Effects on birds of Offshore Wind farm Egmond aan Zee (OWEZ)

An overview and integration of insights obtained

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Commissioned by: NoordzeeWind

19 June 2012
NoordzeeWind report nr OWEZ_R_233_T1_20120619
Bureau Waardenburg report nr 12-005

Status:	final report
Report nr.:	Bureau Waardenburg 12-005 / NoordzeeWind OWEZ_R_233_T1_20120619
Date of publication:	19 June 2012
Title:	Effects on birds of Offshore Wind farm Egmond aan Zee (OWEZ)
Subtitle:	An overview and integration of insights obtained
Authors:	J.C. Hartman MSc. drs. K.L. Krijgsveld drs. M.J.M. Poot R.C. Fijn MSc. drs. M.F. Leopold drs. S. Dirksen
Pictures cover:	Large picture: K.L. Krijgsveld; OWEZ wind farm Upper small picture: J.D. Buizer; kittiwake Middle small picture: J.D. Buizer; gannet Lower small picture: K.L. Krijgsveld; K14 platform
Number of pages incl. appendices:	146
Project nr:	02-248
Project manager:	drs. K.L. Krijgsveld
Name & address client:	NoordzeeWind, ing. H.J. Kouwenhoven 2e Havenstraat 5B 1976 CE IJmuiden
Reference client:	Framework agreement for the provision of “MEP services” 30 May 2005
Signed for publication:	Director Bureau Waardenburg bv drs. A.J.M. Meijer
Initials:	

The Quality Management System of Bureau Waardenburg bv has been certified by CERTIKED according to ISO 9001:2008.

Preface

‘NoordzeeWind’ (a joint venture of Nuon Duurzame Energie and Shell Wind Energy) has built a wind farm consisting of 36 Vestas V90/3MW wind turbines off the coast of the Netherlands, near Egmond aan Zee. The turbines were built in the summer of 2006 and the site is in operation since January 2007. The main goal of this wind farm is to evaluate the economical, technical, ecological and social effects of offshore wind farms in general. Therefore a Monitoring and Evaluation Program (NSW-MEP) has been developed to gather the knowledge resulting from this project. This knowledge will be made available to all parties involved in the realization of large-scale offshore wind farms. Bureau Waardenburg and IMARES in cooperation have been commissioned to execute both the baseline and the effect study on the effects the wind farm has on flight paths, flight altitudes and flux of local and migrating marine birds as well as non-marine migrating birds.

The bird research in OWEZ, before and after the realization of the wind farm, took place between 2002 and 2010. The research included studies on the effects of the wind farm on local birds (Leopold *et al.* 2011), as well as on flying birds (Krijgsveld *et al.* 2011) and also included an assessment of the cumulative effects of the hypothetical realisation of multiple offshore wind farms in the Dutch North Sea (Poot *et al.* 2011a). Finally, in 2010-2011, the situation at OWEZ was compared to the situation at a location much further offshore, at the gas production platform K14C (Fijn *et al.* 2012).

In the report at hand, the knowledge gathered at OWEZ on the effects of the wind farm on birds is summarised and integrated in order to obtain a comprehensive overview of the current knowledge on potential effects of offshore wind farms on birds. The conclusions presented in this report can be used in the site-selection process for future offshore wind farms, to minimise the potential effects of these wind farms on birds.

The Offshore Wind farm Egmond aan Zee has a subsidy of the Ministry of Economic Affairs under the CO_2 Reduction Scheme of the Netherlands.

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Summary

Study aim

In the report at hand we present a comprehensive overview of the effects of the OWEZ wind farm on birds, in which the various bird tasks within the OWEZ effect research projects are summarised and integrated. The report is largely based on the following studies:

- Leopold *et al.* (2011): occurrence and distribution of local birds at OWEZ;
- Krijgsveld *et al.* (2011): fluxes, flight altitudes and behaviour of flying birds at OWEZ;
- Fijn *et al.* (2012): density and flight altitudes of birds further offshore at the K14C platform;
- Poot *et al.* (2011a): cumulative effects of multiple offshore wind farms on population levels in seabirds.

A summary of the results and conclusions of the aforementioned studies is provided in chapter 2. In the subsequent chapters, this knowledge is integrated and conclusions are presented. In chapter 3 we provide a comparison between two standard visual observation methods that were used in the program to assess abundance of birds.

Bird abundance and species composition

Bird numbers were relatively low in the OWEZ area, due to the location of the wind farm. The area lacks high densities of nearshore species (divers, grebes, seaducks) as well as high densities of offshore species (Northern Fulmar, Kittiwake, auks). By far the most common species group in the area were gulls (Lesser Black-backed Gull, Herring Gull and Common Gull). Distribution of these birds was largely driven by fishing vessels. Of the seabirds, Northern Gannets were most common in the area. Other seabirds such as scoters, divers and alcids were present but in lower numbers. During the migratory seasons, a large array of species of landbirds was seen flying through the area. Most numerous of these were thrushes and small songbirds. Other species include geese, swans, waders, raptors, owls and herons.

Great cormorants were attracted to OWEZ, because the wind farm provided an offshore resting place and good fishing habitat (presented in §2.1). Photo: Hans Verdaat, IMARES.

Avoidance behaviour

Offshore wind farms can evoke avoidance behaviour (both deflection of flight paths around the wind farm, so-called macro-avoidance, and micro-avoidance of birds flying within the wind farm close to turbines) and also disturbance of birds. The result is the same, in that a certain percentage of birds avoid close proximity to wind turbines. The level of avoidance that we measured differed largely between bird species (Leopold *et al.* 2011; Krijgsveld *et al.* 2011).

Of all species observed, the pelagic seabirds such as gannets, seaducks, divers and alcids showed the highest levels of avoidance (figure 1). Concerning the migrant birds, geese, swans and also passerines (in the dark) strongly avoided OWEZ. Many of the migrating passerines however passed the wind farm above turbine height without showing avoidance in horizontal directions. There were also species (especially gulls) that seemed relatively indifferent to the presence of the offshore wind farm, or that were even attracted to it (Great Cormorant).

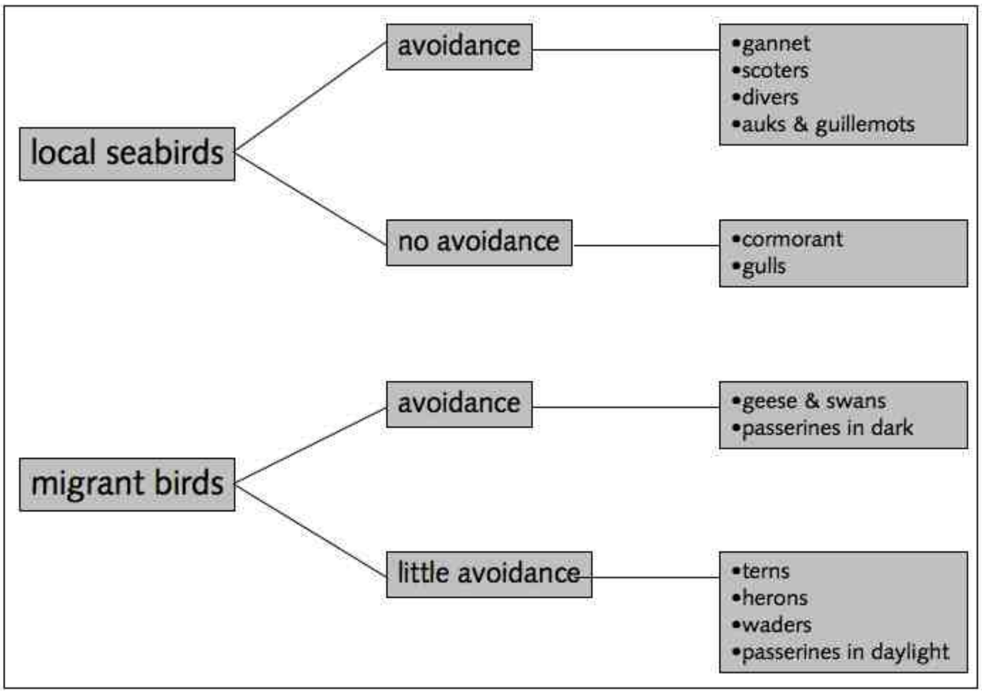

Figure 1 Levels of avoidance of the wind farm of birds flying in the OWEZ area, as observed for the individual bird species (presented in §2.2).

Barrier effects and disturbance
As a consequence, both the results of Leopold *et al.* (2011) and Krijgsveld *et al.* (2011) do not suggest the occurrence of barrier effects or large-scale disturbance from OWEZ, meaning that there was no indication that the presence of OWEZ renders favourable foraging, resting or breeding grounds inaccessible for any bird species. Specific species (groups) avoided passing through the wind farm or avoided foraging inside it, but were still seen at all sides of the wind farm. Disturbance from foraging grounds was shown for alcids, which occurred in the OWEZ area in higher densities, but never 100 %.

On a larger scale than OWEZ however, the realisation of multiple or large-scale offshore wind farms might evoke barrier effects and/or disturbance for seabirds, which strongly avoided the OWEZ wind farm, implicating that areas that are often used by seabirds for foraging or resting may become inaccessible for these species due to offshore wind farms.

Patterns in fluxes and flight altitudes at the Dutch North Sea
To be able to more accurately estimate the location specific collision rate, we assessed differences between different offshore locations in species composition and flight patterns. For this purpose we integrated the available knowledge on species composition, fluxes and flight altitudes, from two nearshore locations (OWEZ and Meetpost Noordwijk) and one location further offshore (K14) in the Dutch North Sea. Several abiotic parameters that influence the distribution of (sea-) birds differed between the nearshore and offshore locations. Examples of these parameters are

distance to the coast, water depth, salinity, turbidity, distribution of fishing vessels and presence of food concentrations. By integrating the available knowledge, we also tried to unravel some general and large-scale patterns in migration routes over the Dutch North Sea.

First of all we concluded that nearshore the relative abundance of gulls and cormorants was larger, while further offshore the relative abundance of more pelagic species such as gannets and alcids was larger. Secondly, the overall flux was higher nearshore compared to further offshore. Autumn migration was much less intense further offshore compared to the region close to the coast, while the intensity of spring migration was comparable between both regions. In general, most flight movements occurred at low altitudes, at least in summer and winter when passerines migrating at high altitudes were absent. The average flight altitude was slightly higher nearshore than further offshore (especially in autumn).

Comparison of panorama scans and ship-surveys

In the effect studies of Leopold *et al.* (2011) and Krijgsveld *et al.* (2011), different visual protocols were applied to assess the effects of OWEZ on birds (ship-based surveys and panorama scans respectively). Comparison of these two standard visual observation protocols is valuable in the light of collision rate modelling. Because of the growing importance of these collision rate models, such as the SNH Band model, it is valuable to gain insight in the possible differences between visual observation methods in the resulting input variables for these models.

Based on the results of the comparison of the two visual observation methods, we concluded that both methods are suitable for detecting all flying bird species commonly present in the area. Regarding the input parameters for collision rate models, panorama scans will provide more reliable estimates for flight altitudes, while ship-based surveys will provide more reliable estimates for densities of flying birds. However, when detailed information is needed on smaller bird species such as passerines, panorama scans offer better opportunities for detecting these birds.

In conclusion, when using either method, observation protocols should be adjusted and additional observations should be carried out to obtain accurate estimates of both flight altitudes and densities. To determine accurate fluxes and flight altitudes, especially of migrating passerines, the use of radar observations is needed because both flux and flight altitudes of these smaller species are severely underestimated with both visual observation methods, as due to the fact that these birds pass at distances or altitudes beyond the visual range or at night.

Collision rates

The species- and location-specific collision rate is largely determined by three bird-related factors, which are flux, flight altitude and avoidance behaviour. These three factors are partly related, because avoidance of wind farms or individual turbines can be effected by changing flight altitude, and because an increased macro-avoidance rate lowers the flux through wind farms.

Table 1 *Species-specific flux and estimated annual number of collision victims in the OWEZ wind farm. Given are: proportional presence of species in the wind farm area as observed in panorama scans; species-specific flux in the wind farm area at rotor height, based on the measured overall flux of 1,866,000 bird groups; macro-avoidance as calculated from flight paths or otherwise average as calculated from horizontal radar data (0.28); altitude adjustments (proportion not at rotor height) based on observed flight altitudes in the wind farm area; flux through the wind farm after correction for macro-avoidance and flight altitudes; crude estimate of the number of collision victims per year, based either on a collision risk of 0.14% as measured on land, or using the Band model (as calculated in Poot et al. 2011a). Fluxes rounded of to nearest decimal (presented in §2.2).*

Species	**prop.**	**flux**	**macro**	**prop. not**	**flux**	**estimated nr, of victims**	
-group	**of birds**	**in area**	**-avoid.**	**@rotor**	**corr.**	**risk 0.14%**	**Band**
divers	0.06	1,130	0.68	0	360	0.5	0.2
grebes	0.00	50	0.28	0.98	1	0.0	0.0
tubenoses	0.03	540	0.28	0.5	200	0.3	0.0
gannets	0.92	17,160	0.64	0	6,090	8.5	1.6
cormorants	4.20	78,430	0.18	0.5	32,160	45.0	30.2
geese & swans	0.35	6,500	0.68	0.5	1,040	1.5	0.9
seaducks	0.41	7,590	0.71	0	2,170	3.0	0.1
other ducks	0.19	3,520	0.28	0.5	1,270	1.8	0.6
raptors & owls	0.02	360	0.28	0	260	0.4	0.1
waders	0.12	2,300	0.28	0	1,660	2.3	0.4
skuas	0.00	90	0.28	0	70	0.1	0.1
gulls	32.75	611,120	0.18	0	501,120	701.6	234.3
terns	0.57	10,660	0.28	0	7,670	10.7	2.9
alcids	0.38	7000	0.68	0.98	50	0.1	0.0
passerines	60.00	1,119,600	0.28	0.5	403,050	564.3	309.9
total in OWEZ / year					957,160	1,340	581
est. nr of victims / wind turbine / year						37	16

Regarding flux, we have shown that further offshore the overall flux was lower compared to the region closer to the coast. This would translate into a lower collision rate further offshore. In general, most flight movements occurred in the lowest altitude band of 0-69 m, at least in summer and winter when local birds defined the species spectrum. This means that altogether many birds flew at turbine height and therefore were at risk of collision. As avoidance behaviour was strongest in pelagic bird species and specifically these species were relatively more abundant further offshore, the overall collision rate at a larger distance from the coast is probably lower. Birds that did not avoid wind farms (gulls) or were even attracted to it (cormorants), and as a result had an increased collision risk, were more abundant nearshore. However, if we consider the possible impact of collision mortality on populations, the collision of a few seabirds further offshore might have a higher impact on the population level than the collision of a larger number of gulls nearshore. Seabirds such as gannets and divers are mostly long-lived species and therefore sooner experience an impact on the population level (Poot *et al.* 2011a).

Cumulative effects in relation to distance from the coast

The first attempt to estimate cumulative effects of multiple offshore wind farms in a part of the North Sea on the population level for a range of bird species, was made by Poot *et al.* (2011a). By using and extrapolating the knowledge derived from OWEZ, they calculated that for most species a tenfold extrapolation of the effects of a wind farm of the size and shape of OWEZ, would not lead to effects at levels at which serious negative impacts with decreasing population trends occur. They also concluded that their impact assessment could be improved with the results from studies further offshore (At the time of writing, the results from the study on bird flight patterns further offshore were not available). In addition they stated that, because of the precautionary assumptions in different aspects that they had to make, future research at locations further offshore would probably yield results that would confirm that in their report a worst-case approach was followed.

Results from the subsequent study on fluxes and flight altitudes carried out further offshore at gas platform K14, showed that fluxes were lower compared to the OWEZ area. These results indicate that further offshore overall fluxes are lower compared to the coastal region. This would lead to a lower collision rate further offshore and also underlines that Poot *et al.* (2011a) followed a worst-case approach by directly extrapolating the higher fluxes that were measured at OWEZ to the offshore situation (at larger distance from the coast). As a result, the conclusion of Poot *et al.* (2011a; see above) on the lack of negative impacts on population levels is maintained and strengthened.

In conclusion

In conclusion, our studies on the effects of the OWEZ offshore wind farm on birds show that collision risks were limited, no large-scale disturbance occurred, and barrier effects were absent (figure 2). Avoidance levels were high however, in particular for pelagic seabird species, which on the one hand decreases collision risks, but on the other hand increases risks of barrier effects and disturbance when wind farms larger than OWEZ are built offshore. Although estimates of offshore collision rates can be made by means of determining fluxes and modelling collision risks, actual collision rates offshore will remain unknown until they can be measured.

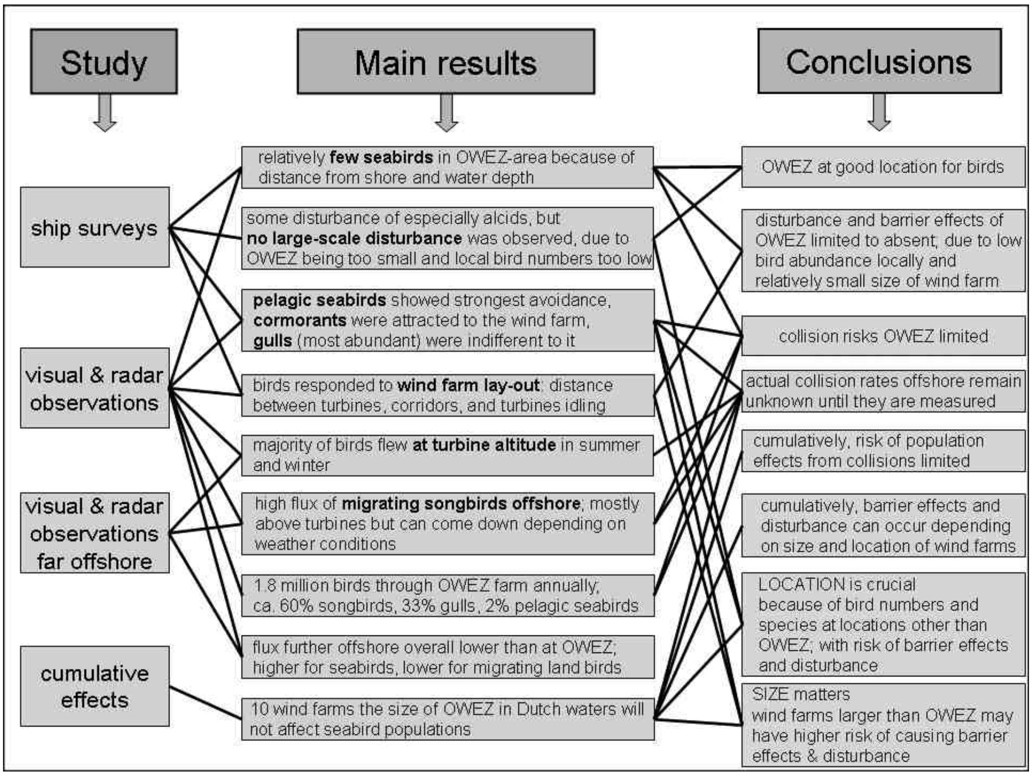

Figure 2 *Flow chart showing the main results (middle) from the four studies that were carried out (left) and the implications for birds both of OWEZ and of offshore wind farms in general (right).*

1 Introduction

1.1 Framework

Wind power is one of the most important and promising forms of renewable energy, and significant growth is projected for the coming years. Offshore wind farms are an attractive alternative to onshore wind turbines, especially in densely populated countries such as the Netherlands. Benefits of offshore wind farms are of economical and environmental nature. Increasing the amount of sustainable energy can go some way to mitigate the effects of global climate change. Drawbacks of offshore wind farms generally heard from the public are effects on the surroundings such as visual pollution, noise emission and impact on the natural environment.

The Dutch government supported the construction of the first offshore wind farm in the Netherlands: ‘Offshore Wind Farm Egmond aan Zee’ (OWEZ). The wind farm is operated by the Dutch consortium “NoordzeeWind” (a joint venture of Nuon and Shell Wind Energy). This wind farm served as a demonstration project to build up knowledge and experience with the construction and exploitation of large-scale offshore wind farms. In order to collect this knowledge, an extensive Monitoring and Evaluation Program (NSW-MEP) has been designed under supervision of the Ministry of Water & Transport, in which the economical, technical, ecological and social effects of the wind farm were gathered. Carrying out this MEP served ‘learning goals’ for future wind farms further offshore as well as ‘effect assessment goals’ for the nearshore wind farm itself.

Within this framework, baseline and effect studies were carried out to measure the impacts of the wind farm on birds. These studies were reported in various reports.

Here we summarise these reports. We present our main findings, as well as how we set about collecting data. Additionally, we integrated the results to yield a complete picture of the effects of OWEZ on birds.

Offshore Wind Farm Egmond aan Zee

The Offshore Wind Farm Egmond aan Zee consists of 36 Vestas V90/3MW wind turbines and is located 10 – 18 kilometres off the coast of Egmond aan Zee. The turbines are placed on monopiles, have a hub height of 70 m above mean sea level (amsl) and contain three rotor blades reaching up to 115 m amsl. The turbines are not illuminated. OWEZ was constructed in 2006 and produced its first electricity in September 2006. The wind farm was commissioned in January 2007. The OWEZ turbines are situated in an area of approximately 27 km^2 and can yield energy for as many as 100,000 households. The design of the wind farm is relatively open and aims to take maximum advantage of prevailing southwesterly winds. The turbines are placed in four rows that are 1,000 m apart. The inter-turbine distance in each row is 640 m. OWEZ is built just east of the -20 m isobath at a depth of 18-20 m.

1.2 Scope

This report aims at presenting an overview of studies carried out and of the results obtained in the various bird tasks within the OWEZ effect research project. By combining and integrating the results of the different bird tasks, we draw general conclusions on the effects of OWEZ on birds. Additionally we discuss the lessons learnt in relation to the research strategies and methods.

In the report at hand we summarise and integrate the following studies:
- Leopold *et al.* (2011): occurrence and distribution of local birds at OWEZ;
- Krijgsveld *et al.* (2011): fluxes, flight altitudes and behaviour of flying birds at OWEZ;
- Fijn *et al.* (2012): density and flight altitudes of birds further offshore at the K14C platform;
- Poot *et al.* (2011a): cumulative effects of multiple offshore wind farms on population levels in seabirds.

OWEZ wind farm. Photo: Karen Krijgsveld.

1.3 OWEZ area in relation to birds

The Offshore Wind farm Egmond aan Zee is situated away from recognised seabird hotspots and other sites of special ecological interest (Lindeboom *et al.* 2005; Skov *et al.* 2007; Poot *et al.* 2010). However, a large variety of birds can still be found in and around the wind farm area. For instance seabirds, such as Common Scoter, Red-throated Diver or Northern Gannet, are found foraging or resting in this region in considerable numbers during specific periods of the year. The site is within reach of some birds breeding on the Dutch shores, such as Great Cormorants or Lesser Black-backed Gulls, making foraging trips out at sea. Many seabirds also migrate along the coastline, and the wind farm is situated within this migration route. Last but not least, large numbers of land birds migrate twice a year from their wintering to their breeding grounds and *vice versa* over the North Sea. This includes migration to and from Britain and Ireland as well as migration to and from southern Europe, Africa, Scandinavia and other northern regions. A large number of species is concerned, including for instance passerines such as Skylark, Meadow Pipit, Starling and Redwing, but also herons, raptors, shorebirds, ducks, geese and swans.

1.4 Effects of offshore wind farms on birds

The NSW-MEP required research to enable an analysis of three types of possibly negative effects on birds, which we define as follows:

- **Collision** of flying birds – being the birds that physically collide with the turbines or that are mortally injured by encounters with the air vortices associated with the revolving blades;
- **Disturbance** – being displacement of the spatial arrangement of resting and/or feeding birds caused by the presence of the turbines, represented by differences in bird distributions between the baseline pre-construction condition and those post-construction (typically a reduction in numbers of birds);
- **Barrier effects** – being the changes in flight trajectories within and around the construction area following erection of turbines (in terms of flight paths) relative to pre-construction conditions.

The ultimate effects of these three themes; collisions, disturbance and barrier effects, can have their impacts through different ecological pathways. Collision has a direct impact on the survival of birds. Disturbance (or attraction) and barrier effects may be translated into the fitness of a species by a cascade of steps; e.g. ecological and energetic effects follow physical effects before being transformed into fitness consequences. Furthermore, the three factors can interact. Birds avoiding a wind farm (disturbance) have a lower risk of collision than birds being ignorant to or attracted by the turbines. Avoidance leading to a prolonged flight (barrier effect) lowers the risk on collision but might render areas used for foraging or resting out of reach.

1.5 Bird research at or related to OWEZ

The study on the impact of the wind farm followed a Before-After-Control-Impact (BACI) design and therefore included both baseline (pre-construction) and effect studies (post-construction). However, due to large differences between years, the comparison of data of the periods before and after realisation of the wind farm was hampered. Therefore most analyses mainly focussed on differences within years between areas inside and outside the wind farm (control and impact), which proved to be an effective way to study the effects of an existing wind farm on the bird community. The bird research for OWEZ consisted of:

- transect studies in and around OWEZ to analyse the distribution and density of seabirds before and after construction;
- radar studies to analyse fluxes, flight altitudes and flight paths of birds during day and night;
- visual observations and flight call recordings to detect movements of passage migrants and foraging birds including avoidance behaviour.

Two turbines of the Offshore Wind farm Egmond aan Zee. Photo: Martin Poot.

Baseline study

In 2002-2004 prior to the construction of OWEZ, the 'reference situation' has been established. The baseline study on the occurrence and distribution of 'local' seabirds is presented in Leopold *et al.* (2004). For flying birds, the results of the baseline study are reported in Krijgsveld *et al.* (2005) and Dirksen *et al.* (2005). Krijgsveld *et al.*

(2005) describe fluxes, flight altitudes and flight paths as they were measured at Meetpost Noordwijk, approximately 40 km south of the OWEZ area, using both radar and a range of visual observation techniques. Dirksen *et al.* (2005) specifically studied the nocturnal movements and flight altitudes of Common Scoters.

Effect study

With the wind farm constructed and operational, the effects of OWEZ on birds were studied from 2007 till 2010. The effects of the wind farm on the occurrence and distribution of 'local' birds are described in Leopold *et al.* (2011). Krijgsveld *et al.* (2011) describe the effects of OWEZ on fluxes, flight altitudes and behaviour of flying birds.

Cumulative effects

A third module of research was carried out, in which the effects of OWEZ as described by Leopold *et al.* (2011) and Krijgsveld *et al.* (2011) were used to estimate the cumulative effects of multiple offshore wind farms on population levels in seabirds. The results of this study are described in Poot *et al.* (2011a).

Flight patterns far offshore

Apart from the research in OWEZ, another study of interest, jointly commissioned by NoordzeeWind and We@Sea, was carried out at the K14C platform of the 'Nederlandse Aardolie Maatschappij' (NAM) (Fijn *et al.* 2012). We@Sea is a combined effort of public and private interests towards realising the desired transition to new offshore wind energy business. The platform is situated approximately 80 km west-northwest of the Dutch coast and 140 km off the coast of England. The aim of the study performed at K14C was to investigate the densities and flight altitudes of flying birds far offshore. This knowledge is very relevant for new offshore wind farms, which are mainly planned (much) further from the coast than OWEZ. By combining the results from OWEZ and K14C, insight into bird fluxes along a gradient perpendicular to the Dutch coast can be gained.

1.6 Outline of chapters

In **chapter 2** an overview of the results of the individual studies involved is given. A comparison of applied methods and how this reflects in the results that were obtained, is made in **chapter 3**. In **chapter 4** the results obtained in the various bird related studies are integrated, to obtain an overall insight in effects of OWEZ on birds. For example, the results that were obtained at the different locations (Meetpost Noordwijk, OWEZ and K14C) are interpreted here in the broader context of general flight patterns of birds migrating between their breeding and wintering grounds. **Chapter 5** contains the final conclusions and recommendations. A brief **glossary** of the relevant terminology is given in appendix 1.

2 Overview of bird studies and main results

In this chapter a comprehensive overview is presented of the four bird studies that were carried out and of the results that were obtained. This overview serves as a complete summary of all the bird research in OWEZ. This is also the basis for the integration of data and conclusions (chapter 4). For further details we refer to the original reports of these studies, listed in chapter 1.

The four bird studies were carried out to determine what the effects of OWEZ are on birds. Possible effects of wind farms on birds are displacement and disturbance, barrier effects, collisions, as well as cumulative effects. Any such effects will become apparent in changes in bird numbers and distribution, in flight patterns of birds such as fluxes, flight altitudes and flight paths, and on the level of bird populations. To determine whether such effects occurred, we carried out ship-based surveys to determine numbers and distribution of local seabirds, we carried out a combination of radar and visual observations to determine bird flight patterns both at OWEZ and at a location further offshore at the NAM gas platform K14, and we modelled cumulative effects of multiple offshore wind farms on bird populations based on the results obtained. The set-up of the program is visualised in the flow chart below (figure 2.1).

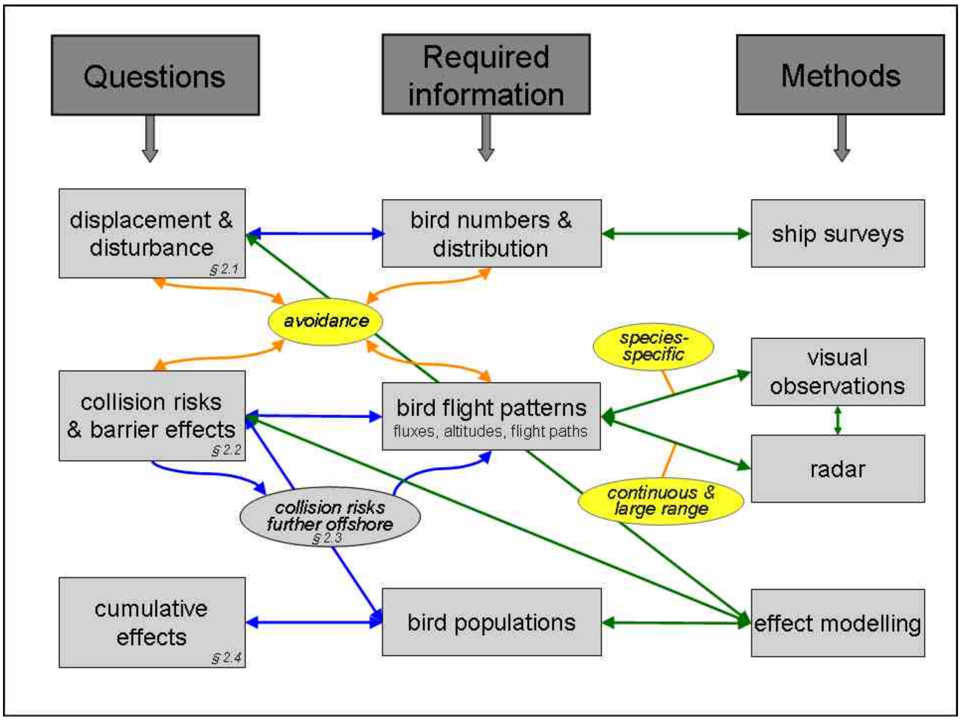

Figure 2.1 *Flow chart of the study questions (left), the information needed to answer these questions (middle) and the methods used to obtain the required information (right). Lines indicate relations between questions, information needed and methods. Yellow circles give additional information, grey circle indicates sub-question.*

2.1 Abundance and disturbance of local seabirds

In this paragraph we summarise the effects (in the form of disturbance / habitat loss) of OWEZ on local seabirds. The results of this study are presented in Leopold *et al.* (2011). The results of the associated baseline study are presented in Leopold *et al.* (2004).

2.1.1 Introduction

The study focussed on the distribution patterns of so-called local seabirds in and around OWEZ. Local seabirds may avoid foraging in or passing through offshore wind farms, but may also respond differently. They may use vantage points within the wind farm for resting or (while swimming) may drift into the wind farm and e.g. continue feeding within its perimeter. They may also use changed hydrography (turbid water at the lee sides of the turbines) or seabed morphology (boulders supplied around the base of the turbines) for feeding. The aim of this study was to determine whether local seabirds would be disturbed by the presence of OWEZ. The study was confined to seabirds, but both local and migrating seabirds were included.

2.1.2 Methodology

Study area

The study was conducted in and also widely around Offshore Wind farm Egmond aan Zee in an area of approximately 725 km^2 (*circa* 22 x 33 km; figure 2.2). Within this area a second offshore wind farm, called the ‘Prinses Amalia Wind Park’ (PAWP), was constructed shortly after OWEZ became operational (For details see Leopold *et al.* 2011). This wind farm has a smaller total surface area (14 km^2) compared to OWEZ, but nearly twice the number of turbines (60). This makes OWEZ a much more ‘open’ wind farm. Distances between turbines in PAWP are approximately 550 m in all directions. A third anomaly situated within the study area was an intensively used anchorage area (southwest of OWEZ), where ships destined for IJmuiden port wait to enter. Within the general study area, seabirds thus had a choice to go into OWEZ, PAWP or the anchorage area, or to stay out of these areas in the remaining, open sea.

Surveys

In 2002-2004, before any turbines were in place, a T-0 study consisting of eight complete ship-based surveys was carried out (Leopold *et al.* 2004). After construction of OWEZ the effect study T-1 was conducted, in which 17 surveys were carried out. During each survey, ten equidistant transect lines (2.47 km apart), running from east to west over the full width of the study area, were sailed (figure 2.2). The T-1 surveys were carried out in three clusters of six surveys each: T-1a from April 2007 to January 2008; T-1b from April 2008 to January 2009 and T-1c from June 2009 to April 2010. Due to bad weather one of the T-1 surveys (September 2008) had to be cancelled. The T-1 surveys were timed to match the T-0 surveys, but with only six T-1 surveys (per cluster) against eight T-0 surveys, full matching was not possible.

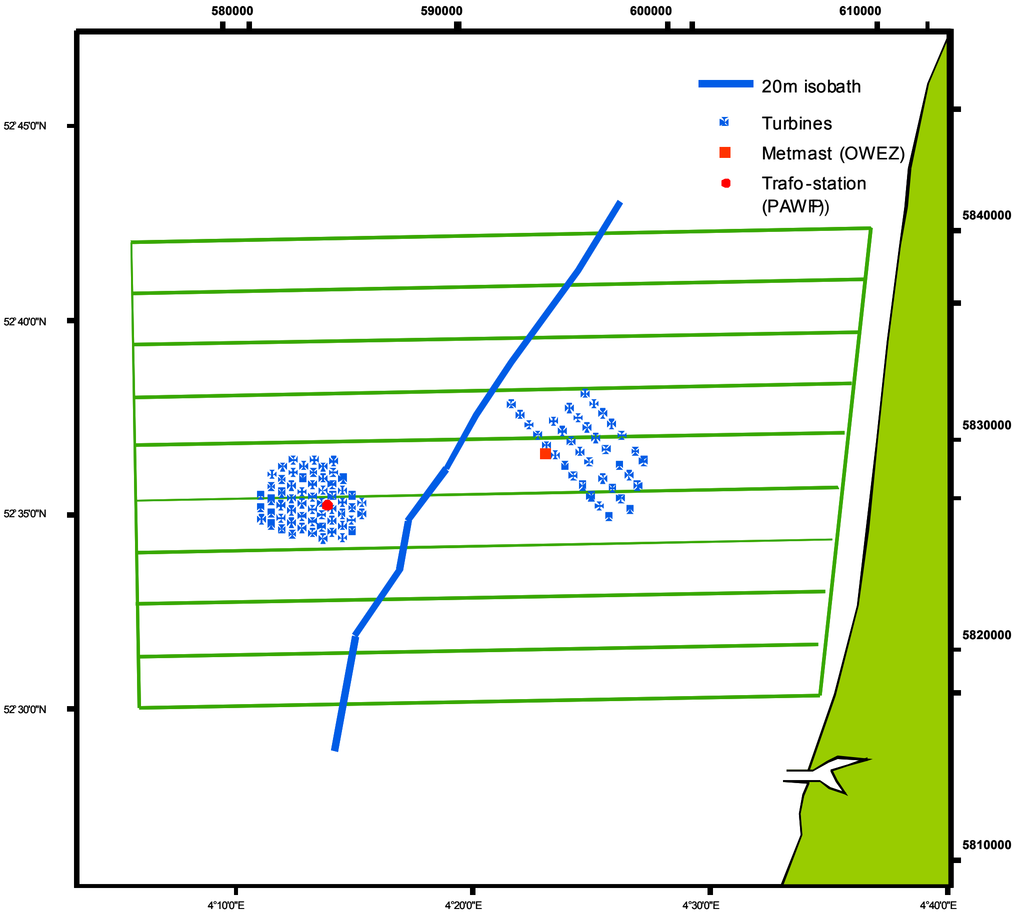

Figure 2.2 Location of OWEZ with 36 turbines and PAWP with 60 turbines, to the northwest of the port of IJmuiden. The two wind farms are situated on either side of the -20 m isobath (blue thick line). In addition to the turbines, OWEZ has a 116 m high met(meteo)mast situated on the seaward side of the wind farm, and PAWP has a transformer platform within the wind farm (both indicated by red symbols). The green lines running east-west are the principal survey lines.

If time allowed, all transects were sailed twice during a full survey. Transect orientation was deliberately chosen to be perpendicular to the main physical and ecological parameters by which seabird distributions are highly influenced, such as distance from the coast, water depth, temperature and salinity. This was meant to facilitate later spatial modelling of the results. In all years surveys were scheduled in such a way that they covered the entire yearly seabirds' calendar; e.g. mid-winter, spring migration, breeding/chick-phase, dispersal of juveniles, autumn migration and onset of winter. The area surveyed (within the standard survey area) differed between surveys, mainly in response to the amount of daylight within the survey weeks, and weather conditions. However, all ten principal survey lines were always covered at least once, in each survey. After two sets of T-1 surveys (T-1a and T-1b) it became clear that too little time and effort was spent within the wind farms themselves. It was therefore decided to add eight extra transects through the wind farms (four through each wind farm). Because these transects were meant to highlight wind farm effects, their orientation was along presumed seabird density gradients (parallel to the isobaths) (figure 2.3).

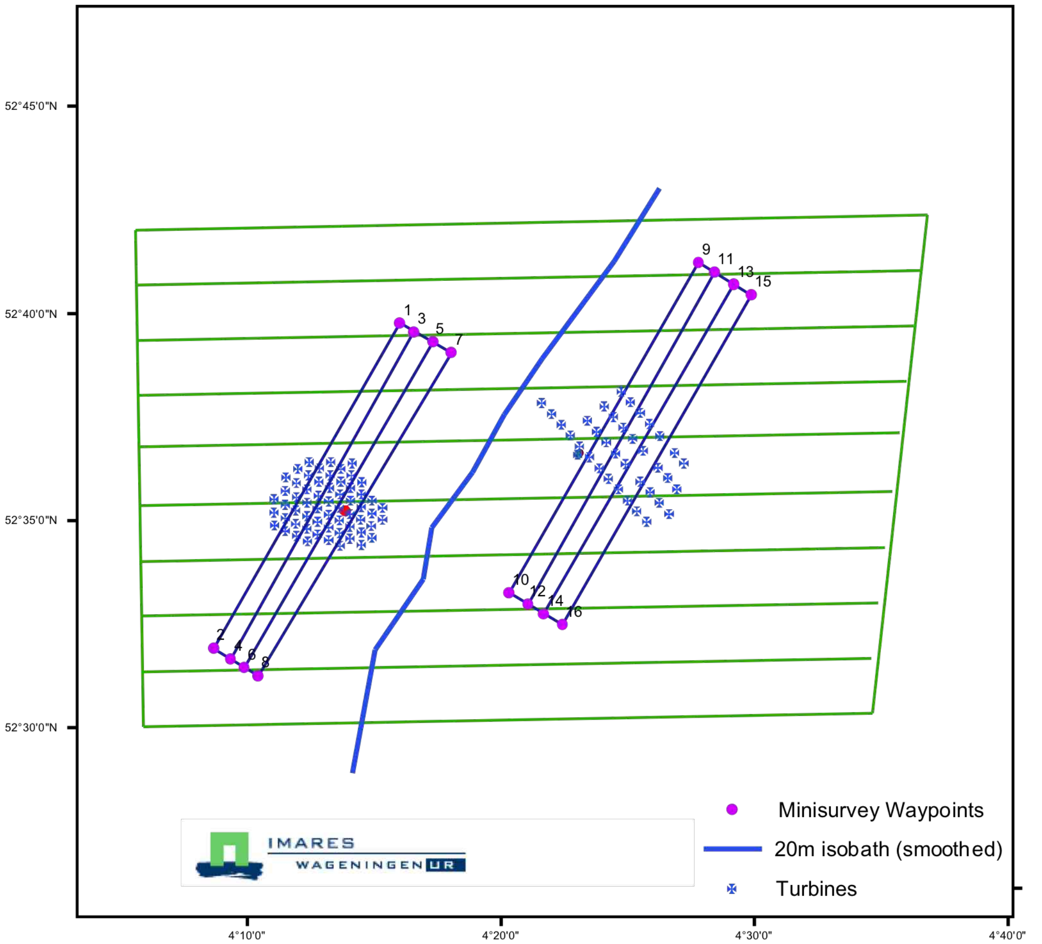

Figure 2.3 The ten principal survey lines (in green, running E-W) and the eight extra lines through the two wind farms, running parallel to the 20 m isobath, surveyed during T-1c.

Counts were carried out following standard ESAS protocol. In brief, on each transect counts were done simultaneously in two parallel strips, each 300 m wide, at both sides of the ship. Counts were done by two separate teams of two observers. Although considerable amounts of seabirds were also seen beyond the 300 m limits, only birds seen 'in transect' were used to determine bird densities and subsequently used for modelling purposes. Transect lines were separated into five minute (time) stretches and birds seen in each individual five minute count were pooled.

Data analysis and statistics
Possible impacts of OWEZ (in the sense of disturbance) on local birds were identified at two ways. First, differences in distribution patterns between the T-0 and T-1 situation could be present. Second, within T-1 surveys, the abundance of birds at the location of OWEZ could differ from the abundance of birds in the area surrounding OWEZ. Therefore always sets of surveys were considered based on the time of year, and comparisons of distribution patterns were made between surveys in different years and within surveys.

Seabird distributions are notoriously patchy, both in time and in space. At-sea seabird counts usually contain many zero values, with some positive counts intermingled, which makes statistical analyses difficult. Large-scale variation in occurrence is usually easy to spot. However, because seabirds are highly mobile, fine-scale variation is often not discernable from noise in the data. Therefore, it should be noted that variation at the spatial level of an offshore wind farm, was difficult to quantify.

Within the study area, there are three anomalies: OWEZ, PAWP and the anchorage area. All three areas were included in modelling and analyses, because all could contribute equally to bird distribution patterns. The bird distribution modelling was confined to using presence/absence data. This approach often has greater predictive ability than presence-only approaches, is less susceptible to large numbers of counts with no birds and less sensitive to errors with determining exact densities. Either GAMMs (Generalised Additive Mixed Models) or GAMs (Generalised Additive Models) were used to model bird distribution, depending on completeness of data. For a full description of the statistical analyses techniques used, we refer to Leopold *et al.* (2011).

2.1.3 Results on abundance and distribution of local birds

Different results were found for different seabird species (table 2.1). **Little impact** of the wind farm on most of the so-called **nearshore species** was found, as these birds rarely ventured out so far to sea, that they would reach OWEZ latitudes. This group comprises the Red- and Black-throated Divers (figure 2.4), Great Crested Grebe, Common Scoter (figure 2.5), Black-headed Gull and "Commic" Terns (Common and Arctic Terns taken together as these could not always be specifically identified) (figure 2.6). Densities of all these birds at wind farm longitudes were mostly very low, as a result of which only few individuals were available to fly or swim into the wind farm.

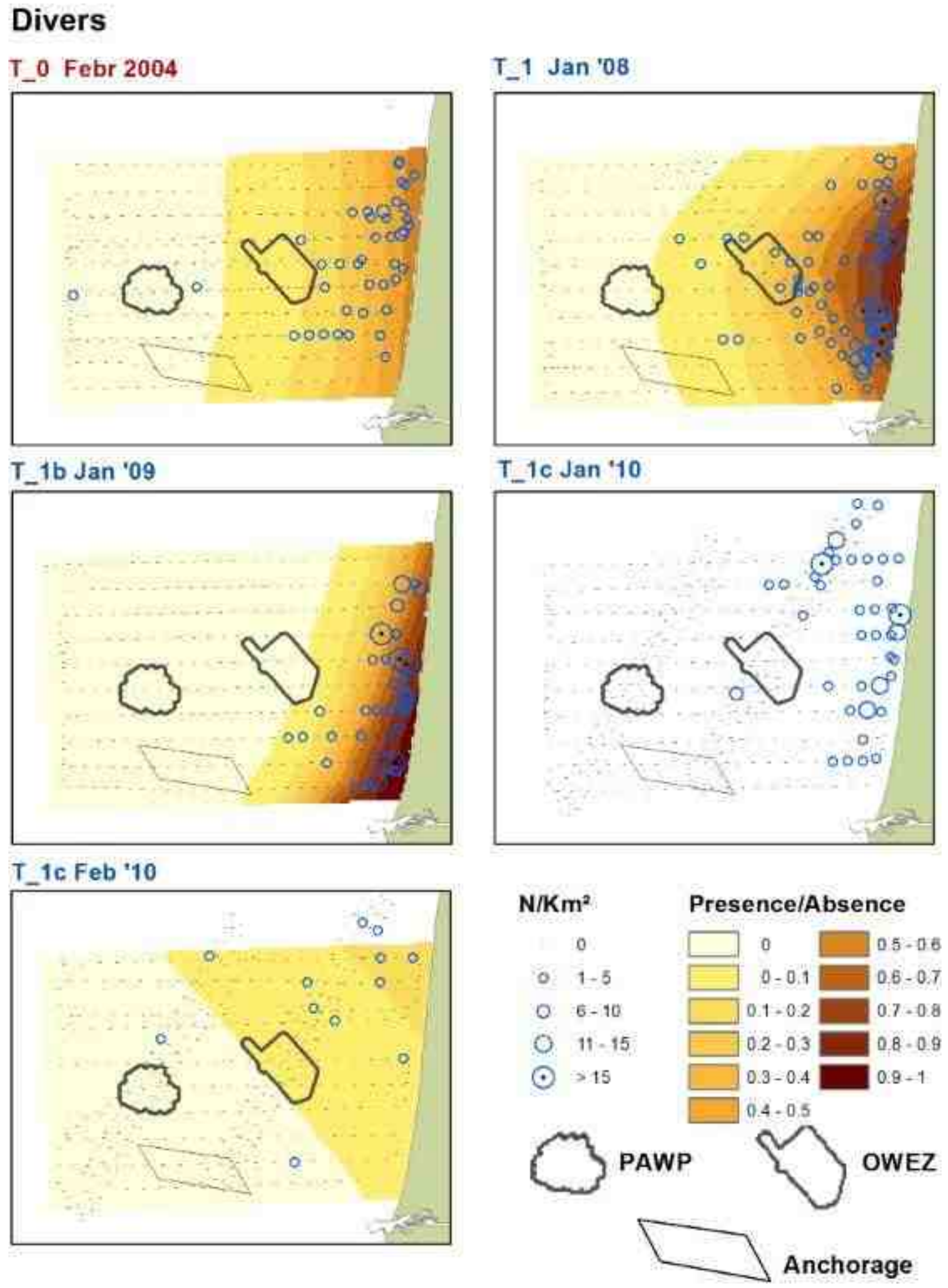

Figure 2.4 *Distribution maps of divers, for February and January. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without divers indicated by -. The background colours, from white (no model output), via light-yellow (zero probability of occurrence) to dark brown (very high probability of occurrence) give modelled probabilities of seabird presence (see Leopold et al. 2011 for statistical methods used). Circles give point estimates of densities, taken directly from the counts at sea.*

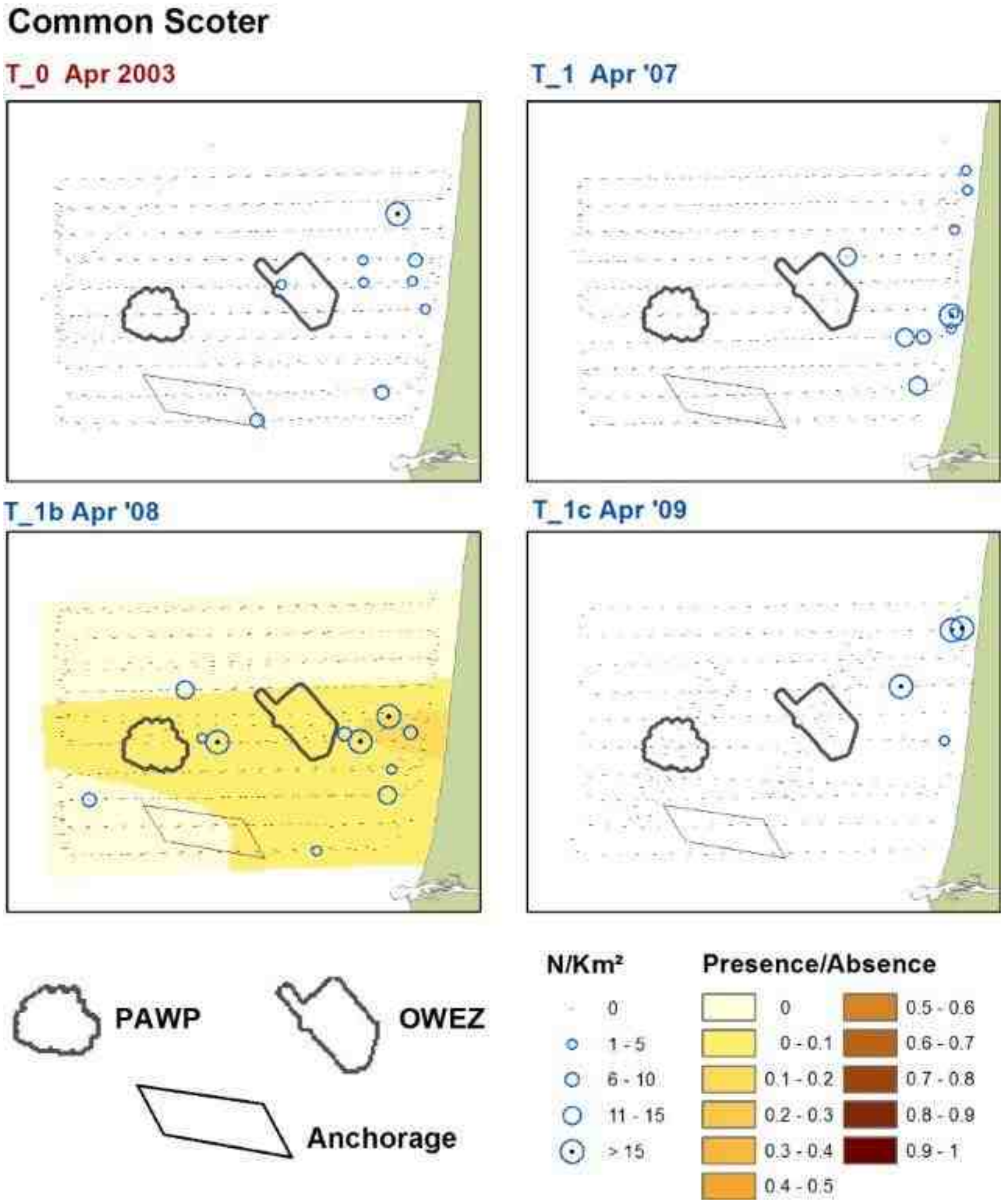

Figure 2.5 Distribution maps of Common Scoter for April. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without Scoters indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours.

Common Tern off the Dutch coast, summer 2006. Photo: Hans Verdaat, IMARES.

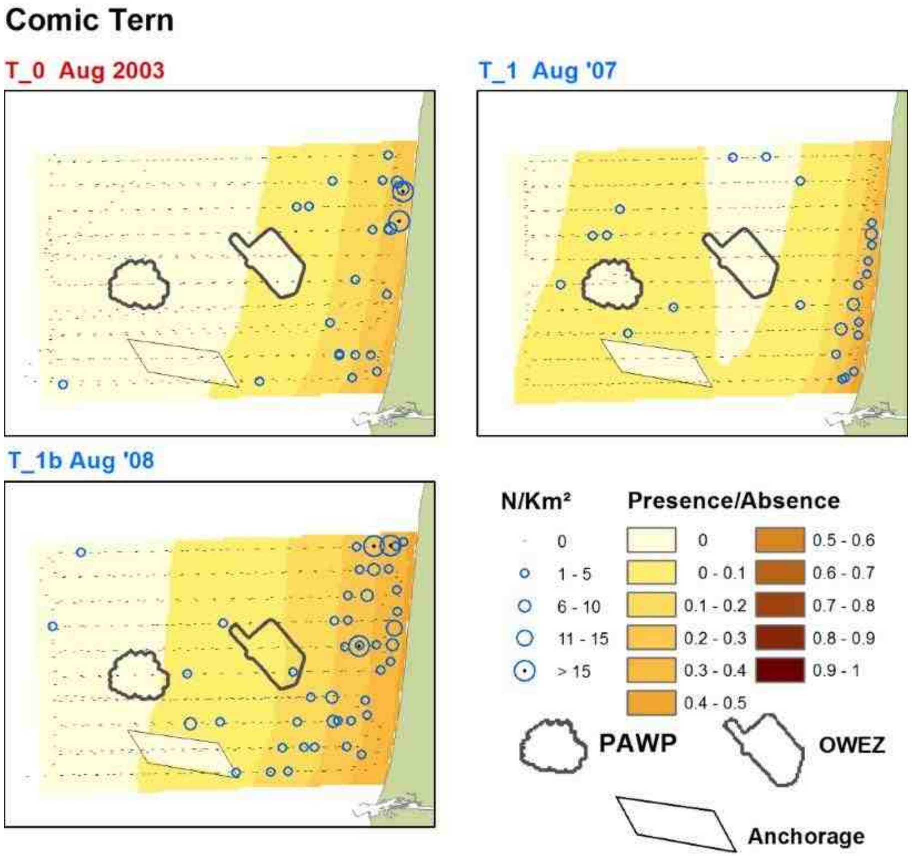

Figure 2.6 Distribution maps of 'Common' Terns, for August. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without 'Common' Terns indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours.

A similar, but mirrored pattern was found in **species that mostly occur further offshore**, to the west of OWEZ. Densities of Northern Fulmars were always low around OWEZ, most of these occurred further offshore. None were ever seen to enter the wind farm, but ecological consequences of the loss of a small surface area of sea at the fringe of its huge range, must be **negligible**. Two other bird species that tended to occur mostly further offshore, showed different reactions to the wind farm. **Northern Gannets** tended to **fly around** the wind farm (figure 2.7), while Kittiwakes seemed mostly indifferent to the wind farm (figure 2.8).

Northern Gannet, taking a close look at the seabird observers, January 2010. Photo: Hans Verdaat, IMARES.

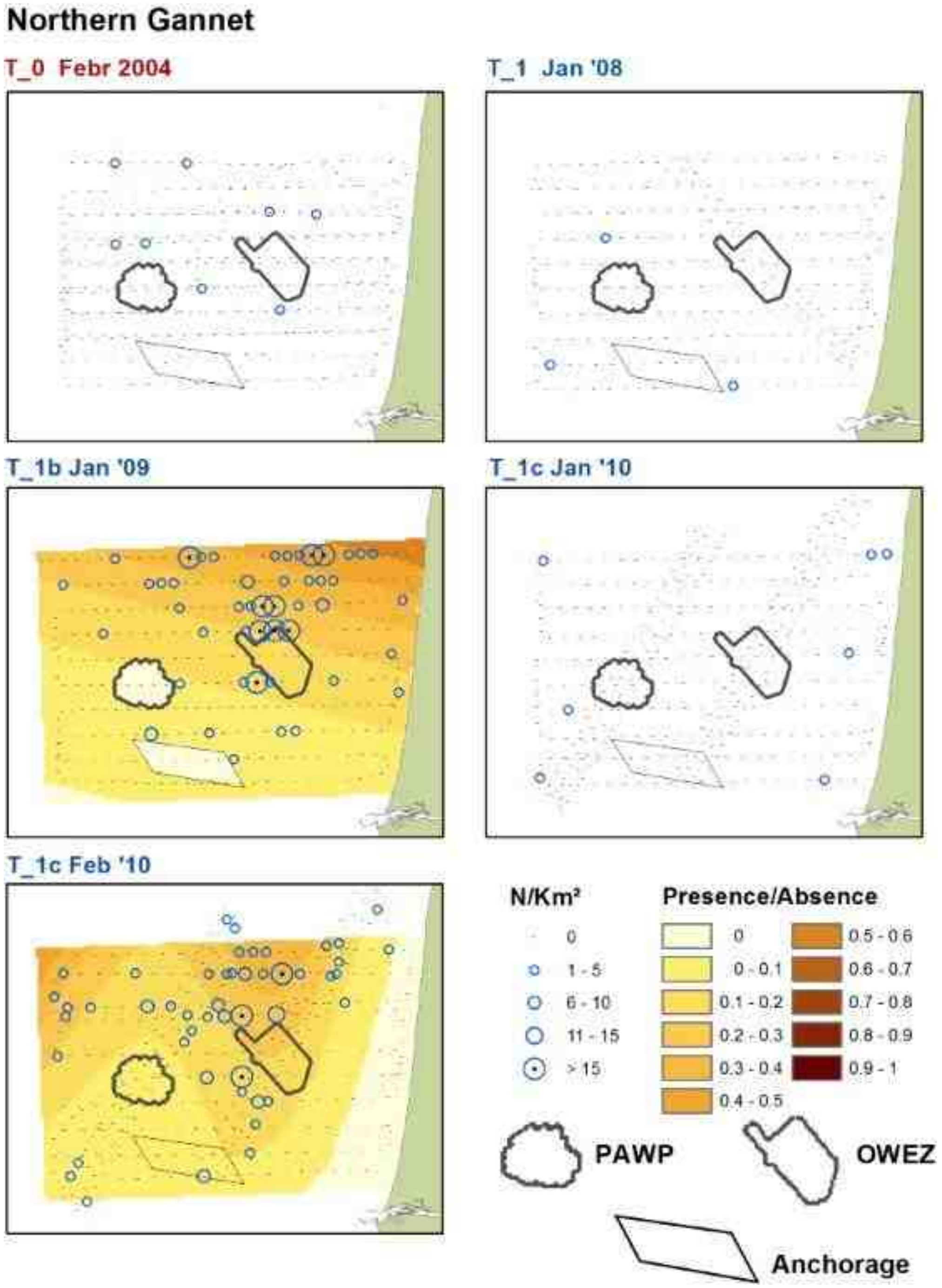

Figure 2.7 *Distribution maps of Northern Gannets for January and February. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without Gannets indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours. Low numbers of observations in three of these surveys made statistical modelling of probabilities of occurrence impossible (backgrounds white). The wind farms and the Anchorage area were used as an additional factor in the models. This resulted in lower modelled probabilities of occurrence in PAWP and in the Anchorage area for January 2009.*

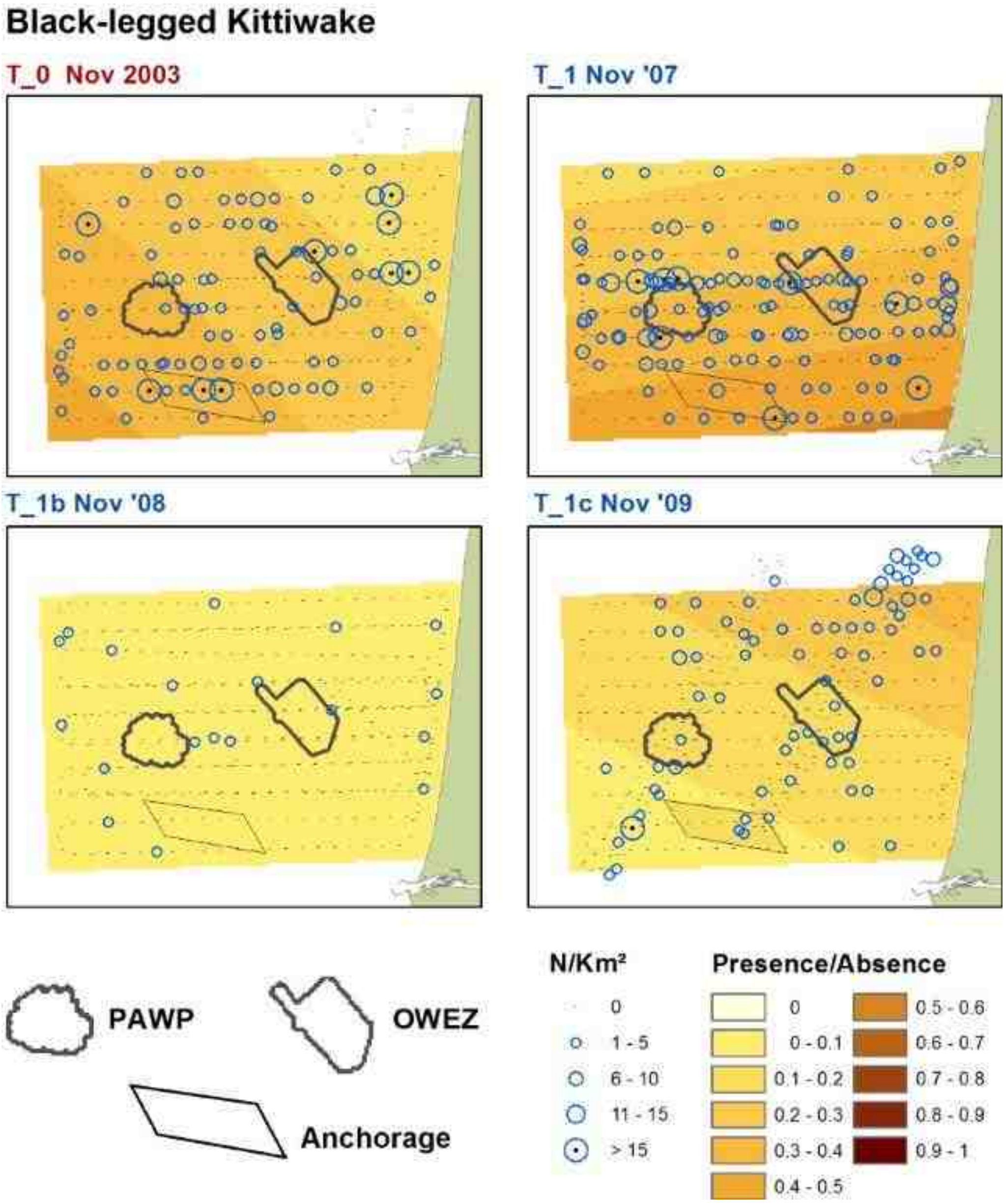

Figure 2.8 *Distribution maps of Kittiwakes for November. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without Kittiwakes indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours.*

Large gulls, the most numerous seabirds in the general area, were mostly found associated with fishing vessels (see also Krijgsveld *et al.* 2005). As fishing is not allowed in the wind farms, gull numbers were never very high here. Large gull distributions were always very patchy around the wind farm, as most gulls go where the fishers go. Most large gulls seemed rather **unconcerned** about the presence of offshore turbines (figure 2.9).

Gull density was largely dependent on the availability of discards from fishing vessels. Fishing was not allowed in the wind farm, and all large gull flocks were found outside the wind farm during T-1 (photo: Hans Verdaat, April 2007).

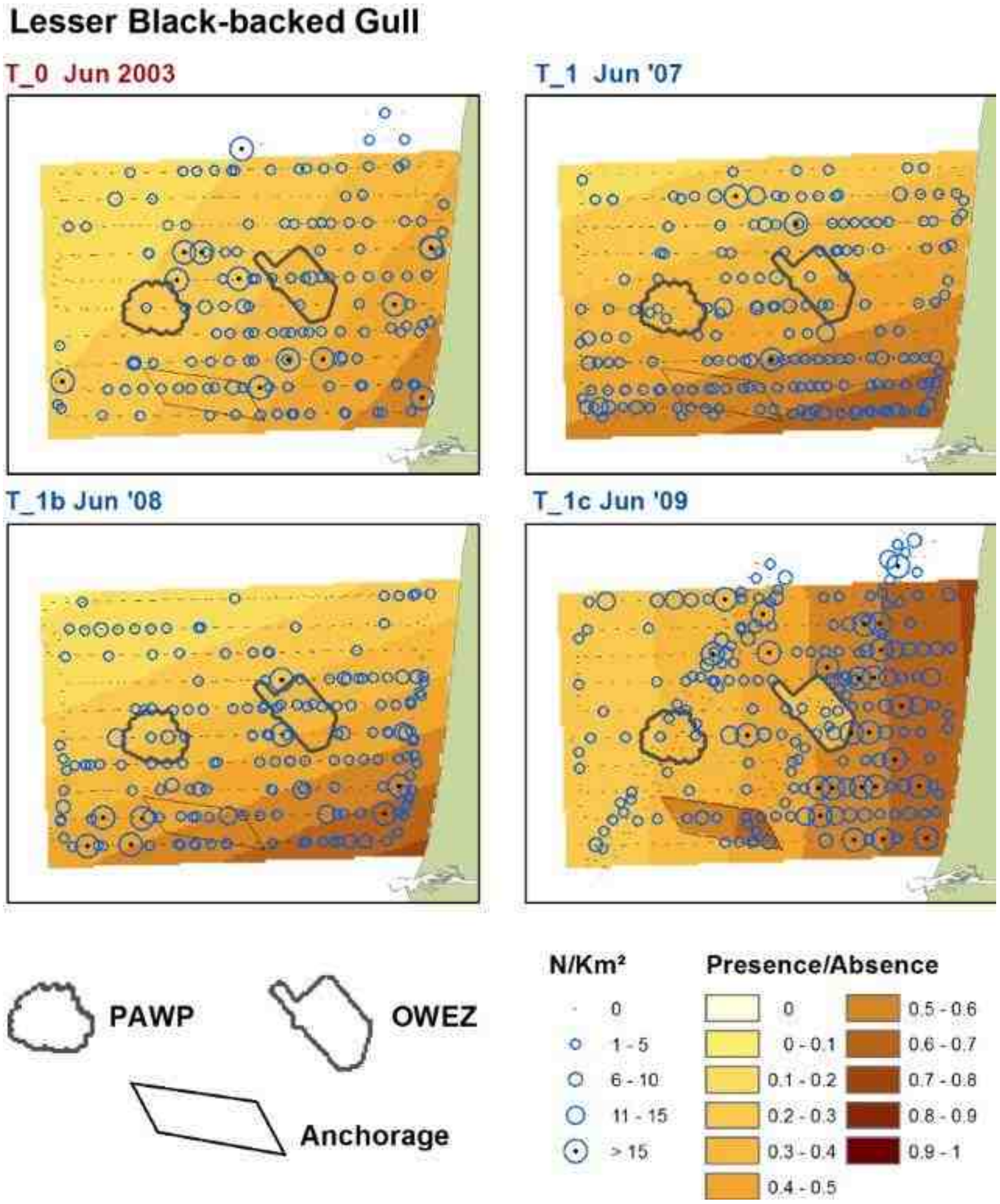

Figure 2.9 Distribution maps of Lesser Black-backed Gull for June. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without Lesser Black-backed Gulls indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours.

Sandwich Terns and **Little Gulls** occurred throughout the study area during migration, and were expected to be able to profit from the presence of the wind farm, by exploiting it for feeding, resting or courtship. However, although both Sandwich Terns (very rarely; figure 2.10) and Little Gulls (rarely) were seen inside the wind farm, but most of these birds were seen outside **the wind farm perimeters**.

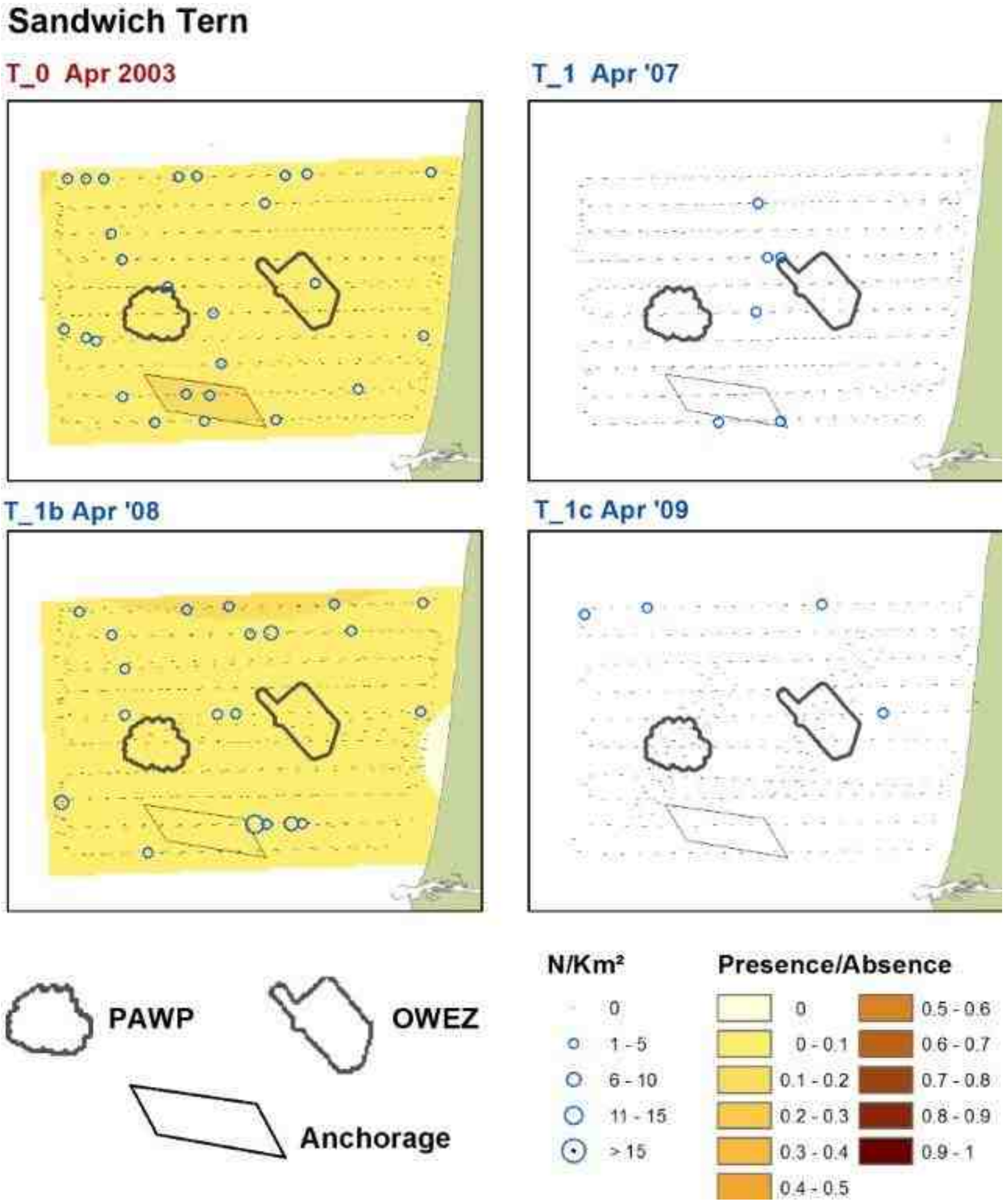

Figure 2.10 Distribution maps of Sandwich Tern for April. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without Sandwich Terns indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours.

One species, the **Great Cormorant**, was clearly **attracted** to the wind farm (figure 2.11). Birds from two coastal colonies (Zwanenwater and Hoefijzermeer), were quick to discover that the wind farm provided good offshore feeding and resting conditions. Availability of resting places (out of the water) is critically important for cormorants that need to dry their feathers after feeding bouts under water. Great Cormorants commuted between the mainland and OWEZ (and later further on, to PAWP as well) in rather large numbers, while OWEZ and certainly PAWP latitudes were off limits to these birds before construction when no seating was provided.

Two first-winter Great Cormorants, discussing the pros and cons of offshore wind farms, while resting on one of the PAWP turbines, 18 January 2010. Photo: Hans Verdaat, IMARES.

Great Cormorants roosting on the OWEZ metmast. Photo: Hans Verdaat, IMARES.

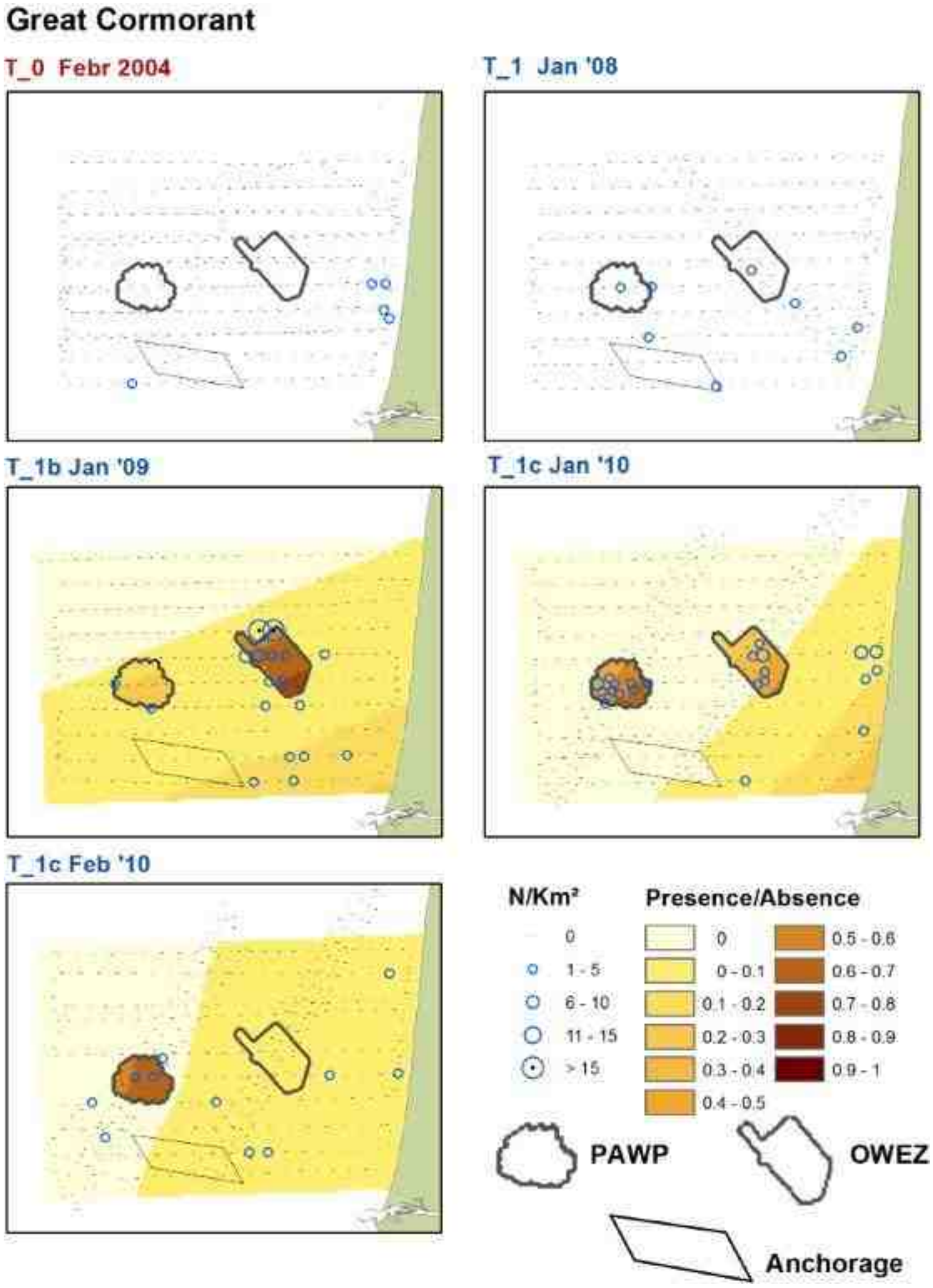

Figure 2.11 Distribution maps of Great Cormorant for January and February. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without cormorants indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours. With sufficient numbers of birds seen per survey, the statistical modelling, with wind farm as an additional factor, clearly picked up the increased presence of birds in the wind farms.

Auks, in these parts Guillemots and Razorbills offered the best possibilities to study disturbance by wind farms, because these birds were relatively abundant, occurred widely dispersed, did not fly around much as they spent most of their time swimming, and did not flock around fishing vessels. Both species were **disturbed** by the presence of OWEZ, and avoided the wind farm area to some extent. However, avoidance was not total, as Guillemots and Razorbills were both seen inside the wind farm, and also inside the neighbouring wind farm PAWP, with a much higher turbine density (figures 2.12 & 2.13). Turbine density probably did have an effect on disturbance though, avoidance being apparently stronger in PAWP (but not 100% either).

Common Guillemot in full breeding plumage, 28 January 2010, Brown Ridge area, just west of the study area. Photo: Hans Verdaat, IMARES.

A flock of Razorbills flying over the Brown Ridge area, just west of the study area, 26 January 2010. Photo Hans Verdaat, IMARES.

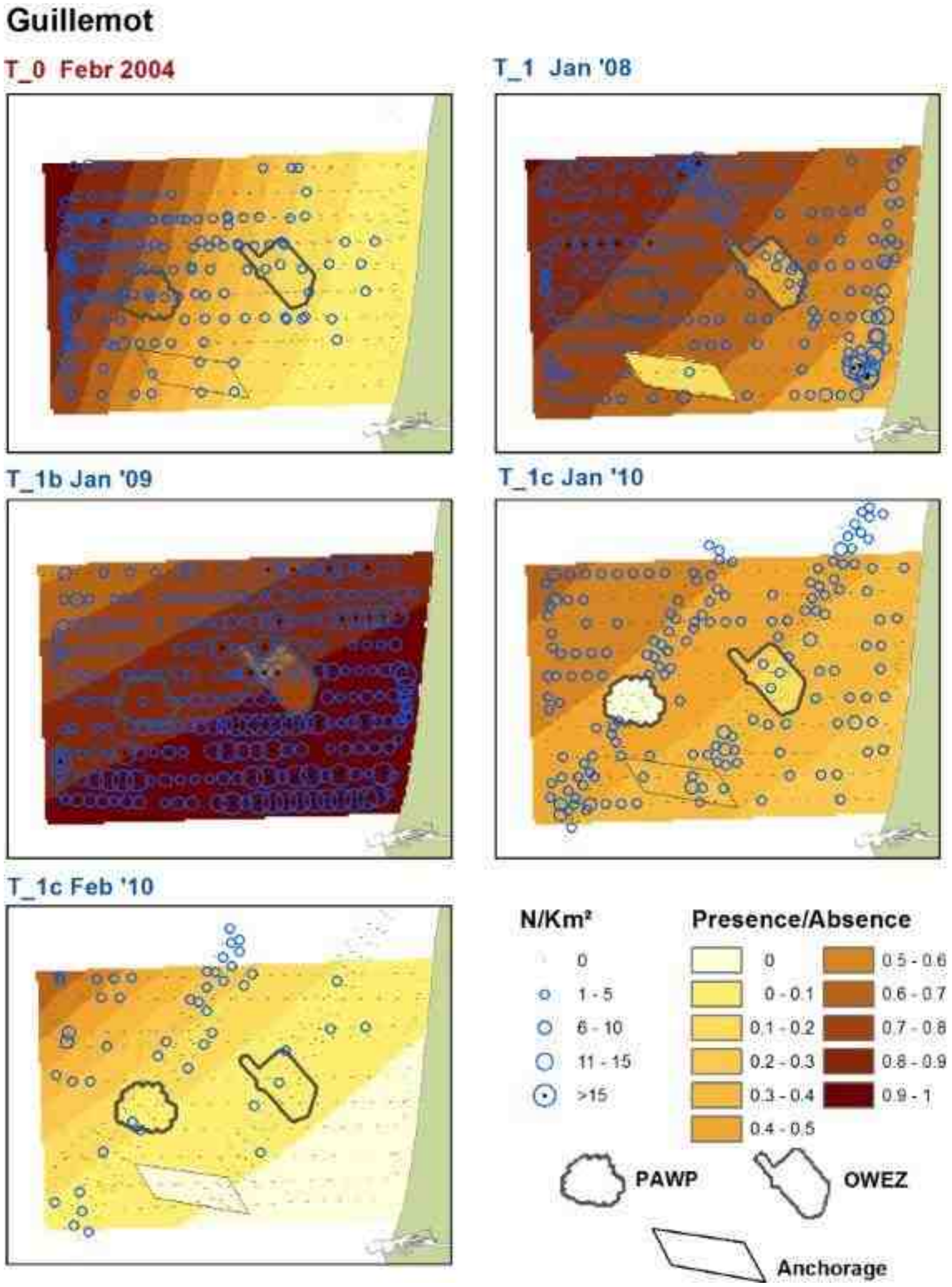

Figure 2.12 Distribution maps of Common Guillemot for January and February. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without Guillemots indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours. Avoidance is illustrated by the lighter shades of yellow in the wind farms, at sufficient Guillemot overall densities.

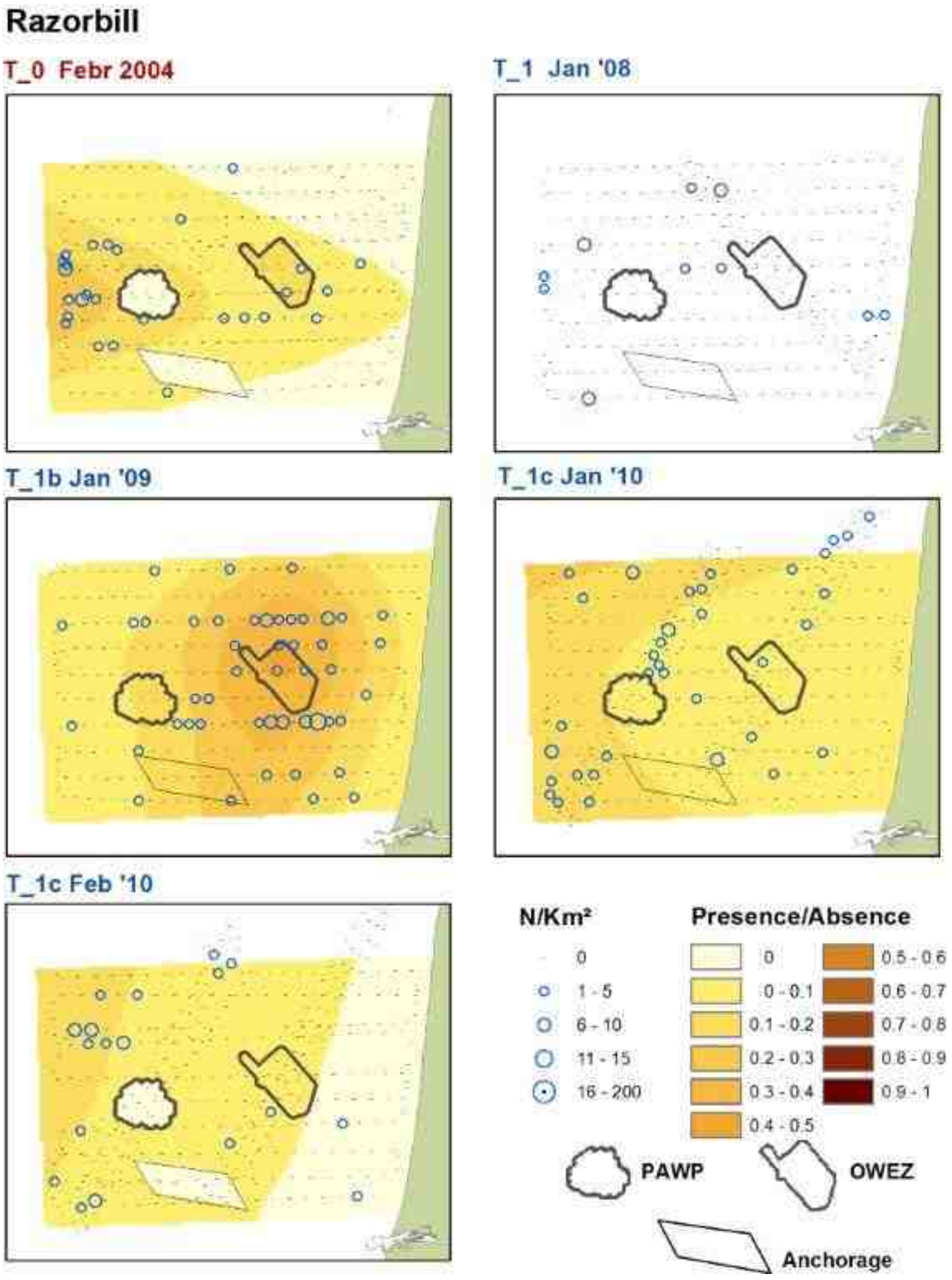

Figure 2.13 *Distribution maps of Razorbills for January and February. All maps show the coastline of Noord-Holland, the outlines of the two wind farms and the anchorage area. Counts without Razorbills indicated by -. Circles give point estimates of densities, taken directly from the counts at sea. See figure 2.4 for an explanation of the background colours.*

Table 2.1 Effects of Offshore Wind farm Egmond aan Zee (OWEZ) on the distribution and occurrence of local birds. The range in which the species generally occurs is shown as: n = nearshore, o = offshore and b = both (nearshore as well as offshore).

Species	**range**	**presence time of year**	**effect of OWEZ & other factors**
Red- & Black-throated Diver	n	autumn – spring	out of range
Great Crested Grebe	n	mainly winter	out of range
Northern Fulmar	o	mainly winter – spring	out of range
Northern Gannet	b	mainly autumn – spring	avoidance
Great Cormorant	n	yearround	attraction
Common Scoter	n	yearround	out of range
Little Gull	b	autumn – spring	possible avoidance
Black-headed Gull	n	yearround	out of range
Common Gull	n	yearround	fishing vessels / indifferent
Lesser Black-backed Gull	b	mainly spring – autumn	fishing vessels / indifferent
Herring Gull	n / b	yearround	fishing vessels / out of range
Great Black-backed Gull	b	autumn – spring	fishing vessels / indifferent
Kittiwake	o	autumn – spring	indifferent
Sandwich Tern	b	spring – autumn	possible avoidance
Common & Arctic Tern	n	spring – autumn	out of range
Guillemot	b	autumn – spring	(slight) avoidance
Razorbill	b	autumn – spring	(slight) avoidance

2.1.4 Conclusions

Contrary to the expectation (based on earlier studies around Horns Rev offshore wind farm that indicated clear-cut avoidance; Petersen *et al.* 2006), the results of this study do not suggest large-scale disturbance of seabirds residing in Dutch waters by the presence of OWEZ. The wind farm, however, is situated in a location that is not particularly rich in seabirds. Located between truly coastal waters and offshore, Central Southern Bight North Sea waters, the area lacks high densities of nearshore species (divers, grebes, seaducks) and also high densities of offshore species (Northern Fulmar, Kittiwake, auks).

Large gulls were the most numerous seabirds in the general area, but particularly so around fishing vessels that discard easy meals for the gulls. As fishing is not allowed in the wind farm, gull numbers were never very high in the wind farm. The main effect of the wind farms on gull distribution patterns is that because trawlers are kept at bay the largest concentrations of gulls now occur outside the wind farms, behind the trawlers that were working around the wind farms.

The Great Cormorant showed the most clear-cut behavioural response to the presence of the wind farms as it was attracted in rather large numbers to offshore parts of Dutch waters, where it did not occur earlier. Cormorants are also the most truly “local” birds, being present yearround, commuting to breeding colonies on the nearby coastline and resting in the wind farms (including spending the nights in many cases in summer).

Other seabirds were disturbed by the presence of the wind farm and avoided the area to some extent. This was clear only in situations with relatively high densities at OWEZ latitudes. Low densities at these latitudes, a rather common feature across many different seabirds, for many species prevented firm conclusions (due to lack of birds). However, birds with sufficient densities often showed avoidance (*i.e.* alcids) although never 100%. Numbers within the wind farm seemed lower in PAWP (which has a higher turbine density) compared to OWEZ.

Many birds, particularly the gulls, also respond to variables that could not be included in the models, such as concentrations of fish (food) or weather conditions. Seabird distribution data generally showed considerable noise, year to year variation and patchiness, which made finding effects of an offshore wind farm difficult. When compensated for the influences of gross topography, *i.e.* distance to coast and northing, indications of avoidance only became apparent for a few species.

2.2 Flight paths, fluxes and altitudes of local and migrating birds

In this paragraph we summarise the effects of OWEZ on flight patterns of birds, including local seabirds, migrating seabirds and migrating landbirds. The results are presented in Krijgsveld *et al.* (2011). The results of the baseline study are described in Krijgsveld *et al.* (2005).

2.2.1 Introduction

The study focussed on the effects of the Offshore Wind farm Egmond aan Zee (OWEZ) on fluxes, flight altitudes and flight paths of birds in the area. Targeted species of interest were local seabirds (such as gulls, divers, gannets, scoters, Guillemots and Razorbills), migrating seabirds (such as divers and scoters) and migrating non-marine birds (such as thrushes and geese). The study was aimed specifically at determining collision risks and barrier effects for birds flying through the area. To assess these effects, the following aspects of flight patterns were studied in response to the wind farm:

- fluxes of flying birds (i.e. flight intensity; number of birds per time unit per surface area in the vertical plane), to provide insight in collision risk of birds;
- flight paths of flying birds, to provide insight in occurrence of avoidance and thus barrier effects;
- altitudes of flying birds, to provide insight in both collision risk and occurrence of barrier effects.

The research questions for the study were:

- What are the flight patterns (meaning flight intensities, flight altitudes and flight paths) of the species of birds that occur in the OWEZ area, 10 – 18 km off the Dutch coast?
- How do these flight patterns vary between seasons, spring and autumn migration, day and night, and under varying weather conditions?
- Are these flight patterns influenced by the presence of the offshore wind turbines in the OWEZ area?

Based on the outcomes of the research a crude estimate of collision rates was made.

2.2.2 Methodology

Flight patterns in relation to OWEZ were quantified using a combination of automated and visual observation techniques. From the meteorological mast (metmast) in the area, visual observations during fieldwork days were carried out, as well as continuous radar observations with both a horizontal radar and a vertical radar (figure 2.14). The techniques used were chosen to obtain maximum coverage (both of the area and in time) as well as to optimise species-specific information on flight patterns. The research was carried out between April 2007 and June 2010, following a baseline study that took place between 2003 and 2005 (Krijgsveld *et al.* 2005).

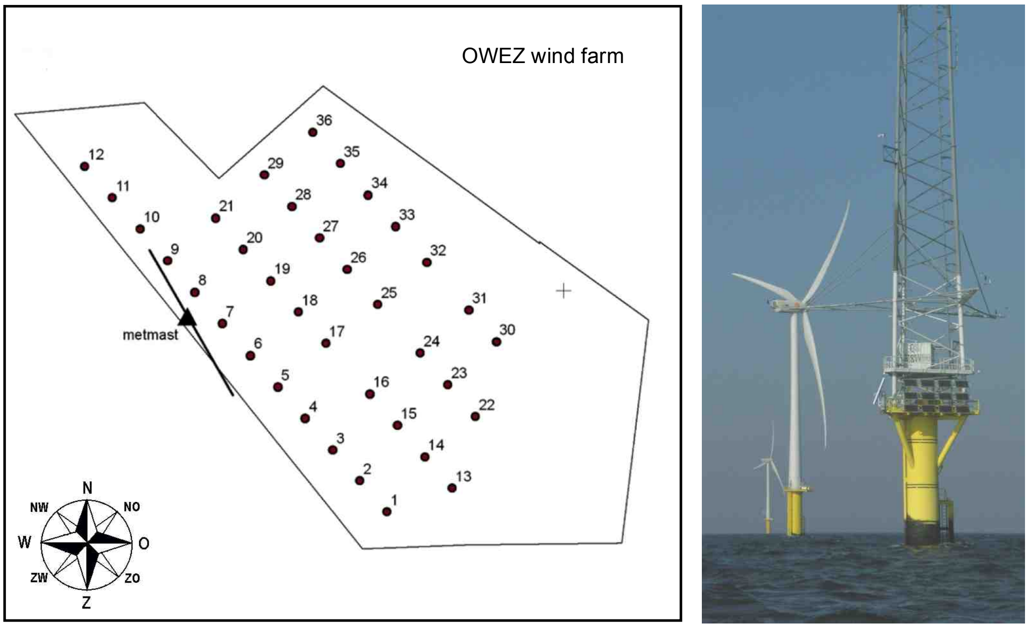

Figure 2.14 Outline of the wind farm with the position of the metmast (triangle) as well as orientation of the vertical radar beam (black line through metmast). The photo shows the metmast from the south and two wind turbines in the back (photo: K. Krijgsveld).

Radar observations

Information on flight patterns on the scale of the wind farm area for an extended and continuous period of time, and on diurnal as well as nocturnal flight movements, requires more than visual observation only. The human eye simply cannot see well enough during hours of darkness, or at larger distances – especially high in the sky. In addition, the offshore study area is remote and subject to high waves, which severely limited the time that observers could be present in the area. To obtain the desired information, marine surveillance radars were employed that were integrated in an automated hard- & software system called Merlin. A horizontal S-band radar was used to measure flight paths of birds as well as flight speeds and directions. A vertical X-band radar (tilted 90°) was used to measure fluxes and flight altitudes of birds. Radar observations were carried out around the clock, each day, all years and thus give insight in overall flight patterns in the area.

The radars were place on the metmast (see fig. 2.14) and radars scanned an area up to 5.6 km around it and up to 1.4 km above it. The horizontal radar scanned an area within and outside the OWEZ wind farm. With this set-up all larger birds were detected throughout the wind farm area. Smaller species (smaller than a Starling) were not detected at the outer limits of the range, unless in high densities.

To study micro-avoidance (avoidance of individual turbines inside the wind farm), flight paths of birds at short distances from the turbines were measured using the horizontal radar at a reduced range of 0.75 NM instead of 3 NM. Data were collected at this range for a period of eight months. .

The beam of the vertical radar was oriented in a southeast to northwest direction, perpendicular to the main direction of migrating birds. With this set-up all larger birds were detected throughout the entire altitude range. Smaller species were not detected at the outer limits of the range, unless in high densities.

Horizontal and vertical radars as positioned on the metmast in the OWEZ area. Photo Camiel Heunks, Bureau Waardenburg.

To be able to continuously record flight movements at a remote and inaccessible location such as OWEZ, regardless of weather conditions or daylight, an automated bird-tracking system was used called Merlin, which incorporated both radars (developed and supplied by Detect Inc., Panama City, Florida, USA). The Merlin system allowed automatic logging of bird echoes into a database. The radar signal was taken directly from the radar and was filtered using algorithms developed specifically for recording bird flight activity at OWEZ. Furthermore, the system allowed the researcher to remotely access the data and control the radars.

With each recorded echo, the Merlin system records a large number of parameters that define the characteristics of each signal. These characteristics were used to separate between echoes from actual birds and from other objects such as waves, rain, turbines ships and interference from other radars (all called clutter). Echoes belonging to birds were stored in a database along with information on flight direction, speed, altitude and other characteristics.

Because the resulting databases still included a large amount of clutter, specific clutter filters were developed to clean-up the data. Especially in the horizontal radar data, a large proportion of recorded echoes originated from waves rather than birds. After filtering, the data were extensively calibrated and validated before analysis.

To allow analysis of flight paths in relation to the wind farm, all data on flight paths were assigned to grid cells covering the entire wind farm area, following the radar data analysis of the Horns Rev wind farm in Denmark (Petersen *et al.* 2006).

The data collected with the vertical radar provided information on fluxes and flight altitudes of local and migratory (sea)birds within OWEZ. Fluxes are given as the number of tracks (bird groups) per kilometre per hour (Mean Traffic Rate; MTR). To be able to calculate this flux, a standardised method was used by selecting only bird tracks within two rectangular areas of 500 m halfway the radar-range (figure 2.15). The two columns were equally divided into 10 altitude bands with the same height (139 m). The lowest altitude band was then split into two to allow small-scale analysis at the lowest altitude.

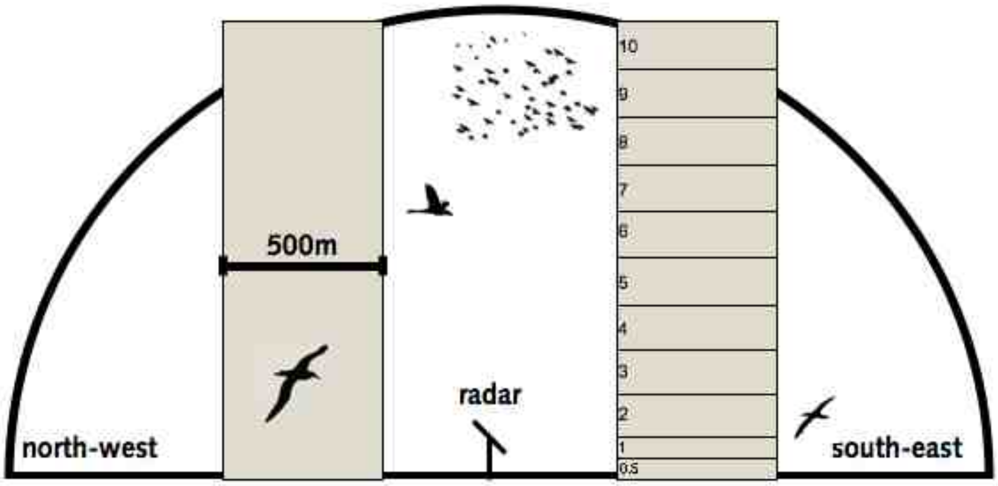

Figure 2.15 Schematic view of the two columns (grey area) in which all tracks were selected for analysis of flux and flight altitude. Columns are each 500 m wide and divided in eleven altitude bands.

Visual observations
To determine flight patterns at species level, visual and auditory observations were carried out at the metmast approximately one day per month. The following protocols were used to answer individual research questions:
1) To get an overview of species composition, distribution, abundance, flight direction and flight altitude within and outside OWEZ, each hour during fieldwork a **panorama scan** was performed. A panorama scan is a visual count of all birds flying within sight of the observation platform (Lensink *et al.* 2000). A panorama scan involved scanning the air and water in a 360° area around the platform, using a high-quality pair of binoculars on a tripod (figure 2.16). Each panorama scan consisted of two full circles, one to count birds at or just above sea level and a second to count birds at higher altitudes (figure 2.17). Of all birds seen through the field view of the binoculars, species, number, altitude (4 classes), location (8 classes), distance (4 classes) and behaviour (following ESAS coding; Camphuysen & Garthe 2001) were registered. To obtain a measure for flight density, the number of birds per scan was transformed to the number of birds per km^2. For most analyses only birds flying within 3 km distance were included. The study focussed on flight paths rather than locally active birds, therefore locally active birds (without distinct flight direction) and birds sitting on the water were analysed separately.

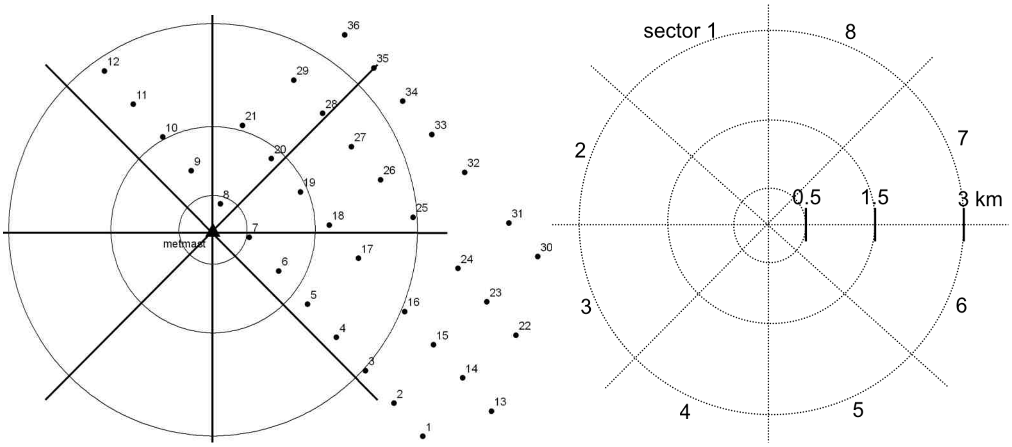

Figure 2.16 Schematic view of the area surveyed with the panorama scans, relative to the position of the wind farm (left), and of the eight sectors and three distance classes (right). The metmast, as observation platform, is situated in the centre. Surface areas are: distance 0 – 0.5 km = 0.79 km^2, 0.5 – 1.5 km = 6.28 km^2, 1.5 – 3 km = 21.21 km^2.

2) To gain insight in individual and species-specific flight paths, avoidance behaviour and (changes in) flight altitude, **individual flight paths** were drawn onto maps and analysed in GIS. Flight paths of individual birds or bird groups were followed as often as possible in between and during regular observation protocols (e.g. panorama scans and visual radar logging). Using binoculars, telescope and radar, birds were picked up, identified to species level and followed as long as possible.

3) To study the species composition of nocturnally active birds, **moon watching** and **flight-call registration** by ear and recorder were performed. Nocturnal observations were exclusively carried out during migratory periods in spring and autumn and during calm weather, leading to a limited number of observation days. Moon watching involves observing, through a telescope, flying birds that pass in front of the moon, and allows recording species, flight direction and altitude of nocturnally flying birds. For a description of the system developed to automatically record and analyse flight calls, see Krijgsveld *et al*. (2011).

4) **Micro-avoidance** of birds around individual turbines was studied visually (as well as by radar; see above) by recording individual flight paths in relation to the turbines. All flying birds within the sample area were recorded, in ten-minute periods. Species, number, flight altitude, distance to nearest turbine and the actual flight path of each bird (group) were recorded.

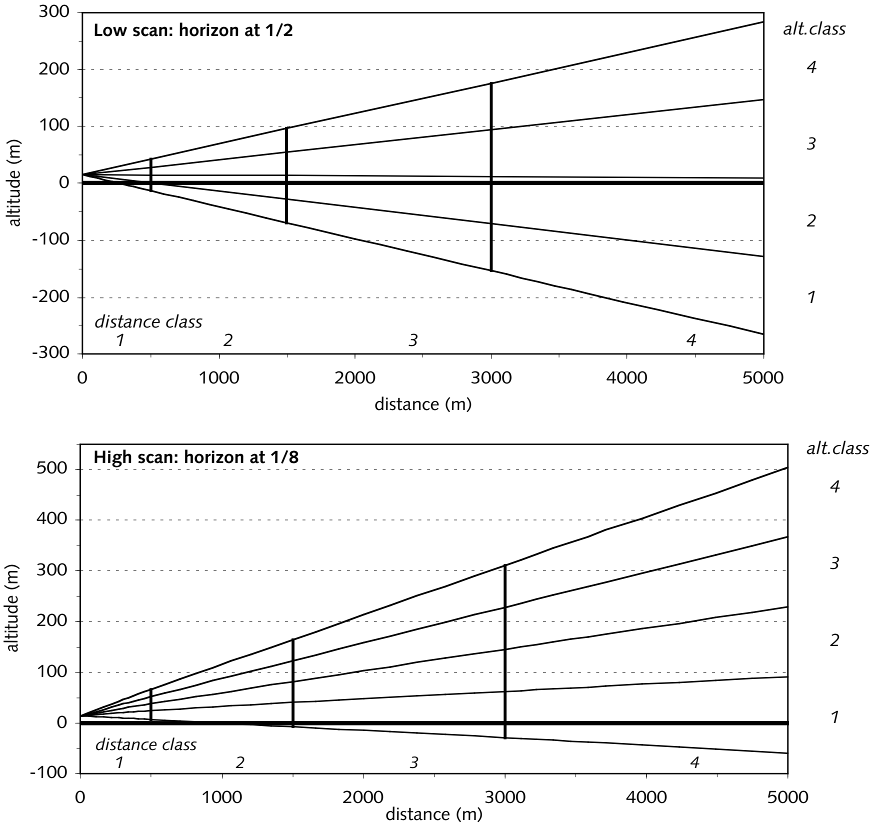

Figure 2.17 Schematic view of the volume of air covered with panorama scans. Scans were performed at two altitudes: a low scan with the horizon halfway the binocular view and a high scan with the horizon at 1/8 in the lower part of the binocular view. With the sea surface visible in the bottom part of the view, maximum altitude at which birds are scanned is 165 m at 1500 m distance.

2.2.3 Results on flight patterns of birds

Species composition and abundance

Overall abundance of birds during daytime was low. This was not due to the presence of the wind farm, but was inherent to the location in itself (Leopold *et al.* 2011). Numbers were lowest in summer and winter when mostly local birds were present, and higher in the migratory seasons. A total of 103 different bird species were recorded within OWEZ. Inter- and intra-annual variation in abundance and species composition was large. This variation was related to a variety of factors, such as season and time of day, weather conditions, and also the presence of the wind farm.

The species group most commonly seen in the area was gulls, of which the majority were Lesser Black-backed Gulls and Herring Gulls in summer (when also the activity of fishing vessels was highest), and Common Gull and Kittiwake in winter (figure 2.18). Also the Great Cormorant was a common species in the area, foraging within the wind farm, and resting on the metmast, on platforms in the vicinity and also on the access platforms of wind turbines. This is a recent development, as Cormorants did not use to occur so numerously so far out at sea. The wind farm with its availability of resting posts and a possibly increasing availability of fish, has contributed to this development.

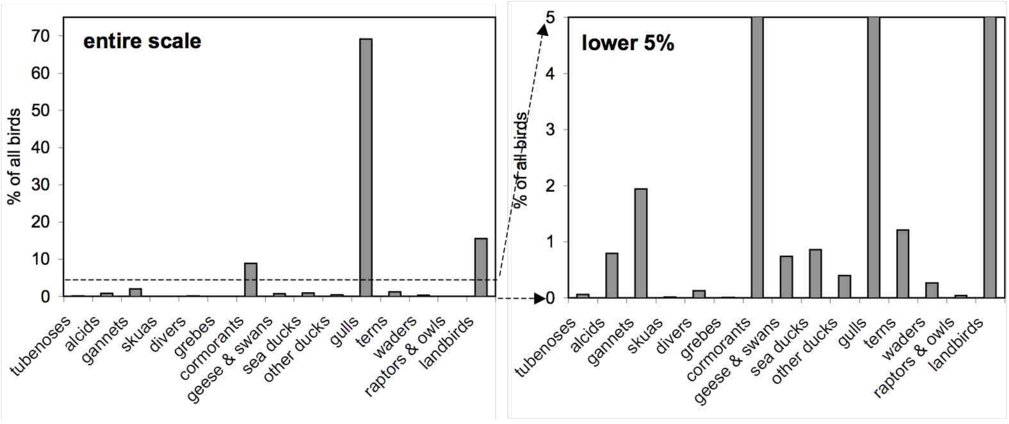

Figure 2.18 relative abundance of all species groups seen in the wind farm area, as observed with panorama scans. Gulls and cormorants dominated the species spectrum, as well as passerine flocks during spring and especially autumn (left). On a smaller scale (right, max on y-axis = 5%) the uncommon versus the scarce birds can be distinguished.

Of the pelagic seabirds, Northern Gannets were most common, especially in March. Other seabirds such as scoters, divers and alcids, did occur in the area but in low numbers. During migration, passerines were the most common birds in the area, as was observed with a combination of visual observations and radar. The most common species of passerines that were seen during daytime were Starlings and Blackbirds. Other migrating non-marine birds were seen in low to very low numbers, including species such as geese, non-marine ducks, terns, herons and raptors. At night species could only be identified to a limited degree and many small songbird specs remain unidentified, although counted with radar. Of the identified species thrushes (Redwing, Song Thrush, Blackbird) dominated the spectrum, but some waders and gulls were recorded as well, as well as a variety of small passerines.

Flight paths and macro-avoidance

Flight paths obtained with the horizontal radar provided detailed information on avoidance behaviour during every time of day, throughout the seasons, and under a range of weather conditions. In general, the avoidance level of birds passing the wind farm was between 18 - 34% (*i.e.* 18 - 34% less birds within the wind farm than outside the wind farm). Avoidance was lowest in winter (18% less birds) and highest in autumn (34% less birds), and avoidance was higher at night than during daytime.

Flight directions were more random in summer and winter when mostly local birds were present in the area, whereas birds had a more uniform flight direction during the migratory seasons. Also during the night, when avoidance levels were higher, flight directions showed less variation than during daytime. The presence of the wind farm did affect flight directions. Birds adjusted flight paths to avoid the wind farm, especially at close range. Overall, birds that approached the wind farm did not change their flight directions at large distances from the wind farm. Adjustments in flight directions were generally made up to one or two kilometres away from the wind farm (figure 2.19). Corrections after leaving the wind farm were visible up to three to four km away from the wind farm.

Design of the wind farm proved to be an important factor in the level of avoidance by flying birds. The single line of turbines protruding at the north-west of the wind farm was passed more often than the main body of the wind farm. Also, flight activity was higher in the area within the wind farm where the space between the turbines was larger (southeast-corner). In addition, turbines that were in operation were avoided more than turbines that were switched off.

Species (group)-specific macro-avoidance

Of the migrating land birds, geese were extremely weary of the wind farm and showed the highest level of avoidance. Of thrushes and smaller passerines that were visually observed, approximately half to three quarters of the bird groups did enter the wind farm when flying during daytime and at rotor height, although most bird groups carefully avoided individual turbines. See figures 2.23 and 2.24 for an overview of avoidance behaviour of different species.

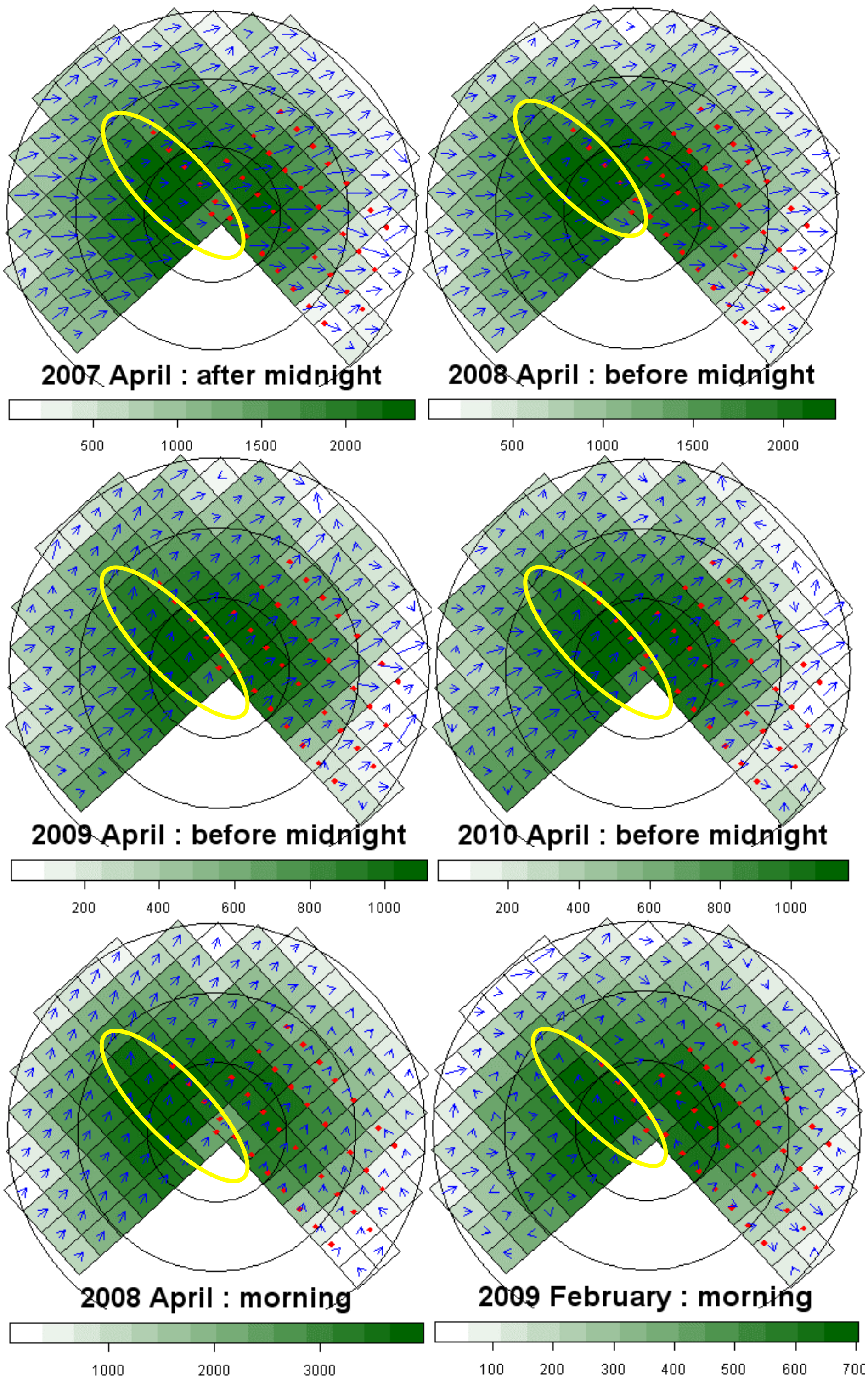

Figure 2.19 Examples of avoidance at close distance from the wind farm. Flight directions and/or uniformity in direction of birds that approached the wind farm from the southwest in April, changed in the grid cells adjacent to the wind farm (indicated by yellow circles).

Of all birds, especially gannets showed high levels of avoidance (figure 2.20). For instance, only 3% of all gannets observed were flying inside the wind farm, and 14% at the edge of the wind farm. Some seabird species, such as seaducks (figure 2.21), alcids and divers, also showed avoidance behaviour. On the other hand, gulls (various species; figure 2.22) did not avoid the wind farm and Cormorants were attracted to it (see also §2.1). Terns tended to avoid the wind farm, although the pattern differed from that of gannets. The proportion of terns encountered at the edge of the wind farm was relatively high (39%), while it was substantially lower within the wind farm than outside of it. The high proportion of terns (predominantly sandwich terns) flying at the edge of the wind farm corresponds with foraging avoiding the wind farm, but making profit of possibly higher fish supplies close to the wind farm.

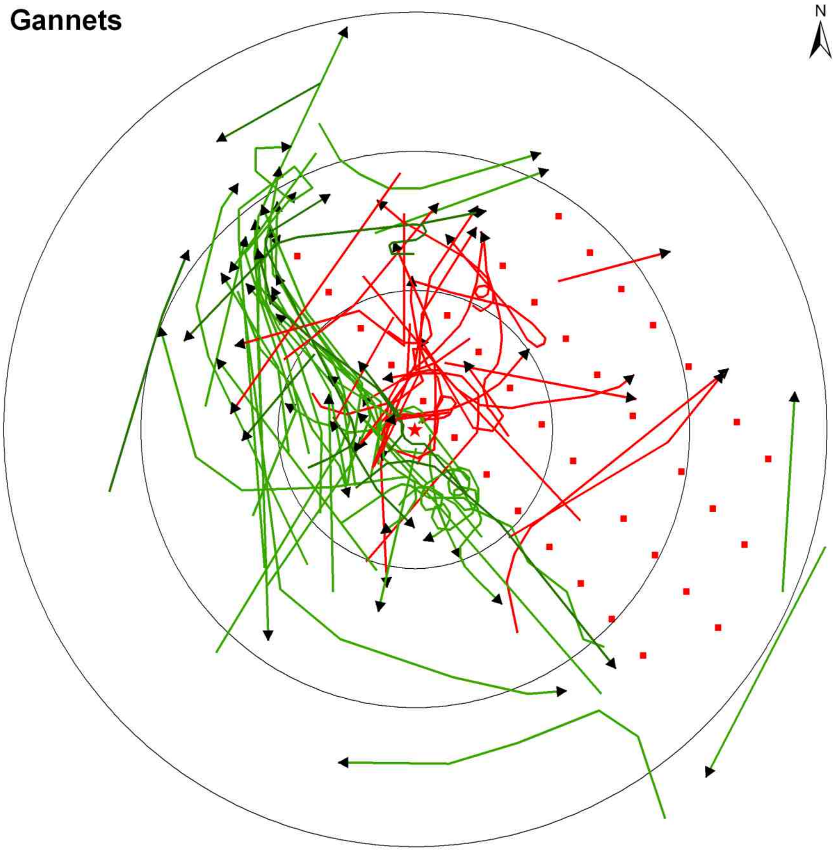

Figure 2.20 Visually observed flight paths of gannets in the wind farm area, showing high avoidance at close range. Red lines mark birds that passed within the wind farm, green lines mark birds that did not enter the wind farm. Red dots mark the wind turbines, red star in the centre marks observation post at the metmast. Rings spaced at 1 NM = 1,852 m.

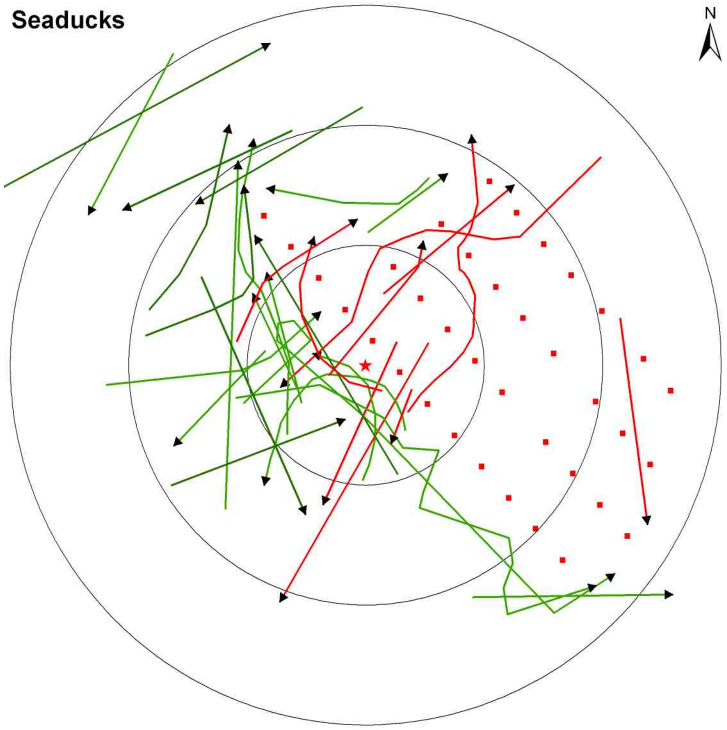

Figure 2.21 Visually observed flight paths of seaducks (scoters & eiders) in the wind farm area. See figure 2.20 for a description of colours and symbols.

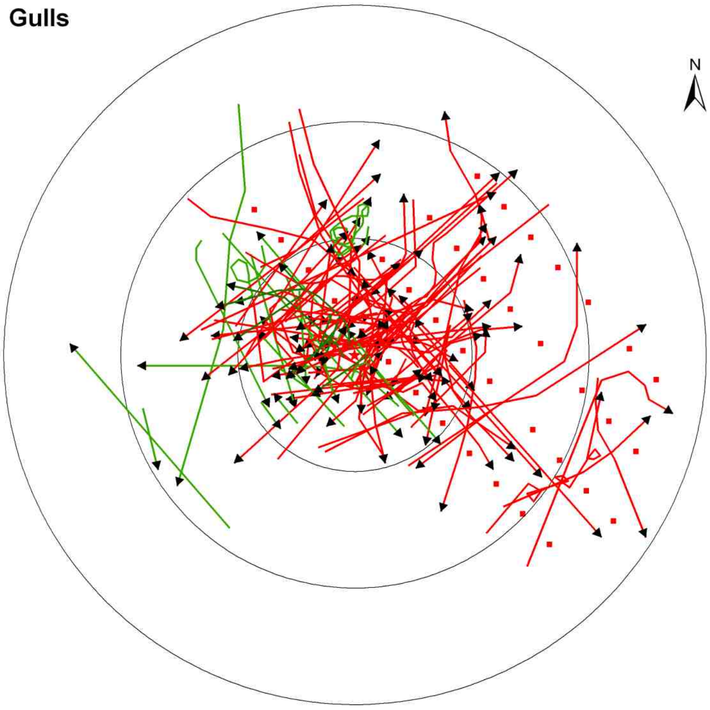

Figure 2.22 Visually observed flight paths of gulls in the wind farm area. See figure 2.20 for a description of colours and symbols.

Based on the combination of radar data and panorama scans, macro-avoidance levels per species group could be quantitatively assessed for the majority of species groups (table 2.2; figures 2.23 & 2.24). These figures could eventually be used to estimate collision rates. For alcids and divers too few observations were available to obtain a reliable avoidance rate, but from flight paths it was evident that their avoidance behaviour was similar to that of Northern Gannets and Common Scoters. Therefore the average avoidance rate of gannets and scoters was used (68%). The same was done for geese and swans that also showed extreme avoidance behaviour when they were passing the wind farm at rotor height. For gulls and cormorants, the average avoidance rate in winter was used as measured with horizontal radar (18%), because in that season species composition was heavily dominated by gulls and cormorants. For the remaining species, the average overall macro-avoidance rate as measured with horizontal radar was used (28%).

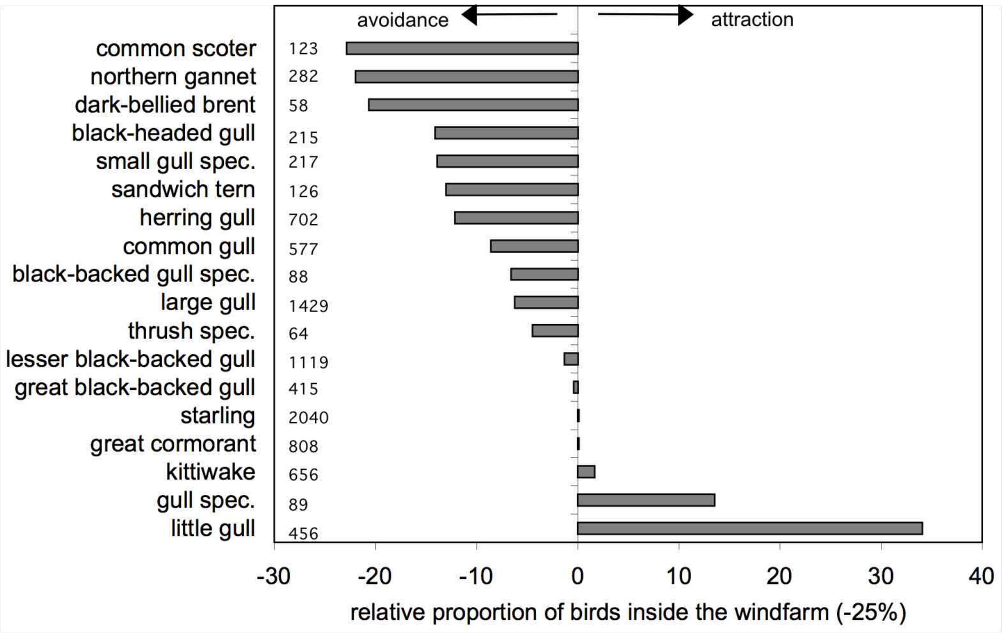

Figure 2.23 Relative proportion of the most abundant species within the wind farm, decreased by 25% to reflect the distribution of surface area within and outside the wind farm. In this graph, proportion of birds inside the wind farm would be 0 when no avoidance occurs (actual proportion 25%). Bird numbers given on left side of graph. Data from panorama scans, only flying birds within 3 km distance from metmast taken into account. Highest level of avoidance observed in species at the top (Scoter), no avoidance or even attraction observed in species at the bottom (Cormorant, various gull species).

*Table 2.2 Macro-avoidance rates for the species groups observed in the wind farm area. Rates show the proportion of birds that did not enter the entire wind farm. * = values for species group based on mostly one species: geese & swans: Brent Goose; seaducks: Common Scoter; terns: Sandwich Tern.*

Species	**macro-avoidance**
divers	0.68
grebes	0.28
tubenoses	0.28
gannets	0.64
cormorants	0.18
geese & swans*	0.68
seaducks*	0.71
other ducks	0.28
waders	0.28
skuas	0.28
gulls	0.18
terns*	0.28
alcids	0.68
raptors & owls	0.28
small passerines	0.28

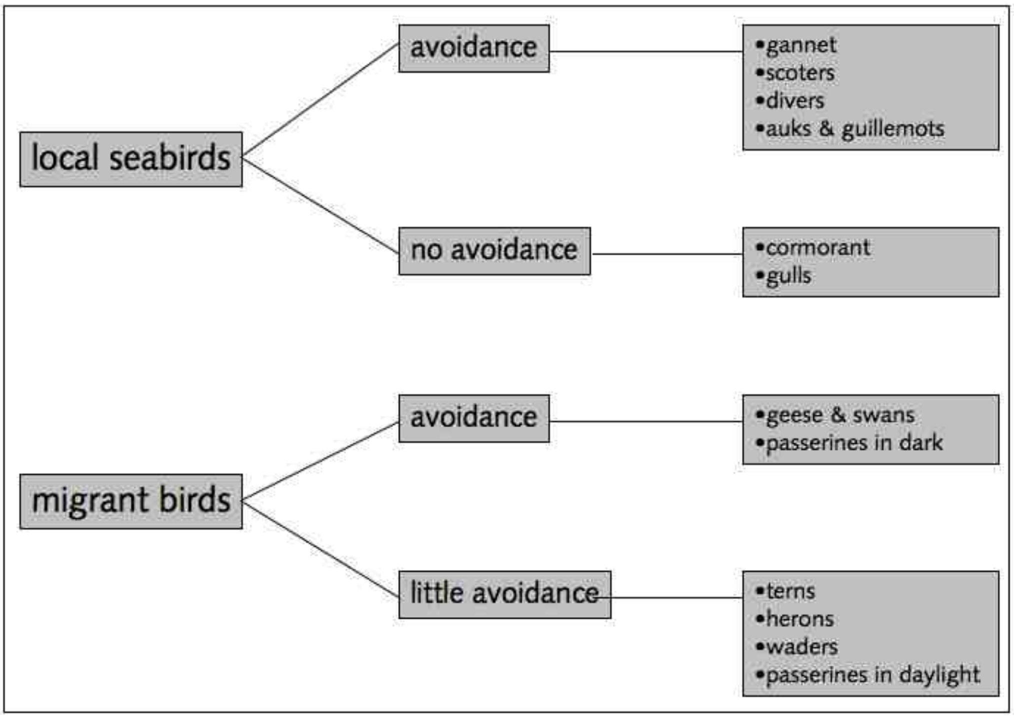

Figure 2.24 Schematic overview of species that did or did not avoid the wind farm, separated into (mostly local) seabird species and migrating land birds. Observed visually for individual species, and additionally with radar for the passerines.

The distribution of large gulls was mainly influenced by the occurrence of fishing vessels, with which they were associated during a large part of their time at sea. Overall, 55% of all recorded large gulls were associated to fishing vessels. As fishery was prohibited within the wind farm, this phenomenon could only be observed at larger distances (>3 km) from the metmast. Although this foraging behaviour was restricted to areas outside the wind farm, it did influence the distribution and behaviour of large gulls within it as well. For instance, during the breeding season, when fishery activity was highest, gulls from the colonies were observed flying through the wind farm towards fishing vessels behind it.

Micro-avoidance

Compared to other areas of the wind farm, high avoidance of wind turbines was observed, with fewer birds close to the turbines than would be expected if birds were distributed evenly. Birds avoided the area close to a turbine with a rate of 0.66 (*i.e.* the number of tracks was on average 34% lower close to turbines than in other areas of the wind farm). Again, avoidance was higher at night and was also higher when turbines were in operation. Birds in the wind farm responded very strongly to the presence of turbines. Less than 1 bird/hr passed within 50 m of each turbine. Of all birds that did come within 50 m of the turbine, very few (7%) came within potential reach of the rotors, as was established with visual observations. Instead, they passed the turbines in the area behind or in front of the rotor blades. When this avoidance at close range is included, the overall micro-avoidance rate (i.e. avoidance of individual turbines by birds that do enter the wind farm) was 0.976.

Fluxes

Fluxes were obtained with the vertical radar, from sea level up to an altitude of 1,385 m. On average, 80 bird groups/km/hr passed through the wind farm area. However, numbers varied largely throughout the year, and during peak hours in the migratory season mean traffic rate (MTR) increased up to 3,600 bird groups/km/hr (figure 2.25). Specifically during the migration periods, numbers of birds differed remarkably per day. From almost zero up to 17% (spring) and 13% (autumn) of the total migration flux passed the OWEZ area per day in these seasons. In some years bird migration was more continuous throughout the season, whereas in others more peak events occurred.

An estimated 0.1 – 2% of the total migration flux over the Dutch North Sea passed the OWEZ wind farm area annually. During spring and especially during autumn the numbers of birds were several times higher due to migratory birds on their way to breeding and wintering grounds compared to during summer and winter, when mainly local seabirds were present. There was a remarkable difference in absolute numbers between spring and autumn migration. The numbers in autumn 2009 for example were roughly three times higher than spring 2009.

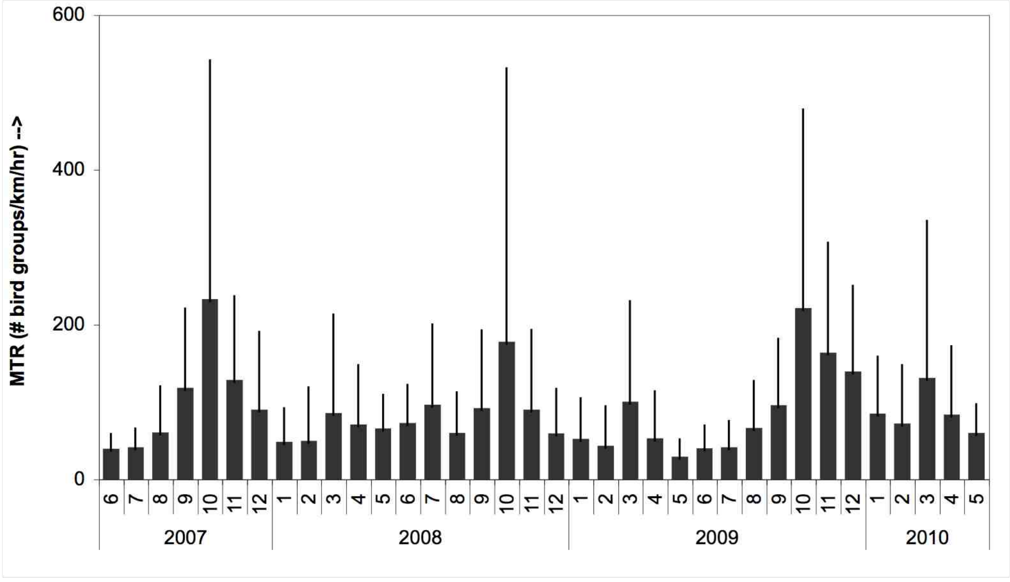

Figure 2.25 High variation in mean traffic rate (MTR) in the OWEZ wind farm, as measured with vertical radar. Means are shown with standard deviations.

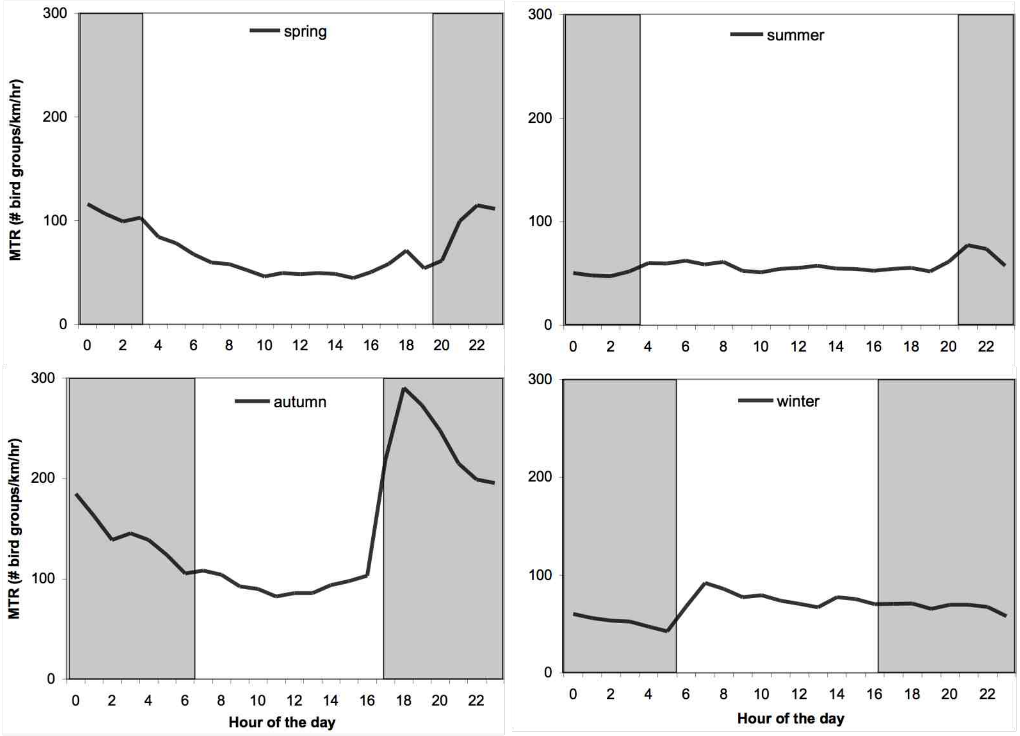

Figure 2.26 Seasonal patterns in the distribution of flight intensity during the day averaged for all years. On the y-axis average MTR is presented. Shaded are the periods of the day when it is dark. In all seasons increased average fluxes were found during dusk and dawn.

Fluxes also varied between day and night, with higher numbers of birds flying at night during migration (especially autumn). In summer and to a lesser extent in winter the majority of flight movements was during the day (figure 2.27). In summer and winter small peaks in flight activity were observed at dawn and dusk. In autumn and spring highest numbers were recorded around dusk and at the beginning of the night (figure 2.26).

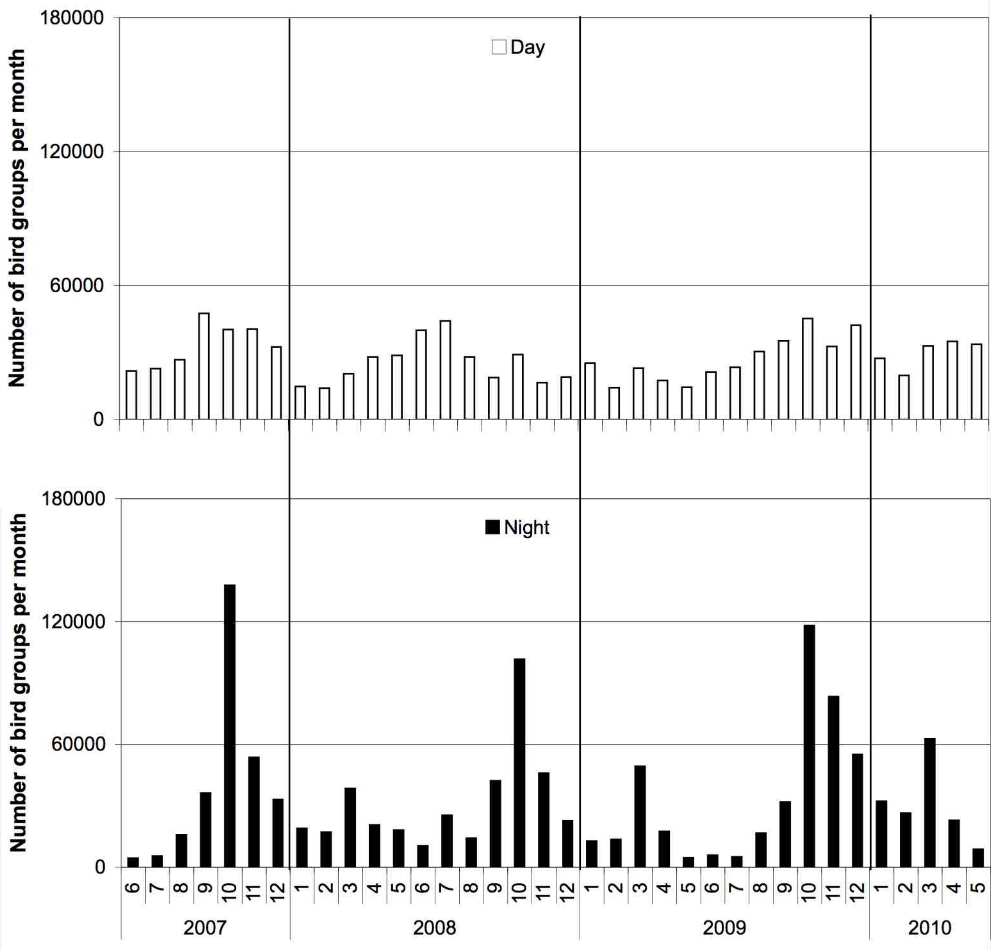

Figure 2.27 Variation in fluxes throughout the year, shown for day (top) and night (below). Shown are number of bird groups per month in a 1 km stretch as measured by vertical radar. These figures are corrected for dissimilar radar effort due to radar interruption caused by weather conditions or technical failure. Daytime fluxes were more constant than night time fluxes.

The radar and bird-tracking software that were used, were not able to distinguish between species. Because of this, fluxes at species level were quantified by extrapolating the visually obtained percentages of presence of species to the radar data. Applying this method had some disadvantages. Firstly, panorama scans could only be performed in the daylight period and with good weather conditions, which made that there were no available data on the relative abundance of species groups at night or under bad weather conditions. Secondly, detection of small birds (mainly passerines) was limited to short distances, which made that a certain proportion of passerines was detected by the radar but not by the human observers. Therefore, a correction method was designed to adjust the proportional abundance of the different species, as determined from the panorama scans, for the low estimate of passerines. To do this it was assumed that in the month with the highest migration rates, virtually all of the tracks above 70 m were of passerine origin. The ratio between migration above and below 70 m was 0.71 in October and 0.65 in March. For summer and winter no difference between the panorama scans and the actual passerine fraction was assumed, because migrating passerines were virtually absent in these seasons. The aforementioned fractions for passerine migration were added to the proportional species composition as determined from the panorama scans (table 2.3 **bold**). The remaining fraction was then distributed over the other species groups. As a result, the combined set of proportions gave an estimate of the overall species composition, with which the total annual flux could then be differentiated by species group (table 2.5).

Table 2.3 Proportional distribution of bird groups (tracks) over the different species groups in the OWEZ wind farm. Distribution is based on the species-distribution determined from adjusted panorama scan data.

Species	%spring	%summer	%autumn	%winter	%total
divers	0.04	0.00	0.00	0.31	0.06
grebes	0.00	0.00	0.01	0.00	0.00
tubenoses	0.01	0.00	0.01	0.17	0.03
gannets	1.11	0.39	1.66	0.53	0.92
cormorants	2.18	19.32	6.58	4.98	4.20
geese & swans	0.15	0.00	0.26	1.61	0.35
seaducks	0.92	0.17	0.12	0.12	0.41
other ducks	0.15	0.04	0.47	0.10	0.19
raptors & owls	0.03	0.04	0.02	0.00	0.02
waders	0.29	0.21	0.00	0.00	0.12
skuas	0.01	0.00	0.01	0.00	0.00
gulls	29.70	74.04	19.22	89.43	32.75
terns	0.41	5.44	0.45	0.00	0.57
alcids	0.00	0.04	0.18	2.33	0.38
passerines	**65.00**	0.30	**71.00**	0.41	**60.00**

Flight altitudes

Flight activity was recorded at all altitude bands up to 1,385 m altitude. Flight altitude varied highly between seasons (figures 2.29 & 2.30). Throughout the study period on average 40% of the total flux was flying in the lowest altitude band (figure 2.28). In the winter and summer season flight altitudes were low, reflecting the dominance of gulls and to a lesser extent other local seabirds, that fly at low altitudes. During migration flight altitude increased, but flight activity occurred at both higher and lower altitudes.

Overall, flight altitude was higher at night than during the day due to the high proportion of migratory birds (figure 2.30). Average flight altitude decreased in the course of the night. At the lowest altitude up to 69 m, numbers were higher during the day. Above 277 m the majority of tracks were of migratory birds. At lower altitudes more local seabirds were present.

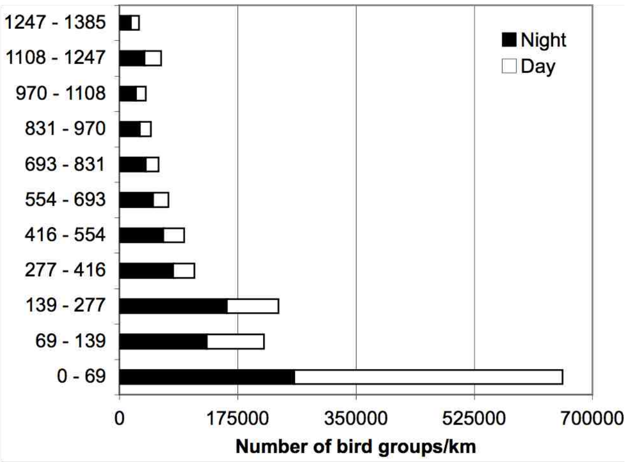

Figure 2.28 Number of bird groups per km, separated into day and night. Shown is the total flux per altitude band. Data recorded by vertical radar in 11 altitude bands (in m) between 2007 and 2010 in the OWEZ area. Note that altitude bands 1 and 2 are half the height of the other altitude bands.

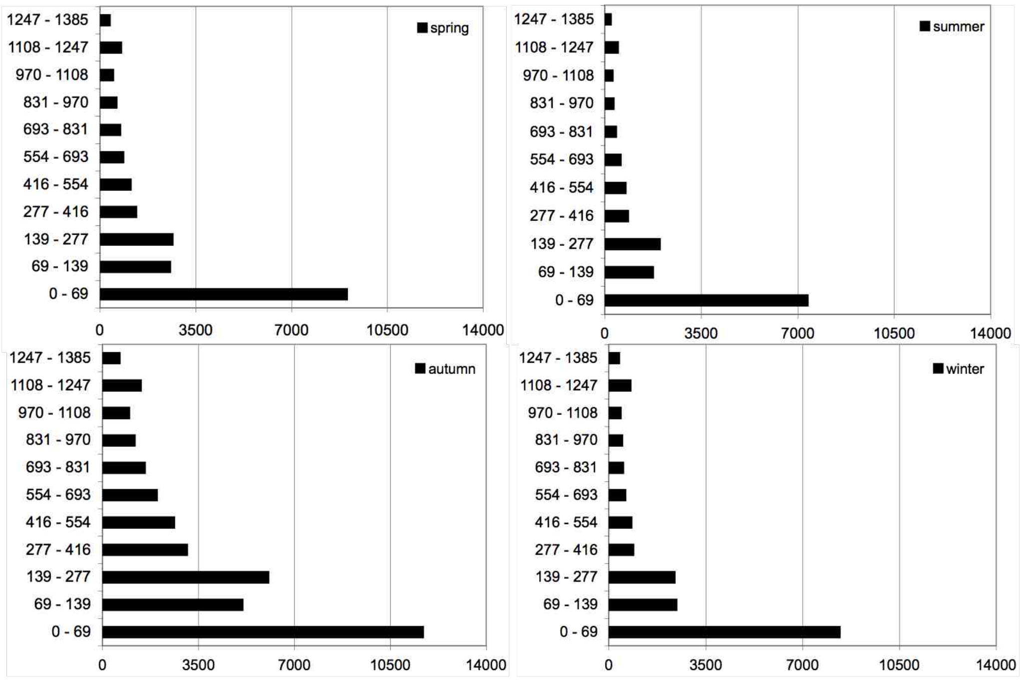

Figure 2.29 Average seasonal sum of numbers of bird groups per km. Data recorded by vertical radar in 11 altitude bands in 2007-2010 in the OWEZ offshore wind farm. Note that altitude bands 1 and 2 are half the height of the other altitude bands.

Visual observations showed that low-flying individual birds that approached the wind farm, generally increased their flight altitude, but not to altitudes above rotor height. Almost all species (groups), including passerines, regularly flew within the collision risk zone of the turbines (25-139 m). Numbers of birds flying through the high-risk zone in the OWEZ wind farm (25-139 m high) were in the order of magnitude of 2 million birds per year.

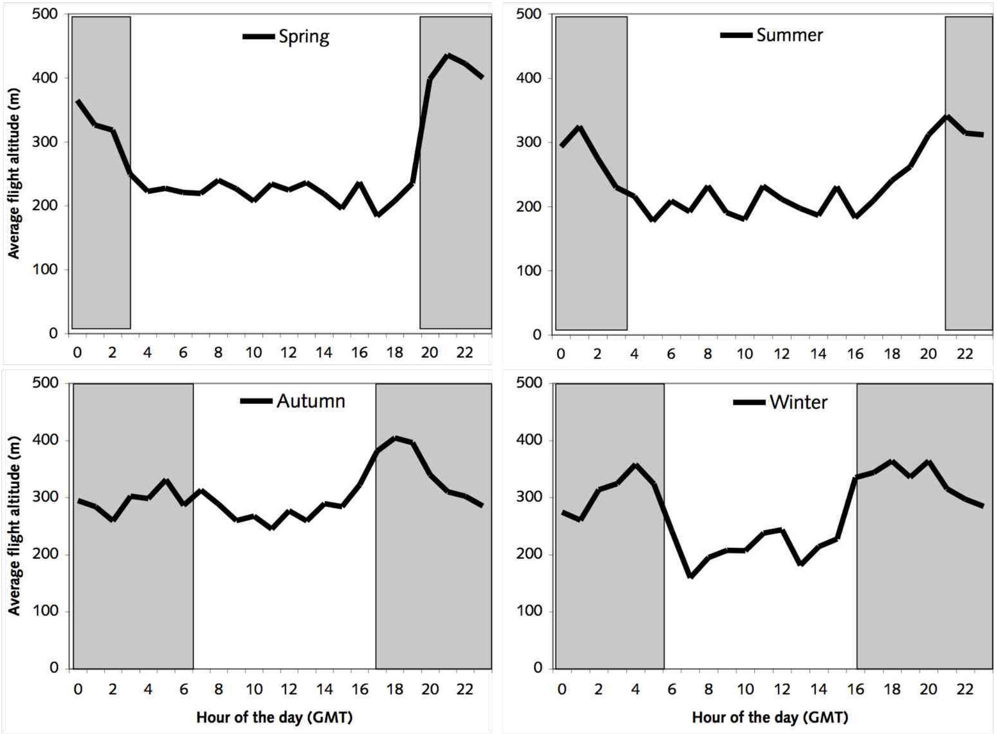

Figure 2.30 Variation in flight altitude in the course of the day, shown for the different seasons. Shown are multi-year (2007-2010) seasonal averages per hour. Note that the average flight altitude on the y-axis does not reflect reality. First it is the average flight altitude of birds in the 0 – 1,385 m window. Second, it is also not precise due to the database design with a distinction in altitude classes rather than absolute altitudes: birds flying in the first altitude band (figure 2.15; 0,5) have an average altitude of 35 m, in band 1: 104 m, band 2: 208 m, etc. Darkness is shaded.

Because many species have very specific flight altitudes, this significantly reduces the collision risk for those species flying consistently above or below rotor height. This has to be accounted for when determining avoidance and flux through the wind farm (figure 2.31; table 2.4). Tubenoses and alcids virtually always flew only a few meters above sea-level. Based on observed flight altitudes it was estimated that of every 50 birds flying into the wind farm, a maximum of one may have flown up to rotor height (98% not flying at rotor height). Gannets and seaducks and also grebes generally flew well below rotor height, while waders and passerines flew above rotor height. However, all of these species may reach rotor heights, e.g. during migration, when disturbed or (for waders and passerines) during headwinds. Based on observations, it was estimated that at maximum half of the birds of the above species will have flown at rotor height (50% not flying at rotor height). Most geese avoided the entire wind farm, but of the birds passing the wind farm area, an estimated 50% flew above rotor height, often increasing altitude in a direct response to the presence of the wind farm (50% not flying at rotor height).

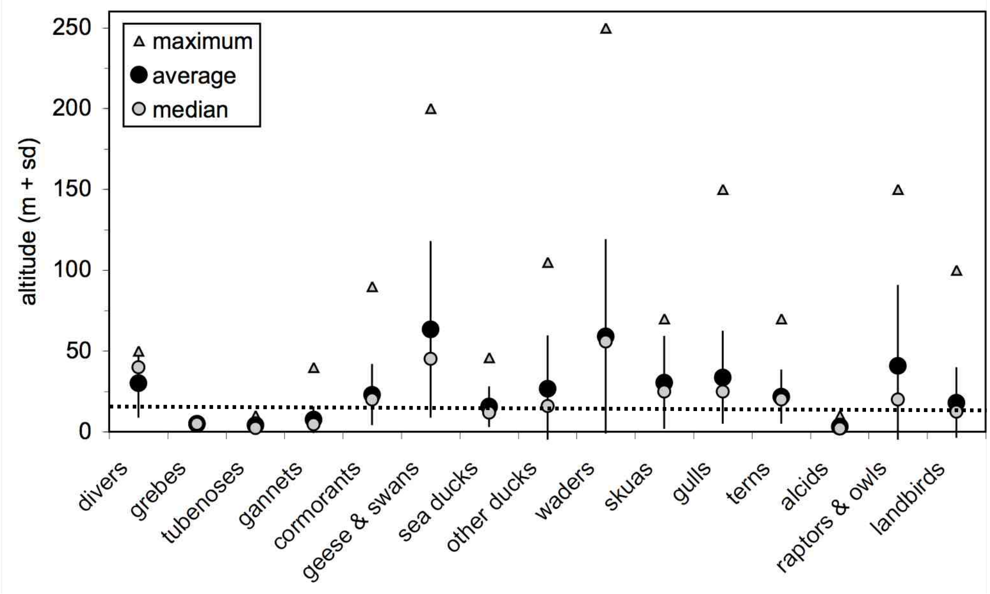

Figure 2.31 Average, median and maximum flight altitude of different species groups as recorded during additional visual observations from the metmast of flight tracks of (groups of) birds. Standard deviations of the average are shown as well. The typical lowest rotor height (20 m) is shown by a dotted line.

*Table 2.4 Proportions of birds not flying at rotor height based on species-specific flight altitudes, shown for some species groups that were observed in the wind farm area. * = values for species group based on mostly one species: geese & swans: Brent Goose.*

Species	**proportion not flying at rotor height**
grebes	0.98
tubenoses	0.50
cormorants	0.50
geese & swans*	0.50
ducks other than seaducks	0.50
alcids	0.98
small passerines	0.50

Numbers of birds at risk

Birds that fly between 25 and 115 m above sea level are at high risk of colliding with the rotors of wind turbines in the OWEZ wind farm because they fly in the rotor-swept zone. A certain area above the rotor was included in the high risk zone as well. Due to the wake of the rotor and individual behavioural shock responses of birds close to the rotor, birds are also at high risk in this range. Consequently, the high-risk zone is between 25 and 139 m. Birds that flew between 0 and 25 m above sea level had an intermediate risk of collision. The wake of the rotor and the turbine tower itself are potentially affecting flying birds at this altitude. Above 139 m birds were not at risk from the wind turbines rotors and therefore this zone is called the low-risk zone (139-1,385 m).

About 35% of the total flux measured by the vertical radar flew through the high risk zone. In this risk-band the highest numbers of birds were found in autumn and the majority of these bird groups flew at night (figure 2.32). On the contrary, in summer the majority of bird groups in the high-risk zone flew during the day. Overall about 50% of all flight movements in the high-risk zone occurred during the night. About 18% of the total flux measured by the vertical radar flew in the Intermediate-risk zone. Also in this risk-band highest numbers were found in autumn. Overall about 64% of all flight movements in the intermediate-risk zone occurred during the night. Finally, about 48% of the total flux measured by the vertical radar flew through the low-risk zone. Again, the highest numbers of birds were found in autumn. Overall about 33% of all flight movements in the low-risk zone occurred during the day.

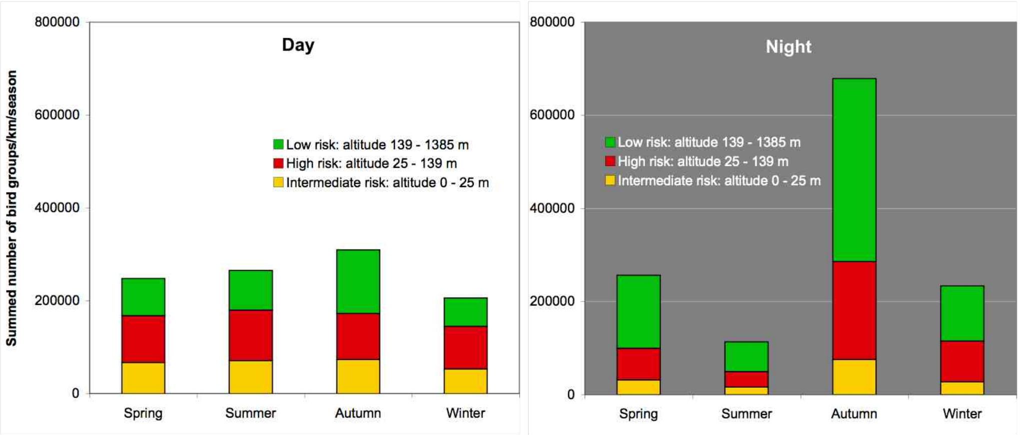

Figure 2.32 Summed numbers of birds flying at day and night in the different risk classes during the study period between 2007-2010 separated per season.

At all altitudes together a total of 2,309,988 bird groups was measured to fly through 1 km of wind farm in three years. This means that 5,389,972 bird groups flew through the OWEZ wind farm (7 km in length) per year. Only part of these birds will fly through the high-risk zone each year. For OWEZ, at wind farm scale, 1,865,996 bird groups were determined as flying through the high-risk zone each year.

Estimates of collision risk

The number of birds colliding with the wind farm could not be assessed during the study period, because no suitable technique had been developed in that time (see review by Dirksen 2006, 2009). To obtain a crude estimate of numbers of victims nonetheless, two ways to calculate this were followed. The first was by using the flux through the wind farm at rotor height and relate this to collision risks measured on land. The second was by using the SNH Band model (Chamberlain *et al.* 2006; Band *et al.* 2007; §2.4). To obtain an estimate of the number of collision victims following the first method, an overall collision risk of 0.14% of the flux was used, as measured on land (Krijgsveld *et al.* 2009). The number of collisions calculated using the Band model were taken from Poot *et al.* (2011a). For both calculation-routes data on species (group)-specific fluxes, flight altitudes, macro- and micro-avoidance levels were used as presented before (table 2.5).

Table 2.5 Species-specific flux and estimated annual number of collision victims in the OWEZ wind farm. Given are: proportional presence of species in the wind farm area as observed in panorama scans; species-specific flux in the wind farm area at rotor height, based on the measured overall flux of 1,866,000 bird groups; macro-avoidance as calculated from flight paths or otherwise average as calculated from horizontal radar data (0.28); altitude adjustments (proportion not at rotor height) based on observed flight altitudes in the wind farm area; flux through the wind farm after correction for macro-avoidance and flight altitudes; crude estimate of the number of collision victims per year, based either on a collision risk of 0.14% as measured on land, or using the Band model (as calculated in Poot et al. 2011a). Fluxes rounded of to nearest decimal.

Species	**prop.**	**flux**	**macro**	**prop. not**	**flux**	**estimated nr, of victims**	
-group	**of birds**	**in area**	**-avoid.**	**@rotor**	**corr.**	**risk 0.14%**	**Band**
divers	0.06	1,130	0.68	0	360	0.5	0.2
grebes	0.00	50	0.28	0.98	1	0.0	0.0
tubenoses	0.03	540	0.28	0.5	200	0.3	0.0
gannets	0.92	17,160	0.64	0	6,090	8.5	1.6
cormorants	4.20	78,430	0.18	0.5	32,160	45.0	30.2
geese & swans	0.35	6,500	0.68	0.5	1,040	1.5	0.9
seaducks	0.41	7,590	0.71	0	2,170	3.0	0.1
other ducks	0.19	3,520	0.28	0.5	1,270	1.8	0.6
raptors & owls	0.02	360	0.28	0	260	0.4	0.1
waders	0.12	2,300	0.28	0	1,660	2.3	0.4
skuas	0.00	90	0.28	0	70	0.1	0.1
gulls	32.75	611,120	0.18	0	501,120	701.6	234.3
terns	0.57	10,660	0.28	0	7,670	10.7	2.9
alcids	0.38	7000	0.68	0.98	50	0.1	0.0
passerines	60.00	1,119,600	0.28	0.5	403,050	564.3	309.9
total in OWEZ / year					957,160	1,340	581
est. nr of victims / wind turbine / year						37	16

Radar observations and visual observations during daytime showed that birds that did enter the wind farm showed a high level of avoidance of the individual turbines. This considerably reduces the risk of birds colliding with the turbines. At night, birds showed higher avoidance rates than during daytime, which also has positive consequences for the number of collisions. Collision victims occur among all types of birds, and during various types of behaviour. In contradiction to what might be expected, a lot of collision victims often appear to be of diurnally active birds. These are (mostly) probably foraging birds that are only paying attention to potential prey and the areas where prey can be found (Krijgsveld *et al.* 2009). In the case of offshore wind farms, this means that birds are looking down at the sea and not forward to the rotors.

Based on the fluxes and flight behaviour of the birds in the wind farm area, collision rate of local seabirds with the OWEZ wind farm will be limited due to the low abundance of local seabirds in the area, in combination with the high level of both macro- and micro-avoidance of these species. Gulls, however, did not avoid the wind farm and also foraged within the wind farm. Although they were observed to be well aware of the turbines and showed high levels of micro-avoidance, the sheer number of gulls within the wind farm will result in gull collisions, given a certain (but unknown) collision risk per passage. Assuming a collision risk similar to that on land, a crude estimate suggests an order of magnitude of some hundreds of gulls colliding with turbines of the OWEZ wind farm on an annual basis, of the various species present in the area.

Calculations with the Band model suggest a collision rate at OWEZ that is half of the number that is estimated based on onshore collision risks (Poot *et al.* 2011a; §2.4). This is mainly due to the fact that with the Band model we can account for the actual macro- and micro-avoidance of the birds as measured in OWEZ in the study at hand. Migrant birds passing the area reached high numbers during spring and autumn migration and the majority of these birds passed through the wind farm area well above rotor height. However, a considerable number, approximately one million bird groups, still passed the area at rotor height. Because of this, and because of the high level of variation in flight altitude, the highest number of collisions is expected among the migrating passerines. Among passerines, rough estimates suggest an order of magnitude of some hundreds of collision victims on an annual basis, among all species of passerines passing the area.

Validation of these estimates can only be done by measuring the actual number of birds colliding with the turbines.

2.2.4 Conclusions

Barrier effects

Deflection of flight paths consisted of 18-34% of the birds in the area avoiding the entire wind farm in general (28% on average), this number being larger or smaller depending on the species. Many birds chose to fly around the wind farm rather than entering it, especially pelagic seabirds. Of the birds entering the wind farm, at least 97.6% avoided flying in the rotor-swept area (micro-avoidance). This high level of avoidance results in a reduced collision risk, and can thus be considered a positive effect. The increased flight distance is marginal compared to the distance covered daily by birds, and was shown to have virtually no energetic effects for e.g. migrating birds (Masden *et al.* 2009). However, for seabirds that strongly avoid wind farms, there is a risk of barrier effects when multiple or large-scale offshore wind farms are erected in such a way that foraging areas become out of reach (see also §4.1).

Collision risks

Of the birds flying through and over the wind farm area (approximately 5,2 million bird groups per year), approximately 35% flew at an altitude where they were at risk of colliding with the turbine rotors (25-139 m). Thus, a yearly total of approximately 1,9 million bird groups were at risk of colliding with the rotors. The species-specific annual flux through the wind farm is given in table 2.5. As avoidance rates determine flux through the wind farm, it strongly influences species-specific collision rate (see also chapter 4).

Disturbance

Disturbance effects on local seabirds are being reported by Leopold et al. (2011) and are described in §2.1. Additionally, the results of Krijgsveld *et al.* (2011) show that pelagic seabird species had the highest avoidance levels, which indicates that these species will avoid the OWEZ wind farm. This may result in disturbance to foraging birds. However, as numbers of birds in the area were low due to reasons other than the presence of the wind farm, the numbers of birds that were disturbed were limited. Gannets, alcids and marine ducks were all seen foraging within or near the wind farm on rare occasion.

2.3 Comparison of flight patterns at OWEZ and a location further offshore

In this paragraph we summarise the results of the study of Fijn *et al.* (2012) at K14C, which was performed to compare flight patterns at OWEZ with flight patterns further offshore.

2.3.1 Introduction

We compared flight patterns at the Offshore Wind farm Egmond aan Zee (OWEZ) with flight patterns further offshore. The study aimed to assess the flux of flying birds, differentiated to flight altitude, season, time of day/night and species (group) at K14, a gas production platform (figure 2.33) owned by the Nederlandse Aardolie Maatschappij (NAM) situated approximately 80 km west-northwest off the Dutch coast in the North Sea.

In the NSW-MEP, a learning goal was included on comparing the situation relatively close to the coast (Meetpost Noordwijk and metmast OWEZ) with a location much further offshore. Such a comparison is very relevant to assess potential effects of new offshore wind farms, which will mainly be planned (much) further from the coast than the two now existing (OWEZ and PAWP), see also §4.2. The Nederlandse Aardolie Maatschappij (NAM) kindly offered the possibility to perform this research on their K14 FA-1 platform (or K14C, hereafter K14). Although being further west and north than was initially aimed for, this was not only the only site available, but has proven to be a good site bearing in mind recent developments in planning round 2 and 3 offshore wind farms.

In the light of the potential effects of wind farms on birds, three aspects of flight patterns of birds are important: flight paths, fluxes and flight altitudes. In the absence of wind turbines at the K14 study site, flight paths were not relevant and were therefore not studied.

2.3.2 Methodology

Observations were made between March 2010 and March 2011, using both visual and radar observation techniques. Methods and techniques were as much as possible identical to those used at OWEZ.

K14 gas platform of the NAM, as seen looking southwards from the vent stack. Left is the production platform and right the compression platform with the accommodation platform behind it. (photo: K. Krijgsveld).

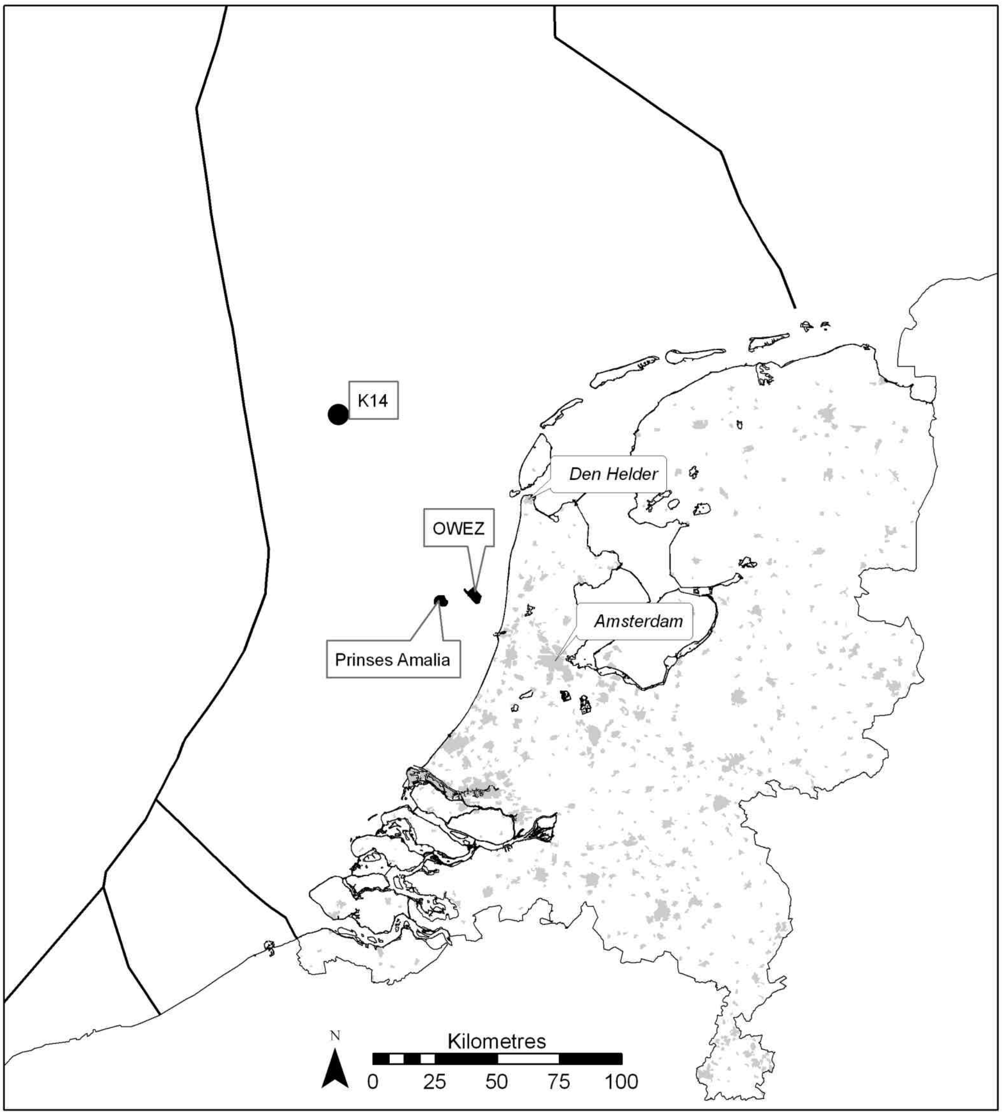

Figure 2.33 Location of NAM gas platform K14 in the North Sea. For reference, the offshore wind farms OWEZ and PAWP are shown as well.

Radar observations

A Merlin bird-tracking system consisting of an X-band marine surveillance radar (25 kW) positioned on a vent stack on the platform, was operating in vertical position at a range of 0.75 NM (up to 1,389 m). The vertical radar scanned in a northwest to southeast direction and continuously recorded bird echoes, thus providing detailed insight in fluxes and flight altitudes in the area. The radar was installed on 11 March 2010 and data were collected until 23 March 2011. Data on flux and flight altitude were collected on 78% of the days. In August 2010, data were recorded during only 2 of the 31 days. To compare results between OWEZ and K14, a similar radar set-up was simultaneously operating at the metmast at OWEZ. At this site data were collected on 89% of the days.

Statistical analysis of radar data

In order to determine whether MTRs and flight altitudes at K14 were significantly different among months, hours or diurnal periods, general linear models (GLMs) were used. Seasonal differences were not statistically tested, as seasons in fact provide a summary of monthly effects. Finally, mean proportions of all birds flying at risk altitude (25-139 m) were compared between K14 and OWEZ.

Attraction of birds and insects to the illuminated K14 platform

In contrast to the metmast and turbines at OWEZ, K14 is a lighted platform. This means that birds can be attracted to the lights on the platform. As a result, fluxes recorded with the radar at this platform can be elevated, when the radar is tracking birds approaching the platform and flying around it in circles. In some instances, attraction around the platform was indeed observed. A rough estimate indicated that attraction may have occurred on 5-10% of the nights at maximum in spring and autumn. Birds circling around the platform were however largely confined to an area that fell outside the two columns that were analysed (see §2.2.2). Therefore, tracks of birds circling around the platform, were mostly excluded from the presented flux. Attraction of birds from higher altitudes down to the platform was not observed in the data.

Merlin also recorded tracks of insects. These tracks were mostly found in summer and straight above the radar. Apparently, insects were also attracted to the illuminated platform at night, because numbers of tracks occasionally increased dramatically during hours of darkness. While at OWEZ the vast majority of insects was removed from the data because they fell outside the two columns that were analysed, this was not the case at K14. Accordingly, data with high concentrations of insects were removed from the database.

Visual observations

Similar to OWEZ, visual observations were used to obtain information on species composition, as well as species-specific fluxes and flight altitudes of birds flying at lower altitudes. Between April 2010 and March 2011, a total of 11 field visits was undertaken covering 29 observation days. Birds were observed visually by means of standardised observation protocols similar to those used at OWEZ. The main protocol was the panorama scan (see §2.2.2). During observations, panorama scans were carried out once every hour.

Additional observations

All species that were observed while at the platform were recorded. This included species recorded during additional observations in between panorama scans or beyond the panorama scan search area. Birds were occasionally recorded on the platform. Every morning the platform decks were searched for resting or dead birds.

2.3.3 Results on fluxes and flight altitudes further offshore

Species composition and abundance
A total of 87 species was recorded during observations from K14, plus an additional 19 species groups that could not be identified to the species level. During the panorama scans a total of 40 species and 14 species groups was recorded of which 47 species (groups) were observed in flight.

Species recorded at K14 included typical seabird species as well as terrestrial species that were on migration. Seabirds recorded abundantly included species such as Northern Fulmar, Northern Gannet, Great Black-backed Gull, Kittiwake and Guillemot, all of which were recorded in most months. Migrating terrestrial species were recorded both in flight and on the platform itself, mostly in spring and autumn. However, six wader species (Oystercatcher, Lapwing, Golden Plover, Woodcock, Snipe and Curlew) were recorded in February and were possibly undertaking migration in response to weather conditions. For a full list of species (groups) recorded during observations from K14, see Fijn *et al.* (2012).

The most abundant species that were seen flying during the panorama scans were Northern Gannet, Starling, Kittiwake, Great Black-backed Gull and Lesser Black-backed Gull. During the panorama scans in autumn a total of 38 species were recorded in flight. The fewest species (five) were recorded in summer. Similarly, the abundance of flying birds was highest in autumn and was over twice that of the other seasons combined. For the majority of species, the highest densities of flying birds were recorded during autumn (also for the seabirds). Exceptions were Common Scoter and Lesser Black-backed Gull that peaked in spring, and Common Gull that peaked in winter.

Gulls were the most abundant species group, making up half (49%) of all birds recorded (figure 2.34). Gannets (Northern Gannet) and land birds each constituted around 20% of all flying birds recorded. During autumn the relative abundance of each of these groups was 26% and 27% respectively. Land birds were recorded in very low numbers during the rest of the year and even in spring only represented 1% of all birds recorded. Over 5% of the flying birds recorded were alcids.

Species composition compared to OWEZ
In order tot allow a comparison with the results from OWEZ, results from Krijgsveld *et al.* (2011) have been reproduced here. The relative abundance of species groups differed between K14 and OWEZ (figure 2.34).

- Gulls made up around 65% of flying birds at OWEZ, whereas this was 49% at K14.
- The proportion of gannets was markedly greater at K14 (20%) compared to around OWEZ (2%).
- The preference of Great Cormorants for the coastal zone and structures on which to rest, such as are found at OWEZ, was clearly visibly with cormorants making op around 10% of flying birds at OWEZ and just 0.1% of birds at K14.

- More alcids were also recorded at K14 than at OWEZ, 5.4% compared with 0.8% respectively.
- Land birds (migrant terrestrial species such as passerines), made up 20% of flying birds recorded during panorama scans at K14, whereas closer to the coast at OWEZ around 12% were land birds. Although a greater proportion of the flying birds at K14 were land birds, the number of species and densities were lower.

Flight intensity recorded visually at K14 was lower than at OWEZ (see below under fluxes). Seven of the species that are typically found at sea had higher densities at K14 than at OWEZ. These species were Northern Fulmar, Northern Gannet, Great Black-backed Gull, Kittiwake, Guillemot, Razorbill and Little Auk. In comparison, just two migrant non-passerine species (White-fronted Goose and Lapwing) were recorded in higher densities at K14 than at OWEZ. The species composition of flying birds recorded visually at K14 was biased towards more pelagic species compared to OWEZ.

Although gulls were the most abundant species group recorded at both K14 and OWEZ, the proportions of each gull species recorded differed between the two locations. The main gull species recorded at K14 were Kittiwake and Great Black-backed Gull, whereas at OWEZ, Lesser Black-backed Gulls, Herring Gulls and Common Gulls were most abundant.

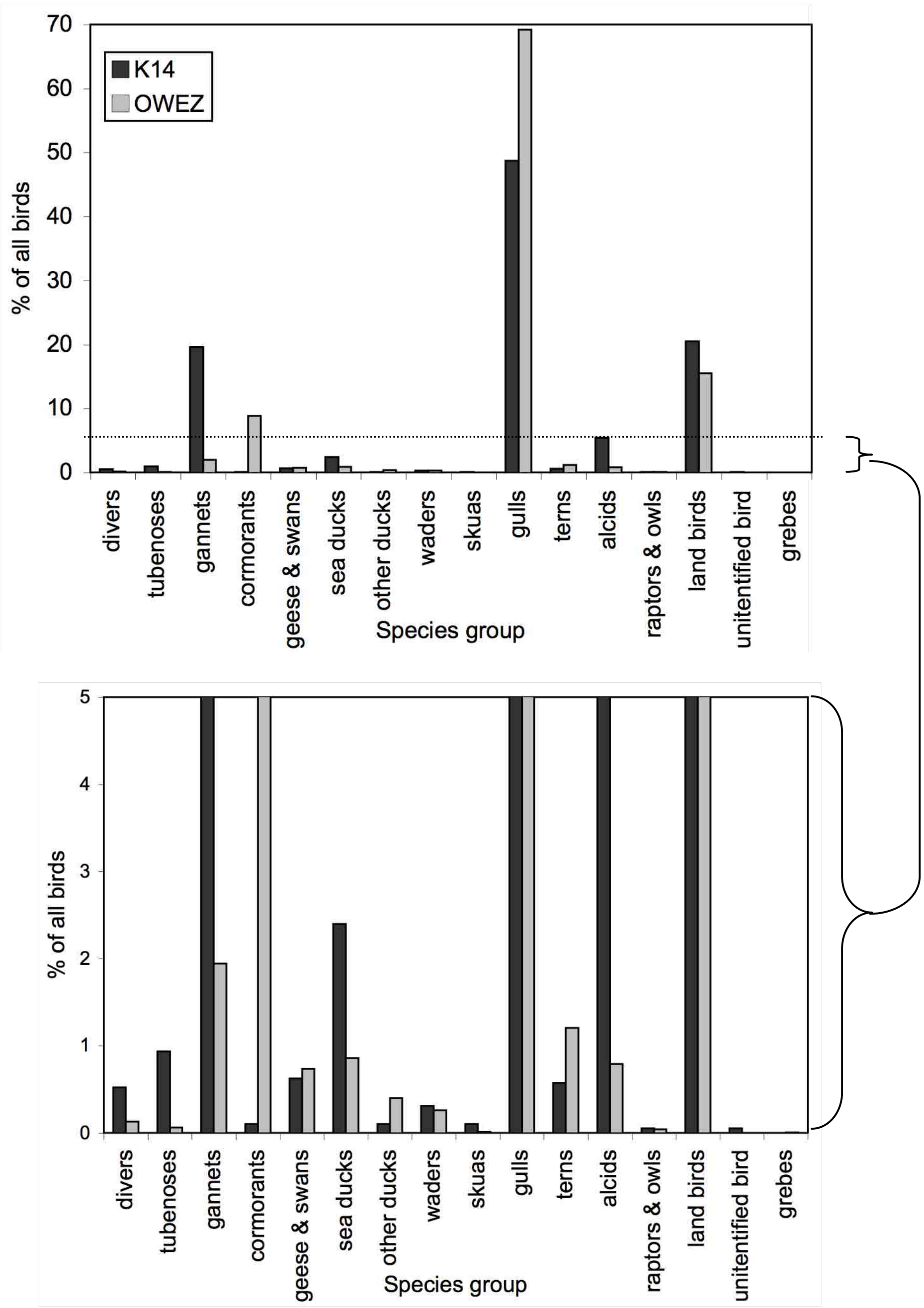

Figure 2.34 Relative abundance of species groups recorded in flight during panorama scans at K14 (black bars) and OWEZ (grey bars). The axis of the lower figure has been limited to 5% to enable comparison of species groups representing a low percentage of the total birds recorded. Data from OWEZ adapted from Krijgsveld et al. (2011).

Fluxes

The highest number of passing birds at K14 was registered by the vertical radar in March 2010 during spring migration. However, during the rest of the spring, numbers were low, while they increased in the course of the summer and autumn (figure 2.35). Interestingly, the migration peak in autumn was much less explicit. Numbers were clearly the lowest in the winter months. Expressing the overall numbers as mean traffic rate, resulted in a similar seasonal picture as the overall numbers (figure 2.35). The yearly mean MTR at K14 was 45 bird groups/km/hour, ranging from 14 bird groups/km/hour in May to 107 bird groups/km/hour in March 2010.

Considering the whole study period, an almost equal number of birds passed K14 during daylight and in darkness: 48% against 52%, respectively. However, a further specification of the records revealed a strong variance in diurnal flight intensity among months. During March and April, as well as during October and November, the percentage of birds recorded during darkness was above 50%, on average 68% in these months, with the maximum of 84% registered in March 2010. In the rest of the year, the proportion of night activity was generally lower. From May to September the proportion of nocturnal flights was only 25%. During winter the proportions were higher (on average 43%), increasing throughout the season, but remained below the values of the migration periods.

Fluxes compared to OWEZ

The yearly mean MTR at OWEZ (73 bird groups/km/hour) was higher than at K14 (45 birds/km/hour). At OWEZ the monthly mean MTR was lowest in January (10 bird groups/km/hour) and highest in September (160 bird groups/km/hour). MTRs measured at K14 and OWEZ were comparable in March and in the winter months (figure 2.35). Compared to K14, the difference in monthly mean MTRs between spring and autumn was more explicit at OWEZ. In both locations the standard deviation was lowest in winter, indicating a rather constant bird flux throughout the season. The largest fluctuations at K14 were recorded in spring and autumn, indicating the passage of large groups of migrating birds.

The diurnal variation in flight intensity, at OWEZ was comparable to that at K14 in summer and winter. Interestingly, however, during the spring months relatively more night activity was registered at K14 compared with OWEZ, whereas the opposite was observed during the autumn months. The diurnal variation in flight intensity was highly comparable between the two sites in spring, summer and winter. In autumn, flight intensities were similar during the day but the peak in flight intensity around sunset was much more prominent at OWEZ, and remained higher until shortly before sunrise (figure 2.36).

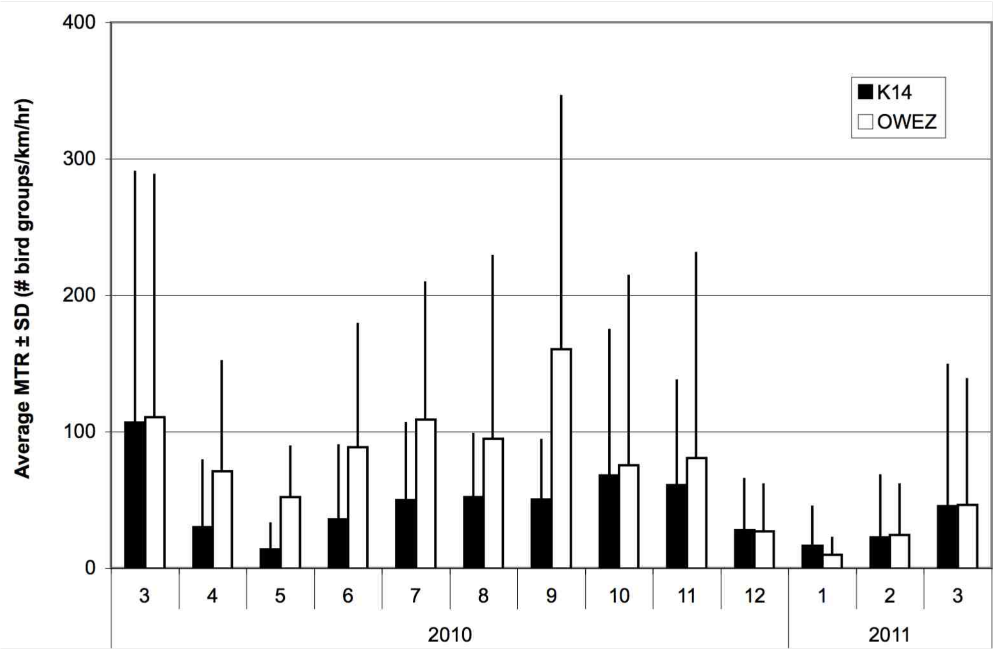

Figure 2.35 Mean traffic rate (number of bird groups/km/hour) per month registered at K14 (black bars) and OWEZ (white bars, as measured by vertical radar. Lines above bars represent standard deviations of the means.

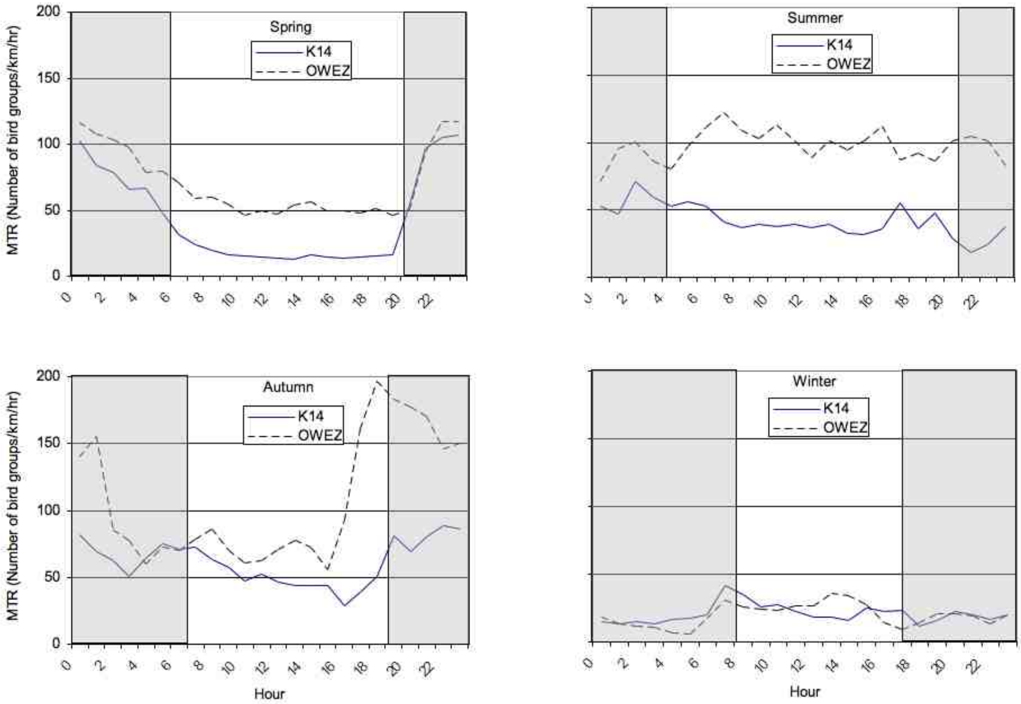

Figure 2.36 Diurnal variation in fluxes (number of bird groups/km/hour) averaged per hour in the four seasons at K14 (solid line) and OWEZ (dashed line). Shaded areas represent periods with darkness within a day in local time (time = GMT).

Flight altitudes

Below, first the overall patterns in flight altitudes as determined with the vertical radar are described, followed by the species-specific variation in flight altitude as determined by visual observations (panorama scans).

Considering the whole study period, most bird groups were detected in the lowest altitude band (0-69 m), corresponding to 49% of the total flux at K14. Above the lowest altitude band, the number of detected bird groups gradually decreased until the highest altitude. The measured MTRs showed a similar distribution per altitude band to the overall numbers. The high number of birds flying in the lowest altitude band was typical for all seasons at K14. The further division of altitude bands revealed a slightly deviating picture in the different seasons (figure 2.37). In spring a relatively high amount of bird movements were recorded between 69 and 277 m. In both spring and autumn, more bird movements were recorded above the lowest altitude band compared to summer and winter (figure 2.37).

Comparing the number of bird groups recorded at a certain altitude band during daylight hours and in darkness, revealed that in the lowest altitude class more birds were flying during daytime than during darkness (57% vs. 43%). In all other altitude bands more bird movements were registered during darkness than during daytime (figure 2.38).

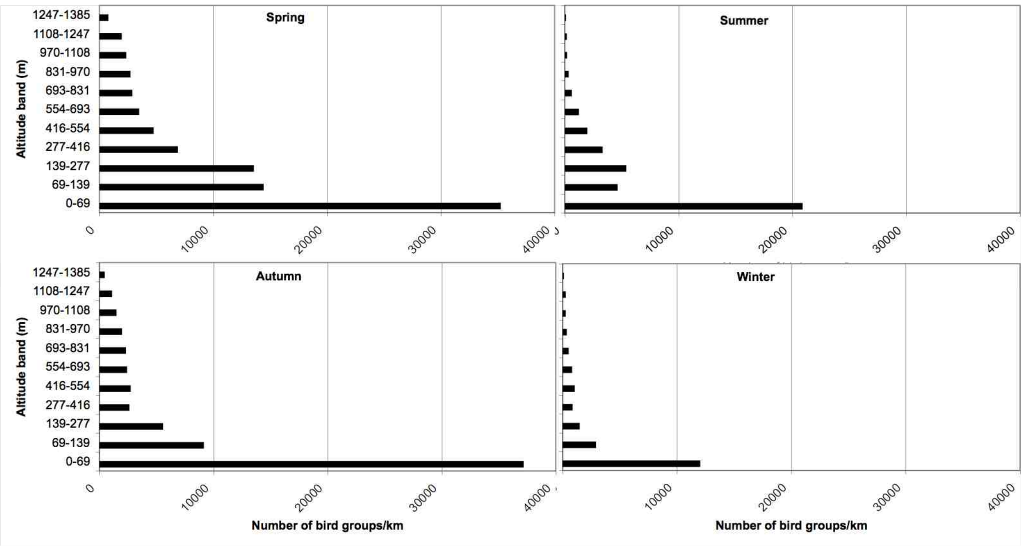

Figure 2.37 Number of bird groups/km registered by vertical radar at K14 in the four seasons divided in 11 altitude bands. Note that the two lowest bands are half the height of the other classes.

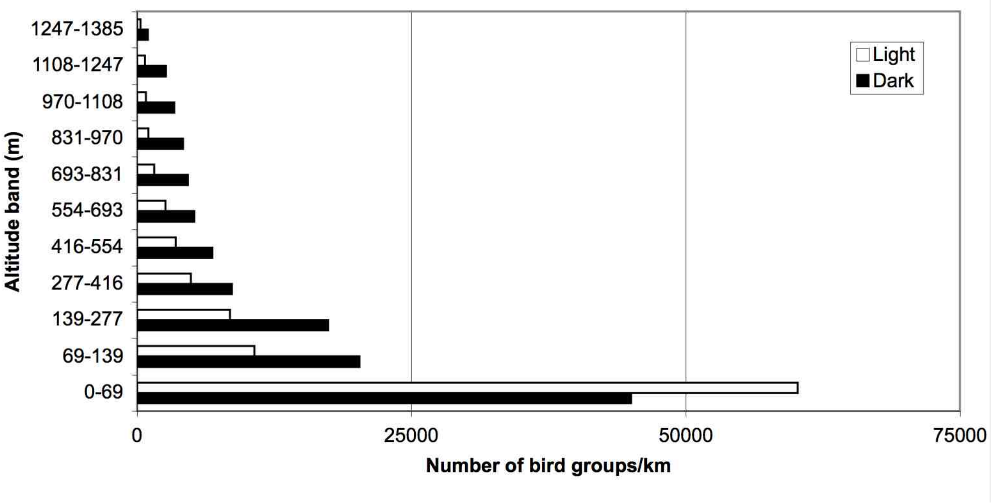

Figure 2.38 Number of bird groups/km registered by vertical radar at K14 during daylight hours (white bars) and in darkness (black bars) divided in 11 altitude bands. Note that the two lowest altitude bands are half the height of the other classes.

Flight altitudes compared to OWEZ

The proportion of birds groups that was registered at the individual height classes was highly comparable between K14 and OWEZ (figure 2.39). At both locations, by far the most bird groups were registered at the lowest altitude band (0-69 m): 49% of the total flux at K14 and 43% at OWEZ.

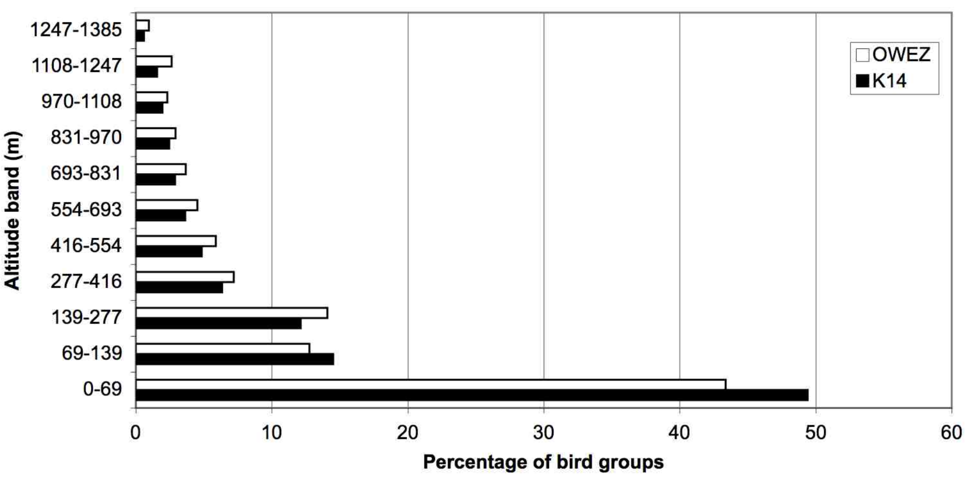

Figure 2.39 Percentage of the number of bird groups/km registered by vertical radar at OWEZ (white bars) and at K14 (black bars) for each of the 11 altitude bands. Note that the two lowest altitude bands are half the height of the other classes. Flight altitudes at K14 were highly comparable to those at OWEZ.

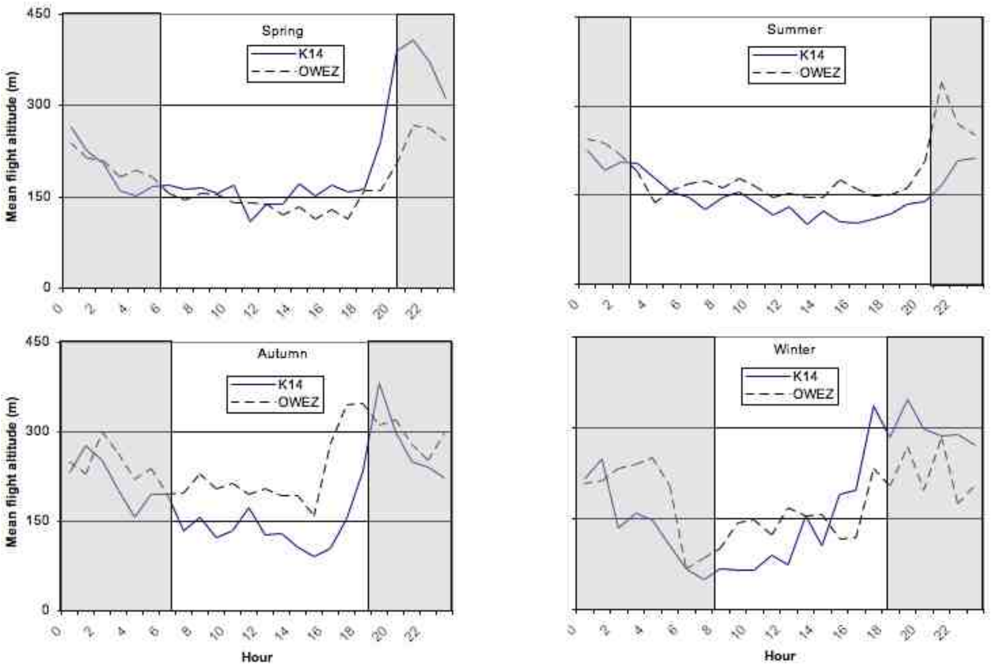

Figure 2.40 *Variation in mean flight altitude (m) at K14 (solid line) and OWEZ (dashed line) averaged per hour in the four seasons. Shaded areas represent periods with darkness within a day in local time.*

The mean flight altitude per hour registered by the radar in different seasons revealed a similar daily pattern at K14 and OWEZ. Patterns generally followed each other closely, sometimes with highly comparable values (figure 2.40).

Species specific flight altitudes

The average species-specific flight altitudes of (low) flying bird groups as recorded during the panorama scans are given in figure 2.41. Average flight altitudes varied between less than 1 m to over 60 m. The actual flight altitudes of some birds were often higher or lower than shown in the figure, as the heights presented are averaged for the distance and height category in which the bird was recorded.

The average flight altitude of divers was around 20 m, although most were under this height with an occasional high-flying bird (*c.* 50-100 m) recorded. The tubenoses (Northern Fulmar) were generally recorded below 20 m, as were seaducks, other ducks, waders, terns and alcids. Gannets (Northern Gannet) and cormorants were recorded at a range of heights, from under 10 m to over 60 m. The same was true for gulls, which were recorded across the widest range of altitudes (<5 to >80 m). Geese and swans were recorded at heights of between 45 m and 80 m. Raptors and owls were also recorded between 50 m and 75 m. The average flight altitude of land birds was around 30 m, although birds were recorded across a wide range of altitudes (higher altitudes not incorporated / visible in panorama scans).

Species-specific flight altitudes compared to OWEZ

The species (group)-specific flight altitudes of birds as recorded during the panorama scans at K14 and OWEZ (outside the wind farm) are given in figure 2.41. In general, the average flight altitudes of most species groups were largely similar at both K14 and OWEZ. For some species groups differences may be due to a small number of observations, for example geese & swans, other ducks, waders and raptors & owls. Gannets and cormorants were recorded at slightly higher altitudes at K14 than at OWEZ. On the other hand, terns flew somewhat higher at OWEZ than around K14. Land birds (mainly migrant passerines) were observed at 30 m altitude on average, due to the fact that with visual observations these small birds are missed at higher altitudes.

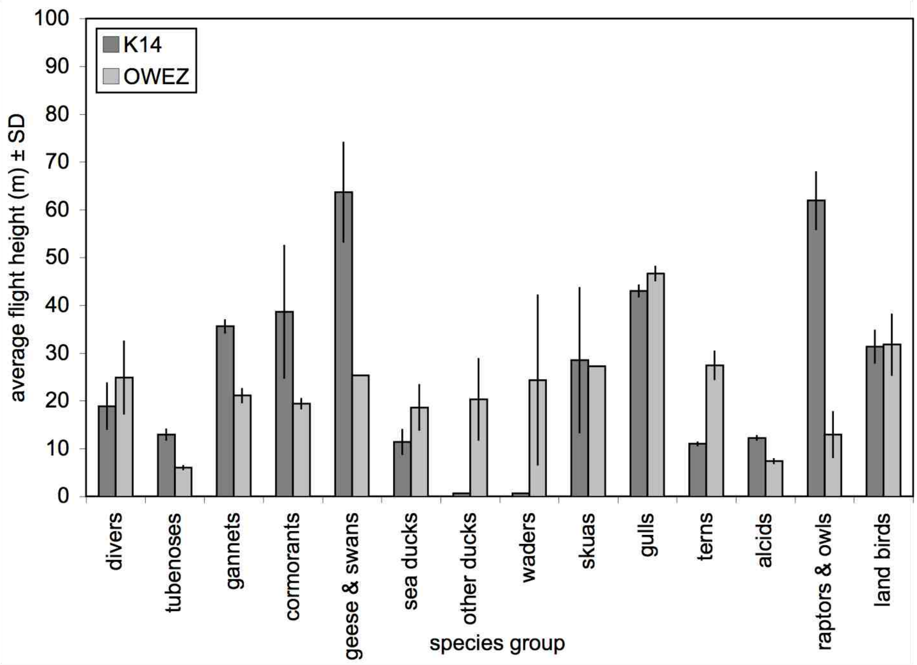

Figure 2.41 Average flight altitudes and standard deviations of species groups recorded in flight during panorama scans on K14 (dark grey) and the metmast at OWEZ (light grey). Data for OWEZ are only for birds outside of the OWEZ wind farm and were derived from Krijgsveld et al. (2011).

Numbers of birds at rotor height

For the OWEZ wind farm, the percentage of bird groups that flew at rotor height and that was therefore at risk of collision was estimated. To compare the flight altitudes at OWEZ with those at K14, a similar analysis of the distribution of flight altitudes at K14 was made (for the interpretation of the three risk-classes see §2.2.3). Note that the OWEZ-data presented here are from a different period than the data presented in §2.2.

At K14, 41% of the bird groups flew in the high-risk zone, 23% flew in the intermediate-risk zone and 36% flew in the low-risk zone (figure 2.42). The highest proportion of bird movements at high-risk height was recorded in autumn (47%) and the lowest in summer (35%).

Numbers at rotor height compared to OWEZ

The distribution of bird groups over the three risk groups was comparable for K14 and OWEZ (figure 2.42). Slightly fewer birds were flying through the high-risk zone at OWEZ compared to K14. The highest percentage of bird groups flying at the high-risk zone at OWEZ was recorded in winter (48%), against autumn at K14 (47%).

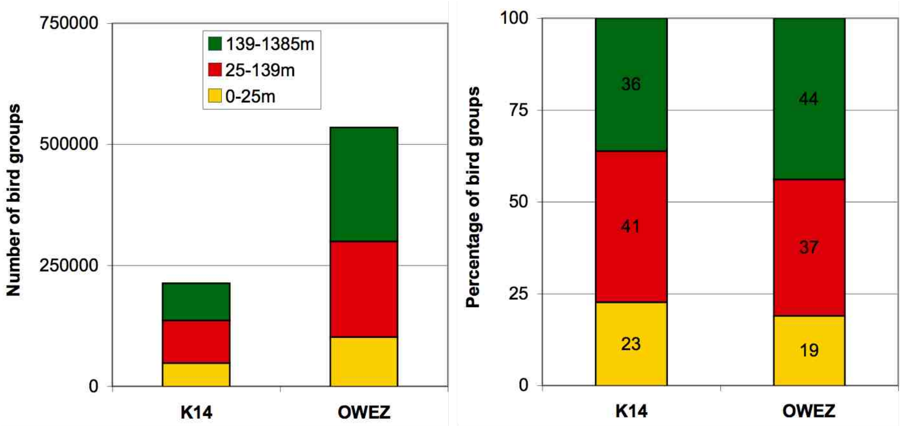

Figure 2.42 Number (left) and percentage (right) of bird groups/km registered by vertical radar (not corrected for interruptions) at K14 and at OWEZ divided in three risk categories. The category 25-139 m represents the class with highest risk of collisions with wind turbines.

2.3.4 Conclusions

Species and numbers of birds

In comparison with OWEZ, pelagic seabirds, such as Northern Gannet, Kittiwake and the alcids, were more abundant at K14 than at OWEZ. Coastal species, such as Lesser Black-Backed Gull, Herring Gull, terns and Great Cormorant, were more abundant at OWEZ. The numbers of birds recorded at K14 were generally lower than at OWEZ. This may at least partly be the result of the location of K14 being farther from the Dutch coast. Except for the first half of the nights in spring, also the passage rates during migration as recorded with the radar were higher at OWEZ. Due to the smaller distance to the shoreline, at OWEZ also migrating birds that follow the coast did pass, whereas this is not the case at K14. In addition, part of the birds that migrate from Scandinavia above open water in the middle of the North Sea, can also cross the coastal zone back to land, elevating the cumulative numbers there, and thus also at OWEZ.

At OWEZ migration was strongest in autumn, while at K14 migration in spring was more profound. This can largely be explained by the main migration routes along the

Dutch North Sea. In autumn the main migration routes follow the Dutch and British coasts, explaining the strong autumn migration at OWEZ and the weaker autumn migration further from the coast at K14 (see also §4.2).

Seasonal variation

Based on the radar observations, the highest number of birds passed K14 in March, during spring migration, and not during autumn migration as at OWEZ. Although not many land birds were seen in March during the visual observations, the radar recorded the highest activity during the night, and thus out of scope of the visual observations. This elevated night activity, together with elevated flight altitudes during the night, also indicated intensive migration in March.

In summer and especially in winter, at both locations lower proportions of nocturnal flights were recorded than in the migratory seasons. This likely reflects that in summer and winter mainly local seabirds were present being active during the day, without large fluxes of night migrants passing by. The total number of birds in summer was comparable to those in spring and autumn. However, the higher proportion of night activity and the higher mean flight altitude during the night in autumn indicates that a larger part of the recorded bird movements were migrating birds, while in summer mostly local seabirds were recorded during daytime without elevated flight altitudes during the night. Finally, the numbers in winter were clearly the lowest of all seasons.

Flight altitudes

Altogether 49% of the birds flew in the lowest altitude band of 0–69 m at K14, most of which (*i.e.* 57%) during daylight. At all other heights more birds flew during the night, resulting in a nearly equal number of birds passing K14 during daylight and in darkness. However, the higher flight altitudes during the night mean that relatively fewer birds flew at risk height in the dark when birds might be more prone to collide with obstacles. On the other hand, comparing the recorded flight altitudes of birds based on the radar observations at K14 and OWEZ, revealed a higher mean flight altitude closer to the coast at OWEZ. This could be caused by the relatively higher proportion of migrants recorded at OWEZ.

Implications regarding effects of wind farms

Based on the findings from visual and radar observations undertaken at K14, the density of flying birds at the Dutch North Sea was lower farther offshore (80 km from the coast) compared to 10-18 km from the coast at OWEZ. The proportion of birds flying at rotor height in the altitude band of 25–139 m, forming the highest risk altitude for birds to collide with a wind turbine, was similar between the two locations, but the mean flight altitude was higher at OWEZ. All in all, in terms of offshore wind farms, mainly due to the lower fluxes at K14, fewer potential collision victims are expected far offshore.

Additionally, avoidance rates of structures such as wind turbines, which have a large influence on the actual numbers of birds at risk of collision, are species- and location-specific. The species that were more abundant at K14 further offshore than at 10-18 km offshore at OWEZ are especially pelagic seabirds such as Northern Gannets and auks/guillemots, and these were found to show higher avoidance of the OWEZ wind farm. Altogether, the lower overall number of birds at K14 and the higher abundance of seabirds showing strong avoidance behaviour, probably leads to a lower collision rate at K14 compared to OWEZ. Nevertheless, in order to fully assess the potential collision risk to species at wind farms far offshore, species- and location-specific studies will be needed, specifically addressing the responses to wind turbines in areas far offshore and under the conditions that prevail there.

2.4 Cumulative effects

In this paragraph we summarise the study that was performed to estimate the effect of multiple offshore wind farms at the population level of different bird species (calculated for the Dutch North Sea and for ten hypothetical offshore wind farms similar to OWEZ). The study is reported in Poot *et al.* (2011a). The model calculations performed in this study are based on the results presented in Leopold *et al.* (2011) and Krijgsveld *et al.* (2011), which are summarised in §2.1 and §2.2 above. The study on fluxes further offshore (§2.3 above) was not available when cumulative effects were calculated.

2.4.1 Introduction

Within the framework of the Monitoring and Evaluation Program (NSW-MEP), baseline studies (Leopold *et al.* 2005; Krijgsveld *et al.* 2005) as well as effect studies (Leopold *et al.* 2011; Krijgsveld *et al.* 2011) have been carried out to measure the impact of the Offshore Wind farm Egmond aan Zee on birds. Those studies describe the impact of a single wind farm. In this study an attempt was made, for the first time, to estimate the cumulative effects of multiple offshore wind farms in the Dutch part of the North Sea on the population levels for a range of bird species.

The Offshore Wind farm Egmond aan Zee was the first offshore wind farm built in the Netherlands, with a second one completed one year later (but not studied by Krijgsveld *et al.* (2011)). The Dutch government supports plans to build more turbines at sea in the coming years. Single wind farms might have a minor impact on reproduction and survival (and thus population sizes) as shown in several studies on single wind farms. However, the construction of multiple wind farms at sea has the potential to cause significant effects on survival and reproduction, which could potentially lead to a decrease in populations at the wider (international) scale. With plans and proposals for expanding the number of wind farms in the Dutch part of the North Sea, the question was:

- What are the cumulative effects (as quantitative as possible) of multiple wind farms in the Dutch North Sea on the population levels of bird species?

2.4.2 Methodology

Two scenarios

This study represents the first attempt to model the cumulative effects of multiple offshore wind farms on the population level for a range of species. The cumulative effects on birds were derived on the basis of impacts measured at OWEZ during the effect study in 2007-2010 (Leopold *et al.* 2011; Krijgsveld *et al.* 2011). This impact was extrapolated for multiple wind farms on the Dutch continental shelf. Two scenarios were considered, the first with multiple wind farms nearshore (all comparable in their effects with OWEZ) and the second with multiple wind farms scattered in deeper offshore waters (partly comparable with OWEZ and partly corrected for differences in species composition and abundance). These scenarios of multiple wind farms were based on having ten extra wind farms in the configuration of OWEZ. For the nearshore scenario it is clear that data from OWEZ are representative since the same bird communities might be expected. For the offshore scenario, however, turbines will be raised in waters deeper than 20 m. Here the bird community might differ from OWEZ, so results from OWEZ are not to be translated directly. Despite these difficulties an attempt was made under strict assumptions.

Extrapolating findings OWEZ to a wider nearshore situation

The first scenario that wind farms are developed in the nearshore zone along the Dutch coast can be studied under the assumption that multiple offshore wind farms will be developed in more or less the same area that OWEZ is situated in and with:

- a species composition and behaviour being very similar to OWEZ;
- a comparable size and configuration of the multiple wind farms as OWEZ;
- the effects of multiple wind farms being additive, due to sufficient distances between the wind farms.

A scenario of ten wind farms was modelled to yield a tenfold increase in the number of related collision victims for the relevant species. In the effect study at OWEZ (nearshore) no significant displacement effects have been found (Leopold *et al.* 2011). Both radar and visual observations have indicated that some seabird species clearly avoid the wind farm (e.g. Northern Gannet, alcids), while others, including the most numerous species present (e.g. gulls and cormorants), show almost no avoidance of the OWEZ wind farm. Although the extrapolation of the findings of OWEZ for a nearshore scenario are limited, we know that it is highly unrealistic that scenario 1 would be realised as many other activities, such as military areas, shipping lanes and mining, prevent the construction of more offshore wind farms in the nearshore areas of the Dutch coast.

Extrapolating findings OWEZ to an offshore situation

A major problem for the extrapolation of the findings of OWEZ for the second scenario of multiple wind farms further out at sea is that another seabird community than that found at OWEZ, will be present in and around such wind farms (Leopold *et al.* 2011). As no comparable data to those gathered in the effect studies in and around OWEZ are available for these offshore areas it is unknown how the fluxes of flying birds differ to the nearshore situation. In order to be able to calculate the potential impacts of an offshore scenario, a long-term database of aerial surveys available for the total Dutch North Sea was used, in order to translate the findings of OWEZ to a situation involving another seabird community. One limitation that remains is that it was unknown whether the proportions in numbers present of different species, as determined by aerial surveys, reflects the proportions of the fluxes of different species, and in turn the potential number of victims. However, the majority of species involved are those that forage in flight, such as Northern Gannet, skuas, gulls and terns. The number of collision victims can only be calculated under the assumption that the numerical proportion has a strong correlation with the amount of activity of the species.

Calculations were carried out using the Band model assuming a similar total number of seabird victims per wind turbine as calculated for OWEZ and taking into account the species specific avoidance behaviour as determined by Krijgsveld *et al.* (2011). Of course, this exercise is of highly speculative nature. Nevertheless, in the light that the aerial database of the total Dutch North Sea represents the most appropriate data currently available, it was chosen to make this first attempt and the observations from OWEZ were applied to other areas further offshore. In addition, the offshore scenario 2 is more likely to be developed than the nearshore scenario 1.

Species of interest

The study focused on seabirds and to a lesser extent also deals with migrant species (passerines, waders, etc.). The seabirds considered are those that breed in coastal areas in the Netherlands (e.g. cormorants, gulls and terns) and those that migrate or winter in the Dutch North Sea (e.g. divers, Northern Fulmars, Northern Gannets, ducks, gulls and alcids). Because some species groups or species have a higher ecological relevance than others, based on for instance abundance in the area and in respect to population size, the study focussed on the species listed in table 2.6. The main argument for the selection of species and species groups is that, based on the monitoring, those species are more or less abundant in the area of the wind farm at least part of the year. Some species have been added to the list as they are considered as vulnerable and/or relevant in relation to international conservation policy. For each species group a flag species was selected for which the population model was built.

Table 2.6 Selection of the species groups of birds for which cumulative effects were thoroughly studied based on population models of selected flag species. Assessment of cumulative effects for other species was based on the outcomes of these selected species (groups).

Species (group)	flag species
local and migrating marine birds	
Great Cormorant	Great Cormorant
divers	Red-throated Diver
alcids	Guillemot
Northern Gannet	Northern Gannet
seaducks	Common Scoter
other ducks	Shellduck
terns	Sandwich Tern
large gulls	Lesser Black-backed Gull
small gulls	Little Gull
skuas	Great Skua
migrating birds	
swans	Bewick's Swan
geese	Brent Goose
waders	Knot
thrushes	Redwing
Starling	Starling

Population models

The cumulative effects were assessed at the population level with the aid of population models. The approach consisted of constructing population models, which were tested alongside known population trends. The data used in constructing the models were obtained from both published and unpublished field studies from the relevant populations, and included parameters such as reproduction rate, mortality by age class, age at first breeding, proportion of non-breeding birds, *etc*. The potential effects of a number of wind farms, such as an increase in mortality, could then be applied to these population models.

A multi-step modelling approach was adopted in order to estimate the cumulative effects on the population levels of seabirds:

1. Construction of population models for the species concerned, which describe the known population trends in recent decades; the **0-model**.
2. Calculating the levels of species-specific mortality resulting from two scenarios (nearshore and offshore) of multiple wind farms in the Dutch part of the North Sea; the **SNH Band model**.
3. Application of the levels of increased mortality to the 0-models. The results provide an indication of the size of the effect of multiple wind farms at the population level; **effect-model**.
4. Calculating the amount of additional mortality needed in order to reach zero growth in each of the 0-models. This provides an indication of the level of

additional mortality that could be sustained by the population without showing a decline; **0-growth-model**.

5. Calculating the maximum sustainable harvest (e.g. the number of victims that can be sustained by the population without serious effect on the population size), by means of the **Potential Biological Removal (PBR) approach**.
6. Finally, comparing the outputs from the steps 3, 4 and 5 in order to provide a number of different viewpoints into the cumulative effects of multiple wind farms at the population level.

The methods described above are based on known techniques that have been proven in earlier studies with similar questions. Population models were based on Leslie matrix models. These are relatively simple, robust models describing the change of a population through time based on reproduction, survival, immigration and emigration (Caswell 2001). Population modelling is generally done by the projection of vital population parameters over time (Perrins 1991; Akçakaya *et al.* 1999). If an accurate historical record of population size is known, a model describing the historical population size can be constructed and validated. Under the assumption that the same population parameters (and their relative importance) describe the population size in the future these models can be used to quantify the effect of changing vital rates on a population size. The size of a population increases by births and through immigration while deaths and emigration decrease the size of a population according to:

$N_{t+1} = N_t + \text{births} – \text{deaths} + \text{immigration} – \text{emigration} = R * N_t + N_t$

Where:

t = time step

N = population size

R = net per capita rate of recruitment

If the vital parameters of a bird population (births, deaths, immigration and emigration) and the size of a population at the start (N_0) are known, the equation can be projected over several time steps (years) to produce a population size over time. If R is >0 the population size will increase (exponential), if R is <0 the population size will decrease and if R is 0 the population size will be stable.

The growth of animal populations is limited (*e.g.* Newton 1998; Perrins 1991). Feedback mechanism usually occur where the rate of reproduction or deaths is related to the size of a population. A very common feedback mechanism is the decrease of reproduction rate with increasing population size. If a population grows, the pressure on resources (*e.g.* food to feed chicks or space to breed) becomes larger thereby increasing the competition between individuals of that (and sometimes other) population(s). At a certain point the consequences of this increased competition affects the individual either through reduced productivity or increased mortality. The consequences of (heavy) competition on individuals can be seen at the population level and is called density dependence. How this mechanism affects different species determines the different type of feedback mechanisms seen in different populations.

For each species a model was built with three stages (first year, sub adult and adult) where average yearly vital rates are used to predict the historical population size through time (figure 2.43). If stochastic variation on demographic rates was available, this was used to examine the effect of fluctuation on the results. Carrying capacity (K) is used to calculate the density dependence in the model, where adult reproduction is related tot population density and where density dependence affects the reproductive rates. The value of K was set at the maximum of the measured population size. Models describing the population size through time were run 100 times allowing stochastic fluctuation. Output graphs were produced where 25/50/75 percentiles per year were drawn as model results, thus allowing insight in the effect of demographic stochasticity on the output of the models (figure 2.44). No environmental stochasticity was taken into account.

Some species have a population structure where a considerable group of the adults within the population does not participate in breeding during each annual cycle. These individuals are known as floaters. This group of individuals does function as a buffer in a population and can compensate for increased mortality among breeding adults (figure 2.43). This leads to a stable breeding population whereas the fluctuations are transposed tot the group of non-breeding adults (floaters).

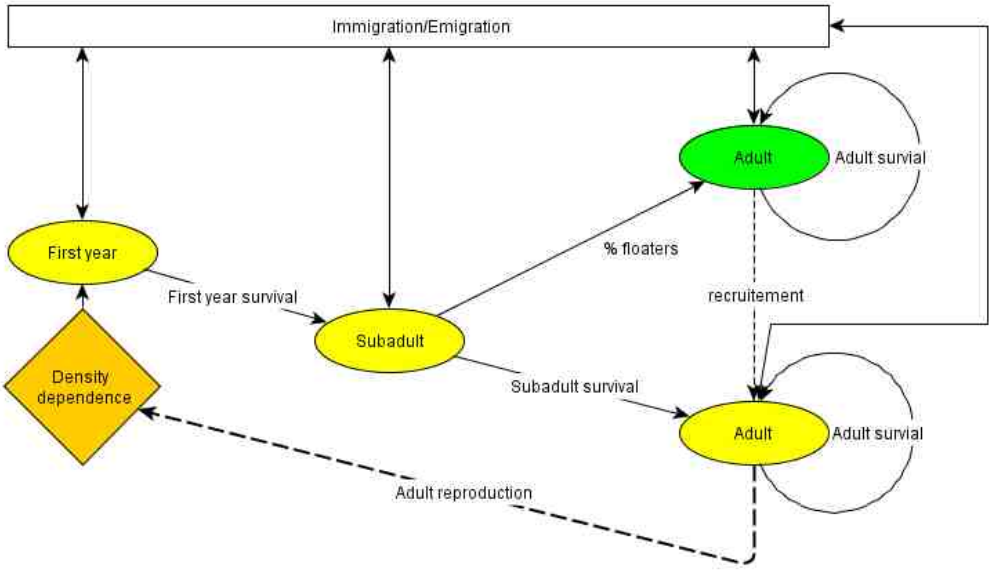

Figure 2.43 Model layout with density dependence and floaters.

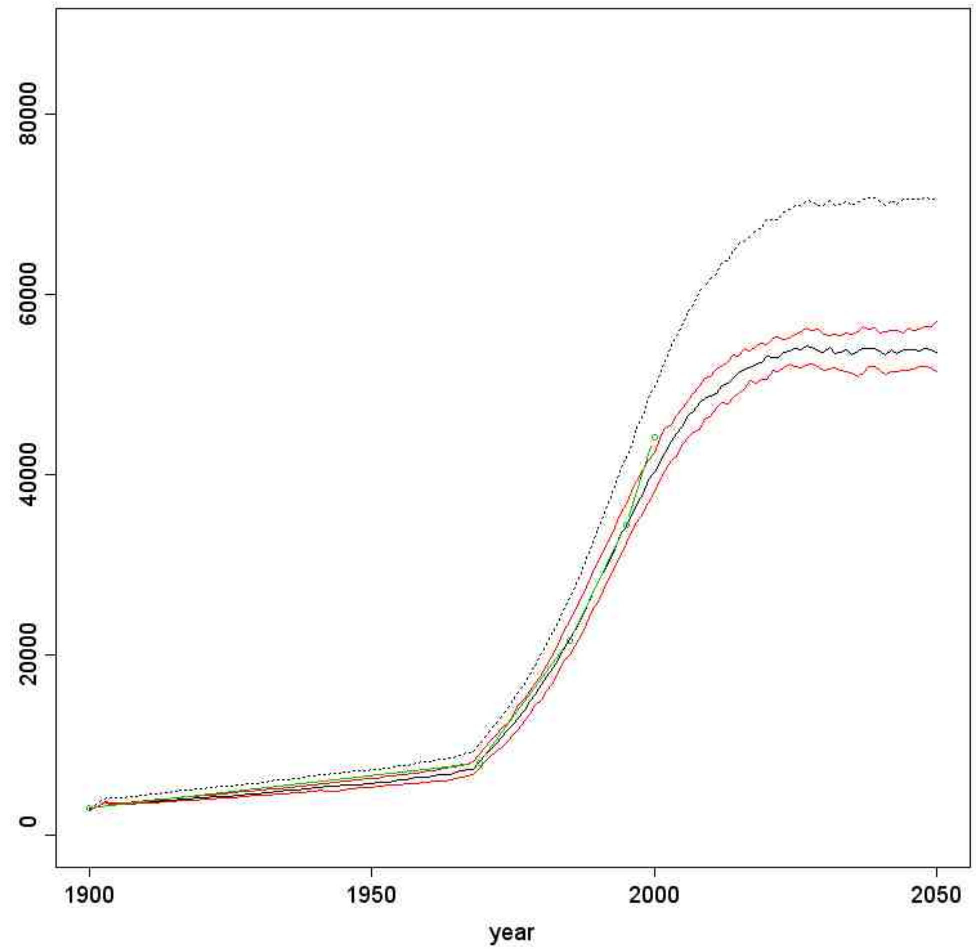

Figure 2.44 Output figure of the 0-model of the Northern Gannets on Bass rock. Counted (green circles and line) and modelled population trend for the Gannet in numbers of pairs (black line = median; red lines = 25 and 75 percentile; black broken line = floater pairs 30%).

Scenarios with increased mortality can be evaluated with the models. Effectively the victims are breeding birds only and they are replaced with floaters when these are available. If the floater surplus is <=0, the number of floaters is set to 0 and the chance to become a floater is set to zero, this is done to prevent adult breeders to emerge in the floater stage after this stage is consumed by loss of breeders. If birds in the floater stage are all transformed into breeders, the model effectively becomes a model without a floater stage. For each species, population models were constructed with 0, 10 and 30% floaters. As in many cases for the seabird species occurring in the Dutch part of the North Sea no information is available on the percentage of floaters. Therefore it was chosen to use conservative floater percentages of 10 and 30% when modelling future trends in breeding birds incorporating increased mortality due to wind farm impacts. Poot *et al.* (2011a) found in their literature review a total of 36 out of 46 seabird studies with a floater percentage higher than 30%.

Where possible, parameter values from Dutch breeding populations were used. Where this was not possible, either as the species does not breed in the Netherlands or as appropriate figures were not available, data from populations in other countries were used; most notably from Belgium, Germany, Ireland, Norway and United Kingdom. For these species, it was assumed that the populations of these species breeding within the North Sea basin would have similar parameter values and be influenced by similar factors to those birds occurring in the Dutch North Sea region.

SNH Band model

Estimates for the numbers of collision victims for each species for each scenario were calculated using the SNH Band model within a Route 3 model (Band *et al.* 2007; Troost 2008). The Route 3 model provides a way of estimating the numbers of birds that will pass through the rotor-swept areas of a wind farm based on the ecological and physical characteristics of both the wind turbines and the species in question. The SNH Band model can then be used to calculate the probability of collision of a certain species passing through this rotor-swept area, again on the basis of the physical characteristics of the wind turbines and the species in question. This collision probability and numbers of birds at risk can be combined to provide an estimate of the total numbers of collisions for each species for the entire wind farm for a specified period of time. An important aspect in calculating the overall collision probability is the level of avoidance that the bird species demonstrates. The Route 3 model is shown below, where ‘p’ can be calculated with the SNH Band model:

$$c = b * h * a\_macro * r * e * a\_micro * p$$

Where:
c = collision (and thus mortality) rate
b = number of birds crossings per time (usually one year)
h = fraction of birds at rotor height
a_macro = rate of avoidance of the entire wind farm
r = ratio of rotor area to side area of entire farm
e = number of turbines per crossing
a_micro = rate of avoidance of individual turbines
p = probability of collision when travelling through rotor-sweep area (here calculated using the SNH Band model)

In the OWEZ field studies both radar and visual data were used to determine the level of avoidance (macro- as well as micro-avoidance). This was combined with species (group)-specific fluxes determined with the same combination of visual and radar observations (see §2.2), so the number of collision victims at OWEZ could be calculated using these data. The SNH Band model is known to be very sensitive for small changes in the avoidance rate (Chamberlain *et al.* 2006), with a 10% reduction in avoidance leading to an increased collision risk of over 2500%.

Migrant passerines passing the area reached high numbers in spring and autumn and dominate the number of estimated collision victims (Krijgsveld *et al.* 2011; §2.2). Approximately one million flocks of migrating passerines passed the OWEZ area at rotor height. Flock size varied between 1 and >5000 individuals (Starling). Among passerines, rough estimates suggest an order of magnitude of some hundreds of collision victims on an annual basis, among all species of birds passing the area. In this study the SNH Band model was used to calculate the numbers of victims of a cumulative scenario of 11 wind farms similar to OWEZ in the Dutch part of the North Sea. For passerines no distinction could be made between the nearshore and the offshore scenario as no data are (yet) available on fluxes of migrant birds offshore.

Worst case scenario

Throughout the study a worst case scenario approach was followed:

- As a precautionary approach all victims were attributed to females with breeding status. For Dutch breeding populations the modelling also did not take into account potential collisions of birds of a foreign origin outside the breeding season (thus outside of the modelled populations) or potential collisions of birds of a non-breeding, juvenile or subadult status.
- For seabird species breeding outside the Netherlands, impacts of new Dutch offshore wind farms are concentrated to one restricted population (mostly Scotland), while in reality a much wider breeding range with 'different populations' might be involved.
- In most models a floater population of 10 or 30 % has been chosen. Literature research has shown that in many long-lived species higher percentages can occur, meaning that a larger buffer function could be present in the floater population.
- In the models used, density dependence is modelled in relation to reproduction only. Density dependence can also act on mortality via the process of intra-specific competition between individual birds outside the breeding season. In case the carrying capacity decreases the intra-specific competition on resources will increase, with the consequence of a potentially lowered survival of birds. This would imply that in this situation the victims occurring due to human-related impacts such as from collisions with wind turbines could have a so-called compensatory effect, as victims taken out from the population will reduce the intra-specific competition.
- The number of calculated collisions put into the population models have been kept stable over the years, assuming that a decrease in the population due to collisions does not affect the intensity of flight movements in and around wind farms. This situation is possible in case wind farms are developed in high quality foraging areas with birds shifting from low quality areas to these high quality areas.

The Potential Biological Removal approach

If the problem is approached from the viewpoint of a bird population using the North Sea we could turn around the question and try to answer the question: At what impact (number of victims, increased mortality) is the effect on a bird population unacceptable large? The results of this approach can be compared with the outcomes of the effects calculated via the species-specific population models (effect-model and zero-growth model).

To answer the before-mentioned question, the approach of Lebreton (2005), Niel & Lebreton (2005) and Dillingham & Fletcher (2008) was followed. Dillingham & Fletcher

(2008) express the number of additional casualties (increased mortality) that can be sustained each year by a population as the Potential Biological Removal (PBR):

$PBR = 0.5 * R_{max} * N_{min} * rf$

Where:

R_{max} = maximum annual recruitment rate
N_{min} = a conservative estimate of population size
rf = a recovery factor between 0.1 and 1

For further details see the original report (Poot *et al.* 2011)..

Effects of offshore wind farms

The potential negative effects of wind farms on birds, e.g. collision, disturbance and barrier effects, can have a negative impact on the survival and/or reproductive output of individuals, which in turn can be reflected in their populations. This may especially be true if numerous wind farms are present within the distribution range or flyway of a species. During surveys of local birds around OWEZ, no significant displacement of foraging birds by the wind farm was identified. Nevertheless, there are indications that the distributions of some species have been altered due to the loss of habitat associated with the wind farm. Little is known on barrier effects, although the increased energetic costs of flying around a wind farm or the possibility that birds decide not to utilise the area beyond a wind farm may reduce their reproductive output or in extreme cases reduce survival.

For each type of effect, collisions with turbines, disturbance and barrier effects, both a most realistic effect scenario based on the outcomes of the field research at OWEZ was modelled, as well as a maximum effect scenario. In the latter case all birds affected were assumed to be lost from the population. in the case of collisions this is a realistic assumption. In the case of disturbance and barrier effects, mortality of all birds affected is only expected in situations with a strictly limited carrying capacity in which the loss of an area of habitat would result in the death of all birds that use that area. In a situation of many increasing populations this is unlikely to be the case, so maximum effect scenarios presented in this report are unrealistic. they give us a first indication about the limits of maximum impact.

The observations gathered around OWEZ are not suitable for directly assessing the consequences of barrier effects or disturbance at the population level. Therefore, the 0-growth model and the PBR-approach were used to get an idea about maximal (acceptable) levels of additional mortality, for a few species that might be affected by wind farms through disturbance (e.g. Guillemot, Razorbill, Northern Gannet and Greater Skua) or the occurrence of barrier effects (Bewick's Swan and Brent Goose).

2.4.3 Results on cumulative effects

Collision victim estimates

For the nearshore scenario the number of estimated collision victims is a matter of applying a tenfold increase in the figures of the Band model calculations as presented in table 2.5 in §2.2. For the offshore scenario the calculations are less straightforward because the species-specific fluxes further offshore might differ from these at OWEZ.

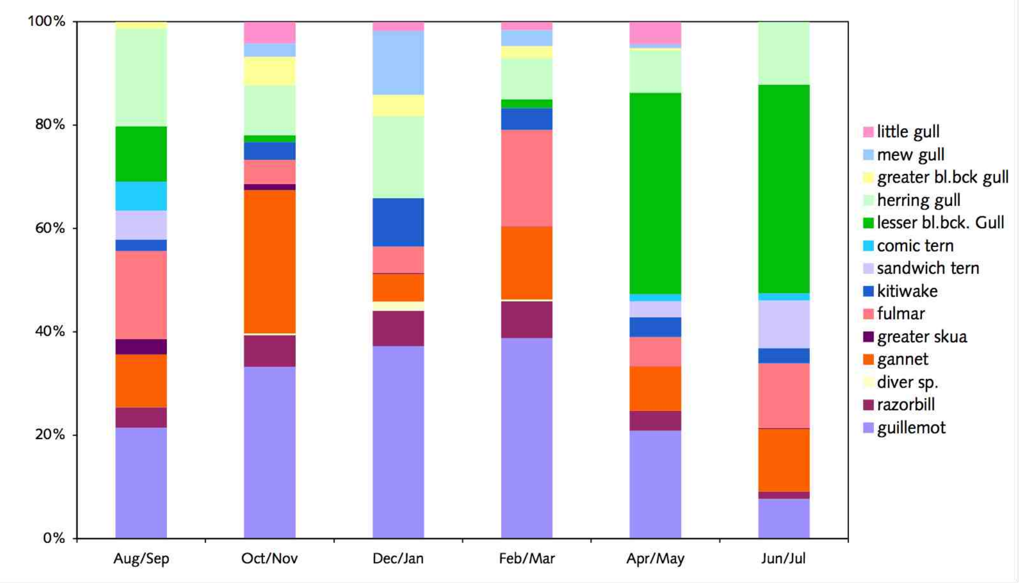

Figure 2.45 Composition of the seabird community present offshore in the course of the year in bimonthly periods (excluding seaducks) based on an analysis of the long-year monitoring of seabirds in the Dutch part of the North Sea (Arts 2010, additionally analysed by Poot et al. 2010).

The fluxes that were incorporated in the Band model calculations were determined using the long-term aerial monitoring dataset available for the Dutch part of the North Sea (Arts 2010; figure 2.45). Using this dataset and the data gathered at OWEZ, species-specific fluxes of seabirds were estimated for the offshore scenario (see also §2.4.2). The outcomes of this approach should be treated as a preliminary analysis of collision for a multiple offshore wind farm scenario. Collision victim estimates based on Band model calculations for both scenarios are shown in table 2.7.

Table 2.7 Total number of estimated collision victims on the Dutch North Sea with ten more offshore OWEZ wind farms developed; a nearshore scenario and an offshore scenario. Numbers of casualties are calculated following the Band model approach. For low-flying Guillemot, Razorbill and Fulmar no casualties are expected offshore. Fraction at sea is based on the extensive dataset of the long year aerial monitoring of the Dutch part of the North Sea (Arts 2010, Poot et al. 2010). See §2.4.2 and Poot et al 2011a for explanation of the calculation methodology.

			total # collision victims in 1 year	
Species	**fraction at sea**	**fraction of risky species**	**Scenario 1 in OWEZ area**	**Scenario 2 outside OWEZ**
Black-headed Gull	0.001		131.5	0.1
Commic Tern	0.014	0.024	2.8	60.5
diver sp.	0.004	0.007	1.8	9.2
Fulmar	0.104		0.1	0.1
Cormorant	0.010	?	332.2	?
Northern Gannet	0.134	0.232	17.2	199.2
Great Black-backed Gull	0.024	0.041	209.4	134.9
Great Skua	0.008	0.014	0.8	39.6
Guillemot	0.269		0.1	0.1
Herring Gull	0.120	0.207	585.6	698.1
Kittiwake	0.043	0.074	345.6	217.1
Lesser Black-backed Gull	0.153	0.264	776.8	875.8
Little Gull	0.021	0.037	172.3	75.1
Common Gull	0.030	0.052	355.7	152.7
Razorbill	0.049		0.1	0.1
Sandwich Tern	0.028	0.049	28.8	154.5

Species specific population information and effects

The reliability of the constructed species-specific population models, depends largely on the amount and quality of information available on the parameters incorporated in the models. Sometimes the lack of quantitative information on parameters made that some to almost all desired models could not be constructed. Table 2.8 provides an overview of the models that were constructed per species (group). The results of the model calculations and the conclusions regarding the cumulative effects on population levels are summarised in table 2.9. In this table the species of interest as shown in table 2.6 were incorporated as well as some extra species for which model calculations were made. For details of the parameters used in the models and for more detailed descriptions of the modelling results per species (group); see Poot et al. (2011a).

Table 2.8 Overview of different models (green) that have been constructed and run for different species (groups).

model	**0-model**			**effect-model**			**0-growth model**		
% floaters	**0**	**10**	**30**	**0**	**10**	**30**	**0**	**10**	**30**
Bewick's Swan	🟩			🟩			🟩		
Brent Goose	🟩			🟩			🟩		
Common Tern	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Cormorant	🟩								
diver sp.									
Fulmar									
Northern Gannet	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Great Black-backed Gull									
Great Skua	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Guillemot	🟩	🟩	🟩				🟩	🟩	🟩
Herring Gull	🟩			🟩			🟩		
Kittiwake	🟩	🟩		🟩	🟩		🟩	🟩	
Lesser Black-backed Gull	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Common Gull									
Razorbill	🟩	🟩	🟩				🟩	🟩	🟩
Sandwich Tern	🟩	🟩		🟩	🟩		🟩	🟩	

For all species (regardless of the models constructed) also the Potential Biological Removal approach was applied (table 2.10). The Potential Biological Removal approach is based on the species-specific maximum population growth rate and a minimum population estimate and calculates the total number of victims feasible without the population becoming into danger. Only for the Herring Gull the calculated number of victims for both scenarios are higher than the PBR calculated using a *rf* of 0.1, which is the recovery factor that provides a minimal increase in recovery time for a depleted population. This specific recovery factor should only be chosen for those species with a near-threatened status (according to the IUCN). For more details on the parameters used in the calculation of the PBR (maximum population growth rates and minimum population estimates) see Poot *et al.* (2011a).

Table 2.9 *Summarised modelling results for the species of interest (table 2.6) and some extra species for which model calculations could be made. For a detailed description of the results see Poot et al. (2011a). Per species the effect of the loss of the maximum calculated number of collision victims is presented. - = not applicable.*

Species	**modelling**	**(breeding) population**	**population trend**	**calculated effect**
Seabird species (mainly) breeding in the Netherlands				
Great Cormorant	0-model	Dutch	stable	-
Shelduck	no	-	-	-
Herring Gull	yes	Dutch	declining	acceleration of the decline
Lesser Bl.-b. Gull	yes	Dutch	stable	population remains stable
Sandwich Tern	yes	Dutch	increasing	population increase will not be stopped
Common Tern	yes	Dutch	increasing	population increase will not be stopped
Seabird species (mainly) breeding outside the Netherlands				
Red-throated Diver	no	-	-	-
Northern Gannet	yes	Bass Rock	stable	population remains stable
Common Scoter	no	-	-	-
Great Skua	yes	Scottish	stable	population remains stable
Kittiwake	yes	Scottish / Eastern UK	declining	acceleration of the decline
Little Gull	no	-	-	-
Guillemot	yes	Scottish	stable	maximum displacement of >3,400 birds per new offshore wind farm
Razorbill	yes	Scottish	stable	maximum displacement of >500 birds per new offshore wind farm
Migrant species (mainly) breeding outside the Netherlands				
Bewick’s Swan	yes	world population (winter counts)	declining	hardly any population effect
Brent Goose	yes	Dutch late winter population	stable	hardly any population effect
Knot	no	-	-	-
Redwing	no	-	-	-
Starling	no	-	-	-

Table 2.10 Potential Biological Removal (PBR) level for selected species for populations occurring in the Dutch part of the North Sea compared to respectively the calculated number of collision victims (expressed as breeding pairs), for OWEZ alone, and two scenarios of multiple new offshore wind farms in the Dutch part of the North Sea. All selected species have an IUCN least concern status in NW-Europe, most with a stable or increasing population trend (recovery PBR factor rf = 1.0) or a least concern with unstable or decreasing population trend (recovery PBR factor rf = 0.5) (IUCN 2011). Bewick's swan, herring gull and knot, because of a strong negative population trend, are treated as a precautionary approach as near threatened species, resulting that for the Dutch population of the herring gull the calculated number of collision victims for both scenarios potentially are beyond the sustainable mortality limits of the PBR approach (indicated in bold) (based on rf = 0.1).

		PBR			**collision victims**	
Species	**rf = 0.1**	**rf = 0.5**	**rf = 1.0**	**OWEZ**	**scenario**	**scenario**
Red-throated Diver	700	**3,400**	**6,900**	0.2	1.8	9.2
Great Cormorant	200	**900**	**1,700**	30.2	332.2	?
Eurasian Shag	200	**900**	**1,800**	0.0	0.0	0.0
Northern Gannet	1,000	**5,200**	**10,400**	1.6	17.2	199.2
Northern Fulmar	1,000	**4,900**	**9,800**	0.0	0.0	0.0
Bewick's Swan	**20**	**110**	230	0.5	5.0	5.0
Brent Goose	800	**3,800**	**7,600**	0.5	5.0	5.0
Shelduck	1,300	**6,300**	**12,500**	0.0	0.0	0.0
Eider	1,900	**9,600**	**19,200**	0.0	0.0	0.0
Common Scoter	6,600	**33,000**	**66,000**	0.1	1.0	1.0
Great Skua	30	**130**	**260**	0.1	0.8	39.6
Great Bl.-b. Gull	1,000	**4,900**	**9,800**	19.0	209.4	134.9
Herring Gull	**200**	**1,200**	2,400	53.2	**585.6**	**698.1**
Lesser Bl.-b. Gull	600	**2,800**	**5,600**	70.6	776.8	875.8
Little Gull	300	**1,600**	**3,200**	15.7	172.3	75.1
Common Gull	4,100	**20,600**	**41,200**	32.33	355.7	152.7
Kittiwake	1,300	**6,700**	**13,500**	31.4	345.6	217.1
Sandwich Tern	100	**600**	**1,300**	2.6	28.8	154.5
Common Tern	100	**700**	**1,400**	0.3	2.8	60.5
Little Tern	4	**18**	**35**	0.0	0.0	0.0
Guillemot	2,700	**13,700**	**27,400**	0.0	0.1	0.1
Razorbill	600	**2,900**	**5,800**	0.0	0.1	0.1
Puffin	1,300	**6,600**	**13,200**	0.0	0.0	0.0
Knot	**2,780**	**13,800**	27,798	0.0	0.0	0.0
Redwing	150,000	**750,000**	**1,500,000**	max. 309.9	max. 3400	-
Starling	840,000	**4,180,000**	**8,370,000**	max. 309.9	max. 3400	-
Skylark	278,000	**1,390,000**	**2,780,000**	max. 309.9	max. 3400	-
Meadow Pipit	108,000	**540,000**	**1,080,000**	max. 309.9	max. 3400	-

Effects at the population level

When the extrapolated numbers of victims calculated for multiple offshore wind farm scenarios are applied to the population models, those species that are stable or increasing do not show a decline in populations. For these populations the influence of the additional mortality resulting from victims of the wind farms is very limited. Instead, the population trends appear to be dominated by ecological changes in the environment, such as is known from the decline in the numbers of Kittiwakes in Scotland in response to changes in food availability.

Two specific cases of decreasing populations were studied, namely the international Bewick's Swan population and the Dutch breeding population of the Herring Gull. The population model outcomes in these two species show that the influence of the increased mortality due to new offshore wind farm developments is relatively small in relation to the current trends of these decreasing populations. It is concluded that stochastic incidents are likely not more influential in case of parallel impacts including offshore wind farms. In case of long-lived species as studied here, such scenarios with consecutive years of strongly decreased recruitment are rare, and most of the time not caused by a natural phenomenon.

The baseline population models showed that a couple of species, such as the Herring Gull and Bewick's Swan had a very negative trend even before the effects of the wind farms were applied. The calculated additional mortality added to this trend. In the case of the Herring Gull the calculated number of collision victims was within the limit of the Potential Biological Removal level for a species with a 'near threatened' status, even though it is classified above this criteria according to the IUCN and is still very common in northwest Europe.

2.4.4 Conclusions

Limitations of the findings

The fluxes and densities of local seabirds as measured by the effect studies have proven to be extremely location-specific; especially based on the ship-based surveys that were conducted across a much larger area than OWEZ itself. The habitat features that determine the distribution patterns of foraging seabirds, both breeding on the coast as well as non-breeding birds, are: distance to the coast; water depth; salinity; turbidity; and presence and availability of food, the latter being of paramount importance. This limits the certainty with which the findings from OWEZ can be applied to locations further offshore. The effects of multiple wind farms might not be simply additive but could also be multiplicative or non-linear. The effect studies on OWEZ do not yield data with which these effects can be assessed, therefore, the assumption that the effects of multiple wind farms were additive was used for the purpose of this report. The knowledge gained from OWEZ in terms of species and numbers of birds present, may not be applicable in areas further offshore. However, the comparisons made between OWEZ and K14 in §2.3, showing that far offshore fluxes of seabirds are much lower than near OWEZ, confirms the idea that based on the assumptions made in this cumulative study the collision rate modelling for the scenario of multiple wind farms offshore must indeed be regarded as a worse case scenario.

Conclusions

This study was the first attempt to estimate cumulative effects of multiple offshore wind farms in a part of the North Sea on the population level for a range of species. The analyses have shown that the effects of the multiple offshore wind farm scenarios are far away from the levels above which decreasing trends occur and as such, this might be representative for multiple wind farms in the Dutch North Sea. This conclusion was confirmed by using the Potential Biological Removal approach; another way for estimating the size of effects without provoking negative population trends. Emphasis should be placed on the fact that calculations were carried out conservatively and followed precautionary assumptions. The results of recent research related to fluxes, species composition and flight patterns in deeper waters confirm that in this study a worst-case approach has been followed (see chapter 5).

3 Comparison of two types of visual observations for birds offshore: the panorama scan and ESAS protocols

3.1 Introduction

In the effect studies of Leopold *et al.* (2011) and Krijgsveld *et al.* (2011), different methods were applied to assess the effects of OWEZ on birds. Leopold *et al.* (2011) exclusively applied a visual observation protocol. They conducted ship-based surveys (following the standard ESAS-methodology) to obtain insight into the distribution patterns of local birds in the wind farm area (and surroundings). Krijgsveld *et al.* (2011) combined the use of radar technology with several visual observation protocols to gain insight into the fluxes, flight altitudes and behaviour of flying birds as well as species composition. The radar was used to continuously measure flight patterns and the visual observation protocols were used to assess species-specific patterns. Of these visual observation protocols applied by Krijgsveld *et al.* (2011), the panorama scans offer possibilities for comparisons with the ship-based surveys applied by Leopold *et al.* (2011).

Here, we compare the data obtained by ship-based ESAS surveys with the data obtained by panorama scans from the metmast. The objective of the comparison is to describe the strong and weak points of these methods and to clarify the way in which the data resulting from the use of these methods complement and compare to each other.

Comparison of both standard visual observation techniques (panorama scans and ship-based surveys) is valuable for several reasons. Firstly, they yield partly comparable results: data on abundance, species composition, flight altitude of local birds etc. Second, in the light of collision rate modelling in recent and future Environmental Impact Assessments. Both visual observation methods yield information on species composition, densities and the proportion of birds flying at rotor height, which are important input variables in collision rate models. Structural differences between observation methods in recorded values (*i.e.* densities or flight altitudes) might lead to structural differences in model outcomes depending on the visual observation technique used. Because of the growing importance of these collision rate models, such as the SNH Band model, it is valuable to gain insight in the possible differences between visual observation methods in the resulting input variables for these models.

The aim of this part of the study is to compare the outcomes of two standard visual observation methods, panorama scans and ship-based surveys, and by that answer the following three questions:

- Is there a difference in the species composition of flying birds recorded by panorama scans versus ship-based surveys?

- Does the recorded flight altitude of the various species (groups) structurally differ between methods?
- Is there a difference between methods in the recorded species-specific densities of flying birds?

The questions stated above are individually discussed in the following three paragraphs. By doing so we could also evaluate the influence of using different methods on the outcome of collision rate models.

Methodological differences

In comparing the results of both methods, the general characteristics of both methods have large effects on the outcome. It is important to realise how these differences affect the results that are obtained.

Firstly, there is a large difference in **sampled area** between the methods. The panorama scans that were conducted at OWEZ, comprised a circular area around the metmast with a diameter of 6 km, while the ship-based surveys were conducted in a much larger area including two wind farms and an anchorage area (see figure 2.2). To limit the comparison to an area that is more or less comparable in scanned surface per scan/survey, only part of the data of Leopold *et al.* (2011) were selected, belonging to an area inside the wind farm and an area of comparable size outside the wind farm (figure 3.1). The selection was made such that as many transects were included as possible, while simultaneously selecting an area with a comparable surface area as in the panorama scans.

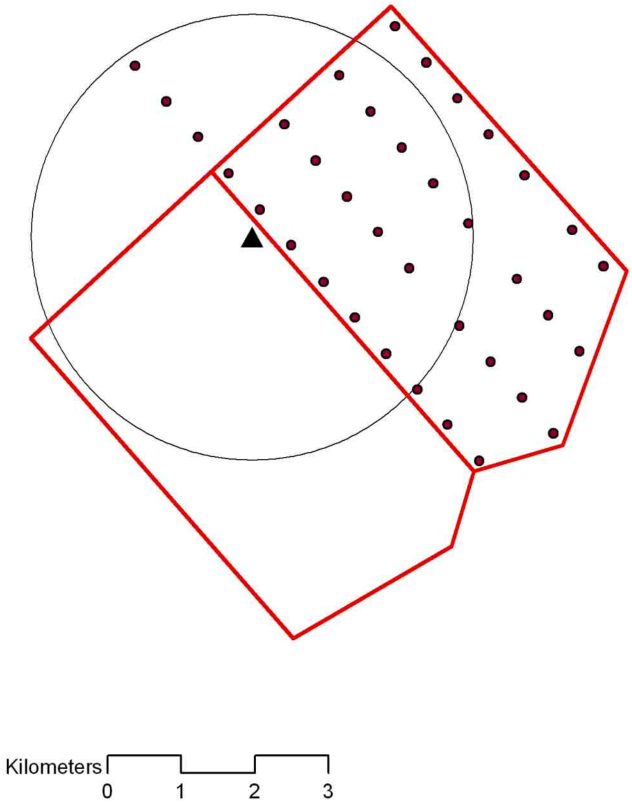

Figure 3.1 *Configuration of OWEZ (dark red dots) and the areas in- and outside OWEZ of which data from the ship-based surveys were selected (red). Also the area that was covered by the panorama scans is shown (circle).*

Secondly, there is a structural difference in the focus of the two visual observation methods, leading to differences in **detection probabilities**. The panorama scans are specifically aimed at recording flying birds up to a distance of 3 km and an altitude of ca. 400 m. All larger flying birds can be detected up to distances of 3 km and only for smaller songbirds the detection probability declines within this distance. However, birds that are swimming or floating at a distance of several hundreds of meters and more from the metmast will be missed more easily due to the influence of wind and waves. Also, because the observations are carried out from one position, they are more susceptible for differences due to small-scale variation in distribution.

Ship-based surveys are aimed at recording local seabirds, including swimming and floating birds, and the focus of these surveys hence is more on birds at or close to the water surface. Within the surveyed distance of 300 m the detection probability for swimming and floating birds is relatively high. However, species such as scoters and divers are easily disturbed by ships and are often already gone by the time the ship passes by (Schwemmer *et al.* 2011), resulting in an underestimate. As a result of the focus on the sea-surface, birds flying at higher altitudes will be overlooked more easily. In ship-based surveys, flying birds are only recorded when they are flying in a specific ‘snapshot’ which represents the area with a width of 300 m (distance from the side of the ship) and a length of approximately 300 m in front of the ship, which agrees with the distance that is travelled by the ship in a specific time period (5-minute interval in the study of Leopold *et al.* 2011), depending on the speed of the ship.

Thirdly, the panorama scan data were biased towards calm **weather conditions** because the observers were not allowed to be present at the metmast when wave height exceeded 1 m. On the contrary, the ship-based surveys were mostly performed under conditions with stronger winds and higher waves. This difference in weather conditions influences the obtained data and leads to differences between the two visual observation methods.

Observer scanning the horizon during a panorama scan. Photo: Karen Krijgsveld.

For an explanation of the methods we refer to §2.1 and §2.2. In all comparisons below, data of the entire duration of the effect study were compared. The ship-based surveys were performed from April 2007 till February 2010 and the panorama scans were performed between February 2007 and October 2009. Both the ship-based surveys and the panorama scans were performed in all seasons of each year. In all comparisons the individual values for all performed surveys or scans were averaged to obtain a value representing the visual observation method. As both the ship-based surveys and the panorama scans were performed in all seasons of each incorporated year, *a priori* the fluctuations in species composition and presence between seasons and years were expected to be covered by both observation methods.

3.2 Species composition

In collision rate modelling, the visually observed species composition can be used to assign the measured fluxes (by radar) to specific species (groups). By doing so, it is also possible to calculate species-specific collision rates. In this light it is important to know if specific species (groups) are systematically missed or estimated differently by the two visual observation methods. Despite the fact that the observations were not performed simultaneously (at the same day), *a priori* it is expected that the species composition will not differ between both methods, because both the ship-based surveys and the panorama scans were performed in all seasons of each incorporated year and therefore both cover the same seasonal and annual fluctuations.

For the comparison of the species composition, all flying birds that were recorded from the ship (also outside the 300 m wide survey strips), and all flying birds that were recorded during the panorama scans (also beyond 3 km) were incorporated in the analyses. A total of 64 different species were seen during the panorama scans from the metmast, of which 37 were not seen during the ship-based surveys. On the other hand 36 species were seen in the selected areas during the ship-based surveys of which nine were not seen in the panorama scans from the metmast (table 3.1). The fact that in total more species were seen in the panorama scans compared to the ship-based surveys is not surprising, as in the panorama scans the observation effort within the analysed area (in the sense of scanned surface) was much higher (between February 2007 and February 2010 in total 11,461 km^2 in the panorama scans versus 326 km^2 in the ship-based surveys). Species that were recorded by one method and missed by the other, were all species that irregularly or rarely visit the area and that are thereby easily missed when using discontinuous monitoring methods. Most of the birds that were missed by one of the two methods belonged to one of the following groups: scarcer seabirds, waterfowl, waders, raptors and land birds (mostly passerines) (table 3.1).

For both methods the relative abundance of species was compared inside and outside the wind farm as well as in the entire selected area (table 3.2; figure 3.2). Again only the flying birds were included in the comparison. Some similarities as well as some remarkable differences between methods were found. In general gulls were the most abundant species group and in both methods 76% of all recorded flying birds consisted of gulls. Also the relative abundance of gulls inside versus outside the wind farm was highly comparable between methods.

Table 3.1 Overview of the species recorded flying in the (selected part of the) OWEZ-area by the panorama scans and/or ship-based surveys.

Species group	**Both methods**	**Only pan. scans**	**Only ship-b. surveys**
divers	Red-throated Diver	Black-throated Diver	
grebes	Great Crested Grebe		
tubenoses	Northern Fulmar		
gannets	Northern Gannet		
cormorants	Great Cormorant	European Shag	
geese & swans	Greylag Goose	Dark-b. Brent Goose	Pink-footed Goose Barnacle Goose
seaducks	Common Scoter	Eider Velvet Scoter	
other ducks	Teal	Northern Pintail Eurasian Wigeon Scaup Goosander Red-b. Merganser	
waders	Eurasian Curlew	Oystercatcher Grey Plover Eur. Golden Plover Lapwing Dunlin Black-tailed Godwit Whimbrel	Green Sandpiper Bar-tailed Godwit
skuas		Arctic Skua	Pomarine Skua
gulls	Herring Gull Lesser Black-b. Gull Great Black-b. Gull Black-headed Gull Common Gull Kittiwake Little Gull	Sabine’s Gull	
terns	Sandwich Tern Common Tern	Arctic Tern Black Tern	
alcids	Guillemot Razorbill		
raptors & owls	Peregrine	Marsh Harrier Goshawk Kestrel Merlin	Sparrowhawk
land birds	Jackdaw Blackbird Redwing Starling Swallow Meadow Pipit	Grey Heron Wood Pigeon Homing Pigeon Carrion Crow Song Thrush Swift Skylark House Martin Pied/White Wagtail Yellow Wagtail Chaffinch Redpoll	Mistle Thrush Fieldfare Northern Wheatear

The largest differences between methods in the relative abundance of species groups were found for gannets, terns, geese & swans and migrating land birds (*i.e.* passerines). The relative abundance of the land birds was (much) higher in the panorama scans than in the ship-based surveys. Also more different species of land birds were recorded in the panorama scans. Especially the relative abundance of the Starling was remarkably higher. The detection probability of small and medium-sized songbirds was probably higher in the panorama scans, because this method focussed specifically on the detection of flying birds, while in the ship-based surveys the observers were more focussed on birds swimming or floating on the water surface. Secondly, more songbirds may have been flying under calm weather conditions, when most of the panorama scans were carried out.

The relative abundance of gannets, geese & swans and terns was somewhat higher in the ship-based survey data. This may well be a consequence of differences in weather conditions. During the ship-based surveys, migrating geese were regularly seen on days with wind velocities that would not allow observers to be present at the metmast (wave-height exceeding 1 m). The flight activity of gannets and terns may well be lower on days with low wind velocities (days on which panorama scans were performed), and increase with higher wind velocities (decreasing again at very high wind speeds). This would explain why relatively more gannets and terns were seen during the ship-based surveys than during the panorama scans.

Table 3.2 Relative abundance of the species that represented more than 1% of all birds recorded, as observed flying in panorama scans and ship-based surveys. Relative abundances are shown for the area outside the wind farm (out), inside the wind farm (in) and for the total analysed area, outside and inside the wind farm combined (total).

Species (group)	**panorama scans from metmast**			**ship-based surveys**		
	out (%)	in (%)	total (%)	out (%)	in (%)	total (%)
Northern Gannet	2	1	2	4	4	4
Great Cormorant	7	7	7	8	15	10
Greylag Goose	0	0	0	1	1	1
Barnacle Goose	0	0	0	2	0	1
Herring Gull	4	6	4	2	4	3
Lesser Black-backed Gull	6	13	7	23	21	22
Great Black-backed Gull	2	4	2	3	13	15
large gull	43	12	39	44	0	33
Black-headed Gull	2	2	2	0	0	0
Common Gull	2	11	14	3	12	5
Kittiwake	3	8	4	3	15	6
Little Gull	1	8	2	0	1	1
gulls	78	65	76	79	65	76
gull spec.	14	1	12	0	0	0
Sandwich Tern	1	2	1	2	1	2
Common Tern	0	0	0	1	2	1
Starling	9	22	10	0	2	1

Regarding the input for collision rate models, for the species regularly present in the area we found that the numbers were not largely underestimated nor (common) species were missed, either of the two methods. We also found that that the structural differences between methods and also the weather conditions during the observations have lead to (slight) differences in the relative abundance of specific species groups.

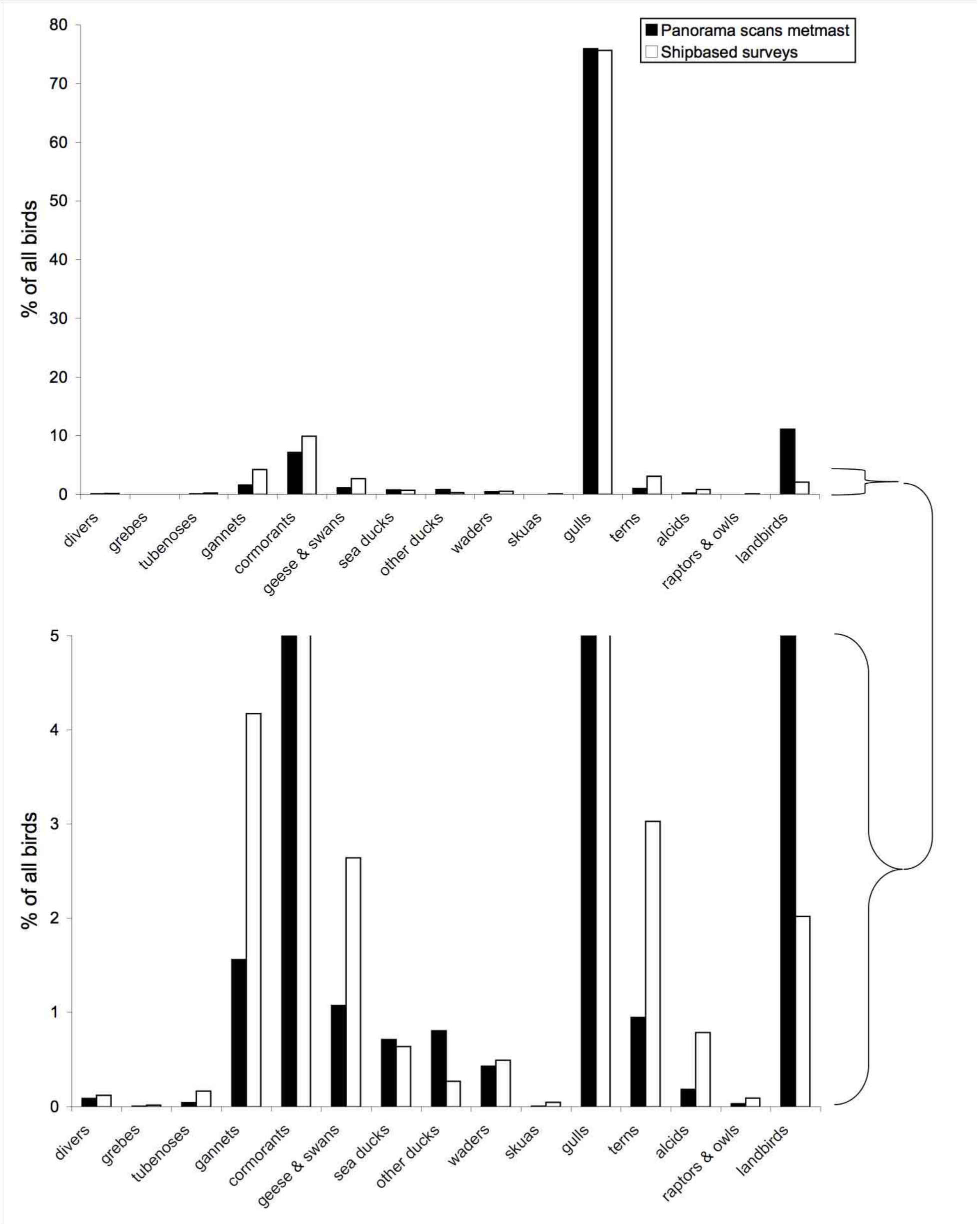

Figure 3.2 *Relative abundance of all species groups seen flying in- and outside the wind farm, as observed with panorama scans and ship-based surveys. The axis of the lower figure has been limited to 5% to enable comparison of species groups representing a low percentage of the total number of birds recorded.*

3.3 Flight altitudes

In modelling species-specific collision rates it is also important to know which proportion of birds of a specific species (group) generally flies at rotor height. The most detailed information on the distribution of flight altitudes is gained by using radar technology (including higher altitudes), however, visual observation techniques remain invaluable to assess species-specific flight altitudes. The average and maximum flight altitudes that were recorded for several species groups using panorama scans and ship-based surveys are shown in figure 3.3.

It appears that in general the recorded average flight altitudes per species group were higher in the panorama scans (on average 10 m higher) compared to the ship-based surveys. If we for instance assume that birds flying above 20 m (typical lowest rotor height) are at risk of collision, no geese & swans, sea ducks, other ducks, waders and raptors & owls were recorded at rotor (risk) height in the ship-based surveys (figure 3.3).

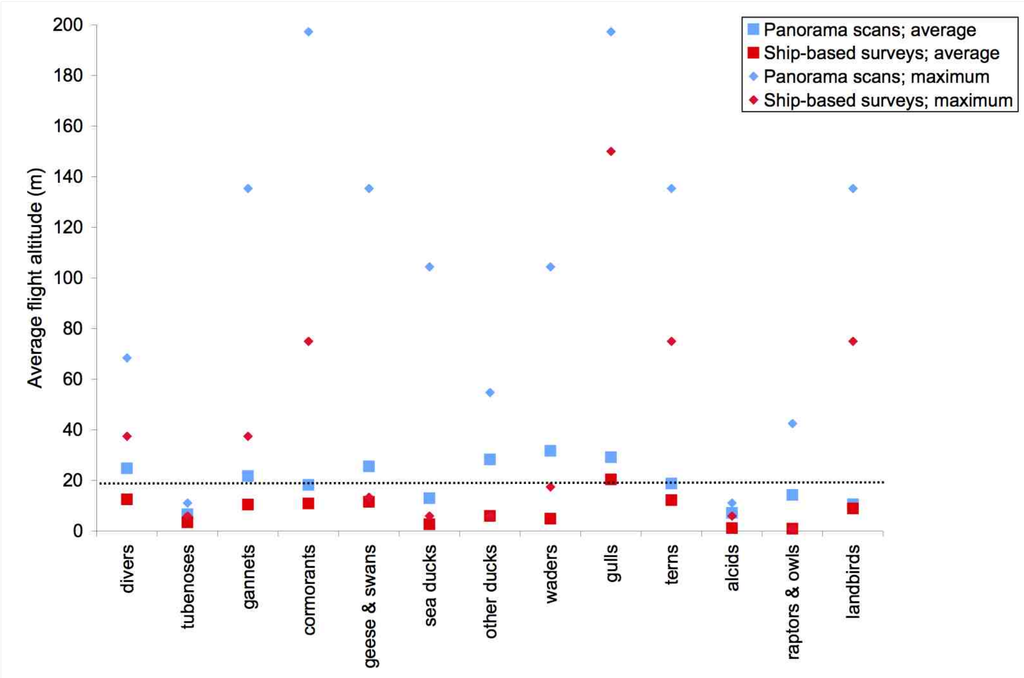

Figure 3.3 Average and maximum flight altitude shown per species group as measured in panorama scans from the metmast or in ship-based surveys. Both the birds flying inside and outside the wind farm are included. For the areas included see figure 3.1. The typical lowest rotor height (20 m) is shown by a dotted line.

The differences in average flight altitudes between the two visual observation methods are caused by a complex combination of differences in observation techniques, search windows, observers and weather conditions. First of all, there is a substantial difference between ship-based surveys and panorama scans in the way flight altitudes of birds are recorded, which potentially leads to differences in the calculated average flight altitudes. In the ship-based surveys the flight altitude is recorded in seven height classes ranging between 0 and >200 m above the water level. In the analysis the average height of the height class was assigned to the birds recorded in that entire height class (ranging between 1 and 250 m; see table 3.3). In the panorama scans the flight altitude was calculated based on the distance at which the birds were detected and the volume of air covered by the binocular view (and the position of the horizon, see figure 2.17 and table 3.4). Accordingly, the calculated average flight altitudes assigned to the detected birds, ranged between 4 and 339 meters (four altitude classes per distance class), resulting in much larger altitude classes. Consequently, an important difference between methods originates in the flight altitude assigned to birds that flew just above the water surface. In the ship-based surveys, these birds were recorded in the first altitude class (0-2 m) resulting in an average flight altitude of 1 m. In the panorama scans these very low-flying birds were also recorded in the lowest altitude classes, however, due to the large size of these classes, the (average) flight altitude assigned to these birds ranged between 4 and 58 m (see figure 2.17 and table 3.4), leading to an overestimation of the flight altitude for all birds flying just above the water level. However, the lowest-flying birds, such as auks/guillemots and fulmars, had a low average altitude in the panorama scans as well. The higher average value for the divers that was recorded in the panorama scans is supported with values of incidental observations from the metmast that also show that divers were often flying at rotor height in the area.

*Table 3.3 Overview of the altitude classes that were used in the **ship-based surveys**. The last column presents for each height class the average height that was assigned to all birds recorded in that height class.*

height class nr.	height class boundaries (m)	average height (m)
1	0-2	1
2	2- 0	6
3	10-25	17.5
4	25-50	37.5
5	50-100	75
6	100-200	150
7	>200	200

Table 3.4 *Overview of the altitude classes that were used in the panorama scans. The last column presents for each combination of distance class, altitude class and position of the horizon the average height that was assigned to all birds recorded in that height class. - = not applicable, as the altitude class is positioned below the water surface (see figure 2.17). Distance classes: 1= 0-500 m; 2 = 500-1500 m; 3 = 1500 – 3000 m; 4 = >3000 m.*

horizon at	distance class	altitude class	average height (m)
1/2	1	1	4.3
1/2	1	2	11.2
1/2	1	3	18.1
1/2	1	4	24.9
1/2	2	1	-
1/2	2	2	7.0
1/2	2	3	27.3
1/2	2	4	54.8
1/2	3	1	-
1/2	3	2	6.3
1/2	3	3	42.6
1/2	3	4	104.4
1/2	4	1	-
1/2	4	2	5.2
1/2	4	3	64.0
1/2	4	4	174.0
1/8	1	1	14.6
1/8	1	2	21.5
1/8	1	3	28.4
1/8	1	4	35.3
1/8	2	1	14.5
1/8	2	2	41.0
1/8	2	3	68.5
1/8	2	4	96.0
1/8	3	1	39.3
1/8	3	2	73.5
1/8	3	3	135.4
1/8	3	4	197.3
1/8	4	1	58.0
1/8	4	2	119.0
1/8	4	3	229.0
1/8	4	4	339.0

Second, in ship-based surveys the flight altitudes of the low-flying birds were recorded accurately, but due to the focus of the observers on the birds at the water surface, birds flying at higher altitudes were missed more often, resulting in an underestimate of flight altitudes. Additionally, for the observers on the ship, no reliable height-reference was available for the birds flying at higher altitudes, which renders the estimation of flight altitudes in the higher altitude classes (above class 3) less precise and more dependent of the observer. In the panorama scans the relatively large size of the four altitude classes that were used (per distance class) has lead to an increase in the average flight altitude compared to the ship-based surveys. Additionally, also the difference in weather conditions between both methods is likely to have played a role in the recorded flight altitudes. The panorama scans were only performed under relatively calm weather conditions, while during the ship-based surveys it became clear that at higher wind speeds (local) birds flew at lower altitudes (unpublished observations M.F. Leopold, M.J.M. Poot). This weather-bias may have lead to a slight overestimation of mean flight altitudes in the panorama scans. For example, in the ship-based surveys, groups of geese were mostly seen flying low above the water surface under weather conditions that would not allow observers to be present at the metmast (strong winds), while at the metmast geese were not only seen flying low above the water, but regularly also at altitudes at or above rotor-height.

The average flight altitude recorded in the ship-based surveys was lower than 20 m (typical lowest rotor height) for all but one species group (gulls). This result is an underestimation of actual flight altitudes as individuals of many of these species groups were regularly seen flying at or above rotor height in the additional visual observations of flight paths of (groups of) birds from the metmast (see §2.2; figure 2.31). Additionally, in the panorama scans several to tens of cormorants, divers, gannets, geese & swans, land birds, seaducks, other ducks, terns and waders were seen flying at or above rotor height, roughly between 20 and 150 m height (figure 3.3). Gulls were mostly seen flying at or above rotor height, and rarely below.

When flight altitude data gathered in ship-based surveys are used in collision rate modelling, the calculated collision rates will be underestimated as the measured average flight altitudes are underestimated. By applying proportions of birds flying at rotor height in collision rate models, these structural differences in results between methods have to be taken into consideration.

3.4 Densities

In both the original and the revised Band model (Band *et al.* 2007; http://www.bto.org/science/wetland-and-marine/soss/projects), which are frequently used to estimate the level of collision-related mortality, densities of flying birds can be used along with a range of other parameters to calculate the numbers of each species (group) passing through the rotor-swept area in a given amount of time. Often these densities of flying birds are based on ship-based surveys. However, ship-based surveys focus on the detection of birds at or just above the sea-surface, by which higher-flying birds are underestimated and thus densities of birds flying at rotor-height might also be underestimated. Therefore it is interesting to see how the densities of birds gained by ship-based surveys are related to the densities gained by using panorama scans.

For this comparison of densities of flying birds, we focussed on a few of the most abundant species (groups). The comparison of absolute densities is hampered by the large difference in the nature of the observation techniques and the bias of the panorama scan data towards calm weather conditions. Especially the distance to which birds were recorded (3 km in panorama scans versus 300 m in ship-based surveys), means that differences in detection probabilities between methods are likely. For some species groups, such as the terns, also the low number of sightings is limiting the reliability of the comparison of densities. In table 3.5 the raw densities are presented, on which no corrections for the detection bias (such as distance analysis) have been applied.

For 9 of the 11 species (groups), the densities calculated with the data from the ship-based surveys are higher compared to the densities calculated with the panorama scan data. As stated above, most likely the large difference in observation distance (300 m versus 3 km) influences the detection probability of flying birds in the panorama scans, which leads to slightly lowered density estimates. The largest difference found was for Starling, whose density was 14 times higher in the panorama scans compared to the ship-based surveys. On the other hand, the density of terns was more than 10 times higher in the ship-based surveys. This could however be the consequence of the fact that both starlings and terns were observed on only a few occasions (albeit in high numbers): in the ship-based surveys all terns were observed during one survey. The fact that the density of large gulls was higher in the ship-based surveys might partly be caused by the (slight) attraction of large gulls by the ship.

In light of the input for collision rate models we have shown that in general calculations of the raw absolute densities are higher for the ship-based surveys compared to the panorama scans, which leads to a slightly higher collision rate.

Table 3.5 *Densities of flying birds of locally abundant species that were recorded during the panorama scans from the metmast as well as during the ship-based surveys. The densities for the gulls are also given for the entire species group and separately for the large gulls to exclude the influence of the level of identification of species. Also for the terns the density for the entire species group is given to minimise the influence of a low number of sightings per species. Only birds recorded inside the official survey areas (strip or circle) were included in the analyses.*

Species (group)	**panorama scans** **# birds/km^2/scan**	**ship-based surveys** **# birds/km^2/survey**
Northern Gannet	0.029	0.080
Great Cormorant	0.089	0.354
Herring Gull	0.100	0.076
Lesser Black-backed Gull	0.132	0.392
Great Black-backed Gull	0.046	0.111
large gulls	0.431	0.579
Common Gull	0.087	0.474
Kittiwake	0.084	0.303
gulls	0.706	1.362
terns	0.021	0.220
Starling	0.249	0.018

3.5 Conclusions and recommendations

Based on the results of the comparison of the two visual observation methods that were applied in OWEZ, some general statements can be made:

- **Species composition:** For the species (groups) that spend most of their time flying, we found no evidence that numbers were largely underestimated or that species were missed, for either ship-based surveys or panorama scans. Small and medium-sized passerines especially had a higher chance of being detected in panorama scans than during ship-based surveys.
- **Flight altitude:** For almost all species groups (except the grebes) the average flight altitude obtained with panorama scans was higher than the average flight altitude obtained with ship-based surveys, and resulted in higher percentages of each species flying at rotor-height than was concluded based on results from ship-based surveys.
- **Flight intensities:** Calculated densities of flying birds yielded by ship-based surveys were generally higher compared to the densities of flying birds yielded by panorama scans. Both methods however yield flight densities that are much lower than fluxes obtained with radar, especially during the migratory seasons.

In relation to collision rate modelling this leads to the following recommendations:

- Both methods are suitable for detecting all flying **bird species** in the area, however, when detailed information is needed on smaller bird species such as passerines, panorama scans offer better opportunities for detecting these birds. It remains important to remember that fluxes of especially passerines are severely underestimated with both methods, as they pass at distances or altitudes beyond the visual range or at night. Therefore, to determine accurate fluxes the use of radar observations are needed.

- Because birds that are flying at higher altitudes have a higher chance of being missed with ship-based surveys, such observations will result in an underestimate of actual **flight altitude**, and therewith in an underestimate of the number of birds flying at rotor-height. The use of panorama scan data leads to a higher proportion of birds passing at rotor height and consequently to a higher collision rate. This is likely to be an overestimation of altitude due to bias in weather conditions and related flight-altitudes.
- As it is not possible to adequately measure flight altitudes using visual observation methods, the use of **radar observations** is essential to determine the overall proportion of birds flying at rotor height.
- By using **densities** of flying birds gained by ship-based surveys as input for collision rate models, the resulting collision rate will generally be higher compared to the collision rate calculated with intensities of flying birds gained by panorama scans. The densities calculated with panorama scan data will be slightly underestimated because of the bias to low flight activity during calm weather conditions, and possibly also detection loss of smaller species due to the relatively large observation distance (3 km).
- Regarding the input parameters for **collision rate models**, panorama scans will provide more reliable estimates for flight altitudes, while ship-based surveys will provide more reliable estimates for densities of flying birds. Consequently, when using either method, observation protocols should be adjusted and additional observations should be carried out to obtain accurate estimates of both flight altitudes and densities.

4 Integration of results

The species- and location-specific collision rate is largely determined by three bird-related factors, which are flux, flight altitude and avoidance rate. These three factors are partly related, as avoidance of wind farms or individual turbines can occur by changes in flight altitude and an increased macro-avoidance rate lowers the flux through wind farms. By integrating the information described in the previous chapters we have summarised the current knowledge on the species-specific effects of OWEZ on birds, related to the aforementioned three factors. The first paragraph focuses on the avoidance rate of different bird species, which was measured for the first time by Krijgsveld *et al.* (2011, table 15.1). In the second paragraph, the patterns in fluxes and flight altitudes, as measured with radars at nearshore locations (OWEZ and Meetpost Noordwijk) and a location further offshore (K14), are discussed and linked to large-scale patterns in migration.

4.1 Avoidance and disturbance

Offshore wind farms can evoke avoidance behaviour (both deflection at larger distances from the wind farm, so-called macro-avoidance, and micro-avoidance of birds within the wind farm close to turbines) and also disturbance of birds. The result is the same, in that a certain percentage of birds avoid close proximity to wind turbines and thereby actively reduce their collision risk. The level of avoidance differs largely between bird species (Leopold *et al.* 2011, see §2.1; Krijgsveld *et al.* 2011, see §2.2). In this paragraph the conclusions of both reports regarding avoidance and disturbance, are summarised per species group. By that we provide an overview on the behavioural influence of bird species on their collision risk.

4.1.1 Overall avoidance figures

Based on Krijgsveld *et al.* (2011) some general statements on avoidance of OWEZ by flying birds can be made. The overall macro-avoidance level (avoidance of the entire wind farm) was 28% on average and varied between 18 and 34% (*i.e.* 18-34% less birds within the wind farm than outside the wind farm). Avoidance was lowest in winter (18%) and highest in autumn (34%) and was higher at night than during the day. Flight activity was higher in the area within the wind farm where wind turbine spacing was larger, and the single line of turbines at the northwest of the wind farm was transversed more often than the main body of the wind farm. On average, 4.1 bird tracks per hour passed grid cells at the edge of the wind farm, versus 2.3 at the centre (Krijgsveld *et al.* 2011; figures 9.19 & 9.20). Turbines that were operating were avoided more than turbines that were not operating. On average, the number of bird tracks was 2.7 (± sd=3.3) per grid cell per hour when the nearest turbine was on, versus 6.4 (± sd=10.1) when the nearest turbine was off (Krijgsveld *et al.* 2011; figure 9.18). Deflection of flight paths occurred in 30% of all bird groups. Birds flying inside the wind farm avoided flying in close proximity of the turbines. The number of tracks was 34% lower close to turbines than in other areas of the wind farm. This micro-avoidance was higher at night and was also higher when turbines were in operation. Birds in the wind farm responded very strongly to the presence of turbines. Of the birds that did come within 50 m of a turbine, very few (7%) came within potential reach of the rotors. Instead they passed the turbines in the area behind or in front of the rotor blades. Krijgsveld *et al.* (2011) were the first to actually measure the overall micro-avoidance rate of birds at an offshore wind farm. The overall micro-avoidance rate (*i.e.* avoidance of individual turbines by birds that do enter the wind farm) was 0.976.

4.1.2 Species-specific avoidance

Studies that employ modelling approaches to estimate the species-specific collision rate, commonly apply an avoidance factor, which largely influences the calculated mortality rate. The revised SNH Band model (http://www.bto.org/science/wetland-and-marine/soss/projects) is known to be very sensitive for small changes in the avoidance rate (Chamberlain *et al.* 2006), with a 10% reduction in avoidance leading to a collision risk more than 25 times as high. Therefore, it is very important to measure actual species-specific avoidance rates to be able to generate more reliable mortality estimates. By multiplying the species-specific macro-avoidance rates (Krijgsveld *et al.* 2011; range 0.18-0.71; see table 2.5) with the measured micro-avoidance rate of 0.976, the resulting total avoidance rate is higher for many species (groups) than the avoidance rate that is recommended by SNH[1] (usually 0.98). As a result the calculated mortality rate for many species (*i.e.* Common Scoter, Red-throated Diver, Northern Gannet, alcids *etc.*) is higher when the avoidance rate recommended by SNH is applied. See Poot *et al.* (2011a, Appendix 8) for a tabular comparison of total avoidance rates recommended by SNH and measured by Krijgsveld *et al.* (2011).

By combining the results of Leopold *et al.* (2011) and Krijgsveld *et al.* (2011) we obtained a comprehensive overview of the avoidance and disturbance of different species (groups) that are relatively abundant at the Dutch North Sea.

Divers
OWEZ is situated at the offshore fringe of the area occupied by divers (mainly Red-throated Diver), which makes that Leopold *et al.* (2011) could not draw firm conclusions on the avoidance behaviour and/or disturbance of divers at offshore wind farms. However, because they did see divers within OWEZ (swimming as well as flying), it is certain that avoidance was less than 100%. Krijgsveld *et al.* (2011) reported that the few (flying) divers that were seen, showed high levels of avoidance of the wind farm, and of all species kept the largest distance from the wind turbines.

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[1] As given in http://www.snh.gov.uk/docs/B721137.pdf (accessed 05-01-2012)

Tubenoses

Only one species of the tubenoses was seen in the OWEZ area, which was the Northern Fulmar. In general this species occurs further offshore. Because of the low number of sightings, mostly only at the western fringe of the OWEZ area, it was not possible to assess avoidance behaviour in this offshore species (Leopold *et al.* 2011; Krijgsveld *et al.* 2011). During two panorama scans Northern Fulmars were observed on the edge of the wind farm.

Gannets

Generally Northern Gannets occurred on all sides of the wind farm, but only rarely within its perimeters, so the modelling results of Leopold *et al.* (2011, table 11) show avoidance during most T-1 surveys. Gannets were never seen to enter PAWP[2] during ship-based surveys. Also Krijgsveld *et al.* (2011) report that of the most abundant (flying) birds, gannets avoided OWEZ most strongly. Only 3% of the recorded gannets were flying inside the wind farm and 14% were flying at the edge (Krijgsveld *et al.* 2011; table 9.3). All remaining gannets were flying outside the perimeters of the wind farm, leading to an overall avoidance rate for gannets of 64% (Krijgsveld *et al.* 2011; table 15.1). Also the change in flight direction was highest in gannets, which approached the wind farm closely before changing direction.

Northern Gannet. Photo: Jan Dirk Buizer.

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[2] See §2.1; page 17

Cormorants

Great Cormorants commuted between two breeding colonies on the mainland and OWEZ. These birds used the wind farm for resting and feeding. Cormorants flew often and without any visible hesitation through the wind farm, at varying altitudes including rotor heights (Leopold *et al.* 2011; Krijgsveld *et al.* 2011). The modelling results of Leopold *et al.* (2011, table 13) show clear attraction during many T-1 surveys.

Geese & swans

Geese migrating to and from Britain, generally strongly avoided the wind farm when they were flying at rotor height. However, there were also some groups of geese observed flying just above the water surface that flew straight through the wind farm. Geese and swans also regularly flew above rotor height and at those altitudes did not show avoidance. Geese and swans flying at turbine height also showed a high level of deflection (Krijgsveld *et al.* 2011).

Brent Geese in flight. Photo: Martin Bonte.

Seaducks

Seaducks (mainly Common Scoters) strongly avoided the wind farm and were rarely observed inside OWEZ (only 3% of flying seaducks was observed inside the wind farm), however, numbers of flying seaducks were relatively low in the entire area (Krijgsveld *et al.* 2011, table 9.3). Birds that were seen crossing the North Sea on a heading that would take them directly into a wind farm (OWEZ or PAWP) always reacted strongly when they apparently first noted the wind farm and changed course markedly to avoid it (Leopold *et al.* 2011).

Gulls

Commonly, gulls showed no avoidance of the wind farm, but numbers were not higher in the wind farm either. Gulls flying within the wind farm were never seen to fly through the rotor-swept zone, although they generally approached individual turbines more closely than most other species (Krijgsveld *et al.* 2011, figure 9.37). The distribution of large gulls (Lesser and Great Black-backed Gull and Herring Gull) was largely dependent on the distribution of fishing vessels, which are not allowed within the perimeters of OWEZ (see also Krijgsveld *et al.* 2005). In total, 55% of all recorded large gulls were associated with fishing vessels (Krijgsveld *et al.* 2011, table 9.4). Regarding the small gulls, there are some differences between species. The distributions of Black-headed Gulls and Common Gulls were concentrated relatively close to the coast, which hampers the assessment of avoidance behaviour in these species. However, observations do not suggest strong avoidance for either species (Leopold *et al.* 2011, tables 19 & 21; Krijgsveld *et al.* 2011). Both Leopold *et al.* (2011) and Krijgsveld *et al.* (2011) report that Kittiwakes were indifferent to the presence of the wind farm and readily entered OWEZ. For Little Gull opposite results were obtained by Krijgsveld *et al.* (2011) and Leopold *et al.* (2011). This difference is due to the low abundance of the species in the area and therewith the low number of observations. Based on the relatively low number of sightings of Little Gulls inside the perimeters of the wind farm, and especially in April a large number of Little Gulls outside the perimeter of the wind farm, Leopold *et al.* (2011, figure 40) conclude that this species might avoid the wind farm (not 100%). On the other hand, Krijgsveld *et al.* (2011) reported that Little Gulls were (just as Kittiwakes) relatively abundant within the wind farm and therefore do not show obvious avoidance of the wind farm, however, this was particularly based on the observation of two larger groups of Little Gulls foraging within the perimeter of the wind farm (see §2.2). Altogether the results for Little Gull are inconclusive, as both possible avoidance (Leopold *et al.* 2011) as well as attraction (Krijgsveld *et al.* 2011) were observed.

Black-legged Kittiwake. Photo: Jan Dirk Buizer.

Terns

The high proportion of terns (predominantly Sandwich Terns) flying at the edge of OWEZ, either corresponds with migrating birds that avoid the wind farm at the last moment, or with foraging birds avoiding the wind farm, but that are making profit of the extra fish supplies close to the wind farm. The latter is confirmed by the disproportionately high number of foraging Sandwich Terns at the edge of the wind farm. Strong (last moment) avoidance of the wind farm by migrating terns was not proven (Krijgsveld *et al.* 2011, figures 9.23 & 9.24). Additionally, Leopold *et al.* (2011) report that there was certainly no attraction of Sandwich Terns, as was the case in the Horns Rev wind farm (Denmark).

Alcids

Alcids (Guillemots and Razorbills) avoided the wind farm area, however, avoidance was not 100% (Leopold *et al.* 2011, see §2.1, figures 2.11 & 2.12; Krijgsveld *et al.* 2011). Razorbills were never observed inside PAWP, which shows the possible influence of turbine density on avoidance behaviour (Leopold *et al.* 2011). Virtually no deflection was observed in the few groups of alcids that were seen flying near OWEZ, however, it may have occurred at larger distances than could be observed visually (Krijgsveld *et al.* 2011, figure 11.7).

Land birds

No clear pattern was visible for migrating passerines. In general, avoidance seemed to be less explicit than in other species such as seabirds and geese. Next to that, especially at night, migration of small passerines largely occurs above turbine height (Krijgsveld *et al.* 2011).

4.1.3 Conclusions

Of all studied species (groups), the pelagic seabirds such as gannets, seaducks, divers and alcids, showed the highest levels of avoidance. Concerning the migrant birds, also geese, swans and passerines (in the dark) seemed to strongly avoid OWEZ, however, many of the groups of these migrating birds passed the wind farm above turbine height without showing avoidance. On the contrary there were also species (mainly gulls) that seemed relatively indifferent to the presence of an offshore wind farm, or that were even attracted to it (Great Cormorant). For some species no firm conclusions could be drawn, because OWEZ was located at the fringe of their distribution and observed numbers were therefore too low. For some of these species, such as skuas and tubenoses, further research at a wind farm further offshore should add valuable information to the overview that is presented here. For a concise graphic overview of the conclusions per species group, we refer to figure 2.24 (Krijgsveld *et al.* 2011).

Both the results of Leopold *et al.* (2011) and Krijgsveld *et al.* (2011, §15.1) do not suggest the occurrence of barrier effects at OWEZ. Specific species (groups) avoid passing through the wind farm or avoid foraging inside it, but were still seen at all sides of the wind farm. This suggests that in the OWEZ area, birds were not cut off from their foraging grounds by the presence of the wind farm. Also the increased energy expenditure of the birds that fly around the wind farm instead of passing through it is assumed to be negligible (Masden *et al.* 2009; 2010). However, it has to be kept in mind that larger or multiple offshore wind farms might induce barrier effects through significant increases in flight durations and distances and by that result in an effective reduction in habitat (Poot *et al.* 2011a). In addition, for certain species also important foraging grounds might become out of reach. This would specifically hold for the seabirds that show strong avoidance behaviour.

4.2 Patterns in fluxes / flight altitudes at the Dutch North Sea

Following the realisation of Offshore Wind farm Egmond aan Zee and Prinses Amalia Wind Park, many new plans for offshore wind farms were developed for the Dutch North Sea (figure 4.1). At present 12 plans are permitted. Simultaneously, other European countries such as the United Kingdom, Belgium, Germany, France and Norway are also planning or constructing (multiple) offshore wind farms in their waters. These relatively fast developments highlight the importance of integration of existing knowledge on the effects of offshore wind farms at different locations on the environment.

Patterns in bird distribution

In the Dutch North Sea, most of the 12 permitted initiatives are located at a larger distance from the coast than OWEZ and PAWP (figure 4.1). As stated previously by Poot *et al.* (2011a), the distribution of seabirds as well as migratory birds at the Dutch North Sea is not homogenous. The distribution of (foraging) seabirds is determined by different habitat features such as distance to the coast, water depth, salinity, turbidity, and presence and availability of food, the latter being of paramount importance. In this paragraph, we have integrated the available knowledge on species composition, fluxes and flight altitudes, from two nearshore locations (OWEZ and Meetpost Noordwijk) and one location further offshore (K14) in the Dutch North Sea. We also tried to relate some differences in species composition and flight patterns between the nearshore and offshore locations, to large-scale migration routes over the Dutch North Sea.

Locations

To assess the differences in species composition and light patterns, we used the data gathered with vertical radars at three different offshore locations (table 4.1). Additionally, data on species composition and migration peaks gathered by observations from the Dutch coast, were used to support the interpretation of the offshore observations (van Gasteren *et al.* 2002; www.trektellen.nl). The three offshore locations represent different distances from the coast and, at the same time, also a gradient from south to north (table 4.1; figure 4.2). The data that were gathered at the individual locations represent different time periods, which hampers the direct comparison of numbers. The same holds for differences in radar performance. However, the data from these three locations are the most comprehensive data that are currently available for the Dutch North Sea and therefore offer (at the present time) the best opportunity for studying offshore species composition and flight patterns.

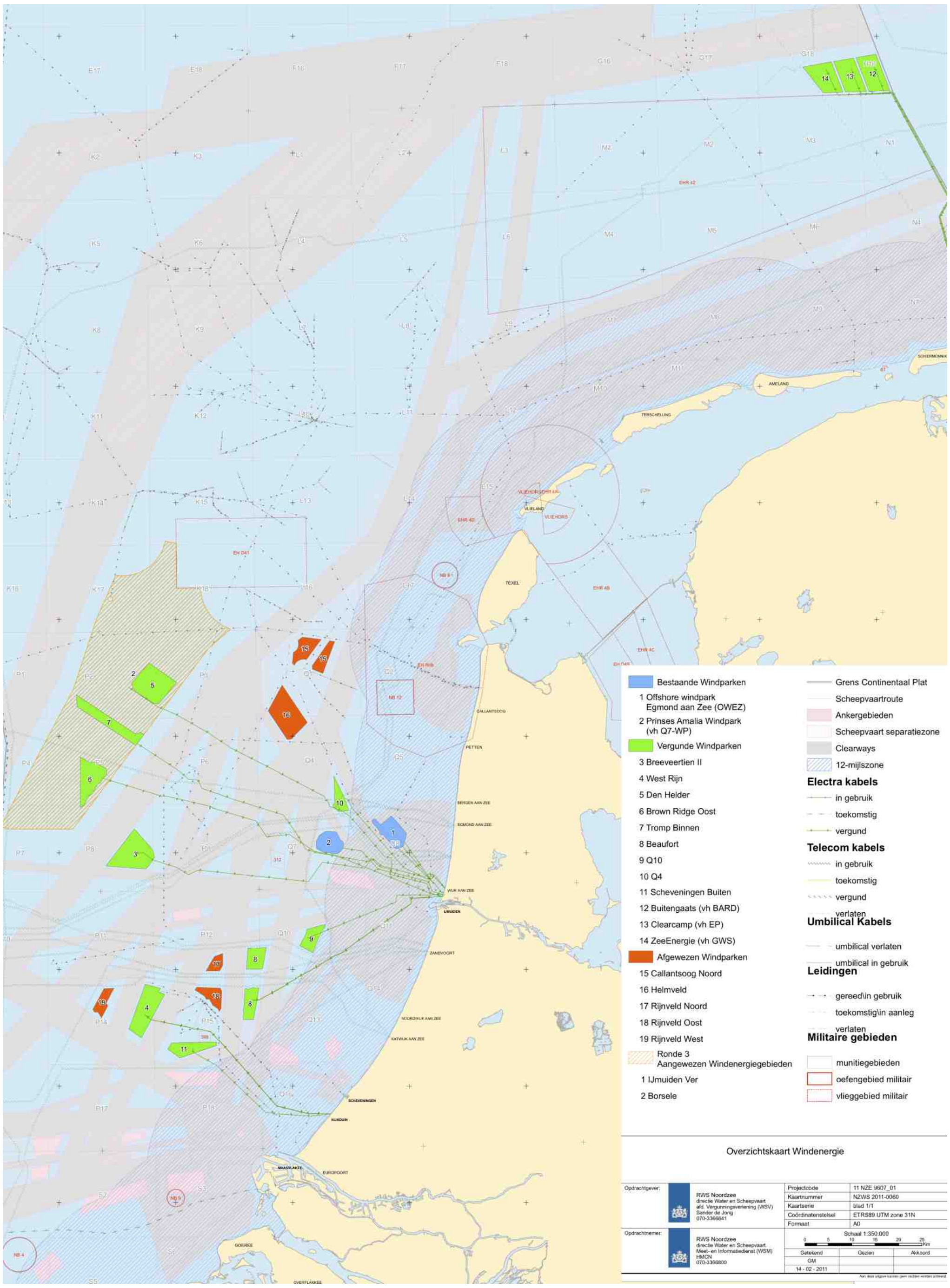

Figure 4.1 *Overview of wind farms in operation (blue; OWEZ and PAWP), wind farms with a construction permit (green) and rejected wind farms (red) in the Dutch part of the North Sea (source* www.noordzeeloket.nl; 18 May 2011*). Also indicated are main shipping lanes (the different bands), military zones (areas outlined in red) and the area designated for wind energy (shaded in orange).*

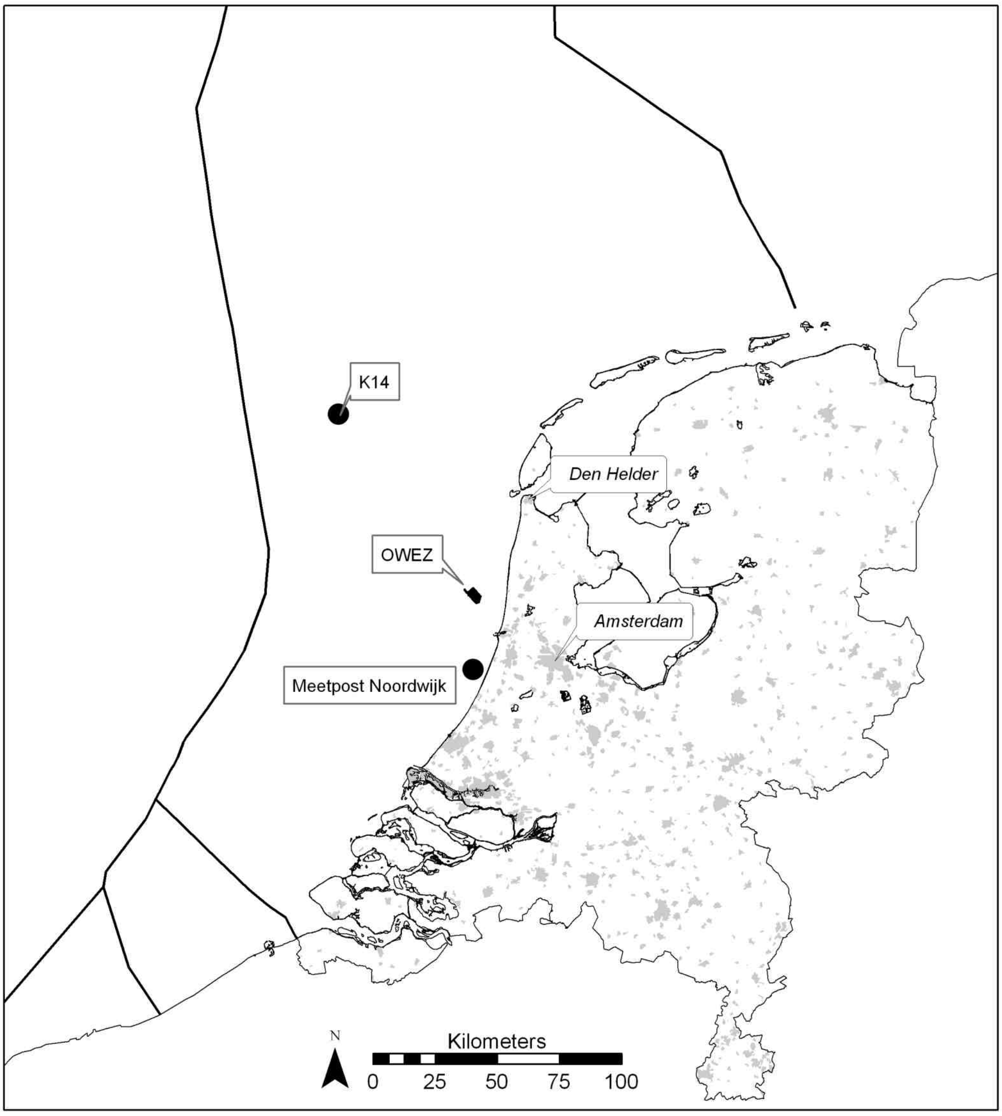

Figure 4.2 Locations of Meetpost Noordwijk (MpN), OWEZ and K14 in the Dutch North Sea. Data on distances to the coast and distances between locations are presented in table 4.1.

Table 4.1 Locations of the three observation points relative to each other and relative to the coast. The last column shows the period during which data were gathered using a vertically positioned radar.

Location	**Distance to coast (km)**	**Distance to OWEZ metmast (km)**	**Period**
Meetpost Noordwijk	9	30	Nov. 2003 – Oct. 2004
OWEZ metmast	15	0	Jun. 2007 – Mar. 2011
K14	80	90	Mar. 2010 – Mar. 2011

Collision rate
The aim of assessing differences in species composition and flight patterns at locations nearshore and further offshore in the Dutch North Sea, is to be able to more accurately estimate the specific collision rate at different offshore locations. The three bird-related parameters that mainly determine the location-specific collision rate of birds are the flux, flight altitude and avoidance rate. These three parameters are related to each other in the way that avoidance of the wind farm or individual wind turbines can be achieved by a change in flight altitude and that an increase in macro-avoidance leads to a reduction of the flux through the wind farm. As species-specific avoidance rates are already discussed in more detail in the first paragraph, we now focus on the overall flux and flight altitudes as measured by radar. Assuming that the collision risk remains stable, the number of collision victims increases when more birds pass the area (higher flux). Similarly, the number of collision victims increases when a larger proportion of birds flies at rotor height. The interpretation of the differences between locations in fluxes and flight altitudes measured by radar is largely based on large-scale patterns in migration at the Dutch North Sea.

Great Black-backed Gull. Photo: Jan Dirk Buizer.

4.2.1 Species composition

It is to be expected that the species composition close to the coast differs from that further offshore. By comparing the species composition as recorded at K14 with the species composition closer to the coast (Meetpost Noordwijk and OWEZ) this expectation is confirmed. The relative abundance of gulls was higher at OWEZ (and MpN) and that of gannets and alcids was markedly greater at K14 (Fijn *et al.* 2012, see §2.3, figure 2.34). Also the preference of Great Cormorants for the coastal zone and structures on which to rest, such as were found at OWEZ and PAWP, was clearly visible with cormorants making up around 10% of flying birds at OWEZ and just 0.1% of birds at K14. In general, the species composition of flying birds recorded visually at K14, further offshore, included more pelagic species compared to OWEZ (closer to the coast). For gulls the species recorded also differed between OWEZ and K14. The main gull species recorded at K14 were Kittiwake and Great Black-backed Gull, whereas at OWEZ Lesser Black-backed Gulls, Herring Gulls and Common Gulls were most abundant. At Meetpost Noordwijk the relative abundance of gulls was very high (94%) and the relative abundance of the more pelagic species was very low (Krijgsveld *et al.* 2005).

These insights are also important with respect to development plans of large-scale wind farms far offshore. The species composition at such locations will differ largely from the species composition closer to the coast. For some of the species that are more abundant further offshore, such as the Northern Fulmar and the Atlantic Puffin, little to nothing is known about their sensitivity to the presence of (large-scale) wind farms. Our data do not allow extrapolation to these locations far offshore and will require additional research.

4.2.2 Flux

Differences in fluxes between locations can be present year-round or only in specific seasons or months. For now we first focus on the possible differences in averaged annual and seasonal fluxes (to sketch the bigger picture) and after that we visualise the differences in monthly fluxes. Comparing fluxes on a monthly scale enables more precise interpretation of the data and extraction of the influence of general patterns in bird migration on location-specific fluxes.

Average annual flux
Because the data of the different locations were gathered at distinct time periods, we first assessed the between-year difference in the overall flux (MTR) using the data gathered at OWEZ for three consecutive years (figure 4.3). If the difference in flux between locations falls within the range of the between-year difference, it cannot be stated that the difference in flux is location-related. When looking at the average annual MTRs for the metmast at OWEZ, the largest between-year difference found was 23 bird groups/km/hour. If differences in fluxes between areas fall within that order, it might also represent between-year fluctuations instead of differences between locations.

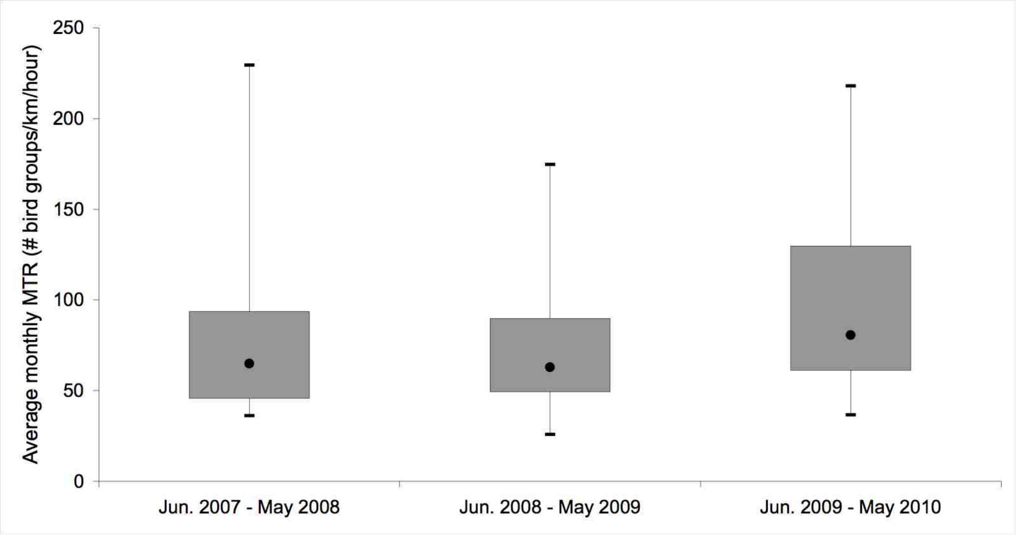

Figure 4.3 Box plots of the distribution of the monthly average MTRs for three consecutive years at the metmast at OWEZ. The box plots show the minimum, maximum, median (black dot), first quartile (lower box boundary) and third quartile (upper box boundary) of the average monthly MTRs for that specific year.

Comparison of the overall seasonal fluxes at OWEZ (nearshore) and K14 (further offshore) reveals that for all seasons the average seasonal flux at OWEZ is higher compared to K14, with the largest difference in flux in autumn (figure 4.4). At Meetpost Noordwijk, deficiency of the vertical radar influenced the results. Due to the sensitivity of the way the system was mounted to strong winds there were several (long) periods of equipment failure. Consequently, the vertical radar only collected data for 30% of all days. Specifically in autumn some days with strong migration were missed, leading to an underestimation of the average MTR for this season (Krijgsveld *et al.* 2005). Secondly, at MpN the radar was operating at a range of 1.5 NM. For the analysis in this report we only considered the echoes recorded to a distance of 0.75 NM (1,389 m). Settings were optimised for the larger range, most likely affecting detection up to 0.75 NM as well. This may have lead to an underestimation of the flux at MpN. Radar performance at MpN was best in spring and early summer (June). By comparing the average MTR at MpN in spring and summer with the average MTR for these seasons at OWEZ and K14, it becomes clear that the average flux at MpN is more or less comparable to the flux measured at OWEZ. Because of the deficiency of the vertical radar at MpN, no reliable calculation of the average annual MTR could be made (see below). Therefore, based on the comparison of MTRs for spring and summer, we further consider the average annual flux at MpN to be comparable to the average annual flux at OWEZ.

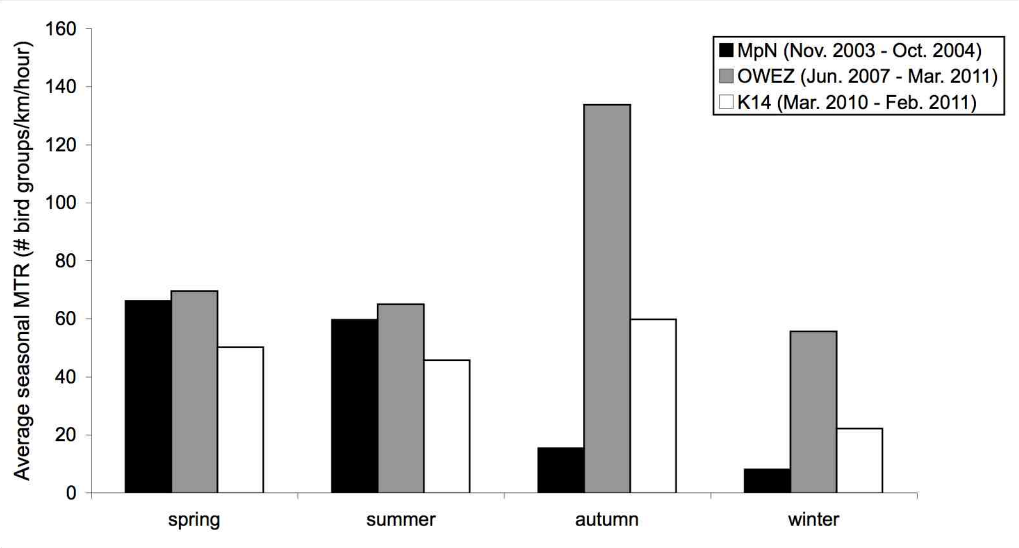

Figure 4.4 Average seasonal MTR (bird groups/km/hour) for each of the three offshore locations: MpN and OWEZ relatively close to the coast and K14 further offshore. The average seasonal MTR at MpN is underestimated in autumn, as the radar was not operating on days with strong migration (Krijgsveld et al. 2005).

Comparison of the overall annual fluxes at OWEZ and K14 reveals that the average annual flux at OWEZ is approximately 36 bird groups/km/hour higher compared to K14 (see also Fijn *et al.* 2012 and §2.3.3), which is roughly one and a half times the maximum between-year difference found for the metmast at OWEZ, so it might point at a structural difference between locations (figure 4.5). Because there were no major radar failures that largely influenced the average MTRs at these locations, we can conclude that in general at K14 (further offshore) the average annual flux is lower than at OWEZ (closer to the coast).

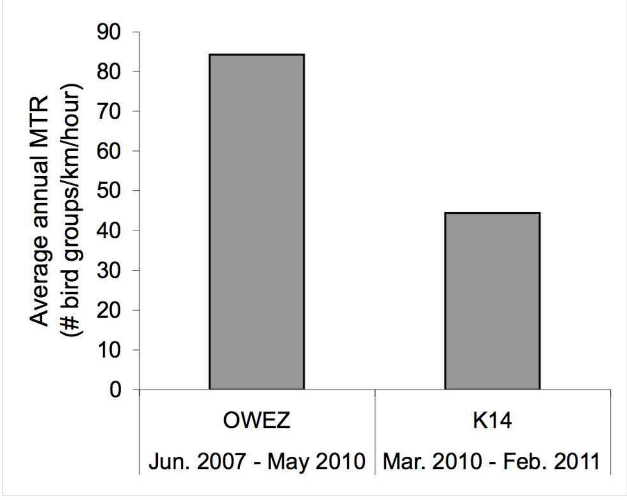

Figure 4.5 Average annual MTR (bird groups/km/hour) for OWEZ (relatively close to the coast) and K14 (further offshore).

Monthly differences

To better understand the differences in fluxes between different locations at the Dutch North Sea in relation to bird migration, we compared the monthly fluxes between OWEZ and K14. Because the vertical radar at Meetpost Noordwijk was out of order for 70% of the time, analysis of the data at a monthly basis was not possible. As can be seen from the OWEZ data, there is of course yearly variation in timing and intensity of migration peaks (figure 4.6), however, the general pattern is comparable between years. By directly comparing monthly fluxes at OWEZ and K14 it becomes clear that apart from the generally higher flux at OWEZ, also the occurrence, timing and intensity of migration peaks differs between both locations.

In OWEZ the strongest peak in monthly fluxes occurred each year in autumn (October or September). From the panorama scans that were regularly performed at Meetpost Noordwijk, we know that also here the highest monthly flux was observed in October. In addition, van Gasteren *et al.* (2002) also measured the highest fluxes in autumn at the South Pier of IJmuiden, and at most sea watching posts at the Dutch coast by far most migrating birds were recorded in October and November (www.trektellen.nl). Conversely, this large peak in the monthly flux in autumn did not occur at K14. Likely, the intensity of autumn migration was much stronger closer to the coast than further offshore, which can be explained by the accumulation of migrating land birds along the coastline. This hypothesis is supported by Fijn *et al.* (2012), who report that in autumn at OWEZ there was a large peak in MTRs around sunset, which was lacking at K14 (see §2.3, figure 2.36). Accumulated nocturnally migrating land birds departing the Dutch coast around sunset probably caused this peak. The lower number of migrating birds at K14 in autumn, can be explained by the general migration routes of birds over and around the North Sea in autumn. Here we only discuss the large-scale routes that are of main importance for the fluxes at the (Dutch) North Sea. During early autumn migration (long distance), birds that are on their way to Africa follow two main flight paths along the North Sea (Lensink *et al.* 2002). First of all, birds coming from the direction of Greenland travel over and along the British mainland and coasts to regions further south (figure 4.7a). Secondly, birds coming from the direction of Scandinavia can go directly south-southwest to the mainland of Europe and thereafter follow the Dutch coast to their wintering grounds further south (figure 4.7a). Additionally, especially later in the season (short distance migration), there are also birds that fly in a relatively broad front from Scandinavia (also over the North Sea) to Britain or the European mainland or that depart from the European mainland and pass the North Sea on their way to Britain, such as finches and thrushes (figure 4.7b). However, the amount of birds following the second strategy is probably much smaller than the amount of birds travelling to Africa following the two main routes southwards. Altogether this makes that the outer edge of the Dutch North Sea (where K14 is located) is probably situated in a sort of gap, leading to less intense autumn migration compared to OWEZ.

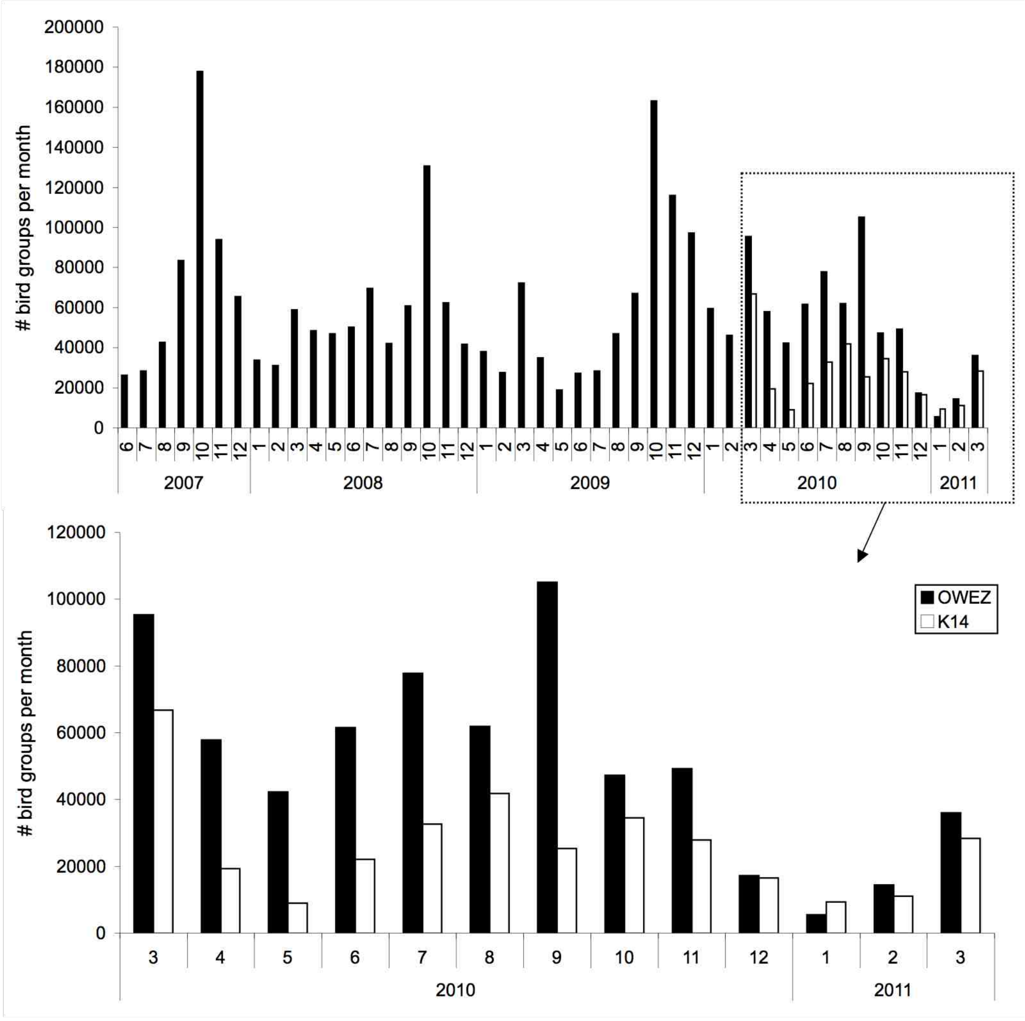

Figure 4.6 Number of bird groups passing per month at OWEZ and K14 as measured with the vertical radar and corrected for radar interruptions.

It is remarkable that autumn migration peaks at the Dutch coast measured by radar are most intense in September/October, while at sea watching posts migration peaks are generally detected later in the season in October/November. This phenomenon can be explained by the difference between bird species that are migrating in a specific period and their destination and associated migration strategy and flight altitude (Lensink *et al.* 2002). In early autumn mostly birds that are on their way to Africa are passing by. Generally these birds fly large distances at a time at relatively large heights. Therefore these birds can be detected by radar, but not by the naked eye. On the other hand in late autumn the migrants that winter in North-Western Europe (for instance thrushes and finches) are passing by. These birds do not have to go such a long way and make shorter continued flights at lower heights and can therefore be seen at the sea watching posts.

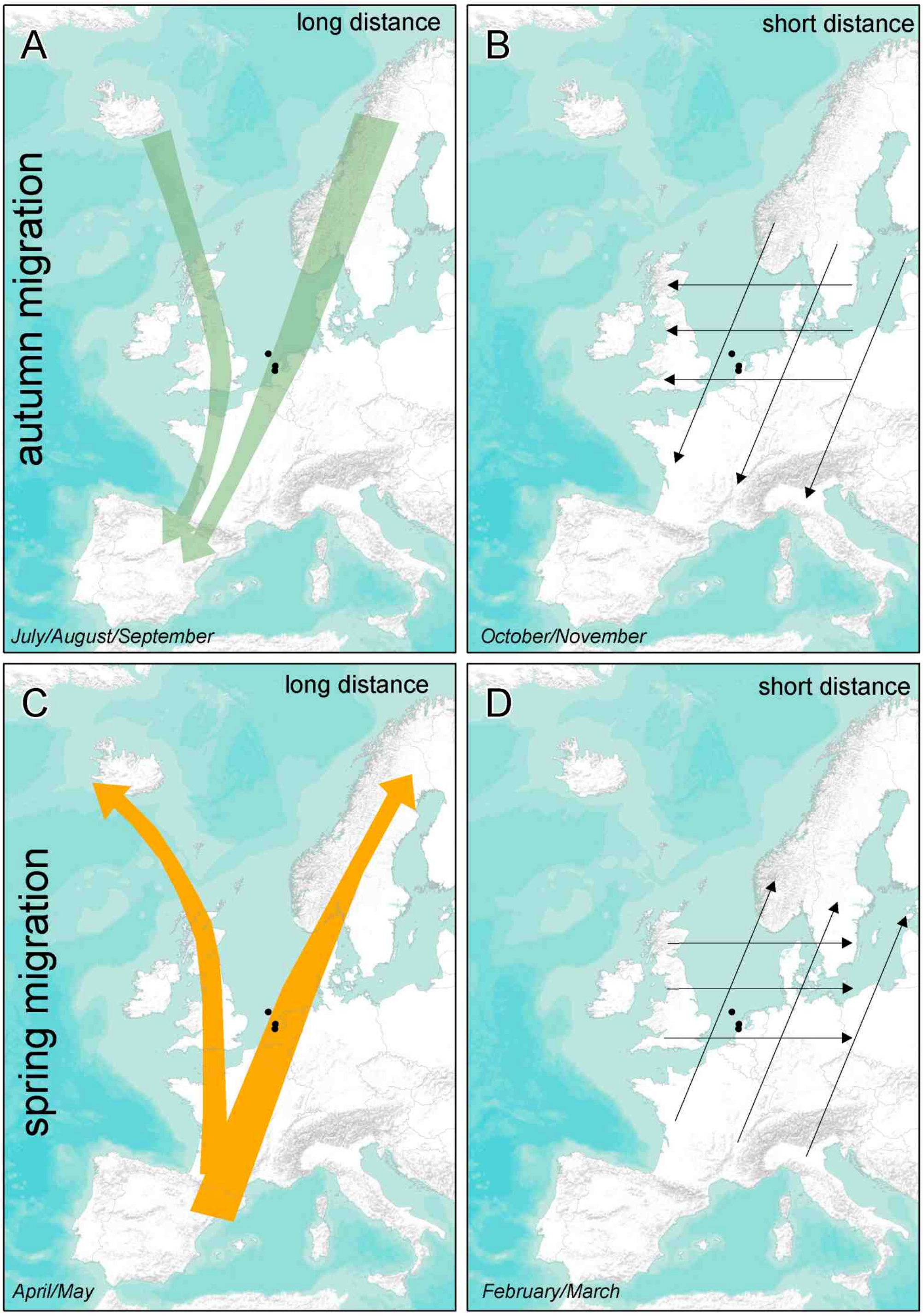

Figure 4.7 *Hypothetical autumn (a&b) and spring (c&d) general migration routes around and over the Dutch North Sea. Both long distance (a&c) and short distance (b&d) migration routes are shown. The number of birds performing long distance migration is of a larger order than the number of birds performing short-distance migration. The locations of K14, OWEZ and Meetpost Noordwijk are shown as black dots. See figure 4.2 and table 4.1 for the specific locations of these three observations points in the Dutch North Sea.*

Compared to migration in autumn, spring migration is a different story. Also in spring, migration peaks occurred at OWEZ (mainly in March), probably mostly representing birds from Africa on their way back north (figure 4.7c). The fact that these migration peaks were always lower compared to those in autumn, can be explained by the large amount of juvenile birds in autumn and the high mortality rate in winter, which makes that simply fewer birds return in spring (Lensink *et al.* 2002). However, at K14 fluxes in spring were more or less comparable to those in autumn, suggesting that there are birds passing in spring that did not pass in autumn. This were probably birds that have spent the winter in Britain and over the course of the winter were forced further south by harsh weather in the northern parts of the country (Lensink *et al.* 2002). In spring (March) these birds might return to Scandinavia by travelling north again over the British mainland or they might go to northwestern Europe by passing the North Sea and migrating onwards via the Netherlands (figure 4.7d). Proportionally this might lead to a higher number of migrants at K14 in spring compared to autumn. By following the second route, many birds pass from west to east over the Dutch North Sea and by that possibly also pass K14.

Finally some smaller though clear peaks in fluxes can be found in late summer, which can be explained by the distribution of adult and juvenile gulls (and to a lesser extend also terns) from the colonies at the coast (OWEZ and K14) and by the early departure of migrants to Africa (OWEZ).

4.2.3 Flight altitude

The flight altitude of a bird defines whether the bird is at risk of collision (flying at turbine height) or not (flying above or below turbine height). Possible differences in the proportion of birds flying at risk height between different offshore locations, influence the specific collision rate of birds at these locations, and thereby the suitability of specific areas for the realisation of future wind farms.

Distribution of flux in flight altitudes

First of all we summarised the general distribution of flight movements over 11 altitude classes (figure 4.8). At all three locations (OWEZ, Meetpost Noordwijk and K14), by far most flight movements were recorded in the lowest altitude band (40 to over 50%). Above that height the proportion of recorded flight movements generally decreased to around 2% between 1,250 and 1,389 m height. At the South Pier of IJmuiden, in 1999, van Gasteren *et al.* (2002) conducted radar measurements of flight movements of birds. They also found that most movements occurred at a low altitude. By day they found that 75% of all recorded flight movements occurred below 100 m. By night that figure was slightly lower, namely 53%. These flight movements at low altitudes originate largely from local birds, in this case mainly gulls that made up 49% (K14) to 94% (MpN) of all birds present. Of the three locations, the percentage of birds flying in the lowest two altitude bands (which represent a rough estimate of the birds flying at risk height) was lowest at OWEZ, where compared to the other locations 10% more flight movements were registered at higher altitudes (above turbine height).

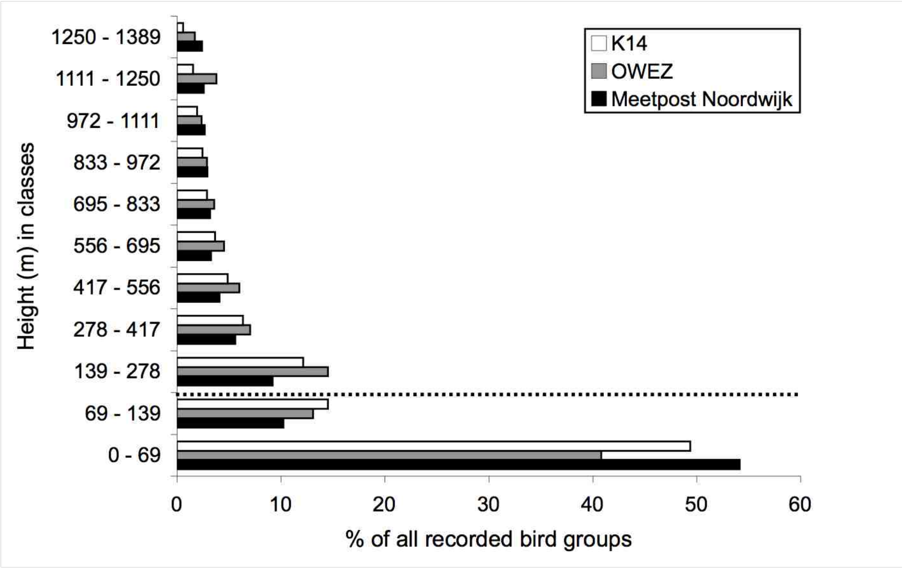

Figure 4.8 Percentage of all recorded bird groups recorded in a certain altitude class at MpN, OWEZ and K14. Note that the two lowest altitude bands are half the height of the other classes. The dotted line shows a rough estimate of the height, below which birds are at risk of collision with offshore wind farms.

Seasonal distribution of flux in flight altitudes

Comparing the distribution of flight movements in the different altitude classes for the three locations, reveals that there are some differences between seasons in the pattern as described before, that are probably largely related to the amount of migrants in the total flux. At K14 the proportion of bird movements in the lowest altitude class is clearly lower in spring than in the other seasons (figure 4.9). This can be explained by the influence of tailwinds, that more often occur in spring compared to autumn. Most migrant birds prefer to fly with tailwind, with which they also fly higher (Lensink *et al.* 2002). At OWEZ and MpN the proportion of birds flying in the lowest altitude band was clearly lower in the autumn season than in the other seasons. Here we might detect the influence of the large amount of migrants in the flux that generally fly at greater heights than local birds. At all locations the largest proportions of birds flying in the lowest altitude class were present in summer and winter, which represents the flight movements of local foraging and wintering birds.

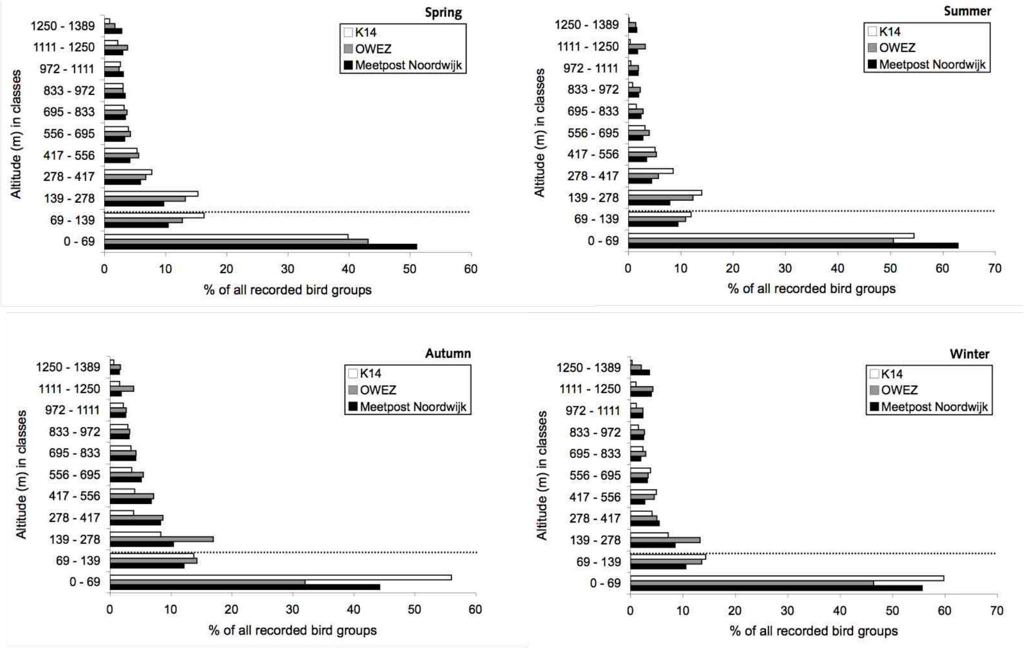

Figure 4.9 Percentage of all recorded bird groups observed in a certain altitude class at MpN, OWEZ and K14 shown per season. Note that the two lowest altitude bands are half the height of the other classes. The dotted lines show a rough estimate of the height, below which birds are at risk of collision with offshore wind farms.

4.2.4 Conclusions

The following patterns in species composition, flux and flight altitudes at the studied part of the Dutch North Sea were extracted from the available data:

- Nearshore the relative abundance of gulls and cormorants was larger, while further offshore the relative abundance of more pelagic species such as gannets and alcids was larger.
- The overall flux was higher close to the coast compared to further offshore.
- Autumn migration was much less intense further offshore compared to the region close to the coast.
- The intensity of spring migration was comparable close to the coast and further offshore.
- At all studied locations, most flight movements occurred at low altitudes, especially in summer and winter.
- The average flight altitude seemed to be slightly higher close to the coast, compared to further offshore (especially in autumn). This might be caused by the larger proportion of migrants in the total flux.

Through the entire integration and interpretation process, it is important to keep in mind that the results and conclusions are based on data from three specific and very small points in a relatively large area of sea. Therefore one must be careful with drawing general conclusions for the entire Dutch North Sea.

5 Conclusions and recommendations

5.1 Conclusions

Building knowledge of the effects of offshore wind farms on birds at various offshore locations, is important in the light of minimising the environmental impact of new offshore wind farms by selecting (relatively) low risk locations. In general, the main effects of offshore wind farms on birds that can occur are disturbance, barrier effects and collisions of birds with turbines. Disturbance and barrier effects are dependent on the level of avoidance of birds as well as the size and configuration of the wind farm(s). Collision rate is largely determined by three bird-related factors: avoidance behaviour, flux and flight altitude. Collision rate will increase with a larger flux, a larger proportion of flight movements at turbine height and/or a lower avoidance rate.

In the flow chart below (figure 5.1) we have summarised the main results of the four bird studies and their implications. These results are discussed in further detail in the following paragraphs.

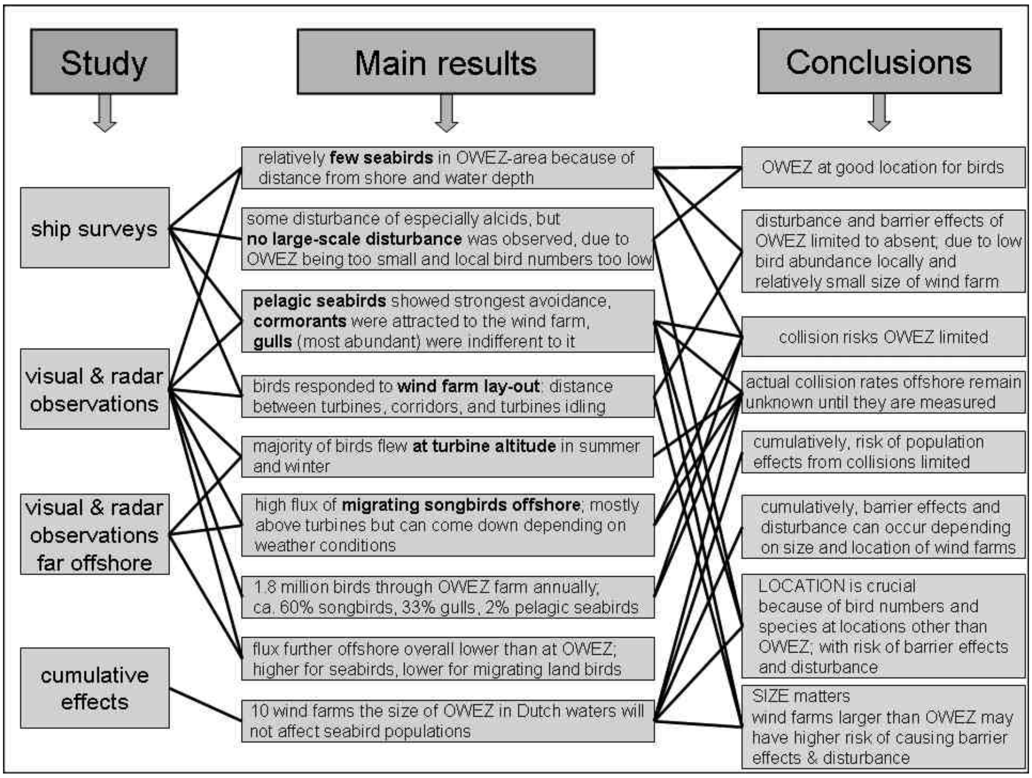

Figure 5.1 Flow chart showing the main results (middle) of the four studies that were carried out (left) and the implications for birds both of OWEZ and of offshore wind farms in general (right).

Avoidance behaviour

Avoidance behaviour was shown to be highly species-specific. At OWEZ, many bird species actively reduced their own collision risk by avoiding the wind farm or individual turbines. As avoidance behaviour was strongest in pelagic bird species such as gannets, and specifically these bird species were relatively more abundant further offshore, the overall collision rate further offshore is probably lower. Birds that did not avoid wind farms (gulls) or were even attracted to it (cormorants), and as a consequence of this had an increased collision risk, were more abundant nearshore. However, if we consider the possible impact of collision mortality on populations, the collision of a few seabirds (further offshore) may have a higher impact on population level than the collision of a greater number of gulls nearshore. Seabirds, such as gannets and divers, are mostly long-lived species and therefore sooner experience an impact on the population level (Poot *et al.* 2011a).

Another aspect that has to be kept in mind is the occurrence of barrier effects and disturbance. At the scale of a single offshore wind farm at the location and with the configuration of OWEZ, barrier effects were not demonstrated. However, for seabirds that strongly avoid wind farms, the realisation of multiple or large scale offshore wind farms might evoke barrier effects and disturbance in such a way that areas that are often used by seabirds for foraging or resting become out of reach for certain species.

Flux

Regarding flux, we have shown that further offshore at K14 the overall flux was lower compared to the OWEZ area closer to the coast. This would translate into a lower collision rate further offshore. According to the fluxes measured by radar, autumn migration was less intense at K14 further offshore compared to OWEZ close to the coast, while the intensity of spring migration was comparable.

Flight altitude

No substantial difference in flight altitude between the nearshore (OWEZ & MpN) and offshore (K14) locations was found. Although mean flight altitude was lower at K14 than at OWEZ, which was probably caused by the relatively higher proportion of migrant passerines at OWEZ, this difference was too small to influence the proportion of birds flying at rotor height. Therefore it is expected that this factor does not induce large differences in collision rate at different locations in the Dutch North Sea. In general, most flight movements occurred in the lowest altitude band of 0-69 m, especially in summer and winter, when local seabirds largely defined the species spectrum. This means that altogether many birds flew at turbine height and therefore were at risk of collision. In the dark a larger proportion of the flight movements occurred at higher altitudes, due to differences in the species spectrum: the highest nocturnal fluxes were measured during the migratory season and were related to migrating songbirds. (Krijgsveld *et al.* 2011, see §2.2 figure 2.26; Fijn *et al.* 2012, see §2.3 figure 2.36). At night, macro- and micro-avoidance rates were also higher than during daytime. This would result in an overall reduced collision rate at night during periods with little migration. During migratory periods, collision rates may increase when changing weather conditions forces migrating birds down to lower flight altitudes.

Conclusions on collision rates, barrier effects and disturbance
Overall, our studies suggest that collision rate at OWEZ is limited due to relatively low bird abundance and generally high avoidance rates. Also micro-avoidance, of birds that entered the wind farm but avoided the individual turbines was very high, which reduces collision rates. Based on abundance and flight patterns, most collisions are expected to occur among migrating passerines and gulls (estimated maximum of between 310-560 and 230-700 birds respectively, annually at OWEZ). Actual collision rates however can only be determined when a methodology to measure collisions with turbines offshore becomes available.

Despite the fact that many species, especially pelagic seabirds, avoided the wind farm, barrier effects or large-scale disturbance were not observed at OWEZ. This may be related to the limited size of the wind farm (36 turbines).

Collision rates further offshore
The lower overall flux at K14 further offshore together with the higher proportion of seabirds showing strong avoidance behaviour, suggest a smaller chance of collisions and hence a lower overall collision rate further offshore compared to the coastal region. This conclusion is based on data from only three study sites in a large expanse of sea, and may therefore not be directly applicable to other offshore wind farm locations in the North Sea or elsewhere.

5.2 Cumulative effects in relation to distance from the coast

The first attempt to estimate cumulative effects of multiple offshore wind farms in a part of the Dutch North Sea on the population level for a range of bird species, was made by Poot *et al.* (2011a). By using and extrapolating the knowledge derived from OWEZ, they calculated that for most species even a tenfold extrapolation of the effects of a wind farm similar to OWEZ, would not lead to effects at levels at which serious negative impacts with decreasing population trends occur. At the time of writing, Poot *et al.* (2011a) were faced with a severely limiting amount of information on fluxes and species composition further offshore. Therefore they concluded that their impact assessment could be improved with the results from studies further offshore. In addition they also stated that, because of the precautionary assumptions in different aspects they had to make, future research at locations further offshore would probably yield results that would confirm that in their report a worst-case approach was followed.

With the research reported in the report at hand, we were able to take the next step by using the data that were gathered at K14 and integrate the knowledge of OWEZ with this knowledge. First of all we now have indications that further offshore at the

Dutch North Sea, at least at the location of K14, overall fluxes are lower compared to the coastal region. This would lead to a lower collision rate further offshore and also underlines that Poot *et al.* (2011a) followed a worst-case approach, by directly extrapolating the higher fluxes that were measured at OWEZ to the situation further offshore.

Secondly, also additional information on the relative abundance of species groups at different offshore locations is now available. For the calculation of the species (group)-specific number of collision victims for the offshore scenario (>20 km from the coast), Poot *et al.* (2011a) directly used the number of victims per turbine per year for all seabirds as calculated for OWEZ and redistributed these victims over the different species (groups) of seabirds by using a long-term aerial monitoring dataset (Arts 2010). Based on the results obtained at K14 it can be concluded that thereby the number of collision victims under seabirds was slightly underestimated, as the relative abundance of seabirds at K14 (further offshore) was higher compared to the nearshore area (around OWEZ). However, the aforementioned overestimation of the collision rate for the offshore scenario by using the coastal flux is expected to be of a much larger scale.

Also for migrating passerines, Poot *et al.* (2011a) were not able to make a distinction between the nearshore scenario and the offshore scenario, as no data were available on fluxes of migrant passerines further offshore. Based on the current knowledge, we can conclude that the collision rate of migrant passerines for the offshore scenario (>20 km from the coast) was overestimated by Poot *et al.* (2011a), as the intense autumn migration at the coast seems to be much less intense further offshore at the Dutch North Sea. Again it is expected that the overestimation of the collision rate of passerines for the scenario further offshore caused by the use of the flux measured at OWEZ, is of a much larger scale than the overestimation based on the erroneous assumption of the relative abundance of species groups.

The findings in the report at hand underline that Poot *et al.* (2011a), as predicted, applied a worst-case approach, especially for the offshore scenario (>20 km from the coast). Their conclusion is therefore maintained and strengthened, that even a tenfold extrapolation of the effects of a wind farm similar to OWEZ, would not lead to effects at levels at which serious negative impacts with decreasing population trends occur. It is important to keep in mind that this conclusion is only applicable to the Dutch part of the North Sea and its local (breeding) bird populations. The effect of multiple, larger wind farms of varying configurations in not only Dutch but also international waters, on international bird populations and species that do not occur in the Dutch waters, was not investigated.

5.3 Recommendations

After summarising and integrating the knowledge that was gathered during several years of research in Offshore Wind farm Egmond aan Zee, we finalise this report with the provision of several recommendations for future research in (offshore) wind farms.

Observation techniques

The combination of long-term continuous measurements (both day and night) using radar technology with visual observation techniques to determine species-specific patterns, proved to be successful. Best results are obtained when a number of visual observation techniques are combined as each technique has its own shortcomings and advantages. By combining several visual observation techniques, an optimal coverage of the research area, weather conditions and species involved should be pursued. Regarding radar technology, it is important to be aware of new developments, because techniques might be developed by which the identification of species is facilitated, which would yield a lot of new possibilities.

Large fluctuations between years in for instance species distribution and weather, underlined the importance of long-term studies. The duration of the baseline studies (one year) was found to be too short to accurately compare the results with those of the effect studies. An important lesson that was learnt from the effect studies at OWEZ, is that the effects of an existing wind farm can most accurately be tested by performing a control-impact study. However, the performance of a baseline study remains important in the process of selecting areas for the development of new offshore wind farms, as the level of effects is related strongly to e.g. bird abundance and species composition at a location.

Avoidance rates and collision rate modelling

In collision rate modelling often estimates of avoidance rates are applied. As the avoidance rate largely influences the collision rate, the most accurate estimates of avoidance rates need to be applied in collision rate models, or preferably avoidance rates that were determined in the field. In the effect studies at OWEZ, species-specific avoidance rates were measured, as well as macro- and micro-avoidance rates. Especially for pelagic birds, these measured avoidance rates were higher than the estimated rates that are currently being applied in collision rate modelling. This implies that collision rates based on estimated avoidance rates may be severely overestimated. Therefore, more measurements of avoidance rates of (offshore) species are needed to render the outcome of collision rate models more reliable.

Barrier effects

Finally, we emphasise the importance of future research to assess the occurrence of barrier effects, especially for pelagic birds, in areas where multiple or large-scale wind farms are constructed. Thereby also the influence of the configuration of the wind farm(s) should be included, covering features such as turbine density and the presence of corridors. By doing so, potential mitigating measures that might be needed in future large-scale offshore wind farms, can be assessed. Because in OWEZ no barrier effects could be demonstrated, no mitigating measures of such kind seem to be needed in wind farms with the configuration and size of OWEZ.

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Appendix 1 Glossary

Glossary of terms used commonly in the report at hand, listed in alphabetical order.

term	definition
Attraction	Change in flight direction of a bird towards the wind farm, resulting in increased occurrence of a species within the wind farm compared to outside of it.
Avoidance	Flight behaviour of birds to avoid close proximity of a wind farm or of turbines. This includes both deflection from the wind farm at larger distances or macro-avoidance, and avoidance of individual turbines or micro-avoidance. In our calculations, avoidance includes both active and passive avoidance, because we compared flight activity within versus outside the wind farm (c.q. rotor area), and therewith include flight paths of birds unaffected by the wind farm (passive avoidance). This is because often active avoidance, where birds actively adjust flight paths to avoid the wind farm or individual turbines, cannot be seen or measured. E.g., when a bird flies on a straight path in between two turbines, equidistant from either turbine, it is not possible to determine whether it is avoiding these turbines or not.
Barrier effect	Effect that occurs when a wind farm creates a barrier that is not passed by birds, and which results in habitat becoming inaccessible or unfavourable. For instance a barrier between foraging grounds, resting grounds and/or breeding grounds. In addition, barrier effects may result in increased energy expenditure or in loss of time. Barrier effects are expected mostly from large-scale wind farms and/or wind farms where turbines are spaced closely together.
Baseline study	Studies on the situation of the OWEZ wind farm area before construction. Fieldwork on flight patterns of birds carried out in 2003-2004 reported in Krijgsveld *et al*. '05. Fieldwork on distribution of local birds and effects of pile-driving reported in Leopold *et al*. '04 and Leopold & Camphuysen '08.
Beam width	Width of the radar beam. In the horizontal radar this reflects the altitude up to which birds are detected. In the vertical radar this reflects the volume of air in which vertical flux is measured.
Bird group	One or more birds, detected by the vertical radar as one individual echo and recorded as such. One echo can reflect either one or more birds, the exact number being unknown. The term 'bird group' refers to this uncertainty.
Clutter	Any signal picked up by the radar and shown as an echo on screen, that does not reflect a bird. Examples of clutter are rain, interference, sea clutter (waves), ships and wind turbines. The Merlin software aims to prevent theses clutter signals from being stored in the bird-databases. Depending on type of clutter, this is more or less successful, and additional data-filtering has to be carried out.
Collision rate	The number of birds that collides with (the wake of) a turbine. The collision rate is dependent on the bird flux through the wind farm and on the collision risk of individual birds. The collision rate can be used to estimate population effects of a wind farm on birds. Collision rate offshore is difficult to determine as collision victims disappear in the waves, and to date no actual counts of collision rates at offshore wind farms have been reported.

Continued on next page.

Appendix 1 continued.

term	definition
Collision risk	The chance that a given bird flying through a wind farm will collide with (the wake of) a turbine. The risk depends on an array of factors such as location and lay-out of the wind farm, type of turbine, landscape features, as well as behaviour and morphology of the bir species. Not to be confused with collision rate. When flux and collision risk are known, collision rate can be calculated as flux × collision risk (with additional correction factors). Calculated estimates of collision risks combined with measurements of bird flux provide the means to estimate collision rates at offshore wind farms, until a technique is developed to measure actual collision rate offshore.
Cumulative effects	The cumulative effects of multiple offshore wind farms at the population level of different bird species; in contrast to the impact on birds of the single OWEZ wind farm. In this context calculated for the Dutch North Sea only and for 10 hypothetical offshore wind farms similar to OWEZ. Reported in Poot *et al*. (2011).
Deflection	Change in flight direction of a bird away from the wind farm. Can be either horizontal or vertical.
Displacement	See disturbance.
Disturbance	Disturbance of birds that occurs due to avoidance behaviour of birds. As a result, habitat loss may occur, as well as reduced reprodiction or survival rate. For instance, when a bird species avoids entering a wind farm, and that wind farm is built on its foraging grounds, disturbance occurs of birds of that species foraging in that area, which in turn may result in reduced survival rate or feeding rate of chicks.
Effect study	Study on the effects of the OWEZ wind farm after construction. Study on flight patterns of birds carried out in 2007-2010 and reported in Krijgsveld *et al*. (2011), study on local birds reported in Leopold *et al*. (2011).
Flight activity	Similar to flux. Indication for the number of flying birds that is recorded in the study area; usually in reference to the time of day or to the seasonal period.
Flight altitude	The altitude at which a bird is flying. In this context expressed in m above mean sea level.
Flight intensity	See flux.
Flight path	The route or path that a bird follows when flying through an area, e.g. through a wind farm or on migration.
Flight pattern	The combination of flight paths, flight altitudes and fluxes of birds.
Flux	Flight intensity of birds, expressed as the number of birds that pass an area of 1 km in length in the period of 1 hour, up to a specific altitude (nr of birds/km/h, MTR).
Furuno radar	Radar brand used in this study.
Horizontal radar	30 kW S-band radar scanning the horizontal plane (around the radar) up to a distance of 3 NM = 5556 m.
Interference	A specific form of clutter, originating from sources such as wind turbines, ships, other radars, and telephone masts.
K14	Gas platform owned by NAM. Located 80 km W-NW off the coast of Den Helder. Used to study flight patterns of birds at a location further offshore, reported in Fijn *et al*. 2012.
Local seabirds	Seabirds flying in the study area because they use the area for foraging or resting during winter or when breeding. In contrast to migrating seabirds, often concerning the same species but at different times of the year.
Macro-avoidance	Avoidance of the entire wind farm. Birds avoid flying into the wind farm and instead stay outside its outer boundaries.

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Appendix 1 continued.

term	**definition**
Marine mammals	Group of 128 mammal species that rely on the ocean for their existence. At OWEZ and PAWP, most common species encountered were harbour porpoise, harbour seal and gray seal. Sightings of marine mammals during bird observatons and surveys at OWEZ and PAWP were always recorded.
Meetpost Noordwijk	MpN. Research platform used for the baseline study on flight patterns of birds (Krijgsveld *et al.* 2005). Located 10 km offshore off the coast of Noordwijk, and ca. 40 km south of OWEZ.
Merlin	Bird-tracking radar system developed and supplied by Detect Inc, which was used in both baseline and effect study on flight patterns of birds at OWEZ. Horizontal and vertical surveillance radars are tuned to record flying birds. Echoes of these birds are filtered from backgound noise and are stored digitally in a database. The system allows 24/7 automated recording of flight activity offshore, as well as remote control of radars.
Metmast	Meteorological mast. Offshore platform from which the radar and visual observations on bird flight patterns for the baseline study were carried out.
Micro-avoidance	Avoidance of individual turbines within the wind farm. Concerns birds that do fly into the wind farm, but that subsequently avoid close proximity of individual turbines within that wind farm.
Migrating landbirds	Birds that forage, rest and breed onshore, but migrate over sea to and from their breeding grounds and can therefore be observed in the OWEZ area. For instance an array of songbirds such as starlings, thrushes, pipits and larks, owls, raptors, herons, geese and swans.
Migrating seabirds	Seabirds flying in the study area because they pass the area on their way to and from wintering and breeding grounds. In contrast to local seabirds, often concerning the same species but at different times of the year.
Moon watching	Method to observe and record flight activity of migrating birds at night. By looking through a telescope at the disc of the moon in a standardised fashion, birds that pass the moon can be seen, identified and counted. Flight direction and flight altitude can be calculated by recording point of enry and exit from the disk of the moon, and size of the bird relative to the crater Tycho. For full explanation see Lowery & Newman (1966) and Zehtindjiev & Liechti (2003).
MpN	See Meetpost Noordwijk.
MTR	Mean Traffic Rate. Unit used to express bird flux. Number of bird groups passing a specified surface of airspace per time unit (standard=1km/hr).
NM	Nautic Mile. 1 Nautic Mile = 1852 m. Unit used to describe scanning range of radars.
NSW-MEP	Near Shore Wind - Monitoring and Evaluation program. Monitoring and Evaluation Program for the OWEZ wind farm, comprising the economical, technical, ecological as well as social effects.
OWEZ	Offshore Wind farm Egmond aan Zee. Formerly known as NSW and Q8. Located 10-18 km of the coast at Egmond aan Zee. Consists of 36 turbines spaced 640 m apart within rows, and 1000 m between rows.
Panorama scan	Method to quantify birds visually in a systematic fashion, by scanning an area of 360° around the observer, using a pair of binoculars mounted on a tripod. Main parameters recorded are: species, number of birds, location, distance, flight altitude and flight direction. Explained in further detail in §2.2.2.
PAWP	Prinses Amalia Wind Park, see Prinses Amalia wind farm.

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Appendix 1 continued.

term	**definition**
Pelagic seabirds	Birds that spend most of their lives at open sea. Birds considered as pelagic in this context are e.g. fulmar, gannet, kittiwake, divers, scoters, auk and guillemot.
Prinses Amalia wind farm	- Prinses Amalia Wind Park, PAWP, formerly known as Q7. Located near OWEZ, but further offshore. Consisting of 60 smaller turbines that are positioned closer together than OWEZ; thus almost twice as many turbines take up half as much surface area as do the 36 turbines of OWEZ.
Radar effort	Amount of time that the radar has been operational and collecting data, within the study period. Radar can be offline due to weather conditions or technical issues.
Rotor	Rotor blades of the wind turbines. Rotor blades of the turbines at OWEZ are 45 m long and are placed on a hub at 70 m above mean sea level. Thus, rotor height reaches a maximum of 115 m above mean sea level in the top position, and a minimum of 25 m in the lowest position.
S-band radar	Radar using the S-band segment of the microwave radio region of the electromagnetic spectrum (frequency between 2.0 and 4.0 GHz). This type of radar pulses at relatively longer wavelengths. See also horizontal radar.
Sea clutter	Echoes detected by the radar that originate from waves, and that are regularly recorded in the database. Level of sea clutter increases with increasing wave height. Due to the nature of the radar, this occurs especially in the horizontal radar, and data filtering is required to remove sea clutter from the database.
T0-study	See baseline study.
T1-study	See effect study.
Vertical radar	25 kW X-band radar scanning the vertical plane (up in the air) up to 0.75 NM distance (1389 m).
Wind farm area	The OWEZ wind farm and the area around it, as was observed with either the visual observations (~4 km) or the horizontal radar (3 NM = 5556 m).
X-band radar	Radar using the X-band segment of the microwave radio region of the electromagnetic spectrum (frequency between 8.0 and 12.0 GHz). This type of radar pulses at relatively shorter wavelengths. See also vertical radar.

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