Bats and offshore wind turbines studied in southern Scandinavia

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VINDVAL


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Preface

There is a real need for knowledge about the impact which wind power has on the environment, plants and animals, people and the landscape. Previous studies on the environmental impact of wind power plants have lacked an overall picture of the effects and of people's experiences. This has led to problems in terms of environmental impact assessments and examinations of applications.

The aim of the Vindval research programme is to bring about greater use of wind power by facilitating additional wind power expansion through improving the basic data available for environmental impact assessments and application processes, and by reducing uncertainty in assessing the impact of wind power on the environment.

Vindval also aims to provide a basis for more reliable assessments of how wind power affects the landscape, the way in which it impacts on those living in the immediate vicinity, and people's experiences of wind power. In addition, the programme will improve expertise on the environmental effects of wind power at Swedish universities, institutions and businesses, and within municipalities and other authorities.

Vindval is operated by the Swedish Environmental Protection Agency. The programme was commissioned by the Swedish Energy Agency, which is also financing the project. The programme committee, which deals with prioritisation and preparing basic data for decision making, includes representatives from the Swedish Energy Agency, the Swedish Environmental Protection Agency, the Swedish Board of Fisheries, the National Board of Housing, Building and Planning, the National Heritage Board, the county administrative boards and the wind power industry.

The project leader, Ingemar Ahlén at the Swedish University of Agricultural Sciences, wrote the report together with Lothar Bach, Hans J. Baagøe, and Jan Pettersson. The writer is responsible for the content, conclusions and recommendations.

Vindval, July 2007

Contents

1 Summary

A pilot study 2002-2003 at turbines on land showed that certain locations in the landscape could explain some of the casualty risks and the main reasons for collisions were found. During the 2005 introductory studies and in the project 2006 on bats in offshore areas in Kalmarsund we could confirm earlier known flyways from coastal points and found an extensive activity of passing migrants but also of resident species coming from various directions to areas with an abundance of insects. Observations were made at Utgrunden and Yttre Stengrund in Kalmarsund in the Baltic Sea and in Öresund between Sweden and Denmark. The observers onboard the boats and at the coastal points where bats take off used ultrasound detectors, strong portable spotlights and at special times also thermal camera. Boxes for automatic recording of bats were used on land, were placed on the turbines, and on the boat's cap. These methods resulted in a total of 12 354 observations of bats, 3 830 over the sea and 8 524 on land. Bats fly over the sea in winds up to about 10 m/s, a major part of the activity took place at wind speeds less than 5 m/s. Bats of 10 species were observed on the open sea and all of them were foraging at suitable weather conditions, which means calm weather or light breeze. The bats did not avoid the turbines. On the contrary they stayed for shorter or longer periods hunting close to the windmills because of the accumulation of flying insects. Hunting close to the blades was observed, why the risk of colliding might be comparable to land-based turbines. Bats also used wind turbines for resting.

Insects were collected at places and times when bats were observed feeding. Chironomids were dominating, but we also found many other flying species of other insect groups. Insects, but probably also crustaceans, were caught by bats in the water surface. Some terrestrial species occurred among the insects and spiders that were drifting in the air. At times we suppose that their origin was in the Baltic Republics or Russia. It was earlier completely unknown that many bat species, migratory and non-migratory, regularly use this food resource on the open sea far from the coasts in the late summer and early autumn.

With radar on Utgrunden's lighthouse data on movements of the largest bat species, mainly *Nyctalus noctula*, could be studied. This gave data on flyways, directions, movement patterns when foraging, especially near the turbines. With the radar it was possible to measure altitude and the results showed that almost all activity took place below 40 m above sea level, while only a few cases of higher flight was recorded. Observations from boat showed that altitude was very variable according to the available insects. Bats were seen hunting from the water surface up to the upper part of the windmills.

Need of further research and developing methods is discussed in the report. An updated risk assessment is presented. A standpoint today is that areas with concentrated flyways and foraging habitats with an abundance of flying insects must be very carefully examined if new windmills are planned. The collision risk at offshore wind power parks is impossible to study as long as there are no such

parks. Investigations on bats needed for environmental impact assessments are suggested.

To minimize the casualty risks at existing turbines further research is needed. Some measures to take have been discussed. In certain cases it is probably most effective to move a turbine a relative short distance because of the sometimes short edges of the flyways and also the insect rich habitats. Another method is to stop the turbine during periods of high risk. Because the accumulation of insects is the reason for bats hunting close to the blades methods to reduce the amount of flying insects at the turbines would be of interest. Methods to keep the bats away from the turbines do not exist and some such ideas might also have negative effects on other animals and also on humans.

2 Sammanfattning

Fladdermöss och havsbaserad vindkraft undersökta i södra Skandinavien
En pilotundersökning 2002-2003 vid vindkraftverk på land i Sydsverige visade lägen i landskapet där riskerna för kollisioner var förhöjda samt de viktigaste orsakerna till olyckorna. Under 2005 års förstudie och i projektet 2006 vid havsbaserade vindkraftverk kunde vi bekräfta tidigare utpekade utsträck över havet av fladdermöss i Kalmarsund och fann en omfattande aktivitet av passerande migranter men även av stationära arter som från olika håll flög ut till områden med mycket insekter. Observationer gjordes framför allt vid Utgrunden och Yttre Stengrund i Kalmarsund och i Öresund. Observatörerna på båtarna och på utsträcksplatser på land använde ultraljudsdetektorer, starka strålkastare och vid vissa tillfällen värmekamera. Automatiskt registrerande boxar användes på land, hängdes på vindkraftverken och placerades på båtens kapp. Metoderna resulterade i totalt 12 354 observationer av fladdermöss, varav 3 830 över havet och 8 524 på land. Fladdermöss flög över havet i vindstyrkor upp till ca 10 m/s, men en stor del av aktiviteten skedde vid vindstyrkor mindre än 5 m/s. Fladdermöss av 10 arter observerades ute till havs och alla sågs söka föda vid tjänlig väderlek, d.v.s. främst vid svaga vindar och blankvatten. Fladdermössen undvek inte vindkraftverken. Tvärtom stannade de ofta till för insektjakt nära verken på grund den ansamling av insekter som förekom där. Jakt helt intill rotorbladen observerades, vilket innebär att kollisionsrisken kan vara jämförbar med landbaserade verk. Fladdermöss kan bevisligen också använda vindkraftverk som viloplats, vilket har skett i det mest insektrika området vi undersökte.

Insamling av insekter gjordes på de platser och vid de tillfällen då fladdermöss sågs jaga. Fjädermyggor dominerade, men många andra flygande arter av andra insektgrupper var också företrädda. Insekter, och troligen även några kräftdjur, togs också i havsytan. Några arter av landlevande arter förekom bland de mängder av insekter och spindlar som drev omkring i luftmassorna. Vid vissa tillfällen antar vi att de har kommit från Balticum eller Ryssland. Det har inte tidigare varit känt att många fladdermusarter, stationära och migrerande, regelbundet utnyttjar denna födoresurs långt ute i havet under eftersommaren och tidiga hösten.

Med radar på Utgrundens fyr kunde data om de största arterna, troligen mest stor fladdermus, insamlas. Det gällde flygvägar, riktningar, rörelsemönster vid födosök, speciellt i närheten av vindkraftverken. Med radarn kunde fastställas att nästan all aktivitet skedde under 40 m höjd, endast enstaka flög högre vid sträckflykt. Direktobservationerna från båt visade att fladdermössen varierade höjd efter tillgången på insekter. Sålunda förekom flyghöjder från havsytan upp kring verkens övre delar.

Behov av fortsatt forskning och utvecklingsarbete diskuteras i rapporten. Vidare görs en uppdaterad riskbedömning. Ståndpunkten är nu att områden med koncentrerade flygvägar och insektrika födosöksområden är de som måste granskas extra noga inför lokalisering av nya vindkraftverk. Risken för kollisioner vid ren

passage genom stora vindkraftsparker kan inte bedömas, eftersom det ännu inte hunnit uppföras några parker. Förslag ges om vilka undersökningar som bör föregå lokaliseringsbesluten. Några krav på vad kontrollprogram vid utbyggnad bör innefattas diskuteras också.

För att minska riskerna vid befintliga vindkraftverk krävs fortsatt forskning och metodutveckling. Några åtgärder som diskuterats hittills redovisas i rapporten. I svåra fall är sannolikt den effektivaste åtgärden att flytta vindkraftverket. Det kan troligen räcka med relativt korta avstånd på grund av att flygvägarna kan ha skarpa gränser och att de insektrika födosöksbiotoperna också kan vara ganska väl avgränsade. En annan åtgärd kan vara att låta vindkraftverket stå stilla vid de tider då risken för kollisioner är stor. Eftersom ansamling av insekter kring vindkraftverken kan vara en viktig orsak till jakt nära rotorbladen kan man också tänka sig åtgärder för att minska mängden flygande insekter runt verken. Fungerande metoder som kan få fladdermöss att väja för vindkraftverk finns inte och idéer som förekommit kan ha negativa effekter i form av störningar eller skador på andra djurarter eller för människor.

3 Background

Studies of migrating bats at the south Swedish coasts have shown the existence of flyways on land and specific points where bats take off for migration across the sea (Ahlén 1996, 1997a, 1997b, 2002, Ahlén et al. 2002, Ahlén & Bach, in prep.). Investigations on bat behaviour at wind turbines on land were carried out 2002 - 2003 in southern Sweden and the most probable explanations for casualties were presented (Ahlén 2003; see also Bach 2002, Bach & Rahmel 2004, in prep., Rodrigues et al. 2006). During the last few years reports from a number of countries also have shown that many bats are killed at wind turbines (Dürr & Bach 2004, Arnett et al. 2005, Johnson 2005, Behr & v. Helversen 2006, Brinkmann et al. 2006, Dürr 2007). Until now these reports are only dealing with wind power on land. Bat Conservation International has reported a mortality of 0.9 and 0.6 individuals per turbine and night at two Windmill parks in West Virginia and Pennsylvania in U.S.A. For a total of 457 mills an assessed mortality was 14 538 killed bats per year (a 6-week period). It was suggested that some earlier investigations have underestimated the number of casualties. Bats' longevity and low reproduction rate make them vulnerable for new mortalities introduced by man. Previously known mortality factors in Sweden, collisions on roads, pesticides and renovation of buildings, are usually considered negligible at a population level. The earlier decrease of bat populations are in most cases thought to be long term effects of large-scale changes in forestry and agriculture and other land use influence on habitats.

When starting this project there was no knowledge about the risks for bats when passing offshore wind turbines. When the Swedish government approved a large wind power park in Kalmarsund the decision implied a control program with studies on the effects on bats occurring in the area. This project was the first stage of such investigations.

The Swedish Energy Administration has funded the project which is a part of the program Vindval coordinated at the Swedish Environmental Protection Agency. The work was planned and based at the Department of Conservation Biology (now Department of Ecology), SLU in Uppsala, Sweden. It was carried out in cooperation between scientists and field personnel from Sweden, Germany and Denmark.

4 Aim and direction

The studies had the main focus on bat behaviour when passing or hunting at off-shore windmills. The aim was to find out whether bats are exposed to collision risks. Factors that might affect the risks, such as geographical position, flyways, insect abundance and weather situation, were of special interest. The intension was also to produce recommendations how casualty risks are avoided or minimized.

5 Project leaders and participants

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Lothar Bach, Dipl.-Biol, zoologist. Bremen. Assistant leader.

Hans J. Baagøe, PhD, curator of mammals, Natural History Museum of Denmark, Copenhagen. Field investigations in the Öresund area 2006.

Tommy Gustafsson, biologist, County Administration in Kalmar. Field assistant.

Alexander Eriksson, biologist, County Administration in Kalmar. Field assistant.

Petra Burkhardt, biologist, Bremen. Analyses of observation data from Kalmarsund 2006.

Julia Lopau, biologst, Bremen. Field work in Kalmarsund 2006.

Dave Karlsson, entomologist, Uppsala University Ecological Research Station, Ölands Skogsby. Studies and collection of insects.

Kajsa Glemhorn, entomologist, Uppsala University Ecological Research Station, Ölands Skogsby. Analyses of insects.

Svante Martinsson, entomolog, Uppsala University Ecological Research Station, Ölands Skogsby. Analyses of insects.

Jan Pettersson, ornitological scientist. Färjestaden. Cooperation on radar studies in Kalmarsund.

Lars Pettersson, senior lecturer, electronics scientist. Developing instruments for ultrasound recording in the project.

6 Methods and investigation areas

In the introductory studies 2005 and in the project 2006 bats were observed on the open sea in Kalmarsund in the Baltic Sea at the wind power turbines Utgrunden and Yttre Stengrund and outside the coastal points Eckelsudde and Ottenby (Figs. 6-7). In 2006 we also made observations in Öresund between Denmark and Sweden, especially around a planned wind park at Lillgrund, but also on some islands and at the bridge between Malmö and Copenhagen. In 2005 the field work was carried out from 15 August to 10 October (18 nights on sea, 15 on land). In 2006 the work in Kalmarsund was done in two periods, 12-19 July and 15 August - 19 September and in Öresund 30 July - 15 September (14 nights on sea, 30 nights on land). The radar studies at Utgrunden in 2005 were made 18 August - 15 October (15 nights) and in 2006 12 July - 4 November (22 nights).

Observations out at sea were carried out on boats (m/s Skagerack in Kalmarsund, m/s Thjalfe in Öresund). We used ultrasound detectors (Pettersson D1000x, D980 and D240x) and instruments for automatic registration of ultrasounds (Smart Store boxes with Pettersson D240x, iRiver IFP799, Casio F-91W etc.) that were hanging on wind turbines and on the boat cap (Figs. 2-5). On land we also made direct observations and used registration boxes. For behavioural studies of bats at the turbines and at the coastal points for take off we used visible light from strong spotlights and at special occasions also a portable thermal camera (Raytheon). About our methods for identification see Ahlén & Baagøe (1999) and Ahlén (2004b).

The big spotlight on the boat was used to detect bats passing the light beam at long distances and also to assess the abundance of flying insects. Insects were collected to get information on what was available for the bats hunting at the windmills and around the boat. The boats could not be used at strong winds, high waves and fog. From our land observations we know that bats were leaving the coast in very small numbers or not at all with such weather.

On the lighthouse at Utgrunden radar for bird studies was also used for detecting and following bats in 2005. In 2006 the radar was equipped with an antenna for altitude measuring. By simultaneous observations from boat and with radar we could find out which species were visible by radar. The radar observations made it possible to study the movement patterns and activity of bats over the sea (Pettersson 2006).

Meteorological data were obtained from the lighthouse at Utgrunden and Ottenby Bird Station. In addition we took own measures of wind speed, direction and temperature at the observation places.

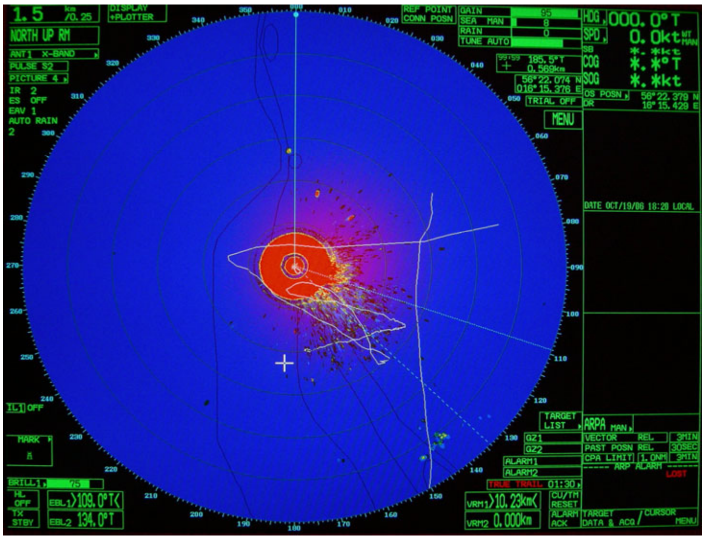

Fig. 1. The radar screen at Utgrunden lighthouse (centre) showing routes of two bats passing. Both came from NE (up to the right) and disappeared to S and SW. From 19 October 2006 at 18:20. The radius of the blue area is 1.5 km and distance between the concentric circles is 250 m.

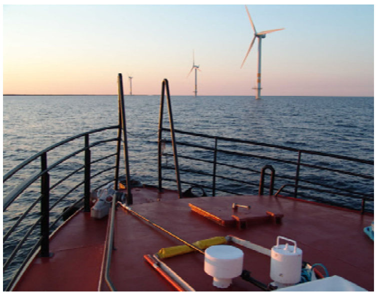

Fig. 2. Approaching Yttre Stengrund

Fig. 3. Preparing the AutoBoxes

Fig. 4. Hanging them up

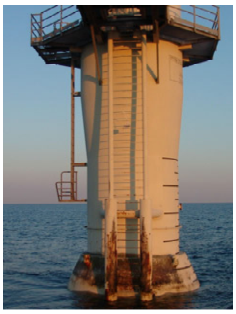

Fig. 5. Listening

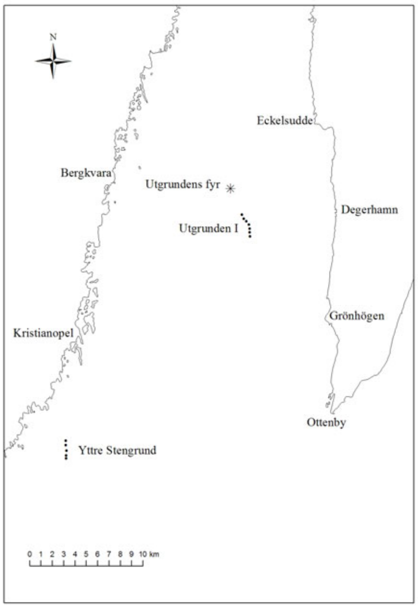

Fig. 6[*]**.** Investigation area in Kalmarsund

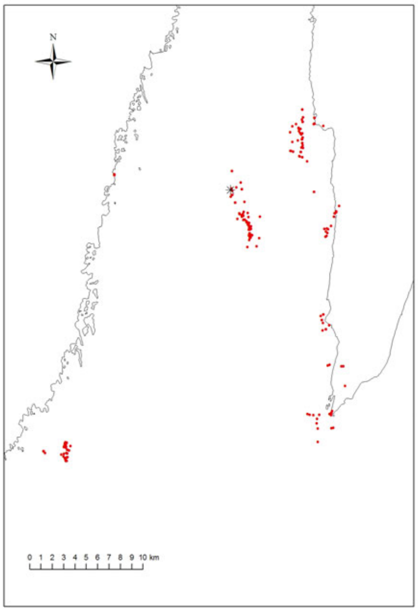

Fig. 7[*]**.** Positions for observations 2005 and 2006

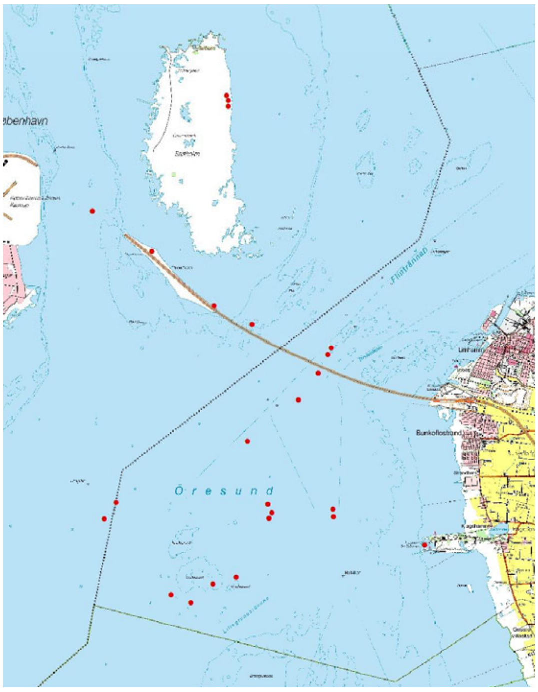

Fig. 8[*]. Positions for observations in Öresund 2006

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[*] © Lantmäteriverket 2006 Medgivande MS2006/03034.

7 Results

In 2005 and 2006 the observations gave a good picture of the occurrence, movement patterns and behaviour of the bats. A total of 12 354 bat observations (3 830 over the sea and 8 524 on land) were made. No less than 10 different species were observed out at sea and 13 at the coastal take-off sites (Table 1). 18 bat species have been found in Sweden (Ahlén 2004a, 2006a) and 17 in Denmark (Baagøe 2001, Baagøe & Jensen 2007). The high number of observations was possible because of an extensive use of automatic registration. The sound quality in these registrations was quite comparable with manual recordings with detectors and digital recorder. Therefore it was only a limited number of the bats that could not be identified. Simultaneous observations by radar and from the boat showed that all bat echoes that we could confirm were from *Nyctalus noctula*. The next largest bat that regularly occurred within reach of the radar was *Vespertilio murinus*. At a number of occasions we found out that this species could not be detected by the radar. Therefore we regard the number of bats seen on radar in almost every case belonged to *N. noctula* even if a few of them might be uncertain as to species. It was quite clear that our radar was unable to detect all the smaller species. To mistake bats for birds would probably lead to an underestimation of bat numbers and is most likely when bats fly at high altitude especially when many birds are migrating.

The species we observed (not including radar) in highest number was *Pipistrellus pygmaeus* followed by *Nyctalus noctula* and *P. nathusii*.

P. pygmaeus was not known as a migrating species before we started the observations in 2000 and is now turning out to the most common species. Most of the bats were observed on land, but the registered number of bats over the sea was surprisingly high. We must keep in mind that observations on land was carried out at points where migrant bats were concentrated in large numbers. On the sea we mainly made observations in areas around the offshore turbines. The probability to find bats at a specific point out at sea is comparatively low, but still the results were a large number of observations.

We also found it remarkable that species like *Eptesicus serotinus*, *Nyctalus leisleri*, and *Pipistrellus pipistrellus* were observed regularly despite the fact that they are very rare in Sweden. To find high numbers of *Myotis daubentonii* and *M. dasycneme* up to 10 km from the coast was also a surprise.

Tabell 1. Antal observationer av olika arter under 2005 och 2006 i Kalmarsund och 2006 i Öresund.

Species	Mm/b	Mdas	Mdau	Mnat	Msp	Pnat	Ppip	Ppyg	Nlei	Nnoc	Enil	Eser	Vmur	Paur	Chir	Tot.
Observations in 2005																
Over the sea, Kalmarsund		5	30			3	1	48	1	47	9	1	6		3	154
Radar observations										425						425
On land, Kalmarsund	25	2	47	1	20	128	11	1180	0	97	50	2	14		1	1578
Total 2005	**25**	**7**	**77**	**1**	**20**	**131**	**12**	**1228**	**1**	**569**	**59**	**3**	**20**		**4**	**2157**
Observationer in 2006																
Over the sea, Kalmarsund		44	58		4	81	4	111	8	214	7	28	25		3	587
Over the sea and islands, Öresund						19		20	3	16	12	2	9		1	82
Radar observations										2564						2564
On land, Kalmarsund	1	18	42	3		626	6	4707	7	1244	151	81	45	4	11	6946
Total 2006	**1**	**62**	**102**	**3**	**4**	**727**	**10**	**4840**	**16**	**4048**	**170**	**112**	**83**	**4**	**15**	**10197**
Total 2005 and 2006	**26**	**69**	**179**	**4**	**24**	**858**	**22**	**6068**	**17**	**4617**	**229**	**115**	**103**	**4**	**19**	**12 354**

Abbreviations

Myotis brandti/mystacinus	**Mm/b**	*Vespertilio murinus*	**Vmur**
Myotis dasycneme	**Mdas**	*Plecotus auritus*	**Paur**
Myotis daubentonii	**Mdau**	Chiroptera	**Chir**
Myotis nattereri	**Mnat**		
Myotis sp	**Msp**		
Pipistrellus nathusii	**Pnat**		
Pipistrellus pipistrellus	**Ppip**		
Pipistrellus pygmaeus	**Ppyg**		
Nyctalus leisleri	**Nlei**		
Nyctalus noctula	**Nnoc**		
Eptesicus nilssonii	**Enil**		
Eptesicus serotinus	**Eser**		

7.1 Bats taking off, flyways and insect hunting

The investigations in 2005 and 2006 could confirm that bats from Öland most often take off from at Eckelsudde and Ottenby. This was achieved by observing bats taking off from land and by observing migrating bats out at sea and by using automatic registration on the offshore windmills and also by the radar observations. In Öresund we also found that bats occurred all over the strait between Denmark and Sweden. Already in 2005 we discovered that not only migrants but also non-migratory species occurred out over the sea, which in 2006 was confirmed as a regular phenomenon, in Kalmarsund as well as in Öresund.

Of the 10 species observed out at sea we found that all of them hunted insects when they got the opportunity. It was often migrants that spent some time in an area with insect abundance and then went on in the same direction. However we also observed that many bats regularly went out over the sea for hunting and then returned to land again. The most activity took place in early autumn when bats were found at all time and places, depending on weather (see below). In July we only found hunting bats close to Yttre Stengrund and over Öresund but not at Utgrunden.

The bat activity out at sea goes on the whole night but our observations indicate a peak of migrants during the first hours of darkness when the migrants leave the coasts. Hunting bats that return to the coast probably adjust to the insect abundance with peaks much later especially when the wind calms down. Data from radar, mainly showing echoes from *Nyctalus noctula*, have peaks after midnight (Fig. 9).

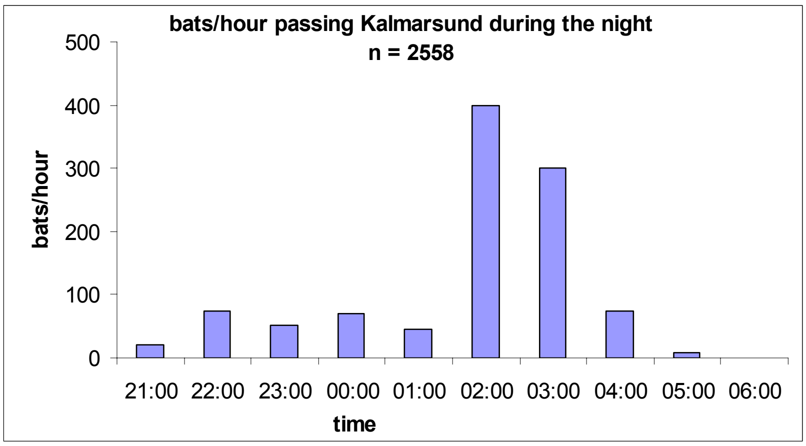

Fig. 9. Number of passing bats per hour observed by radar in Kalmarsund.

7.2 Insect abundance in offshore areas

In our study areas there were insects everywhere but the abundance varied with the weather conditions. By calm weather or light breeze we observed the most abundant occurrence of flying and drifting insects and spiders and that was the situation when we saw the most intense hunting. With the same or comparable weather we also found marked differences in abundance between areas, differences that persisted at all our visits through the two years. At occasions when we observed intense hunting we collected samples of available prey organisms in the air some metres up and also from the water surface. The samples contained the following group and species:

Nematocera: Chironomidae, Cecidomyiidae, Culicidae, Tipulidae
Trichoptera: Leptoceridae
Hymenoptera: Ichneumonidae
Lepidoptera: Noctuidae

The two first families were represented by very large numbers, sometimes like clouds. In the surface there were also crustaceans (Crustacea; Idotea sp., Amphipoda) that probably were taken by bats, *Myotis daubentonii* and *M. dasycneme*.

Many spiders were observed on the boat. Some of them came drifting with threads in the air, while other had established themselves making nets in the gunwale, where lots of insects, primarily chironomids got caught (Fig. 10).

Fig.10. Spider with net catching chironomids onboard m/s Skagerack at Yttre Stengrund, Blekinge.

7.3 Where did the insects and other invertebrates come from?

It became quite obvious that the great amounts of prey organisms, flying, drifting and in the water surface, are an important food source for migrating bats and also for non-migratory species. Until now this was completely unknown. We also have

evidence that offshore wind power turbines can be used by bats as roosts where they are near to rich feeding areas (more about that below).
The question from where this food source is coming is complicated. We found that large amounts of the animals, e.g. chironomids, are produced in the sea. However there were also a lot of land insects drifting across the sea. At some occasions we observed insects in passive drift from east as air plankton. They moved in the direction of the east coast of Blekinge and as some of them were from terrestrial ecosystems, we assume they came from the Baltic states or Russia.

The dominant biomass of available prey is almost certainly chironomids which are produced in the Baltic sea. The strange fact is that some of the spots with high abundance of these insects are not over bottoms with high production of them. The phenomenon can not be explained by present stage of knowledge. The effects of winds, currents, waves, swell and bottom topography could play a role.

7.4 Effects of weather

Bats' take-off and flight across the sea is affected by weather. Strong winds stop the activity. Bats migrating over land that reach coastal points at bad weather usually accumulate until a change in weather occurs. At such situations, e.g. at Ottenby, it is possible to observe large swarms of bats, sometimes several hundred, waiting for better weather. At such improvements they all can suddenly disappear and be on their way towards Poland, Germany or the southeast corner of Blekinge. What kind of weather bats avoid for travelling across the sea is different for different species. We have data on migration activities from the last ten years. Take off is always most intense at calm or light breeze. *Nyctalus noctula* is the most wind tolerant species in our study. From radar observations we know that it is still crossing the sea at wind speeds up to about 10 m/s, while about two thirds of them flew in winds less than 2.5 m/s. At Ottenby we occasionally observed that *Pipistrellus pygmaeus* could leave the coast in winds up to 9 m/s. Most bats of all species preferred winds up to about 5 m/s.

Observations from the boats showed that insect hunting takes place at very light winds or calm weather. In such situations more insects fly and they are easily available over the smooth surface. At the occasions when we observed the greatest abundance of flying insect the wind was 0 - 1 m/s at sea level and the water was smooth as a mirror.

We experienced that precipitation and thunderstorms also could affect the activity of bats out at sea. We have observed how a thunderstorm many kilometres away over the sea stopped all activity at the shoreline and no bats took off despite good weather on land. Heavy fog also can stop the migration activity.

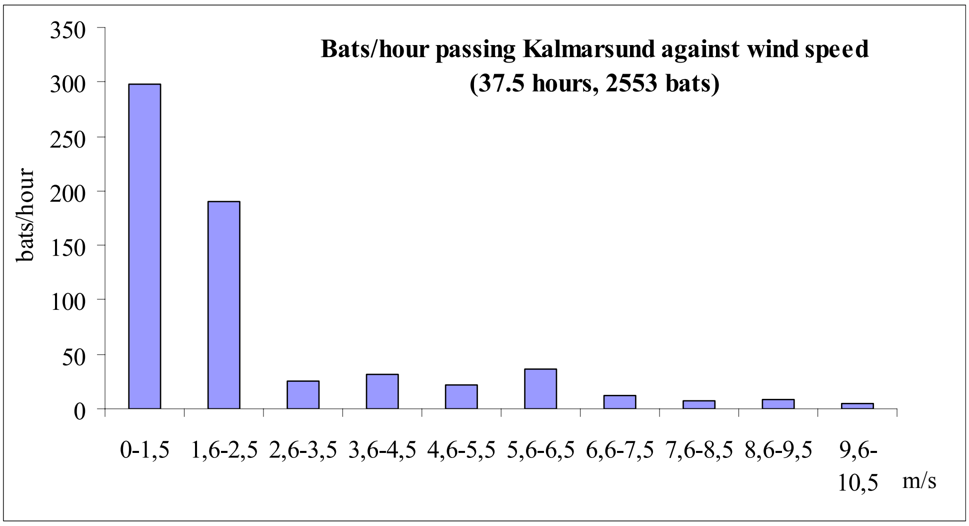

Fig.10. Bats/hour in relation to wind speed when passing Kalmarsund (Utgrunden) according to radar observations from the lighthouse at Utgrunden in 2006.

7.5 Flight altitude

From a large amount of observations at sea we know that bats usually migrate close to the surface, i. e. often 0 - 10 m over the sea. The larger species usually fly somewhat higher. Radar studies showed that the detected large species, most often *Nyctalus noctula*, mainly fly below 40 m above the surface while only a few individuals were observed at higher altitudes. However it is not unlikely that more bats are missed at higher altitude.

Things are quite different when bats are hunting. They can rapidly change height to hunt insects. Our direct observations of hunting bats repeatedly showed that one minute they could go down to the surface near the boat or a turbine and the next change to hunting near the blades at the upper part of the turbines. Most small species only do this close to objects while the larger species more often go higher up in the free air. A few years ago we got evidence for a number of cases when *Nyctalus noctula* observed through a heat image camera were hunting at an altitude up to 1 200 m above the ground (Ahlén, Bach & de Jong, unpublished data).

The smaller species (e.g. *Pipistrellus nathusii* or *P. pygmaeus*) can also vary the altitude very much according to insect availability even if migration flight usually takes place at 1-3 m above the sea surface. *Myotis daubentonii* and *M. dasycneme* usually take prey in the surface or close to it. These species can at special occasions hunt tens of metres up.

7.6 Activity affected by wind turbines

The investigations in Kalmarsund showed at once that working wind turbines were not avoided by passing bats. On the contrary we soon discovered that some bats were attracted by the turbines. In suitable weather passing bats spent some time searching and hunting insects around turbines (also around the moving blades) and then went on in the same direction. Radar studies also showed that the large species, mainly *Nyctalus noctula*, searched wide areas around the turbines and went to and fro in all directions. By direct observations we saw them hunting close to the blades but also near the water surface.

Flying insects were often gathering around the turbines and also at the non-moving boat. This attracted bats for hunting there. There is no doubt that offshore wind turbines often can attract insects and thereby hunting bats.

Bats can use windmills as roosts sometimes regularly over a longer period. According to an interview with a service technician, bats were found in the generator house of an offshore wind turbine east of Blekinge in the summer 2003. When we visited the windmills in case in 2005 and 2006 we repeatedly observed *Pipistrellus pygmaeus* flying early in the evenings with territorial calls, a number of *P. nathusii*, and we also observed the rare species *Nyctalus leisleri* repeatedly, facts that might indicate that the mills served as roosts. We also observed how *Nyctalus noctula* tried to find rest sites on a turbine.

7.7 Activity season at sea

To begin with, we expected all activity out at sea to be the autumn migration from Sweden to the continent. Because of this the introductory field studies in 2005 were made from the end of August to early October. Because of our discovery that non-migratory species, also came out for insect hunting far from the coasts, we also included a summer period in 2006, both in Kalmarsund and Öresund.

Thus there is activity out at sea already during the summer. This activity increases toward the end of the summer. The distance out to the feeding areas may be too long for nursery colonies until the young fly and are more independent. For this reason the activity increases in August at the same time as the first migrants appear.

The activity goes on through September and finish in October. Weather can influence on the season and the different species have their own activity peaks that can vary from year to year. More data on this, especially for the most exposed species, are important to gather which could be done by automatic registration.

8 Further research and method development

In order to avoid or minimize new mortality it is important to locate new turbines and parks to areas where we expect low risks for bat collisions. To minimize risks at already existing turbines can be expensive and reduce the power production. By further research we can better find high-risk areas and map them, e.g. concentrated activity in flyways and preferred feeding areas. We can also get more precise data on activity at different parts of the night and the season. This can be done by further use of automatic registration. The technique is working fine today but must have better capacity to store data so handling of many boxes can be reasonably affordable for a large-scale use. The way to do this is to test a number of prototypes. It is important to use the high sound quality technique we have used until now which is necessary for species identification. Software for sorting and analysing recordings is underway but needs a lot of testing before a use in full scale.

At the already existing turbines, and most important at all the planned offshore wind parks, automatic registration can give data on activity in flyways and preferred feeding areas, data on influence of weather, (wind speed, direction etc.) waves, swell etc.

Methods for observations from boat are working satisfactory as to passing bats. For behavioural studies of bats hunting close to the turbines there is a need to use better portable thermal cameras of the most modern version. Stationary thermal cameras at fixed positions on the turbines could also give more knowledge about actual casualties and get information about how and when it happens.

For planning offshore wind parks general knowledge on where problems could be expected is valuable. We are still lacking knowledge about to what extent and how far bats go out to feeding areas at sea as the phenomenon has just been discovered. It is a need to collect information on this from other parts of our coasts and also some of the great lakes, e.g. the west coast north of Öresund, the east coast north of Kalmarsund, the sea around Gotland, and the lakes Vänern and Vättern. To begin with, it would be possible to use profiles out from the coasts with observation points by ultrasound detectors and strong spotlights at calm weather. Automatic registration could also be done at lighthouses, bridges, seamarks etc.

9 Risk assessment

The results from our studies allow us to draw some conclusions about the risk for bats to be killed at offshore wind turbines. We have found that passing bats can be attracted by the turbines when insects are gathered there (Ahlén 2002, 2003, 2006b; Bach & Rahmel 2004). We have also shown that both migrating and resident species are searching and hunting insects close to the turbines. We found nothing indicating that bats avoid the turbines like some birds do.

At turbines on land a number of bat species are killed at certain locations (Ahlén 2002, Arnett et al. 2005, Behr & v. Helversen 2005, Brinkmann et al. 2006, Dürr 2007, Dürr & Bach 2004, Rodrigues et al. 2006). At offshore turbines there are no data on casualties. In our project we had no possibilities to detect or measure incidents and no such data have yet been published from any other country. The second best way to assess the risks was to observe the bat activity at the turbines and under which conditions they come close to the blades or use the turbines as roosts. Our experience from land-based turbines is that this is strictly correlated to the real casualty risks.

The wind turbines in Kalmarsund do not have strong lamps that can affect the behaviour of bats. If strong light on the turbines are prescribed, this could increase the attraction of insects and thereby the hunting activity of bats (see e.g. Rydell & Baagøe 1996a, 1996b).

In case casualties occur, this is deplorable and it is a serious matter if this mortality lowers the density or wipe out local populations. This will probably only happen where bats are concentrated to flyways, e.g. outside take-off points on coastlines or preferred feeding areas out at sea. The risk for casualties are most probably smaller where bats only pass and not are attracted by insects. If bats use turbines as roosts there are certainly other risks especially if they are exposed to high voltage.

As yet there are no real offshore wind parks in Swedish waters only small groups of mills that we used for our study. Therefore we can not study the risks for bats when they have to pass a large number of mills out at sea. It is important that this will be studied by observations of behaviour and by automatic registration as soon as an offshore park has been built or perhaps in already built parks in Denmark.

10 Investigations before locating offshore wind turbines

To evaluate if locations might cause problems for bats, it is possible to start with some general facts about the area. From earlier knowledge about the fauna of the area, known flyways, feeding areas, guiding linear landscape elements, habitats with insect abundance, it is often possible to plan what kind of studies that are required to assess the risk for collisions. In Sweden there are plans to build many wind turbines the coming years, while number of competent specialists capable to carry out the investigations is very limited. As a rule it is necessary to use a whole season to get data enough on the fauna, the flyways and preferred feeding areas. For wind power parks comprehensive investigations are needed while single turbines requires less efforts. At every installation activity in the area has to be studied and documented in an EIA (Environmental Impact Assessment).

The field studies must clarify whether the planned area is within a regularly used flyway for migrants or is an important feeding area for resident or migrating species. If there are fixed installations such as light-houses, seamarks, bridges etc in the sea area these could be used for automatic registration. In most cases it is also necessary to make observations from boat in still position at various points in the area. Data about species, time, position, flight direction, behaviour (passing, hunting) should be collected. These studies have to be carried out in August and September, in some parts of Sweden also at the end of July for resident and non-migratory species. All sound recordings should be saved for subsequent control of species identification. In some areas there also may be relevant to study the spring migration, especially if it is concentrated enough to result in regular activity.

The investigations should make it possible to evaluate whether risk can be considered acceptable or not. The risks must always be regarded as not acceptable if they can affect the population level.

In borderline cases the collected data should have a precision enough to show if a change in the exact position can lower the risks.

In the European Bats Agreement EUROBATS (under the Bonn convention) draft recommendations for investigations before locating wind parks have been produced (Rodrigues et al. 2006) and will be worked over during the next years when new data are available.

11 Minimizing risks at existing turbines

If it becomes evident that an already existing turbine causes serious problems for bats it is necessary to take measures. In the European Court of Justice a verdict against Germany in 2006, based on the habitats directive, has been interpreted as a prohibition to let turbines run if bat collisions are to be feared. As a result many turbines are now stopped for periods. To handle such questions further research and technical development are needed. Some possibilities to minimize casualty risks that have been discussed are the following:

1) Move the turbine. In very serious cases this is the most radical and safest way to minimize the problem. There are experiences on land which indicate that it could be enough to move a turbine relatively short distance to pass the sharp limits of flyways and especially insect rich habitats. This procedure should not be necessary if the positions are selected more carefully in the future.
2) Stop turbine wings during periods of high risk. It is possible to limit this measure to parts of the night, to the weeks in the season, and also to weather situations (e.g. wind speed) that have the highest risks. As a rule the risk can be expected to be highest in calm weather or light breeze in Sweden during some weeks in August and September, in some areas also in late July.
3) Accumulations of insects attract bats and therefore methods to reduce the insect abundance around the tower and wings could be useful. Today there are no methods that can be used. To find methods research and practical experiments are required.
4) Bat repelling methods. In 2005 we discovered that bats avoided a small area around the Utgrunden lighthouse. This was found to be an effect of the radar for sea navigation that is in permanent use there. We found that further experiments could be of interest but it would probably lead to environmental problems with the strong radiation in all directions and also to very expensive investments when many turbines are built. Nicholls & Racey (2007) discuss whether electromagnetic fields as in radar could be used to deter bats from colliding with turbines.

12 Comments on the observed bat species

Table 1 shows the number of observations of each species at sea and on land. The following comments give some details on how and where the species were observed. All recordings are saved to enable verification of species identification.

Myotis dasycneme
Observed and recorded passing and hunting over the surface in Kalmarsund outside Eckelsudde, Degerhamn, Grönhögen, Ottenby and Yttre Stengrund at calm weather with smooth water surface. At several occasions they hunted close to the boat. They also passed very close to the turbines. The species is very rare in Sweden.

Myotis daubentonii
Observed at many occasions hunting over the sea surface at calm weather.

Myotis nattereri
Observed on land. This is a species that probably not migrate across the sea, at least not regularly. However in the autumn it often comes out to coastal habitats for insect hunting.

Myotis brandti/mystacinus
Only observed on land. These two species are difficult to separate during short observations as in normal census work. On Öland only *M. mystacinus* has been found. In autumn they often come out to coastal habitats for insect hunting.

Pipistrellus nathusii
Observed in 2005 on many places over Kalmarsund och at Ottenby and Eckelsudde but only in small numbers. This species was dominating among the migrants earlier years. In 2005 the peak number never came, probably because the migrants that are crossing the Baltic Sea missed Öland and hit the Swedish east coast more to the north. In 2006 the species occurred in normal numbers again and was fairly numerous at Yttre Stengrund outside the coast of Blekinge. A number of observations were also made in Öresund. Males of this migrant species stayed and performed territorial flight at places with abundant insects such as Ottenby, Yttre Stengrund in Kalmarsund, and Saltholm in Örensund.

Pipistrellus pipistrellus
An exteremly rare species in Sweden but regular among migrants at Ottenby. It is also found in summer in Blekinge, Småland, and Gotland (Ahlén et al. 2004). Observed in 2005 at Ottenby and at the Utgrunden turbines (recorded in autobox) and in 2006 also at Yttre Stengrund.

Pipistrellus pygmaeus
This species occurred in great numbers at the coast sites and was also observed on many places out at sea with a concentration to the flyway SW-W of Eckelsudde and Ottenby. Like *P. nathusii* males of this species also stayed and performed territorial flight in the same places. The species seems to be increasing among migrants in Kalmarsund. Until recently it was considered as a non-migratory species.

Nyctalus leisleri
A very rare species in Sweden found in Skåne, Småland, Öland, Gotland and Västergötland. During the field work 2005 one individual was observed at Yttre Stengrund. The sounds were recorded manually from detector and by automatic recording as well. In 2006 it was observed again, several times, at Yttre Stengrund. It was also observed at Ottenby and in Öresund.

Nyctalus noctula
The noctules occurred all over Kalmarsund and Öresund and at the coasts. In Kalmarsund the migrating noctules often had a SW direction. Many of them were searching, hunting, and moving around in large areas, especially near the windmills. In the sea outside Eckelsudde and at Yttre Stengrund many individuals hunted at calm and warm weather when great amounts of insects were flying. They sometimes hunted very close to the turbine wings. Radar studies showed that they also came from other coastal areas than the mentioned points, from both sides of Kalmarsund strait and that they returned to these coasts, e.g. the area around Degerhamn.

Eptesicus nilssonii
The most common species in Sweden with a distribution all over the country. It is not considered to migrate except for local movements to autumn and winter sites. Under many years we have never seen this species fly out over the sea, so it was a surprise to observe the species hunting insects many kilometres out at sea in Kalmarsund. Also in Öresund between Skåne and Sjælland we observed the species, but flying near the bridge or over land (the island of Saltholm). Before this there has been no record for many years in Denmark (Baagøe 2007).

Eptesicus serotinus
This species is regularly observed in various parts of southernmost Sweden, but still no colony has been found. At Eckelsudde and over the sea outside the point we made a number of observations. It also occurred at Ottenby and a number of times at Yttre Stengrund. It was also observed over Öresund and over land on the island Saltholm.

Vespertilio murinus

Observed passing and hunting at the Utgrunden turbines and at Ottenby and Eckelsudde. Over Öresund the species was observed a number of times. The species is known to fly long distances across the sea and is e.g. found on the Faroe Islands (Baagøe & Bloch 1994).

13 Conclusions

This report justifies some conclusions summarized below. These could be relevant for further research and for handling the problems, e.g. planning, risk assessment, decisions about locating windmills and monitoring effects of wind power on bats.

Take off points and flyways
South Swedish coastal points where bats take off for flight across the sea are well known since many years. From these points there are flyways over the sea which to begin with is rather concentrated but they become more diffuse through dispersal, wind drift and by the fact that the species have somewhat different directions towards S and SW. In springtime they come back from the continent much more dispersed and observations of them coming in to the coast are made all along the coasts of Southern Sweden. Therefore it is very important to know about the southward flyways used in the autumn which are most concentrated nearest the Swedish coasts. This means that we can expect many sea areas without such frequent activity of migrating bats.

Effects of wind turbines and available insects
In Kalmarsund and Öresund there are 10 different bat species that fly across the sea and hunt insects there when weather conditions permit. Wind turbines, boats, bridges, and light houses attract insects, which explains why bats are searching and hunting close to such objects. Migrating bats usually stop for a while to feed and then they go on in the same direction. Resident, non-migratory bats also go out several kilometres over the sea to feed on insects and then return back to land. Abundance of food available to bats vary between different sea areas. There are limited areas where there almost always is an abundance of insects and thus regularly used as feeding grounds by bats. It is important to know such areas before planning new wind power installations. At the same time there are many other areas where abundance of insects is too low to attract hunting bats.

Effect of weather
It is only at calm or light winds that the majority of all bats fly across the sea. The larger species are most tolerant to winds but all species prefer fine weather. Bats seldom take off from coasts at wind speed above 10 m/s and the most of the activity out at sea takes place under 5 m/s. Most intense hunting was observed at winds close to 0 m/s with smooth water surface and no waves. At such situation the insects are more abundant around the higher parts of the windmills.

Risk of casualties
When bats on migration are passing single turbines at low altitude this should mean a low risk for collisions. However we need more knowledge on altitudes used by the different species during straight migration flight. The behaviour of bats passing

a park with many turbines is not possible to study before such parks have been built.

It is in fine weather when insects gather around the turbines that bats are attracted to hunt there. The risk is therefore highest at the lowest wind speeds when the wings are still running. We have observed that some of the turbines do run for hours even when we measured wind speed of 0 m/s at sea level. If the blades are not rotating there is certainly no risk for collisions.

Other risks are possible when bats establish roosts inside the turbines, e.g. when exposed to high voltage.

Investigations before locating turbines

Already from the start of planning it is to some degree possible to decide if it is necessary to study the location in detail and if it could be a high-risk area. With further studies and better knowledge about the problems it should be possible to direct most of the investigations to areas where they are most needed. Already now we have some knowledge about the most important areas around the coast of south Sweden where the migration direction from take off points must have higher risks for bat collisions. Such positions should already now be avoided or very carefully investigated to find limits of the flyways by observations and registrations.

Areas at sea with high abundance of insects that are regularly used by bats are also very important to map and keep in mind when planning areas for wind power. Such areas are used by migrants but also by resident species going out for foraging and returning to land again. We have found such areas that offer more food to bats than is available on land. This can be studied by ultrasound detectors, spotlights and automatic registration.

Suitable time for investigations

Collecting observations and data on migrants in offshore areas in southern Sweden should be done from about 15 August to 20 September when the activity is best. In addition is necessary to find out whether areas are used by resident species in summertime, probably most efficient at the end of July or the period 20 July - 5 August.

Observations in spring can be done but more difficult to evaluate because dispersal and drift makes it less likely that there is a concentrated flyway all the way to the Swedish coasts. If future studies in Denmark, Germany or Poland show that concentrated flyways towards specific parts of our coasts we should pay more attention to that.

Minimizing collision risks

For already existing wind turbines it can be necessary to take certain measures to minimize the casualty risks. One method is to stop the blades at situations when the risk is high, e.g. at winds less than a certain speed, during a part of the night in those weeks when bat activity around the turbine is high. In some areas this could be from 20 July to 20 September every night from sunset to 02:00 or 03:00. These wind and time limits must be adjusted to the local conditions.

The high risk is limited to certain periods when electricity production is low and the method to stop the mills would not cause any important losses.

Another more radical method is to move the turbine. This could be necessary in a few very special situations, e.g. when decisions are not based on available knowledge about the problems.

Further research

There is need of research to give more general knowledge about how bats fly across the sea, behave in areas with wind turbines and how we can avoid casualties. One part of it is how bats normally use the food resources out at sea irrespective of wind power turbines. With such knowledge it must be easier to locate installations in the best areas with least problems with regard to the bat fauna. To limit the minimizing efforts close to what is needed there is a need of more data from observations and automatic registrations that show flyways, feeding areas, activity pattern, time, weather influence etc. For a more extensive use of automatic registrations there is a need of further technical development of the instrument to get better capacity and new software for efficient analysis of recordings is also needed. For observations of behaviour at the turbines, the new generation of thermal cameras should be used, mobile units for behavioural studies and stationary at fixed position to get knowledge of how and when casualties occur.

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Bats and offshore wind turbines studied in southern Scandinavia

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When establishing a farm of wind turbines it is of importance that an estimation of possible risks for the animal populations is performed on a proper basis. Until recently, little has been known about the behaviour of bats in the proximity of offshore wind farms.

This report summarizes the experiences of a study aiming to analyze in what range bats passing or hunting near offshore wind turbines are exposed to collision risks. It also identifies the factors that might affect the risks of bat mortality caused by offshore wind energy.

In the report conclusions are drawn from a total of more than 12 000 bat observations along Kalmarsund on the Swedish east coast and in Öresund between Sweden and Denmark. The results include information on activities of 10 different species of bats observed out at sea and 13 at coastal take-off sites.

The report is a good guide on how to successfully mitigate potential risks for bats when locating offshore wind energy installations. It should be of value when planning Environmental Impact Assessments and monitoring programmes.

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

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