched regularly over a season or more, and where the number of dead bats found is high enough to give a statistically meaningful picture of the variation. The French study has continued over four seasons and is still running, so in this case we can also get an idea of the variation from year to year.

Fatality data from several wind parks in Sachsen in eastern Germany collected in 2002 and 2004 are shown in fig. 4.2. A minor part (10%) of the fatalities occurred in early June, a major part (90%) in August and September, but there were no fatalities in between. Dramatic increases in the fatality rate were observed in late summer in this area in both years. Predominantly common noctules and Nathusius´ pipistrelles, both considered long-distance migrants, were affected.

The wind farm at Bouin on the Atlantic coast of France, which has been followed regularly since 2003 (Dulac 2008), shows a pattern which is consistent with the German data cited above. A small (8%) peak in the number of dead bats is usually evident in the spring and there is also a much higher one (92%) in late summer and early autumn (fig. 4.3). At this site mostly common pipistrelles, a species believed to be resident in this area, are killed, but sometimes Nathusius´ pipistrelles and common noctules, which pass the area during migration, are found dead as well. Interestingly, the late summer fatality peak occurs in every year, but the exact time when this happens varies by several weeks.

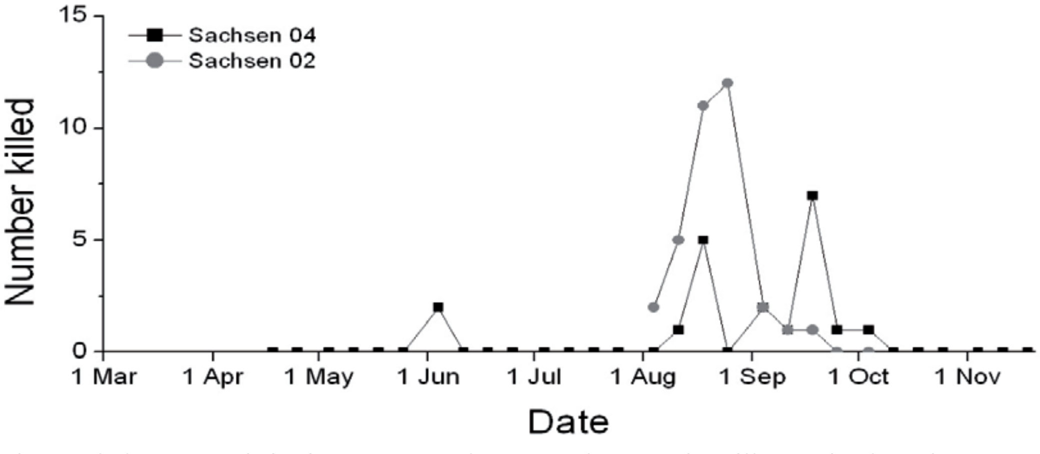

Figure 4.2. Seasonal variation in the number of dead bats found at nine different wind farms in Sachsen in Eastern Germany during two seasons 2002 and 2004 (data from Trapp et al. 2002 and Endl et al. 2004, respectively).

There are several studies from North America that show the same thing, namely that most (on average 90%) fatalities occur in the late summer and early autumn period, from late July to early October. Occasionally a minor fatality peak occur in late spring or early summer, whereas fatalities usually are very few during the bats´ maternity period in the middle of the summer (Howe et al. 2002, Young et al. 2003, Erickson et al. 2003, 2004, Brown & Hamilton 2004, 2006 a and b, Johnson et al. 2004, Kerns & Kerlinger 2004, Kerlinger et al. 2006, Jain et al. 2007, 2009, Arnett et al. 2009).

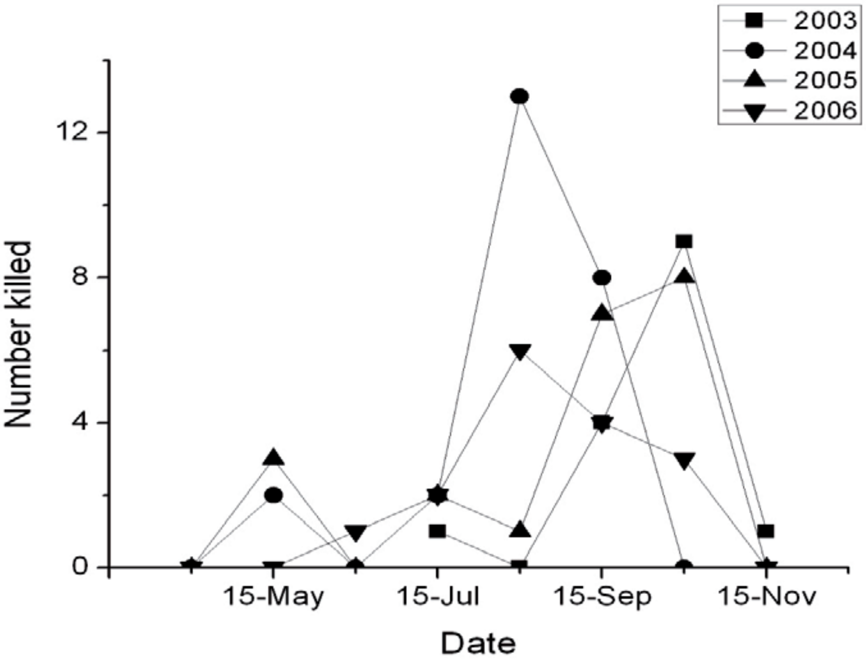

Figure 4.3. Seasonal variation in the number of dead bats found at the Bouin wind farm at the Atlantic coast of France during four consecutive years (Dulac 2008).

4.6. The behavior of bats at wind turbines

To observe bats and insects over long distances (>100m) under poor light conditions is not trivial. Nevertheless there are some studies that have provided some insight in what bats do when they visit wind turbines. For the observations, ultrasound detectors, spot lights, heat image cameras or combinations of these instruments have been used (Ahlén 2002, Ahlén et al. 2007, 2009, Endl et al. 2004, Traxler et al. 2004, Behr & Helversen 2005, Brinkmann et al. 2006, Behr et al. 2007, Grünwald & Schäfer 2007, Horn et al. 2008a). Bach and Bach (2010) and Bach and Niermann (2011) used ultrasonic detectors placed in turbine towers 30 m above the ground. Despite the new technique the process towards understanding of what happens at wind turbines at night has been far from straight. Many hypotheses and ideas have been suggested, and most of these have been reviewed by Cryan & Barclay (2009). We will go through some of the hypothesis later in this report (sections 5.1 and 5.2). We also refer to one of our published articles (Rydell et al. 2010b).

Taken together the studies cited above show quite clearly that some species of bats actively visit wind turbines in order to feed on insects that accumulate around the turbine towers and the rotor blades. The bats sometimes fly close to the blades and make rapid turns and dives, a behavior normally associated with the capture of flying insects, and they also frequently seem to be sucked in by the vortices behind the rotor blades. It has also been described how the sonar pulses vary as they normally do during attacks against insect prey, including so called “feeding buzzes”, in which the echolocation pulse intervals are shortened so that the entire sequence sounds like a “buzz” at ca. 200 pulses/s. Brinkmann et al. (2006) and Horn et al. (2008) have described and filmed how bats sometimes ”investigate” the machine house or the tower of the turbines, a behavior that indicates that the bats actually may glean prey from the surface (Ahlén et al. 2007). It is well known that large amounts of insects sometimes accumulate at wind turbines and get stuck to the rotors. This may increase the noise and decrease the efficiency of the turbine (Corten & Veldkamp 2001).

Ahlén (2002) noticed that the behavior of bats at wind turbines is the same regardless of whether the rotor is moving or not. This means that the magnetic fields, heat or ultrasound produced by the turbine or Doppler-effects produced by the movements itself (Long et al. 2009, 2010b) cannot be responsible for the attraction of bats to the turbines, as has been suggested (Kunz et al. 2007a). The white or red warning lights on top of the turbines do not attract bats to any extent (Horn et al. 2008) and playback of sounds generated by wind turbines has no effect on bats either (Ahlén 2003). Ahlén (2003) and Ahlén et al. (2007, 2009) noticed that bats (common noctules and pygmy pipistrelles) show exactly the same behavior at two wind farms up to 10 km from land in the Baltic Sea, as they normally do when they feed at wind turbines on land. In both cases accumulations of insects around the turbine towers could be seen. The insects were apparently drifting or migrating across the Baltic Sea. Ahlén et al. (2007) also provide evidence that bats sometimes, after having fed, may stay at sea until the next evening, finding suitable roosts in the towers or nacelle houses of wind turbines off shore.

4.7. Weather effects

As has already been mentioned, bats are killed at wind turbines predominantly in August and September. But even within this period, the number of accidents varies dramatically from day to day and the variation shows a clear relationship with shifts in the weather. Bats forage at wind turbines almost exclusively at slow wind speeds (Behr & Helversen 2005, Brinkmann et al. 2006, Ahlén et al. 2007, Grünwald & Schäfer 2007, Bach 2007, Bach & Bach 2010, Bach & Niermann 2011) and this is also when most accidents occur (Traxler et al. 2004, Behr & Helversen 2005, Seiche 2008). The highest bat activity at wind turbines and most fatalities coincide with wind speeds below 4 m/s (measured at nacelle height). The bat activity at turbines decreases in the 4-8 m/s interval. Few if any bats remain feeding at wind turbines at higher wind speeds, although there is some variation with respect to the location of the turbine and the species of bat. For example, the common noctule, a relatively large species, appears to be more wind tolerant than the smaller bats. On average, common noctules feed at wind turbines at higher wind speeds and also get killed there, compared to the smaller *Pipistrellus* species (Seiche 2008).

An investigation from eastern USA is particularly illuminating. Kerns et al. (2005) counted dead bat every day at two wind farms located far apart but still within in the Appalachian Mountains (Mountaineer Wind Farm in West Virginia and Meyersdale Wind Farm in Pennsylvania) during August and September 2004 and 2005 (diagram in Arnett et al. 2008). They found that the number of dead bats varied dramatically from day to day, but also that it co-varied at the two localities. Particularly high (or low) mortality always occurred on the same night at both sites. They also found that the pattern differed randomly between the two years. These observations clearly showed that the fatality rate, and presumably also the activity of bats at the turbines, depended strongly on the prevailing weather, and not on local conditions. Kerns et al. (2005) also found that high numbers of dead bats usually occurred a few days after rain storms (cold fronts), when high air pressure, low humidity and slow winds usually from the north prevailed. There was also a weak relationship with the temperature, because more bats were killed in warm weather.

The same thing has been described from Europe, but the investigations have not been carried out with the same precision as that of Kearns et al. (2005). Bat mortality peaks typically occur simultaneously at several sites, but vary drastically from day to day and between years at a given locality (Trapp et al. 2002, Endl et al. 2004, Brinkmann et al. 2006).

4.8. Causes of death

In contrast to most birds bats rarely collide with objects such as skyscrapers, light houses or radio towers (Gelder 1956, Crawford & Baker 1981). The increased mortality of bats at wind turbines has a very different explanation, and is intimately linked to the movement of the rotor in combination with the fact that bats normally react to surrounding objects only at very short distances. This in turn is because ultrasound, as used by bats to find obstacles and track insects in the air, is a short range detection system (one or a few meters in practice, depending on species; Rydell and Jones 2003). Therefore a bat would not have as a chance to detect a moving wind turbine rotor in time to avoid it. This also means that bats will not be able to “learn” to avoid the danger or become “habituated” to it.

Seiche (2008) investigated 76 individual bats of several species found dead under wind turbines in Germany. Three of these were alive but they subsequently died. The most frequent injuries observed were fractures and hemorrhages in the head (11), wing fractures (32), external body injuries (18) and internal hemorrhages (27). Seven individuals showed no obvious injuries. Behr & Helversen (2006) and Brinkmann et al. (2006) investigated 40 individuals of pygmy pipistrelles and Leisler´s bats collected under wind turbines in the Black Forest in Germany. Their result was similar to that of Seiche (2008), but is addition several individuals showed inner hemorrhages particularly in the lungs, which may have arisen through rapid changes in the air pressure. In the latter case that bats could have died either from collision with the rotor blades or from the drop in air pressure behind them. All individuals investigated were in good conditions and had food in their stomachs when they died, which corroborates the idea that bats are killed as they feed on insects attracted to the wind turbines.

A similar piece of work has been carried out in Canada, where Baerweald et al. (2008) examined 188 bats belonging to two different species (hoary bat *Lasiurus cinereus* and silver-haired bat *Lasionycteris noctivagans*) that had been killed during the previous night. Approximately half of the specimens had died through collision with the rotors, but all individuals also showed potentially fatal lung damage, suggesting that they had been subject to drastic air pressure change.

4.9. Other possible effects

Wind power facilities may also have less obvious effects on bats. For example, the quality of their hunting area may be changed in either direction, following the building of access roads, drainage of the ground, removal of trees or buildings during the exploitation for wind plants. Bats may either leave the area or they may be attracted by the new situation. The reproductive performance and survival may also be affected for those that remain in the area after the exploitation. Obviously, the magnitude of the indirect effects like these may increase with the size of the wind farm. However, most future wind farms in Sweden will most likely become established in forested areas where intensive forestry already occurs, which means that the wind farming normally will have a modest environmental effect compared to the forestry. Nevertheless, there may be a risk that new access roads may lead bats to the wind turbines, particularly if the new roads add linear landscape elements to the area. Such roads are typically followed by barbastelles and some other forest bats, while travelling between roosts and feeding sites.

At larger wind parks it seems likely that maintenance roads may sometimes require illumination. Smaller facilities and single turbines are usually maintained using minibuses in daytime, and illumination beyond single lights may not be necessary. Artificial light is otherwise a particularly sensitive issue with respect to the protection of bats. Lights, particularly if including a UV-component (mercury or high-pressure sodium), tend to attract insects and therefore also some abundant and invasive species of bats such as northern bats and common pipistrelles, which in turn may exclude other bats from the lit areas (Rydell 1992a, 2005). In the long run the serotine may perhaps also be included in this group, at least if it becomes more common in the future (Baagøe 1986). These species attract conspecifics to places where there is food, because their echolocation pulses may be heard by other bats over considerable distances (Barclay 1982). Hence, several individuals may then efficiently exclude members of other species, which may be relatively uncommon, less competitive or both (Haffner & Stutz 1985, Arlettaz et al. 2000).

To estimate the importance of such indirect effects it is probably necessary to obtain a good idea about the bat community in the area, including the species composition, number of individuals, sex distribution and reproductive success, food availability (insects), roosting sites and more before and after the establishment of the wind farm. To gather such information is very labor- and time consuming, particularly since it would probably have to be repeated over a few years. Bats are long-lived and slowly reproducing animals (Barclay & Harder 2003), and it may take a long time before changes in the availability of food or roosts become evident in the population counts. Moreover, mortality and reproductive success in bats depend strongly on the weather and therefore tend to vary considerably from year to year. It will always be difficult to show that the observed effects are due to the wind turbines, to the weather or to something else. In any case, to be worth collecting the data must be compared in a statistically meaningful way.

We are not aware of any bats studies where all this has been done but there is at least one report where bat activity before and after construction of a wind park was compared. The activity was measured with ultrasound detectors (Bach & Bach 2010). The result showed that the bat activity was lower after construction compared to before construction, particularly for one of the species included in the survey (the serotine). However, lower activity of serotines may not necessarily have been an effect of the wind farm construction, but it may just as well have been the result of movement of a colony for a reason unrelated to the wind farm. We argue that this problem is general, and that it may not always be meaningful to make comparisons, unless the source of observed the effects are known or can be investigated. Hence, in this review we have largely left the indirect effects aside. Instead we have concentrated on situations where bats are killed at wind turbines. The number of dead bats is easily measurable and such data are suitable for comparisons in time and space as well as for hypothesis testing.

In other reviews on the bat and wind turbine issue, other views have been expressed. In particular, the indirect effects are considered important and should be given considerable attention. This is true for American (Kunz et al. 2007b) as well as European (Rodrigues et al. 2008) work. We do not necessarily share view, because there may be risk that inclusion of too many different "effects" may result in less focus on what is really important. With respect to Sweden at present, we consider the guidelines provided by Kunz et al. (2007) and Rodrigues et al. (2008) to be too complicated and labor intensive in relation to the usefulness of the results.

5. Ecological connections

5.1. Why bats are attracted to wind turbines – a possible explanation

During warm nights in late summer, when the wind is slow and the air pressure is high, millions of moths and other insects, including gamma moths *Autographa gamma* (Chapman et al. 2008), other moths (Westbrook 2008) and song birds (Alerstam 1990) start on their southern migration from northern Europe. Such weather usually follows passing cold fronts. The migration takes place in weak and relatively stable air layers that form at night within the atmospheric boundary layer at 100-1200 m altitude (Taylor 1974, Reynolds et al. 2008, Wood et al. 2010).

From southern USA it is well known that the Mexican free-tailed bat *Tadarida brasiliensis* to some extent feeds on migratory insects, which are caught at high altitude at certain times of the year (McCracken et al. 2008). It seems unlikely that this is an isolated phenomenon. Instead bats probably make use of the enormous resource, consisting of insects in the atmosphere, in other parts of the world as well. For example, a brief look in the literature reveals that the radio tracking of common noctules, carried out by Kronwitter (1988) during two summers in Germany, clearly showed that the bats consistently changed their behavior in August and September. At the same time the color and structure of the droppings that accumulated at the roosts also changed in an obvious way. During this period the bats abandoned the hunting areas in forests, over lakes and along lit roads, places used earlier in the summer, and rather spent the time at high altitudes, at least 250-500 m above the ground. Kronwitter (1988) presented a hypothesis that possibly may explain the observed behavior. He suggested that ”the explanation … may be found in the migration of various insects which occurs sometimes at high altitudes”. With respect to Sweden, it has been observed by using a heat image camera, that common noctules sometimes hunt insects over the Falsterbo peninsula in Skåne at high altitude (up to 1200 m) in August (Ahlén et al. 2007, 2009; the technique was described by Zehnder et al. 2001). The species identification was possible because the flight speed and hunting technique could be recognized. It is also known that the close relative of the common noctule in southern Europe *Nyctalus lasiopterus* regularly complement its insect diet with migrating song-birds, which are captured and eaten high in the air (Ibáñez et al. 2001, Popa-Lisseanu et al. 2007).

So far, Kronwitter´s (1988) hypothesis may not have been taken too seriously, and we still do not know much about high-altitude foraging by bats in Europe. Investigation of this subject requires exclusive and sophisticated equipment such as vertical radar and heat image cameras. Nevertheless, the high altitude foraging by bats seems to coincide with the southward migration of birds (Alerstam 1990) and insects (Taylor 1974) both in space (100-1200 m altitude) and time (August and September). This also coincides with the activity of bats at wind turbines and the associated risk of being killed. Modern wind turbines have become so tall (> 100 m) that the tower and the rotor blades may reach the lower part of the atmospheric boundary layer, and thereby may be expected to get in contact with nocturnally migrating insects. As we have seen earlier (4.2), the risk for bats increases dramatically as the turbines become higher and higher (fig. 4.1 and Barclay et al. 2007), which is consistent with this hypothesis. “Clouds” of insects have been observed around wind turbines while bats have been studied there (Ahlén 2002, Horn et al. 2008), which suggests that insects are attracted to (or stop at) the wind turbines under certain conditions. The same thing apparently happen at marine wind turbines (in the Baltic Sea), which implies that the concentrations of insects sometimes seen at wind turbines consist at least in part of migrating or drifting insects (Ahlén et al. 2007, 2009).

Hence, it seems quite possible that the large-scale movements of insects in the atmosphere at night may help explain why some bats feed at high altitudes in late summer. Hence, the high-altitude occurrence of insects may also be responsible for at least some dead bats found at wind turbines (Rydell et al. 2010b). However, we must remember that the ideas presented here are no more than speculative and yet largely untested. Nevertheless, they seem to find some support in the observations made by Ahlén (2002), Kronwitter (1988) and others.

5.2. Other hypotheses

Several reasons why bats sometimes die at wind turbines have been suggested and several reviews of the hypotheses have been published (Kunz et al. 2007a, Arnett et al. 2008, Cryan & Barclay 2009). Some of the hypotheses have already been discussed in this report, and we have reviewed them in more detail elsewhere (Rydell et al. 2010b). Here we will merely review what we think are the most important hypotheses and the ideas behind them.

North American scientists observed that accident with bats at wind farms usually affected a few migratory bat species and also coincide with the southward migration of these bats. It was therefore assumed that the fatalities at wind turbines may have been a consequence of the migration as such. For example, it was suggested that migrating bats may shut off their sonar system, perhaps to save energy, during flight above the trees, and therefore may have difficulties to detect the turbine rotors in time (Kunz et al. 2007a). This idea may find support in the observation that most bats are killed at wind farms located along the Appalachians or the Rocky Mountains, which may also be used as a flyway by migrating bats. It has also been suggested that the bats navigate along the lines of wind turbines (Cryan & Brown 2007).

This hypothesis has been discussed several times, but we do not find it very likely. Firstly, we know that bats use their vision rather than the echolocation system, when they navigate over longer distances (more than a few meters; Eklöf 2003), and therefore, a wind turbine would probably be detected at the same distance regardless of whether the echolocation is on or off. Secondly, observations of bats that migrate over the sea suggests that they always echolocate even where no obstacles occur (Ahlén et al. 2009). Thirdly, observations from Europe show that accidents at wind turbines are equally frequent in east-west running mountain chains, which are not followed by migrating bats, as they are in the north-south running mountains of North America (Behr & Helversen 2006, Brinkmann et al. 2006). Fourthly, in parts of Europe the most frequent victims at wind turbines are non-migratory bat species, such as the common pipistrelle in the German mountains (Behr & Helversen 2006, Brinkmann et al. 2006) and the northern bat in Sweden (Ahlén 2002). Hence, although the fatalities of bats at wind turbines usually coincide with the migration in space and time, there does not seem to be any direct connection between the two phenomena (Rydell et al. 2010b).

North American scientists also recorded that bat species that normally roost in trees are more vulnerably at wind facilities composed to those that typically roost in buildings (Kunz et al. 2007a, Cryan 2008). One hypothesis therefore assumes that the bats collide by the rotors while they look for roosts in the turbine tower or tall trees nearby (Kunz et al. 2007a). This idea may be supported by observations of bats that "investigate" the turbines at close distance (Horn 2008a). However, Ahlén et al. (2009) observed a similar behavior of bats at wind turbines in Sweden and suggested that the bats gleaned insects from the surface of the nacelle. Hence, the roost hypothesis seems to be contradicted by observations form Europe, where migratory bats may not be as closely dependent on trees as they are in North America. The parti-colored bat, for example, is a long-distance migrant, sometimes killed at wind power facilities (Dürr 2009). This species almost never roost in trees, but rather in cliffs and high buildings (Baagøe 2001).

Cryan (2008) suggested a variant of the roosting hypothesis, namely that high trees or wind turbines may be defended by males during the mating season, which to some extent coincides with the late summer migration. Mating stations in tress certainly occur in several bat species, including the common noctule (Sluiter & Heerdt 1966) and the pygmy pipistrelle (Lundberg & Gerell 1986) in Europe, but it seems unclear if this also applies to the North American species of *Lasiurus*, the species most frequently killed at wind turbines. These species are rather believed to mate in the air like swifts (Barbour & Davis 1967). We have been unable to find any evidence that corroborates the hypothesis that wind turbines are used as mating stations by bats, although this may sound quite likely (Rydell et al. 2010b).

Another factor that may contribute to the observed altitudinal movements of insects and bats during calm summer nights and the resulting accumulations above the tree canopy or on the upper part of slopes may be mist that form at lower levels. At the same time the sexual communication of moths through airborne pheromones works poorly on windless night with mist, which usually results in low activity of these insects under such conditions. The bats´ echolocation system does not work in mist either, because the energy in the ultrasound is rapidly absorbed by the aerial water drops so that the mist appears as an acoustical “black wall” to the bat (Pye 1971). Hence, both bats and insects have good reasons to move upwards as the temperature falls and mist is formed. The mist hypothesis alone cannot explain why bats come to wind turbines, however. Mist formation is not confined to August and September, but also occurs in June and July, a period when bat fatalities at wind turbines are comparatively unusual.

6. The effects of wind power in perspective

6.1. Comparison with traffic

How extensive is the mortality of bats caused by wind turbines in relation to that caused by other anthropogenic factors such as traffic? There are a few recent investigations from Poland and the Czech Republic that we can use to illuminate the problem. If they are representative, which may be questionable, the results of these studies suggest that traffic kills many more bats than the wind turbines.

Along the intensively used motorway between Warszawa and Bialystok in Poland, on average 1.5 bats (0.3-6.8) are killed annually per kilometer by the traffic (Lesinski 2007). The fatality rate is much higher in some specific places, however. For example, along a 1 km section near Warszawa, where the road passes near a mating and hibernation site for Natterer´s bats, an average of 26 bats are killed annually. At this locality the bats are forced to cross the road regularly in order to reach the roosting site (Lesinski 2008). Along an 8 km section of the Brno-Vienna motorway in southern Czech Republic the fatality rate was even higher. On average 15 bats were killed annually per kilometer (Gaisler et al 2009). Again most bats were killed where the road divided water bodies, forest edges and other linear landscape elements and where the bats thus had to cross the road on their way between roosts and feeding sites.

As was the case at wind turbines, traffic accidents involving bats also show an increase during August and September, but the explanation to the seasonality is different. Bats killed by traffic are mostly young and inexperienced individuals that may just have started to fly, and not the reproducing adults. Although traffic may kill any bat species, those that are most vulnerable at wind turbines seem to be those least affected by traffic, probably because they fly relatively high. Instead the species that normally fly lower, such as the long-eared bats, Daubenton´s bat and Natterer´s bat, seem to be the ones that most frequently collide with cars and other traffic (Kiefer et al. 1995, Haensel & Rackow 1996).

The surveys cited above are rather preliminary. For example, carcasses were searched for only on the road and the immediate roadside, so bats that had been thrown further away from the road or that had moved by themselves were presumably missed. Furthermore, the time intervals between the searches were sometimes as much as a week. This means that many carcasses may have been eaten or removed by scavengers between the searches and, therefore, the numbers than can be cited here are probably much lower than the real number of bats that actually were killed (Slater 2002). We have not found any figures showing how many bats are killed by other vehicles such as trains and aircraft, but we can be almost certain that such accidents occur (Aas & Kooij 2007).

To sum up, information from two intensively used motorways in central Europe suggest that one kilometer of these roads kill bats to an extent similar to a wind turbine located where there is an elevated risk that bats will be killed. However, it should be noticed that the information cited here is limited to studies in the vicinity of big cities, and there is no evidence that these motorways are representative for the rest of Europe, and particularly not for the comparatively calm motorways in Sweden. We are not aware of any information that may suggest how many bats may be killed by traffic in this country. Furthermore, wind turbines and traffic are not strictly comparable, because the accidents tend to hit differently with respect to species and age classes of bats.

7. Effects of wind farming on bats at the population level

7.1. A simple population model

An important part of this project is to evaluate if current and future wind farming are likely to affect bat populations in Sweden at the national level. To do this with reasonable accuracy, we have developed and analyzed a simple population model. We start by a stable population which is unaffected by mortality from wind turbines. We assume that the size of this population in the year t is N_t, that reproduction occurs once annually and that young born in the year t will reproduce for the first time when they are one year old, which means in the year t+1. We also assume that the annual survival is age dependent, so that s_{ad} and s_{juv} represent the survival rates of fully grown (adult) and young (juvenile) individuals, respectively. Fecundity, the number of young born per adult female per year x ½ (half of the young are males, which do not count in this case) is $b_{0.}$ We assume that the fecundity is density dependent, which means that it declines with increasing population size. Finally, there is mortality due to wind power facilities $h\ N_w$, which depends on the annual mortality at each wind turbine N_w and the number of turbines h.

Hence the population model can be written

$$N_{t+1} = s_{ad} N_t + s_{juv} (b_o - \beta N_t)\, N_t - h\ N_w$$

where β represents the density dependence of the fecundity. If we assume that the population is stable (year 2000) and fit numbers to population size, survival and fecundity (see text below and table 7.1) into the equation, the parameter β becomes 1.13 x 10^{-7} for the common noctule and 1.13 x 10^{-6} for Nathusius´ pipistrelle. These values are then used in the model to calculate the population trends for the two species, as shown in fig 7.1 and 7.2.

Unfortunately, there are no estimates from Sweden on how many bats are killed at wind power facilities, so we are forced to use figures from Germany. To introduce numbers in the model, we primarily use information about the common noctule, which is the species that we believe is most vulnerable at wind turbines in northern Europe. Demographic data for this species are available from Sachsen in eastern Germany (Heise 1989, Heise & Blohm 2003), and from the same area there is also reliable information on how many bats are killed at wind turbines (Seiche 2008). The common noctule is a long-distance migrant which is more or less common in agricultural areas throughout northern Europe north to Dalälven in central Sweden (61°N) and a little further north (62°N) along the Baltic coast. However, noctules tend to avoid larger areas with boreal (coniferous) forest particularly at higher elevations, and occurrences outside coastal and agricultural areas in Sweden are relatively sparse (Ahlén 2006).

Estimates of the effect of a particular kind of mortality on bat populations have not been made previously, as far as we know, presumably because reliable estimates of population sizes are largely missing. This certainly applies to Sweden. Nevertheless Sohlman (2008) provides a figure of 65 00-110 000 individuals as the current size of the population of common noctules in Sweden. In our model we used the middle value 90 000 individuals. We do not know how this figure was obtained and we cannot evaluate its reliability. The annual survival rates s_{ad} and s_{juv} are 0.56 and 0.54, respectively, and the fecundity b_0 is 1.65 x 1/2 per adult female (Heise 1989; again the fecundity is multiplied by ½ because only females count, the males do not give birth to any young).

The population trend has been calculated based on three scenarios (fig 7.1)

1. no mortality caused by wind power facilities
2. freezing of wind power at the current level, which means 1000 turbines within the range of the common noctule in Sweden
3. a five-fold increase in the number of turbines within the range of the common noctule in Sweden until the year 2020 and then freezing. We have assumed that half of the new turbines will be established in upland forest areas, and therefore will not affect the common noctule

The annual fatality rate of bats at wind turbines in eastern Germany is 2.3 individuals per turbine, of which 0.9 individuals (39%) are common noctules (Seiche 2008, Dürr 2009). This fatality rate means that 1% of the Swedish population of the common noctule would die each year if we had 1000 turbines, which is roughly what we have today (in the year 2010; provided we exclude about 100 turbines located in areas without common noctules; http://www.energimyndigheten.se). With this level of mortality the population of common noctules will decline by about 1% per year until the year 2010 and then at a higher rate as the establishment of wind facilities continues (fig. 7.1).

Considering the uncertainties in our assumptions the calculations must be used with great care. For example, we have assumed that the sex ratio is equal, but this is essentially without any supportive evidence, and also that the mortality at wind turbines is the same regardless of sex and age. This is not necessarily the case. In at least some populations of common noctules, the females migrate considerably further to the north than the males during the summer (Sluiter & Heerdt 1966). We have also assumed that the mortality of bats in general and of the common noctule in particular is the same in Sweden as in eastern Germany. This assumption may perhaps be justified with regard to the agricultural regions of southern Sweden and along the southern coast lines. We know from the study of Ahlén (2002) that the fatality rate of bats in these areas is roughly comparable to that in Germany (Endl et al. 2004, Kusenbach 2004, Seiche 2008). On the contrary the assumption may be questionable with regard to the boreal forests in Sweden, where the common noctule is relatively rare (Ahlén 2006). This means that the population decline, as calculated in the model, probably is too rapid in relation to the actual population size. In this case the effect of wind power establishment will thus be less than suggested by the model. How much less it will be depends on how many bats will be killed at future wind farms in forested areas (we will return to this issue in part 8.3).

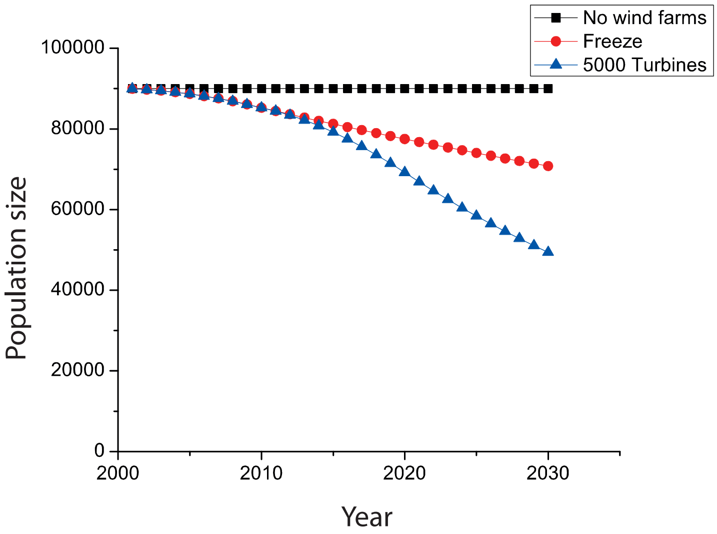

Figure 7.1. Estimated population trend for the common noctule Nyctalus noctula in Sweden under three scenarios; black – no mortality caused by wind power, red – freezing of the wind power at the current level (1000 turbines), blue – a five-fold increase until the year 2020 followed by freezing. The trend shown by the blue line hinges on the assumption that the mortality at wind turbines is the same as in Germany and that it remains at this level (0.9 individuals per turbine and year; see table 7). Hopefully, the guidelines presented in this report will result in considerably lower mortality of noctule bats in Sweden.

It should also be mentioned that a five-fold increase in wind farming in southern Sweden within the near future, as we have assumed, is probably quite unrealistic. Hence there are several reasons why the blue line in fig. 7.1 should be considered a worst possible scenario for the common noctule. Nevertheless, even we view our calculations with considerable caution, they still show that future wind farming in Sweden could have a negative effect on the population of the common noctule at the national level.

Like the common noctule, Nathusius´ pipistrelle is a long-distance migrant. It passes through the eastern part of Sweden in spring and autumn but also breeds within the country. The species has increased in numbers over the last decade in Sweden and it is now rather common in certain areas along the east coast particularly during the migration periods (Ahlén 2011). Sohlman (2008) provides an estimate of the population size of Nathusius´ pipistrelle (table 6.1), but it remains unclear if this estimate includes individuals that pass through the country without reproducing. There are reliable estimates of the fatality rate of this species at wind turbines from Sachsen in eastern Germany (Seiche 2008, Dürr 2009; table 6.1). An investigation from nearby areas in Brandenburg suggests annual survival rates s_{ad} and s_{juv} of 0.71 and 0.56, respectively, for this species, and a fecundity b_0 of 1.8 x 1/2 per adult female per year (Schmidt 1984, 2000).

Table 7.1. Estimated population sizes (number of individuals) of Swedish bats that normally forage in the open air space (Sohlman 2008) and fatality rate (number of dead bats per turbine and year) of these species as observed at wind turbines in eastern Germany (Seiche 2008, Dürr 2009).

Species	Population size (Sweden)	Fatality rate at wind turbines (Germany)	Notes
Common noctule	65-115 x 10^3	0.9	
Nathusius´ pipistrelle	2.5-6.0 x 10^3	0.7	Hard to define the population
Pipistrelle	1.8-3.0 x 10^6	0.4	Two species!
Parti-colored bat	600-1500	0.1	Unrealistic population estimate
Northern bat	3.5-6.3 x 10^6	<0.1	
Other species		0.2	

Comments; ”Pipistrelle” include two species that has been separated only recently (Ahlén & Baagøe 2001); the pygmy pipistrelle Pipistrellus pygmaeus which is abundant in Sweden but uncommon in Germany and common pipistrelle P. pipistrellus, which is rare in Sweden but common in Germany. The numbers given in the table represent the two species combined, because they have usually not been distinguished in the past. Nathusius´ pipistrelle is a long-distance migrant and it is unclear if the given population estimate includes only breeding individuals or also those that pass during migration.

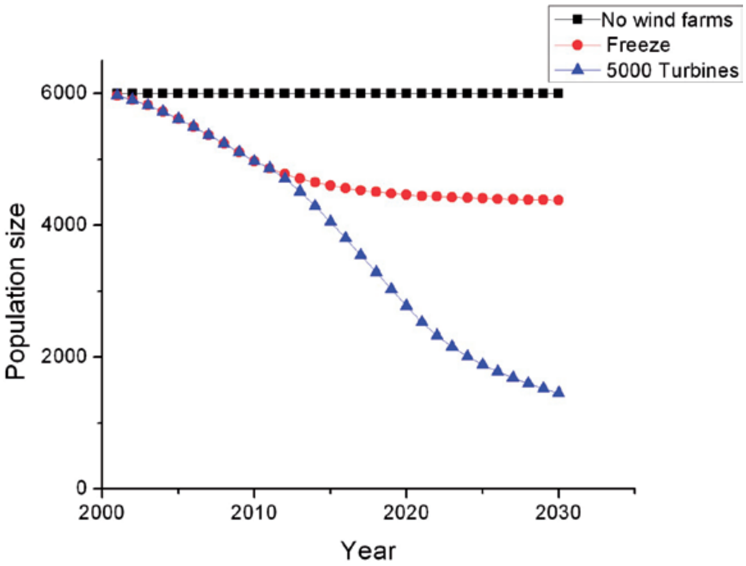

Figure 7.2. Estimated population trends for the Nathusius´ pipistrelle Pipistrellus nathusii in Sweden under three scenarios; black – no mortality caused by wind power, red – freezing of the wind power at the current level (1000 turbines), blue – a five-fold increase until the year 2020 followed by freezing. The trend shown by the blue line is even more unreliable than that shown for the noctule (fig. 7.1). It hinges on the assumption that the mortality at wind turbines is the same as in Germany and that it remains at this level (0.7 individuals per turbine and year; see table 7.1). Hopefully, the guidelines presented in this report will result in considerably lower mortality of Nathusius ´ pipistrelle in Sweden. Furthermore, we have assumed that the population would have been stable if there was no mortality caused by wind turbines (black lines). In reality, this is unlikely because the species is increasing rapidly in Scandinavia at present, which means that an increased mortality at wind turbines will result in a slower rate of increase rather than a decline.

Since Nathusius´ pipistrelle is uncommon or rare in western Sweden, we have assumed that wind turbines in this part of country will not affect the species. Therefore, in the calculations we have used half the number of wind turbines as compared to the common noctule (which occurs both in the western and eastern halves of the country; Ahlén 2011). Using otherwise the same assumptions as for the common noctule, the Nathusius´ pipistrelle will, if the current wind turbine capacity is retained, decline by 17%, and then even faster following the continued establishment of wind farms. However, we should remember that the population estimate for this species is a good guess at best and also that an unknown part of the population consists of non-reproducing individuals that only pass the country during migration.

So far we have assumed that the populations had been stable if there were no mortality caused by wind turbines. This situation is shown by the black lines in fig. 7.1 and 7.2. This is obviously unrealistic particularly with respect to Nathusius´ pipistrelle, which is known to increase rapidly in distribution and abundance in Sweden at present (Ahlén 2011). This means that increased mortality at wind farms probably will not have the have the drastic effect shown in fig. 7.2, but rather result in a slower rate of increase. The reason why we have not included the population increase of this species in the model is that we have no idea of the rate of the increase. Providing a guess on how fast the species increases would be meaningless and would complicate the interpretation of the result even further.

The pipsitrelles too (composed of two species; table 7.1) show a relatively high fatality rate at wind turbines particularly at certain sites in Germany (0.4 individuals per year; Seiche 2008). This species is still probably less affected, compared to the common noctule and Nathisius´ pipistrelle, because the population is much larger. The annual survival rates s_{ad} and s_{juv} are also a little higher; data from York in northern England suggest 0.76 respectively 0.50, respectively (Thompson 1987). An increase in wind farming capacity will therefore most likely have a smaller effect on this species (or the two real species taken together), compared to the common noctule and Nathusius´ pipistrelle.

It seems clear that the common noctule and Nathusius´ pipistrelle are the bats likely to be most affected by wind turbine mortality in Germany and probably in Sweden as well, but there are also some other species that we suspect may be affected by large-scale wind farming in Sweden. The northern bat occurs throughout the country and it is common also in the forest regions, where most wind farms are likely to become established in the near future. This species constitutes about one half (8 of 17) of the bats that have been found dead under wind turbines in Sweden so far (Ahlén 2002), but because we do not know how many bats that actually die, we cannot use the model to estimate future effects on the population. Numbers from Germany are of no help in this case, because the species is much less common there than in Sweden. This is also true for the parti-colored bat, a species for which we cannot even provide a reasonable guess about its population size. According to Sohlman (2008) the population may include 600-1500 individuals, but we believe that this figure is far below the real number (table 6.1). To complicate the picture even more, this species is has a patchy distribution in different parts of southern Sweden. How the continued establishment of wind farming will affect the latter two species will largely depend on the risk they will face at wind turbines in boreal forest regions.

In addition, we have a group of less common species for which we have not considered it meaningful to make predictions. This applies to the serotine and Leisler´s bat and also the barbastelle. These species are all more or less rare and have patchy distributions in southern Sweden. Nevertheless, the risk that a particular wind park or turbine located near a colony of these species or near a frequented flyway will have a serious effect on the local populations should not be ignored. Likewise we have not found it meaningful to include bat species that normally spend their time near the ground or close to water, and which therefore are unlikely to be killed by wind turbines (see part 4.3 and table 4.3).

7.2. Conclusions from the model

To summarize, the result of our modeling suggest that there may be a risk that large-scale establishment of wind farming in Sweden will affect populations of bats through increased mortality. The risk is considerably higher for some species than for others, however. The most vulnerable species are those that typically feed in the open air and therefore regularly move through the air space occupied by wind turbine rotors, including, for example, noctules, pipistrelles and parti-colored bats. However, it is not possible to present a detailed and reliable prediction because the assumptions and numbers we have used are very uncertain. We cannot present any estimate on the number of bats that will be killed at wind farms located in forest regions even in rough terms.

8. Measures to minimize the risk to bats

8.1. Pre-construction – Avoid dangerous sites

The most important method to minimize fatalities of bats at wind turbines is to avoid potentially dangerous locations. The reports that we have cited above suggest that the most dangerous locations are along the coasts and probably also along other distinct landscape elements where bats may concentrate, near wetlands and particularly on top of distinct hills and ridges. However, it is not possible to tell how high the hills must be before they count as risky for bats, and is not possible to evaluate if coniferous or broadleaved forests on top affect the risk. This must be investigated in future research and post-construction surveys (see below, part 9.4).

Data clearly show that large numbers of bats move along coastlines and on nearby islands during the late summer migration period (Ahlén 1997, Petersons 2004, Bach et al. 2009, Walter et al. 2004). It is also clear that migrating bats of several species assemble on narrow peninsulas such as Falsterbo in Skåne and Ottenby on Öland before they venture out at sea (Ahlén 1997, Ahlen et al. 2009). Most likely the same thing happens at larger lakes (Dzal et al. 2009). Hence there seems to be strong relationship between these movements and the high fatality rates of bats that have been observed at such places (Dulac 2008).

Data from Oder in northwestern Poland show that migrating bats tend to follow the river (Jarzembowski 2003, Furmankiewicz & Kucharska 2009). However, although it seems likely, we do not know if wind turbines located along rivers are particularly dangerous to bats and result in increased mortality. The same situation probably applies to other major linear landscape elements such as lakes shores and motor ways, for example, which most likely also are used by bats for navigation. At present it is difficult or even impossible to present a reliable safety distance, beyond which wind turbines would be unlikely to interfere seriously with the movement of bats. This is simply because we do not have sufficient knowledge about how bats make use of the landscape. Do they fly in small groups in close contact with rivers and other elements or do they move on a broad front? To obtain basic information on this issue is a good reason to carry out pre- and post-construction surveys as parts of wind farm establishments (sections 9.3 and 9.4).

In open agricultural areas wind turbines should not be built too close to isolated tree lines and other linear landscape elements (Limpens & Kapteyn 1991). Accidents with bats at wind turbines can be expected to be more frequent if the distance between the turbines and the nearest trees line is less than 100-200 m, compared to if it is longer. The shorter distance applies to the relatively small pipistrelles whereas the longer distance refer to the much bigger noctule bats (Endl et al. 2004, Seiche 2008). Two hundred meters may therefore be considered a mimimum distance between a wind turbine and the nearest trees in a predominantly open landscape.

8.2. Post-construction – Mitigation methods

It seems quite likely that the conditions with respect to bats will change as a wind farm is built. Perhaps the tower may make the location more attractive to bats because insects may accumulate at the towers because of their height (Rydell et al. 2010b) or color (Long et al. 2010a). Such effects are very difficult if not impossible to predict in each case. Therefore, pre-construction surveys made as part of EIAs (Environmental Impact Assessments), will probably not be able to predict the occurrence and behavior of bats in a relevant way, as it will appear after the construction. Fortunately, however, there is a possibility to account for this risk by working out a mitigation program. The turbine rotors may be stopped during periods with high risk for collisions with bats.

As we have seen, the great majority of fatalities of bats at wind turbines occur during a restricted time of the year, namely in August and September, always at night and nearly always in particular weather conditions with warm air and slow and usually northern winds. If particular turbines are stopped during such conditions, the risk to bats can be minimized even in cases where the turbine in question has been built in a dangerous location. This means that, even if a thorough inventory is made as part of an EIA, a post-construction survey for dead bats may also be required, one that should evaluate if mitigation at the site in question is needed or not. This may be necessary for wind turbines planned at potentially high-risk sites, such as near linear landscape features or wetlands or on top of hills or ridges. It should also be considered if turbines are planned in areas near occurrences of rare or threatened species, the response of which may be difficult to predict based on a pre-construction survey alone. More than occasional occurrence of dead bats should lead to mitigation during specified conditions. These specifications should be based on the post-construction survey and must be designated before the permission is given. If this requirement is introduced early in the process, the cost of any potential mitigation program and the associated loss of energy production can be included in the calculations right from the start.

The idea to stop energy facilities during periods when animals are particularly vulnerable is not new. The method has long been used in Sweden in hydroelectric plants, in which the turbines sometimes are stopped to facilitate the migration of fish at certain times, as required by some authorities based on the environmental law (Miljöbalken, chapter 11, 8 §). Recently, occasional shut down of wind turbines for the purpose of bat protection has also been applied in some countries including USA (The Beech Ridge Bat Lawsuit; Animal Welfare Institute 2009).

We are aware of three investigations that show that mitigation at wind turbines for the protection of bats really works in practice (Behr & Helversen 2006, Baerwald et al. 2009, Arnett et al. 2009b, 2010a, b). In all three cases the turbines were stopped experimentally during periods with slow wind speeds (< 4-6.5 m/s), at night (roughly between sunset and sunrise, but with slight variation between the studies) during the summer. The fatality rates observed at the mitigated turbines were then compared with those of the turbines run normally. It was clear that the fatality rate decreases drastically (79-90%) at the turbines that were mitigated, and at the same time the energy loss from the mitigation was quite marginal (3-11% over the experimental periods; 0.3-1.0% for the entire year). The turbines were mitigated during periods with slow winds and when they would not have produced much electricity anyway. The lower figures refer to cases where turbines were stopped below 4 m/s and the higher figures refer to 6.5 m/s as the minimum wind speed. For more information about statistics and other details we refer to the original articles, two of which are accessible on the internet (Baerwald et al. 2009, Arnett et al. 2010a).

The turbines were shut off in a rather standardized way in these experiments, but the mitigation nevertheless showed the desired effect. More detailed background information on why and when bats come to wind turbines will presumably permit more sophisticated and efficient mitigation protocols in the future. By including more weather factors or even somehow automatically scanning the activity of bats and insects near the turbines (Lazarevic et al. 2008), it should be possible to make the systems more efficient and reliable, and hence minimize the periods when the turbines will have to be stopped. Furthermore, the Scandinavian summer nights, and hence the activity periods of bats, are much shorter than in the studies cited above and we also have much fewer nights with warm and calm nights. We should therefore be able to reduce the mitigation costs considerably in comparison with the studies cited above.

A wind turbine normally starts to deliver electricity at a wind speed of 4 m/s as measured at nacelle height. This is called the "cut-in-speed", and can be adjusted upwards to 6 m/s, for example. At lower wind speeds the rotor does not move, at least in principle. However, at decreasing wind speeds the rotor may continue to move long after the wind have fell below the cut-in-speed, although without delivering any electricity. It is technically feasible to stop the rotor, however, so that it always remains still at wind speeds below the cut-in-speed, and this cut-in-speed can also be adjusted to a suggested 6 m/s. If wind turbines are run in this mode it seems likely that the risk to bats can be minimized at a relatively low cost.

There have been considerable efforts to deter bats from approaching wind energy facilities by the use of various technical installations. Warning lights do not seem to have any noticeable effect on the bats´ behavior at wind turbines regardless if the lights are red or white (Horn et al. 2008a). Intense ultrasound (Horn et al 2008b) and radar (Ahlén et al. 2007, Nicholls & Racey 2007, 2009) broadcast from the turbine towers do seem to have a repelling effect at least over shorter distances, however, and the effects also seem to be consistent and of long duration. This implies that bats do not get used to the signal or ignore them after a while. An interesting explanation of how this may work with respect to bats has been presented (Nicholls & Racey 2009). Nevertheless, sound and radar must still be considered as possibilities for the future. We are not aware of any utility scale tests of these systems (BWEC 2011).

9. The proposal – What should be required?

9.1. The law and international agreements

In Sweden bats are strictly protected through the Species Protection Act (Naturvårdsverket 2009). Primarily this means that they must not be captured or killed but also, as may be more relevant in the present context, that areas used for their reproduction or roosting may not be destroyed, and, likewise, that the bats must not be disturbed during their reproductive period and during migration. Places used for reproduction may include hollow trees, bridges or various kinds of buildings, for example, used by pregnant and lactation females in the summer or by territorial males in late summer and autumn. Some bat species mate in the winter quarters, and in these cases, also cellars and mines may also considered as reproduction sites (Naturvårdsverket 2009, appendices 4 and 5). As we have seen, accidents with bats and wind power facilities often occur during the late summer and autumn migration periods and mostly affect long-distance migratory species. Hence the implication that areas of importance for migratory bats have a certain degree of protection is important, when establishment of wind turbine facilities along the coasts are suggested. According to Appendix II of the EU Habitat Directive, particular protection areas for some species of bats should be established. For Sweden, these are the barbastelle, the pond bat, the greater mouse-ear and Bechstein´s bat. The areas in question may be protected as Nature Reserves or within the Natura 2000 program. We suggest that wind power facilities should not be established in such areas and not within a surrounding buffer zone of 2 km from the boundary of the protected area. At www.eurobats.org there is more information about the agreement, including the full agreement text and the national reports.

The Swedish handling program for protection of bats (Ahlén 2006) is a fairly extensive program, which rests on Artskyddsförordningen, the EU Habitat Directive and the EUROBATS agreement, as cited above. Several parts of this program are now being applied. For example, the potential effects on bats are frequently considered in EIAs during various kinds of exploitations and bat inventories are being made throughout the country in various other contexts as well. These questions have recently become particularly obvious during wind energy establishments, so it is fair to say that the establishment of wind farming may provide a good reason to effectuate at least parts of the EUROBATS agreement. This may perhaps also be true for Europe in general (Rodrigues et al. 2008). Nevertheless, there is still a lot to be desired with respect to research on bats and their environments, as included in the EUROBATS agreement. The need for this kind of research has become very apparent through the questions raised in response to the recent increase in wind farming. We will return to this problem (part 10).

9.2. A model for handling of proposals

Ahlén (2010a) suggested a simplifying model that can be used for the evaluation of an area´s potential importance to bats before the establishment of a wind power facility. As suggested by this model, the first step may be a rapid evaluation of the area with respect to the potential risk to bats, and at the same time the greatest efforts can be concentrated to the potentially most important or sensitive areas. Hence, each area proposed for wind power establishments is first placed in one of three different categories with respect to the evaluated risk to bats (Ahlén 2008, 2010a):

1. **High-risk locations** where there is an obvious risk that bats will be negatively affected. Examples of such locations may be on narrow peninsulas at the coast or any of the larger lakes or on top of topographically distinct hills in open farmland areas or where important concentrations of bats are known to occur regularly.
2. **Locations uncertain** with respect to the risk for bats and where no qualified evaluation can be made based on present knowledge. In these cases a more careful evaluation, usually including a field survey (EIA) and sometimes also a post-construction survey, may be necessary. This category will most likely include most application for wind farm establishments in inland forested areas or near the coast and perhaps also proposals for wind farms offshore.
3. **Low-risk** locations where it can be safely assumed that the risk for bats will be negligible. Examples of such locations include open agricultural areas without any linear landscape elements or distinct topographical features and also most of the higher and medium elevation alpine areas in the north.

According to this model it is only locations initially placed in category 2 that will require extended field surveys and detailed evaluations (fig. 8.1). The handling process, including the application and permission procedures, should hence be faster as the information base improves. To begin with, it is likely that most application will go into category 2, but with time, this category will presumable become smaller. Perhaps this model will prove too categorical, but we nevertheless believe that it may contribute to a faster and simpler handling process. Finally, we like to stress that it is extremely important that decision makers have access to the relevant competence in order to make the right decisions. The handling process should rest on a scientific basis so that and that arbitrary decisions can be avoided in the future.

9.3. The pre-construction survey

An EIA should include a professional evaluation of the potential importance of the actual area for bats and what consequences may be expected following exploitation according to the proposal. This evaluation may then be used by the authority to make the decision. In principle, there are two different ways that a wind farm establishment may affect bats

a. Indirectly as the habitat for bats are altered or destroyed as a cause of the exploitation (1 and 2 below). This is of potential concern for all species of bats although some may be more vulnerable than others (part 8.4).
b. Directly as bats are killed during collisions with turbine rotors or because of rapid air pressure changes (3 below). This is most applicable to the high-risk species, those that routinely fly at the altitudes occupied by wind turbine rotors, as defined previously (table 3.3). The potential risk for other species of bats is relatively small.

Hence, an inventory of bats as part of an EIA should include the following information, condensed into three parts.

1. **A professional evaluation of the potential importance of the area as habitat for bats** should be provided. The evaluation may be based on maps and other pieces of available information and in some cases also a brief daytime survey. It should include the potential to house many or rare species, including the high-risk species that are particularly vulnerable at wind farm sites, such as common noctules, particolored bats and Nathusius´ pipistrelles. An indication that a particular area may harbor many species may be, for example, presence of key habitat (Jong & Ahlén 1991) or an otherwise variable environment, perhaps including a mixture of open water, various old buildings and broad-leaved woodlands or hedgerows. Some particular sites which are or have been heavily affected by human activities, such as old mills and churches for example, may nevertheless form rich bat habitats, provided that the human influence is small scale and varied. In contrast, areas that normally have very low potential as bat habitats include open agricultural landscapes without any obvious landscape elements, and production forests with or without extensive clear-cut areas. The primary objective with this part of the inventory is to make sure that potentially important bat habitats are not destroyed by the wind farm establishment.
2. **A relatively thorough field inventory** of selected parts of the area or the entire area when small, using ultrasound detectors at night, may show which species of bats occur at the site during the maternity period in June-July. Regular observations of a species within a restricted area may indicate the presence of a maternity colony in the vicinity, but to find such colonies may often require more work than expected during an EIA-inventory. Occasional observations of a certain species show that the area is used although not necessarily by members of a maternity colony. The purpose of this part of the

inventory is primarily to investigate if the area is used regularly by rare or endangered species, the potential effect on which in that case should be considered further. However, colonies of the commonest and most competitive species, such as the northern bat, the pygmy pipistrelle and Daubenton´s bat, would normally not need any particular attention, except possibly in some northern regions, where bats are generally rare.

3. In places where wind farms are planned along linear landscape elements or on top of hills or other distinct topographical features, the **presence of high-risk bat species in late summer and early autumn**, and perhaps also in early summer, should be investigated. Turbines located in such places have proven to be the most dangerous to bats in other countries. The inventory should be carried out by means of manual (short-term) and automatic (long-term) ultrasound detectors. For several of the high-risk species, late summer and autumn inventories may also include registration of territorial calls or mating calls, which is a relatively simple means to find mating stations. This applies to the *Nyctalus*, *Pipistrellus* and *Vespertilio* species, where the males perform species specific territorial displays, including songs which usually are relatively easy to recognize (Hemmingsen 1922, Sluiter & Heerdt 1966, Ahlén 1981, Lundberg & Gerell 1986, Ahlén & Baagøe 2001).

9.4. The post-construction survey

To follow up, a post-construction survey may be necessary. The purpose of this is to investigate if and how the new wind power facility is used by bats and, if so, if the bats are killed there as well. Dead bats should be counted and collected under the turbines (all or some, depending on the size of the facility) from late July to late September. The counts should be made at intervals of a few days at most, preferably in the early morning before any dead bats have been removed by scavengers, and preferably following mild and calm nights. An area with at least 50 m (or better, with radius = rotor diameter) around each turbine should be searched carefully, and if possible, using a trained dog (Arnett 2006). It is very important that any dead bat is retrieved and frozen for later determination of species, age and sex.

The collection of dead bats under wind turbines should preferably be complemented by measuring the bat activity at one or several turbines during at least a few mild and calm nights. The purpose of this exercise is to evaluate if bats of the high-risk species regularly hunt or otherwise fly near the turbines and therefore are at risk of being killed. In this case, bat activity may be measured by means of automatic bat detectors, which register short sequences of bat echolocation calls that later can be used to identify the species of bat. Ideally, two detectors should be used simultaneously, one of which may be placed as high as possible in the turbine tower.

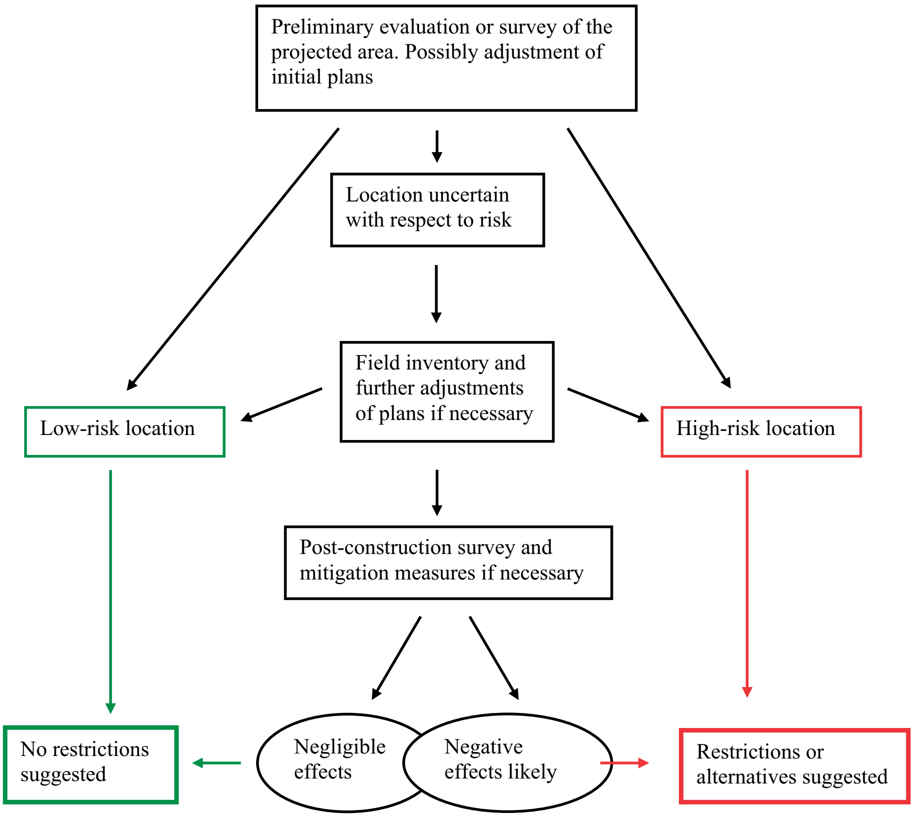

Figure 9.1. Flow chart of a suggested procedure to be followed during the planning process of proposed wind farms. The principal aim is to minimize the negative effects on birds and bats. The idea is from Ahlén 2010a. For further details see text.

Regular activity of bats around the tower and rotor and/or presence of more than an occasional dead bat, calls for a more careful investigation to quantify the fatality rate. The latter should be sufficiently qualified and also long enough (preferably a season) to be used for to decide if the turbine should be mitigated during periods when there is an elevated risk to bats.

With respect to collection of dead bats under wind turbines it is important to use gloves that protect from bites, as is always the case when handling wind mammals. Although bats found on the ground may appear to be dead, they may still be able to bite in self-defense. Antibodies against bat-rabies have recently been found in some Swedish bat populations, which suggest that the disease occurs or have occurred in the country. In rare cases, bat rabies may infect humans in which case it may be fatal (SVA 2010). If bitten, one should get vaccinated (post-exposure prophylaxis).

9.5. Comments

It seems likely that most land-based wind power facilities in Sweden will be located in more or less high elevation coniferous forest areas. Unfortunately, we have almost no information on how this will affect bats, and this applies to southern Sweden as well as to the north. So far the majority of the facilities have been located in agricultural areas or along the coasts. Larger areas of coniferous forests are usually relatively poor with respect to bats and their food (insects), particularly when used for intensive forestry, but, as we have seen, there are examples from Germany and USA showing that wind power facilities in such areas sometimes kill many bats. This gap in our knowledge is potentially quite serious, because it is difficult or impossible to predict what will happen as wind power facilities become established in the forested parts of Sweden. This also means that the value of pre-construction surveys as part of EIAs will be quite limited for the decision process. What happens to bats at wind turbines located in coniferous forests needs to be investigated, and this is particularly important for facilities built on topographically obvious hills or ridges. Are such locations really of high-risk to bats, and if so, why?

It is also important to realize that all bat species are not the same with respect to their vulnerability. While some species are relatively competitive and invasive, others appear to be declining in numbers or distribution. Obviously the least competitive ones are in greater need of concern. That some species of bats seem to be excluded from certain areas by more competitive species is an old idea (Baagøe & Jensen 1973) which has been taken up again recently (Arlettaz et al. 2000). It has become apparent that some unusual species seem to disappear from areas as a response to the introduction of street-lights, and competition for feeding sites may well be a possible explanation for this. Street-lamps attract insects from surrounding habitats and make them accessible to some light-tolerant species. It seems possible that wind turbines could have similar effects although there is no evidence at present that this is actually the case.

Particularly competitive species among the high-risk group include the northern bat (Rydell 1992a, 2005), the pygmy and the common pipistrelles (Haffner & Stutz 1986/87) and perhaps also the serotine (Baagøe 1986). Among other species, Daubenton´s bat also seems to be highly competitive and expanding (Kokurewicz 1994).

9.6. Report accessibility

It is very important that the results of inventories and EIAs are made generally accessible as soon as possible. Report accessibility is a prerequisite for an open discussion on the subject. Such discussions may be necessary if we want to learn from mistakes and hence increase the precision and speed of the application and handling process. Report accessibility may also be necessary if we want to learn how to deal with proposals of wind farm establishment in uncertain locations such as the boreal forest. We also need to arrive at a suggested safety distance that can be applied in situation other than open agricultural areas. This almost certainly would require several pre- and post-constructive surveys and associated evaluations. We therefore suggest that all surveys involving bats at wind energy facilities are published in journals or otherwise made accessible on the Internet as soon as possible. A suitable site for this would be, for example, the home page of the deciding authority.

10. Missing information – Suggested research

10.1. Effects of wind farming in ”new” environments

The conclusions reached during this work depend on the results of surveys and research representative of relatively few countries and environments. Some of the North American information represent habitats which have little relevance for northern Europe, such as the Appalachian Mountains and high altitude prairie in northwestern USA. Nevertheless, we believe that generalizations can be made at least to some extent. For instance, we should expect that the fatality rate of bats will be high at wind turbines located near the coastline or on top of forested hills. At the same time, we can also expect low rates of mortality at turbines in open agricultural areas away from the coast.

On the other hand, we have almost no way to predict how bats will react to wind turbines in “new” habitats, locations from which little or no information about the risk to bats exist. The most immediate examples include the boreal and hemi-boreal (coniferous) forests, habitats where the effect of wind power establishment on bats have not been investigated in any country and where most wind facilities in Sweden are likely to be built within the near future. To facilitate the safe establishments in these areas, it is important that we make the required surveys as soon as possible. We should measure the fatality rate at wind farms in coniferous forests throughout the country and record its variation according to topography and occurrence of linear landscape elements in the vicinity of the facilities. As we have said already, such post-construction surveys should preferably be part of the planning and permission process and thus included from the start. It is also important that the results of the surveys are made generally accessible.

The same conditions may apply to wind power facilities located near rivers and lakes. We know that bats often follow shorelines during their large-scale movements (Limpens & Kapteyn 1991, Furmankiewicz & Kucarska 2009) but we are not aware of any information on fatality rates in such places. In this context we also need to decide on a practically useful safety distance between wind turbines and shorelines. It may be expected that elevated areas near the coast or near any of the larger lakes may be high-risk locations with respect to bats, but, again, there is no information indicating whether this is really the case. Considering that the relevant information is all but missing, applications for establishments of wind turbines in such places should include pre- and post-construction surveys as well as a careful evaluation of the potential risk to bats.

What have said above may to some extent also apply to off shore wind turbines. We know that bats more or less regularly make use of wind turbines located as far 10 km away from the shore (Ahlén et al. 2007, 2009) but we have no idea whatsoever how many bats are killed in such places. As in the cases with the boreal forest and the rivers, it would also be desirable to survey the marine facilities, but this would probably be difficult for logistic reasons.

10.2. Mitigation strategies

We need to develop efficient strategies that can be used for mitigation of wind turbines during periods when there is an elevated risk that bats will be killed. Such strategies would include the conditions that should apply before mitigation is executed and should be applicable to wind turbines located in high-risk areas or in places where the potential risk to bats could not be evaluated beforehand. Inclusion of detailed information on the time of year and day, and, in particular, the weather conditions prevailing when bats are attracted to the turbines, will be necessary.

Until now, only the effect of wind speed has been evaluated (Behr & Helversen 2006, Baerwald et al. 2009, Arnett et al. 2009a, 2010b), but it seems very likely that other factors also may be important. If the accidents with bats is somehow linked to accumulation of migrating insects at the turbines, as we have discussed earlier (Rydell et al. 2010b), the mitigation strategies should perhaps also consider what we may know about movements and behavior of insects. Preferably, the development of such mitigation strategies should be part of a research project with the more general aim of increasing our understanding of what actually happens when insects and bats accumulate at wind turbines.

10.3. Potential importance of color and construction of wind turbines

As we have seen (part 3.3), wind turbines become more dangerous to bats the taller they are. There is also an additional effect of the length of the rotor blades, where longer rotor blades sweep over a larger area and therefore kill more bats. There are also other possible ways that the construction of the turbine may affect how dangerous they are to bats. For example, the number of insects that accumulate in the low pressure area behind the nacelle house could depend on its form. However, we are not aware of any attempts to investigate this or other construction differences with respect to how bats are affected.

Wind turbines in Sweden should in principle be painted in one of three grey-white colors (Transportstyrelsen 2010; TSFS 2010:155). Since wind turbines are of potential danger to aircraft, they must have a contrasting coloration which is visible from the air both in daytime and at night. At the same time, the turbines should not be considered more obvious landscape features than necessary. On the other hand, white or grey-white colors have the less desired effect of attracting insects particularly at night (Long et al. 2010a). Therefore, it would probably have been better, seen from a bat-insect conservation perspective, if turbines were painted red or purple instead of white. The eyes of insects and bats are less sensitive to these colors, so red turbines would be expected to attract fewer of these animals than white ones.

The color of wind turbines may perhaps affect the reaction of bats and insects, but this has not been investigated so far. The same applies to the construction of the nacelle house and the tower, and, in any case, it may be important to investigate this. With respect to the color that may be used on wind turbines, the Transport Authority must consider arguments relevant to conservation provided such arguments are presented.

10.4. Population dynamics and migration routes

It may already have become apparent that our knowledge about population biology of bats is insufficient at best. Much has to be done if we want to make realistic population models that can be used for various purposes. In particular this is necessary if we want to predict the effect of changes in land use, for example, that may lead to higher mortality or lower fecundity. Bats are generally long-lived animals, but at the same time, their reproductive success is highly dependent on the weather and therefore varies strongly from year to year. Hence, research aimed to illuminate the population dynamics of bats must necessarily continue for several years. Such projects easily become relatively expensive and less attractive compared to other kinds of research, where the results may appear faster.

Our knowledge about population sizes of Swedish bats is also very poor. The estimates that we have used in this report (Sohlman 2008) are very unreliable, and in practice no more than educated guesses, which means that the figures we have presented are equally unreliable. In this field innovations as well as hard work are badly needed.

Reliable evaluations of the potential environmental impact of particular wind energy facilities depend on our knowledge of where sensitive bats occur and their movements. Of particular importance are their migration routes. So far, we know from several studies in southern Sweden that migrating bats of several species fly along the coasts and become concentrated at sites, notably certain peninsulas, from which they head out over the sea (Ahlén 1997, Ahlén et al. 2007, 2009). In this field too, we badly need innovations if the problem is to be investigated further in an efficient and novel way. Hedenström (2009) has presented a theoretical approach to migration in bats, which may be used as a start in any basic research project in this field.

11. Literature – bats and wind power

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The effect of wind power on birds and bats

A synthesis

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This report is a translation of the previous report in Swedish: ”Vindkraftens effekter på fåglar och fladdermöss”. (Naturvårdsverket report no 6467).

It has been known for some time that wind turbines can be a danger to birds and bats. Until now, the extent of the risks have been less known. This report summarizes the research from Europe and the U.S. that so far have been done in the field. The main conclusion is that if wind turbines are placed correctly, with proper knowledge of bird and bat behavior, risks will be minimized. The report contains knowledge that office at the county administrative boards and municipalities, policy makers and planners need to make informed judgments for the sustainable expansion of wind power on land and at sea. The report cites what is important to consider before licensing, areas that should be avoided, and species that are particularly vulnerable.

Vindval is a programme that collects knowledge on the environmental impact of wind power on the environment, the social landscape and people's perception of it. It is aiming to facilitate the development of wind power in Sweden by improving knowledge used in IEAs and planning- and permission processes. Vindval finances research projects, analyses, syntheses and dissemination activities. The programme has a steering group with representatives for central and regional authorities and the wind power industry.

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