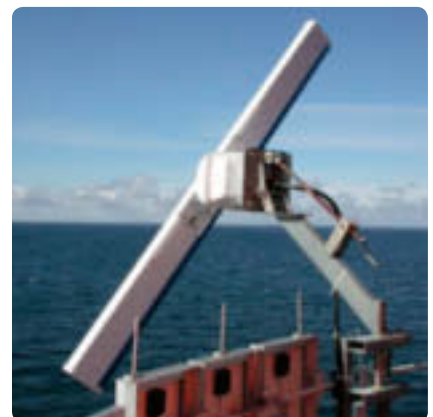


# Night migration of songbirds and waterfowl at the Utgrunden off-shore wind farm

JAN PETTERSSON

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# Night migration of songbirds and waterfowl at the Utgrunden off-shore wind farm

– A radar-assisted study in southern Kalmar Sound

Jan Pettersson, JP Fågelvind

SWEDISH ENVIRONMENTAL  
PROTECTION AGENCY

**Order**

Phone: + 46 (0)8-505 933 40

Fax: + 46 (0)8-505 933 99

E-mail: [natur@cm.se](mailto:natur@cm.se)

Address: CM gruppen AB, Box 110 93, SE-161 11 Bromma, Sweden

Internet: [www.naturvardsverket.se/bokhandeln](http://www.naturvardsverket.se/bokhandeln)

**The Swedish Environmental Protection Agency**

Phone: + 46 (0)10-698 10 00, Fax: + 46 (0)8-20 29 25

E-mail: [registrator@naturvardsverket.se](mailto:registrator@naturvardsverket.se)

Address: Naturvårdsverket, SE-106 48 Stockholm, Sweden

Internet: [www.naturvardsverket.se](http://www.naturvardsverket.se)

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## Preface

There is a great need for knowledge concerning the impact of wind power on humans and landscapes, the marine environment, birds, bats and other mammals. Previous studies regarding the environmental impacts from wind farms have lacked an overall view of the effects. This has led to deficiencies in the processes of establishing new wind farms.

Vindval is a program of knowledge and a cooperation between Energimyndigheten (Swedish Energy Agency) and Naturvårdsverket (Environmental Protection Agency). The purpose of the program is to collect and provide scientific knowledge of wind power impacts on humans and nature. The commission of Vindval extends to 2012.

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

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

This report was written by Jan Pettersson, JP Fågelvind. The author is responsible for the content.

Vindval in July 2011

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## Summary

The nocturnal flights of migrating waterfowl and songbirds (passerines) were tracked by radar at the Utgrunden Lighthouse in southern Kalmar Sound on a total of 23 autumn and 26 spring nights from 2006 to 2008. Both the routes and the altitudes of the birds' flights were studied. The radar echoes were classified as follows: birds that flew at no more than 20 km/h were considered *songbirds*, whilst those that flew at least 45 km/h were considered waterfowl waders (the report calls them waterfowl). For eight autumn nights and eight spring nights, there was heavy bird migration. A great amount of data was gathered on a total of 14,172 songbird echoes in the autumn and 1,014 in the spring, as well as on 1,105 flocks of marine birds in the autumn and 295 flocks in the spring. Southern Kalmar Sound is known as a location frequented by many marine birds, with heavy migrations both in the autumn and spring (daytime about 6 – 8,000 bird echoes/h/km). The peak reading for this study was 1,840 echoes/h/km for autumn nights and 355 echoes/h/km for spring nights. These figures can be compared with readings taken at Falsterbo, where the peak readings in the autumn were about 6,600 bird echoes/h/km, and at Kriegers Flak on the southern Baltic, about 3,000 echoes/h/km. Migration over southern Kalmar Sound is thus relatively heavy in the autumn, but in the spring, nocturnal songbird migration is fairly light, and involves relatively few birds in the area studied.

The nocturnal bird migration above the sea occurs at higher altitudes for both marine birds and songbirds. On autumn nights, marine birds fly at an average altitude of 156 metres above the sea, as compared to 17 metres during the day. In spring, the corresponding figures are 106 metres at night and 24 metres during the day, respectively. The average altitude for songbirds in the autumn is 330 metres by night and 35 metres by day. On spring nights, the corresponding figures for songbirds are 529 metres at night and 50 metres by day.

Waterfowl fly so high at night that they risk colliding with wind turbines that are 150 metres tall (most commonly off-shore). About 50 – 90 % of the migrating waterfowl are affected. They need to either veer off or fly above the wind turbines in order to avoid a collision.

This study shows that waterfowl veer off from the wind turbines. This veering off occurs closer to the turbines at night than during the day. The study does not demonstrate that the risk of collisions is either greater or less than that shown in previous studies.

Regarding nocturnal flying in conditions of poor visibility, the marine birds either veer off somewhat closer to the wind turbines at night, but not closer than an average of 500 metres (compared to an average of 570 metres on nights without fog) or flew above the turbines, with their average flight altitude being higher on nights with poor visibility.

These distances at which birds veered off at night differed from the distances found during the day (i.e. 1– 3 km before the wind turbines). Only 0.1-0.5 % of the marine birds flew between the wind turbines during the day

(the distance between each of the area's seven turbines is about 400 metres). On nights without fog, 5 % of the flocks flew between the turbines, and this figure rose to 9 % on foggy nights, which may indicate a higher risk of collisions at night than by day.

The large number of songbirds that migrate across this stretch of sea at night flew at an average altitude that was high above the turbines (330 metres in autumn and 529 metres in spring). They seem to fly a little higher on foggy nights (343 metres as compared to 330 metres when there is no fog). This flight altitude in fog only applies to autumn nights, and the difference is not statistically significant. However, on certain nights, there are statistically significant differences. On nights without fog, songbirds fly about 100 metres higher than on foggy nights.

The great majority of songbirds fly above the wind turbines at night, but there is a great range as to where these songbirds fly. In spring, 8 % of the migrating birds are affected by wind turbines, which are 150 metres tall, and in autumn, this figure is 17 %. However, this study cannot give any answer as to how low-flying birds pass the turbines, as the area studied for songbirds was more than 1,500 metres away from the lighthouse where the radar was located.

However, it was shown that songbirds flew higher above the sea on two of three foggy nights, and thus clearly flew above the approximately 100 metre high fog. The observations of night-flying marine birds also show a higher flight altitude on nights with fog (averaging 240 metres) as compared to nights without fog (156 metres).

The study shows that there are some (albeit a few) songbirds that rest after a night of migration. This most often happens when a night of migration is followed by a foggy morning. Even under those conditions, there are few birds out around Utgrunden. The great danger involving songbirds and off-shore wind turbines arises when mass landings occur. This happens when birds are flying over the water and encounter a stormy area of rain and mist, which makes them fly lower and search out places to land. No such phenomenon has been observed on Kalmar Sound in this study.

Based on new data, a rough calculation of the risk of collision encountered by songbirds at the seven existing wind turbines located at Utgrunden indicates that 16 songbirds will be killed out of the approximately half million songbirds that pass that point at night. The collision risk for waterfowl is not considered to have changed as a result of these data, and remains at a total of about 10-15 waterfowl being killed annually by the seven wind turbines at Utgrunden and the five at Yttre Stengrund (Pettersson 2006).



**Picture 1.** Eiders fly at lower altitudes during daytime migrations in the spring, at an average altitude of 24 metres (this flock, however, is flying at 40 metres), whilst night migrations maintained an average altitude of 109 metres. For the autumn migration, the flight altitude at night averaged 156 metres.



# 1. Background

This project was started for the purpose of providing a better basis for assessing migratory bird risks when building future off-shore wind turbines. In 2006, when an application was made for this project, E.ON was planning on building a 24 wind turbine wind farm at the site of the seven existing wind turbines. This is still planned, and E.ON has a building permit but has not yet commenced the construction of the wind turbines. As a result, no studies were able to be conducted regarding how migrating birds react to the large offshore wind farm that was planned, but were instead limited to the smaller Utgrunden wind farm with its existing seven turbines (see area of investigation, Figure 1).

This study has focused on the nocturnal flight altitudes of the birds above the sea, as well as their behaviour when encountering wind turbines. This information, in turn, is necessary so as to enable more accurate calculations to be done in the future regarding the risks to migrating birds. This study primarily provides information regarding the night migrations of songbirds and waterfowl, and contributes new knowledge regarding birds that migrate over the sea.

The modern radar technology, which was installed and tested in a preliminary study (the name and number of the report are indicated in Pettersson 2006) was supplemented by an additional radar facility in the spring of 2006 to obtain better flight altitude data for both songbirds and waterfowl. This radar equipment was placed in the Utgrunden lighthouse, located in the middle of Kalmar Sound where the bird migration, especially that of marine birds, is most intense. Another advantage of this location is that smaller and easier to handle radar equipment with a range sufficient to monitor the Sound could be used (a similar radar had previously been used in Denmark and in wind turbines studies see Petersen et al. 2006). The same study could have been done using stronger and better radar equipment, with the radar placed farther away, as in the monitoring of Lillgrund in Skåne, which was done using radar in Lund (Green & Nilsson 2006).

There are primarily three important questions regarding off-shore wind turbines that this study was required to answer:

1. Which flight altitudes do waterfowl use during their migration over open seas and at night as well as in conditions of poor visibility?
2. How high do songbirds (passerines) fly over the sea at night and in conditions of poor visibility?
3. How do both waterfowl and songbirds react under conditions of poor visibility when they come close to off-shore wind turbines?

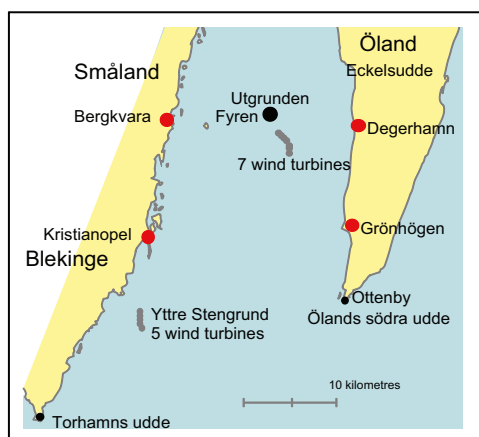
An understanding of these matters is very important in order to calculate the risk of birds colliding with off-shore wind turbines. These calculations are based on the flight altitudes the birds use, and their reactions when they encounter wind turbines.

There are currently some data regarding the flight altitudes of birds over the sea, which have been compiled in other places in Europe with a view of understanding the problems relating to planning large wind farms with off-shore wind turbines. A number of comparisons will be made primarily between a large German study in the southern Baltic Sea (IfAö 2004) and the Kalmar Sound material presented in this report.

In autumn, there is a large migration of songbirds that cross the Sound at the level of Utgrunden, according to waterfowl studies 1999 - 2003 (Pettersson 2005), which was a preliminary study to this study. The radar technology used in that study (Pettersson 2005) was military overview radar, which could hardly detect songbirds to any great extent. But this was nevertheless used for this purpose during the heaviest migration. For several autumn nights in 1999 to 2003, a very heavy nocturnal migration of songbirds was noted (Pettersson 2005). During the day there was a relatively heavy songbird migration over the Sound (observations in this study), especially in the autumn. This was also noted by the observers in the waterfowl study of 1999-2003, even though they did have not enough time and were not able, to detect the migration by radar.

Consequently, there is much that speaks for southern Kalmar Sound as an appropriate location to study the migration of songbirds in the vicinity of off-shore wind turbines. The preliminary study in the summer and autumn of 2005, however, indicates that on certain days and nights in the area, there are heavy bird migrations with an estimate of half a million songbirds passing this well-monitored area of about 10 kilometres wide (Pettersson 2006).

The material gathered in this study is very extensive, even though it does not cover many study days. However, those days it has covered have been selected with precision so as to be able to detect migrating birds when migration is heaviest. In addition, I have attempted to choose nights with fog and bird migrations, which are considered the conditions that can increase the risk of birds colliding with off-shore wind turbines.



**Figure 1.** Study area in southern Kalmar Sound around Utgrunden with radar equipment placed in the lighthouse.

This report discusses only night migration, as the radar equipment reveals what occurs then, and this is the area of where our knowledge is subject to the greatest degree of uncertainty. The daytime migration material is naturally also extensive, but has not been compiled for this final report.

An additional issue has been covered in this radar-assisted study – the problems of flying bats and off-shore wind turbines. The preliminary study for this bird study (Pettersson 2006) showed that the radar can be adjusted so that large bats are detected as well. The results regarding bats have been compiled in a different Vindval report (see Ahlén et al. 2006).

## 2. Methods and equipment

Marine radar equipment with a horizontal antenna was set up in the Utgrunden lighthouse during the preliminary study (Pettersson 2006). In the initial stages of this study, the Utgrunden lighthouse (Spring 2006) was equipped with additional radar equipment with an antenna angled vertically at 90 degrees, to enable the detection of flight altitudes.



**Pictures 2 and 3.** The two Furuno radars with antennas (Picture 2) where the left one can be angled at a 90 degree slant so that flight altitudes can be obtained (on the screen in the middle of Picture 3). Inside the lighthouse, all these data can be seen. On the screen to the right, all events are filmed. On the computer (the smaller screen) all monitoring that can be done by homing is stored, and flight speed can be documented.

Radar detection has the following advantages compared with visual observations of bird migrations in the study regarding wind power and birds:

- At night, birds can be detected. Many species migrate at night. There is probably an increased risk of collision with wind turbines at night, primarily when there is fog.
- A relatively large area can be quantitatively detected.
- The measured results are concrete (flight altitude, direction, distance).
- Detection can be done in a continuous manner without any fatigue.

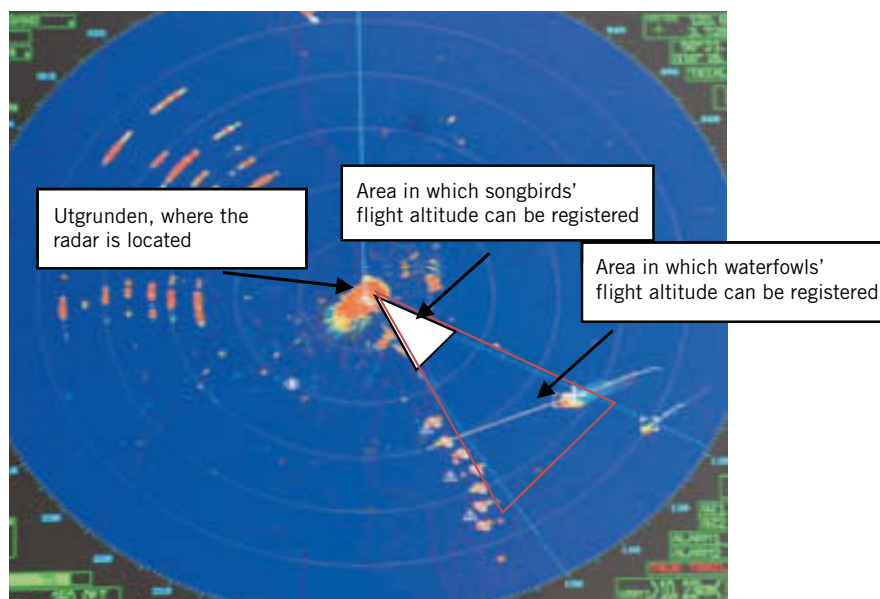
The most important limitations in the interpretation of data detected by radar are the following:

- It is not possible to determine the species of bird that triggered the signals.
- The number of birds cannot be determined. A large signal can be caused by a single large bird or by several smaller birds.
- When birds fly very low, bird echoes can be superimposed by reflections from waves and will not be able to be distinguished. It is difficult to ascertain the altitude range in which this effect occurs.
- A bird's radar cross-section (RCS), and thereby its probability of detection, is significantly affected by the angle at which the radar beams hits the bird. The probability is greatest from the side, and least from in front or behind.

- A large number of flying insects, rain and snow cause strong echoes that distort the bird echoes.
- The probability of detecting a bird is affected by the distance to the radar. It is therefore necessary to correct for distance in order to achieve quantitative measurements.

Despite these limitations, it is possible to make quantitative statements if one uses correction factors to take into account the fact that detection probability decreases with increasing distance. However, for some limitations there are no practical correction factors (for example, the number of birds per echo is unknown, and some of the lower flying birds are not detected), and the values indicated can be considered to be underestimations (i.e. the values that are indicated for migration intensity are minimum values). Regarding the professional assessment of data, it is very important to mention that radar cannot be used in poor weather conditions, such as heavy wind and rain, but functions well in fog and mist). Migration intensity is very low in both rain and heavy wind, according to visual daytime observations in Kalmar Sound.

In this study, horizontal radar set to detect songbirds has been able to be used parallel with vertical radar that detects flight altitudes. The advantage of this is that many echoes closer than 1,500 metres to the lighthouse have been able to be documented at the same time as the speed of the birds (songbirds are around 20 km/h, and waterfowl are more than 45 km/h) (Bruderer 1971 and Alerstam 1990). This makes for somewhat of an improvement in nocturnal detection over detections where the species in no way is ascertainable. All this work has partially been able to be implemented retroactively as almost all the nocturnal studies have been videofilmed.



**Picture 4.** Within 1,500 metres from the radar, songbirds' flight altitude can be detected with some degree of certainty. The flight altitude of marine bird flocks, however, can be detected up to 4,500 metres from the radar.

In summary, we can conclude that a ship’s radar used properly to detect bird migrations will result in scientifically acceptable data, which otherwise is impossible to obtain (especially in nocturnal observations). The major drawback regarding data gathering with radar at night, however, is that the size of the group or flock represented by an echo cannot be directly determined. Visual observations supplement detection by radar, but this is possible only during the day. At night, however, it is possible to hear mating calls that can reveal which species are involved, or to count the birds that are seen passing through the moonlight.

## 2.1 Specification of the radar equipment used

The study used Furuno vertically and horizontally operated ship’s radar to measure flight altitude and migration intensity. Specifications and settings are shown in Table 1.

The filter settings were adjusted on each occasion so as to do whatever possible to achieve good visibility of bird signals. No filter was used to suppress signals. Signal gain was reduced until disturbing signals were no longer detected (setting during the period was about 65 %). These settings were found by trial and error during the entire period of measurement. The vertical radar was adjusted so as to cover an area southeast of the lighthouse. Up to an altitude of 1,200-1,400 metres, the echoes were detected. Songbirds and other birds were detected in what is close to a rectangular detection field extending up to 1,500 metres from the lighthouse (see Picture 5).

**Table 1. Specifications and settings for Furuno 25 kW (2127B) radar equipment. Same basic settings of both instruments, whilst the vertical detecting is used only on the east side of the lighthouse, as sensitivity was adjusted to the highest setting there.**

Frequency (MHz) 9410±30	Range used (km) 1.5 and up to 12 (horizontal)
Wavelength (cm) 3	Pulse length (µs) 0.15
Broadcast output (kW) 25	Pulse repetition frequency (PRF; Hz) 1,500
Antenna length (m) 2	Antenna rotation speed (rpm) 24
Radar beam’s horizontal opening angle (°) 0.95	Search time (sec) 30
Radar beam’s vertical opening angle (°) 20	Auto-Tune (receiver’s fine tuning) ON

The position of the lighthouse and radars (2 units) 56°22’379 North latitude, 16°15’429 East longitude.

Both the radar units were installed in the Utgrunden lighthouse at an altitude of 16 metres above sea level. This study used only the vertically driven radar to detect the change in altitude, as well as the intensity of migration. The horizontal radar in this compilation has been used to ascertain the speed of the echoes (through tracking shorter flights) and thereby was able to determine whether they were from songbirds or marine birds. But with regard to the study of how the birds fly near the wind turbines, only the horizontal radar was used. The horizontal radar, despite its altitude above the water, encounters a great deal of disturbance from the wave movements when there

are strong winds. It is difficult to see close and low-flying flocks when the wave disturbances are great. In the measurement of migration speed, the horizontal radar falls short, as the closest flying flocks tend to be over-represented. In this case, horizontal radar has been used only to ascertain the speed of the echoes, as well as to show how some flocks (waterfowl) fly near the wind turbines.

## 2.2 Detection range and material safety

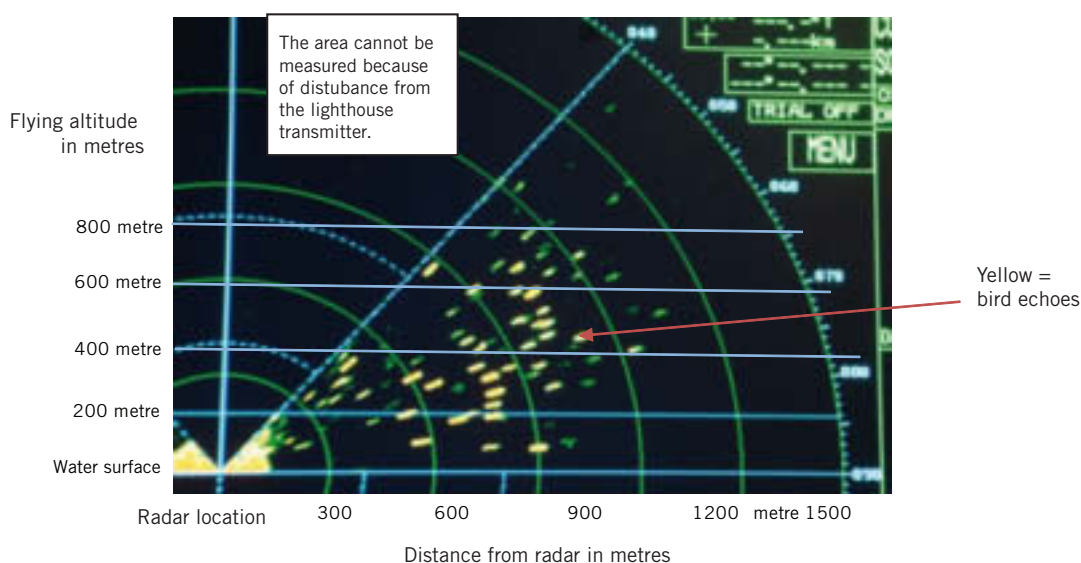
The predominant migration direction for the birds in southern Kalmar Sound is northward in the spring and southward in the autumn (see Pettersson 2005). As a result, these birds are picked up by the radar from the side (both in autumn and spring), making for better detection here than in other locations.

The radar beams often hit the birds from the side or from beneath, making them easier to track and observe. However, a bird that flies directly toward the radar makes a more difficult target, as the distance to the radar changes, and it becomes harder for the radar to provide good data regarding speed and route. It is a known fact that birds that cross the radar beam vertically are represented on the radar screen as point echoes because the distance to the radar changes at an uneven rate. When the radar is used for homing, these kinds of echoes are difficult to follow (IfAö 2004). When the front or back of the bird(s) is shown on the radar, this also leads to longer distances and poorer observation opportunities, as the radar beams don't hit as well. Bird migration in the Sound where most of the birds fly relatively parallel to the coasts is thus an excellent area for radar study (possibility of tracking many long flights, see Pettersson 2005).

## 2.3 Superimposition of echoes

The most important limiting factors are the transmission output of the radar, the wavelength of the radar beams, the reflection cross-section (individual bird/flock, size of bird/birds), as well as the distance to the target. Highly efficient equipment can distinguish birds from a longer distance than can radar with a lower kW value, assuming that the wavelengths are the same. The wavelength of the radar equipment used was 3 cm (x-band radar), which enabled detection of even songbirds within the range of the radar. Even though it is possible to reach further with poorer resolution (e.g. wave lengths of 15-30 cm, for which this equipment can be adjusted) and in this way cover a larger area, this will not enable the detection of songbirds. On the other hand, the volume of the radar beam (at a nominal opening angle of  $1.3^\circ \times 24^\circ$ ) increases with distance, but the energy density of the beam decreases by a factor of  $4TTR^2$  ( $R$  = distance, 4th power law – radar equation, see Eastwood 1967) after transmission and reflection by the bird. If you also include the reduced

detection in the vicinity (the minimum distance depends on the time the antenna requires to switch between transmitting and receiving; the decrease in output acts as self-protection in the case of a strong reflection) this leads to the typical bell curve distribution of the echoes. At first, the probability of detection increases until it reaches optimum detection, and then decreases again as distance is increased. In order to come to a conclusion regarding quantity, there must be a correction of observability, which is dependent on distance. In order to calculate the distance correction, the Distance program is used, which *inter alia* limits the area of use for the data pertaining to flight altitude information at a greater distance than 1,500 metres (Buckland et al. 2001).



**Picture 5.** Flight altitude measurement with 37 bird echoes on the screen, autumn 2007, 4 September at 21:25. This is the first of the pictures taken during that minute.

## 2.4 Correction of radar data

In order to perform a quantitative analysis of the migration intensity and the flight altitude, these data were corrected. The purpose of this was to even out distance-related variations in the probability of detection for the radar equipment, as well as to have the comparable unit (echoes/h/km). Regarding the distance correction, a direct distance-related weighting of echoes was performed so that the number of echoes (e.g. those between 1200 and 1500 metres away) are not not exhaustive, regarding number, whilst those in the outer sector were weighted to make up a comparable number, which occurred within the 300-metre zone (see Picture 5).

On the other hand, manual counts were used to check averages. In order to estimate the intensity (echoes per minute), data were used only from the manual counts (counted retroactively) that were done every ten minutes (each count covered two minutes) directly on the screen. This kind of count is recommended for use for verification when utilizing the Distance computer program.



All bird echoes have been included in the intensity estimates, including those of birds flying at speeds between 20 km/h and 45 km/h. Half of the birds that flew at the lowest speed were classified as songbirds whilst those flying at high speeds were classed as marine birds.

Video recording and filming of the screen were done continually. These show an average picture for each half minute. The retention of echoes on the screen since the previous display was estimated at 50 %, and this was taken into account before the final notation was made (See further IfAö 2004, which reports in detail how this method was used, and how to use the Distance computer program).

The area that was covered by the radar due to disturbances in the recording transmission at the Utgrunden lighthouse was removed (see Picture 4) as the disturbance wipes out some of the echoes.

During the latter part of the nights on which only the radar screens were filmed (on the nights with fog, however, the screens were monitored manually all night long) and no verification counts were made, the same estimation principles were used as when the verification counts were done. The evaluation only took into consideration the notes immediately before the more unmonitored filming.

In the final calculation of migration intensity in the form of echoes per hour and kilometre, the calculated data were placed in relation to the defined area (altitude and lateral). Only one migration 1500 metres out in the Sound was monitored, and with a restriction in the altitude parameter for songbirds.

After adjustment of certain radar settings, marine bird flight altitudes could be detected up to 4,500 metres away. This kind of adjustment of radar settings was done on a regular basis during short periods. Altitude monitoring of songbirds was prioritised during the entire study.

## 2.5 Choice of study days

It was difficult to choose good migration nights, and try to obtain a combination of nocturnal bird migration and fog. This is the reason why the number of nights used in this study was limited.

Practical conditions at and around the lighthouse made it difficult to cover longer periods. I therefore chose to do short and intensive studies, rather than long series. A diesel generator provided current to the radar equipment, and the amount of fuel limited the study to shorter periods. The periods were chosen based on weather conditions, periods of fog and mist, as well as the times of most intensive bird migration.

## 2.6 Weather data

All weather data, especially data pertaining to winds, were evaluated at the Utgrunden lighthouse every three hours, or more often in the event of a weather change. Evening wind directions and wind intensity were noted more often (every hour where possible).

Atop the Utgrunden lighthouse, there is a 90 m tall wind measurement mast. This mast's distance markings were used to determine how high the fog reached at night.

## 3.1 Results

### 3.1 Autumn

#### 3.1.1 The scope of the study

The study was performed during eight nights with good migration (see Table 2), with fog occurring on three of the nights (at least parts of the night). I consider this a large enough sample to serve as a basis for assessments. How common the combination of fog and bird migration is has been discussed previously (Pettersson 2005). It does occur, albeit quite rarely.

**Table 2. Description of the total of 23 study nights on which observations were made during the period from 2006 to 2008 at Utgrunden, weather conditions, as well as the number of songbirds flying around the lighthouse on the following mornings.**

Resting songbirds on the lighthouse after nocturnal migration from dawn and three hours ahead.

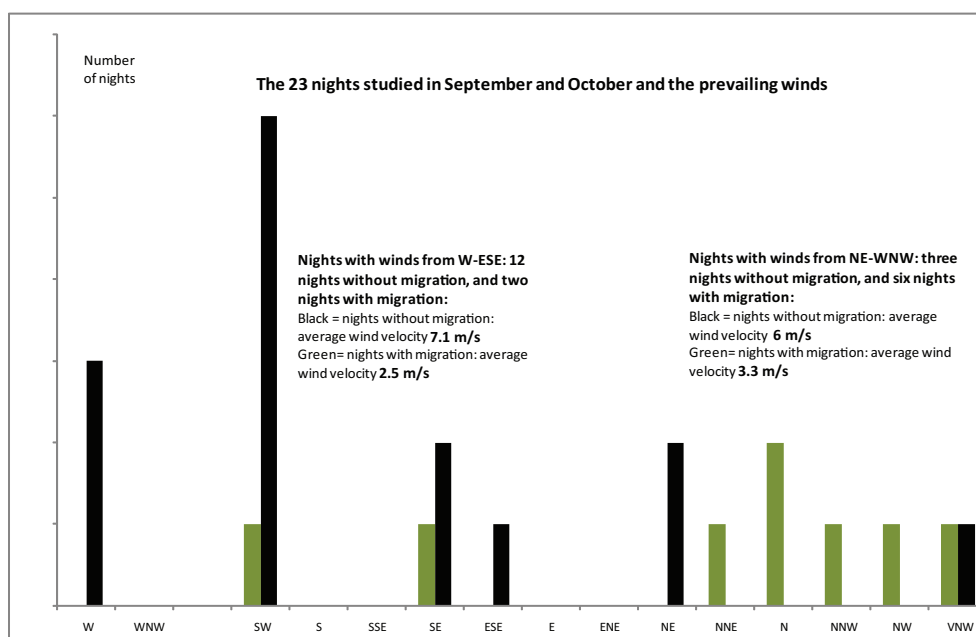
Year	Date	Songbird nocturnal migration	Winds m/:	Visiblity	Resting birds	Number
2006	10.9	Good migration	NW 5	Good	Willow warbler 2	2
2006	14.9	Good migration	SE 3	Good	Wagtail 3+4+10	17
2006	19.9	Bra sträck	NNV 2	Fog	Wagtail 1, robin 4, hedge sparr	7
2006	20.10	No migration	ESE 7	Rain	No resting birds	0
2006	30.10	No migration	NE 4	Rain	No resting birds	0
2006	2.11	No migration	N 18	Good	No resting birds	0
2006	3.11	No migration	N 14	Good	redwing 2 och skylark 1	3
2007	5.9	Good migration	N 5	Good	Wagtail 2, willow warbler and s	4
2007	12.9	Good migration	NNE 2	Rain	Wagtail 1	1
2007	13.9	No migration	SW 7	Good	No resting birds	0
2007	14.9	No migration	W 6	Good	No resting birds	0
2007	15.9	No migration	SW 8	Good	No resting birds	0
2007	16.9	No migration	SW 10	Good	No resting birds	0
2007	27.9	Good migration	SW 2	Fog	Wagtail 12, robin 5, willow war	19
2007	4.10	Good migration	N 1	Fog	Wagtail 11, robin 2 and goldcre	14
2007	12.10	No migration	SW 6	Rain	No resting birds	0
2007	13.10	No migration	W 6	Showers	No resting birds	0
2007	23.10	No migration	NE 4	Good	No resting birds	0
2007	1.11	No migration	WNW 10	Rain	No resting birds	0
2007	2.11	No migration	NE 18	Good	No resting birds	0
2007	3.11	No migration	N 10	Good	No resting birds	0
2007	4.11	No migration	NW 12	Good	No resting birds	0
2007	5.11	No migration	N 9	Good	Redwing 1	1
2008	16.9	No migration	SE 8	Good	Wagtail 2	2
2008	17.9	No migration	SE 10	Good	No resting birds	0
2008	16.10	No migration	SW 6	Showers	No resting birds	0
2008	17.10	No migration	W 6	Showers	No resting birds	0
2008	18.10	Good migration	WNW 5	Good	Robin 4, goldcrest 2, wren 2 ant	9

In the autumn, marine bird migrations occur, but to a significantly lesser degree than migration of songbirds. It is probable that on about the same nights, both marine bird and songbird migration occurred.

#### 3.1.2 Nights with bird migration and winds

It is known that tail winds are what encourage bird migration in autumn, as well as spring, and in the autumn these winds are from the north. Figure 2 presents the nights studied and their wind conditions, and shows that migra-

tion occurred in winds from Sector W-ESE (headwind) with an average velocity of 2.5 m/s. On the other days, when migration did not occur, the wind blew at 7.1 m/s. Nocturnal bird migration is greatest on nights with light winds. These are nights with winds from Sector NE-WNW (tailwind). On the six nights with migration, the average wind velocity was 3.3 m/s. On the three days when no migration occurred, the wind velocity was 6 m/s.



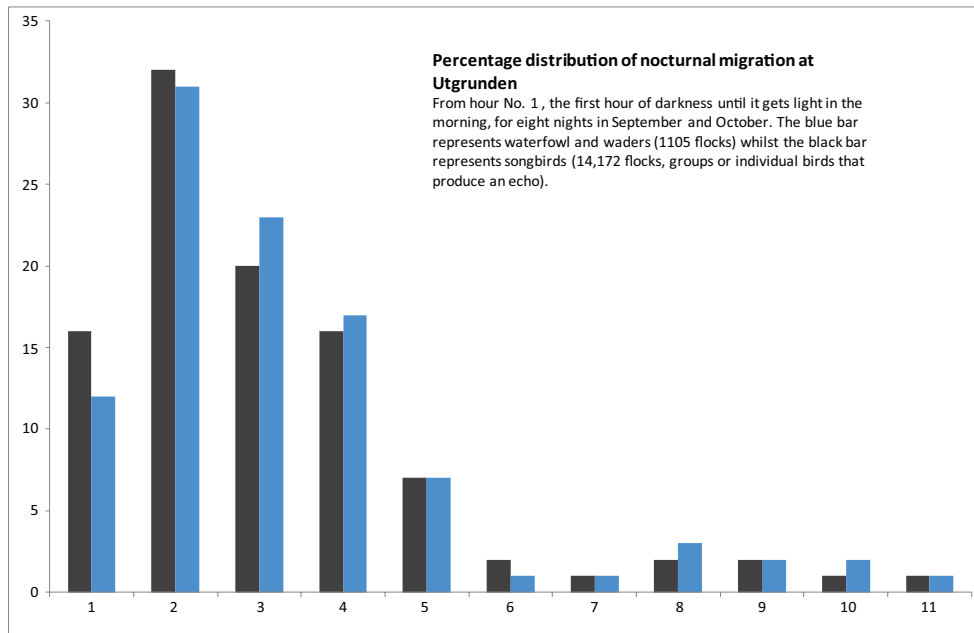
**Figure 2.** Autumn nocturnal bird migration occurs mainly in tailwinds and light wind conditions.

Differentiating between echoes from songbirds and those from marine birds was done by using the horizontal radar for homing in on some of the echoes. If the speed was around 20 km/h or slower, the birds were classified as *songbirds*. If speeds were around 45 km/h or faster, the birds were classified as waterfowl or waders, which are described in the report as waterfowl. For the speed of various birds, see Alerstam 1990.

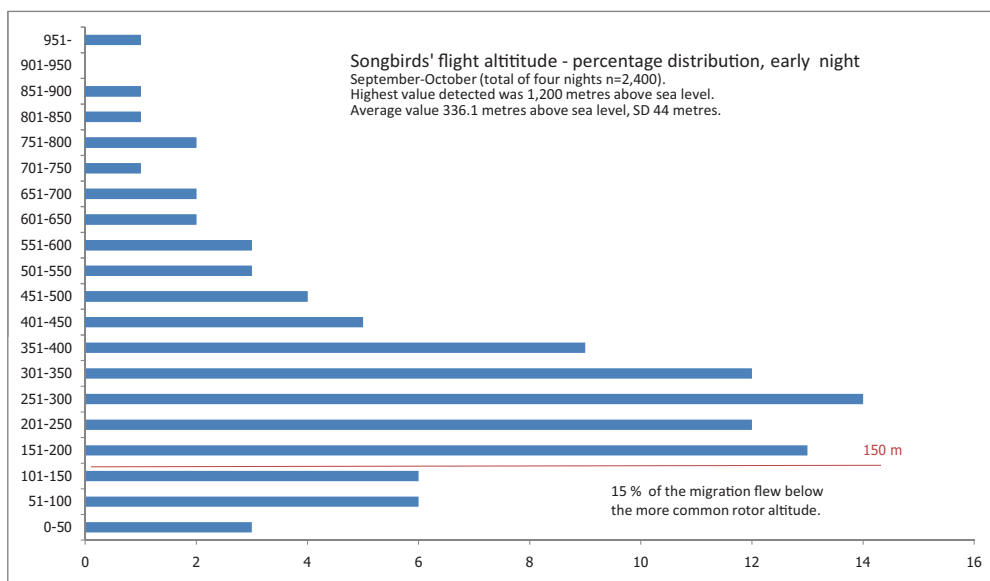
### 3.1.3 The course of nocturnal migrations

Both of these groups of birds showed similar trends during the course of the night, from a definite peak at the beginning of the night, to practically an absence of migrating birds six hours after dusk (i.e. an hour after midnight). The studies show that especially marine birds' migration picked up a bit again toward dawn, as did that of some of the songbirds (see Figure 3). There is a large amount of material in this study of nocturnal migration, and that which provides new insights are the flight altitudes noted on autumn nights for more than 14,000 songbird echoes, as well as more than 1,100 echoes from flocks of waterfowl. To show the distribution of flight altitudes, these data have been divided into an early night (before midnight) and a late night (after midnight) period.

Figures 4 and 5 show the percentage distribution of the various flight altitudes of songbirds. It shows that they fly an average of 50 metres higher before midnight than after midnight. It is surprising that as many as 15% and 22 %, respectively, of the songbird echoes come from altitudes lower than 150 metres, which is currently a normal altitude for rotors. Thus, some of

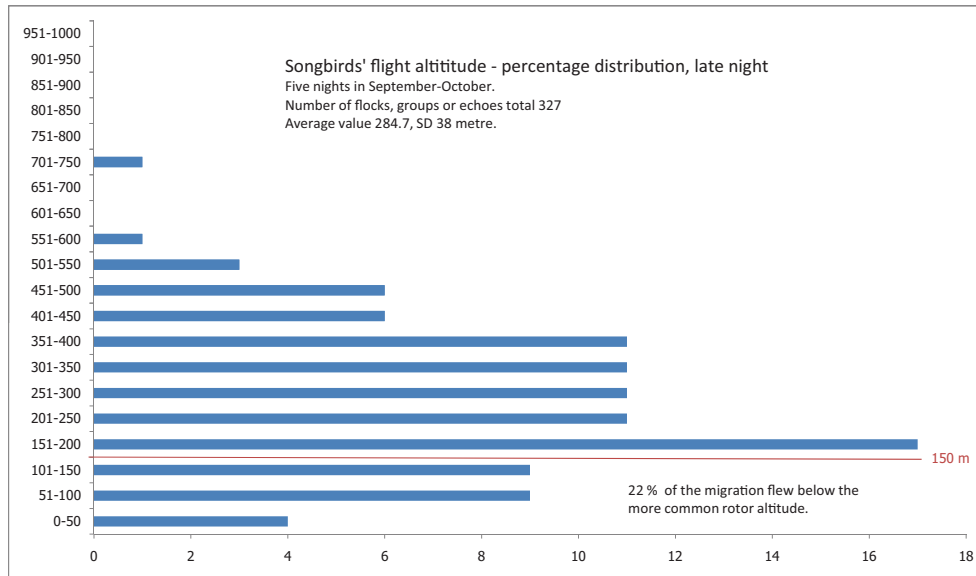


**Figure 3.** Percentage distribution of migrating songbirds and waterfowl at night, where Hour 1 is the first hour after dusk, midnight falls in Hours 4 or 5, with darkness lasting to Hours 10-11.

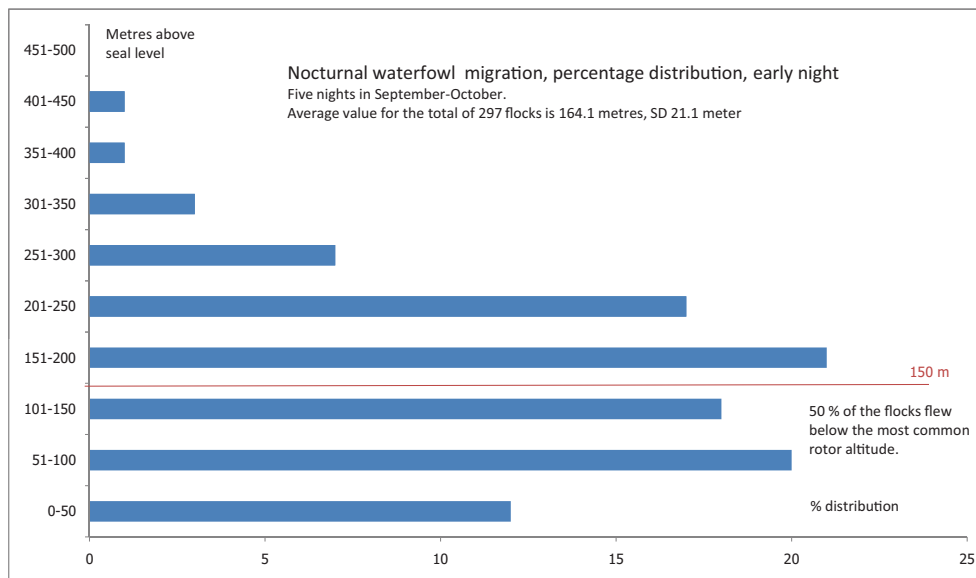


**Figure 4.** Percentage distribution of the flight altitude of migrating songbirds at night. Early night migration only.

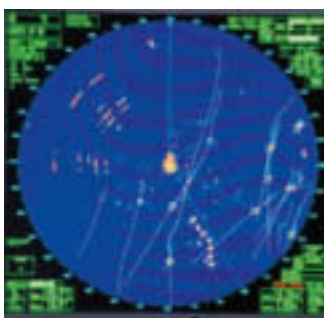
the songbirds can be affected by off-shore wind turbines during their flights, when flying at the altitude of the rotors. Waterfowl (see Figures 6 and 7) fly 80 metres higher, on average, before midnight, as compared to after midnight, but most of them (50 % or more) fly at rotor altitudes all night long.



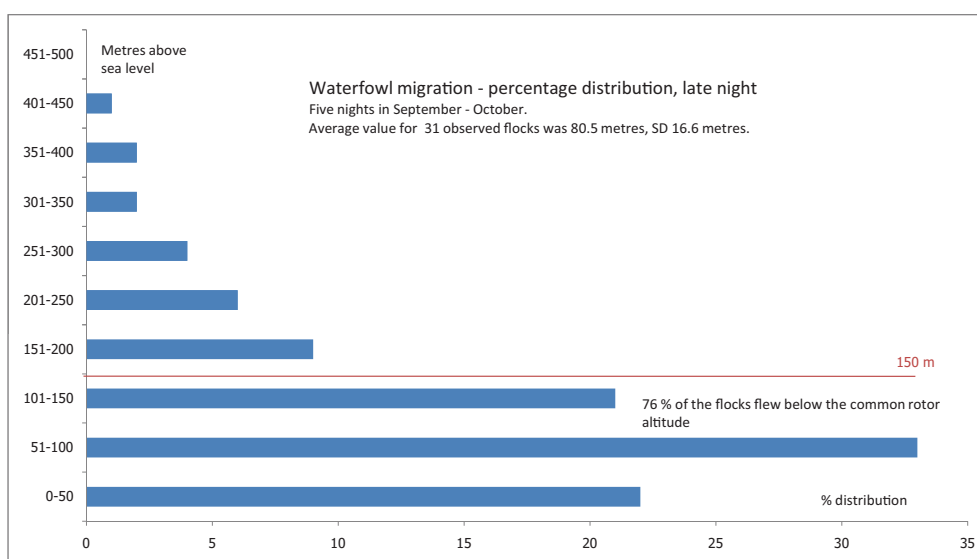
**Figure 5.** Percentage distribution of the flight altitude of migrating songbirds at night. Late night migration only.



**Figure 6.** Percentage distribution of the flight altitude of migrating marine birds at night. Early night migration only.



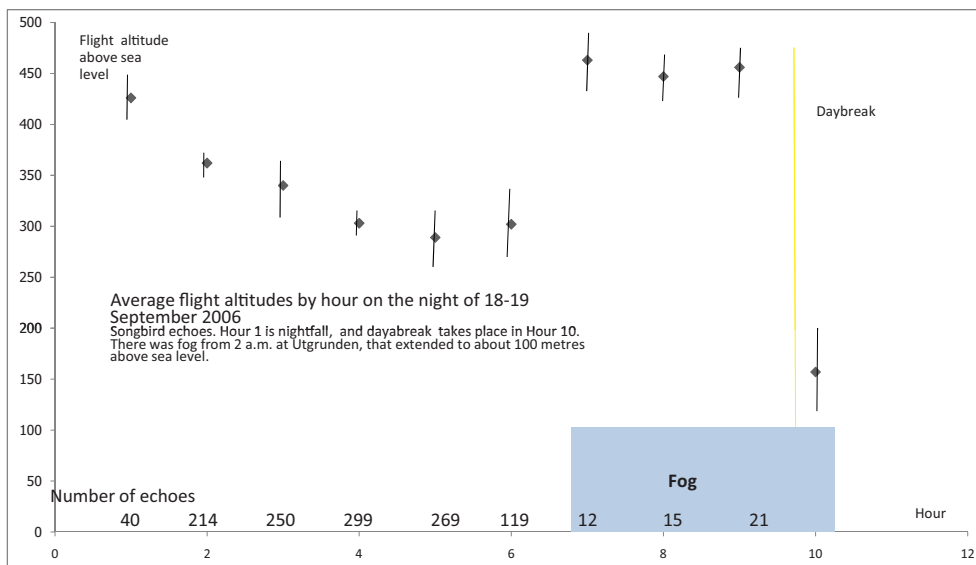
**Picture 6.** Waterfowl monitoring from Utgrunden using the horizontal radar, 4 October 2007 at 01:17. The white lines are the paths of waterfowl flocks taken with the help of homing and (Arpa) monitoring. The area of coverage is six kilometres from the lighthouse.



**Figure 7.** Percentage distribution of the flight altitude of migrating waterfowl at night. Late night migration only.

### 3.1.4 Nocturnal bird migration in fog

During these autumn studies, I was able to identify three nights when fog occurred at the same time as the birds migrated. However, fog only occurred after midnight. Birds would hardly start their migration in an area where there was fog. The combination of fog before midnight and heavy migration is very rare. On the three foggy nights studied, there is an hourly record of how birds migrated and the flight altitudes they maintained (see Figures 8, 9 and 10).



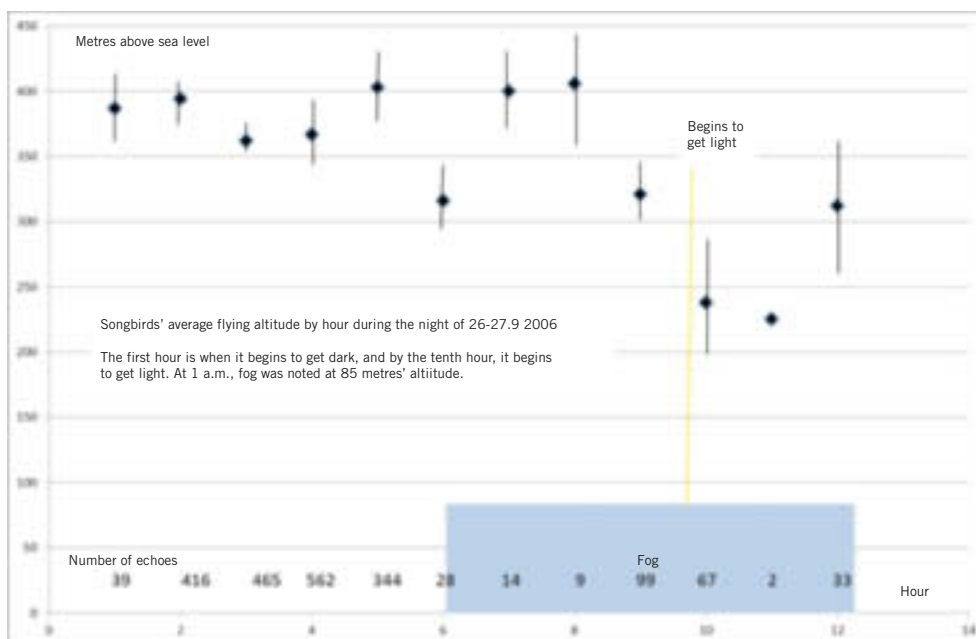
**Figure 8.** Average migrating songbird flight altitudes, hour for hour, on the night of 18-19 September, 2006 when a fog reaching up to 100 metres above sea level began to appear about 2 a.m., at the lighthouse. The variation from the average is shown by a line through the mean value. In the morning, seven songbirds were observed resting during the first hour, but as it got lighter, wagtails could be heard flying around without landing.

The observations on the night of 18-19 September 2006 showed that when the fog began to appear, songbirds migrated at higher (from ca 300 metres to 450 metres) altitude, even though the fog appeared to extend only about 100 metres above sea level. The fog lifted relatively soon after dawn arrived.

On the night of 26-27 September 2006, the fog appeared early, about 1 a.m., at Utgrunden. During the fog, the migration did not show any increase in altitude, but as dawn came, the flight altitude became much lower. Part of the nocturnal migration appeared to consist of wagtails, based on observations the next morning.

On the night of 3-4 October 2007, the fog at the lighthouse appeared half an hour after midnight. At that point the songbird migration changed to a higher average altitude, as compared with earlier that night. In the morning, the fog remained, and a return flight of mostly wagtails toward the northwest was observed, with only a few resting on the lighthouse.



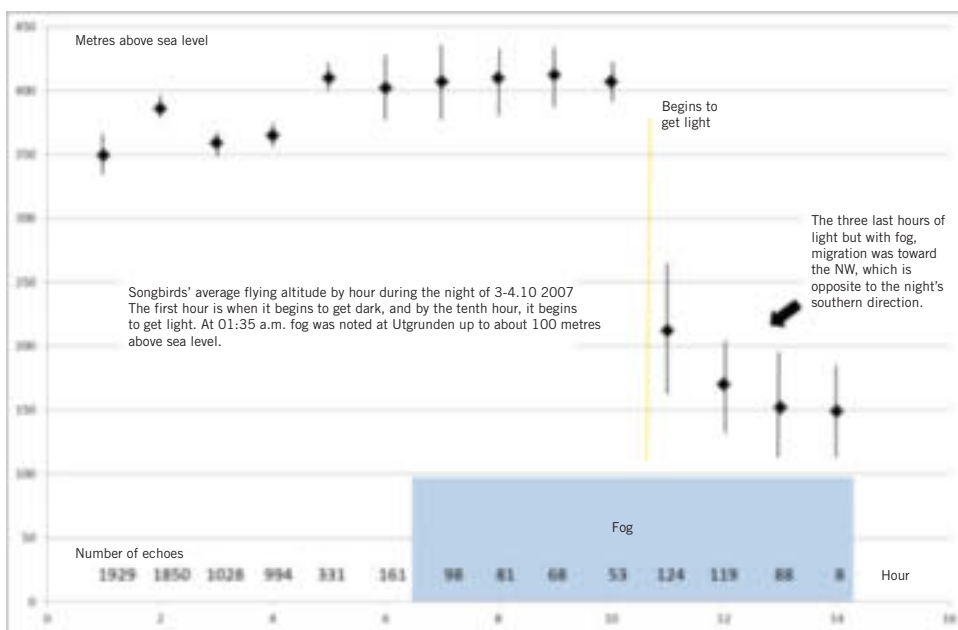


**Figure 9.** Average altitude of songbird migrations, hour for hour, on the night of 26-27 September, 2006 when a fog with an altitude of up to 80 metres above sea level began appearing at 1 a.m. at the Utgrunden lighthouse. On the morning, 19 songbirds, 12 of which were wagtails, were observed resting. At 7 a.m. on 27 September, when the fog began to lift, wagtail flocks of 5-10 bird flew in various directions over the sea.

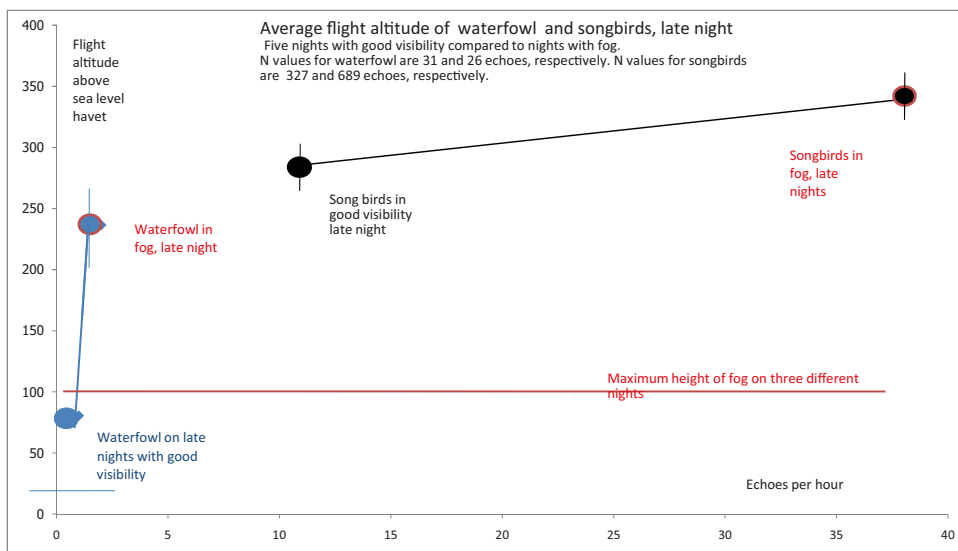
### 3.1.5 Flight altitudes and various correlations

On autumn nights, songbirds fly at an average altitude of 330 metres, as compared to at 35 metres during the day (data gathered for daytime migration in this study  $n=412$ ,  $SD 19$  metres, but have not been set out in this report). Their higher altitude at night than during the day is statistically significant ( $\chi^2$ -test).

It has been proven that at night, migration occurs mostly in tailwinds and relatively light winds, but regarding flight altitudes, the autumn data for songbirds and waterfowl fly at a higher average altitude in fog than on nights with good visibility (see Figure 11). However, the material can only demonstrate this for the early night, as no night has been observed on which fog appears before midnight. Although the material does include such a night, there was no migration then.

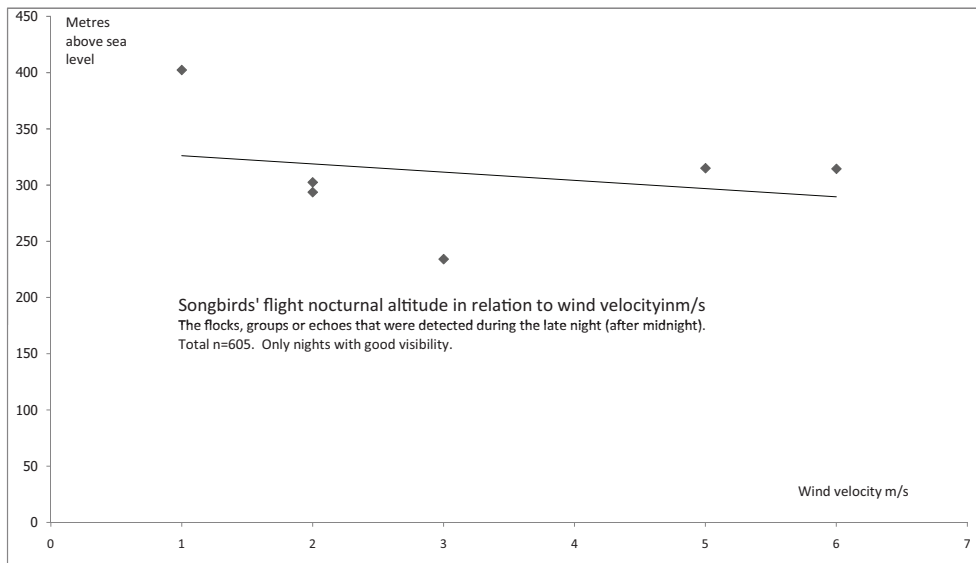


**Figure 10.** Average flight altitude of songbird migration on the night of 3-4 October 2007, hour by hour, when a fog up to an altitude of 100 metres above sea level appeared at 00:30 out near the lighthouse. In the morning, 14 songbirds, of which 11 were wagtails, were observed resting. During the last three hours under conditions of fog and daylight, on 4 October, wagtail flocks of 20-30 birds migrated toward the NW. This is a return flight after the southerly direction of their flight the previous night.



**Figure 11.** The respective average flight altitudes of songbirds and waterfowl after midnight with good visibility compared to nights with fog. The variation from the average is shown by a line through the mean value.

An additional correlation regarding flight altitudes is that songbird migrations show a linear relationship: During migration nights (before midnight) with stronger winds, the birds fly a little higher than they do on nights with light winds (see Figure 12).



**Figure 12.** The average flight altitudes of songbird migration before midnight with good visibility, compared to tailwind velocity. The statistic significance of a correlation between higher flight altitudes and increasing wind velocity has not, however, been established in this study.

### 3.1.6 How do waterfowl pass wind turbines at night?

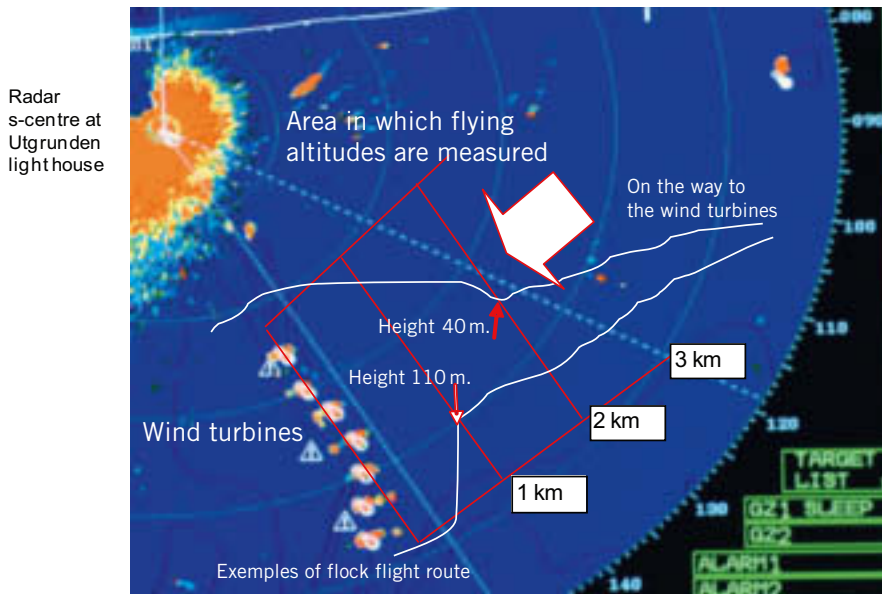
Detecting with certainty the flight altitudes of songbirds more than 1,500 metres from the radar has not been possible, nor have we been able to count how many birds can be tracked or detected. Consequently no analysis was performed of whether, and if so, how, songbirds veer when encountering the 100 metre high wind turbines. However, there is an exception, and that concerns an observation during the spring when a heavy migration, most likely of thrushes, occurred. Information regarding the flight of these birds further away than 1500 metres from the lighthouse could be documented (see section regarding songbirds' flights near the wind turbines in spring). In the case of waterfowl, which can be detected at much longer distances, data regarding flight altitudes can be obtained, but in this study detection was only (most often at night) done within 1,500 metres of lighthouse so as to avoid changing the settings.

A small part of the waterfowl flocks fly directly toward the wind turbines. This occurs during the day, and those birds that do so, most often choose to fly on the side of the turbines. This is well documented in a study of Kalmar Sound in 1999-2003 (Pettersson 2005). The marine birds begin to veer away from of turbines between one and three km from them. Many flocks fly closer than 200 metres (Pettersson 2005). The material gathered from the autumn studies show that on average they fly a little higher at night near the wind turbines. The material show that marine birds veer off an average of about 570 metres before the turbines (see Table 3).



**Figure 7.** Eiders that fly near the wind turbines at Utgrunden during the day. But how do they pass the turbines at night?

**Radar image toward the east of Utgrunden lighthouse, and three kilometres away from the lighthouse. Question of where and at what flying altitude waterfowl flocks veer off from wind turbines.**



**Figure 14.** At Utgrunden lighthouse, there are two ship's radar facilities. One that measures where flocks of birds are flying (horizontal radar), and the other that can detect the flight altitude in a triangular area toward SE (indicated on the picture). Flocks flying in a direction toward the wind turbines can be tracked. It is possible to see where they veer off, and on which side of the turbines they will be flying. In the case of the two flocks shown, one veers off at 1 km, while the other veers off at 2 km. This behaviour is common in the case of flocks that come during the day, and can be tracked as far away at 12 kilometres.

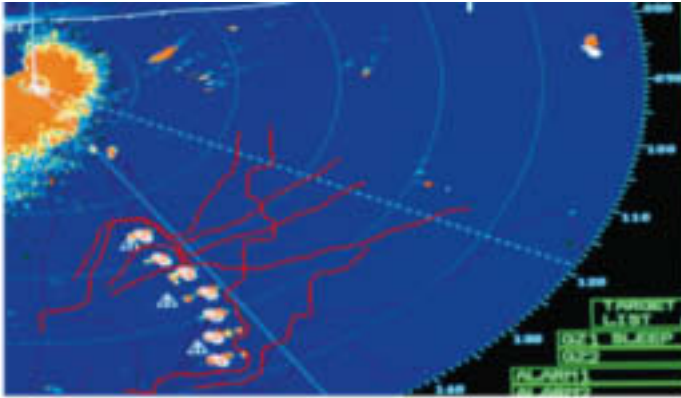
**Table 3.** The table shows the distance at which waterfowl flocks in their autumn migrations veer off from the seven wind turbines at Utgrunden on nights with good visibility, compared to how they act in fog (low-lying fog, no more than 100 metres above sea level).

Autumn material		
Distance in metres	Night No. of flights	Night/fog No. of flights
1500	1	
1400		
1300	2	
1200		
1100	2	
1000	6	1
900		2
800	8	2
700	10	2
600	12	2
500	11	2
400	8	5
300	8	2
200	7	2
100	1	
between	4	2
Total number	80	22
Distance, metres	568,8	500
Distance, SD	34	52
Flight altitude, metres	168,3	167
Flight altitude, SD	22	24

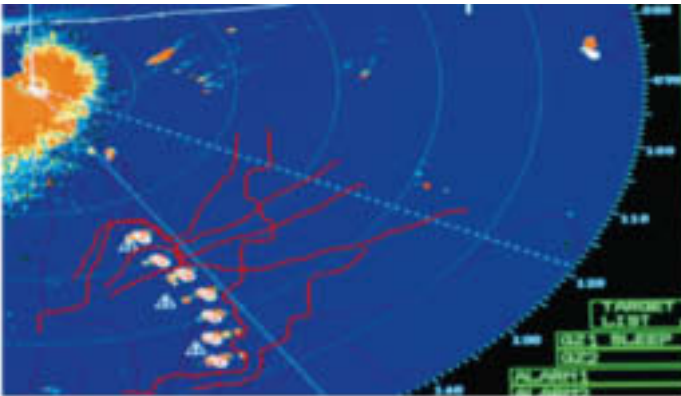
In this case a different setting of the radar has been used from that used to measure the flight altitudes of songbirds. Consequently, it detects a limited number of flocks, with data gathered on eight different nights.

The material compiled shows that at night, the flocks veer off from the wind turbines at an average distance of 570 metres from the turbines. This figure is much closer than that applying during the day, when the distance at which the birds veer is between one and three kilometres (see Pettersson 2005 and Fox et al. 2006). On nights with fog, the bird flocks veer of an average of 500 metres from the turbines, and 9 % of the flocks flew between the wind turbines, while only 5 % of the flocks flew between the turbines on nights without fog. An earlier study in the same area (Pettersson 2005) shows that during the day, between 0.1 and 0.5 % of the marine bird flocks fly between the seven wind turbines at Utgrunden.

Figures 15 and 16 show examples of how such a tracking shows marine birds flying at lower speed, and not having the same definite direction, but rather trying to find their way to a greater extent than what flights tracked on nights with good visibility would show.



**Figure 15.** Ten selected flight trackings of waterfowl or waders (average speed 65 km/h) on the night of 3-4 October between 20:59 and 23:59. Only the paths of those flocks that are flying in the direction of the lighthouse have been drawn (there were about 80 additional flocks in the area at the same time) in nocturnal conditions of good visibility.



**Figure 16.** Six selected flight trackings of waterfowl or waders (average speed 43 km/h) on the night of 3-4 October between 4:59 and 5:59. Only the paths of those flocks that are flying in the direction of the lighthouse have been drawn (eight flocks in the area at the same time) in nocturnal conditions of fog (up to about 100 metres).

## 3.2 Spring

### 3.2.1 Scope of the study

Eight of a total of 26 nights had good amounts of migration (see Table 4). In the autumn both songbird and waterfowl migration occurred. On one of these 26 nights, there was fog from the beginning of the night, but no bird migration. The question of how common it is to have fog and bird migration at the same time has been previously discussed (Pettersson 2005) and has been found to be something that does occur but relatively rarely. This combination was noted on several occasions in the spring of 2000, but not in the springs of 1999-2003 (Pettersson 2005).



**Picture 8.** Eider flock fly far out over Kalmar Sound during the day. Here they are flying only about half a metre above the water.

**Table 4.** All 26 spring nights studied at Utgrunden in 2006-2008. The weather conditions, as well as the number of songbirds resting on the lighthouse in the morning after a night's migration, are shown.

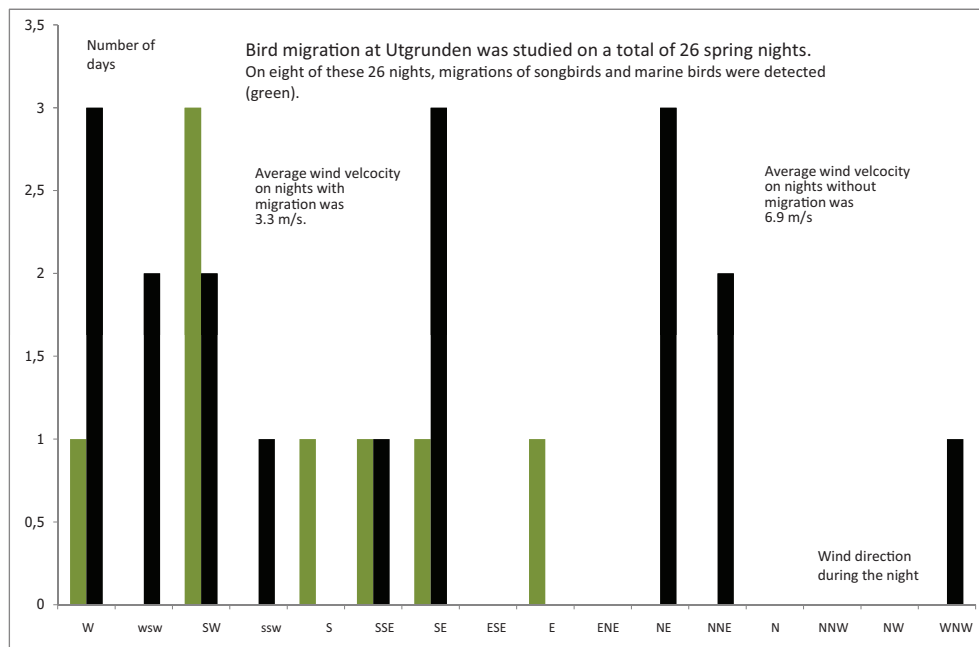
Year	Date	Songbird nocturnal migration	Winds m/s	Visibility	Resting birds	
2006	4.4	Good migration	S 3	Good	Robin 4, wren 2 and goldcrest 2	8
2006	5.4	No migration	W 8	Haze		0
2006	6.4	No migration	W 10			0
2006	7.4	No migration	WSW 8		Robin 1 and wagtail 1	2
2006	8.4	No migration	WSW 4			0
2006	11.4	Good migration	SW 3		Robin 8, wren 4, hedge sparrow 4	18
2006	12.4	No migration	W 6		Wagtail 2 and meadowlark 1	3
2006	13.4	Good migration	SW 4		Wagtail 4, robin 2, great tit 2 and 1	12
2006	19.4	No migration	SE 8		Song thrush 1	1
2006	6.5	Good migration	SW 2		Willow warbler 6, tree pipit 2 and	9
2006	26.5	Good migration	W 4		Willow warbler 2, wood warbler 1	4
2006	27.5	No migration	NNE 4			0
2006	28.5	No migration	NE 2	Fog		0
2007	28.3	No migration	NE 4	Height radar broken		0
2007	29.3	Good migration	E 1	Height radar broken	robin 6, wagtail 2 and 1	10
2007	30.3	Good migration	SSE 2	Height radar broken	robin 4, song thrush 2	8
2007	5.5	No migration	SE 4	Height radar repaired		0
2007	6.5	No migration	SSE 6	Haze		0
2007	1.6	No migration	SE 6	Rain		0
2007	2.6	No migration	NE 10			0
2008	28.3	Good migration	SE 2	Haze	Robin 4, goldcrest 4, blackbird 1, s	11
2008	29.3	No migration	WSW 8	Showers		0
2008	4.4	No migration	WNW 6			0
2008	5.4	No migration	SW 7			0
2008	17.4	No migration	SW 8		Wagtail 2	2
2008	26.5	No migration	NNE 4	Haze		0

### 3.2.2 Nights with bird migration and winds

It is an established fact that tailwinds act to encourage bird migration during both autumn and spring, and that in spring, these are winds from the southern sector. Figure 17 presents the nights studied and their wind conditions (assessed at the Utgrunden lighthouse once every three hours), indicating the main wind direction and wind velocity in early night. Migration has occurred with winds from sector W-E (tailwind), but at an average velocity of 3.3m/s compared with the other days without migration, when wind velocity was 6.9 m/s. The fact that nocturnal bird migration is more likely to occur on nights with tailwind is also indicated by the fact that nights with northerly winds (direct headwind) do not show any migration.



**Picture 9.** An eider flock on its way north, with Öland in the background.



**Figure 17.** The spring migration of birds at night takes place mostly when there is a tailwind or light winds.

Differentiating between echoes from songbirds and those from marine birds was done by using the horizontal radar for homing in on some of the echoes. If the speed was around 20 km/h or slower, the birds were classified as *songbirds*. If speeds were around 45 km/h or faster, the birds were classified as *waterfowl* or *waders*. For the speed of various birds, see Alerstam 1990.



### 3.2.3 The course of nocturnal migration and flight altitudes

Both of these groups of birds showed similar trends during the course of the night, from a definite peak at the beginning of the night, to practically an absence of migrating birds six hours after dusk (i.e. an hour after midnight). The studies show that especially marine birds' migration picked up a bit again toward dawn, as did that of some of the songbirds (see Figure 18 and 19). This primarily indicates that songbird migration in the spring is only about 10% of what it is in the autumn, but that nocturnal waterfowl migration in the area is at least as strong in spring.

There is a large amount of material in this study of nocturnal migration, and what provides new insights are the flight altitudes noted on spring nights for more than 1,014 songbird echoes, as well as more than 294 echoes from flocks of waterfowl.

Figures 18 and 19 show the percentage distribution of the various flight altitudes of songbirds and marine birds. It shows that on average songbirds fly higher on spring nights than on autumn nights, but that waterfowl fly at



Picture 10. Eiders landing when migration conditions have changed.

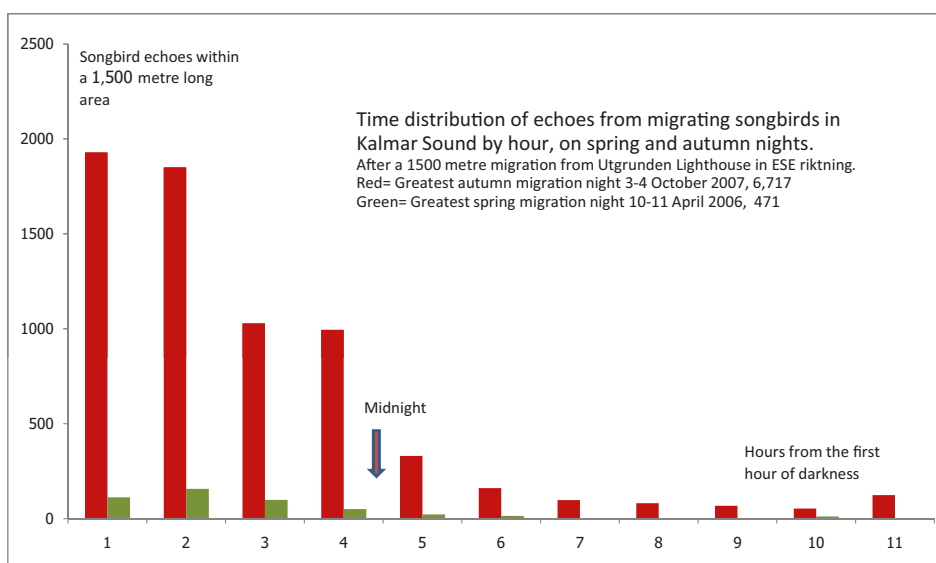
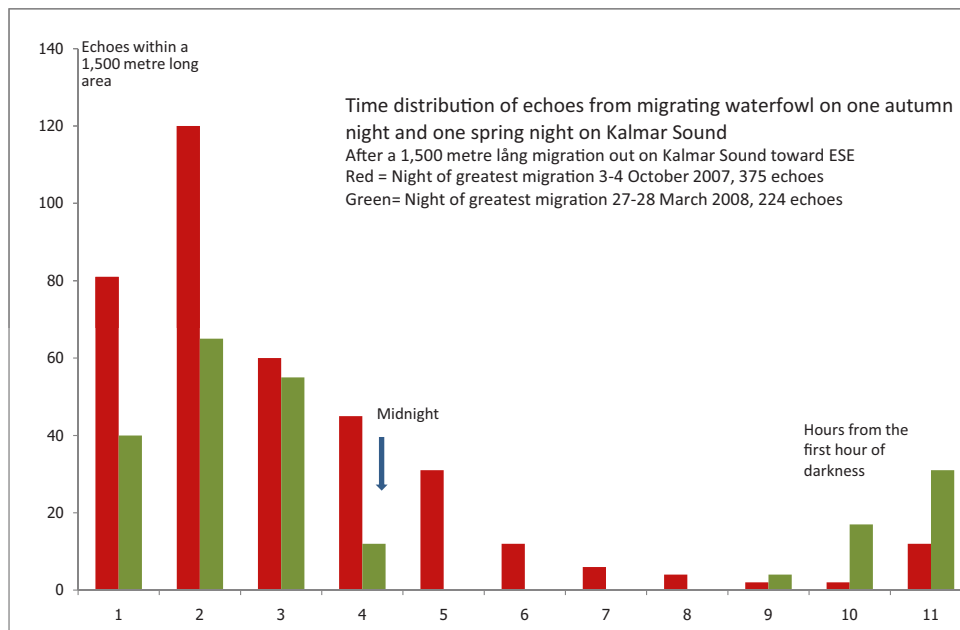


Figure 18. The spring nocturnal migration of songbirds and its distribution over time in relation to the autumn migration (with examples from days when the migration is heaviest). The migration is strongest in the early night, and then almost entirely disappears after midnight.

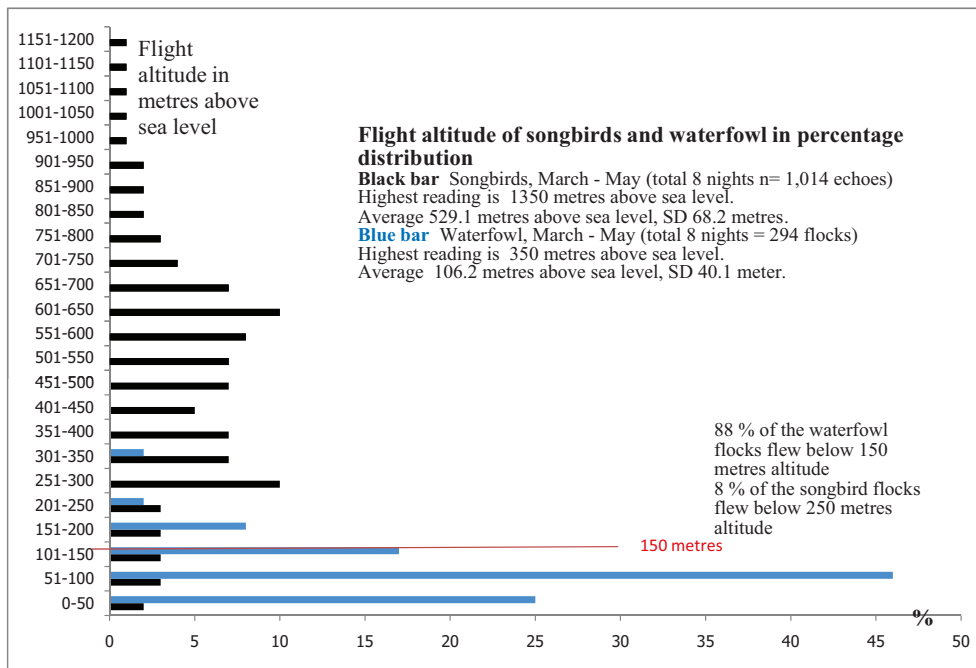


**Figure 19.** The spring nocturnal migration of waterfowl and its distribution over time in relation to the autumn migration (with examples from days when the migration is heaviest). The migration is strongest in early night, and then almost entirely disappears after midnight. In spring, some of the migration occurs during the part of the night after midnight or early in the morning (this tendency is also evident in the autumn migration).

about the same altitudes whether in spring or autumn. It is somewhat surprising that as many as 8 % of the songbird echoes come from altitudes lower than 150 metres, which is currently a normal altitude for rotors. Thus, some of the songbirds can be affected by off-shore wind turbines during their flights, when flying at the altitude of the rotors. Waterfowl (see Figure 20) mostly (88 % or more) fly at rotor altitudes or lower all night long. On spring nights, marine birds fly at an average altitude of 529 metres, as compared to 50 metres during the day (data gathered for daytime migration in this study n=326, SD 16 metres, but have not been set out in this report). Their higher altitude at night than during the day is statistically significant ( $\chi^2$ -test).



**Picture 11.** Six of the seven wind turbines at Utgrunden in southern Kalmar Sound with Långe Jan (the lighthouse at the southern tip of Öland) in the middle of the picture, 24 kilometres away.



**Figure 20.** Percentage distribution of the flight altitude during the spring migration for songbirds and waterfowl, respectively

### 3.2.4 When do waterfowl veer off from off-shore wind turbines?

This study was scheduled to be implemented at the planned Utgrunden II wind farm with its 24 wind turbines, which was to be built in the vicinity of the present wind farm (Utgrunden I) with its seven wind turbines. As the large wind farm has not yet been built, the results regarding the impact on songbirds and waterfowl, respectively, are based on studies of the seven wind turbines at Utgrunden I. This means that the studies of how songbirds fly near the turbines have not been able to be fully conducted. As mentioned above, the radar used does not detect the flight paths of songbirds further than 1,500 metres away, with any certainty, but there is an exception, as we will see further on in the text.

On spring nights with good visibility, waterfowl marine birds choose to fly around the seven wind turbines, and those flocks flying directly toward the turbines (about one out of every ten flocks) veer away from the turbines at an average distance of 482 metres, which is shown by the 50 trackings done during these springs (see Table 5).

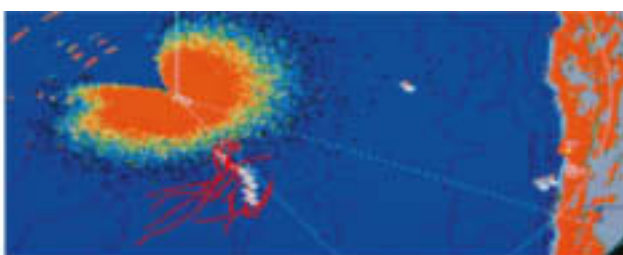


**Picture 12.** Cranes passing on the side of the wind turbines at Utgrunden.

**Table 5.** The table shows the distance at which waterfowl flocks in their spring migrations veer off from the seven wind turbines at Utgrunden on nights with good visibility. The radar settings for these studies have been somewhat different than for the studies of songbird flight altitudes.

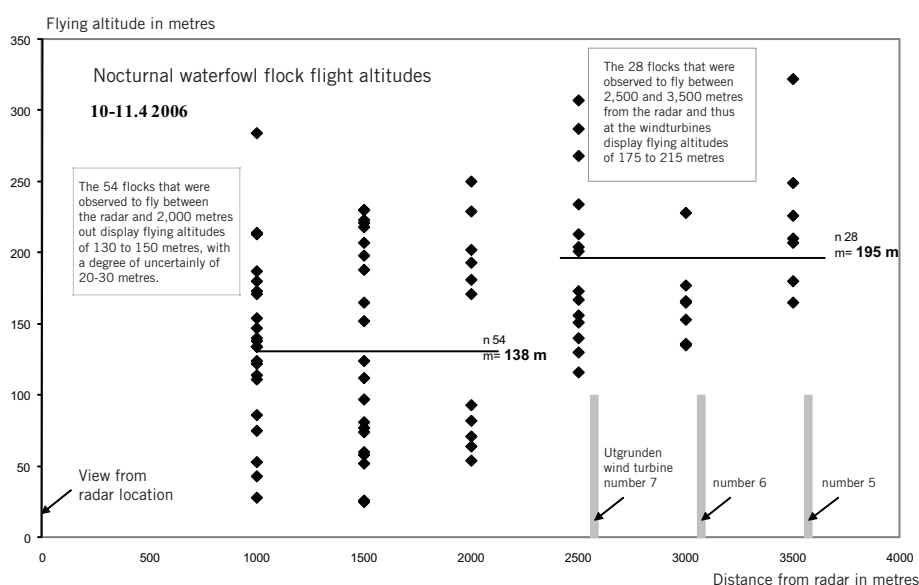
Spring material	
Distance in metres	Night No. of flights
1500	
1400	
1300	
1200	
1100	
1000	5
900	
800	
700	3
600	11
500	13
400	4
300	5
200	3
100	2
between	4
Total number	50
Distance, metres	482
Distance, SD	42
Flight altitude, metres	185
Flight altitude, SD	18

Flocks that fly in the direction of the wind turbines on nights with good visibility do not veer off 1-3 km before the turbines as they do during the day. This limited material of 50 flocks shows that they veer off at 482 metres' distance (SD 42 metres) and at a flight altitude of about 185 metres (SD 18 metres) (measured, however, after they've passed the turbines). The fact that these flocks veered off so close to the turbines is shown by the tracking examples in Figure 21 taken on the night of 10-11 April, at which time radar conditions were good. The cause of this is unknown. Flight tracking on that night could be done more easily and clearly than on many other nights. Consequently, a separate analysis was done on the waterfowl near the wind turbines, that night.



**Figure 21.** Ten selected flight trackings of waterfowl or waders (average speed of 65 km/h) from the night of 10-11 April 2006 as well as 28-29 March 2008 (it was noted that 28 additional flocks flew past the turbines on these nights, but resulted in only occasional tracking). Flight altitudes were measured as the birds passed the turbines, and averaged 167 metres, which perhaps explains why so many birds flew above. A strong wave disturbance is shown on the picture, which was taken on 29 March 2008.

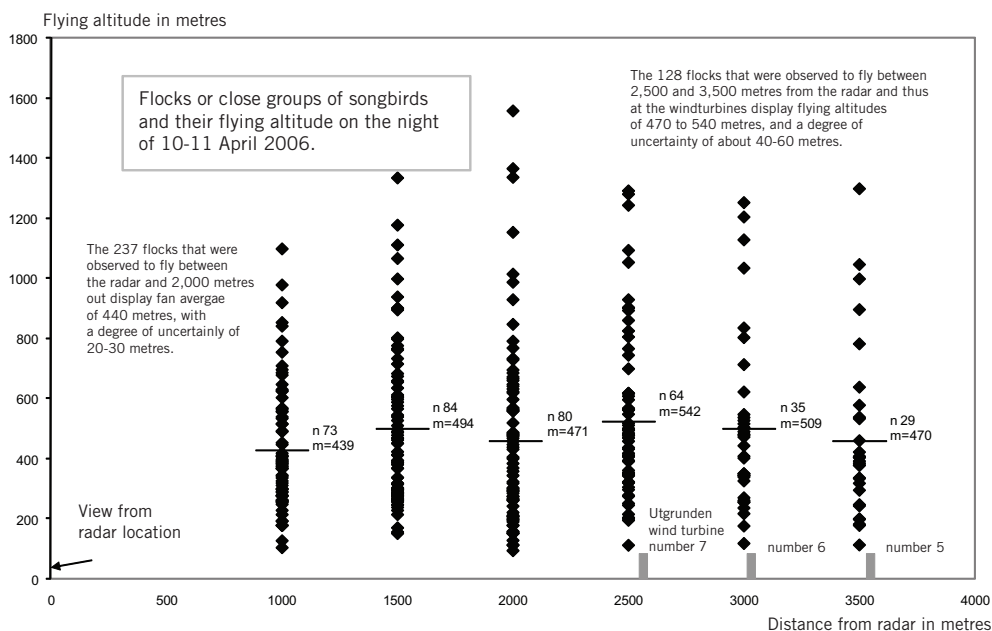
The result shows that on the night of 10-11 April, marine birds passed mainly above the wind turbines and most likely raised their flight altitude before passing. The flocks that flew between the lighthouse and the wind turbines flew at an altitude that was almost 60 metres lower (there are, however, certain problems with measurements here. Uncertainty is greater out near the turbines than closer to the radar), see Figure 22. The fact that they fly at an average of 138 metres altitude (SD 27 metres) above sea level at night without wind turbines can be compared with a previous study in Kalmar Sound, which showed that marine birds during the day flew at an altitude of 30 metres or lower in all the various winds (Pettersson 2005). As there is a great deal of uncertainty in ascertaining flight altitude at a longer distance, there is no statistically significant difference between how high the marine birds fly over the turbines and their flight altitude outside the wind turbine area, as the distance is 3,500 metres from the radar.



**Figure 22.** Waterfowl migrations on 6-7 April and 10-11 April. Favourable migration conditions prevailed on those dates (especially 10-11 April) and radar tracking conditions were extremely favourable. This figure shows the flight altitude above sea level of about 80 waterfowl flocks (average 138 metres, SD 27 metres). When they passed the 100 metre tall wind turbines, they flew higher (average 195 metres, SD 39 metres). The uncertainty of the altitude values increases with distance, but waterfowl showed a higher flight altitude above the wind turbines than above open seas on this night.

### 3.2.5 Songbirds' nocturnal migration near wind turbines

The radar equipment used can only track songbirds with a reasonable degree of certainty up to a distance of ca 1,500 metres from the radar (see method section). On the night of 10-11 April, songbird migration over Kalmar Sound was unusually heavy for the spring. It appeared to me that many of the birds were thrushes, and possibly Starling in early night (both Song Thrushes and Redwings were heard before midnight). However, Robins, predominated amongst the birds that rested on the lighthouse on the morning of 11 April. A subsequent analysis of the video films has also been done of the migration of songbirds (thrushes) taking into account the uncertainty resulting from the distance. The average flight speed for all songbirds (45) during this period is 32 km/h, which indicates that some of the larger songbirds, such as Starling or thrushes, might be involved. In Figure 23, all flight altitudes noted for 10-11 April have been plotted out to 3,500 metres from the radar. The fact that the flight altitude above the three closest turbines did not deviate significantly from how high the birds flew between the lighthouse and the wind turbines would indicate that they do not increase their altitude when they pass the 100 metre tall wind turbines. They maintain an average altitude of 400-600 metres above sea level. It is surprising that so few flights below 150 metres were detected. On some other spring nights, about 8 % of the echoes have come from altitudes below 150 m. On this night, only 12 bird flocks (3 %) flew so low.



**Figure 23.** On the night of 10-11 April, favourable migration conditions prevailed, as apparently did extremely favourable radar tracking conditions. This figure shows the flight altitude above sea level of about 365 songbirds echoes (probably mostly thrushes or Starling, with an average flying speed of 32 km/h) at flight altitudes over the sea without wind turbines, and after having passed the 100 metre tall wind turbines. These small differences in flight altitude are not statistically significant, but it is probable that the birds do not fly higher above the turbines than above the sea, in general.

## 4. Discussion

### 4.1 Bird migration at night – general issues

#### 4.1.1 Comments regarding radar identification of birds

One advantage of radar is that it can detect flight altitude and the intensity of bird migration even in darkness. That is why radar has been used in this study of nocturnal migration to provide a picture of this migration, which can be heavy, even though we don't see it. By using radar instruments, objects that reflect electromagnetic beams can be localised. These include birds, bats and insects. Ornithology uses all kinds of radar, from high-capacity radar and target tracking radar (see "Fledermaus" Bruderer 1997a; "Flycatcher" Buurma 1995), through surveillance radar, which covers large areas (used by the Armed Forces, e.g. Jellmann 1989, Alerstam 1974a and 1974 b, as well as, Pettersson 2005) to commercial ship's radar. In recent years, the latter has been used increasingly often to study local bird migrations (see, *inter alia*, Hyppop et al. 2006 and Pettersson 2006). If the radar is placed at a 90 degree angle, it can also determine the exact flight altitude (Harmata et al. 1999, IfAö 2004 and Hyppop et al. 2006). The development of capability to process all the echoes received by the radar, together with the development of computer programs, make it possible to track even insects and bats now and in the future with this type of radar (see Petersen et al. 2006 and Ahlén et al. 2007).

In order to provide a good answer to the question of how marine birds fly and react, as compared to songbirds, the birds have been categorised in the same way as in other studies (Petersen et al. 2006). Birds with flying speeds of less than 20 km/h are *songbirds*, and those with speeds of 45 km/h or faster are waterfowl or *waders*. This means that about 15 % of the echoes in autumn, and 10 % in spring are eliminated, in order to avoid obtaining incorrect values for the two groups of birds. In calculating migration intensity, this 15 % and 10 % have been halved, and added to songbirds and waterfowl, respectively.

The preliminary study (Pettersson 2006) for this study discovered that certain bats could also be detected on the radar. The wavelength of the radar had to be changed in order to enable tracking of the bats, which are mostly of the common noctule species. It is also possible to track bats out to about 2,500 metres from the radar (see Ahlén et al. 2007). After a long tracking, it is possible to determine that the objects tracked are bats and not songbirds. Bats most often fly at speeds of about ca 10-25 km/h, and sometimes reverse their direction in flight when hunting for insects during their migration (see Ahlén et al. 2007). The echoes observed closest to the lighthouse to about 100 metres away may have included some tracking of bats that were classified as songbirds, as the distances are short. Other than that, these groups have been able to be kept separate.

#### 4.1.2 Scope of migration at Utgrunden

As there are significant differences between daytime and night-time migration (mix of species and visibility conditions) migration intensities are presented for the night in this report. Another reason why nocturnal migration is prioritised is that there is greater uncertainty as to the extent of bird migration at night when we, ourselves, do not see especially well.

Migration altitudes at night are naturally more uncertain. This uncertainty has also been brought up in the planning of off-shore wind farms, and it is feared that wind turbines can create a great danger for birds, especially in darkness and fog conditions.

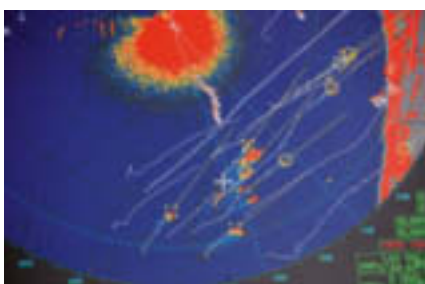
There are various methods of measuring nocturnal bird migration, with the use of radar equipment being of great importance. However, it is not possible to use the detected bird echoes to determine how many individuals a single echo shows (unless target tracking radar is used on every flock or echo). When estimating intensity (e.g. in a comparison of night and day migration), one must take into consideration that songbirds at night generally fly alone or in groups, while during the day, they often fly in large flocks (see Bruderer 1971 and Alerstam 1990). The intensity of nocturnal migrations, in general, follows the same mechanisms as daytime migrations (i.e. the mainly migration preparedness of the respective species, and the weather conditions (see Zehnder et al. 2001 and Alerstam, 1990). Migration intensity is naturally also related to season, and generally showed very sizeable variations both within a single year and between years.

Differences between the intensity of day and nocturnal migrations can also depend on the species mix. Songbirds that fly at night are often long-distance migrators who arrive at their breeding grounds late in the season, and depart from these relatively early. The peaks in the migration in these groups therefore generally occur in different periods. There are some quantitative data regarding nocturnal migration intensity in the Baltic Sea area. Zehnder et al. (2001) was able to determine migration proportions for autumn migration in southern Sweden by using a passive infra-red camera. The proportions of migration through the area vary between 6 and 6,618 bird echoes/h/km. The average was 1,319 bird echoes/h/km. In preparation for the construction of a wind farm at Kriegers Flak, IfAö (2004) performed a large radar study during several springs and several autumns, and their values for the maximum daytime migration intensity were 1,355 echoes/h/km. At night significantly more echoes were detected, up to maximum values of 2,967 echoes/h/km.

This Kalmar Sound study, after conversion of the nocturnal values (according to the IfAö 2004 method) for all bird echoes observed, yields a maximum value of 1,840 echoes/h/km under the autumn, while the spring nocturnal maximum value is 355 echoes/h/km. Generally speaking, southern Kalmar Sound is a location for songbird migration that is relatively heavy in the autumn, but much less in the spring. In comparison with peak location, Falsterbo in southern Skåne, Kalmar Sound has only one bird migration, with an intensity that is about 0.25 % of the autumn migration at Falsterbo.



Marine bird migration in Kalmar Sound studied at different times by Alerstam et al. (1974a and 1974b) and most recently by Pettersson (2005) shows that the maximum migration intensity per kilometre and hour for marine bird migration during the day in the Sound is 6000-8000 birds/h/km, estimated based on flocks of marine birds (eiders, both spring and autumn), which is in the “Falsterbo class”. As far as I know, the nearby peak migration location on the southern cape of Öland, near Ottenby, a classic bird location, has no comparable values, but the nocturnal migration of songbirds should be at least in the “Falsterbo class”. This is also indicated by the radar studies in Kalmar Sound, 1999-2003, which had nights with very intensive migration over southern Öland (Pettersson 2005).



**Picture 13.** Radar trackings of white-cheeked geese that migrated on 6 May 2007 at 12:32 a.m. These trackings related to 3,000 geese in various flocks, all of which flew south of the Utgrunden wind turbines. That day, a total of 12,000 Barnacle Goose were observed moving into the area.

#### 4.1.3 Phenomena that affect the intensity of migration

In general, most bird migration occurs in “good weather and tailwind” (Bruderer 1997b and Alerstam 1990). In the northern hemisphere, these situations appear when there is a low pressure area in the west and a high pressure area in the east, relative to the main direction of migration. In autumn, this happens often in conjunction with a passing cold front, and in spring this occurs in connection with a passing warm front (see Alerstam & Ulfstrand 1974b, Alerstam 1978 and Richardson 1978, which also contains a detailed summary of how the weather affects bird migration). In addition to rain and wind, the general weather also affects individual factors such as temperature, air pressure and visibility, but these individual factors rarely affect migration intensity.

In addition to weather, wind conditions (wind direction and wind velocity) are a major factor relating to migration intensity (see Alerstam 1978). When there is a tailwind during migration, it saves the bird’s time and conserves its energy. This is the situation birds prefer for their migration. On the other hand, headwind, especially, contributes to limited migration intensity (Bruderer & Liechti 1998. See also Alerstam 1990). Various species also differ in their sensitivity to headwinds. In the case of Wood pigeon and Jackdaw, tailwinds are crucial in their migration choices, while finches and Starling are less selective (Alerstam 1978). Wood pigeons are also very sensitive to driv-

ing wind. When winds are from the northwest, they fly toward open seas, which they cannot compensate for to any major extent (Alerstam & Ulfstrand 1974b). Fog can affect the sense of direction of birds that migrate by day, and result in deviations from "normal" migration routes. Land birds have the opportunity of temporarily interrupting their migration due to unfavourable visibility and flight-related conditions. Where there is fog over the sea, birds fly lower in a search for a possible landing location, and a great many birds may land on ship, for example, if there is one in the vicinity. Rain reduces the departure for large migrating birds (e.g. Alerstam 1978, Alerstam et al. 1974a), as well as the winter migrations of waterfowl (Alerstam & Ulfstrand 1974b).

#### 4.1.4 Many songbirds migrate over southern Kalmar Sound

Birds that migrate by night generally begin their flight when it gets dark (about 1-2 hours after sunset, when there is often still a possibility of optical orientation. That's the reason why nocturnal migration begins very suddenly, and then quickly grows in intensity. Often the peak of migration intensity is reached before midnight, and then declines as the night passes (Alerstam 1990, Bruderer 1997b and Fortin et al. 1999). The reduced intensity during late night shows that the birds begin landing after only 3-6 hours of flight (Bruderer & Liechti 1998, Zehnder et al. 2001 and 2002). At Falsterbo, half of the birds pass during the first 40 percent of the night. This corresponds to just under five hours after dusk (the sun is 6° below the horizon, Zehnder et al. 2001). The pattern described is shown clearly in the southern Kalmar Sound material in both spring and autumn, and especially in the case of the songbird migration. The actual process of nocturnal migration at a given location is crucially affected by the distance to the main area of departure. In this way, migration peaks may clearly be postponed until later in the night if certain populations start at a greater distance from the main area of departure (Zehnder et al. 2001). At the same observation sites, there can be seasonal differences of the timing of the migration process.

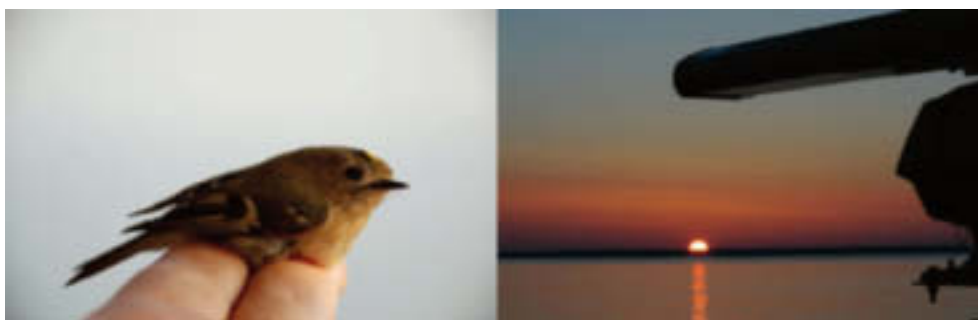
Despite the above-mentioned general notions of a very concentrated departure at dusk, combined radar and telemetry studies of night-flying songbirds show significant variations as to time of departure, depending on the species, season and location (Åkesson et al. 1996, 2001). Most of the birds start out at nautical twilight (with the sun 0-12° below the horizon), with birds departing anytime from clearly before sunset to late at night. Thrushes start out very early not only during nautical twilight, but also clearly prior to sunset. The Thrush Nightingale (*luscinia luscinia*) and the Robin do not start out until the first stars are visible in the sky. More than half of the Reed Warblers (*Acrocephalus scirpaceus*) studied start out 30 to 150 minutes after sunset, with the rest not beginning their flights until 3-4 hours after sunset (Åkesson et al. 2001). Thrushes often start out in flocks then take an intermediate position between night flyers that start when it is still light and fly in flocks (ducks, terns, waders), and solitary night fliers that start out very late. The fact that species that start out late are not dependent on visual structures

clearly shows that birds, when starting their flights, do not necessarily need visual orientation, and that there is probably a combination of different orientation mechanisms present at the time of departure.

The results of this report, with regarding to the distribution of nocturnal migration both in autumn and spring, indicate a great deal of activities during early part of the night, which then later almost disappears during the rest of the night. It indicates that there is a departure point on Öland (in the autumn) or on the mainland (in the spring). In other words, nocturnal migration starts very close to the Sound. Those birds that land after a night's migration seem to rarely do so directly over Kalmar Sound. Perhaps, however, more birds lost their way on foggy nights over the Sound, than on other nights (See, e.g. the night of 3-4 October 2007). The waterfowl migrations show a similar pattern, but in that case, especially the spring material shows that the migration starts again toward the end of the night or that the birds starting off from afar reach southern Kalmar Sound, but that there is not a night-long migration passing this location.

Migration intensity is naturally dependent on many different factors, and is determined primarily by the migration preparedness of a species according the seasonal migration phenomenology (see Berthold 2000 and Alerstam 1990). The start of migration occurs in a window of a few days, as the birds primarily wait for appropriate weather conditions (Richardson 1978 names tailwind and low wind velocity). However, a bird's individual condition and fat reserves affect the actual starting time (see Sandberg & Åkesson 1999). At the close of this window, however, there is also a time by which the birds must depart, regardless of wind conditions (Åkesson & Hedenström 2000). The fact that the birds wait for certain wind and weather conditions can lead to a kind of migration queue. Many birds, when they encounter ecological obstacles such as open seas, wait for better weather conditions. When the weather improves, a mass-migration ensues, and most of the total migration takes place during a few days (see Alerstam & Ulfstrand 1972, 1974a). These kinds of periods are often followed by days with very light migration (Zehnder et al. 2001). During migration season, there are typically very great fluctuations in migration intensity with days of mass-migrations and phases with very little migration activity.

In northern and central Europe, the main migration in autumn goes toward the SW, and toward the NE in the spring. Especially northern populations or certain species may also fly toward the S or SE to a certain degree during the autumn, such as Willow Warblers (see Hedenström & Pettersson 1987) as well as White Wagtails (see Fransson & Pettersson 2001). The migration direction is determined by species and population, although there can be significant modifications, especially due to the effects of wind. In low-flying day-time fliers, landmarks play an important role. This leads, for example, to clear differences in the migration directions observed at the same time by means of visual observations (low-flying birds) and radar observations (Alerstam & Ulfstrand 1972). As a result, it is entirely foreseeable that the differences in migration winds show a varied pattern in this, which includes entire migration seasons, both spring and autumn, involving many different species.



**Pictures 14 and 15.** The Goldcrest is one of the songbirds that rest on the Utgrunden lighthouse, after a night of migration. Picture 15 shows the horizontal radar antenna in the sunset.

#### 4.1.5 Migration altitude

Migration altitude generally varies greatly, depending on a large number of different factors, such as species, weather conditions and geographical structures. Despite a great deal of knowledge still lacking, it is possible to formulate several rules of thumb (see Alerstam 1990 and Berthold 2000), such as that birds migrating during the day usually fly lower than those that fly at night. Most likely, the reason for this is that there is little visual contact with structures on the ground, thus causing the birds to avoid the lower altitudes to reduce the risk of collisions (see Bruderer 1997b and Erickson et al. 2001, Bellrose, 1971). In this study, no migration was detected at a lower altitude than 30 metres, such as during a flight with an ultra-light aircraft at night. Over southern Germany, the average daytime migration altitude was 175 metres, as compared to 450 metres at night (Bruderer & Liechti 1998). In Switzerland, 50 % of the migration detected during the day was below 400 metres. At night, this value was 700 metres in spring (Bruderer 1971). Van Gasteren et al. (2002) used target tracking radar ("Flycatcher") to measure the relative altitude distribution just off the coast of Holland, as well as to provide exact quantitative values of the altitude distribution of off-shore bird migrations. On all the altitude levels, the highest intensity was measured in the evening and at night. Nocturnal flying, especially, was mostly found at higher altitudes. However, on the lower levels, as well, there was a peak of a size that can be compared with the daytime values. In the morning, and during the day, a much higher bird concentration was reported only in the lower regions (0-200 metres). This target tracking radar makes it possible to ascertain groups of species on the basis of the wind stroke frequency.

Measurements taken at night show that gulls and terns fly almost exclusively in the lower 100 metres, while larger marine birds show an even distribution up to 500 metres. Larger songbirds, however, seem to choose specific altitude bands. They flew in greater numbers, either very low or on an altitude level of between 200 and 300 metres.

#### 4.1.6 Various factors that affect flight altitude

In general, birds fly lower in headwinds than in tailwinds (Alerstam 1978, 1990, Bruderer 1997b, Dirksen et al. 1998, Liechti et al. 2000, Kryger & Garthe 2001).

Birds probably know the most appropriate altitude for a given set of circumstances in light of atmospheric conditions, most likely through testing rising and falling altitudes during migrations. The fact that birds fly at lower altitudes when there is a headwind, may be related to wind velocity usually rising with increased altitude. Adapting the flight altitude to wind conditions can greatly increase flying speeds while strongly decreasing energy consumption (Liechti et al. 2000). Especially in waterfowl, there is a clear correlation between wind and flight altitude (Kryger & Garthe 2001, Kahlert et al. 2004 and Fox et al. 2006 and Petersen et al. 2006). In headwinds, divers and sea ducks (Eider, Common Scoter) often fly very low over the water (less than 1.5 metres), but in tailwinds, the flight altitude increases. This effect is clearly reinforced as wind velocity increases. Terns encountering headwinds prefer the area up to 12 m, but where there is a tailwind, they fly much higher (up to 25 metres according to Kryger & Garthe 2001).

Birds avoid flying through clouds, which is why they generally fly at altitudes above or below the clouds.

## 4.2 Discussion regarding the results

### 4.2.1 Fog and songbirds resting at sea

The previous Kalmar Sound study from 1999-2003 showed that waterfowl migration almost disappears completely if fog occurs during the day (Pettersson 2005), but this study, which examined three foggy autumn nights, showed that when low-lying fog is present (up to 100 metres), the migration continues. But two of three nights showed that the birds flew even higher when the fog appeared, even though they were already flying several hundred metres above their average flight altitude. The material compiled regarding resting birds at Utgrunden (see Tables 1 and 3) show a clearly increased number of resting songbirds after good migration nights, but hardly a great increase. The maximum number is 18 songbirds. The highest number of resting songbirds, however, was noted on foggy mornings following nights with migration. The maximum number of resting songbirds on such a morning was 19. From the North Sea, there are descriptions of mass landings of songbirds on nocturnal migrations. This can cause massive problems relating to offshore wind turbines as a result of increased risk of collisions (Hyppop et al. 2006, see also Exo et al. 2003). These phenomena relate primarily to songbirds, which have high reproductive capacity, and can thereby rebound from losses faster than larger birds, which have low reproductive capability. However, populations can be negatively impaired by local reductions as well (see Drewitt & Langston 2006 and Drewitt & Langston 2008). No such phenomenon was found by this study to exist at Kalmar Sound. Everything indicates

that when the detected migrating birds start out near this area on Öland or the mainland, they are at the beginning of their migrations, and their chances of encountering bad weather are less probable, as in such a case, they would probably not have started on their nocturnal migration.

Landings of birds migrating at night occur fairly regularly when birds fly over the sea, but this seems to happen when birds migrating at night, that mass landings of this type occur. (Hyppop et al. 2006). The songbirds start their nocturnal flying in good weather may encounter this phenomenon. This is not at all the same phenomenon that this study documented in Kalmar Sound with low-lying fog that forms at night, and which songbirds appear to fly above.

The risk of these breaks in migration and mass landings of migrating songbirds taking place in Kalmar Sound is small, as nocturnal migrations of songbirds almost always take place immediately after the beginning of the night. However, the problem admittedly exists. In the Swedish Ornithological Society's policy on off-shore wind energy, this phenomenon is characterised as a major threat to migrating birds (SOF 2009). How common is it to have a large break in migration take place in the Kalmar Sound area? We can only make an assumption based on a comparison with the nearby location of Ottenby (a place almost surrounded by sea, which would probably be more affected by such a phenomenon). There, some form of mass landing has occurred on average, about one to three nights during a five-year period. The extent of this phenomenon naturally varies, and it occurs mostly in autumn, when migrating birds regularly arrive in Ottenby from the other side of the Baltic Sea (see the "Lighthouse Night" section in Engström 1988). These data are based on experiences from my 28 years at the Ottenby Bird Observatory in southern Öland, and not on direct results of research.

What happens at sea near the wind turbines when there is such a mass landing? There are probably large numbers of songbirds that try to land on the wind turbines (I have experienced this myself on a small ship in the Baltic Sea, with about one bird per dm<sup>2</sup> perched on the boat). The birds will then probably fly around the wind turbines, and there is a risk that some will collide with the rotor blades.

In all likelihood, most of the birds will not be involved in collisions, and the songbirds can remain on the turbines until it gets light, and fly around them, which additionally increases the risk of collisions. Such a phenomenon, however, is limited in time, and the risk of collisions can be reduced by taking the turbines out of operation on these nights and days.

Predicting this phenomenon, which can be catastrophic for a large number of individual birds, should most likely be easy to do with the help of weather data in combination with an understanding of migration. The turbines would hardly need to be taken out of operation more than an average of two to four days per year.

#### 4.2.2 Answers to questions regarding the results

In light of what we know about various factors that affect the intensity, flight altitudes and times of bird migration, we should view the answers to the questions posed at the start of this study.

##### **Which flight altitudes do waterfowl use during their migration over open seas and at night as well as in conditions of poor visibility?**

*The waterfowl s fly significantly higher at night in Kalmar Sound (an average of 156 metres' altitude in the autumn and 106 metres in the spring) than by day (the flight altitude is an average of 17 metres in the autumn and 24 metres in the spring), (Pettersson 2005). They fly even higher in fog when it occurs at night, with an average altitude of 240 metres above sea level (proved only for the autumn).*

In daytime studies in the autumn of 1999-2003 (Pettersson 2005), the 603 the waterfowl flocks (mostly eider) detected showed an average flight altitude of 17.2 metres above sea level (SD 5.1 metres). The study of autumn nights with good visibility shows (flocks both before and after midnight) 328 waterfowl flocks with flight altitudes averaging 156.2 metres (SD 20.3 metres) above sea level. Waterfowl thus fly 140 metres higher at night than what they do during the day in the autumn, which is clearly proven as statistically significant ( $X^2$ -test = 10.4 df=1,  $p < 0.01$ ).

In daytime studies in the spring of 1999-2003 (Pettersson 2005), the 156 waterfowl flocks (mostly eider) detected showed an average flight altitude of 24 metres above sea level (SD 8 metres). The study of spring nights with good visibility shows (flocks both before and after midnight) 294 waterfowl flocks with flight altitudes averaging 106.2 metres (SD 40.1 metres) above sea level. Waterfowl thus fly 84 metres higher at night than what they do during the day in the spring, which is clearly proven as statistically significant ( $X^2$  -test = 9.6 df=1,  $p < 0.05$ ).

On nights with poor visibility as fog (autumn only, as there were no spring nights with both fog and migration), the average flight altitude of 266 waterfowl flocks was found to be 240.6 metres above sea level (SD 55 metres). Waterfowl thus fly even higher on foggy nights than on nights without fog (84.4 metres higher on nights with fog) which has been shown to be statistically significant ( $X^2$ -test=9.5 df=1,  $p < 0.05$ ).

##### **How high do songbirds (passerines) fly over the sea at night and in conditions of poor visibility?**

*Songbirds fly significantly higher on spring nights on Kalmar Sound than on autumn nights (200 metres higher) with an average flight altitude of 529 metres in the spring and 330 metres average flight altitude in the autumn).*

*They appear to fly a little higher at night in fog (an average of 343 metres above sea level as compared to 330 metres good visibility). However, this was demonstrated only in the autumn, and this has no proof of statistical signifi-*

*cance). In autumn, they fly at an average altitude of 330 metres at night, as compared to about 35 metres during the day (data regarding daytime migration compiled in this study) and 529 metres' flight altitude on spring nights, as compared to 50 metres during the day (data regarding daytime migration compiled in this study).*

This study of autumn nights with good visibility show (flocks both before and after midnight) 2,727 songbird echoes or flocks at flight altitudes averaging 329.9 metres (SD 42.2 metres) above sea level. In nights with poor visibility, such as foggy nights (autumn only, as there were no spring nights with both fog and migration), the average flight altitude for 689 songbird echoes or flocks was 343 metres above sea level (SD 46 metres). Songbirds fly an average of 13 metres higher on nights with fog than on nights without fog, which, however, has not been proved statistically significant ( $X^2$ -test= 7.3 df=1,  $p<0.05$ ).

This study of spring nights with good visibility shows (both echoes and flocks before and after midnight) 1014 songbird echoes or flocks at flight altitudes averaging 529.1 metres (SD 68.2 metres) above sea level. Songbirds thus fly 200 metres higher on spring nights than they do on autumn nights (which is clearly statistically significant ( $X^2$ -test= 8.3 df=1,  $p<0.05$ )).

#### **How do both waterfowl and songbirds react under conditions of poor visibility when they come close to off-shore wind turbines?**

*On nights with good visibility, waterfowl veer off from the Utgrunden wind turbines at an average distance of 570 metres from the turbines, and in fog at night, at an average distance of 500 metres. This differs significantly from the distance at which the birds veer off during the day, which is 1-3 kilometres from the turbines. The fact that only 0.1-0.5 % off waterfowl flocks have been observed flying between the seven wind turbines at Utgrunden during the day (the distance between turbines is about 400 metres) and more (5 %) were observed doing this on nights without fog, and many more on foggy nights (9 %), may well indicate a greater risk of collisions at night than during the day.*

*This study shows that on autumn nights, an average of 17 % of the songbirds fly at lower altitudes than 150 metres, and that on spring nights an average of 8 % fly this low over the sea, creating a considerable risk of collisions. Songbirds, however, could be observed flying at higher altitudes on two of the three foggy nights, thereby flying considerably above the approximately 100 metre high fog.*

Trackings of how waterfowl fly when they pass the wind turbines show that during the day they veer off and fly on the side of the turbines. They begin to veer between 1-3 kilometres from the turbines (Pettersson 2005 and see also Fox et al. 2006). This study shows that waterfowl flocks flying at night in good visibility veer off from for the wind turbines at an average distance of 570 metres from the turbines (SD 44 metres). On the three foggy nights in the autumn covered by the migration study, the average veering distance



is 500 metres (SD 55 metres). Of the flocks that could be tracked, 5 % flew between the area's seven wind turbines on nights with good visibility, while on foggy nights, 9 % of the flocks flew between the turbines. This also indicates that marine birds fly closer to the turbines when visibility is not good. It's worth noting that the waterfowl that were tracked in fog almost all flew above the fog, as well as at a somewhat lower speed of 43 km/h (SD 6.2 km/h) as compared to 65 km/h (SD 7.8 km/h) on nights without fog (not on a statistically significant level as a result of the great variation here,  $X^2$ -test=5.2 df=1  $p<0.1$ ) than on nights with good visibility. The normal flight altitude for waterfowl at night, however, leads to the conclusion that they only fly above the 100 metre tall wind turbines at Utgrunden and not the now more common wind turbines that reach 150 metres. All of 50 % (88 % in spring) of the marine bird flocks flew below 150 metre at night in this study, and they most likely had to veer off or fly above these turbines to avoid the risk of collisions.

The night migrations of songbirds have been difficult to track in this study, as due to technical constraints, it has not been possible to track them further than 1,500 metres, and the closest wind turbine is 2,600 metres from the lighthouse (this is due to the fact that the previously planned new wind turbines were not built any closer).

On the night of 10-11 April 2006, an intensive thrush or starling migration was observed over the Sound, and songbird echoes were detected out to 3,500 metres from the radar. A compilation of flight altitudes here was made, and this indicates that those songbirds that fly at an average altitude of about 450-500 metres do not climb to higher altitudes above these wind turbines, but rather pass them without reacting to the turbines.

There are no values available for nocturnal migrations of songbirds under conditions of poor visibility, but as songbirds in general flew even higher on two of three nights, it is reasonable to assume that they are not close to a collision course. As the distribution of songbirds' nocturnal flight altitudes ranges from 10 to 1,350 metres in this study, and a certain percentage of this migration occurs below 150 metres' altitude, which is currently the most common altitude for rotors, 17 % of the migrating birds in autumn as well as 8 % in spring fly at the altitude of the wind turbine rotors.



**Picture 16.** A tightly packed golden plover flock flew close to the Utgrunden lighthouse on 18 October 2008 at 08:10 a.m.

### 4.2.3 Risk of collision of waterfowl and songbirds

This study demonstrates that waterfowl fly at a higher altitude at night over Kalmar Sound than during the day (average altitude of 17 metres compared to 156 (autumn) and 24 compared to 106 in the spring). Observed nocturnal flight altitudes of marine birds at Utgrunden reported in this study does not indicate any need to revise the previous estimates of collision risk for marine birds at off-shore wind turbines (see Pettersson 2005, Chamberlain et al. 2006 Fox et al. 2006 and Petersen et al. 2006), as, on average, they continue to fly at the level of the rotors (the most common altitudes of a wind turbine rotor is 150 metres or lower). The fact that nocturnally migrating marine birds rarely fly above the wind turbines means that they must veer off. This fact has been taken into consideration in the calculations of previous studies, and is simply confirmed here. The fact that they veer off closer to the wind turbines at night at a distance of 570 metres and at 500 metres on foggy nights does not make the risk of collisions greater than during the day, when they veer off 1-3 kilometres from the wind turbines.

On the other hand, the fact that only 0.1-0.5 % of marine bird flocks were observed flying between the seven wind turbines (separated by about 400 metres) at Utgrunden during the day (Pettersson 2005) as compared to 5 % being observed doing this on nights without fog, and 9 % on foggy nights, can indicate a greater risk of collision at night than during the day.

Certain more recent studies of birds and wind turbines have shown that waterfowl and waders can become accustomed to wind turbines and fly close to them without risking any collisions (Petersen & Fox 2007 and Madsen & Boertmann 2008), but this applies to resting birds, and not to actual migrating birds, which are common in Kalmar Sound.

The proportion of the total migration represented by marine birds that fly at night studied in spring and autumn in Kalmar Sound does not appear to reflect the 20% figure found in previous studies (Pettersson 2005). In this study, they represent a smaller percentage of the total migration - 5-10 % instead of 20 % or more (Alerstam et al. 1974 b and Pettersson 2005). However, this is not certain, as not all the nights have been covered by the studies, and there are great variations between years, as is to be expected. If a smaller percentage of the total birds migrating fly at night, however, this can have some significance, and can mean that the previous collision estimates do not indicate too high a number of birds that risk colliding with wind turbines on one day. Most likely even fewer risk colliding with off-shore wind turbines, as fewer waterfowl fly at night.

Although it is known that songbirds migrate at high altitudes at night, little is known about their nocturnal flight altitude above the sea. This study shows that during normal migration, most nocturnal fliers are not affected by off-shore wind turbines (which reach a maximum of 150 metres) to any significant degree. The study shows that on autumn nights 17 % of the songbirds, on average, fly at lower altitudes than 150 metres, and on spring nights, an average of 8 % fly that low over the sea. This means that although there

is a risk of collisions that must be taken into account, that risk is most likely a small one, as songbirds probably can veer off more easily than larger birds can, when encountering a sudden obstacle (see next section, which nevertheless contains a calculation).

The other risk described occurs in connection with what is known as a mass landing, a phenomenon that has not been observed in this study. A certain presence of resting songbirds, however, was observed on the Utgrunden lighthouse, but no large gatherings were observed, despite migration under foggy conditions late at night. However, this was a low-lying fog. On two of three nights in this study, it was noted that nocturnally migrating birds pass a low-lying fog by flying over it, and increasing their in flight altitude. This is important to understand and consider when describing the effect of off-shore wind turbines on migrating birds.

Large gatherings of resting songbirds after their encounters with bad weather, seems to occur more nearby at Ottenby, which is almost surrounded by the sea. The movements of songbirds studied here, probably start on the same side of Kalmar Sound, and the birds do not risk encountering any unexpected bad weather on the Sound, in any case, not so soon after they start off.

#### **4.2.4 Magnitude of the risk of collision**

The collision risk of waterfowl in Kalmar Sound was calculated in a previous study (Pettersson 2005) (one for spring and one for autumn) as a total of 10-12 marine birds per year in the wind turbines at Utgrunden and the five at Yttre Stengrund. About half a million birds pass these areas in spring, and up to a million marine birds in autumn (Pettersson 2005). There is thus no major reason to revise these data subsequent to the submission of this report.

For songbirds, migration intensity (assuming that the echoes belong to a single songbird, which is not always the case, as sometimes they relate to more than one bird) in the autumn was 1,840 songbirds/h/km, and 355 songbirds/h/km in the spring. The wind turbines at Utgrunden stand on a stretch of about 2 km, so that two such stretches should be calculated, for about six hours per night (i.e. only the period before midnight) and for about 20 of these migration days (spring and autumn). The wind turbines are only 100 metres tall at their highest rotor altitude. This means that 11 % of the songbirds fly lower than the highest rotor in the autumn, with a corresponding figure of 5 % in the spring. In autumn, this means that we estimate that  $1840 \times 2 \times 6 \times 20 = 441,600$  songbirds fly across the wind turbine area. Of these, 11 % (48,576 birds) fly lower than the rotor altitude. If they fly evenly distributed throughout this area (see calculation in Pettersson 2005) 14 % of the songbirds will be affected. This will mean that about 6,800 songbirds fly through the wind farm, where each turbine stands 400 metres from the next one, and has a rotor diameter of 70 metres. If we intentionally overestimate the figure for songbirds flying through the area by taking twice the figure that was established for golden eagles (According to Hunt & Hunt 2006, one out of 225 eagles flying through such an area will die), we arrive at a figure of one out of

450 birds, which would mean that 15 songbirds per autumn risk being killed at the Utgrunden wind farm.

According to estimates, in the spring  $355 \times 2 \times 6 \times 20 = 85,200$  songbirds will fly over the wind farm, and 5 % of these will fly lower than the rotor altitude (4260 songbirds). If they fly evenly distributed throughout this area (see calculation in Pettersson 2005) 14 % of the songbirds will be flying at rotor altitudes. If we intentionally overestimate the figure for songbirds flying through the area in the spring as well, by taking twice the figure that was established for golden eagles (According to Hunt & Hunt 2006, one out of 225 eagles flying through such an area will die), we arrive at a figure of one out of 450 birds, which would mean that one songbird per spring would risk being killed at the Utgrunden wind farm. In one year, the seven wind turbines in the wind farm could kill 16 nocturnally migrating songbirds of a total of about half a million songbirds that pass through this area. In all estimates of this nature, there are always a number of assumptions that hardly ever apply. For example, that the birds fail to veer off from the turbines, but instead continue to fly straight ahead (about 98-99 % of marine birds choose to veer off when they encounter wind turbines, and most likely so do songbirds). Although this is a worst-case scenario, it still gives an idea of some reasonable assumptions that have been prepared, and should thereby show the approximate size of the relevant death toll.

#### **4.2.5 Migration nights**

The results of this study clearly show that both songbirds and marine birds choose to migrate on nights with relatively weak tailwinds (lower than 4-5 m/s), which is the case both in the spring and autumn. One can predict with a reasonable degree of certainty the nights on which migrations will occur, on the basis of good local weather data. In order to reduce the risk of collision, wind turbines located on a bird migration path (e.g. Kalmar Sound) should be able to be taken out of operation on these nights, so that the risk of collision is reduced even more.

## 5. Conclusions

- Waterfowl fly significantly higher at night on Kalmar Sound than during the day, but still at rotor altitudes. They fly even higher in fog (i.e. above it) if it appears after midnight.
- Songbirds fly significantly higher at night on Kalmar Sound than during the day. They fly even higher in fog (i.e. above it) if it appears after midnight. They fly at higher altitudes in the spring than in the autumn.
- Most songbirds fly higher than the upper limits of wind turbine rotors (150 metres), but as there is a large range of flight altitudes, 17 % of the songbirds fly lower than 150 metres, as do 8 % in the spring, and these are the birds that risk collisions.
- On nights with good visibility, marine birds veer off from the Utgrunden wind turbines at an average distance of 570 metres from the turbines, and at an average distance of 500 metres from the turbines on foggy nights, which differs greatly from the day values of 1-3 kilometres before the turbines.
- On two of three foggy nights, both songbirds and marine birds were observed flying at a higher altitude over the sea clearly above the approximately 100 metre high fog.
- The study shows that some (a few) songbirds rest after a night of migration, that this is most common after a night of migration when there is fog in the morning, but even in such a case, there are only a few songbirds out near Utgrunden.
- The results of this study clearly demonstrate that both songbirds and waterfowl choose to fly on nights with relatively weak tailwinds (lower than 4-5 m/s) which is the case both in the spring and autumn.
- A rough estimate of the collision risk of nocturnal songbirds with the seven existing wind turbines at Utgrunden indicates that during a year, 16 of the nocturnally migrating songbirds would be killed. The total number of songbirds that pass this area each year is about 500,000.



**Picture 17.** The Svea, which Tommy Ternström operated, picking up and dropping off the author during the almost 85 days the author spent at the Utgrunden lighthouse since 2005.

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# Night migration of songbirds and waterfowl at the Utgrunden off-shore wind farm

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JAN PETTERSSON

The nocturnal flights of migrating waterfowl and songbirds (passerines) were tracked by radar at the Utgrunden Lighthouse in southern Kalmar Sound on a total of 23 autumn and 26 spring nights from 2006 to 2008.

There are primarily three important questions regarding off-shore wind turbines that this study was required to answer:

1. Which flight altitudes do waterfowl use during their migration over open seas and at night as well as in conditions of poor visibility?
2. How high do songbirds (passerines) fly over the sea at night and in conditions of poor visibility?
3. How do both waterfowl and songbirds react under conditions of poor visibility when they come close to off-shore wind turbines?

An understanding of these matters is very important in order to calculate the risk of birds colliding with off-shore wind turbines.

The knowledge can be used as a basis for planning, licensing and environmental impact assessments concerning offshore windparks.

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

