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Contents

Summary

Novem (Netherlands Organisation for Energy and Environment) wishes to advance the development of wind energy in the North Sea. As a result of this plan there is a need for knowledge on the effects of wind turbines on birds in nearshore and offshore situations. One of the gaps in knowledge concerns the diurnal and nocturnal flight activity of wintering sea ducks in the vicinity of turbines.

Since there is no offshore windfarm in the Netherlands, a study on this subject was not possible in the Dutch part of the North Sea. In Denmark, however, a windfarm (Tunø Knob) was built in 1994, 7 km offshore in the Kattegat. Large numbers of Eiders and small numbers of Common Scoters spend the winter in the vicinity of this windfarm. A study of potential disturbance effects of this windfarm was undertaken by researchers of the Danish National Environmental Research Institute (NERI, Guillemette *et al.* 1998). This study comprised only the daylight period. As collision risks are largest in twilight and darkness, Bureau Waardenburg and the Institute for Forestry and Nature Research (IBN-DLO), in close co-operation with NERI, conducted a study into the nocturnal flight activity of sea ducks near this windfarm in the winter of 1998/1999.

The questions to be answered in this study were:

- Do sea ducks show nocturnal flight activity?
- Does the windfarm influence the flight pattern of ducks in the area at night?
- How do Eiders flying in the immediate vicinity of the windfarm respond to wind turbines ?

Using nocturnal radar observations, visual observations and surveys from an observation tower located close to the windfarm, as well as ship-based radar and visual observations, data were collected on the nature and intensity of nocturnal flight activity of Eiders in the vicinity of the windfarm and of Eiders and Common Scoters in a situation without turbines.

Eiders showed nocturnal flight activity, both in situations with and without turbines. Most flights were relatively short (max. 1 km) and occurred within the feeding area and between feeding and resting areas. Flight activity occurred throughout the night and the intensity was predominantly determined by (moon)light conditions. In the absence of moonlight, flight activity was lower than during twilight. When the moon was out, nocturnal flight activity was 3-6 times as high as in night situations without moon, and comparable to the activity during dusk. During calm weather, massive movements over large distances took place at dawn, resulting in large congregations of displaying Eiders. Mist and strong winds reduced the intensity of these morning flights. During dusk and at night, flight activity in the vicinity of the windfarm was lower than away from the windfarm. This effect was noticeable up to a distance of 1000-1500 m from the nearest turbine and increased in strength closer to the windfarm. The effect was strongest in moonlit nights, small during dusk and non-existent during dawn. We tentatively interpret

these effects to be the result of active avoidance behaviour by the Eiders, rather than a passive reflection of feeding distribution.

Within the windfarm sector (windfarm plus the area up to 500 m outside the windfarm) more groups of Eiders flew along the outside of the windfarm than through the windfarm compared to expectations based on the windfarm's dimensions. Groups approaching perpendicularly to the longitudinal axis of the windfarm crossed the windfarm less often than groups approaching the windfarm parallel to the length axis. Although circumstances for birds approaching from both directions differed, this seems to indicate that Eiders prefer to fly through an opening of 400 m rather than one of 200 m. The proportion of groups flying through the windfarm was similar under different light conditions. Seven percent of all movements changed track when approaching the windfarm. Most changes of track occurred under light conditions.

Common Scoters were also nocturnally active. Their movements concerned short displacements within the feeding area. Nocturnal flight activity was more intense under moonlit conditions than under dark conditions. In these aspects Common Scoters resembled the Eiders.

The research yielded new information on nocturnal flight behaviour of sea ducks in situations with and without wind turbines. These results seem to be in line with earlier comparable studies on land and in fresh waters and show that even species that are not used to find obstacles in their flight path in their natural habitat, actively avoid wind turbines. In the application of the results of this study to the planning of windfarms at sea the following conclusions are most important:

- Both Eiders and Common Scoters are nocturnally active, but in dark periods flight intensity is far less than in moonlit periods. The total number of collision victims is determined by the product of flight intensity and the probability of collision. We know that flight intensity under dark conditions is lower than in moonlit situations, but have no information on the way collision risks are influenced by light conditions at open sea. This means that due to the lower flight intensity in dark nights the probability of collision victims is smaller than if flight intensity in dark nights would be as high in as in light ones. To arrive at accurate estimates of potential number of victims, measurements of collision risks in various light conditions are necessary.
- Eiders actively avoid the vicinity of the windfarm in their flight movements. This further decreases the risk of collision.
- The effect of the windfarm was noticed up to a distance of 1500 m from the windfarm. We do not know whether this distance is similar or greater in larger windfarms.
- The reduced flight activity in the vicinity of the windfarm and the low number of flight movements through the windfarm indicate that windfarms can act as flight path barriers. This effect is probably related to the size of the windfarm. Whether or not this effect is a problem in reaching favourable feeding and resting areas depends on the size and the local situation of the windfarm, relative to resting and feeding sites. Especially long line-shaped windfarms are risky in this respect.

The results of this study can be applied in decision-making about windfarms in the North Sea. A study on the local situation, however, remains crucial to be able to apply the results from the study in Denmark in the right way. Knowledge on the local flight patterns during the night and the location of roosting and feeding areas of sea ducks is essential to evaluate and minimise risks.

In decisions on windfarms in the North Sea actual recommendations are:

- Whether or not Eiders will fly in between turbines, fly around them or choose a different feeding or roosting area altogether, will be determined by a number of factors: the size of the corridor, the length of a possible detour and the availability of alternative feeding and roosting areas. To take the flight routes of sea ducks into account, measures should be taken to enable them to follow their route with a small detour. Gaps in the arrangements of turbines can act as corridors. Based on the results of this study, these corridors need to be several kilometres wide in order to be effective.
- From the birds' point of view long line-shaped arrangements perpendicular to the main flight direction must be avoided as these can cut off or deteriorate flight routes or make areas inaccessible.
- Despite the fact that the locations of shellfish beds can vary from year to year, it is possible to take the location of favourable feeding areas into account by placing the turbines as deep as possible.
- Since local birds will likely be familiar with the surroundings and obstacles, the collision risk for this group is smaller than for birds that are only passing through. In any case it is worthwhile to make the turbines as visible as possible (light colour).
- As it is difficult to predict whether and in what manner sea ducks will fly through large windfarms, it is preferable to keep the distance between turbines small and by doing so minimise the total surface area of the windfarm.

1 Introduction

1.1 Background

To further the development of wind energy exploitation at sea Novem (Netherlands Organisation for Energy and Environment) aims to build a demonstration windfarm near shore. A study on the feasibility of such a project is being carried out and a Environmental Impact Assessment (EIA) is in preparation. The possible effects on birds were identified as an important point of concern in the further development of the Near Shore Windfarm (NSW). Therefore Novem chose to initiate further research along with the EIA procedure on the possible effects of a sea-based windfarm on birds.

In the area where the Near Shore Windfarm is planned, interactions with several groups of birds can take place (Van der Winden *et al.* 1997). A distinction can be made in: birds that pass the area on migration (1), locally foraging birds (2) and birds that stay in the area in the nonbreeding season (3).

1. The North Sea is used on migration by birds that migrate to their breeding- and wintering areas.
2. Birds that breed in the coastal region and use the area as feeding area. These include mainly colonial species (Cormorants, gulls and terns).
3. Birds that stay in the area in the nonbreeding season use the area for feeding, moulting and resting. This group includes grebes, divers, Cormorants, sea ducks, gulls and guillemots.

To date little is known about the possible effect of wind turbines on seabirds (review in Van der Winden *et al.* 1997). This major gap is considered a problem in the planning of windfarms in offshore situations. Results obtained in studies carried out in freshwater semi-offshore areas can not be directly applied to the open sea. Seabirds might react differently to turbines, since they are not habituated to obstacles in their flight path. The placement of wind turbines can potentially effect the population of staging birds. Wintering sea ducks are an important group among these birds. The reasoning for choosing sea ducks as study objects are the following:
1. The Dutch coastline harbours large numbers of sea-ducks and is of international importance for these species;
2. The food (shellfish) of these species occurs in the relatively shallow areas where the Near Shore Windfarm is planned;
3. There are indications that ducks, compared with other species, have a relatively high risk of collision with turbines (Winkelman 1992a).

Previous research on land and in fresh waters has shown that collision risks are low during daylight and largest during twilight and under dark circumstances. Furthermore diving ducks have been shown to avoid a short line formation of turbines by flying around them (Van der Winden *et al.* 1996, Spaans *et al.* 1998b). It is still unclear though whether sea ducks respond in a similar way to turbines. This considerable gap in knowledge can be solved by studying the nocturnal flight behaviour of sea ducks in the proximity of offshore wind turbines.

In The Netherlands no offshore windfarm is currently present, that enables such a study. In Denmark however, a windfarm (Tunø Knob) was established in the Kattegat in 1995. Large numbers of Eiders and Common Scoters occur around this windfarm. A study on the disturbance effects of the wind turbines on the birds was carried out by Danish researchers (Guillemette *et al.* 1998), but they limited themselves to the distribution of ducks during daylight. This location is also very suitable to investigate the nocturnal flight behaviour of sea ducks.

1.2 The problem

Based on the knowledge gap observed the following questions were posed for a study near Tunø Knob:

Do Eiders and Common Scoters show nocturnal flight activity in offshore situations?
Does the windfarm affect the nocturnal flight behaviour of Eiders and Common Scoters?

The study was focused on the nocturnal flight behaviour of Eiders. Apart from the immediate surroundings of the windfarm, the flight behaviour was also studied in a wider area in the vicinity of the windfarm (see chapter 3 for an overview of research questions). Additionally, we gathered information on the nocturnal flight behaviour of Eiders and Common Scoters in situations without turbines. In this study no information was collected on the disturbance effects by wind turbines (Guillemette *et al.* 1998, 1999) nor on the effect of wind turbines on migration.

1.3 Execution

The study was carried out by Bureau Waardenburg and the Institute for Forestry and Nature Research (IBN-DLO) in close co-operation with the National Environmental Research Institute (NERI) of the Danish Ministry of Environment and Energy.

2 Study area and representativity

2.1 The study area in the Kattegat

Tunø Knob is situated in the Kattegat which is separated from the Baltic Sea by the Storebælt, Øresund and Lillebælt. The Danish Baltic is 2 to 25 m deep (Durinck *et al.* 1994) and is characterised by a tidal range of 0.2-0.3 m (Ib Clausager, NERI, pers. comm.). The tidal range is influenced by wind, resulting in a range of 0.5 m or even more. The current is not strong and is influence by wind speed as well. On average the current amounts to 0.5 m/s. The area near Tunø Knob (Fig. 2.1) is shallow and contains numerous sand banks and stone reefs at depths of 2-3 m. The ten turbines are placed at depths of 3-5 m (Fig. 2.2). The Baltic is brackish and the salinity equals 22-24 ‰. Winds from the west and Southwest prevail. The average wind speed is highest in December and equals 7-9 m/s. Mist occurs in the Baltic in when warm air is transported over the cold water surface under calm stable weather conditions (Rheinheimer 1996). The sea was ice covered in four winters in the 1980s and in one winter in the 1990s. During 13 winters in the period between 1960 and 1990, ice occurred in the area near Tunø Knob (Rheinheimer 1996). Such an ice period lasted 25 days on average. Ice cover has strong influence on the distribution of the birds. Birds wintering in the eastern part of the Baltic, migrate to the western part. Numbers of especially Long-tailed Duck, Eider, Common and Velvet Scoter increase considerably in the Danish part of the Kattegat under such circumstances.

The windfarm was built in the summer of 1995 and is situated approximately 7 km east off the coast of Jutland and 400 m north of a reef named Tunø Knob. The windfarm consists of ten 500 kW turbines grouped in two north-south oriented rows of five turbines each (Fig. 2.2). The distance between turbines is 200 m, between rows of turbines 400 m. The turbines measure 40.5 m in length, the rotor diameter is 39 m, resulting in a total height of 60 m and a sweeping area of 1195 m^2. A lamp is mounted at the base of each turbine, that lights the lowest few meters of the turbine at one side; the rotor is not illuminated. During the observations in December nine out of ten turbines were working, one was out of order. The observation tower was located at 600 m Southeast of the turbine in the Southeast corner of the windfarm. The **census area** is defined conform Guillemette *et al.* (1998, 1999) and enclosed an area with a radius of 1600 m from the observation tower (Fig. 2.2). The area that was covered by the radar was slightly larger than the census area and will be referred to as the **study area** (with a radius of 2850 m from the tower). When referring to **the surroundings of the study area** the area as indicated in figure 2.3 is envisaged. **Park sector** is used for the windfarm including the area up to a distance of 500 m around it. We chose the same **reference area** that was used in a previous study (Guillemette *et al.* 1998). The numbers of Eiders in this area are strongly correlated to the numbers in the study area (Guillmette *et al.* 1998).

Figure 2.1. The study area near the East coast of Jutland in the Kattegat. The hatched areas indicate the locations of the study area (Tunø Knob) and the area to the Northeast, where observations were carried out on a ship. The control area Ringebjerg Sand is located west of Samsø.

Figure 2.2. The census area at Tunø Knob, covering an area with a radius of 1.6 km from the tower. The area that was covered by the radar (study area) was larger and had a 2.85 km radius (1.5 nautical miles).

2.2 Representativity of the windfarm at Tunø Knob for other situations, the North Sea in particular

To be able to apply the results of the study in Denmark to other areas it is necessary to investigate the representativity of the Danish windfarm for the situation in the North Sea. Therefore we summarise here the differences and similarities between the two areas and species concerned.

2.2.1 Numbers of sea ducks

In the Baltic sea large numbers of Eiders and Common Scoters occur. On average 593,000 Eiders spend the winter in the Kattegat and 78,000 in the Bay of Kiel in the period 1988-1993 (Durink *et al.* 1994). In total over one million Eiders occur in the Baltic Sea. 528,000 Common Scoters spend the winter in the Kattegat, of which 33,000 occur in the south-western part (1988-1993, Durinck *et al.* 1994).
In The Netherlands the largest concentrations of Common Scoters are found near the shore. The exact location varies from year to year. On average 60,000 Common Scoters occur in the Dutch coastal waters (Camphuysen & Leopold 1994). In the years 1980-1994 on average 100,000 Eiders spent the winter in the North Sea. The highest numbers occurred in the Danish Wadden Sea and along the Scottish east coast (Skov *et al.* 1995). In the Danish, German and Dutch Wadden sea 200,000-300,000 Eiders spend the winter (Swennen 1991). In the coastal zone of the Dutch North Sea on average 16,800 Eiders were observed (1985-1993, Camphuysen & Leopold 1994).

2.2.2 Food

Eiders and Common Scoters feed on shellfish that live on the surface or buried in the top layer of the sea bottom. They dive for their food and swallow the shellfish whole, and crack the shells in their stomach. Shellfish occur in concentrations on banks and attract large numbers of sea ducks. Because of these food concentrations sea ducks are also concentrated and massive movements can occur when a food patch is depleted or in case of disturbance. Common Scoters can use different species of shellfish, depending on what is available. The suitable shellfish species have a few properties in common: relatively small size, occurrence in high densities and a lifestyle on or buried in the top layer of the sea bottom.
In southern Sweden and Denmark, Eiders and Common Scoters feed on Blue Mussels *Mytilus edulis*, Cockles *Cardium* spp., Baltic Tellins *Macoma* spp. and *Spisula subtruncata* (Nilsson 1972, Asferg 1990, Durinck *et al.* 1993). Mussels occur in beds and patches over large parts of the sandy and gravel substrates. Although several other prey species occur in the study area at Tunø Knob, Mussels are likely to be the major food source (Guillemette *et al.* 1998).

2.2.3 Representativity

The largest difference between the two areas concerns the species composition: at the study area in the Kattegat, Eiders are the most common, while in the coastal zone of the North Sea Common Scoters predominate. However these two species show strong similarities in their behaviour, feeding methods and food choice. This means that studies on nocturnal flight behaviour on Eiders in the Danish situation probably provide valuable information for both species in the Dutch situation. Furthermore the fact that both species are nocturnally active, as shown in this study, implies that collision risks and barrier effects are realistic. The difference between the Kattegat and the North Sea in features such as water depth, currents and the weather are not expected to severely influence the flight behaviour in relation to wind turbines.

Figure 2.3. Locations of the ship during the observations. 1: 2/3 February; 2a: 3 February evening; 2b: 4 February morning; 3: 3/4 March; 4: 4/5 March.; 5: 30/31 March; 6: 31 March/1 April.

3 Methods

3.1 Plan of action

In December 1998 we carried out a pilot study during which possibilities of studies in the windfarm were assessed. Due to positive experiences in the pilot study, the project was continued during three more visits to the area in February-April 1999.
Before starting the actual study we needed to know whether sea ducks were at all active during the night in the study area, and if not, whether the presence of the windfarm was causing this. Therefore we also carried out observations on a control location.

In the pilot study carried out in December 1998 we wanted to answer the following questions:

- Do Eiders show flight activity at night in the Tunø Knob area and at the control location near Samsø?
- If Eiders are nocturnally active, is it possible to quantify the flight behaviour with the methods available and is it possible to recognise patterns in the flight behaviour?
- If there is no nocturnal flight activity at one or both sites, is there a possible cause that can be identified?

The idea of the pilot study was to get a general idea of the activity pattern of the birds in the dark, both in the windfarm area and in a control area without turbines. Based on the results of the pilot study we decided to continue with the follow-up study on the nocturnal behaviour of Eiders in the vicinity of offshore windfarms.

The question in the study following the pilot study consisted of two parts:

- Is it possible to identify an effect of the windfarm in the nocturnal flight patterns of Eiders?
- How do Eiders respond to the turbines when they are in the vicinity of the windfarm?

In addition to this we were able to collect information on the nocturnal behaviour of Common Scoters in an area without turbines Northeast of the windfarm. The question we wanted to answer here was whether Common Scoters showed nocturnal flight activity and whether it was possible to discover patterns therein.
Since the pilot study already yielded quite a lot of useful quantitative data we decided to incorporate this study as a normal observation period in the follow-up study and to leave out one of the planned periods.
In the original plan we aimed to introduce variation in light conditions by including both new moon and full moon periods. The plan was to make observations during two full moon and two new moon periods. It was full moon during the period in December, but due to weather conditions the moon was only visible on one of the three nights. Also during the full moon period in January it was cloudy. Therefore we switched the scheme to three full moon and one new moon period. When the third period again yielded two

dark nights we decided to do all observations during full moon periods. This way variation in cloud cover yielded enough variation in light conditions.

3.2 Observations at Tunø Knob

At Tunø Knob observations were carried out from an observation tower, that was located at a distance of 600 m from the nearest turbine and was elevated 5 m over the water surface. A ship radar was used for the nocturnal observations on flight movements. A list of all observation sessions is given in table 3.1.

Before dusk, at the beginning of the evening observations, in the morning in conclusion to the observations and during the middle of the day, counts were carried out of all birds in the census area. The locations of all groups were plotted on a map.

During dusk and dawn the radar was used to study bird movements. Before dusk, and after dawn visual observations were made in combination with radar observations. The visual observations allowed species identification of the radar echoes. Radar observations were continued in the dark and carried out during several periods in the night (December) or continuously (other periods).

To record flight movements a ship radar was used (Furuno FR 8111). The antenna was mounted on the roof of the tower. The range used was 1.5 nm (2.85 km). Flight movements were visible on the screen in relation to the topographic surroundings (windfarm, reef and the island Tunø, Fig. 2.3). Using the distance markers on the screen, all occurring movements were copied onto a form with pre-printed distance circles. The topographic surroundings were indicated on each new form. Data on flight movements were registered in periods of 15 minutes. The radar is equipped with a so called *echo trail*, which is set in such a way that each echo remains visible on the screen for 30 sec. The result is that a moving object can be identified by a trace of dots. The species involved in flight movements were derived from visual observations (during twilight), the type of echo (shape and speed) and the counts preceding the radar session. The group size can not be estimated with the radar, but it is possible to obtain an indication of the group size from the type of echo. the radar reception is influenced by rain and waves. It is possible to make correction for this to a certain degree. Also the detection decreases with increasing distance from the radar.

3.3 Observations in the surrounding area

In the vicinity of Tunø Knob observations were carried out to obtain information on the behaviour of sea ducks in situations without turbines. In all four periods a small ship equipped with radar was used for this purpose. During the first four periods a radar with a range of 0.75 nm was used; in the last period a different ship with a radar range of 1.5 nm was used (for an overview of observation periods and times see table 3.2). Neither of these echo's was equipped with an echo trail. Because of this and the movements of the ship observing and tracking bird movements was more difficult than with the tower-based radar.

During the pilot study in December (period 1) in the area near the island Samsø (control area) ship-based observations on the occurrence and flight movements of Eiders were carried out. Since the purpose of this study was to investigate whether Eiders were active in this area, we did not opt for a fixed position but instead moved to collect information at a number of sites. Before dusk we tracked a group of Eiders and collected information in the vicinity of such a group. Because of this way of collecting data, a quantitative analysis is only partly possible. Whenever there was enough light we used a light amplifier to carry out observations.

Later in the season (March) the number of Common Scoters increased. This offered the possibility to collect data on nocturnal activity of Common Scoters. Within the study area small numbers of Common Scoters occur mixed with eiders. Therefore we looked for an area were exclusively reasonable numbers of Common Scoters occurred. Such an area, which was slightly deeper than the area near Tunø Knob, was situated several kilometres Northeast of the study area (Fig. 2.3). During the last two periods, data were collected in this area.

In the ship-based radar observations the same procedures were followed as from the observation tower. Apart from the first period, the ship stayed in the same position throughout the observation period.

Table 3.1. Observation periods and type of observations carried out from the observation tower at Tunø Knob.

date	time	type of observation
period 1		
1/2 Dec	15.00-15.30	census
	16.00-20.00	radar observations
	23.15-01.30	radar observations
2/3 Dec	05.15-08.26	radar observations
	09.00-09.35	census
	11.15-12.00	radar observations
	11.45-12.10	census
	15.45-16.10	census
	16.00-19.00	radar observations
	20.50-23.00	radar observations
	01.00-03.00	radar observations
3/4 Dec	05.00-09.00	radar observations
	11.00-12.00	radar observations
	11.10-11.30	census
	14.50-15.10	census
	15.30-19.00	radar observations
	21.00-23.00	radar observations
	01.00-02.00	radar observations
	06.00-09.00	radar observations
	10.00-10.30	census
period 2		
2/3 Feb	14.00-15.00	census
	16.15-17.00	census
	17.30-07.40	radar observations
3/4 Feb	09.25-10.25	census
	11.00-12.00	census
	16.15-17.00	census
	16.30-08.10	radar observations
	08.30-09.05	census
period 3		
3/4 March	15.00-16.00	census
	17.00-07.30	radar observations
4/5 March	08.30-09.20	census
	15.40-16.25	census
	17.00-07.30	radar observations
period 4		
30/31 March	17.45-18.45	census
	18.30-06.55	radar observations
31 March/1 April	19.15-07.00	radar observations
	08.00-08.20	census

Table 3.2. Observation periods and radar range used during the ship-based observations in the surrounding area of Tunø Knob. See for locations figures 2.1 and 2.3.

date	location	time	range (nautical mile)
period 1			
1/2 Dec	Samsø	18.00-22.00	0.75
		05.50-07.35	0.75
2/3 Dec	Samsø	15.30-16.45	0.75
		05.20-07.40	0.75
		08.05-09.05	0.75
period 2			
2/3 Feb	N of windfarm	17.00-20.00	0.75
		23.00-01.00	0.75
		05.45-08.40	0.75
3/4 Feb	N of windfarm	17.00-19.00	0.75
		06.00-08.30	0.75
period 3			
3/4 March	NO of windfarm	17.40-20.30	0.75
		22.30-01.00	0.75
		04.30-08.00	0.75
4/5 March	NO of windfarm	17.20-20.00	0.75
		23.05-02.00	0.75
		04.40-08.00	0.75
period 4			
30/31 March	NO of windfarm	20.10-04.00	1.50
31 March/1 April	NO of windfarm	20.15-03.30	1.50

3.4 Division in periods and data selection

The observations in each 24 h period were divided in three time periods, according to previous studies on nocturnal flight movements (Dirksen *et al.* 1996b, Van der Winden *et al.* 1996, Spaans *et al.* 1998b). When weather conditions hindered observations and there were doubts about the reliability of the results, the periods concerned were excluded from the analysis.

The periods distinguished are:
A daylight/dusk: until 45 min. after sunset;
B night: from 45 min. after sunset until 45 min. before sunrise;
C daylight/dawn: from 45 min. to sunset.

For each period (A, B or C) the observation period was subdivided in hours, taking account of the transition between A to B and B to C. As a consequence incomplete hours remained. These were classed in the middle of the night. This subdivision in hours was used to be able to show the flight intensity in the course of the night.

3.5 Data analysis

3.5.1 Flight movements in the study area

The analysis of flight movements in the study area can be divided in two parts:

1. In order to answer the question whether there is an effect of the presence of the windfarm in the way flying ducks use the area, the area was divided in grid cells of 200 x 200 m. Within each cell the number of flight movements per unit of time was calculated. This grid size was chosen because it enabled a high enough resolution to allow recognition of patterns and enable an evaluation of the influence of the windfarm.

2. Questions concerning the reactions of the ducks in the close vicinity of the windfarm, or the reactions to turbines in their flight paths are investigated by analysis of movements in an area up to 500 m outside the turbines (windfarm sector).

For both types of analyses we first established for the night periods (B) per form whether that period was moonlit or dark. In this way three different light conditions were distinguished: twilight (A and C), dark nocturnal periods and light nocturnal periods.
The flight movements, as they were registered on the forms, were digitised and co-ordinates were assigned to the scanned flight patterns. The accuracy of this method was between 25 and 75 m. In GIS (Arcinfo/Arcview) a grid consisting of cells measuring 200 m x 200 m was placed over of these flight movements, whereafter the number of flight movements per cell could be counted. A movement that crossed more than one cell, was included in all the cells it crossed. During some observation periods a part of the screen was unsuitable for observations due to showers or waves. We estimated for each form which cells were unsuitable or for which cells observations were missing. The differences in amount of observation time between cells that was created in this way was corrected for in the analysis. The result of this exercise was a database with the number of flight movements per cell per hour per night. For every cell the distance to the nearest wind turbine was calculated. The detection of the radar decreases with increasing distance from the radar. To be able to correct for this we also determined the distance from each cell to the radar.

The question we wanted to answer in this analysis was:

Is there an effect of distance to the nearest wind turbine on the number of movements per unit of time?
This question was analysed using a loglinear regression model (Genstat 5 Committee 1993), correcting for the distance to the radar, the part of the night (A, B or C), the light

conditions and the number of Eiders present in the census area. After these variables were included in the model, the distance to the nearest turbine was entered to test whether this explained a significant proportion of the deviance.

3.5.2 Flight movements in the turbine sector

In order to analyse the movements in the vicinity of the turbines, the flight movements were divided in movements parallel to the two lines of turbines and perpendicular to them. Flight movement that formed an angle of less than 45° with the line of turbines were classified as parallel. Larger angles were classified as perpendicular to the line of turbines.

Movements perpendicular to the windfarm were classified according to the manner in which they crossed the imaginary line connecting the five turbines (Fig. 3.1). Parallel movements were scored with respect to the way they crossed the imaginary lines connecting the first or last two turbines of each line (the way of crossing Fig. 3.1). The following classification was used:

- The flight route of the group crossed the line of turbines between the turbines, this means that the birds flew in between or over the turbines (**T**). This could take place either in between the two lines of turbines (**Tl**) or in between two turbines of one line (**Tb**).
- The route of a group crossed the line of turbines outside the windfarm; the birds flew along the turbines (**L**).
- The route of the group crossed the line of turbines outside the windfarm, but only after the group had turned off from their original track (**A**).
- The flight route did not cross the line of turbines, because a group was only flying for a short time (for example landed in reaction to the turbines), or disappeared from the radar screen for another reason.

The number of flight movements is summed up per night, per light class (moonlit, dark or twilight), per angle (parallel or perpendicular) and per category as mentioned above. In the statistical analysis of the number of flight movements in the windfarm sector loglinear regression models were used (Genstat 5 Committee 1993). Separate analyses for movements parallel and perpendicular to the windfarm were carried out. The questions we wanted to answer in this analysis were:

1. Is the number of flight movements within the windfarm sector dependent on the light conditions?
2. Are there equal numbers of groups (per unit of time and length) flying through the windfarm (Tl + Tb) and alongside the windfarm (L+A)?
3. Is there a light effect on the ratio of groups flying through and alongside the windfarm?

Apart from the questions concerned with flying through the windfarm or not, we were also interested in the way groups were flying through the windfarm. The question whether birds rather fly through an opening of 400 m than 200 m was investigated in two steps:

4. Does the ratio between the number of groups that fly through or alongside the windfarm differ between the two angles of approach (parallel or perpendicular)?

5. Because not all groups that cross the windfarm in between the two lines of turbines are groups that approach parallel to the windfarm, we analysed how many groups of both angles of approach crossed the windfarm in each direction (in between the two lines of turbines or in between two turbines). In other words: how many groups from both angles cross the windfarm through an opening of 400 m, respectively 200 m?

Considering the fact that sudden turn-offs are rare in normal flying behaviour of diving ducks, any turn off is an indication that groups are turning off in reaction to the windfarm. In this respect we analysed what percentage of the total number of movements turned off and whether the (relative) number of such movements is influenced by the light conditions.

6. What proportion of the total number of movements shows deviations from the original path and is this proportion influenced by the light conditions.

Because the length of the imaginary lines that fall outside the windfarm are not equal to the length of those lines that fall within the windfarm, we had to take this into account in the analysis. The probability for a flight movement to cross the imaginary line within the windfarm is not equal to the probability that it crosses the line outside the windfarm. For movements parallel to the windfarm, the length of the imaginary line outside the windfarm is 1000 m and 800 m inside the windfarm. For movements perpendicular to the windfarm these distances are 1000 m and 400 m (Fig. 3.1). Also, the observation time per light class varied between nights. By including an offset variable in the statistical model we could correct for both these problems (Oude Voshaar 1995). In the analysis for questions 1 to 3 the offset variable used was the logarithm of the product of the length of the line (inside/outside windfarm) and the observation time. In this way not the number of movements is the response variable, but the number of movements per unit of length and time.

For the analysis of question 4 the time is no longer important since the ratios between routes were analysed within every observation period. Since we are interested in the proportion of all movements that cross the windfarm in this case, it is essential to correct for the total number of flight movements (coming from each angle of approach). this was done by including the length of the line and the total number of movements from each angle in the offset variable (offset = log (length x total number of movements). In this way the proportion of the total number of flight movements that crosses the windfarm (Tl + Tb) per unit of time is the response variable.

For the analysis in question 6 we are interested whether the number of turn-offs is related to light conditions. Therefore we incorporated the total number of movements and the observation time in the offset variable (offset = log(total number of movements x observation time).

The following predictor variables were tested in the regression analysis (questions 1 to 3): way of crossing (inside or outside the windfarm), light conditions (twilight, moonlit, dark) and the interaction term between these two variables. Significance of the variables was tested by starting with an empty model and adding variables stepwise. Because the numbers of Eiders present in the area is likely to influence the number of movements, we corrected for this effect by including the number of Eiders as the first variable in the model. In the final model, only significant variables were included.

Figure 3.1. Examples of flight movements and subdivisions in movements perpendicular to and parallel to the length axis of the windfarm (see text for explanations of abbreviations). The dotted lines indicate the zones that were used to assign the movements to different categories.

3.6 Weather

Data on weather were collected every two hours during the observation nights. A short overview of the light and weather conditions and study locations is given in table 3.3.

1-4 December 1998

During the three days weather conditions varied considerably. It was clear, calm weather on the first day and night and the second day (1-2 December). The wind was south-easterly (2-3 Bf); visibility was perfect and the temperature was just above freezing. Due to the full moon the night was very light. In the second night the sky clouded over. From 01.00 the moon was no longer visible and the wind increased to 3-4 Bf, resulting in more waves. It was misty on the morning of 3 December, with visibility varying between 300-1000 m. For some time the turbines could not be seen from the hut. The temperature dropped below zero and the clouds and mist lasted until the observation period ended on 4 December. In the afternoon of 3 December the wind turned further towards the west. During the last night the moon was not visible and there was a strong wind (5-6 Bf). A few snow showers passed in the night and morning of 4 December. Due to the dark weather of the last two observation periods, the onset and end of the dark period was influenced strongly. The moment when darkness started varied between half an hour to one hour after sunset and the end of the dark period was recorded between 15 minutes and one hour before sunrise.

2-4 February 1999

Despite the full moon, both observation nights were extremely dark due to permanent overcast. Winds were strong, especially in the morning of 4 February observations were hindered by strong winds, increasing to storm. The visibility was good and there was no precipitation.

3-5 March 1999

There were regular showers on 3 March, the wind was moderate from the south and the visibility was good. During the first night the moon was visible for two hours. Also the next night was calm with many clouds. Mist started from 02.00, and even blanked out the lights of the turbines. The moon was only visible for a very short period.

30 March- 1 April 1999

It was partly clouded with moderate winds on 30 March. In the course of the evening a thick mist formed that persisted throughout the next day as well. There was some light rain during the second night. The next day the visibility was less than 100 m. Only from 22.00 the visibility became better and the full moon was visible. There was hardly any wind and temperatures were exceptionally high.

4 Results

4.1 Bird numbers in the census area

The number of Eiders in the census area varied between 500 and 3500 in the first period, between 1000 and 1800 in the second, between 1000 and 4600 in the third and between 4500 and 7300 in the last period (Table 4.1). Most of the Eiders occurred near the reef and up to 1.5 km east of the reef (Fig. 4.1). The use of the reef as a resting place depended on how much it was exposed., which varied due to the tide and wind.

Figure 4.1. Concentrations of Eiders during the censuses.

The development of Eider numbers in course of the winter agrees with wintering numbers in 1994/95 and 1997/98 as reported by Guillemette *et al.* (1998, 1999), showing a peak between mid March and early April. The numbers counted are on average slightly higher, indicating a continuation of the increase in the winter 1998/99 as compared to 1997/98 (in March c. 3000, early April 5000 Eiders), a winter in which numbers had increased considerably compared to the two preceding winters.

In December Common Scoters were present in small numbers. In February and March the numbers in the census area increased to 270. Gulls (Herring Gulls and a few Great Black-backed Gulls, maximum 194) were mainly seen in the proximity of Eiders. Cormorants were only seen when they were resting on the reef. They were never seen using the bases of the turbines as a resting place, but considering the large amount of Cormorant faeces present there, they must be used at some time. Other birds species were only observed in very small numbers (<10) or incidentally.

4.2 Behaviour of eiders during daylight and twilight

During daylight Eiders spent most of the time resting and displaying. Especially on calm mornings (2 December, 1 April) the majority of Eiders was displaying. Displaying was less common on dark and windy mornings and the main activities were resting and feeding. Feeding and resting mainly took place in the area near the reef and at 1-1.5 km east of the observation tower (Fig. 4.1). Early April groups of foraging Eiders were also present between the turbines and west of the windfarm. Only few small groups were present north of the windfarm.

Herring Gulls were seen in the proximity of Eiders nearly all the time. Groups or pairs were accompanied by one or more gulls. The gulls were trying to take the food collected by the Eiders and successful attempts were observed several times. As far as we were able to observe the food in December concerned mainly Mussels, while in February also Sea-stars and Cockles were surfaced by the Eiders.

During the day, small groups of Eiders were seen flying. Distances flown were mostly short and took place between different feeding groups or between feeding locations and the reef. The highest flight intensity was observed during morning twilight. This 'morning flight' started at first light, sometimes later, and lasted approximately half an hour. Under calm, clear conditions the morning flight was massive and concerned several thousands of birds (2 December, 1 April); in strong winds (4 February) or fog (31 March) it was virtually non-existent. These flights were mainly directed towards the south-eastern part of the reef, where large concentrations of Eiders congregated and there was a high display activity. The displaying birds included local birds, but especially during massive morning flights, large numbers of birds came from outside the radar range, from north, north-easterly and to a lesser degree north-westerly directions. This influx of Eiders to the reef was not noticed from southerly and south-westerly directions.

The flight in the morning was not repeated during the evening. Only at one out of nine evenings a similar pattern was observed. On most evenings, flight intensity was only somewhat increased. Dispersion of the daytime concentrations apparently took place either flying, in small groups and during a longer time span, or by swimming or drifting.

4.3 Nocturnal flight movements of Eiders: general patterns

4.3.1 Flight movements at Tunø Knob

Before we started the study it was not known whether or not Eiders were flying at night near Tunø Knob. No nocturnal activity at all or dispersal by swimming only were included in the possibilities. But our observations at Tunø Knob indicated that both Eiders and Common Scoters were flying in the dark. Depending on light and weather conditions , several tens of flight movements per hour were recorded with the radar in the darkness. A large fraction of these movements was most likely made by Eiders, based on the following considerations:

1. Eiders were the most common of all birds present, 10 to 2000 times as numerous as gulls.
2. Flying Eiders were observed during dusk until near-darkness and in the early morning at first light. In calm weather their sounds were heard throughout the night, indicating continuing activity during the night.
3. During one calm night when there was hardly any wave activity large groups of swimming eiders were visible on the radar screen and many flight movements started or ended in such groups. Also in windier nights, most of the flying activity took place at sites where foraging Eiders had been present in the morning and the afternoon.
4. Speed and course of many movements were similar to those observed in earlier studies of diving ducks, notably Scaup in lake IJsselmeer (Spaans *et al.* 1998b, Tulp *et al.* 1999).
5. Gulls were mainly seen flying in the neighbourhood of Eiders during the day but were inactive during the night. Calling gulls were heard during the day and at dusk and dawn, but rarely at night. On several evenings a lot of flight activity was observed of gulls flying near groups of foraging Eiders, but these disappeared from the screen shortly after dark. These movements also differed in pattern from those of Eiders, because gulls flew in an irregular way within a mall area.

A relatively large proportion of the nocturnal flight movements concerned short flights, that disappeared from the screen after several hundreds of meters to one km. This type of movement can be caused by (groups) of birds moving between different sites within a feeding area, or even within large feeding flocks. In those flocks foraging takes place mainly in the front part of the group. Eiders that have full stomachs drift to the rear side for a digestion break and fly forwards when they commence feeding again. Longer range flight movements occurred regularly as well. A different type of movements concerned the long and straight movements, mostly along a SW-NE axis (flying towards NE), that were observed during several nights. These movements resembled seasonal migration, most likely of ducks, but we could not identify the species concerned.
A strong effect was found of light conditions on nocturnal flight activity. When the moon was out three to six times as many flight movements were recorded compared to moonless nights. This effect was present both in comparison between nights with varying light conditions and within one night (Fig. 4.2-4.5). This effect was not influenced by the season: the difference in flight activity between light and dark nights

was present both in December and in April. In moonlit conditions the flight activity was nearly as high at night as at dusk, but in dark nights nocturnal activity was much reduced compared to dusk. During partially moonlit nights the flight activity in the dark periods was slightly higher than in completely dark nights.

Figure 4.2. The number of flight movements per hour in the study area in period 1 (1-4 December 1998). Open circles: moonlit periods; closed circles: dark periods. A, B and C indicate the three periods as described in section 3.4. Hatched time periods indicate periods during which no observations were carried out. The date refers to the date when the observations started (total number of flight movements: 1 Dec: 2572, 2 Dec: 617 en 3 Dec: 145; not corrected for periods during which no observations were carried out). Radar range: 1.5 nm.

Figure 4.3. Number of flight movements per hour in the study area in period 2 (2-4 February 1999, total number of flight movements: 2 Feb: 369 en 3 Feb: 81; not corrected for periods during which no observations were carried out). Explanation as in figure 4.2.

Figure 4.4. Number of flight movements per hour in the study area in period 3 (3-5 March 1999, total number of flight movements: 3 March: 488 en 4 March: 751; not corrected for periods during which no observations were carried out). Explanation as in figure 4.2.

Figure 4.5. Number of flight movements per hour in the study area in period 4 (30 March-1 April 1999, total number of flight movements: 30 March: 652 en 31 March: 1724; not corrected for periods during which no observations were carried out). Explanation as in figure 4.2.

Figure 4.6. Number of flight movements per hour in period 1 (1-3 December) in the control area near Samsø. A, B and C indicate the three periods as described in section 3.4. Hatched time periods indicate periods during which no observations were carried out or data were not collected in a quantitative way. The date refers to the date when the observations started. Radar range: 0.75 nm.

4.3.2 Flight movements in the control area

Also in the control area Eiders showed nocturnal flight activity. Since the first period was originally meant as a trial period, not all data from this period were collected in a quantitative manner. In the periods during which quantitative data were collected, the activity was comparable to the activity measured in the study area. The smaller number of movements per hour can be explained by the smaller range of the ship's radar (0.75 nm, Fig. 4.6). The area covered by the 1.5 nm range is Four times larger than that covered by the 0.75 nm range.
During the night of 1/2 December, observations were carried out with a light amplifier. Despite the fact that a group of Eiders could be identified it was not possible to see whether they were foraging. This must have been the case, judging from the type of flight movements, short ones in a small area around the group. In the morning of 2 December, groups of 2-30 birds flew from the open water to the coast of Samsø (in Fig. 4.6 starting at 07.45).
In the control area Eiders were nocturnally active and flying, approximately at the same level as in the study area.

4.4 Flight movements in the study area

The numbers of flight movements per hour per square of 200 x 200 m were averaged for the four different parts of the day/light combinations (dusk, dawn, light nocturnal period, dark nocturnal period). The results of the analysis of the number of flight movements in the study area are given in figures 4.7 to 4.10. The darkest squares indicate the areas where most movements per hour were recorded. During dusk (period A), flight intensity was less intense than during dawn (period C, Fig. 4.7 and 4.8). In both periods there were fewer flights in the region around the windfarm than in other regions at comparable distances to the radar. Also at night the windfarm was avoided, both in light and in dark nights (Fig. 4.9 and 4.10). At night, the flight activity during light periods was greater than in dark periods. Furthermore, the activity decreases from the centre to the edge of the radar range (Figs 4.7 to 4.10). In the statistical analysis the largest part of the variation in flight activity per 200 x 200 m square could be explained by the distance to the radar. This is an artefact caused by a reduced detection of birds with increasing distance to the radar. After correction for this effect and for the factors: part of the night (A, B and C), light and the number of Eiders present, also the distance to the nearest turbines explained a significant proportion of the deviance (Tab. 4.2): at a short distance to a turbine less movements were observed than further away.

To investigate the shape of the distance-to-turbine effect, we used the residuals of a loglinear regression analysis incorporating distance to radar, part of the night, light conditions and number of Eiders present as independent factors, but not the distance to the nearest turbine. These residuals reflect the variation in number of flight movements after correction for the independent factors. In figure 4.11 these residuals are averaged per distance class of 100 m, and plotted for the different light conditions against the distance to the nearest turbine. The residuals can be interpreted as the proportions of the number of movements that would occur in the absence of an effect of the distance to the nearest turbine. Both in dark and in light nights there was less flight activity in the proximity of the turbines than further away. This effect is only (and in increasing degree) noticeable within 1000-1500 m from the turbines. The flight activity in moonlit nights amounted to 60% of the undisturbed situation at 500 m and 85% at 1000 m. At a distance of 1500 m a higher density of flight movements was recorded compared to the undisturbed situation. Possibly this is the result of an accumulation of groups deviating from their original path closer to the windfarm. In moonlit nights, 20% more flight activity was measured compared to the undisturbed situation. Both the degree of avoidance of the turbines and the increase in activity at 1500 m seemed to be higher in moonlit periods than in dark situations. During dusk, an avoidance effect was noticeable up to 1200 m from the turbines, although it was less strong than at night. No such effect occurred at dawn.

The residuals are plotted in (averaged per square) in figures 4.12 and 4.13. An increase in flight activity with increasing distance to the turbines is noticeable on all sides of the windfarm. Therefore the patterns in figure 4.11 are not caused by the fact that the areas with the largest concentrations Eiders were situated more than 1500 m from the windfarm (in the southerly and eastern parts of the study area). We conclude that a negative effect of the presence of the windfarm on the number of flight movements is noticeable up to 1000-1500 m from the turbines during dusk and at night, but not at dawn.

Table 4.2. Results of loglinear regression analysis of the number of flight movements per hour per grid cell. Only significant predictor variables are shown here. The night was subdivided in: dusk (A), night (B) or dawn (C). Light conditions were classified as twilight (dusk and dawn, equal to A and C, moonlit nocturnal periods and dark nocturnal periods (both B).

model	(change in) deviance	df	p	effect
empty model	51743	25827		+
distance to radar	17553	1	<0.001	-
part of night	5027	2	<0.001	C>B>A
light conditions	1543	1	<0.001	twilight=light night>dark night
n Eiders	633	1	<0.001	+
distance to turbine	116	1	<0.001	+

Figure 4.7. Flight movements during evening twilight

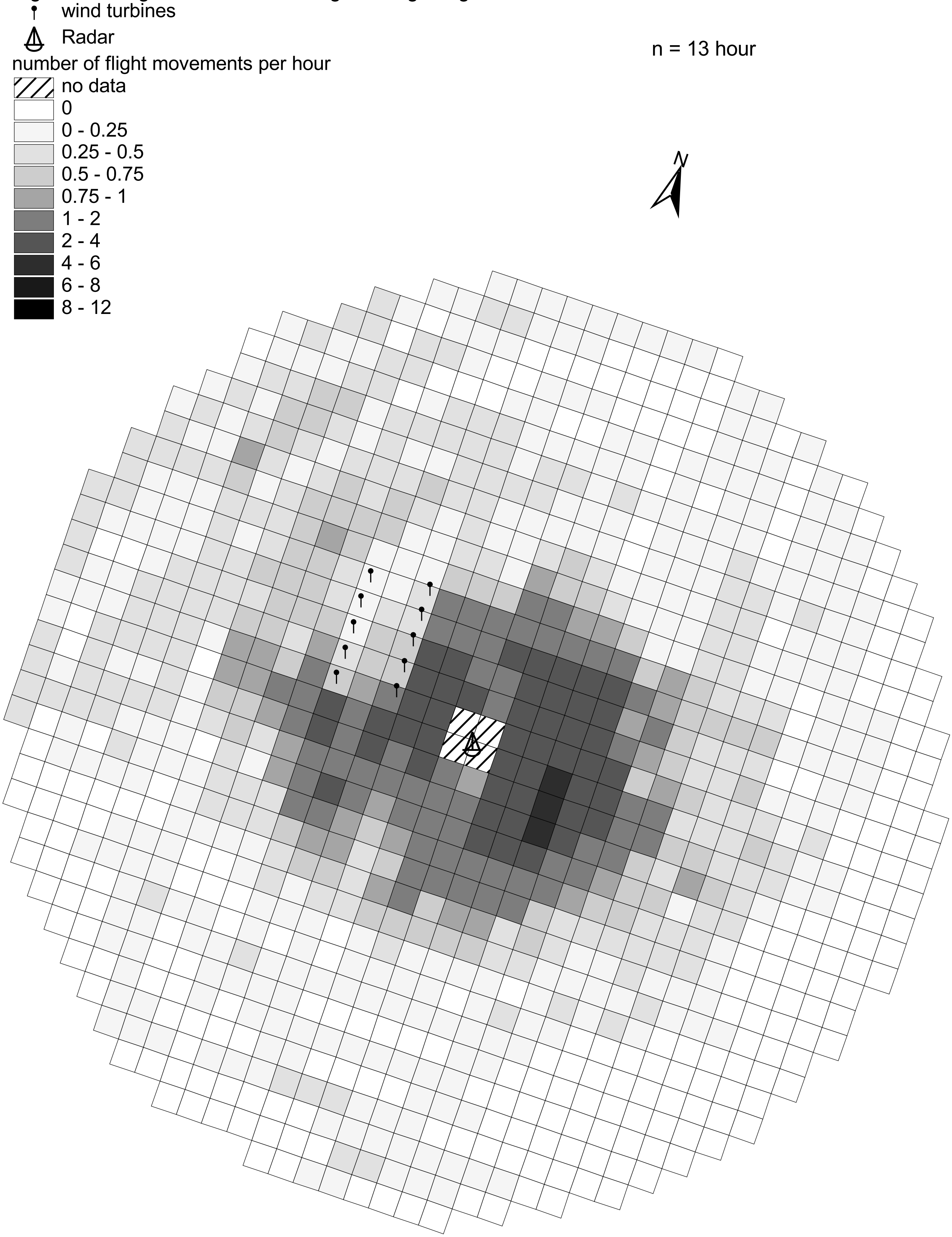


Figure 4.8. Flight movements during morning twilight

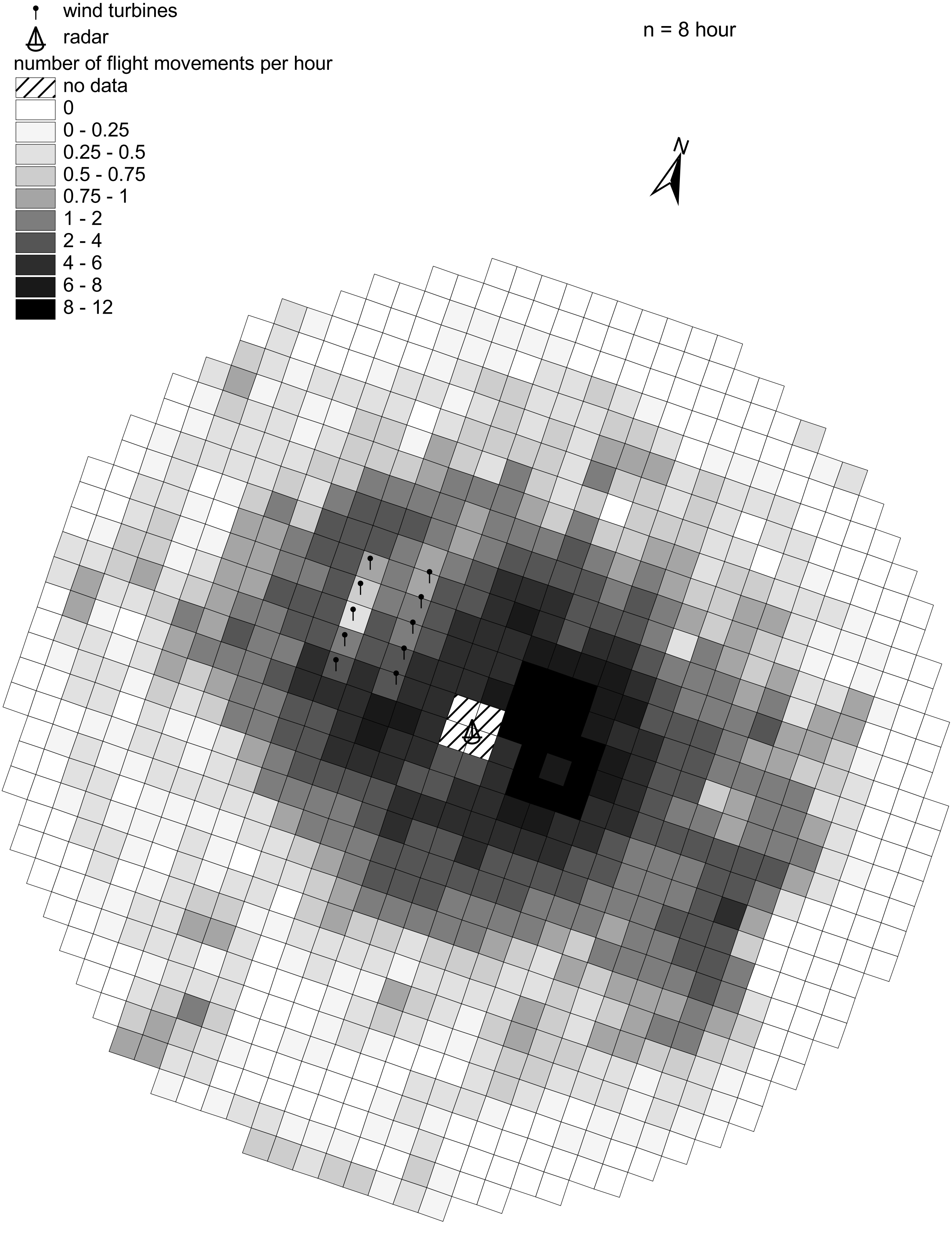


Figure 4.9. Flight movements during dark nocturnal periods.

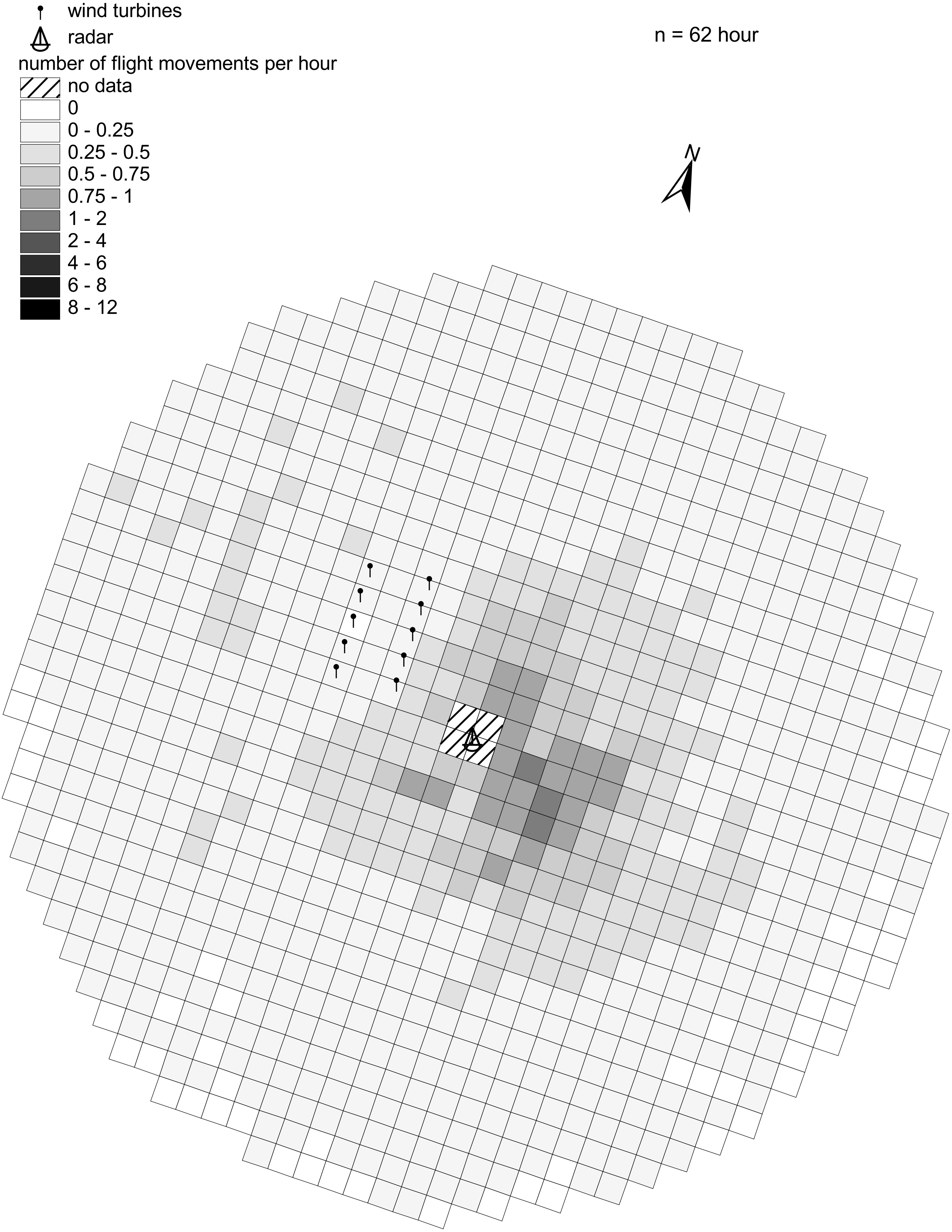


Figure 4.10. Flight movements during moonlit nocturnal periods

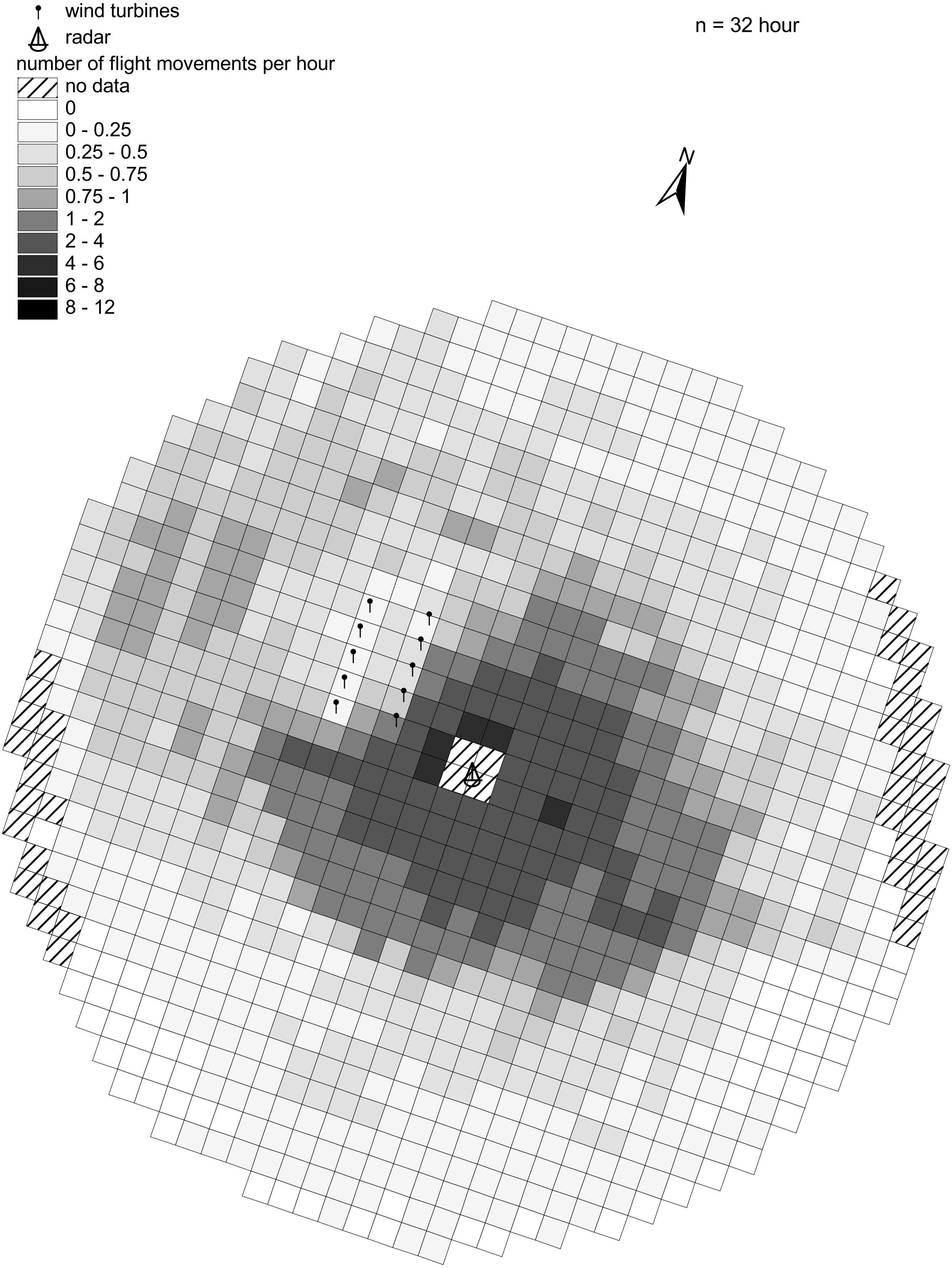


Figure 4.12. Spatial distribution of flight activity in moonlit nocturnal periods, after correction for the effects of distance to radar, numbers of Eiders present, part of the night and light condition (mean residuals of the loglinear regression per square, backtransformed to a linear scale).

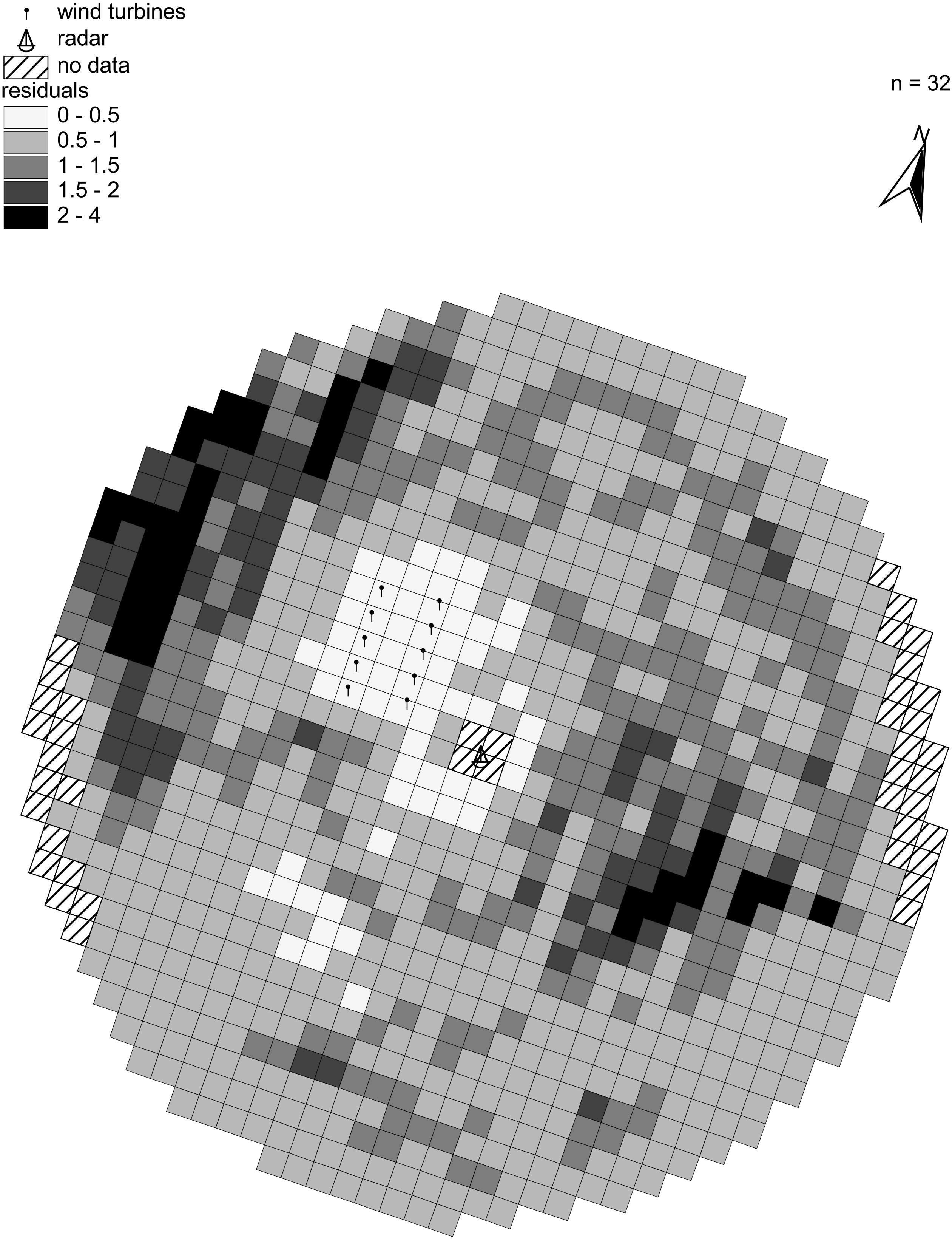
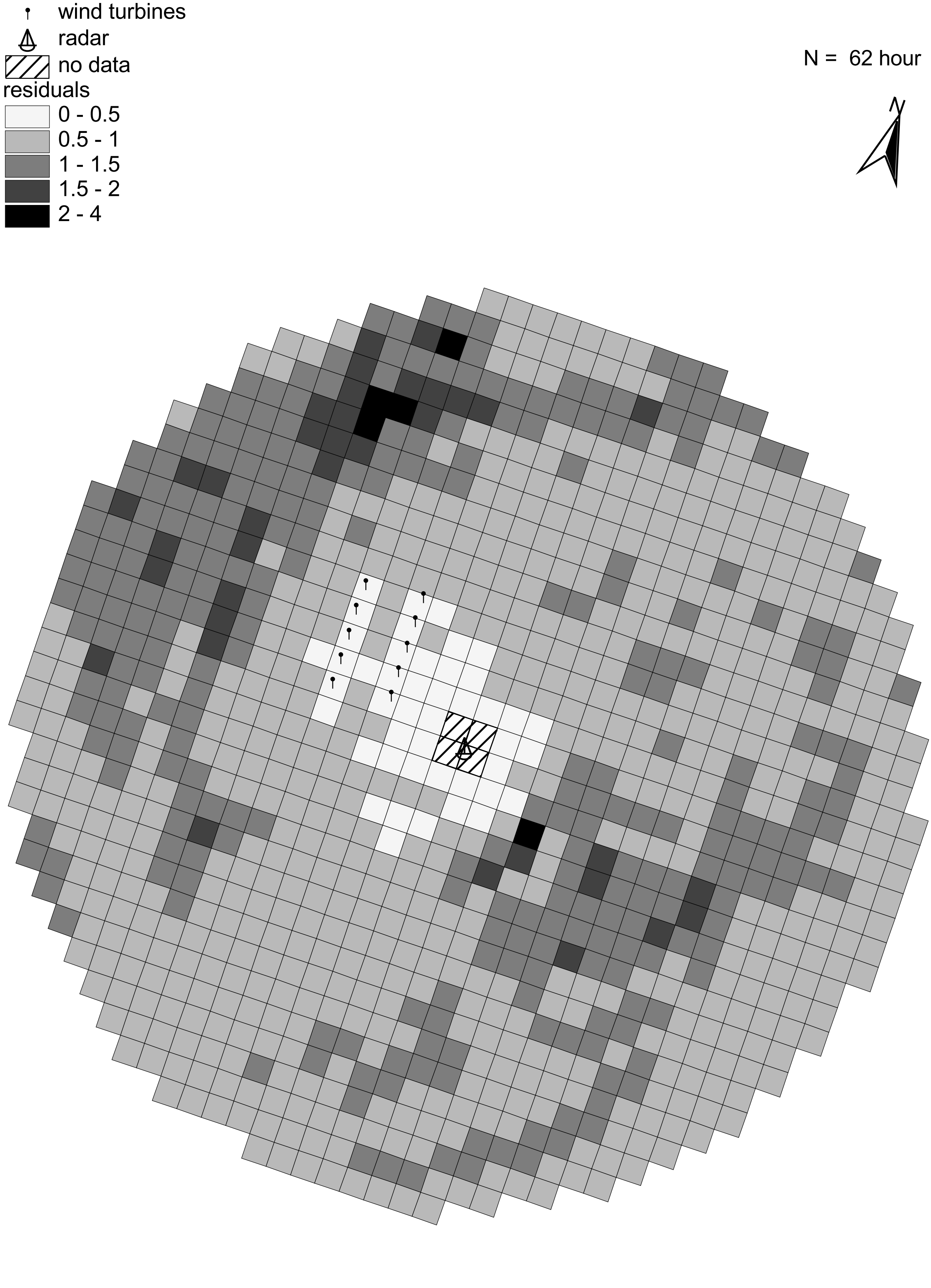


Figure 4.13. Spatial distribution of flight activity in dark nocturnal periods, after correction for the effects of distance to radar, numbers of Eiders present, part of the night and light condition (mean residuals of the loglinear regression per square, backtransformed to a linear scale).



4.5 Flight movements in the close vicinity of the windfarm

The data that were used to carry out all regression analyses in this paragraph are given in table 4.3

Table 4.3. The number of flight movements in the windfarm sector per observation period for movements parallel and perpendicular to the windfarm.

period	between rows	between turbines	along turbines	along after turn off	not crossing	total
parallel to the windfarm						
1-4 Dec	39	7	70	17	55	188
2-4 Feb	15	0	31	7	14	67
2-4 March	6	5	62	3	51	127
30 March-1 April	28	11	174	5	143	361
perpendicular to the windfarm						
1-4 Dec	0	9	52	3	28	92
2-4 Feb	0	0	5	0	0	5
2-4 March	0	1	12	2	17	32
30 March-1 April	0	12	95	7	138	252

Both for movements perpendicular and parallel to the windfarm, significant effects were found of the number of Eiders present in the census area prior to the observations, the way of crossing and of light conditions (Tab. 4.4). In both directions, more movements occurred outside than inside the windfarm. For parallel movements the number per unit of time was largest in twilight periods and smallest in dark parts of the night. For perpendicular movements, the flight activity in twilight periods was intermediate between that in moonlit and in dark nights. The interaction term between way of crossing and light condition was not significant, indicating that the ratio of the number of movements inside and outside the windfarm did not differ under different light conditions.

In conclusion the answers to the first three questions from paragraph 3.5 are:

1. Is the number of flight movements within the windfarm sector dependent on the light conditions?

The number of movements is related to light intensity: the more light, the more movements. The least movements were recorded in dark nocturnal periods, while most movements were recorded under light conditions: twilight or moonlit nights.

2. Are there equal numbers of groups (per unit of time and length) flying through the windfarm (Tl + Tb) and alongside the windfarm (L+A)?

More groups flew outside the windfarm than inside. This is true for both directions.

3. Is there a light effect on the ratio of groups flying through and alongside the windfarm?

The interaction term between way of crossing and light condition was not significant for any the directions. This means that the ratio between flight movements outside and inside the windfarm is equal under different light conditions.
In general, the windfarm was crossed more often in the parallel direction (total in four periods: 88 times) than in the perpendicular direction (45 times, Tab. 4.3). However these numbers are not corrected for the numbers that approach the windfarm from both directions. Since these numbers are not equal, we corrected for this in the analysis as described in paragraph 3.5.
After correction for the number of groups from both directions, the ratio between flight movements inside and outside the windfarm differed between the two directions. Groups flying perpendicular to the windfarm crossed the windfarm less often than groups flying parallel to the windfarm (significant interaction term between direction and way of crossing, X^2_1=25, p<0.001. Tab. 4.5).
All groups that crossed the windfarm perpendicularly, flew in between two turbines of one turbine line (Tb, when flying in perpendicular to the windfarm it is virtually impossible to cross the windfarm in another direction). From 111 groups flying parallel to the windfarm and crossing it, 88 did so between the two rows of turbines (Tl, through an opening of 400 m) and 23 in the other direction (Tb, through an opening of 200 m, see Fig. 3.1).
Of all movements parallel to the windfarm that actually crossed the windfarm, 7.5 % deviated; 6.5% of all perpendicular movements did so. Deviations were recorded in total 44 times (Tab. 4.3). Light had a significant effect on the number of deviations (X^2_2=11, p=0.004). Relative to the total number of flight movements, fewer deviations occurred in moonlit nights than in twilight; in dark nights the least deviations occurred.

In conclusion the answers to the questions 4, 5 and 6 from paragraph 3.5 are:

4. Does the ratio between the number of groups that fly through or alongside the windfarm differ between the two angles of approach (parallel or perpendicular)?

The ratio is different: groups flying perpendicular to the windfarm cross the windfarm less often than groups flying parallel to the windfarm.

5. How many groups from both angles cross the windfarm through an opening of 400 m, respectively 200 m ?

All groups flying perpendicular to the windfarm crossed the windfarm through openings of 200 m. Of groups flying parallel to the windfarm 79% crossed the windfarm through an opening of 400 m.

6. How many of the total number of movements shows deviations from the original path and is the number of turn-offs on approach to the windfarm influenced by the light conditions?

Of all parallel movements 7.5% showed deviations, of all perpendicular movements 6.5% deviated. Deviations occur mostly under light circumstances.

Table 4.4. Results of loglinear regression analyses concerning the questions on number of flight movements (per hour per km) inside and outside the windfarm. Only significant variables are included in the table (questions 1 to 3).

model	(change in) deviance	df	p	effect
parallel to windfarm				
empty model	744	43		
n Eiders	100	1	<0.001	+
crossing	62	1	<0.001	outside>inside
light conditions	190	2	<0.001	twilight>light>dark period
perpendicular to windfarm				
empty model	450	43		
n Eiders	108	1	<0.001	+
crossing	122	1	<0.001	outside>inside
light conditions	72	2	<0.001	light period>twilight>dark period

Table 4.5. Results of loglinear regression analyses concerning the questions on the way in which the windfarm was crossed. Only significant variables are included in the table.

model	(change in) deviance	df	p	effect
empty model	623	87		
direction	63	1	<0.001	parallel>perpendicular
crossing	172	1	<0.001	outside>inside
interaction	25	1	<0.001	parallel inside>perpendicular inside

4.6 Common Scoters

In December, Common Scoters occurred in small numbers in the census area (max. 65). In early February (max. 163) and early March (max. 131) the numbers were slightly larger. In these three periods most of the birds were foraging in groups of 5-80 birds predominantly in the area Northeast of the observation tower. On 30 March the number had further increased to 270, among which a group of 250 displaying birds in the centre of a much larger group (3770) of Eiders. These numbers are within the range of numbers reported by Guillemette *et al.* (1998, 1999) in the winters of 1994/95-1997/98.

At Tunø Knob no specific observations were carried out on Common Scoters apart from the censuses. In the third and fourth period ,additional ship-based radar observations were carried out approximately 3 km Northeast of Tunø Knob (55º59'N, 10º25'E), where larger concentrations of Common Scoters occurred in deeper water (10-12 m). On 3 and 4 March the ship was anchored at dusk in the vicinity (<500 m) of several hundreds of Common Scoters. On both these nights a higher flight intensity was observed during dusk than later in the night (Fig. 4.14); several flight movements could be confirmed visually as Common Scoter flights. In the night (clouded and foggy, but calm) not many flight movements were recorded, although the Common Scoters were active: sounds were heard continuously. During both mornings, an increase in flight activity was observed at dawn, but most of these movements appeared to be caused by Eiders and gulls (no correction for this could be carried out in figure 4.14).

On 30/31 March and 31 March/1 April, observations were carried out near a larger group of Common Scoters (ca. 800), with several Velvet Scoters and Long-tailed Ducks. Eiders were hardly present in this area, so that most nocturnal movements were caused by Common Scoters. More flight movements were recorded than in early March, possibly as a consequence of the larger numbers present. Flight activity was observed throughout the night, with a predominance of relatively short flights (≤ 1km). Some started or ended at groups of swimming scoters that were visible on the radar screen. Now and then the sound of ducks taking-off was heard and their calls were heard throughout the night. Because of the absence of an *echo trail* option on the radar screen, following of individual flight movements was difficult and not all movements could be registered, but on 31 March the observer noted an increase in flight activity starting at 02.30, when the moon came out through the mist. Also in the night of 31 March, when the moon came out around 22.00, a strong increase in flight activity was noted. The activity remained high throughout the night, but due to the absence of the *echo trail* option and the turning of the ship, only a part of this could be registered (and included in Fig. 4.15). There was clearly more flight activity than in the preceding night.

Based on this limited amount of observations, the following conclusions can be made:
1. Common Scoters fly in the dark: probably flight activity concerns mainly short movements inside the feeding area.
2. The nocturnal activity is intensified under moonlit conditions as compared to dark periods.
In both these aspects, the behaviour of Common Scoters parallels that of Eiders. However, Common Scoters showed no increase in flight activity during morning twilight.

Figure 4.14. Flight activity (number of flight movements per hour) of Common Scoters in period 3 (3-5 March). A, B and C indicate the three periods as described in paragraph 3.4. Hatched areas indicate periods, during which no observations were carried out. The date refers to the date on which observations were started. Radar range used: 0.75 nm.

Figure 4.15. Flight activity (number of flight movements per hour) of Common Scoters in period 4 (30 March-1 April). Explanation as in figure 4.14. Radar range used was 1.5 nm, but numbers are converted to 0.75 nm.

5 Discussion

As an introduction to the discussion, a short overview will be given below of the results obtained by the Danish researchers of NERI on the effect of the turbines at Tunø Knob on foraging Eiders during daylight (paragraph 5.1). In the subsequent paragraphs the results of the study on nocturnal flight behaviour will be discussed.

5.1 Distribution and flight movements in daylight: results of Danish research

During the construction of the windfarm NERI carried out a BACI (Before After Control Impact) study (Guillemette *et al.* 1998). The study focused on possible disturbance effects of the windfarm on feeding Eiders during daytime. After the construction of the windfarm Guillemette *et al.* (1998) found a strong decline in numbers of Eiders in the census area as opposed to the control area. However they concluded that the difference in food situation caused this difference: at Tunø Knob the density of the Mussels of the appropriate size was considerably lower than in the control area. This conclusion was confirmed by a sequel-study carried out in the winter of 1997/98, when the shellfish stock had increased at Tunø Knob and numbers of Eiders were back on the level of the year preceding the construction of the windfarm (Guillemette *et al.* 1999). Our counts show that this increase has continued in the winter of 1998/99 (Tab. 4.1).

Apart from the BACI study three other experiments were carried out by Guillemette *et al.* (1998) after erection of the turbines:

-Decoys were placed in the vicinity of the turbines and observations were carried out on the response of flying and landing birds to these decoys. at a distance of 100 m to the turbines flight activity was less than at distances of 300 and 500 m from the turbines
-In an experiment during which the turbines were switched on and off, no effect was found of the rotor movement and sound on the distribution of the ducks.
-In the last experiment, the availability and exploitation of food by Eiders was studied throughout a complete winter in four quadrates at varying distances from the turbines. The most of the variation in numbers of Eiders in the quadrates was explained by the local food situation. The authors concluded that the turbines had no effect on the food exploitation in the vicinity of the windfarm during an entire winter.

The authors concluded that the decline in Eider numbers in the census area was not caused by the construction of the windfarm. As a drawback of the study they indicate that the group sizes during the study were very small. Since the risk of disturbance increases with group size, the study must be interpreted carefully. Besides this, the study did not take into account all aspects of possible conflicts between birds and windfarms. The authors suggest that information on other periods than the winter (moult period), other species, the effect of weather on collision risk, the effect of disturbance by maintenance ships and the effect of large windfarms is still lacking, and needs further study. In addition to these aspects, the nocturnal situation was not studied.

5.2 Numbers, distribution and species composition in 1998/1999

The numbers of Eiders showed a maximum between mid March and early April. This is in agreement with what Guillemette *et al.* (1998, 1999) report for the winters of 1994/95 and 1997/98. The numbers counted in the winter of 1998/99 were on average slightly higher than in these winters. This indicates that numbers showed a continuation of the increase compared to the winter 1997/98, during which they increased compared to the two preceding winters. The decline just after the construction of the windfarm and the increase in numbers in the latest winters mirror the changes in availability of shellfish food. Although no sampling of the food availability was carried out in 1998/99, it is likely that the food availability further increased due to good spatfall in the summer of 1997 (Guillemette *et al.* 1999). These data support the idea that the relatively small Eider numbers of sin the two winters after construction of the windfarm were caused by a decline in food abundance and not by the turbines as such. Therefore the increase in numbers during the last two winters can not be attributed to habituation to the turbines.

The distribution of resting and feeding groups of Eiders did not differ between the four observation periods, and was very similar to the distribution in the winter of 1997/98 (Guillemette *et al.* 1999). The largest groups were present on the reef, south of the reef and in the eastern part of the census area.

The species composition of birds near Tunø Knob resembled observations in previous years. Eiders were by far the most numerous. This enabled an interpretation of the flight movements at night: most likely the majority of movements recorded by the radar were carried out by Eiders. Because of the presence of slightly larger numbers of Common Scoters in an area close to Tunø Knob, comparable observations could be carried out on this species in a situation with few Eiders and without turbines.

5.3 Variation in numbers of flight movements

Both Eiders and Common Scoters showed nocturnal flight activity. About this aspect of the behaviour of sea ducks, little was known so far (Van der Winden *et al.* 1997). The shape and length of flight movements and the distribution of these movements in the study area suggested that the flights mainly concerned movements over short distances associated with nocturnal foraging: short flights within a large group or between groups and flights between feeding areas and resting areas near the reef. Although we did not succeed in confirming actual nocturnal feeding using the light amplifier, we are convinced that the sea ducks were feeding at night based on the type of movements.

The analyses showed that the number of nocturnal flight movements was related to the numbers of Eiders present in the census area prior to the radar observations. Apart from this effect, the differences observed in flight activity between nights could largely be explained by differences in light conditions. Under dark conditions, flight activity was much less than under light conditons. Variation in flight activity in the course of the night was determined by light conditions rather than by the time. This means that in conditions when the collision risk is high (dark circumstances) relatively few birds are airborne.

During our study, moonlit nights always coincided with calm weather. Insufficient data on different combinations of light and weather circumstances (wind, precipitation) are available to indicate the effect on flight activity of for example, the combination of moonlit nights with strong winds.
Flight intensity of Eiders was highest at dusk and dawn. Especially the hour before sunrise flight activity increased strongly. The reason for these morning flights remains unclear, but the observations suggest that on clear calm mornings large numbers of Eiders congregate near the reef to display. Under these conditions, social communication is the most effective. In rough weather, the birds might tend to stay in or near their feeding areas during the day.
The activity pattern of Common Scoters resembled that of Eiders. The timing of evening and morning flights of both species are more similar to that of Scaup than to that of Tufted Ducks in lake IJsselmeer (Spaans *et al.* 1998b).

5.4 Spatial distribution of flight movements in the study area

In general, relatively many flight movements were observed in areas with the highest concentrations of swimming Eiders: near the reef and east of the observation tower. Numbers of Eiders could only be counted in the smaller census area and these numbers were used in the analyses of flight movements in the larger area that was covered by radar. Due to the different characteristics (e.g. water depth) of these two areas we cannot simply assume that numbers in both areas were correlated. However, since the number of Eiders in the smaller area explained a significant proportion of the variation (Table 4.2) in the distribution of flight movements in the larger area, numbers in both areas are likely to be correlated.
A clear decline was noticeable in the number of radar echoes going from the tower outwards, as a result of decreasing probability of detection with distance from the radar. After correction for this decrease in detection and for several other factors that affect flight activity (total number of birds in the area, part of the night and light conditions), a negative effect of the distance to the nearest turbine remained. This effect was noticeable within 1000-1500 m from the nearest turbine. The effect occurred mostly Northwest and Southeast of the windfarm. Active avoidance behaviour could possibly cause the increase in flights that occurred at a distance of 1500 m from the windfarm. Alternatively, the decrease in flight activity at a distance of 1000-1500 m and the increase outside of that range could be caused by a lower respectively higher number of Eiders resting or feeding in these areas. We can not test this possibility, as we did not map the (daytime) distribution of the birds at a sufficiently fine scale and in the larger study area to incorporate the density of feeding/resting birds per square as an additional independent variable. However three points can be made. Firstly, in the study performed by Guillemette *et al.* (1998) no effect of the presence of the windfarm could be detected on the distribution of Eiders beyond 300 m from the turbines. Secondly, while the cluster of high residuals to the South and East of the tower did coincide with concentrations of feeding and resting Eiders, we did not observe equally large concentrations of ducks Northwest of the windfarm during daytime. Although this area was far away from the observation tower, we crossed it several times by boat while going to and leaving the

tower, and did not observe very large numbers of Eiders here. Thirdly, if nocturnal flight activity were simply a passive reflection of feeding distribution, one would expect to see the same pattern also during dusk and dawn, which was not the case. These points suggest that, in addition to a possible effect of the feeding distribution of the ducks, active modifications of flight behaviour are involved.

The reduction in flight activity was strongest in moonlit nights, less in moonless periods and weak at dusk. At dawn the effect was non-existent. This might be caused by a different nature of the morning flights as compared to flights during the evening and night. Contrary to the short and undirected local movements in the evening and night, the morning flights were directional and longer. Despite the fact that avoidance behaviour was observed in these morning flights when approaching the turbines at close range, the wider area surrounding the windfarm was not avoided. The nocturnal flight movements most likely involved local birds, that might have been present in the area for a longer period and become familiar with the windfarm. Perhaps they maintained a safety margin around the windfarm at night. The turbines were probably visible enough during the morning flights, so that a safety margin may no longer have been necessary.

It is important to realise that the avoidance effect within 1500 m of the windfarm, concerns *flight movements* only. We cannot deduct from our observations whether Eiders did not enter this area at all, or did so by swimming.

The avoidance effect found up to 1500 m from the windfarm is larger than the avoidance effect noticeable up to 300 m that was established experimentally during daytime (Guillemette *et al* 1998). This smaller distance, however, does agree with our findings at dawn, when avoidance was not noticeable or occurred at the most up to a distance of 200 m.

5.5 Flight movements inside the windfarm sector

The avoidance behaviour that was found in the study area was also noticeable on a smaller scale in the area within 500 m from the windfarm. Both groups approaching parallel and perpendicular to the length axis of the windfarm cross the windfarm more often outside the windfarm than inside. In a study that was carried out near windfarm Lely in lake IJsselmeer (Spaans *et al.* 1998b), a similar effect was found in Tufted Ducks.

Turns in the flight path, that are a direct indication of avoidance behaviour, occurred under all light conditions, but relatively more at dusk and in moonlit periods. In the study at windfarm Lely turns occurred both at full moon and at new moon (Spaans *et al.* 1998b). Under light conditions (dusk or moonlit) the turbines were visible to the human eye. This was not the case during dark period, when at best the lights at the bases of the turbines were visible. The fact that avoidance takes place less in dark conditions compared to light conditions, might suggest that Eiders do not see the turbines in the dark. As a precaution they would choose a route further away from the turbines, which makes turning off unnecessary. If they would be aware of the position of the turbines, one would expect that in dark conditions relatively more groups would fly outside than through the windfarm. This was not the case however: the ratio between flights inside and outside the windfarm was similar under different light conditions.

The distance between two neighbouring turbines within one line was 200 m, while the distance between the two lines of five was 400 m. It would be interesting if the results could tell whether Eiders prefer to fly through an opening of 400 than through one of 200 m. All groups approaching perpendicular to the windfarm, and crossing the windfarm, did so through openings of 200 m. Of all groups approaching parallel to the windfarm, 79% crossed the windfarm through an opening of 400 m, while 21% did so through an opening of 200 m. Groups approaching the windfarm in a perpendicular direction crossed the windfarm less often than groups flying parallel to the windfarm. This might indicate that an opening of 400 m is less of a barrier than an opening of 200 m, but a few caveats must be made here. Apart from the space in between two turbines also other aspects of the windfarm differed for these directions: when approaching parallel to the windfarm, it looks long and narrow, with two rows of turbines that are lined up; when approaching perpendicular to the windfarm, it looks much wider, with turbines that are not lined up but alternate between the two lines. This effect optically further reduces the distance between two turbines. Ducks approaching parallel to the windfarm need to make a smaller detour if they want to avoid flying through the windfarm than birds approaching perpendicular to the windfarm. Apart from this, the majority of ducks approaching the windfarm in the parallel direction were on its way to the reef. A similar attraction was absent in the direction perpendicular to the windfarm. To be able to really test whether birds prefer to fly through an opening of 400 than of 200 m, a square windfarm would be needed with no special features on either side of the windfarm.

5.6 Consequences of the results for collision risks and barrier effects

The possible disturbing effect of the presence of the windfarm on the use of Tunø Knob as a feeding and or resting area has been the subject of the study carried out by NERI (Guillemette *et al.* 1998, 1999) and was not considered in our study. The other two types of effects that can be distinguished are risk of collision and barrier effects. Regarding both these effects the results of our study can contribute.

Collisions with turbines take place almost exclusively at night and in twilight (Winkelman 1992a). Most victims occur in nights with strong winds and bad visibility. In calm conditions and good visibility there are no victims (Winkelman 1989, 1992b). In our study a strong effect of the amount of light was found on flight activity of Eiders and Common Scoters: under light conditions flight activity was higher than in dark conditions. This means that in conditions when the risk of collision is high, relatively few birds are flying. Furthermore, less flight activity of Eiders occurred close to the windfarm at night and at dusk. Turn-offs occurred in all situations but especially in light conditions. The smaller number of turn-offs in dark conditions gives reason to believe that this is caused by the visibility of the windfarm. All these factors reduce the risk that Eiders collide with the turbines. It is not possible, however, to estimate the risk of collision based on these results. To do this, measurements of the number of collisions in relation to the total number of flight movements through the windfarm are necessary.

While avoidance behaviour by Eiders reduces the risk of collision, as a consequence the windfarm might become a barrier in the flight path of birds. The result that more birds were flying outside than through the windfarm indicates that both the opening of 200 m and 400 m are too small to leave the flight path unaffected. As a consequence of the windfarm's presence, Eiders changed their flight path. Nocturnal flight intensity was strongly reduced within a distance of 1000-1500 m from the windfarm. This means that the area with a reduced flight activity not only concerned the windfarm itself (800 x 400 m), but also a larger area surrounding it (in total 3400 x 3800 m). The size of the windfarm in this study is most likely not large enough to completely cut off the flight path between feeding and resting areas. In the 'trade-off' of a bird whether or not to fly through the windfarm or make a detour, or to stop using the area altogether, the length of the detour to arrive at the destination will probably play a part. One can imagine that this detour becomes so long near a large windfarm that birds disperse to other areas for feeding or resting (if available). Whether or not this happens will depend strongly on the location of possible alternative feeding and resting areas.

6 Conclusions

6.1 Nocturnal flight movements of Eiders: general

1. Eiders do fly at night, especially with short flights (<1 km) within the feeding area and between feeding and resting areas.

2. In calm weather, massive movements over large distances can take place in early morning, when Eiders congregate at certain sites to display. Strong wind and mist reduce the intensity of this 'morning flight'.

3. Flights occur throughout the night. Activity is largely determined by the amount of light, more than it is affected by time.

4. In dark conditions the nocturnal flight activity is lower than at dusk and (especially) dawn. In moonlit nights the nocturnal activity is three to six times as high, and comparable to activity at dusk.

6.2 Nocturnal flight movements of Common Scoters: general

1. Common Scoters are nocturnally active and fly over short distances within their feeding area.

2. The nocturnal flight activity is more intense in light situations than in darkness.

In both these aspects Common Scoters resemble Eiders.

6.3 Flight movements of Eiders in the vicinity of the windfarm

1. The general rule is: the more light, the more movements. The fewest movements took place in dark nights, while most flight activity was recorded in light circumstances: twilight or moonlit nights.

2. At night and at dusk, flight activity in the direct vicinity of the windfarm is lower than further away from it. This effect is noticeable up to a distance of 1000-1500 m from the turbines and is stronger closer to the turbines. The effect is strongest in moonlit nights and relatively small at dusk. At dawn, no effect of the windfarm on flight movements was noticeable. We tentatively interpret these effects to be the result of active avoidance behaviour by the Eiders, rather than a passive reflection of feeding distribution.

3. More groups of Eiders flew outside the windfarm than through the windfarm. This holds for birds approaching from both parallel and perpendicular directions.

4. Groups approaching the windfarm perpendicularly cross the windfarm less often than birds approaching parallel to the windfarm. This is an indication that Eiders prefer to fly through openings of 400 m than of 200 m. However one must realise that options for birds coming from these two directions were not similar.

5. All groups approaching the windfarm perpendicularly and crossing it, did so through an opening of 200 m. Of all groups that flew parallel to the windfarm and crossed is, 79 % did so through an opening of 400 m.

6. The ratio of flights outside and through the windfarm was similar under different light conditions. This holds for both directions of approach.

7. 7.5% of all parallel movements turned off, 6.5 % of all perpendicular movements did so.

6.4 Consequences for effects of offshore windfarms

The study yielded information on nocturnal flight behaviour of sea ducks in situations with and without turbines. The flight movements in relation to a windfarm are to a large extent in agreement with findings of studies on land and in fresh water lakes. Species that are not used to obstacles in their flight path, do show avoidance behaviour in the dark. For the application of this information on the planning of future windfarms the following conclusions can be drawn:

1. Both Eiders and Common Scoters are nocturnally active, but flight intensity is less in dark periods compared to light periods. The total number of collisions is the product of the number of flight movements and the collision risk. No information is available on the relation between light condition and the collision risk at open sea, while it is known now that flight intensity is less in dark conditions. As a result, the probability of casualties is less in dark nights than it would be if flight activity would be equal to that in light nights. To arrive at an accurate estimate of potential numbers of casualties, measurements of collision risks in different circumstances are needed.

2. Eiders actively avoid the windfarm area and are partly able to correct their flight paths to avoid collision. This phenomenon further reduces collision risk.

3. The area where an effect on the number of flight movements was noticeable ranged up to 1500 outside the windfarm. It is unpredictable whether this area is equally large around a larger windfarm. Possibly this area is equally large, but most likely it will be larger.

4. The reduced flight activity near the windfarm and the low number of flight movements through the windfarm indicate that the windfarm might function as a flight barrier. The severity of this effect will depend on the size of the windfarm. Whether or not this barrier effect will reduce the possibilities to exploit food resources and/or reach resting areas, will depend on the local situation and the size of the windfarm. Especially long line-shaped formations may potentially cause a problem.

6.5 Recommendations for the Near Shore Windfarm

The results are important in decision making on windfarms in the North Sea, although in every new situation a detailed study is needed to be able to apply the results from this study in Denmark. Knowledge on local flight patterns during the night and on the location of resting and feeding areas of sea ducks is essential to evaluate and minimalise risks.

Based on the results presented, the following recommendations are made for decision making on windfarms in the North Sea:

- In the trade-off of Eiders to fly outside or through the windfarm or leave the area and go to a different feeding/resting area altogether different factors are important: the size of the gap between turbines, the length of the detour and the availability of alternative feeding/resting areas. To take sea ducks and other birds that fly between their feeding and resting areas into consideration, possibilities should be created for them to follow their route with as short a detour as possible. Corridors can be created by leaving large gaps between turbine formations. Based on our results the size of these spaces must be several kilometres.
- Long continuous formations perpendicular to the general flight direction of ducks must be avoided, since possibly flight routes are cut off or become unattractive. In the worst case areas can become unsuitable.
- Although locations of shellfish can vary from year to year, the distribution of favourable feeding areas can be taken into account by placing the turbines in the deepest water possible.
- Since locally familiar birds, such as wintering sea ducks are probably familiar with obstacles in their area, the collision risk for this group is smaller than for groups that only pass occasionally. In any case it is recommendable to make the turbines as visible as possible (light colour).
- Since it is hard to predict whether sea ducks will fly through large windfarms we recommend that the surface area of the total windfarm is kept as small as possible. Therefore the distance between turbines within clusters should be minimised.

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