The effects of wind power on birds and bats

– an updated synthesis report 2017

JENS RYDELL, RICHARD OTTVALL, STEFAN PETTERSSON AND MARTIN GREEN

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– an updated synthesis report 2017

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Preface

The Vindval research programme is a collaboration between the Swedish Energy Agency and the Swedish Environmental Protection Agency that aims to develop and communicate science-based facts about the impacts of wind power on humans, nature and the environment.

The programme's first two phases in 2005–2014 produced nearly 30 research papers and four so-called synthesis reports. In the synthesis reports, experts compile and assess overall research results and experiences regarding the effects of wind power, both nationally and internationally, in four areas: human interests, birds and bats, marine life and land mammals. The results have provided the basis for environmental impact assessments and for the planning and permit processes associated with wind power installations.

Vindval's third phase, launched in 2014 and ending in 2018, also includes conveying the experience and new knowledge from the wind farms currently in operation. Results from the programme will also be useful in supervisory and monitoring programmes, as well as guidance for government agencies.

As before, Vindval sets high standards for the scientific review of research applications and research results, as well as for decisions on approving the reports and publishing the results.

This report has been written by Jens Rydell and Richard Ottvall, Biology Department, Lund University, Stefan Pettersson, Enviro Planning, Gothenburg, and Martin Green, Biology Department, Lund University.

This report has been translated from the Swedish original "Vindkraftens effekter på fåglar och fladdermöss – uppdaterad syntesrapport 2017" (report no 6740, 2017) by Jens Rydell.

The authors are responsible for the content, conclusions and recommendations.

Vindval, December 2017

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Summary

1. Since the previous report on the impact from wind power on birds and bats was published in 2011, much new and important information have appeared both internationally and in Sweden. The present report is a summary of the international research in this area in recent years, and also of the Swedish post-construction surveys made until 2015. This report is hence an update of the previous (2011) report.
2. With respect to birds, the results of new research largely confirm the conclusions from the previous report. For bats, however, new results show that wind power is a larger problem than we realized five years ago, but, on the other hand, new mitigation methods have recently been developed and tested, so that the problem can now be handled more efficiently.
3. Wind power facilities are generally a larger problem for bats than for birds. This is because more bats are being killed, and also because the mortality is concentrated to a few species of bats, which therefore may be affected seriously. At the same time, wind power facilities can also be a problem for certain kinds of birds, some of which may be affected negatively at the population level. Common for birds and bats that risk being negatively affected at the population level is that they have low reproductive potential, and therefore may have difficulties compensating for increased mortality.
4. The fatality rate of birds at wind turbines remain at 5–10 birds per turbine and year on average, even after several and more detailed surveys that have been conducted recently. The location of the turbine is often an important determinant of the fatality rate. While most turbines kill few birds, others may kill up to 60 birds per year. So far there is only one study from Sweden that has been executed in sufficient detail to allow estimation of annual fatality rates. This study was conducted at Näsudden on the island of Gotland, a coastal site very rich in birds, and show, as expected, fatality rates much higher than average. Regarding fatality rates of birds and bats at marine wind farms, no new evidence-based knowledge have been presented since the previous report.
5. Bird mortality at wind turbines generally increases with the size of the turbines. However, in relation to installed effect and produced electricity the mortality declines with increased turbine size. As fewer new, large plants replace old, small ones, the total mortality per wind farm can be lowered at the same time as the electricity production increases. This was the case at Näsudden when the old turbines were replaced by new ones. If a similar effect also is achieved for bats has not been investigated.
6. All kinds of birds can be killed at wind turbines. Also, birds are probably killed at all sites where modern wind turbines are being used. Most fatalities are small songbirds. Raptors, gulls and game birds are killed at higher rates than expected based on their population sizes. Relatively few swans,

geese and cranes are killed at wind turbines, probably because these birds show strong avoidance behaviours. Relatively few birds are killed while in flight during migration. Generally, mortality is higher for birds that stay in an area over longer periods such as during breeding, wintering or at stopovers during migration.

7. Estimates of fatality rates for bats at wind turbines presented in 2011 were much too low. New research from Europe and North America suggest that on average a wind turbine kills 10–15 bats per year, in some cases up to 100 or more. We still have no comparable estimates from Sweden, but an ongoing study from a site in Halland suggests that the fatality rate is about 5 bats per turbine and year at that site.
8. Mortality of bats at wind turbines is limited to a few species that move and feed in the open air above the tree-canopies. We call them high-risk species. The consideration of bats at wind turbines should focus on them. The noctule, the parti-colored bat and in the north also the northern bat are those that we believe are in most need of concern, but the soprano-, common and Nathusius' pipistrelles as well as the rarer Leisler's bat and serotine are also high-risk species and thus potentially affected. Remaining species are rarely or never killed at wind turbines.
9. There have been some recent attempts to investigate if the mortality caused by wind turbines has negative population effects on bird species. In USA it was found that present wind farms probably do not affect any national population of songbirds. Similar results were obtained for Canada, but in this case the results applied to all breeding birds. No such broad studies have been made in Europe, but estimates have been made for species considered as particularly vulnerable. In northern Germany, with particularly many wind farms in operation, it is believed that the populations of red kites and common buzzards are already being affected negatively and this may perhaps apply to the white-tailed eagle as well.
10. We still have no estimates of population sizes for bats in Sweden or internationally and therefore we cannot evaluate if and how the increased mortality from wind turbines affects bat populations. However, there are concerns from North America and Europe that serious negative effects on bat populations of certain species already have occurred.
11. Recent results from studies on the impact of wind turbines on habitats, avoidance and disturbance of birds confirm the pattern from the previous report. There is large variation among different species, areas and habitats and general conclusions are difficult to draw. Nevertheless, avoidance behaviour is usually less obvious during the breeding season compared to the rest of the year. During the breeding season avoidance is usually obvious only within a few 100 m, the greatest distances are found among waders. During other parts of the year, it is birds that live in flocks and certain marine birds that show the greatest avoidance distances. Nothing

new has appeared regarding habituation of birds to wind turbines and there is still considerable variation between different studies. There are some recent studies suggesting that the distance and habitat between the turbines affect the degree of avoidance behaviour and disturbance. Marine wind farms are avoided by most marine birds, but some species (cormorants and gulls) are attracted to the turbines, probably because the towers provide resting sites or access to food. Long-term studies of avoidance and disturbance are still lacking.

12. Impact on the habitats, avoidance behaviour and disturbance has not been investigated with respect to bats so far and may generally be less of a problem for bats than for birds. It is nevertheless obvious that drastic physical changes of the habitat will have effects also on bats, one way or another. On the contrary, it is clear that bats are attracted to wind turbines and that they search for them actively, in contrast to birds, which means that the problem usually requires different solutions for the two groups of animals.
13. Measures to minimize negative impact on birds are still mostly focused on avoiding building wind turbines in places that are rich in birds, particularly sites with high numbers of birds during breeding, wintering and stopovers during migration. Areas around specific occurrences and breeding sites of birds belonging to species or groups of species that have turned out to be particularly vulnerable to negative impact from wind turbines should be avoided. One such example is the larger raptors. Maintaining buffer zones, areas within which wind turbines should not be built, is a way to reduce the risks in such cases. In this report we review the current use of protection zones for birds and provide new suggestions for their future application. We discuss how we can achieve new and more scientifically based protection zones, particularly for our eagles. We appreciate that protection zones is a useful way to reduce the risks for some birds, but at the same time we emphasize that that this method cannot eliminate the risks entirely.
14. Although we consider buffer zones as an effective and practically useful way to reduce negative impact on particular birds, we and many other scientists are realising that this method may not always be sufficient for the protection and formation of viable populations of the species in question. To achieve such goals, planning at a larger scale may be necessary, where areas with the lowest risks of negative environmental impacts are designated suitable for e.g. establishment of wind farms. We believe that this would increase the efficiency of the planning and handling processes during wind turbine establishment and also facilitate the protection of both birds and bats, in comparison with current practices. This would also ensure that sufficiently large areas with relatively low risks are maintained for long-term conservation of (bird and bat) populations.

15. Once the turbines are built the available mitigation options are few when it comes to protection of birds. To mitigate by temporary halting the turbines during periods of high risk, as employed for bats, is a less useful method for birds. For birds there is no clear and general relationship between prevailing conditions on one hand, and the mortality risk on the other, which is in sharp contrast to the situation for bats. Although there are some cases from other countries where wind turbines have been halted to protect birds, this method do not seem to be useful in Sweden, as far as we can see. However, there is a promising development of various technical monitoring solutions that aim to keep bird fatalities at a very low level. As far as we know, no such system is yet fully developed and operational, but this is probably only a matter of time. Finally we also have the option of using compensation measures at a different site, a method that may help minimize the total effect on a population. It has barely been used in Sweden so far, but is more common internationally.
16. The most important measure for protection of bats at wind farms is to adjust the operation of turbines according to the occurrence of certain high risk species. This should be done by halting the rotors during periods when bat activity at rotor height is most frequent. Halting the rotors is a feasible method where noctules, parti-colored bats and serotines, and, particularly in the north, northern bats occur. This measure is expected to inhibit 60–90% of the potential fatalities.
17. To evaluate if mitigation at a particular site is feasible and decide how it should be applied locally, activity of the high risk species at rotor height should be measured continuously over longer periods, preferably during three seasons. Alternatively, searches for dead bats can be made, but this is quite complicated and requires more work. In some cases it may be more efficient to use a general mitigation scheme based on general knowledge about potentially dangerous situations, without spending resources and time to investigate bat activity. This option can be worth considering particularly in cases where it is clear already from the start that mitigation will be necessary.
18. How often halting the rotors will be required at a site depends primarily on the weather, and is hard to predict. A rough estimate for southern Sweden suggests that turbines need to be stopped during about 10 nights on average per year. Most likely mitigation will be required less frequently in the north.
19. Post-construction surveys so far made in Sweden have not contributed much new and useful data on how birds and bats are affected by wind farming. Unfortunately, most of them have not been up to expected standards and have not been able to answer even the most basic and relevant questions. A common impression is that it has been more important to do something, no matter why and how, rather than focussing on what has actually been achieved. There are certainly exceptions. A few

programs have been carefully planned and well executed and have contributed with significant and important results that will be well used. This applies to birds and bats alike. There is every reason to reconsider the system of post-construction surveys as used at present in Sweden, so that future programs can contribute with useful information about local conditions and also can be used together with results from other programs to investigate broader patterns. Particularly for bats but sometimes also for birds, well designed programs are needed for efficient mitigation so that the negative impact on the fauna can be minimized.

20. We present guidelines on how surveys should be made and standardized to provide the best possible foundation for decisions and at the same time be cost-effective. Standardization of the methodology is important if the results are to be useful also in a broader context, although this is usually not the primary objective of the surveys. A national standard consisting of common guidelines for how surveys and measures should be employed with respect to methods and equipment is needed.

Sammanfattning

1. Sedan den första syntesrapporten om vindkraftens effekter på fåglar och fladdermöss publicerades 2011 har en hel del ny och viktig kunskap tagits fram både internationellt och i Sverige. Den här rapporten är en sammanställning av internationell forskning under senare år samt av de svenska kontroll- och uppföljningsprogram som genomförts fram till 2015/2016. Rapporten är en uppdatering av den tidigare syntesrapporten.
2. Nya resultat befäster i stort sett slutsatserna från den första syntesrapporten 2011 när det gäller fåglar. När det gäller fladdermöss visar ny kunskap å ena sidan att vindkraften är ett större problem än vad vi trodde för fem år sedan. Å andra sidan har nya metoder för att begränsa skadorna hunnit utvecklas och testas så att vi nu kan hantera problemet bättre.
3. Vindkraft är generellt sett ett större problem för fladdermöss än för fåglar. Detta beror dels på att fler fladdermöss dödas, men också på att dödligheten koncentreras till några få arter som därmed riskerar att påverkas kraftigt. Samtidigt kan vindkraft också innebära problem för, och populationspåverkan på, vissa typer av fåglar. Gemensamt för de fåglar och fladdermöss där det finns risk för negativ påverkan på populationsstorlekar är att de har låg reproduktionspotential, vilket innebär att de kan förväntas få svårt att kompensera för en kraftigt ökad dödlighet.
4. Genomsnittsvärden för antalet dödade fåglar per vindkraftverk och år ligger även efter nya och mer detaljerade undersökningar kvar på mellan fem och tio per kraftverk och år. Vindkraftverkens läge har ofta betydelse för hur många fåglar som dödas. Medan vissa verk dödar mycket få fåglar, kan andra orsaka upp till ca 60 fåglars död per år. Än så länge finns endast en enda svensk studie som genomförts så pass noggrant att det går att beräkna den årliga dödligheten. Denna gjordes vid Näsudden på Gotland, ett mycket fågelrikt område, och visar inte helt oväntat på en dödlighet som ligger klart högre än i medelfallet. Miljön där vindkraftverken står är av betydelse för hur många fåglar som dödas och allra högst dödlighet har funnits i anslutning till våta miljöer, såsom vid Näsudden. Det har inte kommit någon ny faktabaserad kunskap om dödligheten vid marina vindkraftverk, vare sig för fåglar eller för fladdermöss.
5. Fågeldödligheten ökar med verkens storlek, ett resultat som visats internationellt och som stöds av studierna på Näsudden. Sett i förhållande till installerad effekt och producerad mängd el minskar dock dödligheten med ökande verksstorlek. Då det dessutom behövs färre nya, stora verk jämfört med gamla, små verk för att producera samma mängd el kan man minska den totala dödligheten per anläggning samtidigt som elproduktionen ökas. Detta blev fallet vid Näsudden när man bytte ut äldre verk mot nya. Om effekten blir densamma när det gäller fladdermöss har inte undersökts.

6. Alla typer av flygande fåglar kan dödas vid vindkraftverk, inga är immuna. Fågeldödlighet förekommer också vid alla platser där vindkraftverk av de typer vi använder idag finns. Det finns sannolikt inga platser där dödlighet aldrig förekommer. De allra flesta fåglar som dödas av vindkraftverk är vanliga småfåglar. Rovfåglar, måsar, trutar och hönsfåglar dödas i högre omfattning än förväntat i förhållande till populationsstorlekarna. Förhållandevis få svanar, gäss och tranor förolyckas, troligen eftersom dessa grupper uppvisar starka undvikandebeteenden. Relativt få fåglar förolyckas under aktiv flyttningsflykt. Dödligheten är generellt högre för fåglar som vistas i ett område under längre tid såsom under häckning, övervintring eller rastning under flyttningstid.
7. De siffror på dödlighet av fladdermöss vid vindkraftverk som presenterades 2011 var för låga. Nya undersökningar i Europa och Nordamerika har visat att i genomsnitt dödar varje vindkraftverk 10–15 fladdermöss per år. Vi har fortfarande inga jämförbara siffror från Sverige, men preliminära resultat från en vindpark i Halland visar på fem dödsfall per kraftverk och år på den platsen.
8. Dödlighet av fladdermöss vid vindkraftverk är nästan helt begränsad till arter som rör sig och jagar i fria luften över trädtoppshöjd. Dessa arter kallar vi högriskarter. Hänsyn till fladdermöss vid vindkraftverk skall fokuseras till dessa arter. Större brunfladdermus, gråskimlig fladdermus och i norr kanske även nordfladdermus bedömer vi vara i störst behov av hänsyn. Men även dvärg-, syd- och trollpipistrell samt de sällsynta arterna mindre brunfladdermus och sydfladdermus är högriskarter och riskerar därmed att påverkas negativt. De övriga svenska fladdermusarterna dödas sällan eller aldrig vid vindkraftverk.
9. Under senare tid har det gjorts ett antal ansatser till att analysera om dödligheten orsakad av vindkraftverk påverkar populationsstorlekar för fåglar. I Nordamerika fann man att dagens befintliga vindkraftverk sannolikt inte påverkar storleken på något av kontinentens småfågelbestånd. Liknande resultat hittade man specifikt för Kanada, men då för samtliga häckande fågelarter. I Europa har man inte gjort några lika övergripande analyser, men istället specifikt analyserat arter som bedöms vara särskilt utsatta. I norra Tyskland bedöms att redan i dag är dödligheten vid vindkraftverk så hög totalt sett, med väldigt många vindkraftverk i drift, att den påverkar antalet röda glador och ormvråkar negativt. Sannolikt gäller detta även för antalet havsörnar.
10. Det finns fortfarande inga mått på storleken på fladdermuspopulationer, vare sig inom Sverige eller internationellt, och därför kan man inte göra några tillförlitliga beräkningar av hur vindkraftdödligheten påverkar bestånden. Det finns farhågor både från Nordamerika och från Europa om att kraftig negativ påverkan på populationsstorlekarna av ett antal fladdermusarter på grund av vindkraftorsakad dödlighet redan kan ha skett.

11. Sentida resultat om påverkan på livsmiljö, undvikande och störning från vindkraftverk på fåglar visar på samma mönster som vi angav i den förra syntesrapporten. Det är stor variation mellan olika arter, olika områden och olika miljöer. Generella slutsatser är svåra att dra, men allmänt sett förefaller undvikande vara lägre under häckningstid än under övriga delar av året. När undvikande under häckning förekommer rör det sig i regel om avstånd på upp till några 100 m. Vadare uppvisar de största undvikandeavstånden under häckningstid. Under andra delar av året är det fåglar som lever i flockar samt en del marina fåglar som visar de allra största undvikandeavstånden. Inget direkt nytt har framkommit när det gäller om fåglar vänjer sig vid vindkraftverk eller inte. Även på den punkten varierar resultaten mellan olika studier. Några senare undersökningar antyder att avstånd mellan verk samt miljön mellan verk påverkar graden av undvikande och störning. Vid marina parker är det fortsatt så att flertalet marina fåglar visats undvika dessa. Ett mindre antal arter (skarvar och måsfåglar) attraheras till vindparker, sannolikt eftersom dessa erbjuder viloplatser och kanske även förbättrade födosöksmöjligheter. Långtidsstudier av påverkan på livsmiljö, undvikande och störning från vindkraftverk på fåglar saknas i stort.
12. Påverkan på livsmiljö, undvikandebeteende och störningar har inte avhandlats i några studier av fladdermöss så här långt och har sannolikt betydligt mindre betydelse för denna djurgrupp än för fåglar. Samtidigt är det självklart att en rent fysisk förändring av livsmiljön påverkar även fladdermöss på något sätt. Å andra sidan har man visat att fladdermöss attraheras till vindkraftverk och söker upp dem aktivt. Detta är en stor och viktig skillnad jämfört med fåglar och gör att problemet måste hanteras på ett annat sätt.
13. Åtgärder för att minska negativ påverkan på fåglar från vindkraft handlar fortfarande i första hand om att undvika att bygga vindkraftverk på särskilt fågelrika platser, speciellt sådana som används under häckning, övervintring eller rastning under flyttningen. Det handlar också om närområden kring förekomster, häcknings- eller boplatser av arter och grupper av fåglar som visats löpa högre risker för negativ påverkan från vindkraft. Exempel på sådana är större rovfåglar. Så kallade skyddsavstånd, zoner där inga vindkraftverk bör byggas, är ett sätt att minska riskerna i sådana fall. Vi går i denna rapport igenom tidigare föreslagna skyddsavstånd, ger nya förslag på sådana, samt diskuterar på vilket sätt och med vilken faktabakgrund man skulle kunna komma fram till mer vetenskapligt grundade skyddsavstånd, särskilt för våra örnar. Vår utgångspunkt här är att skyddszoner är ett bra sätt att minska risker, men samtidigt ska man vara medveten om att det inte är och aldrig har varit avsikten att skyddszonerna ska eller kan ta bort riskerna helt och hållet.

14. Samtidigt som vi anser att skyddsavstånd är ett verkningsfullt och praktiskt användbart redskap för att minska risker för negativ påverkan på vissa typer av fåglar, lyfter vi och ett ökande antal forskare också frågan om att detta kanske inte är tillräckligt för att bevara eller skapa livskraftiga bestånd av de arter vi vill ha. För att nå sådana mål menar vi att det krävs en mycket mer storskalig planering där man från centralt håll pekar ut de områden där en utbyggnad av exempelvis vindkraft ger så liten negativ miljöpåverkan som möjligt. Vi menar att detta skulle kunna leda till en smidigare hantering av ansökningsärenden för vindkraft, samtidigt som det skulle gagna fågelskyddet, i jämförelse med dagens hantering av ärende för ärende. Ett sådant förfarande innebär samtidigt att tillräckligt stora ytor med en relativt sett riskfri miljö förblir oexploaterade, och relativt sett riskfria för de bestånd vi vill ha. För att kunna genomföra detta krävs att samhället gemensamt sätter upp målnivåer för olika fågel- och fladdermusarter.
15. När verken väl står på plats finns i dagsläget ett mer begränsat antal åtgärder att ta till när det gäller fåglar. Att på samma sätt som för fladdermöss anpassa driften för att minska risker är av allt att döma betydligt svårare för fåglar. Detta beror på att det inte finns lika klara, tydliga och generella kopplingar mellan olika omvärldsfaktorer och fågeldödlighet vid vindkraftverk, som det finns för fladdermöss. Tillfällig avstängning i riskabla situationer har använts på några platser i världen även för fåglar, men är inte direkt användbart i svenska förhållanden såvitt vi kan bedöma. Här finns stora förhoppningar på tekniska lösningar som ska kunna förhindra olyckor, eller i alla fall minska antalet olyckor till en mycket låg nivå. En lovande utveckling sker på detta område, men såvitt vi kan bedöma finns det idag inga färdiga och fullt ut fungerande system som visats kunna utföra det som eftersträvas. Med största sannolikhet är detta dock något som kommer i framtiden, frågan är endast när det kan bli praktiskt möjligt. Till sist har vi även möjligheten att genomföra kompensationsåtgärder på annan plats, för att se till att den totala påverkan blir så låg som möjligt. Detta har så här långt knappt använts alls i Sverige, men är mer vanligt internationellt.
16. Den viktigaste åtgärden för att skydda fladdermöss vid vindkraftverk är att se till att kraftverkens drift anpassas till förekomst av högriskarterna, där sådana förekommer. Detta sker bäst genom att låta vindkraftverken stå stilla under de tider och väderförhållanden då aktivitet av fladdermöss i rotorhöjd är mest frekvent. Tillfällig avstängning under förhållanden med störst risker kan förväntas hindra 60–90% av de olyckor som annars skulle ha inträffat.

17. För bedömning av om tillfällig avstängning är lämplig i en specifik vindpark och hur den skall anpassas lokalt bör man mäta aktivitet av högriskarterna i rotorhöjd under längre sammanhängande perioder, helst under tre säsonger med kraftverken i drift. Alternativt görs eftersök av döda fladdermöss, men detta är dyrare och mer arbetskrävande. Man kan även driva verken med tillfällig avstängning i risksituationer redan från början, utan att först behöva undersöka aktiviteten av fladdermöss i rotorhöjd. Detta kan vara en billigare och snabbare metod i vissa lägen, särskilt där man redan på förhand kan säga att avstängningsrutiner kommer att behövas.
18. Hur ofta tillfällig avstängning kommer att behöva användas på en viss plats beror i första hand på vädret och är därför mycket svårt att förutsäga. En grov och preliminär bedömning för södra Sverige antyder att det kommer att behövas under ett tiotal nätter per år i genomsnitt. Behovet kommer antagligen att vara lägre i norr.
19. Hittills avrapporterade svenska kontroll- och uppföljningsprogram har inte bidragit med särskilt mycket ny och användbar kunskap om hur svensk vindkraft påverkar fåglar och fladdermöss. Tyvärr har huvuddelen inte utförts så att de ens har kunnat besvara de allra enklaste frågorna som ställts. Ett genomgående intryck är att det många gånger har varit viktigare att genomföra något (oavsett vad det är), än vad man faktiskt har genomfört. Några undantag finns givetvis i form av mycket väl utförda program som genererat användbara resultat, för båda djurgrupperna. Det finns stor anledning att se över hela systemet med kontroll- och uppföljningsprogram så att dessa framöver kan bidra med kunskap i första hand kring de lokala förhållandena på den plats de genomförs, men också så att resultaten tillsammans med resultat från flera platser kan användas för att analysera mer generella mönster. Särskilt för fladdermössen, men ibland också för fåglar, behövs även väl genomtänkta kontrollprogram för att anpassa drift och minimera riskerna för negativ påverkan.
20. Vi presenterar riktlinjer för hur inventeringar, kontroll- och uppföljningsprogram bör utföras och standardiseras för att ge bästa möjliga beslutsunderlag och samtidigt vara så kostnadseffektiva som möjligt. Standardisering av metodiken är viktig om resultaten skall kunna användas i ett större perspektiv, även om detta inte är den primära avsikten med kontrollprogram. Det bör tas fram en nationell standard i form av gemensamt beslutade riktlinjer för hur program och åtgärder skall genomföras med avseende på metodik och utrustning.

General introduction

The expansion of the wind power industry has continued at high pace in Sweden since the previous synthesis report on the Impact of wind power on birds and bats (Rydell et al. 2011) was released about five years ago. Today (October 2016), according to Swedish Wind Energy, 3384 wind turbines are operating within the country, including those currently under construction. This means an increase of 1723 wind turbines, more than a doubling, since we wrote the previous synthesis. Considering the installed effect, the increase is even greater, from 2018 MW in May 2011 to 6029 MW in October 2016, or about three times. The estimated annual production of wind energy has increased from 3.5 TWh in 2010 to 16.6 TWh 2016, an almost five-fold increase. Wind power now accounts for more than ten percent of the total net-production of electricity in Sweden (www.energimyndigheten.se). The expansion that has taken place over the last five years has almost entirely occurred on shore, usually in forested areas. Only two percent (74 plants) of the Swedish wind turbines are located off shore. The expansion of wind power in Sweden is expected to continue within the near future and Swedish Wind Energy (autumn 2016) estimates that the most likely scenario is that annual production will reach about 20 TWh by 2020. The politically planned framework aims at 30 TWh wind power, but this should be considered an aid for municipalities, county administrative boards and other authorities, not as an absolute goal (www.energimyndigheten.se).

This report is an update of the first synthesis report on the impact of wind power on birds and bats (Rydell et al. 2011). The purpose of the updated report is to summarize the new findings and the new knowledge that has emerged since 2010, when the literature searches were made for the first report. We have searched widely for both scientifically published and so called "grey literature". In addition to summarizing the current state of knowledge about wind power, birds and bats, we have also specifically compiled results from the Swedish post-construction programs on the impact on birds and bats that we have been able to find.

We use the concept of post-construction program in the broadest sense to include, in principle, all types of studies (except pure research projects) of bird and bat presence before and after a wind farm has been constructed, as well as all studies on mortality of birds and bats at wind power plant in Sweden. This is done without making any distinction of programs imposed on the projectors by the authorities as a condition for decision making under the Environmental Code (Miljöbalken) chapter 26, paragraph 19 about self-control. So called follow-up programs may also be imposed on projectors by the authorities or programs may be conducted on their own initiative by companies, organizations or individuals. As long as some kind of monitoring of how birds or bats are affected by wind power we have included them here. However, we have not included pure research projects, which so far are not carried out in Sweden except for a project on the golden eagle *Aquila* *chrysaetos*. Our purpose is to present results from Sweden or that are applicable to Swedish conditions, and to evaluate the post-construction surveys and other follow-up programs initiated by Swedish authorities. Are these implemented in the way it was intended? Do they fill any function? Last but not least, a final purpose is to present a guide on how future post-construction programs should be designed and implemented to fulfill the purposes they may have. In our review of both literature and programs, we have included everything we have found that addresses the impact on birds and bats from wind power, regardless of the kind of impact.

A. BIRDS

1. Introduction

There are in principle three ways that wind turbines may affect birds (see Rydell et al. 2011 and references therein). Most attention has been and still is focused on the facts that (1) birds may be killed or fatally injured when they are hit by the moving turbine rotors, or, much less frequently, for certain groups of birds, when they fly into the turbine tower. This problem is sometimes referred to as "collisions", but we prefer to use "fatality" or "fatal injury", which we think is a better description of what actually happens. Less attention has been paid to the problem of (2) habitat loss, which may occur because the habitat used by birds is exploited or changed in a way that makes it less attractive for birds, or that the birds avoid the area near the wind turbines, resulting in lower densities locally. Most recently there have been a few studies investigating if the behaviour of birds is the same in areas with wind turbines compared to areas without them. These studies have the general purpose of evaluating if and why birds living in the vicinity of wind turbines may be affected, which may represent indirect habitat loss. Finally, barrier effects (3) may also be considered as another special form of habitat loss, where birds avoid flying near wind turbines and therefore may be excluded from areas used for wind farming, or may be forced to fly long distances around the wind farms, resulting in an increased cost of transport.

1a. State of knowledge 2011

In the previous synthesis report (Rydell et al. 2011, 2012), we concluded that a modern wind turbine on average kills relatively few birds (median 2.3 per turbine per year; mean 7.3 birds per year). Behind these figures there was a large variation and also a bimodal distribution, with most turbines killing very few birds but with a few turbines each killing relatively high numbers. Surveys reported up to 2011 showed a variation in the fatality rate between zero and more than 60 birds per turbine per year at different places. We also concluded that the location of the turbines with respect to the topography and surrounding habitat was critically important for the number of dead birds recorded. The highest mortalities were usually associated with wetlands or other areas near water, including many coastal localities. Elevated places, with high altitudinal differences within limited areas, such as ridges and hill tops, were sometimes also associated with increased risks, while turbines on open fields and in other relatively flat areas usually showed low bird mortality.

Birds of prey, gallinaceous birds, gulls and terns were killed more frequently than expected based on their numbers. Also, birds that breed, rest or overwinter within a particular area were killed more frequently at wind turbines located within this area, compared to those that only pass the area on migration.

The direct loss of habitat for birds connected with construction of wind farms is relatively small in most cases, and the indirect effects are usually more important and interesting. When we reviewed these effects five years ago, we found that the results were far from conclusive. This applied both to changes in the density of birds in response to the turbines as well as their behavioural reaction to the turbines in a longer perspective, i.e. if their evasive reactions diminish over time. In both cases it was hard to find general patterns. Instead the effect seemed to vary considerably depending on the species of bird and from place to place. Studies suggesting that birds tend to avoid wind turbines where about equally frequent compared to those pointing in the opposite direction. Recorded avoidance distances for birds during the breeding season were usually short, within a few hundred meters, but often longer and of more general occurrence for waders than for other birds. More obvious avoidance reactions were found outside the breeding season and then mostly for birds that live in flocks on open farmland and/or in water, such as divers, geese and ducks and waders. For these birds, avoidance reactions were regularly recorded up to several hundred meters from the turbines, and in some cases, particularly for divers at sea, evasive reactions were observed up to 2 km from the turbines.

Migrating sea-birds had generally been shown to avoid flying near wind turbines both during the day and night. In daytime obvious changes in the flight direction had been recorded 1–2 km (occasionally 5 km) from wind turbines, but at night the reaction distances were shortened to 0.5 to 1 km. Avoidance of the area near the turbines may result in "barrier effects" and thereby extended flights past the turbines. Such effects were usually small in the few cases where they have been measured and in most cases probably of little importance. More importantly and quite positively, the avoidance behaviour shown by the marine birds means that the accidents are very few in such cases. Similar avoidance behaviour was also found in other birds and in other contexts on shore. Not surprisingly, a lack of a strong avoidance reaction was most prevalent among those birds that are killed at wind turbines more frequently than expected.

2. Methods

Following the publication of our first report in 2011 (Rydell et al. 2011, 2012) many investigations and surveys on the effects of wind turbines on birds have been carried out, and in many cases the studies have been published as reports or scientific papers. To find these reports and publications we used the same methods this time as we did in 2011, which means that Web of Knowledge (BIOSIS; http://apps. Isiknowledge.com/biosis) and Google Scholar (www.scholar.google.com) were used as search engines to find appropriate scientific articles. The searches were restricted to include publications from 2010 onwards. For free searches on the Internet we used Dogpile meta-search (www.dogpile.com).

The following search-terms were used to find literature on birds and wind power:

- 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*
- bird* AND wind AND park*
- raptor* AND wind*
- wader* AND wind*
- duck* AND wind*
- swan* AND wind*
- geese AND wind*
- goose AND wind*

When searching for Swedish reports we used Google with search terms in Swedish such as e.g. “fåglar AND vindkraft”. The search terms “bird AND wind turbine”, “bird AND wind AND turbine”, and “bird AND wind AND farm” generated about 160 hits each in BIOSIS. In Google Search the same terms resulted in 20 000 hits and we therefore used only the first 50 hits for each search term in these cases. In some cases we found the relevant literature in the literature list of a reviewed article. A little more than 100 articles or reports, mostly from work carried out outside Sweden, were saved in an Excel-file, and 75 of them could be found in full text and another 25 were discarded. Of these we retained about 50 of which could be considered as post-construction surveys and which were then used for this review.

Rather late in the process we became aware that within the International Energy Agency (http://www.iea.org) over several years have collected material, reports and scientific articles about wind power within the cooperation WREN (**W**orking Together to **R**esolve **En**vironmental Effects of Wind Energy).

Thanks to this there is now a generally available data base, TETHYS (http://tethys. pnnl.gov/knowledge-base-wind-energy). Using this data base we complemented the list of literature that we had already found. A few reports from a Vindval research project on post-construction programs on marine wind farms were obtained from Carolina Enhus, Aquabiota Water Research (Enhus et el. 2017).

A list of completed and reported Swedish post-construction programs for birds and bats was supposed to be compiled and provided to us by the Regional Council in Jönköping. However it turned out that the list was neither complete nor updated, and we therefore had to obtain the information again by contacting all relevant wind companies, decision makers and consultants. This worked well in most (but by no means all) cases. Our compilation of 27 programs was done in 2016. Thereafter, another few unfinished or unreported programs have been made available to us and important results are included in the update, although the programs are not included in the literature lists at the end.

3. Updating the state of knowledge

In the following chapter we first provide a general review of recent knowledge about the effects of wind power on birds. It is divided into the major questions of mortality and loss of habitat, and in the latter case we also include effects on the behaviour and barrier effects. The effect of marine wind farms on birds has its own section. Thereafter, we highlight some new knowledge about particular species or groups of species that have turned out to be important or widely discussed in connection with wind power. It is followed by a review of investigations that have tried to evaluate the effects on populations, which are relatively few so far. The chapter is concluded with several sections about measures to mitigate the negative effects on birds from wind turbines, including a review of buffer zones and an updated suggestion on how such protective zones can be used to protect specific bird species or localities.

3a. Mortality at wind turbines and its variation

Throughout this report we use "number of dead birds per wind turbine and year", also called the "fatality rate", which is a unit that is intuitively easy to understand. It is also applied internationally and is most frequently used when the problem of bird mortality at wind turbines is discussed. On the other hand we are aware that by using this definition, we imply that all wind turbines are equally dangerous to birds, which is not necessarily the case, since turbines vary considerably in size. It may perhaps have been better to consider the mortality in relation to the total installed effect (no. of dead birds per MW), which is indeed done in some recent scientific studies. This definition may also be more relevant with respect to the current planning process and forecasts regarding establishment of wind energy in Sweden (as outlined in the introduction of this report), which rather consider the amount of electricity produced rather than the number of turbines constructed. In the future we are likely to see a change in the use of the terms, but for now we stick to the traditional ones, realizing that this is a bit simplified and by no means ideal.

The general picture of the number of dead birds per wind turbine and year (the fatality rate) that we presented in the previous synthesis report (Rydell et al. 2012), stands well in comparison with several comprehensive studies presented since then. The mean fatality rate for birds at wind farms in the entire U.S., based on 53 separate studies, is 5.2, with a variation between 2.9 and 7.9 depending on the region (Loss et al. 2013). Similarly, a compilation of 43 studies such from Canada gave a mean fatality rate of 8.2 dead birds per turbine and year (Zimmerling et al. 2013). There are no recent summaries of this sort from Europe, and the observed interval of 0–60 dead birds per turbine and year, as presented earlier (Rydell et al. 2012) remains, because we have not found any recently published evidence of higher fatality rates. Although there are different ways to estimate the mortality at wind turbines and also variable quality of the data base, there seems to be an agreement that on average a wind turbine kills between five and ten birds per year.

So far only a few Swedish studies have been carried out with a protocol sufficiently detailed to allow a meaningful and reliable estimate of the mean fatality rate. At two of these sites, Frösösund in Jämtland and Räpplinge on the island of Öland, only a few carcasses were found and the mortality was presumably low (Falkdalen et al. 2013, Ekelund 2015f). The third program was done in order to study the shift from older smaller turbines to modern, larger ones at Näsudden on the island of Gotland (Hjernquist 2014). The wind-turbine related mortality was noticeably higher, up to 37 dead birds per turbine and year, compared to the sites and mean values that we mentioned earlier. This may be as expected, however, considering that the number of birds that move in this area is unusually high. The fatality rate recorded at Näsudden is well within the range recorded in other countries. Nevertheless, at present it is not possible to present a general level of the fatality rate for Sweden as a whole, but we cannot see any reason why it should differ substantially from that observed in other parts of the world, as considered above.

We have not found any new information about how the fatality rates vary between different habitats, so our conclusion does not differ compared to what we have said previously (Rydell et al. 2011, 2012). Hence, wetlands and other habitats near water, including lakes and coastlines, are the habitats with the highest risks. Näsudden is a representative example of such habitats. Increased risks are also evident in elevated places, particularly on slopes and precipices facing the prevailing wind direction (which is usually south-west). Generally low risks have been recorded in open fields and other open habitats. Few studies have been made in production forests, but those that have suggest that the risk is relatively low in such habitats as well. There are no new empirical figures of the fatality rate at off-shore wind farms, although model-based estimates from Belgium and the Netherlands suggest on average about two bird fatalities per turbine and year in far off-shore habitats but higher in more coastal areas (Brabant et al. 2015, Poot et al. 2011).

Loss et al. (2013) concluded that higher turbines with a larger rotor-swept area kill more birds than smaller turbines. The data considered by Loss et al. (2013) included turbines between 36 and 80 m high at nacelle level. Within this interval the mean fatality rate increased from 0.64 to 6.20 birds per turbine and year. However, the turbines included in this study were considerably smaller than most of those constructed in Sweden at present, and the fatality rates are therefore probably lower. Turbines 80 m high at the nacelle are approximately 120 m in total height, including the rotor blades. Many of the turbines that are constructed in forests in Sweden today are more than 150 m in total height, and some are up to 200 m high or more.

Erickson et al. (2014) did not record any direct linear relationship between the turbine height and the fatality rate for small birds (songbirds) in 116 studies from USA and Canada. The authors argued that much of the variation that could be referred to turbine height may have been hidden behind variation related to geographical area and age of the turbines. Smallwood (2013) also analysed the effect of turbine height. He found that the fatality rate declined with increasing turbine size, when the size was given as installed effect. This applied to raptors throughout the USA and also to all birds in the well-known wind farm at Altamont in California.

In the Näsudden study on Gotland, where old turbines were replaced by new and higher ones, bird fatality was higher at the new (80 m at nacelle, 120 m total height) turbines, compared to the older turbines (nacelle height 40 m, total height not given, but probably 50–60 m; Hjernquist 2014). The new turbines each killed on average 37.4 birds per year, while the older ones killed 21.3 birds per year. Most importantly, however, although the 28 new turbines killed more birds than the 58 old ones, as measured per turbine, the mortality for the entire wind farm was lower after the shift. In relation to the installed effect, the fatality rate decreased from 57.0 to 12.5 birds per MW and year, which means an almost 80% lower mortality at the new turbines compared to the older and smaller ones (Hjernquist 2014).

Considering which species of birds that are killed at wind turbines, the overall pattern remains the same as reported earlier (Rydell et al. 2011, 2012). After all, we should remember that all types of flying bird can be killed at wind turbines, and there are no species or groups that are "immune" to the risk faced at wind turbines or that show avoidance behaviours so strong that accidents cannot occur. Likewise there are no habitats or areas in which birds will not be at risk near wind turbines. However, there are some groups of birds that are more at risk than others, and which are killed more frequently than expected based on their abundance.

The majority of all birds that are killed at wind turbines are probably small birds (or songbirds). Erickson et al. (2014) estimated that such birds comprise 62.5% of the birds killed at wind turbines in the USA, but they also note that this most likely is an underestimate. Other estimates from USA suggest that 75% or more of the fatalities are songbirds (Kuvlesky et al. 2007). Of the fatalities reported spontaneously in Europe, only 28.6% are songbirds (Dürr 2016), but this is presumably a considerable underestimate of the real proportion. In the most comprehensive study carried out in Sweden so far, at Näsudden, it was found that passerine birds comprise 25.9% of the fatalities at this site. In this case the corvids were included in the passerine group and the author note that the fatality rate of small birds probably was severely underestimated (Hjernquist 2014). In the remaining Swedish surveys that included carcass searches, about 60% of the recovered carcasses were passerine birds. Most studies indicate that small birds are harder to find than larger birds and there are indications that no more than 20–25% of the dead passerines are found during systematic searches (Graff et al. 2016). For spontaneous searches the figure is probably even lower. Despite all the uncertainties we can be quite sure that the great majority of birds killed at wind turbines are small passerines (songbirds).

Within the group of small passerines some new and interesting information has been presented in recent years. Nocturnally migrating passerines are among the fatalities, but rather at a lower frequency than expected (Erickson et al. 2014, Grünkorn et al. 2016). Both in Europe and in North America the species of larks have turned out to be most frequently killed within this group (Erickson et al. 2014, Dürr 2016, Bastos et al. 2016, Grünkorn et al. 2016). This is partly caused by the tendency to build wind turbines in places where larks are common, such as on open grassland, but the specific flight behaviour of larks is most likely also involved. Males are over-represented among the fatalities at wind turbines, and it could be that they were killed during their aerial display (Bastos et al. 2016).

Swallows have been mentioned as a group of small birds that may be expected to turn up dead under wind turbines, assuming that they, like some bats, are attracted to the turbines by insects that accumulate there. However, relatively few swallows have been found so far (Dürr 2016, Grünkorn et al. 2016). On the other hand, swifts are over-represented among the fatalities, and this could indicate that there is a connection with insects and birds, like between insects and bats, as suggested. However, this is entirely speculative, but the problem is interesting and needs further study.

For other groups of birds recent surveys generally agree with earlier ones and quite clearly indicate that raptors and gulls are killed more frequently than expected based on their abundance (Erickson et al. 2014, Hjernquist 2014, Dürr 2016, Langgemach & Dürr 2016). Hjernquist (2014) also found that waders are killed more frequently than expected at Näsudden on Gotland, but we have not found any evidence that this also applies more generally. Other bird groups showing relatively high fatality rates are gallinaceous birds (Erickson et al. 2014) and ducks (Erickson et al. 2014, Dürr 2016, Graff et al. 2016). In the case of ducks, the fatality rates found are not higher than expected based on occurrence and abundance (see e.g. Hjernquist 2014).

There are groups of birds that often are mentioned in the discussion about bird mortality at wind turbines, but which, in fact, are not killed very frequently, such as swans, geese and cranes. These birds show strong avoidance reactions during active flight and thereby minimize the risk of being killed (Grünkorn et al. 2016).

The terns is another group of birds that we previously (Rydell et al. 2011, 2012) identified as showing a higher fatality rate than expected. However, most results behind this conclusion were obtained at a few localities in Belgium, where wind turbines were built in the middle of commuting routes used by colonies of breeding terns. Hence, the fear that terns are a particularly vulnerable group of birds has diminished considerably since our previous report (Rydell et al. 2011, 2012), presumably because wind farm are no longer established near tern colonies, following the mistake in Belgium.

Regarding the owls and nightjars very little new information on wind turbine fatalities have appeared in recent years, although, for both groups fears have been expressed that they may be particularly vulnerable. However, only two nightjars (of two species) have so far been found dead under wind turbines in Europe (Dürr 2016). To some extent this also applies to owls. Although individuals of eight owl species have been found dead, the number for each is low (Dürr 2016). It remains unclear if and how the relatively low fatality rate for these birds is affected by localisation of the wind turbines.

3b. Loss of habitat – Avoidance behaviour and other responses

In recent years there have been quite a few studies presented on how birds use the area around wind turbines, and the revealed patterns are in good general agreement with what we presented earlier (Rydell et al. 2011, 2012). If birds avoid areas with turbines or not seem to depend on the species and group of bird and it also varies from place to place and between different habitats. General conclusions that unambiguously show one or the other are therefore hard to draw. Overall most studies show relatively limited avoidance reactions during the breeding season for most groups of birds. When avoidance reactions have been found they usually take place at distances of a few 100 m at most (Langgemach & Dürr 2016). For some groups the results suggest that avoidance reactions are less obvious in places where the habitats between the turbines remain relatively intact (Schaffer & Buhl 2015). Worth considering is that the groups of birds that are more frequently killed than expected also show the least obvious avoidance reactions and vice versa (Grünkorn et al. 2016, Langgemach & Dürr 2016). The waders are still the group that show the strongest and most obvious avoidance reactions during the breeding season (Langgemach & Dürr 2016, Sansom et al. 2016). Stronger or more general reactions have been recorded during other seasons, particularly in flock-living birds like cranes, geese and waders (Langgemack & Dürr 2016). In general, avoidance behaviour in birds has been studied mostly in small wind farms and with respect to single turbines and not in larger wind facilities or those that cover extensive areas.

A few relatively recent studies have considered the behaviour and/or reproductive success of birds in relation to wind turbines. In a North American study of the horned lark *Eremophila alpestris* and a relative to our Lapland bunting *Rhynchophanes mccownii*, no difference in brood size or in the number of flying young between birds inside the wind farm and birds in a reference area outside could be demonstrated. However, at the landscape level, survival rate in the nest was lower in areas with many wind turbines within a range of 1–5 km from nesting areas (Mahoney & Chalfoun 2016). The mechanism behind this effect is not clear, however, but possibly more wind turbines could affect survival indirectly through habitat fragmentation and an increasing number of potential nest predators.

Likewise, no negative effect on reproductive success could be demonstrated for golden plovers *Pluvialis apricaria*, although there was a rather strong avoidance reaction as such in this species (Sansom et al. 2016). In North American prairie chicken *Tympanuchus cupido*, there was no visible effect on the number of females that visited leks and not on the display behaviour or interactions between the males that could be referred to the wind turbines. The males spent less time on other activities such as e.g. foraging in areas near wind turbines compared to areas away from wind turbines (Smith et al. 2016).

In a very recent study from U.K. it was demonstrated that the noise from wind turbines affect the territorial defence of the European robin *Erinaceous rubecula* (Zwart et al. 2016). In order to study the effect of sounds from wind turbines specifically, recordings of wind turbines were played back to robins in areas where no wind turbines existed. The birds reacted by excluding the low-frequency components of the songs. It was concluded that they did so because the low frequencies were concealed by the sounds of the turbines. The authors have previously demonstrated that low frequency components in the songs signal social dominance, possible because they are associated with larger individuals. The authors argue that an absence of low frequency sounds may lead to more frequent physical disputes during territorial interactions, with higher risks of body injuries for the combatants (Zwart et al. 2016).

We will consider more details of the specific species in sections 3e–l further below in this report.

3c. Barrier effects

There is little new evidence on barrier effects and nothing that revolutionizes the knowledge evidence has appeared in recent years. However, our knowledge about the problem, as we presented it in 2011, has been substantiated considerably. Generally, birds that show distinct avoidance behaviours also show rather strong barrier effects. This applies, for example, to divers (at sea), gannets, auks, swans, geese and cranes (Krijgsveld et al. 2011, Plonczkier & Simms 2012, Grünkorn et al. 2016, Langgemach & Dürr 2016). Avoidance reactions were also observed among nocturnally migrating songbirds at a marine base off the coast of the Netherlands, while cormorants and gulls did not show any avoidance of the same park (Krijgsveld et al. 2011).

For migrating raptors there are three new studies that provide partly conflicting evidence. A study in the Rocky Mountains showed that raptors changed their flight bearings after the construction of a wind farm, so that the risk of collisions appeared to be lower than expected based on pre-construction studies (Johnson et al. 2014). In Mexico, along the major migrating route between the North American breeding grounds and the over-winter areas in South America, a large scale avoidance of land-based wind farms was observed (Crabnrera-Cruz & Villegas-Patraca 2016), and this agrees well with earlier observations from e.g. southern Spain (Marquez et al. 2014). At two off-shore wind parks off the coast of Denmark it was observed that actively migrating raptors actually were attracted by the wind turbines, particularly during head-wind conditions. The authors of the latter report speculate that the birds may consider the turbines as “land” and fly there to pick up winds that may carry them aloft. If this is true, off-shore wind farms located along migratory routes of raptors could increase the fatality risk for such birds (Skov et al. 2016).

3d. Marine wind farms

Investigations of the effects of wind turbines on birds at sea are much fewer than those on shore, but along with the large-scale construction efforts primarily for the North Sea area, the knowledge increases considerably. However, constructions off-shore has so far been less comprehensive compared to those on land. Studies offshore are much more demanding logistically and more expensive compared to studies on land. Searches for carcasses at sea is nearly impossible and estimates of the fatality rates have been done mostly based on observations of flying birds and theoretical modelling of these data. The resting behaviour of birds near wind farms at sea has been studied by counts from ships or airplanes or observations of migrating birds with the aid of visual observations or radar. Sometimes but not always, observations have been made both before and after construction of the wind turbines.

In Sweden studies on birds have been made at three off-shore wind farms. The most comprehensive study was carried out in Öresund at Lillgrund, the largest off-shore wind farm in Sweden so far, with 48 turbines. In this case, migratory as well as stationary birds were studied within and around the farm. At the two other localities, namely Utgrunden in Kalmarsund (between Öland and the mainland) and Kårehamn east of Öland, the studies have been concentrated on migrating birds. Together with about 20 other studies carried out at other off shore wind farms in north-western Europe, there is now a base of knowledge from the construction phase and the first few years after installation. However, there are yet virtually no comparable studies of the long-term effects.

The present knowledge about the effects of marine wind farms on birds were recently summarized by Dierschke et al. (2016). There are some fairly clear and consistent patterns which largely agree with those that we presented previously (Rydell et al. 2011, 2012). A very clear and almost total avoidance of wind turbines at sea has been recorded for divers and gannets *Sula bassana* and similar results have been obtained for great crested grebe *Podiceps cristatus* and fulmar *Fulmarus glacialis*. In addition, there is a large group of birds where avoidance behaviours have been recorded to varying degree, but always less consistently and total as in the species mentioned above. This applies to the common scoter *Melanitta nigra*, the long-tailed duck *Clangula hyemails*, Manx’ shearwater *Puffinus puffinus*, the razorbill *Alca torda*, the common guillemot

Uria aalge, the little gull *Larus minutus* and the sandwich tern *Thalasseus sandwichensis*. The avoidance reactions have turned out to be stronger when the turbine rotors are moving compared to when they are not moving. A few species were classified as "barely affected by marine wind turbines or studies are inconsistent, some showing attraction and others avoidance". In this category are found the common eider *Somateria molissima*, the kittiwake *Rissa tridactyla*, the common tern *Sterna hirundo* and the arctic tern *Sterna paradisaea*. Some (minor) attraction to marine wind turbines has been observed in the red-breasted merganser *Mergus serrator* and most species of gulls. A strong attraction has been recorded for the great cormorant *Phalacrocorax carbo* and common shag *Phalacorocorax aristotelis*. In the cormorants case it is believed that much of the attraction is because the turbine towers and fundaments provide places for rest, and this may also be true for most of the gull species. Improved food availability may occur thanks to artificial reef effects and since commercial fishing no longer occur in the immediate vicinity of wind turbines and this may explain why it is predominantly the fish-eating birds that are attracted to wind turbines at sea (Dierschke et al. 2016).

The short term effects of wind farm establishment in shallow water localities off shore are rather distinct, as they result in many of the birds being displaced from such areas. The displaced birds apparently find alternative areas nearby in most cases, so the total number of birds around such wind farms may remain the same. If the survival is affected in the long run is unknown, however, because this problem has not been studied so far. The long-term consequences of displacements presumably depend on the availability of alternative localities that are suitable and not already occupied by other populations. For species dependent on e.g. shallow water areas it is obviously important that not all suitable localities are exploited but that some are left intact. Likewise, the persistence of any displacement effects over time remains unstudied, so it is not known if it declines or increases as the birds get used to the situation.

The fatality risk for most of the bird species that pass near marine windparks is hard to estimate because hard data on mortality are largely missing for obvious reasons, and therefore have to be inferred through visual observations, radar studies or theoretical modelling of the collision risk. The species and groups that show the strongest avoidance reactions (see section 3c above) will most likely show relatively low fatality rates at the actual wind parks. At the same time we may expect that birds that do not show any strong avoidance reactions (section 3c) may be killed more frequently.

3e. Divers

The Swedish "Project Lom" (http://birdlife.se/sveriges-ornitologiska-forening/fagelskydd/artprojekt/projekt-lom) has recently started to collect data on breeding performance and occurrence of the arctic loon *Gavia arctica* and the red-throated diver *Gavia stellata* in connection with wind farm establishments in Sweden. The amount of data collected is still small and clear trends cannot be seen, but, on the other hand, negative effects on the reproductive success cannot be excluded (Eriksson 2016). For the arctic diver there are results from 8 lakes with breeding pairs and with 1–21 wind turbines within 0.6–6.0 km away. In summary, when comparing the breeding success before and after the wind turbine construction, it remained the same in four cases but was lower in four. There was no indication that the breeding success was lower specifically for pairs within 1 km from the wind turbines. However, the number of large chicks per breeding pair was somewhat lower (0.33 young/pair) after construction of the wind turbines compared to before construction (0.54 young/pair). The difference is not statistically significant. The proportion of broods with large chicks was 14% in cases without wind turbines and 20% with wind turbines, which suggests that the survival of young was not affected by the turbines (Eriksson 2016). It should be noticed, however, that the amount of data are skewed. There were 47 cases ("pair-years") without wind turbines and 21 with wind turbines, and this could possibly have affected the results. Divers are long-lived birds and the reproductive performance varies considerably from year to year, and therefore observations over many years are usually necessary before reliable estimates of lifetime reproductive success can be obtained.

3f. Swans, geese and cranes

We have already mentioned these groups in sections 3a–c with respect to mortality and avoidance of areas near wind turbines both with regard to foraging birds on the ground as well as migrating individuals. Because these birds so often appear in the discussions we still consider them separately here.

There are relatively few confirmed fatalities of birds belonging to these groups at wind turbines (Grünkorn et al. 2016; Dürr 2016) and this applies to areas where they breed, rest, overwinter or pass during active migration flights (Langgemach & Dürr 2016). Cranes *Grus grus* have been observed to breed near wind turbines, but on the other hand, the densities have been reported to be 40% lower and the breeding success 30% lower in the vicinity of wind farms compared to other areas. Behind these conflicting reports seems to be observations indicating avoidance reactions in some places but not in others (Langgemach & Dürr 2016).

All three groups show clear and consistent avoidance reactions when foraging on open farmland, but the reactions are more obvious for large flocks than for small ones. There are many studies and estimates presented from farmlands in Germany, indicating that the avoidance distances may vary between 100 m and more than 1 km for very large flocks. There is some evidence from a few sites that the avoidance reactions decline with time, but it remains unclear to what this reaction represents a general behaviour (Langgemach & Dürr 2016).

All three groups show strong avoidance reactions in flight, including active migratory flight, and this is most likely the reason behind the relatively low fatality rates (Grünkorn et al. 2016). Nevertheless, accidents occur occasionally, and there are examples of how individuals at the end of the flight formation were killed, at the same time as the great majority managed to avoid the turbines, possibly because birds in large flocks maintain better control over other flock members than over the surroundings (Langgemach & Dürr 2016).

The only study from Sweden that in any way has considered swans, geese and cranes with respect to wind turbines is a migration observation from Hörnefors, where birds of these groups largely avoided flying in the vicinity of wind turbines (Umeå Energi 2012).

3g. White-tailed eagle

According to the European statistics over wind turbine fatalities, many more white-tailed eagles *Haliaetus albicilla* than golden eagles *Aquila chrysaetos* have been found dead. Dürr (2016) indicate 209 white-tailed eagles compared to only 16 golden eagles. There is no exact statistic over the number of white-tailed eagles that have been killed at wind turbines in Sweden, but is clear that the number of killed white-tailed eagles is much higher than the number of killed golden eagles in our country as well. The latest records suggest that at about 60 white-tailed eagles have been found dead at wind turbines in Sweden until the 2016/17 winter (Peter Hellström, pers. comm.). There are probably several reasons why white-tailed eagles are killed, or at least found dead, more frequently than golden eagles. Possible reasons include the fact that the white-tailed eagle generally is more abundant than golden eagles in areas exploited for wind farming. Behavioural differences between the two species may perhaps also be involved.

From Germany it is reported that an increasing proportion of the human-related mortality of white-tailed eagles is caused by wind turbines (Langgemach & Dürr 2016). Nearly half of the fatal accidents occur during the breeding season (March–May) and more than 40% occur when the nesting activities are over and old as well as young individuals have begun to move over more extensive areas (August–September). In Germany only a small part (14%) of the fatalities are young of the year. Most are birds at least three years old. No obvious avoidance reactions in this species have been observed in Germany, although disturbances and some avoidance reactions most likely occur in response to construction and other human activities in wind parks (Langgemach & Dürr 2016).

On the island of Smøla in Norway a detailed investigation has been carried out on a predominantly ground-breeding, local population of white-tailed eagles (Dahl 2014). After the establishment of a wind farm with 68 turbines in an area with a dense breeding population, an increased mortality of eagles breeding with 5 km from the turbines was observed. The effect was strongest for those breeding within 1 km of the wind farm, and it declined at further distances.

Breeding success, as measured as the proportion successful attempts, was lower within 500 m of the wind farm compared to further away (Dahl et al. 2011). In a later analysis using a larger sample, the number of flying young per territory was lower within 1 km of the farm compared to further away (Dahl 2014). The declining breeding success was probably caused indirectly by abandonment of territories near the wind farm (Dahl et al. 2011). The number of breeding pairs declined drastically near the wind farm, which may have been caused by disturbance during the construction phase or fatalities at the turbines. In addition the area became more accessible because of the new roads, which also resulted in increased levels of disturbance and this could also have affected the eagles that nevertheless decided to attempt breeding within or near the wind farm.

From October 2005 to August 2016 about 60 dead white-tailed eagles have been found at Smøla, which means about six fatalities per year of this species (May et al. 2010, 2013, Dahl et al. 2015) or, expressed another way, 0.1 fatalities per turbine and year. About half of the dead individuals were from the local breeding population while the other half represented non-breeding individuals originating from a more extensive area. Of these 54% were adults, which mean that young and adults are killed at similar frequencies. The annual survival rate for white-tailed eagles at Smøla has declined from 96% to 94%, but the population size has remained stable at 45–50 pairs. This is because the killed individuals are replaced by individuals from successfully breeding pairs more than 5 km from the wind farm (Dahl et al. 2014). Hence, the eagle population at Smøla is still thriving despite the increased mortality caused by the wind turbines and produces a surplus of individuals that either move to other areas or become "floaters" (adult individuals without breeding territory) on Smøla (Dahl et al. 2014). Avoidance behaviour at turbines or the wind farm generally by white-tailed eagles has not been observed on Smøla, and this is in agreement with observations at other places (Dahl et al. 2013).

In a Finnish study of 104 breeding pairs of while-tailed eagles dispersed along the Baltic coast and Åland around 27 places with wind turbines, no increased mortality of young individuals could be observed after they left the nest (Balotari-Chiebao et al. 2015). The mortality of adults was not investigated in this study, but the breeding success declined at shorter distances from the turbines, although the difference was relatively small. The number of young per breeding attempt was independent of the distance to the nearest wind turbine, but the breeding success was 10% lower at nests within 2 km from the wind turbines compared to nests about 5 km away. The reason was that unsuccessful breeding attempts were more frequent closer to wind turbines. Why this happened was not investigated, however, but the authors assumed that the reason was an increased mortality in adults breeding near wind turbines.

The Finnish study indicated that the probability of successful breeding declined below 60% at 4 km from wind turbines (Balotari-Chiebao et al. 2015). This also happens to be the threshold frequency believed to be required for maintenance of stability in populations of white-tailed eagles and success rates of 60–80% have been observed in populations recovering from previous low levels (Helander et al. 2013).

3h. Golden eagle

Altamont Pass in California is probably the world's most famous wind park with respect to fatalities of golden eagles. In this place an estimated 67 individuals of this species are killed per year on average (Smallwood & Thelander 2008). A recent analysis of dead birds from this locality, with the use of both DNA and stable isotopes from the feathers, indicates that more than 255 of the birds killed had recently arrived to the area from at least 100 km away. In most cases their origin was more than 400 km away from Altamont and in some cases the birds arrived from even longer distances. Using population modelling it was suggested that the local mortality at the wind farm was so high that there is little room for additional mortality if the population is to remain stable. However, because additional mortality indeed occurs, the conclusion was that the population at Altamont relies on immigration at a continental scale (Katzner et al. 2016). Results like this illustrate that cumulative effects at a large scale must be considered when the effect of a certain wind farm on bird populations is evaluated.

From Europe there are rather few (16) recorded cases of golden eagle fatalities at wind turbines (Dürr 2016). The number of Swedish cases is at least seven, all from Gotland. The evidence indicates that accidents with trains and electricity facilities cause many more fatalities of golden eagles in Sweden than the wind turbines.

No avoidance reactions of foraging golden eagles at wind turbines have been documented in North America, but observations from Scotland suggests that such behaviour may occur there (Langgemach & Dürr 2016).

Golden eagles move over large areas and breeding pairs use 20–200 km^2 (Watson 2010). In a recent study financed by the Swedish Energy Agency through the Vindval program, a total of 70 eagles have been equipped with GPS transmitters between years 2010 and 2014. Of these about 30 were adult breeding birds, while the rest were young or half grown individuals. The movements of some of these particular individuals have been followed in great detail and sometimes over several years (Hipkiss et al. 2013, Singh et al. 2016, 2017). The areas used by foraging adult birds were on average 200 km^2 but with much variation between individuals and territories. The core areas, which covered 50% of the GPS positions, were between 5 km^2 and 30 km^2 in extent and usually divided into smaller sections, some of which were used particularly often, and with less utilized areas in between. The home ranges, which contain most of the area used during the breeding season, were estimated at 30–70 km^2, but locations even outside this area were used occasionally. The home ranges were generally rather coherent areas, containing the cores areas and the transport routes between them. The areas of these were similar to those previously presented by Watson (2010) and Hjernquist (2011).

Analysis of the habitat use revealed that the birds generally preferred recently clear cut areas, probably because they are suitable for hunting, as well as mature forest with intact canopies, where the nest usually were located. Young forest plantations, bogs and mires were used less frequently than expected, while steep slopes which provide up-winds were used extensively (Hipkiss et al. 2013, Singh et al. 2016, 2017). With modern transmitters that provide altitudinal information with better precision, it was possible to analyse flight altitudes both within and outside wind farms for a few individuals nesting in the vicinity of the turbines. The eagles generally flew higher inside the wind farms than they did outside (Singh et al. 2017).

3i. Other birds of prey

The red kite *Milvus milvus* is a raptor species that relatively often is found dead under wind turbines (Dürr 2016). This obviously depends on where the wind turbines are built but also on the behaviour of the kites. No avoidance reactions have been recorded for this species in Germany (Langgemach & Dürr 2016). Wind turbines are the most important anthropogenic cause of mortality for red kites in Germany and the mortality peaks twice during the year, in the breeding season in spring and also in autumn. The great majority (83%) of the birds found dead are adult breeding birds and adults also dominate (63%) among the fatalities in the autumn. Young birds that die at wind turbines usually do so away from the nesting place, indeed there are no records of dead young kites within 500 m of the nest (Langgemach & Dürr 2016). The black kite *Milvus migrans* is in many way similar to the red kite, but with the important difference that fewer fatalities have been recorded, presumably an effect of lower densities of this species in north-western Europe, the area from which we have the most extensive information.

The pattern for the common buzzard *Buteo buteo* is also very similar to that of the red kite. It is the species of which most wind turbine fatalities have been found in northern Europe (Dürr 2016). Little or no avoidance behaviour have been recorded in Germany, the species sometimes even builds the nest inside wind farms. However, in Scotland lower (41%) densities of common buzzards have been recorded within 250–500 m from wind farms. Most accidents occur during the breeding season and like in kites, the majority of the fatalities are adult birds (Langgemach & Dürr 2016).

Very few rough-legged buzzards *Buteo lagopus* have been found dead under wind turbines so far (Dürr 2016). Nevertheless, occasional fatalities have been recorded in Sweden (Falkdalen 2015). In a study at Hörnefors it was found that migrating rough-legged buzzards relatively frequently pass through wind farms, compared to other migrating birds at that site (Umeå Energi 2012).

For ospreys *Pandion haliaetus* no obvious avoidance reactions have been recorded (Langgemach & Dürr 2016). Relatively few (31) fatalities of this species have been found under wind turbines in Europe. A pair of ospreys nested 800 m from a wind farm with four turbines of 108 m tower height near Em in Småland, and produced three flying young in the same season as they were discovered (Björkman 2013).

The shortest distance between a wind farm and a nesting honey buzzard *Pernis apivorus* in Germany was 750 m (Langgemach & Dürr 2016). This is not to say that honey buzzards always avoid nesting near wind turbines, but rather that the knowledge of this species in relation to wind turbines is very limited. Few (21) individuals have so far been found dead under wind turbines in Europe (Dürr 2016).

Harriers do not show any obvious avoidance behaviour at wind turbines, regardless of species. Montagu's harrier *Circus pygargus* have been found breeding as close as 100 m from a wind turbine. A slightly more obvious reaction has been observed in the hen harrier *Circus cyaneus* in the U.K but no such behaviour was mentioned for the marsh harrier *Circus aeruginosus* (Langgemach & Dürr 2016). Fatalities occur but are rare for these three species (Dürr 2016).

Both sparrow hawks *Accipiter nisus* and goshawks *Accipiter gentilis* have been found dead under wind turbines but only in very low numbers (Dürr 2016).

The kestrel *Falco tinnunculus* is near the top of the list of raptors found dead under wind turbines in northern Europe, following common buzzard, red kite and white-tailed eagle (Dürr 2016). The other falcons species have much smaller populations are not found dead as frequently. One of the species, the hobby *Falco subbuteo* is the only species of falcon reported not to avoid wind turbines, and this species has been observed nesting inside a wind farm (Langgemach & Dürr 2016). Considering the high fatality rate, it seems likely that the kestrel behaves similarly in this respect.

3j. Gallinaceous birds

It has recently become clear that gallinaceous birds as a group suffer from fatalities at wind turbines more frequently than expected (Dürr 2016). At Smøla in Norway and at Frösörum in central Sweden the willow ptarmigan *Lagopus lagopus* is the species most often found dead (Bevanger et al. 2010, Falkdalen et al. 2015).

Hovick et al. (2014) presented an analysis of the effects of anthropogenic structures including oil, gas, buildings, roads, power lines and wind turbines, on the avoidance and survival of gallinaceous birds. The analysis included 24 studies, but wind farms could not be included because the sample size was too small in this case. The authors found considerable effects of the other anthropogenic structures on survival as well as avoidance and also on the resulting displacement and habitat loss. The analysis was dominated by studies of prairie chicken on open grassland in western USA and in this type of habitat, earlier studies has shown relatively small effects of wind turbines on this species (Winder et al. 2014a,b, 2015). It remains to be seen which relevance these studies may have for our forest species. Possibly, it may be more relevant for the species that live on open land in subarctic habitats and on farmland in the south?

Zwart et al. (2015) could not demonstrate any effect of wind turbines on the numbers of black cocks *Lyrurus tetrix* in Scotland, but the leks were displaced away from the wind turbines following their construction. The compilation was based on seven wind farms and some of the sites were followed for up to 15 years after the construction. The number of lekking cocks in the vicinity remained constant regardless of the construction and presence of the wind turbines. However, there was a clear tendency that leks located within 500 m from a turbine were deserted and re-established further away, on average about 500 m from the location of the old lek. The Scottish heaths were shaped through human activities and differ from the Swedish forest landscape, where leks usually are located on bogs, open places in the forest such as small fields, clear-cut areas and roads, but the results from Scotland nevertheless seem to agree with the sparse results from Swedish studies available so far. For example at Korpfjället in Dalarna the number of lekking black cocks declined during the construction phase but recovered afterwards, as the wind turbines became operative. The nearest leks were located 260 m from wind turbines (Pettersson 2013). At Stor-Rotliden in Västerbotten three black cock leks remained intact following the construction of a wind park with 40 turbines nearby. One of the leks was located less than 100 m from the nearest turbine (EKOM AB 2013).

The only new scientifically published report on capercaillie *Tetrao urogallus* and wind turbines is from Spain (Gonzales et al. 2016). Much fewer tracks of capercaillies were found over four years after construction of a wind farm compared to the period before the construction. Hence, the results of this study shows that the Spanish version of the capercaillie, which lives in broadleaf forests, shows considerable avoidance reactions of wind farm areas, but it is not clear how these results can be applied to the Swedish caparcaillies that live in coniferous forests. Results from Swedish forest habitats are so far few and rather unspecific. In a study using surface-covering line transects, no difference in the number of capercaillies could be detected between areas with and without wind turbines (EKOM AB 2013). Likewise, more detailed studies of leks have failed to demonstrate avoidance behaviour, but the locations surveyed are few. Leks have been observed 350 m from wind turbines at the closest (Pettersson 2013). At Storrun in Jämtland a general decline in the density of capercaillies following the construction of a wind farm, but the leks and the wind farm were located far in between and it remains possible that the presumed effect on the birds actually was caused by something else (Falkdalen et al. 2013). A new international research program on capercaillies is ongoing, partly within the Vindval program (www.auerhuhn-windenergie.de and http://www.naturvardsverket.se/vindval), and hopefully this project will illuminate the capercaillie-wind turbine relationship within the next few years.

We have not found any new information on how ptarmigans use or avoid the area near wind turbines. As mentioned in our previous report (Rydell et al. 2011, 2012) no difference was found between the densities of willow ptarmigans between areas with wind turbines and reference areas on Smøla in Norway (Bevanger et al. 2010). Nevertheless, Falkdalen et al. (2013) did observe a decline in the immediate vicinity of wind turbines at Storrun, but no decline was observed following construction, when a slightly more extensive geographical area around the wind farm was considered.

3k. Waders

Waders as a group have shown a tendency to avoid areas with wind turbines (Rydell et al. 2011). The disturbance distances during the breeding season are shorter than for some other groups of birds, for example 850 m at most for lapwing *Vanellus vanellus* and golden plover *Pluvialis apricaria* and an average of ca 200 m in 32 different studies (Hötker et al. 2006 in Rydell et al. 2011).

Pearce-Higgins et al. (2012) studied the development in 18 different wind parks in the U.K. for effects on some breeding waders. Curlews *Numenius arquatus* and common snipes *Gallinago gallinago* declined in abundance during the construction phase and there was no sign of recovery after the turbines came into operation. The decline of curlews and common snipes were evident within ca 600 m from the wind turbines. Golden plovers did not show any decline in this study.

Breeding golden plovers were studied in a wind park with 35 turbines in northern Scotland from 2009 to 2013 (Sansom et al. 2013). The study was of before-after design with two years before construction, one year during construction and two years during the operation phase. The number of breeding pairs declined from 12 before construction to 2–3 during the drift phase, a decline of ca 80%. With the turbines constructed, golden plovers were entirely absent within 400 m from the turbines. Hence the disturbance distances were similar to those observed for waders in previous studies. The authors argued that the effect was caused by a straightforward avoidance reaction of the turbines rather than by disturbance or increased human activity.

In the comprehensive and detailed compilation made by Langgemach & Dürr (2016) there are more examples of effects on waders, some of them similar to those mentioned above. Avoidance reactions are most common but there are also examples of studies that do not show this behaviour. When avoidance reactions occur during the breeding season, it is usually evident up to a few hundred metres. For example, a study of woodcocks *Scolopax rusticola* in display flight showed a drastic decline (88%) near in wind farm with turbines recently constructed but with the rotors halted. The avoidance was evident up to 300 m from the turbines and the authors argue that the birds probably considered the towers as barriers. There is no information if the study has continued after the turbines came into operation (Langgemach & Dürr 2016).

Grünkorn et al. (2016) indicate that species of wades that rest or overwinter in large numbers on open fields, such as e.g. lapwing and olden plover, relatively often are killed at wind turbines. Despite this the great majority of the relevant studies indicate that the vicinity of wind turbines generally is avoided by these species outside the breeding season. The behaviour is similar for the two species and the avoidance distance is 175–340 m for golden plovers and

260–500 m for lapwings. For both species there is a tendency that birds get used to the situation after a while, but there are also studies that suggest the opposite. There also seems to be difference relating to the size of the flock, with larger flocks (>500 individuals) showing longer reaction distances than smaller flocks (<200 individuals). Members of small flocks have even been observed to forage within wind farms, which perhaps could help explain some of the observed fatalities.

3l. Nightjar

It has been suggested that wind turbines may affect nightjars in two different ways, 1) they may be killed when hit by the moving rotors in flight, and b) disturbance from wind turbines and associated activities may result in nightjars avoiding such areas, leading to decreasing nightjar density locally.

In the statistics over fatalities at wind turbines there is a record of a killed nightjar *Caprimulgus europaeus* from Spain (Langgemach & Dürr 2016). From the same country there is also a record of a red-necked nightjar *C. ruficollis*, another species found in the western Mediterranean, found dead under a wind turbine. These are the only reported cases of nightjars being killed at wind turbines, which may indicate that this is a rare occurrence. However, nightjars are camouflaged and extremely hard to find on the ground, and it remains unclear to what extent searches have been made where nightjars actually occur. The statistics over fatalities at wind turbines could therefore be rather irrelevant in the case of nightjars.

There is also a risk that nightjars may be attracted to wind turbines because insects accumulate there under certain weather conditions, just like bats (Rydell et al. 2011 and the bat section of this report). We are not aware of any documented cases where nightjars have been attracted to wind turbines, but there are anecdotal observations suggesting that nightjars sometimes may forage at altitudes where they may be hit by moving wind turbine rotors.

It is the noise generated by the moving rotors that has been suggested to cause disturbance to nightjars and that may be the reason why they avoid establishing territories near wind turbines. According to Langgemach & Dürr (2016), Garniel et al. (2007) claim that nightjars may be disturbed by noise with an amplitude exceeding 47 dB(A) and they also speculate that this may be a reason why nightjars avoid wind farms in Brandenburg (see further below). We have not found any further information that may support this idea.

It is relevant to ask if nightjars use an area with wind turbines to the same extent as they did before the turbines were built. The results of five studies in Brandenburg in Germany have been compiled by Langgemach & Dürr (2016). The most detailed study was made at the wind farm Heidenhof during seven years. The park consists of 31 turbines. There were 23 nightjar territories within 1 km of the wind park in 2006 before the turbines were installed. Of these territories ten were within the park boundary, five were 150–350 m from the park and eight were 350–1000 m from the park. During the years

2007–2012, after construction of the wind turbines, there were 28, 24, 28, 22, 30 and 18 territories, respectively, but with a distinctive decline in the number of territories within the park (0–4 per year) and a corresponding increase within the 350–1000 m zone. There was no decrease in the total number of territories, suggesting that the nightjars avoided the windfarm but established territories in the adjacent area (within 1000 m) instead.

In a second study, where five territories were found before the wind turbines were constructed, no nightjars remains the year after, when the turbines were in operation. However, there were three territories 200–250 m from the park. The following year there were no territories within the park and the nearest territory was 400 m away. In the third study the area was deserted as the turbines were constructed, but also in this case, territories remained nearby.

A forth study was conducted in a wind park with 18 turbines. In 2002, before the construction, there were 19 territories within the park and another 11 within 1 km from the park. In 2005 there were 4 and 20 territories, respectively. Part of the site was revisited in 2013, four years after construction of the turbines. In sections that had 12 and 7 territories in 2002 and 2005, respectively, no territories were found within the park and only two within 1 km. The two territories were located 830 and 1050 m from the nearest wind turbine. There were additional territories >2 km from the turbines. This study indicates more distinct avoidance behaviour than the other studies, although details about the distribution are missing.

In a fifth study there were three territories within the wind park, three at a distance of 150–500 m from the park and two at 500–1250 from the park before construction. So far there is only one year of results after the construction, and there were no territories within the park, one at 150–500 m and two at 500–1250 m.

The conclusion from the Brandenburg studies is that nightjars mostly avoid establishing territories near wind turbines. The decline in the wind parks was obvious (60–100%) and the end result is that nightjars have disappeared from the areas where there are now wind turbines. There is no clear pattern in the surrounding areas. In some cases a slight avoidance is evident of up to 1 km from the turbines, but the distance is shorter in other cases. At the same time there is evidence from the first and most detailed study that the density of territories may increase within the range 350–1000 m, so that that there may be no net change when a larger area is considered.

There are only three Swedish studies of territorial nightjars before and after establishment of wind farms. One of them was made at three distinct areas in Munkedal in Bohuslän (Enetjärn Natur AB 2014a, 2015b, 2016). In 2009, before the turbines were built, six calling nightjars were found. After construction new inventories were made in 2014, 2015 and 2016, resulting in 8–10, 4–5 and seven nightjars scored, respectively. Calling nightjars were observed close to wind turbines and there was no indication that the turbines were avoided. The surveys will continue until 2018 according to the plan.

Another study has been made on a private initiative by the ornithologist K. E. Axelsson in Lemnhult wind farm in Vetlanda (Småland), which consists of

35 turbines. A thorough inventory in 2012, the year when all infrastructures except the wind turbines were constructed, resulted in 26 calling males. During the following years (2013–2016), when the turbines were in operation, 22, 21, 19 and 18 calling males were recorded (Axelsson 2012, 2013, 2014 and unpublished observations), which means a 20% decline on average after construction compared with the year before. According to Axelsson, the noise from the turbines at short distances may have drowned the calls from some of the nightjars and made them less detectable. His suspicion was supported by an inventory during an evening without any moving rotors. In 2013 the wind park was visited at night in June and July with the purpose of making more detailed observations of nightjar behaviour near the turbines. No nightjars were seen to forage near the turbines but several individuals were seen and heard calling about 100 m from a turbine.

In the Västra Derome wind farm near Varberg (Halland), the nightjar territories were found closer to the turbine locations after construction of the turbines compared to before construction and the number of calling individuals was about the same (Naturcentrum AB 2015b). In this case there was a time span of five years between the inventories and the forest landscape had changed, with new clear-cut areas and higher forest in other places. Such changes in the habitat may possibly have affected the nightjars more than the localisation of the wind turbines.

In summary, current knowledge suggests that wind turbines may affect nightjars. In some German parks, the nightjars are displaced at distanced up to at least 150–200 m from the turbines. In some cases there was a corresponding increase at further distances, so that the total number of territories remained the same. No such effects have been demonstrated in Swedish studies, and we can imagine two factors that may explain the difference. Firstly, we believe that the German wind farms were located in areas that are more fragmented with respect to nightjar habitats, and with fewer nesting possibilities. Presumable the German wind farms consisted of smaller wind turbines with shorter distances between them. In contrast, the modern Swedish turbines are bigger and located further away from each other. With more suitable habitat between the turbines, the avoidance behaviour of the nightjars may perhaps be less pronounced.

3m. Effects on populations (cumulative effects)

The knowledge about the cumulative effects of wind turbines on birds is still very limited. Therefore, we need more studies that run over long periods and cover several wind farms at the same time. We also need modelling of the effects on populations to better understand the cumulative effects. This is one of the major remaining gaps in our knowledge, despite some recent attempts to illuminate this problem (Rees 2012, Marques et al. 2014, Schuster et al. 2015).

Birds in general

Erickson et al. (2014) analysed if wind turbine fatalities of songbirds in North America may have effects on the populations of the species found dead under wind turbines. They estimated the proportion of the total populations that were killed annually to evaluate the probability that present North American wind turbines can affect the populations of songbirds on the continent. They found that the wind turbines killed between 0.0001 and 0.043% of the populations of each species per year. For 20% of the species the estimated mortality was >0.001%. Among the 20 species subject to the highest mortality rate caused by wind turbines, it was in the interval 0.008–0.043% of the population. The authors conclude that none of the populations of the species included in the study are at risk of being affected numerically (i.e. declining in number) by the current wind turbine industry. They also conclude that the North American wind industry contribute very little to the mortality of these species in comparison with other anthropogenic mortality. Therefore, mitigation in other sections of the society would probably benefit the small birds to a higher extent than mitigation of wind turbines. At the same time the authors request a stronger focus on populations of endangered species (Erickson et al. 2014).

A similar exercise has been made for Canada alone, but then for all species of birds, and in this case the effect of loss of habitat through construction of infrastructure such as roads and access spaces near the turbines has also been considered (Zimmerling et al. 2013). They consider habitat loss as a form of mortality, assuming that birds disappear as their habitat is destroyed. The result of this particular study was that the habitat loss is of less importance than the direct mortality, at least in Canada with about 3000 wind turbines. Otherwise, the study shows that at present, at most 0.2% of any bird population is affected by wind turbine mortality in Canada, considering direct mortality as well as habitat loss. For the ten species most frequently killed, this represents 0.001 and 0.12% of the total Canadian populations of the species. The authors conclude that population effects are unlikely, provided wind farm establishments in areas with concentrations of sensitive species are avoided (Zimmerling et al. 2013).

Brabant et al. (2015) modelled the population effects of the estimated wind turbine mortality on gannets and a number of gull species according to the scenario of 10 000 turbines in the North Sea, which is considered a likely scenario given the goal of the EU. The result of this exercise was that the extra mortality might possibly affect the population sizes of the greater black-backed gull *Larus marinus* and the lesser black-backed gull *L. fuscus* in the North Sea negatively.

Birds of prey

A detailed analysis of wind turbine mortality and modelling of the population trend for red kites in the German region of Brandenburg showed that the more than 3 000 wind turbines kill more than 300 individuals per year, which means 3.1% of the summer population after the young have started to fly. The modelling suggested that the current population can tolerate a total mortality of 4% without showing any decline. In other words the observed mortality at wind turbines (3%) is near the estimated threshold (4%) where the number of red kites may decline. Hence there is a risk for negative population effects in Brandenburg in the near future, as the number of wind turbines has increased even further (Bellebaum et al. 2013).

In an extensive analysis of bird mortality at wind turbines and modelling of its impact on the populations throughout northern Germany, it was found that common buzzards and red kites currently are killed at a rate that is so high that there is a considerably risk that the populations will decline (Grünkorn et al. 2016). The result was similar for white-tailed eagles but at the same time not confident enough to allow any definite conclusion.

3n. Mitigation measures – generally

Several comprehensive reviews of the methods that may be used to mitigate the negative effects form wind turbines on birds have been published recently. Marques et al. (2014) and May et al. (2015) have thoroughly considered all mitigation measures that have been used to minimize the mortality at wind turbines. Both reviews show three possible methods that have proven effective for avoiding high mortality either before construction at the site or after, when the turbines are in operation.

1) **Selection of sites for construction of new wind farms**
   By careful pre-construction surveys and planning a high bird mortality can usually be avoided at the site. The key is to select localities without high bird values and sites where relatively few birds occur. This was highlighted already in our first synthesis report on the subject (Rydell et al. 2011) and still remains as the practically most suitable and cost effective method (Marques et al. 2014, May et al. 2015).
2) **Replacing old turbines with new**
   By replacing many old, small and relatively inefficient turbines with fewer larger and much more efficient ones, more electricity can usually be produced with fewer turbines at any given site. Although each larger turbine may kill more bats than each one of the smaller turbines (see chapter 3a), the net effect is usually that fewer birds are killed in total, because there are much fewer turbines (Marques et al. 2014, May et al. 2015). The recent generation shift of wind turbines at Näsudden (Gotland) is a Swedish example of precisely this (Hjernquist 2014).
3) **Curtailment during conditions of high risk**
   This method has so far been used and proven to work well under certain situations and in a few places with high mortality of large raptors and vultures. It has usually been based on manual observations where ornithologists have warned for situations with many birds, predominantly vultures,

were on the move near the wind farm (Marques et al. 2014, May et al. 2015). Detection systems involving "smart wind turbines" with automatic identification of bird species and curtailment are promising innovations. However, they are not yet in operation routinely (see also section 3o below).

Marques et al. (2014) and May et al. (2015) also consider a number of measures classified as of "high potential" or as being "possible", with respect to minimizing the mortality of birds in existing wind parks. However, we believe that the authors are too enthusiastic or positive with respect to what other studies have shown. For example, they mention curtailment of turbines based on mathematical modelling of when the high-risk periods may occur. However, the modelling made so far have shown very low correlation with the actual mortality rates in cases where this has been estimated independently using other methods (Grünkorn et al. 2016). Our understanding of the processes that lead to increased mortality could certainly be improved by modelling and the models may also become better with time. However, we are by no means near this situation at present, and therefore, curtailment based on modelling is not a useful mitigation method in practice, at least not at present.

Experiments with different colours and colour patterns on the wings of turbines with the purpose of scaring away birds have so far met with very little success so far (Marques et al. 2014). Maintenance of areas near turbines in ways that make them less attractive to birds has also been suggested in several cases, but are difficult to execute in practice and may also result in other undesired effects. The only successful method mentioned so far is the removal of larger carcasses from wind farms in Spain to minimize the risk for vultures (Marques et al. 2014).

Arnett and May (2016) discuss how to minimize the negative effects of wind turbines on animals in general. They argue for a hierarchic thinking in three steps:

1) Avoid high-risk locations
2) Adjust the drift in order to minimize the negative effects
3) Apply compensation measures in other areas

Again we can conclude that careful planning and avoidance of certain high-risk areas is the first and most important step, as we have argued earlier (Rydell et al. 2011). Adjusted drift has proven to be effective for bats (part C of this report) and it may to some extent also work for birds, at least for some species and in some situations. However, it is not a suitable method to apply as a general strategy to minimize the negative effects of wind turbines on birds. Compensation should only be used in cases where 1) and 2) above have already been employed, but where additional action is needed (Arnett & May 2016).

3o. Automatic curtailment or "smart wind turbines"

As the wind industry expand in Sweden and elsewhere and turbines are more often constructed near sensitive bird areas, explicit needs for techniques that may allow a combination of wind turbine construction and automatic mitigation of the inevitable accidents at the site. With increasing amounts of wind power in the country we approach the threshold for negative population effects, perhaps first for certain raptors, and the wind turbine industry may become a real environmental problem rather than the opposite (section 3m). Mainly for this reason, automatic mitigation systems to detect approaching birds and, if necessary, stop the turbines under risky conditions, are currently being developed.

There are several systems of "smart wind turbines" under development. Those that are most developed so far rely on camera techniques connected to complex digital recognition routines for birds. The birds are detected through the camera and are then recognized to species or species group with a computer program. If birds that should be protected approach the turbine too closely, an auditory signal is emitted in order to frighten them or make them change their flight course. If the birds nevertheless continue towards the turbine another signal is emitted before the turbine finally is stopped to prevent an accident.

Such systems have been tested at several sites around the world including in Sweden, and the technique is now good enough for relatively reliable bird identification (Litsgård et al. 2016). However, there is still a lot remaining when it comes to the signalling function and the rapid stopping of the rotor when necessary. In Sweden it is mostly the presence of eagles that can motivate the use of such systems. It is therefore of interest to know if the signals used actually cause the desired reaction in eagles. Observations from Smøla in Norway rather suggest that this may not be the case, the observed reactions are very weak (May et al. 2012). Instead, the rotor halting function may be the critical step if such technical solutions will be used to restrict the accidents. We are not aware of any published information indicating that it actually may reduce the mortality of e.g. eagles. According to manufacturers the fatality rate of birds can be reduced to <0.005 birds per turbine per year when using their system fully (e.g. http//www.dtbird.com), but this remains to be demonstrated in practice. Our own calculations based on data in Litgård et al. (2016) suggest that to avoid accidents the rotors must be halted very quickly. For raptors the size of common buzzards or larger moving straight towards the turbine, the rotor must be halted within 10–15 s, depending on the size of the bird and its flight speed. The time is measured from detection and identification of the bird until the rotor has been halted or moves slowly so that the risk of collision is small. We have not found any indication that this is possible with the present technique.

With a continued development of the systems, the camera range may be improved and each camera may be able to coordinate several wind turbines, it seems likely that automatic systems may be used to reduce the mortality of e.g. eagles at wind turbines. Systems that have a similar function and that work at night are also under development, but seem to be at a less advanced stage at present as far as we know. Hence, the solutions of most commercial interest at present are only available for diurnal species. We conclude that quite a lot remain before "smart wind turbines" with automatic recognition and warning and/or halting of the rotor is ready for use and can be employed in a larger context to reduce the accidents in any important way.

3p. Buffer zones for sensitive bird localities – generally

Buffer zones for certain sensitive species were discussed in the first synthesis report (Rydell et al. 2011) and it has been used subsequently to minimize the risks of negative effects of wind turbines. The buffer zones that we (Rydell et al. 2011) recommended were originally suggested by the Swedish Ornithological Society – BirdLife Sweden (SOF-BirdLife) although some of those recommended were changed compared to the original suggestions. For example, the buffer zone suggested by SOF-BirdLife for eagles was 3 km, but in the synthesis report we recommended 2–3 km (Rydell et al. 2011). Two years later (autumn 2013) the wind power policy of the SOF-BirdLife was revised (http://birdlifr.se/sveriges-ornitologiska-forening/fagelskydd/vindkraft/sof-birdlifes-vindkraftspolicy/) and some additions were then introduced.

Hence there are some differences between the buffer zones recommended by Rydell et al. (2011) and those that are suggested by SOF-BirdLife. In cases where buffer zones have been used in juridical decisions it has so far always been about nesting sites of eagles and other larger raptors. An accepted agreement seems to be that wind turbines must not be constructed within 2 km from a known eagle nest. A few exceptions from this principle have been made in recent years, however.

In the following, we will review previously suggested buffer zones, those of SOF-BirdLife Sweden as well as those of Rydell et al. (2011), evaluate the new knowledge that have appeared since 2011, and finally suggest our new and in some cases adjusted recommendations for buffer zones. We also review the current state of knowledge and suggest what is needed in order to make scientifically informed decisions on buffer zones and also what can be done instead of applying buffer zones routinely in particular cases. We have not always followed the recommendations of SOF-BirdLife in our evaluations of when and where buffer zones should be used, and we have made it obvious when this is the case.

We are perfectly aware that buffer zones are far from a perfect tool that provides total protection for the birds concerned. However, it is a practical and often reasonable way to consider the Habitats Directive (Artskyddsförordningen) in specific cases, and by using buffer zones, the current law and directives are followed. Nevertheless, we also highlight that by following the law we will by no means provide any guarantee that viable populations of the species concerned are maintained. We rather argue that our goal must be to maintain viable populations of all species (in this case of birds) that occur naturally in the country, at the same time as a democratically decided development of the society can continue. We will discuss alternative approaches to issues about the protection of species, although we are aware that this means that the legislation has to be changed in some cases or at least interpreted in slightly different ways before the ideas presented here can be exploited practically.

Before we start a more detailed discussion about the suggested buffer zones for different species and groups it is important to clarify the ideas behind the buffer zones that already are in use or are suggested below. Unfortunately there are several common and widespread uncertainties and in some cases also erroneous information.

Buffer zones may be used as a tool to minimize the risk for something, in this case birds at wind turbines. The logic behind this is simple – the further away the smaller the risk. The zones used at present do not have the purpose of eliminating the risk altogether, which would be impossible in any case. For example, it has never been intended to include the entire area used by e.g. a pair of eagles, in the buffer zone, neither during the breeding season nor throughout the annual cycle.

There are rarely any scientific reasons behind the decisions on the sizes of the buffer zones that are used. The sizes used are compromises between those with interests to protect the birds and those who want to exploit the habitat, in this case for the construction of something with a potential negative impact such as wind turbines. Buffer zones can certainly be based on scientific grounds, but it is then necessary to define exactly the purpose. For example, this is usually stated using the somewhat unclear term “negative impact”, which is what normally should be minimized, but which kind of negative impact and to what extent should it be considered? This is not always easy to clarify. We will exemplify what we think could be used as scientific grounds with respect to buffer zones for the two species of eagles. With this we mean that we want to illustrate how scientific results can be used to design buffer zones and nothing more. What happens in practice is another matter.

Wishes are often expressed that buffer zones should be adjusted to fit the actual world and particularly to data showing how the animal of interest uses or has used the area under consideration, rather than using standardised circles around the nest, as has been the case so far. We agree that this basically is a good idea, but argue that it is unlikely to result in better protection of the birds. This is simply because it is impossible to predict with any certainty how the birds will behave in the future. Nature is almost never stable and static except over very short periods. Food availability and other conditions vary considerably from year to year and the movements of the birds will vary accordingly. In such cases it seems more likely that standardised, often circular, buffer zones will give a better protection in the long run, compared to those that were designed based on the conditions prevailing several years ago.

Generally, we recommend that buffer zones, whenever used, should be of general shape and usually circular, even in the future. Observations and measurements may certainly provide useful information, but should not be used during for designation of the buffer zones.

As more and more of the habitats will be used for wind farming and other forms of large scale exploitation, we will encounter situations where buffer zones is not a sufficient or even a useful strategy for the efficient protection of important bird occurrences. We will provide more on this issue towards the end of the next chapter.

3q. Divers – buffer zones

No buffer zones for divers were suggested in the previous synthesis report (Rydell et al. 2011). SOF-BirdLife and "Projekt lom" recommend a buffer zone of one km from lakes where divers breed regularly. On top of this maintenance of free fly-ways (without wind-turbines) between breeding and fishing lakes are recommended. These recommendations are based largely on general observations of behaviour and occurrence and originate from recommendations made for Scottish conditions (Bright et al. 2006).

As we have mentioned above (section 3e) "Projekt lom" has recently started to record occurrence and breeding results of divers in the vicinity of wind turbines. The data is still scarce and there is yet no indication that the buffer zones that are used need to be modified.

Considering the somewhat thin information available and the fact that Sweden houses considerable parts of the European breeding population outside Russia, both of the red-throated diver *Gavia stellata* (just below 20%) and the arctic loon *Gavia arctica* (just above 30%), we find it reasonable to be careful and maintain the use of the present buffer zones until a better information base has become available.

We therefore recommend maintenance of buffer zones of one km from waters where divers nest, and that flyways between nests and fishing locations should be kept free from wind turbines as far as possible. The buffer zones should preferably extend from the shores of the lake used for nesting, not from the exact location of the nest. For nesting sites of arctic loons in larger lakes and archipelagos we suggest that the buffer zones start from the shore of the part of the lake or archipelago where the nest is located.

By nesting waters we mean lakes where divers have been nesting at least once during the past 10 years. Red-throated divers in particular change nesting locations frequently and in the long run a given pair may need many more sites than are used during a single year.

3r. Swans, geese and ducks – buffer zones

We previously recommended 500 m buffer zones at resting locations used regularly by many ducks, geese and swans (Rydell et al. 2011). With resting locations we meant bird lakes, shore meadows and coastal localities but not fields. According to SOF-BirdLife, wet lands and shore meadows are always important for birds and should never be used for wind farming.

There is no new information that would motivate a change in the previous recommendation of a 500 m buffer zone around resting localities with many ducks, geese and swans in lakes, wetlands and coastal localities. Trying to define what we mean with localities with "many", we suggest that localities with more than 1% of the Swedish breeding population of any species, or with at least 1000 individuals (of all species of ducks, geese and swans), should be defined as such. Population sizes of all Swedish breeding bird populations can be found in Ottosson et al. (2012). The 1% criterion is used by the international convention for protection of wetlands (the so called Ramsar-convention; http://www.ramsar.org; http://naturvardsverket.se/miljoarbete-i-samhallet/EU-och-internationallt/Internationellt-miljoarbete/miljokonventioner/Vatmarkskonventionen). The buffer zones should extend from the edge of the habitat, not at the exact location used by the birds.

SOF-BirdLife recommends use of one km buffer zones around breeding sites of bean goose *Anser fabalis* and lesser white-fronted goose *A. erythropus*. There is no specific knowledge about these species with respect to wind turbines, but the fact that the bean goose is listed as near threatened and the lesser white-fronted goose as endangered according to the Swedish Red List (ArtDatabanken 2015), and that Sweden has the only breeding population of the latter species in EU, are reasons enough to maintain the recommended buffer zones. For the bean goose the buffer zones should start at the edge of the wetland used for breeding. At present it seems unlikely that wind turbines will be constructed in areas used by lesser white-fronted geese.

3s. Golden eagle – buffer zones

In the previous synthesis report (Rydell et al. 2011) we recommended the use of buffer zones of 2–3 km around known eagle nests (both species). However, we gave few details in the 2011 report, but several additions and clarifications have been made in various contexts since then, which mean that current recommendations also include alternative nests, in cases where they are known. Based on several recent judgements, a buffer zone of 2 km around each eagle nest has become a kind of guideline, which the wind industry and decision makers have used for the planning process. However, the 2 km buffer zone is not carved in stone, and there are cases where wider zones have been considered necessary (e.g. case no. M 1394-14, Mark- och Miljödomstolen, Östersunds Tingsrätt).

Others' views and recommendations regarding buffer zones for golden eagles

According to SOF-BirdLife's current policy about wind power, buffer zones around nests of golden eagles should normally be at least 3 km, and in some cases more, depending on how the eagles move within the area in question. The NGO "Kungsörn Sverige", which attracts the majority of those that survey eagles sin the country, including ornithologists attached to local and national golden eagle groups, suggest that the eagles need a 5 km buffer zone around each nest, within which no wind turbines should be established. Like SOF-BirdLife, they argue in version 1 of their guide for surveys, and post-construction programs for golden eagles in connection with wind farms establishment (http://www. kungsorn.se/inventeringsvagledning_vindkraft.pdf; version 1, 30 September 2014), that this zone may be extended, for example through documentation of flyways and hunting grounds.

The regional councils in Västerbotten (Alatalo & Bernhard 2010) and Jämtland (Länsstyrelsen i Jämtlands län 2016), both in the northern half of Sweden, have produced guidelines for golden eagle management and wind farming in their respective regions. By ranking the current golden eagle territories according to certain criteria, including young production over time and also other historical information, recommendations for construction of buffer zones are presented for the two regions. For the most important breeding territories buffer zones around each nest of at least 10 km is suggested, or, as expressed in the first report, of sufficient size that no negative effects can occur. Hence, in practice, it is not buffer zones that are suggested, but rather areas free from wind turbines, although they express it in terms of buffer zones. This is near the ideas presented below, that in order to maintain a favourable population status for the Swedish golden eagles, sufficiently large area relatively free from the threat in question, in this case wind turbines, should be set aside (see below).

At the second most important territories, buffer zones around nesting sites should be maintained according to current knowledge about the site. They suggest that the buffer zones are constructed according to the terrain and the movements of the eagles, so that a low risk of negative effects on the eagles can be expected. They also suggest that in areas in direct contact with known territories, in known flyways between nest and feeding areas as well as in known areas with strong thermals, wind turbines should not be constructed at all. Buffer zones around nesting sites are suggested to be 2 km, but can also be wider. For the lowest ranked territories, use of general (circular) buffer zones of at least 2 km is suggested. For the most valuable territories within this group, zones of 3–4 km around each nest are recommended.

In the Jämtland region, recently discovered territories are suggested to be studied in detail during three years, while maintaining a buffer zone of at least 10 km around the nest until more information have been obtained (Länsstyrelsen i Jämtlands län 2016). For Västerbotten it is suggested that buffer zones of 1–2 km may be used for territories of very little importance (Alatalo & Bernhard 2010). What this sentence means remains unclear.

Singh et al. (2017) have recently produced a report on north Swedish golden eagles, including a list of protective measures for golden eagles with respect to wind turbines that they suggest. They start the discussion by claiming that circular buffer zones of 2–3 km around each nest represent a rough and simple protective method which may be over-simplified and insufficient. They continue by suggesting that the buffer zones should be modified according to how the eagles use their home ranges. In other words, they suggest that detailed studies would be necessary at each territory before the actual buffer zones can be designed. They also suggest that the wind parks should be designed according to the preferences of the eagles, so that habitats preferred by the eagles (recent clear-cut areas for hunting and mature forest with closed canopy for nesting) should comprise as little as possible of the area. They recommend placing the wind turbines in dense young stands, and the time until felling should preferably exceed the life span of the wind turbines. They also recommend that wind turbines should be placed at suitable distances from ridges, steep slopes and the like, while turbines in young stands on high plateaus may work well as long as steeper sections are avoided. As possible measures to minimize the risks in already operating as well as planned wind farms, the authors suggest that it must be ensured that suitable hunting grounds (recently clear-cut areas) are available at suitable distances from the wind farms, and that agreements with the local hunting teams should make sure that no animal remains, which may attract eagles, are left in or near the wind farm. They also suggest a better long-term planning process and that, like in the cases mentioned above, the reproductive rate and other historical information should be considered before decisions on the protective measures are taken.

Based on the same data set as for the report, Singh et al. (2017) concludes that it is mostly mature forest rich in lichens that is preferred by golden eagles. This type of forest is not only used for breeding but may also be attractive as hunting ground.

Our view on buffer zones for golden eagles and the new insights from northern Sweden

A zone which is kept free from wind turbine around the occurrence of golden eagles cannot give a total protection to nesting birds or young individuals against accidents regardless of its size. The idea of buffer zones relies on the logic that the risk is likely to decrease as the distance between the bird's nest and the wind turbine increases and the amount of flight activity near the turbine is likely to decrease. We knew long ago that golden eagles in northern Sweden usually move over much larger areas than were suggested for buffer zones, so the purpose of buffer zones have never been and is unlikely to become a matter of covering the entire area used by the birds. This is certainly the case for the breeding season and even more so for the entire annual cycle. Instead, it is a matter of finding a compromise between a reasonable protection to the birds and other interest such as from the wind industry.

The detailed information obtained from the radio-tracking of adult golden eagles in northern Sweden (Hipkiss et al. 2013, Singh et al., 2016, 2017) can be used to create more scientifically founded buffer zones for golden eagles in relation to wind farms. But even so, there will still be several possibilities on how to decide on the size and shape of the buffer zones that will be advocated. For example, if we consider what is defined in Singh et al. (2016, 2017) as core areas for the tracked eagles (= the area within which 50% of the activity occurs), and if it is decided that this is what should be protected, the resulting areas correspond to circular buffer zones extending between 1.3 and 3.1 km from the nesting site. However, in the latest and most detailed analysis of the tracked eagles' use of the landscape around the nests in northern Sweden the core areas are not continuous but consist of several smaller sections, within which 50% of the observations were made, and with less frequently used sections in between (Singh et al. 2017). This means that a core area in reality does not comprise a cohesive area that covers the entire surface within a circle with radius of 1.3–3.1 km. Instead, the core area is spread over a much larger range. However, based on the results presented by Singh et al. (2017), it is not possible to calculate how much larger a buffer zone would have to be in order to cover the entire core area, and with great probability, this would vary widely between different territories. If the entire home range, where the majority (95%) of all activity during the breeding season took place, is used, the buffer zones would have a radius of 3.1–5.6 km from the nest. This may be somewhat easier to interpret, as it is a single coherent area, roughly corresponding to a circle of said radius. If we instead consider the entire home ranges used by male and female golden eagles over an entire season, we arrive at buffer zones extending up to 9.4 km from the nest. Finally, if we base our decision on the individual with the most extensive movement over an entire season, it corresponds to a buffer zone with a radius of 20.3 km from the nest.

We mention these different variants here to show that depending on which assessments and priorities that are made, the resulting buffer zones will vary considerably in size. Which of these areas is chosen as basis for decision on buffer zones ultimately depends on which protection is considered reasonable in relation to other evaluations that need to be made.

Our recommendations on buffer zones for golden eagles in the forest landscape of northern Sweden

Our previously proposed buffer zone of 2–3 km corresponds relatively well to the total core areas of golden eagles in northern Sweden (Norrland and Dalarna) and is therefore the basis of our continued recommendations. If we combine general buffer zones of this size with the avoidance of building wind turbines in certain specific environments within the larger range around the core area, where golden eagles spend more time, a reasonable compromise can probably be reached in most cases. The larger area should then correspond to the home range, i.e. an area within ca. 6 km from known nests. Within the larger area wind turbines may be allowed in areas that are not preferred by the eagles.

Environments where golden eagles spend more time and where we should avoid building wind power plants include ridges, quays and steep slopes where up-winds are often formed. Those that are aimed at between south and northwest are in most cases facing the prevalent wind direction, and thus those where up-winds most often occur. In direct connection with these places, no wind turbines should be built within the larger protective zone set around known golden eagle nests.

Forests with higher general conservation values (values 1, 2 or 3, SS 199000:2014) as well as older fully grown forests rich in lichens are also considered as higher-value environments for golden eagles as well as for many other animals. Cohesive, old-growth forests with a large part of lichen-covered ground within ca. 6 km of known eagle nests should also be omitted from wind farm considerations.

In contrast, we cannot find any good reason to avoid constructing wind turbines in parts of the larger zone that are clear-cut during the time of application and planning, although such habitats actually are preferred as hunting grounds of golden eagles. Areas that are clear-cut today or when the application is submitted will have become young dense forest, a habitat not preferred by the eagles, by the time the wind turbines are in operation.

If we want to include clear-cut areas, it is the presence of future areas that we should focus on, i.e. forests that are as close to harvesting as possible during the time of application. Full consideration of future clear-cut areas would be quite possible within the framework of a more landscape-oriented, large-scale planning, where forestry, wind power construction and other possible impacts are weighed together. We appreciate that we are not yet in a state where this is fully realistic.

Hence, we largely retain the recommendation that we made earlier (Rydell et al. 2011), but supplies it with the additions as mentioned above. In practice, this means that we recommend an inner, smaller buffer zone with 2–3 km radius around nesting sites, including known alternative nests. Within this area, no wind power should be built at all. To this we add a larger outer zone, within 6 km radius of the nest, where wind power should not be built directly adjacent to steep mountain ridges, slopes and quays where up-winds are often formed. Likewise, within 6 km of known nests, wind turbines should not be built in areas with high general conservation values or in continuous old-growth forests with a large part of lichen-covered ground, which make the area particularly valuable for hunting and breeding of golden eagles (as well as for many other organisms). Within the outer zone, i.e. between 2–3 km and 6 km from the nest, wind turbines may be built in areas that are not used frequently by golden eagles or that will not be used frequently once the wind turbines are in operation. Such areas include young, dense forest stands that will remain of low interest for much of the life span of the wind turbines.

Our recommendations on buffer zones for golden eagles in southern Sweden

In the southern half of Sweden (i.e. Götaland and Svealand exclusive of the province of Dalarna) we retain our former recommendation of using circular buffer zones that extend 2–3 km from known nests, including known alternative ones, but without the additions included for northern Sweden. The omission is mainly because correspondingly detailed knowledge about territory sizes and habitat preferences of golden eagles in southern Sweden are missing. However, if local knowledge about stable hunting environments for golden eagles appears, the information may certainly be weighed into the local planning process. Stable hunting environments for golden eagles in southern Sweden may consist of, for example, open grassland.

Some final words on buffer zones for golden eagles

As we have already mentioned, we are sceptical to the use of buffer zone designs based on detailed behavior and movements of the eagles. Our assessment is that zones that are adapted precisely according to local fine-scale movements are unlikely to result in better protection in the long run, simply because the variation between years in where the best hunting grounds are found are likely to be considerable, particularly in the northern forest. This also means that we do not recommend detailed studies of the movements of each pair of eagles in areas where there is interest in building wind power. We believe that generally designed buffer zones with the additions mentioned above will provide protection that is at least as good.

In terms of population conservation, both regional and national, it may in some cases be more beneficial to ensure that the construction of wind power plants is planned in areas where as few eagles are affected as possible, or where the breeding performance and site-fidelity have been low. In such cases it may also be considered to deviate from the general buffer zone designs for a smaller number of pairs or territories. A designation of areas used for wind power exploitation based on where there is the least risk for eagles, will automatically mean, in practice, that other extensive areas are exempted from wind power development. Such a procedure may be reasonable to use in both southern and northern parts of the country.

3t. White-tailed eagle – buffer zones

For the white-tailed eagle we proposed (Rydell et al. 2011) that buffer zones of 2–3 km from nests should be used. Just as for the golden eagle, 2 km zones have since become something of a general practice, even if shorter distances have been decided in one case. In the latter case (Object No. M 1132-14; District Court in Umeå) one kilometer distance from the nesting site was considered enough, as the flyways from and to the nest were well within this and were well documented. SOF-BirdLife proposes buffer zones of at least three kilometers also for white-tailed eagles.

As explained in section 3g above, studies of white-tailed eagles on Smøla in Norway (Dahl et al. 2011, Dahl 2014) and along the coast of Finland (Balotari-Chiebao et al. 2015) have contributed new knowledge about the impact of wind power on breeding white-tailed eagles. On Smøla increased mortality for white-tailed eagles was recorded within five kilometers of the wind farm at the same time as mortality was highest for birds breeding within one km of the park. Impact on the breeding success was also observed for eagles breeding within a kilometer of the park. At the same time, in Finland, the threshold distance of four km from wind power plants where the likelihood of successful breeding fell below 60% was found, and this level is needed to maintain the stock on a stable level.

Depending on the priorities, based on the information from Norway and Finland, we could propose buffer zones of one kilometer (based on the Norwegian breeding success and the highest mortality; Dahl et al. 2011, Dahl 2014), four km (threshold for sufficient proportion of successful breeding in Finland; Balotari-Chiebao et al. 2015) or five km (increased Norwegian mortality; Dahl et al. 2011, Dahl 2014). In the light of all this, we argue that the previously proposed buffer zones of 2–3 km seem reasonable even in the future, although the exact size and form of each zone can of course be discussed.

For the white-tailed eagle, it is reasonable to make some modification in the design of buffer zones, based on surrounding geography. White-tailed eagles hunt mainly in wet environments and in some cases it might be preferable to reduce the size of the buffer zone by excluding areas where no suitable habitats are found within reasonable range.

3u. Other large and medium sized raptors – buffer zones

Without specifying exactly which species we aimed at, we recommended (Rydell et al. 2011) buffer zones of one km from nests for this group. Here we try to be more precise and list the species we consider relevant for Swedish conditions.

Red kite

SOF-BirdLife recommends buffer zones of at least one km from places with many nests and areas where concentrations of red kites regularly occur. A very large part of Sweden's red kites are so far restricted to Skåne, the southernmost province, although a slow spread is taking place towards the north, so far mainly in Götaland. The positive trend that we see today is, in many ways, a recovery following persecution and threats from toxic wastes in the past (Ottosson et al. 2012). We do not consider general buffer zones as a reasonable tool for this species for most of the Swedish main distribution area. Possibly buffer zones of one km around nesting sites can be used in parts of the country where the species expands but where it is not yet common. Instead, we encourage the use of large-scale planning to ensure that sufficiently large areas without wind power plants will continue to exist in order to maintain viable regional stocks of red kites.

Black kite

The black kite is a rare breeding species in Sweden and is not considered in SOF-BirdLife's Wind Power Policy. We suggest that nesting places of black kites should be protected by one km buffer zones around the nest.

Honey buzzard

SOF-BirdLife proposes buffer zones of one km around the nest or the area that constitutes the core of the territory. Nesting places for honey buzzards are notoriously difficult to find, and therefore the recommendations may be hard to follow in practice. In cases where nests or core areas within territories are found, we agree with the suggestion of SOF-BirdLife. Just as for red kites, we would otherwise recommend the use of larger scale planning to make sure that there are sufficiently large areas of appropriate environment, so that a favorable conservation status of the species can be maintained.

Osprey

SOF-BirdLife proposes buffer zones of one km from nests and also free passage (no wind turbines) between the nest and current fishing waters. We agree with this recommendation. Flight corridors without wind turbines between nests and feeding sites within 5 km of the nest should be one km wide.

Rough-legged buzzard, hen harrier and short-eared owl

For the three species rough-legged buzzad *Buteo lagopus*, hen harrier *Circus cyaneus* and short-eared owl *Asio flammeus*, SOF-BirdLife proposes buffer zones of one km from places where these species breeds regularly. A practical problem here is that all three species are dependent on rodent cycles and therefore do not breed every year. "Regularly" will therefore be difficult to interpret. We are currently uncertain if there is any place where hen harriers breed regularly in Sweden, and we also believe that this species is less vulnerable to negative impact from wind turbines compared to e.g. the rough-legged buzzard. We therefore propose that buffer zones of one km are used only for the rough-legged buzzard, and also that breeding sites for this species should be allocated buffer zones only if they were used during the previous rodent peak. As with some other birds of prey, we also advocate large scale planning in order to make sure that there are sufficiently large areas with suitable habitats, so that a favorable conservation status for this species can be maintained.

SOF-BirdLife also considers the short-eared owl in this context, probably because it is a specialist on rodents, and therefore shows some ecological similarities with the rough-legged buzzard and the blue harrier.

Hence SOF-BirdLife recommended the use of one km buffer zones around regularly used nesting sites of this species as well. However, we consider that short-eared owls certainly may breed with some regularity within certain larger areas in Sweden, but at very variable intensity and usually without any regularity with respect to the exact breeding localities. We cannot see any practical possibility to use buffer zones for this species.

Montagu's harrier

Also for this species, SOF-BirdLife proposes one km buffer zones, but in this case the protected area should include areas where the birds are regularly staying or nesting.

Because Montague's harrier is a scarce species in Sweden and classified as endangered in the Swedish Red List (Artdatabanken 2015), we find it reasonable that breeding sites are protected through a one km buffer zones with respect to wind power plants. This should especially apply to breeding sites in natural habitats, breeding sometimes occurs among growing crops in arable land. We also advocate increasing use of large scale planning. We argue that sufficiently large areas with appropriate habitats in suitable parts of the country should be kept free from wind turbines, to facilitate survival of the Swedish stock of this rare species. This is particularly important on its Swedish stronghold on Öland.

3v. Gyrfalcon – buffer zones

Rydell et al. (2011) and SOF-BirdLife have proposed buffer zones of at least three km around nests of gyrfalcons *Falco rusticolus*. We haven't found any information that may motivate change in this recommendation.

3w. Peregrine falcon – buffer zones

Like for the gyrfalcon, we agree with SOF-BirdLife that buffer zones of at least two km around nests should apply, and we suggest that this continue also for the peregrine falcon *Falco peregrinus*.

3x. Capercaille and black cock – buffer zones

In Rydell et al. (2011) and in SOF-BirdLife's wind power policy, it is recommended that buffer zones of at least one kilometer from lekking sites with more than five capercaillies or more than ten (Rydell et al. 2011) or five (SOF-BirdLife) black cocks should be applied. However, at present we consider that buffer zones applied to lekking sites alone, and only in relation to wind power facilities, is hardly anything that will benefits the conservation status of the capercaillie or the black cock. Instead, we propose a greater focus on the entire habitats of these species, where the lekking sites are included. Hence, with habitats, we imply lekking locations as well as breeding habitats and also the environments where adults spend the remaining parts of the year. Such environments should be managed in a way so that favorable conservation status may be maintained even in areas used for wind farming. Permissions may be given under conditions similar to those that currently apply to buffer zones.

Detailed instructions for suitable forest management of habitats for capercaillies and black cocks are found in the forest management guidelines for considerations of birds at https://www.skogsstyrelsen.se/lag-och-tillsyn/artskydd/. We recommend that these guidelines are used also in connection with wind power establishments. At the same time, we want to draw attention to the fact that there are even sharper proposals for corresponding guidelines, produced by SOF-BirdLife. These are available together with comments on the Forestry Agency's guidelines at http://birdlife.se/sveriges-ornitologiska-forening/fagelskydd/skogen/artskyddeti-skogen/artvisa-vagledningar.

Interesting efforts to identify important habitats for capercaillies have been made in at least three counties in recent years, Jönköping, Västra Götaland and Östergötland (Länsstyrelsen i Jönköpings län 2014). Through habitat modelling based on satellite data, parts of these counties have been identified as areas having the qualities required to be considered important habitats for capercaillie. In many cases field investigation on the ground have also been made in order to verify this. Such efforts are a very useful tool in the large-scale planning processes for several species. As long as there is good information about environmental requirements of the species and access to high quality satellite data, this provides an opportunity that definitely should be taken further.

3y. Waders – buffer zones

We previously (Rydell et al. 2011) proposed buffer zones of 500 m around important breeding- and resting localities for waders. We meant to include breeding localities on shore-meadows, mires, bogs and bird islets that harbor red-listed species or species in Annex 1 of the Bird Directive, which includes all listed waders except golden plover *Pluvialis apricaria* and greenshank *Tringa glareola*, or localities with high densities of waders except those on arable fields. With resting localities we meant shore-meadows and coastal localities with high densities of waders on stop-over or resting, except localities on arable fields. We did not define what we considered as "many".

SOF-BirdLife proposed buffer zones of one km around sites used for breeding or display for a suite of threatened or neat threatened species of waders. These are the ruff *Philomachus pugna*x, the greater snipe *Gallinago media*, the southern dunlin *Calidris alpina schinzii* and the red-tailed godwit *Limosa limosa*. We propose that the two recommendations are combined in the future and thus used together. For the particular red-listed species mentioned above we recommend the use of one km buffer zones around breeding- and display-sites. In remaining cases we recommend 500 m buffer zones.

We also explain what we mean by ”many resting waders” and suggest that areas which regularly hosts at least 1% of the Swedish breeding population of any species of wader, or regularly at least 500 waders of all species taken together, shall be considered as such. Population sizes for all bird species nesting in Sweden can be found in Ottosson et al. (2012). The buffer zones should apply from the edge of the area in question, not from the exact location where the birds have been observed or from the exact positions of the nests or display sites.

3z. Gulls and terns – buffer zones

Our recommendation of one km buffer zones around colonies with at least ten breeding pairs of species within these groups (Rydell et al. 2011) remains unchanged. The zone should start at the outer edge of the colony. SOF-BirdLife does not specifically address gulls and terns in their recommendations, but lists, among other things, bird islets as habitats that should not be used for construction of wind turbines, and mention that one km buffer zone should be used where wind turbines can be expected to affect bird occurrences in current areas. In practice this means exactly the same as in the recommendation above.

3å. Eagle owl – buffer zones

No new knowledge about the impact of wind turbines on eagle-owls has emerged and thus our (Rydell et al. 2011) and SOF-BirdLife recommendations remain as in the past, i.e. two km buffer zones around eagle-owl nests.

3ä. Nightjar – buffer zones

Although impact of wind turbines on nightjars has not been documented and remains uncertain, we consider that implemented Swedish inventories indicate marginal interference. At the same time it is well known that nightjars regularly fly long distances (several kilometers) in search of food and, therefore, employing buffer zones around places with calling males may have limited effect in reducing the risk of fatal accidents. Therefore, we consider that buffer zones are not necessary to protect nightjars, but we recommend continued monitoring within post-construction programs.

SOF-BirdLife recommends that areas with dense occurrences of nightjars should be exempted from wind farming for precautionary reasons, and, although we do not suggest the use of buffer zones, we agree with this to some extent. Hence, we recommend that dense occurrences of nightjars (>2 territories per km^2) in natural environments, such as sparse pine forests in rocky habitats or on bogs or the equivalent, should be exempted from wind power establishment. However, we do not see much benefit from exempting such occurrences on recently clear-cur areas or young planted forests. In these cases the birds will move as soon as the forest grows older and denser.

3ö. Beyond site-specific evaluation and mitigation measures

An increasing number of researchers agree that we may not be able to avoid negative impacts on biodiversity from the expansion of the renewable energy industry and other ”necessary exploitation”, by employing only, for example, buffer zones and direct actions at individual locations that we decide to exploit. Increasing criticism is also heard against the site-specific assessment case by case that is the routine not only in Sweden but also in many other countries. New and more comprehensive approaches are required. Kiesecker et al. (2010, 2011a) believes that more strategic, large-scale planning must be used to identify areas where impacts are minimized and others where exploitation can be accepted. At the same time, such a management implies that sufficiently large areas are set aside to protect biodiversity and where exploitation is not permitted. By combining the strategic, large-scale planning with the action hierarchy we mentioned in section 3n, the best results may be achieved with respect to biodiversity as well as renewable energy development. Grünkorn et al. (2016) use the same way of thinking. These ideas are results of the fact that the present wind industry in northern Germany is likely to adversely affect the populations of some birds of prey. Therefore, the authors suggest that areas which currently have with high densities and good breeding results for certain species and which are without wind power plants must be set aside and be given formal and permanent protection. At the same time, programs are proposed to improve the quality of the environment and to some extent compensate for the mortality caused by wind turbines. This could be done in terms of improved access to food, better protection of nesting sites and by reducing other anthropogenic mortality. This could all be achieved within the framework of regional large-scale planning. In this concept, generation shift of old wind turbines to new ones should also be made, so that the number of existing wind power plants in areas with many wind turbines can be reduced while the production of wind energy can increase at the same time.

In the US it has recently been suggested that construction of wind power facilities could be concentrated to areas that are already exploited and/or otherwise disturbed by human activity. A possible way to achieve this would be to launch a planning system that makes projections in already disturbed areas cheaper, while projections in relatively undisturbed or unexploited areas or areas with high natural values would be more expensive (Kiesecker et al. 2011b). Such ideas have not been used in Europe so far, but could perhaps be another way of allowing the expansion of the wind power industry with as little impact on biodiversity as possible. Köppel et al. (2014) argue that much more of so-called adaptive planning must be used to limit negative impacts on biodiversity. Adaptive planning means that in connection with the expansion of wind power plants, the consequences should always be carefully monitored so that any negative effect will be followed by measures to limit or reverse it. Continued monitoring will then provide an opportunity to test the most suitable solutions for the particular location and the specific problems that have arisen. Köppel et al. (2014) believe that in this way, it will be possible to authorize the building of wind power facilities in more places than if the decisions are based on initial risk assessments alone.

4. Summary and evaluation of Swedish post-construction programs

4a. Completed and on-going programs

We have found 27 post-construction programs for birds implemented in Sweden during the period 2001–2016 (Figure A 4.1, Table A 4.1 and A 4.2). Most but not all of them were imposed on the projectors by the decision-making authorities. The majority has been carried out in southern Sweden, while six programs were executed in northern Sweden. Programs in forest habitats dominate with 17 programs, followed by four programs on agricultural land, three marine programs, two in low mountain areas and one at a site with coastal meadows. Eight of the programs have been restricted to a single year (in four programs as a follow-up of a previous study), five of them have continued for two years, six for three years, two for four years and six for at least five years. Some of the programs are still running, such as the one at Sidensjö wind farm in the north, which will continue for at least ten years. In 15 of the programs, carcass searches under the turbines have been carried out. More than half of the programs have been designed as before-after-studies, and in these cases changes in bird occurrences after the wind turbines were built have been analyzed. A control program at Näsudden, Gotland was made as a before-after study at a generation shift of wind turbines in an existing park. Most of the programs involving carcass searches have, for natural reasons, been made only after the construction of the wind turbines, but in two cases, both studies of breeding birds and search have been carried out at the same site. One program involving estimates of bird densities was made as a post-construction study with an associated reference area. Six of the programs claimed to have followed up the impact on migrating birds. In eleven of the programs, particular species or groups of birds have been in focus. Most frequently, such particular interest has been on eagles, but also red-throated divers, gyrfalcon, nightjar and wetland birds such as waders and ducks have been designated target species. All control programs in our compilation with the exception of two were/are carried out by the owners of the wind farms or by their consultants. One of the control programs (no. 10) was carried out on a private initiative by local ornithologists (mainly K. E. Axelsson), who surveyed nightjars in a large wind farm and another (no. 23) was made by Seppo Ekelund on his own initiative and included birds as well as bats. The latter includes a thorough carcass search and is one of only four Swedish programs in which bird carcasses were placed in the field to monitor their removal rate (Table A 4.3).

Figure A 4.1. Map showing the localisation of the post-construction programs reviewed in this report.

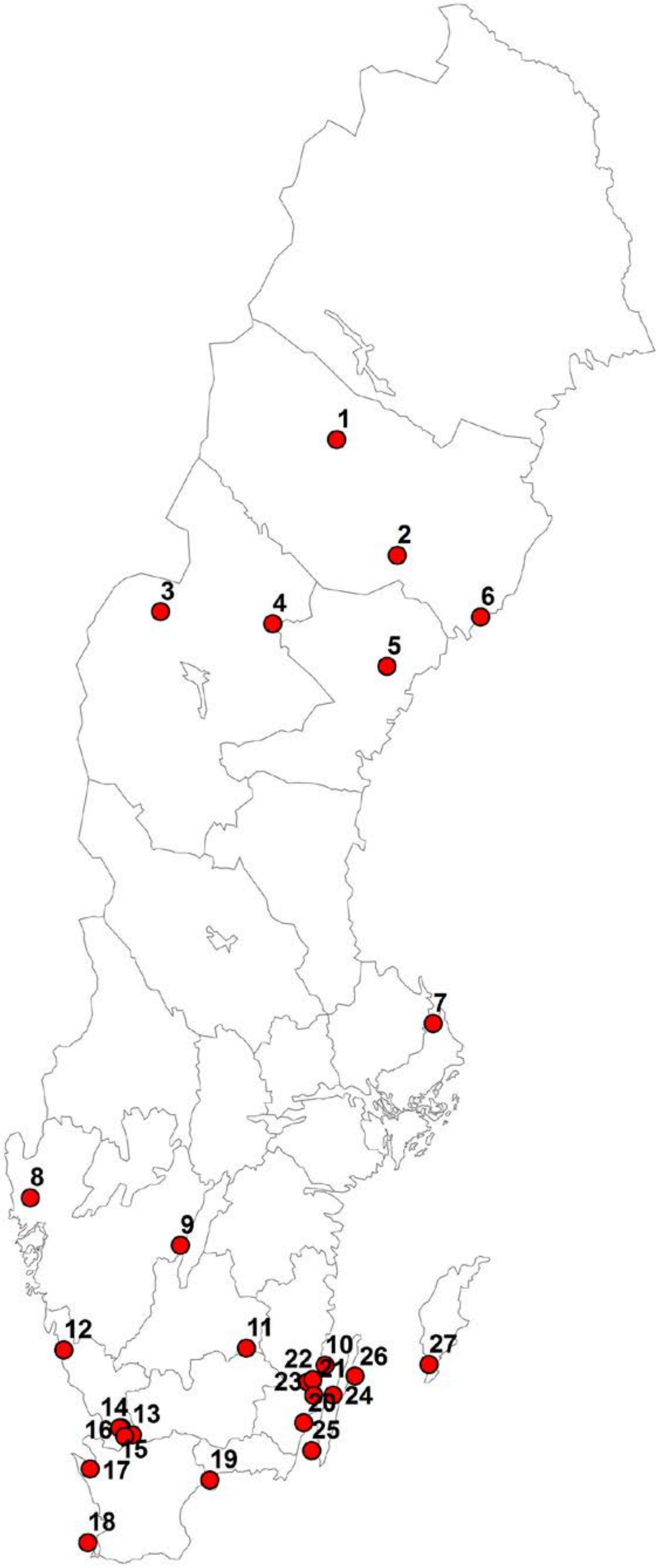

Table A 4.1. Post-construction programs carried out at Swedish wind farms 2001–2016, together with their respective methodology and content.

No.	Name	Habitat	Year	No. of turbines	Type of survey	Carcass search	Density and breeding success	Species specific study	Migration
1	Storblaiken	Alpine	2010–15	90	Before-after		x		
2	Stor-Rotliden	Forest	2009–12	40	Before-after		x	Golden eagle	
3	Storrun	Alpine	2003–11	12	Before-after	x	x	Gyrfalcon and golden eagle	x
4	Stamåsen*	Forest	2012–16	26	Before-after	x		Golden eagle	
5	Sidensjö	Forest	2012–15	48	Before-after		x	Red-throated diver and waders	
6	Hörnefors	Forest	2011	11	Before-after	x	x	White-tailed eagle	x
7	Varsvik	Forest	2015	8	After	x			
8	Dingle-skogen	Forest	2014–16	14	Before-after		x	Nightjar	
9	Skalleberg	Forest	2015	10	After	x			
10	Em	Forest	2012–13	4	After	x			
11	Lemshult	Forest	2012–15	32	Before-after		x	Nightjar	
12	Västra Derome	Forest	2015	6	Before-after		x	Nightjar	
13	Grytsjö	Forest	2014	12	Before-after		x		
14	Uddared	Forest	2014	9	Before-after		x		
15	Skogaby	Forest	2014–15	4	After	x		Eagles	
16	Oxhult-Kåphult	Forest	2011–12	19	After		x		x
17	Rögle-Västraby	Arable	2014–16	13	After	x		Eagles	
18	Lillgrund	Marine	2001–11	48	Before-after		x	Sea-birds	x
19	Lönneborg	Arable	2015	2	After	x			
20	Vassmolösa	Arable	2015	5	After	x			
21	Idhult	Forest	2011–13	9	After	x			
22	Skräppentorp	Forest	2011–13	1	After	x			
23	Rockneby	Forest	2013–15	5	After	x			
24	Räpplinge	Arable	2013–15	4	After	x			
25	Utgrunden	Marine	2006–08	7	After				x
26	Kårehamn	Marine	2011–12	16	Before-after			White-tailed eagle	x
27	Näsudden	Coastal	2009–13	66	Before-after	x	x		

* includes Stamåsen, Bodhögarna, Ögonfägnaden, Björkhöjden och Björkvattnet.

Table A 4.2. Localisation and company of ownership or outsourcer for the programs carried out at Swedish wind farms during 2001–2016, together with references to relevant articles and other reports for respective program.

No.	Name	County	Municipality	Company	References
1	Storblaiken	Västerbotten	Storuman and Sorsele	Blaiken Vind AB	Grensman 2015
2	Stor-Rotliden	Västerbotten	Åsele	Vattenfall Vindkraft AB	EKOM 2013
3	Storrun	Jämtland	Krokom	Storuman Vindkraft AB	Falkdalen et al. 2013
4	Stamåsen*	Jämtland and Västernorrland	Strömsund and Sollefteå	Statkraft SCA Vind AB	Enetjärn Natur 2014b, Falkdalen 2015
5	Sidensjö	Västernorrland	Örnsköldsvik	Nordisk Vindkraft AB	Enetjärn Natur 2015a
6	Hörnefors	Västerbotten	Hörnefors	Umeå Energi	Umeå Energi 2012
7	Varsvik	Uppland	Norrtälje	Holmen Energi AB and Varsvik AB	Ekelund 2015a
8	Dingle-skogen	Västra Götaland	Munkedal	Rabbalshede Kraft AB	Enetjärn Natur 2015b
9	Skalleberg	Västra Götaland	Hjo	Eolus Vind AB	Ekelund 2015b
10	Em	Kalmar	Mönsterås	Statkraft Sverige AB	Björkman 2013
11	Lemnhult	Jönköping	Vetlanda	Stena Renewable AB and private initiative	Axelsson 2012, 2013, 2014
12	Västra Derome	Halland	Varberg	Varberg Energi AB	Naturcentrum 2015b
13	Grytsjö	Halland	Laholm	Stena Renewable AB	Naturcentrum 2015c
14	Uddared	Halland	Laholm	Stena Renewable AB	Naturcentrum 2015a
15	Skogaby	Halland	Laholm	Arise AB	Arise 2015, Ottwall 2015
16	Oxhult-Kåphult	Halland	Laholm	Stena Renewable AB	Ottosson 2012
17	Rögle-Västraby	Skåne	Helsingborg	Vardar Vind AB	Enetjärn Natur 2016b
18	Lillgrund	Skåne	Malmö	Vattenfall Vindkraft AB	Nilsson & Green 2011
19	Lönneborg	Blekinge	Sölvesborg	Eolus Vind AB	Ekelund 2015c
20	Vassmolösa	Kalmar	Kalmar	Eolus Vind AB	Ekelund 2015d
21	Idhult	Kalmar	Mönsterås	Arise AB	Arise 2011, 2013a,b
22	Skräppentorp	Kalmar	Mönsterås	Arise AB	Arise 2013b
23	Rockneby	Kalmar	Kalmar	Eolus Vind AB	Ekelund 2015e
24	Räpplinge	Kalmar	Borgholm	Eolus Vind AB and private initiative	Ekelund 2015f
25	Utgrunden	Kalmar	Mörbylånga	Enron Wind and Eon AB	Pettersson 2011
26	Kårehamn	Kalmar	Borgholm	Eon Vind Kårehamn AB	JP Fågelvind 2014
27	Näsudden	Gotland	Gotland	Stugyi AB and others	Hjernquist 2014

* includes Stamåsen, Bodhögarna, Ögonfägnaden, Björkhöjden och Björkvattnet.

4b. Carcass searches

Of 15 control and follow-up programs with post-search studies, at least one wind power-killed bird was found in nine programs and at six sites no dead birds were found. There was a large variation in the number of birds found within each program, which can be explained by several factors. The number of searches made is of course an important source of variation, as well as the number of turbines visited each time, but the environment in which the wind turbines were located was also an important factor.

On the bird-rich shore meadows at Näsudden on the island of Gotland, 281 bird carcasses were found at 27 investigated wind turbines during five years of study (Hjernquist 2014). This corresponds to just over two carcasses per turbine and year. By placing dead birds on the ground below the turbines and monitoring their disappearance and their detection rate by the searchers, values of the carcass removal rate and the searcher efficiency could be estimated. Calculations based on these parameters estimated the bird mortality per wind turbine at Näsudden to 21–37 birds per year. The variation was dependent on whether the turbine in question was a small and older turbine or a higher, more modern one.

The wind farm in Rögle-Västraby in Skåne was put into operation in January 2016 and a retrospective study began at that time. By January 2017 at least ten dead birds of prey of five species (white-tailed eagle, common buzzard, red kite, kestrel and peregrine falcon) had been found. Most of these were not found in the post-construction study but rather during spontaneous searches by others (Svahn & Dahlén 2017). In this study, experiments to estimate the carcass removal rate and searcher efficiency are ongoing. The calculations of actual mortality have not yet been made, but the number of dead birds of prey suggests that actual mortality, at least for raptors is rather high in this particular wind park.

At wind farms located in forests and farmland, relatively few dead birds have been found generally, but Stamåsen may be an exception in forest environment and perhaps Rögle-Västraby in agricultural environments. At Stamåsen a trained dog was used to improve the carcass searches. A dog was also used in the Storrun wind power plant, in Hörnefors and partly in Idhult as well. A dog not only searches faster than a human, it is also significantly more effective and finds a significantly higher proportion of the dead birds on the site (Paula et al. 2011). A trained and experienced dog finds virtually all bird remains, including single feathers. In addition to the study at Näsudden, the control programs in Storrun and Rögle-Västraby, as well as the follow-up in Räpplinge, have been sufficiently extensive and included experiments as mentioned above and scientifically based calculations of the number of fatalities. In Storrun, for example, it was estimated that at least 0.5 willow ptarmigans were killed at each wind turbine per year.

At the wind farm on the open farmland in Räpplinge, eight small bird carcasses disappeared within 3.5 and 8 days. At Näsudden, 27.5% of the carcasses remained after a week while at Storrun 50% remained after 10 days. In the wind farm Rögle-Västraby, about 60% of the carcasses remained after one week. Of the carcasses that remained and thus were possible to detect, 58% were found by the searchers. At Näsudden, the searchers found 32.5% of the carcasses that remained and hence were detectable.

The methodologies used in the respective programs have varied considerably. For example, the number of visits at the site varied between 8 and 560. The extent of the searched area also varied considerably. In four programs a 40 m radius around the turbines was used, in two programs a 50 m radius and in five programs 100 m radius. In two programs, squares with 100 m sides were employed, and finally in two studies rectangular areas of 120 × 126 m were used. Altogether, the searches resulted in 365 bird carcasses and 61 species identified. By comparison with Table 5.4 in Rydell et al. (2011), we can now add 27 species that have not previously been documented as being killed at Swedish wind turbines. This means that at least 80 bird species have now been found dead under wind turbines in Sweden. Obviously, some bird species or groups have been found in much higher numbers than others.

In the list of species in Table 4.3., it is mainly the willow ptarmigan in Storrun's wind farm that stands out. Four years of post-construction studies at Näsudden resulted in detection of 32 laughing gullls *Larus ridibundus*, 27 mute swans *Cygnus olor*, 21 common larks *Alauda arvensis*, 20 lapwings and 17 mallards *Anas platyrhynchos*. Carcasses of birds of prey were few but still overrepresented relative to their presence at Näsudden. This was also true for waders in the fall as well as for gulls and terns during spring and autumn.

4c. Local bird densities

In eleven post-construction programs, the development of the resident local bird community has been followed up after a wind power establishment. At the southern localities these efforts have only included nightjar and a few other species, usually raptors. In many cases, the program has only been a repetition of the pre-construction survey, and usually made only during a single post-construction season. The three programs carried out in the north have been more extensive, where surveys prior to the establishment have also been included in the programs. In particular, the post-construction surveys at the Storrun wind farm covers many bird groups and employ a well-developed and thought-out methodology that requires a lot of time investment.

Table A 4.3. Carcass searches for birds at Swedish wind farms 2000–2015.

No.	Name	Year	Month	No. of turbines	Experiment	No. of searches	Total no. of carcasses found	Species and numbers recovered
3	Storrun	2010–11	Feb–Dec	12	x	29	26*	Willow-ptarmigan 18, lesser crossbill 3, fieldfare 2, redwing 2, golden plover 1
4	Stamåsen	2013–14	Mar–Jun and Aug–Oct	12–26		14	35	Black cock 5, fieldfare 5, redwing 4, caf-finch 4, thrush 3, crossbill 3, wagtail 2, rough-legged buzzard 1, hazelhen 1, ringed dove 1, swallow 1, brambling 1, greenfinch 1, siskin 1, redpoll 1, reed bunting 1
6	Hörnefors	2010–11	April–May and Aug–Sep	3		28	0	
7	Varsvik	2015	May–Sep	8		8	1	White-tailed eagle 1
9	Skalleberg	2015	May–Aug	10		8	0	
10	Em	2012–13	Mar–Oct	4		16	7	Mute swan 1, mallard 1, tawny owl 1, ringed dove 1, swift 1, fieldfare 1, jay 1
15	Skogaby	2014–15	May–Sep	4		33	3	Ringed dove 1, swift 1, house martin 1
17	Rögle-Västraby	2016–17	Dec–Feb	13		5?	10	White-tailed eagle 3, common buzzard 3, red kite 2, kestrel 1, peregrine falcon 1 (several found outside the study)
19	Lönneborg	2015	May–Sep	2	x	8	0	
20	Vassmolösa	2015	May–Oct	5		12	0	
21	Idhult	2010–13	Jan–Dec	8	x	120	3	Capercaillie 2, goldcrest 1
22	Skräppentorp	2012–13	Jan–Dec	1	x	43	0	
23	Rockneby	2013–15	Jun–Sep	5		15	0	
24	Räpplinge	2013–15	Mar–Oct	4	x	560	9	Mallard 1, common buzzard 1, swift 1, house martin 2, lark 1, wheatear 1, pipit 1
27	Näsudden	2009–13	Jan–Dec	27	x	214	281	41 species: ducks, geese and swand 100, song birds 73, gulls and terns 67, waders 23, raptors 7, others 11
Total							**365**	

”No. of turbines” means the number of turbines investigated, not the total number of turbines in the park. ”Experiment” mens that placing of dead birds (or raw meat balls ad Idhult and Skräppentorp) were used to estimate carcass removal rate and/or searcher efficiency.
* Just 9 fatalities from the wind turbines and 17 feather remains that may och may not represent wind turbine fatalities.

The post-construction program on Näsudden on Gotland, with the purpose of monitoring the effect of the generation shift of the turbines, included inventories of mainly the breeding bird population, but also the temporary resting migrants. In this case, a decline of 20% in the number of bird pairs was noted over the period 2009–2013, but this decline could probably not be explained by the replacement of the old turbines (based on our own analysis using data from the County Administrative Board "Länsstyrelsen", Gotland). There are no indications that the bird populations present during autumn, winter and spring was affected by the generation shift of the turbines.

The number of calling nightjars seems to have declined by about 20% in the Lemnhult wind farm in Småland 2012–2016 (Axelsson 2012, 2013, 2014, Axelsson personal communication) while the numbers remained unchanged in two other wind farms, namely in Dingle-Skogen and in Derome in Västra Götaland and Halland, respectively (see section 3l). Comparisons in southern Sweden between inventories made before and after the construction of wind power plants, suggest that the number of birds of prey has remained unchanged or increased slightly To some extent the increases can be explained by the expansion of the red kite north of Skåne and the establishment of territories within or near wind farms in e.g. Halland and Västra Götaland.

In the three northern programs at Storrun, Storblaiken and Stor-Rotliden, slight declines in the occurrence of some species were observed over the monitoring periods, but overall there were no changes that could be attributed to the wind power construction. In the wind park Storrun, surveys of territories were conducted in a way so that the registered birds could be related to distances to wind turbines. This inventory showed reductions for several species of small birds within 50 m of wind turbines, but no significant changes at a greater distance. It should be noted that three display sites of black cocks remained intact even after the construction of the power plants in the Stor-Rotliden wind farm, including one lekking site within 100 m from one of the turbines.

In the post-construction programs that we have compiled, little or no impact on the local bird populations have been demonstrated. However, as the programs have been of short duration so far, we cannot exclude that future or ongoing studies that will continue over longer time eventually may detect such changes.

4d. Actively migrating birds

Post-construction monitoring at three marine wind farms, one located in Öresund, one in Kalmarsund and one in the Baltic Sea a few kilometers east of Öland, have focused on actively migrating birds at sea. The main results of these surveys show that moving seabirds usually change the flight course and flight altitude 1–2 km from the wind farm, to avoid approaching the turbines. Radar studies have shown that birds avoid flying in the absolute vicinity of the wind turbines also at night. The conclusion from these surveys is that the risk of accident with wind turbines for most birds moving over the sea is low.

Already in 2011 (Rydell et al. 2011) studies were conducted which indicated that even moving migratory birds of prey avoid flying near wind power plants to some extent A post-construction program at Hörnefors wind farm showed that an overwhelming majority (97.5%) of all migrating birds avoided flying through the park, which consisted of eleven turbines, and rather flew over or around it. This also included other large birds like swans, geese and cranes. However, rough-legged buzzards as well as gulls and terns more regularly passed the wind farm, but about 40% of the rough-legged buzzards changed the flight course to avoid the wind turbines.

5. Suggestions for new guidelines

5a. Evaluation of the methodology used 2001–2016

Carcass searches

Examination of 15 completed post-construction programs that included carcass searches revealed that the number of visits has varied between eight per season and weekly or nearly daily visits throughout the year. The searched area around each wind turbines has varied between 40 m circle radius and just over 100 m radius or in some cases searched areas were rectangular. For three studies, trained dogs have been used to improve the searches. Experimental placing of carcasses for estimation of search efficiency and disappearance time has been conducted in two studies, and estimation of disappearance time alone has been made in another study. In most cases, these studies have not been very illuminating, and even when dead birds were found, mostly contributed to the general statistics. For example, it seems likely that if no bird carcasses were found after eight completed searches, the risk of wind-turbine caused accidents is quite low in this location, but nevertheless the number of searches has been too few in several surveys. Since bird carcasses may disappear quickly and the inventor's search efficiency may be limited, the number of dead birds found can be gross underestimates of the real number of fatalities. In addition, birds hit by the wind turbine's rotor blade may travel far beyond the searched area, where they are never recovered, and such "cryptic deaths" can of course never be included in the estimates of bird mortality at wind turbines. In any case, eight searches per season is far from enough to provide a meaningful estimate of the number of wind-turbine killed birds at a site.

Bird inventories

There are actually only two programs that so far have included well-conducted inventories of breeding birds, namely the Storrun and Näsudden programs. Other programs have essentially made rather limited and basic surveys during one or a few years and compared it to the result of a one-year inventory that was made before the wind farm was built. However, it should be mentioned that within some ongoing programs that concern, for example, red-throated diver, golden eagle and nightjar, inventory and follow-up studies are made using standardized and solid methodology. However, it is still too early to provide definitive statements about these programs.

5b. Function and design of post-construction programs

A problem with the assessment of the impact on local bird populations is that it may be difficult to obtain a sufficiently large sample for a useful statistical analysis at the local level. But if several inventories from different places are combined, it may be possible to make comprehensive analyzes with more universal results. Therefore, it is important to carry out further surveys of birds before and after construction of wind power plants. To facilitate combination of different surveys and comparisons between them, it is essential that the inventories are standardized and implemented in a similar manner. Improved understanding of the impact of wind power on, for example, birds of prey, black cock, capercaillie and nightjar, therefore requires that the studies are designed as a contribution to an overall analysis. When standardized data are available from a number of programs, the possibilities to make scientifically based conclusions increase.

In some of the post-construction programs, one or more reference areas have been used for comparison with the development in the wind farm. In addition to the fact that it is difficult to draw scientific conclusions with only one studied area (the wind farm) it is not always easy to find reference areas comparable in terms of habitat and bird occurrence. We therefore suggest that when selecting a reference area in connection with a wind power establishment, it may be convenient to consider use of data from the National Environmental Monitoring in Swedish Birdwatching (www.fageltaxering.lu.se) as well.

5c. Execution of post-construction programs

Carcass searches

So far, we lack general knowledge about how many birds are killed in Swedish wind turbines. Therefore, it is of general interest that such data is collected so that we can better assess mortality rates in different environments, for different species and bird groups. For some species it is particularly important to obtain better data on mortality levels at Swedish wind turbines. First and foremost, we are thinking of long-lived species such as birds of prey and some disputed species such as capercaillie and nightjar. In some cases it may also be of interest to follow up local bird populations in order to investigate specific questions. In localities with eagles or other birds of prey, requests to investigate the movements of the birds have been presented during the pre-construction phase, partly so that the locations and numbers of turbines can be adjusted accordingly, and partly to make before-after studies of the birds' behavior and use of the area. However, if there are concerns about the impact of wind power on birds of prey in an area, we believe that it usually is better to focus on carcass searches than making observations of the flight behavior. However, if carcass searches are to be made, it is essential that they are made properly. Preferably, searches should be conducted at least once a week during at least the most important periods of the year, and it is essential that estimates of the disappearing rate and search efficiency of observers with or without dogs are obtained experimentally, so that meaningful calculations of the actual fatality rate can be made. Note that using bird types other than those that would be expected in the actual area for experimental purposes may not provide correct results (Urquhart et al. 2015).

To make the search more efficient, dogs are often preferred. In a circular area with a radius of 100 m, a dog can complete the search in 10–30 minutes, while it often takes 1–2 hours for a person to go through the same area. It is advisable that the search area has at least 100 m radius around the wind power plant, but it may be hard in difficult terrain to perform without a dog, especially in woodland or forest habitats. It is difficult for a person to find bird carcasses in high vegetation, but this is largely unproblematic for a trained dog. When the terrain is uneven or rocky, one may need to search along denser lines, as carcasses can remain in leeward positions and therefore be more difficult for the dog to find. The larger the wind turbines and the rotor blades, the larger the search areas need to be in order to cover the area likely to receive killed and/or injuring birds. This means that the search surface should be adapted to the size of the wind turbines and rotor blades. A realistic alternative to total search within the entire surface area is to examine parts of the surface, e.g. those where it is easiest to find carcasses, and to compensate for those parts in the analysis.

Bird inventories

If post-construction programs are to contribute towards better knowledge of the effects of wind power plants on birds, it is important that the inventories are executed using standardized methodology and experienced field personnel. In order to facilitate future bird inventories, a very first methodology for bird studies related to wind power has been published by Vattenfall (Haas et al. 2015). The catalog is freely available at https://corporate.vattenfall.se/globalassets /sweden/hallbarhet/rapporter/ metodkatalog_for_fagelinventering_2015_10_06.pdf. This catalog is intended to be a living document that develops as inventory methods develop, and partly to be a reference tool for authorities, wind farm companies and other interested parties. The catalog proposes a number of different types of bird surveys that can be performed depending on the part of the country and habitat. Methods that can be used in connection with pre-construction surveys and environmental impact assessments as well as for post-construction controls and follow-up programs are reviewed.

We recommend that the methods included in this methodology directory are used in future surveys and monitoring programs related to birds and wind power. Since it is seldom possible to make a statistically assured impact of wind power in a particular location, it is important to keep in mind that collected data may be included in a larger material for overall analyzes. It is therefore by no means necessary that bird surveys or follow-up studies at wind farms are costly research projects. Indeed, it may be more important that they follow a standardized method and provide accurate pictures of the situations both before and after a wind power establishment.

It is desirable with more than one year of inventory before the wind turbines are in operation. To date, there have also been too few post-construction monitoring programs of the birdlife extending over a longer period of time. In order to remedy this, it would desirable if post-construction programs could be followed up with additional surveys also after five and ten years. It may take even longer before impacts from exploitation become noticeable, especially for some particularly long-lived species, and in such cases, it may be reasonable for even further follow-up periods. Such surveys or counts do not necessarily need to be annual but may, for example, be carried out as recurring inventories.

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7. References

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B. BATS

1. Introduction

Wind turbines harm bats primarily because the rotor blades hit and kill bats that fly at such altitudes. This happens quite frequently and the problem has increased considerably in recent years as more and more wind farms are constructed and as this industry spreads over an increasing part of the globe. We have also acquired a better understanding about the magnitude of the negative effects particularly in an international perspective. In contrast, there are few improvements when it comes to our understanding of other possible effects that wind turbines may have on bats, such as fragmentation of their feeding grounds because of road construction and the like. For bats, research and mitigation efforts are still almost totally concentrated on the problem that bats may be killed when they fly near the moving rotors. The estimates on the number of bats killed at wind turbines that we published earlier (Rydell et al. 2011) were apparently much too low. At present there is concern that some bat populations particularly in North America already have been seriously affected by the increased mortality at wind turbines.

After our previous reports about the effect of wind turbines on bats (Rydell et al. 2010 a, b, 2011) many new international compilations and reviews have been published, for example by Smallwood (2013), who makes an interesting comparison between bats and birds, Ellison (2012), Rodrigues et al. (2015), Arnett et al. (2015), Peste et al. (2015) and Barclay et al. (2017). There are also several theoretical studies where mathematical models have been used to understand and predict how wind farm establishment may affect bats and bat populations (for example Roscioni at al. 2012, 2013, Santos et al. 2013, Ferreira et al. 2015). We refer to these publications for more information and a deeper analysis than we can provide in this report.

2. Methods

The literature search for this project was made in 2015 and 2016 and the material we obtained was also used for two international reviews written in cooperation with international research authorities on the bat and wind turbines problem. One of them (Barclay et al. 2017) is a summary of our present knowledge about why bats are killed at wind turbines. In the other review (Arnett et al. 2015), the problem about bats and wind turbines is considered in a global perspective. Hence, the material used for this report was obtained and evaluated in close cooperation with leading international expertise in the field.

To summarize and evaluate the reports of Swedish post-construction projects about bats we obtained the background data and other information by contacting the relevant wind farm companies, decision makers, and consultants directly and asked them to share the data with us. This straight-forward method usually (but not always) worked smoothly and without problems.

We have been directly responsible for some of the projects summarized in this review. Some of the reports from these projects have been published in the scientific literature (Rydell & Wickman 2015a, Rydell et al. 2016) while others are in the process of being published and has been presented orally (Pettersson et al. 2016). In these publications the research is presented in more detail than there is space for in this report.

3. Updating current knowledge

3a. Mortality at wind turbines and its variation

The estimates of the number of bats that are killed at wind turbines that we presented in the previous synthesis (Rydell et al. 2011) have turned out to be far too low. This is partly because some of the surveys that were included in the summary were incomplete with respect to the methodology and in some cases were restricted to part of the season. In some cases the estimates were not properly compensated for the fact that many carcasses are never found because they have been carried away or eaten by predators or scavengers or are hard to find because they have ended up in places that are difficult to search because of dense vegetation or outside the searched area. It is also likely that some bats are hit by a moving rotor but in a way that is not immediately fatal but may cause damages that may be fatal later so that bats finally die elsewhere. Such cases are called cryptic deaths and because the carcasses are never found their number is unknown and does not appear in the statistics. We are not aware of any estimate of the number of cryptic deaths.

Several recent summaries of the death statistics from different countries tell a similar story, namely that the fatality rates are higher than we anticipated earlier (but sometimes declining dramatically; see section 3d "Effects on populations" below).

In Germany the average fatality rate seems to be about 10–12 bats per turbine per year plus an unknown number of cryptic deaths (Voigt et al. 2012). Some places are much more dangerous than other places, however, so the variation is high from site to site. Numbers from southern Europe suggest similar or even higher fatality rates (Dubourg-Savage et al. 2012, Camina 2012, Georgiakakis et al. 2012) but there too is a lot of variation. At some particularly dangerous places in southern Europe up to 100 or more bats are killed per turbine and year.

A recent summary of surveys at 62 wind farms in Canada, where the estimated fatality rates were controlled for predator removals, searching efficiency and the searched area, show approximately the same thing (Zimmerling & Francis 2016). On average 15.5 bats are killed per turbine per year but again with a high variation between the different wind facilities (0–103 per turbine). This means that Canadian wind turbines currently kill about 47 000 bats per year, and, if their numbers increase according to the plan, 166 000 in 15 years, unless the development plans are associated with active and efficient mitigation measures that lower the mortality rate. Of the killed bats as much as 73% belong to only three migratory species. A compilation from USA gives a similar picture (Hayes 2013).

The increased mortality of bats at wind farms is no longer of concern only for Europe and North America, where the problem was first recognized, but has become a global issue as the wind industry rapidly extends to other parts of the world as well. Countries where the problem has recently been recognized include, for example, India (Kumar et al. 2013), Taiwan (Chou et al. 2017), Australia (Hull & Cowthen 2013), South Africa (Aronson et al. 2013, Dothy & Martin 2013, McEwan 2016), Mexico (Villegas-Patraca et al. 2012), Chile (Escobar et al. 2015), Brazil (Barros et al. 2016) and Puerto Rico (Rodriguez-Durán & Feliciano-Robles 2015). In contrast, we found nothing from China, the country in the world with by far the highest number of wind turbines.

Bats that are killed at wind turbines do not only belong to migratory species, as often assumed some years ago (Kunz et al. 2007, Arnett et al. 2008), but local and non-migratory populations are also affected (Barclay et al. 2017). This certainly applies to the tropics but also to e.g. southern Europe and other warm areas. In Spain, for example, the migratory populations are absent during the period in late summer, when most fatalities occur, because they are in the northern breeding grounds (Ibañez et al. 2009). Rather than the migratory behaviour, it is the species' foraging and movement patterns that determine if it is vulnerable at wind turbines or not. The species that are adapted to feed and move in more or less open air above the trees, using fast and straight flight, comprise the great majority of the bats killed at wind turbines everywhere in the world (Barclay et al. 2017). In northern Europe and North America several such species are also long-distance migrants, which is associated with fast flight in open terrain.

We still have no data from Sweden that can be compared with the estimated mortality in other countries. How many bats that are killed at Swedish wind turbines therefore still remains unknown. It would seem likely that fewer bats are killed in Sweden compared to more southern latitudes but this still has to be documented. There seems to be a trend with higher fatality rates in warmer climates, but at the same time we should not rely on this assumption. Relatively few bat carcasses have been found under wind turbines in Sweden, compared to Germany and southern Europe, for example, but our surveys are not done as thoroughly and intensively, so we would be careful to make any detailed comparisons. This also applies to wind turbines off shore. We are not aware of any survey at a marine wind park where an estimated fatality rate has been presented.

3b. How bats are killed at wind turbines and why

Bats that have died at wind turbines have either been hit by moving rotors or been trapped in the turbulence around the moving wing, where rapid changes in the air pressure have caused fatal damage to vital organs such as blood vessels, the heart, lungs and ear-drums, so called barotrauma (Baerwald et al. 2008, Brownlee & Whidden 2011, Grotsky et al. 2011, Rollins et al. 2012). The tips of a wind turbine rotor move at a speed that is much higher than a bat is adapted to and capable of handling, and in principle there is no way a flying bat can avoid an approaching rotor wing even if is detected at some distance. This also means that there is no way that bats ca learn to avoid the danger of a wind turbine rotor.

Is has been suggested that bats collide with wind turbine rotors more or less randomly, simply because they happen to be in the wrong place at the wrong time and without realizing the danger or being unable to detect it in time. This is the simplest of the hypotheses used to explain why bats are killed at wind turbines and is still adhered to by many researchers worldwide (Barclay et al. 2017). The increased mortality at wind turbines in late summer is assumed to be related to the autumn migration period, when many bats pass through a given area in a short period (Cryan & Barclay 2009) but it seems more likely that bats in general move higher and over larger areas at the end of the summer (Staton & Poulton 2009, see also section 4.3 below). Such movements could be related to the large scale movements of insects in the atmosphere at this time of the year (e.g. Rydell et al. 2010 b), and, in contrast to what we believed earlier, more or less independently of structures on the ground such as roads and hedges, for example. In contrast, such habitat features are very important for the movements of bats at low elevation, for example when they commute between roosts and feeding sites in the open farming landscape (Verboom & Huitema 1997, Kelm et al. 2014).

There are several studies indicating that bats sometimes are attracted to wind turbines (Cryan et al. 2014, Roeleke et al. 2016) but why this happens is still not clear. The most likely explanation in our view is that wind turbines sometimes attract insects which in turn attract bats. The bats are then assumed to visit the turbines actively to evaluate if there is food to find (Kunz et al. 2007). One possible reason why there may be insects at the top of wind turbines is that many insects do just that, namely gather at the highest point such as a hill-top, a high tree or a high building. The behaviour is called hill-topping and has been known for a long time. It occurs in many different insects particularly during mating and migration (Rydell et al. 2010b).

Wind turbine towers absorb heat during the day, because they are made of metal, and therefore attract flies and other insects that depend on external heat sources. Some of them remain on the surface overnight and are probably captured there by bats (Dudek et al. 2016, Rydell et al. 2016). It has been shown recently that bats really are attracted to the turbines and also that they behave almost exactly as expected if they were engaged in insect capture on or near the tower surface (Horn et al. 2008, Hale et al. 2013, Cryan et al. 2014, Rydell et al. 2016). Investigations of the stomach contents of bats found dead under wind turbines, including some locations in Sweden, have shown that the type of insects that sit on the tower surface also are eaten by the bats that forage there, but it also shows that many other insects are eaten as well (Reimer et al. 2010, Valdes & Cryan 2013, Rydell et al. 2016). The insect hypothesis is still speculative to some extent, although we think it is the hypothesis that has the most support.

There are also other hypotheses that may explain why bats are killed at wind turbines, however, but there is little supporting evidence. For example, it has been suggested that ultrasonic noise produced in the nacelle may have an attractive effect on bats, but this does not seem to be the case (Barclay et al. 2017). The warning lights on top of the turbine towers have also been suggested to have an attracting effect, but this too seems unlikely (Bennett & Hale 2014).

Another idea, one which has received more attention, is that a wind turbine tower may function as a roost or mating station. The attractiveness of a tower to bats is thought to be because they are the highest structure in the vicinity and therefore may be "mistaken" for tall trees (Cryan 2008). There is some support for this hypothesis with respect to the tree-roosting red and hoary bats (*Lasiurus borealis* and *L. cinereus*) in North America, but it seems unlikely as a general explanation of why so many different bat species are killed at wind turbines worldwide (Barclay et al. 2017).

We also would like to point out that wind turbines should not be lit by flood-lights and the like, because lights (particularly UV) attract insects that may attract bats. Installation of lights on wind turbines would most likely increase the number of bat fatalities and make the problem worse.

3c. Small and tall turbines

With respect to the effects on bats, nearly all attention has so far been on tall wind turbines, which means those with towers at least 130–150 m, while almost nothing has been said about the small turbines, those with total heights of 20–50 m and/or rotors with diameters of at least 3 m. However the small turbines seem to have some impact on bats, but mostly because bats tend to avoid foraging in their immediate vicinity. Nevertheless bats are sometimes killed at such facilities, presumably because they often are located near farm buildings where bat colonies may occur and they operate at the height where many bats routinely move (Minderman et al. 2012, 2015). In summary, small wind turbines do not seem to have any major effect on bats, although the evidence for this conclusion is quite weak.

It was shown some years ago that the height of the turbines is important for how many bats that are killed. There are more fatalities at higher turbines on average (Barclay et al. 2007). However, the survey did of course not include the highest turbines that are in operation today. It is not known if the same conclusion would still apply today, when some turbines are 200 m high or more.

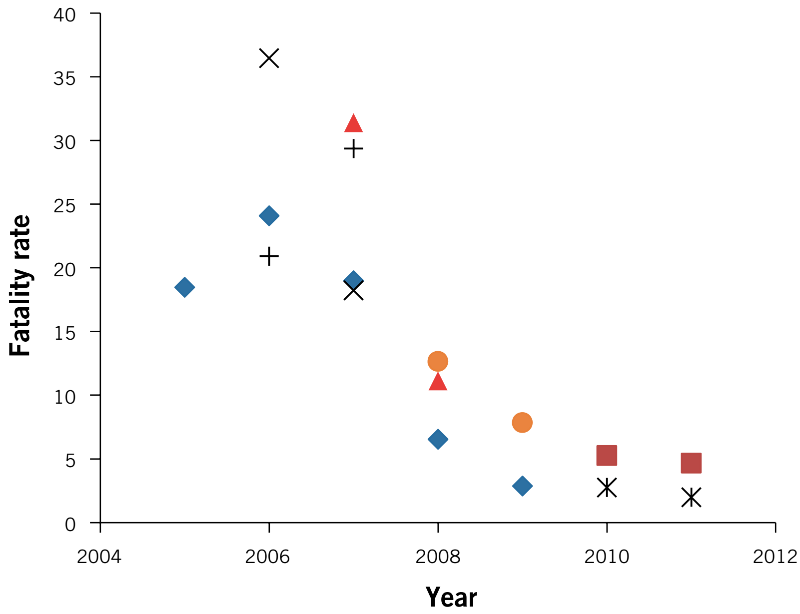
3d. Effects on populations

Unfortunately, reliable estimates of the size of bat populations are still rare or missing and it is therefore impossible to estimate if and how the increased mortality due to the wind turbines affect bats at the population level. This problem is by no means restricted to Sweden or EU but applies globally and to virtually all species of bats. Hence any effect that wind farms may have on bat populations would probably be difficult to detect and estimate. Hence, with the present knowledge there is no possibility to demonstrate that the mortality observed at a wind farm, for example, have any real effect on the bat population, and this applies locally as well as at the national level.

By analysing the proportions of stable isotopes of carbon and hydrogen in the fur of bats that have been killed during the autumn migration, it can be shown where they resided earlier during the summer, when the new fur was grown. Atoms have slightly different isotope composition in different geographical areas and it has been shown that many of the bats that are killed at wind turbines do not belong to local populations but originate from wide areas, including from areas much further north. This is as expected, because migratory species are often involved. Bats that are killed at wind turbines in Germany, which are mostly long-distance migrants, come not only from Germany but also from the Baltic countries and Russia and to some extent also from Scandinavia (Voigt et al. 2012, Lehnert et al. 2015). In the same way, many bats that are killed at wind farms in USA and southern Canada during migration originated from areas further north in Canada (Baerwald et al. 2014, Pylant et al. 2016), to where they migrate before they give birth. Hence, the effects of wind power plants on migratory bats extend far beyond the national borders and should therefore be handled at the international level (Voigt et al. 2012).

Over a long time concern has been expressed that some populations of bats will not be able to compensate for the increased mortality at wind turbines to maintain the population size and therefore may not survive in the long run (Kunz et al. 2007a). In the past there has been little or no support for this prediction, because the original population sizes and reproductive rates are generally unknown. Nevertheless, the current mortality rate is so high in some areas that it is be hard to see how negative population effects could be avoided. For example, in Germany many migrating noctules *Nyctalus noctula* are subject to high mortality as they pass the 35 000 wind turbines in the country twice per year (Lehnert et al. 2014, Voigt et al. 2015, 2016). Likewise, east of the Rocky Mountains in Alberta, Canada, the number of hoary bats found dead under wind turbines has declined drastically over the period when wind turbines were established in the area 2005–2011 (figure 3.1 and also Barclay et al. 2017). This could be interpreted as an indication of a real decline in the population size, and if so it is probably serious. However, it is by no means certain that the observed trend actually represents a real decline caused by the wind turbines, and the scenario therefore remains speculative.

Figure B 3.1 Decline in the fatality rates of bats observed at seven wind farms in Alberta, Canada 2005–2011.



Fatality rate is the number of bats that died per wind turbine and year, including those that were NOT recovered during the carcass searches. Each wind park was surveyed at least twice and the fatality rate was estimated in the same way each time. The symbols represent the different wind farms. Thanks to Prof. Robert Barclay, Calgary University, for permission to use this figure.

3e. Mitigation measures

The first measure to consider when trying to minimize the risk that bats are killed at wind turbines is to avoid establishment in the wrong place, which means where bats of certain high-risk species live and move more or less regularly. These places are often the same for bats and birds, generally speaking. We have discussed this in some detail earlier (Rydell et al. 2011), so we feel no need to repeat it. However, when it comes to the barbastelle *Barbastella barbastellus*, a rather rare and threatened (red-listed) bat species, which because of its presence in forests in southern Sweden has stopped several wind farm projects, the situation is a little different. Research under the Vindval program to investigate how barbastelles react to wind turbines is currently ongoing. The results will almost certainly lead to revisions in the guidelines on how we should handle this species with respect to wind farms.

In an operating wind turbine the best way to protect bats is to halt the rotors during specific periods when there is a high the risk that bats will move near the rotor and get killed. This is the most important mitigation measure under the conditions prevailing in Sweden, and it has been tested and evaluated several times (Baerwald et al. 2009, Arnett et al. 2011, 2013a, Brinkmann et al. 2011). The method is not a 100% insurance against bat fatalities, but used the right way it can mitigate the fatality rate by about

60–90%. A difficulty is, however, that it must be determined when the rotors should be halted in relation to time of the year, wind speed, temperature and perhaps other factors as well. Mitigation is usually recommend when the wind speed is below 4–6 m/s (at the nacelle level), between sunset and sunrise and it is sometimes restricted to a specific period in summer.

Later in this report we will present a suggested mitigation guideline for bats, designed for the conditions that prevail in Sweden. The suggested guide is based on experiences from the post-construction surveys that we review in this report.

Other methods to discourage bats from approaching wind turbines have also been tried, but they require introduction of other environmental pollutants such as UV-light (Gorresen et al. 2015), ultrasound (Arnett et al 2013b), or radio waves (radar; Nicholls & Racey 2009) of more or less high intensity. We believe that halting the rotors is clearly preferred, as long as it works efficiently, because it is passive and does not introduce any other potential problems secondarily.

4. Summary and evaluation of Swedish post-construction programs

4a. Completed programs

This compilation deals with post-construction surveys and monitoring in its various forms. Such programs are made after the construction and start of the wind turbines and with the purpose of

a) Controlling or following up the environmental consequences of the installation
b) Deciding if the current mitigation measures are adequate and if they are executed according to the permission
c) Assessing the need of additional measures, such as halting the rotors to protect bats, for example, in the specific wind farm, and how such measures should be designed

The post-construction survey and monitoring programs would normally include an estimation of the fatality rate caused by the specific wind turbines, or, since this has proven very difficult and expensive in practice, a measurements of something that can be assumed to be closely related to the fatality rate such as the amount of activity of bats near the place where bats are killed. This is done using automatic ultrasound detectors placed at the turbine tower and with the microphone mounted on the nacelle house connected to the detector through a cable.

We found 22 post-construction programs that involved bats, executed and reported before the end of 2015. They are summarized in tables B 4.1 and B 4.2. Most but not all were programs imposed by the deciding authorities, but there are also some programs that were initiated voluntarily by the prospecting companies or the owners (e.g. no. 1, 5, 13, 14 and 21). One of the programs (no. 11) was initiated and carried out by a private person alone. We include it here because it is one of few relatively thorough post-construction bat surveys made in this country so far, with 560 carcass searches over three years and with 10 carcasses found (table B 4.3).

The programs have included carcass searches and/or acoustic monitoring of bat activity and sometimes also occurrence of insects at the surface of tower and/ or nacelle. Several programs only included carcass searches. Six programs were designed as before-after studies, which mean that bat activity was measured both before and after construction of the turbines.

Most programs were carried out in areas with more or less intensive forestry (production forests) and consequently there is a considerable bias towards this habitat type. Just two marine (off-shore) wind parks are represented, both located in the Baltic Sea but within a few km from the shores of Gotland and Öland, respectively. There is also a strong over-representation of wind farms in the south (Götaland), which is because this part of the country was exploited first and therefore more programs have been reported to date. Just one program has been completed in the northern half of the country so far (figure B 4.1), although several programs have recently been initiated there.

Figure B 4.1. Localization of the 22 post-construction programs for bats that are summarized in this report.

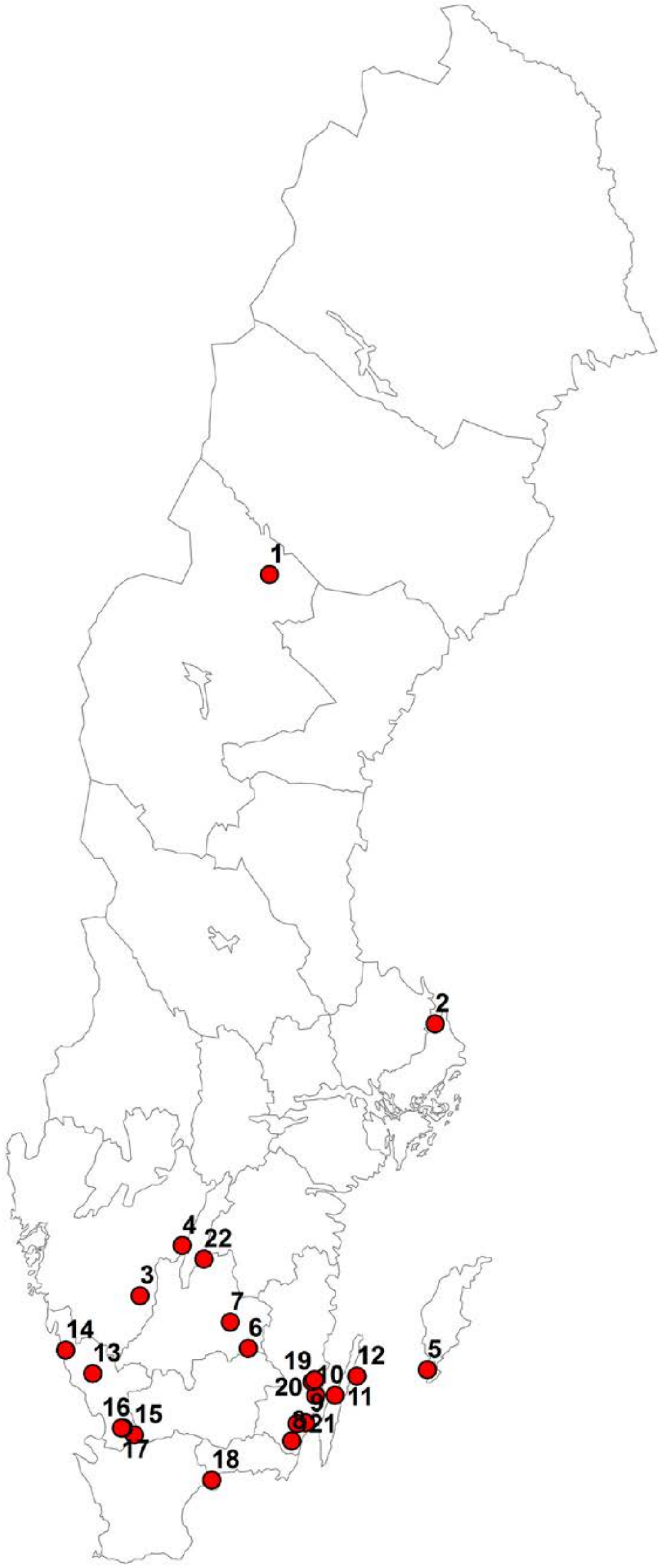


Table B 4.1 Summary of the post-construction programs that include bats and were carried out in Sweden until 2015, the methodology used and the contents.

No.	Name	No. of turbines	Habitat	Year	Design	Carcass search	Activity ground	Activity tower
1	Havsnäs	48	Production forest	2012	After		x	x
2	Varsvik	17	Production forest	2015	After	x	x	x
3	Bondegärde	3	Production forest	2013	After	x	x	
4	Skalleberg	10	Production forest	2015	After	x		
5	Bockstigen	5*	Marine	2013	After		x	
6	Lemnhult	33	Production forest	2013–15	After	x	x	x
7	Stensåsa	8	Production forest	2014–15	Before-after	x	x	x
8	Kvilla	6	Production forest	2014	Before-after		x	x
9	Vassmolösa	5	Production forest	2015	After	x		
10	Rockneby	5	Production forest	2013–15	After	x		
11	Räpplinge	4	Agriculture	2013–15	After	x		
12	Kårehamn	16	Marine	2014	Before-after		x	x
13	Askome	10	Production forest	2014–15	After	x	x	x
14	Västra Derome	6	Production forest	2014–15	Före-efter	x	x	x
15	Grytsjö	12	Production forest	2014	After		x	
16	Uddared	10	Production forest	2014	After		x	
17	Skogaby	15	Production forest	2014–15	Before-after	x		
18	Lönneborg	2	Agriculture	2015	After	x		
19	Idhult	8	Production forest	2013	After	x		
20	Skäppentorp	1	Production forest	2013	After	x		
21	Mortorp	6	Production forest	2015	Before-after		x	
22	Brahehus	9	Production forest	2014–15	After	x	x	

* indicates older (1997–1998) and smaller (56 m) turbines than used in the other wind farms (all modern and >150 m).

Table B 4.2 Geographical localization and owners/commissioners for the 22 programs involving bats and that were completed until 2015.

No.	Name	Province	District	Company	References
1	Havsnäs	Jämtland	Strömsund	Eon AB	Gunnarsson et al. 2013
2	Varsvik	Uppland	Norrtälje	Holmen Energi AB	Eklöf 2016*
3	Bondegärde	V Götaland	Ulricehamn	Eolus Vind AB	Rydell 2014*
4	Skalleberg	V Götaland	Hjo	Eolus Vind AB	Ekelund 2015d*
5	Bockstigen	Gotland	Gotland	Wickmanvind AB	Rydell & Wickman 2015
6	Lemnhult	Jönköping	Vetlanda	Stena Renewable AB	Eklöf 2015*
7	Stensåsa	Jönköping	Vetlanda	Eolus Vind AB	Rydell 2015*
8	Kvilla	Kalmar	Torsås	Green Extreme AB	EnviroPlanning 2016a*
9	Vassmolösa	Kalmar	Kalmar	Eolus Vind AB	Ekelund 2015e*
10	Rockneby	Kalmar	Kalmar	Eolus Vind AB	Ekelund 2015b*
11	Räpplinge	Kalmar	Borgholm	Private initiative	Ekelund 2015c*
12	Kårehamn	Kalmar	Borgholm	Eon AB	Ecocom 2015*
13	Askome	Halland	Falkenberg	Askome Vind AB	Rio Göteborg & EnviroPlanning 2016a*
14	Västra Derome	Halland	Varberg	Varbergs Energi AB	Rio Göteborg & EnviroPlanning 2016b*
15	Grytsjö	Halland	Laholm	Stena Renewable AB	Naturcentrum 2015a*
16	Uddared	Halland	Laholm	Stena Renewable AB	Naturcentrum 2015b*
17	Skogaby	Halland	Laholm	Arise AB	Arise 2016*
18	Lönneborg	Blekinge	Sölvesborg	Eolus Vind AB	Ekelund 2015a*
19	Idhult	Kalmar	Mönsterås	Arise AB	Arise 2013*
20	Skäppentorp	Kalmar	Mönsterås	Arise AB	Arise 2013*
21	Mortorp	Kalmar	Kalmar	Green Extreme AB	Enviro Planning 2016b*
22	Brahehus	Jönköping	Jönköping	OX2	Enviro Planning 2016c*

* indicated that the report is unpublished and found in reference list 7b. The other reports are found in 7a.

4b. Carcass searches

Programs include carcass searches in order to estimate the fatality rate of bats at a particular wind farm or turbine. The purpose of the survey is to evaluate if mitigation is needed and ideally also to assess the impact or potential impact on local and migratory populations. To obtain a reasonably accurate estimate of the fatality rate it is necessary to make many and regular searches and obtain sufficient numbers of carcasses to make a meaningful statistical analysis. It has turned out that the mortality is very unevenly distributed over the season, with most (about 90%) of it occurring in August and September. This pattern is generally the same throughout Europe and North America, but the mortality is more spread out over the year at lower latitudes (Arnett et al. 2015, Barclay et al. 2017). Therefore it is essential that the searches are made regularly and over a sufficiently long period so that the annual variation is covered.

The carcasses found during a survey only represent a minimum mortality, and it does not tell much about the real mortality until the number of carcasses that were **not** found has been estimated as well.

Carcasses may be missed by the observer because

a) Scavengers have removed the carcass before the search
b) The carcass is not found although it is still there. For example, it could be hidden in dense vegetation or it may be missed for other reasons
c) The carcass may fall outside the searched area, either beyond the recommended 50 m search radius or within but in a place that is not searched for other reasons

The first two (a and b) must be estimated experimentally for each place and searcher separately, e.g. according to the Eurobats guideline (Rodrigues et al. 2014). Other descriptions are also available, based on work in USA (Kunz et al. 2007b) and Germany (Brinkmann et al. 2013). It is usually necessary to compensate for differences in search efficiency between various parts of the searched area. The gravel plain and road next to the turbine are usually very easy to search, while other areas may be difficult or even impossible to search efficiently such as field with growing crops or other dense vegetation (Huso & Dalthorp 2013). There are several different models that can be used to calculate the fatality rate based on data from carcass searches (e.g. Jain et al. 2007, Huso 2010, Bernardino et al. 2013, Korner-Nievergeld et al. 2013) and there is also a free web-based calculator for the purpose (http://www.wildlifefatalityestimator.com/).

Bats sometimes survive a collision with a wind turbine rotor and manage to leave the area but may die later from injuries on e.g. lungs and blood-vessels, ears-drums or other vital organs. The number of such "cryptic deaths" is usually impossible to estimate (Klug & Baerwald 2010). In reality, we should compensate for a–c above and then be aware that there is also additional mortality of unknown magnitude.

In total 16 programs involving search for bat carcasses have been made in Sweden. They are summarized in tables B 4.4 and B 4.3. Most of them have been made in the simplest possible way and with few searches, resulting in far too few (0–10) carcass recoveries per program. There are no cases where the experiments needed to compensate for a–b (scavenger removal and searching efficiency) have been made, and in many cases the figures were not even adjusted for c (the searched area). This means that we, despite 16 programs with carcass searches, still have none completed and executed in the correct way, and therefore, we still have no reliable estimate of the fatality rate of bats at any wind farm in Sweden. Hence, there is no way we can compare the impact of wind turbines on bats in Sweden with those in other countries, e.g. Germany (Voigt et al. 2012), southern Europe (Camina 2012), USA (Hayes 2013) and Canada (Zimmerling & Francis 2016) in a meaningful way.

We have named certain species of bats “high-risk species” (Rydell et al. 2011). This group includes the common noctule *Nyctalus noctula*, the parti-coloured bat *Vespertilio murinus*, the northern bat *Eptesicus nilssonii*, the soprano pipistrelle *Pipistrellus pygmaeus* and Nathusius’ pipistrelle *P. nathusii* (and potentially also the lesser noctule *Nyctalus leisleri*, the serotine *Eptesicus serotinus* and the common pipistrelle *Pipistrellus pipistrellus*, all of which are much rarer). “High-risk” does not necessarily mean that the species is rare or threatened, but that it suffers a relatively high risk of being killed at wind turbines. In table 4.4 we list the English and Latin names of the species involved.

The results of the search efforts show that the high-risk bat species are killed at Swedish wind farms predominantly in August and September. This is by no means new, however, and agrees with previous experience and observations from elsewhere (Rydell at al. 2011, Arnett et al. 2016). The number of recoveries are surprisingly few (1–10 per program), which either means that the fatality rate really is low at Swedish wind farms or that the search efforts were too low overall and therefore resulted in a serious under-estimate of the real fatality rate. Before we can distinguish between the two and arrive at a useful estimate of the fatality rate, we first have to estimate a, b and c, according to what we have said before. We believe that the number of searches is sufficient in some of the programs and it could be possible to estimate the fatality rate for these sites, provided the required experiments are carried out. Ongoing studies at some sites near the coast in southern Sweden suggest that the fatality rates at these sites are comparable with those estimated in Germany (on average 10–12 fatalities per turbine and year; Voigt et al. 2012). There will probably be fewer fatalities inland and towards the north, compared to the southern coastal areas. However, we emphasize that this is yet no more than an educated guess.

Tabell B.4.3. Summary of the carcass searches carried out at Swedish wind farms until 2105. The species referred to listed in table B 4.4.

No.	Name	Year	Period	No. of turbines searched	No. of visits	Total no. of searches	No. of carcasses found	Species	Month
2	Varsvik	2015	May–Sep	8	6	48	0		
3	Bondegärde	2012	Jul–Oct	3	5	15	0		
		2014	Aug–Oct	3	14	42	0		
4	Skalleberg	2015	May–Aug	10	8	80	3	1 Ppyg, 2 Enil	Aug x 3
6	Lemnhult	2013	Jul–Sep	5	3	15	0		
		2014	Jul–Sep	6	3	18	0		
		2015	Jul–Sep	6	3	18	2	1 Nnoc, 1 Ppyg	Aug, Sep
7	Stensåsa	2015	Aug–Sep	8	3	24	1	1 Ppyg	
8	Kvilla	2014	Sep	6	2	12	5	4 Nnoc, 1 Ppyg	Sep
9	Vassmolösa	2015	Feb–Oct	5	12	60	0		
10	Rockneby	2013	Jun–Sep	5	5	25	2	2 Nnoc	Aug x 2
		2014	Jun–Sep	5	5	25	6	3 Nnoc, 3 Ppyg	Aug x 6
		2015	Jun–Sep	5	5	25	1	1 Nnoc	Aug
11	Räpplinge	2013	May–Oct	4	50	200	5	1 Nnoc, 2 Ppyg, 2 Enil	Aug x 3, Sep x 2
		2014	May–Oct	4	50	200	2	1 Nnoc, 1 Ppyg	Sep x 2
		2015	May–Oct	4	90	360	3	3 Ppyg	Jun, Aug x 2
13	Askome	2015	Jun–Oct	10	12	110	1	1 Enil	Aug
14	Västra Derome	2015	Jun–Oct	6	11	66	0		
17	Skogaby	2014	May–Sep	4	16	62	0		
		2015	May–Sep	4	16	64	0		
18	Lönneborg	2015	May–Sep	2	8	16	0		
19	Idhult	2013	Jul–Aug	8	15	120	1	1 Vmur	Aug
20	Skäppentorp	2013	Jul–Aug	1	15	15	0		
22	Brahehus	2014	Aug–Sep	9	4	36	1	1 Ppyg	Aug
		2015	Aug–Sep	9	4	36	3	3 Ppyg	Aug, Sep x 2
Tot							32	17 Ppyg, 13 Nnoc, 5 Enil, 1 Vmur	Jun x 1, Aug x 22, Sep x 8

To estimate the fatality rate of bats at wind turbines by using the carcass search method has turned out to be extremely time-consuming, quite complicated and therefore not very cost-effective, if done properly. Because this method has still not been used in full in Sweden, and our experience with it is very limited, it is not suitable for routine work prior to decisions on mitigation measures. For this, we need faster and more efficient tools. Monitoring the activity of bats using ultrasonic detectors mounted on the turbine is such a method that seems to work well. There is a close association between the activity of bats near the rotor and the risk that the bats will be killed there (Kunz et al. 2007, Baerwald & Barclay 2009, Amorim et al. 2012, Korner-Nievergeld et al. 2014).

Table B.4.4 The "high-risk" species of bats that relatively frequently are found dead under wind turbines in Sweden and in the rest of Northern Europe.

Latin name	English name	Acronym
Nyctalus noctule*	Common noctule	Nnoc
Nyctalus leisleri	Lesser noctule	Nlei
Pipistrellus pygmaeus*	Soprano pipistrelle	Ppyg
Pipistrellus pipistrellus	Common pipistrelle	Ppip
Pipistrellus nathusii	Nathusius' pipistrelle	Pnat
Vespertilio murinus*	Parti-coloured bat	Vmur
Eptesicus nilssonii*	Northern bat	Enil
Eptesicus serotinus	Serotine	Eser
Plecotus auritus*	Brown long-eared bat	Paur

* indicates that the species has been found dead under wind turbines in Sweden. The other species are more or less uncommon in Sweden but are relatively often found dead under wind turbines in other parts of northern Europe. The brown long-eared bat is not considered a high-risk species, but nevertheless has been killed at a wind turbine in Sweden.

4c. Acoustic monitoring of bat activity

Monitoring the activity of bats with ultrasonic detectors (bat detectors) is a relatively simple and cheap way to find out which species occur in a certain area and how they use the various habitats therein. The purpose of measuring bat activity in a proposed wind park could be, for example, to determine if any of the high-risk species occur there and how their presence varies seasonally. Pre-construction surveys which are made before exploitation (by definition) as part of and EIA (Environmental Impact Assessment) may have exactly this purpose.

However, it should be remembered that conditions may change quite drastically for bats in an area when wind-turbines are built there. There are not always any close correlation between bat occurrence and activity as measured before construction and how it turns out to be afterwards, which means that pre-construction surveys usually have a low or very low predictive value (Hein et al. 2013, Lintott et al. 2016). Hence, to use recordings made before the turbines were constructed to evaluate the risk that bats will later be killed by the turbines is not very meaningful. Instead, we have to realise that post-construction programs will sometimes be required to evaluate the risk and also if and how mitigation measures are necessary. There is no longer any obvious need for routine pre-construction surveys, particularly since we now have a much better idea about the occurrence and behaviour of the different species involved, compared to just a few years ago. However, if post-construction programs will replace pre-construction surveys as the principal tool for decisions on mitigation schemes, this must be specified and conditioned early in the process. It may be difficult or impossible to present new demands after the permission has already been granted.

In this report we will concentrate on post-construction programs and we largely ignore surveys made before construction. We review seven programs from Swedish land-based wind farms, where bat detectors have been used to monitor bat activity at the turbines. The two marine programs that have been carried out in Sweden will be presented in the next section.

Methods

Continuous monitoring of bat activity with ultrasound detectors requires specific equipment designed for this purpose, and which can be left unattended to collect data automatically for extended periods. The information is stored on memory cards, which have to be replaced more or less regularly. The detectors are usually left inside the tower or the nacelle house and connected with a cable to an external ultrasonic microphone mounted on the tower or the nacelle house. The detectors are most conveniently run on the 220V AC output available inside the turbine tower.

The recordings obtained are subsequently sorted and identified to species or species group, using different software. It has turned out that some species or even different genera are difficult to distinguish on the recorded sounds alone. In particularly, the noctules and the serotine and the parti-coloured bat are sometimes hard to classify. We therefore consistently treat these species as one group. Likewise, we also treat the common, soprano and Nathusius' pipistrelles as one group. Hence, the bat species that have been recorded at rotor height will be grouped as a) noctules/serotine/parti-coloured bat, b) northern bat, c) the pipistrelles and d) brown long-eared bat. The latter has been registered at rotor height at least once and one individual has been found dead under a wind turbine.

The recordings form the detectors have been correlated with wind- and temperature-data for each 10 min period, as provided by the respective wind companies. Ideally, the bat activity has been recorded in relation to wind and temperature for each 10 min period continuously throughout the summer. However, in reality there are more or less extensive gaps in the recordings in several of the programs due to technical or logistic difficulties.

Figure B 4.2 An ultrasonic microphone mounted on the nacelle house and connected with a bat detector inside the tower via a cable.

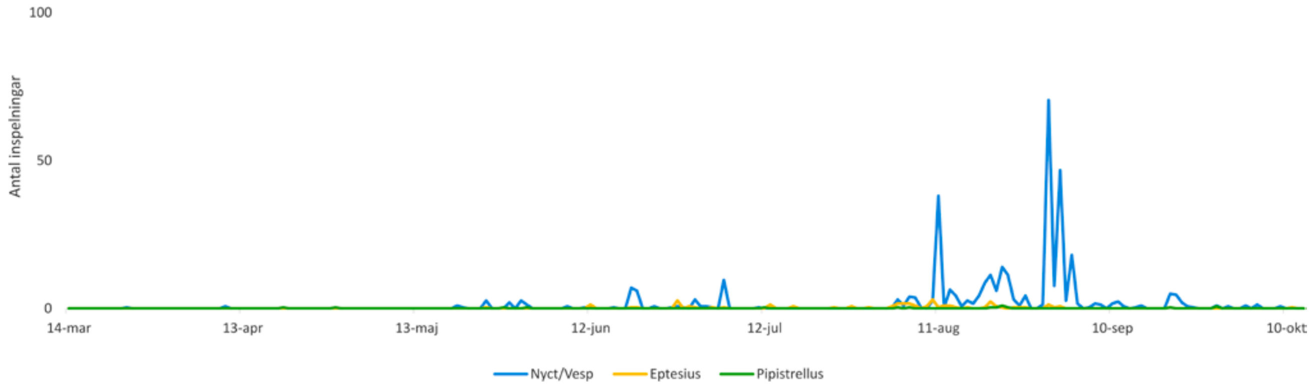
Table B 4.5. Summary of the programs where bat activity has been measured at the nacelle level.

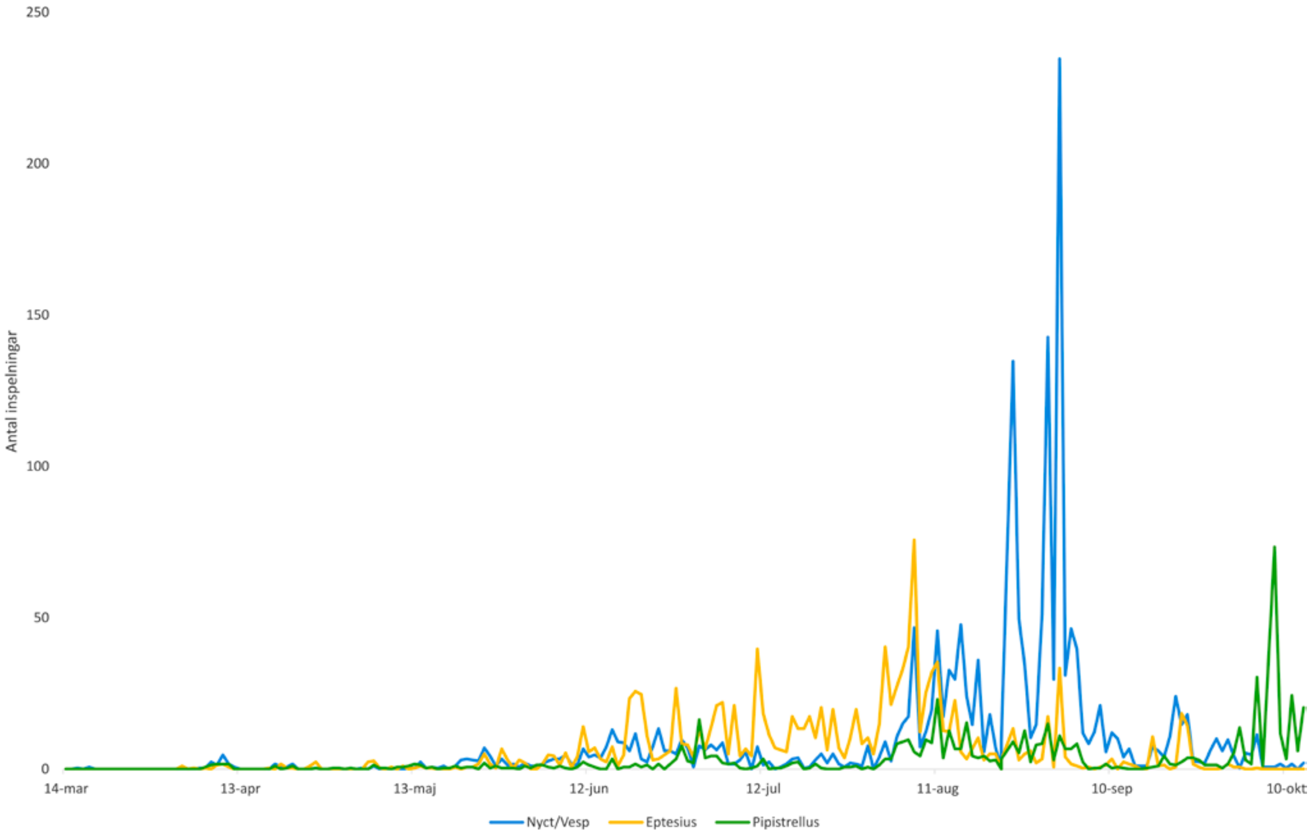
No.	Name	Year	No of. turbines monitored	Period	No. of nights per turbine
2	Varsvik	2015	2	17 Jun–29 Sep	104
5	Bockstigen*	2013	1	14 Aug–20 Oct	50
6	Lemnhult	2014	1	13 Aug–14 Sep	33
		2015	1	10 Aug–15 Oct	65
7	Stensåsa	2014	1	20 Jul–17 Sep	32
		2015	1	20 Jul–28 Sep	42
8	Kvilla	2014	1	29 Jul–15 Oct	76
		2015	3	13 Mar–14 Oct	215
12	Kårehamn*	2014	2	12 May–31 Oct	172
13	Askome	2014	2	25 Jun–6 Oct	103
		2015	2	25 Jun–8 Oct	105
14	Västra Derome	2014	1	26 Jun–28 Aug	62
		2015	1	24 Jun–30 Oct	98

Havsnäs (no. 1) is not included because essential information is missing.

* indicates marine parks. For Bockstigen (no. 5) the activity was measured from the tower, not from the nacelle.

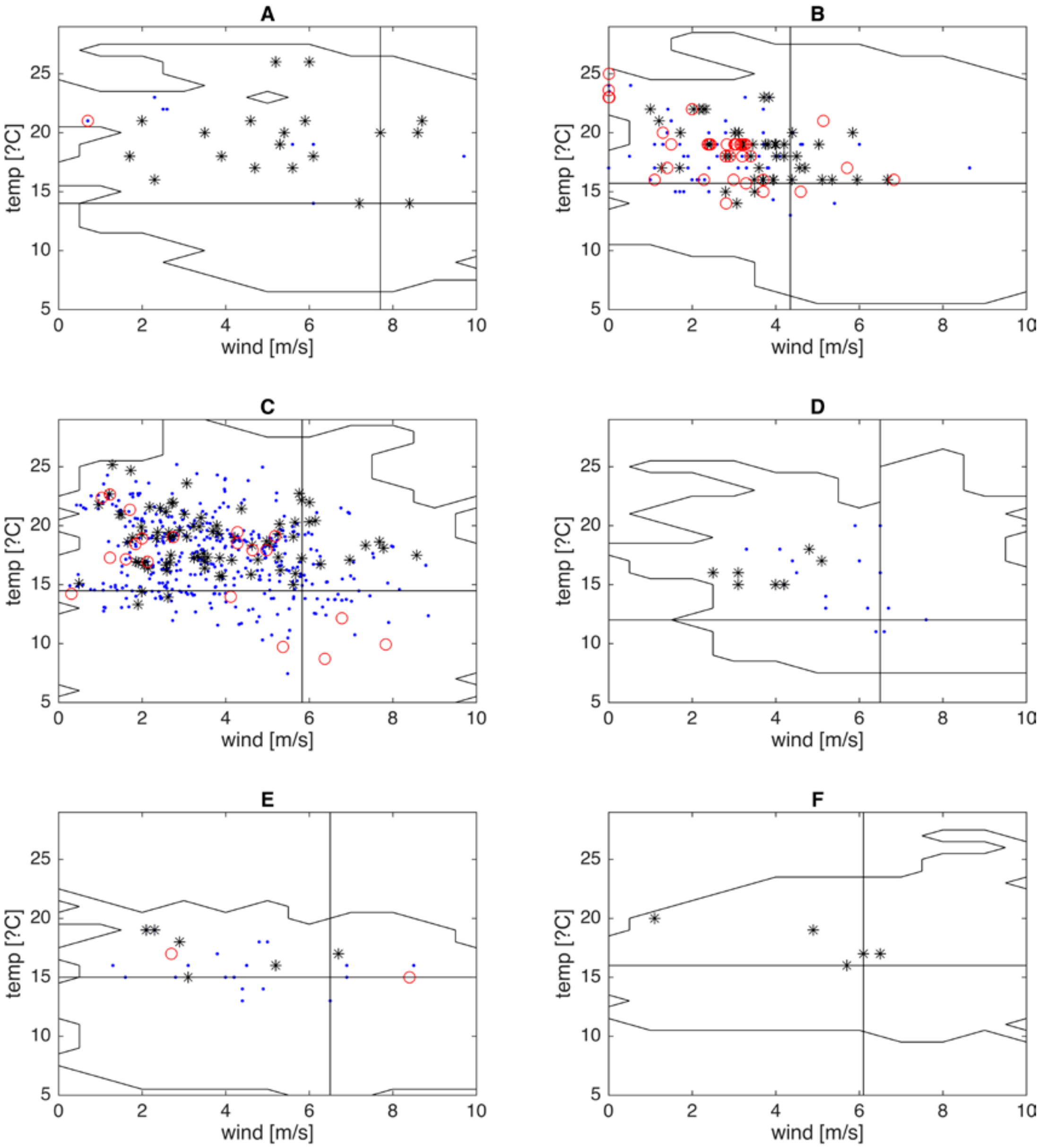
Figure B 4.3.a and b. Activity of bats as recorded at the Kvilla wind farm (no. 8) throughout a full season (2015).





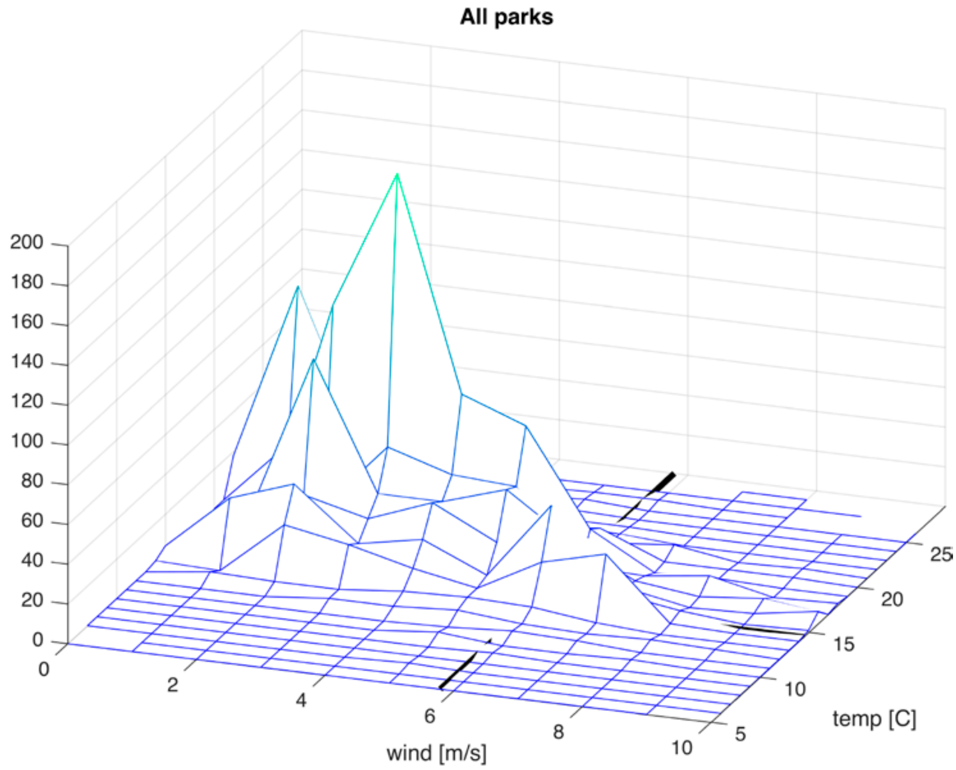
The recordings were made with bat detectors placed at the base of the tower (lower figure) and at ca. 100 m at the nacelle (upper figure). The colours represent the different genera or species of bats (blue = noctules/parti-coloured bats, yellow = northern bat, green = pipistrelles). Species or species groups that are not considered as "high-risk" species (such as the *Myotis* species and the long-eared bats) are not included in this figure.

Figure B 4.4. Bat activity at the top of wind turbines in six Swedish wind farms on shore 2014 and 2015.



The farms are: top left – Västra Derome (no. 14), top right – Askome (no. 13), middle – Kvilla (8) and Stensåsa (7), bottom – Lemnhult (6) and Varsvik (2). The horizontal and vertical lines are the 90-percentiles for wind speed and temperature, respectively, i.e. 90% of the observations are in the upper left quadrant of the figure. The symbols denote the different species groups or species; blue dots = noctules/parti-coloured bats, stars = northern bat, red rings = pipistrelles.

B 4.5 A summary of all bat activity measurements at nacelle level at six on-shore wind farms in Sweden carried out in 2014 and 2015.



The observations are pooled across species, sites and years. The black lines show the 90-percentiles for wind speed and temperature.

Results

Altogether 2030 recordings at rotor height have been made at the six land-based wind parks covered in the report and summarized in figure B 4.3, 4.4 and 4.5. Most of them (80%) were made in late summer (15 July to 15 September), which is in good agreement with observations from other countries (Arnett et al. 2015, Barclay et al. 2017). The overall pattern is most obvious in figure B 4.3, where the activity of bats over a full season at the Kvilla locality (no. 8) is shown. Kvilla is so far the only wind park in Sweden where recordings have been made continuously (without any gaps) from spring to autumn. The activity at rotor height to some extent reflects the activity at ground level but is much lower. When many bats move within or through an area, the increased activity is also evident at the nacelle level, particularly of bats belonging to the noctule/parti-coloured species group.

The bat activity both at the nacelle level and near the ground are very unevenly distributed among the different regions and wind farms. The variation in activity from night to night is also considerable within a single wind farm, even during the time of the year (late summer) when activity is generally highest. The activity at nacelle level shows distinct peaks during certain nights, which, moreover, are rather few (<10) each season. At Kvilla the peaks represent mostly noctules/parti-coloured bats that are increasingly active at this altitude, and if the patterns is the same or not at other sites depends on the presence of these species. At the other wind farms the pattern is not as clear as in Kvilla, partly because the observations have been less consistent and of shorter duration but also because the noctules/parti-coloured bats are less common or absent.

In figure B 4.3 the species groups are shown separately. It is clear that the activity at rotor height is dominated by the noctule/parti-coloured group of bats and this is also evident from figure B 4.4. The great majority of the recordings at rotor height was from this group (n=1669), but also northern bats (n=234) and pipistrelles (n=125) were recorded frequently. We also obtained one recording of a brown long-eared bat from the top of a turbine tower, which shows, a bit unexpected, that this species also could be at risk at wind turbines. We speculate that the long-eared bats fly along the turbine tower, perhaps gleaning insects from the surface (Rydell et al. 2016).

Comparing the different species or species groups in the figures and tables above must be done with some care, because they emit ultrasound of very different amplitude (loudness) and frequency (pitch). Sound of lower frequencies travel further than higher frequencies and sound of higher amplitude also travel further. This means that some species are detected much further away than others. For example, the noctules always are overrepresented because they use very loud pulses and relatively low frequencies (about 20 kHz). Likewise, the pipistrelles are underrepresented since they use higher frequencies (40–60 kHz) and lower amplitudes.

The activity of bats at the nacelle level is concentrated to late summer nights with relatively low wind speed and high temperature (measured at nacelle level, ca. 100 m). Ninety percent off the observations at nacelle level were made when the wind speed was <5.8 m/s and temperature >14.6 °C (figure B 4.4, all data summarized in figure B 4.5).

Figures B 4.4. and 4.5 show that the overall bat activity at nacelle level varies considerably between the different wind farms. At two sites (Askome and Kvilla, no. 8 and 13, respectively) the activity was high, with hundreds of recordings each year, mostly of the noctule/parti-coloured species group, while the activity was much lower at the other sites (5–46 recordings per year). Hence the activity of bats at rotor height varies in a way that we did not really expect, and this means that the need for monitoring and mitigations will also vary considerably from site to site. However, Askome and Kvilla are located at low altitude and in biologically relatively diverse areas near the coast, while the other sites are dominated by coniferous forests at slightly higher altitudes, where bat density in general is much lower. An important and obvious difference between Askome and Kvilla is that the noctules/parti-coloured group is abundant only in the latter place, which means that the need for mitigation is highest there.

Overall the results from the Swedish program are in good agreement with those carried out in other countries (e.g Amorim et al. 2012, Arnett et al. 2015, Barclay et al. 2017), but in this case our measurements at nacelle level were made in a more consistent way and with shorter intervals (10 min), so our surveys are made with higher precision than other work that we are aware of. This is why we can see a more distinct connection between bat activity at rotor height and the weather factors (wind and temperature). Our results, although the data base is still very limited (but growing), will provide a useful guideline for decisions on the need of mitigations measures and their design.

4d. Marine wind farms

Just two post-construction programs from off-shore wind farms in Sweden have yet been completed, both located within 8 km from the shore. However, there is evidence that bats occur much further out at sea, not least during migration (Ahlén et al. 2009, Rydell et al. 2014). The two programs clearly show that individuals of the high-risk bat species, including noctules (Rydell & Wickman 2015), occur at rotor height near wind turbines at least several kilometres from land. The migratory pipistrelle species as well as Daubenton's bat *Myotis daubentonii* and the pond bat *Myotis dasycneme* have also been recorded at wind farms off shore, but the latter two only near the surface, as far as we understand (Ahlén et al. 2009, Ecocom 2015). There is no evidence that the *Myotis*-species are at risk at wind turbines and we do not consider them in need of any particular concern from the wind industry.

In summary, there is no evidence suggesting that we can ignore the bats when planning or operating marine wind farms. The available evidence rather suggests that the same requirements should apply as on land. Hence, it is important that the activity of the high-risk species at rotor level is monitored and that the drift of the turbines is adapted to this and mitigation measures are taken whenever needed.

4e. Northern Sweden

Recent inventories in the northern half of Sweden, made in connection with wind farm establishments, have shown much more abundant and diverse bat faunas than we were aware of only a few years ago, and individuals of the high-risk species may well turn up at wind turbines even in the far north. This is certainly the case of the northern bat that occurs almost throughout the country, except in alpine habitats. However, also other high-risk species such as the migratory pipistrelles, the noctules and the parti-coloured bat, may occur in the north, particularly along the coast.

A single program (Havsnäs, no 1) has been carried out in the north, and it showed activity of northern bats near the ground but there was no activity recorded at rotor height (Gunnarsson et al. 2013). If this pattern is representative for northern Sweden as a whole remains to be seen. At present we do not know how to deal with the expanding wind industry in the north with respect to bats, because we lack much of the basic knowledge about the behaviour of bats under conditions prevailing in the north. This is rather serious because the north is where most wind farms will be established in the near future. A research project under the Vindval Program is on-going, however. It will concentrate on the northern bat and its behaviour with respect to wind turbines in the north. The aim is to evaluate if there is a potential problem and, if so, suggest how it should be handled.

5. Suggestions for new guidelines

5a. Value of pre-construction surveys

The information that can be obtained from a pre-construction survey can be used to assess which species of bats occur in the area, which in turn may be an important piece of information needed to evaluate

a) If the projected area is suitable for wind farm establishment or not
b) If the high-risk species occur or not, which in that case may require a more thorough investigation after construction

If high-risk species such as noctules are already known to occur regularly in the area, a pre-construction survey may not be necessary. In fact, it may be faster and cheaper to plan and introduce mitigation measures (e.g. halting the rotors in calm and warm weather at night in late summer; see below) from the start, and, if necessary, adjust them afterwards based on a more thorough post-construction program. At present we suggest that we should employ the same guidelines for pre- and post-construction surveys and mitigation measures in the north as in the south, but at the same time, as knowledge will improve over the next few years, it may perhaps turn out that surveys and mitigation measures will be less often required in the north.

It has turned out that short surveys, covering only a few days, entirely miss particular species that move over large areas and only occasionally occur in certain areas, but then perhaps sometimes in higher numbers. This applies to programs no. 8 and 21, for example, where the pre-construction surveys lasted only for a couple of days and therefore probably missed important occurrences of noctules, which only was discovered later, during the post-construction programs. The surveys were done correctly and according to the guidelines, so it is the guidelines that need a revision. The lesson from this is that pre-construction surveys, if they are at all necessary, should continue for more than a few days, preferably for most of the season, much longer than suggested previously. As a start, we suggest that it is applied in the same way in the north as in the south.

It has been suggested that activity of bats at rotor height should be measured before construction, by using communication masts or other high towers. However, in our view the value of this is questionable, because bats and insects are not necessarily attracted to a mast in the same way as a turbine tower, which is more massive and therefore stores more heat. It seems possible that it is the heat that attracts at least some insects to wind turbines (Rydell et al. 2016).

Based on the results of the programs reviewed here, for example no. 21, as well as those of other studies (e.g. Lintott et al. 2016), we suggest that pre-construction surveys may be more or less restricted to cases where the suitability of a site for wind farming needs to be evaluated, i.e. should the site be exploitation or not. If a pre-construction survey is required, nevertheless, it should be focused on the period between 15 July and 15 September and it should preferably continue throughout this period. This will reveal which species of bats live and move with the area and also when this occurs in relation to the weather and other factors. It means a much more extensive survey compared to what was recommended earlier, but on the other hand the work can be concentrated to much fewer sites, where the information is really needed, such as in particularly diverse or remote areas which have not been surveyed before. Our knowledge about the occurrence and distribution of bats in Sweden has improved drastically over recent years, partly because of many surveys carried out in connection with wind farm establishment. Short-term surveys before construction no longer provide any new and useful information in most cases.

5b. Evaluation of the methodology

Carcass search

Carcass searches in one form or another were carried out at 16 of the wind farms. The number of searches varied between 2 and 60 per year, depending on the requirements of the deciding authorities. However none of them were carried out in a way that the data could be used to estimate the fatality rate, which actually should have been the principal purpose of the searches. To evaluate the effect of the wind farm on bats based on the result of a carcass search program, much more work is needed. Programs based on a few searches in August and September, and without the experiments needed to estimate the scavenger removal rate and search efficiency, leaves no chance to make conclusions about the fatality rate or the total mortality in the park, contrary to what we expected previously (Rydell et al. 2011). If carried out correctly and at a sufficient scale the carcass search method probably provides the best possible data base to estimate the fatality rate and finally the total mortality in a park. However, the method is very time consuming and therefore expensive to carry out and the experiments require that more personnel is involved.

Activity measurements from the ground

Measurements of bat activity by using a bat detector from the ground can provide information about which species occur in the area and also give an idea about how abundant they are. However, for such a survey to be meaningful requires that the bats are monitored more or less continuously at least between mid-July and mid-September. Obviously this method provides little or no information about movements of bats at rotor height, but it gives good information about which high-risk species occur in the area and how frequently this happens. The common noctule and the parti-coloured bat are the most vulnerable bat species at wind turbines in Sweden, but at the same time the northern bat and the pipistrelles are the most common of the high-risk species and they are the most vulnerable in areas where the noctule and parti-coloured bats are rare.

Activity measurements from the ground can be used for decisions about curtailment or other mitigation measures if made continuously over extended periods. However, if high-risk species are frequently recorded, the survey should be extended and complemented with other methods, primarily a carcass search and/or measurements of activity from a high position such as the nacelle house.

Activity measurements at rotor height

Measurements of bat activity at rotor height using bat detectors should be carried out continuously oven extended periods, and at least from June to September. This is important because most of the activity at higher elevation is concentrated to only a few calm and warm nights each summer, and these can easily be missed if the investigation only continues for shorter periods or single nights. The activity at rotor height is closely correlated with the mortality such as higher activity at rotor height results in higher mortality. This is evident from the programs covered in this report (no. 2, 3, 6, 8, 13, 14) and also from international studies (Kunz et al. 2007, Baerwald & Barclay 2009, Amorim et al. 2012). However, it is still not clear how we should correlate the activity at rotor height with mortality in a quantitative way. The activity that will be recorded depends to a large extent on the equipment used, the detector settings and the direction of the microphone etc. (Korner-Nievergeld et al. 2014). However, since the difference in activity varies to such as large extent among Swedish wind farms (see figure B 4.4), but is consistent within each, it may still be possible to make a at least a rough distinction between "low" and "high" activity sites even if the equipment and settings are not identical.

Continuous monitoring of bat activity using bat detectors is a much cheaper and probably more efficient way to evaluate the risk that bats will be killed, but, unfortunately, the method cannot be used to make any quantitative estimate of the fatality rate at present, because we do not know how to do it. By monitoring the activity simultaneously at the ground and from the nacelle we can get a good idea about how bats of the different species within the park move in relation to the height of the tower, and hence how the risk for fatalities changes.

5c. Curtailment

Based on the results of the post-construction programs reviewed here we suggest that for southern Sweden (Götaland and Svealand) wind turbines are curtailed (the rotors halted) to protect bats during the period from 15 July to 15 September, from sunset to sunrise and provided the wind speed is <6 m/s (average over 10 min) and the temperature >14 °C. Curtailment is not necessary in heavy rain or mist, when bats are not expected to be active at rotor height, regardless of wind speed and temperature. In northern Sweden

(Norrland) the same measures should be taken to protect the northern bat in particular, but in this case the need for mitigation and the associated costs will probably be much lower, because the summer nights are both cooler and shorter. Mitigation by stopping the rotors has the primary purpose to protect the noctules and parti-coloured bats, and secondly, the northern bat, particularly in the north, and the other high-risk species, such as the pipistrelles.

The need for curtailment will be limited to part of the summer and it will also be restricted by the weather and will therefore vary considerably from year to year. Figure B 4.3 suggests that curtailment would have been needed during 10 nights or less at that site in 2015.

It would not be meaningful to apply mitigation measures in places where the high-risk species, primarily noctules/parti-coloured bats and in the north also northern bats, do not occur in or near the wind farm during late summer. The easiest way to demonstrate that this is not the case would be to employ continuous activity measurements at nacelle level in late summer. The responsibility for this must be on the exploiter.

5d. Function and design of post-construction programs

The purpose of the post-construction program is to investigate the environmental effects caused by the exploitation and to control if any measures required from the authorities have been executed as intended. The results of the programs are also needed to decide on how further measures to protect bats should be designed for the specific wind farm, such as, for example, if the turbines need to be curtailed, and if so, how this should be done with respect to time and weather. In any case, it must be clear from the beginning that such restrictions may be necessary. It would probably be difficult to introduce new restrictions after the permissions have been given, at least if the restrictions are against the will of the exploiter.

Preferably the programs should be carried out using a standardised method, so that they later can be used in a wider context such as for comparisons between different wind farms or for estimating the cumulative effects on the fauna. It is therefore important that the programs are carried out consistently and in a comparable way.

If the pre-construction surveys have shown that noctules/parti-coloured bats or serotines occur in or near the wind farm, curtailment can be used without further investigations, to save time, or, if preferred by the exploiter, a post-construction survey can be carried out after installation of in order to decide if curtailment really is necessary. If it turns out that this is not the case, the initial restrictions can be changed or removed. Such a program could consist of activity monitoring at the ground and from the nacelle and/or carcass search during at least three seasons.

At present the priority is to obtain more and better post-construction surveys in the north as soon as possible. This also applies to the sea, whenever any wind turbines are constructed there. Until the results of such programs have been presented, there is no way we can design guidelines for the protection of bats in these areas.

5e. Execution of post-construction programs

Carcass search

To be meaningful, carcass searches must be done correctly and include experimentally based estimates of the rate of scavenger removal of carcasses, searcher efficiency and with consideration of the search area and its quality, as outlined above. How this should be done is reviewed by Rodrigues et al. (2014) in some detail. There are also other estimators that can be used to calculate the fatality rate (see above). What this means in terms of time and cost is hard to say at present, because the method has yet to be tested at full scale in Sweden.

Activity measurement using bat detector

Activity can be monitored from the ground or from the nacelle, or preferably, from both heights simultaneously, which give a good idea about the occurrence and behaviour of bats at the wind turbine. If the purpose is limited to the documentation of the presence of certain species it is sufficient to monitor from the ground, but if the data will be used to decide on mitigation measures such as curtailment, registration of activity at rotor height would probably be required as well. In the first case it is enough to monitor over one season, but the second case two or three seasons will be needed, because the variation in activity from year to year may be considerable at rotor level. I both cases the monitoring should cover at least the period between 15 July and 15 September, but preferably the entire season when bats are active, roughly April to October in the south, but for a shorter period in the northern part of the country.

There may be some variation in bat activity between the different turbines within a park and it may not always be sufficient to monitor one turbine alone. How many that should be monitored depend on the size of the park, its design and the environmental variation within it. This also implies that restrictions in the drift could differ between different parts of the park, provided of course that there is a corresponding variation in bat activity.

The bat detectors employed normally do not require any attention, except when installed and deployed and when the memory cards are replaced about once per month. Therefore, in the end the cost of a survey is not closely related to its duration. In total, the cost of a survey will roughly correspond to two or three weeks of work plus hire or purchase of the equipment.

It is important that the actors use the same equipment and employ the same methodology and also that they are consistent between pre- and post-construction surveys. This is certainly true if the results are to be compared before and after construction or with other studies. So far, there are no standards for which equipment and settings should be used or recommended, but it is important to produce such a guide, as this would facilitate future comparisons and conclusions later on. Recorded sound files are compared with wind- and temperature data (usually provided as means over 10 min periods) as measured at rotor height, and preferably also with precipitation data if available. Normally this data can be provided by the companies that run the turbines.

There is currently on the market several software that automatically sort and classify recordings of bat calls. If this worked properly, it would be a useful tool that could speed up the analysis considerably and save money that otherwise would be spent on time-consuming manual identification. We have recently tested three such programs, two commercial ones and one free that can be downloaded from the web. It is clear that the programs are efficient for sorting files but are unable to classify many of the Scandinavian bats reliably. However, they can identify certain easy-to-recognize species and also separate most bats into genera or group. Hence the programs can be used for sorting bat files from those containing only noise and also to classify the bats into genus or group and in some cases to species. This is important because there is money to save and there is a clear risk that the software will be used uncritically, without testing the performance beforehand. The programs are already in use frequently throughout Europe (Russo & Voigt 2016).

Finally, we repeat that we find it essential that all pre- and post-construction programs are carried out by personnel well experienced with work on bats and the methods, including recording and analysis of bat echolocation calls. Indeed, several programs reviewed in this report were not professionally executed and this also applies to similar work made in other countries. Professionality is an extremely important issue, as we want to be taken seriously by industry representatives, decision making authorities as well as the rest of the society, both nationally and internationally.

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The effects of wind power on birds and bats

– an updated synthesis report 2017

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The report is an update of the previous synthesis report **The effects of wind power on birds and bats**, published in 2011. The updated report compiles international research in recent years and provides an analysis of Swedish post-construction surveys implemented until 2016.

The report describes the types of environments to be avoided, what is important to consider prior to licensing, as well as which species that can be affected in different areas. It includes species facts with a review of species that may be adversely affected by wind power. The report contains in-depth reasoning about how to use scientifically based buffer zones, especially for eagles.

For bats, new knowledge shows that wind power is generally a more serious problem than was realized five years ago. At the same time results of recent research suggest that relatively simple measures can limit the damage to bats considerably.

The researchers highlight the need for a more large-scale planning, so that sufficiently large areas with a relatively risk-free environments can be set aside for the species that we want to preserve.

The Vindval research programme collects, creates and communicates information and facts about the environmental impact of wind power on the environment, the social landscape and people's perception of wind power installations. Vindval provides funding for research, including literature reviews and syntheses regarding the effects and experiences of wind power.

Swedish Energy Agency

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