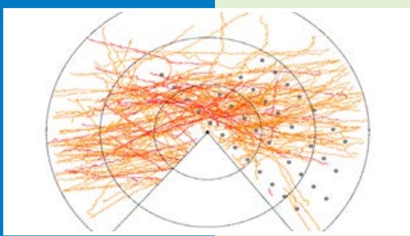
Effect studies Offshore Wind Farm Egmond aan Zee

Final report on fluxes, flight altitudes and behaviour of flying birds



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NoordzeeWind

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Observer recording a flight path visually, by R. Fijn;
Long flight paths of birds flying across the wind farm at dawn and dusk in November, as recorded on horizontal radar;
Lesser black-backed gull, by R. Smits.

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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 baseline study, describing the reference situation before construction of the wind farm, has been carried out in 2003-2005 (Dirksen *et al.* 2005; Krijgsveld *et al.* 2005). The study design of the effect study is presented in the strategy of approach (Krijgsveld *et al.* 2006a), including the general set-up of the study and the techniques that are employed. Two reports were published on preliminary results (Krijgsveld *et al.* 2008; Krijgsveld *et al.* 2009b).

In the report at hand the final results are presented on fluxes and flight altitudes of flying birds, collected from the start of the program in the spring of 2007 until the end of the program in May 2010. Data are based on both radar and visual observations, carried out in the wind farm area.

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 this report the results are presented of a study of the effects of the Offshore Wind farm Egmond aan Zee (OWEZ) on flight patterns of birds in the area. Targeted species of interest were local seabirds (such as gulls, divers, gannets, scoters, guillemots and auks), migrating seabirds (such as divers and scoters) and migrating non-marine birds (such as thrushes and geese). The research was carried out between April 2007 and June 2010, following a baseline study that took place between 2003 and 2005.

The study was aimed specifically at determining collision risks and barrier effects for birds flying through the area. To assess these effects, we studied the flight patterns in response to the wind farm, being flight paths, fluxes (*i.e.* flight intensities), and flight altitudes of birds. Based on the outcomes of this research a crude estimate of collision rates was also made.

Observation techniques
Observations were done by a combination of radars and visual observation techniques. These were chosen to obtain maximum coverage (both of the area and in time) as well as to optimize species-specific information on flight patterns. *Radar observations* included both a horizontal radar to measure flight paths, and a vertical radar to measure fluxes and flight altitudes. A bird tracking hardware and software system (Merlin, developed by Detect.Inc) was used to continuously record flight movements at a remote and inaccessible location, regardless of weather conditions or daylight. A clutter filter was developed to clean-up the collected data. Afterwards data was extensively calibrated and validated before analysis was started.

To determine flight patterns at species level, *visual and auditory observations* were carried out at the location of the wind farm approximately one day per month. Because these visual observations were restricted in time and conditions, due to the harsh nature of the offshore environment, they were extrapolated to general patterns. This was done by assigning visually obtained proportional abundances of the various species to the radar data. Furthermore, visually obtained patterns were used to interpret flight patterns recorded by radar as belonging to specific species(-groups).

Species composition
Overall abundance of birds in the wind farm area 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 and 3 marine mammal species were recorded in the OWEZ wind farm. 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, and common gull and kittiwake in winter. Also cormorants were a common species in the area, foraging

within the wind farm, and resting on the meteorological mast, on platforms in the vicinity and also on the access platforms of wind turbines. This was observed on a daily basis, especially during summer. 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. Of the pelagic seabirds, 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. Most common species of the passerines that was 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 or raptors. Also at night, the large majority of migrating species were passerines, as determined with the radar. Species-determination at night was limited due to the lack of light and access of observers to the metmast, which has resulted in especially species of small nocturnally migrating passerines being overseen. However, thrushes (redwing, song thrush, blackbird) dominated the species spectrum at night, although some waders and gulls were recorded as well.

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 (see fig. 1 for an impression of flight paths). 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.

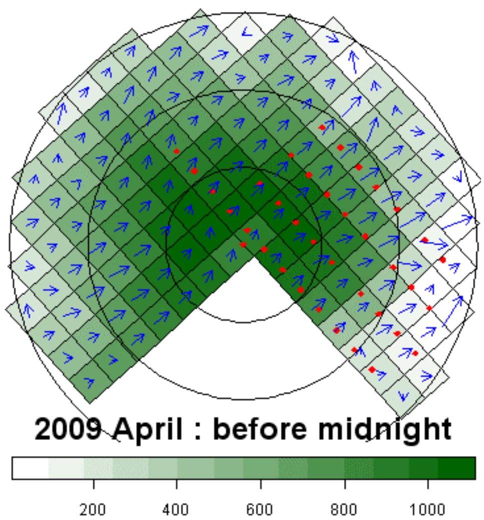


Figure 1 *Flight direction and avoidance of migratory birds in April. Colour intensity reflects abundance of tracks. Arrows indicate average flight direction of tracks; longer arrows reflecting more unifrom flight directions. Red dots: wind turbines and metmast. Figure shown in chapter 9, fig. 9.29.*

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 individual turbines and also, especially at close range, the entire wind farm. 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. 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 (lay-out of wind farm see fig. 1) 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 (SE-corner). In addition, turbines that were in operation were avoided more than turbines that were switched off.

Seabirds such as gannets, scoters, alcids and divers showed the highest levels of avoidance, while gulls (various species) and especially cormorants did not avoid the wind farm and most likely were attracted to it. Of the migrating landbirds, geese and swans were extremely weary of the wind farm and showed the highest level of avoidance. Of thrushes and smaller passerines, 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 figure 2 for an overview of avoidance behaviour of different species.

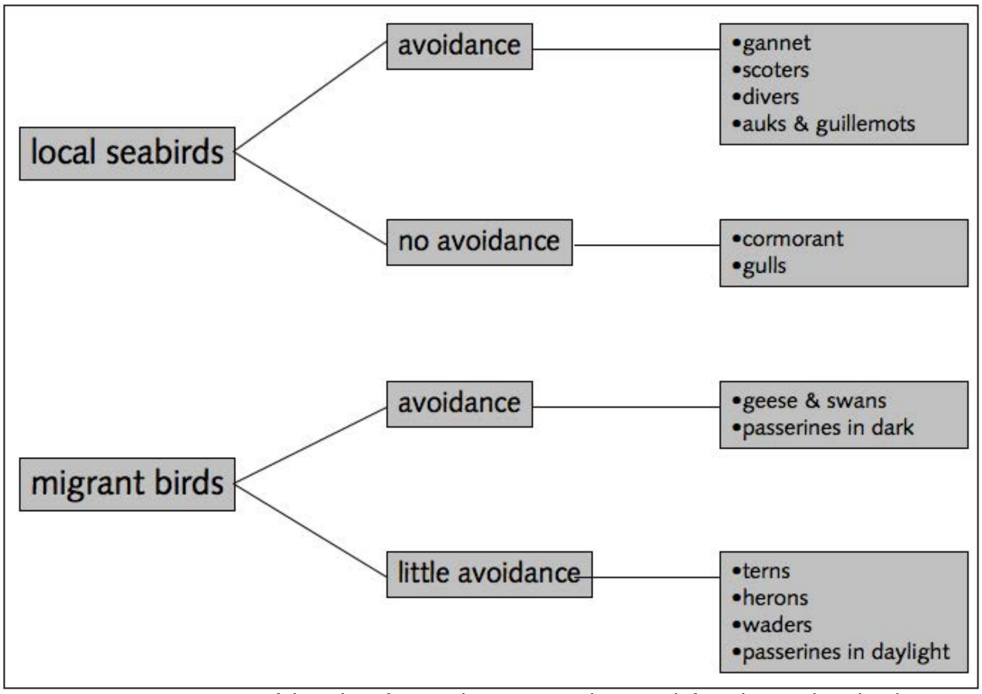


Figure 2 *Overview of levels of avoidance, as observed for the individual species. Figure shown in chapter 15, fig. 15.1.*

Micro-avoidance

Micro-avoidance (responses of birds to individual turbines) was studied with a combination of visual and radar observations, that was focussed on quantifying bird behaviour when they flew in close proximity of the turbines. For this purpose, the range of the horizontal radar was reduced from 3 to 0.75 NM to increase resolution around the turbines, and visual observation protocols were adjusted. Less than 1 bird/hr passed within 50 horizontal m. of each turbine, with the highest numbers in October and December.

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. 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 all birds that did come within 50 m of the turbine, very few (7%) came within the rotor-swept area of the turbine, 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 1385 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 (see fig. 3 for an overview of the flux through the study period, and fig. 4 for an example of migration visible on the vertical radar).

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 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.

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. In summer and winter small peaks in flight activity were observed in morning and evening. In autumn and spring highest numbers were recorded around dusk and the beginning of the night.

Weather, particularly wind speed and direction, was of great influence on fluxes. Migration fluxes were higher during tailwind situations compared to headwinds in both spring and autumn, and maximum fluxes were measured during wind speed of 4 Bft. Variation in intensity, direction and other flight characteristics of different cohorts of migratory birds was found on several specific days throughout the season.

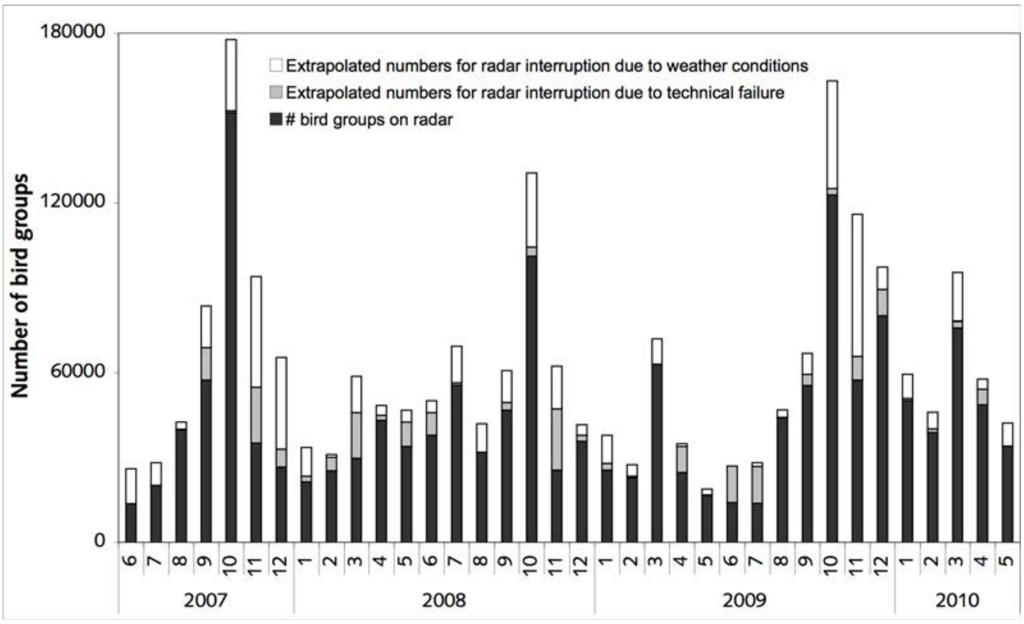


Figure 3 Number of bird groups per month in a 1-km stretch, as measured with vertical radar, showing the seasonal variation in flux, and also the variation within seasons. Dark bars are the detected echoes, grey bars represent the estimated additional tracks due to technical failure and the white bars represent the estimated additional tracks due to weather conditions. Figure shown in chapter 10, fig. 10.2.

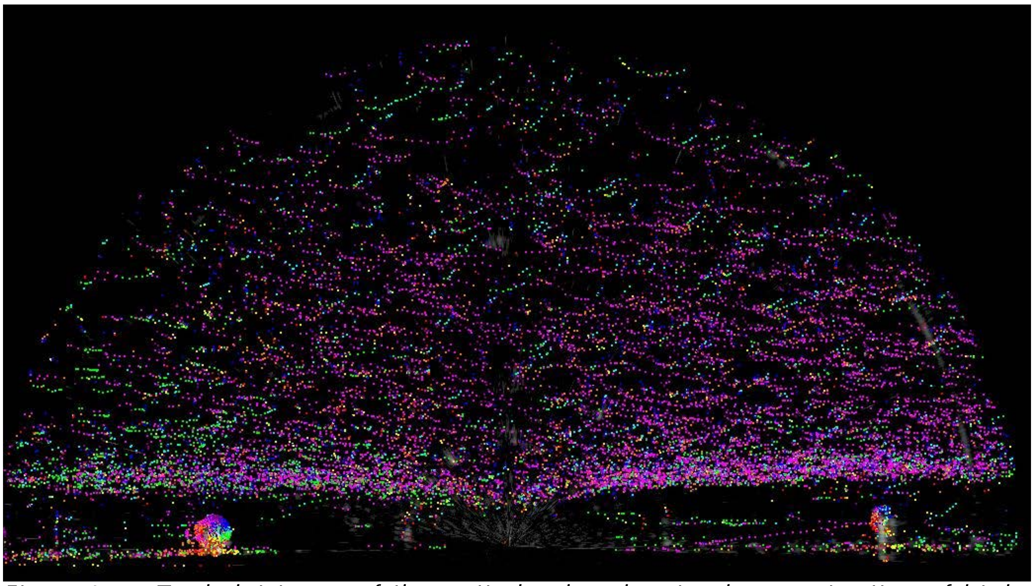


Figure 4 Trackplot image of the vertical radar, showing heavy migration of birds heading west (purple tracks).

Flight altitudes

Flight activity was recorded at all altitudes (measured up to 1385 m altitude) and varied highly between seasons (see fig. 5 for an overview of the number of bird tracks recorded at each altitude). 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 activity occurred at both higher and lower altitudes, especially at night.

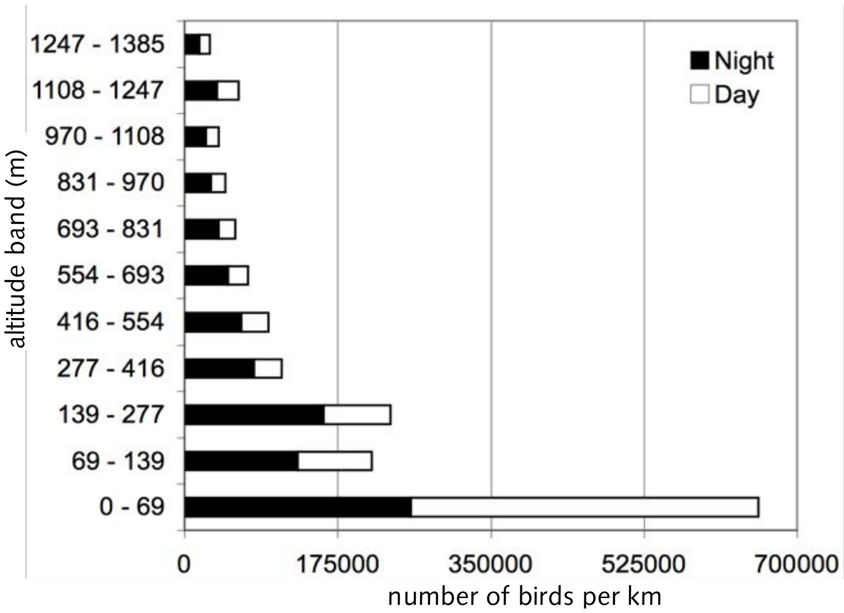


Figure 5 *Altitude distribution of all bird groups that were tracked during the study period, divided into day and night. Figure shown in chapter 11, fig. 11.1.*

From September until March the majority of birds flew at night, from April until August most birds flew during the day. Overall, flight altitude was higher at night than during the day due to the high proportion of migratory birds. 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. Average flight altitude decreased in the course of the night.

Weather, especially wind speed and wind direction, influenced flight altitude of migrating birds. In headwind conditions birds generally flew at lower altitudes than during tailwind. Also clearly segregated migration streams occurred under influence of specific weather conditions (wind speed/directions or cloud cover).

Visual observations showed that individual birds that approached the wind farm, generally increased their flight altitude but not to altitudes above rotor height. The highest-flying bird species were passerines and waders. Particularly low-flying birds were the alcids. Of birds that flew within the collision risk zone of the turbines (25 – 139 m), most species groups were represented, including divers, gannets, cormorants, all waterbirds, marine ducks, raptors and owls, skuas, gulls, terns and passerines.

Bird numbers flying through the high-risk zones in the OWEZ wind farm (25-139 m high) were in the order of magnitude of 2 million birds per year.

Barrier effects
Deflection of flight paths consisted of 18-34% of the birds in the area avoiding the entire wind farm in general, this number being larger or smaller depending on the species. Many birds chose to fly around the wind farm rather than entering it. This results in a reduced collision risk of course, 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). The cumulative effects of the total number of wind farms that are currently planned in the Dutch North Sea are quantified by Poot *et al.* (2011).

Collision risks
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, as observed with the radar, which also has positive consequences for the number of collisions. Collision victims occur among all types of birds, and during various types of behaviour. Migrating birds at night are known to be prone to collision, but also birds foraging during daytime and only paying attention to potential prey and the areas where prey can be found. 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 very limited due to the low abundance of local seabirds in the area, the relatively high avoidance level of pelagic seabirds such as gannets, divers and scoters, and also the high level of both macro-and micro-avoidance of these species. Gulls 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.

Avoidance rate presented here is likely to be an underestimate of actual avoidance rate. First, by 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. The collision risk onshore however is probably higher than offshore. Landbirds, that continuously face man-made and natural structures such as buildings, powerlines and trees, generally seem to have a more risky behaviour around wind farms (Akershoek *et al.* 2005; Fijn *et al.* 2007). In contrast, the offshore species that were active in and around OWEZ avoided the wind farm, except for gulls, cormorants and nocturnal migrants. Calculations with the Band-model suggest half of the number as estimated based on onshore collision risks (Poot *et al*. 2011). This is mainly due to the fact that the Band-model accounts for the actual macro- and micro-avoidance of the birds as measured in OWEZ in the study at hand, and is therefore thought to more closely approach actual numbers of collisions.

Second, the macro – and micro avoidance figures presented here must be regarded as conservative, because results had to be interpreted cautiously due to radar limitations. With a better resolution in the analysis of micro avoidance, more birds can be positively identified as flying outside the rotor area. We therefore think that with technical innovations in radar ornithology or alternative studies on individual flight paths, future estimates of avoidance rates will be higher, resulting in lower collision rates.

Migrant birds passing the area reached high numbers. The majority of these birds passed through the wind farm area well above rotor height. A considerable number, approximately one million bird groups, still passed the area at rotor height however. 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.

Adult gannet flying past the OWEZ wind farm (photo R. Fijn).

Nederlandse samenvatting

Achtergrond en onderzoeksdoel
In dit rapport worden de resultaten gepresenteerd van een onderzoek naar de effecten van het Offshore Windpark Egmond aan Zee (OWEZ) op vliegpatronen van vogels in en rond het windpark. Effecten zijn onderzocht voor lokale zeevogels (zoals meeuwen, duikers, jan-van-genten, zee-eenden, alken en zeekoeten), op trekkende zeevogels (zoals duikers en zee-eenden) en op trekkende landvogels (zoals lijsterachtigen en ganzen). Het onderzoek is uitgevoerd van april 2007 tot en met mei 2010. Deze effectstudie is het vervolg op een studie tijdens de nulsituatie, uitgevoerd van 2003 tot 2005 (Krijgsveld *et al.* 2005).

Het doel van het onderzoek was om vast te stellen wat de aanvaringsrisico's waren voor vogels, en of er barrièrewerking optrad. Hiertoe zijn de vliegpatronen onderzocht van vogels in reactie op het windpark: vliegpaden, fluxen (ofwel vliegintensiteit) en vlieghoogtes.

Observatiemethodes
De vliegpatronen zijn gemeten middels een combinatie van radar- en visuele observatiemethodes. Door gebruik te maken van radars die voorzien waren van automatische tracking software, werd een zo groot mogelijk gebied rond het windpark onderzocht en kon vrijwel continu worden geobserveerd. Om de vliegpatronen te meten, is een horizontale radar ingezet om vliegpaden te registreren, en een verticale radar om fluxen en vlieghoogtes te meten. De radars waren uitgerust met een bird-tracking hardware&software-pakket (Merlin, ontwikkeld door Detect.Inc) waarmee continu vliegpaden konden worden geregistreerd ondanks het feit dat de locatie in zee lag en slecht toegankelijk was. De gegevens verzameld door Merlin zijn uitvoerig gekalibreerd en gevalideerd alvorens met de analyse gestart is.

De radars hebben uitgebreide en gedetailleerde gegevens opgeleverd betreffende vliegpatronen van vogels in en rond het windpark, maar niet op soortsniveau. Om te bepalen welke soorten in het gebied aanwezig waren en in welke aantallen, alsook om te bepalen hoe de verschillende soorten reageerden op het windpark, zijn ongeveer een dag per maand visuele en auditieve observaties gedaan in het windpark.

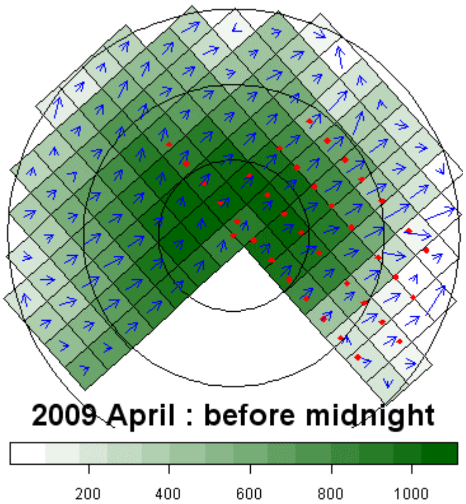
Soortsamenstelling
Over het algemeen was het aantal vogels dat in het gebied rond het windpark vloog erg laag. Dit lag niet aan de aanwezigheid van het windpark, maar was inherent aan het gebied zelf (Leopold *et al.* 2011). De aantallen waren het laagst in de zomer en de winter, toen vooral lokale vogels in het gebied aanwezig waren. In de trektijd waren de aantallen hoger. In totaal zijn 103 verschillende soorten gezien in het gebied, alsook 3 soorten zeezoogdieren. De variatie binnen en tussen jaren was groot. Deze variatie was gerelateerd aan diverse factoren, zoals seizoenen, tijd van de dag, weersomstandigheden, en daarnaast ook de aanwezigheid van het windpark.

De meest algemene soortgroep in het gebied betrof meeuwen. In de zomer waren vooral kleine mantelmeeuwen en zilvermeeuwen aanwezig, 's winters vooral drieteenmeeuwen en stormmeeuwen. Daarnaast waren er veel aalscholvers aanwezig in het gebied, die dagelijks in het windpark foerageerden en op nabijgelegen platforms rustten. De soort was jaarrond aanwezig, met vooral 's zomers grote aantallen. Dit is een recente ontwikkeling, en waarschijnlijk heeft het windpark door de toegenomen beschikbaarheid van rustplaatsen en mogelijk ook een toenemende beschikbaarheid van voedsel, bijgedragen aan het zo veelvuldig voorkomen van de soort zo ver op zee.

Van de pelagische zeevogels, kwamen jan-van-genten het meest voor, voornamelijk in maart. Daarnaast kwamen kleine aantallen zee-eenden, duikers en alkachtigen in het gebied voor. In de trektijd waren het voornamelijk kleine zangvogels die werden waargenomen met de radar. Overdag waren spreeuwen en lijsterachtigen het meest talrijk. Lage aantallen van andere soorten trekkende landvogels werden ook waargenomen, waaronder ganzen, zoetwatereenden, sterns, reigers en roofvogels. Ook 's nachts bestond the meerderheid van de langstrekkende vogels uit kleine zangvogels, op basis van de radardata. In het donker was soortsbepaling slechts beperkt mogelijk door het gebrek aan licht en door beperkte toegang tot de meetmast. Daardoor konden vooral 's nachts trekkende zangvogels slechts in beperkte mate gedetermineerd worden. De resultaten laten echter zien dat lijsters (koperwiek, zanglijster, merel) 's nachts het soortenspectrum tijdens trektijd domineerden. Ook enkele steltloper- en meeuwensoorten werden in die periode gezien.

Vliegrichtingen en macro-avoidance

Vliegpaden, waargenomen met de horizontale radar, gaven gedetailleerde informatie over uitwijkgedrag in alle seizoen, op elk moment van de dag en tijdens een groot aantal weertypen (zie figuur 1 voor een voorbeeld van vliegpaden). Over het algemeen week tussen de 18-34% van de vogels uit voor het windmolen park (in andere woorden: 18-34% minder vogels binnen het park dan erbuiten). Uitwijking was het laagst in de winter (18%) en het hoogst in de herfst (34% minder). 's Nachts werd meer uitgeweken voor het park dan overdag.

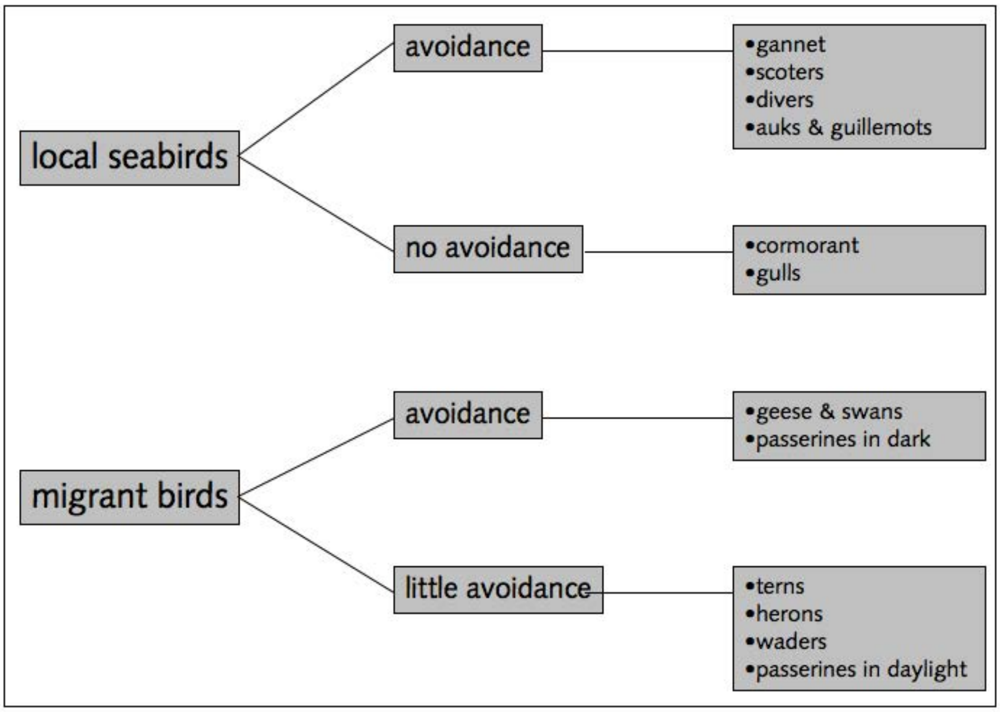


Figuur 1 *Vliegrichting en vermijding van het windpark door trekvogels in april. Groen geeft het aantal vogels per gridcel aan, de blauwe pijlen de gemiddelde vliegrichting. Hoe langer de pijl, hoe meer vogels in dezelfde richting vlogen. De windturbines en de meetmast zijn aangegeven met rode stippen. De figuur komt uit hoofdstuk 9, fig. 9.26.*

In de zomer en de winter waren de vliegrichtingen meer willekeurig, omdat in die periode vooral lokaal foeragerende zeevogels in het gebied aanwezig waren. In de trektijd was de vliegrichting eenduidiger. Ook 's nachts, als de uitwijking het grootst is, werd een kleinere variatie in vliegrichting gevonden dan overdag, waarschijnlijk ook door het verschil in vlieggedrag tussen lokaal foeragerende vogels overdag en meer gericht vliegende vogels 's nachts. De vliegrichting van vogels werd beïnvloed door het windpark. Meerder vogelsoorten pasten hun vliegroutes aan om het gehele windpark te vermijden en ook, op korte afstand, om losse turbines te vermijden. Aanpassingen in de vliegrichting werden waargenomen op relatief korte afstand, zo'n 1 tot 2 kilometer van het windpark. Correcties na het verlaten van het windpark zijn waargenomen tot 3 à 4 kilometer na het verlaten van het windpark.

Ook de opstelling van de turbines in het windpark speelde een rol voor vermijding. De uitstekende lijn turbines in het noordwesten van het park werd vaker doorkruist door vogels dan het stuk met de vier rijen turbines naast elkaar. Ook was de vliegactiviteit van vogels groter in het gedeelte van het windpark waar de turbines verder uit elkaar stonden (ZO-deel). Daarnaast werden draaiende turbines meer vermeden dan stilstaande turbines.

Zeevogels zoals jan-van-genten, zee-eenden, alkachtigen en duikers weken het meest uit terwijl meeuwen (alle soorten) en aalscholvers in het geheel niet uitweken (en zelfs actief het windpark opzochten). Ganzen en zwanen waren uitermate gevoelig voor de windturbines en weken sterk uit. De helft tot driekwart van de lijsters en kleine zangvogels vloog overdag door het windpark op rotorhoogte, maar vermeden wel actief de turbines. Figuur 2 geeft een overzicht van het het vermijdingsgedrag van de verschillende soortgroepen.



Figuur 2 Overzicht van de mate van uitwijking per soortsgroep. Figuur komt uit hoofdstuk 15, fig. 15.1.

Micro-avoidance

Micro-avoidance (d.w.z. de reactie van vogels die in het windpark vliegen op individuele turbines) werd met een combinatie van visuele waarnemingen en de horizontale radar met aangepaste instellingen (range gereduceerd van 3 NM naar 0.75 NM voor een hogere resolutie) bestudeerd rond individuele turbines. Minder dan 1 vogel/u kwam binnen een straal 50 m. van een turbine, met de hoogste aantallen in oktober en december.

Minder vogels werden binnen de 50-meter zone rond turbines waargenomen dan verwacht op basis van een gelijkmatige verspreiding van vogels door het windpark. Het uitwijkingsniveau was 0.66. Uitwijking was ook hier hoger in de nacht en wanneer de turbines draaiden. Vogels in het windpark reageerden snel en sterk op de aanwezigheid van turbines. Vogels die binnen de 50 meter zone vlogen, kwamen namelijk nauwelijks binnen bereik van de rotorbladen, maar vlogen voor of achter de rotobladen langs. Deze uitwijking op zeer korte afstand meenemend, bedroeg de totale micro-avoidance 0.976.

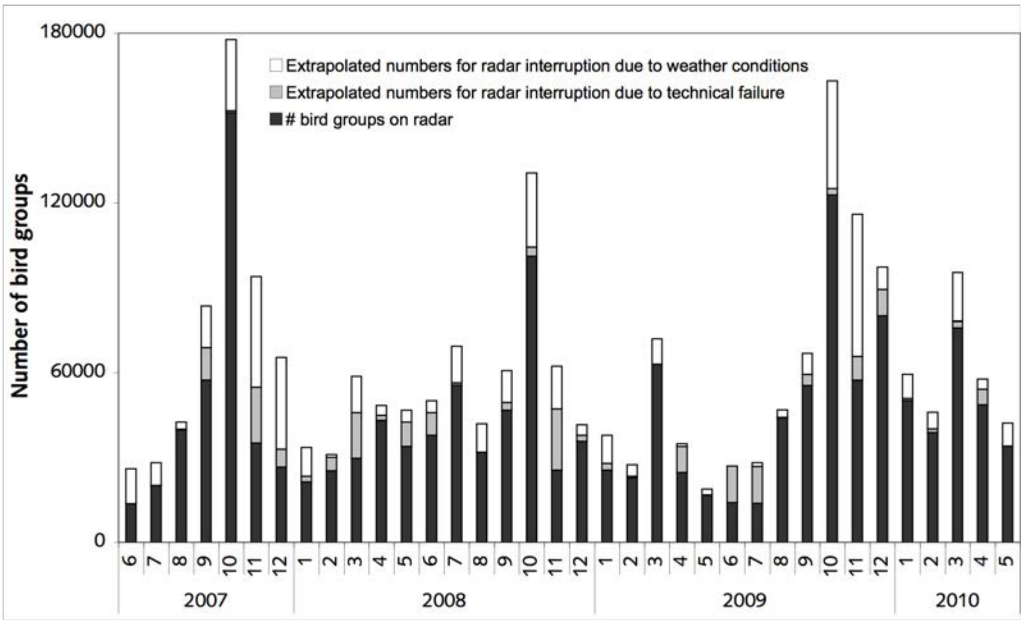
Fluxen

Met behulp van de verticale radar kon de vliegintensiteit (flux) van vogels worden bepaald tot op 1385 m hoogte. Gemiddeld vlogen er ca. 80 vogelgroepen/km/u door het windpark. De aantallen varieerden sterk gedurende het jaar. Op het hoogtepunt van de trek kon de vliegintensiteit (MTR, Mean Traffic Rate) oplopen tot 3.600 vogelgroepen/km/u (zie figuur 3 voor de gemeten fluxen en figuur 4 voor een voorbeeld van trek op de verticale radar).

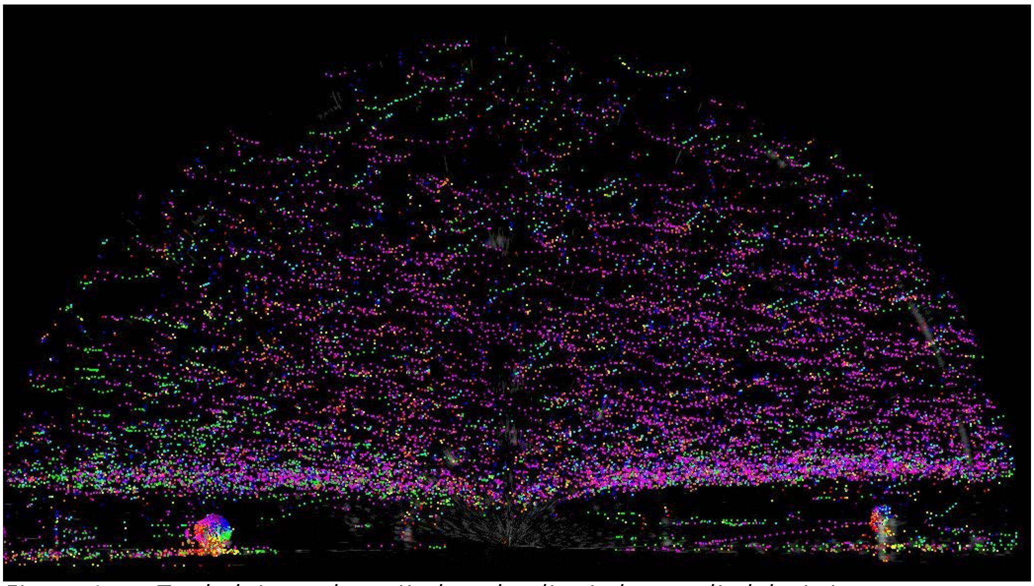
Naar schatting vloog jaarlijks 0,1 tot 2% van de totale trekgolf van vogels over de Nederlandse Noordzee door het windpark. In het voor- en najaar vlogen veel trekvogels door het park in tegenstelling tot de zomer en winter toen voornamelijk lokale zeevogels aanwezig waren.

Fluxen varieerden sterk tussen dag en nacht, met verhoogde activiteit in de nacht in de trektijd. In de zomer en in mindere mate ook in de winter werden de hoogste fluxen gemeten in de ochtend en avond. In het voor- en najaar vloog het grootste gedeelte van de vogels net na zonsondergang tot ongeveer middernacht.

Het weer, en dan voornamelijk windkracht en –richting, had een grote invloed op de gemeten fluxen. Zowel in voor- als najaar was de trekactiviteit groter bij meewind dan bij tegenwind. De hoogste fluxen werden gevonden bij een meewind van 4 Bft. Verschillende cohorten trekvogels konden worden aangewezen tijdens verschillende tijdsperiodes binnen een seizoen, op basis van timing, vliegintensiteit, vlieghoogte, vliegrichting en treksnelheid.



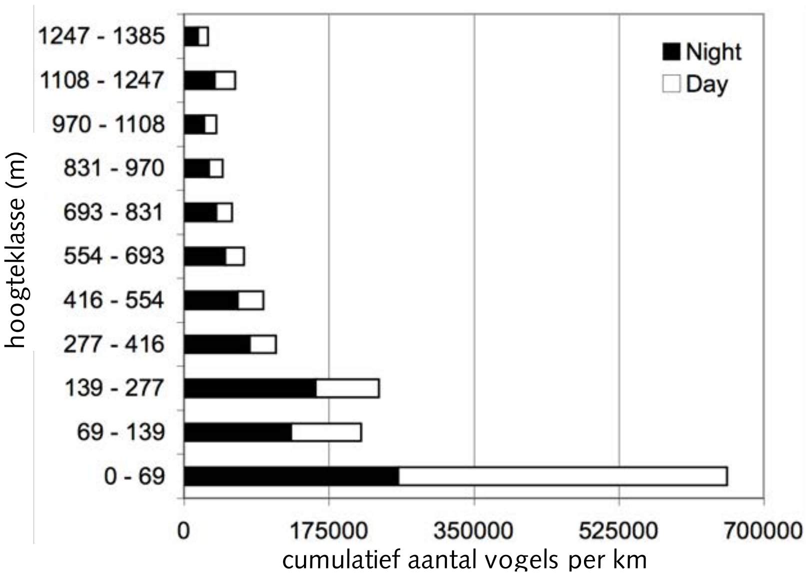
Figuur 3 *Gesommeerde aantallen vogelgroepen per maand per km gemeten met de verticale radar, die de variatie in fluxen over de seizoenen laat zien. De donkere balken zijn de aantallen gedetecteerde sporen op de radar en de grijze en witte balken de maandelijks bijgeschatte aantallen waarmee de hoogte van de flux gecorrigeerd is voor de tijd dat de radar noodgedwongen uit stond. Figuur komt uit hoofdstuk 10, fig. 10.2.*



Figuur 4 *Trackplot van de verticale radar die sterke vogeltrek laat zien.*

Vlieghoogte

Vogels werden waargenomen op alle hoogtes (metingen gedaan tot een hoogte van 1385 m). Vlieghoogtes varieerden sterk tussen de verschillende seizoenen (zie figuur 5 voor een overzicht van de gemeten fluxen op de verschillende hoogtes). In de winter en de zomer werd voornamelijk op lage hoogte gevlogen door meest meeuwen en andere lokaal verblijvende zeevogels. In de trektijd werd ook op grotere hoogte veel activiteit gemeten, zeker tijdens nachten met veel trek.



Figuur 5 Hoogteverdeling van de vogelgroepen die werden waargenomen tijdens de studieperiode, onderverdeeld in dag en nacht. De figuur komt uit hoofdstuk 11, fig. 11.1.

Gemiddeld over het gehele jaar vlogen de meeste vogels 's nachts. Deze verdeling werd op alle hoogtes gevonden, behalve in de laagste hoogteband (0-69 m). Boven de 277 m was het grootste gedeelte van de echo's afkomstig van trekvogels. Op lagere hoogte waren voornamelijk lokale zeevogels actief. In het algemeen was de vlieghoogte hoger gedurende de nacht dan tijdens de dag. Tijdens de trek kwamen de vogels omlaag in de loop van de nacht.

Weersomstandigheden, en dan voornamelijk windrichting en windkracht, waren van invloed op de vlieghoogte van trekvogels. Bij tegenwind vlogen vogels in het algemeen lager dan bij meewind. Sterk gescheiden trekstromen zijn waargegnomen onder invloed van specifieke weerscondities (windsnelheid, -richting, wolkbedekking).

Uit de visuele waarnemingenkwam naar voren dat individuele vogels bij nadering van het windpark in het algemeen wat hoger gingen vliegen, maar niet boven de rotorbladen. Zangvogels en steltlopers vlogen het hoogst, terwijl alken bij uitstek erg laag boven het water vlogen. Van de vogels die ter hoogte van de rotorbladen vlogen, waren vrijwel alle soortgroepen vertegenwoordigd, inclusief duikers, jan-van-genten, aalscholvers, zee-eenden, roofvogels, jagers, meeuwen, sterns en zangvogels.

Het aantal vogels dat op risicohoogte door het windpark vloog (25-139 m) lag in de ordegrootte van 2.000.000 vogels per jaar.

Barrièrewerking
Van alle vogels in het gebied week ongeveer 18-34% uit (barrièrewerking). Dit percentage verschilde tussen soorten. Veel vogels kozen ervoor om om te vliegen in plaats van door het windpark te vliegen. Hierdoor nam het aanvaringsrisico uiteraard af wat kan worden gezien als een positief effect. De toegenomen vliegafstand is marginaal vergeleken met de dagelijkse vliegafstand van vogels en heeft dus geen energetische consequenties voor bijvoorbeeld trekvogels (Masden *et al.* 2009). De cumulatieve effecten op vogels van het totaal aan windparken dat op dit moment is gepland in het Nederlandse deel van de Noordzee is onderzocht door Poot *et al.* (2011).

Aanvaringsrisico's
Vogels die het windpark in vlogen weken sterk uit voor individuele turbines. Dit verminderde het aanvaringsrisico van deze vogels met de turbines. Aanvaringen vinden plaats onder alle soorten vogels en zowel in de trektijd als daarbuiten. Nachtelijke trekvogels lopen een risico als het gaat om aanvaringen met windturbines, maar ook foeragerende vogels overdag kunnen in botsing komen met de rotorbladen als ze teveel gefocussed zijn op hun prooidieren en niet genoeg aandacht hebben voor hun omgeving. Ze kijken dus naar de zee in plaats van vooruit naar de rotorbladen.

De hoeveelheden aanvaringsslachtoffers in het OWEZ windmolenpark zijn naar schatting laag, door de lage dichtheden vogels in het gebied, de relatief hoge uitwijking van zeevogels en het hoge niveau van zowel macro- als micro-avoidance. Meeuwen weken niet uit voor het windpark en foerageerden zelfs binnen het park. Hoewel ze de turbines goed in de gaten lijken te hebben en een grote mate van micro-avoidance vertonen kunnen de grote aantallen meeuwen binnen het park er toe leiden dat deze soortgroep voornamelijk een aanvaringsrisico loopt bij het doorkruisen van het windpark.

Het percentage vogels dat uitwijkt zoals dat hier gepresenteerd is, is waarschijnlijk een onderschatting van het werkelijke percentage. Ten eerste, aannemende dat het aanvaringsrisico op zee gelijk is aan het risico op land, wordt geschat dat jaarlijks enkele honderden meeuwen in aanvaring zullen komen met de turbines van het OWEZ windpark, naast een enkel individu onder andere zeevogelsoorten. Waarschijnlijk ligt het aanvaringsrisico op zee echter een stuk lager dan op land. Soorten op land, die continu te maken hebben met allerlei structuren in de lucht zoals gebouwen, bomen en hoogspanningslijnen, lijken zich een stuk risicovoller te gedragen rond windturbines (Akershoek *et al.* 2005; Fijn *et al.* 2007). De soorten zeevogels die aanwezig waren in en rond het OWEZ windpark vermeden het windpark, met uitzondering van meeuwen, aalscholvers en nachtelijke trekvogels. Berkeningen met het Band-model komen uit op een schatting van het aantal aanvaringsslachtoffers dat half zo hoog is als de schatting op basis van aanvaringsrisico's op land (Poot *et al.* 2011). Dit verschil zit hem vooral in het feit dat het Band-model rekent met de werkelijke macro- en micro-avoidance van de vogels, zoals die gemeten is in het voorliggende OWEZ onderzoek. Het Band-model geeft dan waarschijnlijk ook een betere benadering van de werkelijke aantallen slachtoffers.

Ten tweede moeten de gepresenteerde percentages uitwijking beschouwd worden als conservatieve schattingen, omdat de resultaten vanwege beperkingen in de radar voorzichtig geïnterpreteerd moesten worden. Met een hogere resolutie in de analyse van micro-avoidance, kan voor meer vogels positief worden bepaald dat ze buiten de rotorbladen om vliegen. We zijn daarom van mening dat met technische verbeteringen in de radar of met alternatieve studies aan vliegpaden, toekomstige schattingen van het percentage uitwijkende vogels hoger zal zijn, en daarmee het aantal aanvaringen lager.

Grote aantallen trekvogels passeren jaarlijks OWEZ. Het grootste deel van deze vogels vliegt op grote hoogte boven het park over. Toch vliegt daarnaast een aanzienlijk deel, ongeveer 1 miljoen vogel groepen, op rotorhoogte door het park. Mede hierdoor wordt geschat dat de grootste aantallen slachtoffers vallen onder de trekkende zangvogels. Op basis van een ruwe schatting zullen op jaarbasis enkele honderden zangvogels, verdeeld over alle soorten die het gebied passeren, in aanvaring komen met de turbines van het OWEZ windpark. Deze schattingen zijn enkel te valideren door het werkelijke aantal vogelslachtoffers in het windpark te meten.

Lesser black-backed gulls were a common sight around OWEZ (photo R. Fijn)

1 Introduction

1.1 Background

Offshore Wind farm Egmond aan Zee

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 economical and social related, as well as benefits gained for mitigating global climate change by increasing the amount of sustainable energy. 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. In the summer of 2006 the OWEZ wind farm was built by order of NoordZeeWind (Nuon Duurzame Energie and Shell Wind Energy) and the site is in operation since January 2007. It consists of 36 Vestas V90/3MW turbines with a hub height of 70 m, positioned 10-18 km off the coast of Egmond aan Zee in the Netherlands.

Monitoring and Evaluation Program

The wind farm serves as a demonstration project to gain knowledge and experience with the construction and exploitation of large-scale offshore wind farms. To collect this knowledge, an extensive Monitoring and Evaluation Program (NSW-MEP) has been designed in which the economical, technical, ecological and social effects of the OWEZ have been gathered. The study on flying birds concerns the ecological effects of the wind farm on flying birds. Effects studied comprise flight paths, flight altitudes and flux of local and migrating seabirds as well as non-marine migrating birds. The report at hand gives the final results of this study. See chapter 2 for a process description of the monitoring program and for an overview of related reports.

Birds in the North Sea

A large variety of birds can be found in the wind farm area. Seabirds, such as common scoter, red-throated diver or northern gannet, are found foraging or resting here in considerable numbers during specific periods of the year, even though the major seabird concentrations are situated elsewhere (Lindeboom *et al.* 2005; Skov *et al.* 2007; Poot *et al.* 2010). Many seabirds also migrate along the coastline, and the wind farm is situated within this migration route. Coastal breeding birds, such as cormorants or lesser black-backed gulls, make foraging trips out to sea and the wind farm is well within reach of these birds. And 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 Great Britain as well as migration to and from southern Europe and Scandinavia. 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.

Report at hand

This report is the final report of the effect study of the OWEZ wind farm on flight patterns of birds. It includes all results obtained in this study and a full analysis of the data. Results are interpreted in the light of collision risks, barrier effects and disturbance.

1.2 Study aims

Birds and wind turbines

Derived from land-based studies, the NSW-MEP requires bird research to enable an analysis of three types of possible effects of wind farms on birds:

1. Collisions of flying birds with turbines or their wake;
2. Disturbance of flight paths, so-called barrier effects;
3. Disturbance of locally resting and/or feeding birds.

The study at hand focuses on effects on flying birds, and covers the first two aspects. It includes measurements of the distance from the wind farm at which various species groups show deflection. A related study carried out by IMARES and Bureau Waardenburg focuses on occurrence and distribution of local birds, and covers the third aspect. For information on this subject we refer to the reports from Leopold *et al.* produced within the same framework as the programme on flux and flight behaviour.

Studying flight patterns

The aim of this study is to address effects of the OWEZ wind farm. This meant that it was necessary to study flight patterns of birds. The following aspects of flight patterns of both local and migrating marine birds as well as non-marine migrating birds in the area were studied:

- Fluxes of flying birds;
  (*i.e*. flight intensity; number of birds per time unit per surface area);
  to provide insight in collision risk of birds.
- Flight paths of flying birds;
  to provide insight in occurrence of avoidance and thus in barrier effects.
- Altitudes of flying birds;
  to provide insight in both collision risk and occurrence of barrier effects.

Flight patterns in relation to the wind farm are being quantified by using a combination of automated and visual observation techniques. From the metmast in the area, visual observations during fieldwork days were carried out, as well as radar observations with both a vertical radar and a horizontal radar. Visual observations give insight in species composition and species distribution in the area, as well as species-specific information on flight patterns. Radar observations have been carried out around the clock, each day, all year, and thus give insight in overall flight patterns in the area.

Species of interest
Targeted species of interest are:
- Local seabirds (such as divers, guillemots and auks);
- Migrating seabirds (such as divers and scoters);
- Migrating non-marine birds (such as thrushes and geese).

All three groups are at risk of the three potential negative effects of wind farms (collision, disturbance, barrier effects). Marine birds are of interest within the framework of this study because seabirds are generally long-lived birds with a low reproduction and are therefore vulnerable to disturbance from the surroundings. The OWEZ wind farm is located close to wintering areas of international importance for seabirds such as red-throated diver and common scoter. Migrating marine and non-marine birds are vulnerable as they fly partly at altitudes with an immediate risk of collision and of disturbance of flight paths. Migration of land birds mainly takes place during the night, when the risk of collision is thought to be increased due to lower visibility (Larsen & Clausen 2002).

1.3 Research questions

The research questions for the study can be summarized as:
- What are flight intensities, flight altitudes and flight paths of the species of birds that occur in the OWEZ wind farm area, 10-18 km off the Dutch coast?
- How do flight intensities, altitudes and flight paths vary between seasons, spring and autumn migration, day and night, and under varying weather conditions?
- Are these flight intensities, flight altitudes and flight paths influenced by the presence of the offshore wind turbines in the OWEZ area?

1.4 Outline of chapters

This report is largely divided in four parts: an introductory part, a methodological part, a part presenting results found, and a summarizing part in which results are discussed in the light of the research questions. Chapters are divided over these parts as follows:
Introduction
- Ch.1 General introduction
- Ch.2 Information on the monitoring program and related publications *Method*
- Ch.3 Information on the study area and the wind farm
- Ch.4 Observation techniques. Description of the various visual and auditory observation methods that were used, such as the panorama scans and visual recording of flight paths of individual species. Includes an overview of weather conditions and observation dates, as well as definitions of season and time of day that were used throughout the report.

- Ch.5 Radar equipment and methods. Description of the equipment that was used, with an explanation of the properties and limitations of both the vertical and horizontal radar. Explanation how the Merlin hard- and software works.
- Ch.6&7 Validation of radar data and data processing techniques. Description of the filtering process that was applied to eliminate clutter such as waves, interference and rain from the radar data, and end up with records of birds only. Chapter 6 deals with the horizontal radar data, chapter 7 with the vertical radar data.

Results

- Ch.8 Species that were observed in the wind farm, with densities and seasonal patterns.
- Ch.9 Flight paths of birds: Macro-avoidance. Numbers and flight directions of birds in relation to the presence of the wind farm, providing insight in the level of avoidance of the wind farm;
- Ch.10 Fluxes: Numbers of birds flying in the area; patterns in flight activity related to season, time of day and weather conditions;
- Ch.11 Flight altitudes: Flight altitudes of birds in and around the wind farm; and seaonal, temporal and environmental variation therein;
- Ch. 12 Fluxes and flight altitudes of birds on days that were typical of flight patterns in each of the four seasons, to emphasize the general fluxes and altitudes that were observed.
- Ch.13 Micro-avoidance: behaviour of birds in response to individual wind turbines; shown as variation in numbers and flight directions of birds closely around turbines.

Interpretation

- Ch.14 Comparison with other locations. The OWEZ results discussed in relation to results found in the baseline study and to flight patterns of birds in nearby locations.
- Ch.15 Conclusions. Interpretation of the results that were found in the light of barrier effects and collision rates, made for the abundant species groups. Rough estimate of the number of bird collision victims in OWEZ.

Common guillemot (with a 'bridled' variety on the right) in summer plumage (photo K. Krijgsveld).

2 Process description

In this chapter we present an overview of the monitoring program for the study of flying birds. The various processes involved are presented in a time frame (§2.1). Reports that were produced within the monitoring program and that are closely related to the report at hand, are listed in §2.2. With this overview, the report at hand and results presented therein can be placed in their proper context.

In addition, we present two flow charts (§2.3) that show how the various methods that were used in this report relate to each other, and how the results obtained with these methods lead back to the research questions of this study.

2.1 Time frame of the study

1999	The Dutch government provided guidelines for an extensive Monitoring and Evaluation Program (MEP-NSW) in which the economical, technical, ecological and social effects of the future OWEZ wind farm were to be collected. The different lots within which research was conducted were: • Lot 1: Benthos • Lot 2: Demersal fish • Lot 3: Pelagic fish • Lot 4: Marine mammals • Lot 5: Local abundance of seabirds • Lot 6: Flight activity of seabirds
2003-2004	Baseline studies were carried out prior to construction of the wind farm. For the baseline studies, contracted out by the Ministry of Transport, Water Management and Public Works, avian research was split in two separate studies: one on local birds (Lot 5) and one in which flight patterns of local and migrating seabirds as well as non-marine migrating birds were studied (Lot 6). Bureau Waardenburg and IMARES were contracted for both studies. IMARES was responsible for Lot 5 on local birds; Bureau Waardenburg was responsible for Lot 6 on flying birds.
2003-2006	Based on a proposal that was part of the tender procedure for the OWEZ concession, Bureau Waardenburg and IMARES were contracted by Noordzeewind for the T1 phase of the bird research.
2006	Strategy of approach for the effect study for flying birds was completed (Krijgsveld *et al.* 2006a).
2007-2010	Effect studies Offshore Wind Egmond aan Zee were carried out. A monitoring program ran from spring 2007 until May 2010 to study the effects of the wind farm on flying birds. Simultaneously, effects on local birds were studied in a related project lead by IMARES.
2010	Measurements related to Lot 6 were finalized and the data were analysed for this final report. Collection of radar data continued at the metmast, to compare with vertical radar data collected at another offshore location.

2.2 Relevant publications

Related reports on flight patterns published in earlier stages

The effects of the OWEZ wind farm on flying birds have been assessed based on a series of studies that were carried out in the previous years. All are published in related reports:

- *Baseline study 2003-2004.* Flight patterns were recorded in the 'reference situation', *i.e.* the situation without wind turbines. This baseline study was carried out in 2003-2004 and results were published (Dirksen *et al.* 2005; Krijgsveld *et al.* 2005). Data from a closely related project on locally foraging birds and marine mammals in a larger area around the wind farm were published as well (Brasseur *et al.* 2004; Leopold *et al.* 2004).
- *Effect study 2007, first interim report.* Effects of the wind farm on flying birds were monitored starting March 2007. A first status report was presented in January 2008 on the data collected from March through October 2007 (Krijgsveld *et al.* 2008). This report showed the first results on flight patterns of birds in the OWEZ area, and discussed the influence of the OWEZ offshore wind farm on flying birds as suggested by the results at that stage.
- *Effect study 2008, second interim report.* A second status report was presented in May 2009 on the data collected from March through December 2008 (Krijgsveld *et al.* 2009b). This report showed more results on flight patterns of birds in the OWEZ area, and discussed the influence of the OWEZ offshore wind farm on flying birds as suggested by the results at that stage. The aim of this second interim report was to give an overview of results obtained thus far and to present preliminary insights on responses in flight behaviour of birds to the wind farm. A substantial amount of technical and analytical improvements were made compared to the first interim report.

Relevant reports from other parts of the program

Within the monitoring programme on the effects of the OWEZ wind farm on the marine environment and its inhabitants, a number of publications appeared in the past years. The following are relevant for the studies on flight patterns presented in this report:

- Closely related studies on locally foraging birds in a larger area around the wind farm were published in several reports. The results from the baseline study were published in (Leopold *et al.* 2004). Interim reports and the final report on effects of OWEZ on distribution of local birds were published in (Leopold & Camphuysen 2008; Leopold *et al.* 2011).
- Effects of OWEZ on marine mammals in the area were published in several reports for both the baseline and the effect studies (Brasseur *et al.* 2004; Brasseur *et al.* 2008; Kastelein *et al.* 2008; Leopold & Camphuysen 2008; Scheidat *et al.* 2008).
- Demersal and pelagic fish in the area were investigated during the baseline and the effect studies of the MEP-NSW and results have been published (Hille Ris Lambers & ter Hofstede 2009; Ybema *et al.* 2009; Winter *et al.* 2010).
- For the development of benthos growing on soft and hard substrate, several reports were published from the baseline and the effect studies of the MEP-NSW

(Bergman *et al.* 2008; Bouma & Lengkeek 2008; Daan & Mulder 2008; Daan *et al.* 2009; Bergman *et al.* 2010).

- The technical possibilities that were available to quantify the number of birds colliding with turbines at offshore locations, were inventoried in two reports *(Dirksen 2006, 2009).*
- The effects of individual offshore wind farms may cumulate when more offshore wind farms are being built in the North Sea, not only in the Dutch waters, but also the North Sea sections of Belgium, England, Scotland, Germany and Denmark. Cumulative effects from all national offshore wind farm projects were modelled quantitatively by Poot *et al.*, partly based on results of the OWEZ-studies (Poot *et al.* 2011).

Final reports of all the different lots within the Effect Studies OWEZ T1, similar to the report at hand, are due to be published in 2011 and 2012.

OWEZ wind farm with the metmast (photo R. Fijn)

2.3 Overview of methods and results, limitations and calculations

The data presented in this report are extensive, and the results obtained from the various observation techniques required a large number of processing steps. In addition, to interpret the results and arrive at conclusions on avoidance rates and collision risks, several limitations of the data needed to be overcome and assumptions needed to be made. To elucidate how we arrived from the techniques that we used and the data that we obtained at the presented results and conclusions, the various steps are summarized in the two flow charts below. In the first chart (fig. 2.1) we show the relationship between researh questions and methods, in the second chart (fig. 2.2) we show limitations of the data, and major calculations that were performed. The various methods are discussed in further detail in chapters 4 through 7.

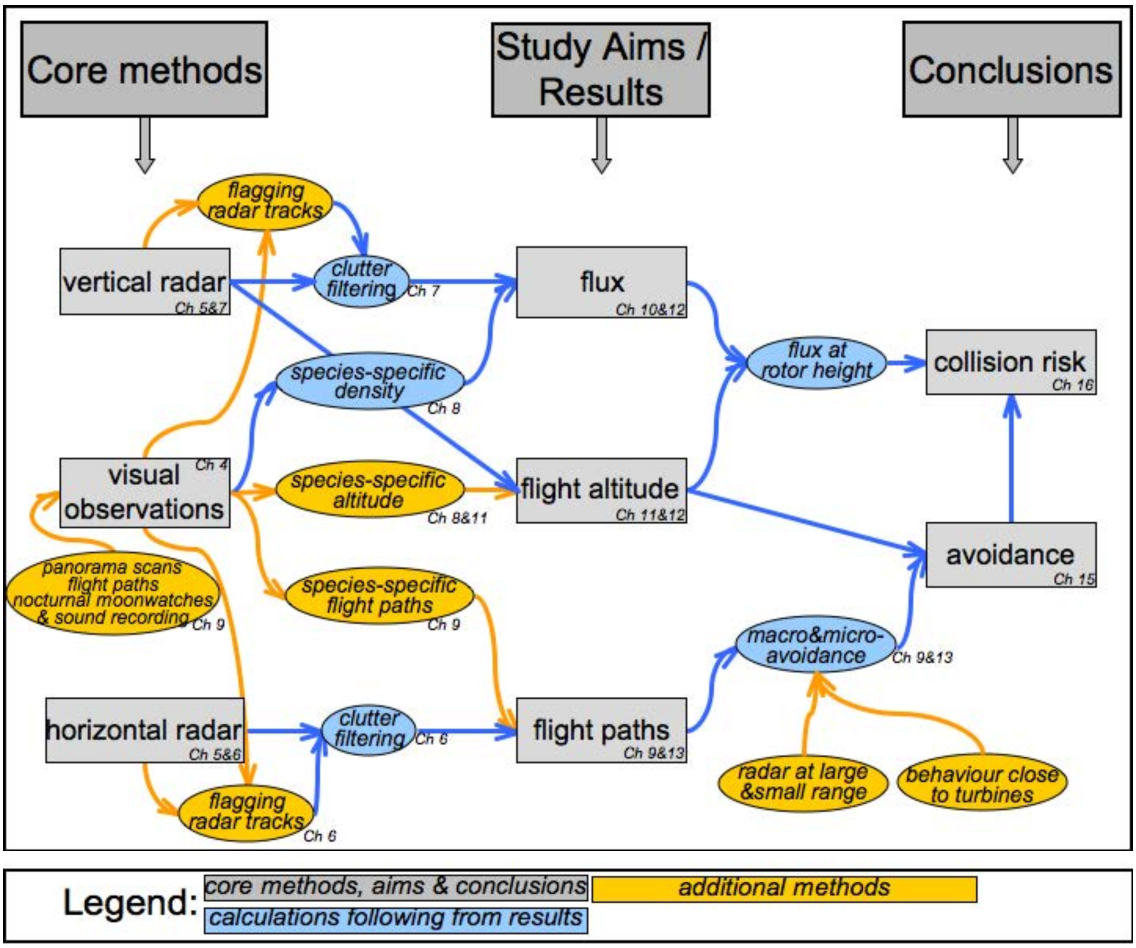


Figure 2.1 Flow chart showing the primary aims of this study (right) and the measurements that were made (left) and of the results (middle), in combination with the assumptions and extrapolations made to obtain desired insight in flight patterns of birds around the OWEZ area.

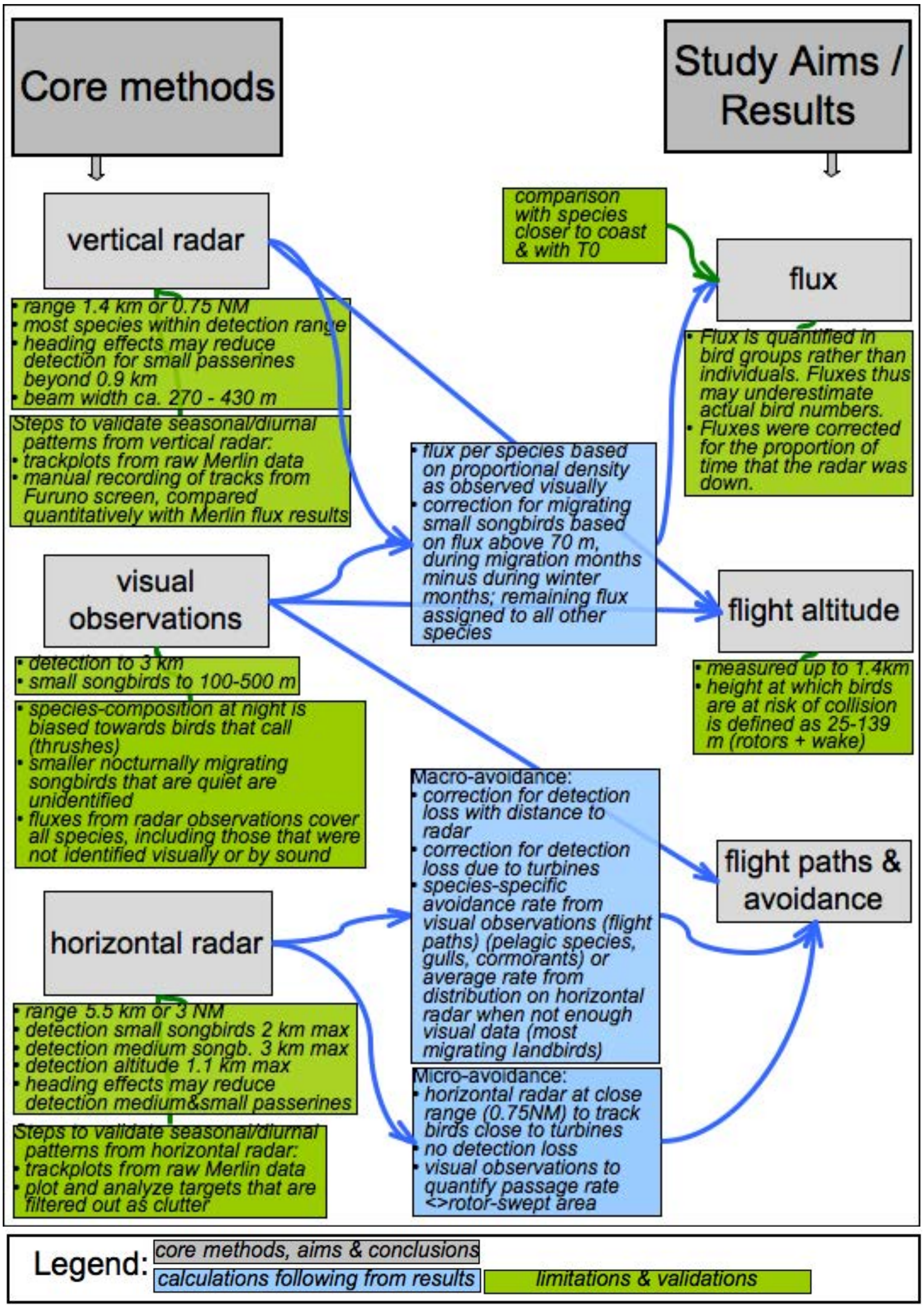


Figure 2.2 Flow chart of limitations in the data and validations that were carried out. Study aims and results and the core methods used to arrive there are shown as grey squares.

3 Study area

3.1 Location

The OWEZ wind farm is positioned 10-18 km off the Dutch coast near Egmond aan Zee, covering an area of 27 km^2 (fig. 3.1). Water depth in this area is ca. 18 m, so waters are neither shallow nor very deep. Water depth increases to 20 m a few km further offshore, at ca. 20-25 km distance from shore. Closer to shore, water depth decreases to 10 m and less within ca. 7 km from the coast. The water depth has implications for the distribution of seabirds, because prey availability like fish or shellfish is dependent on water depth (chapter 15). The seabed consists of sand, with a stone bed around the monopiles of the turbines.

Construction at site of the wind farm started in April 2006 with the installation of the first monopile. In September 2006 all turbines were in place and the wind farm started generating electricity. The wind farm is closed to all ships, including fishing vessels. Only maintenance vessels are allowed into the wind farm. The line around the turbines in figure 3.2 marks the boundary of the wind farm.

The nearby Princess Amalia wind farm
Shortly after the OWEZ wind farm was built, a second offshore wind farm was constructed ca. 12 km from OWEZ and ca. 5 km further offshore than OWEZ (23 km offshore). This Princess Amalia wind farm consists of 60 Vestas V80/2MW wind turbines on an area of 14 km^2. Turbines are smaller than the OWEZ-turbines and are placed closer together than the OWEZ-turbines. Construction started in October 2006 and was completed in June 2008. It is likely that this wind farm affects flight paths of birds near OWEZ, but these effects were not addressed specifically in this study. The study of local birds near OWEZ does also address impacts of the Princess Amalia wind farm on bird distribution (Leopold *et al.* 2011) .

Gulls in the OWEZ wind farm (photo R. Fijn)

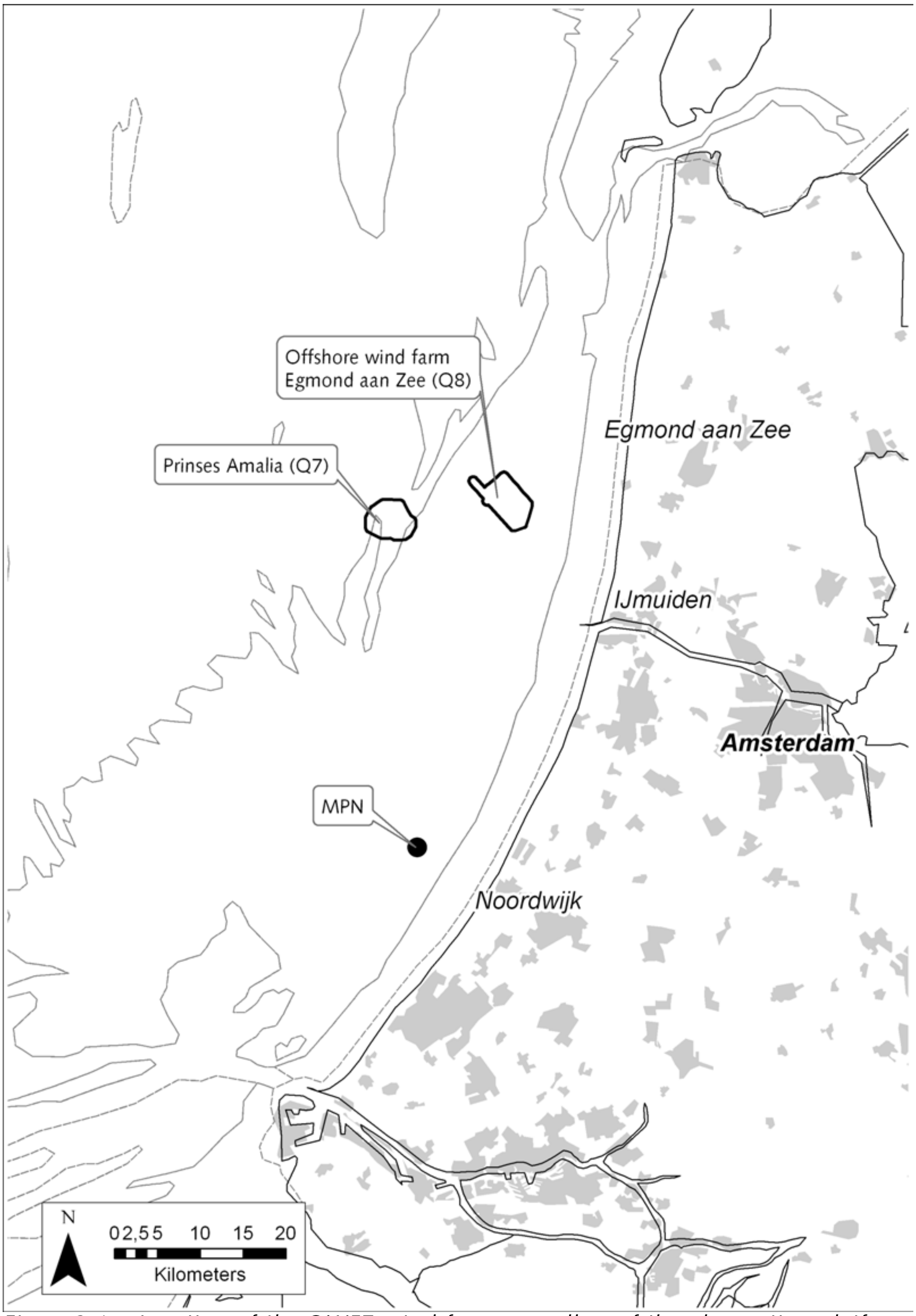


Figure 3.1 Location of the OWEZ wind farm, as well as of the observation platform 'Meetpost Noordwijk' (MPN) that was used in the baseline study. Grey lines in the water are the 10- and 20 m depth lines.

3.2 Wind turbines

The OWEZ wind farm consists of 36 Vestas V90 turbines (specifications listed in table 3.1) and can yield energy for as many as 100.000 households. The total area covered by the wind farm is ca. 27 km^2. The distance between the turbines is relatively large with 650 m within rows and 1000 m between rows. The turbines are constructed on monopiles founded in the seabed. The base of the turbines up to about 15 m above sea level is coloured yellow, the top with rotors is light grey (see photo below). A permanent red light on top of each hub marks the position of the turbines at night. No other illumination is employed.

Table 3.1. Specifications of the turbines used in the OWEZ wind farm.

capacity per turbine	3 MW
hub height	70 m*
rotor diameter	90 m
rotor altitude max	115 m*
rotor altitude min	25 m*

*above mean sea level

Row of turbines in the OWEZ wind farm (photo R. Fijn)

3.3 Location of observations

Location

The observations in this study were carried out from a meteorological mast (metmast) where several types of meteorological data were collected. This metmast is positioned midway on the south-west side of the wind farm, at a distance of ca. 500 m from the nearest turbines (fig. 3.2). The metmast can be reached by ship from IJmuiden harbour.

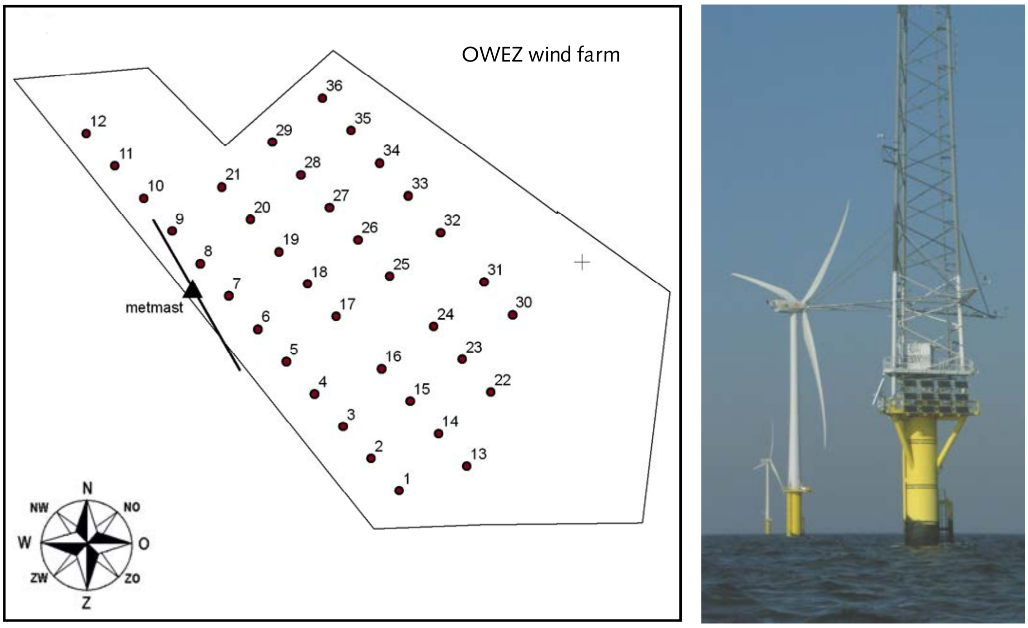


Figure 3.2 Outline of the wind farm with the position of the metmast (triangle) as well as orientation of the vertical radar beam (black line through metmast). The photo shows the metmast from the south and two wind turbines in the back (photo: K. Krijgsveld).

Also at wind turbine 21 fieldwork was carried out (fig. 3.2). Here a ship-monitoring radar of the Vessel Traffic Service for the port of IJmuiden, was equipped with Merlin, to study migration and possible avoidance in the northern section of the study area.

Safety regulations

Fieldwork was highly dependent on local weather conditions due to safety regulations for working within the OWEZ wind farm. Ships could not attach to the turbines or the metmast to allow safe passage from the ship to the turbine when waves exceeded 1.5 m. When travelling with the Rigid Inflatable Boat of Distel Sail, significant wave height was not allowed to exceed 1.0 m. All people working in the OWEZ wind farm were obliged to have a NOGEPA 0.5 (or similar) Survival at Sea training certificate, a valid medical certificate and to have followed an approved Vestas site instruction. Before each visit, risk assessments and work protocols were to be made and approved in order to work safely, certainly when a nocturnal visit was involved (O&M Procedure Offshore Windpark Egmond aan Zee (OWEZ). Ship-to-turbine or ship-to-metmast transfer was only allowed during day-light and length of visits was restricted to a maximum of 12 hours. All visits required a party of at least 2 pax and presence of emergency nutrition, drinking water and a first aid kit on the metmast. During nocturnal observations helmet and headlight were obligatory, as well as presence of a guard vessel and regular radio contact with this vessel. All clothing, safety requirements and regulations as well as contact with ship or Vestas office by radio or mobile phone were similar to those of Vestas Offshore Personnel.

3.4 Environmental conditions

Meteorological data were collected at the metmast throughout the study period and were made available at www.noordzeewind.nl. Occasional gaps in the databases due to equipment failure were filled as much as possible by downloading related data from Waterbase (www.rws.nl) for the location 'Munitiestortplaats IJmuiden' or occasionally from the KNMI meteorological station in IJmuiden (www.knmi.nl; ambient temperature and wind).

An overview of environmental conditions during the study period such as wave height, wind speed, temperature and precipitation is given in figure 3.3 and table 3.2.

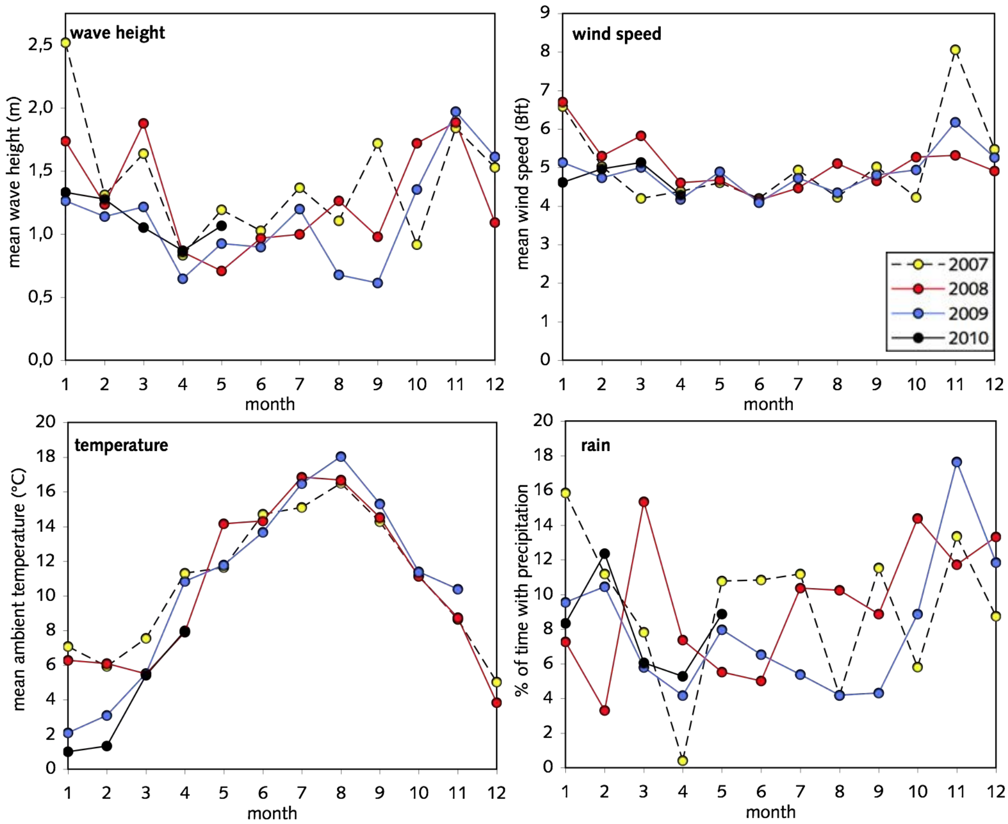


Figure 3.3 Weather conditions at the wind farm during the study period, averaged per month and shown for all study years. Data for wind speed measured at 116 m above mean sea level.

Table 3.2 Weather conditions at the wind farm during the study period, average with minimum and maximum per month. Shown are wave height, wind speed at 116 m, ambient temperature and % time that there was precipitation.

		wave height (m)			wind speed (Bft)			T ambient (°C)			precip.
year	month	mean	min	max	mean	min	max	mean	min	max	% time
2007	January	2,52	0,89	6,97	7	1	10	7	-1	11	16
	February	1,31	0,36	3,53	5	1	8	6	-2	11	11
	March	1,64	0,35	5,21	4	1	6	8	0	14	8
	April	0,83	0,21	1,59	4	1	7	11	5	25	0
	May	1,19	0,26	2,99	5	1	8	12	7	18	11
	June	1,03	0,37	4,69	4	1	9	15	10	22	11
	july	1,37	0,41	3,43	5	1	9	15	12	21	11
	August	1,10	0,27	3,12	4	1	8	16	13	27	4
	September	1,72	0,41	4,28	5	1	8	14	10	18	12
	October	0,92	0,20	2,72	4	1	8	11	3	15	6
	November	1,84	0,49	5,91	8	8	8	9	9	9	13
	December	1,53	0,19	4,24	5	1	10	5	-4	12	9
2008	January	1,74	0,49	4,71	7	3	10	6	-1	10	7
	February	1,24	0,22	4,72	5	1	10	6	-1	12	3
	March	1,88	0,31	5,10	6	1	10	5	0	11	15
	April	0,86	0,23	2,44	5	1	8	8	3	19	7
	May	0,71	0,18	1,96	5	1	8	14	8	24	6
	June	0,97	0,23	2,64	4	1	8	14	10	22	5
	july	1,00	0,21	3,89	4	1	8	17	11	27	10
	August	1,26	0,25	3,93	5	1	10	17	14	24	10
	September	0,98	0,22	3,58	5	1	8	15	11	23	9
	October	1,72	0,33	4,82	5	1	10	11	4	16	14
	November	1,89	0,41	6,77	5	1	10	9	1	13	12
	December	1,09	0,29	3,21	5	2	8	4	-4	10	13
2009	January	1,26	0,23	3,40	5	1	9	2	-4	7	10
	February	1,14	0,37	2,68	5	1	9	3	-3	9	10
	March	1,22	0,27	3,58	5	1	9	6	2	9	6
	April	0,65	0,20	2,18	4	1	8	11	5	20	4
	May	0,92	0,22	2,51	5	1	8	12	7	22	8
	June	0,90	0,25	2,21	4	1	7	14	8	22	7
	July	1,20	0,22	3,11	5	1	8	16	12	24	5
	August	0,68	0,19	1,85	4	1	8	18	14	28	4
	September	0,61	0,40	1,11	5	1	10	15	12	24	4
	October	1,35	0,27	4,78	5	1	9	11	5	17	9
	November	1,97	0,45	4,76	6	2	10	10	6	14	18
	December	1,61	0,33	3,26	5	2	9				12
2010	January	1,33	0,29	3,13	5	1	8	1	-8	6	8
	February	1,28	0,32	3,96	5	1	9	1	-7	10	12
	March	1,05	0,28	3,49	5	1	9	5	-2	17	6
	April	0,87	0,15	2,52	4	1	7	8	3	19	5
	May	1,07	0,14	3,39							9
overall mean		1,27	0,14	6,97	5	1	10	10	-8	28	9

4 Methods of visual and auditory observations

4.1 Overview of applied methods

To gather information on flight paths, flight intensity and flight altitudes within the OWEZ wind farm, several different observation protocols and methods were involved. These involved both visual and radar observations. The visual observations were carried out at the metmast, and are described in this chapter. The methods used for radar observations are described in chapter 5.

The main goal of visual observations at the wind farm was to gather species-specific data on flight patterns of birds, as our radar data did not yield such information (see chapters 5 - 7). A series of protocols was used for individual research questions:

- To get an overview of the species composition, distribution, abundance, flight direction and flight altitude within and outside the OWEZ wind farm, each hour during fieldwork a **panorama scan** was performed (methodology in §4.3).
- 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 (methodology in §4.4).
- In between panorama scans sea-watches were done from fixed observation points on the metmast to study species-specific distribution of birds **in and outside the wind farm** (methodology in §4.5).
- During nocturnal visits to the metmast, several different observation protocols were used to determine species composition, flight intensity and flight altitude of birds. These observations included moon watching (on cloud-free nights when the moon was close to full phase) and flight-call registration by ear and microphone to study species composition of **nocturnally active birds** (methodology in §4.6).
- Towards the end of the fieldwork period in 2009 and 2010, **micro-avoidance** was studied visually by recording individual flight paths and patterns in relation to the turbines (§4.7). This was combined with adjusted measurements with horizontal radar.
- Furthermore, visits to the metmast were opportunities to **calibrate and validate the radar data** with visual observations. These results allowed to see the radar data in the appropriate context when compared to visual observations of researchers at the same time. Results of this will be discussed in chapter 6 & 7.
- Finally, visits to the metmast were made to **service the radar equipment**. Maintenance of the radar, software and hardware updates were needed to let the whole set-up run smoothly. The Merlin software and hardware was updated and revised regularly to allow good-quality data collection.

Throughout this report definitions of time periods are used to analyse and explain patterns and variation of data on a temporal scale. For convenience, these definitions are listed in table 4.1. Throughout the study as well as in this report, Greenwich Mean Time was used as standard.

Table 4.1 Definition of seasons, daylight hours and time of day, as used in this report.

period	definition
seasons	
spring	March – April – May
summer	June – July – August
autumn	September – October – November
winter	December – January – February
daylight hours	
light	from dawn twilight until dusk twilight*
dark	from dusk twilight until dawn twilight*
time of day	
night – before midnight	1 h after dusk twilight until midnight
– after midnight	midnight until 1 h before dawn twilight
dawn	1 h before until 2 h after dawn twilight
day – morning	2 h after dawn twilight until noon
– afternoon	noon until 2 h before dusk twilight
dusk	2 h before dusk until 1 h after dusk twilight

*twilight is the first or the last light of the day, and lies 40-55 min before sunrise or after sunset, depending on the time of year

4.2 Visual observation days

Visual observations were carried out during 53 days and 6 nights. A total of 405 panorama scans were carried out (table 4.2). Most scans were performed during the periods of spring and autumn migration. Of observations days in daylight, 14 were carried out in spring, 12 in summer, 16 in autumn and 11 in winter. Nocturnal observations were exclusively carried out during migratory periods in spring (3 nights) and autumn (3 nights).

Weather conditions during all fieldwork dates are listed in table 4.3 as well. In general, observations lasted from just after first daylight to just before dark. Due to safety regulations some field days were shorter than others, for instance because of changes in weather conditions or restrictions in working hours.

Table 4.2 Total number of days and nights and total number of panorama scans that were carried out in the study period from spring 2007 through December 2009. Numbers are summarized per season and per month, starting with spring months.

	total number of			number of scans per month											
season	days	nights	scans	M	A	M	J	J	A	S	O	N	D	J	F
spring	14	3	140	29	74	37									
summer	12		71				16	20	35						
autumn	16	3	121							53	56	12			
winter	11		73										19	21	33
total	53	6	405												

Table 4.3 Overview of observation days and nights (shaded) in the study period from spring 2007 through December 2009. Shown are dates, wind direction and force, significant wave height, visibility, ambient temperature (T_a) and clouds/precipitation.

date	remarks	weather conditions					
		wind dir	force Bft	waves cm	visibility km	T_a °C	details
Winter 2006/2007							
Feb21	start-up/installation	SSW	3-4	50-90	3	10	cloudy, rain
Spring 2007							
Mar 15	start-up/installation	SW	4	60	5	10	clear, dry
Mar 26	start-up/installation	E	4		5	10	clear, dry
Apr 5		W	3		10	12	partly cloudy, dry
Apr12		N	3	80	10	15	clear, dry
May 25		S	1	30	10	20	partly cloudy, dry
Summer 2007							
Jun 5	radar maintenance	NE	5	90			dry
Jun21	1/2d; thunderstorm	VAR	3	50	25	18	partly cloudy, dry
Aug 2		NW	4	60	10	18	partly cloudy, dry
Aug 20		SSE-NNE	1-4		15	18	cloudy, few showers
Autumn 2007							
Sep 6		NW	4	90	10	16	cloudy, dry
Sep13		NE-SE	3-1	70	10	17	cloudy, dry
Oct 2/3 night		E	3-2		-		cloudy, dry
Oct 3		E	4-2	60	2	12	cloudy, showers
Oct 10		NE	2-4		4	15	fog / clear
Oct 25		NE	4		5	10	cloudy, dry
Nov 2		NW	3-2		4-1,5	13	fog, afternoon rain
Winter 2007/2008							
Jan 28		SW	3	100	10-5	7	cloudy, later hazy
Feb 11		SE	2-1		25	8	sunny
Feb 19		E	2	100	0,5	5	cloudy with fog
Spring 2008							
Mar 27		NE	3	80		5	cloudy
Mar 27/28 night		NE-S-W	3-1	100-70	-	5	drizzle and overcast
Apr 4		SW	3	90	10-3	8	overcast, dry, foggy
Apr 9		S-SW	2-3	80	10	10	sunny
Apr 23/24 night		SE-SW	2-1-3	50	1	10	drizzle but clearing

Continued on following page.

Table 4.3 Continued.

date remarks	weather conditions					
	wind dir	force Bft	waves cm	visibility km	T_a °C	details
Apr 24	SW	4-5	90	1	10	
May 08	E	3	60	5	13	
May 21	ENE	4	100	10	15	
Summer 2008						
June 25	NE-SW	2-4	70	50	15	sunny, some clouds
July 23	NW	2		15	20	clear, sunny
July 29	NW	3-4		2-3	20	cloudy
Aug 6	SW	3	80	10	20	cloudy, dry
Fall 2008						
Sep 11	S	3-4		5	15	cloudy
Sep 17	E	1-2	40	15	15	sunny, some clouds
Sep 17/18 night	NE	2			10	clear
Oct 13	WSW	3-4		5	12	Cloudy, blue patches
Oct 30	NE	3-4	90	15-8	5	clear later overcast
Nov 4	NE	1	100-80	0,2-1	8	thick fog all day
Nov 6/7 night	SE-SW	3-4		5	10	cloudy,some showers
Winter 2008/2009						
Dec 1	NE	2-3	60	3-5	5	overcast and fog
Dec 18	S	2-3	50	0,5-1,5	2	thick fog all day
Jan 8	SW	3	40	10-5	0	clear sky, later hazy
Jan 15	S	4	100	5	3	overcast, clear view
Jan 29	SE	3	100	3-5	3	overcast, dry
Feb 4	SE	1	50	5	2	clear sky, later hazy
Feb 18	SW	2	50	10	5	hazy, partly clearing
Spring 2009						
Mar 5	NW	2-3	20-80	25	5	clear, later cloudy
Mar 19	NNE	3-4	50-100	3-25	5	foggy, later sunny
Apr 1	NE	3-4	50-100	0,5-5	10	foggy, later sunny
Apr 1/2 night	ENE	4	80-100	-	8	clear start, later cloud
Apr 9	S	3	50	0,1-10	12	fog late morning
May 20	SW	3	80	25	15	clear and sunny
Summer 2009						
Jun 24 (maintenance VTS)	NE	3	80	15	20	clear and sunny
Jul 14	S	2-1	30	25	20	clear and sunny
Jul 23	SW	3-4	100-150	10	20	cloudy, clearing, dry
Aug 25	WSW	3-4	80	10	17	overcast, showers
Fall 2009						
Sep 21	SW	2-4	100		17	overcast
Oct 14	E-NW	1-2	0,25-0,5	>25	15	clear, some cloud later
Oct 22	SE	4-5	0,25-0,5	2-5	8-12	rainy start, later dry
Oct 28	S-SW	4-5	0,25-0,75	10-6	8-13	Cloudy, later sun
Nov 11	NW	3-4	1.3	5	9	cloudy some showers
Winter 2009/2010						
Dec 16	SW	3-4	0,8-1,2	10	-1	overcast, later sunny

4.3 Panorama scans

During observations, panorama scans were carried out once every hour during daylight. A panorama scan is a visual count of all birds flying within sight of the observation platform (Lensink *et al.* 2000). It serves as a backup and calibration of the radar counts, and supplies us with information on species composition, density, flight altitude and flight direction of birds around the platform. The technique has been extensively calibrated (Lensink *et al.* 1998; Poot *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 10*42 binoculars fixed on a tripod. The 360° area was divided into 8 sectors (fig. 4.1), to be able to register where the bird was flying (e.g., NW or SE). The eight sectors were observed from three different observation points on the metmast to allow unobstructed viewing. Each panorama scan consisted of two full circles, one to count birds at or just above sea level (low scan, 1/2; horizon transects the middle of the field of view of the pair of binoculars) and a second to count birds at higher altitudes (high scan, 1/8: horizon at the lowest eighth of the field of view). Of all birds seen through the field of view of the binoculars, species, number, altitude (4 classes), distance (in 4 classes: fig. 4.2) and behaviour (following ESAS coding (Camphuysen & Garthe 2001)) was recorded. A list of bird species names in Dutch, English and Latin can be found in Appendix I. Observations were recorded on pre-printed forms by a second person, meaning that the observer could continually observe birds.

The panorama scan is in essence comparable to a radar scan: by slowly moving the binoculars in one direction, the observer scans the air for flying birds and for birds floating on the sea surface. If the density of flying birds is expressed as density per scan, the data of the panorama scan are comparable with those of the horizontal radar.

Results of panorama scans are given in densities of birds per scan (number per unit surface area). Because distance and altitude of each bird was recorded, these numbers could be transformed to number of birds per km^2. The furthest distance class includes all distances over 3 km. Birds recorded in that distance class cannot be transformed to densities per surface area. Also, at distances over 3 km, not all birds will be recorded, due to the large distance, especially in conditions of poorer visibility. For this reason, only birds flying within 3 km distance were included in the analysis.

The analysis carried out for the report at hand focuses on flight paths rather than locally active birds. Birds sitting on the water are covered in the research program carried out by IMARES (Leopold *et al.* 2011). These birds form a separate group that should be considered separately rather than being included in the main data set on flying birds. For these reasons, locally active birds (without distinct flight direction) and birds sitting on the water were analysed separately from flying birds. The data collected in this study allowed performing a more detailed study on relationships between birds and weather conditions or fishing vessels. Results are also discussed in comparison to the baseline study (Krijgsveld *et al.* 2005).

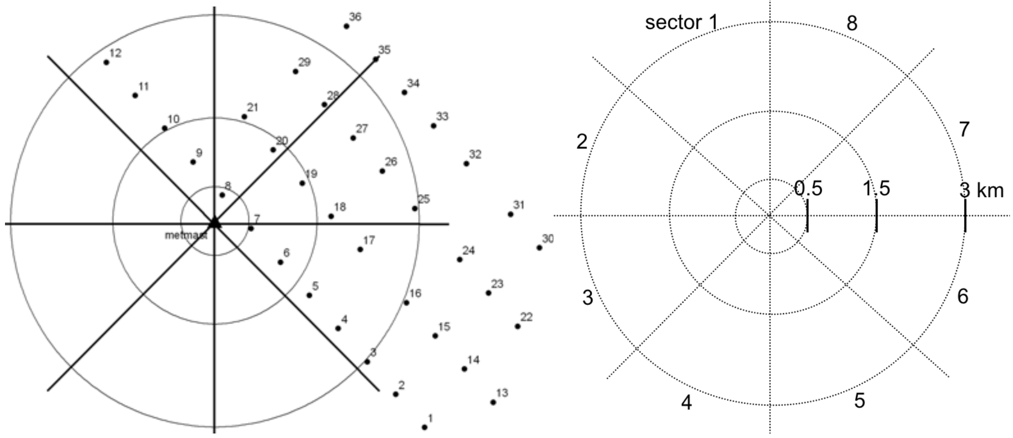


Figure 4.1 *Schematic view of the area surveyed with the panorama scans, relative to the position of the wind farm (left), and of the eight sectors and three distance classes (right). The metmast, as observation platform, is situated in the centre. Surface areas are: distance 0 - 0.5 km = 0.79 km², 0.5 - 1.5 km = 6.28 km², 1.5 – 3 km = 21.21 km².*

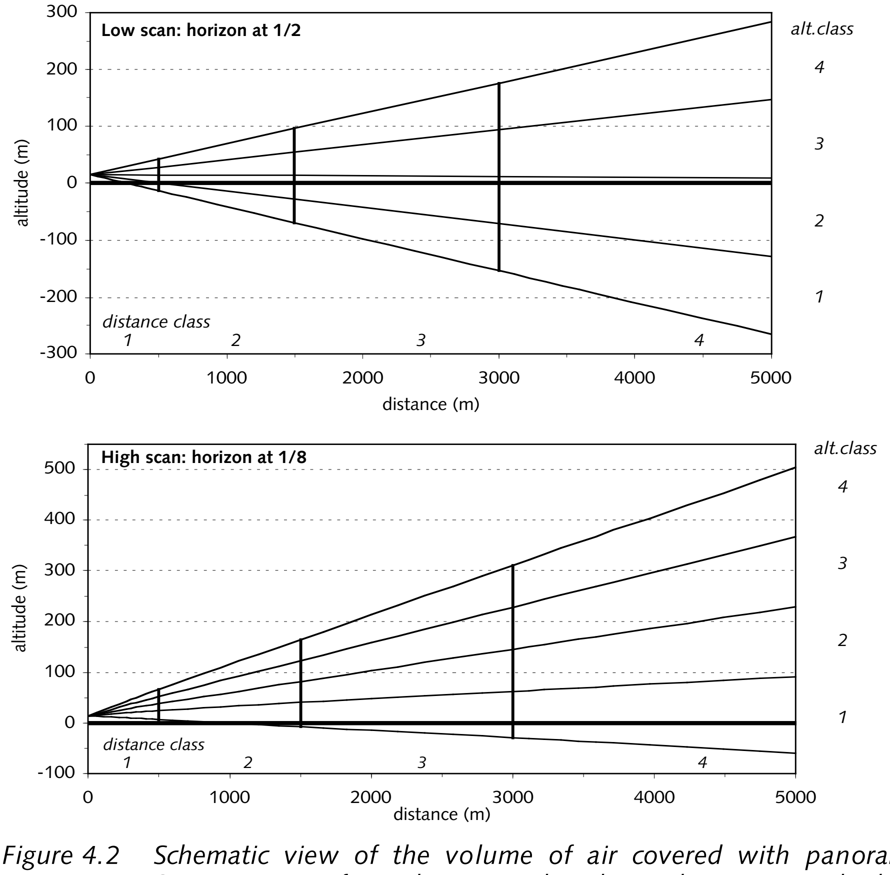


Figure 4.2 *Schematic view of the volume of air covered with panorama scans. Scans were performed at two altitudes: a low scan with the horizon halfway the binocular view and a high scan with the horizon at 1/8 in the lower part of the binocular view. With the sea surface visible in the bottom part of the view, maximum altitude at which birds are scanned is 165 m at 1500 m distance.*

4.4 Flight paths of individual birds

Flight paths of individual birds or bird groups were followed as often as possible in between and during the regular observation protocols (panorama scans and visual radar logging) during fieldwork on the metmast throughout the whole study period. Emphasis was laid on flight paths of birds flying through the wind farm, and less on birds flying outside the wind farm (in the south-western sectors). Birds or bird groups were either picked up in the field with binoculars or telescope, or on the radar and were followed for as long as possible. Birds picked up on the radar were tried to find in the field, identified to species level and followed with binoculars or telescope or radar in case of bad visibility or long distance. All tracks were drawn onto maps, digitalized in the office and analysed using ArcGIS. Additional information on bird characteristics such as sex and age, aberrant behaviour, flight altitude and altitude changes were noted as well. These flight path data, together with the additional information, yield patterns of flight behaviour of birds in response to the wind farm, such as changes in direction, altitude or behaviour.

4.5 Activity inside versus outside wind farm

To measure differences in flight activity of various bird species flying in the wind farm area, the number of birds flying through a transect line both within and outside the wind farm was counted (fig. 4.3). Each transect was observed with a pair of binoculars for 5 minutes. The two transects were observed alternately (so-called paired observations), to prevent observer differences and differences in timing and frequency of observations. This kind of observations was done from February until December 2007. As no additional information was gathered compared to the panorama scans (§4.3), this part of the program was discontinued. Results are presented in an interim report of this study (Krijgsveld *et al.* 2008).

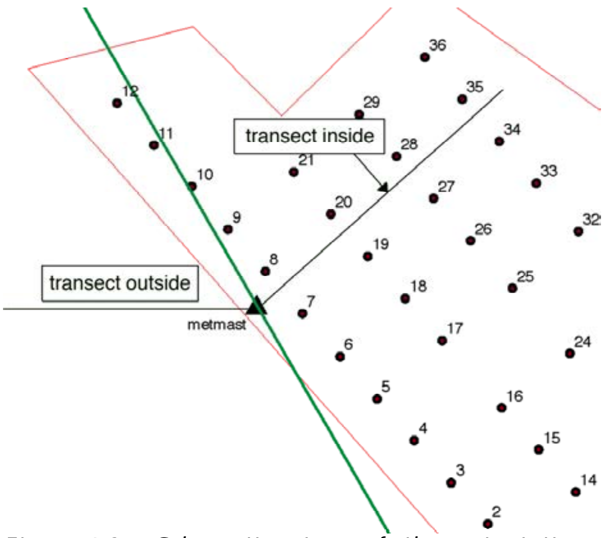


Figure 4.3 Schematic view of the orientation of the transect lines within and outside the wind farm.

4.6 Nocturnal observations

Visual measurements of flying birds, as described in §4.3-4.5, can only be carried out during hours of daylight. However, flight movements can also be a nocturnal phenomenon. Especially during the migratory period, when large numbers of non-marine species may pass the area on migration but also locally foraging birds will fly within the OWEZ wind farm at night (Alerstam 1990; Garthe & Hüppop 1996; Newton 2010). Fluxes and flight paths at night were monitored with the radars (see chapter 5). However, to obtain information on species composition at night, alternative observation techniques have to be used. During migration, species composition at night differs substantially from that during daytime; this is because most species have a strict preference for diurnal or nocturnal migration.

Information on species composition of birds flying in the wind farm area at night was obtained by nocturnal observations carried out from the metmast on six nights, of which three were in spring and three in autumn (table 4.4). The number of nocturnal visits is limited due to safety regulations. Visits were only possible when significant wave height was 1.00 m or less. This is not often the case on the North Sea. Such calm conditions do occur, however, mostly with easterly winds from land, which are often also good conditions for bird migration. Nocturnal observations were combined with diurnal observations on the day prior to or following the nocturnal observation.

Information on species composition and flight intensities was obtained by using a combination of observation methods. These comprised moon watching, call registration by ear and call registration by microphone. All three methods are explained below.

Table 4.4 Overview of periods on which nocturnal observations were carried out, and weather conditions on these nights. Weather data are for 23:00 on first date of period. Observation types refer to: C = calls, M = moonwatching, R = radar.

date	sunset	sunrise	wind dir	max Bft	avg Bft	temp °C	cloud cover	moon phase	obs type **
2/3 Oct '08	17:14	05:45	E	5.0	2.8	12.0	4/8	¼	C/M/R
27/28 Mar '08	18:06	05:24	NW	5.5	3.0	5.2	6/8	½	C/R
23/24 Apr '08	18:52	04:24	W	8.9	4.7	8.7	8/8	1	C/R
17/18 Sep '08	17:49	05:20	E	7.9	3.5	12.5	1/8	1	C/M/R
6/7 Nov '08	16:02	06:48	SE	10.6	4.5	10.3	0/8	½	C/M/R
1/2 Apr '09	18:14	05:13	NE	12.3	5.0	6.9	6/8	½	C/M/R

4.6.1 Moonwatching

The identification of species as well as visual registration of flight paths is possible through moon watching (Lowery & Newman 1966; Zehtindjiev & Liechti 2003; Krijgsveld *et al.* 2005). This technique involves observing, through a telescope, the birds that fly in front of the moon. As well as recording species and flight direction, this technique also allows the altitude of nocturnally flying birds to be estimated by comparing the size of the bird to a standard crater of the moon. Ideally observations are carried within 3 days of the full moon period and in clear conditions, however, due to safety regulations the timing of visits could not always be planned to coincide with these conditions. Moonwatch data correlate rather well with other methods of nocturnal flight intensity determination and are a useful additional tool for measuring fluxes and flight altitudes of nocturnal migratory birds (Liechti *et al.* 1995; Liechti 2001).

4.6.2 Call registration by ear

Migrating birds often call at night. Most of these calls are for contact between migrating birds, either within or between flocks or individuals (Dolnik & Blyumental 1967; Farnsworth 2005). The frequency and type of call differs between species as well as in relation to external factors such as time and weather. For many species the intensity of registered calls is highest after midnight and just before dawn (Graber & Cochran 1959; Graber 1968). In general, the number of calls is related to the number of birds passing overhead, however, a number of external factors, such as lighting and particularly cloud cover, as well as flight altitude, also influences the number of calls heard (Farnsworth *et al.* 2004). As such, call intensity is not always a reliable measure of the level of migration but does provide an insight into the types of species present in the wind farm area for the vocal ones. The distance over which bird calls can be heard varies with species and with environmental noise levels, but is roughly estimated to be 25-100 m for soft calls of small passerines, and up to 500 m for louder calls of species such as gulls and waders. This is under calm conditions; the distance will decrease with high noise levels from strong winds and waves.

4.6.3 Call registration by microphone

Many bird species give flight calls during nocturnal migration, especially water birds and songbirds. These calls can be identified to the level of species or at least species group by a trained ear and offer a way to identify nocturnal migrants and for some species to quantify (low altitude) migration during hours of darkness. Using these nocturnal flight calls, an automatic bird call recording, detection and identification system for North-western European species has been developed. This system has been developed by Leiden University in cooperation with Bureau Waardenburg. With it calls can be recorded and analysed automatically (Schrama *et al.* 2006).

An automated monitoring system has several advantages over human observation such as the ability to make observations 24 hours a day, in a human-unfriendly environment as the metmast, and to perform objectively and consistently over time. Although the system was still in a developing phase, it was operated on the metmast during two periods in the migratory seasons, from late October through half December 2007 and during May 2008, during which time it continuously recorded birdcalls. Recordings were made on a total of 73 days, up to 38 of which had good conditions for sound-analysis, with low noise-levels. To save some digital storage capacity,

recordings were made in two bouts from 17:00 – 00:00, and from 00:00 until 13:00. So between 13:00 and 17:00 (4 hours) no recordings were made, during the period with lowest chance of acoustic events by birds based on general patterns of flight activity of migrant species.
Recordings were made with a self-built permanent outdoor set-up consisting of the following parts:

- *Microphone* (outdoor, see fig. 4.4):
  Seven Panasonic WM-61 electret microphone elements in a custom made wind- and rain-shield construction (ref. B. Evans) powered by an accompanying pre-amplifier. Sensitivity (incl. integrated pre amplifier): 1300 mV /Pa @ 1KHz. Equivalent Input Noise (EIN) measured less than 1mV corresponding to 32 dB SPL.
- *Preamplifier* (indoor):
  Battery-powered low-noise discrete design, custom-built pre-amplifier, with integrated voltage-supply for the electret microphone; operating on 2 AA batteries. Gain: 30 dB, noise : less than 10 nV/sqrt(Hz)
- *Recorder* (indoor):
  Recordings were made with a laptop computer, using the analogue audio input feature (resolution 16bit, fs 22050 Hz, mono). Data were stored on the local harddrive, recordings were managed with the 'Absolute MP3 recorder' software program.

Calibrations were done with a Tandy Corporation Incl. Digital Sound Level Meter, set to C-weighting, 0.5 response time.

The software program was written on the Matlab® and LabVIEW® platforms to detect so-called Regions Of Interest (ROIs) in continuous recordings. We developed a Maximum Normalized Narrowband Amplitude (MNNA) algorithm to detect the faint bird calls in continuous recordings. This consists of normalizing frequency bands by a low-pass filtered version of those same frequency bands. For each instant of time the maximum amplitude from all normalized frequency bands was selected.

The distance over which calls were registered is estimated to be similar to distances covered with the human ear, based on experience. However, the technical specifications of the microphone were such that it detected sounds in a volume of air above the metmast, and not to the sides of it or below it. This has the advantage that aberrant noise from waves and sounds from the metmast itself were not recorded. Simultaneously, the disadvantage is that the volume of air that was sampled was smaller than the volume that is covered with the human ear.

Figure 4.4 The set-up of the outdoor microphone at the metmast. The microphone consisted of 7 Panasonic WM-61 electret microphone elements in a custom made wind- and rain-shield construction. A jackdaw is safeguarding the equipment.

Method of selecting regions of interest

A software program was written on the Matlab® platform, to detect so-called regions-of-interest (ROI) on the continuous recordings. Principle of the selection method consists of a Fast Fourier transformation (FFT) of the recording into a high number of normalized frequency bands between 3.2 and 8.2 kHz, a selective range of frequencies covering most bird calls (and therefore excluding other sounds). We used a Maximum Normalized Narrowband Amplitude (MNNA) method. It consists of normalizing each frequency band by a 0.2 Hz low-pass filtered version of the same frequency band and the selection of the maximum amplitude from all normalized frequency bands. For an ROI to be indicated, this amplitude has to exceed the average MNNA by 6 dB (fig. 4.5). This method has proven to be very simple in coding (50 lines of code) as well as fast in execution (about 30 times faster than real time) and very sensitive to bird calls, while maintaining an excellent robustness against slow varying environmental noise such as traffic, aeroplanes or sea waves.

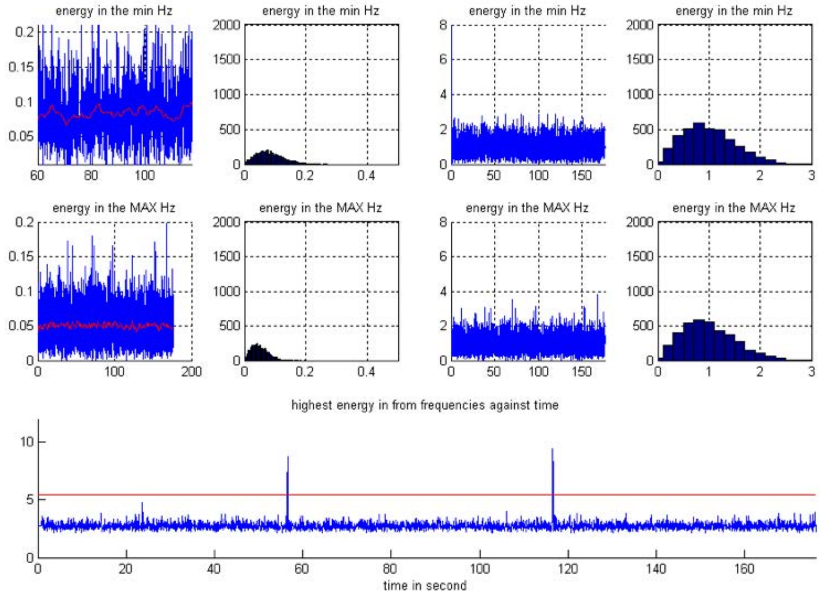


Figure 4.5 Illustration of the selection of regions of interest (ROIs) by normalization of different frequency bands (upper and middle panels, of two bands as an example) and the identification of the high amplitudes (exceeding the 6 dB-limit, lower panel).

The classification system

The program associates a bird species with the regions-of-interest by finding a match within a pre-established flight call library using an algorithm based on a set of seven acoustic parameters: call duration, highest frequency, lowest frequency, loudest frequency, average bandwidth, maximum band width, and average frequency slope (left graphs in fig. 4.6). A Euclidian distance[1] was calculated based on these seven parameters between the ROIs and the known mean parameters of 12 species in the library (based on a total of 574 calls, recorded by Sound Approach) (right graph in fig. 4.6, with an example of the comparison of three acoustic parameters).

For the results on the calibration of this system we refer to (Schrama *et al.* 2008).

[1] In mathematics, the Euclidean distance is the distance between two points in an one or multidimensional space that one would measure with a ruler, and is given by the Pythagorean formula. In this way a set of parametres of a recorded bird call can be compared with the parametres of recorded and identified bird calls in a library. By calculating the pythagorean distances between the acoustic parametres of recorded bird calls and bird calls from the library, the recordings can be automatically identified according calculations rules . In this study samples of these automated identifactions have been checked by human observers.

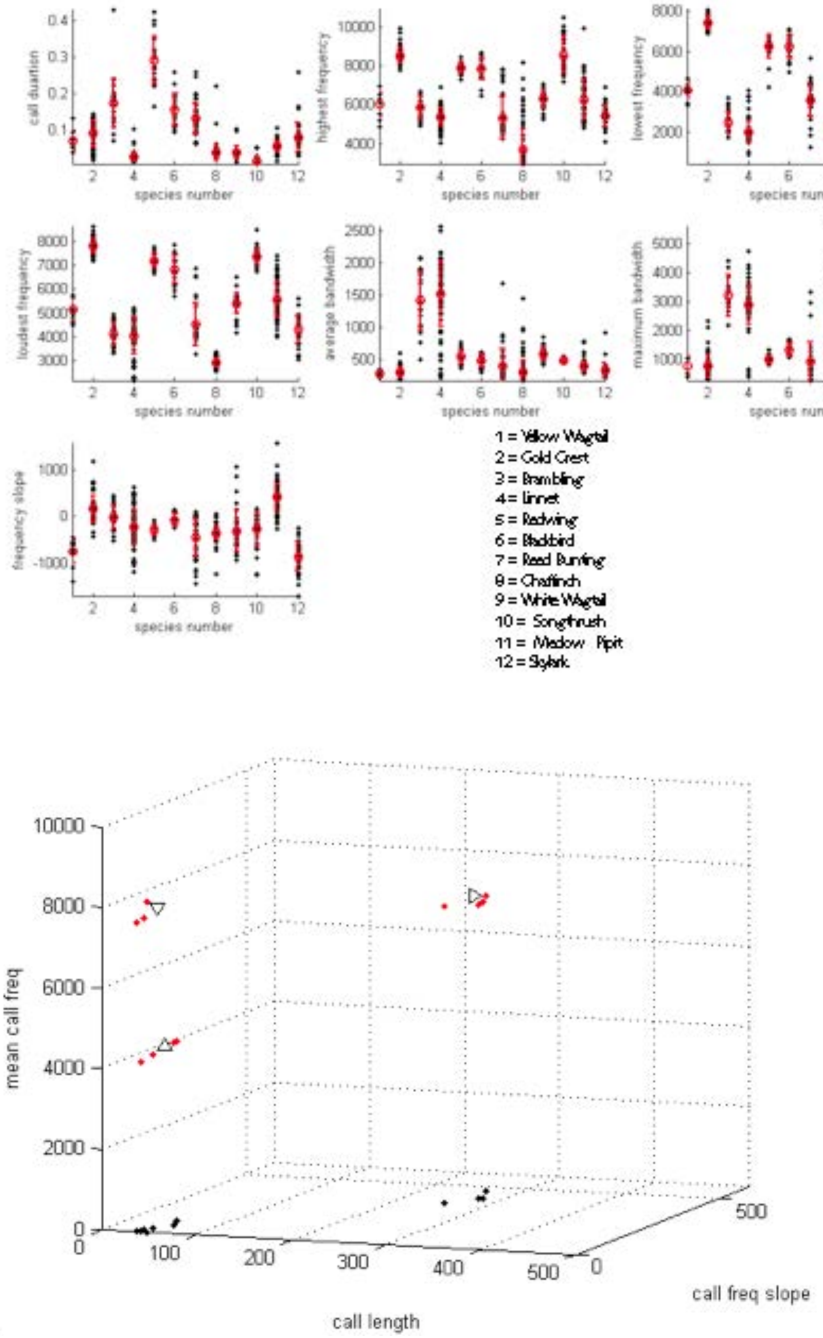


Figure 4.6 Graphs of a set of 7 acoustic parameters for the 12 species of migrant birds in the acoustic library (top). In the lower graph an example is given of the comparison of 3 acoustic parameters based on a Euclidian distance analysis (with a concentration of points in the three dimensional space indicating five different species).

4.7 Micro-avoidance: Flight paths close to turbines

The level of micro-avoidance, or the avoidance of individual wind turbines, was studied based on both visual observations and continuous radar data. During visual observations, all flying birds within a specified section of the wind farm were recorded. This section included turbines numbers 6, 7, 8, 9, 19 and 20 (see fig. 3.2). For each flight path we recorded the species, number of birds, whether it flew through the rotor-swept zone or above/below and/or beside it, and the actual flight path. Whenever possible we also estimated flight altitude and distance to nearest turbine; regularly by finding the track on the horizontal radar. All tracks were drawn onto maps, digitized in the office and analysed using ArcGIS. This is similar to the analyses of long flight paths described in §4.4. To allow quantitative analysis of flight behaviour around the turbines, all flying birds were recorded that were seen within the sample area during 10-minute observation sessions. Although it was attempted to record all flying birds within the observed section of the wind farm, it is possible that some birds, particularly smaller birds such as passerines, were overlooked.

The observations were accompanied by an adapted protocol of observations with the horizontal radar, aimed at high-resoluton observations of bird behaviour around individual turbines. This radar-protocol was followed between 14th July 2009 and 31st December 2009. The methods that were used for these related radar observations are discussed in §5.4 and §6.7.

Observer scanning sector 5 during a panorama scan (photo K. Krijgsveld).

5 Methods of radar observations

In this chapter we describe what types of radars were used, how the radars were employed to collect data on flight paths of birds, and how the Merlin system works. We also describe the types of observations that were done with the radar, and on what dates.

Monitoring birds with radar

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 observations only. The human eye simply cannot see well enough during hours of darkness, or at larger distances – especially higher up in the sky. In addition, the fact that the offshore study area is remote and subject to high waves, severely limit the time that observers can be present in the area. Consequently, a different technique needed to be used to obtain the desired information. Therefore marine surveillance radars were employed. Radars have been widely accepted as tools to study flight patterns of birds (Eastwood 1967; Poot *et al.* 2000; van Belle *et al.* 2002; Petersen *et al.* 2006) and meet the above-stated requirements.

Radar equipment used

Of the various types of radar available, marine surveillance radar was chosen because it best answered the need for information on fluxes and flight altitudes of birds flying in the wind farm area at altitudes up to 1000-1500 m as well as flight paths through the wind farm area. For these purposes a vertical X-band radar and a horizontal radar S-band radar were used (see §5.1). Both radars were an integrated part of a system called Merlin, developed by DeTect Inc., Florida (see §5.2). This system allows automatic logging of the radar echoes into a database that was created in a connected computer. It also makes it possible to deal with large quantities of data as the radar signal is taken directly from the radar and is filtered using algorithms developed specifically for the registration of birds. Furthermore, the connection with computers in combination with an Internet connection, allows the researcher to remotely access the data and control the radar. Thus, progress of measurements could be monitored and settings adjusted when needed. Also was it possible to switch off the radar remotely during periods of strong winds (not uncommon) to prevent damage to the radar system.

At the time that the choice for equipment had to be made in 2006, Merlin was the only radar system available that allowed automatic registration of bird echoes. Automatic registration was an absolute prerequisite for the offshore measurements at OWEZ, which could not be accessed by observers for periods longer than one day or on a regular basis.

5.1 Horizontal and vertical radar in general

Radar observations were made with two radars: one placed horizontally and one placed vertically. These radars are used to record two different types of observations.

- The first is the observation of **flight paths**, which was done using a **horizontal** marine surveillance radar (S-band frequency). This is a standard radar as used on ships, that scans the area in the horizontal plane around the radar (fig. 5.1, left panel). Using a radar in the somewhat longer S-band frequencies makes it easier for the radar to deal with sea clutter. With this radar, flight paths of birds flying through the radar beam were tracked and flight speeds and directions were recorded, as well as other flight characteristics.
- The second type of radar observation is the observation of **fluxes and flight altitudes**. This was done using a comparable type of radar (marine surveillance radar, X-band frequency), which was tilted 90° to rotate **vertically**, and thus scanned the air vertically rather than horizontally (fig. 5.1 right panel). Using a radar in the relatively short X-band frequencies allows high-resolution target identification and information. In this way, bird flux could be quantified by counting the number of birds that crossed the radar beam during a fixed amount of time, and flight altitude of birds could be measured by recording the vertical distance of the bird to the sea surface.
- Technical specifications of both radars are given in table 5.1 in §5.3.

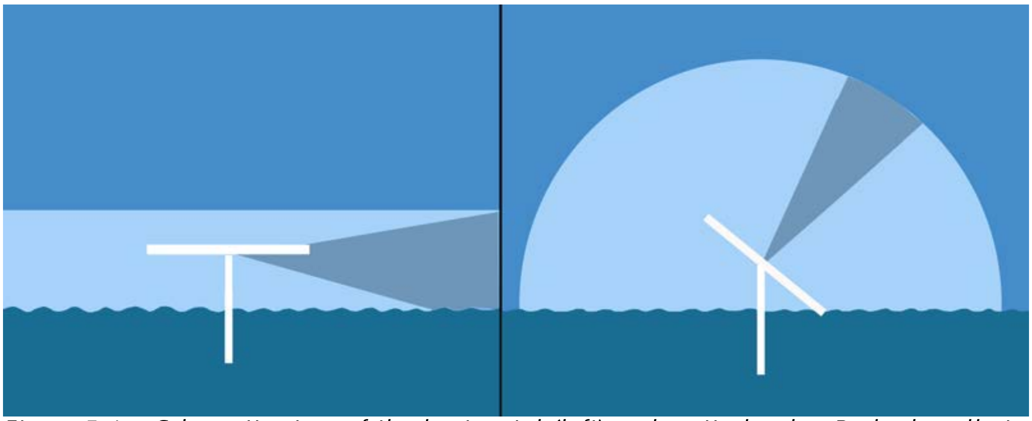


Figure 5.1 Schematic view of the horizontal (left) and vertical radar. Radar bundle is shaded in the image.

The radars were set to scan an area of up to 5.6 km around the observation platform (3 NM; horizontal radar) and up to 1.4 km above it (0.75 NM; vertical radar). These ranges were chosen for the horizontal radar to record flight paths in an area well beyond the wind farm but simultaneously while covering the majority of flight paths of smaller species as well, and for the vertical radar to record tracks of virtually all species up to 1.4 km (see also §5.3.2). The radars automatically recorded echoes continuously throughout the year, every day, both day and night, and thus recorded all bird movements within the area. The exact location, direction, speed, and altitude was registered of birds flying within the scanned area.

Horizontal and vertical radars as positioned on the metmast in the OWEZ wind farm area (photo: M. Poot).

5.2 Merlin radar system

Merlin, a system developed and supplied by DeTect Inc. (Panama City, Florida, USA), was used to process and record echoes detected by the radars. This system entails the radars, the computer-radar interfaces as well as the tracking-software. The radar signal was processed and recorded in Merlin, resulting in a database in which echoes belonging to birds were stored along with information on flight direction, speed, altitude and other characteristics (see appendix II for a full list).

Recording bird echoes with Merlin

In brief, the Merlin system functions as follows. A moving object (a bird or group of birds, but also rain, ships or clutter) is detected by the Furuno radar (the ‘black box’ in fig. 5.2). This signal is digitised in computer 1 (signal processor; located at the metmast) and sent to a second computer (data processor; located in the onshore substation in Wijk aan Zee). Here it is processed with Merlin tracking software to identify signals as belonging to birds or not, and simultaneously to get rid of as many false echoes (clutter) as possible. All tracks classified as birds are then stored in a database in the second computer. Subsequent echoes identified as belonging to a single object (the echo track or trail) are given the same trackID in the database. This enables analysis of the flight path of that specific object.

Radar echoes could thus be seen on screen in two ways:

- Unprocessed image from the Furuno radar, visible on the '**Furuno screen**' (fig. 5.3);
- Image processed by the Merlin software, visible on the '**Merlin screen**' (fig. 5.4).

This differentiation and terminology is of importance in the calibration experiments (chapter 6&7).

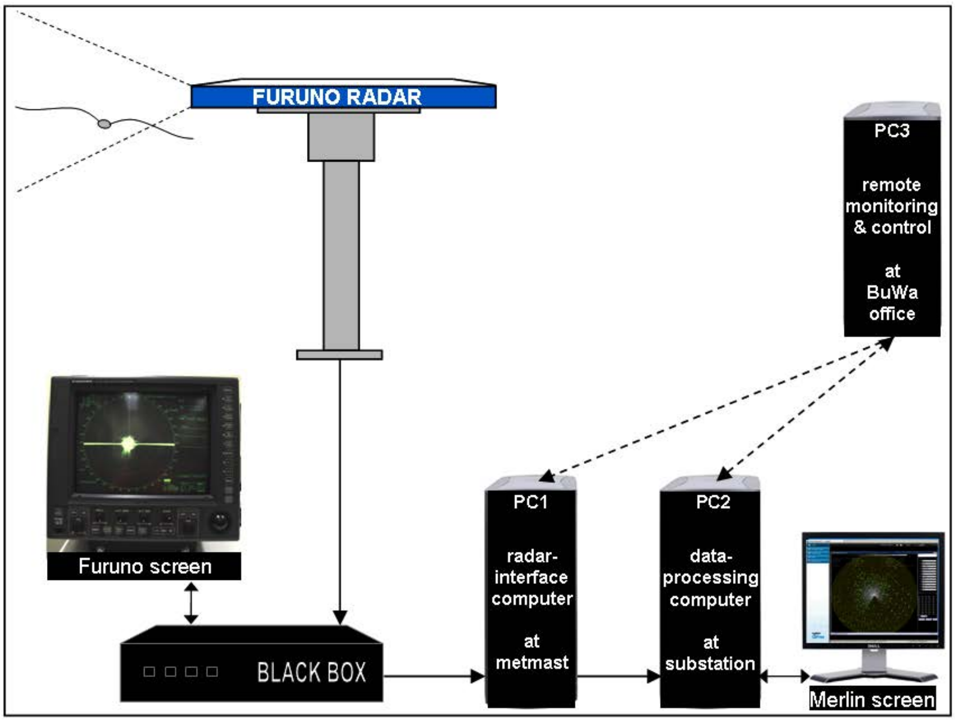


Figure 5.2 Schematic overview of the radar equipment used. The set-up for the horizontal and the vertical radar is identical.

Computer cabinet on the metmast. Note the remains on the window of cormorants resting on the metmast (photo M. Poot).

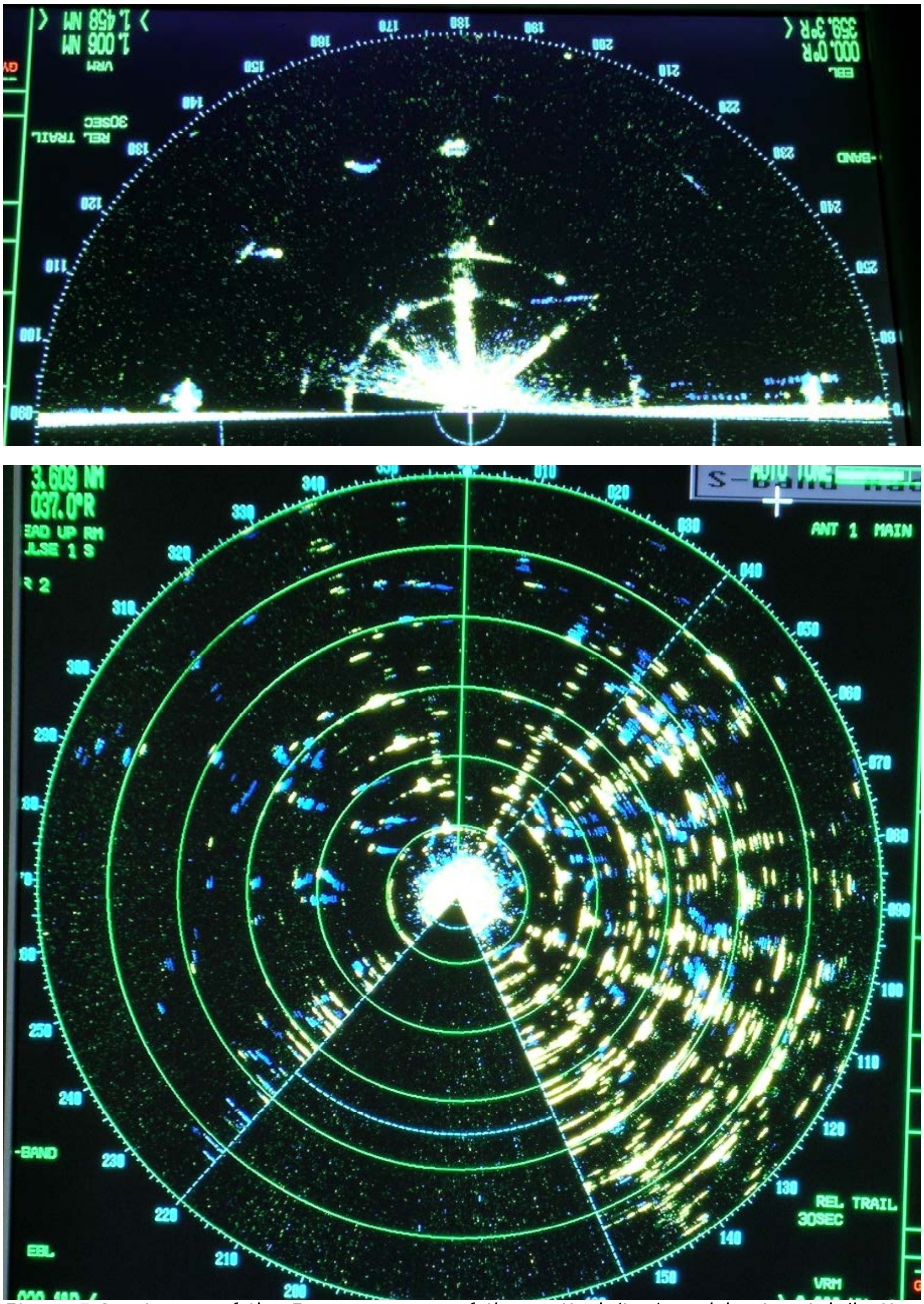


Figure 5.3 *Image of the Furuno screen of the vertical (top) and horizontal (bottom) radar, showing unprocessed raw echoes. Yellow blurs on the right indicate the turbines. Blue trails of dots indicate echo trails of flying birds; the current position of those birds is shown by the yellow dot at the head of the trail. Maximum range is 0.75 NM (vertical) and 3 NM (horizontal). On the On the horizontal a small band of ca. 0.25NM of clutter is visible as a white circle just around the radar on the metmast in the centre of the screen. The blanked sector is visible as a triangle in the southern end of the screen.*

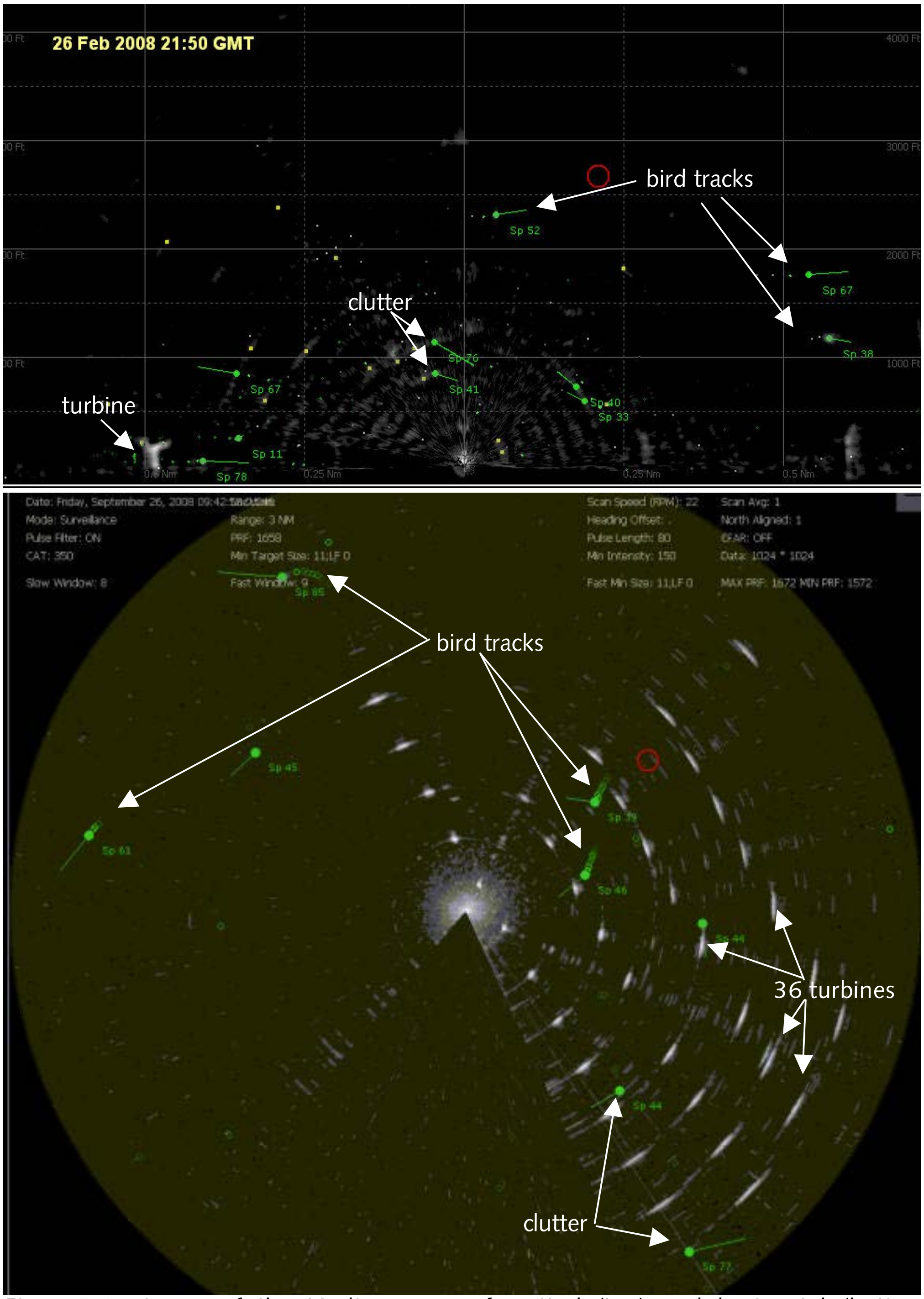


Figure 5.4 *Image of the Merlin screen of vertical (top) and horizontal (bottom) radars. Solid green dots reflect recorded tracks. Flight direction is indicated by a green line. Small (top) or open green (bottom) dots: track history; white: non-recorded signals received by the radar. Visible on the vertical screen are 2 turbines as well as interference around the radar (white), some recorded interference in the clutter around the radar, and several bird tracks. Visible on the horizontal screen are metmast (centre), 36 turbines, some clutter around the metmast (white), some bird tracks (green, upper half) and some tracks of clutter (green dots, lower half).*

Remote control
Both radars could be turned on and off or switched to standby remotely from the Bureau Waardenburg office in Culemborg. All four computers, both on the metmast and in the substation could be remotely accessed similarly. Data stored on the computers in the substation were transported digitally to the Bureau Waardenburg office. This extensive remote control access possibility allowed digitally access to radars and computers at all times, even under windy conditions with high waves that would not have permitted physical access to the metmast. This prevented a lot of mechanical damage as encountered during the baseline study, where a substantial amount of observation time was lost due to radar failure and maintenance.

Echo characteristics
With each recorded echo, the Merlin system records a large number of parameters that define the characteristics of each signal. These characteristics can be used to separate between actual birds and erroneously recorded objects other than birds (clutter). On the one hand, these parameters represent the shape and intensity of the echoes, such as area, reflectivity, elongation, perimeter, radius, etc. On the other hand there are a number of derived parameters that represent position and movement of the echo, such as latitude and longitude, X- and Y-position relative to the radar, speed, heading, bearing, as well as length of the entire track. Echo characteristics that are stored by the Merlin system, as well as derived parameters, are listed and described in Appendix II.

Horizontal radar on the metmast (photo Ruben Fijn)

Box I - Trackplots
One way to visualize raw radar data is by means of trackplots. These are images of the Merlin screen showing all recorded echoes (see fig. I.1). These images can be made per day or per hour and give an indication of all tracked targets stored in the Merlin database in that given period. They show unfiltered data, so non-birds such as clutter, turbines and rain are still present in the image. The different colours in the trackplot represent the different directions the targets are moving to. These trackplots are very useful for quickly assessing a situation in a certain time frame during the study period. Throughout this report trackplots are used to illustrate different situations or phenomena.

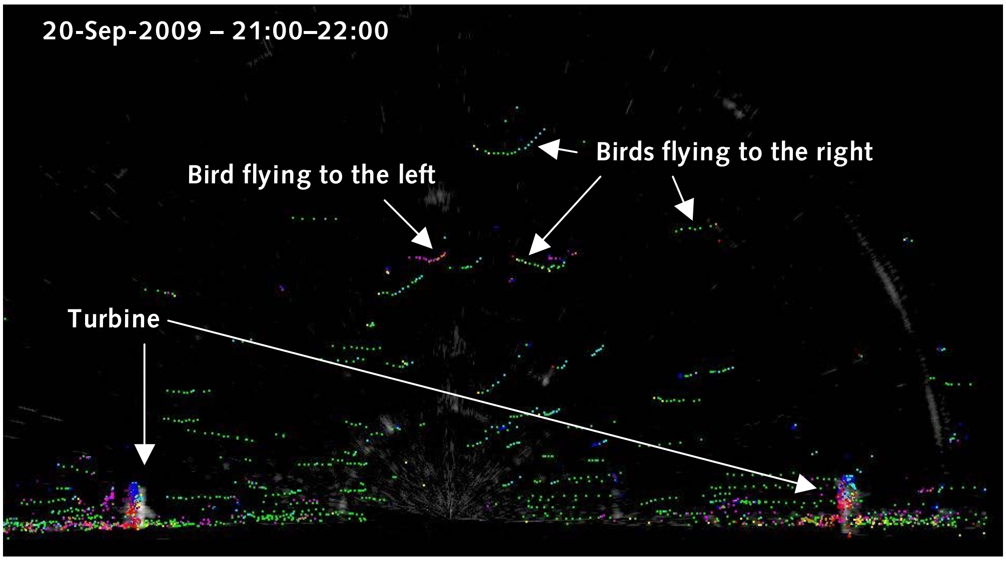


Figure I.1 Trackplot image of one hour, showing several bird tracks and 2 turbines.

5.3 Data collection with horizontal S-band radar

The horizontal radar on the metmast was positioned to the south-west of the wind farm on the metmast and scanned an area within and outside the OWEZ wind farm to record flight direction and flight paths of migrating and local birds.

5.3.1 Technical specifications

The technical specifications of both radars are listed in table 5.1. A radar of 30 KW is a strong but commonly used type of radar on ships. It being an S-band radar, means that the wavelength is longer than in an X-band. This has the advantage that it will pick up less echoes from waves, which is the reason that ships generally use S-band radars. The disadvantage is that it has somewhat less resolving power, and is therefore less sensitive in picking up small birds.

The section where the metmast was in the way was blanked, because no echoes could be picked up in that area (65°, from 155° to 220° degrees, or the area S to SE of the wind farm; see fig. 5.4). This means that in this section of the wind farm area, no data were collected on flight paths. Although no signal was transmitted in this area, the radar still received echoes from this area. This means that echoes seemingly from this area could be recorded. These echoes all originated from clutter such as interference and reflection, and were removed from the database.

Table 5.1 Specifications of the vertical and horizontal radar.

	vertical radar	horizontal radar
Used range	0.75 NM *i.e.* 1389 m	3 NM *i.e.* 5556 m (& 0.75 NM)
Wavelength freq	X-band	S-band
Power	25 KW	30 KW
Antenna length	2.50 m	3.00 m
Beam width	20°	25°
Rotation speed, avg	25 rpm	22 rpm
Orientation	NW – SE	360°
Altitude	axis ca. 13 m	axis ca. 13 m above mean sea level
Merlin software	versions 3.4.44 – 4.0.6	versions 3.4.44 – 4.0.6

5.3.2 Effective range of detection and beamwidth

The range of the horizontal radar was set at 3 NM. Based on experiences from the baseline study, range was reduced from 6 NM to 3 NM, because a large proportion of bird tracks was not recorded beyond 3 NM. A range of 3 NM was large enough to cover the wind farm (see fig. 5.5) and flight paths of approaching birds, and small enough to detect larger birds throughout the range and smaller birds in the majority of the range. In the baseline study it was shown that smaller species were not detected at the outer limits of the 6 NM-range, unless they were flying in groups or in high densities.

Detection range and height

Based on the range and the beam angle of the radar, the mathematical beam width of the radar was calculated following a model by Van Gasteren *et al*. (2002) (described in Krijgsveld *et al.* 2005). This model is discussed in further detail in §5.5.2, along with a figure showing the detection ranges for birds of various sizes (fig. 5.8). Based on this model we calculated that large birds such as gulls were detected up to ca. 4.5 km distance, medium-sized birds such as thrushes up to ca. 3 km and small birds such as passerines up to ca. 1.5 km when flying alone.

The beam had a maximum width of 2.2 km at a distance of approximately 3.3 km from the horizontal radar. At both larger and smaller distances, the beam width decreased again. However, the effective range and effective beamwidth, in which all individual birds are detected, is not only dependent on the mathematical shape of the beam but also on the size of the bird (expressed as "radar cross-section" of a bird) and the specifications (power, wavelength and beam angle) of the radar (e.g. see Poot *et* *al.* 2006). This implies that birds were tracked up to a maximum altitude of 1.1 km (half of the total beam width, because the other half is 'below sea level').

These effective ranges and beam widths were calculated for three different bird sizes, and for a 25 kW X-band radar with a beam angle 20° (used as vertical radar in this study) t (see §5.5.2). The order of magnitude of these figures will be similar for the horizontal radar, however, due to a different beam angle (25°), a different output power (25 kW) and a different wave length (S-band) these calculated figures cannot directly be extrapolated. The greater output power and beam angle indicate that this radar would detect smaller birds further away from the radar, but the different wavelength might cause smaller birds to be missed more than with an X-band radar.

Effect of flight direction and flock size on detection

If we assume that the calculated effective ranges and beam widths of the X-band radar (table 5.3) are similar for the S-band radar, the calculated values for the 25 kW X-band radar give an indication of detection within the used radar range. Under this assumption almost all larger birds were detected throughout the wind farm area, although not all were detected at the outer limit of the range and when beamed on the tail (max detection: 2.5 km). For differences between beaming on the tail, head and side see §5.5.2 and §7.1. Smaller species (e.g. thrushes) were not detected beyond 1.6 km when flying individually and when beamed on the head. When beamed on the side they were detectable up to 2.5 km. Smaller species (e.g. passerines, being smaller than a starling) were not detected beyond 0.9 km when flying individually and when beamed on the head. When beamed on the tail or side this distance was respectively 1.0 km and 2.0 km. From direct observation we know that large birds or birds flying in groups, detection covered the entire range of 5.5 km (=3 NM). This limitation implies that results from the horizontal radar on flight directions and distribution around the farm can be biased towards larger species, especially at night when most migratory birds fly alone. However, during migration periods, the density of passerines was often so high that the radar detected movements of groups of passerines, and therewith was able to establish the overall flight patterns of songbirds around the wind farm. This confirms again that the horizontal radar is a useful tool to establish qualitative data on flight movements and flight directions and can only be used for quantitative measures if corrections are made for detection loss.

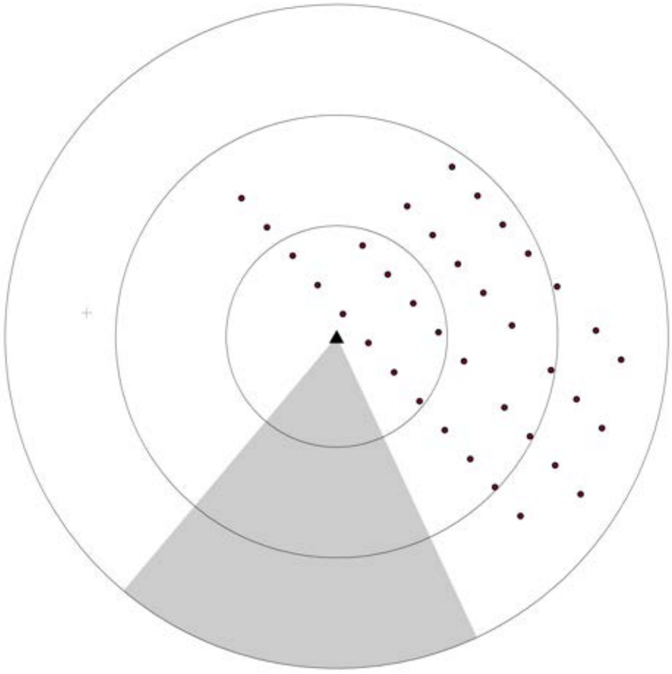


Figure 5.5 *Area covered by the radar. Range is set at 3 NM, which includes the entire wind farm (rings drawn at 1 NM intervals). Turbines are shown as 36 bullets, the metmast with the radar is shown as a triangle in the centre. The sector that would be obstructed by the metmast structure was blanked and is shown as a grey triangle to the south of the radar.*

Detection of birds flying north and northeast of the wind farm

The horizontal radar was placed on the metmast, located on the south-west side of the OWEZ wind farm (see §3.3 and fig. 5.5). Due to this location, birds flying on the north side of the wind farm potentially could be invisible to a smaller or larger extent to the radars on the metmast, caused by interference from the wind turbines. Therefore a trial project was initiated in October 2008 to gain insight in flight paths of birds approaching the wind farm from the north side. This trial involved placing a Merlin system to the VTS radar system positioned on wind turbine nr 21. Results of this trial are discussed in Appendix III.

5.3.3 Dates of data collection and volume of database

Data collection started in April/May 2007 and ended 31 May 2010. Data collection at long range ended mid July 2009, when the range was reduced to 0.75 NM for the purpose of studying micro-avoidance (§5.4). Mid March 2010 the range was restored to 3 NM, after which data at long range was continued until 31 May 2010. The horizontal radar was remotely switched off during wind conditions of 8 Bft or more to prevent damage to the radar unit. An overview of the number of days per month on which data were collected, is given in table 5.2. In total, data on flight paths were collected on 817 out of 918 days, or on 89% of the days.

Between 1 and 38 access-files (number was mostly dependent on variation in wind and waves; see chapter 6) were stored on a daily basis. Each file was 50 MB in size, corresponding to roughly 90,000 records. By July 2009, the entire horizontal database, excluding the data on micro-avoidance, consisted of 6888 files or 659,000,000 records or ca. 344 GB. After removal of clutter, the database was reduced to 30,200,000 records. This is 5% of the original. The remaining 95% was mostly sea clutter. For 67 days (7% of total number of days recorded) data were filtered out entirely because clutter levels were too high (see §6.4 for filtering rules).

Table 5.2. *Overview of the number of days per month on which data were collected for horizontal radar (flight paths, macro-avoidance), vertical radar (fluxes and altitudes) and horizontal radar small range (micro-avoidance). An overview of visual observation days is given in table 4.2.*

year	season	month	hor.radar	vert.radar	micro-avoidance
2007	spring	April	30	*	-
		May	26	*	-
	summer	June	20	20	-
		July	31	25	-
		August	30	31	-
	autumn	September	27	27	-
		October	30	31	-
		November	22	19	-
	winter	December	19	20	-
2008		January	31	28	-
		February	15	27	-
	spring	March	27	27	-
		April	30	30	-
		May	21	28	-
	summer	June	29	28	-
		July	27	31	-
		August	29	31	-
	autumn	September	28	29	-
		October	31	30	-
		November	20	18	-
	winter	December	31	31	-
2009		January	31	25	-
		February	23	28	-
	spring	March	26	31	-
		April	28	24	-
		May	31	31	-
	summer	June	30	20	-
		July	13	18	18
		August	-	31	31
	autumn	September	-	29	29
		October	-	31	31
		November	-	21	30
	winter	December	-	30	28
2010		January	-	31	31
		February	-	28	28
	spring	March	22	29	9
		April	28	28	-
		May	31	30	-
overall			817	976	235
% of number of days available**			89	90	98

* several setting adjustments caused incomplete data, data left out of analysis
** % prior to data filtering

5.4 Data collection with horizontal radar at small range

Flight paths of birds at short distances of the turbines were measured by using the horizontal radar at a reduced range of 0.75 NM instead of 3 NM. Data collection at this range started on 14 July 2009 and finished on 9 March 2010 (see table 5.2 for an overview). All other radar specifications were the same as for the data collection at long range (table 5.1). Merlin settings were optimised to best record bird tracks at this range. Track data were stored and processed in the same way as the long-range dataset.

In total, data on flight paths were collected on 235 out of 239 days, or on 98% of the days. For 59 days (25% of total number of days recorded) data were filtered out entirely because clutter levels were too high. This is a much higher percentage than for the long-range dataset. Because of the smaller range, the radar was much more sensitive to clutter from waves than at a range of 3 NM. As a result, bird tracks disappeared in the high levels of clutter at lower wave heights. For results on filtering out this clutter, see §6.7.

An area that was scanned included six turbines located both at the edge of and further within the wind farm (fig. 5.6). The mathematical beam width was 330 m at turbine 8 (distance 390m), based on calculations folllowing Van Gasteren *et al.* (2002). This model is discussed in further detail in §5.5.2. The effective beam width is bigger for birds larger than starlings and slightly smaller for the smallest passerines (§5.5.2). This implies that all birds flying up to 165m altitude were tracked (half of total beam width, because the other half is 'below sea level'). This covers all tracks in the rotor-swept zone of the turbines within the radar range. Although individual tracks recorded by the radar could refer to groups of one or more birds, it is likely that while operating at small range, most tracks refer to individual birds due to the resolution of the radar signal.

5.5 Data collection with vertical X-band

The vertical radar was used to record fluxes and flight altitudes of migrating and local birds. It was positioned on the metmast at the southwestern side of the wind farm, on the south-western corner of the metmast. The beam was oriented in the direction south-east to north-west (fig. 5.7). It scanned the area sideways and upwards of the radar, up to a distance / altitude of 1390 m.

5.5.1 Technical specifications

Fluxes and flight altitudes in the OWEZ wind farm area were studied using an X-band radar positioned to scan the vertical plain. The technical specifications of this radar are listed in table 5.1 along with the characteristics of the horizontal radar. A 25 kW radar is a strong but commonly used type of radar on ships and other utilities. X-band radars use a shorter wavelength than S-band radars. These shorter wavelengths make it a sensitive tool to pick up smaller birds at higher altitudes, and thus to measure fluxes of birds in the air. Simultaneously, it makes an X-band radar less useful than an S-band radar to measure tracks horizontally over sea, because it also is more sensitive to signals reflecting from the water, and thus would have more problems with echoes from waves and other types of clutter. This is why an S-band radar was used horizontally, and an X-band vertically.

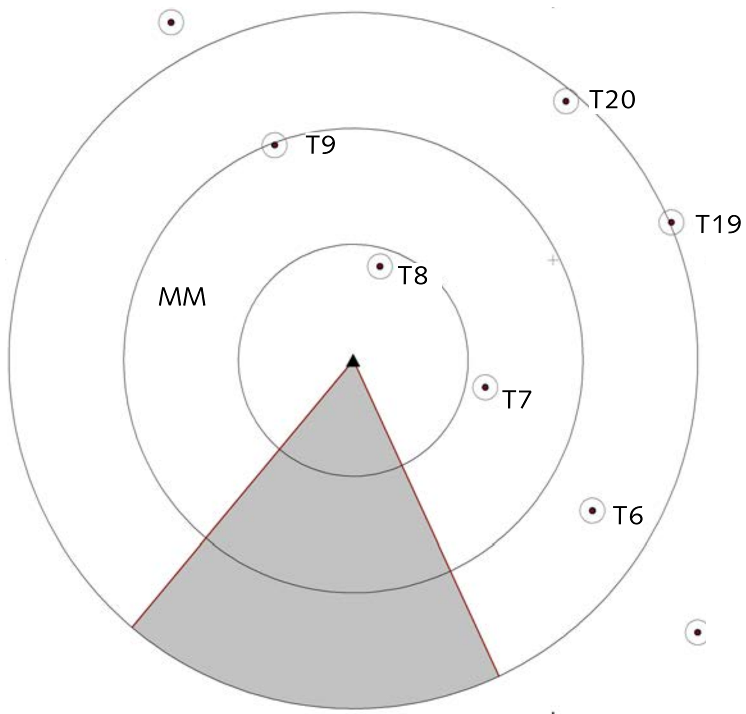


Figure 5.6 Area covered by the horizontal radar with range set at 0.75 NM for observations on micro-avoidance close to the turbines. At this range, 6 turbines were monitored. Turbines shown as bullets, around which an area of 50 m radius is drawn to mark the sweeping area of the turbine rotors. Metmast with radar situated in the centre (black triangle). Grey triangle indicates the blanked sector; rings spaced at 0.25 NM intervals.

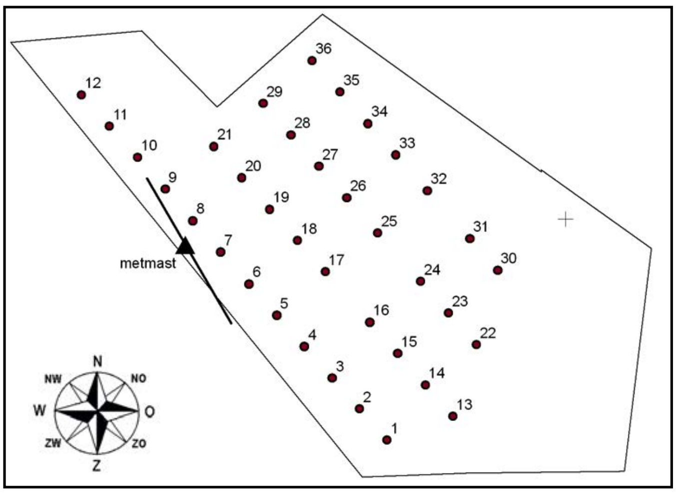


Figure 5.7 View of the vertical radar from above. Direction and length of the black line indicate the direction of the radar beam and the area covered by it.

5.5.2 Effective range of detection and beam width

The range of the radar was set at 0.75 NM. The radar scanned 0.75 NM *i.e.* 1389 m up in the air. This range was small enough to identify different risk classes within the height of an individual turbine, and large enough to cover the altitude spectrum in which the migration activity takes place that is relevant with respect to the wind farm. Also the beam width was large enough for birds flying through the beam perpendicularly, to be present in the beam during several rotations and thus to get recorded by Merlin.

Detection range and height

Based on the 0.75 NM range and the beam angle of the radar the mathematical beam width of the radar was calculated following Van Gasteren *et al.* (2002) (described in Krijgsveld *et al*. 2005). This beam width was 0.5 km at maximum at a distance of approximately 0.9 km from the radar. At both larger and smaller distances, the beam width decreased again. However, the effective range and effective beamwidth, in which all individual birds are detected, is not only dependent on the mathematical shape of the beam but also on the size of the bird (expressed as "radar cross-section" of a bird) and the specifications (power, wavelength and beam angle) of the radar (Poot *et al.* 2006).

For a 25 kW X-band radar with a beam angle 20° (used as vertical radar in this study) these effective ranges and beam widths have been calculated for three different bird sizes (table 5.3). All larger birds were detected throughout the wind farm area (max. detection at 'worst' angle (tail): 2.5 km). For differences between tail, head and side beaming see §7.1. Smaller species (e.g. thrushes) were not detected beyond 1.5 km when flying individually and when beamed on the tail. When beamed on the side they were detectable up to 2.5 km. So, both groups are detected well within the vertical radar range. Smaller species (e.g. passerines, being smaller than a starling) were not detected beyond 0.9 km when flying individually and when beamed on the tail. When beamed on the head or side this distance was respectively 1.0 km and 2.0 km. This leads to the conclusion that small species are potentially missed when flying at altitudes above 0.9 km. with a flight direction in which they are beamed on the head or the tail. However, during migration periods, the density of passerines is often so high that the radar detects movements of groups of passerines, and therewith is able to measure flux of small passerines at higher altitudes. The consequences of detection limitation due to bird size are therefore thought to be small.

Effect of flight speed on detection probability

The maximum mathematical beam width of the vertical radar was 430 m following the beam width calculations of Van Gasteren *et al.* (2002) presented in Krijgsveld *et al.* (2005). When the analysis method is applied on the data in this study (two-column analysis; chapter 7) the mathematical bandwidth of the beam in these two colums is 269 m (the nearest side of the column, horizontally from the radar) and 432 m (top of the column furthest away from the radar). Knowing the mathematical beam width and the rotation time of the radar, we can assess the probability for a bird to be 'caught' in the radar beam. Doing so, assumptions should be made on the maximum flight speed of birds and a random flight direction of these birds. Taking 50 km/hr (13.9 m/s) as an average flight speed of birds, it takes this hypothetical bird at least 19 seconds to cross the smallest width of the beam when flying perfectly perpendicular into the beam. The radar spins with 25 rotations per minute, which means that 20 seconds is more than 8 rotations of the radar. Merlin starts recording a track on the third consecutive hit, which means that the beam is wide enough to record these kinds of tracks. Even birds flying with 80 km/hr (e.g. a duck with tailwind) needs more than 4 rotations to pass the beam. Even more, from figure 5.3 is derived that for most birds the effective beam width is much larger than the mathematical beam width. This makes the 'passage time' even longer and we can therefore conclude that the beam is wide enough, at the smallest width of the two columns in which flux is measured, to caputer all bird (flocks) passing this part of the column. Note that this is an approximation because the maximum detection range is dependant on the size and charateristics of the birds. For small passerines at high altitude the beam width might be too small for the birds flying perpendicular into the beam to be detected by Merlin. However, consequences for measured fluxes are thought to be small.

Effect of flight direction on detection

From the beam width figures an effective range of the radar could be determined (fig. 5.8 & table 5.3). Effective range is dependent on the size of the bird, the side of the bird on which the radar beam hits the bird and the specifications of the radar. For the vertical radar set-up in this study all larger birds down to the size of thrushes/starlings, are detected throughout the entire altitude range (1389 m = 0,75 NM). Even when beamed on the tail and head, birds are detected at 1.5 km. Smaller species, like small passerines (size meadow pipit), are not detected at the outer limits of the range, when they are beamed on the head (1.0 km), or the tail (0.9 km) (see chapter 7). When they are beamed on the side, they are detected throughout the range of the radar.

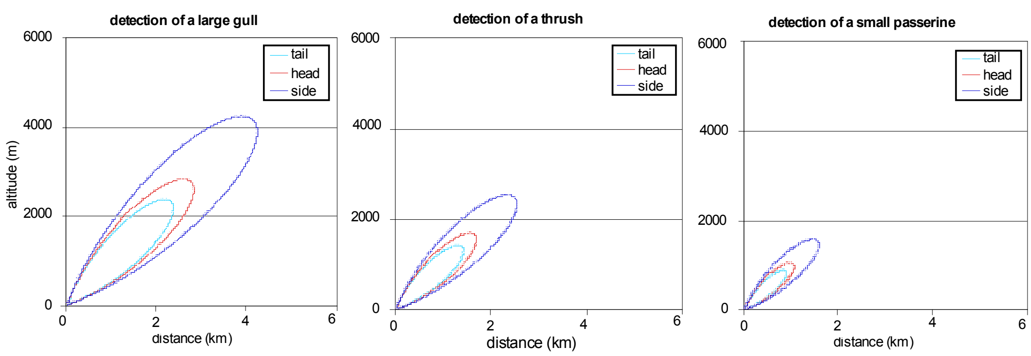


Figure 5.8 Detection ranges of large gull, thrushes and small passerines under three different beam conditions (head, tail, side), as calculated for a 25 kW X-band radar, and assuming 95% detection.

Table 5.3 Maximum detection range and approximate maximum beam width (in m.) in which 95% of all large gulls, thrushes and small passerines are detected, calculated based on the model by Van Gasteren et al. (2002).

species	orientation	95% detection max. range (m)	95% detection max. beam width (m)
large gull	side	4400	1120
	head	2950	740
	tail	2470	670
thrush/starling	side	2530	660
	head	1650	430
	tail	1480	410
small passerine	side	2080	420
	head	1030	330
	tail	930	310

5.5.3 Dates of data collection and volume of database

Data collection for this study started in February 2007 and ended 31 May 2010. The first months (Feb, Mar, Apr 2007) several setting changes and adjustment procedures caused unreliable data collection. In May 2007 a major breakdown interrupted data collection but from June 2007 onwards the radar almost continuously collected data on flux and flight altitude within the OWEZ wind farm, except for closure days due to weather conditions or breakdowns. The vertical radar was remotely switched off during wind conditions of 7 Bft or more to prevent damage to the radar unit. An overview of the number of days per month, on which data were collected with the vertical radar, is given in table 5.2 along with the other radars. In total, data on flight paths were collected on 817 out of 918 days, or on 89% of the days.

Between 1 and 8 MS-Access-files (depending on bird activity, weather and sea state) were stored on a daily basis from the vertical radar. Each file was 85 MB in size, corresponding to roughly 85,000 records. By May 2010, the entire vertical database consisted of 1,787 files or 150,000,000 records or ca. 151 GB. Removal of clutter, rain, turbines and other non-bird tracks reduced total database size to 5.3 GB before analysis could start (see §7.4 for filtering rules).

6 Horizontal radar data interpretation

In this chapter we describe how echoes from the horizontal S-band radar were translated into flight paths of birds (see schematic overview in fig. 6.1). Most of this process was carried out in a similar fashion for the vertical radar (see Ch.7), such as the flagging and filtering process described in §6.4.

First, we describe in §6.1 what the radar actually saw: how did the radar cope with waves, strong winds and rain? And how did range, beam width and detection loss affect detection of birds over distance? Second, we evaluate performance of the radar in §6.2 by comparing visual counts of birds flying in the area and visual quantifications of bird tracks from the Furuno screen with results from Merlin after filtering. Steps taken to clean up the data and allow data analysis are described in §6.3. Then, sea clutter had to be removed from the data. The filtering steps to do so are described in §6.4. The quality of the resulting data after filtering out clutter is evaluated in §6.5. Post-processing steps such as rasterizing the data into a grid is described in §6.6, as well as procedures and methods used for data analysis. Data on micro-avoidance were recorded at a much smaller range, and differences with the data collected at long range are described in §6.7, as well as the clutter filter for these data.

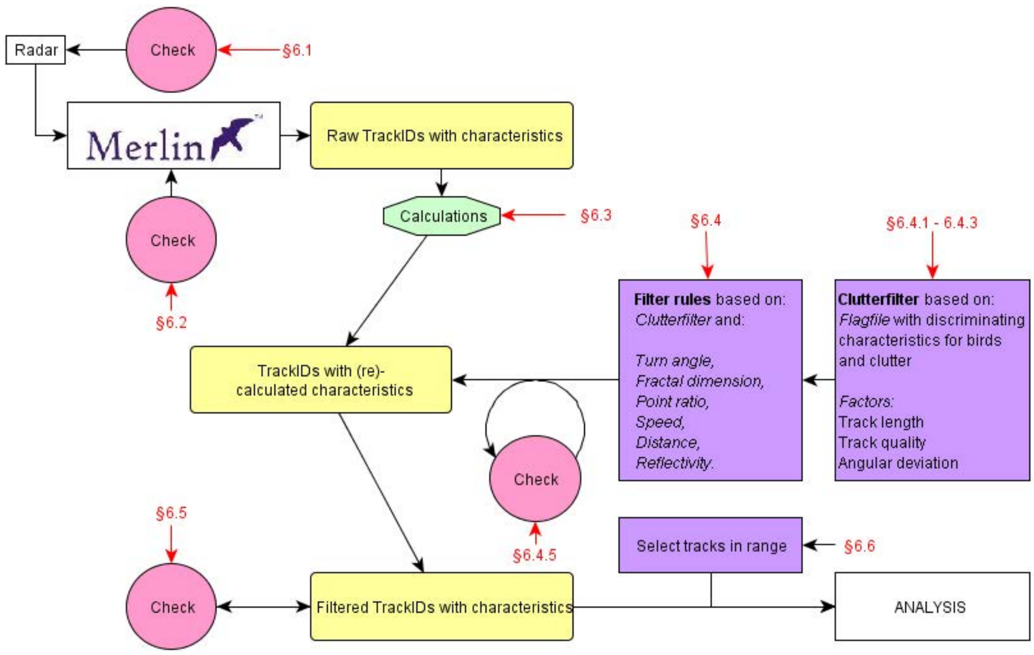


Figure 6.1 Schematic overview of the necessary steps taken to prepare the raw data for analysis.

6.1 Radar performance

What did the radar detect apart from birds?

The horizontal radar was an S-band radar, which means that is was less sensitive than the vertical X-band radar to receive echoes from objects such as waves and rain.

- **Waves** on the North Sea are short and sharp compared to for instance oceanic waves, which meant that despite it being an S-band radar, waves were still quite visible to the radar (fig. 6.2). Wave height was measured at the metmast. It varied between 0 and 7 m, and averaged 1.3 m (fig. 3.2). The amount of echoes reflected from waves back to the radar increased with increasing wave height. At low wave heights, no waves were reflected or only in a small zone around the radar. With increasing heights, the distance from the radar at which waves were still reflected increased, up to a point that the majority of the screen would be filled with clutter from waves.
- **Rain showers** that passed over the area were also detected by the radar (fig. 6.3) (but were hardly ever tracked by Merlin; see following paragraph).
- Tracks of **insects** (slow moving, tight concentrations of tracks close to the radar) were never seen on either the Furuno screen or the Merlin screen, nor were they detected in the processed data. This is due to the fact that the radar was an S-band radar, transmitting at longer wavelengths and thus less sensitive to small objects.
- Some **interference** was detected, probably mainly originating from the metmast, but this was a minor issue in comparison to the amount of sea clutter from waves.
- Ships were all detected readily. Supply vessels from Vestas moved within the wind farm on a daily basis. Fishing vessels were the main other type of vessel present in the area. They are not allowed within the boundaries of the wind farm, and were mostly seen on radar in the areas west and north of the wind farm.

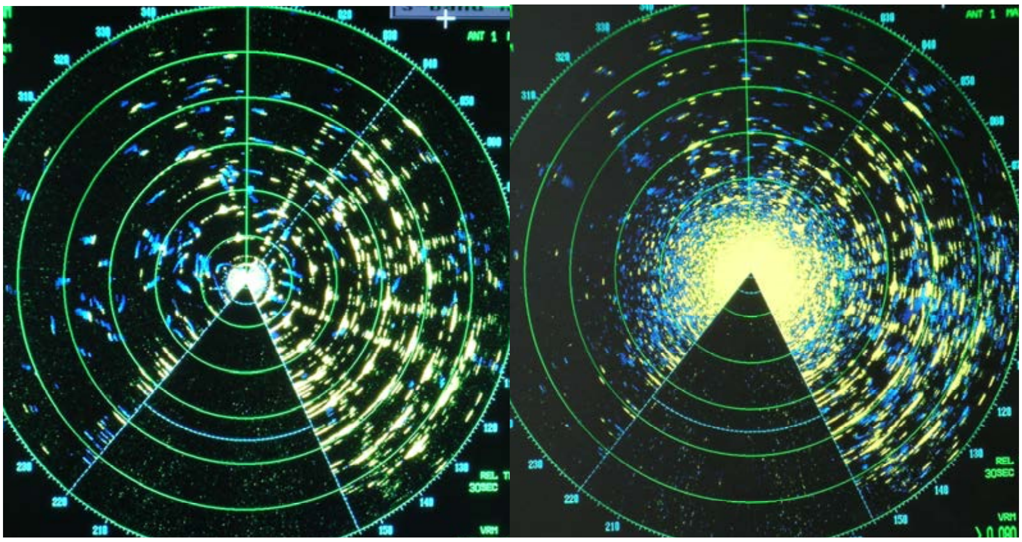


Figure 6.2 Raw radar images from the Furuno horizontal radar taken at different wave heights. Left: a clear radar view of the study area during periods with low wave heights. Right: radar view more obscured by sea clutter during higher wave heights, birds still visible in outer ranges (yellow dots with blue 'tails').

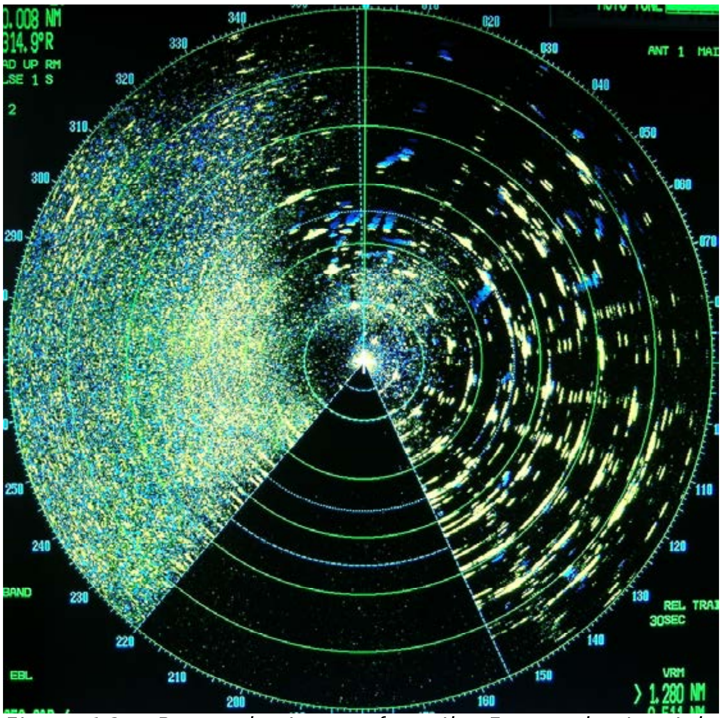


Figure 6.3 Raw radar images from the Furuno horizontal radar, taken during a rain shower. Rain showers passing over the area were detected by the radar but not tracked by Merlin. Some bird tracks are also visible above the centre of the sceen (yellow dots with blue 'tails').

Detection loss

The data showed a strong relationship with distance. The overall number of bird tracks peaked at distances between 1000 and 2000 m (fig. 6.4). Within 500 m from the radar, far less tracks were recorded. This can be due either to the limited range in altitude covered at that distance, and / or to the generally high proportion of sea clutter at such close range, which may have obscured flight paths at that distance. At distances beyond 2000 m, the number of tracks gradually decreased as a result of decreasing detection probability.

Detection loss at closer distances was higher for smaller than for larger birds (see §5.3.2). This means that especially at larger distances, larger birds will be overrepresented in the data, whereas smaller birds will be increasingly underrepresented. Because of this it will be less easy to obtain information on flight paths and avoidance levels of small bird species at larger distances from the wind farm.

Detection loss due to distance was accounted for in two ways. Firstly, in statistical analysis, distance from the radar was always entered as the first parameter in accumulated generalized linear models (using Genstat v.13 statistical software). Thus, the effect of distance is accounted for and the effects of other parameters can subsequently be entered and tested in the model. Secondly, when numbers of flight paths were compared for different areas of the wind farm, the comparison was always carried out pairwise within the various distance classes. Thus, estimates were always obtained for data collected at comparable distance away from the radar, thus avoiding distance effects.

Details of detection loss are discussed in §9.3.1, both for detection loss due to distance from the radar and for detection loss due to interference from turbines.

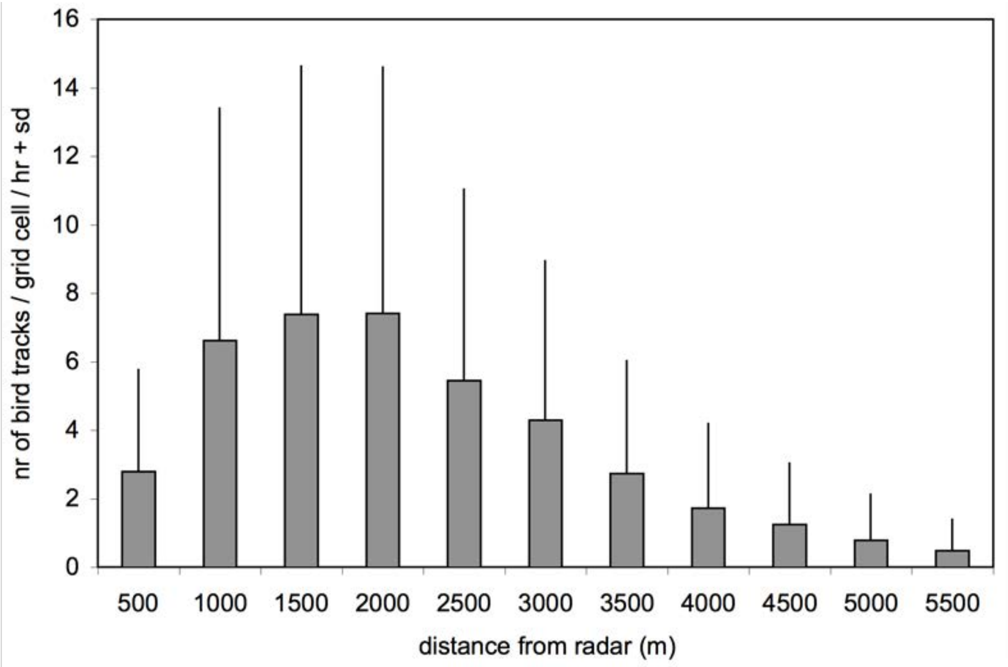


Figure 6.4 Detection probability changed with distance from the radar. Shown is overall number of bird objects tracked on average per grid cell per hour. Standard deviations illustrate high level of variation, caused by variation in the numbers of birds flying, e.g. between seasons.

6.2 Merlin performance

What did Merlin record apart from birds?

Under calm sea conditions, Merlin showed clear tracks of birds (fig. 6.5). There were several sources of clutter potentially affecting Merlins success of tracking birds:

- Merlin did generally not track **rain** on the horizontal radar. Only under very specific conditions did Merlin track rain to some extent. It is unclear what specific aspects of these rain spells made Merlin track them. Although rain was hardly ever tracked, fewer bird tracks were recorded during rain. For example, in April 2009 it rained during 4% of the time. During these rainy spells, Merlin tracked on average 0.2 tracks per 10 minutes, whereas 0.7 tracks were recorded during dry weather. This had to do with the fact that rain was indeed detected by the radar, which made it more difficult for Merlin to track any birds that may have flown within this rain clutter. It is also very likely that during rain, fewer birds were flying in the area, but this could not be determined from the radar data.

- **Waves** induced a severe problem for bird detection. The radar gradually detected more waves with increasing wave height, and Merlin could not discriminate well between echoes from birds and waves (fig. 6.5). Thus, the database was full with tracks originating from waves, and all this sea clutter had to be removed in order to see flight paths of actual birds (see §6.4.5 & §6.5). Analysis showed that up to a wave height of 1.80 m, Merlin could still detect birds. At larger wave heights, the level of sea clutter prevented bird tracks to be detected. Data on wave heights is given in §3.4.
- **Ships** were also tracked by Merlin. As they produced a strong reflection, ships created long tracks that could follow the ship on its course through most of the radar screen. Because reflection was strong, a large proportion of ships was filtered out from the database. However, some have remained and may occasionally result in misleading flight paths. This effect is strengthened when large numbers of birds, that are being tracked by Merlin and remain in the database, follow fishing vessels.
- **Wind turbines**, although detected by the radar, were hardly tracked by Merlin. This was due to the fact that their position did not change, and thus tracks were discarded because their 'speed' fell below the limit of that of bird objects.

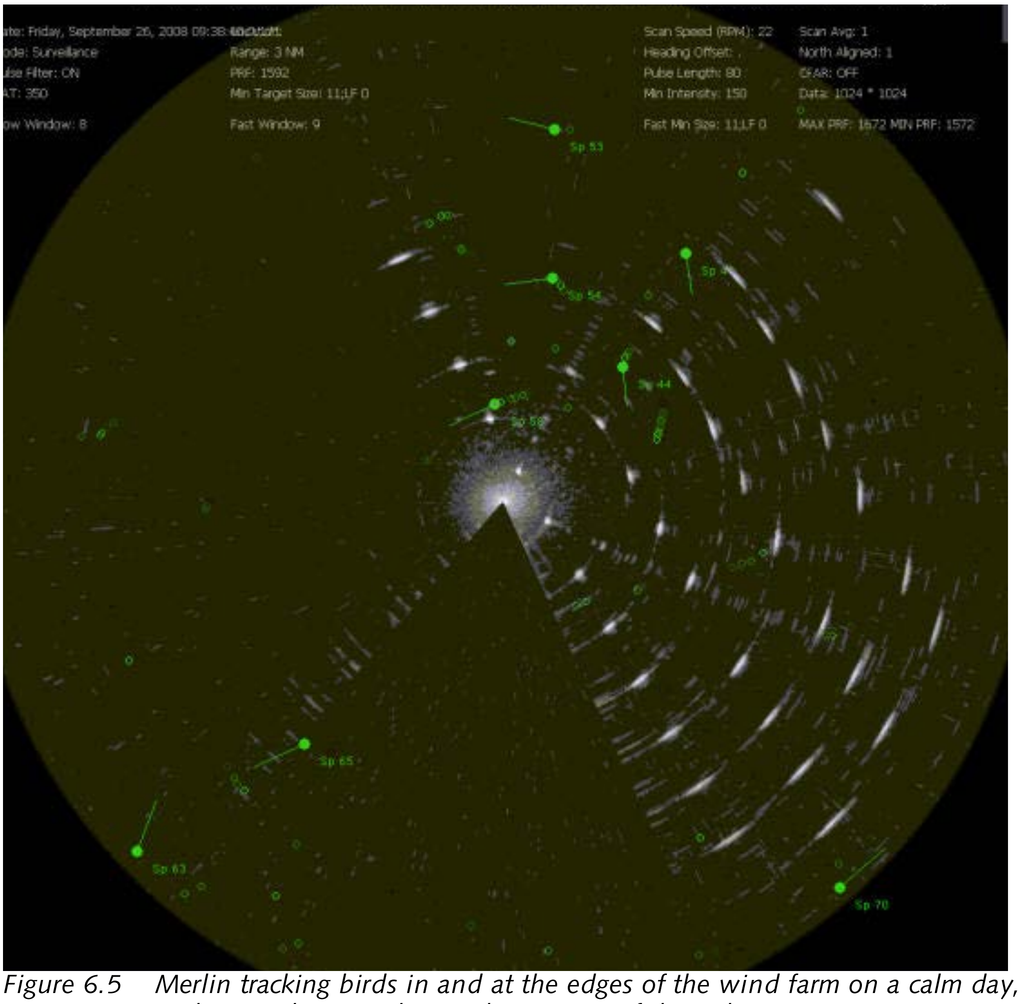


Figure 6.5 *Merlin tracking birds in and at the edges of the wind farm on a calm day, and some clutter at the southern range of the radar.*

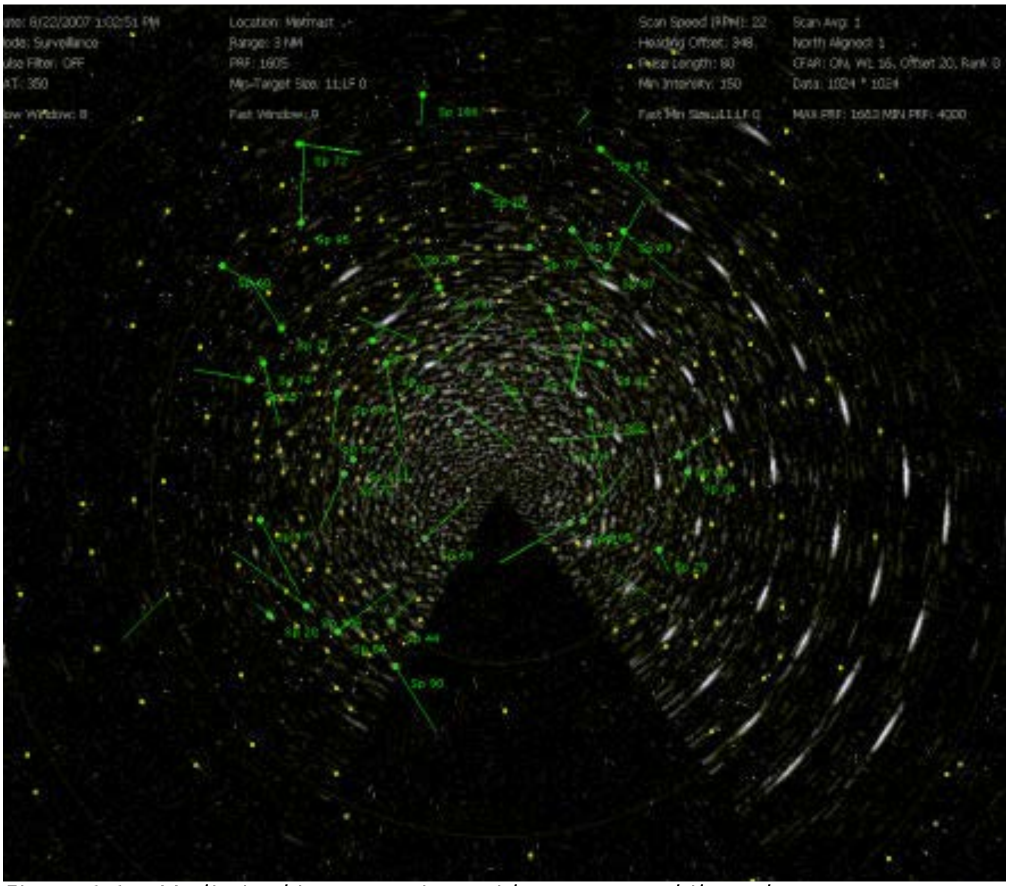


Figure 6.6 Merlin tracking waves in a wide area around the radar.

Comparison with Furuno data

To assess differences in bird tracks recorded by Merlin and visible on the Furuno screen as judged by an experienced observer, we quantified the number of bird tracks visible on the Furuno screen and compared these with results produced by Merlin after data filtering (see §6.4). Bird tracks were quantified in two 90° areas of the Furuno screen, one inside and one outside the wind farm area (fig. 6.7). Tracks were quantified from photos and time-lapse movies taken from the Furuno screen (fig. 6.8). From each movie between one and three time frames were counted, depending on the recording time, thus providing data in a spot-sample fashion (*i.e.* one radar scan with a 30 second-history). A total of 80 images was thus analysed, recorded on 40 different hours spread over 8 days throughout 2007. These data were then linked to the data recorded by Merlin at that time, in order to validate the Merlin data.

The number of tracks recorded averaged 30 per scan per 90°-sector and varied between 5 and 115.

The Furuno data also show that on average, 40% of all bird tracks were seen within the wind farm (fig. 6.9). This figure is highly similar to the 42% resulting from Merlin-data, presented in §9.4.

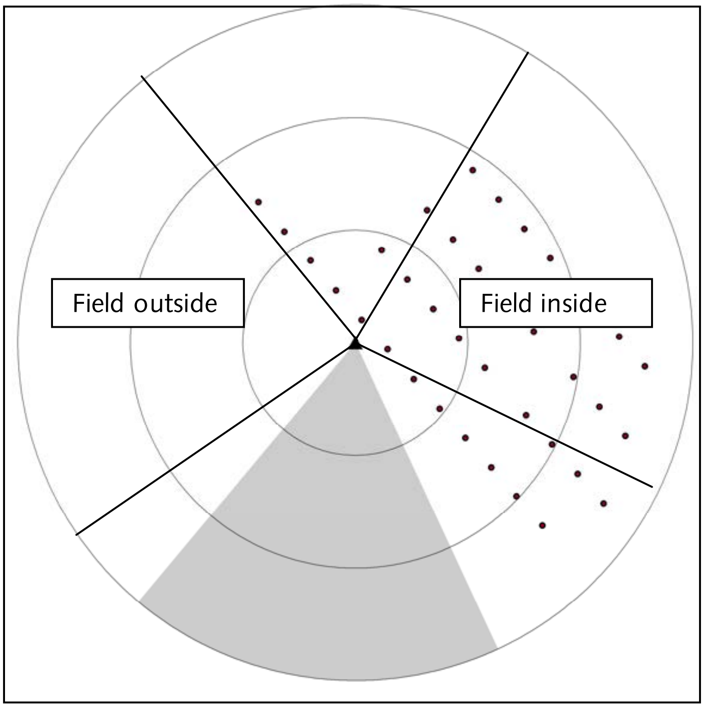


Figure 6.7 *Schematic view of the two fields in which flight movements were counted on both the Furuno screen and from Merlin data.*

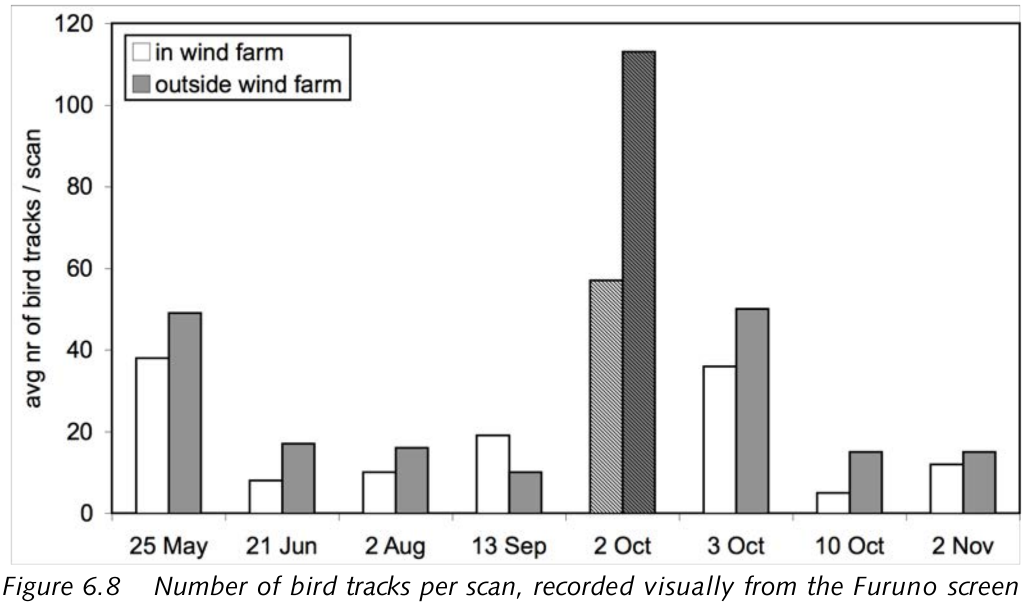


Figure 6.8 *Number of bird tracks per scan, recorded visually from the Furuno screen in two sections of 90°, both inside and outside the wind farm. Hatched bars reflect data collected at night on Oct 2 2007.*

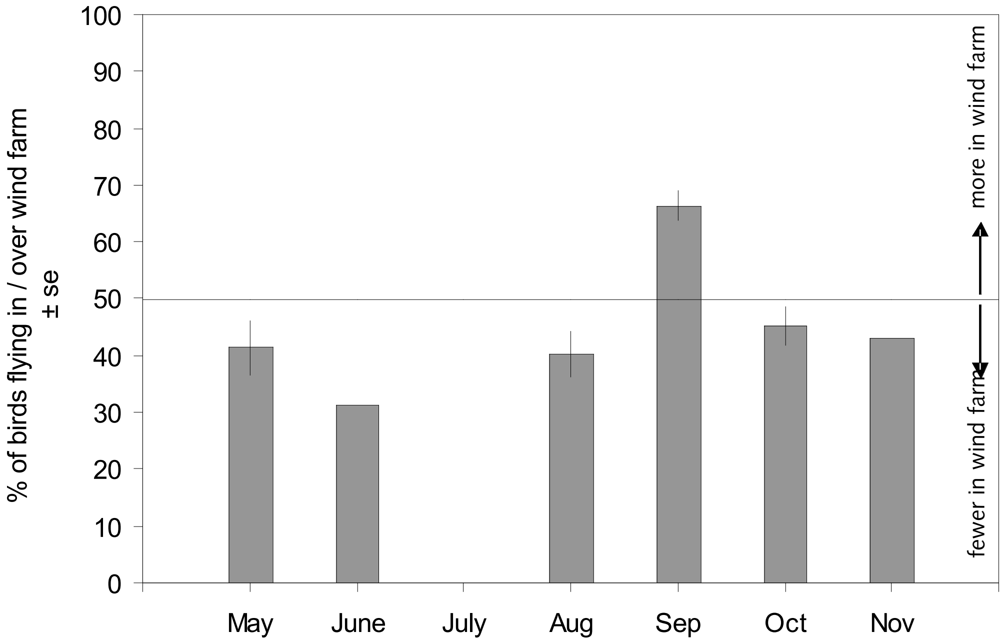


Figure 6.9 Distribution of tracks within versus outside the wind farm, as quantified visually from the Furuno screen. Shown are mean percentages with standard errors.

6.3 Data pre-processing

Data were moved from Access to Postgres to allow data processing and increase processing speed. All collected files were collated and split into monthly and eventually seasonal databases to facilitate data processing and analysis. All variables related to position and movements of objects were calculated from the parameters target_X1 and target_Y1, which define the current position of an echo in pixels relative to the Merlin screen (1-1024 in both directions). This concerns the following variables:

- position in pixels on X and Y axis
- heading
- bearing
- speed
- range
- altitude (for vertical radar)

Variables describing physical properties of the echoes were used as provided by Merlin. These included e.g., area, reflectivity, elongation and orientation of the echo.

The database was checked for completeness and inconsistencies, such as date corrections, tracks stored in duplicate, and consistency in minimum and maximum values of variables. Additional information was added to the data, such as weather and sea conditions.

Additional variables were then calculated to obtain more information about the track. These were all variables that summarized 'behaviour' of the entire track, and were calculated to either allow discrimination between birds and clutter or yield information on the bird (for an explanation see appendix II):

- track length
- track quality
- variables reflecting variation in heading, such as: turnangle, angular deviation, distance ratio, point ratio
- airspeed

6.4 Clutter filtering and data processing

Sea clutter

The database from the horizontal radar contained a high number of tracks originating from waves rather than from birds. The level of this so-called sea clutter was so high that it at times entirely obscured patterns in flight paths of birds. It was therefore urgent to develop a way to remove sea clutter from the database.

Clutter removal from the S-band data was done aggressively, with the aim to remove as much clutter as possible, rather than retaining as many bird tracks as possible as was the case for the vertical radar data (§7.4). The reason for this is that the purpose of studying horizontal flight paths is primarily to obtain flight directions of birds around the wind farm, and these would be affected severely if high levels of clutter remain in the database. The filtering method and the results on cleaning up the database are described in this and the next paragraph.

Steps involved in sea clutter removal

The Merlin tracking process was validated by an observer who characterized echoes on the radar screen as either bird, sea clutter, or otherwise (flagging, §6.4.1). The filtering method that was developed to remove sea clutter from the database is presented in §6.4.2 and 6.4.3. Filtering rules are summarized in §6.4.4. The resulting database was then screened to evaluate whether clutter was effectively removed and whether tracks of all different bird species were still in the database (§6.5).

6.4.1 Flagging tracks of birds and clutter

Echoes that are recorded by Merlin, can be marked digitally on-screen, which makes it possible to assign information to that specific echo (fig. 6.10). Thus, if it is known that an echo belongs to a bird, that echo can be flagged as being a bird. Similarly, echoes can be flagged as being ships, rain, sea clutter, interference, etc. This has allowed us to build a database of recorded echoes of which the origin is known, both for the horizontal and the vertical radar (see §7.4). With this database, we could analyse whether bird echoes have characteristics that differ significantly from those of e.g., waves. This in turn allowed us to eliminate records from the database of objects other than birds, erroneously recorded by Merlin.

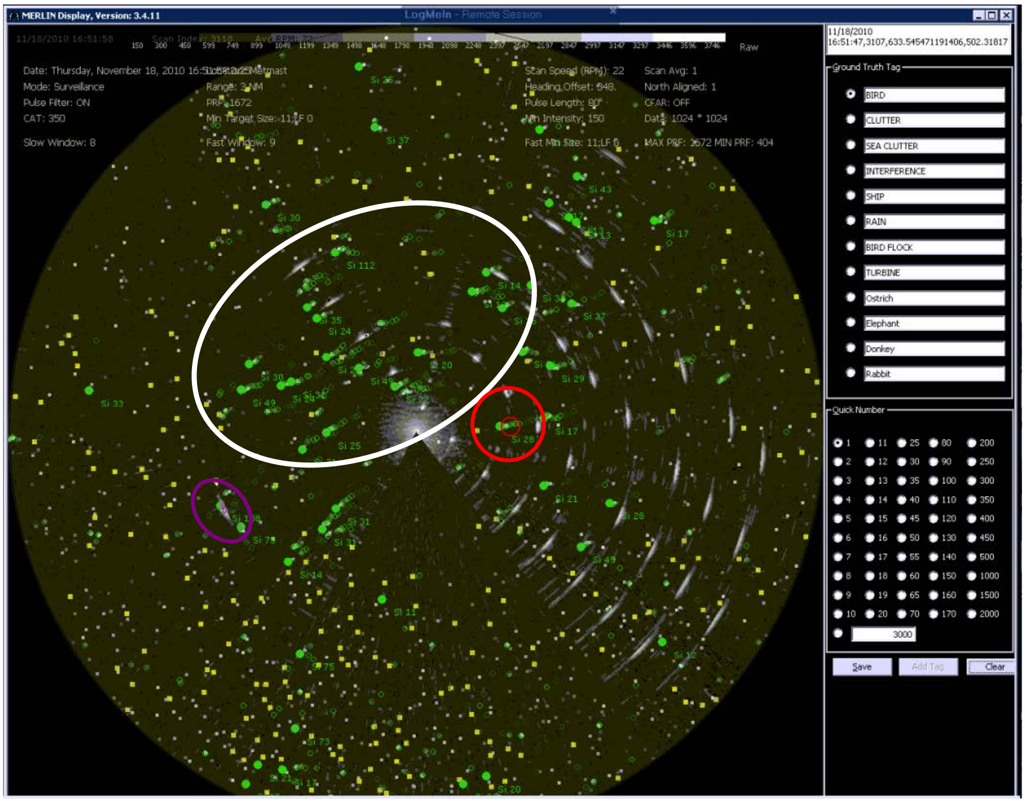


Figure 6.10 Flagging procedure for horizontal radar. Echoes recorded by Merlin are visible as green closed circles on the Merlin display screen. Each recorded signal remains visible as a green open circle for some time after it has been recorded, leaving a so-called echo-trail. These green circles can be selected with the cursor (small red circle, indicated with the larger red circle), and flagged digitally as belonging to e.g., a bird, ship, rain, sea clutter or otherwise (panel on right side of the image). Here, thrushes migrating SW in autumn were flagged as 'birds'. The birds are especially visible in the area marked by the white circle. The purple circle indicates a slowly moving fishing vessel with associated gulls, that is being tracked by Merlin and shows up in purple due to the high intensity of the signal. See fig. 7.8 for a simultaneous view of the vertical radar.

Flagfile

In the period between July 2007 and February 2009, we built a database consisting of 987 flagged echoes from the horizontal radar (table 6.1). The characteristics of echoes of each type were then investigated to establish differences between them. On the horizontal Merlin screen, tracks differed clearly between birds and waves (see fig. 6.10). Sea clutter generated 'tracks' on the Merlin screen in random directions, without an apparent echo trail. Birds created consistent, regular tracks with an evident echo trail. A flag was only assigned to a record when a positive identification could be made. Echoes from ships could mostly be distinguished from bird echoes by the intensity of the signal (purple circle in the lower left corner of fig. 6.10).

Table 6.1 Number of echo-tracks that were flagged, for the various groups of the distance willobjects, for horizontal radar.

type	nr. of flagged tracks
bird	599
clutter	313
rain	8
ship	31
unidentified long track	36
total	987

6.4.2 Clutter analysis based on weather conditions

Number of echoes recorded per scan

The higher the waves were, the more clutter was recorded by Merlin. At a certain level, the amount of clutter is so high, that bird tracks become invisible. The level of sea clutter was well described by the number of echoes that Merlin recorded in each scan of the radar (a scan being one 360° turn of the radar beam).

We monitored whether the Merlin screen showed only sea clutter or clear bird tracks and very little clutter, or both. This was done during regular checks of the system from the office, over a period of almost a year, and resulted in a data set of over 200 records. In 46 instances birds were clearly visible, and in 56 instances only clutter was visible. We linked these data with the number of echoes that were recorded per scan at that moment. This showed that no bird echoes were recorded when the number of echoes per scan exceeded 60 (see table 6.2), while above 40 recorded echoes per scan, significantly fewer instances occurred that birds could be recorded (fig. 6.11). Thus:

- Data were considered to reflect birds only when the number of echoes recorded in each scan was 60 or less. This was limited to periods without heavy migration, as explained below.

On nights with peak migration, the number of echoes recorded per scan could well exceed the cut-off level of 60. On Sep 22 2008, migration was particularly strong between 0:00 and 2:00 (fig. 6.12). The mean number of echoes recorded per scan varied between 15 and 38, and the maximum lay close to the cut-off level of 60 (58 and 59 echoes per scan at 0:00 and 1:00 h respectively). On April 23 2008, migration reached levels up to 150 records per scan. In general, number of echoes recorded per scan did not exceed 60 on nights with peak migration, but as shown, there were some instances that it did. To avoid data on bird migration being filtered out of the database with this step, removal of data with more than 60 echoes per scan was limited to months without heavy migration, being:

- January, February, June, August and December.
- During the other months, data were considered to reflect birds only when the number of echoes recorded in each scan was 180 or less.

Table 6.2 *Number of tracks recorded per scan during periods that birds were visible on the Merlin screen, during periods that only clutter was visible, and during periods when this was not evident.*

tracks visible of	nr of echoes recorded per scan mean	median	min	max	nr of records
birds	27.1	27	3	60	46
clutter only	108.3	100	30	300	56
not evident	52.5	40	4	246	102

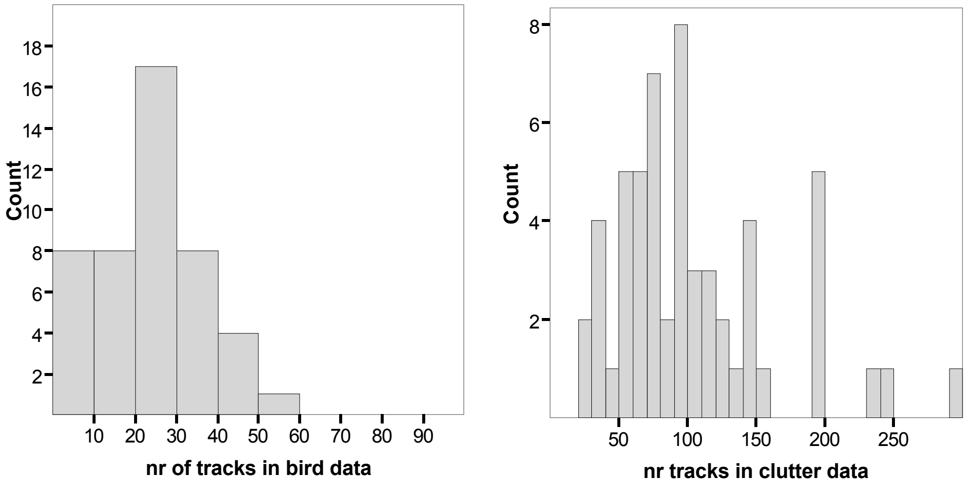


Figure 6.11 *Frequency distributions of the number of tracks (echoes) that Merlin recorded per scan at times when birds were visible (left panel) and at times when only sea clutter was visible on the horizontal Merlin screen. Note the difference in scale. When birds were visible, the number of echoes per scan was lower than 60.*

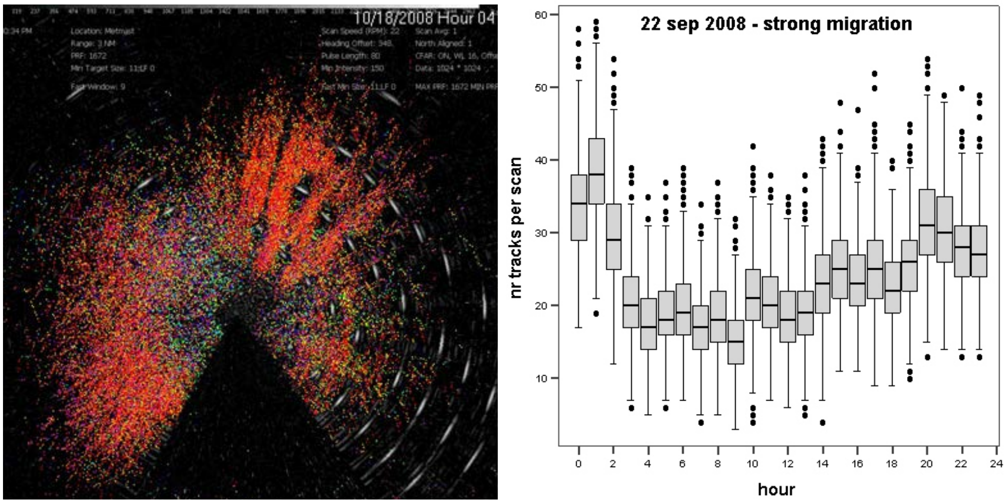


Figure 6.12 Heavy migration in the night of October 18 2008, resulted in high numbers of echoes per scan. Migration visualized in the left panel as individual echoes recorded during 1 hour; orange colour reflects SW-heading. Number of echoes or tracks per scan, averaged per hour in the boxplot on the right, with maxima approximating the cut-off level of 60 for clutter filtering. Interpretation of boxplot: see fig. 6.13 below.

Wave height

The same data set described above, was used as well to analyse the relationship between visibility of bird tracks versus sea clutter, and wave height. Again, there was a clear correlation, although data of birds and clutter showed considerable overlap. Birds were not recorded at wave heights more than 1.80 m. Wave height was mainly dependant on wind speed but also wind direction. Above 3 Bft. wind from the west, waves were generally above 1 m whereas with wind speeds up to 5 Bft from the east wave height was below this 1 m mark. Wave height during periods that birds could be seen on the Merlin screen, was 0.73 m on average (min 28 cm, max 1.72 m). Wave height during periods that only sea clutter could be seen, was 1.70 m (min 47 cm, max 2.85 m). Thus:

• Data were considered to reflect birds only when wave height was 1.80 m or less.

6.4.3 Clutter analysis of flagged data

Track length

Tracks belonging to birds were significantly longer than tracks from clutter (table 6.3 & fig. 6.13). This is in line with visual observations of the radar screen: birds were visible on the radar screen as consistent, regular tracks with a clear echo trail. Tracks from sea clutter seemed all over the place, and one echo could not be linked visually to the previous one. Visually, birds were not identified as such on the Merlin screen unless a consistent echo trail of three or more echoes was seen. This corresponds to an actual track length of six echoes in the database, because Merlin doesn't consider a series of echoes to be a track until three to four echoes are recorded as belonging to the same track.

Because such a small proportion of bird tracks had a track length less than three echoes, and because such a large proportion of sea clutter did have a track length of three echoes or less, it was decided that only tracks consisting of more than three echoes were considered as birds, and the remainder was removed from the database as clutter. A large proportion of bird tracks had a track length of four echoes. Therefore, the threshold for data filtering was set at a track length of three rather than four.

With this step, 87% of tracks flagged as clutter and 13% of tracks flagged as birds in the flagged data were removed from the database. This was the first step in clutter removal, and resulted in a reduction of the database by ca. 85%.

Table 6.3 Distribution of track length among bird tracks and clutter tracks. For birds, the majority of tracks was longer than 5 echoes, while in clutter, the majority of tracks was shorter than 3 echoes.

type	track length	n	%
bird	2	28	5
	3	34	6
	4	51	9
	≥ 5	486	81
clutter	1	204	65
	2	68	22
	3	18	6
	4	10	3
	≥ 5	13	4

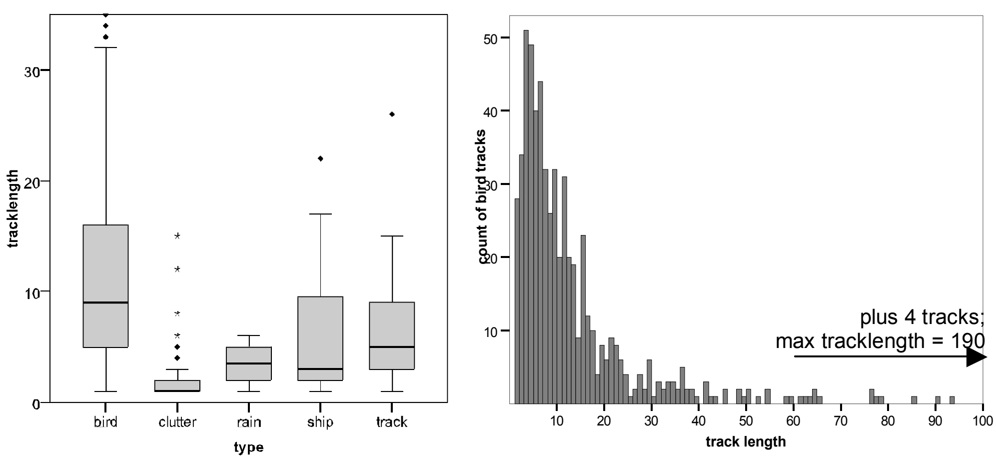


Figure 6.13 Track lengths of birds, clutter, and other type of objects recorded on horizontal radar. Interpretation of boxplot: horizontal line indicates median; box indicates lower to upper 25% around median, or 50% of data; whiskers represent highest and lowest values that are not outliers or extremes; remaining data are outliers (1.5-3 times interquartile range) and extremes (>3 times interquartile range).

Similar analysis of other variables showed that several echo characteristics of flagged echoes differed markedly between birds and the various types of clutter. However, none of the characteristics showed a clean difference without overlap, nor did any combination of echo characteristics. Threshold values of several characteristics were therefore determined with a Classification And Regression Tree analysis (CART), performed in R with the package Rpart.

Classification and regression tree analysis

Similar to the baseline study and described extensively in Krijgsveld *et al.* (2005) and Meesters *et al.* (2007), thresholds can be accurately determined with a classification and regression tree analysis. This analysis was carried out for the flagged data set in R with the package Rpart. The first step was to remove all tracks with a track length of three or less hits, as described above. The CART-analysis was run on the remaining data set. Echo characteristics that were likely to differ between birds and clutter given the 'behaviour' of bird- and clutter tracks, were included in the analysis. These included, among others, track quality (sum of track type-values of all echoes within a track, divided by the number of echoes within that track more information in the next section of this paragraph), several variables representing variation in the heading of the track (clutter had more irregular direction than birds), range and speed (clutter differed more in speed between echoes than birds). The CP-tree used to determine the cut-off level is shown in figure 6.14. The CP-value that Rpart determined was 0.14. The resulting classification tree used no more than two echo characteristics (fig. 6.15). These were track quality and angular deviation of heading.

Based on this, data were considered to be from birds when:

- track quality was less than 3.6
- angular deviation of heading was less than 58.1

The tree was selected to yield the best result in filtering out clutter successfully. CART-analysis in itself only provides the separation in which an optimum is achieved between correctly assigning birds and correctly assigning clutter. For us, emphasis lay on correctly assigning sea clutter, because it was more important to remove the exceptionally high percentage of clutter rather than to retain all birds.

Most sea clutter was removed from the flagged data set by limiting track length to values higher than three. Including smaller track lengths in the CART-analysis, did not improve classification. Improvements were achieved in the process by selectively entering different combinations of variables into the analysis. The tree with the best discriminating power, also for the other radar databases (vertical and close-to-turbine), was finally obtained by entering variables that made sense physically, such as variation in heading, range, area and reflectivity, and speed. Other trees with a larger tree size (more variables to separate birds from sea clutter) did not yield a better result. Running the data through MVpart-analysis yielded a worse overall root-node-error, but gave useful insight in parameters that could be used for additional clutter removal (see next paragraph).

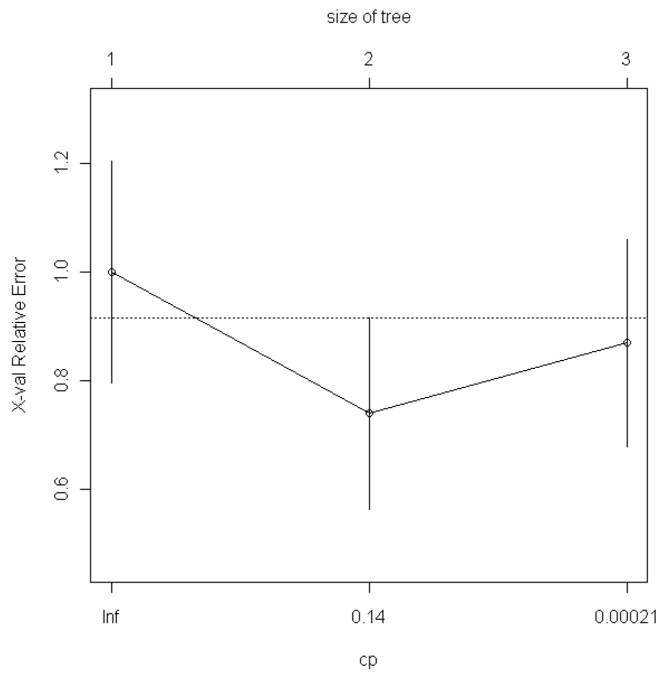


Figure 6.14 Cp-tree of flagged data from horizontal radar. Size of tree needed to effectively separate birds and clutter is 2, at the optimal cp-value of 0.14.

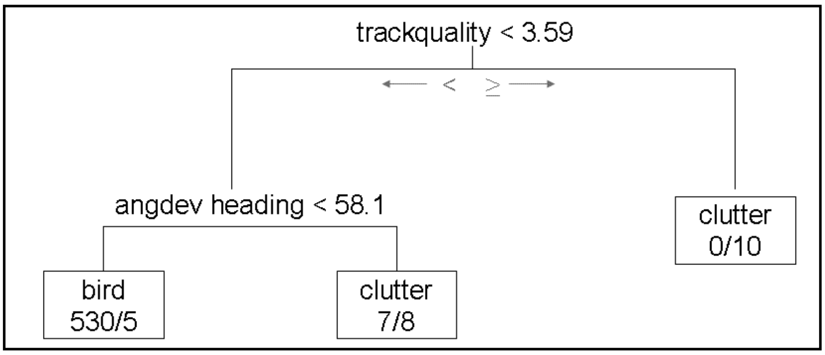


Figure 6.15 Regression tree based on flagged bird and clutter data from horizontal radar, used to define threshold values between data from sea clutter and from birds. Based on data with track length > 3, and a CP-value of 0.14. Below each branch the predicted outcome of class is given, followed by the number of observations in both classes. Interpretation: If track quality is > 3.586, tracks are judged as clutter. With this split, 0 bird tracks are incorrectly classified as clutter and 10 clutter tracks are correctly classified as clutter.

Track quality and angular deviation of heading

Track quality was defined as the sum of track type-values of all echoes within a track, divided by the number of echoes within that track. Thus, it combines track type and track length and therewith formed a useful parameter to discern between the various types of echoes. Track type reflects the consistency with which a track was recorded. The more echoes are recorded sequentially, the lower the track type-value. For example, if an object was recorded during only 2 out of 4 scans, the track type-value is higher then when an object was recorded 4 out of 4 scans. Birds and ships generally had lower values for track quality than clutter (fig. 6.16, left panel). Track quality of ships was slightly higher on average, but showed a large overlap with that of bird tracks.

Angular deviation is a measure for the variation in heading of the object, and is comparable to the circular standard deviation of the heading (see app. II). The larger the angular deviation, the more the track changed its heading during its course. Angular deviation was larger for sea clutter and rain than for tracks of birds and ships (fig. 6.16, right panel). The values for ship- and bird tracks overlapped. The parameter was suggested by Brookes, who used it to filter birds from clutter in a Merlin radar study of flight paths of birds over sea in Scotland (Brookes 2009).

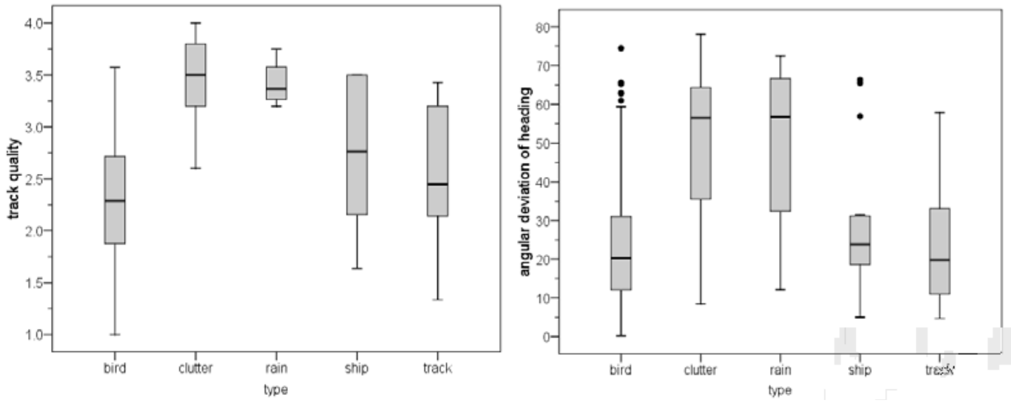


Figure 6.16 Track quality and angular deviation in heading of various types of objects. Interpretation of boxplot: see fig. 6.18 below.

6.4.4 Additional clutter analysis of flagged data

The filtering tree presented above is limited by the fact that most sea clutter was removed in the first few steps. After those steps no more records of sea clutter were available in the flagged data set to improve filtering rules. For example, by removing tracks as suggested by the regression tree, only 5 out of 313 clutter records were left in the flagged database. However, in the main database the majority of the data belonged to sea clutter. Because the proportion of sea clutter was so high, filtering should be as robust as possible to avoid contamination of flight patterns with clutter data.

To achieve further removal of clutter data, additional filtering steps were carried out, based on observed differences in characteristics between bird and clutter tracks. These are presented below. Most of these characteristics relate to the fact that birds fly in more or less straight, regular lines (fig. 6.17), while sea clutter generates tracks that move much more randomly. Threshold levels were defined by examining means and ranges of the variables. Tracks that formed outliers in the boxplots were plotted to evaluate why they were outliers and whether they should be included or not. An example of this process is given below for the variable turning angle.

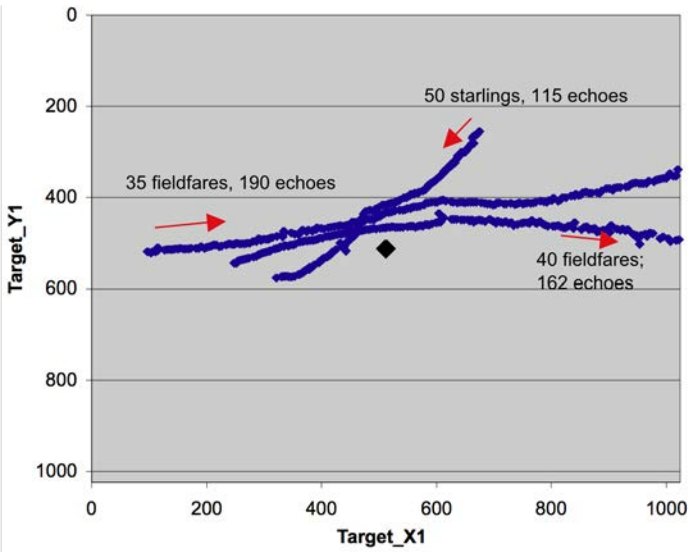


Figure 6.17 Three bird tracks recorded by Merlin, reflecting long and consistent tracks easily recognisable as birds. Scales reflect the Merlin screen in pixels (1-1024); the radar is positioned in the centre (black diamond). Tracks were identified visually on the metmast.

- **Turning angle** is another parameter that is a measure for the level of variation in the heading of a track, besides angular deviation of the heading, is the mean turning angle of that track. This is the change in heading between one and the former echo within a track, averaged for that track. Mean turning angle showed considerable separation between bird and clutter tracks, but with quite some overlap between the two (fig. 6.18). No clear bird tracks were observed above a level of 73. The threshold level was therefore set at 73, which includes the whiskers (and thus the majority of the data) but not the outliers and extremes.
- **Fractal dimension** is another measure for variation in heading, and is calculated from a combination of distance ratio and track length (see app. II). The fractal dimension of birds covered a very narrow range, in contrast to sea clutter (fig. 6.19). Outliers covered a larger range, but upon inspection these tracks turned out to be very inconsistent and not convincingly of birds. Below a value of 1.40, tracks started to look more like bird tracks, with some abberations. The threshold level was therefore set at 1.40.
- **Point ratio** and **distance ratio** also reflect how straight the track was, as they compare the total number of echoes in that track (point ratio) or the total flight distance of that track (distance ratio) with the distance covered by that track 'as the crow flies'. Both variables showed considerable separation between tracks of clutter and of birds (fig. 6.20 top). Point ratio separated more when only tracks > three hits were considered.
- **Speed** of tracks is given as ground speed in Merlin. Thus, flight speeds measured for birds will show a wider range than the range in airspeeds of birds, which generally lies between 30 and 85 km/h (Alerstam *et al.* 2007a). Maximum ground speed of flagged bird tracks was 105 km/h, with a few outliers up to 130 km / h. Although ground speeds of bird tracks did not vary much from clutter tracks (fig. 6.20, centre), ground speed was included as a filter step because any track that moved faster than physically possible for birds, had to be clutter. In addition, Merlin was set to limit tracking to echoes with a speed of 105 km/h at maximum, which means that the database should be limited to speeds of 130 km/h max in any case.

- **Distance from the radar**, or delta range, varied much more for clutter tracks than for bird tracks, again because of the more random movement of clutter across the screen (fig. 6.20 centre).
- **Minimum reflectivity** differed between sea clutter and bird tracks. Reflectivity is the intensity of an echo. Compared to average and maximum reflectivity, the minimum values showed the highest level of separation between birds and sea clutter, but the difference is still very small (fig. 6.20, bottom).
- **Multiplying point ratio with turn angle mean** provided a means to further reduce the number of irregular tracks, without losing bird tracks that were regular but had one echo that was an outlier (fig. 6.20, bottom).

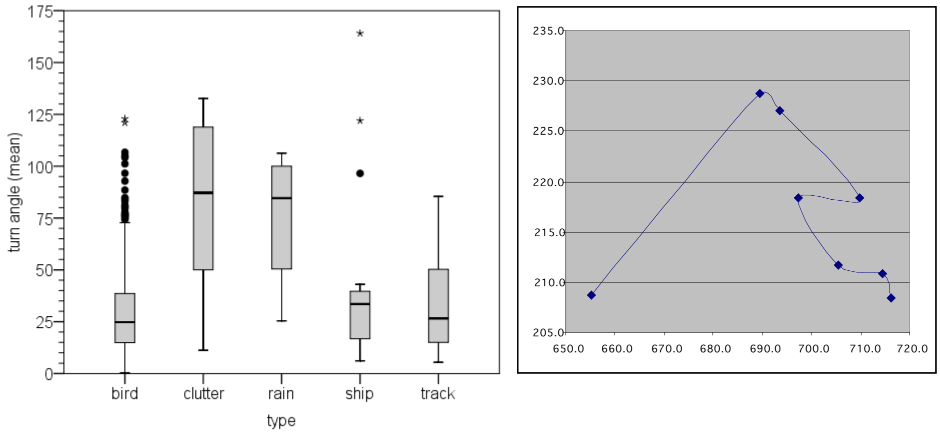


Figure 6.18 Turning angle of the heading of different types of tracks (left), and a plot (X and Y of Merlin screen in pixels) of a recorded track with a turning angle of ~80, that falls outside the threshold level (right). Interpretation of boxplot: horizontal line indicates median; box indicates lower to upper 25% around median, or 50% of data; whiskers represent highest and lowest values that are not outliers or extremes; remaining data are outliers (1.5-3 times interquartile range) and extremes (>3 times interquartile range).

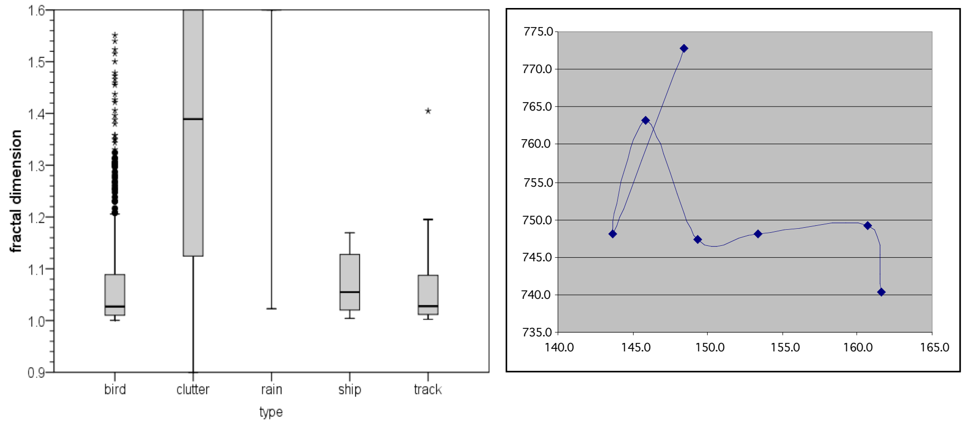


Figure 6.19 Fractal dimension of different types of tracks (left), and a plot (X and Y of Merlin screen in pixels) of a recorded track with a fractal dimension of 1.8, that falls outside the threshold level (right). See figure 6.18 above for a legend of boxplots.

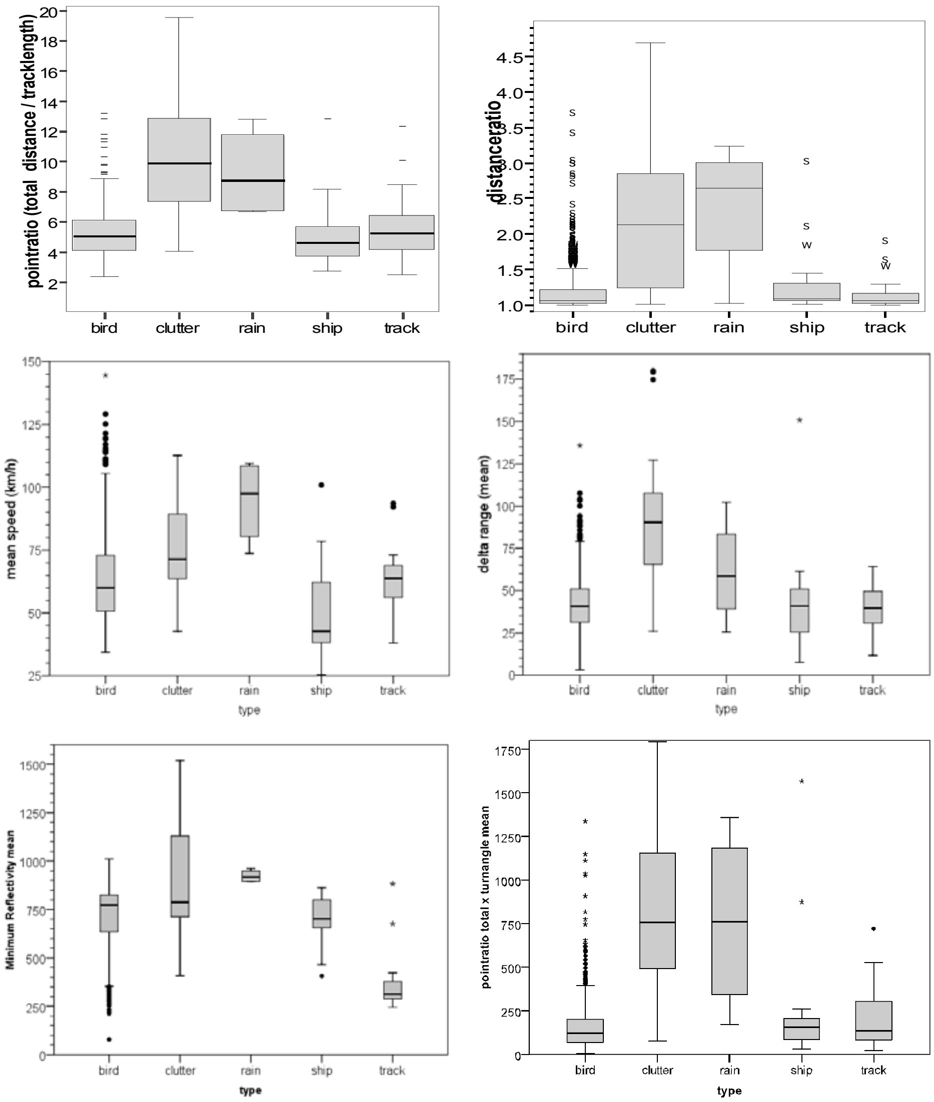


Figure 6.20 Variation between tracks of birds, sea clutter, rain, ships and undefined tracks (ship or bird) in a number of track characteristics. Shown are point ratio (top left), distance ratio (top right), speed (middle left), variation in distance from the radar (delta range, middle right), minimum reflectivity (bottom left) and the product of point ratio and turning angle (bottom right). Interpretation of boxplot: horizontal line indicates median; box indicates lower to upper 25% around median, or 50% of data; whiskers represent highest and lowest values that are not outliers or extremes; remaining data are outliers (1.5-3 times interquartile range) and extremes (>3 times interquartile range).

6.4.5 Filtering rules

Summarizing the two paragraphs above, data were considered to be sea clutter and were removed from the data following the rules listed in table 6.4.

Table 6.4 Criteria used to filter the horizontal data. Data were deleted when they satisfied the listed conditions. All parameters are explained in app. II.

filter-step	parameter	cut-off level		
1.	track length	≤	3	echoes
2.	a. number of echoes recorded per scan	>	60	in non-migratory months[1]
	b. number of echoes recorded per scan	>	180	in migratory months[2]
3.	wave height	>	1.80	m
4.	track quality	≥	3.6	
5.	angular deviation of heading	≥	58.1	
6.	mean turn angle (tam)	≥	73	
7.	point ratio (total)	≥	12.0	
8.	distance ratio	>	2.10	
9.	mean speed	≥	130	km/h
10.	fractal dimension	<	1 or > 1.40	
11.	mean variation in range (delta range)	≥	110	
12.	mean minimum reflectivity	≥	1010	
13.	point ratio x tam	≥	600	

[1] January, February, June, July, August & December
[2] March, April, May, September, October & November

Effect of filtering on size of database
After filtering the database with steps 1 through 3, the number of records in the main horizontal radar database was reduced to 17.1% of the original, from 735,825,926 records to 126,136,322 records.

After steps 4 through 13, the number of records was further reduced to 4.6 % of the original, to 33,832,443 records. These records reflected individual echoes that belonged to 153,897 tracks in total.

6.5 Evaluation of data filtering

Reduction of database
To evaluate how effective the clutter filter was in removing sea clutter from the database and leaving in bird tracks, we analysed the various filter steps on a selection of data. For this purpose, we selected data from dates on which either mostly clutter or many bird tracks were recorded (table 6.5). As described in §6.4.2, the number of echoes recorded per scan was much higher for files recorded during periods with a lot of sea clutter. Also the number of Access-files created per day was higher at such periods, but the relationship with the occurrence of birds versus sea clutter was much

weaker than the number of echoes per scan. Two periods with especially strong winds and high wave heights were selected as well, to investigate the specifics of sea clutter during such conditions, and the efficiency of removal of sea clutter (18 Jan 2008 and 12 Aug 2008 in table 6.5).

Table 6.5 Selection of data from dates on which either mostly clutter or a lot of birds were recorded. For each selection, the average number of echoes recorded per scan is shown, as well as the number of Access-files created on that day (size limit of 50MB per file), the average wave height, and specific patterns observed visually for that period of time.

date	time	echoes/scan (avg. nr)	files/day (nr)	wave height (avg. m)	patterns
Clutter days					
18 Jan 2008	18:35-19:22	204	26	1.60 – 3.00	
12 Aug 2008	17:44-18:38	260	12	2.50 – 3.00	(after 14h)
25 Jan 2009	19:07-21:06	41	12	1.50	
10 Feb 2009	16:53-19:24	115	9	1.30 --> 2.70	
25 Mar 2009	06:07-07:25	99	10	2.20	
3 Jun 2009	01:49-02:50	80	15	1.30	
6 Jun 2009	21:31-23:59	30	4	1.00 – 1.60	(end of day)
20 Oct 2008	21:43-22:34	96	33	2.00 – 2.80	
Bird days					
19 Mar 2009	08:42-12:11	23	13		starling migration
1 Apr 2009	00:00-03:45	22	3	0.40 – 0.90	
23 April 2008	04:00-05:33	78	12	0.70 --> 0.40	strong migration; peak @4h
6 May 2008	12:48-14:58	60	11	0.30 – 0.50	
21 May 2008	12:52-15:00	49	6	ca. 1.00	many large gulls; ca13h
5 Jun 2009	17:48-19:28	18	4	1.20 <-- 1.70	
30 Oct 2008	12:26-16:27	20	31	1.80 -->0.70	(after 13h)
6 Nov 2008	17:11-18:48	50	7	0.60 – 0.80	thrushes & starlings

The filtering steps were then applied to this selection of data, and the percentage reduction was tracked with each filtering step (step numbers as given in § 6.4.5). Step 2 and 3 were omitted in this evaluation, because it would have resulted in complete removal of most of selections of clutter data, which would have made it impossible to assess the filtering efficiency of the remaining steps.

The final percentage of data that remained in the database was significantly lower in 'clutter-data sets' (0.2%) than in 'bird-data sets' (4.0%). This indicates that tracks originating from clutter are removed effectively from the database (only 0.2% remaining). Because steps 2 and 3 are excluded in this analysis, the actual percentage of clutter data remaining in the database after clutter filtering is even lower than the 0.2% presented here. The fact that the percentage of remaining data is higher in bird-data sets, indicates that a significant percentage of bird tracks remain in the database. An analysis to evaluate whether bird tracks are removed from the database in the filtering process, is discussed below.

For the two days with exceptionally high waves (first two rows in table 6.6), the percentage data remaining was much higher than for the other clutter data sets. This is because the waves were so high or sharp that they were being tracked as consistent, bird-like tracks by Merlin (fig. 6.21), which were not recognized as clutter in the subsequent filter steps because they were quite consistent in behaviour. This was a specific type of error that did not occur in the other clutter-data sets. Because more than 200 echoes were recorded per scan, these data would be removed from the database during the actual filtering process with filter steps 2 (selection on number of tracks) and/or 3 (selection on wave height > 1.80m). Data sets were not considered in defining the remaining percentage of clutter in the data because of the discrepancy with the specifics of clutter data in general.

The percentage of data was reduced most drastically in the first filtering step, in which all tracks shorter than three hits were removed. The additional steps did contribute significantly in cleaning up the database, because with these steps the final percentage of data that remained in a 'clutter-data set' was reduced to only 0.2 % with these steps.

Table 6.6 Reduction of database with each filtering step, for the selection of dates given in table 6.5. For each selection, the original number of records is shown, and the percentage of records that remain in the database after each filtering step (s1-s13 following §6.4.5).

date	original	filtered (% remaining after each filtering step)										
	nr	s1	s4	s5	s6	s7	s8	s9	s10	s11	s12	s13
Clutter days												
18 Jan 2008	33346	24	19	8	5	4	4	4	3	3	1.4	1.4
12 Aug 2008	34671	22	18	10	6	6	5	5	4	4	2.2	2.0
25 Jan 2009	57710	8	5	2	1	1	1	1	1	1	0.2	0.2
10 Feb 2009	44353	15	11	3	2	2	2	2	1	1	0.2	0.2
25 Mar 2009	42569	17	12	4	2	2	2	2	1	1	0.3	0.3
3 Jun 2009	44779	15	11	3	2	2	2	2	1	1	0.2	0.2
6 Jun 2009	50743	9	6	2	1	1	1	1	1	1	0.2	0.2
20 Oct 2008	41833	17	13	4	2	2	2	2	1	1	0.2	0.2
Bird days												
19 Mar 2009	43259	14	11	8	7	7	6	6	5	5	4.1	4.1
1 Apr 2009	54584	8	8	7	7	7	6	6	5	5	5.3	5.3
23 April 2008	47477	11	10	8	6	6	6	6	5	5	5.0	4.9
6 May 2008	66163	4	3	2	2	2	1	1	1	1	1.1	1.0
21 May 2008	55305	8	6	3	2	2	2	2	2	1	1.2	1.2
5 Jun 2009	18970	11	8	4	3	3	2	2	2	2	1.2	1.2
30 Oct 2008	53615	8	8	7	6	6	5	5	5	5	4.5	4.5
6 Nov 2008	42167	16	15	13	12	12	11	11	10	10	9.6	9.5

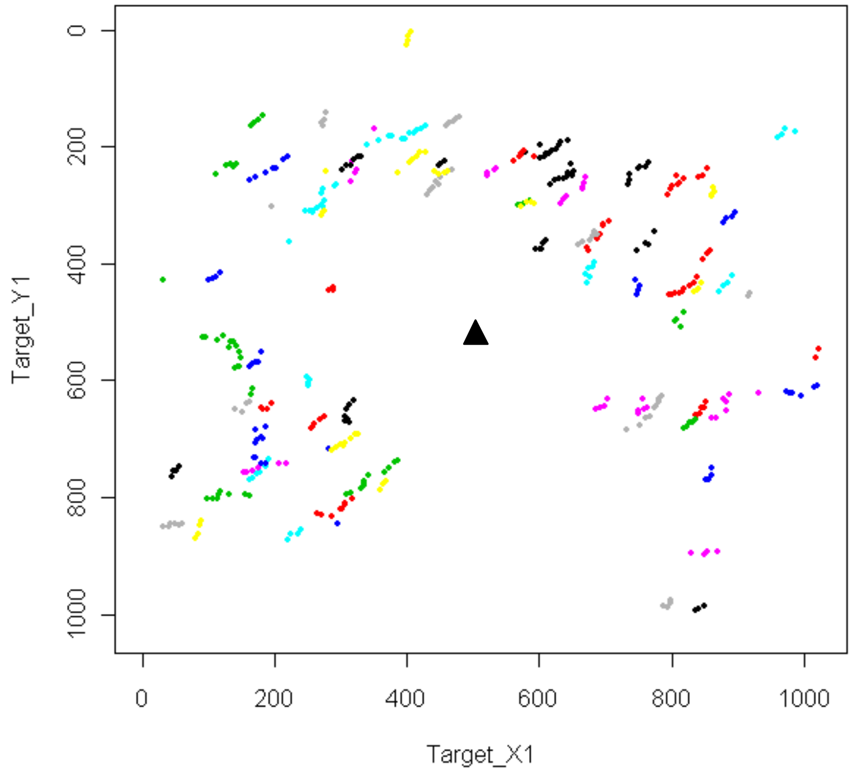


Figure 6.21 Image of clutter tracked on August 12 2008 during a south-westerly storm force 8 Bft and a significant wave height of 3m. Shown are data remaining after filtering, collected in a period of 5 minutes from 18:00-18:05Zulu. Scales reflect the Merlin screen in pixels (1-1024); the radar is positioned in the centre of the figure (triangle). Each symbol represents one recorded echo, symbols with the same colour reflect echoes belong to the same track. Because as many as 260 echoes were recorded per scan and waves were 3m high, these clutter data would be removed from the actual database in filter steps 2 & 3.

Were bird tracks lost in the filtering process?

Bird tracks may have been lost in the filtering process. The clutter filter was built primarily to filter out clutter, rather than retain all birds. Based on CART-analysis, 7 out of 530 flagged bird tracks (1.3%) would be removed from the flagged database in step 1 and 4 alone. It is not possible to quantify what this percentage is in the actual database, because we had no means to identify the true number of bird tracks in (parts of) that database. We therefore visually analysed the effect of filtering on the data sets from table 6.5, for which we knew whether birds were present or not and what kind.

Each of these data sets was filtered step by step, and the intermediary results were plotted to visualize presence or absence of bird tracks in each subsequent step (fig. 6.22).

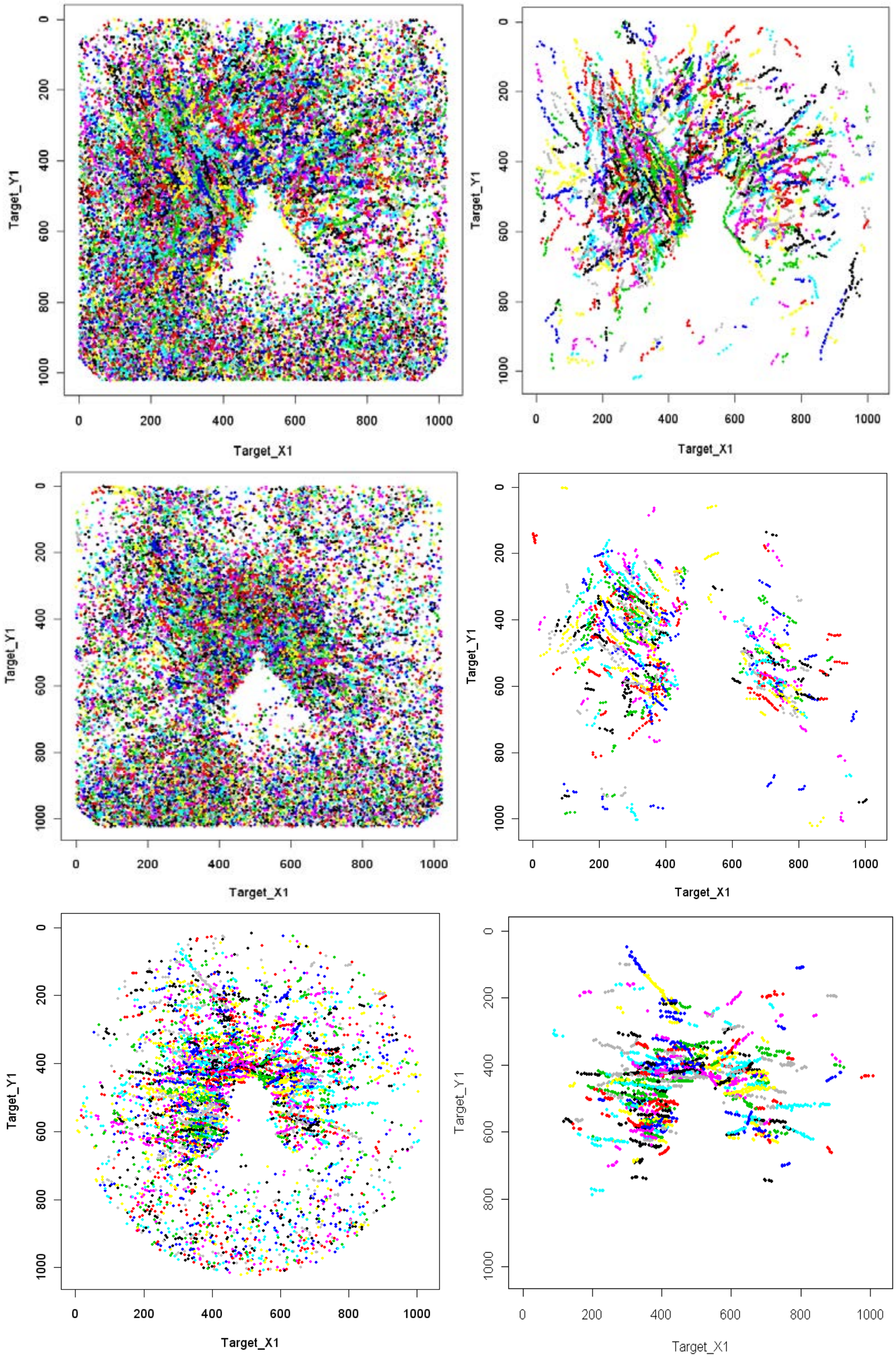


Figure 6.22 *Examples of the effect of filtering on data sets containing birds. Unfiltered data on the left, filtered data on the right. Top: songbird migration on April 23 2008. Centre: high gull activity on May 21 2008. Bottom: migration of starlings and thrushes on Nov 6 2008.*

Tracks that were removed in each of the filtering steps, generally looked like clutter tracks, so the filtering process seemed to work well in general. However, large flock of songbirds, such as starlings, were occasionally filtered out, for example in the final step 13 (fig. 6.23, left). This is caused by the fact that the birds were flying in a large flock. Merlin picked up the flock, but combined echoes of different birds in that flock, resulting in a track with a high degree of variation in position and heading.

This could potentially remove a large fraction of tracks specifically belonging to passerines from the database. However, only 21 tracks were removed from a specific data set with high levels of passerine migration, while 1094 tracks remained (fig. 6.23, right). This is only 2% of the tracks. We therefore concluded that flight paths of song birds remained highly visible in the remainder of the data, and that such a marginal part of these flock-tracks were lost that it would not affect the flight patterns.

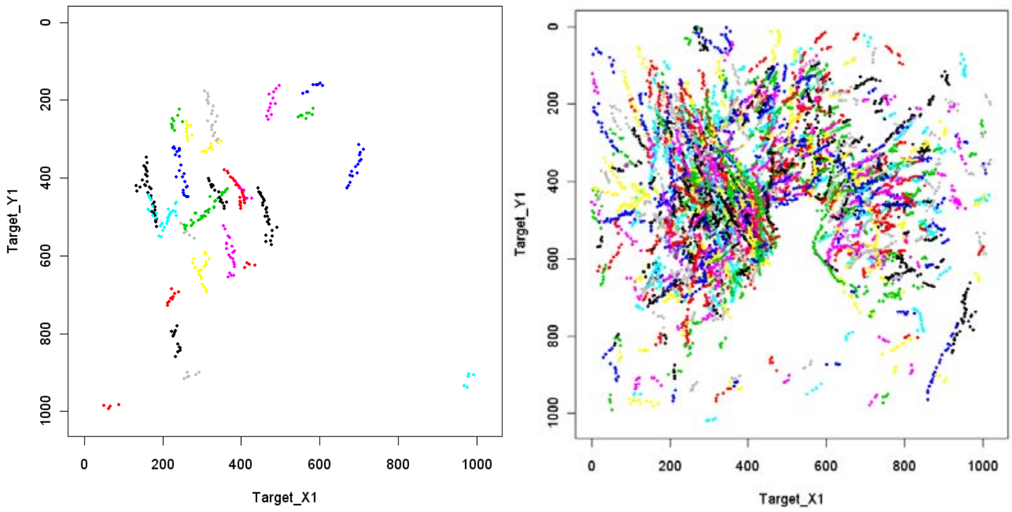


Figure 6.23 Tracks of flocks of song birds removed from the data in filter step 13 (left), and tracks remaining after filtering (right). Despite loss of some bird tracks, the overall flight patterns remain visible. Data recorded during half an hour in the night of April 23 2008.

Do 'clutter data' contain bird tracks?

Data sets that were judged as sea clutter, did not show tracks of birds after filtering (fig. 6.24). The assumption was therefore correct that periods with large amounts of clutter could be removed from the data set (filter steps 2 and 3), because no bird tracks would be regained from that data.

Conclusion

In conclusion, by filtering the database, an estimated 98.8% of clutter was removed from the data. Tracks of birds remained in the database and flight patterns became evident after sea clutter was removed.

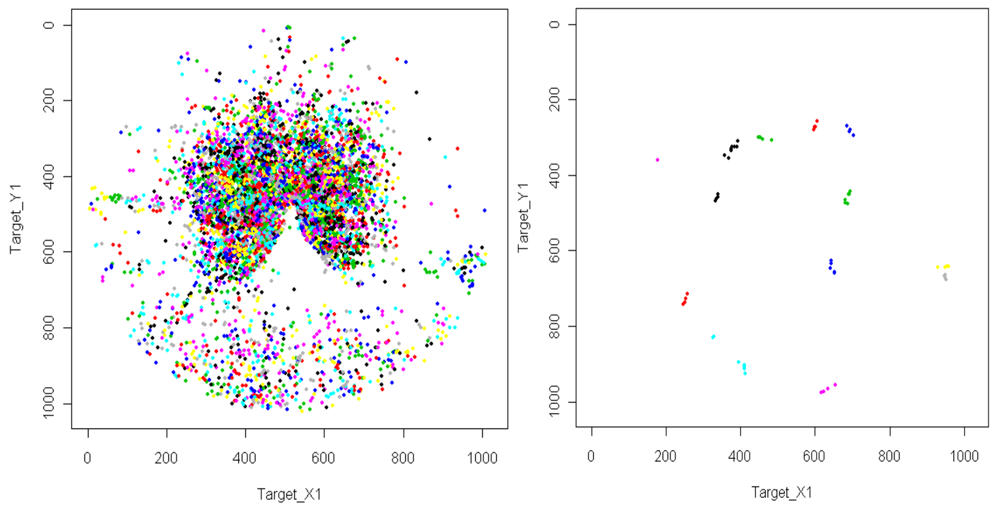


Figure 6.24 Sea clutter recorded on June 3 2009 during 5 minutes. Data before (left) and after filtering (right). Each echo is a symbol, echoes belonging to the same track have the same colour.

6.6 Data post-processing and analysis

After filtering, the data were reduced to 1 record for each individual track, accessible in PostgreSQL in four files, one for each season. Spatial information of the tracks was included in this record by converting subsequent echoes of a track into a line. Data outside the set detection range of 3 NM were removed, as well as interference recorded in the area that was blanked where the metmast was in the way (see §5.3.1). Additional general information was then added, such as whether turbines were operating or not.

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) (fig. 6.25). The grid cells measured 750x750 m, thus chosen to optimize assignment of cells within and outside the wind farm, and the amount of information on flight paths within cells. Each track was thus split up over the cells that it passed, and the flight direction of the part of the track within that cell was defined. This way, average flight direction and number of tracks for each cell could be calculated, as well as vector length and variance.
The following formulas were used to calculate these circular variables (R; package circstat; where x is the heading in radians of an individual flight path in a grid cell):

- circular mean: circular mean = sin(r)=arctan(sinr, cosr)
  where sinr=sum(sin(x)) and cos(r)=sum(cos(x));
- circular variance (or dispersion): var = 1-rho = 1-r/n
  where r=the resultant length=√((sum(cos(x))^2)+(sum(sin(x))^2)) and n=sample size;
- mean resultant vector length (or rho): √(sinr^2 + cosr^2) / n
  where sinr = sum(sin(x)), cosr = sum(cos(x)), n= sample size.

Data analysis

Data were analysed using PostgreSQL, QuantumGIS, R and SPSS. QuantumGIS was used to visualize flight paths. SPSS and Genstat were used for statistical analysis. Because the number of recorded tracks showed a strong relation with distance from the radar, all analysis involving numbers of tracks were corrected for this distance (§6.1).

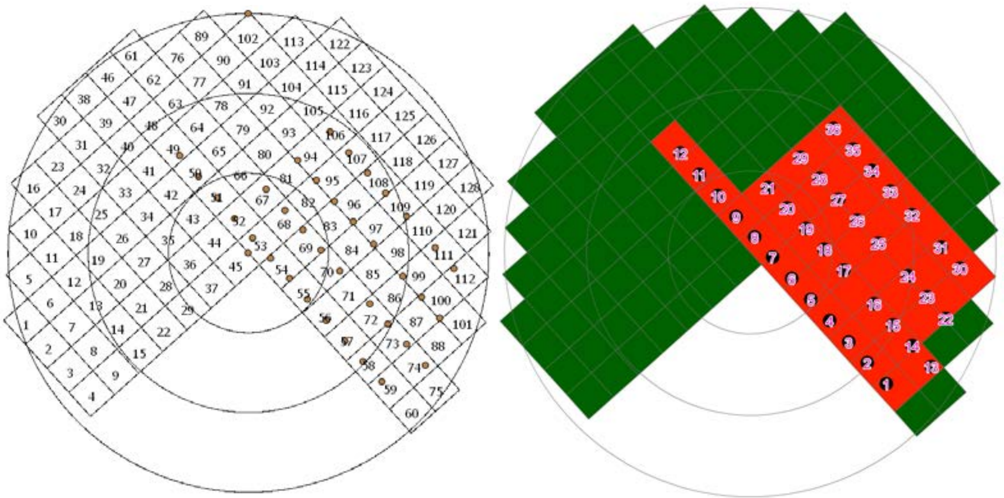


Figure 6.25 Lay-out of grid cells across the wind farm area, used to analyse numbers of tracks and flight directions in relation to the wind farm. Red cells on the right indicate cells that are defined as within the wind farm.

6.7 Horizontal radar at short range

To obtain detailed information on the behavioural response of birds flying close to the turbines, the range of the radar was reducedfrom 3.0 to 0.75 NM. Processing and analysis of these data is discussed in this paragraph.

6.7.1 Merlin performance

By reducing the range of the radar, the resolution of the recorded data is increased. This can be easily understood when we calculate the size of a pixel. The entire Merlin screen is built up from 1024 pixels in both vertical and horizontal direction. At a range of 3 NM, one pixel therefore reflects 11 m, whereas at a range of 0.75 NM one pixel reflects only 3 m. A similar difference occurs with the echoes. Thus, detection is more detailed at smaller ranges. Using a range of only 0.75 NM therefore allows us to more accurately record the behaviour of birds at small distances from the radar and thus quantify micro-avoidance (fig. 6.26).

Sensitivity to sea clutter

Reduction of the range resulted in an increased sensitivity to detect not only birds but also waves. The amount of sea clutter detected increased to such an extent that birds were not detected any more when wave heights increased above ca. 1 m, which on the North Sea is a common situation. Studying the nature of the echoes revealed however that at smaller ranges, the difference between birds and sea clutter became more evident. While at 3 NM there was no difference in the size of the echo reflected from birds or from waves, at 0.75 NM echoes from sea clutter had a much smaller size than echoes from birds. Bird echoes indeed increased to such a size that DeTect had to alter the standard range in settings of Merlin to allow birds to be tracked and sea clutter to be disregarded. This significantly improved tracking of birds, and also provided a tool to filter out sea clutter from the database (see below under clutter filtering).

Minimal distance to turbines

Detection loss near to turbines was not a major problem. Birds were regularly detected at distances down to 10 m and less from the turbine; and occasionally right down to less than 1 m. Tracks within 10 m from the turbine were also detected at turbines 7 and 8 that are placed closest to the radar. Because at such close distance the radar beam is still low, birds flying here would be flying at turbine height and not above it. Bird tracks were sometimes lost when they were passing behind turbines, but not when they were flying beside or in front of turbines.

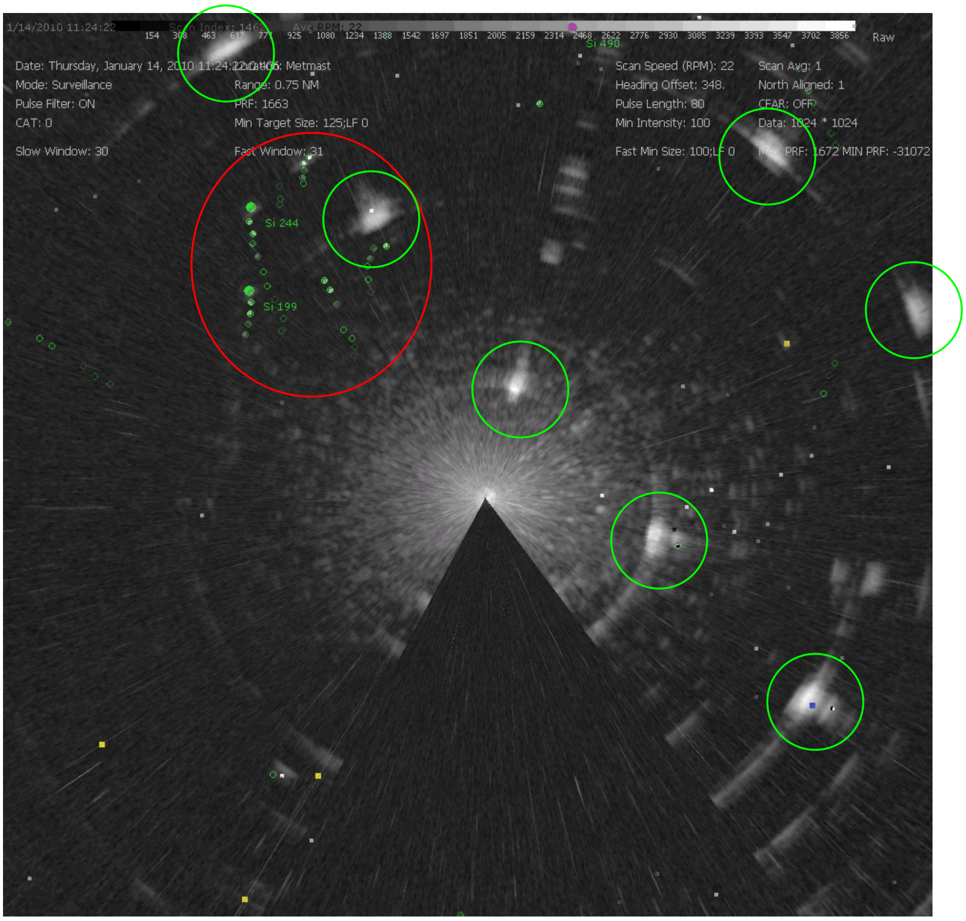


Figure 6.26 Merlin-image of the horizontal radar with range set at 0.75 NM for close-to-turbine recording of bird tracks. Birds flying around turbine 9 are tracked by Merlin and are visible as trails of green circles (red circle). Metmast with radar located in the centre, 7 turbines visible as large whitish dots in the upper right half of the screen (green circle).

6.7.2 Data processing, clutter filtering and data analysis

Data processing

Data were processed and analysed in the same way as the long-range horizontal dataset, described in §6.3. Because the range was reduced, echo characteristics of birds and clutter were different from those in the long-range dataset. The entire filtering process was therefore repeated for these data, including building a new flagged data set and determining a new clutter filter.

Clutter filtering rules

Filtering parameters and threshold values differed from those of the long-range dataset. Filtering rules are described in table 6.7. After filtering, a total of 6,394,926 records remained in the database.

Table 6.7 Filtering rules used to remove sea clutter from the horizontal close-to-turbine database. Data were deleted when they satisfied the listed conditions.

filter-step	parameter	cut-off level	
1.	track length	≤ 3	echoes
2.	number of echoes recorded per scan	> 40	in non-migratory months
3.	track quality	> 3.21	
4.	mean turn angle (tam)	≥ 93.62	
5.	mean minimum reflectivity	≥ 1045	
6.	mean maximum reflectivity	≥ 2750	

Data analysis

After filtering, data were analysed in the same way as the long-range dataset, using Postgres and Quantumgis. No grid was used however. Details are given in the results chapter of this topic, chapter 13.

7 Vertical radar data interpretation

The radar used in this study was equipped with Merlin software. When the OWEZ monitoring programme was initiated, this system was one of the best available to continuously record (nocturnal) bird data at sea. However, this system was not perfect and not all birds were detected and recorded in the database. Objects other than birds and interference were also detected and recorded in the database. Therefore collected data required several processing steps before data analysis could start.

In this chapter we present data that were collected specifically to monitor, validate and evaluate the performance of the vertical radar system (see schematic overview in fig. 7.1). Most of this process was carried out in a similar way as for the horizontal radar (see ch. 6), such as the flagging and filtering processes.

First, the analysis on the performance of the vertical radar was presented in §7.1. Here we investigated what the radar actually saw. Also questions such as how the radar coped with waves, strong winds and rain were analysed and are discussed. Also the influence of range and beam width on bird detection was examined as well as altitudinal detection loss. Second, radar performance was evaluated in §7.2. For this we compared visual counts of birds flying through the radar beam and visual quantifications of bird tracks from the Furuno screen with visual results from Merlin. Steps taken to clean up the data and allow data analysis are described in §7.3. Then, turbine-generated clutter, interference and sea clutter from waves had to be removed from the data. The filtering steps to do so are described in §7.4. The quality of the resulting data after filtering out clutter is evaluated in §7.5. Post-processing steps such as removing rain-polluted hours and two-column analysis steps are described in §7.6. Consequences of all of the above for interpretation of the data is summarized in §7.7, as well as procedures and methods used for data analysis.

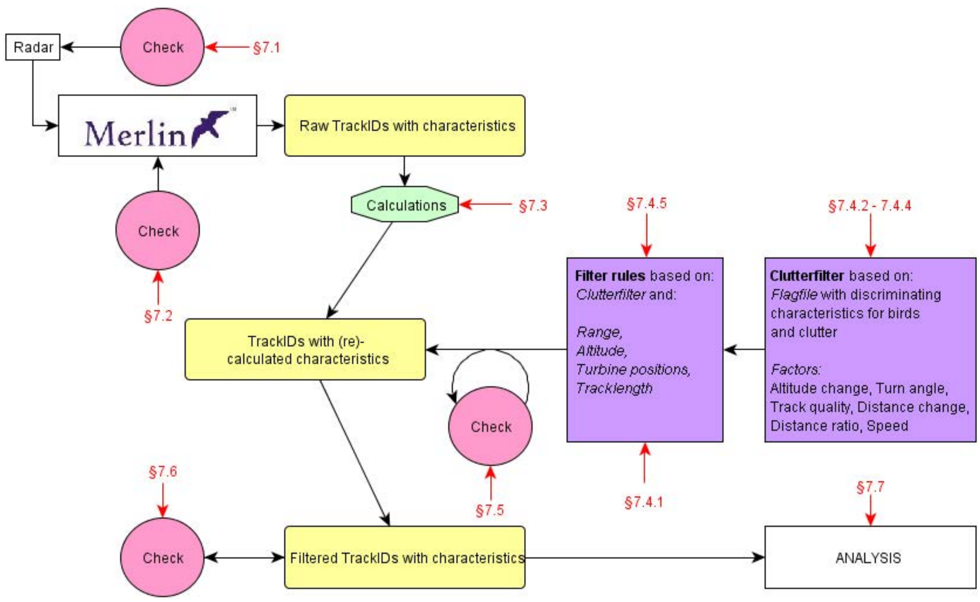


Figure 7.1 *Flowchart of the steps taken to prepare the raw data for analysis.*

7.1 Radar perfomance

What did the radar detect apart from birds?
The vertical radar used was an X-band radar. This means that it was more sensitive to receive echoes from objects such as waves and rain than the horizontal S-band radar (see §5.3.1).

- **Waves** on the North Sea are short and sharp compared to for instance oceanic waves, which means that a vertical X-band radar will record some wave clutter in the lowest altitude band and interference close to the radar (fig. 7.2). Wave height varied between 0 and 7 m, and averaged 1.3 m. The amount of wave-generated tracks increased with increasing wave height (§7.7). At low wave heights, no wave-generated tracks were stored in the Merlin database (§7.4). To leave wave clutter out of the database, altitudinal selections were made during analysis (§7.4).
- **Turbines** rotating within the radar beam were detected by the radar (fig. 7.3).
- **Rain showers** that passed over the area were also detected by the radar (fig. 7.3) but were easy to delete from the Merlin database (§7.6).
- Tracks of **insects** were seen on the Furuno screen, but were filtered out of the database based on echo characteristics and methodological choices (§7.6 and §7.7).
- Some **interference** was detected, probably mainly originating from the metmast or from the turbines, but could be deleted from the database quite easily (§7.4).

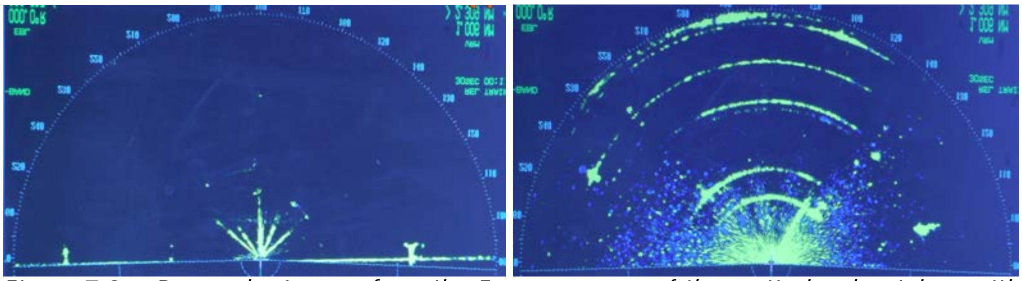


Figure 7.2 *Raw radar images from the Furuno screen of the vertical radar, taken with minimal (right) and a lot of interference (left).*

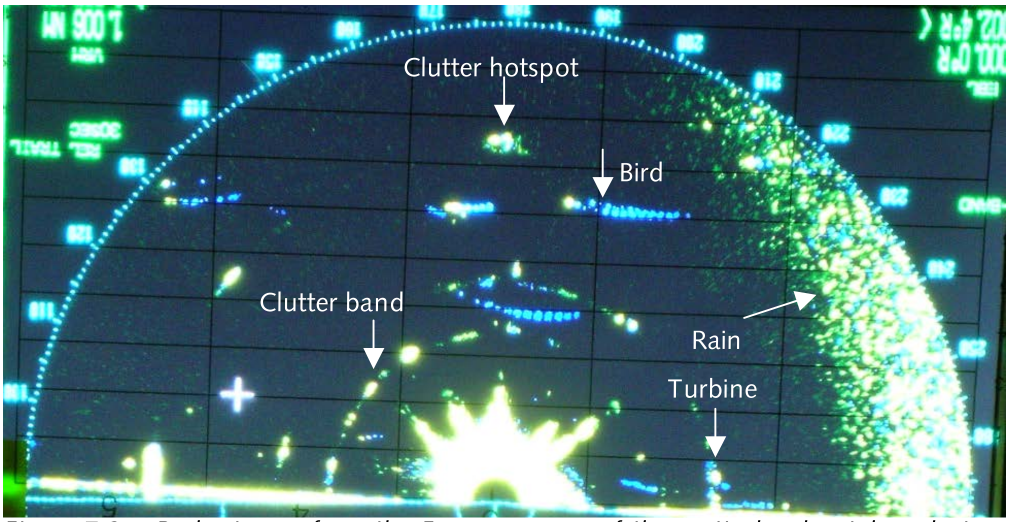


Figure 7.3 *Radar image from the Furuno screen of the vertical radar, taken during a rain shower on November 6 2008. Rain showers passing over the area were detected by the radar and were also tracked by Merlin (see fig. 7.6). Two turbines are in the picture as well.*

Detection loss at higher altitudes

Detection loss of smaller passerines in this study is expected at altitudes above 930 m (Poot *et al.* 2006), as discussed in §5.5.2. From the size of a starling and up, more than 95% of all birds were recorded with the used set-up (Poot *et al.* 2006). Potential decreases in abundance of smaller birds at higher altitudes could be caused by detection loss, but also simply by the fact that these species do not travel that high. Abundance of smaller birds at the highest measured altitudes (e.g., robins, phylloscopes, goldcrests, pipits) is unknown and not possible to study with our radar. Therefore detection loss is unknown and a possibly necessary correction was not possible. Whether high intensities of birds at lower altitudes could shadow migratory birds at higher altitudes (due to flooding of the radar beam) is also unknown and impossible to assess. However, this phenomenon would need a very dense layer of birds at lower altitudes. These kinds of conditions only occurred very incidentally. We never observed numbers of birds to be so high that above a certain altitude no birds were visible anymore. Therefore it is expected that this possible phenomenon is not of great influence on the annual or monthly fluxes found. The implications for the overall estimates of flux in the vicinity of the OWEZ wind farm will be discussed further in §7.7.

Detection loss at the lowest altitudes

Often tracking birds in the first 100 m of altitude is a problem when doing vertical radar research on land. Due to the location of the radar in this study (high above sea level and not many obstacles around) these problems did not occur in this study. Occasionally wave-generated clutter caused numbers to be underestimated in the lowest altitude region. Many seabirds also fly in the troughs between waves where they use the local winds to fly energetically efficient. Here they are effectively undetectable for the radar. Only at the moments they travel to the next trough they will be visible on the screen. Seabirds such as tubenoses, gannets, sea ducks and alcids are prone to show this flight behaviour and total numbers of these species could potentially be underestimated. Because the birds use this flying technique mostly during windy weather and because wave height is only then large enough to cause problems, such tracks remained undetected only during those conditions. However, these kinds of conditions were not usually found (§7.6).

Detection probabilities in relation to heading

Birds flying head-on into the radar beam, slightly toward the radar itself, have a higher chance of being detected by the radar than birds that approach the radar in such a way that the beam hits the tail side of the bird (Box II and Poot *et al.* 2006). Due to these different detection probabilities in relation to heading of the bird, overall differences in detection probability might have occurred between both sides of the radar beam. This was the case in the baseline study, where birds flying north-east on spring migration had a higher detection probability in the southern than in the northern side of the radar beam (Krijgsveld *et al.* 2005). However, in contrast to the baseline study where the vertical radar was oriented north-south, the radar on the metmast was oriented north-west to south-east. As a consequence, the radar was positioned almost perpendicular to the main flight direction during spring migration, and detection thus was expected to be more or less similar for migrating birds that fly in northeast-southwest directions. This turned out to be a correct expectation (fig. 7.4) and this substantially improved detection probability.

Box II Schematic overview of birds beamed on the head, tail and side by a radar beam

Birds flying head-on into the radar beam, slightly toward the radar itself, have a higher chance of being detected by the radar than birds that approach the radar in such a way that the beam hits the tail side of the bird. Birds flying sideways towards the radar beam have the highest cross-section for the beam to hit and are therefore detected most easily. Due to these different detection probabilities in relation to heading of the bird, overall differences in detection probability may occur between both sides of a radar beam.

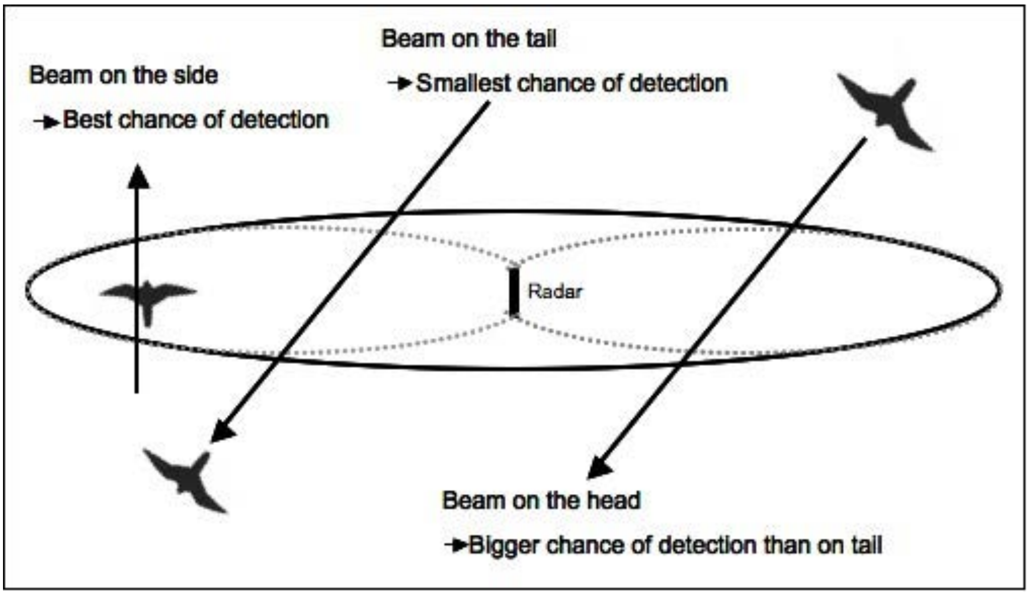


Figure II.1 Schematic overview of birds flying into a vertical radar beam, with different ways of receiving the radar signal. Arrows indicate flight direction.

Mean traffic rates (MTRs) were calculated separately for data from the north-western and the south-eastern sides of the radar to test whether heading effects still occurred in the Merlin bird track database (despite the perpendicular orientation). On average the ratio between NW and SE was 0.9 ± 0.1 throughout the year, meaning that on average MTR was slightly lower on the NW side of the radar beam (fig. 7.4). The difference between the SE - and NW side was much smaller than in the baseline study, as a result of the more perpendicular angle of the radar to the main flight direction. If the visible difference would be related to heading aspects, one would expect the ratio to change in relation to season: in spring a pattern opposite to that in autumn should emerge. Similarly, during the summer months, when locally foraging birds dominate the flight paths, no consistent difference between both sides of the beam would be expected. No such patterns were found (fig. 7.4, inset). Therefore just a difference in abundance on the two sides could be causing the skew between the NW and SE side of the radar.

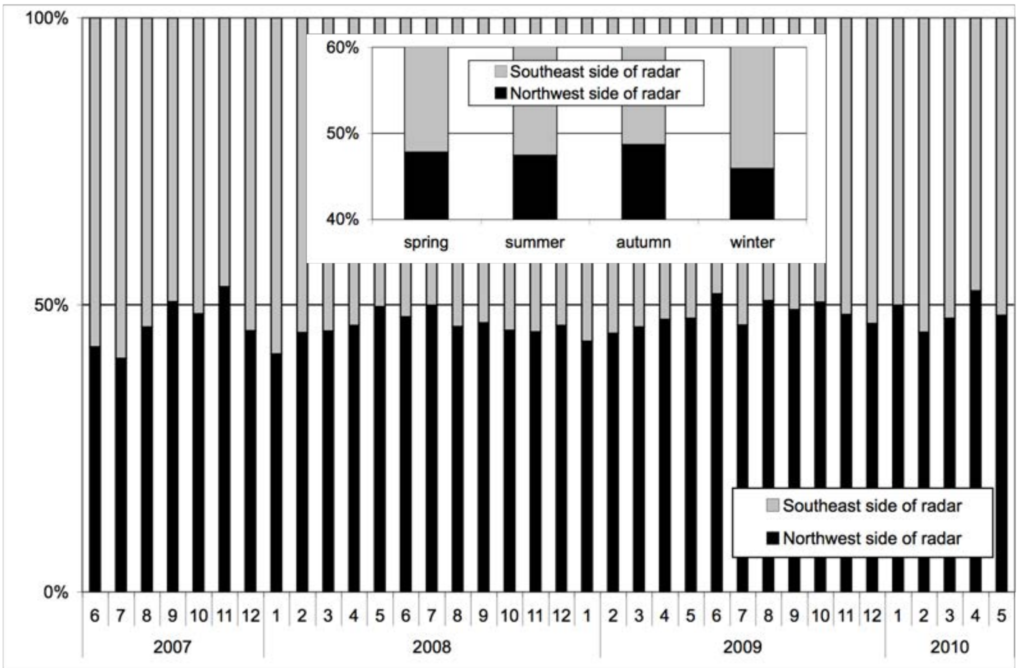


Figure 7.4 Heading effects: ratio of mean traffic rate per month in the southeast (grey bars) and northwest side of the radar beam (black bars). Inset: same analysis on seasonal scale. Data from all altitudes, for day and night combined, as measured by vertical radar.

Differences in detection probability between the left and right side of the radar are likely to be influenced by altitude as well due to species group-specific flight altitudes. For example, migrating passerines are more prone to heading effects because they are small and might be detected less easily at high altitudes. As these birds might be more abundant at higher altitudes compared to the very lowest altitudes, heading effects could be more visible at higher altitude. The opposite was observed when analysing the data (fig. 7.5). In summer and winter much more variation occurred in mean traffic rates in different altitude bands than during spring and autumn migration. Remarkable was that in spring more birds at mid-latitudes were detected on the south-east side of the radar screen, whereas in autumn at mid-altitudes more birds seemed to be detected on the north-west side of the radar screen. This supported the initial idea that in spring birds generally fly to the north-east, and at that time are beamed on the head in the south-east side of the screen. Therefore more bird movements should be detected on that side of the screen, similar to our findings. On the contrary in autumn birds migrate to the south-west, and at that time are beamed head-on in the north-western part of the screen, resulting in more tracks on that side of the radar. This is also similar to our findings.

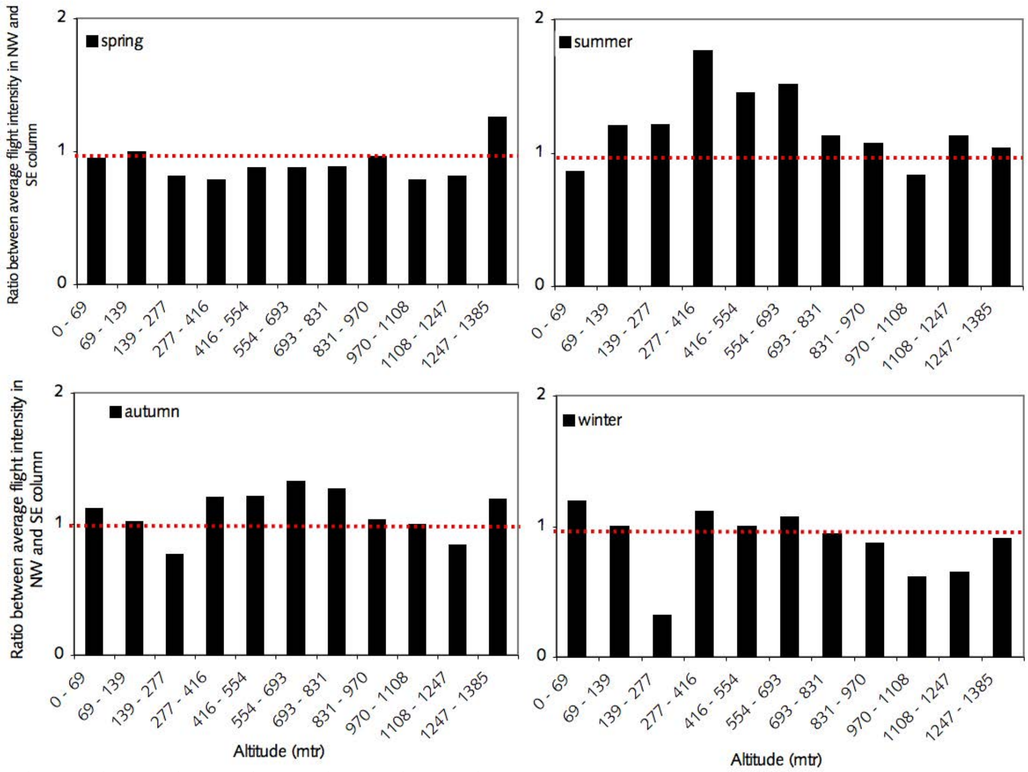


Figure 7.5 *Heading effects: ratio of mean traffic rate per month between the southeast and northwest side of the radar beam. Data from all altitudes, for day and night combined, as measured by vertical radar. The red-line indicates a ratio of 1 so similar numbers in the NW and the SE column.*

7.2 Merlin performance

What did Merlin record apart from birds?

Merlin showed clear tracks of birds under dry circumstances (fig. 7.6). There were several sources of clutter potentially affecting Merlin's success of tracking birds:

- **Rain** was commonly tracked by Merlin, which polluted the flight tracks database (fig. 7.7). All tracks that were rain needed to be removed from the database (§7.6).
- **Waves** were sometimes tracked by Merlin when wave height was above 1.5 m. Increasing wave height led to increased detection by radar and increased tracking of waves by Merlin. These tracks needed to be deleted from the database (§7.4). Analysis showed that above wave heights of 2.5 m, Merlin did not record significantly more tracks than below this wave height.
- **Wind turbines** were commonly tracked by Merlin as moving echoes on the screen. These were easy to define based on location and in this way easily deleted from the Merlin database (§7.4).
- Tracks of **insects** were sometimes tracked by Merlin, mostly in summer straight above the radar around dusk (§7.5). This is similar to peak insect-movements on land (Rydell *et al.* 1996; Feng *et al.* 2004). Insect tracks were largely filtered out of the database based on echo characteristics and methodological choices (§7.6 and §7.7).

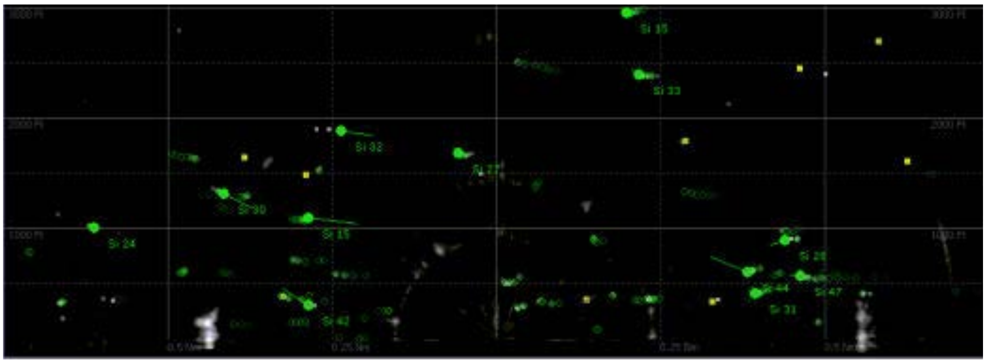


Figure 7.6 Merlin tracking birds during strong migration in October on vertical radar.

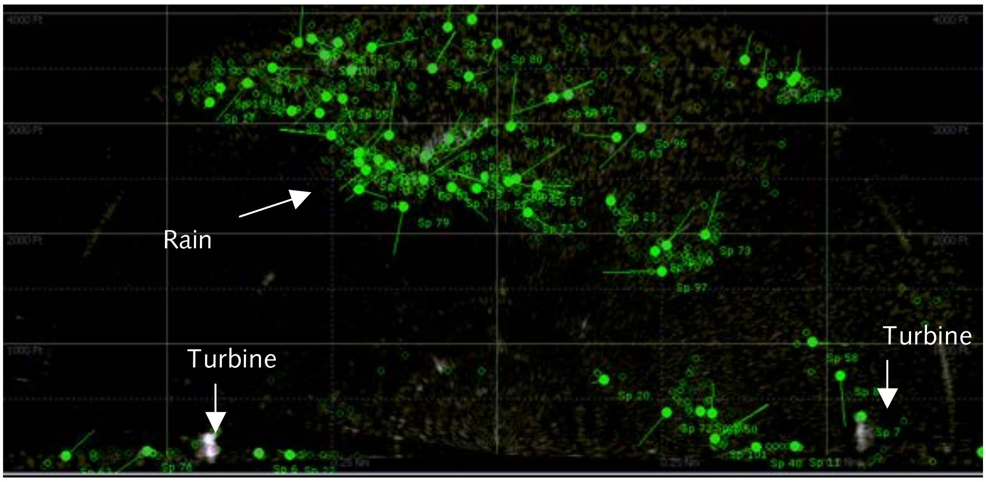


Figure 7.7 Radar images from the Merlin screen of the vertical radar, taken during a rain shower. Rain showers passing over the area were detected by the radar and tracked by Merlin. Two turbines are in the picture as well.

Comparison of tracks visible on the Merlin screen and on the Furuno screen

The most direct test of the performance of the Merlin bird detection system was a comparison of the numbers of tracks visible on the Furuno screen (raw radar) and the numbers of tracks tracked on the Merlin screen within the same time span. Therefore, simultaneous recording of flight movements observed on the Merlin screen (in the BuWa office) and on the Furuno screen (on the metmast), gives detection chances of Merlin compared to visual detection from 'raw' radar. Two observers were connected by telephone and recorded and discussed all bird tracks present on both screens. A total of 179 tracks were recorded, of which 79% was correctly detected by Merlin (table 7.1). The remaining 21% of incorrect detections were split in two conditions. Condition 1 was 'detection failure' and occurred in 9% of the error cases. This is the circumstance where a bird was seen on the Furuno screen but not recorded by Merlin. Condition 2 was 'observer failure' and occurred in 12% of the error cases. This is the circumstance where a track was recorded by Merlin but not seen on the Furuno screen. The latter error occurred either when a bird flew in an area with heavy clutter on the Furuno screen and was thus invisible to the eye, or when Merlin logged a non-bird in the database. If the latter was the case, this track should be filtered out during the database treatments described in the following paragraphs.

Table 7.1 Comparison of the number of tracks seen on the Furuno raw radar screen and recorded by Merlin. Given are the number of tracks recorded visually from the Furuno screen, and the number tracked by Merlin in the same time frame, based on simultaneous counts by observers.

	number	chance (%)
total number of sightings	179	
correct detections	141	78.8
Furuno positive and Merlin no sighting	16	8.9
Furuno no sighting and Merlin positive	22	12.3

7.3 Vertical radar data pre-processing

Data collection with the vertical radar was done from the 8th of June 2007 until the 30th of May 2010, almost exactly three years of non-stop data collection. The radar was running from February 2007 but the first months were dominated by a major breakdown and several adjustments in the settings to optimize data collection. Reliable data were collected from the 8th of June 2007 onwards. Merlin generated MS-Access database files with echo characteristics that needed to be processed before analysis could start. Data were moved from MS-Access to SPSS databases (SPSS 18.0). Additional variables were calculated to obtain more information about individual tracks. These were partly similar to those of horizontal data, but included some that were specific for vertical data:

- track length (similar to horizontal)
- track quality (similar to horizontal)
- variables reflecting variation in heading, such as: turnangle, angular deviation, distance ratio, point ratio
- screen speed of echoes and screen distance travelled of echoes

7.4 Vertical radar data processing

7.4.1 Filtering based on position

The Merlin software has been designed to only select and record tracks originating from birds, based on echo characteristics such as speed, size and intensity that are characteristic for birds (see §5.2). When objects other than birds produced an echo with characteristics similar to those of birds, these echoes could be erroneously stored in the database. For the vertical radar, these objects typically were interference from other radars or from the metmast, wind turbines, rain, insects and occasionally ships. Unlike the horizontal radar, a large proportion of clutter on the vertical radar consisted of interference, scattered over the screen. Also rain was tracked, unlike the horizontal radar. Waves, that formed the majority of clutter in the horizontal radar data, were hardly an issue in the vertical radar, as the sea surface was only detected as a straight line at the bottom of the radar screen, and could thus easily be filtered out.

The database was treated in several ways to reduce the amount of clutter present before the actual filtering was done (table 7.2). Obviously all tracks with a range (distance radar – target) beyond 0,75 NM (1389 m) were removed from the database as they are situated outside the limit to which detection range of the vertical radar was set. As some clutter was generated on the edge of the radar range, the limit of detection was set to 1370 m instead of 1389 m. The back lobe[2] of the radar beam, reflections from turbines T7 and T8 that were closest by, as well as interference from the metmast, produced large amounts of clutter up to 200 m from the radar (increased frequency of non-bird tracks). Consequently, all data within 200 m from the radar were removed from the data. This part of the radar screen was not taken into account in the flux analysis anyway (§7.7). Reflection of the turbines that were most prominent in the radar beam generated clutter in the south-eastern part of the screen at a range of 1090 up to 1110 m. All records in this band were deleted as well. Also some other clutter hotspots that were constantly present on the screen (fig. 7.3) were deleted from the database. This interfered not or negligibly in the flux analysis due to methodological procedures (§7.7). At last, all records at or below sea level reflected sea clutter and were removed from the data set (altitude < 0 m). The wind turbines generated quite a lot of tracks in the database due to movement of the rotor blades. Removing all tracks generated on positions where turbines were placed reduced the overall amount of data in the analysed databases by 16%.

[2] A radar bundle consists of one main lobe and several side lobes.

Table 7.2 Criteria and threshold values for discriminating echo characteristics to remove non-bird tracks from the Merlin database.

echo characteristic	criterium and threshold level
range	tracks at a range < 200 m or > 1370 m were removed
range	tracks between 1090 and 1110 in the south-eastern part of the screen were removed
tracklength	tracks with a tracklength < 3 hits were removed
turbine position	tracks on turbine positions
altitude	tracks where mean flight alt. was < -1,5 m (below sealevel) were removed

Compared to the baseline study (Krijgsveld *et al.* 2005), the amount of clutter recorded on the vertical radar was substantially smaller, due to new filter techniques and updated versions of Merlin. However, clutter was still recorded. It was important to be able to distinguish these clutter-echoes from those of actual birds, to clean up the database and quantify fluxes and flight altitudes in the wind farm area as precisely as possible. So, additional filter steps needed to be explored.

7.4.2 Filtering based on flagging

To establish the characteristics of various bird and non-bird radar echoes and differentiate between them, a 'flagfile' of objects detected with vertical radar was built, similar to the horizontal radar (see §6.4.1). For an explanation of the flagging procedure see § 6.4. On the vertical Merlin screen, tracks differed clearly between bird and non-bird objects (fig. 7.8). Interference was visible as spikes on the Furuno screen, and generated 'tracks' on the Merlin screen in random directions, without an apparent echo trail. Wind turbines were detected by the radar, and 'tracks' generated by the rotor were recorded as such at the location of the turbine. Birds created consistent, regular tracks. A flag was only assigned to a record when a positive identification could be made. Echoes were flagged on the vertical radar during the entire study period, resulting in a total of 1922 flags, on 88 different days (table 7.3).

Table 7.3 Number of flagged echoes for vertical Merlin data with percentage of original.

group	nr of flagged tracks
bird	880
clutter	827
turbine	79
insect	41
ship	7
rain	88
total	1922

Figure 7.8 Flagging procedure for vertical radar. Echoes that are recorded by Merlin are visible as green closed circles on the Merlin display screen. Each recorded signal remains visible as a green open circle for some time after it has been recorded, leaving a so-called echo-trail. These green circles can be selected with the cursor, and flagged digitally as belonging to e.g., a bird, ship, rain, sea clutter or otherwise. Here, thrushes migrating SW in autumn are flagged as 'birds'. Two turbines are visible as white objects at the bottom of the screen. See fig. 6.10 for a simultaneous view of the horizontal radar.

7.4.3 Clutter analysis

The data set (flagfile) consisted of bird and non-bird tracks and to be able to distinguish between these different groups, the characteristics of echoes recorded by Merlin needed to vary between the groups (most importantly birds versus non-birds). Preferably, the groups did not overlap at all, since this would make it easy to classify the echoes. However, in practice characteristics did overlap, making it more difficult to assess whether a certain value of a characteristic represented a bird or clutter. Differences between the various groups were visualized in boxplots of the echo characteristics (example in fig. 7.9), to give an indication of the variability within and between the different groups. Reading a boundary value from the graph between two groups gave an indication what criteria could be set for the different echo characteristics.

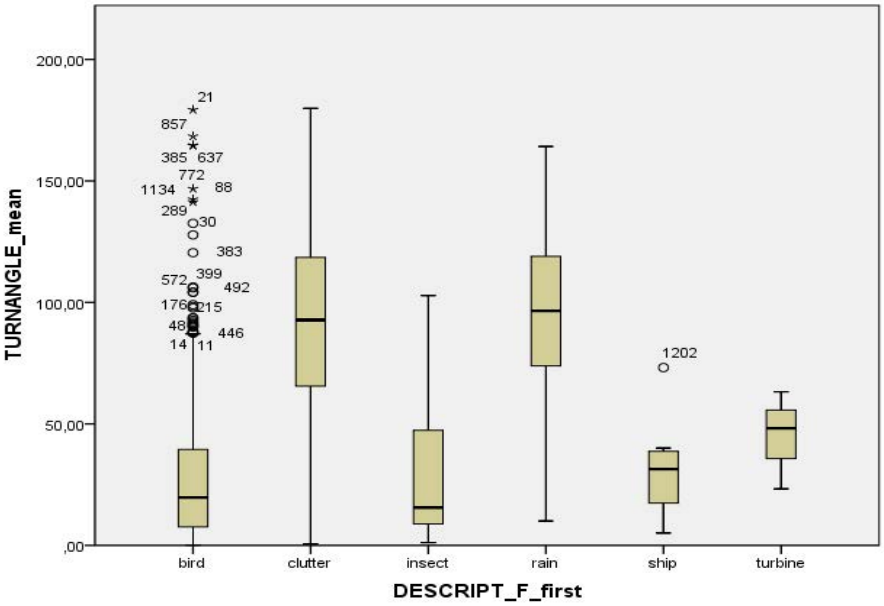


Figure 7.9 Example of boxplot (mean turnangle) of flagged echo characteristics of vertical Merlin data, used to assign boundary values for the distinction between different groups of objects. Interpretation of boxplot: horizontal line indicates median; box indicates lower to upper 25% around median, or 50% of data; whiskers represent highest and lowest values that are not outliers or extremes; remaining data are outliers (1.5-3 times interquartile range) and extremes (>3 times interquartile range).

There were several echo characteristics of flagged echoes that differed markedly between birds and the various types of clutter. However, none of the characteristics showed a clean difference without overlap, nor did any combination of echo characteristics. Based on the observed differences, 'threshold values' of various characteristics were determined with a Classification And Regression Tree analysis (CART), performed in R with the package RPart.

7.4.4 Classification and regression tree analysis

Similar to the clutter filtering procedure described for the horizontal radar (§6.4.3), a CART analysis was done to separate birds and clutter in the database. Generally bird tracks consisted of four echoes or more based on flight speed (max. of 100 km/hr for ducks with tailwind), radar rotation time (2.5 sec), range (1389 m) and radar beam width (min. of 290 m) conform Krijgsveld *et al.* 2005 and this study §5.5.2).

A first step to filter out clutter was therefore to remove all tracks with a track length shorter than three echoes. The CART analysis then was performed on the remaining data set. Biologically and mathematically meaningful echo characteristics that were likely to differ between bird and clutter data (given the 'behaviour' of bird- and clutter tracks) were chosen as input for the regression tree analysis. These included measures quantifying variation of the heading (clutter has more irregular direction than birds), speed (clutter differs more in speed between echoes than birds), flight altitude (birds have a more or less constant flight altitude), and track length. The CART analysis provided a set of filtering rules to remove clutter from the database. In contrast to attempts in earlier interim-reports (Krijgsveld *et al.* 2009), CART analysis provided filtering thresholds that withstood the tests of validation (see §7.5). The CP-tree used to determine the cut-off level is shown in figure 7.10. Different from the horizontal data, the resulting classification tree used a large number of characteristics to effectively separate bird tracks from clutter tracks (fig. 7.11). A slightly higher CP value was chosen as the cut-off point (0.011 with 11 branches) in favour of the lowest CP value (0.006 with 16 branches). The additional branches chosen with the 0.006 tree were with biologically less relevant parameters and this more complicated model did not add substantially to a further classification of birds and clutter.

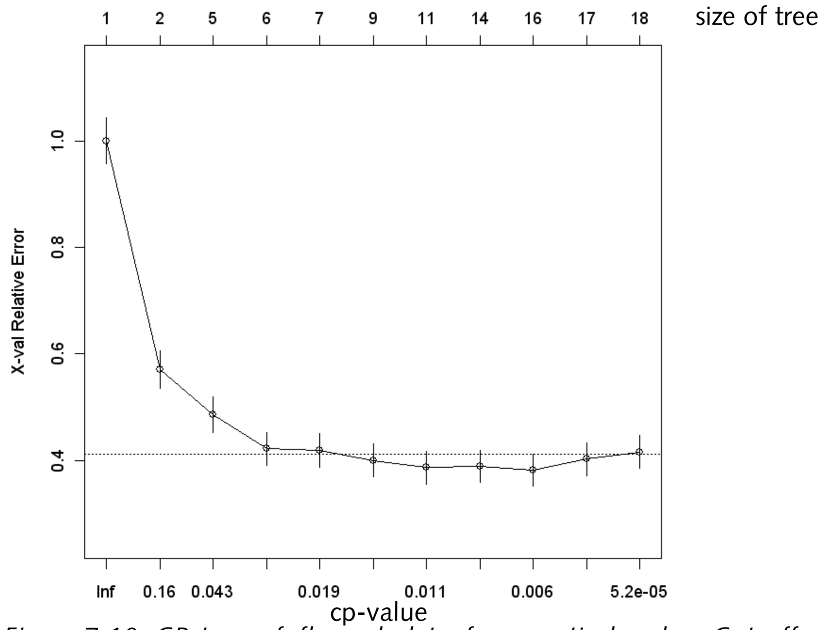


Figure 7.10 CP-tree of flagged data from vertical radar. Cut-off point selected at 0.011, at a tree size of 11 branches.

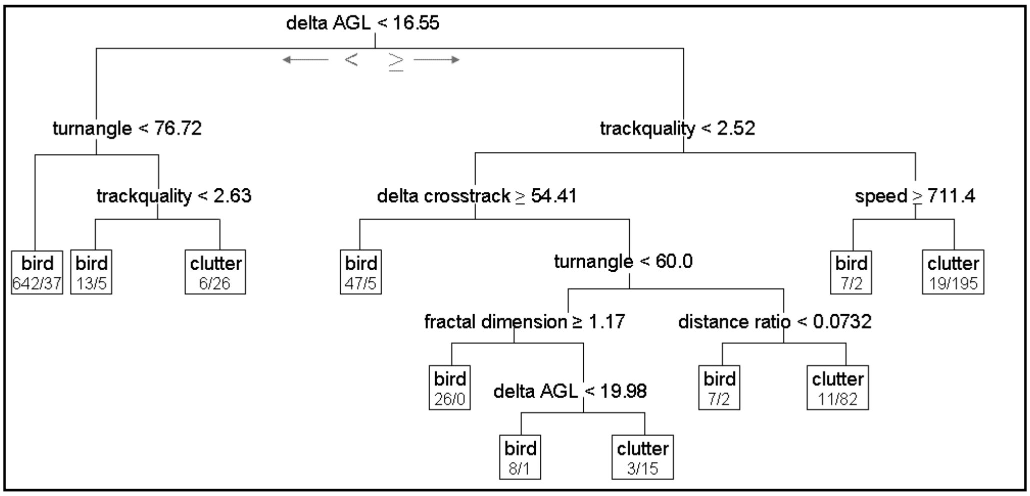


Figure 7.11 Regression tree based on flagged bird and clutter data from vertical radar, used to define threshold values between clutter and bird data.

7.4.5 Filtering rules

Filtering clutter from the vertical Merlin database was done based on the following characteristics for which CART analysis provided threshold values in different filtering paths:

- DELTA AGL - mean altitude change of individual hits per track
- TURNANGLE - mean change in heading between individual hits per track
- TRACKQUALITY - a measure for the quality of the track (sum track type / track length)
- DELTA CROSSTRACK - mean change in horizontal distance to the radar per track
- SPEED – mean speed of echoes
- FRACTAL DIMENSION – measure for linearity of track, based on tracklength and distance ratio
- DISTANCE RATIO – ratio between the straight distance (first hit to last hit in one track) and total distance (sum of distance from individual hit to the next in one track)

The thresholds of these characteristics were set to such a level that the minimal number of bird records would be removed. This is important as the vertical radar is used to determine fluxes (numbers of bird groups/km/hr). Losing birds would imply smaller and thus incorrect fluxes. Some clutter still remained in the data after filtering, but in a much smaller number than before (§7.5).

7.5 Evaluation of filtering rules

Results of flagging

Originally 1922 tracks were manually flagged. Application of the filter described above yielded 842 individual bird tracks in the database. The distribution of the assigned flags to these tracks was 748 birds, 40 clutter, 27 insects, 19 rain, 7 ships and 1 turbine (table 7.4).

Table 7.4 Number of flagged echoes for vertical Merlin data that were removed using filtering rules with percentage of original.

group	nr of flagged tracks	deleting turbine positions & tracklength < 3		applying filter criteria	
bird	880	789	(90%)	748	(85%)
clutter	827	370	(45%)	40	(6%)
turbine	79	4	(5%)	1	(1%)
insect	41	35	(85%)	27	(66%)
ship	7	7	(100%)	7	(100%)
rain	88	66	(75%)	19	(22%)
total	1922	1271	(66 %)	842	(44 %)

Insect migration is often tracked on vertical x-band radars (Chapman *et al.* 2003; Reynolds *et al.* 2009) and insects can potentially be a problem in estimating bird fluxes. In this study, insects were only located straight above the radar (example in fig. 7.12) and not in the area that was analysed (Two columns, see §7.7). It was possible that insects were left in the database after filtering because filter criteria were not sufficient for removal. In that case they were not seen within the two columns and therefore not taken into account for flux calculations.

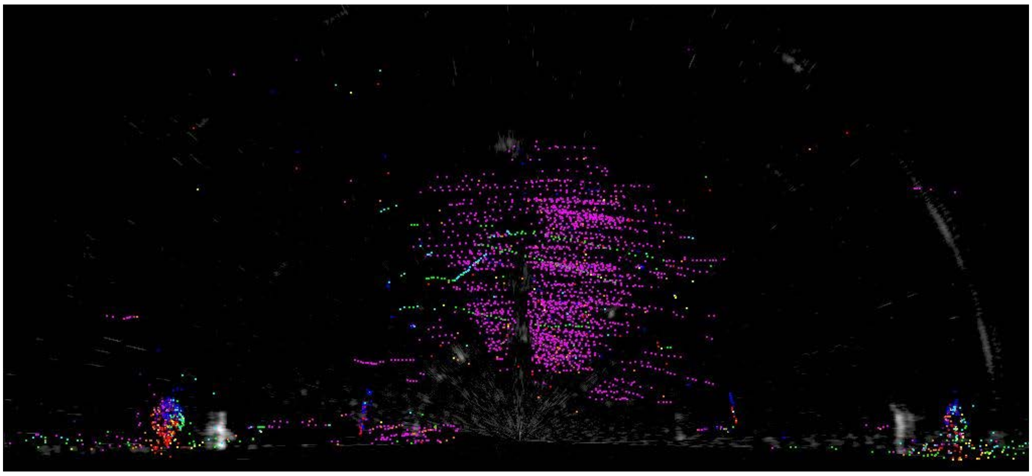


Figure 7.12 Trackplot picture of Merlin screen of one hour on the 6th of June 2009. Clearly visible are insect movements (purple movements straight above the radar), some birds (e.g. purple line above left radar) and echoes of turbines.

Rain was completely deleted from the database (§7.6). All tracks during hours in which rain occurred (measured on the metmast) were deleted (about 9% of all hours). During these hours no birds could be tracked as the screen was completely covered in clutter (example in fig. 7.13). A correction for this was made during analysis (§10.2) because otherwise fluxes were underestimated due to periods with rain (§7.7).

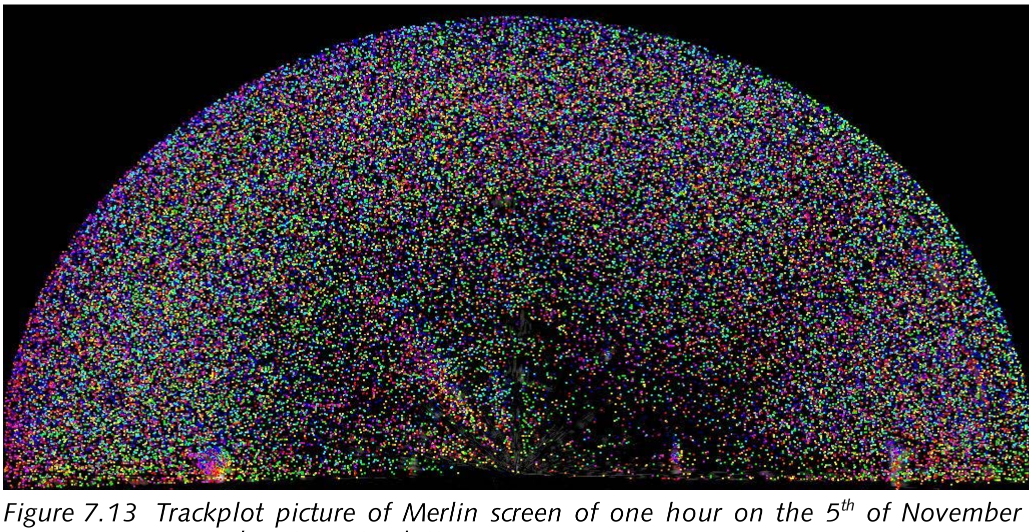


Figure 7.13 Trackplot picture of Merlin screen of one hour on the 5th of November 2009 showing rain clutter.

The number of ships in the vertical Merlin data was extremely low, so leaving these tracks in the database was not considered a problem for analysis. Turbines were mostly deleted in the turbine filters and any turbine tracks left were well outside of the area that was analysed (§7.7).
In other words, table 7.4 can be interpreted as:

- 85% of flagged records manually identified as bird, fell within bird-criteria (*Correct*)
- 15% of flagged records manually identified as bird, fell outside bird-criteria (*Wrong**)
- 94% of flagged records manually identified as non-bird, fell outside bird-criteria (*Correct*)
- 6% of flagged records manually identified as non-bird, fell within bird-criteria (*Wrong***)

* records were erroneously classified as clutter and removed from the data set.
** records were erroneously classified as bird and stayed in the data set.

A negligible percentage of bird tracks were removed upon applying the turbine filter (removal of tracks at turbine positions). Most birds deleted from the flagfile disappeared in the step of deleting all tracks with track length < 3 hits. In this step almost 10 % of the tracks flagged as 'bird' disappeared from the database. These flags were suspicious as these kind of very short tracks are not likely to be of avian origin. Generally bird tracks consisted of 4 echoes or more (based on flight speed and radar beam width), and it was therefore questionable whether such short tracks were indeed from birds. The reason for the high proportion of very short tracks in the flagfile was unknown but deleting these tracks did not induce a major error in the determined fluxes. The application of the clutter filter caused the disappearance of 5% of the tracks flagged as birds. It is very likely that a comparative fraction of bird tracks is deleted from the Merlin database as the flagfile was a representation of the actual database. This removal needs to be taken into account when assessing the results in this report, as it leads to an underestimation of fluxes. This is discussed in further detail in §7.7.

The group identified as non-bird but within bird criteria (6% of clutter), incorrectly remained in the flagfile. This was an important feature as these data polluted the database with tracks that were not from birds but could not be filtered out with the applied criteria. However, the majority of these tracks originated from interference around either the metmast or the wind turbines, and as such were filtered out of the database based on position: turbines, and close proximity to radar. Much of the remaining clutter fell outside the analysed area (§7.7). Therefore the actual percentage of clutter erroneously remaining in the database was well below 6%.

Comparison of tracks recorded by Merlin and visually seen on the Furuno screen
Analysis of the flagfile resulted in a clutter filter that was applied to all generated Merlin data from the field seasons 2007-2010. The question was if this clutter filter based on the flagfile 'worked' for the actual Merlin data as well. The most direct test to evaluate the applied clutter filter was a comparison of the numbers of tracks visually observed on

the screen (raw radar) and the numbers of tracks recorded in the Merlin database within the same time span.

Bird tracks visible on the vertical Furuno screen were recorded during fieldwork sessions on the metmast. Data were recorded in 5-minute time intervals, and were classified in 10 altitude bands of approximately 140 m each (=0,75NM/10). Furthermore, tracks were recorded in either of five rectangular vertical columns (2 of which roughly correspond to the columns analysed in the Merlin data, §7.7), and flight direction was recorded as well (to the left, to the right, or perpendicular). This provided a measure of the accuracy with which Merlin recorded bird tracks, because it allowed comparison of flux as recorded by Merlin (and presented in this report), and flux as observed visually on the raw radar screen.

Similarly, bird tracks visible on the vertical Merlin screen were recorded regularly in the same way. This could be done at any time, by remotely logging in on the Merlin computer. This data set allowed an additional analysis of the effectiveness of the clutter filter, as visual monitoring resulted in a database of actual bird tracks with clutter excluded.

In general about twice as many tracks were present in the Merlin database compared to visual counts of tracks seen on the radar, although large variation existed (table 7.5). Especially during busy migratory periods, Merlin saw more tracks than visual observers did. This is mostly due to the limitations of the human eye and the sensitivity of the radar and Merlin settings. Apart from actual birds being missed by the human eye, a part of the higher numbers of tracks in the Merlin database was probably clutter that could not be removed from the database. This 'background-noise' was present in all seasons and years and was visible throughout the results. The extent of this noise is difficult to measure but will be higher during less favourable weather conditions. These conditions were not regularly encountered and also overall the extent of the noise was small and did not affect overall flight patterns (see table 7.6 in §7.7).

Table 7.5 Merlin/Furuno visual counting and Merlin tracking database in different intervals of the study period.

date	start	end	# min	Furuno count	Merlin dbase	% stored
interval 1						
02-08-2007	06:45	07:15	30	40	34	85
02-08-2007	13:45	14:50	70	104	70	67
20-08-2007	16:37	16:57	20	26	64	246
06-09-2007	08:20	08:45	25	22	62	282
02-10-2007	23:09	23:29	20	56	406	725
03-10-2007	03:02	03:27	25	162	381	235
03-10-2007	10:17	10:42	25	108	244	226
25-10-2007	14:23	15:03	40	164	66	40
27-03-2008	19:51	21:56	125	58	32	55
28-03-2008	01:00	01:15	15	285	1396	490
28-03-2008	03:15	03:40	25	131	664	507
04-04-2008	12:40	13:25	45	90	21	23
24-04-2008	02:03	2:18	15	200	315	158
19-09-2008	21:35	21:57	22	68	172	253
01-04-2009	8:00	08:30	30	43	50	116
sum & average			532			234
interval 2						
12-09-2007	23:03	23:33	30	59	60	102
13-09-2007	03:50	04:40	50	96	69	72
27-09-2007	17:27	18:12	45	131	165	126
30-09-2007	20:40	20:55	15	180	268	149
18-02-2008	17:28	17:43	15	0	6	-
25-02-2008	20:02	20:32	30	41	59	144
14-03-2008	18:25	18:50	25	14	52	371
08-04-2008	17:40	17:55	15	47	96	204
08-04-2008	21:45	22:00	15	74	32	43
22-04-2008	20:23	20:33	10	39	98	251
sum & average			250			163

7.6 Vertical radar data post-processing

Merlin vertical radar data were reduced to one record for each individual track after filtering in SPSS V18.0. Weather details on wind, temperature and precipitation were assigned to each track to be able to filter out hours in which precipitation was present. Furthermore it provided the opportunity to analyse flux and altitude data in relation to meteorological conditions.

In a similar way as filtering out all hours with precipitation, filtering out all days with an average wave height above a certain threshold could in principle have been a solution to delete wave clutter from the database. However, this filtering step was not implemented, because the disadvantages of this step were larger than the advantages. Firstly, only 1.8% of the days had an average wave height above 2.5 m, so the effect of removing data on the resulting fluxes and flight altitudes would be negligible. In addition, although the numbers of birds flying at an altitude of less than 25 m seemed to increase from an average wave height of 2.5 m and more (fig. 7.14a), this was not significant and was seen in the numbers of birds flying at higher altitudes as well (fig 7.14b). Furthermore, all this activity is far below the rotor-swept zone, and leads to an underestimate of fluxes of low-flying seabirds only.

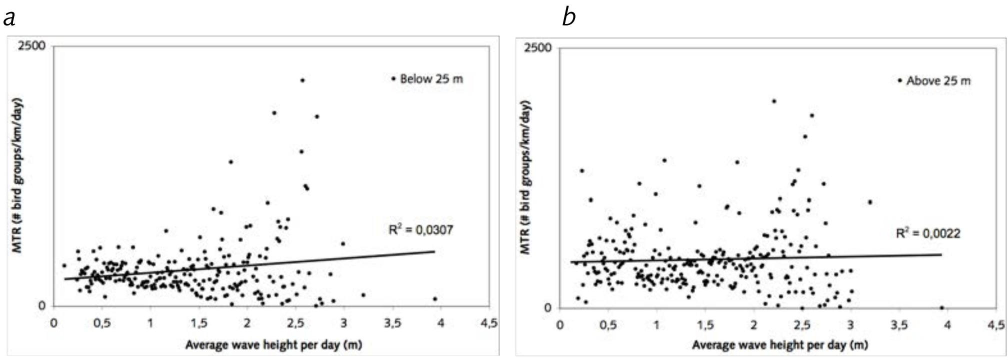


Figure 7.14 Number of tracks in the Merlin database in relation to wave height in the altitude band from 0–25 m (a) and above 25 m (b).

7.7 Vertical radar data analysis

The data collected with the vertical radar were intended to give information on fluxes and flight altitudes of local and migratory (sea)birds within the OWEZ wind farm. Fluxes in this report are given as the number of tracks (bird groups) per kilometre per hour. This figure is also known as Mean Traffic Rate (MTR), which is commonly used in the literature to quantify flight intensity (Bruderer & Steidinger 1972; Krijgsveld *et al.* 2005; Schmaljohann *et al.* 2008). In order to be able to calculate this flux a standardized method was used by selecting two rectangular areas with a length of 500 m halfway the radar-range. In these columns the number of bird tracks was determined per hour for flux measurements. This area is called the 'Two Column Analysis Area' in this report (grey in fig. 7.15). These two columns were equally divided into 10 altitude bands with the same height (139 m). The lowest altitude band was then split into half (0 – 69 m and 70 – 139 m) to allow more small-scale analysis at the lowest altitude.

Restricting the analysis to two columns has several advantages. For instance, effects of beam-shape close to the radar were minimized as the columns were sampled in the area where beam width is more or less constant (§5.3.2). As a result, fluxes were good representations of the actual MTRs in the area. However, some disadvantages occurred, which may potentially have consequences for the calculated MTRs:

- In most studies MTR is the number of birds per hour that crosses an imaginary line of 1 km on the ground. Due to beam shape of the radar the columns are 3D columns instead of 2D planes. This means that birds could be recorded in the column but did not physically cross the 1-km line. Comparing radar studies with visual migration counts should therefore be done with some care. This is not so much a consequence of selecting only two columns for analysis, but of using radar to quantify fluxes. The impact of this issue is limited however, because the radar was placed perpendicularly to the main migratory directions.

- Two columns on either side means that potentially birds could fly through both columns when flying parallel to the radar beam and get recorded twice. From visual observations of the radar screen we know that chances of this phenomenon were small and were of minor effect.
- At altitude bands 9 and 10 (see fig. 7.15) parts of the column were outside the range of the radar. Only a minor part of altitude band 9 was not analysed and half of band 10. The numbers of birds in the sampled volume at altitude 10 were corrected during the analysis. The consequences for the calculated MTRs are discussed below.

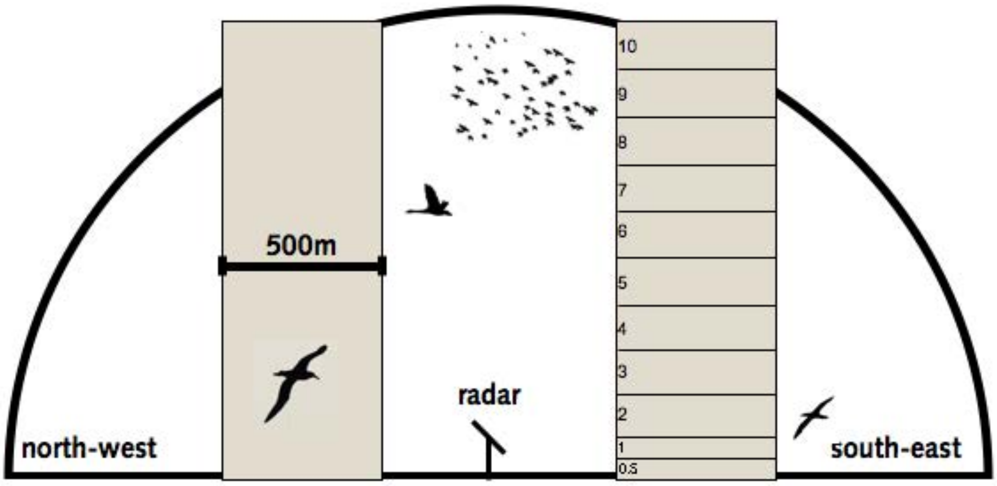


Figure 7.15 Schematic view of the two columns (grey area) in which all tracks were selected for analysis of flux and flight altitude. Columns are each 500m wide and divided in eleven altitude bands.

Consequences for MTRs

This chapter deals with all kinds of aspects of radar and Merlin performance and detection limitations. All these aspects potentially influence the MTRs that were calculated for flux and flight altitude in this report. Two situations can be applicable to the results found in this study. Our MTRs could potentially be either overestimated or underestimated, as discussed below (summarized in table 7.6). These considerations point out a level of uncertainty around the MTRs that were found. Despite this, the reported MTRs give the best possible measurement of bird fluxes in the area, and are considered accurate reflections of actual fluxes in the wind farm area.

1. **Overestimated.** Some of the factors described in this chapter (e.g. incomplete filtering of clutter, two-column analysis) will cause the found MTRs to be overestimates. For example, all tracks are not passage over a imaginary line of 1 km but through a volume of 1000x±500 m due to radar beam width and shape. In this way our radar MTRs are expected to be higher than conventionally (visually) measured MTRs. In case of wind farm effect studies, this problem is minimal as the calculated MTRs will

always be on the 'safe' side (safe meaning more recorded tracks than actual birds). Also some of the clutter detected by Merlin was not filtered out completely and stayed in the database and was thus treated as bird tracks in analysis. In §7.5 was shown that a factor 2 could be applied to the visually observed numbers but it was unknown to what extent seasonal variation occurred and which numbers are the best estimates.

2. **Underestimated.** The radar and tracking software had limitations regarding detection (§7.1) and accuracy (§7.2), which will have caused total fluxes to be underestimated. Also the radar did not always allow us to differentiate between individual birds and bird groups, which may have caused small bird groups to be tracked as one individual, or large bird groups (e.g., > 100 individuals) to be tracked as a much smaller number. Especially during the day migrating passerines (such as starlings) are known to fly in groups compared to more individual flight behaviour at night (Zuur 1984; Berthold 1992; Lensink *et al.* 2002), which would result in only one or two recorded echoes by Merlin (e.g., 02 Nov 2007, 4-6 tracked echoes for a group of 600 and 800 starlings). Influence on MTRs is expected to be low, because these large groups mainly occurred during the day and, based on the panorama scans, only in small numbers.

Table 7.6 Summarized effects of validation and calibration on MTRs found in this study.

source	influence on flux in database	level of influence
waves	increase of # tracks	very small (<5%)
turbines	increase of # tracks	none
rain	increase of # tracks	none
insects	increase of # tracks	none to very small
interference (and thus filter *)	increase of # tracks	small (<10%)
altitudinal effects on detection	decrease of # tracks	small
heading effects on detection	decrease of # tracks	small (±10%)
performance of radar	decrease of # tracks	small (9%)
performance of Merlin	decrease of # tracks	small (<10%)
performance of filter *	decrease of # tracks	small (only on busy nights)

8 Results: Species present in the wind farm area

In this chapter data are presented on the species composition and abundance within and around the OWEZ wind farm. First, an overview is given of all species, birds and marine mammals) observed during fieldwork (§8.2). Next, seasonal variation is discussed (§8.3) as well as the effect of weather on species composition (§8.4). Then, variation between day and night in species abundance is discussed (§8.5 and §8.6). Distribution of individual species in relation to the wind farm is discussed in chapter 9.

8.1 Summary of results

- A total of 103 different bird species were recorded in the OWEZ wind farm area. Inter- and intra-annual variation in abundance and species composition occurred throughout the study period. This variation was induced by a variety of factors, such as season, weather, time of day and also the presence of turbines.
- Overall abundance of birds in the area during daytime was low. Numbers were lowest in summer and winter.
- Most common species group was gulls, the majority of which were lesser black-backed gulls and herring gulls in summer and common gulls and kittiwakes in winter. Also cormorants formed a common species in the area and were regularly seen at the metmast and in the wind farm. Of the seabirds, 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, landbirds were commonly seen, of which the most commonly seen species during daytime were starlings and blackbirds.
- Nocturnal species could be identified to a limited degree. Species identified were mostly thrushes (blackbird, redwing, song thrush), but also some waders and gulls.

8.2 Species observed and abundance

8.2.1 Species observed

A total of 103 different bird species were seen during visual observations at the metmast (table 8.1). Of these species, 64 were seen during panorama scans. The abundance and distribution of only these species is included in the analysis, because only the panorama scans are designed to allow such an analysis. The remaining 40 species were seen during other types of observations (specified in table 8.1). The majority of these were seen during observations on flight paths, because these took up most of the observation time, besides panorama scans. Species that were seen outside of panorama scan sessions were generally also seen during panorama scans, and thus were included in analysis. This was less likely to be the case for very rare species that passed the area incidentally, such as an occasional Bohemian waxwing. Compared to other types of observations at the metmast, the number of small passerines and of wader species was relatively low during panorama scans and thus will be underestimated in the analysis. In addition to birds, the marine mammals harbour porpoise, harbour seal and grey seal were encountered.

Table 8.1 Overview of all species encountered at the metmast in the reported period. The columns indicate during which type of observation the birds were seen. Numbers are given in table 8.2.

			observation method				
group	subgroup	species	panorama scans	flight paths	incidental	close-to--turbine	in-out
divers		black-throated diver	+	+			
		red-throated diver	+	+	+		
		diver spec.	+		+		
grebes		great crested grebe	+	+			
tubenoses		northern fulmar	+	+			
		tubenose spec.				+	
gannets		northern gannet	+	+	+	+	+
cormorants		European shag	+	+	+		
		great cormorant	+	+	+	+	+
geese & swans	anser geese	greylag goose	+	+		+	
		white-fronted goose		+			
	branta geese	dark-bellied brent goose	+	+			+
		barnacle goose		+			
		greater Canada goose		+			
	bean goose	bean goose		+			
	unidentified geese	goose spec.	+	+			
	unidentified swan	swan spec.		+			
sea ducks		common scoter	+	+	+	+	+
		velvet scoter	+				
		eider	+	+			
other ducks	diving ducks	scaup	+	+			
	mergansers	goosander	+	+			
		red-breasted merganser	+	+			
	swimming ducks	eurasian wigeon	+	+			+
		northern pintail	+	+	+		
		teal	+	+			
		mallard			+		
		northern shoveler		+			
	unidentified ducks	duck spec.	+	+			
raptors & owls	raptors	goshawk	+				
		sparrowhawk		+			
		kestrel	+	+			
		marsh harrier	+	+			
		hen harrier		+			
		merlin	+	+			
		peregrine falcon	+	+	+		
waders		Calidris spec.	+	+			+
		red knot		+			
		dunlin	+				
		little stint		+			
		purple sandpiper			+		
		sanderling		+	+		
		Eurasian curlew	+	+	+		
		Eurasian golden plover	+	+			
		grey plover	+	+			
		lapwing	+	+			
		common ringed plover		+			
		dotterel		+			
		oystercatcher	+				
		black-tailed godwit	+				
		bar-tailed godwit		+	+		
		whimbrel	+	+		+	
		ruddy turnstone				+	
		spotted redshank				+	
		greenshank			+		
		woodcock		+	+		
		jack snipe		+	+		
		wader spec.	+	+			
skuas		arctic skua	+	+			+
		pomarine skua				+	
		great skua		+			+

(Continued on next page.)

Table 8.1 Continued.

group	subgroup	species	observation method				
			panorama scans	flight paths	incidental	close-to- -turbine	in-out
gulls	large gulls	lesser black-backed gull	+	+	+	+	+
		great black-backed gull	+	+		+	+
		black-backed gull spec.	+	+			+
		herring gull	+	+		+	+
		common/herring gull	+				
		Mediterr. yellow-legged gull				+	+
		large gull spec.	+	+	+	+	+
	small gulls	little gull	+	+	+	+	
		black-headed gull	+	+	+	+	+
		common gull	+	+	+	+	+
		kittiwake	+	+	+	+	+
		Sabine's gull	+				
		small gull spec.	+				+
	unidentified gulls	gull spec.	+				+
terns		arctic tern	+				
		common tern	+	+		+	
		common/arctic tern	+	+			
		sandwich tern	+	+	+	+	+
		black tern	+	+			
		tern spec.	+				+
alcids		guillemot	+	+	+	+	
		razorbill	+	+	+		+
		razorbill/guillemot	+	+	+		
landbirds	medium-sized pass	blackbird	+	+	+	+	
		redwing	+	+	+		+
		fieldfare		+	+		
		song thrush	+	+	+		
		waxwing		+			
		starling	+	+	+	+	
		thrush spec.	+	+	+		
	small passerines	redpoll	+				
		chaffinch	+		+		
		house martin	+	+			
		swallow	+	+			
		swift	+				+
		pied wagtail	+	+	+		
		yellow wagtail	+	+			
		grey wagtail					+
		meadow pipit	+	+	+		
		pipit spec.	+				
		skylark	+	+	+	+	+
		robin		+	+		
		songbird spec.	+	+	+		
		black redstart			+		
		chiffchaff			+		+
		willow warbler/chiffchaff			+		
		blackcap			+		
		gold crest			+		
		siskin			+		
		northern wheatear		+	+		
		stonechat			+		
	other large birds	carrion crow	+				
		grey heron	+	+			+
		homing pigeon	+		+		
		collared dove			+		
		jackdaw	+		+		+
		pigeon spec.	+				
		wood pigeon	+				
		Eurasian coot		+			
		Eurasian spoonbill		+			
sea mammals	sea mammals	grey seal	+	+	+		
		harbour seal	+	+	+		
		harbour porpoise	+	+			+
number of bird species			64	73	44	22	23
total							103

8.2.2 Overall and relative abundance of species

Overall abundance

The abundance of each species encountered during panorama scans is given in table 8.2. For only a few species the maximum average densities were higher than 0.1 birds / km^2. This was the case for great cormorant, herring gull, lesser black-backed gull and starling. During the peak seasons of those species at least 3 birds were encountered within 3 km distance from the metmast during one panorama scan. For most species the maximum average densities were lower than 0.01 birds per km^2. This means that within 3 km distance from the metmast, for those rare species only one bird was encountered during 4 panorama scans.

Relative abundance

The relative proportion of all birds seen during panorama scans is depicted in figure 8.1, which shows that the majority of birds were gulls and cormorants, and landbirds (mainly starlings and blackbirds) as well. The proportion was largely comparable in all seasons, except for the proportion of landbirds, which was 45% of all birds in autumn, 10% in spring, and less than 0.5% in summer and winter.

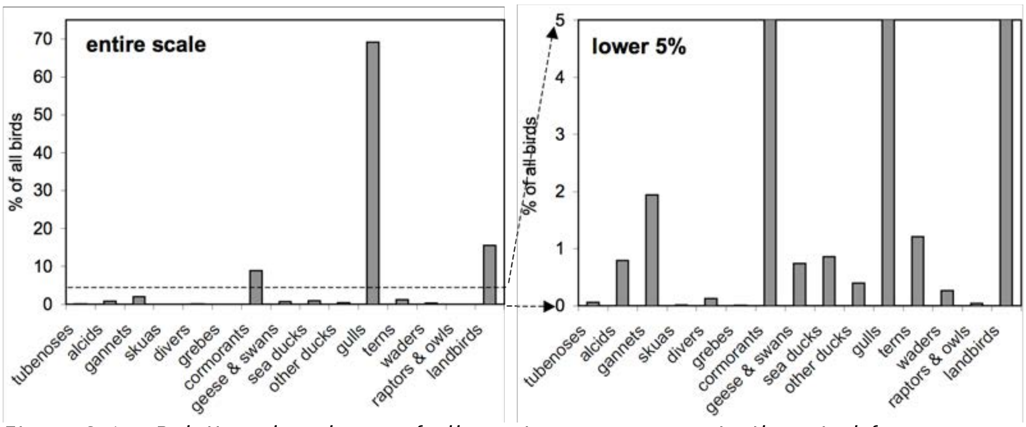


Figure 8.1 Relative abundance of all species groups seen in the wind farm area, as observed with panorama scans. Gulls and cormorants dominated the species spectrum, as well as passerine flocks during spring and especially autumn (left). On a smaller scale (right, max on y-axis = 5%) the uncommon versus the scarce birds can be distinguished.

Geese such as brent and barnacle geese (photo M.Bonte) passed OWEZ during migration.

Table 8.2 Density of flying birds observed in panorama scans. Shown are averages per season (birds/km²/scan). Maximum densities for a species are bold and underlined. Only birds within 3 km from the metmast taken into account. No value indicates species not seen that season. Colour indicates max. density: dark blue > 0,1; mid blue 0,01-0,1, light blue 0,005-0,01. N indicates the number of panorama scans carried out.

			mean density (birds/km²/scan)				
group	subgroup	species	spring (n=140)	summer (n=71)	autumn (n=121)	winter (n=73)	total (n=405)
divers		black-throated diver				<0,005	<0,005
		red-throated diver	<0,005			**0,01**	<0,005
		diver spec.	<0,005			<0,005	<0,005
grebes		great crested grebe			<0,005		<0,005
tubenoses		northern fulmar	<0,005		<0,005	<0,005	<0,005
gannets		northern gannet	**0,03**	<0,005	0,05	0,02	0,03
cormorants		European shag				<0,005	<0,005
		great cormorant	0,06	**0,18**	0,08	0,07	0,09
geese & swans	anser geese	greylag goose				<0,005	<0,005
	branta geese	dark-bellied brent goose	0,01		0,01	**0,04**	0,01
	unidentified geese	goose spec.				<0,005	<0,005
sea ducks		common scoter	0,03	<0,005	<0,005	<0,005	0,01
		eider			<0,005	<0,005	<0,005
		velvet scoter	<0,005				<0,005
other ducks	diving ducks	scaup	<0,005			<0,005	<0,005
	mergansers	goosander				<0,005	<0,005
		red-breasted merganser	<0,005		<0,005		<0,005
	swimming ducks	Eurasian wigeon			<0,005	<0,005	<0,005
		northern pintail			0,01		<0,005
		teal	<0,005				<0,005
	unidentified ducks	duck spec.		<0,005	<0,005		<0,005
waders		Eurasian curlew		<0,005			<0,005
		grey plover	<0,005				<0,005
		calidris spec.	<0,005				<0,005
		dunlin	0,01				<0,005
		Eurasian golden plover	<0,005				<0,005
		lapwing	<0,005				<0,005
		oystercatcher		<0,005			<0,005
		wader spec.	<0,005				<0,005
skuas		arctic skua	<0,005				<0,005
gulls	large gulls	black-backed gull spec.	**0,02**	0,01	0,01	0,01	0,01
		lesser black-backed gull	**0,23**	0,20	0,06	<0,005	0,13
		great black-backed gull	0,03	<0,005	0,05	**0,11**	0,05
		herring gull	**0,19**	0,06	0,02	0,10	0,10
		common/herring gull			<0,005		<0,005
		large gull spec.	**0,21**	0,13	0,09	0,10	0,14
	small gulls	black-headed gull	0,05	**0,05**	0,01	0,03	0,03
		common gull	0,06	<0,005	0,03	**0,31**	0,09
		kittiwake	<0,005		**0,14**	0,23	0,08
		Sabine's gull			<0,005		<0,005
		little gull	**0,12**			0,01	0,04
		small gull spec.	0,02		0,01	**0,06**	0,02
	unidentified gulls	gull spec.	0,01		**0,02**	0,01	0,01
terns		arctic tern	<0,005				<0,005
		common tern	<0,005	<0,005			<0,005
		common/arctic tern	<0,005	<0,005	<0,005		<0,005
		black tern	<0,005				<0,005
		sandwich tern	0,01	**0,06**	0,01		0,02
		tern spec.	<0,005		<0,005		<0,005
alcids		guillemot			<0,005	<0,005	<0,005
		razorbill		<0,005	<0,005	<0,005	<0,005
		razorbill/guillemot			<0,005	**0,01**	<0,005
raptors & owls	raptors	goshawk			<0,005		<0,005
		kestrel	<0,005				<0,005
		marsh harrier		<0,005			<0,005
		merlin	<0,005				<0,005
		peregrine			<0,005		<0,005
landbirds	other large birds	grey heron		<0,005			<0,005
		wood pigeon			<0,005		<0,005
		homing pigeon	<0,005		<0,005		<0,005
		pigeon spec.				<0,005	<0,005
		carrion crow	<0,005				<0,005
		jackdaw			<0,005		<0,005
	small passerines	redpoll			<0,005		<0,005
		skylark			<0,005		<0,005
		swallow	<0,005				<0,005
		swift		<0,005			<0,005
		yellow wagtail			<0,005		<0,005
		songbird spec.	<0,005		<0,005		<0,005
	medium-sized pass.	blackbird	<0,005		<0,005		<0,005
		redwing			<0,005		<0,005
		song thrush			<0,005		<0,005
		thrush spec.			0,02		0,01
		starling	0,17	<0,005	**0,63**	0,01	0,25
	small passerines	chaffinch	<0,005		<0,005		<0,005
		house martin	<0,005				<0,005
		meadow pipit			<0,005		<0,005
		pied wagtail			<0,005		<0,005
		pipit spec.			<0,005		<0,005
all birds			**1,28**	**0,71**	**1,26**	**1,15**	**1,15**

8.2.3 Trends over the years

Fieldwork was carried out from spring 2007 through December 2009. In this period a few species showed either an increase or a decrease in abundance. Among the common species (with average densities > 0.01), only alcids showed a significant increase in numbers between 2007 and 2009 (GLM, accumulated model: the effect of year added to effect of season was significant: $F_{1,\ 57}$=9.9, P<0.01) (Data tested in Genstat V13. Data were averaged per observation date and were Poisson distributed. Dispersion parameter was estimated). Only flying birds were included in this analysis. Herring gulls and kittiwakes showed a significant decrease in numbers between 2007 and 2009 (same test as for alcids; herring gull $F_{1,\ 57}$= 6.0, P<0.05; kittiwake $F_{1,\ 57}$= 9.0, P<0.01). A considerable number of species showed a peak in abundance in 2008 (eg., gannets, divers, scoters, other ducks, terns, gulls overall).

Naturally, bird numbers vary largely between years due to a large number of factors such as weather conditions and variation in distribution at sea. Even though we observed some significant changes in bird numbers between years, these changes can be both incidental and related to any factor other than the presence of the wind farm.

Seabirds such as red-throated diver (photo J. de Jong) and northern gannet (photo R. Fijn) were all regular guests in the vicinity of the OWEZ wind farm.

Common tern and sandwich terns were regularly seen in the OWEZ wind farm area in spring and summer (photo R. Fijn)

8.2.4 Marine mammals

During all visual observations marine mammals were recorded as well. Marine mammals were observed from the metmast or during transfer form the harbour towards the metmast. The harbour porpoise was most frequently observed (13 times) (table 8.3). In winter months (January and February) harbour porpoises were more commonly seen than in other months. On February 4 2009 a group of 5 harbour porpoises was present during a panorama scan in sector 4. Harbour porpoises were observed outside as well as inside the wind farm. Grey seal and harbour seal were very uncommon. There are only four recordings of seals in the entire study period. Only individual animals were seen. On September 13 2007 a grey seal was sleeping at the foot of turbine 8 and later approached the metmast.

Table 8.3 Observations of sea mammals per season during panorama scans and incidental visual observations. For each species the number of days that animals were observed is given and (in brackets) the maximum group size recorded.

	grey seal	harbour seal	harbour porpoise
panorama scans	1 (1)	1 (1)	9 (5)
incidental observations	3 (1)	3 (1)	3 (3)
total	4 (1)	4 (1)	12 (5)

8.3 Seasonal variation in abundance of species

Highest densities were encountered in spring and autumn when large groups of migrating birds pass the area of OWEZ (respectively 1.28 and 1.26 birds per km^2) (table 8.2). The lowest densities were, on average, calculated for summer, when apart from large gulls and cormorants few birds passed the area. Among all species observed starlings occurred in highest densities (0.80 birds per km^2 in autumn). Among all species groups that were observed during panorama scans, gulls were the most abundant. In spring especially large gulls (herring gull and lesser black-backed gull) were numerous in the area, whereas small gulls (common gull and kittiwake) were more numerous in winter. For starling as well as kittiwake and common gull, attention should be paid to the irregular occurrence of the species. The high density of starling for instance is caused by three groups of respectively 600, 800 and 550 birds passing the wind farm area during three panorama scans in autumn.

Divers were very scarce in the area and occurred only from December towards April. The majority of divers were red-throated divers. Numbers doubled in January and February, because of migrating birds passing the area. The maximum average densities of flying birds never exceeded 0.01 bird per km^2, which means that only one bird per three complete scans was encountered during peak seasons. If local, floating, birds are also taken into account, the densities are slightly higher.

Gannets were a rather common species during spring and autumn migration. Especially in March high numbers were encountered. Birds passed the area towards colonies on the British east coast (e.g. Bass rock) and Helgoland. During peak season almost 6 birds on average were observed within 3 km distance from the metmast during each complete scan. In spring mostly adult birds passed the area, whereas in autumn the proportion of immature and juvenile birds was higher.

Cormorants were present in the area throughout the year. Maximum densities were encountered in June, when birds from the colonies on the Dutch coast visited the area to feed. In this period about 8 flying birds were recorded during each scan (0.28 birds per km^2). In November and December densities dropped almost to zero.

A shag was present on two days on the metmast (left, seen from above, photo R. Fijn). Cormorants (right, photo M. Bonte) were regular sights in the OWEZ wind farm.

Geese and swans, of which dark-bellied brent goose was the only numerous species, were scarce except in winter. In January several groups of up to 60 birds were encountered during panorama scans. The maximum density was 0.15 birds per km^2. All recorded birds were flying towards west. This concerns midwinter migration towards Great Brittain, driven by weather conditions. Only one swan of unknown species was observed during the entire study, flying high above the turbines over the wind farm in December.

Sea ducks (scoters and eider ducks), the majority of which were common scoter, passed the area in highest numbers during spring migration. Maximum densities were recorded in March when several small groups passed heading west. Only small groups were encountered (maximum group size 15 birds). In autumn and winter sea ducks were scarce. Apart from panorama scans, common scoters were recorded irregularly, although numbers were always low (maximum group size 26 birds).

Marine ducks such as eider (photo B. van den Boogaard) occasionally were seen foraging within the wind farm. Common scoter (photo R. Fijn) was regularly seen flying by, mostly at larger distances from the wind farm.

Other ducks, such as scaup, red-breasted merganser and northern pintail, were observed to pass the area only during spring and autumn migration. The most abundant species was northern pintail with a maximum density of 0.02 birds per km^2. This is equal to one bird in every two panorama scans. However, the species was recorded only once. On October 30 2008 a group of 30 birds passed the area heading west. Eurasian wigeon was seen in the area in low numbers and very irregularly. Once, a group of five birds rested on the water inside the wind farm (October 3 2007).

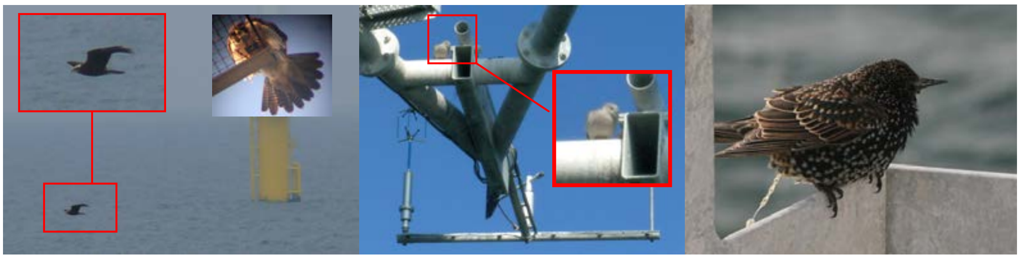
Gulls were present all year round and were most abundant in spring and winter. Only in these periods were densities higher than 1 bird per km^2, which equals 30 birds or more per panorama scan. In autumn and summer, densities were much lower. Patterns of gull abundance can be explained from the phenology of different gull species (fig. 8.3). High numbers in spring were caused by high numbers of lesser black-backed gull and herring gull. Both species nest in colonies along the Dutch coast. In spring, birds passed through the area during foraging flights. Many of these foraging gulls were associated with fishing vessels. The activity of these fishing vessels was highest during spring and summer (fig. 8.4). The majority of litte gulls was seen in spring, often foraging in groups on the edges of and within the wind farm. In winter, lesser black-backed gulls were almost absent, and high numbers of gulls observed during this season were caused by high numbers of common gull and kittiwake, especially in December and January. Herring gull and great black-backed gull were also common in winter. For both species highest numbers were recorded in January.

Terns were flying in the area from March through September. Highest numbers were recorded in July, when adult sandwich terns whose nests failed disperse over larger areas and juvenile birds from colonies on the Dutch coast join adult birds. No terns were recorded in June during panorama scans or during any other visual observation. This is probably because breeding terns have young chicks during this period and forage close to the colonies. The nearest colony of sandwich terns is on Texel, and this is too far away from OWEZ to see this species in the area during the breeding season.

Small gulls such as kittiwake (photo J.D. Buizer), little gull (photo group R. Fijn, individual M. Poot), black-headed gull (photo J.D. Buizer) and common gull (photo J.D. Buizer) were regularly encountered in the vicinity of the OWEZ wind farm.

Large gulls such as lesser black-backed gull (photo R. Smits), great black-backed gull and herring gull (photo J.D. Buizer) were the most numerously encountered species group in this study.

Landbirds were seen mostly during autumn migration. During spring migration far less migrating landbirds were seen, despite good coverage of observation days and favourable weather (see also §9.2.2, §11.2.4 & Ch 12). In November average density reached 4.3 birds per km^2. Of all the passerine species, the starling was by far the most numerous species. As mentioned before, the high densities of starlings were caused by three groups of respectively 600, 800 and 550 birds passing the area during three panorama scans in autumn. In March 2008 and 2009, several groups of 10-100 birds passed the metmast heading west.



Several types of landbirds, such as this marsh harrier, passed through OWEZ on migration (left, photo H. Prinsen). Others such as peregrine (left, inset, photo C. Heunks), collared dove (centre, photo R. Fijn) and starling (right, photo M. Collier) were sometimes present on the metmast.

Alcids (guillemots and razorbills) were uncommon in the area. Guillemots and razorbills were only present in winter (October-February), with highest numbers observed in February. The maximum average densities of flying birds never exceeded 0.02 bird per km^2, which corresponds to one bird in every two panorama scans during peak seasons. When floating birds are also taken into account, the maximum density was 0.12 birds per km^2, corresponding to six birds per panorama scan. Occurrence and numbers of alcids are highly variable, related to local weather and food conditions.

Guillemots were regularly observed within and around OWEZ (photo R. Fijn).

An overview of the annual phenology is given in figure 8.2. Species groups taken into account are based on the selection in Krijgsveld *et al.* (2005). For several common gull species the phenology is given in more detail in figure 8.3.

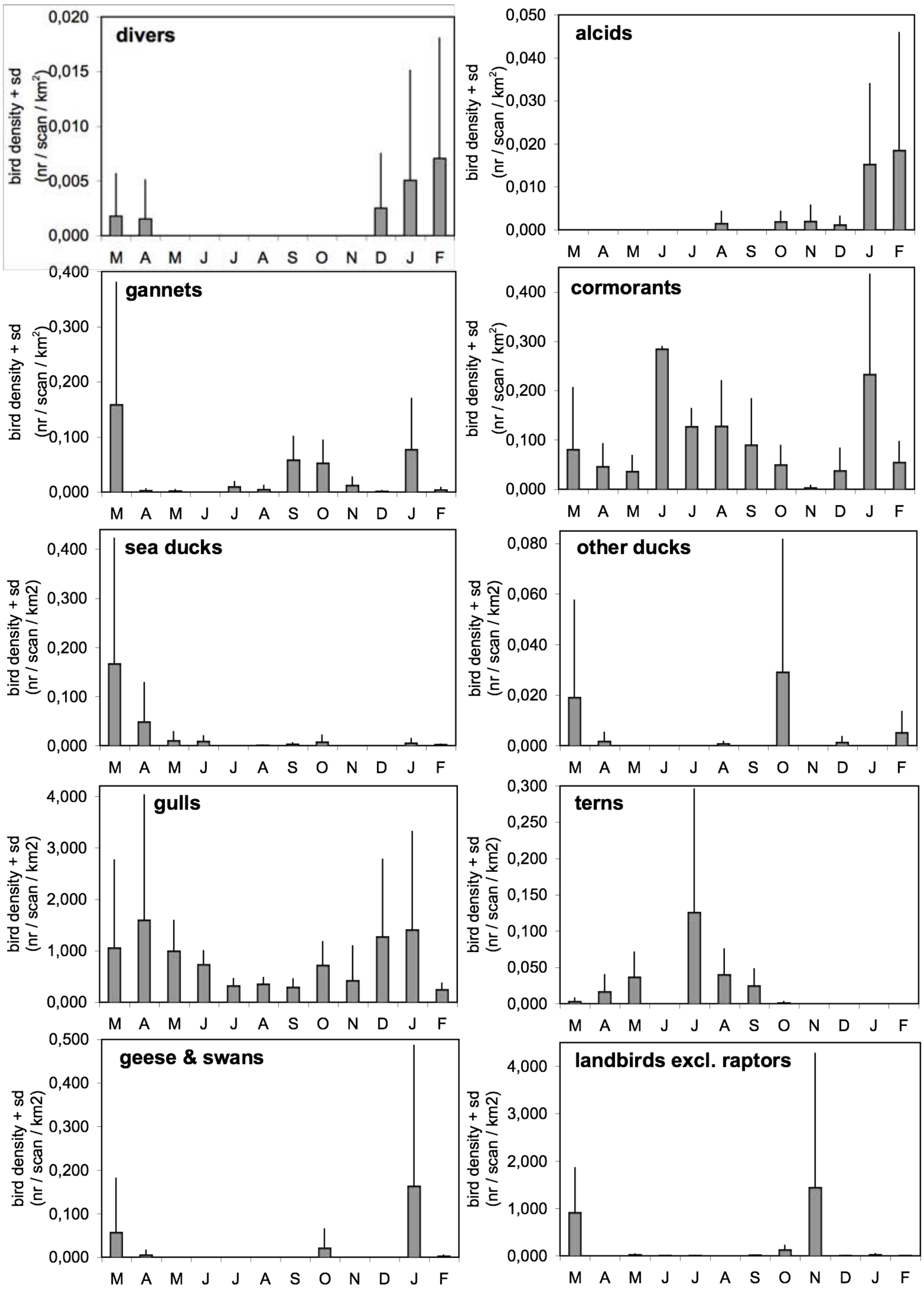


Figure 8.2 *Variation in density of flying birds throughout the year, for various species groups, as observed in panorama scans. To obtain means, all panorama scans made during one observation day were averaged, and these daily means were averaged per month. Standard deviations show variation between observation days. Only birds within 3 km distance from the metmast taken into account.*

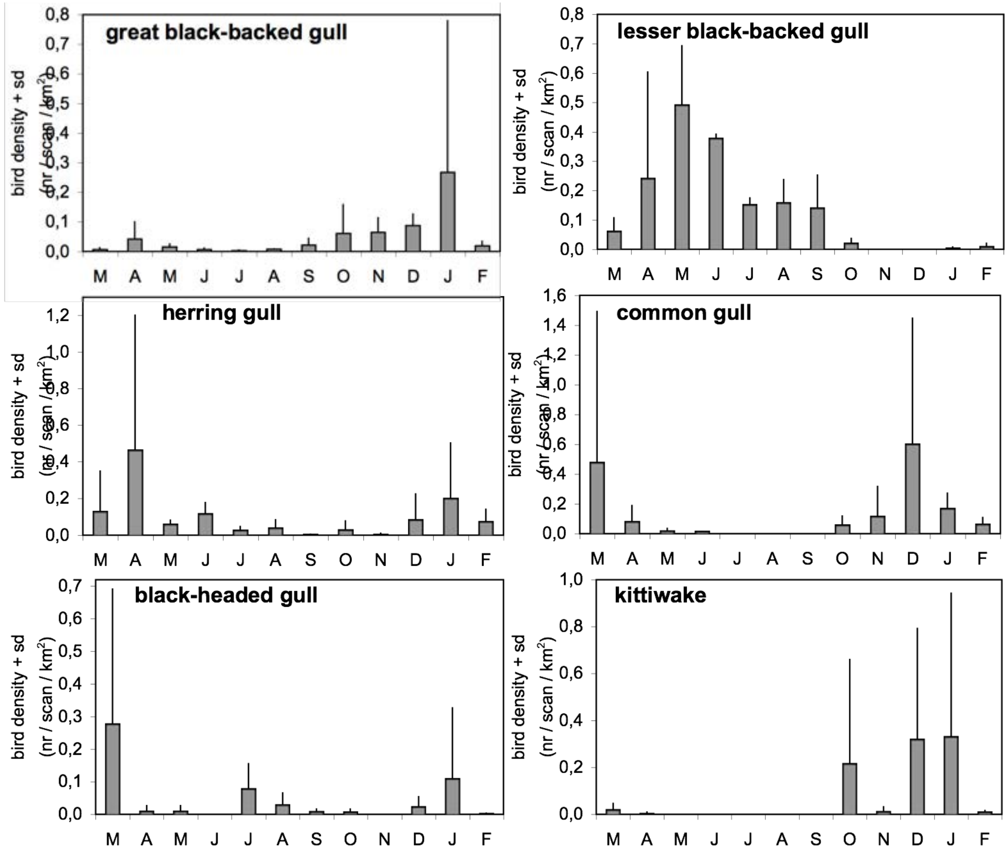


Figure 8.3 Density of flying gulls, specified for individual species. Shown are the regularly observed species. Panorama scan data, depicted as in fig. 8.2.

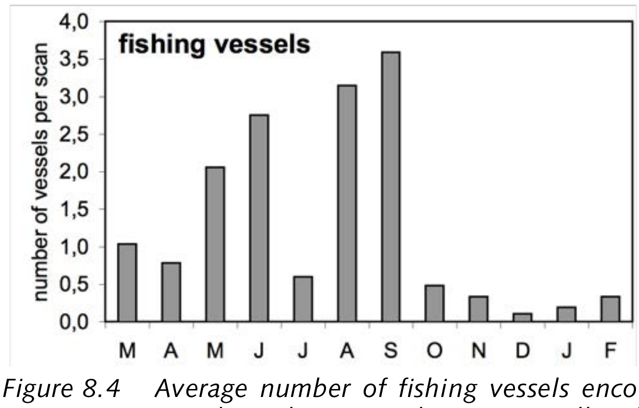


Figure 8.4 Average number of fishing vessels encountered per panorama scan per month. Fishing vessels were usually observed at large distances, and always outside the wind farm. Because all visible fishing vessels are taken into account, including those at distances >3 km from metmast, the number seen is shown instead of density.

8.4 Effect of weather conditions on species composition

Apart from the species-specific seasonal variation (§8.3), weather conditions may also affect species composition. We analysed the effect of wind speed, as this is a factor that has large influence on flight activity. Other factors such as rain, fog, and also wind direction affect flight activity, but these effects cannot be quantified as straightforwardly, because of interactions with observation conditions and low sample sizes (rain, fog) and interrelations with flight directions (wind direction). To examine the effect of wind speed, the abundance of different species groups was calculated as percentage of the total abundance of flying birds, and related to different wind speeds. Effects of wind speed on fluxes is discussed in §10.3. The results show that during calm weather conditions (wind speed 1-2 Bft) in the migratory seasons (spring and autumn), landbirds were the dominant species group in panorama scans (fig. 8.5). During moderate and rough weather conditions gulls became relatively more abundant. In summer and winter, gulls were the dominant species group under all wind speeds. The relative number of cormorants was higher during rough weather than under calmer conditions. In winter the number of alcids was relatively high during calm weather conditions. This may be a matter of detection probability, because alcids often flew low above the water and thus will have been less visible when increasing wind speeds resulted in increasing wave heights.

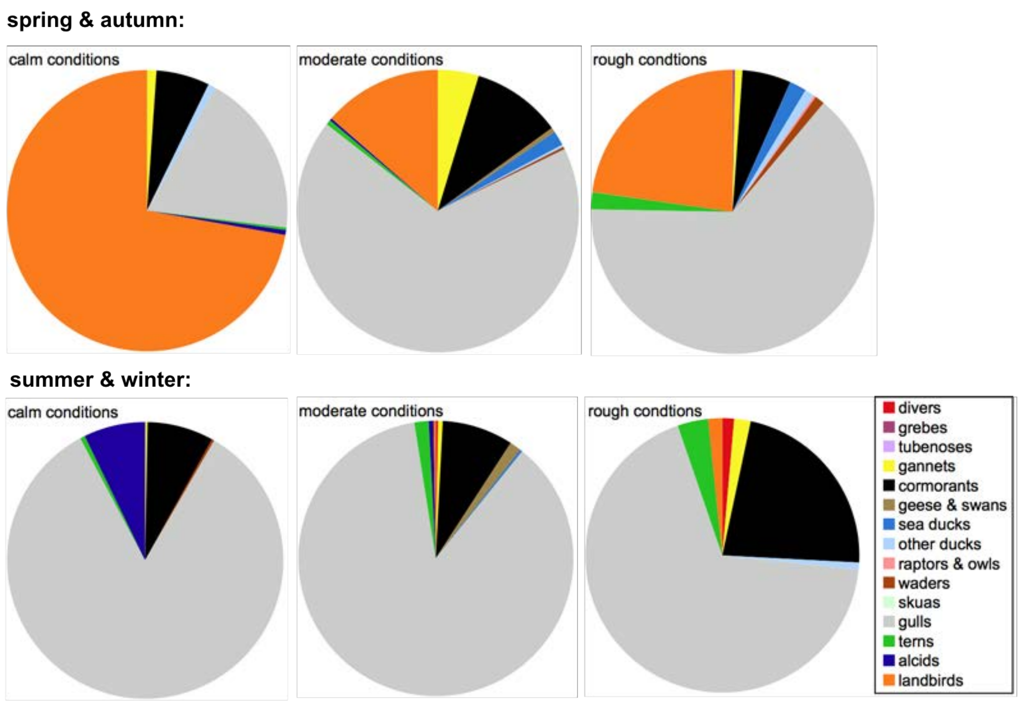


Figure 8.5 Effect of wind speed on species composition. Proportion of species groups is shown for increasing wind speeds (left to right), and for the migratory seasons (top), when large numbers of passerines passed through the area, versus the winter and summer seasons (bottom) when mostly local seabirds were present. Data based on panorama scans. Only flying birds within 3 km from metmast taken into account. Calm conditions: wind speed <3 Bft; moderate conditions: wind speed 3-4 Bft; rough conditions: wind speed >4 Bft.

8.5 Species present at night

To assess what species were flying in the wind farm area at night, various methods were used. These included moonwatching (§8.5.1), listening for calls during nocturnal stays at the metmast (§8.5.2), and recording calls continuously with a microphone and laptop (§8.5.3).

8.5.1 Moonwatching

Moonwatching was undertaken during four nights (see also table 4.4). A total of 30 birds were recorded during 230 minutes of observation. The number of birds recorded in each species group during each observation period is shown in figure 8.6.

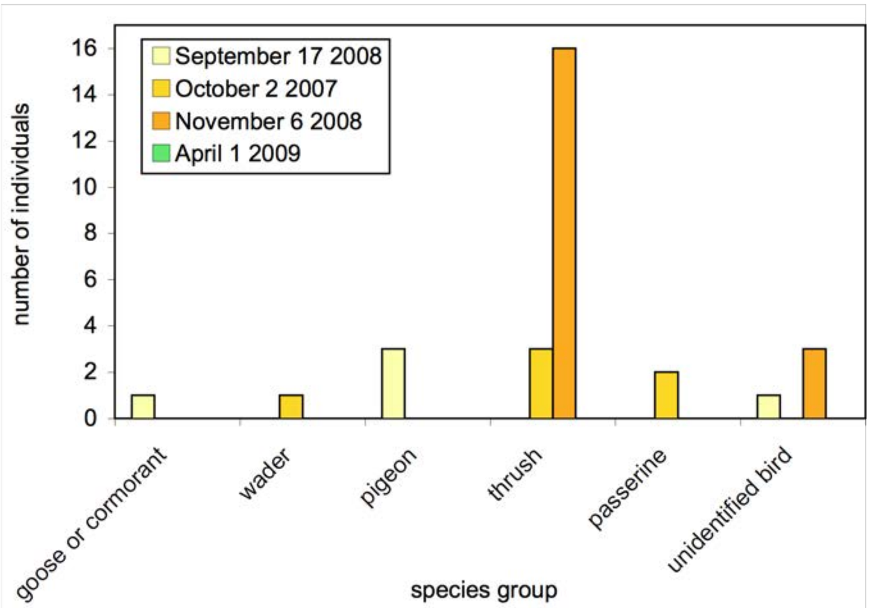


Figure 8.6 Numbers of birds by species or group, recorded during moonwatching.

On average, 8 birds were seen per hour, with a maximum of 14 and a minimum of 0 birds per hour. Most birds were recorded during 6 November 2008, when a total of 19 birds were recorded in 80 minutes of observation (14 per hour). Most records are of single birds although two groups of two thrushes were recorded as well as one group of five thrushes. Although conditions for moonwatching were not ideal on 2 October 2007, the moon being in the last half and with an overcast sky, a total of six migrating birds were recorded in 30 minutes (12 per hour). A total of eight ten-minute periods of observation were carried out on 17 September 2008, during this time five birds were recorded (4 per hour). With the exception of a record of two pigeon species during the latter visit, all records were of single birds. No birds were recorded during moonwatching on 1 April 2009. However, during the 40 minutes of observation the cloud cover increased and prevented further observation.

Fluxes of birds passing during the moonwatching periods were calculated for the three evenings with observations (fig. 8.7). These were calculated by D. Peter (Vogelwarte, Switzerland). Fluxes ranged between 428 birds/km/hr on 17 September 2008 and 1355 birds/km/hr on 2 October 2007. On 6 November 2008 the calculated flux was 1155 birds/km/hr. During the evening of 6 November 2008 most birds were flying at an altitude of between 200 and 400m and in a westerly direction. During both 2 October 2007 and 17 September 2008 the flight direction was also predominantly westerly. Fluxes were concentrated between 200-400m on 17 November 2008, and were more spread between 0-400m on 2 October 2007.

These fluxes are within the range recorded with radar (chapter 10), although they only represent very limited periods of observation and do not provide any indication of changes in fluxes throughout the night (few observations, generally mid to late evening).

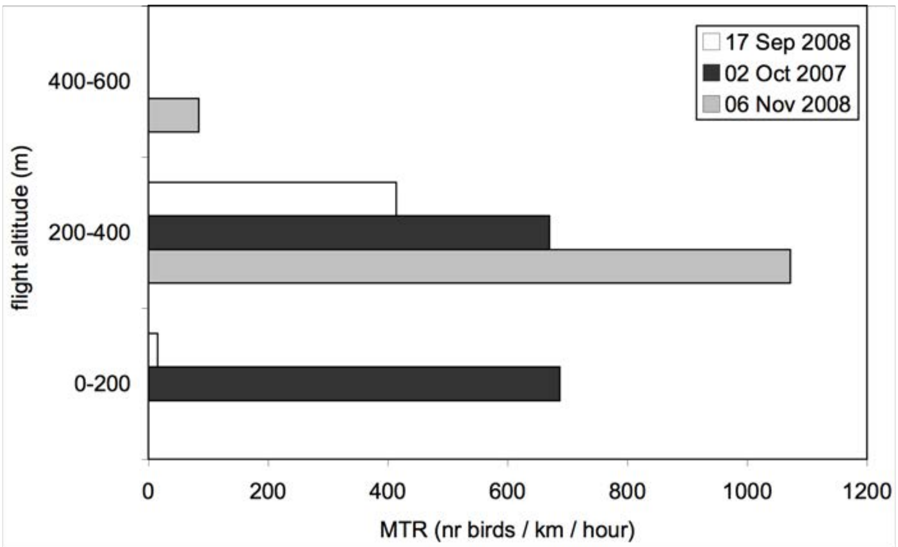


Figure 8.7 Fluxes and flight altitudes of nocturnal birds as derived from moonwatching data (calculated by D. Peter, Vogelwarte, Switzerland). Data based on three nights only.

8.5.2 Calls registered by ear

Registering vocalization of migrating birds is one of the only available measures to quantify numbers and identify species of nocturnally migrating passerines. Results thus obtained show a strong relationship with flux data found in radar studies (Farnsworth *et al.* 2004). During hours of darkness species were identified by call identification from the metmast; the type and number of calls heard indicating the species and numbers per species migrating overhead. Two observers carried out dedicated night-time observations to register calls of birds during six nights (see table 4.4 for an overview of observation nights). Observations were carried out for a total of 34 hr. Birds were heard during a third of the five-minute observation periods. Numbers of birds were estimated based on the number of calls, with a single call assumed to be one bird.

Species

A total of 881 birds of twelve species (and two identified to species group) were recorded during nocturnal observations, the majority of these being thrushes (85%; redwing, song thrush, blackbird and thrush spec.) (fig. 8.8). Although most birds were recorded in autumn, a greater number of species was recorded in spring (fig. 8.9). Thrushes constituted as much as 95% of all birds recorded in autumn, whilst in spring this figure was 40%.

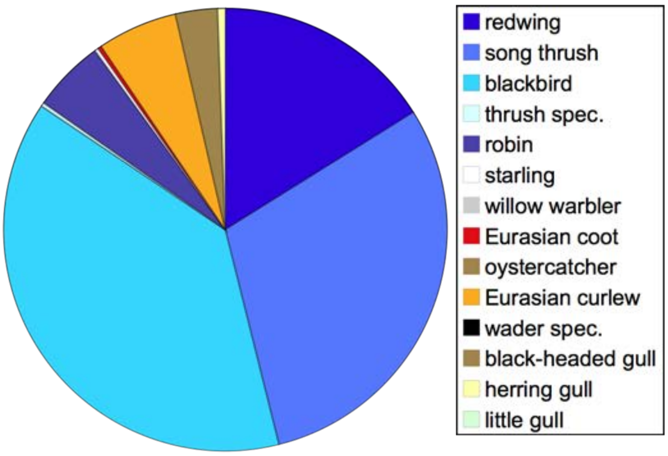


Figure 8.8 *Species composition of birds recorded during nocturnal detection of calls by ear during six visits between 2 October 2007 and 2 April 2009.*

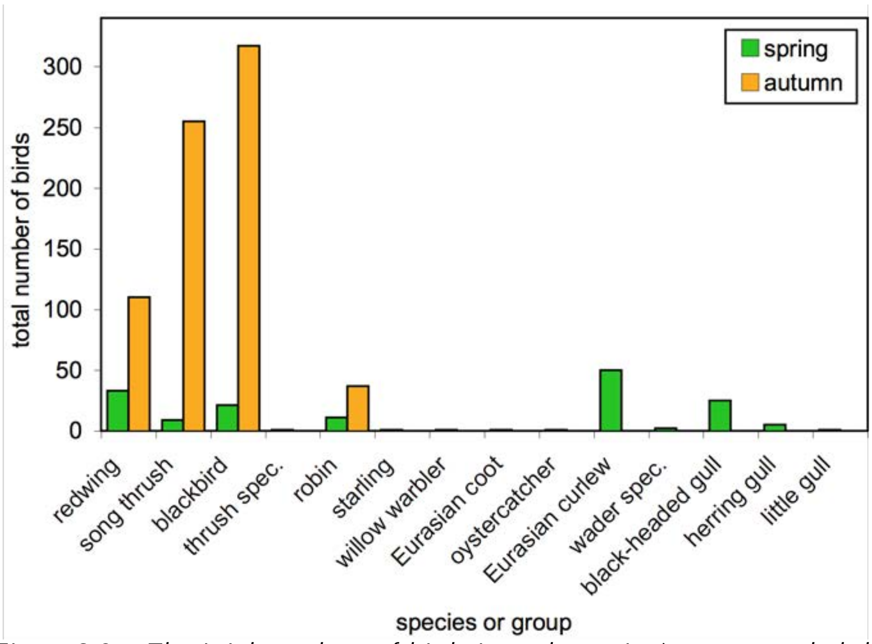


Figure 8.9 *The total numbers of birds in each species/group recorded during spring and autumn nocturnal observations.*

Variation in numbers during the night

The numbers of birds recorded varied during the night from 0 to 173 birds/hr (fig. 8.10). Between eight and six hours before midnight the mean number of birds/hr was 11. The level of activity fell to a mean of 2 birds/hr between four hours before and midnight, before rising again to a peak of 173 birds/hr four hours after midnight (fig. 8.10). The numbers recorded during autumn largely influenced these figures. With the exception of four hours before midnight and five hours after midnight thrushes were recorded during every hour of nocturnal observations and constituted the majority of birds in each hourly period. The numbers of both small passerines and gulls peaked during four hours after midnight whilst wader numbers peaked one hour earlier.

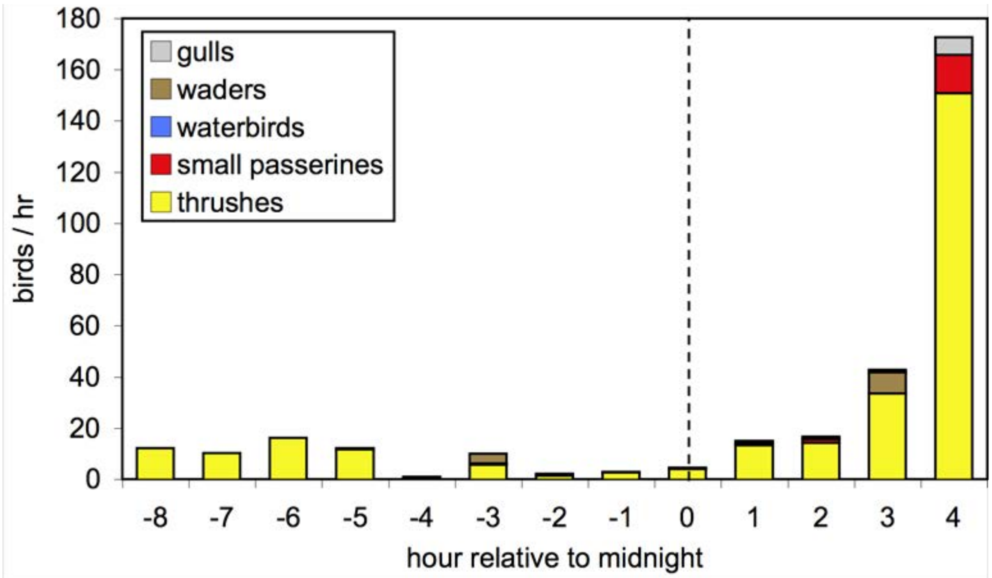


Figure 8.10 Total number of bird calls per hour for each species group, in the course of the night (hours relative to midnight, shown as striped line).

Differences between spring and autumn migration

Throughout the night, more birds were recorded in autumn than in spring (fig. 8.11). The two exceptions to this were during four hours before and three hours after midnight when the number of calls was slightly higher in spring than in autumn.

Peak activity during autumn was recorded during four hours after midnight and in spring the peak activity was three hours after midnight. The peak intensity during autumn, however, was over four times higher than that of spring (278 birds/hr compared to 67 birds/hr); most of this activity was due to thrushes, largely due to high numbers being recorded on 3 October 2007 which was a night with strong migration.

During autumn, the pattern of activity throughout the night largely reflected that in figure 8.10, with the fewest calls recorded between four hours before midnight and midnight, before numbers increased to peak levels at four hours after midnight. Only thrushes (redwing, song thrush and blackbird) and small passerines (robin) were recorded during autumn (fig. 8.9).

In spring, most calls were recorded after midnight (fig. 8.11). Calls were identified as being from coot, waders (oystercatcher, Eurasian curlew and unidentified wader species), gulls (black-headed gull, herring gull and little gull), thrushes (redwing, song thrush, blackbird and thrush species) and small passerines (robin, willow warbler and starling). Most activity of gulls was recorded during three hours after midnight. During this period waders constituted approximately three-quarters of all birds recorded.

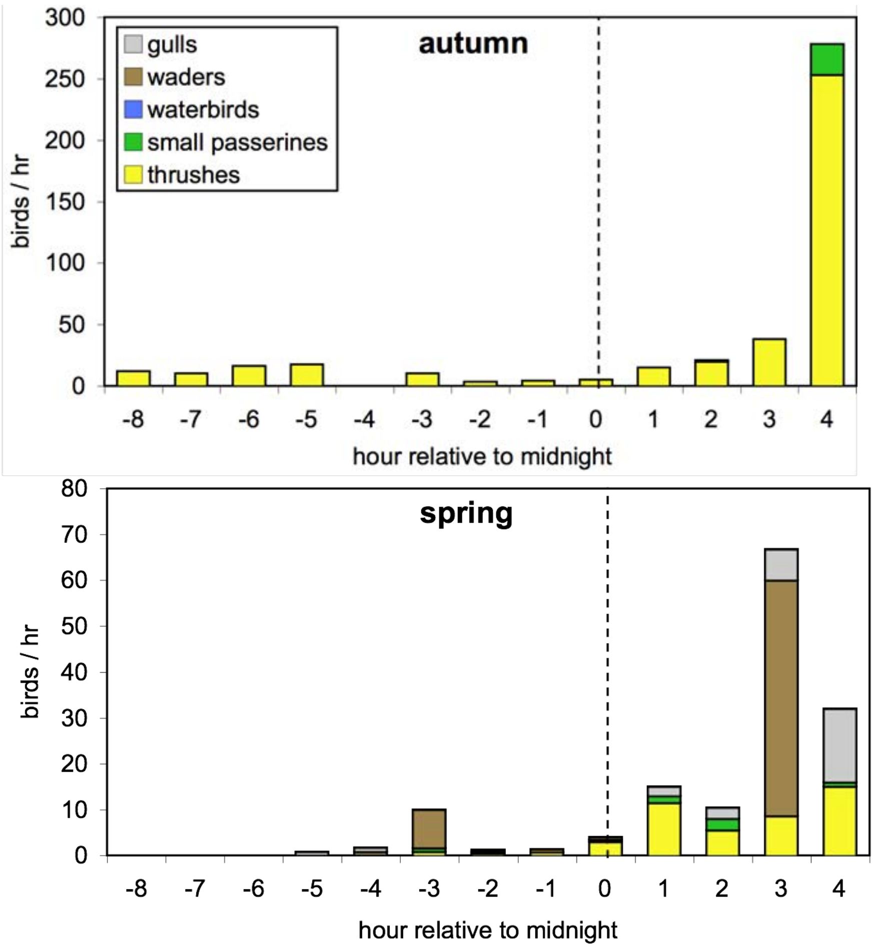


Figure 8.11 Total number of bird calls per hour for each species group, in the course of the night (hours relative to midnight, shown as striped line), and separated for autumn (top) and spring (bottom). Note the difference in scale: numbers were much higher in autumn than in spring.

Migration patterns

The pattern of thrushes recorded throughout the night differed in spring and autumn (fig. 8.11). The peak of thrush activity was recorded during four hours after midnight during both spring and autumn. In autumn, however, thrushes were recorded throughout the night, whereas in spring the number of thrushes recorded was not only much lower than in autumn, but was also higher after midnight than before. These differences may be indicative of patterns of thrush migration.

In general, thrushes migrate at altitudes below 2500 m (Eastwood 1967) and at speeds between 39 and 50 km/h (Alerstam *et al.* 2007b) and typically at night. During spring, the records of thrushes at the metmast from midnight onwards coincided with

birds leaving the eastern UK, approximately 200 km away, from dusk onwards. The peak during four hours after midnight could be indicative of birds decreasing their altitude during down as they search for land where they can rest and feed. Furthermore, studies have shown that flight altitudes are, on average, lower during day than during night (Eastwood 1967; Wernham *et al.* 2002).
The pattern during autumn, of relatively few calls detected through the night compared to the peak at four hours after midnight, can be explained by the relatively high altitude of thrushes during migration (Eastwood 1967) as they leave the Dutch coast, which may reduce the likelihood of birds being detected by call. Again as dawn approaches birds decrease their altitude in search of land and during this time birds that have started to cross the North Sea may return to the Dutch coast.

Summary and implications
The registration of nocturnal calls of migrating birds provides an insight into the species passing the area of the wind farm at night, and to a lesser extent the intensity of migration. A number of migratory landbirds (most notably thrushes) were recorded, showing that a different suite of species was present during night than during daytime (see also ch. 13).

The intensity of thrush migration estimated from the registration of nocturnal calls (figs. 8.9 & 8.10) showed a similar pattern to the vertical radar with more birds in autumn than in spring. However the nominal fluxes were much lower due to an altitude effect. The human ear can only hear birds up to a certain altitude and vertical distance so the sampled area in these listening sessions was much smaller compared to the area investigated with the radar.

The peak numbers found in the call registration session were in both seasons in the end of the night (fig. 8.11). This is in contrast to the findings of the vertical radar when peak migration was found in the beginning of the night and around midnight (chapter 10). This is probably due to an effect of migration altitude as migratory birds decreased their flight altitude towards the morning (see ch. 11).

The most important finding of these flight call identifications was to be able to establish a species-spectrum of migratory birds passing the wind farm area at night. For a number of species (thrushes and waders) this could be done but some particular species (e.g. non-calling species) were likely to be missed.

8.5.3 Calls registered with the automated acoustic recording system

Because call registration was one of the few ways available to identify nocturnally flying species, we extended call registrations by ear with prolonged sound recordings during migration and analysing these for occurrence of bird calls. See §4.6.3 for methodology.

Background noise
Recordings were made on a total of 73 days during spring and autumn. On up to 38 of these days ambient noise levels were low enough to allow sound analysis of bird calls. Of the 156,615 registered ROIs, a overall fraction of 14.2 % has been checked by the human observers, which was a total of 22,303. The numbers of birds recorded

were low (1.7% of all 22,303 acoustic events checked by human observers). This was due to several issues with the automated registration system. The main obstacle was that the platform itself created a lot of acoustic events even with low winds. Especially the metal chains and some cables were sources of sounds, covering the same frequency range as bird calls (fig. 8.12). This lead in many cases to wrongly identified ROIs as birds (of potentially identified birds only 7.7% turned out to be actual birds). Especially hard ticks and clicks from metal on metal and some waves breaking against the post cover of a wide frequency range, overlapping with the parameters on which ROIs were identified by the software as potential bird calls (fig. 8.13).

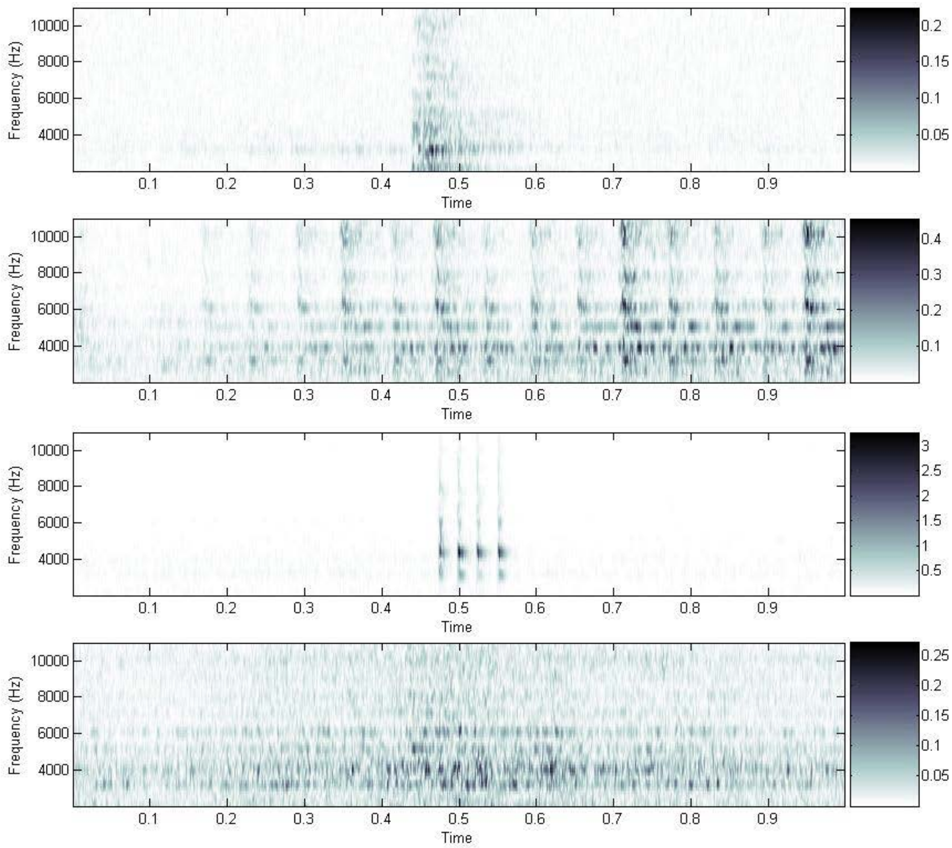


Figure 8.12 Sonograms of regions of interest of several more typical non-bird sounds on the metmast, that were also identified correctly as non-bird sounds by the automated system. Bar on the right indicates signal strength. Top: metal door slam of container; second from above: trembling floor plate; third from above: raindrop falling with vibrating plastic protection sheet of the microphone; bottom: a typical large wave breaking on the post of the metmast.

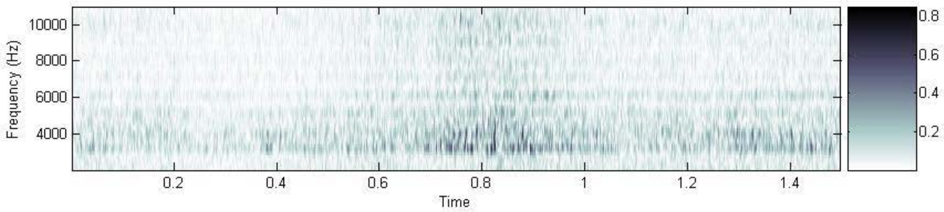


Figure 8.13 Sonogram of regions of interest of a non-bird sound on the metmast, falsely identified by the automated system as a redwing. The sound is with certainty the splash of a large wave against the post, creating a sound with tones in the same frequency band and of a similar duration as a redwing. Bar on the right indicates signal strength.

A second reason for poor detection of bird calls was that the system turned out to be positioned too close to the sea. The sound of the waves against the base of the metmast created a lot of background noise, which implicated that the trigger to detect a bird call in relation to the background noise level had to be large. From the recorded bird calls it could be deduced by the observers checking the recordings, that the birds recorded were birds passing by closely. Some birds could still be selected by the automated system as ROI, but the signal/background noise ratio was too low to allow the ROI to be identified as a bird (fig. 8.14). The automated identification could not be finalized and the ROI was wrongly classified as a non-bird. This happened in 1.2% of the cases. Of these 23.4% turned out to be redwings or blackbirds calling too softly to be parameterized by the system.

For all sound files the automated identification was checked by human observers by taking samples. Of the 156,615 registered ROIs, the effort of checking samples by the human observers was more or less equally divided per month, with a higher effort before midnight. This was because of the higher numbers of nocturnal migrants starting from the coast in autumn and thus reaching the metmast before midnight (table 8.4), as found also in the frequency of bird calls in the samples.

Species recorded

The main species recorded were redwing and blackbird, during autumn (table 8.5). Especially in the May-recordings, also gulls and cormorants resting on the metmast were identified (fig. 8.15). Other species recognized were jackdaw, fieldfare, robin and goldcrest. It is likely that all these birds were sitting or landing on the metmast.

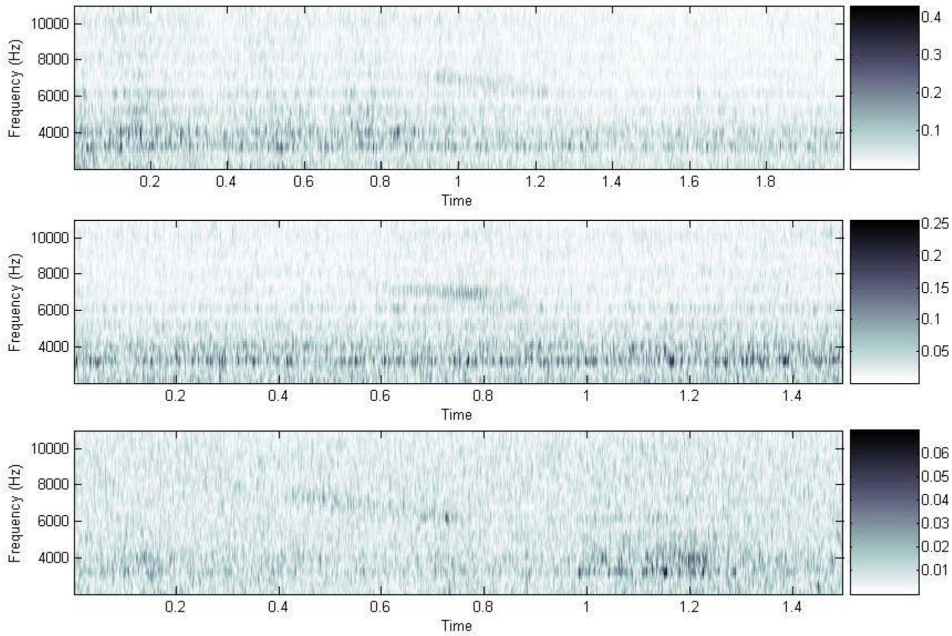


Figure 8.14 Three sonograms of detected calls of redwings by the automated acoustic recording system. These three calls were identified by the system as ROI (region of interest), but could not automatically be identified to species level because the sound was too low for a good parameter description. The human observers however could still detect the call, and the call can also be faintly recognized in the sonogram (diagonal to horizontal line in the centre of each graph). Bar on the right indicates signal strength.

Table 8.5 Number and percentage of all species identified based on 22,303 recorded and by human observers checked acoustic events (October-December 2007 and May 2008).

species	number	percentage
redwing	121	32,1%
gull spec.	81	21,5%
cormorant	68	18,0%
blackbird	52	13,8%
songthrush	18	4,8%
cormorant or gull	17	4,5%
songbird spec.	10	2,7%
bird spec.	4	1,1%
goldcrest	3	0,8%
jackdaw	1	0,3%
fieldfare	1	0,3%
robin	1	0,3%
total	377	100,0%
ticks, waves and other sounds	21926	-

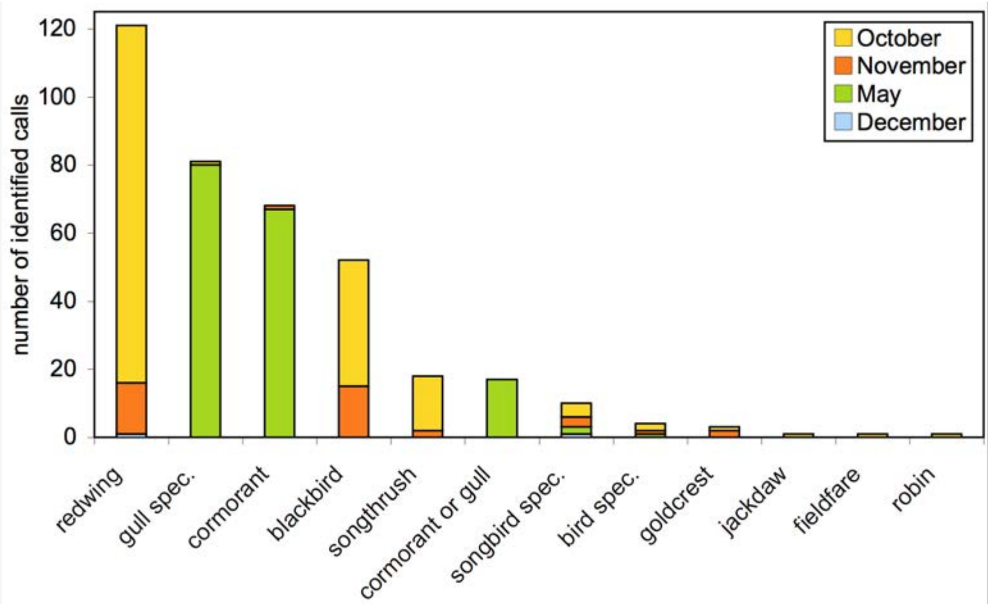


Figure 8.15 Bird species that were identified with acoustic identification software, arranged according to the number of calls heard per species. Colours reflect the months in which the sounds were recorded.

Conclusion

Despite good efforts, the sound recordings have not resulted in an extended spectrum of bird species passing the wind farm area at night. The recordings reflect the same species spectrum as was recorded by human ear during nocturnal visits to the metmast. The quality of the recordings was not high enough to exclude the possibility that other audible species passed the area.

The principle of automatically retrieving and identifying bird calls from audio recordings has proven to work well: regions of interest were marked successfully by the software, and a large number of different species could be identified. Because of the local circumstances at the metmast with a high level of background noise, the application hasn't worked very well in the project at hand. In hindsight, the microphone should have been placed further away from the sea and higher in the mast, to reduce the noise level. But even high in the tower the main source of disturbance, being the permanently present ticks from moving metal, would still have been present.

9 Results: Flight paths

In this chapter, data are presented regarding the effect of the wind farm on flight paths of birds, *i.e.* behavioural responses to the wind farm in flight activity and flight directions. General flight paths in and around the wind farm are based on observations made with the horizontal radar. Because the radar does not give information on species level, visual observations were needed to provide insight in flight paths and behavioural responses of individual species. The distribution of local birds in the wind farm and in a large area around the wind farm is presented in Leopold *et al*. (2011).

General patterns in flight directions and bird numbers in the studied part of the North Sea, regardless of effects of the wind farm, and as measured with the horizontal radar, are presented in §9.2. Whether or not birds flying in the area avoided the wind farm and to what extent, is quantified in two ways: one is the distribution of birds flying in and around the wind farm, the other is the flight directions of birds in the area and changes therein in response to the wind farm. The distribution of all birds, regardless of species, flying in the wind farm area is discussed in §9.3 (radar data). The distribution of individual species is discussed in §9.4 (visual observations). Results on flight directions in the area in general, regardless of species, are presented in §9.5 (radar data), and in §9.6 flight directions of individual species are presented (visual observations). Effects of OWEZ on flight paths of individual species is shown in §9.7 (visual observations).

9.1 Summary of results

- Overall avoidance level of the wind farm lay between 18-34% (*i.e.* ca. 18-34% less birds within the wind farm than outside the wind farm), with an average of 28%. Avoidance was lowest in winter (18% less) and highest in autumn (34% less). Avoidance was higher at night than during day; at night the proportion of birds in the wind farm was roughly half to two thirds of the proportion during daytime.
- Flight activity was higher in the area within the wind farm where wind turbine spacing was larger (in SE section), and the single line of turbines at the north-west of the wind farm was passed more often than the main body of the wind farm. Turbines that were operating were avoided more than turbines that were standing still. Thus, design and also activity of the wind farm is an important factor in the level of avoidance by flying birds.
- Flight directions were more random in summer and winter, whereas birds followed more similar flight directions during the migratory seasons. Also during the night, flight directions showed less variation than during daytime. Avoidance levels were higher at night than during daytime. The wind farm did affect flight directions: birds adjusted flight paths to avoid individual turbines and also, especially at close range, the entire wind farm. Overall, flight directions did not change over large distances when birds approached wind farm. Adjustments in flight directions were generally made up to one or two kilometres away from the wind farm. This pattern was also

visible in the distribution of tracks around the wind farm. Corrections in flight directions of birds that had just passed the wind farm area were visible up to three to four km away from the wind farm.
- Seabirds such as gannets, scoters, alcids and divers showed the highest levels of macro-avoidance. Gulls (all species) and cormorants did not avoid the wind farm. Cormorants flew to the wind farm from shore to forage in the area, and used the turbines and the metmast to rest and dry their feathers. Of migrating landbirds, geese were extremely weary of the wind farm and showed the highest level of avoidance. Of thrushes and smaller passerines, approximately half to three quarters of the groups did enter the wind farm when flying during daytime and at rotor height, although virtually all groups avoided the immediate area around individual turbines.

9.2 General patterns in flight paths

9.2.1 Flight directions

Flight directions were recorded to a large extent with the horizontal radar. In this paragraph, we show the general patterns in flight directions that we observed with the radar. This serves on the one hand to illustrate how birds used the wind farm area, and on the other hand as a validation that the filtered horizontal radar data reflect flight patterns of birds rather than sea clutter. The observed flight directions (fig. 9.1) reflected commonly known seasonal patterns in bird behaviour and species composition for the area, such as local foraging movements and migratory movements in spring and autumn. In the light of the large amount of clutter data that was removed from the data base, this was a strong confirmation that the filtering process had resulted in a data base with data on bird tracks.

Spring

In spring, flight activity was highly directional and was overall oriented in easterly directions, except at dusk. Migration towards NE did occur on a large scale (13% of all tracks in spring, fig. 9.2), but a similar percentage of tracks flew towards W and NW, while the majority of tracks was oriented to E (24%) and SE (16%). These patterns suggest that at OWEZ large numbers of birds pass by that migrate from the UK towards the Netherlands, rather than birds migrating from southern countries to more northern countries. It is unlikely that these patterns reflect correction flights (*i.e.* birds that were migrating over sea returning to the coast at daybreak or nightfall) at the site towards the coast, because this should occur mostly in the hours around sunrise and sunset, and not during the night. Alternatively, these flight paths only reflect migration activity at low altitudes, as they were recorded with the horizontal radar, which measures up to limited altitudes. This does however not explain why such a high percentage of flight paths was oriented east. Flights towards the west occurred in April and May rather than in March, and were limited to the hours of dusk, specifically at 17h and 18h.

Summer

In summer, flight directions had a surprisingly high south-westerly component. Given the time of year, we would expect mostly non-directional movements of locally foraging birds. Only during daytime did flight directions reflect the random movements of the most dominant species group present at that time, the gulls.

The south-westerly component in flight directions occurred mainly in the hours around sunset and up to midnight (fig. 9.3). In addition, flights to the SW mostly occurred at the end of the summer season, in the second half of July and in August (fig. 9.4). These two aspects indicate that the south-westerly flight paths may reflect species such as waders and terns and to a lesser extent also black-headed gulls migrating south from the Waddensea and/or the IJsselmeer area. These species were also seen during daytime in visual observations. Airspeed of these bird tracks was 65 km/h on average, and flight altitude lay around 200-400 m (taken from vertical radar). Observers at the coast also reported numerous migrating terns, waders and black-headed gulls at this time of year (www.trektellen.nl; e.g., bird counts at Noordwijk). Apart from that, songbird migration already starts at the end of the summer season, and may have contributed to SW flight activity.

Autumn

In autumn, flight paths were dominated by strongly directional migratory movements oriented southwest. This reflected large numbers of a large variety of landbirds migrating from their breeding grounds to the wintering grounds in Great Britain, southern Europe and Africa.

Winter

In winter, flight paths did not show a strong direction, which reflects the expected movements of locally foraging sea birds. Flight activity at this time of year was low (see ch. 10 & §9.2.2), but of the birds that were flying, a considerable proportion flew at night-time, and these nocturnal flight movements did show a strong orientation towards SW and, to a lesser extent, NE. The highest level of nocturnal activity was measured in late December 2007 and early January 2008. The south-westerly flight activity occurred mostly in late December, early January in both 2007/08 and in 2008/09. These movements always occurred in the early evening, from sunset until some time before midnight, and took place at altitudes ranging from just above rotor height up to ca. 1000 m. These movements are likely to reflect cold-related movements, of species moving further south after cold spells in either the Netherlands or countries further north. The data therefore probably mostly reflect flights of black-headed and common gulls as well as lapwings and golden plovers, that all show cold-related behaviour, and often fly at night. The tracks were mostly followed along the full range of the horizontal radar, which indicates that birds were rather large, in line with the above (e.g., January 1-5 2008, fig. 9.5). On a few nights, smaller birds were involved, as concluded from the fact that the range of detection was much smaller (e.g., December 30 2007). This may reflect species such as sky larks.

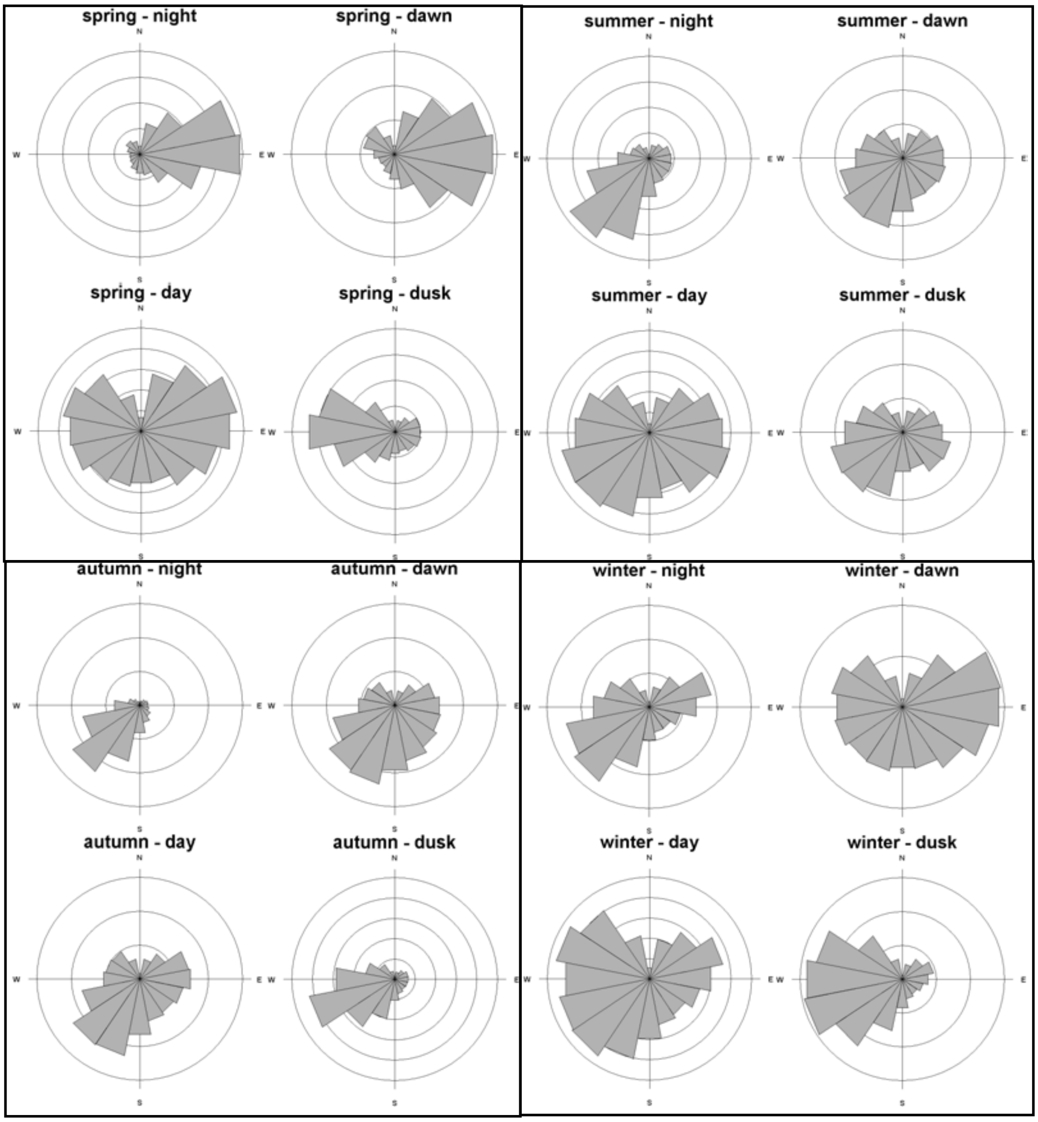


Figure 9.1 Distribution of flight directions of bird tracks over the seasons and over the time of day, for all study years combined. Data from horizontal radar. No scale is given as it is a relative measure (proportion per wind direction for each indicated period) and the scale therefore only reflects the level of variation in proportions. For quantitative information on fluxes see ch.10.

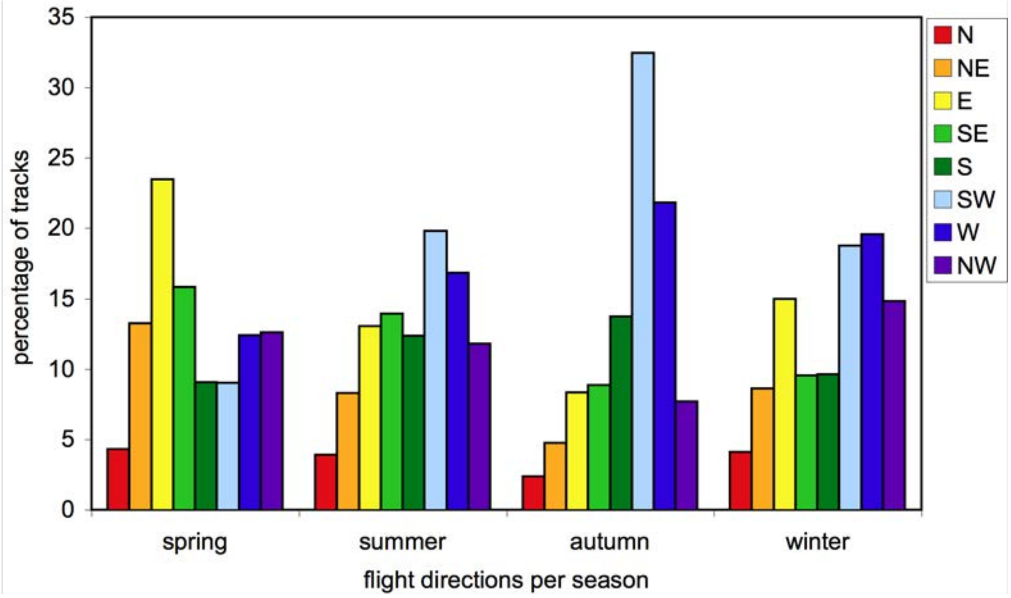


Figure 9.2 Distribution of flight directions per season. Percentage calculated as percentage of all tracks in that specific season. Data from horizontal radar.

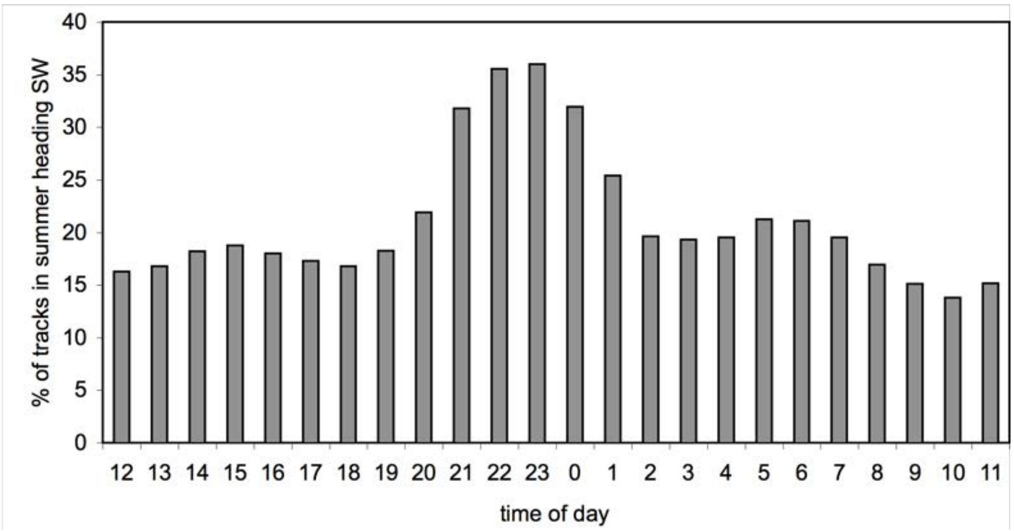


Figure 9.3 Percentage of tracks heading SW in summer, shown over the course of the day, for all years combined. Percentage calculated as percentage of all tracks in that specific hour. For clarity, midnight is shown in the centre of the graph. Data from horizontal radar.

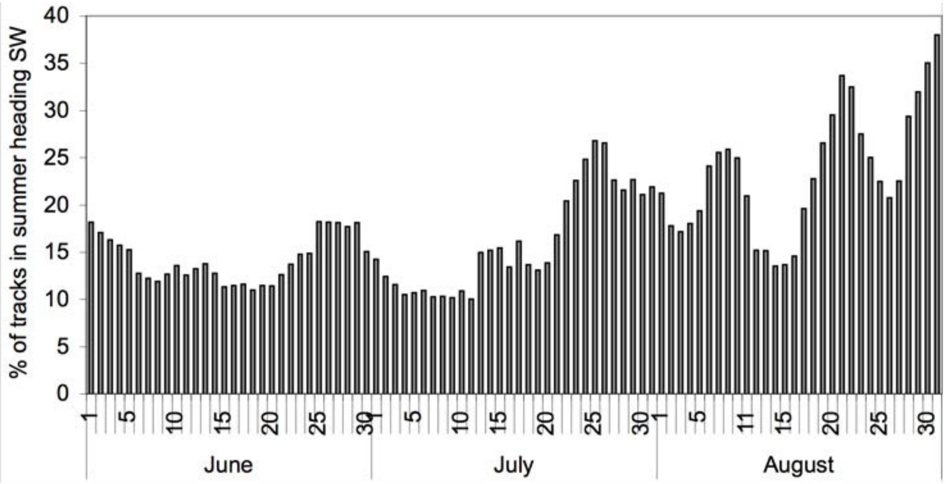


Figure 9.4 Percentage of tracks heading SW in summer, shown per day over the course of the season, all years combined. Percentage calculated as percentage of all tracks on that specific day, and given as a running mean over five days to emphasize patterns. Data from horizontal radar.

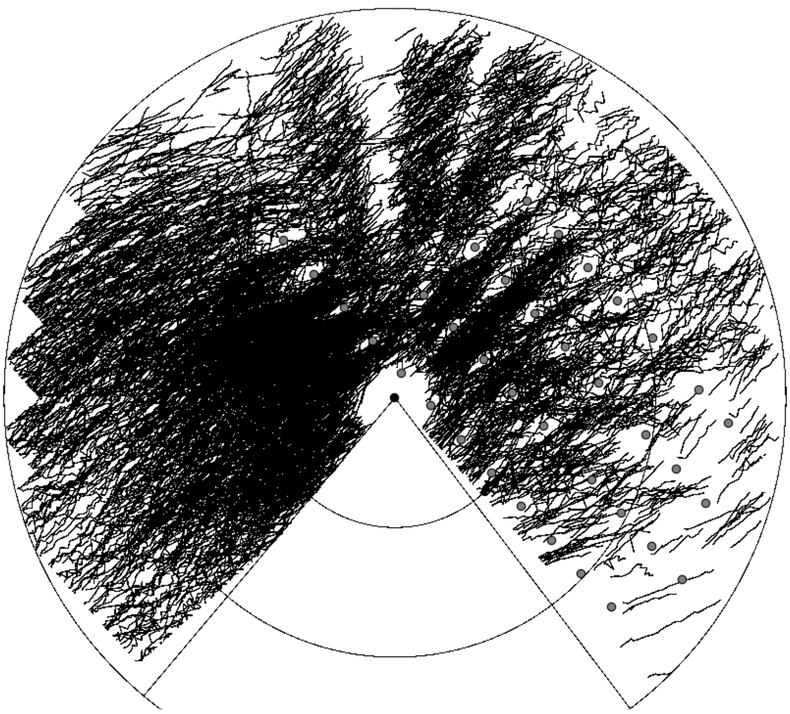


Figure 9.5 Image of tracks of birds heading south to west in the hours before midnight, in the first 5 nights of January 2008. Only tracks longer than 10 echoes are shown. Data from horizontal radar.

9.2.2 Flight activity

The activity patterns shown in this paragraph were more accurately measured with the vertical radar, and are discussed in more detail in chapter 10. Here, they serve merely to elucidate the patterns underlying results on flight behaviour around the wind farm area, as well as possible differences with vertical radar measurements on fluxes. Overall flight activity, as measured with the horizontal radar, was highest in spring and autumn, and lowest in winter and summer (fig. 9.6). This corresponds well with densities recorded visually (§8.2.2, table 8.2) and with fluxes recorded with the vertical radar (ch. 12, fig. 12.1), and thus confirms the validity of the clutter filter and the resulting data on flight paths discussed in this chapter.

Variation in flight activity was high (as shown by the large standard deviations), reflecting the variation between time of day, weather conditions, etcetera. In winter and spring, the majority of bird tracks was recorded at dawn (fig. 9.7). In spring, nocturnally migrating birds come down from higher migration altitudes at dawn, to rest on land during the day. The high percentage of tracks at dawn may be a result of this pattern, indicating that during the night the migration altitude was too high to be recorded by the horizontal radar, while at dawn birds flew low enough to be tracked with the radar, as was observed with the vertical radar (see §11.2.4, fig. 11.7 & ch. 12). In summer, flight activity at night was very low and the majority of birds flew during daytime. The highest nocturnal flight activity was measured in autumn. Mean number of tracks recorded per month during the study show no overall increase or decrease in numbers of birds flying in the study area (fig. 9.8). This is in line with results from visual observations on individual species (§8.2.3) and with fluxes obtained with vertical radar (§10.2).

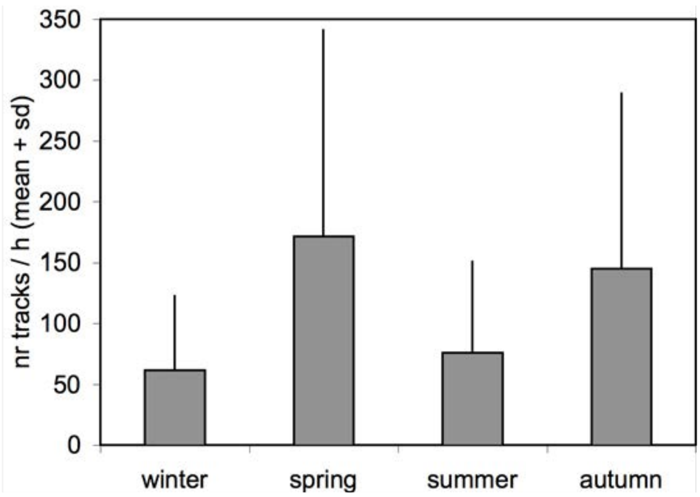


Figure 9.6 Flight activity in each of the seasons, as measured with horizontal radar. Bird activity was lowest during summer, and highest in migratory months.

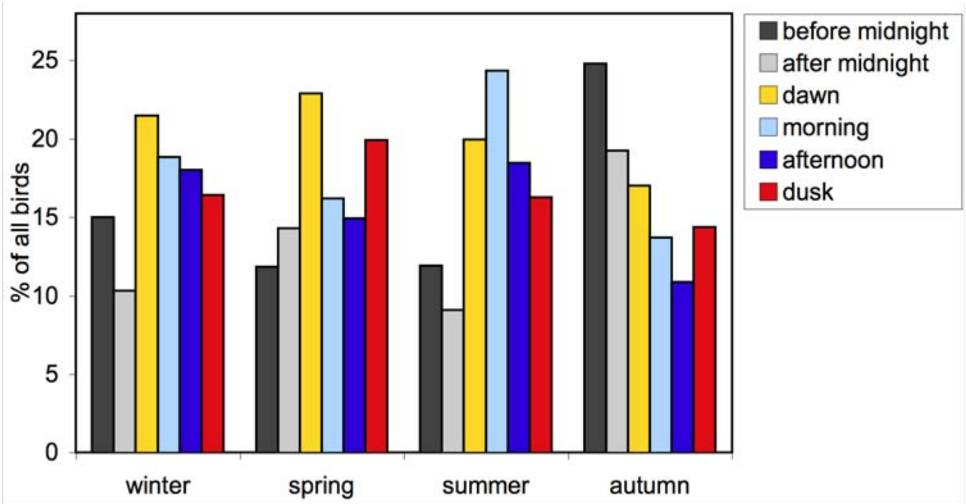


Figure 9.7 *Distribution of flight activity over the day, shown for all seasons separately, as measured with horizontal radar. In spring, the majority of birds was recorded at dawn and dusk, in summer during daytime, and in autumn during the night.*

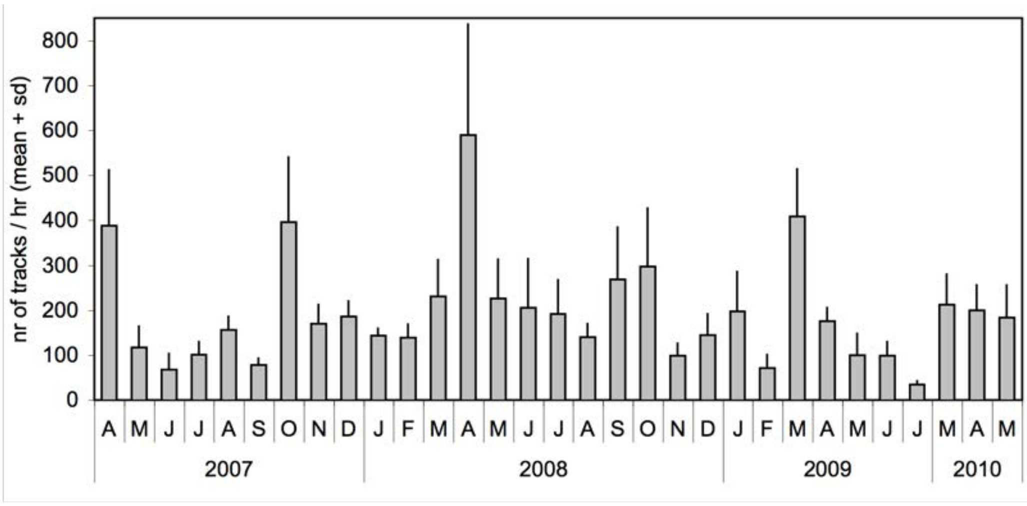


Figure 9.8 *Overview of the average number of bird tracks per month recorded with horizontal radar through the years.*

9.2.3 Effects of weather in data collected with horizontal radar

Data collected with horizontal radar were strongly related to the level of clutter caused by waves. Overall they do however show a similar pattern in fluxes as observed with vertical radar and during visual observations. In this paragraph, the effects of wind speed and wave height on the horizontal radar data are described.

During the measurements with horizontal radar, wind speeds of 4 to 5 Bft were most common (fig. 9.9). Very calm periods (<1 Bft) or periods with very strong winds (>7 Bft) were, not surprisingly, much more rare. Although the radar had to be turned off during periods with very high winds (>7Bft), the horizontal radar was most resistant to strong winds, and a considerable number of observations could be obtained with winds of 7 and 8 Bft, in contrast to vertical radar and visual observations. Most data are available for wave heights between 0.30 and 1.50 m (fig. 9.9). At wave heights of 1.80 m and more, too much clutter was generated to be able to see bird tracks, and these data were filtered out. Generally this means that in the horizontal data base, periods with very strong winds reflect coastal easterly winds, because winds from that direction come from land and result in waves that are less high than during winds from the SW. Waves were highest during winds from the north-west and the north, and lowest during easterly winds (fig. 9.10). The number of flying birds recorded decreased steadily with increasing wind speeds (fig. 9.11). This probably reflects sea clutter increasingly obscuring flight paths of birds with increasing wave heights, rather than an actual decrease in numbers of flying birds.

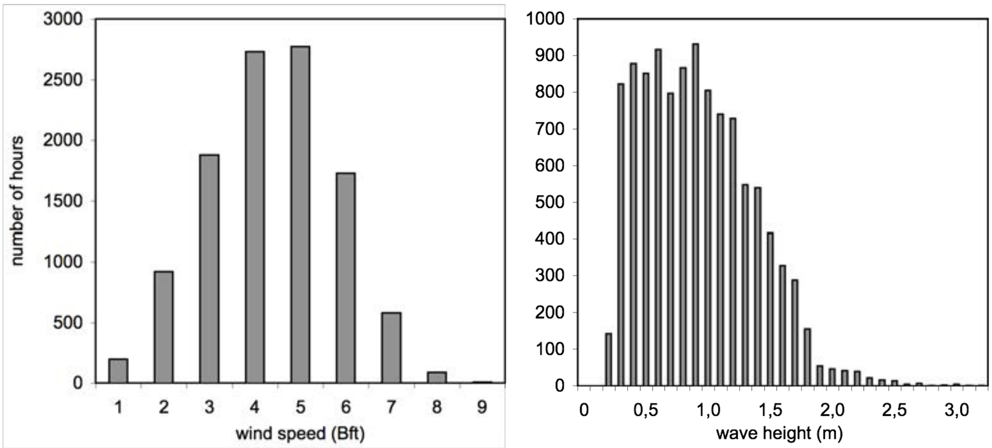


Figure 9.9 *Availability of different wind speeds and wave heights in the horizontal radar data. Shown are the number of hours with specific wind speeds (left panel) and wave heights (right panel).*

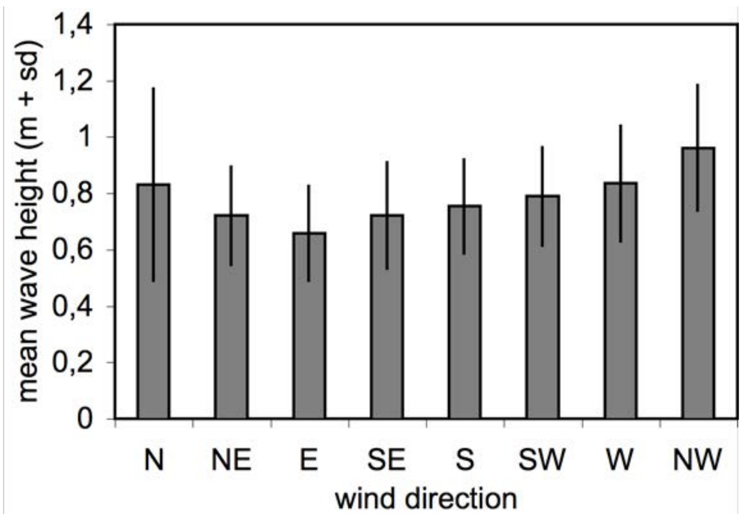


Figure 9.10 *Mean wave height in relation to wind direction. Wave height was lowest at easterly winds and highest at north-westerly winds. Data limited to horizontal radar data base on bird tracks.*

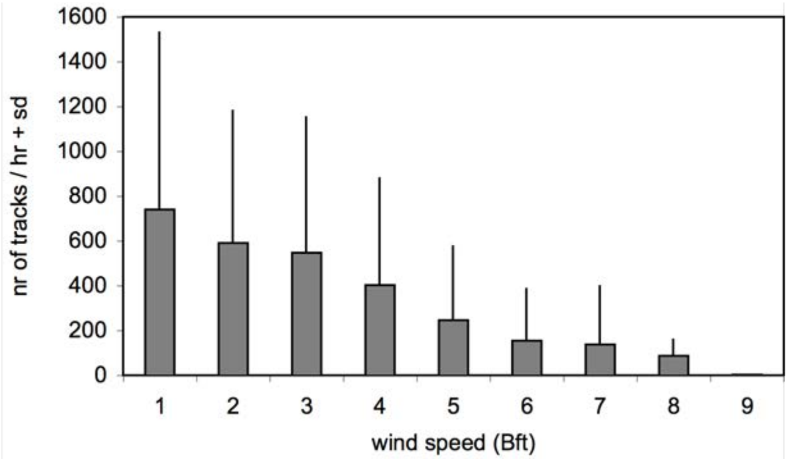


Figure 9.11 *Number of bird tracks recorded with horizontal radar as a function of wind speed. An average of 0.8 bird tracks/hr was measured during six hours with wind force 9. This presumably reflects increasing levels of sea clutter obscuring flight paths of birds.*

9.3 Spatial distribution of flight paths in response to the wind farm

One of the main questions of this study is whether flying birds avoid the wind farm, and to what extent this occurs. To assess this, we divided the flight directions and the number of tracks as recorded with the horizontal radar over a grid of cells placed across the wind farm area (see fig. 6.24) and analysed the data using the distribution over grid cells. This analysis deals with the distribution of flight paths in the study area in and around the wind farm, in order to assess the extent to which avoidance of the wind farm occurred. Whether or not the wind farm affected the distribution of local seabirds, also in a larger area around the wind farm, is discussed in Leopold *et al.* (2011).

9.3.1 Detection loss

Detection loss due to distance from the radar

Because the number of tracks recorded was heavily correlated with distance (fig. 9.12), the data needed to be corrected for distance from the radar. For instance, the comparison of the number of tracks in- and outside the wind farm was made for similar distance classes. In the statistical analysis, distance from the radar was included as random factor (GLMM) or as primary (accumulated GLM) explanatory variable. This way, any effects of distance from the radar are accounted for, and do not interact with the significance of the variables (such as within or outside of the wind farm, season, etc.) of which we want to know the effect on flight paths.

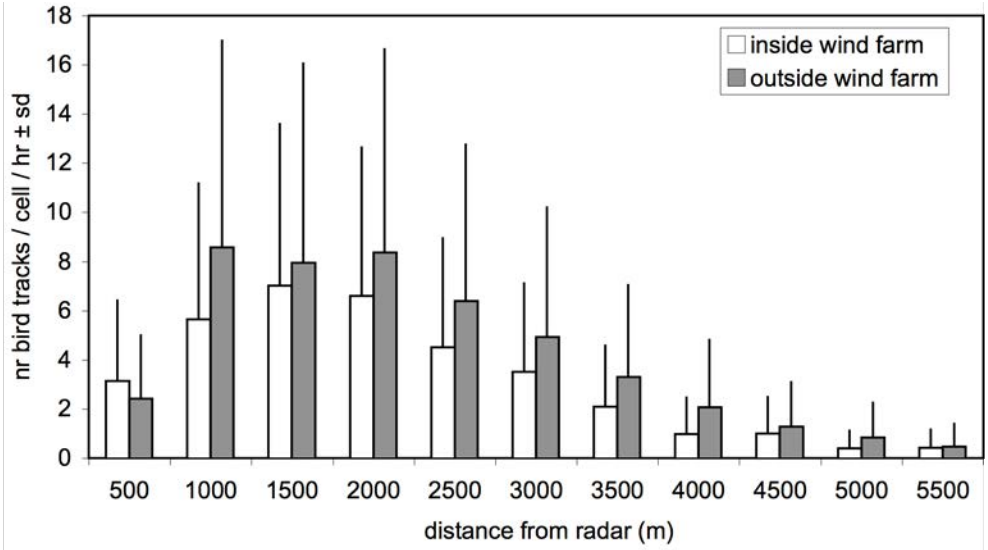


Figure 9.12 Number of recorded tracks in relation to distance from the horizontal radar, showing the effect of limited detection altitude close to the radar, and increasing detection loss further away from the radar. Shown as well is the difference in the number of bird tracks within and outside the wind farm, given the distance of the tracks from the radar. Lower numbers inside the wind farm are partly a result of detection loss due to the presence of the turbines.

Detection loss due to interference from turbines

The number of tracks varied largely due to differences between seasons, time of day, weather conditions, etc., but within these conditions, showed a pattern of higher numbers outside the wind farm (fig. 9.12). This does not directly reflect actual lower numbers of tracks inside the wind farm, because it can also be a result of detection loss due to the presence of and/or interference from the turbines. This would lead to lower numbers of bird tracks inside the wind farm even if the actual number of birds flying there were the same.

To quantify this detection loss, we compared the number of bird tracks in areas around the wind farm, that either were obstructed by turbines (blocks C, D, F & E in fig. 9.13) or were not obstructed by turbines (blocks A & B in fig. 9.13). The area with turbines was also included in the analysis (block T in fig. 9.13). To avoid interactions with distance effects, we limited the analysis to data at distances over 4000 m away from the radar. By limiting the analysis to these larger distances, the different blocks were all represented in the analysis. Because of the selection of larger distances only, it is possible that the data reflect larger species than on average, which could in turn affect the detection loss that needs to be quantified. However, because flight paths at closer distances are limited to blocks A and T, a comparison at smaller ranges would always include data on flight paths within the wind farm. Because these may be reduced due to actual lower flight activity within the wind farm, block T cannot be used to assess detection loss. Therefore it was not possible to compare flight paths in the blocks at smaller distances.

The difference in number of tracks between blocks was tested statistically with an accumulated GLM. Analysis was based on numbers of tracks/grid cell/hr, averaged to the level of time of day for three periods per month. The parameters season, year, time of day and wind speed were entered first, being the main explanatory variables for variation in numbers of tracks, after which the effect of block was added to the model. Block added significantly to the model, and the number of tracks varied significantly between blocks (table 9.1). The differences between the blocks in number of tracks is visualized in figure 9.14.

The number of tracks in each of the blocks differed significantly from the number in block A. Only numbers in block B did not differ significantly from block A. Numbers in the blocks behind the turbines (blocks C, E & F) were all significantly lower than in block A. Block D formed an exception in this respect, as numbers here were slightly but significantly higher than in block A, even though the block lies behind the turbines. This is discussed below (§9.3.6, fig. 9.19). Lowest numbers relative to block A were measured in the block with the turbines (T). The fact that numbers were lower within than behind the wind farm, reflects the reduced flight activity of birds within the wind farm, because detection loss due to turbines also affects the numbers in the blocks behind the wind farm.

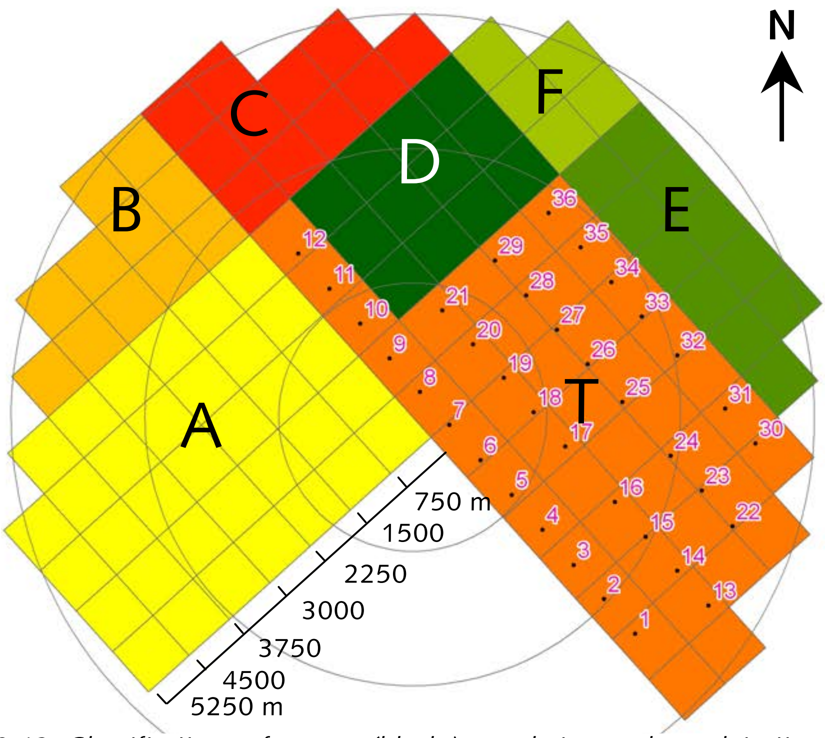


Figure 9.13 Classification of areas (blocks) used to analyse detection loss in horizontal radar data due to interference from turbines. Scale indicates distance of grid cells from radar in m.

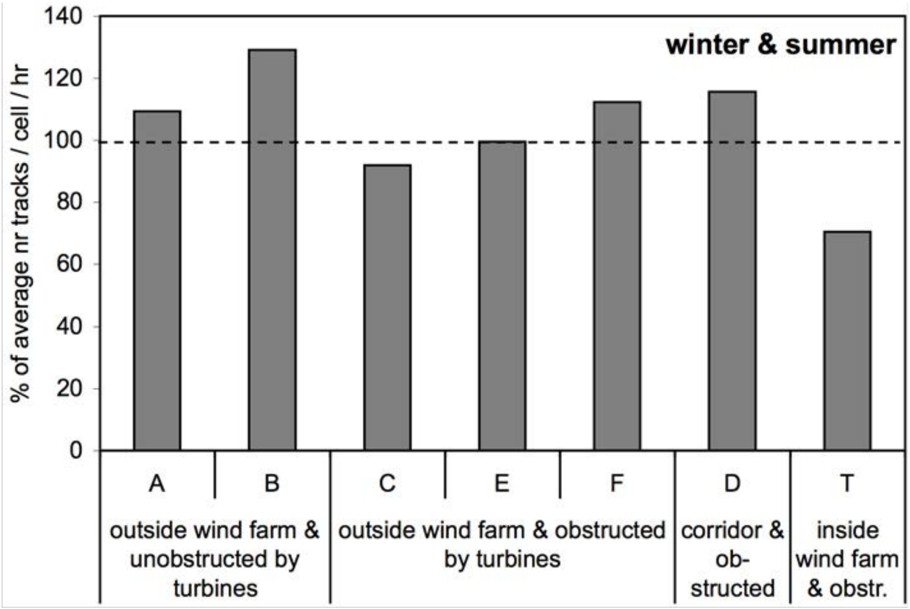


Figure 9.14 Difference in detection between areas that did or did not suffer interference from turbines, expressed as percentage relative to the overall average number of tracks/cell/hr, at distances >4000 m from the radar. Data from horizontal radar. Highest detection rate in unobstructed blocks A&B, intermediate behind turbines in C-F, lowest in wind farm area T. Numbers are high in obstructed block D compared to A due to corridor in wind farm construction. Relatively high numbers in C-F (behind turbines) compared to T (within wind farm) reflect low numbers of birds flying in T but not C-F.

To quantify the level of detection loss due to interference from turbines, we have to take into account differences in flight activity in the various blocks, due to for instance seasonal differences. In autumn, when flight paths originated mostly from migrating birds flying in south-westerly directions, patterns were significantly different from the overall pattern. The difference in the number of tracks between block A and blocks E and F behind the wind farm was much smaller in autumn than in all seasons combined. This may indicate either that detection loss behind the wind farm was very limited, or that the numbers of tracks in the blocks behind the turbines increased to such an extent that the effect of detection loss is rendered invisible. This could be the case when birds approaching the wind farm change their flight direction only at very short distances from the wind farm (a few km), resulting in a build-up of flight-activity in that area, similar to fig. 9.16).

The difference between numbers of tracks in blocks A and T was smaller in autumn than for all data combined, and larger in spring. This is in line with the latter hypothesis that in autumn, birds arriving from north-easterly directions will deflect away from the wind farm at that side (e.g., from blocks E and F to blocks C and B), resulting in more similar numbers in block A and T. In spring, migrating birds heading to north-easterly directions will deflect away from the wind farm in block A, resulting in larger differences between blocks A and T.

To obtain an estimate for detection loss in and behind the turbines, we compared data from the summer and winter season, when flight activity was dominated by local birds, and excluded flight paths in block D. These seasons were chosen because in spring and/or autumn, the numbers of tracks in blocks B, C, E and F were higher than numbers in T due to deflection of flight paths. Because of this, data from these seasons could not be used to determine detection loss due to the turbines. Numbers in block D were elevated and therefore could not be used either.

In the blocks behind the turbines (C, F & E) the number of tracks in these seasons was on average 15% lower than in the blocks unobstructed by the turbines and at the same distance from the radar (A & B). Thus, numbers of tracks within and behind the wind farm have to be increased by 15% in order to correct for detection loss due to interference form turbines, and represent the actual number of tracks.

After correction for detection loss due to interference from turbines, the distribution of birds inside and outside the wind farm was established. Numbers of tracks in the different blocks were compared within distance classes from the radar, because of the effect of distance on detection rate. Numbers of tracks in blocks C-F were increased with 15% to correct for detection loss due to interference from the turbines.

This was also done for the number of tracks in block T (the wind farm). However, because the majority of the wind farm was situated closer to the radar than 4000 m, assuming a detection loss of 15% will overestimate the number of tracks inside the wind farm. To allow for this effect, we increased the number of tracks in block T and between 0-4000 m from the radar with 0.5*15 = 7,5%. Although this is a rough estimate, it approaches the actual number of tracks inside the wind farm better than doing no correction or using 15% for all distances within the wind farm.

9.3.2 Distribution of birds in relation to the wind farm & macro-avoidance

Birds may or may not fly into the wind farm as they move from one location to the other. Birds may avoid either the entire wind farm, or just individual turbines within the wind farm. The former behaviour is called macro-avoidance, the latter micro-avoidance. This paragraph focusses on macro-avoidance, micro-avoidance is discussed in detail in ch. 13. To assess whether or not avoidance occurs, and to what extent, we can investigate the number of tracks recorded within the wind farm versus outside it, and we can study changes in flight directions of birds.

A comparison of the *number of flight paths* results in good quantitative information on whether avoidance occurred. This is especially the case since we rasterized the wind farm area, and determined both the number of tracks and the average flight direction and variation therein for each grid cell and for each time unit. It is hampered however by detection loss as described in the former paragraph. This was dealt with by comparing areas inside and around the wind farm that had comparable levels of detection loss (distance from radar), or by correcting for detection loss (distance and turbines interference). Because of the detection loss in the wind farm and in the areas behind the wind farm, we had to limit the analysis to specific areas of the wind farm for which comparisons were justified.

Table 9.1 Statistical results of the difference in numbers of tracks due to turbine interference. The number of tracks in each block is given relative to block A. Behind the turbines, fewer tracks were recorded. This effect was weaker in autumn, when migrating birds approached the wind farm in blocks E and F behind the turbines. Test was an accumulated GLM with Poisson distribution and estimated dispersion (Genstat v.13). Data restricted to distances over 4000 m from the radar.

	parameter estimate	test-statistic *F* or *t*	degr. freedom (regr./total)	F-probability *P*
All seasons:				
Model with significant effects of season, year, time of day and wind speed:				
		951	8 / 27334	<0.001
Added effect of block:		171	6 / 27334	<0.001
Parameter estimates of blocks:				
block A	0	0		
block B	0.004	0.2	27320	NS
block C	-0.297	-13.2		<0.001
block D	0.100	3.1		<0.005
block E	-0.160	-7.9		<0.001
block F	-0.276	-10.1		<0.001
block T	-0.622	-26.0		<0.001
Autumn:				
Model with significant effects of year, time of day and wind speed:				
		300	5 / 4687	<0.001
Added effect of block:		45	6 / 4687	<0.001
Parameter estimates of blocks:				
block A	0	0	4676	
block B	-0.084	-2.0		<0.05
block C	-0.416	-8.6		<0.001
block D	0.247	4.0		<0.001
block E	-0.026	-0.7		NS
block F	-0.236	-4.3		<0.001
block T	-0.564	-11.6		<0.001
Spring:				
Model with significant effects of year, time of day and wind speed:				
		373	5 / 10514	<0.001
Added effect of block:		66	6 / 10514	<0.001
Parameter estimates of blocks:				
block A	0	0	10503	
block B	0.035	1.0		NS
block C	-0.248	-6.4		<0.001
block D	-0.013	-0.2		NS
block E	-0.257	-7.0		<0.001
block F	-0.350	-7.1		<0.001
block T	-0.691	-16.1		<0.001

A comparison of *flight directions* gives direct insight in whether birds adjust their flight paths to avoid the wind farm or not. This would be especially true for longer flight paths that can be followed through or around the wind farm. However, because of the large amount of sea clutter, most tracks of birds were of limited length. A bird would be tracked, then the signal would be lost for a while in the clutter, and would be picked up again a little further. When the signal was picked up again, it was however given a different trackID, and could not be joined to the previous recorded part of its flight path. Longer tracks do exist in the database, but these did not reflect general flight directions, as they are mostly of larger birds species such as gulls, or larger flocks of birds. In addition, flight directions were very pluriform, even during migration. Depending on wind direction and speed, as well as the species groups flying by, flight direction changed considerably. Spring migration for instance varied in the course of the night and between days from NE to E to even SE, and different groups of birds simultaneously could fly in different directions. This variation made it difficult to pinpoint patterns and quantify deviance from the prevailing route. And just this deviance is the required parameter to assess occurrence of avoidance. Because of these issues, analysis was focussed on uniformity in heading of tracks within grid cells, as well as average flight direction in relation to position around the wind farm. To illustrate specific behaviours, we added examples of typical flight behaviour that were observed.

Macro-avoidance of the wind farm
The percentage of birds that flew within the wind farm was 72% on average of the number outside of the wind farm (after correction for detection loss due to interference from turbines; see previous paragraph). Avoidance level was lowest in winter when the number of tracks inside the wind farm was ca. 82% of the number outside the wind farm (avoidance level 18%; fig. 9.15). In autumn, the avoidance level was highest, with only 66% of the number outside of the wind farm (avoidance 34%). Avoidance thus lay between 18 and 34%.

This estimate of 18-34% avoidance (28% on average) is a cautious estimate of the macro avoidance rate, not only because it is subject to high levels of variation (e.g. between species and between seasons), but also because corrections had to be made for detection loss due to distance from the radar, and due to interference from the turbines. If there are biases in the corrections, then this will affect the calculated avoidance levels.

For instance, in the wind farm the flight path of one bird may be recorded relatively more often as more than one track, because the track may be lost temporarily behind a turbine, and then be picked up again as a different track. This effect is probably limited, and if present occurring mostly for smaller birds species, as based on visual evaluation of tracks of various lengths and of various species (small and large; during different seasons and times of the day). Such an effect would lead to an overestimation of the actual number of birds in the wind farm, and therewith to an underestimation of the actual avoidance rate.

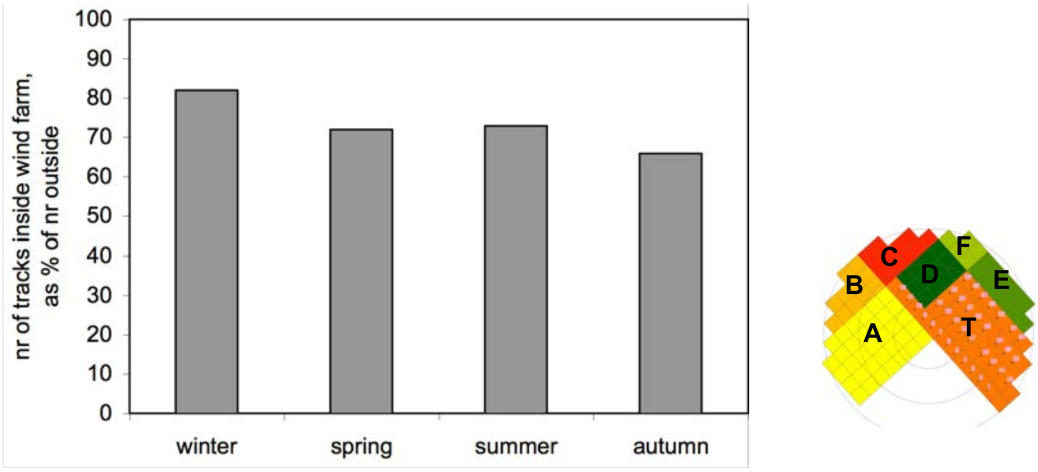


Figure 9.15 Number of bird tracks flying within the wind farm, shown as percentage of the number of tracks outside the wind farm, for each season. Data corrected for detection loss due to distance effects and turbine interference, analysis based on comparison between area T versus A-F. On average, 28% less birds flew within the wind farm than outside. Data from horizontal radar.

9.3.3 Distribution of birds in relation to distance from wind farm

Adaptation of flight paths may occur up to large distances from the wind farm. If this occurs, it should be visible in increasing numbers of bird tracks at larger distances from the wind farm. The number of birds did however not increase with larger distances (measured up to 5.5 km from the wind farm). In contrast, the number was highest at 750–1500 m from the wind farm (not to be confused with distance from the radar), and then decreased or remained similar at larger distances (fig. 9.16). The high numbers at close distance from the wind farm compared to further away, suggests a build-up of flying birds at short distances around the wind farm. This in turn suggests that the majority of birds that were flying in the area, deflected away from the wind farm only at short distances from it, rather than several kilometres away. This is confirmed by the visually observed flight paths of individual species, presented in §9.7.

The above patterns were analysed statistically. For this purpose, data in blocks A and B were selected, as well as data from the adjacent row of turbines. Distance from the wind farm was expressed in nr of grid cells away from the wind farm. Detection loss related to distance *from the radar* was accounted for by entering this parameter first in an accumulated generalized linear model (Genstat v. 13). For all seasons combined, the number of tracks in the grid cells just outside the wind farm (ca. 750 m) was significantly higher than the number of tracks at the adjacent single row of turbines (*i.e.* grid cells containing the adjacent single row of turbines) (accumulated GLM: effect of in- or outside wind farm on the number of tracks/gridcell/hr : $t_{(2228)}=3.4$, $P<0.001$, parameter estimate = 0.13 for tracks outside the wind farm). The number of tracks outside the wind farm decreased significantly with increasing distance *from the wind farm* (accumulated GLM: effect of distance from the wind farm on the number of tracks/gridcell/hr : $t_{(8915)}$=-11.3, P<0.001, parameter estimate = -0.09 for increasing distance). A highly similar result was obtained for data from spring only.

The distribution of birds in relation to distance from the wind farm was tested for flight paths in blocks A and B only (*i.e.* blocks unobstructed by turbines). This was done to avoid effects of detection loss due to turbine interference. This selection represents the flight patterns during the spring season well, because during this time birds approach the farm in blocks A and B. The selection may however misrepresent flight patterns in other seasons, especially in autumn, because birds approaching the wind farm from the north-east will have adjusted their flight paths already when they arrive in blocks A & B. In summer and winter, mostly local birds were present in the area, with random flight directions. Limiting the selection to blocks A & B will therefore not affect the resulting patterns of this group of birds.

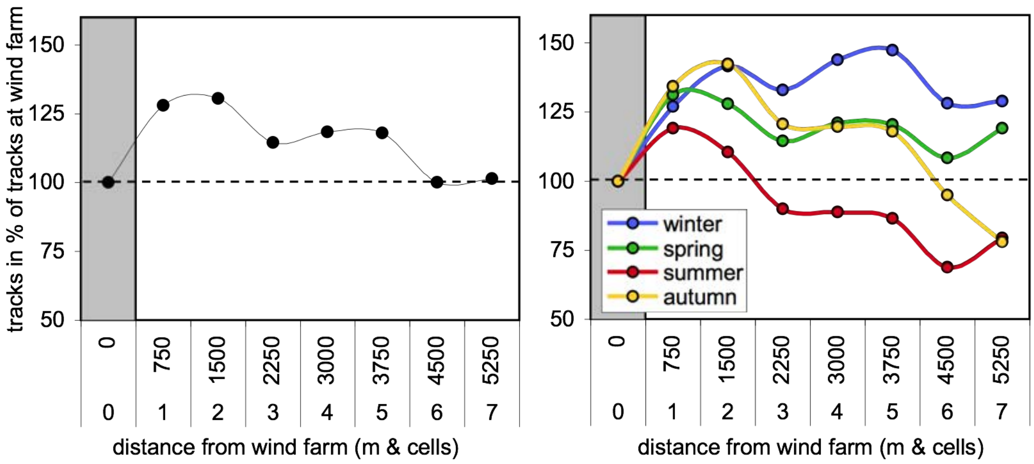


Figure 9.16 Number of tracks in relation to distance from the wind farm, expressed as % of the number at the adjacent single row of turbines. Overall average in left panel, seasonal averages in right panel. Distance given both in m as in grid cells. Grey area marks first turbine row. Comparison based on tracks in blocks A&B, including the adjacent single row of turbines, and between cells at equal distances from radar. Data from horizontal radar. Bird numbers were highest at close distances away from the wind farm, suggesting a build-up of birds flying closely around the wind farm.

9.3.4 Differences between day and night in distribution of birds

In summer and winter, flight activity was higher during the day than during the night, reflecting activity of mostly local seabirds, which are active during daytime and much less during nighttime. During the migratory season, flight activity often was higher during the night, reflecting activity of large numbers of nocturnal migrants (especially in autumn, in spring high fluxes of birds were also measured during daytime). These patterns were established with vertical radar (see §10.2.3), and observations with the horizontal radar yielded similar results.

To determine whether birds respond differently to the wind farm during daylight than in the dark, we tested whether the percentage of flight paths inside the wind farm was different between day and night. Because local birds may respond differently to the wind farm than migratory birds, seasonal patterns have to be included in this analysis. The percentage of birds flying in the wind farm (block T) relative to the number outside the wind farm was higher during daytime than at night (fig. 9.17). In other words, in the dark a lower proportion of birds entered the wind farm than during daylight. This difference was significant when data from spring were excluded from the analysis (Anova: $F_{1,114} = 9.7$; $P<0.005$). This result is analogous to the results obtained from studying flight activity close to turbines (micro-avoidance, §13.5), as well as to results obtained at the Horns Rev offshore wind farm in Denmark (Petersen *et al.* 2006).

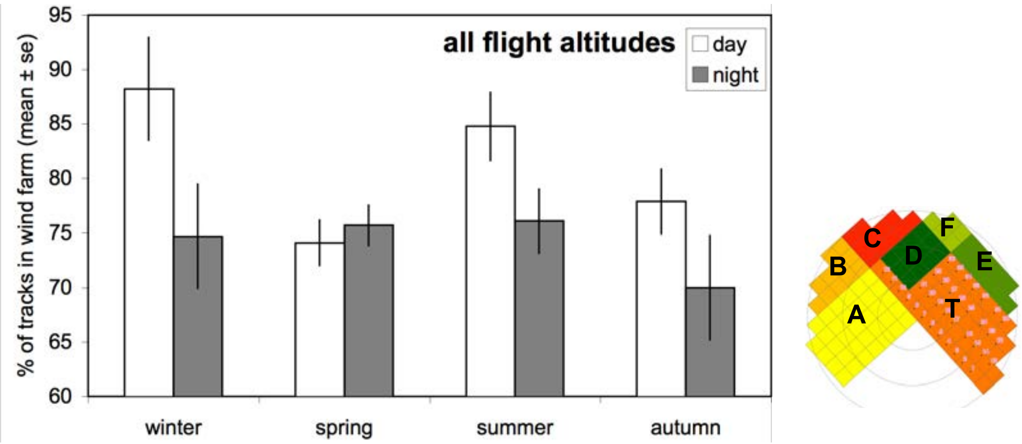


Figure 9.17 Comparison between day and night in the percentage of flight paths measured inside the wind farm. At night, significantly fewer birds flew through the wind farm than during daylight except in spring. Percentage calculated as number of tracks in block T relative to block A. Results similar for other blocks around the wind farm. All flight altitudes included. Data from horizontal radar. The percentages given can only be used to compare relative activity in the wind farm between day and night, and do not reflect actual avoidance levels because distance-effects are included.

Here we show results for comparison between blocks T and A. Patterns were comparable for other blocks, but showed seasonal effects. We included all flight paths that were recorded with the horizontal radar. These included flight paths up to altitudes well above rotor height. Birds that fly well above rotor height are less prone to fly around the wind farm than birds flying at rotor height (as established visually, see §9.7). This means that when we would consider flight paths of birds flying at rotor height, it is very likely that an even lower proportion of birds would enter the wind farm during dark. A rough estimate suggests that the proportion of birds entering the wind farm at night is half to two thirds of the number entering the wind farm during day time. Differences between day and night were largest in summer and winter, when mainly local birds flying at low altitudes are present in the area. Migratory birds in spring and autumn generally flew at higher altitudes, resulting in smaller differences between day and night and a higher level of variation. The difference in avoidance between day and night at rotor height is not quantifiable, because for the horizontal data altitudes of flight paths are unknown.

Selecting only periods when flight altitudes were low (based on flight altitudes from vertical radar, resulting in selections of either 20 or 10% of all data) resulted in an increased difference between day and night in the percentage of flight paths in the wind farm, but this was mainly visible in data from summer and winter. For the migratory seasons, variation in flight altitudes was too high within the time periods that were available for analysis.

9.3.5 Distribution of birds in relation to turbines being in operation or down

During visual observations, birds were often seen entering the wind farm there where a turbine was down. This is relevant, because periodically shutting turbines down is seen as a means to prevent bird collisions for instance during periods with high migratory activity. This prompted us to investigate how birds in the wind farm were distributed in relation to turbines that were operating and turbines that were idling. Based on the radar data, we calculated how the number of bird tracks in a grid cell within the wind farm differed between when the nearest turbine was operating and when it was idling (less than 1 rotation per minute; corresponding to a maximum tip speed of the rotors of 17 km/hr. Standard ca. 12 rotations per minute). The number of bird tracks was two to three times higher when the nearest turbine was off than when it was on. 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. This difference occurred both day and night, and in all seasons (fig. 9.18). During dark, slightly more birds seemed to avoid the turbine when it was on than during daytime, but this difference was not significant (GLM; effect of daylight on proportion of birds (arcsine transformed) flying past turbines that were idle, tested on residuals of year). There was also no significant difference between seasons. The increase in bird tracks near turbines that were idle was most explicit when distance to the turbine was 250 m or less. These results are in line with results found on a more detailed scale, as described in §12.5.

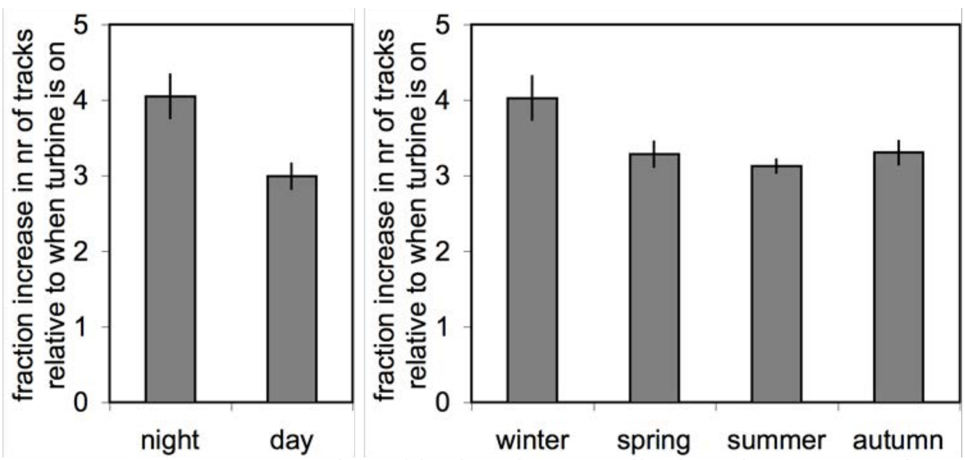


Figure 9.18 Increase in number of bird tracks in a cell when the nearest turbine was idling compared to in operation. Shown are means with standard errors). Effect was stronger during night than during day (left panel), and was somewhat stronger in winter than in other seasons (right panel). Data from horizontal radar.

9.3.6 Relations with design of the wind farm (micro-siting)

Passages through single line of turbines versus main body of wind farm

Birds avoiding the wind farm, structurally avoided the main body of the wind farm more than the single line standing out at the NW-side of the wind farm (see also §9.3.2). When approaching from southerly or westerly sides, they more often passed turbines 9 through 12, that are positioned on the edge of the wind farm, than they did turbines 6 through 3, that are positioned in the centre of the wind farm. Birds passed especially often between turbines 9 and 10, which is where the main body of the wind farm ends and only one single line of turbines remains. This is depicted in figure 9.19, where the number of bird passages per grid cell per hour is plotted against distance from the radar. Data are shown only for the south-westerly row of turbines, numbers 1 through 12 (see fig. 3.2), or grid cells 46 through 60 (see diagram in fig. 9.19 below). This was done to avoid differences in detection loss due to turbine interference. Because detection loss increases with increasing distance from the radar, data are plotted as function of this distance, and the comparison was made pairwise for similar distances. At the same distance from the radar, the number of passages towards the NW of the turbine row and the edge of the wind farm was compared to the number towards the SE of the turbine row and the centre of the wind farm. The number of passages was significantly higher at the outer turbines of the wind farm than at the centre of the wind farm, for each given distance (paired samples T-test: T_{3454}=-45.5, P<0,001). On average, 4.1 bird tracks per hour passed grid cells at the edge of the wind farm, versus 2.3 at the centre.

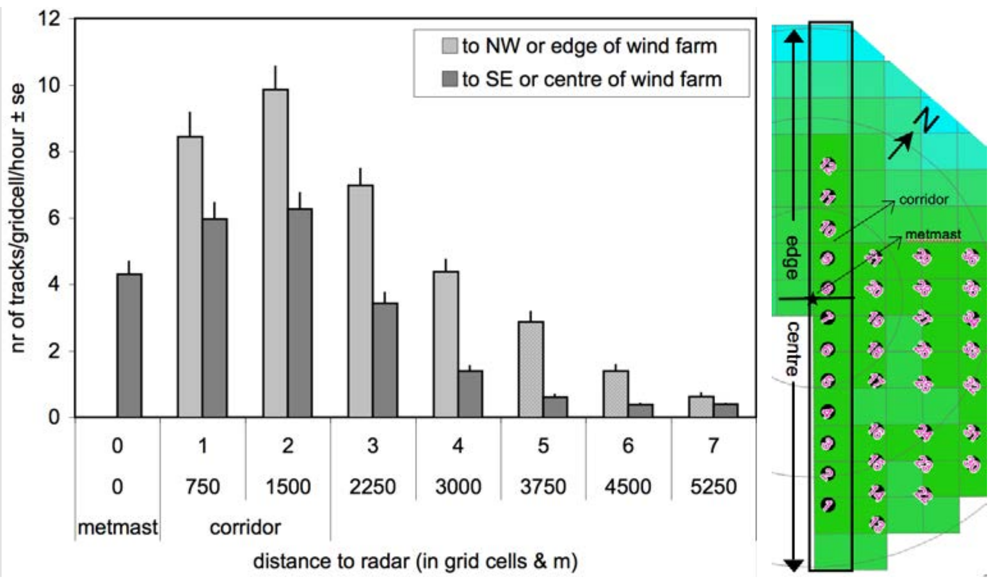
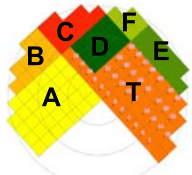


Figure 9.19 Number of bird tracks in spring during daytime, passing the outer row of turbines, shown for increasing distance to the metmast and radar (MM). Significantly more birds passed the turbines at the edge of the wind farm than the turbines more in the centre of the wind farm. The 'corridor' at the outer turbines lies between turbines 9 & 10, between distances 1 & 2. Selection of grid cells for analysis is outlined in black, in diagram of wind farm on the right. Data from horizontal radar.

In line with this pattern, the number of tracks was relatively high in block D, which has turbines on two sides. When taking into account the effects of distance, season, wind speed etc., numbers of tracks were even slightly but significantly higher than in block A, even though block D lies behind the turbines (from radar perspective) and thus suffered more detection loss than the wind farm itself (statistical results in §9.3.1, table 9.1, see fig. 9.14 for percentage of flight paths in block D versus A and T). These high numbers are a result of the fact that many birds that did avoid the main body of the wind farm, did not avoid the single line formed by turbines 10-12, and often passed between turbines 9 and 10. This behaviour was also recorded repeatedly in the visual observations of flight paths of individual species (see §9.7). In addition, densities were slightly elevated in the areas bordering the wind farm, due to a build-up of birds flying at short distances around the wind farm (see fig. 9.16).



Spacing of turbines

In addition, within the wind farm, the number of bird tracks was significantly higher in the area in the wind farm where the turbines were spaced further apart (fig 9.20). The distance between turbines 16&17, 24&25 and 31&32 was larger than between the other turbines. The number of birds flying in the grid cells in between these turbines was significantly higher than in other areas of the wind farm, given variation in distance, season, year, and wind speeds (accumulated GLM; Poisson distribution, dispersion estimated: added effect of spacing of wind farms: $F_{1,\ 19615}$=16, P<0.001; parameter estimate = 0.10). This implies that the design of the wind farm affected the level of avoidance of the wind farm, and that avoidance levels may be lower in wind farms where turbines are spaced further apart. Similar observations were done by and reported in Leopold *et al.* 2011.

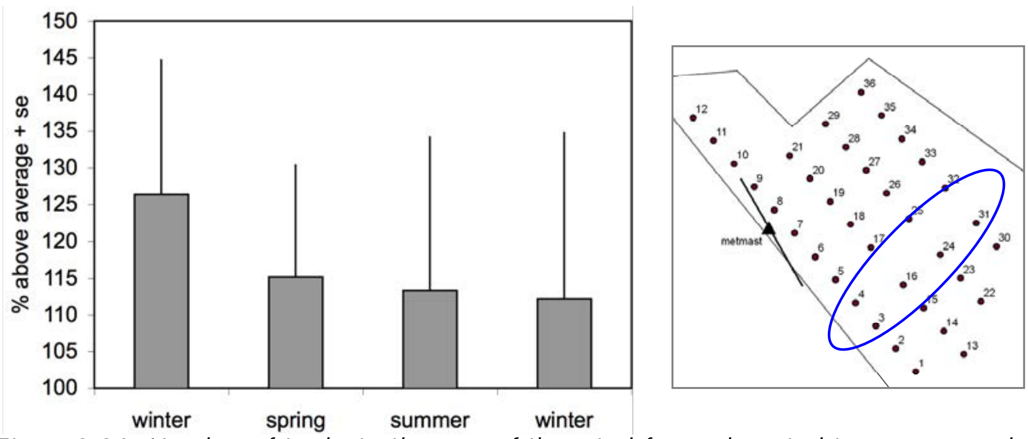


Figure 9.20 Number of tracks in the area of the wind farm where turbines are spaced further apart, shown as % above the number in cells with average turbine spacing. Data from horizontal radar. Significantly more birds flew in the area with larger spacing, in all seasons but especially in winter. Diagram on the right shows the turbines, with the area with larger spacing indicated by the blue circle.

9.4 Spatial distribution of individual species

With the horizontal radar data, no distinction could be made between species or species groups, other than by means of general patterns such as seasonal migration or local flight activity. To assess how individual species of birds or bird groups responded to the presence of the wind farm, we analyzed the visually obtained data from the panorama scans. In these data, location in relation to the wind farm was always recorded, allowing analysis of the effect of the wind farm on spatial distribution of individual species (groups). To minimize detection loss due to distance, analysis of data was limited to observations of birds within 3 km distance from the metmast.

The distribution of birds around the metmast is visualized in figure 9.21. In these graphs, the wind farm is located in the upper-right half. Distribution of birds in relation to the wind farm (in versus out) is discussed in more detail further on in this paragraph. The highest numbers of birds were present in sector 1 (north-north-west, on the edge of the wind farm). Lowest numbers were recorded in sector 6 (east-south-east, inside the wind farm). The relatively high numbers of small gulls in sector 4 and 8 are due to high numbers of common gulls and kittiwakes foraging in this area close to the metmast in autumn. Cormorants and gulls showed no avoidance of the wind farm, but numbers were not higher in the wind farm either. Terns, predominantly sandwich tern, were mostly migrating birds that foraged en route. They were regularly seen flying and foraging inside the wind farm.

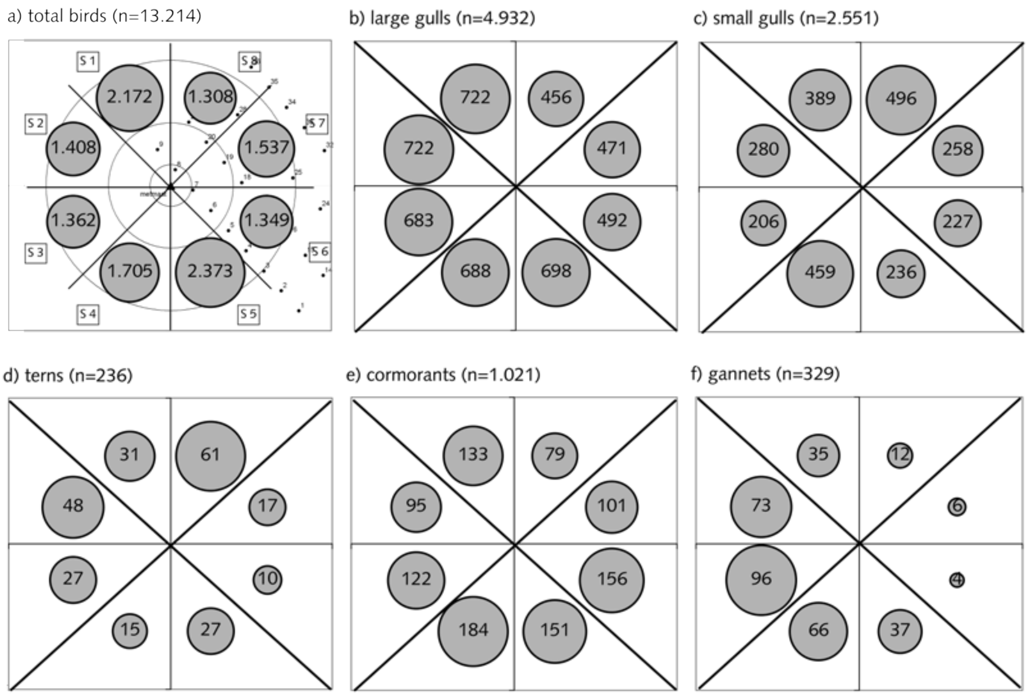


Figure 9.21 Distribution of birds in the wind farm area as observed during panorama scans. The wind farm is located in the upper-right half (pictured in a, together with sector numbers). Observations do not cover the entire wind farm but are centred around the metmast (centre of each graph). Only flying birds within 3 km from the metmast were taken into account.

The degree to which the distribution of flying birds was affected by the wind farm, varied largely between species. Some did not show any variation in distribution, while other showed strongly reduced numbers inside the wind farm fig. 9.21). To investigate this further, we divided the area within 3 km distance from the metmast into 24 segments (8 sectors, each with 3 distance segments; fig. 9.22). This division allowed us to quantify whether or not bird numbers inside the wind farm were lower than expected based on equal distributions. The 2 sectors NW and NE of the wind farm were categorized as 'edge' (green circles in fig. 9.22) because the major part of these sectors actually contained no turbines. The total surface area classified as 'outside' the wind farm was 50% (14.1 km^2) of the entire area that was observed. The total surface area 'inside' the wind farm and on the 'edge' of the wind farm were both 25% (7.1 km^2) (see fig. 9.22 and table 9.2).

Overall, birds did not seem to avoid the wind farm, because 52% of all birds were encountered outside the wind farm (fig. 9.23). When taking the separate species into consideration, the pattern changes. Of the most abundant species groups, gannets avoided the wind farm most strongly. Only 3% of all gannets were flying inside the wind farm, and 14% at the edge of the wind farm. This corresponds with observations of birds flying around the wind farm (see §9.7). Similar to gannets, seaducks (predominantly common scoter) and alcids were rarely observed inside the wind farm. Only 3% of all flying seaducks were recorded inside the wind farm, and 17% at the edge. However, numbers of flying seaducks and alcids were relatively low in the entire area.

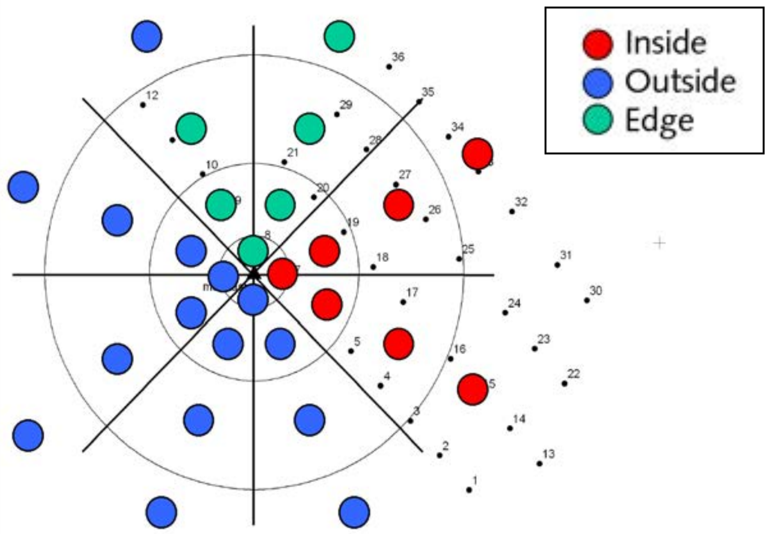


Figure 9.22 Classification of the segments that were recorded during panorama scans. Segments were either classified as being inside the wind farm, outside the wind farm or the edge of it. Classification was based on characteristics of each segment and the number of wind turbines present. The metmast (in the centre of the graph) and the turbines are visualized in the background.

Table 9.2 Total surface area of all panorama segments inside, outside or at the edge of the wind farm. Only segments within 3 km distance from the metmast taken into account (see fig. 9.22 for spatial layout of segments).

	distance (m)				total	
surface (km^2)	0-500	500-1500	1500-3000	>3000	km^2	%
inside	0.2	1.6	5.3	-	7.07	25
outside	0.4	3.1	10.6	-	14.14	50
edge	0.2	1.6	5.3	-	7.07	25
total	0.8	6.3	21.2	-	28.28	100

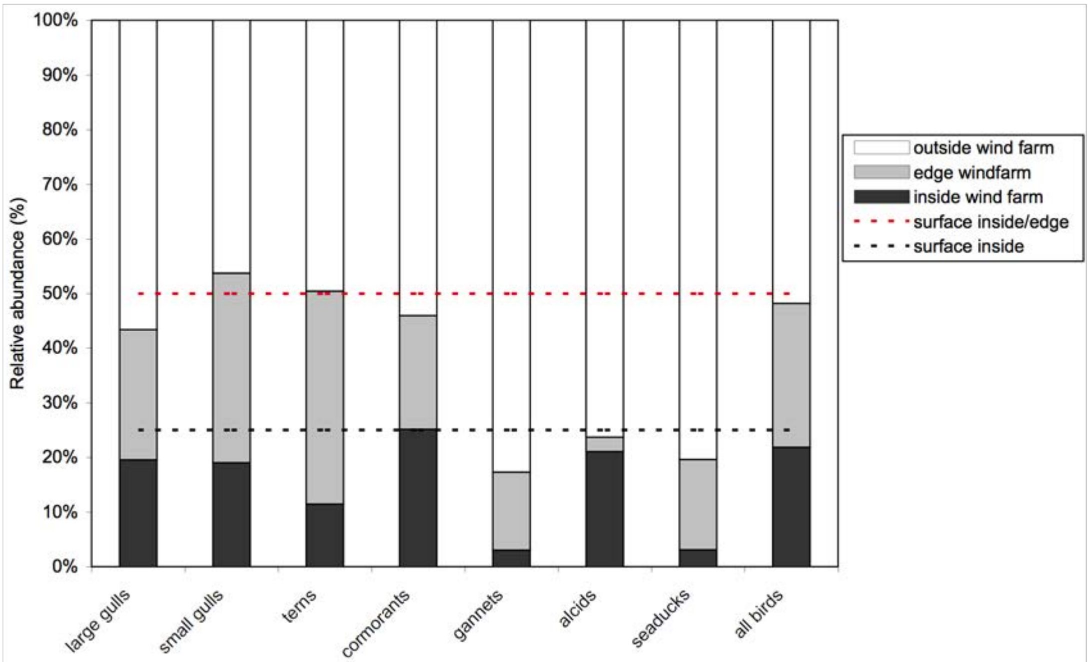


Figure 9.23 Relative proportion of the most abundant species groups within, outside and at the edge of the wind farm. Given the layout of the wind farm within the area observed with panorama scans, the proportion of birds outside the wind farm should be 50% when no avoidance occurs (red dotted line). The black dotted line reflects the expected proportion of birds inside the wind farm when no avoidance would occur. Only flying birds within 3 km distance from metmast taken into account. See fig. 9.22 for spatial layout of segments. Proportions of gulls and cormorants show no avoidance, terns were concentrated on the edge of the wind farm, low proportions of the seabird species inside the wind farm reflects avoidance.

Terns (predominantly sandwich terns) were relatively scarce inside the wind farm (11% of al terns seen, fig. 9.23). However, the proportion of terns encountered at the edge of the wind farm was relatively high (39%). Like gannets, terns seemed to avoid the wind farm, although the pattern differed from that of gannets. The high proportion of gannets outside the wind farm corresponds with birds flying in a wide range around the wind farm, not even passing the edge. In contrast, the high proportion of terns (predominantly sandwich terns) flying at the edge of the wind farm 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 (fig. 9.24). Highest numbers of foraging sandwich terns were observed in sector 8 (north-northwest of the metmast). Although numbers are low, data do not show that migrating sandwich terns avoided the wind farm at the last moment, because the number of non-foraging terns was not disproportionately higher at the edge of the wind farm (64% of all non-foraging terns flew outside, 23% on the edge and 13% inside the wind farm). Visual observations on flight paths do not suggest strong avoidance of the wind farm either (see §9.7).

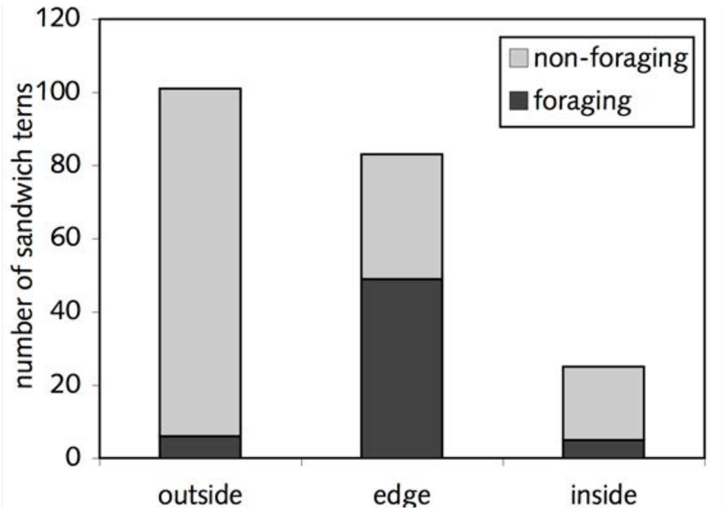


Figure 9.24 Number of sandwich terns outside, on the edge and inside the wind farm, separated for birds that were foraging or not, as observed during panorama scans. Only flying birds within 3 km distance from metmast taken into account. Within the wind farm total numbers were lower than outside, but a higher proportion was foraging, especially at the edge.

Of the more abundant species, common scoter showed the strongest avoidance of the wind farm. Only 2% of all common scoters were flying inside the wind farm (table 9.3), although the number of observations is very low and therefore may not accurately reflect flight behaviour. Other observations however show similar results (see §9.7). Apart from common scoter, also northern gannets, geese and unidentified small gulls showed relatively high avoidance of the wind farm (3% and 11% respectively of all birds flying inside the wind farm). Possibly these observations reflect black-headed gulls, which showed relatively high avoidance levels compared to other gull species. Little gull and kittiwake were relatively abundant within the wind farm compared to outside of it (fig. 9.25).

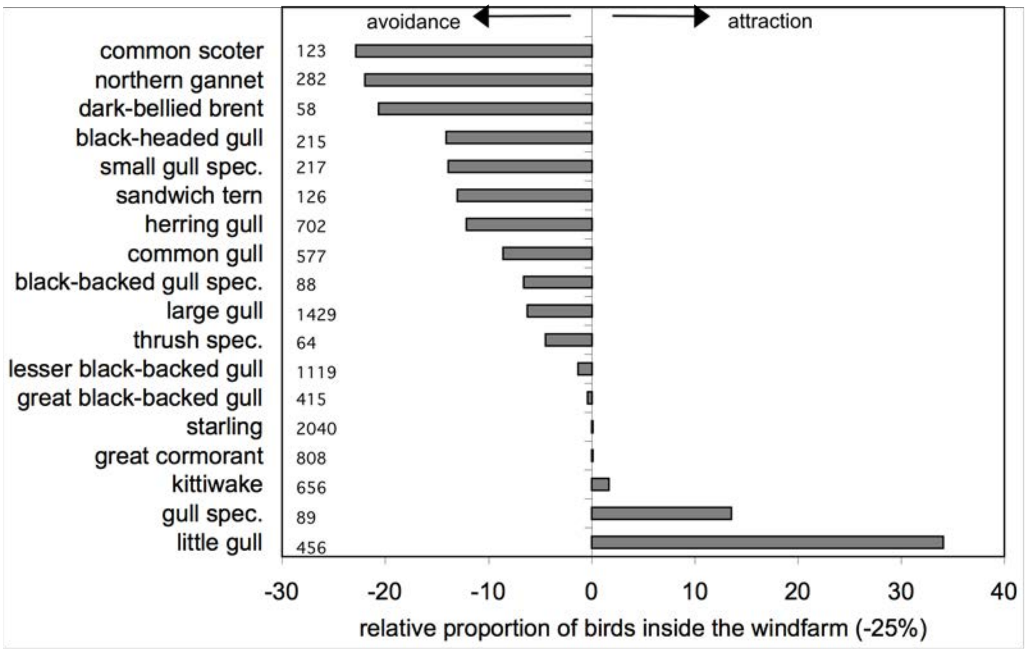


Figure 9.25 Relative proportion of the most abundant species within the wind farm, decreased by 25% to reflect the distribution of surface area within and outside the wind farm. In this graph, proportion of birds inside the wind farm would be 0 when no avoidance occurs (actual proportion 25%). Bird numbers 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).

Effect of fishing vessels on bird distribution

The distribution of sea birds was influenced by the wind farm, but also by the occurrence of fishing vessels. Especially large gulls were associated with fishing vessels during a large part of their time at sea. Overall, 55% of all recorded large gulls were associated to fishing vessels (table 9.4). As fishery was prohibited within the wind farm, this phenomenon could only be observed at larger distances (>3 km) from the metmast (fig. 9.26). Highest numbers of associated large gulls were found south and west of the metmast, where fishing was not prohibited. Although this foraging behaviour was restricted to the 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 (see fig. 8.4), gulls from the colonies were observed flying through the wind farm towards fishing vessels behind it.

Compared to the baseline study the proportion of birds associated to fishing vessels was much lower (table 9.4). Among all species groups, unidentified gulls formed the majority of birds that were associated with fishing vessels, due to the large distance at which the phenomenon usually was observed. The proportion of large gulls, small gulls and cormorants, though, was much lower at the metmast than during the baseline study at Meetpost Noordwijk. The main reason for this difference is not the presence of the wind farm, but the abundance of fishing vessels, which was much higher at the more southerly location of Meetpost Noordwijk during the baseline study. In the baseline study the average number of trawlers (recorded during one scan) exceeded ten during peak seasons (October). During the effect study, the average number of fishing vessels never exceeded four (see fig. 8.4). For cormorants, the structures of the turbines and the metmast have in addition created the possibility for the birds to venture further out to sea.

Table 9.3 Relative proportion of the most abundant species within, outside and at the edge of the wind farm. Given the distribution of surface area within and outside the wind farm, the proportion of birds outside the wind farm would be 50% when no avoidance occurs. Data from panorama scans, only flying birds within 3 km distance from the metmast taken into account. See fig. 9.22 for spatial layout of segments.

	relative abundance (%)		
species	outside	inside	edge
neutral / no effect	*≤ 50*	*≥ 25*	*≥ 25*
northern gannet	83	3	14
great cormorant	54	25	21
dark-bellied brent goose	38	4	58
common scoter	86	2	12
great black-backed gull	53	25	22
lesser black-backed gull	50	24	26
black-backed gull spec.	52	18	30
herring gull	49	13	39
large gull spec.	70	19	12
black-headed gull	48	11	41
common gull	42	16	42
kittiwake	41	27	32
little gull	36	59	5
small gull spec.	85	11	4
gull spec.	34	39	27
sandwich tern	48	12	40
starling	46	25	28
thrush spec.	67	21	12

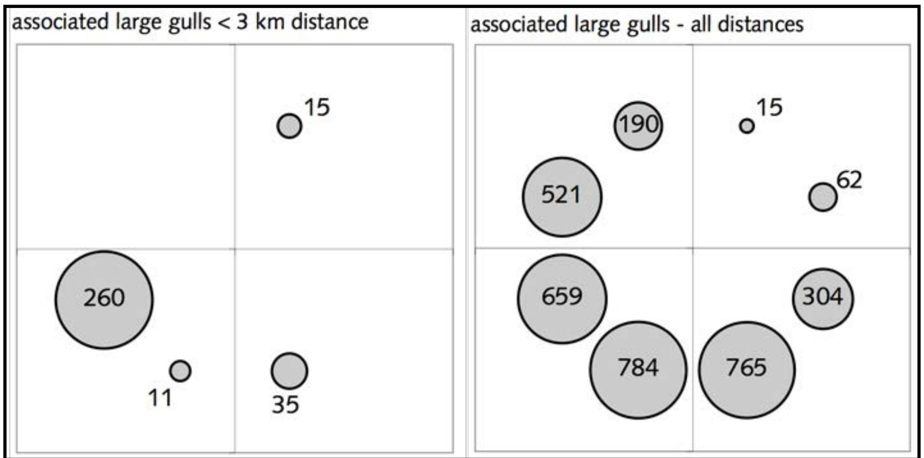


Figure 9.26 Distribution of large gulls associated to fishing vessels within a distance of 3 km from the metmast (left) and at all distances (right), as observed during panorama scans. The wind farm is situated in the upper right diagonal (see fig. 9.21). Associated gulls were mostly seen at distances beyond 3 km.

Table 9.4 Proportion of birds associated with fishing vessels around the metmast during the effect study (T1) and during the baseline study at Meetpost Noordwijk (T0, Krijgsveld et al. 2005, p. 140), as observed in panorama scans. Only flying birds taken into account.

	% associated to fishing vessel	
species group	T0	T1
alcids	0.2	0.0
gannets	3.6	0.0
sea ducks	0.5	0.0
tubenoses	0.4	0.0
cormorants	13.1	0.0
large gulls	67.2	55.4
small gulls	46.7	6.3
little gull	9.1	0.0
unidentified gulls	92.1	90.8
all birds	73.8	51.9

9.5 Flight directions of birds in and around the wind farm

In this paragraph we present flight directions of birds, and changes therein in relation to the wind farm. These are flight directions as measured with the horizontal radar, and thus are overall directions regardless of species. The flight directions of individual species are presented in the next two paragraphs (§9.6 & §9.7).

Flight directions of birds show a large degree of variation. Much of this variation is closely related to the time of year (e.g., autumn and spring migration, local wintering birds). Moreover, migration patterns change along with changes in the species that are migrating, because they all have their specific destinations, preferred flight altitudes and preferred migration routes. Also the time of day influences flight directions, for instance when migrating birds return to land at the break of day in autumn. Similarly, weather conditions (especially wind) affect how many birds are flying and whereto. Any effects that the wind farm may have on flight directions, will only become visible when we take this natural variation into account. The results are therefore mostly presented by time of year and by time of day. The data are summarized in grid cells per time unit. These time units are defined as time of day (6 periods: before and after midnight, before and after noon, and dawn and dusk). Data were summarized for periods of 10 days (*i.e.* 3 periods per month). This way, each grid cell contained enough tracks to allow analysis. Ideally, shorter time periods would be used to avoid averaging out variation in flight direction, but this was not possible given the need to fill most grid cells with enough data..

9.5.1 Seasonal and diurnal variation

Flight directions were more uniform during migration in spring and autumn than during winter and summer when most of the flight activity was from locally foraging birds. This is visualized in the length of the arrows in figure 9.27. The longer the arrow, the more birds flew in the same direction (see §6.6 for mathematical formulas).

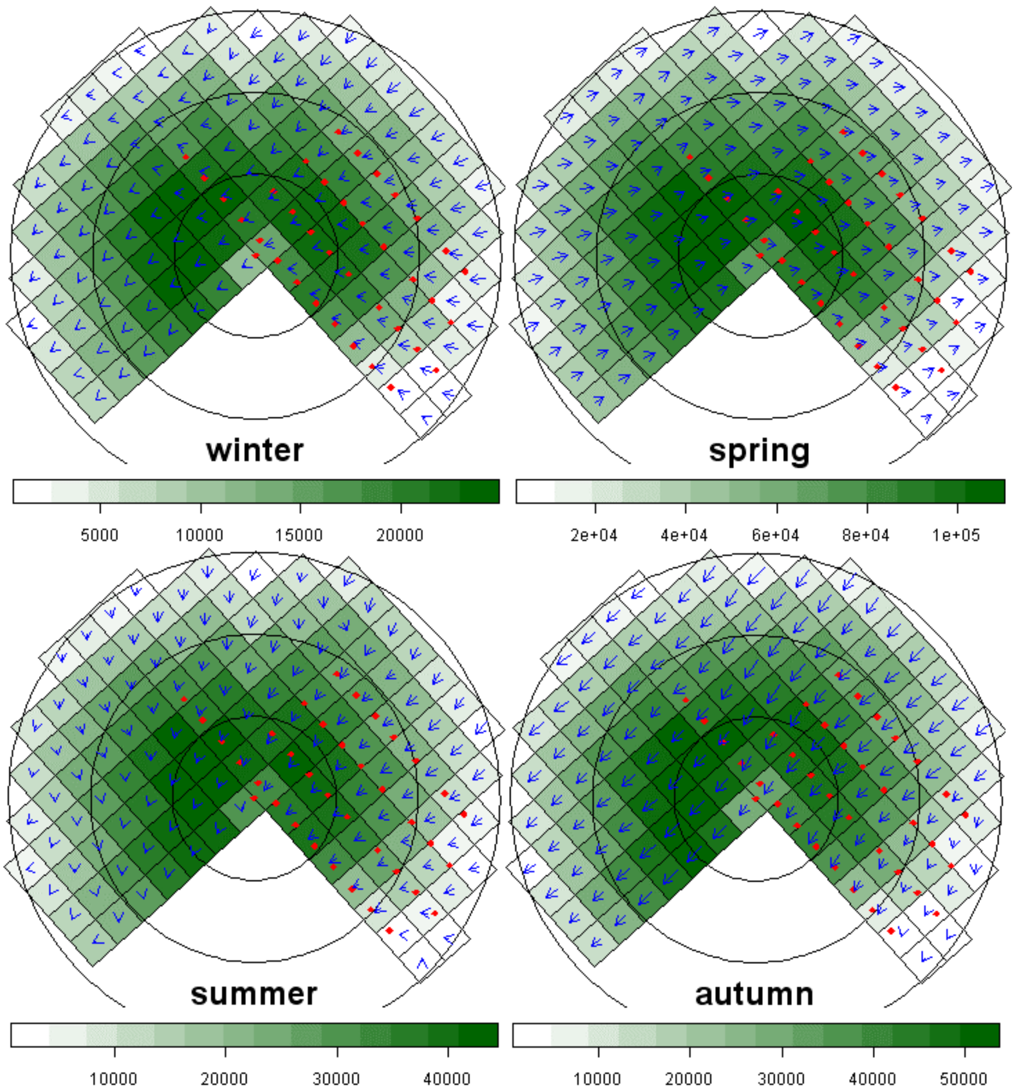
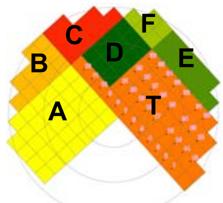


Figure 9.27 Flight directions of bird tracks per season, shown per grid cell to illustrate differences between different areas of the wind farm area. Directions are shown as arrows. Variation in direction is shown in the length of the arrow: the longer the arrow, the more birds flew in the same direction. Number of tracks per cell is the sum of all tracks in that period, indicated in green colours and scaled at the bottom of each graph (note the differences in scale). Circles at 1NM-intervals. Data from horizontal radar. The colours show the detection loss with increasing distance from the radar. In winter and summer variation in direction was much higher (shorter arrows). In spring and autumn directions were more uniform, and numbers were higher.

The variation in flight direction was higher during daytime than at night (fig. 9.28, blue lines depicting day show higher values compared to the black and grey lines depicting night). Levels of variation at dawn and dusk were intermediate. This is presumably related to the fact that during the day higher proportions of foraging birds flew in the area, with more random flight directions, while at night birds flying in the area were more goal-oriented and therefore showed less variation in flight direction. It does not indicate that avoidance levels were higher during day than at night.

Figure 9.28 shows variation in flight direction as function of distance from the closest wind turbine. No overall increase or decrease with distance is evident. Only in spring, an increase in variation occurred at short distance (up to 1-1,5 km) from the turbines, most explicitly occurring at night (black and grey line), and to a lesser extent at dawn (orange line). In spring, interstingly, variation in flight direction then decreased up to a distance of ca. 3 km, after which it increased again. The reason for this pattern is not clear. Numbers of tracks included are high enough to rule out edge-effects. Possibly, the birds lined up when approaching the wind farm in order to pass the area in the most likely or evident direction, while at larger distances birds follow more individual routes uninfluenced by the wind farm. This would imply that the wind farm affected flight directions up to a distance of ca. 5 km from the wind farm (*i.e*. 6 grid cells). At close approximation, individual flocks then changed flight direction again, either to avoid the entire wind farm, or to enter the wind farm in between turbines. The fact that this pattern occurred especially at night, indicates that birds were more cautious at night than during the day, similar to results found in other parts of this study.

Data shown in figure 9.28 are limited to the area west of the wind farm (block A in fig. 9.13), as well as the adjacent line of turbines. This selection was made because here the largest range in distances away from the wind farm was available. Also, this area was clear in view from the radar, and thus data were not affected by turbine interference. In this area, tracks of birds approaching the wind farm are mostly of birds migrating north and east in spring. This explains why the changes in flight direction with decreasing distance away from the wind farm are most explicit in the data from spring. Birds flying in southerly and westerly directions in autumn have already changed their flight direction when they arrive at the north-eastern sides of the wind farm. Any changes in direction will reflect adjustments after leaving the wind farm. In winter and summer, flights directions were more random anyway, and any overall patterns in variation in direction were not expected. Although nocturnal flight directions showed less variation than patterns during daytime, no effect of distance from the farm is visible.



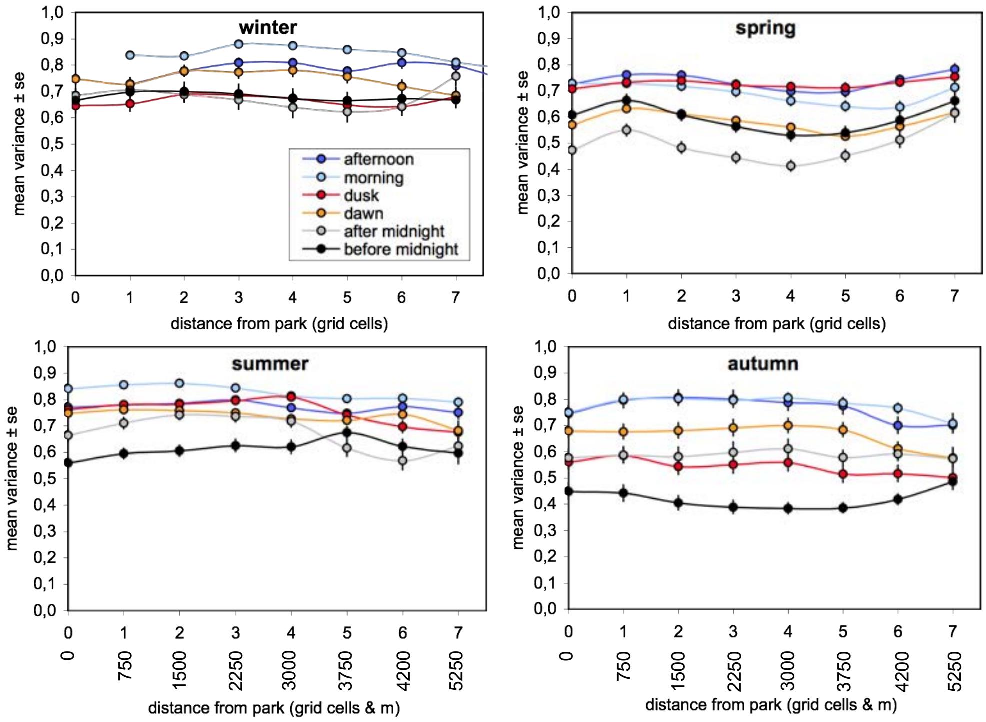


Figure 9.28 Variation in flight direction in relation to distance from the wind farm, shown per season and for different times of day. Shown are averages with standard errors. Data from horizontal radar, only the area west of the wind farm (block A in fig. 9.13) and the adjacent single row of turbines (distance=0). Variation was higher at night than during the day. Variation did not change with distance from wind farm, except in spring when variation increased when birds closely approached the wind farm (ca. 300-1200m distance).

9.5.2 Avoidance mostly at short distances from wind farm

Large numbers of birds adjusted their flight routes at short distances from the wind farm (fig. 9.28 spring; §9.7 visual observations flight paths). This behaviour is evident in data from smaller periods of time. The flight directions remained largely unchanged at large distances from the wind farm, and showed a pronounced change in the grid cells adjacent to the wind farm at ca. 1 km distance from the wind farm. This was most explicit in April during night-time (fig. 9.29; yellow circles).

Also while flight directions were otherwise random, close to the wind farm birds tended to fly more in a direction around the wind farm. This is visualized in the graph on the lower right of figure 9.29, where birds in the morning in February 2009 were flying in random directions, but were more oriented in a direction to avoid the entire wind farm in the grid cells adjacent to the wind farm. This is in line with species composition during daytime in February, which consists mostly of local seabirds that have high avoidance levels (see §9.7). This pattern should be visible at the other sides of the wind farm as well. The fact that it is not, indicates that either numbers of birds in these areas were too low for the effect to become visible, or that more birds were approaching the wind farm from the south side of the wind farm than from the north or east side. The latter is in line with gulls flying from the breeding colonies on the coast in the south-west towards sea in the morning.

Overall, flight directions did not change over large distances when birds approached the wind farm. Because measurements were limited to a distance of 5.5 km from the radar, we cannot exclude the possibility that adjustments in flight direction took place at larger distances, outside the observed area. However, if a large proportion of birds adjusted their flight paths outside the study area, it is likely that this would have been visible to some extent at closer distances as well, and thus would have been visible within the study area and in the data. These results indicate that avoidance did not occur at large distances from the wind farm, and that the majority of avoidance, at least during migration, occurred at distances up to one to two km away from the wind farm.

A large number of flight paths in and around the wind farm originated from foraging gulls such as this herring gull (photo K. Krijgsveld).

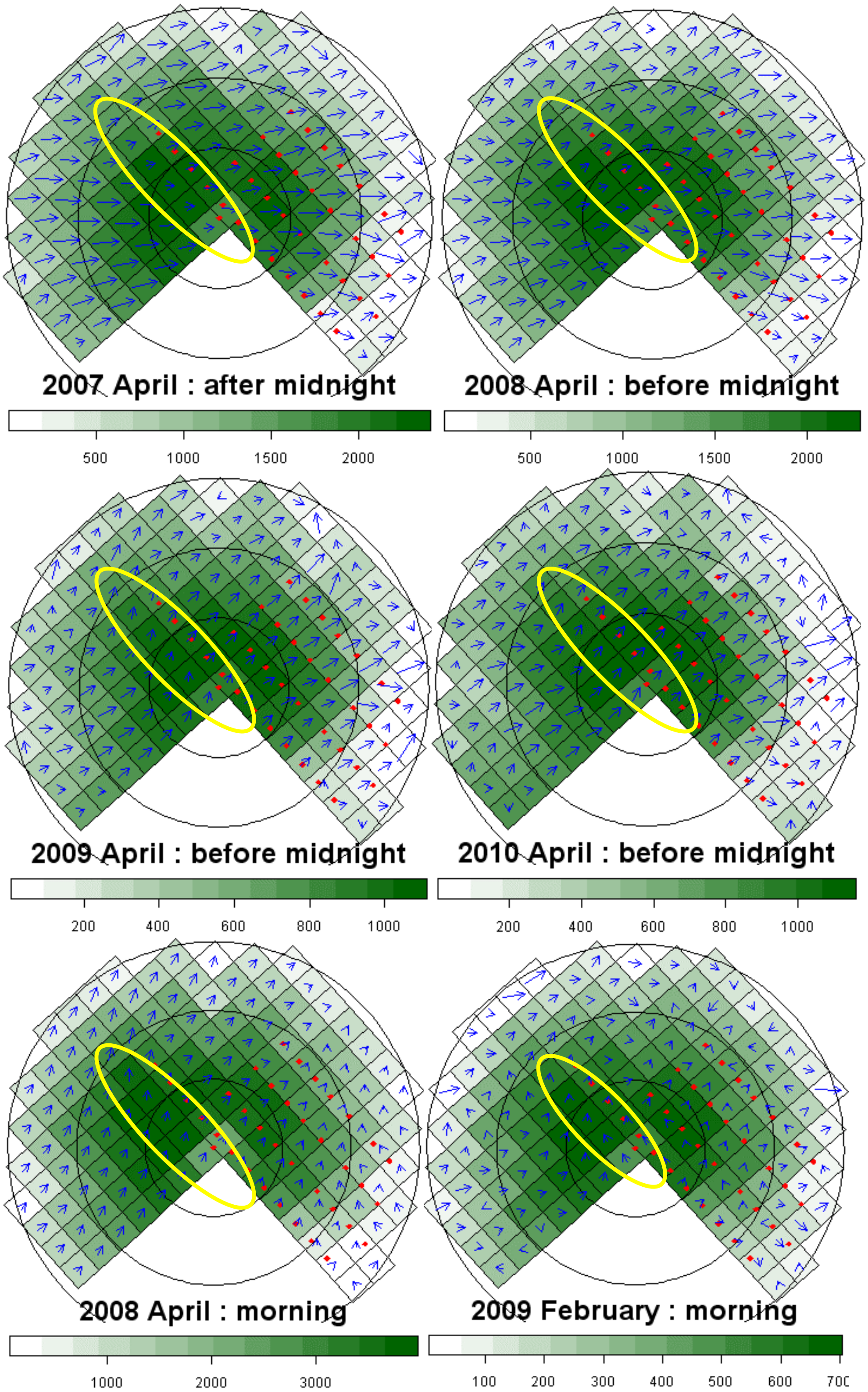


Figure 9.29 Examples of avoidance at close distance from the wind farm. Flight directions and/or uniformity in direction of birds that approached the wind farm from the south-west in April, changed in the grid cells adjacent to the wind farm (indicated by yellow circles).

9.5.3 Micro-avoidance

We have shown that birds avoided close proximity to the turbines, especially at night (§9.3 & see ch.13). Adjustments of flight directions to lanes was not visible in the flight directions in grid cells. This could be due to large numbers of birds flying above rotor height, however, also on a selection of days and nights during which flight altitudes were confined to rotor height, no evidence was found of birds staying in lanes (fig. 9.30). Micro-avoidance, where birds avoided individual turbines, was however visible on many nights with heavy migration, as well as during daytime (fig. 9.31 & 9.32).

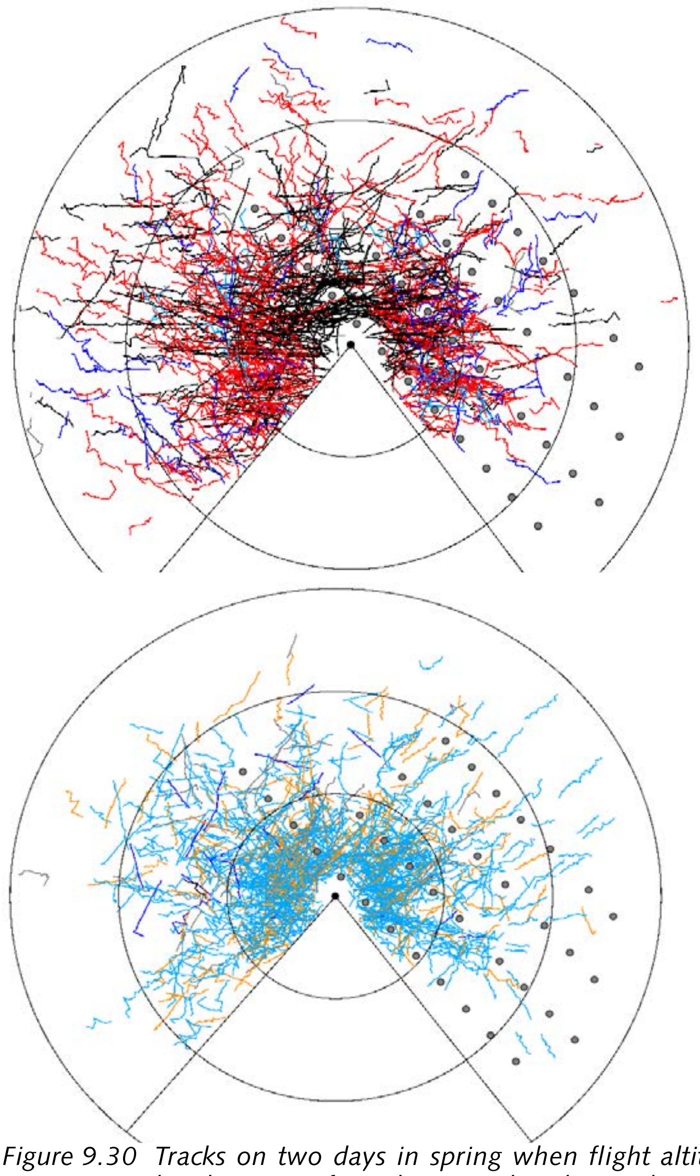


*Figure 9.30 Tracks on two days in spring when flight altitudes were limited to rotor height. Data from horizontal radar, only tracks longer than 10 hits shown. Top: April 6 2008, bottom: April 12 2009. Colours reflect time of day: **before midnight**, after midnight, dawn, morning, afternoon, dusk. Circles at 1 NM intervals from metmast. Flight paths did not stay in one lane of turbines, despite low flight altitudes.*

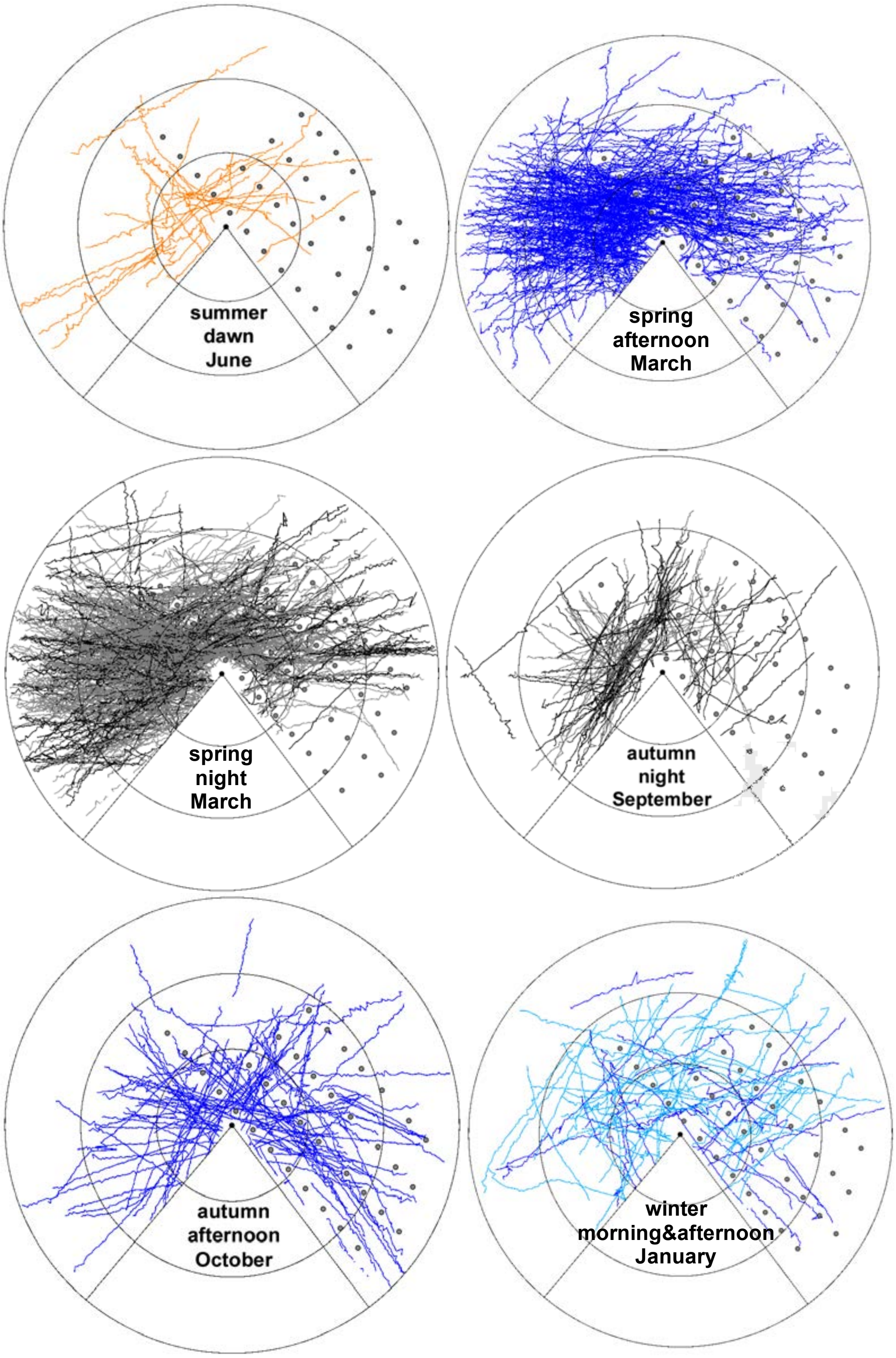


Figure 9.31 Typical examples of bird tracks through the wind farm during various seasons and times of day, as observed with horizontal radar. Only tracks longer than 50 hits shown, reflecting larger birds or flocks. Circles at 1 NM-intervals from radar & metmast.

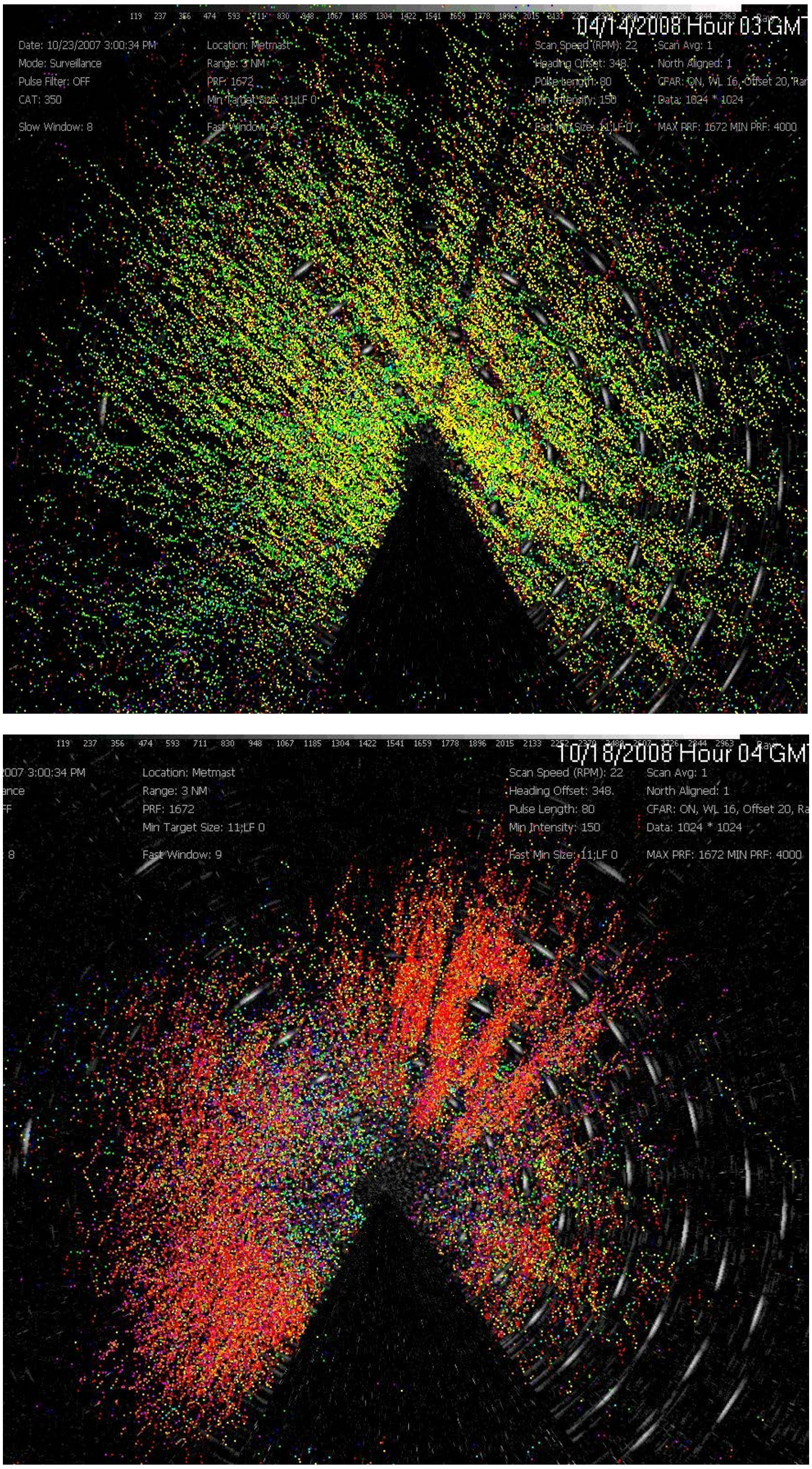


Figure 9.32 Birds avoiding wind turbines, shown in trackplots in which each echo recorded with the horizontal radar during one hour is plotted. Data from April 14 '08 03:00hr (top) & October 18 '08 04:00hr (bottom). Colours reflect flight direction: yellow SE, green E, red S, orange SW, purple W.

9.5.4 Changes in flight directions after leaving the wind farm

Flight directions generally remained unaltered after passing the wind farm. This could only be observed for birds flying in south-westerly directions and exiting the wind farm at the south-west side of the wind farm, because flight patterns were unobstructed and thus clearest in this area. During migration, flight altitudes were generally well above rotor height (see ch.11). The flight patterns show that at these altitudes, flight paths are unaffected by the wind farm. Sometimes a general change in both flight direction and variation in flight direction was visible after passing the wind farm (examples in fig. 9.33, see also appendix IV). This indicates that flight directions could indeed be affected by the wind farm, possibly especially during period with migration at low altitudes. The graphs also indicate that flight directions of migrating landbirds were on average back to normal within range of the radar, at ca. 3-4 km distance from the wind farm.

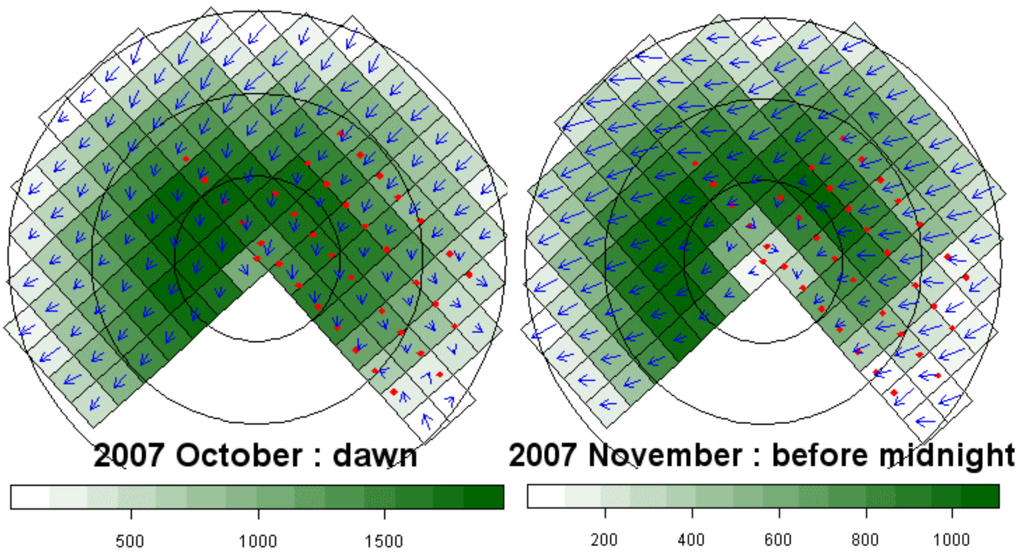


Figure 9.33 Examples of changes in flight direction and variation in flight direction of birds after leaving the wind farm, at short distances from the wind farm, and visible in the area to the south-west of the wind farm.

9.6 Flight directions of individual species

In this paragraph, data are presented on visually observed flight directions describing species-specific patterns that were not discernable with the radar data.

The predominant flight directions of birds flying during daytime were extracted mainly from panorama scans and are depicted in figure 9.34 and table 9.5. In spring (March-May) more than 50% of all flying birds observed were heading towards north, northeast or east. Not surprising, this corresponds with the migratory direction of many species towards the breeding grounds in the north and east. Among many others, the most dominant species observed were starling, lesser black-backed gull and black-headed gull.

In summer (June-August) flight directions were more random. In this period the wind farm area was used as feeding area by birds from breeding colonies on the coast, or was passed en route to other feeding grounds further offshore (including fishing vessels, see §9.4). Those birds passed the wind farm in varying directions. In August, first migration activity of species (e.g. black headed gulls and sandwich terns) towards the south-west was observed (figs. 9.34 and 9.35). This corresponds with the south-westerly flight directions in summer, as observed with both visual observations and horizontal radar data.

In autumn, predominant flight directions were west and south. Flight activity in these directions was heavily dominated by medium-sized songbirds; especially starlings that migrated through the area in large flocks.

In winter, flight directions were random, like in summer. For some species spring migration starts as early as February, which was visible as a northerly component in the flight directions during that time. Species that started migrating in this month were small gulls in particular (figs. 9.34 and 9.35).

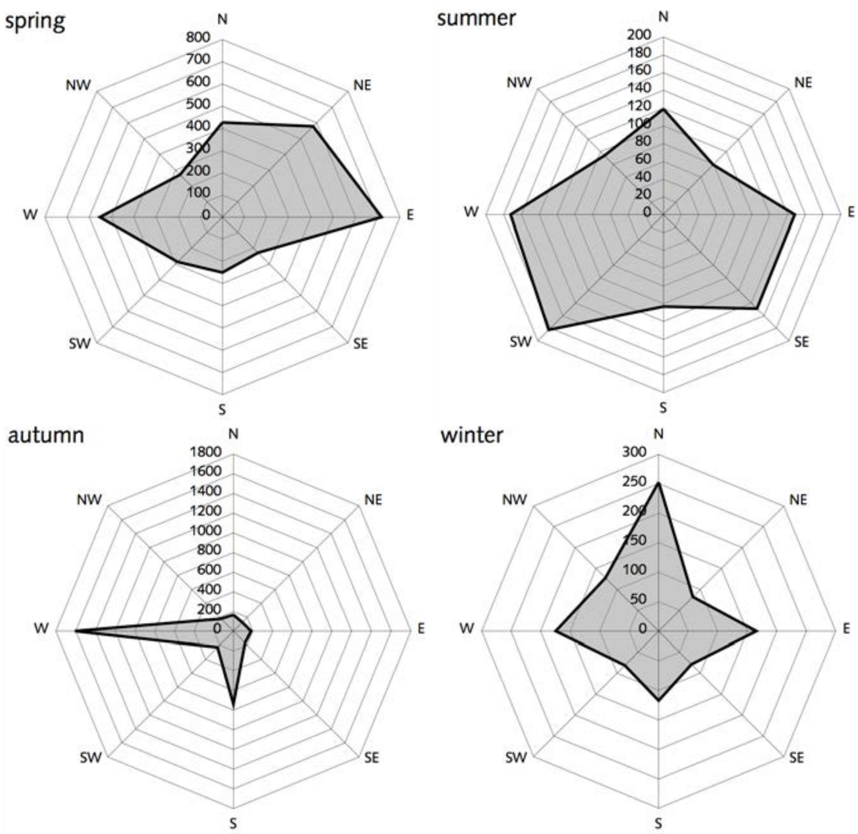


Figure 9.34 Flight directions of all flying birds in the wind farm area in different seasons, as observed in panorama scans. Scale indicates the total numbers of flying birds for each fligth direction. Only flying birds within 3 km distance from the metmast taken into account. Birds in association with ships, platforms or other structures not included.

Table 9.5 Flight directions ***in spring and autumn*** *of different birds species (sub-groups), as observed with panorama scans. For each direction the total numbers of flying birds are given. Colours refer to the proportion of birds per species group that was heading in that direction; red>25%, orange>18,75%; yellow>12,5%. Only flying birds within 3 km distance from the metmast taken into account. Birds associated with ships, platforms or other structures not included.*

Spring

Species (sub-group)	N	NE	E	SE	S	SW	W	NW
	flight direction							
alcids	0	0	0	0	0	0	0	0
cormorants	35	21	23	27	46	5	10	11
divers	3	1	0	0	0	0	0	3
gannets	31	7	5	1	13	3	9	11
anser geese	0	0	0	0	0	0	0	0
branta geese	16	8	0	0	0	0	0	0
unidentified geese	0	0	0	0	0	0	0	0
grebes	0	0	0	0	0	0	0	0
large gulls	208	111	182	136	116	183	408	146
little gull	33	3	14	5	5	51	50	17
small gulls	31	43	136	19	20	18	62	27
unidentified gulls	0	0	4	0	1	0	4	3
medium passerines	0	298	306	29	48	0	0	0
other large birds	0	0	1	0	0	0	1	0
small passerines	3	8	10	1	0	0	0	0
diving ducks	0	8	0	0	0	0	0	0
mergansers	5	2	0	0	0	1	0	0
swimming ducks	0	0	8	0	0	0	0	0
unidentified ducks	0	0	0	0	0	0	0	0
raptors	2	0	1	2	0	0	0	0
sea ducks	32	27	20	3	0	16	4	40
skuas	1	0	0	0	0	0	0	0
terns	21	9	5	4	0	10	4	3
tubenoses	1	0	0	0	0	0	0	0
waders	4	32	2	0	0	0	0	8
sea mammals	0	0	0	0	0	0	0	0
All birds	426	578	717	227	249	287	552	269

Autumn

Species (sub-group)	N	NE	E	SE	S	SW	W	NW
	flight direction							
alcids	2	1	0	0	0	0	0	3
cormorants	25	28	25	14	30	26	24	25
divers	0	0	0	0	0	0	0	0
gannets	47	13	2	13	3	2	6	21
anser geese	0	0	0	0	0	0	0	0
branta geese	0	0	0	0	0	17	9	0
unidentified geese	0	0	0	0	0	0	0	0
grebes	0	0	0	0	0	1	0	0
large gulls	57	35	62	74	56	42	61	93
little gull	0	0	0	0	0	0	0	0
small gulls	20	14	19	30	25	30	17	26
unidentified gulls	1	0	1	3	3	0	0	0
medium passerines	0	28	61	22	570	88	1465	7
other large birds	0	2	1	0	1	0	1	2
small passerines	3	0	2	3	9	18	7	0
diving ducks	0	0	0	0	0	0	0	0
mergansers	0	0	0	4	0	0	0	0
swimming ducks	0	0	0	0	30	0	3	0
unidentified ducks	0	1	0	0	0	0	0	0
raptors	0	0	0	0	0	0	1	0
sea ducks	2	4	5	0	0	0	0	1
skuas	0	0	0	0	0	0	0	0
terns	5	2	1	4	11	1	13	1
tubenoses	1	0	0	0	0	0	0	0
waders	0	0	0	0	0	0	0	0
sea mammals	0	0	0	0	0	0	0	0
All birds	163	128	179	167	738	225	1607	179

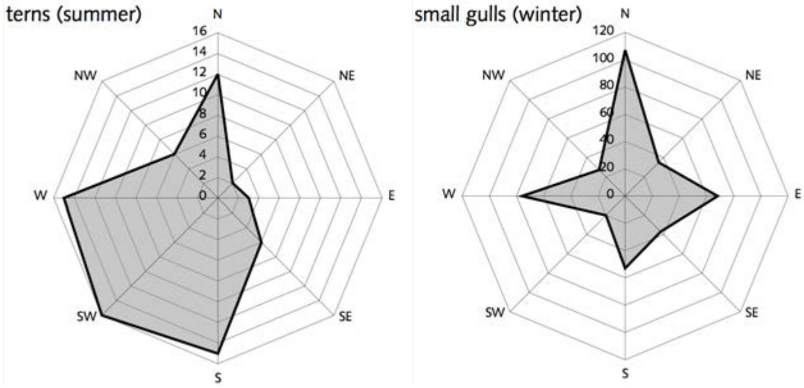


Figure 9.35 Flight directions of terns in summer (left) and small gulls in winter (right), shown as examples of early migratory activity in late summer and late winter. Scale indicates total number of flying birds for each flight direction. Data from panorama scans. Only flying birds within 3 km distance from the metmast taken into account. Birds associated with ships, platforms or other structures are not taken into consideration.

Flight directions of lesser black-backed gulls

Of all species, lesser black-backed gull was one of the most abundant species in the wind farm area. Because of this, the pattern in flight directions was investigated in somewhat higher detail. Especially in summer the overall flight pattern was strongly determined by lesser black-backed gull. This species visited the wind farm area throughout the day either for feeding or as transfer towards other feeding grounds further offshore. Figure 9.36 shows lesser black-backed gulls heading west and east throughout the day. Increasing numbers of birds were heading west in the hours after sunrise. Birds headed towards the breeding colonies at the coast well before sunset. Birds were still seen heading west at sunset, albeit only a few, and around and after sunrise birds were still seen heading east. Evidently birds stayed offshore during the night as found previously (Shamoun-Baranes *et al.* 2011) or even continued their foraging flights during the night (this study).

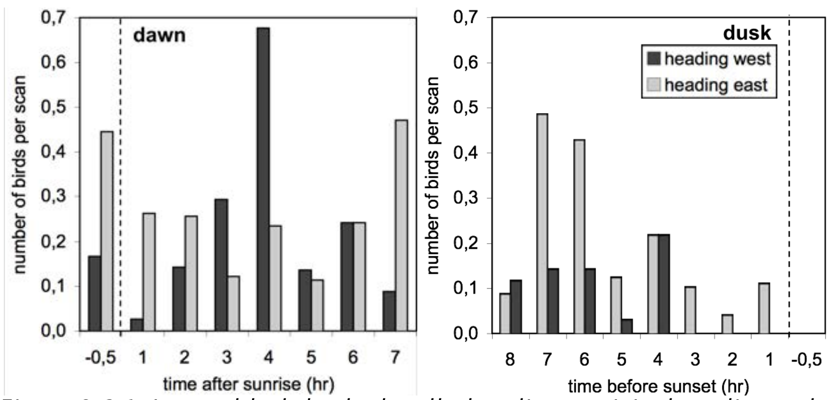


Figure 9.36 Lesser black-backed gulls heading east to breeding colonies or west to feeding grounds during the hours after dawn (left) and before dusk (right) during summer in the wind farm area. Average numbers of birds per hour after sunrise or before sunset. Data from panorama scans. Only birds flying within 3 km distance from the metmast taken into account. Birds associated with ships, platforms, etc. and non-flying birds not included. Birds stayed out at sea at night.

9.7 Flight paths of individual species in and around the wind farm

Visual observations on flight paths of individual birds flying in the wind farm area yield additional information on occurrence of deflection for individual species. Because these observations were made from the metmast, the results are centred on an area of 3-4 km around the metmast. Lack of flight paths further away does not indicate a lack of birds in those areas, but merely that that area was not covered by observations. Flight paths could be recorded fairly accurately due the presence of the wind turbines and buoys in the area, which served as a reference. In addition, many tracks were visible on radar as well, in which case the flight path could be drawn accurately from the radar screen.

A total of 666 flight paths of 85 species from 16 species groups were recorded through visual observation. The two species for which most flight paths were recorded are great cormorant and northern gannet, that together made up 25% of all tracks recorded. The group size of birds for which flight paths were recorded varied between 1 and 850 (for starling), but group size was mostly 1.

From the 666 flight paths, 434 or 65% flew through the wind farm (table 9.6). This high average is caused by large numbers of gulls and cormorants in the database, that do not show avoidance of the wind farm. When studying individual species groups, the percentage of birds flying through the wind farm is much lower, especially in seabirds such as gannets, alcids, divers and scoters.

Table 9.6 Occurrence of avoidance and deflection around wind farm for various species groups, as observed visually. Shown is the percentage of bird groups that flew through the wind farm, as well as the percentage of bird groups that showed deflection around the wind farm. Number of bird groups observed in total is shown as well to illustrate the accuracy of the mean %.

species group	through wind farm		showing deflection	
	nr observed	% through	nr observed	% deflection
divers	17	**41**	8	**38**
grebes	2	**50**		
tubenoses	10	**50**		
gannets	81	**36**	38	**89**
cormorants	82	**85**	52	**35**
geese & swans	29	**69**	13	**62**
sea ducks	41	**37**	16	**38**
other ducks	21	**71**	9	**56**
waders	28	**75**	16	**31**
skuas	3	**100**		
gulls	146	**75**	78	**40**
terns	34	**76**	24	**38**
alcids	40	**55**		
raptors & owls	13	**77**	9	**11**
landbirds	105	**70**	45	**47**
sea mammals	14	**50**	7	**14**
total	666	**65**	320	**44**

Deflection, defined in this context as a change in flight direction away from the wind farm, occurred in 30% of all bird groups. Whether or not deflection occurred was not always notated, so the dataset on this is smaller. Deflection was highest in gannets, that approached the wind farm closely before changing direction. Also geese and swans showed a high level of deflection, even though many groups that flew above rotor height passed the area without showing horizontal deflection (see below).

The average distance of the various species (groups) showed a similar result as the data on deflection (fig. 9.37). Distance was calculated as the minimum distance of a track to the closest turbine, and was averaged for all tracks within a species (group). Minimum distance was highest in the seabirds such as divers, gannets and scoters, while also geese and swans maintained high minimum distances to the turbines. Cormorants approached the turbines most closely.

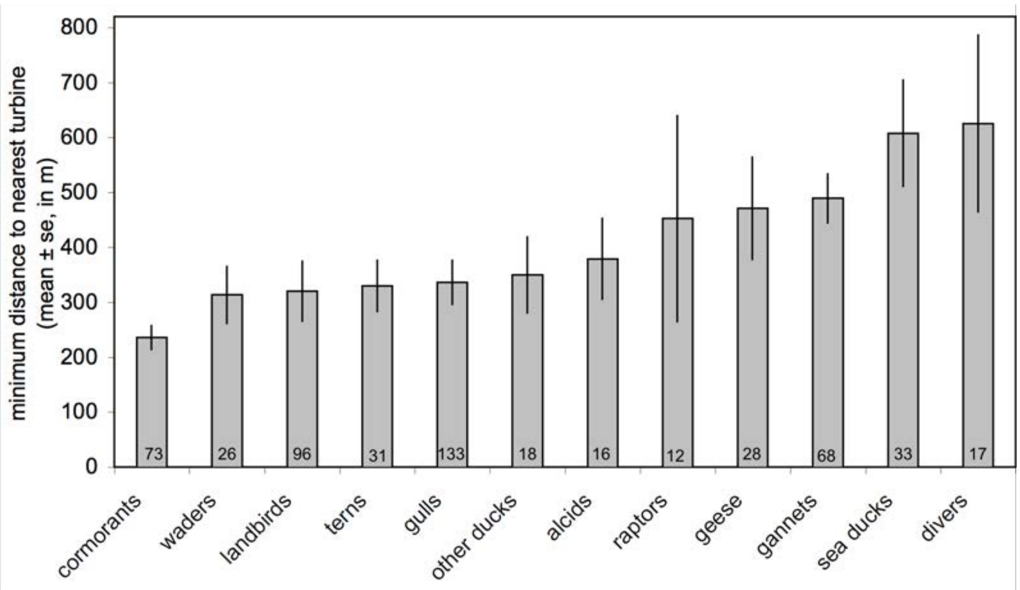


Figure 9.37 The distance that bird groups maintained to turbines, as observed visually. Shown is the minimum distance of each flight path to the nearest turbine, averaged per species group, with standard errors. Number of birds per species (group) given in the bars. Pelagic species maintained the largest distances to the turbines.

Maps of flight paths

Below, maps of the actual flight paths of individual species and species groups around the wind farm are shown (figs. 9.38-9.43). All flight paths are divided in paths that crossed the wind farm area (green arrows), and tracks that did not (red arrows, division at 50 m from turbines). Data were obtained visually, supported with horizontal radar to assess position and routes.

- **Seabirds** such as **auks, guillemots, divers, scoters and eiders** strongly avoided the wind farm (figs. 9.38 & 9.39). Most of these birds were observed flying at large distances around the entire wind farm (scoters, alcids, divers; often too far away to record accurate flight paths; > 5 km away) or deflecting upon approaching the wind farm (gannets). Occasionally birds of this group were seen flying through the wind farm. On one occasion (winter '08-09) a pair of **eiders** was seen diving within the wind farm. The same winter a few small flocks of **guillemots** were seen foraging in as well as near the wind farm. In general however these species stayed away from the wind farm.

- Of the seabirds, **gannets** most strongly avoided the wind farm (fig. 9.38). Although the majority of individual birds avoided the wind farm, a number of them did enter the wind farm, and were even seen foraging and diving within the wind farm. Although the sample size is small, the percentage of gannets that flew through the wind farm increased over the study years, from 26% in 2007 to 38% in 2008 and 45% in 2009. Such an increase can be explained by an increasing availability of fish due to an increase in benthic fauna within the wind farm as was potentially found in Danish wind farms (Leonhard & Pedersen 2006), possibly in combination with gradual customization of these birds with the wind farm.

- Virtually no deflection was observed in the few groups of **alcids** that were seen (fig. 9.39). These birds were scarce in the wind farm area, and when seen, they usually flew by at large distances from the farm. The lack of deflection is in that sense misleading, as it may have occurred at larger distances than could be overseen visually (>4-5 km). Further information on this topic can be found in the report on locally foraging birds (Leopold *et al.* 2011), where avoidance was shown to occur. Birds flying through the wind farm all flew low above sea (2-3 m, see also §11.4).

- The few **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 (fig. 9.39).

- **Tubenoses** were only seen on one day, during which several foraging birds passed the area. Unfortunately, they were all picked up only when leaving the area, so no clear information could be gathered concerning their use of the wind farm. However, their flight paths suggest that they hardly avoided the wind farm (fig. 9.39).

- A total of three flight paths of **skuas** was recorded, flying in or very near the wind farm (fig. 9.39). An arctic skua was observed to actively hunt resting kittiwakes from the water (October 10 2007).

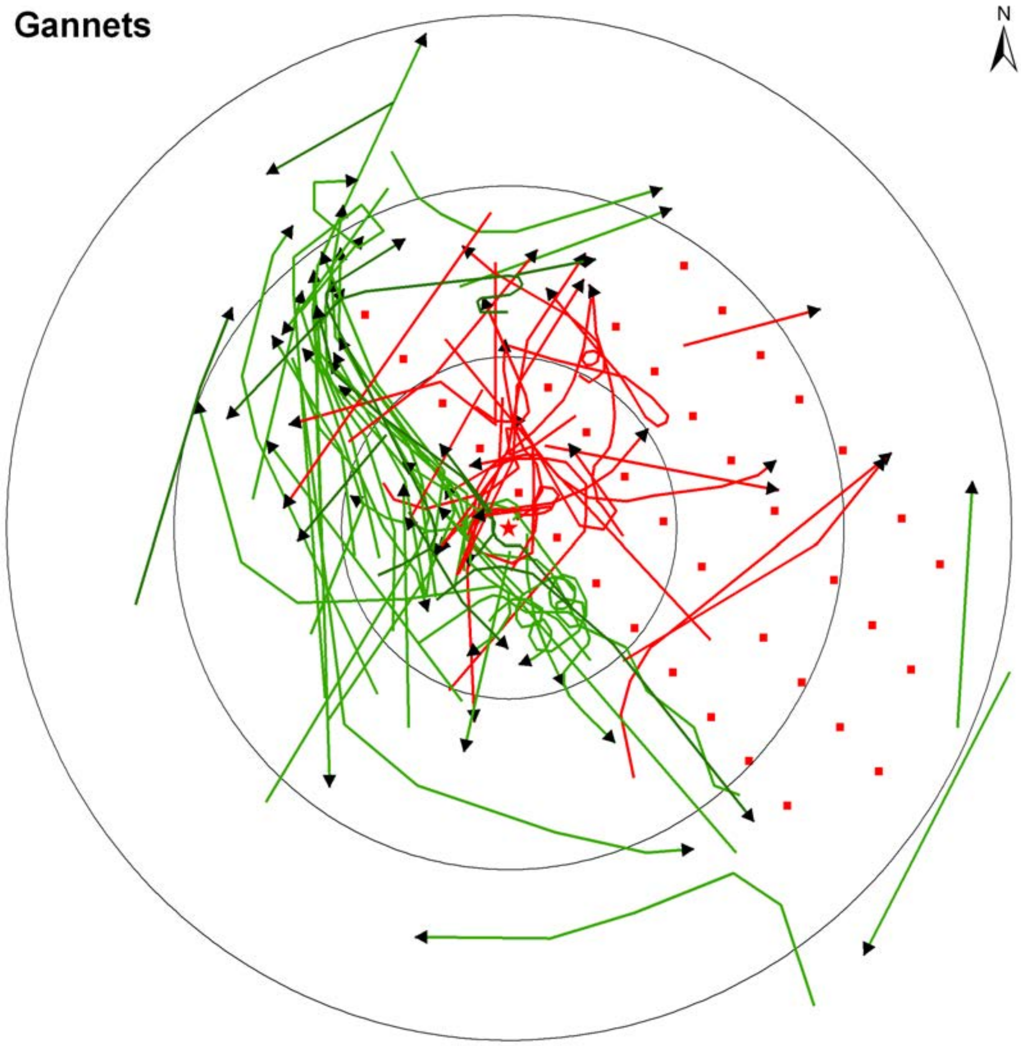


Figure 9.38 Flight paths of gannets in the wind farm area, showing high avoidance at close distance. Data from visual observations. Red lines: birds that passed within the wind farm, green lines: birds that did not enter the wind farm. Red dots: wind turbines; red star in centre: metmast. Rings spaced at 1 NM = 1852 m.

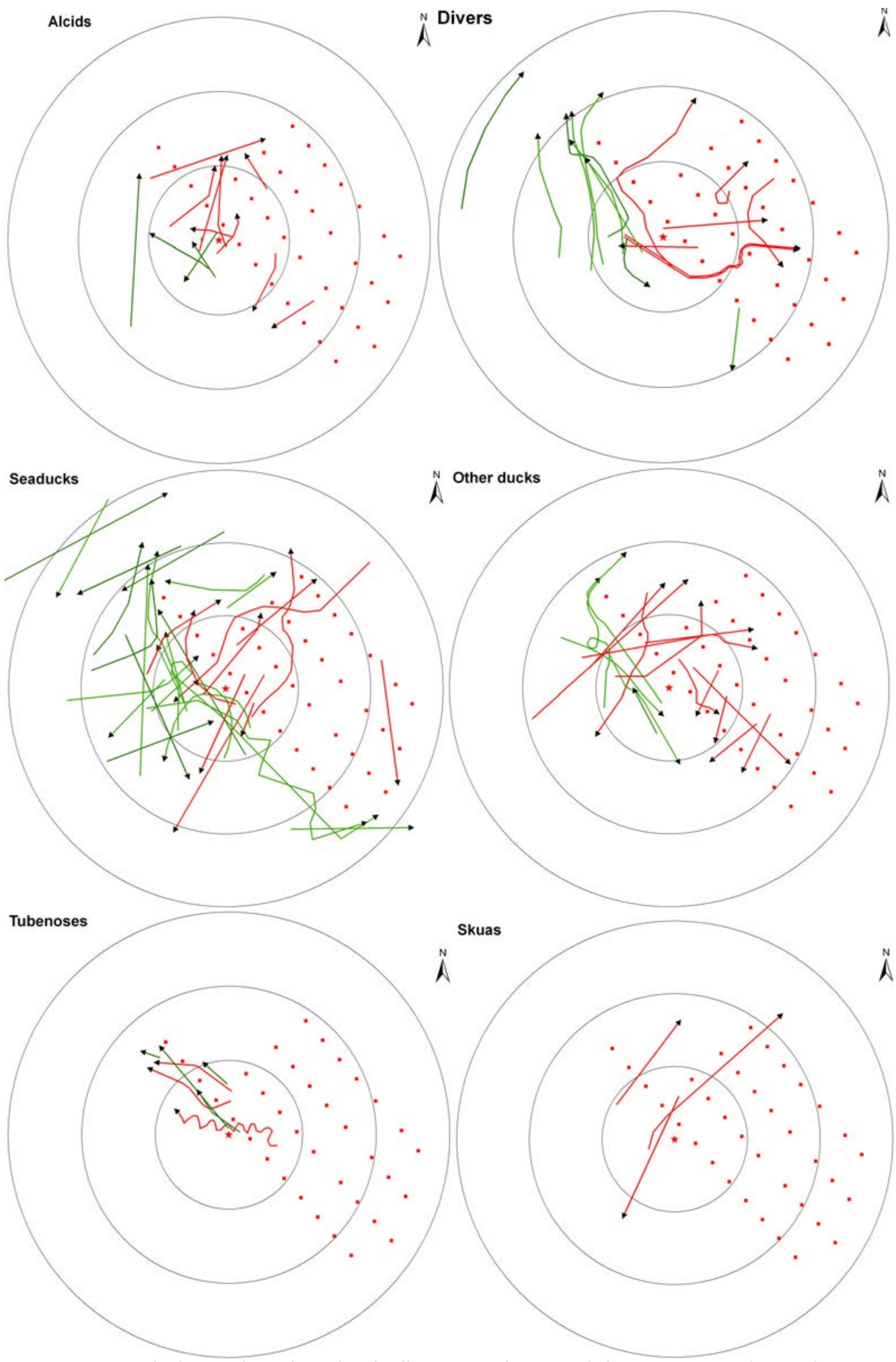


Figure 9.39 Flight paths of seabirds flying in the wind farm area, such as (from top left to bottom right) auks & guillemots, divers, scoters & eiders, other ducks tubenoses and skuas. Legend see fig. 9.38. Note the high level of avoidance in divers and seaducks.

- **Gulls** did not show deflection when they were flying in the wind farm area (fig. 9.40). All observed species of gulls were regularly seen foraging or resting within the wind farm (little gull, kittiwake, black-headed gull, common gull, herring gull and both black-backed gulls).

- **Cormorants** were seen in the wind farm area throughout the study (fig. 9.40). The metmast was used as a resting place, as well as the gas production platform north of the wind farm. The birds flew through the wind farm on a regular basis, often using the turbine platforms as a resting place as well. Cormorants were seen foraging for fish in the wind farm on a regular basis. No avoidance is visible in their flight paths.

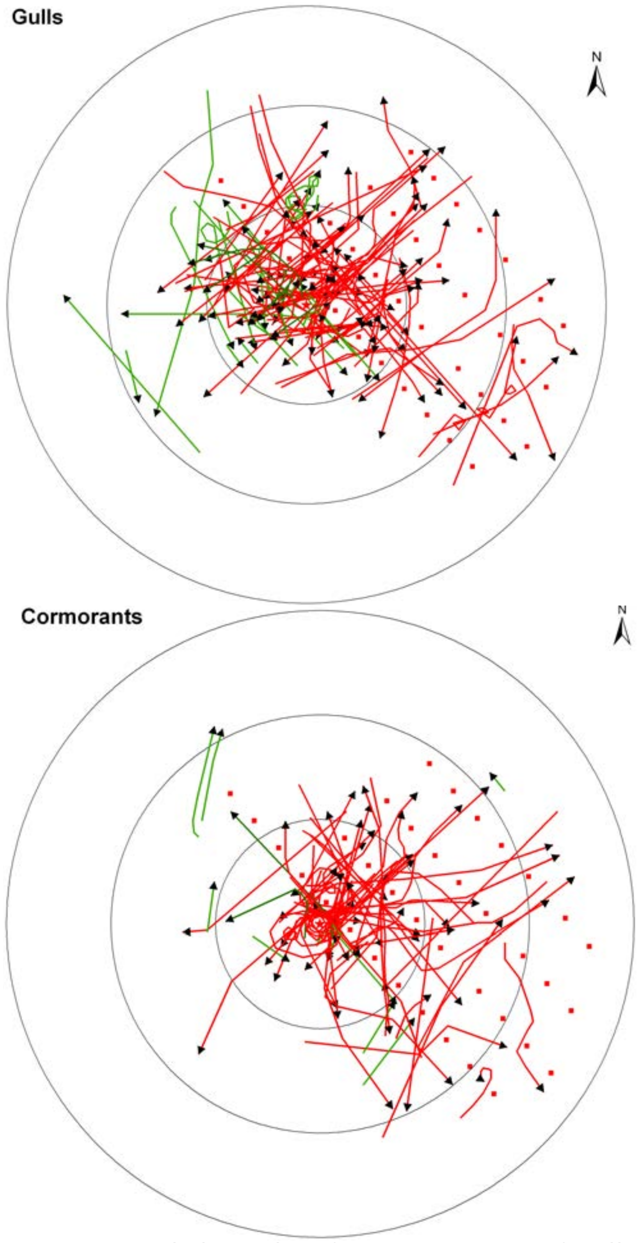


Figure 9.40 Flight paths of various species of gulls (top) and cormorants (bottom). Legend see fig. 9.38.

- **Geese** migrating to and from Britain strongly avoided the wind farm when they were flying at rotor height. It was observed repeatedly that flocks of geese flying at rotor height broke apart when arriving at the wind farm. The individual birds circled around, and took some time before regrouping, after which they flew around the entire wind farm. Geese also regularly flew above rotor height and at those altitudes did not show avoidance. These high flight altitudes explain why the percentage of birds flying 'through' the wind farm was relatively high: the birds were flying well above the rotors (fig. 9.41 and see table 9.6). The fact that the percentage of birds showing deflection was high, illustrates the high avoidance levels of this species. Only once, mid December, a swan was seen flying by, well above rotor height over the centre of the wind farm.

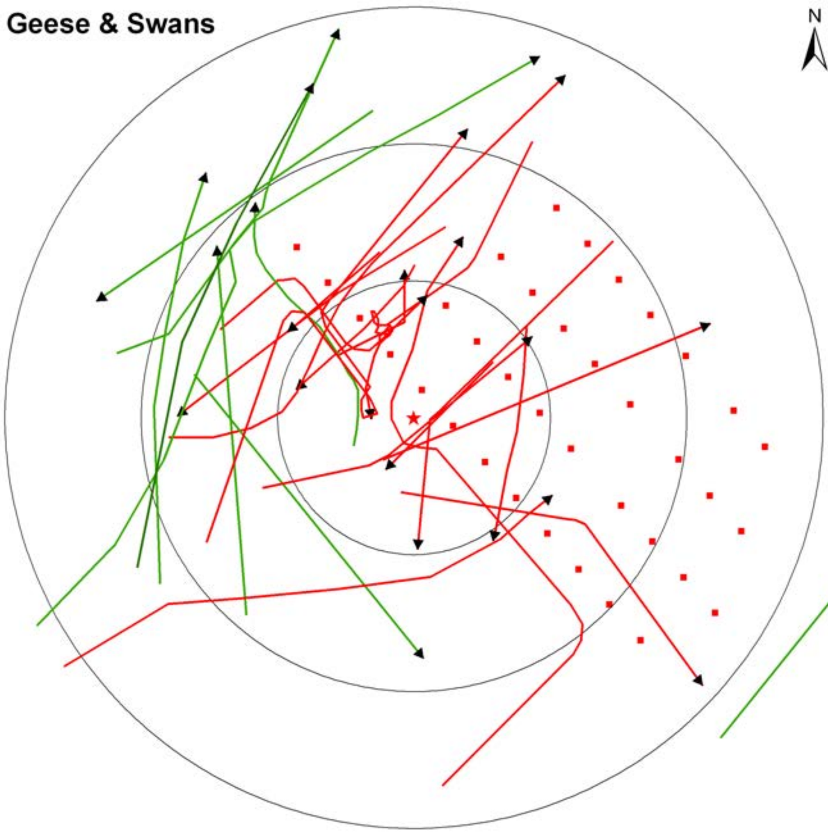


Figure 9.41 Flight paths of geese and swans in the wind farm area. Birds passing the wind farm almost always flew above rotor height (red lines). Legend see fig. 9.38.

- **Terns** migrating through and/or foraging in the area did not show strong avoidance, although they generally flew at rotor height (fig. 9.42). They were regularly seen foraging within the wind farm.

- **Waders** migrating through the area generally flew above rotor height and did not show avoidance. Those birds that did fly at rotor height showed some deflection in their flight paths, but often entered the wind farm (often at a location where a turbine was out of operation) (fig. 9.42).

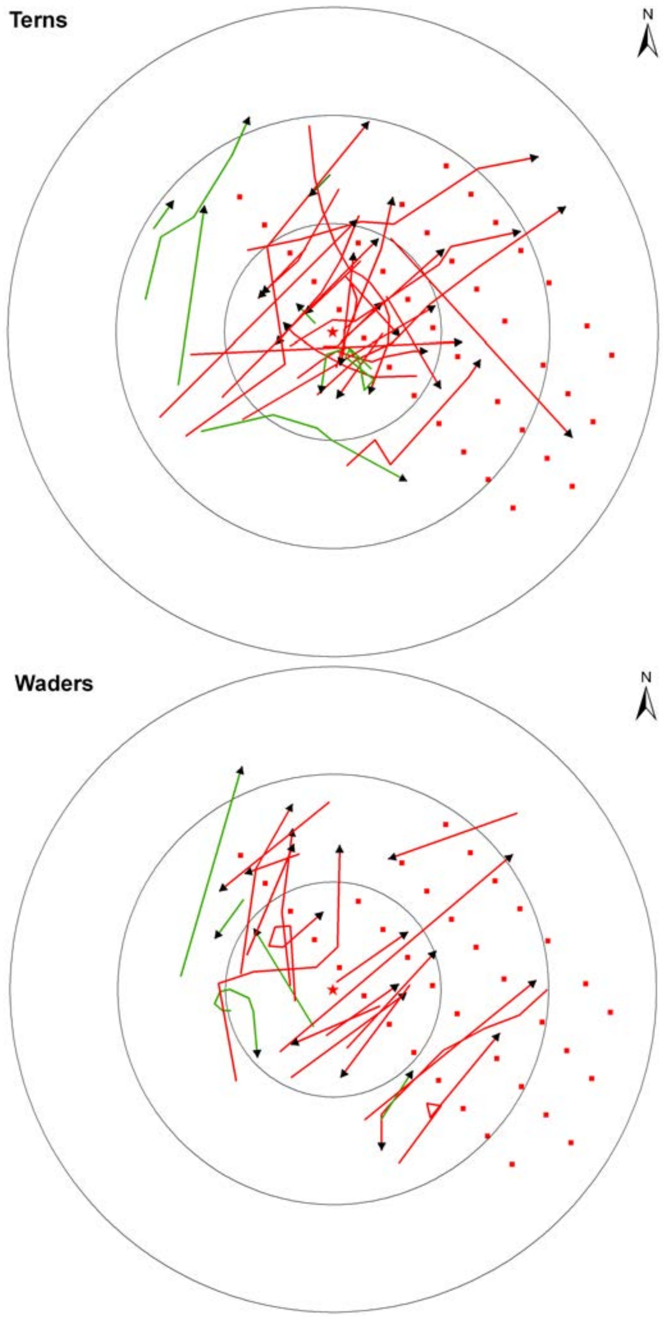


Figure 9.42 Flight paths of terns and waders in the wind farm area. Waders mostly passed the wind farm above rotor height. Legend see fig. 9.38.

- Most observations of migrating **passerines** were of thrushes and starlings. Smaller passerines included meadow pipits, sky larks, chaffinches and a few barn swallows. No clear pattern is visible in this group (fig. 9.43). Both birds avoiding the wind farm and birds showing no avoidance were observed. In general, avoidance seemed to be less explicit than in other species such as seabirds and geese. Passerines showing avoidance tended to enter the wind farm after initial avoidance.

- A **peregrine** was seen on several occasions. The bird (unclear if observations concern one individual or different birds) chased migrating passerines, outside as well as inside the wind farm without showing changes in flight path upon entering the farm. It was seen to use the metmast (with observers present) as well as turbine platforms to perch. Other raptors that were seen (**marsh harrier, sparrowhawk, goshawk**) showed no strong avoidance (fig. 9.43).

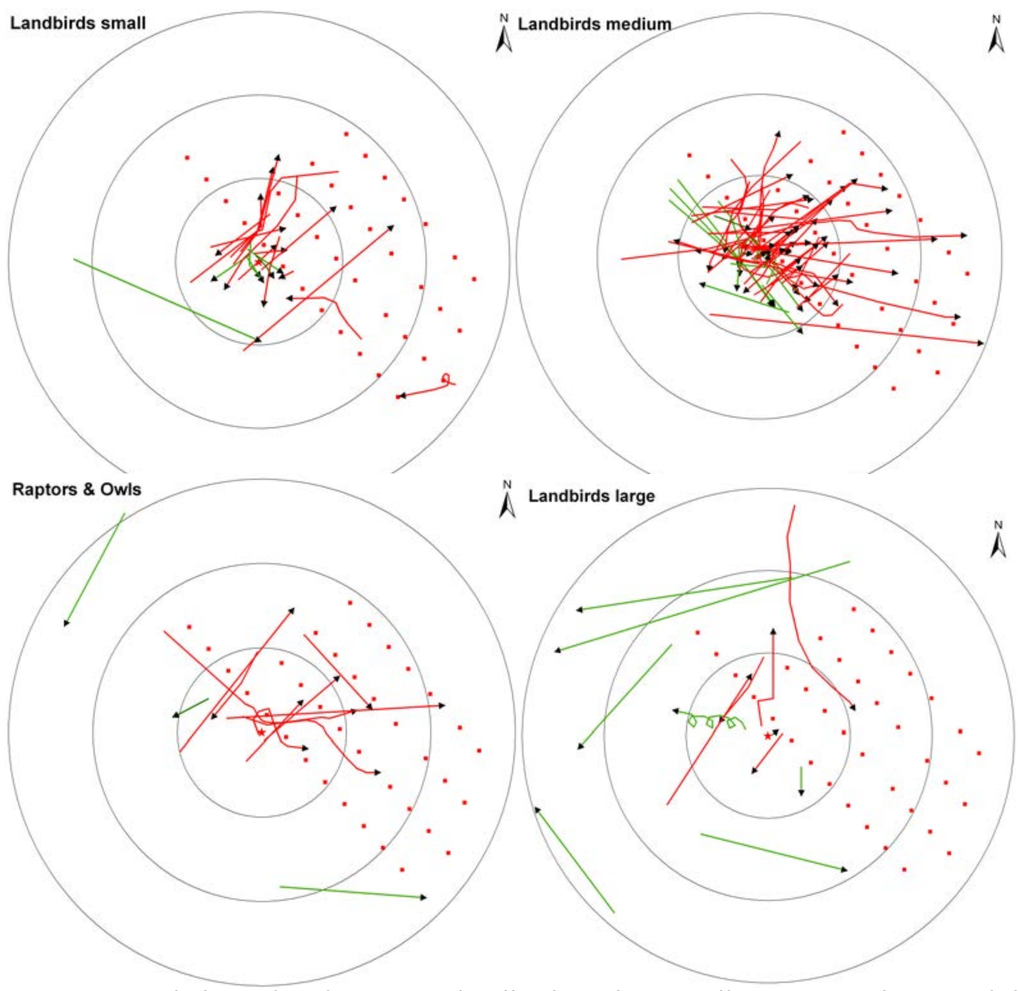


Figure 9.43 Flight paths of migrating landbirds such as small passerines (from top left to bottom right), thrushes & starlings, raptors and other large landbirds such as hooded crow, coot and grey herons. Legend see fig. 9.38.

General observations from flight paths

Flight paths were **concentrated** in the NW corner of the wind farm, between turbines 9 & 10 (see fig. 3.2 for position). This observation suggests that birds were avoiding the main body of the wind farm, but showed less hesitation to cross the single line of turbines. This observation was supported by data from the horizontal radar (see §9.3.6) The single line extends 2 km from the main body of the wind farm. For example, gulls (herring gull, kittiwake) were seen following this route, as well as flocks of starlings and thrushes on autumn migration, twice a flock of ca. 20 brent geese, and a black-throated diver.

Birds that were flying through the wind farm, did not always remain in one single corridor (the area between two rows of turbines), but were regularly seen **changing between corridors**, by changing their flight direction (e.g. flocks of starlings and thrushes in autumn, a blue heron). Birds that did stay in one corridor, were mostly larger gulls (herring gull, black-backed gulls). Also, flight paths were not equidistant from the turbines between which they flew. Some birds maintained their course once inside the wind farm, irrespective of corridors, with occasional small deflections to avoid single turbines (flocks of starlings). Some birds did stay within a specific corridor, and changed back to their original flight direction after exiting the wind farm (e.g., a flock of curlews). These data are in contrast to results reported from the Horns Rev and Nysted wind farms in Denmark (Petersen *et al*. 2006), where birds were largely flying through the corridors. The distance between turbines is slightly larger in the OWEZ wind farm than in the Danish wind farms (650-1000 m versus 480-850 m respectively), which could possibly explain this difference.

Groups of migrating birds such as passerines, thrushes or geese, often were '**hesitant**' to enter the wind farm. Birds would follow the edges of the wind farm for some kilometres before entering it, and repeatedly starting to enter (*i.e*. approaching the wind farm), but then refraining from that, and following the outer edge further. Often, groups were seen to finally enter the wind farm there where the nearest turbine was down.

Observer carrying out panorama scan. Photo D. Beuker.

10 Results: Fluxes

In this chapter data are presented on the flux, or flight intensity, of birds flying in the area of the OWEZ wind farm. First, overall patterns in flux are shown, based on the data collected with the vertical radar. These give an insight in the flux of all birds in the area combined, at different times of day and night as well as throughout the season (§10.2). In the next paragraph the influence of weather on flux is discussed (§10.3). In the last paragraph an assessment of flux is made for individual species or species groups, based on the visual observations and literature findings (§10.4).

The occurrence and abundance of different bird species varies year-round and inter-annually in the Dutch coastal waters. The variation in bird abundance is linked to the annual cycle of species, due to which local breeding birds are expected in summer, migrants mainly in spring and autumn, and wintering birds in winter. Migration of land birds can cause huge numbers of birds to fly above the sea in certain parts of the year (Lack 1959b). In addition, environmental conditions affect the occurrence of birds above sea. Bird migration takes place over a wide range of altitudes (Newton 2010). Below rotor-height birds experience a risk of collision with wind turbines. Flight activity at the various altitudes is reported in chapter 11.

10.1 Summary of results

- Mean traffic rates showed high variation throughout the year with average MTRs of 80 bird groups/km/hr. Peak hours occurred of more than 3,600 bird groups/km/hr.
- An estimated 0.1 – 2% of the total migration flux over the Dutch North Sea passed the OWEZ wind farm annually. During spring and autumn the numbers of birds were several times higher, due to migratory birds on their way to breeding and wintering grounds, than during summer and winter when mainly local seabirds were present.
- Variation also occurred between day and night with elevated numbers of birds flying at night during migration (especially autumn). In summer and to a lesser extent in winter the majority of flight movements were during the day. In summer and winter small peaks in flight activity were observed in morning and evening. In autumn and spring highest numbers were recorded around dusk and the beginning of the night.
- Weather, particularly wind speed and direction, was of great influence on fluxes. Migration fluxes were higher during tailwind situations compared to headwinds in both spring and autumn with an optimal wind speed of 4 Bft.
- Variation in intensity, direction and other flight characteristics of different cohorts of migratory birds was found on several specific days throughout the season.
- The most numerous birds tracked by vertical radar were gulls and passerines (the latter only during spring and autumn migration). Furthermore several tracks were of gannets, cormorants, waders and alcids were recorded. Smaller numbers of divers, terns and marine ducks, were present in the database in addition to some grebes, tubenoses, skuas, geese/swans, other ducks, raptors and owls.

10.2 Patterns of fluxes in the wind farm area

Avian fluxes are expressed in literature predominantly as mean traffic rate (MTR). In this study, MTRs were calculated based on observations with the vertical radar and by visual scanning methods (panorama scans, line transect scans ('sea watching') or moon-watching. By combining these methods we obtained an almost complete picture of the flux at different times of day and night, and throughout the seasons.

10.2.1 Variation in flux through the study period

In the OWEZ wind farm highly variable MTRs were found during all three years of field study, but on average in general between 30 and 230 bird groups per km per hour passed the wind farm (fig. 10.1). Higher numbers of birds flew through the wind farm area during autumn migration (mainly October) and to a lesser extent during spring migration (mainly March). Remarkable were the relatively 'high' fluxes (compared to the migration periods) found during summer and winter. These probably reflected locally foraging breeding birds (summer) and wintering birds (winter). The standard deviation bars indicate that variation within the months was large and peak events occurred in all months (fig. 10.1).

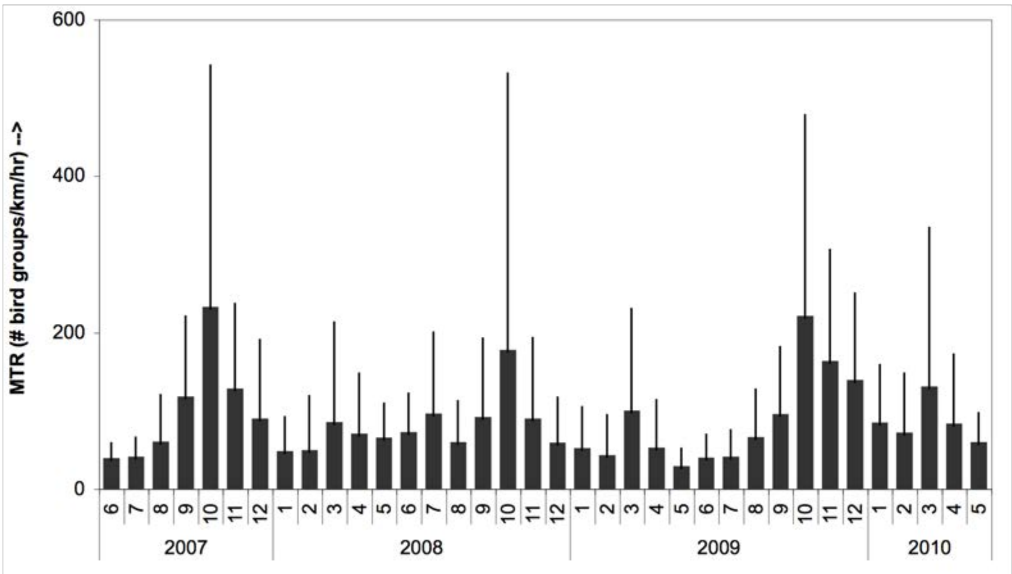


Figure 10.1 High variation in mean traffic rate (MTR) in the OWEZ wind farm, as measured with vertical radar. Means are shown with standard deviations.

Due to the high variation in MTRs within months, gaining an insight in the actual numbers that passed (or can potentially pass) the wind farm over the year was difficult. Therefore summed numbers of bird groups per month were extracted from the database as well (fig. 10.2). A disadvantage of using summed numbers was the dissimilarity in radar effort between the different months. To counteract this effect, bird numbers were extrapolated based on the radar effort data (see Box III for method).

Box III – Extrapolating fluxes based on radar effort

A reliable estimate of the total numbers of birds that pass the OWEZ wind farm is a prerequisite for an accurate assessment of the effects of the wind farm. Therefore summed numbers of recorded bird groups per km were determined with the vertical radar. However these numbers needed to be adjusted due to the dissimilarity in radar effort between the different months.

Two separate circumstances caused a gap in the radar data. First, the radar was sometimes turned off due to technical failure. Second, the radar was remotely switched off during wind speeds above 7 Bft. (to prevent mechanical damage). Data collected during hours with rain could not be used for analysis either and caused gaps in radar data as well (specific fraction of total time in table 3.2).

To fill these gaps, bird numbers were linearly extrapolated based on radar effort data. This method required the assumption of a linear distribution of birds over the month. This is not the case, but it is the best available method to fill gaps in the data. Potentially, this method overestimates the total number of birds because during adverse weather conditions, when the radar is switched off, a smaller proportion of birds is likely to migrate through the area compared to during good weather. However, observations on bird migration with other radars revealed that also during high winds (when the vertical radar was switched off) migration peaks occurred (for instance on the 9th of March 2008 when migration was high while the radar was switched off). Due to methodological limitations flux data collected with the horizontal radar could not be used for the reconstruction either, as the increased wave height caused the detection of bird targets by the horizontal radar to be much lower.

A possibility to check the extrapolated numbers was to calculate the monthly flux from the average MTR (flux/hr) recorded with the vertical radar. The two different methods correlated very well (fig. III.1; R^2 = 0.99).

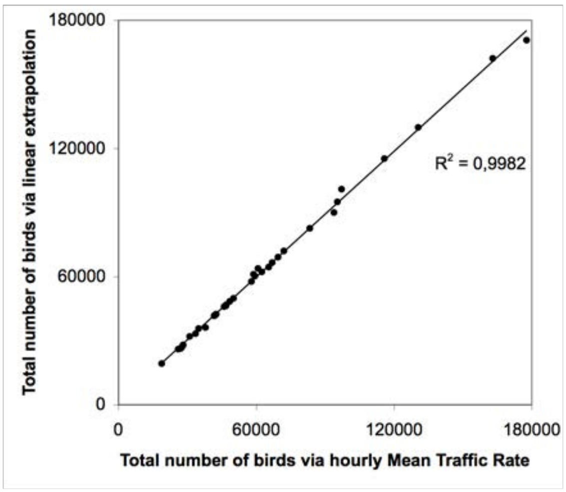


Figure III.1 Linear relation between two extrapolation methods to reconstruct monthtly numbers of birds passing through.

The number of birds passing through the wind farm area clearly altered during the study period from periods with high flight intensities to phases with lower flight intensities (fig. 10.2). In total 1,619,881 bird groups were recorded and are present in our vertical radar database. In other words a minimal number of more than 1,600,000 birds flew through a 1-km stretch of wind farm up to 1385 m altitude during the 3-year study period. In general, fluxes were low in the summer months (Jun–Aug), moderate in the winter months (Dec–Feb), slightly elevated during spring migration (Mar–May) and highest during autumn migration (Sep-Nov) (fig. 10.2).

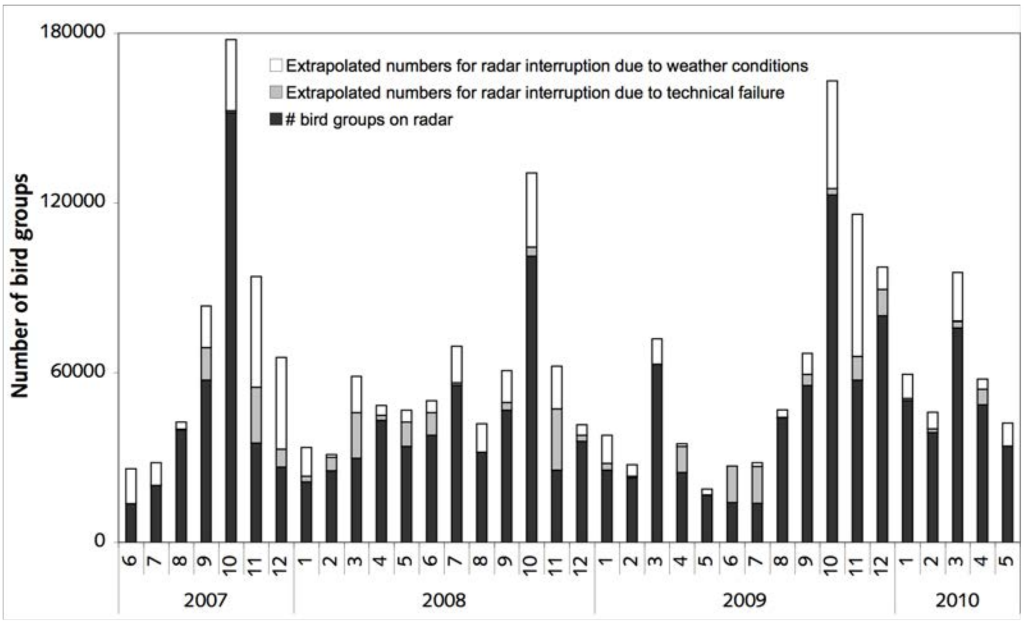


Figure 10.2 Number of bird groups per month in a 1-km stretch, as measured with vertical radar. Dark bars are the detected echoes, grey bars represent the estimated additional tracks due to technical failure and the white bars represent the estimated additional tracks due to weather conditions.

There was a remarkable difference in absolute numbers between spring and autumn migration (fig. 10.2). The numbers in autumn 2009 for example were roughly three times higher than spring 2009. This seems contradicting, as birds that go to their winter areas must return as well. An explanation might be that birds fly at higher altitudes during spring and are thus missed with the vertical radar, however, evidence for these phenomena is absent in the literature. Moreover, in most years many more birds are seen during autumn migration than in spring in the Netherlands (Lensink *et al.* 2002). Especially the most common migrants in the OWEZ wind farm (thrushes, chaffinch, and starling) can be very numerous in autumn but much less numerous in spring (e.g. 3.3-4.3 million redwings in autumn and 0.72-0.95 million in spring (Lensink *et al.* 2002)). This phenomenon has different causes. In spring total bird populations are smaller due to mortality in winter and the higher fraction of juvenile birds in autumn. Also different return routes (loop-migration) can explain inter-seasonal variation in numbers (Newton, 2010).

10.2.2 Diurnal variation in flux throughout the study period

The highest numbers of bird groups flying through the OWEZ wind farm area were recorded during the night in the migratory periods. In some months fluxes were several times higher at night than during the day (fig. 10.3). March 2009 and 2010 were remarkable months as most migration occurred during the night in contrast to the other spring months and March 2008, when migration was more evenly distributed during day and night. In summer, nocturnal flight activity was low, but activity during the day could be quite high. In winter flight activity at night was low but could be quite substantial in comparison to the number of flight movements during daytime.

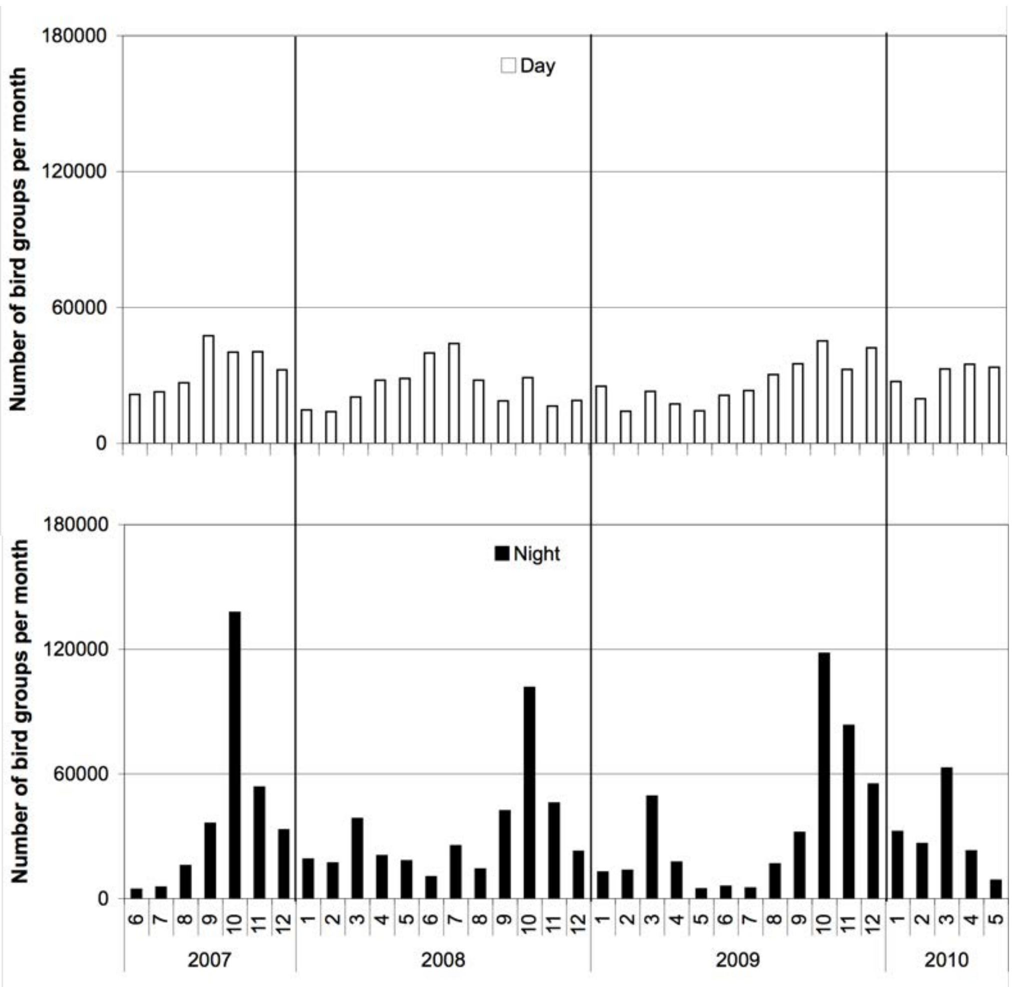


Figure 10.3 Number of bird groups per month in a 1-km stretch measured by vertical radar. Dark bars are the detected echoes at night and white bars during the day. These figures are corrected for dissimilar radar effort as shown in fig. 10.2. Daytime fluxes were more constant than night time fluxes.

10.2.3 Monthly and diurnal variation in flux

Variation in total flux was found over the years of the study period with a large variability in measured MTRs. Peaks occurred every March and October during spring and autumn migration respectively (fig. 10.4). During our three-year study period a clear pattern of high numbers in March and October and smaller numbers in summer and winter was seen. The lowest numbers of birds passed the OWEZ wind farm area in June and the highest in October. From April to August the highest fraction of birds flew during daytime, whereas from September until March most birds flew at night (fig. 10.4).

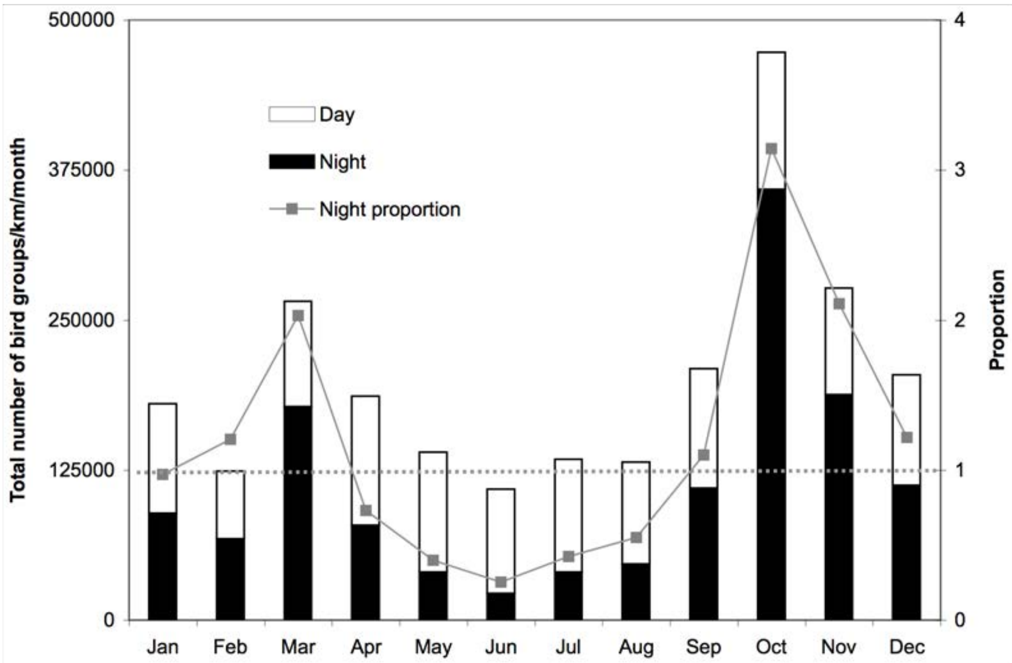


Figure 10.4 Number of bird groups per month in a 1-km stretch measured by vertical radar. Dark bars show echoes detected at night and white bars those during the day. Figures are corrected for dissimilar radar effort as done in fig. 10.2. Peaks in numbers are found in spring and autumn and from April to August the highest fraction of birds flew during daytime, whereas from September until March most birds flew at night.

The numbers of bird groups were highest during autumn migration (up to 180.000 bird groups in October on a stretch of 1 km). Also during spring migration elevated numbers of bird groups were seen, but overall numbers were considerably lower than during autumn. During summer numbers of birds were generally lowest, with mainly breeding lesser black-backed gulls and post-breeding cormorants present in the wind farm area. At the end of summer (from July onwards) several species already started migrating to post-breeding and wintering areas, resulting in increasing fluxes towards the migratory peak in autumn. These first migratory birds were observed during fieldwork to be several species of waders (e.g. lapwings), black-headed gulls and starlings. Also swallows and swifts were expected to fall within this first category of migrants through the wind farm, but these species were only occasionally observed and only in low numbers.

In winter flight movement of birds was slightly higher, due to the higher number of wintering birds (gulls, gannets and guillemots) compared to the lower numbers of breeders and post-breeders during summer. Some exceptional numbers of birds were found in December 2009. Initially an increase in clutter echoes due to bad weather conditions was expected to be the cause. However, closer examination of the data revealed that these increased numbers were not clutter but included several days with high altitude flight movements. This month was characterized by cold weather, which induced some 'frost-flight movements'. These frost-flights are mainly low-altitude coastal movements of inland waterbirds, that disperse from their wintering habitats in search of open (unfrozen) water. Another very likely explanation for the high-altitude movements was a late peak of thrush migration from Scandinavia. Thrush migration can show very species-specific flux patterns (Lack 1959; Lensink *et al.* 2002; fig. 10.5). From September onwards song thrushes are the first to arrive, followed by redwings, fieldfares. Blackbirds migrate throughout the autumn and start of winter. Due to severe weather conditions in more northerly wintering grounds, migratory waves of birds can still be seen during winter time, which may explain the high flight activity recorded in December.

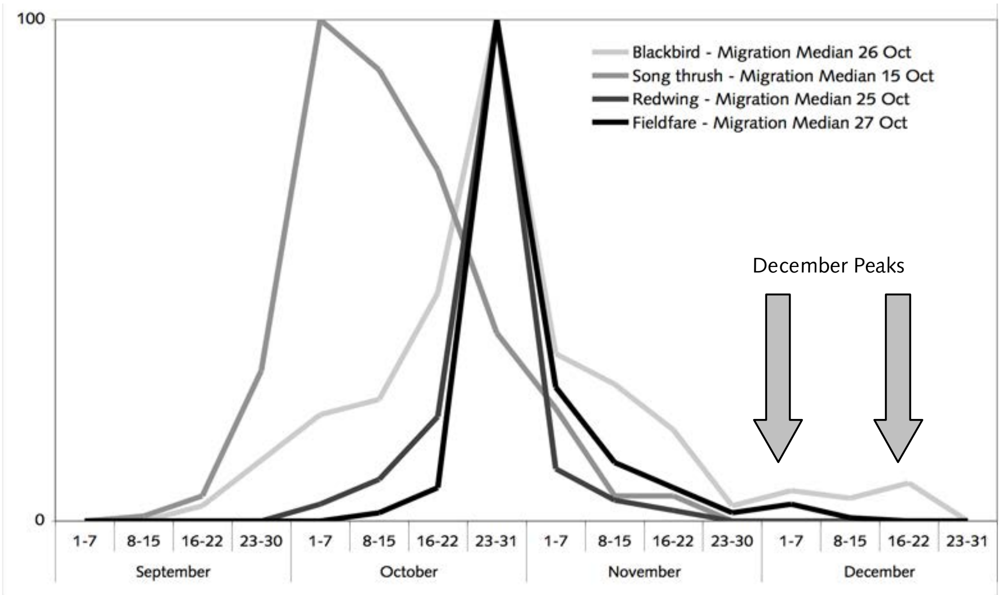


Figure 10.5 Indexed thrush migration along the North Sea coast of the Netherlands (adapted from Lensink et al. 2002). Note timing differences of the individual species and the peaks in December.

Up to 180,000 bird groups per month (Oct. 2007) passed a 1-km line on the ground within the OWEZ wind farm during the study period. Extrapolating these numbers to the entire OWEZ wind farm area (7 km in length) would mean that 1.3 million bird groups flew through the OWEZ wind farm during October. This implies that an order of magnitude of roughly 2-3 million bird groups potentially flew through and over the wind farm during the entire autumn migration (more about this subject in chapter 11.5, where 2.3 million bird groups were estimated per autumn each year).

In the past a few studies have been done estimating the migration intensity of birds over the southern North Sea in spring and autumn, based on migration watches and estimated population sizes (Lack 1959a, 1960, 1962, 1963b, a; Lensink & van der Winden 1997; Lensink *et al.* 2002). These studies identified ten migration routes in the Dutch coastal and offshore waters. At least five routes covered the area where the OWEZ wind farm is situated. The estimates of numbers of birds travelling these routes varied from 85 million (Lensink *et al.* 2002) to several hundred million birds (estimates of Helgoland mentioned in Hüppop *et al.* 2006) each season.

Our total figure of 2-3 million bird groups probably consisted of approximately 80% migratory birds and 20% local seabirds. This is based on the assumption that the fraction of local seabirds in the migratory periods is the same as the total number of birds in December (when only local seabirds are assumed to be present). This would mean that a maximum in the order of 1-2% of the total migration flux passed the wind farm area. Due to the uncertainty in the total numbers of birds travelling above the North Sea a better representation would be to say that in the order of magnitude of 0.1 - 2% of the total migration flux passed the wind farm each year. This is of course at all altitudes up to 1,389 m high. What this number would mean in terms of birds flying at rotor height is discussed in chapter 11.5.

10.2.4 Migration or local seabirds?

In the above paragraphs a separation in flux of migratory birds and local resident birds is assumed. The distinction between the two categories was solely made based on timing, in other words migratory birds were only found in spring and autumn. This was verified in this study by visual observations but could also be confirmed by measuring flight-direction. Measuring flight direction was mainly done with the horizontal radar (as explained in chapter 9) but also the vertical radar could be used to give indications on directional patterns (see box IV for method).

Box IV – Screen speed and screen distance of echoes

The vertical radar recorded travel distance and travel speed but not from the birds themselves but from the two-dimensional echo tracks on the screen. As the radar was oriented from the northwest to the southeast, birds that flew in these directions were making long, fast-moving echoes on the screen. To a lesser extent birds flying to the north, west, south and east would show these longer tracks as well. On the contrary, birds that flew to the northeast or southwest (the main migration routes in spring and autumn) would form small, slow-moving echoes as they penetrated the screen rather than flying along with the radar beam (fig. III.1). From these figures, the average flight direction of all birds in the area can indicate whether birds are flying together in one specific direction or whether birds are flying more randomly in the area (as expected in summer and winter).

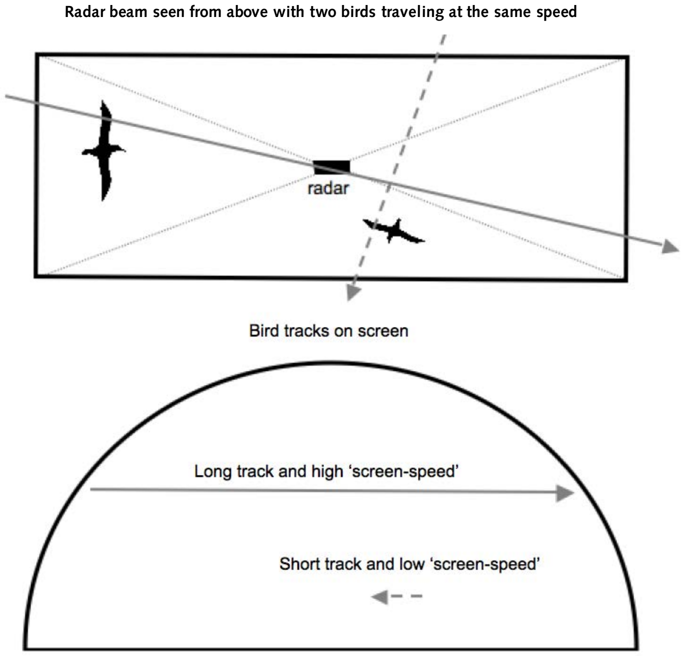


Figure IV.1 *Schematic overview of two birds flying with the same speed through the radar beam giving different 2D trail lengths and echo speeds in Merlin. 2D speed and distance thus provides information on actual heading.*

Speed and distance of the echo on the screen were found to be lower in spring and autumn (fig. 10.6). This was expected, as large quantities of birds during migration will have a northeast (spring) or west/southwest (autumn) component in their flight direction. On the contrary in summer and winter flew in more random directions (chapter 9). Although March was generally the month with the highest numbers of spring migrants, in May lowest echo speeds were found. This might be explained by a different origin of the different cohorts of migratory birds. In March and April many migrants come from Great Britain, resulting in a more westerly component in the flight direction (e.g Lensink *et al.* 2002). Later in spring the migrants from southern Europe and Africa arrive, from a more south-westerly direction.

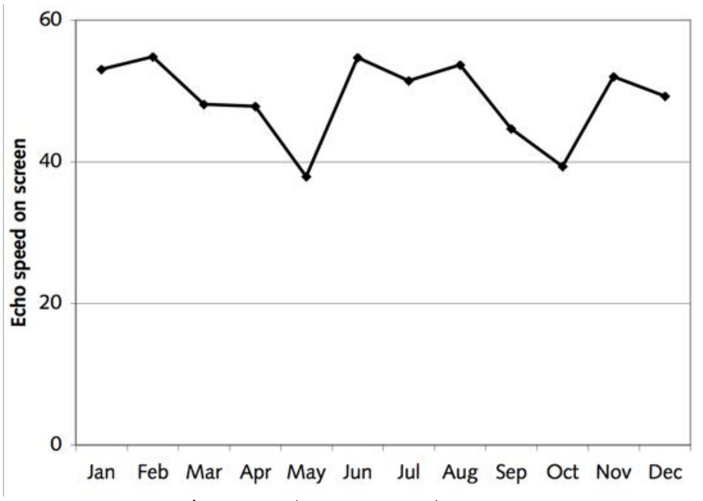


Figure 10.6 Multi-year (2007-2010) average screen speed of echoes per month. Spring and autumn migration can be discerned clearly as two dips in recorded speed, which reflects the higher proportion of birds passing the beam perpendicularly during the migratory seasons.

10.2.5 Daily flux patterns

Variation between days

Flight activity between months (cf. fig. 10.1-10.4) as well as within months showed strong variation. Not all days of a specific month were equally busy with flying birds. Specifically during the migration periods, numbers of birds differed remarkably per day. From almost zero to up to 17 (spring) and 13% (autumn) of the total migration flux of that year passed the OWEZ wind farm per day in these seasons (fig. 10.7 (spring) and fig. 10.8 (autumn)). Some years had bird migration more continuously throughout the season (spring: 2010; autumn: 2007), whereas in others more peak events occurred (spring and autumn: 2008 and 2009).

In each of the three years during the fieldwork period the cumulative migration figures gradually increased in the course of the migration season. However timing of the main peaks differed between the years (fig. 10.7 and 10.8). For example in spring 2008 birds tended to pass the OWEZ wind farm later in the year than in 2009 and 2010 (fig. 10.7). In 2008 a similar phenomenon was seen when birds passed later in the autumn as well. This might indicate a causal effect with a delayed spring passage resulting in a delayed autumn passage.

On average 10% of the total migration flux of a specific year in spring and autumn passed the OWEZ wind farm in respectively 1 and 2 days (table 10.1). An average of 46 days was needed for 95% of the migratory birds to pass the OWEZ wind farm in spring and autumn together. This is indicative of the fact that migration occurs in concentrated bursts of flight activity.

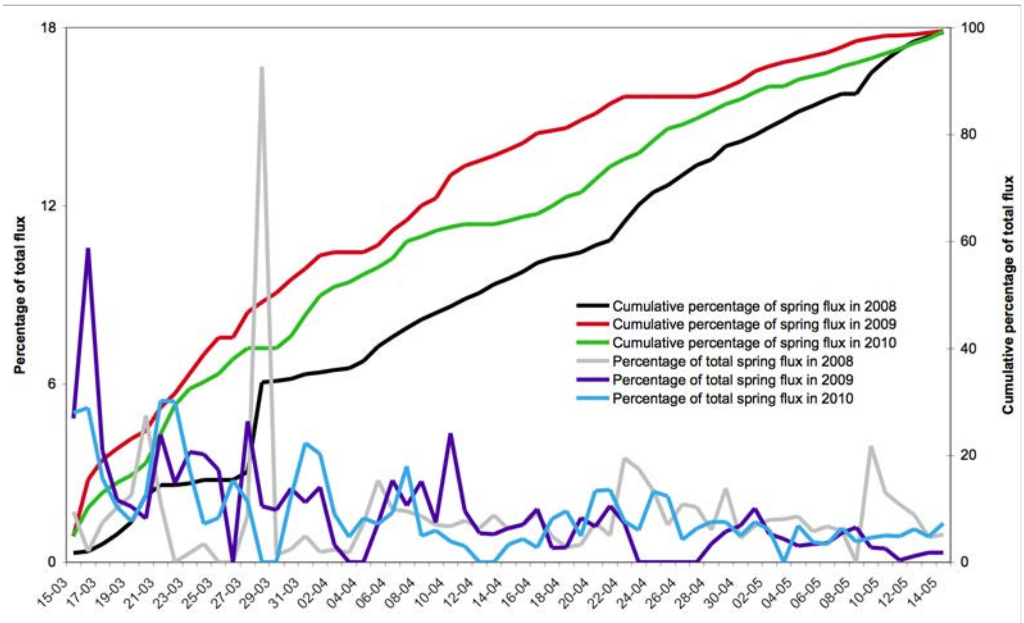


Figure 10.7 Inter-annual variation in nominal and cumulative fractions of the total spring migration fluxes through the OWEZ wind farm measured by vertical radar. Remarkable is a more delayed passage in both spring and autumn of 2008 compared to 2009 and 2010.

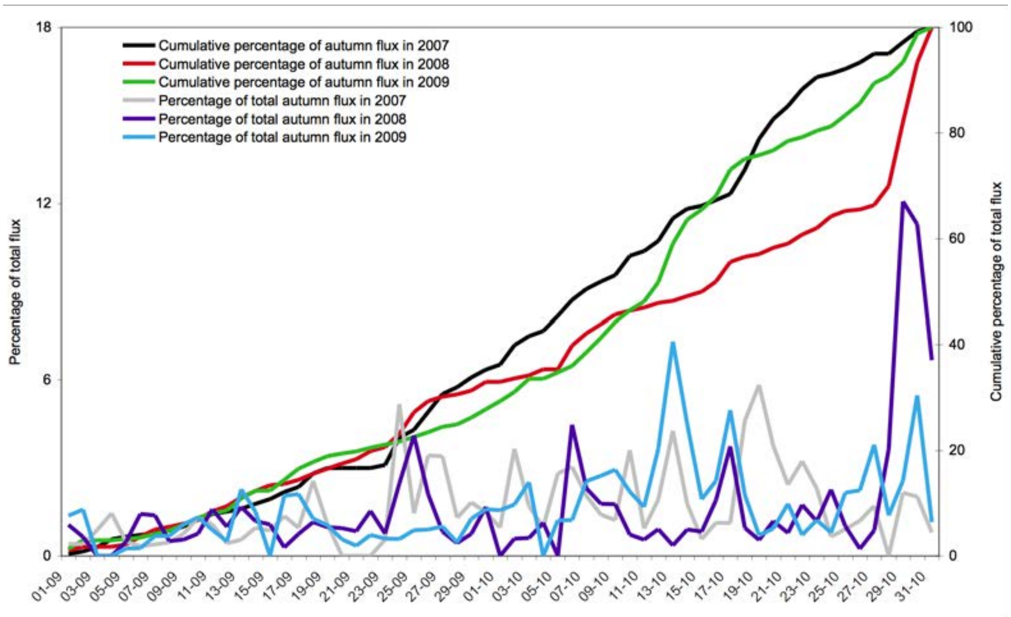


Figure 10.8 Inter-annual variation in nominal and cumulative fractions of the total autumn migration fluxes through the OWEZ wind farm measured by vertical radar. Remarkable is a more delayed passage in 2008 compared to 2007 and 2009.

Tabel 10.1 Time in days in which a given fraction of the total migration flux passes the OWEZ wind farm in 3 consecutive years.

	Spring				Autumn			
	2008	2009	2010	**mean**	2007	2008	2009	**mean**
10%	1	1	2	**1**	2	1	2	**2**
25%	3	4	5	**4**	6	3	5	**5**
50%	13	12	14	**13**	14	9	14	**12**
95%	47	42	49	**46**	46	46	47	**46**

Highly variable peak MTRs per hour were measured in the different months (table 10.2). Also the mean MTR for that month was determined. Weather conditions and timing of the day were important factors affecting the MTR in a month, as was discussed in §10.3.

The highest MTR was measured in the night of the 29th of October 2008 (19:00 – 20:00), with 3,638 bird groups/km/hr. This was a night at the end of the migratory season, with south/south-easterly winds up to 4 Bft. Not ideal for southward migration but with regards to the time of the year and prevailing wind this was possibly a good night for thrush migration to the UK.

Juvenile kittiwakes are a common sight in OWEZ, especially with westerly winds in winter time (photo R. Fijn)

Table 10.2 Peak hours in which highest fluxes of flying birds were recorded over the wind farm area, calculated as MTR (#/km/hr) and given for each month.

Date	Hour Interval	MTR (# bird groups/km/hr)	Monthly Mean MTR
12-06-07	09:00 - 10:00	177	36
19-07-07	18:00 - 19:00	367	38
20-08-07	21:00 - 22:00	535	57
27-09-07	04:00 - 05:00	637	115
19-10-07	19:00 - 20:00	1955	229
28-11-07	12:00 - 13:00	818	125
11-12-07	22:00 - 23:00	1339	87
28-01-08	18:00 - 19:00	625	45
28-02-08	17:00 - 18:00	1368	46
28-03-08	01:00 - 02:00	1416	82
29-04-08	18:00 - 19:00	1076	67
21-05-08	12:00 - 13:00	517	62
21-06-08	21:00 - 22:00	482	69
16-07-08	21:00 - 22:00	1443	93
27-08-08	17:00 - 18:00	696	56
25-09-08	00:00 - 01:00	838	89
29-10-08	19:00 - 20:00	3638	174
06-11-08	17:00 - 18:00	779	86
17-12-08	16:00 - 17:00	685	56
05-01-09	13:00 - 14:00	473	49
18-02-09	18:00 - 19:00	712	40
16-03-09	21:00 - 22:00	1250	97
08-04-09	19:00 - 20:00	738	50
01-05-09	18:00 - 19:00	254	26
09-06-09	18:00 - 19:00	314	37
21-07-09	11:00 - 12:00	235	38
18-08-09	13:00 - 14:00	589	63
16-09-09	18:00 - 19:00	745	92
13-10-09	04:00 - 05:00	1957	218
08-11-09	19:00 - 20:00	1067	160
18-12-09	16:00 - 17:00	930	136
03-01-10	11:00 - 12:00	502	81
24-02-10	21:00 - 22:00	992	68
21-03-10	23:00 - 20:00	2124	128
07-04-10	13:00 - 14:00	1209	80
30-05-10	18:00 - 19:00	330	57

Variation within days

Flight activity around the OWEZ wind farm was not constant throughout the study period. Diurnal variation occurred (fig. 10.3) as well as variation within the period of daylight (fig. 10.9). In summer the number of flight movements during the day was low and fairly constant, whereas during the night activity was even lower. Just before dusk a peak in activity was found, probably reflecting gulls flying towards the roosting sites. During daytime periods in spring, flight activity was generally low. In spring a peak in flight movements was found in the evening just before dark. Later on in the night a second peak in flight movements occurred and activity remained elevated during the night, easing down towards the morning. The peak later in the night was from nocturnally migrating species that had to fly for a while across sea before they reached the OWEZ wind farm. This is in contrast with the situation in autumn when higher flight activity was recorded during the day, building up to a large peak in the early evening just after dark. This reflects the exodus of migratory birds from the mainland dunes where numbers have been building up during the day as a result of 'migratory culmination' (Lack, 1963a). The numbers of bird groups gradually decreased during the night but remained elevated until the morning. In the course of the night the flow of migratory birds remains high due to the gradual addition of cohorts of migrants from further locations. Similar to the autumn situation, flight movements in winter were high during daylight as well. Throughout the day flight activity was high, in contrast to low numbers of flight movements in the night. These were mainly locally wintering birds (gulls, cormorants, guillemots a.o.) that used the area for foraging during the day. A clear peak was visible in the morning and a smaller one in the afternoon and evening (fig. 10.9).

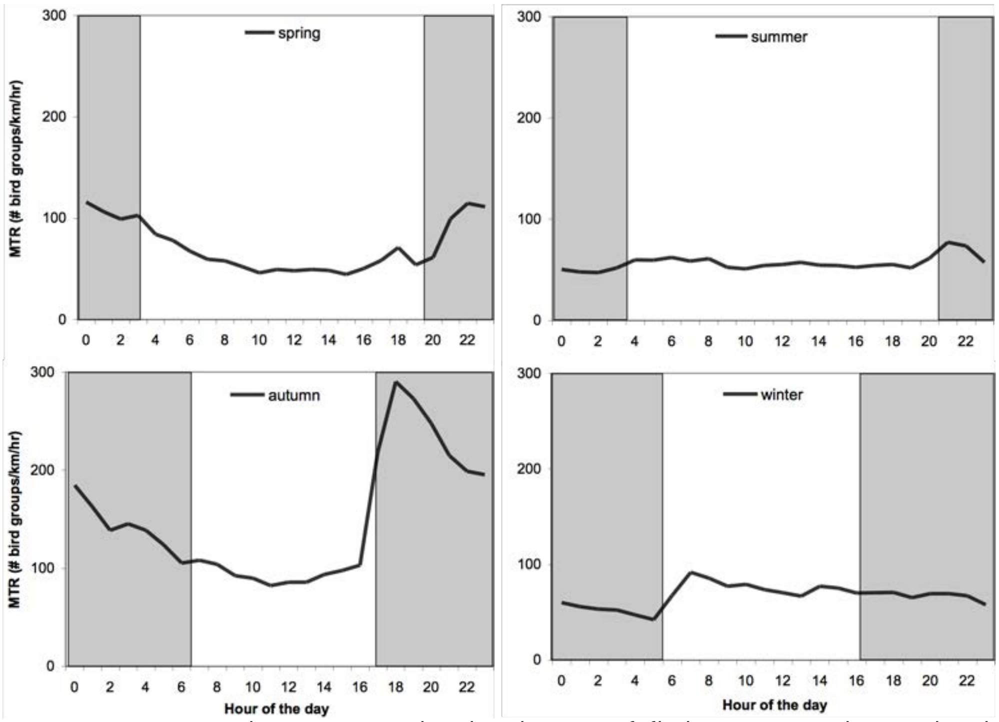


Figure 10.9 Seasonal patterns in the distribution of flight intensity during the day averaged for all years. On the y-axis averag MTR is presented. Shaded are the periods of the day when it is dark. In all seasons increased average fluxes were found during dusk and dawn.

10.3 Influence of weather on flux

Weather is an important factor in migration density and direction in both spring and autumn (Lensink *et al.* 2002). It is known from the literature that in general, temperature is the driving force of the onset of migration in spring and wind direction is the main trigger in autumn (Lack 1960). On the other hand, migration peaks occur mostly during fair weather with tailwinds, regardless of the season (Richardson 1978; Alerstam 1979). Birds can fly more effectively in tailwind situations (Liechti & Bruderer

1998; Shamoun-Baranes *et al.* 2003), and therefore it was expected that in these conditions higher migration peaks would be found. When birds choose the most favourable wind conditions, they are able to increase their flight speed by almost 40% (Liechti & Bruderer 1998). In this way a substantial and valuable part of the energy budget of the bird could be saved during migration (Liechti 2006). On the contrary, some species, especially the species with higher wing-loading such as Alcids and some Procellarids favour headwind situations to fly (Spear & Ainley 1997). As divers and grebes have high wing-loads as well, these species groups could potentially favour slight headwinds too. Arctic terns are another example of birds that favour headwind conditions for migration (Gudmundsson *et al.* 1992). 'Strong' flyers such as passerines and ducks, or 'gliders' such as shearwaters and gannets are most likely to favour tailwind situations. Birds are able to adapt their migration response and direction to the weather conditions that they meet underway, which makes them more flexible to search for profitable migration conditions (Alerstam & Lindström 1990; Russel & Lehman 1994; Tøttrup *et al.* 2008). Rain is also known to have a a large influence on migration activity (Alerstam 1979; Erni *et al.* 2002). Especially seabirds are known to avoid areas with rain, by flying past the area or staying at the sea surface during rain. Also land migration is known to be low during periods of rain (Lensink *et al.* 2002) and birds often precede rain fronts (Agostini 1992). Below we present results on the effects that weather conditions had on fluxes measured by radar and visually.

10.3.1 Effects of weather conditions in data collected with vertical radar

Average numbers of migrating birds varied substantially with wind direction. In spring a peak was found during winds from west and south-west, whereas in autumn a peak was visible during winds from the north and east (fig. 10.10). In autumn significantly higher numbers of migrating birds were found during tail-wind conditions (wind directions between 0 and 100 degrees) (fig. 10.11). Also in spring the same phenomenon was present (wind directions between 170 and 270 degrees).

The highest numbers of migrants passed the OWEZ wind farm in the autumn under tailwind condition of 3-4 Bft. (fig. 10.12). Above this optimum wind speed, average numbers of migrating birds were found to decrease. In spring no optimum was found, and average numbers of birds just decreased slightly with increasing wind speed.

Measuring the influence of rain on intensity of flight movements within the wind farm was not possible, as the radar was not recording properly during rain. Therefore all echoes stored in the database during rain periods were filtered in pre-analysis data-filtering steps (see chapter 7). The influence of cloud cover and cloud base altitude on migration was studied in the past and seemed mostly to influence migration altitude rather than migration intensity (Griffin 1973; Richardson 1978; Zehnder *et al.* 2001). Therefore it is discussed in chapter 11.

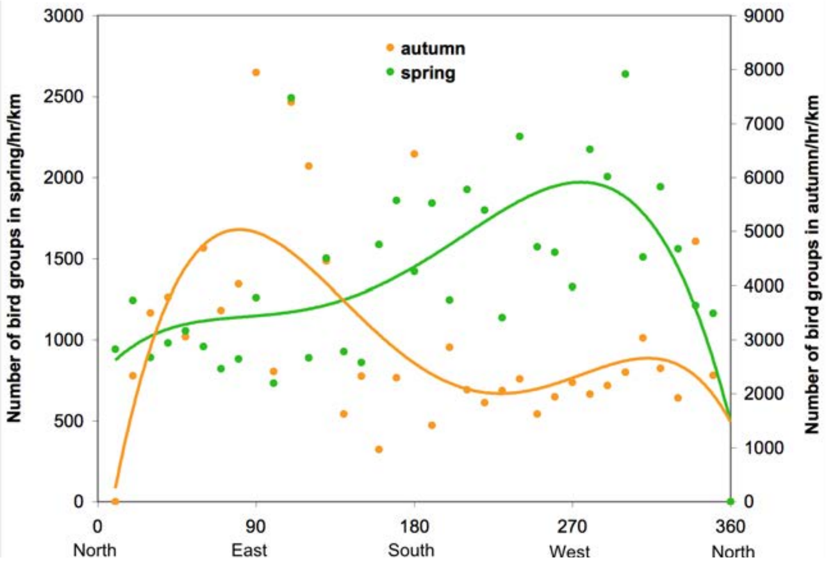


Figure 10.10 Mean number of birds in autumn and spring per wind direction with a polynomial trendline (n=4) plotted through the points.

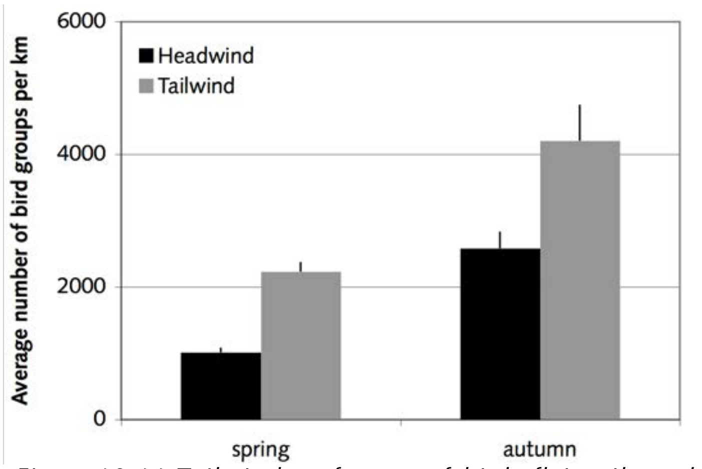


Figure 10.11 Tailwind preference of birds flying through the OWEZ wind farm in autumn (mean number of birds per day plus standard error).

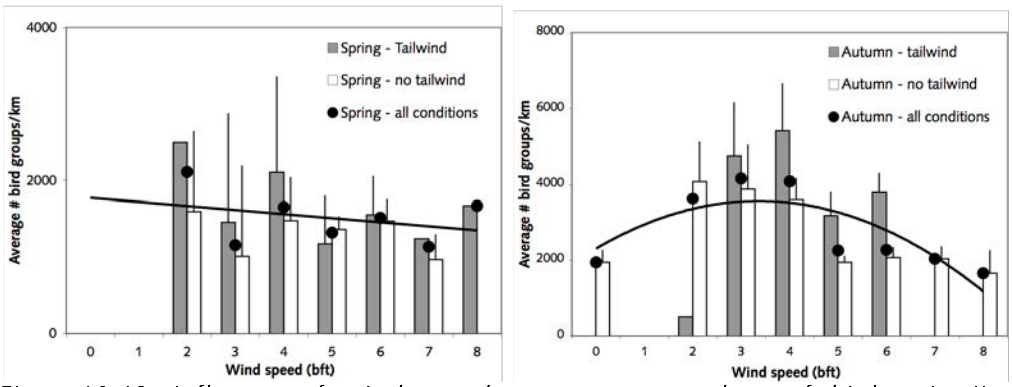


Figure 10.12 Influence of wind speed on average numbers of birds migrating through the OWEZ wind farm in spring (left) and autumn (right) (mean number of bird groups plus standard error).

10.3.2 Effects of weather in data collected during panorama scans

The influence of weather on flight activity was also studied using the data collected in the panorama scans. Flight activity, expressed as the average number of all flying birds encountered during one complete panorama scan, dropped dramatically with increasing wind speed (fig. 10.13). During calm weather with average wind speeds of 2 Bft, flight activity was twice as high as during wind speeds of 6 Bft. Because only a few panorama scans were carried out during extreme weather conditions (wind speed 1 Bft or above 6 Bft), the calculated flight activity at these speeds were not taken into account.

The high numbers of birds that were observed during calm weather conditions were mostly medium-sized passerines and small gulls (table 10.3). During windy conditions (6 Bft and higher) only cormorants and gulls (large and small) were still flying in the wind farm area (table 10.3).

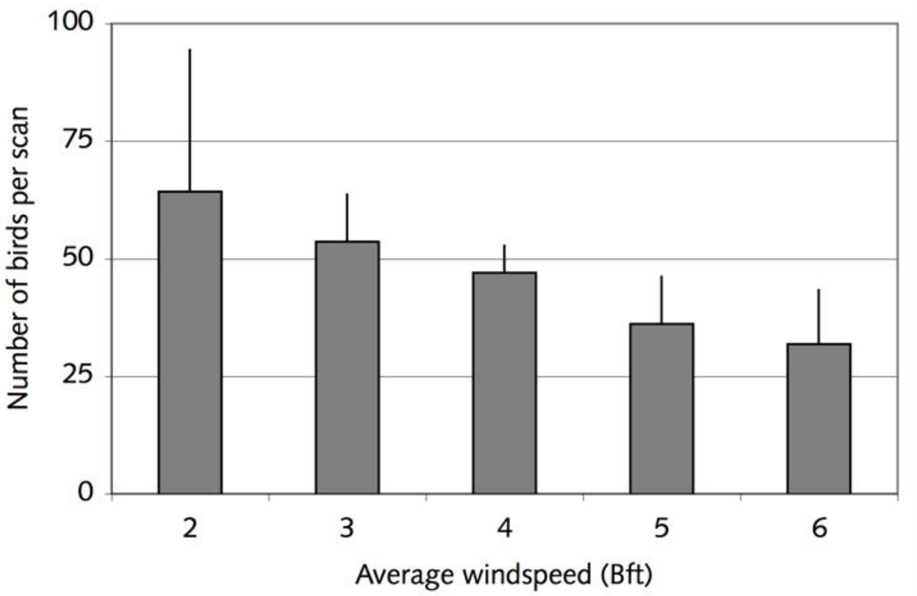


Figure 10.13 Average number of birds (with standard errors) observed during panorama scans at different wind speeds. Only flying birds within 3 km distance of metmast taken into account. As only very few panorama scans were carried out during extreme weather conditions (windspeed 1 Bft or above 6 Bft) these observations were not taken into accunt.

Table 10.3 Average number of birds encountered during a panorama scan at different weather conditions. Grey shading reflects whether values are higher or lower than the overall average value of that sub-group. Dark-grey: number > overall sub-group average; grey : number > 0,5 x overall sub-group average. Only flying birds within 3 km distance from metmast taken into account. As only very few panorama scans were carried out during extreme weather conditions (windspeed 1 Bft or above 6 Bft), those wind speeds were excluded.

		wind speed (Bft)				
group	subgroup	2	3	4	5	6
divers		0.0	0.1	0.0	0.1	0.0
grebes		0.0	0.0	0.0	0.0	0.0
tubenoses		0.0	0.0	0.1	0.0	0.0
gannets		0.5	0.5	1.7	0.3	0.7
cormorants		2.7	6.2	3.6	2.9	2.2
geese & swans	*Anser* geese	0.0	0.0	0.0	0.0	0.0
	Branta geese	0.0	0.2	0.7	0.0	0.0
	unident. geese	0.0	0.0	0.0	0.0	0.0
other ducks	diving ducks	0.0	0.0	0.1	0.0	0.0
	mergansers	0.0	0.0	0.0	0.1	0.2
	dabbling ducks	0.0	0.0	0.1	0.4	0.0
	unident. ducks	0.0	0.0	0.0	0.0	0.0
sea ducks		0.1	0.3	0.5	0.8	0.0
raptors & owls		0.0	0.0	0.0	0.1	0.0
waders		0.1	0.0	0.1	0.0	1.5
skuas		0.0	0.0	0.0	0.0	0.0
gulls	large gulls	10.6	23.8	20.4	14.1	16.3
	small gulls	19.6	20.0	13.1	6.8	9.6
	unident. gulls	0.2	0.1	1.0	0.9	0.0
terns		0.3	0.1	0.3	0.7	0.8
alcids		2.1	0.2	0.2	0.0	0.0
landbirds	large pass. & others	0.0	0.1	0.0	0.1	0.1
	medium-sized pass.	28.0	0.9	4.9	8.5	0.2
	small passerines	0.1	0.1	0.1	0.3	0.4
all birds		64.3	53.6	47.0	36.1	31.9

10.4 Species-specific fluxes

Due to the properties of the radar observation technology, it cannot be prevented that one radar-echo might represent more individual birds. This introduces a bias to the overall flux numbers. Also, the radar and bird-tracking software that was used was not able to distinguish between species. It was therefore not possible to define a species-spectrum based on the radar data. Because of this, fluxes at species level could only be quantified by visual observations of human researchers. Because these visual observations were restricted in time and conditions, due to the harsh nature of the offshore environment, they needed to be extrapolated to general patterns. This weather- and time condition also slightly biased the species distribution that was found. For example, numbers of kittiwakes and tubenoses were highly dependent on weather conditions. In this paragraph we assigned visually obtained percentages of presence of species to the radar data. This had several limitations. Nocturnal species could not be identified visually. Some species called at night and could thus be identified, but many were quiet. This was an issue during migration, when many birds passed the wind farm area at night. Also the presence of some rare species may have been missed because visual observations were limited. Therefore, although species-specific fluxes are presented in this paragraph, these limitations should be considered when interpreting the numbers of bird groups given.

Hundreds of thousands of birds passing the OWEZ wind farm each year were recorded with the vertical radar each (table 10.4). In this table, data on annual fluxes are separated into the four different seasons and into day and night. Most birds were seen during the night, especially in autumn.

Table 10.4 Sum of total numbers of bird groups per year in 1-km of the wind farm, determined by vertical radar and corrected for radar effort (§10.1).

	night	day	total
spring	85,367	82,613	167,980
summer	37,735	88,411	126,146
autumn	226,296	103,228	329,524
winter	77,809	68,537	146,346
total	427,207	342,789	769,996

To be able to estimate how many birds of each species passed through the wind farm, the fluxes given above needed to be converted into species-specific fluxes. This proved to be a challenging task. The best estimate of species-specific fluxes could be given for the daylight period in which panorama scans could be performed. However, detection of small birds (e.g. mainly passerines but also storm petrels) was limited to short distances. This caused larger birds to be more evident in the panorama scan database. Therefore the passerine fraction of the flux based on the panorama scans will be underestimated substantially. For the night situation, species-specific information on ratios between species groups lacks completely as some (e.g. alcids, divers, scoters) may be present but not heard at all.

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, we assumed that in the month with the highest migration rates (based on fig. 10.1), virtually all of the tracks above 70 m were of passerine origin. This assumption was based on the nocturnal observations done in this study and on literature on nocturnal activity and migration of pelagic seabirds such as divers, gannets and alcids (Prince & Francis 1984; Tulp *et al.* 1999; Dall'Antonia *et al.* 2001; Daunt *et* *al.* 2002; Weimerskirch & Guionnet 2002; Mañosa *et al.* 2004; Sittler *et al.* 2010). This assumption did not take into account that a small proportion of the passerines will have flown below 70 m and that also a small fraction of the flux above 70 m will have been of migratory waders and waterbirds. However, the assumption is critical for the adjustment and determination of species-specific fluxes.

The ratio between migration above and below 70 m was 0.71 in October (71% of flux above 70 m) and 0.65 in March (table 10.5). 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.

Table 10.5 Summed total numbers of bird groups throughout the study period and fraction between tracks above and below 70 m for October, March and the total study period.

	< 70 m	> 70 m	fraction
October	107,866	267,722	**0,71**
March	58,414	110,265	**0,65**
total year	655,687	964,194	**0,60**

These fractions for passerine migration were then added to the proportional species composition as determined from the panorama scans (table 10.6 **bold**). The remaining fraction (spring – 0.35; autumn – 0.29; total – 0.40) was then distributed over the other species groups. As a result, the combined set of proportions gives an estimate of the overall species composition. With this species composition (table 10.6) the total annual flux could then be differentiated by species group (table 10.7).

Table 10.6 Proportional distribution of bird groups over the different species groups in the OWEZ wind farm. Distribution is based on the species-distribution determined from adjusted panorama scan data.

	% 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
sea ducks	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

Table 10.7 Annual number of bird tracks recorded by vertical radar, separated by species group per year. These numbers were based on the species composition as determined by adjusted panorama scans figures (table 10.6). Note that these numbers are species group ***movements*** *and not actual numbers. First the radar cannot identify multiple passages of one individual and second during multiple panorama scans during the day; individuals can be recorded more than once as well.*

	nr spring	nr summer	nr autumn	nr winter	nr total
divers	74	0	0	452	466
grebes	0	0	33	0	19
tubenoses	11	0	33	251	224
gannets	1,872	486	5,455	779	7,080
cormorants	3,658	24,375	21,686	7,283	32,363
geese & swans	255	0	865	2,361	2,683
sea ducks	1,542	216	399	176	3,130
other ducks	255	54	1,563	151	1,453
raptors & owls	53	54	67	0	149
waders	489	270	0	0	950
skuas	11	0	33	0	37
gulls	49,893	93,393	63,329	130,875	252,178
terns	681	6,864	1,497	0	4,397
alcids	0	54	599	3416	2,888
passerines	109,187	378	233,962	603	461,998

* Note that the last column is not the sum of the four seasons but the species group specific proportion of the annual total number of bird group tracks.

Species group accounts

In the following section the occurrence and abundance of each species group is discussed. Consequences for the vertical radar track database of nocturnal activities are considered. Also some thoughts about species that were very scarce or might be missed during fieldwork are suggested, as tracks of these species will be included in the vertical radar tracks database.

Divers were very scarce and occurred only in winter and stayed until spring. The majority of divers were red-throated divers, but also black-throated diver was occasionally seen. Most birds were probably migrants passing the area, but some winter-residents of the Dutch coast may have wandered out into the OWEZ wind farm. Based on sea watch data along the coast (NZG databases and reports, see chapter 14), the baseline study, literature and individual observations it is expected that diver migration could also continue during the night, as highest numbers of divers are generally found in the early morning (Newton 2010). Compared to daytime, nocturnal migration is expected to comprise lower numbers of divers. Several hundreds of bird tracks in the flux database collected with the vertical radar will have been of divers.

Grebes were rarely seen and individuals were only recorded in autumn. Great crested grebe is a coastal species in winter, which migratea from inshore waters to the marine environment during frost conditions. Also red-necked grebe and horned grebe can be expected in the OWEZ wind farm in very low numbers. Grebes are known to migrate mainly at night (Jehl Jr. 1998; Snow & Perrins (eds) 1998) and daytime migration is mostly an extended flux of nocturnal migrants. Frost-related migration is mainly diurnal (Lensink *et al.* 2002). Based on this nocturnal flight preference, a larger number of grebes would be expected to be stored in the vertical database, but grebes in this area are specifically bound to the coast (Poot *et al.* 2010), and therefore no particularly high numbers of grebes are expected in the vicinity of the park. Several tens of bird tracks in the flux database collected with the vertical radar will have been of grebes.

Tubenoses were rarely seen during fieldwork, probably due to a weather effect. The presence of tubenoses in the wind farm will mainly be limited to weather conditions during which the metmast was not accessible for fieldwork (strong westerly winds). Petrels, shearwaters and storm-petrels can potentially occur throughout the year under the right environmental circumstances. However, only one species, the northern fulmar, was seen from the metmast. Several other species such as sooty-, manx- and Balearic shearwater, leach's and European storm-petrel could be expected as rare visitors in the area. Any shearwaters and storm-petrels will show up in the wind farm area mainly in late summer and autumn, but only during no-go weather conditions for fieldwork. All species of tubenoses are nocturnally active and migrate at night (Furness & Todd 1984; Prince & Francis 1984; Mougeot & Bretagnolle 2000; Weimerskirch & Guionnet 2002; Marshall & Serventy 2009), so similar orders of magnitude bird tracks of tubenoses are expected during night and day in the right period of the year. Up to hundreds of bird tracks in the flux database that was collected with the vertical radar consequently will have been of tubenoses.

Gannets were the most abundant of the pelagic seabirds during the entire study period. They were mostly seen during spring and autumn migration, but also in summer and winter. Gannets were likely to be encountered during fieldwork, and especially in March high numbers were observed. In the OWEZ wind farm locally wintering birds will have been seen, probably some foraging breeding birds, and also birds migrating from colonies on the British east coast, Norway and Helgoland towards the wintering grounds. Gannets are mainly inactive during midday and during the night (Garthe *et al.* 2003, Mullers 2009). Therefore all tracks of gannets in the database will be included in the number given in table 10.6. Several thousands of bird tracks in the flux database collected with the vertical radar will have been of gannets.

Cormorants were present in the area throughout the year. Occasionally, shags were seen from the metmast as well. Maximum densities were encountered in June, when birds from the colonies on the Dutch coast visited the area for feeding. Late autumn and early winter was the period with the lowest numbers of cormorants. The OWEZ turbines and the metmast are used for resting in order to dry their feathers after foraging. Therefore expansion of the offshore foraging range of cormorants was possible, probably explaining the higher numbers in the OWEZ wind farm. It is also possible that a concentration of food below the water surface compared to the surrounding waters provides a foraging 'oasis', attracting large numbers of cormorants to the wind farm. Cormorants that were flying from the resting platforms to the feeding areas in and adjacent to the wind farm, were recorded numerously in the vertical radar database. Although cormorants generally flew at very low altitudes (see chapter 11), and thus were sometimes not seen by radar, the estimate of individual birds flying through the farm is overestimated. This is because all individuals were likely to be locally resident birds and will have been recorded more than once. Foraging and flight activity of cormorants during the night is unknown, but is expected to be small. Being visual hunters, their hunting success would probably be limited during the dark. Therefore nocturnal flight activity is thought to be low.

Cormorants used the metmast and the turbines to resting (photo K. Krijgsveld).

Geese and swans, of which dark-bellied brent goose was the only numerous species, were scarce. Highest numbers occurred in winter, most likely representing migrants between Europe and Great Britain, as most of these birds flew west or east. Wildfowl is known for its nocturnal migration habit, so geese and swans are expected to travel through the OWEZ wind farm area also in the night. Unknown is the ratio of birds flying at night or during the day, but numbers in general were low. Each year several thousands of bird tracks in the flux database will have been of geese and swans.

Marine ducks, the majority of which were common scoter, passed the area in highest numbers during spring migration. Also velvet scoter and eider duck were seen in the OWEZ wind farm. Marine ducks are known to fly actively at night (Tulp *et al.* 1999;

Dirksen *et al.* 2005) so it is expected that several of the nocturnally recorded bird tracks are of migrating (sea)ducks. Each year several thousands of bird tracks in the flux database will have been of marine ducks.

Somewhat the same as for sea ducks, **other duck** species, such as scaup, red-breasted merganser and northern pintail, were found in the OWEZ wind farm as well. The occurrence of this species group was limited to spring and autumn, during migration. The most abundant species within this group was the northern pintail. Eurasian wigeon occurred very irregularly in the area but was expected to pass the area in much higher numbers than visually recorded. Wigeon are nocturnal migrants, which has resulted in numbers of this species being largely underestimated. At least several hundreds of the nocturnal birds tracks were thought to be of wigeon. Several thousands of the bird tracks in the vertical radar flux database will have been of other ducks in general.

Raptors and owls were very scarce in the OWEZ wind farm and were mainly confined to diurnal flight activity, although nocturnal migration of owls is poorly understood. The one owl species that could be a visitor (although in very small numbers) in the OWEZ wind farm (unpublished observations of BuWa on other North Sea platforms), is the short-eared owl. This is both a diurnal and nocturnal migrant. However, this species was not visually observed during fieldwork. One raptor species, the peregrine, was regularly feeding on migratory birds that passed the wind farm. Prey remains of this bird found in the metmast provided additional insight in species of migrants passing the OWEZ wind farm. Other species of raptors occasionally seen in the area include kestrel, merlin, sparrowhawk and marsh harrier. Only tens to a hundred of the bird tracks in the vertical radar database will have been of raptors and owls.

A peregrine was regularly seen hunting and feeding on migrants in the wind farm area (photo C. Heunks).

Waders were a difficult species group in terms of estimating the numbers of birds travelling through the OWEZ wind farm. The proportion of waders in the total number of birds is certainly largely underestimated, as wader migration occurs mainly at night and at very high altitudes (Lensink *et al.* 2002; Newton 2010). These were both conditions that were very difficult to cover with visual panorama scans. Species seen during fieldwork included lapwing, grey plover, golden plover, curlew, dunlin and other Calidris sandpipers. Some hundreds of bird tracks in the database resembled waders according to table 10.6. However, several thousands of the bird tracks in the vertical radar database are expected to be waders. The underestimation in table 10.6 is caused by the limitations of observing waders during the panorama scans.

The **skuas** were another difficult group and were probably underestimated in the panorama scans. This had several reasons. First, most skuas were expected to migrate through the area in non-fieldwork weather conditions such as strong westerly winds. All western-European skuas (great, arctic, pomarine and long-tailed skua), can be expected in the area, but only great and arctic skua were observed during fieldwork. Second, skuas (similar to gulls) are known to be nocturnally active (Votier *et al.* 2006) and even migrate during the night (Sittler *et al.* 2010). Overall skua numbers were low and bird tracks in the vertical radar database originating from skuas will be low as well, but certainly higher than the numbers in table 10.6. Here, only tens of bird tracks in the database would resemble skuas. However, in a similar way as described for the waders some hundreds is probably a more reliable estimate of number of bird tracks in the vertical radar database originating from skuas.

Gulls were present all year round and were most abundant in spring and winter. In autumn and summer abundance was much lower. As a percentage of the total number of birds, gulls were most abundant (up to 80% of all birds) in all seasons (except autumn). In autumn the percentage of passerines was higher but this figure was biased as explained above and below. Gulls in summer were mainly lesser black-backed gulls and herring gulls. Both species nest in colonies along the Dutch coast, with the nearest colony in the harbour of IJmuiden. The OWEZ wind farm is within their normal feeding range, but even the colonies in Texel and the Voordelta can be reached during foraging flights in the breeding season (Camphuysen *et al.* 2008). Many of those foraging gulls were associated to fishing vessels. In winter lesser black-backed gulls were almost absent, but were replaced by wintering great black-backed gulls. Also higher numbers of common gull and kittiwake occurred, especially in December and January. Herring gull was present year-round. In spring and autumn smaller numbers of little gull, black-headed gull and Sabine's gull were seen passing the OWEZ area. Nocturnal foraging and migration during the night of gulls is not quantified but known to be extensive (Garthe & Hüppop 1996; Hebert & McNeil 1999), so it is expected that a similarly large proportion of nocturnal bird tracks in the database will be of gulls. Several hundreds of thousands of bird tracks in the flux database collected with the vertical radar will have been of gulls, making it the second most numerous species group in the OWEZ wind farm (tabel 10.6). Outside the migration periods gulls were the most numerous species group (tabel 10.6).

Terns were flying in the area from March to September. Sandwich tern was the most abundant species, together with common tern and smaller numbers of arctic tern and black tern. Highest numbers of sandwich terns were recorded in July, when adults whose nests failed disperse over larger areas, and juvenile birds from colonies on the Dutch coast join adult birds. Terns were absent in June during visual observations. This was probably because breeding terns were foraging nearby the colonies in this period. Terns are known to migrate at night at rather high altitudes (Gudmundsson *et al.* 1992; Johansson & Jakobsson 1997; Lensink *et al.* 2002; van der Winden 2002). Therefore probably a small but substantial part of the bird tracks in the database in spring and autumn will have been of terns. Several thousands, or up to maybe ten thousand of the bird tracks in the vertical radar database will have been of terns.

Alcids (guillemots and razorbills) occurred in small numbers in the area. Guillemots and razorbills were only present in winter (October-February), with highest number in February. Many of the birds seen during panorama scans were seen floating and diving rather than flying. This made it difficult to estimate the proportion of flight movements from alcids. The locally wintering population of alcids mostly sits on the water and floats with the tidal currents. Flight movements are mainly correction flights when birds drifted to far from favoured foraging grounds. Nocturnal flight movements were expected for alcids, and sunset or even nocturnal migration probably occurred (Croll *et al.* 1992; Camphuysen 1998; Dall'Antonia *et al.* 2001; Newton 2010). Possibly a larger proportion than based on table 10.5 of alcid flight movements occurred during the night. Consequently, several thousands of the bird tracks in the vertical radar database will have been of alcids.

The last species group recorded in the panorama scans were the non-marine **passerines**. Passerines were mainly seen during spring and especially autumn migration. In summer passerine species included some swifts and swallows foraging in the vicinity of the OWEZ wind farm. In winter the occasional thrush, crow or pipits flew past. Among all different passerines, starling was by far the most numerous species. As mentioned before, high density of starlings was caused by a few groups of large numbers of birds passing the area of OWEZ in autumn. This is reflected in the panorama scan bird species group distribution (table 10.4) but will not subsequently be reflected in the vertical radar database, due to detection limitations (§7.7). In spring and autumn, migrating passerines will have been the most numerous group of birds within the OWEZ wind farm. Migration waves are very species-specific (Lensink *et al.* 2002; Tøttrup *et al.* 2006) and timing shows high inter- and intra-annual variability (Tøttrup *et al.* 2008). Many different species were encountered and expected during fieldwork in the OWEZ wind farm (Lensink & van der Winden, 1997). The first passerine migrants from the north were species such as starlings (mainly dispersal of juvenile birds), swifts, swallows and small singing birds such as goldcrests and Phylloscopus species. Thrushes started to appear later in the season. First the song thrushes were coming in, then redwing, fieldfare and blackbirds throughout the autumn. Together with the thrushes, also smaller passerines such as chaffinches and robins passed the OWEZ wind farm. In addition, wagtails, meadow pipits and skylarks were seen throughout the autumn. Most of these species solely migrate during the night. The only species migrating exclusively during the day are the swallows, swifts and wagtails (Lensink *et al.* 2002). All other species migrate mainly during the night, and only to a limited extent during the day as well. The number of passerines was highly underestimated during the panorama scans (although the groups of starlings caused a positive bias), therefore the proportion of passing passerines was much higher in the vertical radar database than estimated. Several hundreds of thousands of the bird tracks in the vertical radar database will have been of passerines, making it the most abundant species group in the OWEZ wind farm (table 10.6). Due to limitations in radar detection, these figures were even somewhat underestimated. The most numerous passerines were probably redwings and song thrushes, followed by starling and blackbird. It is unknown in which ratios these species were distributed over the total number of passerines.

Migrating starling resting on the metmast (photo K. Krijgsveld).

11 Results: Flight altitudes

In this chapter, data on flight altitudes of birds are presented. These data originate from measurements with the vertical radar and provide data on flight activity up to altitudes of 0.75 NM or 1385 m. The overall flight altitudes of birds that are present in the wind farm area are described in §11.2. Effects of weather on flight altitudes are described in §11.3 In §11.4 data are presented on species-specific flight altitudes. These data are limited to much lower altitudes than those that were obtained with radar, because they were obtained by visual observations. Species-specific observations available from moon watching are described as well.

Bird migration takes places at a wide range of altitudes (Alerstam 1990; Hüppop *et al.* 2006). It generally occurs at lower altitudes during daytime than at night. Variation occurs between as well as within species (Lensink *et al*. 2002). Waders and thrushes can reach high altitudes, while pelagic seabirds such as gannets, divers and alcids generally remain at relatively low altitudes. In addition, flight altitudes vary considerably with weather conditions (Bruderer *et al.* 1996). Collision with wind turbines can occur when birds fly at rotor height, i.e. 25-115 m. Birds flying close to these altitudes also are at risk, as flight altitudes may easily change, depending on e.g. weather conditions or behavioural changes.

Flight altitudes were classified in 10 altitude bands, for reasons of analysis and comparability with literature and visual observations. Each band represents 139 m altitude. The lowest altitude band was divided into 2 sub-bands (height 0.5 and height 1). Some of the results are presented in three risk zones, with a high (25-139 m), an intermediate (0-25) and a low risk (above 139 m). The maximum height of the turbine rotors is 115 m. The high risk zone was chosen up to 139 m to allow for wake effects of the rotor blades and sudden drops in altitude of birds. These can occur due to for instance sudden changes in weather conditions or shock reactions of birds when approching the wind farm. The zone between sea level and the lowest tip of the rotor is regarded as a zone with an intermediate risk of collision, due to wake effects of the rotors and collisions with the turbine tower.

11.1 Summary of results

- Flight activity was recorded at all altitude bands (measured up to 1385 m high) and varied highly between seasons. 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 activity occurred at both higher and lower altitudes, especially at night.
- On average and throughout all seasons, more birds flew at night. This was true for all altitudes except the lowest altitude band up to 69 m. Above 250 m the majority of tracks were of migratory birds. At lower altitudes more local seabirds were present. In

general, flight altitude was higher during the night than during the day and average flight altitude decreased in the course of the night.

- Weather, especially wind speed and wind direction, influenced flight altitude of migrating birds. In headwind conditions birds generally flew at lower altitudes than during tailwind. Also clearly segregated migration streams occurred under influence of specific weather conditions (wind speed/directions or cloud cover).
- When approaching the wind farm, birds generally increased their flight altitude, but in general altitude still was within the range of the rotor blades. The highest-flying birds were passerines and waders. Particularly low-flying birds were alcids. Of birds that flew within the risk zone of the turbines, most species groups were represented, including divers, grebes, gannets, cormorants, all waterbirds, marine ducks, raptors and owls, skuas, gulls, terns and passerines.
- The number of birds flying through the high-risk zones in the OWEZ wind farm was in the order of magnitude of 2 million birds per year.

11.2 Patterns of flight altitudes in the wind farm area

11.2.1 Flight altitudes throughout the study period

Bird tracks were found at all altitudes throughout the study period, with most birds occurring in the lowest altitude band (0-69 m). At high altitudes a larger proportion of the total number of bird tracks was found at night. At the lowest altitudes, on the contrary, a larger proportion of birds flew during the day (fig. 11.1 left). Throughout the study period, 40% of the total flux on average was flying in the lowest altitude band (fig. 11.1 right). In general the largest proportion of birds flew below 277 m (68% of the total flux). This is a minimum estimate, as it was likely that some birds flew too low to be detected by the vertical radar (see ch. 7). Therefore the percentage of birds in the low altitude band was expected to be even larger. However, detection of small birds at high altitudes was limited by beam width, so in theory birds in the highest altitude bands were expected to be slightly more numerous as well (see ch. 7).

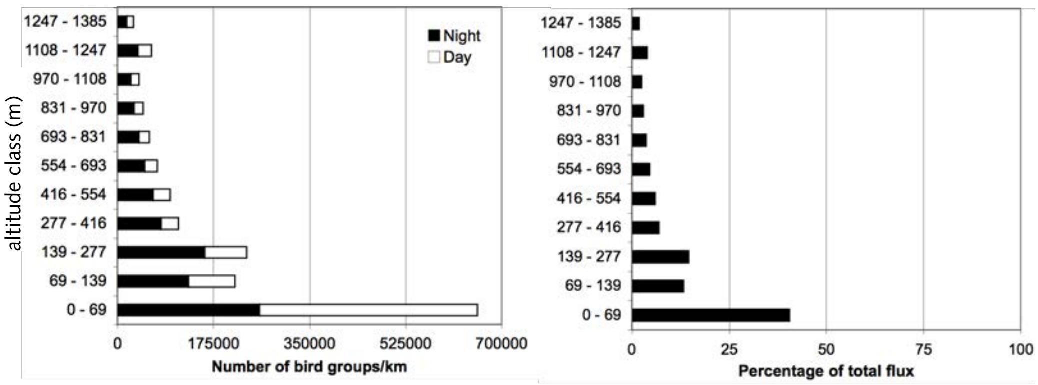


Figure 11.1 Number of bird groups per km, separated into day and night. Shown is the total flux per altitude band per km (left) and the percentage of the total flux (right). Data recorded by vertical radar in 11 altitude bands (in m) between 2007 and 2010 in the OWEZ offshore wind farm. Note that altitude bands 1 and 2 are half the height of the other altitude bands.

11.2.2 Variation in flight altitude between day and night

Average numbers of birds were higher during the night than during the day at all altitudes, except in the lowest band (0-69 m). Birds in this altitude band reflected mostly birds that were searching for food and travelled short distances. Because this behaviour occurs mainly during the day, the highest numbers during daytime were seen in this altitude band. The proportion of birds that flew at night increased with altitude up to 416 m and then levelled out to a 1:1 ratio in the highest altitude band (1370 m) (fig. 11.2). This was slightly unexpected as it was thought that high-altitude movements would be restricted to nocturnal activity. However, the data showed that these movements occurred during the day as well. It is not known of which species these tracks were, although even gulls resident to this area were found at high altitudes (own observations Bureau Waardenburg, from various marine wildlife monitoring programmes). In all seasons flight altitude was higher at night than during the day (see also fig. 11.7).

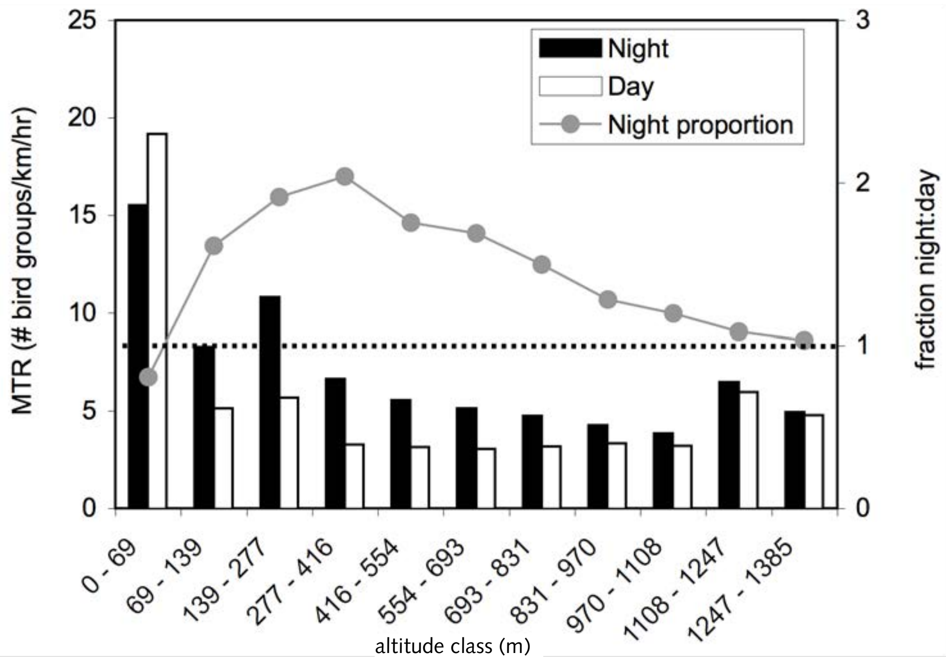


Figure 11.2 Night/day ratio of average number of bird groups per km per hour, separated into day and night. Data recorded by vertical radar in 11 altitude bands between 2007 and 2010 in the OWEZ offshore wind farm. Note that altitude bands 1 and 2 are half the height of the other altitude bands.

11.2.3 Variation in flight altitude between months

Birds were found at all altitudes during all months of the year (fig. 11.3). Bird movements at higher altitudes were most common during the night in migration periods such as March and September/October. These movements probably reflect waders and passerines (especially thrushes) on their way to the breeding and wintering grounds. The main peak for wader migration is somewhat later in the year, mostly in

April and May, than the peak for passerines (Lensink *et al.* 2002). In all months, most activity clearly occurred in the lowest three altitude bands (up to 277 m). December and January showed high fluxes in the very lowest altitude band. Probably these tracks reflected seabirds (gulls and cormorants) locally present in the wind farm area. However, even outside the migration periods small numbers of birds flew at high altitude. It is unknown which species these were but from trackplots was seen that those tracks were in fact birds and not clutter.

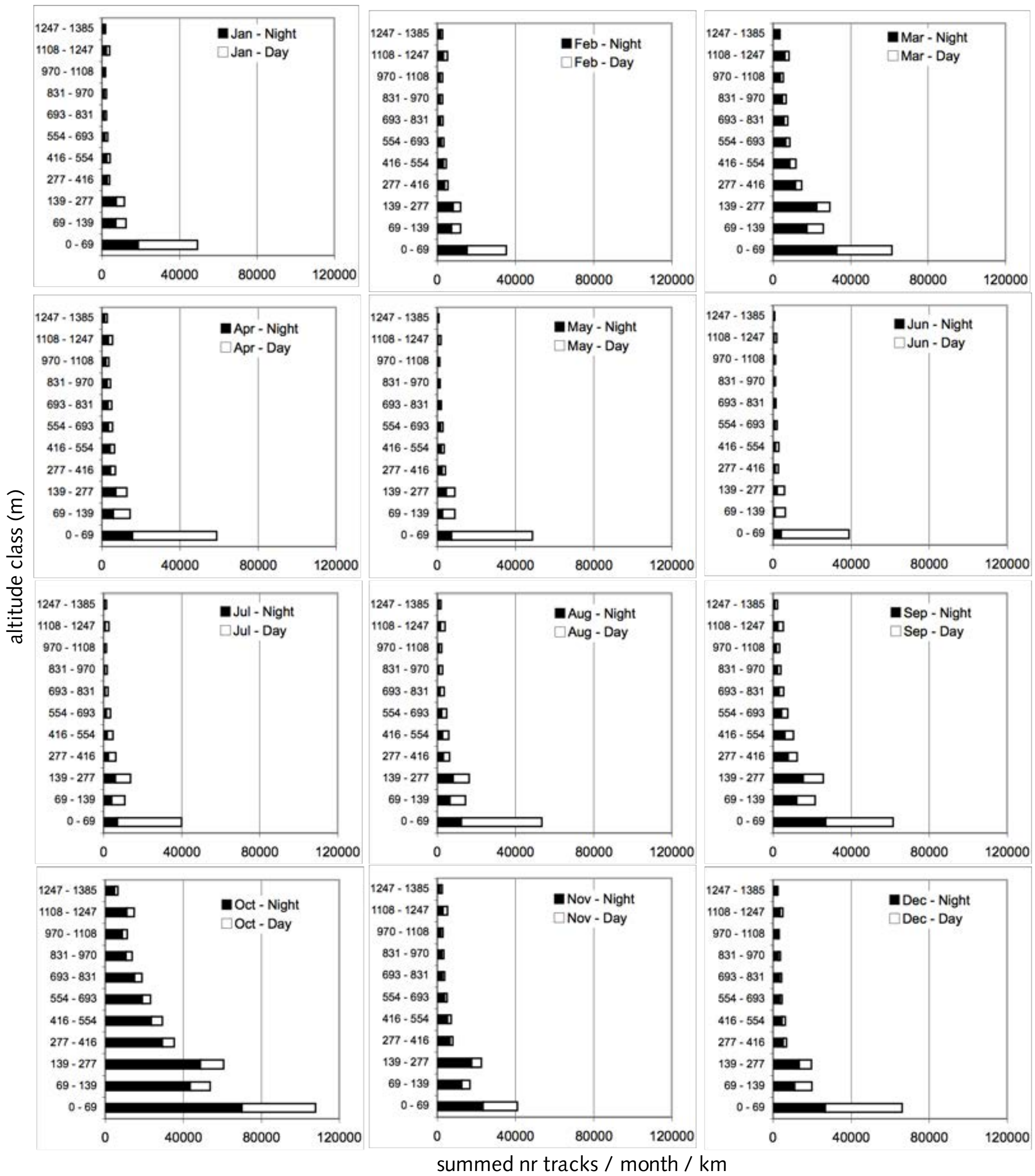


Figure 11.3 Summed number of bird groups per km per altitude band for the different months and separated into day and night. Monthly data reflect summed numbers from all three years. Data recorded by vertical radar in 11 altitude bands in 2007-2010 in the OWEZ offshore wind farm. Note that altitude bands 1 and 2 are half the height of the other altitude bands.

11.2.4 Seasonal variation in flight altitude

In autumn the highest diversity in altitude of birds was found (fig. 11.4). Migrants flew at all different altitudes past the wind farm but concentrated in the lower altitude layers. These high numbers are migratory birds that take off from the coast in westerly direction. They have just departed and are therefore at relatively low altitude. Also prevailing winds from the west during autumn cause birds to stay quite low. In contrast ,in spring birds tend to arrive from further away when passing the OWEZ wind farm and are therefore expected to fly at higher altitudes. In the other seasons the variation was less and in summer and winter most birds flew below 277 m.

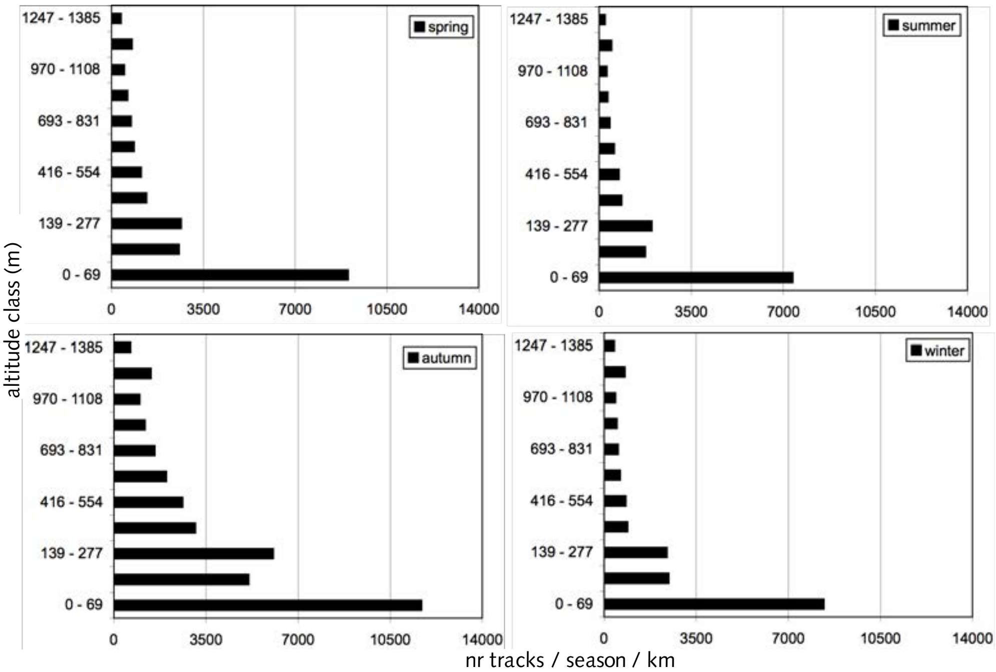


Figure 11.4 Average seasonal sum of numbers of bird groups per km. Data recorded by vertical radar in 11 altitude bands in 2007-2010 in the OWEZ offshore wind farm. Note that altitude bands 1 and 2 are half the height of the other altitude bands.

As explained in Box III (§10.2), the distance travelled by echoes on the Merlin screen can be used as a measure of determining whether bird movements are of migratory birds or of local residents. Migrants in spring and autumn were expected to show a shorter travel distance on the screen and a lower travel speed on the screen than resident birds. Resident birds were expected to have a rather constant speed and distance on the screen, as their movements were more randomly directed in the area. As most resident birds flew at lower altitudes, altitudinal segregation was expected in the level of variation in travel distance and travel speed (fig. 11.3). Indeed, travel distance remained fairly constant throughout the year at lower altitudes, while it was highly variable at high altitudes with two dips in spring and autumn (fig. 11.5). This was another indication that flight movements above 250 m were mainly migratory movements.

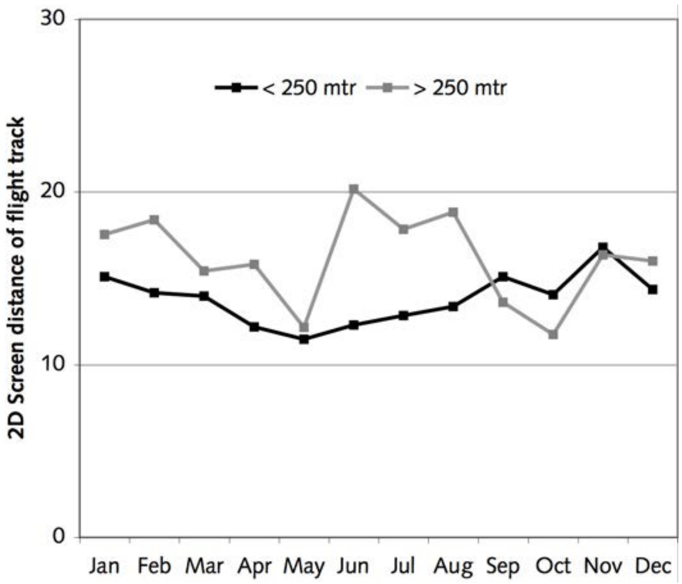


Figure 11.5 Multi-year (2007-2010) screen speed of echoes recorded below or above 250 m, averaged per month. Level of variation at high altitudes was lower during migratory seasons.

11.2.5 Daily variation in flight altitude

Outside the bird migration periods, in summer and winter, high altitude movements were stable throughout the day, with slight increases in numbers in the evening (fig. 11.6). These might have been gulls that flew to the night roosts in the evening (observed on a number of observation days), but a more likely explanation would be the occurrence of late-summer migratory movements of waders and passerines and frost-flight movements in winter. This sort of migration occurred particularly during calm weather at higher altitudes. At lower altitudes (below 277 m) the daily pattern of movement consisted in both summer and winter of a peak in numbers in the morning and lower flight activity during the night. These probably reflected gulls flying towards and from the roosting sites. During migration in spring and autumn migration patterns at all altitudes consisted of peaks in the evening and decreasing numbers in the course of the night (fig. 11.6).

In spring the average flight altitude of migrating birds increased clearly in the evening, with a maximum altitude just before dark at 21:00 hr (fig. 11.7). In the course of the night the average flight altitude decreased. From the literature we know that birds tend to fly lower before sunrise and then higher just after sunrise (Myres 1964; Lensink *et al.* 2002), which was found in the OWEZ wind farm as well, although only a very small peak was visible (fig. 11.7). The average flight altitude during the day was rather constant throughout the year. In autumn the average flight altitude was slightly higher than in spring, but only in the evening and rather constant throughout the night. In winter a highly variable average flight altitude was found. Equally, decreasing migration altitudes of streams of birds were observed to occur over very short time spans, sometimes within an hour (fig. 11.8).

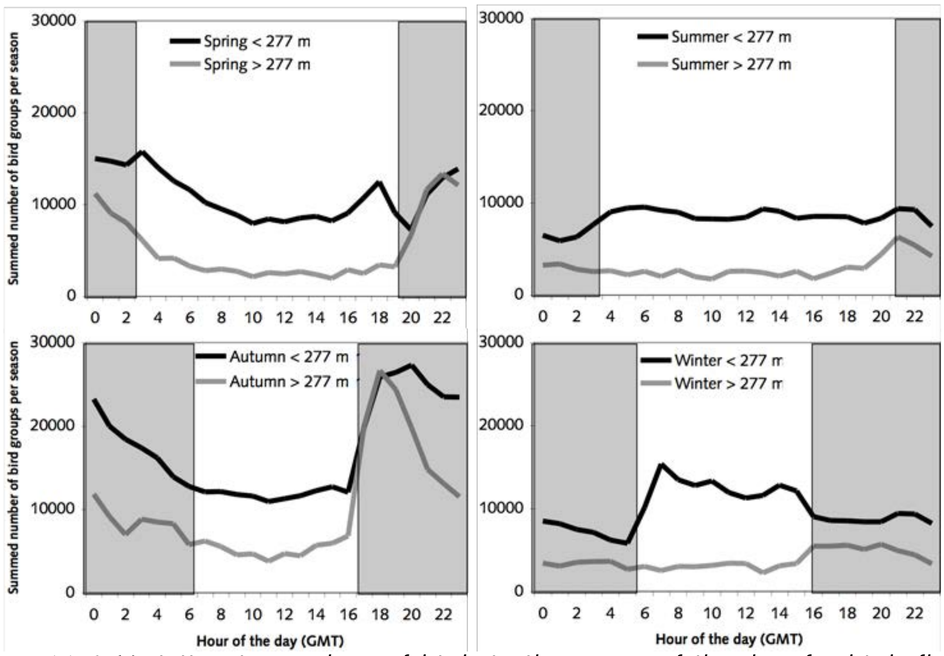


Figure 11.6 Variation in numbers of birds in the course of the day, for birds flying low or high (above vs. below 277 m, (first 3 altitude bands), shown for the different seasons. Values are multi-year (2007-2010) seasonal averages of numbers of bird groups per km per hr. Darkness is shaded.

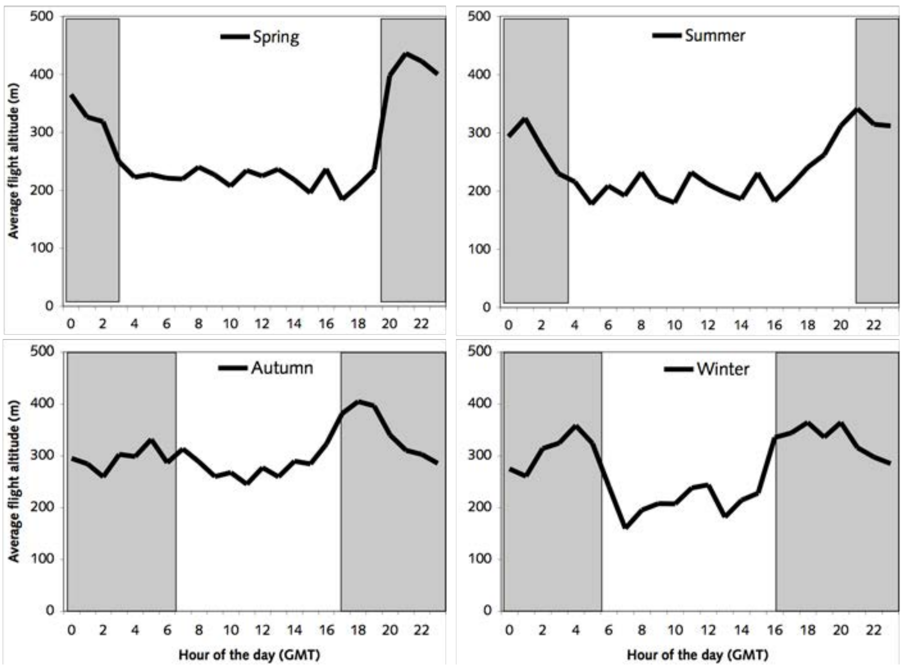


Figure 11.7 Variation in flight altitude in the course of the day, shown for the different seasons. Shown are multi-year (2007-2010) seasonal averages per hour. Note that average flight altitude on y-axis does not reflect reality: 1) it is average flight altitude of birds at 0-1385 m; 2) it is imprecise due to the database design with separation in classes rather than absolute altitudes: birds flying in the first altitude band (§11.1: 0.5) have an average altitude of 35 m, in band 1: 104 m, band 2: 208 m, etc. Hours of darkness are shaded.

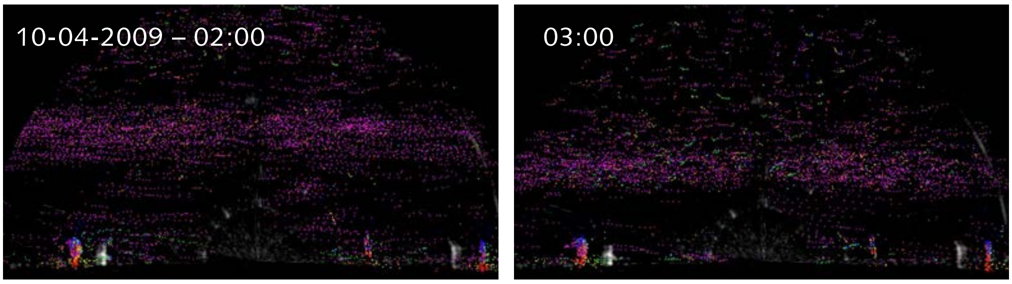


Figure 11.8 Trackplots of 2 consecutive hours with decreasing flight altitudes.

11.3 Influence of weather on flight altitude

In a similar way as flight intensity is influenced by weather conditions, flight altitudes also vary under changing conditions (Alerstam 1990; Shamoun-Baranes *et al.* 2006). In general birds tend to fly higher during tailwinds than during headwind conditions (Alerstam 1990, Krüger & Garthe 2001).

Differences between spring and autumn migration also occur. In many species spring migration is much more under time-pressure than autumn migration (Alerstam & Lindström 1990; Fransson 1995; Klaassen *et al.* 2008). Several theories have been identified as driving mechanisms, for instance selection for early arrival (Kokko 1999) and also day length (Bauchinger & Klaassen 2005). Arriving in the breeding areas early in spring results in first choice for a mate and nesting place, and thus in a selective advantage. In addition, the longer day length means that a prolonged period of the day is suitable to fly using thermals and visual navigation. On the contrary, in autumn birds are less under time stress and can allow to wait longer. Thus they have more time available to wait for more profitable weather conditions for long-distance travelling.

Cloud cover is also known to influence bird migration (Newton 2010). This mostly seems to affect migration altitude rather than migration intensity (Zehnder *et al.* 2001). Most birds fly below the clouds enabling them to visually see the ground, probably as a navigational aid (Richardsson 1978). If the cloud base descends, migration streams are also compressed downwards. On the other hand, birds can fly above clouds as well and then rely completely on celestial or magnetic cues for navigation (Beason 2005). In conclusion, birds generally seem to avoid areas with clouds, as disorientation is a likely consequence (Bourne 1980).

11.3.1 Effects of weather in data collected with vertical radar

Fluxes were higher during tailwind (fig. 10.10) and this effect was found at all altitudes. In the entire altitude spectrum up to 1385 m fluxes were lower during head wind conditions. This effect was the strongest at higher altitudes and more profound in autumn (fig. 11.9). This difference between spring and autumn was probably due to dissimilar migration strategies between the seasons as described in the literature.

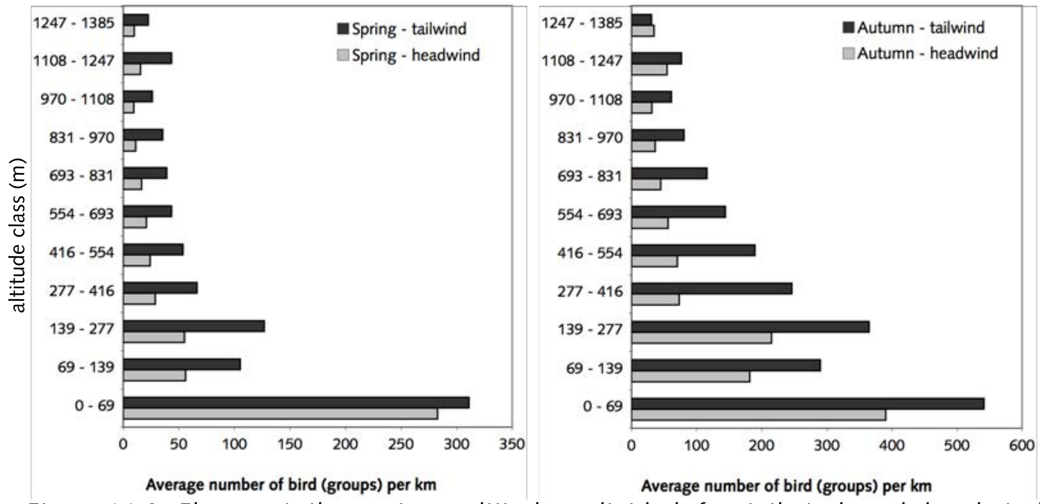


Figure 11.9 Fluxes at the various altitudes, divided for tailwind and headwind conditions in spring (left) and autumn (right).

During tailwind conditions flight altitude was higher in the OWEZ wind farm, both in spring and autumn (fig. 11.10), similar to findings in the literature (e.g. Krüger & Garthe 2001, Lensink *et al* 2002). In autumn large numbers of birds were found migrating during headwinds as well, but always on days with very low wind speeds (below 3 Bft), so effectively the headwind they experienced did not influence too much the birds' flight capabilities in a negative way.

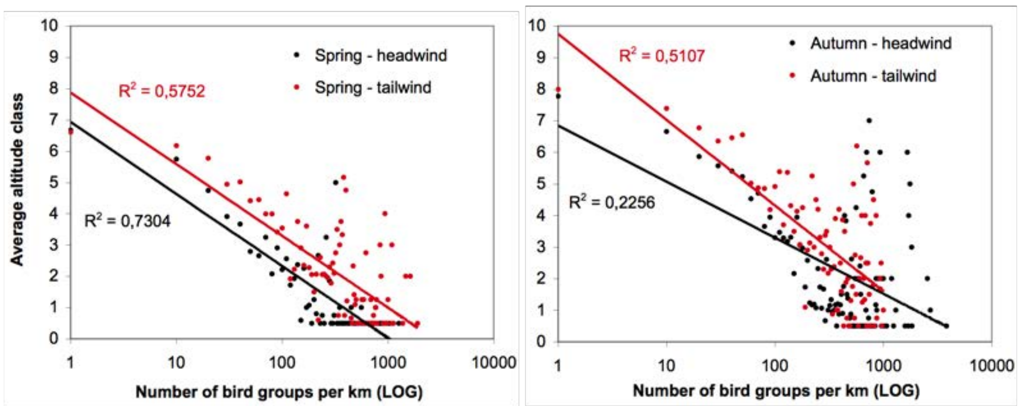


Figure 11.10 Average altitude class of bird groups per km (log-transformed data) divided for tailwind and headwind conditions in spring (left) and autumn (right). Logarithmic trendlines are included.

Also within the OWEZ wind farm, effects of cloud cover on flight altitude were visible. Mainly during autumn migration this influence was observed, but also during spring migration (fig. 11.11). The different colours in these trackplots represent different direction the targets were moving in. In case of the vertical radar this direction is the 2D

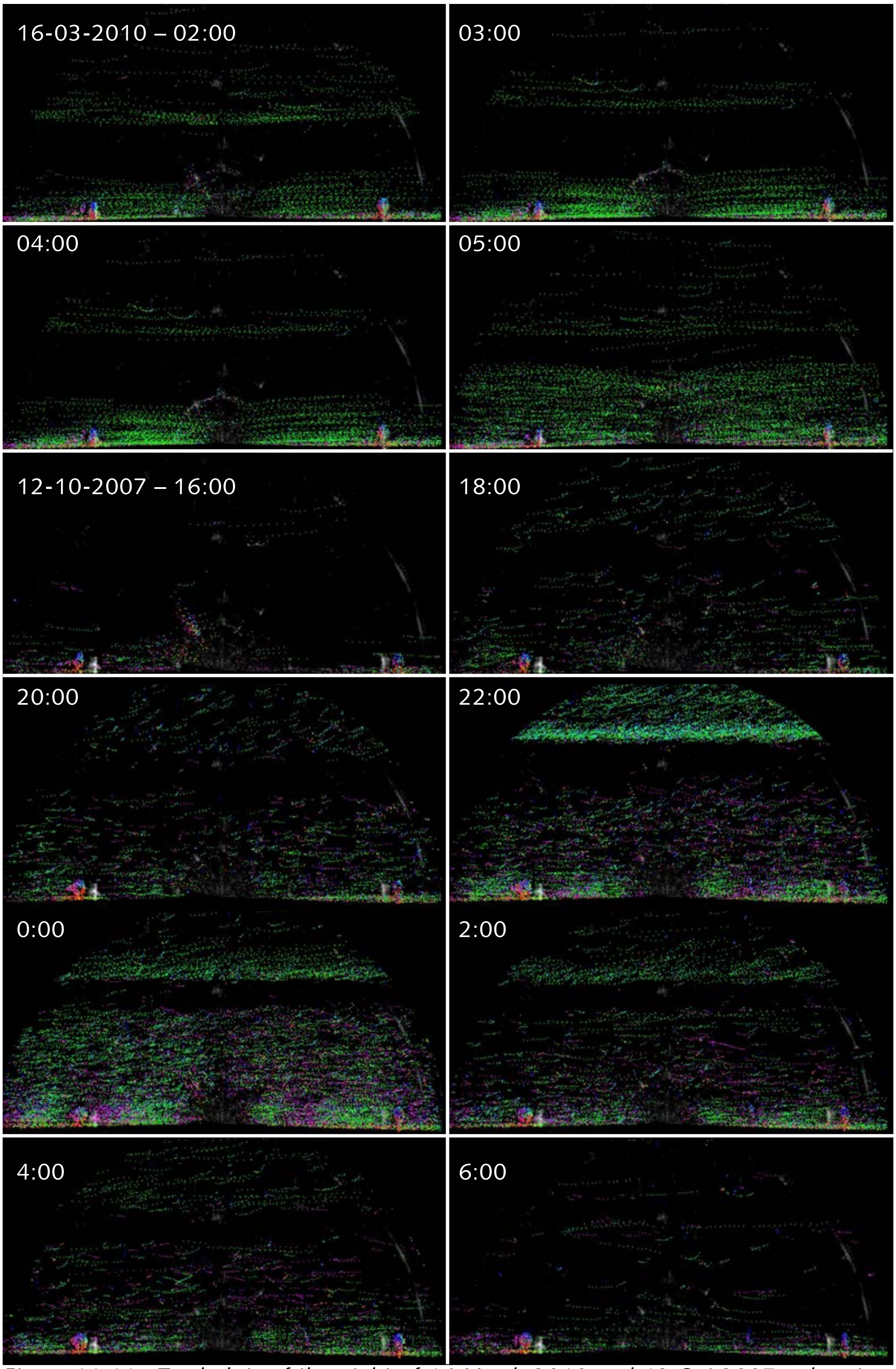


Figure 11.11 Trackplots of the night of 16 March 2010 and 12 Oct 2007, when two distinct migration streams were visible at distinct altitudes, probably caused by cloud bands at 400-1000 m (spring) and 1050 m altitude (autumn).

direction on the screen and not the actual direction of the bird. Note that these are unfiltered data of all tracked targets within one hour (without rain), see Box I – chapter 5. As can be seen in fig. 11.11 the screen was virtually clutter free except for the immediate vicinity of the radar.

In the course of the night of the 12th of October 2007 two distinct altitude bands of bird migration occurred around a 250m wide 'bird-free' zone around an altitude of 1050m. These tracks probably represented migration of thrushes, meadow pipits and skylarks although visual or acoustic evidence does not exist. However, migratory counts published on www.trektellen.nl, and the timing of the day suggested this species spectrum. Also on the night of the 16th of March 2010 two altitude bands existed. These kind layered migration streams have been observed before (Griffin 1973) and in our view might be induced by altitudinal segregation of birds from different origins. It is possible that e.g. below cloud birds left from the Dutch coast whereas above cloud birds originate from further away (where this cloud-band was not present and birds could ascend to these altitudes). Another hypothesis is that this altitudinal segregation could be species-specific but sound evidence lacks so far.

Birds flying above layers of cloud was also seen within the OWEZ wind farm when birds flew above a layer of fog in the night of the 8th of November 2009 (fig. 11.12). On that night all migratory movement took place above 150 m. During these conditions birds increase their flight altitude above this layer for better visibility and navigation. Sometimes birds travelling between different migration layers or streams were observed, e.g. on the night of the 31st of October 2008 in the hour 17:00 when several tracks downwards were observed from the top migration layer (fig. 11.13). Why these birds decreased their flight altitude so rapidly is unknown.

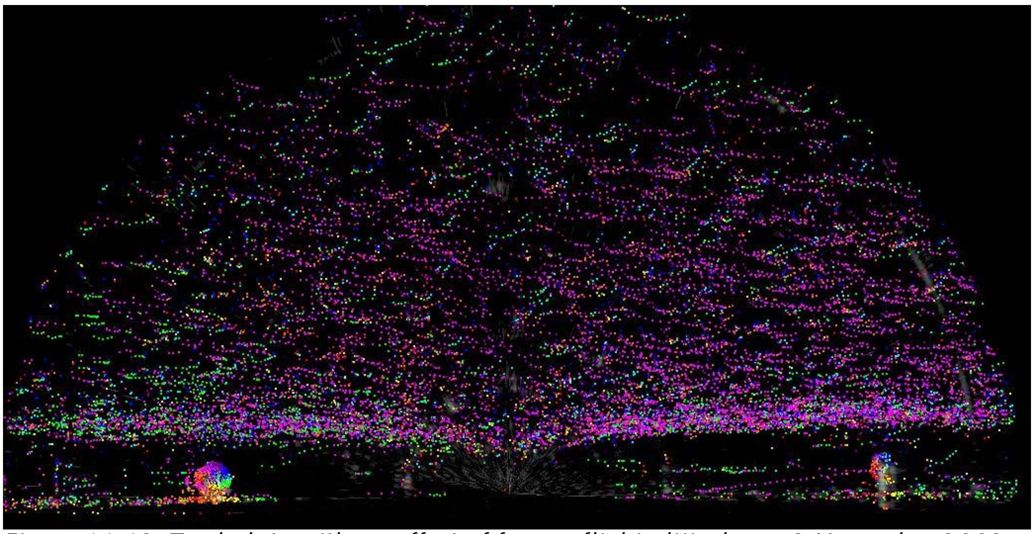


Figure 11.12 Trackplots with an effect of fog on flight altitude on 8 November 2009.

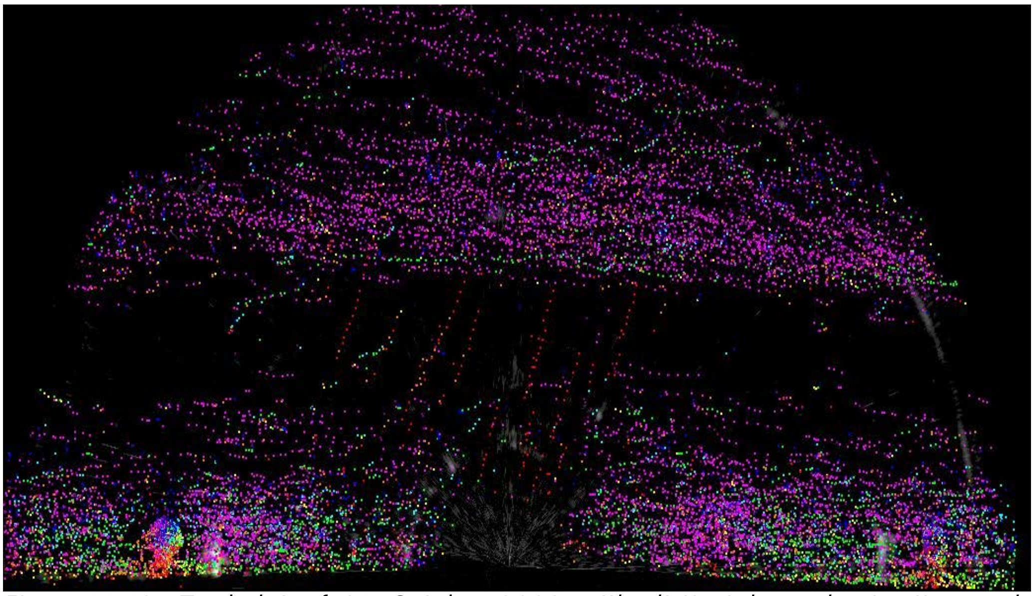


Figure 11.13 Trackplot of 31 October 2008 with distinct layered migration and some tracks between these layers (downwards).

11.3.2 Effects of weather in data collected during panorama scans

The influence of weather on flight altitude was also studied using the data collected in the panorama scans. The proportion of all birds flying at rotor height was calculated at different wind speeds and did not change with wind speed (fig. 11.14a). Of the individual species groups, only medium-sized passerines showed an increase in numbers flying at rotor height with increasing wind speeds (fig. 11.14b). The effect of wind speed on bird migration is heavily related to wind direction. When, for instance, during migration wind direction is unfavourable for certain species over longer periods of time, birds can delay their migration. When the wind direction changes and becomes more favourable for migration, birds will fly even if wind speed becomes unfavourable.

a *b*

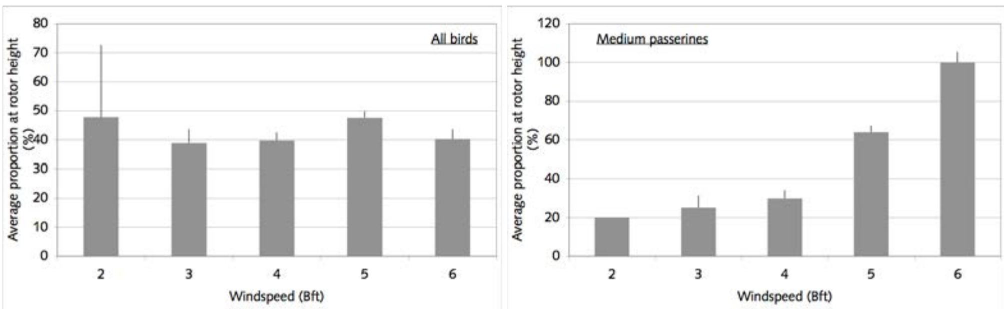


Figure 11.14 Proportion of all birds (left) and of medium-sized passerines (right) flying at rotor height (25-115 m above sea level), as observed in panorama scans. Shown are average percentages with standard error. Proportions first calculated for each panorama scan separately. Only flying birds within 3 km distance of the metmast taken into account. As only very few panorama scans were carried out during extreme wind speeds (1 Bft or above 6 Bft), those numbers are not shown.

11.4 Species-specific flight altitudes

The vertical radar was used in this study to record flight altitude of birds within the OWEZ wind farm. Regarding species-specific flight altitudes it is not possible to distinguish species from the echoes. Only based on experience and visual observations, echoes and patterns of echoes could be assigned to species groups and sometimes to species level. This was mainly possible because migration waves are timed very clearly and are species-specific. Visual observations were restricted in time and weather conditions, due to the harsh nature of the offshore environment and safety regulations, and needed to be extrapolated to general patterns. Flight altitudes of individual birds were assessed during visual observations on a total of more than 1000 tracks (fig. 11.15). See also §14.5 for a comparison of flight altitudes as measured during ship-based surveys versus panorama scans.

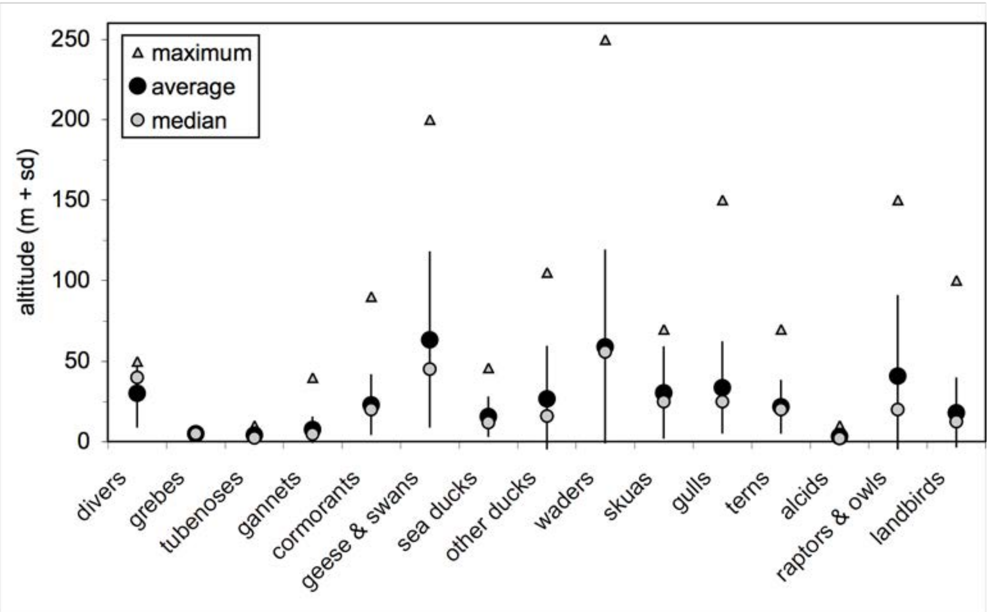


Figure 11.15 Average, median and maximum flight altitude of different species groups as recorded during visual observations on individual flight paths. Vertical lines depict standard deviations of the average.

In some literature the majority of migrating seabirds was found to fly at less than 10 m above sea level (Mateos-Rodriquez 2009) but in this study and in several others, higher flight altitudes were found during migration. Also foraging seabirds tended to exploit higher altitudes for searching and starting foraging activity such as plunge-diving. Migrating land birds such as waterbirds, waders and passerines were more likely to be found at higher altitudes and ranged from sea level up to the maximum measured altitude of 1385 m. In general alcids, grebes and tubenoses were the lowest flying species groups. At slightly higher altitude flew divers, gannets, cormorants, sea ducks and other ducks. Above this, skuas, gulls, terns and geese were seen and highest above sea level flew the waders and passerines. Below, some species-specific accounts are given about flight altitudes in the OWEZ wind farm area.

11.4.1 Species group accounts

In the following section the flight altitude of each studied species group is discussed. Also some thoughts about species that were very scarce or might be missed during fieldwork are suggested, as these species will be included in the vertical radar tracks database.

The flight altitude of **divers** was variable throughout the study period, but was generally in the lower segment up to 30 m above sea level. Also in the literature only low altitude movement below 50 m is found. However, flight altitude is dependent on wind direction, with mostly low-altitude flights in headwind conditions and higher flight altitudes during tailwind situations (Sherony *et al.* 2000; Krijgsveld *et al.* 2006b). Migration flights occurred at higher altitude than correction- and foraging flights.

Grebes were expected to have a similar flight-altitude pattern as divers. Flight altitude is known to be rather constant and to generally occur in the lower segment up to 50 m (Binford & Youngman 2010). Nocturnal flight altitude during migration is unknown, but is suggested to occur at higher altitudes, based on ongoing turbine- and powerline victim research (own observations, Bureau Waardenburg). The small number of grebes that flew through the OWEZ wind farm most likely passed at low altitude.

All recorded **tubenoses** flew near to sea level throughout the study period. This is typical behaviour for this group of species, that use the waves and the wind in between these waves to fly effortlessly over long distances (Alerstam *et al.* 1993; Spear & Ainley 1997). Only during high wind conditions, especially from the side, average flight altitude is higher, when tubenoses make arches above the sea surface to optimize the use of wind (Spear & Ainley 1997). Other seabirds that exploit this flying technique in high winds are gannets, skuas and most species of gulls. Another reason that tubenoses fly close to the sea surface, besides profiting from wind and waves, is the possibility for opportunistic feeding during migration along the route (Alerstam *et al.* 1993). This in contrast to passerines and waders that are not able to forage at high seas (besides phalaropes) and thus have no advantage of low altitude migration. It is highly unlikely that tubenoses will ever fly at or above rotor height.

The flight altitude of **gannets** was generally low (below 10 m) but some foraging birds reached altitudes up to 50 m when searching for food. Usually foraging gannets plunge from an altitude between 10-30 m (Nelson 1978; Mullers 2009). It is highly unlikely that gannets will ever fly above rotor height.

Mostly **cormorants** were observed flying at low to intermediate altitudes above the water. The bulk of cormorants flew below 5 m and not higher than 75 m, similar to altitudes found in the literature (van Belle *et al.* 2000; Krijgsveld *et al.* 2006b). High altitude migration of cormorants has been observed on land but is not likely to occur at sea, although occasionally cormorants are expected fly at altitudes up to rotor height.

Geese were generally seen at altitudes below 100 m during the day, but this could be an observer bias, as high altitudes close by were not scanned during panorama scans. Usually geese migrate between 200 to 600 m, but they can go up to several hundreds or even thousands of metres (Alerstam *et al.* 1990; Green & Alerstam 2000). Nocturnal flight altitude is largely unknown, but could potentially be at higher altitude than during the day (Cooper & Ritchie 1995; Alerstam & Gudmundsson 1999). Swans were observed flying lower than geese, but from the literature a similar altitude distribution is known ranging between 0 and 750 m (Pennycuick *et al.* 1999). It is likely that a part of the tracks above rotor height in the vertical radar database was from migrating geese and swans.

All recorded **marine ducks** flew below 100 m and the majority of birds flew below 10 m. All findings in the literature similarly report low altitude movements for different species of marine ducks with all flight altitudes below 50 m, and the majority below 10 m (Krijgsveld *et al.* 2006b). A tendency was found that marine ducks flew higher during darkness with up to 8% of all passing marine ducks entering the rotor swept zone, in other words flying above 25 m (Pettersson 2005; Larsen & Guillemette 2007).

Somewhat similar results as for marine ducks were expected for **other duck** species. Non-marine ducks were found to fly higher above sea level than marine ducks, but high altitude movements may have been missed during panorama scans. Ducks mostly migrate nocturnally at higher altitudes (Lensink *et al.* 2002, Newton 2010). Altitude is also weather dependent, with higher altitudes during tailwind and lower flight altitudes during headwind conditions (Dirksen *et al.* 2007).

The small number of **raptors and owls** that passed the offshore wind farm all flew around 20-30 m above sea level. Over land raptors are mainly exploiting thermals to migrate and often soar up to (very) high altitudes (Spaar 1997). At sea these heat thermals are often absent, certainly in spring and autumn, so raptors generally fly at low altitudes and only soar during windy conditions. Raptors prefer tailwind during migration across water bodies, which allows them to pass quickly and make use of the wind to remain at higher altitudes (Meyer *et al.* 2000; Agostini *et al.* 2005). All raptors seen during fieldwork were using flapping-flight passing the wind farm. About the flight altitude of owls during nocturnal migration nothing is known but numbers are expected to have been very low or even absent in the OWEZ wind farm area.

Waders use a very wide array of migration altitudes from sea level up to several kilometres (Cooper & Ritchie 1995; Alerstam & Gudmundsson 1999). Especially during nocturnal migration very high altitudes can be reached, but also low altitude movements are possible (Alerstam *et al.* 1990; Dirksen *et al.* 1995). In the OWEZ wind farm area waders were found to migrate at all altitudes. From the visual counts waders flew on average at 70 m with a maximum up to 200 m, but with the vertical radar wader movements were recorded up to the maximum measured altitude of 1385 m. It is very likely that at even higher altitudes waders will have been migrating through the area.

Skuas are one of the species groups that might favour headwind conditions during migration (Spear & Ainley 1997), although they migrate in substantial numbers during tailwind situations as well. All skuas observed during fieldwork flew at rather low altitude, but they are known to use a wide array of flight altitudes (Alerstam & Gudmundsson 1999) both during day and night.

Flight altitude of **gulls** was highly variable and depended on several factors. Locally foraging gulls were flying at average altitudes of 50 m above sea level. These were mostly birds looking for food or travelling to breeding and roosting sites. Specifically in summer but also in other seasons, gulls were observed circling high above sea level (up to 250 m). Gulls are known to use these high altitudes for orientation and searching for food (Woodcock 1975). Most gulls around the OWEZ wind farm use fishing vessels for foraging. When foraging behind ships, gulls were flying at altitudes of 20 m or below. Migrating gulls are known to fly up to 750 m (mean 380 m) but these results were found on land. At sea, it is expected that gulls tend to fly at lower altitudes (Shamoun-Baranes *et al.* 2006). For example flocks of migrating black-headed gulls were mostly seen passing in the rotor-swept zone but also above rotor height. Flying at lower altitude provides the opportunity for opportunistic feeding along the route. Gulls are also known to migrate nocturnally (Lensink *et al.* 2002) and will then probably exploit higher altitudes, as the possibilities of opportunistic feeding are scarce. Both during day and night gulls were flying within the rotor-swept zone of the OWEZ wind farm.

Another species group that favours head wind situations during migration are the **terns**. Head winds give them the opportunity to forage along the migration route (Gudmundsson *et al.* 1992; Spear & Ainley 1997). The general foraging altitude of terns ranges up to 20 m and this was also found to be the average flight altitude in the OWEZ wind farm area. Terns are known to migrate nocturnally at higher altitude (Camphuysen 1992; Dirksen *et al.* 1995; Lensink *et al.* 2002), so terns are definitely expected to have migrated through the OWEZ wind farm within the rotor-swept zone.

Alcids are almost exclusively very low-flying seabirds. They hardly ever reach altitudes higher than 50 m and the majority stays below 5 m above sea level (Krijgsveld *et al.* 2006). Only little auks have been observed flying at higher altitudes above sea level (pers. obs. R. Fijn), but this species was never encountered during fieldwork. Alcids are known to migrate nocturnally, but large changes in flight altitude are not expected. It is unlikely that alcids ever entered the rotor-swept zone in the OWEZ wind farm.

Passerines use a very wide array of migration altitudes from sea level up to several kilometres (Alerstam 1990; Bruderer *et al.* 1996; van Belle *et al.* 2000; Lensink *et al.* 2002; Hüppop *et al.* 2006; Shamoun-Baranes *et al.* 2006). Starlings that migrate during the day were mostly observed at low altitudes above the sea, below or at rotor height. Thrushes were observed flying at rotor height as well during the day, but they mostly migrate at higher altitudes at night. The low-flying flocks of blackbirds seen during daytime were generally birds returning to the coast at dawn, and therefore often will have faced unfavourable wind directions, driving them to lower flight altitudes. Both diurnally and nocturnally migrating passerines flew through the rotor-swept zone to some extent.

11.4.2 Altitudes inside versus outside the wind farm

With respect to the wind turbines, birds are in danger of collision when they fly at rotor height (in case of OWEZ between 25 and 115 m above sea level). Outside the wind farm several species were observed to be more numerous at rotor height than at altitudes below or above (fig. 11.16, proportion > 50%). Those species included: dark-bellied brent goose, lesser black-backed gull, great black-backed gull, herring gull, and sandwich tern. Inside the wind farm the proportion of sandwich terns that flew at rotor height was much lower (36%). Other species that showed significantly lower proportions at rotor height inside the wind farm compared to the area outside the wind farm, were kittiwake (50% outside vs 40% inside), black-headed gull (41% outside vs 21% inside) and northern gannet (41% outside vs 21% inside), Species that tended to fly more frequently at rotor height inside the wind farm were common gull (46% outside vs 55% inside), great cormorant (24% outside vs 33% inside), unidentified small gulls (56% outside vs 71% inside) and little gull (23% outside vs 38% inside). Those species were confronted with relatively higher collision risks inside the wind farm.

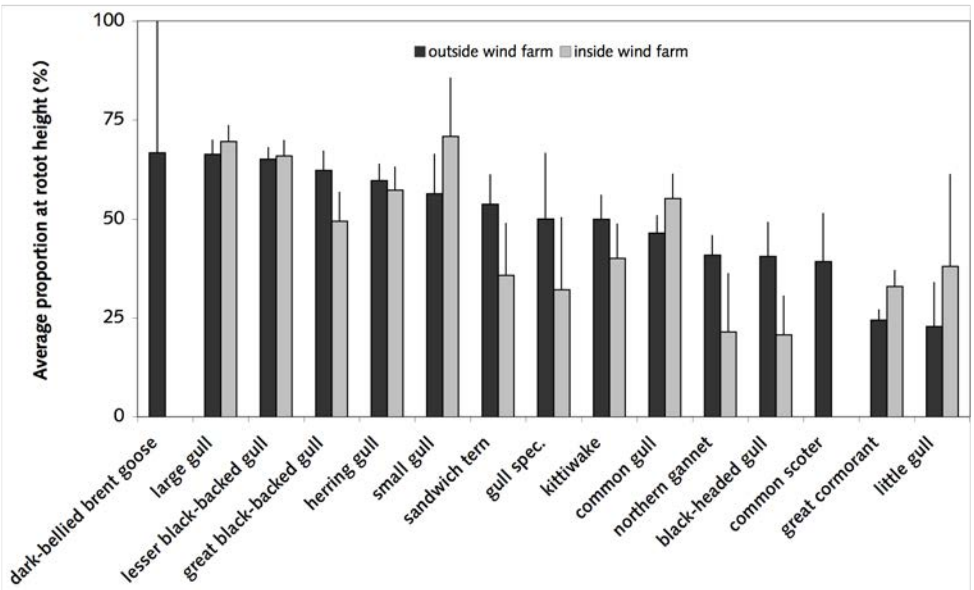


Figure 11.16 Average proportion (and standard error) of birds flying at rotor height (25-115 m above sea level) in the wind farm area, as observed in panorama scans. Proportions were first calculated for each panorama scan separately. Proportions are given for birds flying both outside the wind farm (dark grey) and inside the wind farm (light grey). Only the most abundant species taken into account. Only flying birds within 3 km distance from the metmast taken into account. See fig. 9.22 for spatial layout of segments.

11.4.3 Changes in altitudes of individual birds approaching the wind farm

Birds can avoid the wind farm either in vertical space by changing their flight altitude or in horizontal space by changing their flight path. Here we discuss the occurrence of vertical avoidance. Some of the most abundant species groups indeed tended to change their flight altitude with respect to the wind farm (fig. 11.17). Large gulls, small gulls and gannets tended to increase their flight altitude inside the wind farm. Terns, on the contrary, tended to fly at lower altitudes inside the wind farm. For cormorants there was no evidence of change in flight altitude.

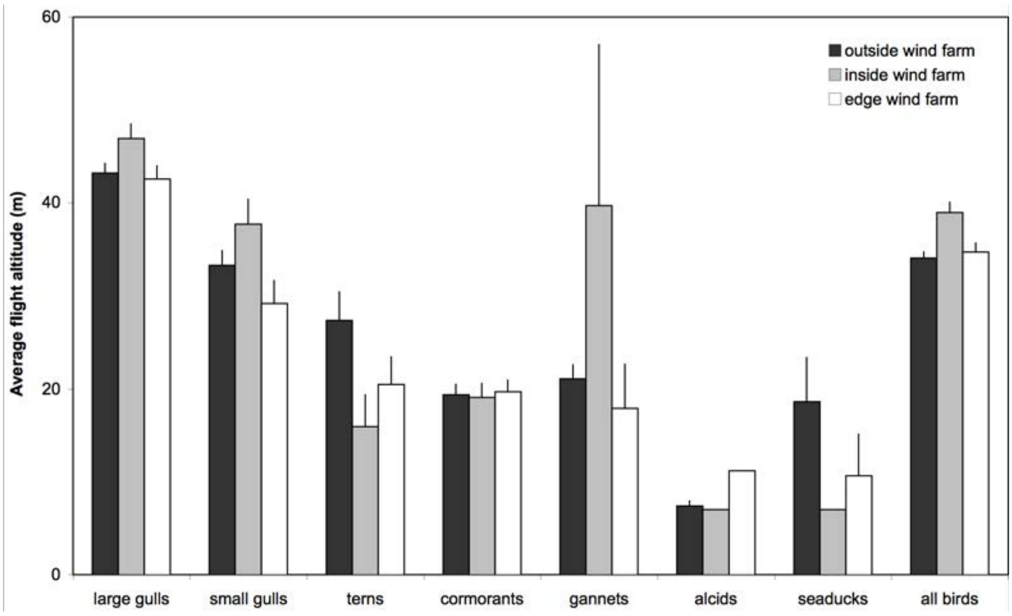


Figure 11.17 Average flight altitude (and standard errors) of birds in the wind farm area. Distinction was made between the area outside, inside and at the edge of the wind farm. Source: panorama scans. Only flying birds within 3 km distance from the metmast taken into account. See fig. 9.22 for spatial layout of segments.

11.5 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. We decided to include a certain area above the rotor into the high-risk zone as well. Due to the wake of the rotor and individual behavioural shock responses of birds close by the rotor, birds are also at high risk in this range. We took about 25 m above the rotor height to be influenced as well. Thus, the high-risk zone is between 25 and 139 m and coloured red in tables and graphs in this paragraph. 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. Also shock reactions of flying birds might cause sudden deflections of flight paths, causing the birds to enter the high-risk zone between 25 and 139 m. In this paragraph this zone is called the intermediate-risk zone (0-25 m, orange colour in tables and graphs). Above 139 m birds were not at risk from the wind turbines rotors and therefore this zone is called the low-risk zone (139-1385 m, green colour in tables and graphs).

High-risk zone

Almost 800,000 bird groups per kilometre flew through the high-risk zone during the study period (three years). This is about 35% of the total flux measured by the vertical radar (table 11.1). In this risk-band the highest numbers of birds were found in autumn, with a total of 309,344 bird groups in three autumns (table 11.1). In one autumn season this means that 103,115 bird groups on average travelled through a 1-km stretch of the OWEZ wind farm at high-risk altitude. In autumn, the majority of these bird groups flew at night (table 11.1, fig. 11.18). On the contrary, in summer the majority of bird groups flew during the day. In spring and winter slightly more flight activity occurred during the day. Overall about 50% of all flight movements in the high-risk zone occurred during the night.

Intermediate-risk zone

Almost 415,000 bird groups per kilometre flew through the intermediate-risk zone during the study period (three years). This is about 18% of the total flux measured by the vertical radar (table 11.1). In this risk-band the highest numbers of birds were found in autumn, with a total of 148,467 bird groups in three autumns (table 11.1). In one autumn season this means that approximately 49,489 bird groups on average travelled through a 1-km stretch of the OWEZ wind farm at intermediate-risk altitude. In autumn, even numbers of birds flew during the day and night (table 11.1, fig. 11.18). On the contrary, in the other seasons the majority of bird groups flew during the day. Overall about 64% of all flight movements in the intermediate-risk zone occurred during the night.

Low-risk zone

Almost 1,100,000 bird groups per kilometre flew through the low-risk zone during the study period (three years). This is about 48% of the total flux measured by the vertical radar (table 11.1). In this risk-band the highest numbers of birds were found in autumn, with a total of approximately 530,759 bird groups in three autumns (table 11.1). In one autumn season this means that approximately 176,919 bird groups on average travelled through a 1-km stretch of the OWEZ wind farm at low-risk altitude. In spring, autumn and winter, the majority of these bird groups flew at night (table 11.1, fig. 11.18). On the contrary, in summer the majority of bird groups flew during the day. Overall about 33% of all flight movements in the low-risk zone occurred during the night.

Total number through entire wind farm

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 (table 11.2). 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 recorded as flying through the high-risk zone each year. An additional 967,385 bird groups flew through the intermediate-risk zone each year. The remaining 2,556,591 bird groups flew above the rotor-swept zone and beyond the influence of the wind turbines.

Note that all the above-mentioned numbers are in fact underestimates of the total number of birds, as the numbers found all refer to bird ***groups***, which may reflect both individual birds and flocks of birds. Furthermore, radar detection was not 100%, meaning that the actual numbers are expected to be higher. The fluxes presented here do however give the best estimate. The bandwidth of inaccuracy is discussed in chapter 7.

Table 11.1 Summed numbers of birds (corrected for radar effort – ch. 10) flying at day and night in the different risk classes during 2007-2010 on a 1-km stretch in the OWEZ wind farm determined by vertical radar.

	spring	summer	autumn	winter	Sum
day					
0-25 m.	66,607	71,103	73,394	52,882	263,987
25-139 m.	100,875	108,823	98,658	92,039	400,395
139-1385 m	80,357	85,307	137,631	60,690	363,985
night					
0-25 m.	31,642	16,065	75,073	27,827	150,607
25-139 m.	67,977	33,578	210,686	87,078	399,318
139-1385 m	156,483	63,563	393,128	118,523	731,696
total	503,941	378,438	988,570	439,039	2,309,988

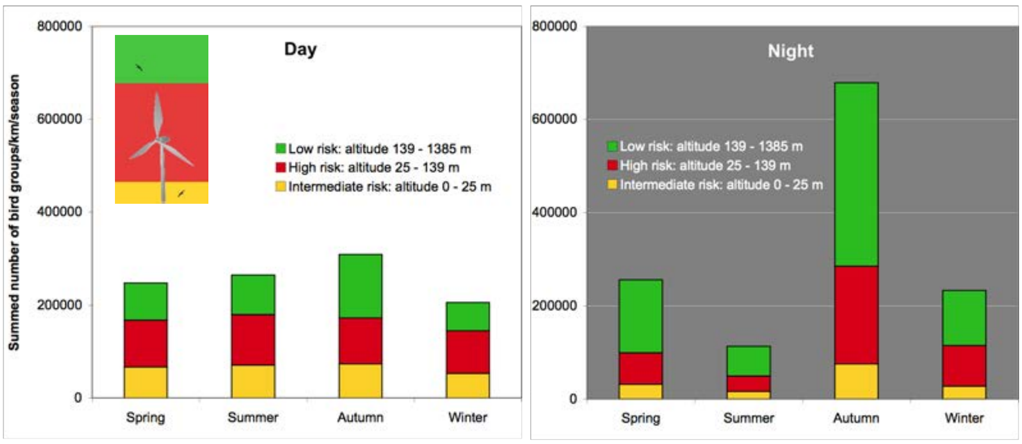


Figure 11.18 Summed numbers of birds flying at day and night in the different risk classes during the study period between 2007–2010 separated per season.

Table 11.2 Summed numbers of birds (corrected for radar effort – ch. 10) flying in the total altitude column and different risk classes per year in the entire OWEZ wind farm. Figures are determined by vertical radar.

	One km of OWEZ in three years	Entire OWEZ wind farm in one year	fraction
0-1385 m.	2,309,988	5,389,972	
0-25 m.	414,593	967,385	17 %
25-139 m.	799,713	1,865,996	35 %
139-1385 m	1,095,682	2,556,591	47 %

Common scoter flying low above the sea surface (photo K. Krijgsveld).

12 Results: Typical examples of fluxes and flight altitudes to illustrate flight patterns at OWEZ

In general, fluxes were expected to be low in summer and winter and higher during spring and autumn migration. Yet, migration mostly occurred in brief waves of very high activity that took place on days/nights with favourable wind (and weather) conditions (§10.3). Focussing on large-scale average patterns, as done in chapter 10 and 11, does give good insight in overall fluxes in the area, which is relevant to assess the effect of the wind farm on bird species passing the area. However, by lumping together the many nights with little or no (migratory) activity with those few nights on which migration peaked, we lost the insight in what happened on those days/nights that migration did peak. Thus, by zooming in on specific days in each season, we obtained a better insight in the flight patterns that occurred when there was high migratory activity. Doing so, in every season some 'representative' days were selected and analysed in more detail. These days were a representation of the processes occurring in these seasons (migration, winter visitors, summer breeders/non-breeders). Most of these examples were days on which fieldwork was done, in order to have both visual and radar data. For reference to altitudinal distribution see chapter 11.

In figure 12.1 average fluxes for representative days in each season are shown, separated in risk classes (§11.5). Fluxes measured on these days were in line with the hypotheses (except that in these example days fluxes are the same for summer and winter):

- Spring: high MTRs – more nocturnal high-altitude movements
- Summer: lowest MTRs – more diurnal low-altitude movements
- Autumn: highest MTRs – more nocturnal high-altitude movements
- Winter: low MTRs – more diurnal low-altitude movements

In the paragraphs below, each date is examined in more detail. Note that the graphs in these paragraphs have similar colour-codings but have different Y-axis values.

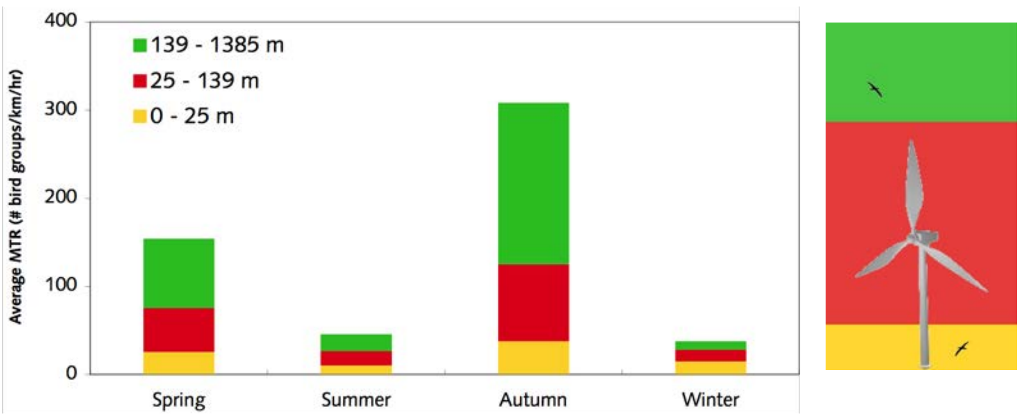


Figure 12.1 Average number of bird groups/km in different risk classes (see chapter 11) on representative days of each season, as measured by vertical radar. High risk at the altitude of the rotor blades at 25–139 m, intermediate risk below 25m and low risk above 139 m.

12.1 Summer

In summer, fluxes were low (fig. 12.1), reflecting mainly local flight movements of gulls and cormorants. These birds used the wind farm for foraging and roosting. On sunny days swifts from the mainland foraged near the wind farm as well. Another group of birds that were encountered on summer days were passing terns, mainly sandwich terns.

A good example of one of those summer days was the observation day of the 6th of August 2008 with SE 3-4 Bft wind and overcast (20°C). On this day small numbers of several gull species (mainly lesser black-backed gull and herring gull) were present in the area, as well as some sandwich terns and cormorants. Panorama scans in the evening yielded most birds.

Coastal migration counts from the previous day showed some starling migration near Egmond aan Zee (www.trektellen.nl) and small groups were seen from the metmast as well. Also waders and some landbirds were observed on migration.

Looking at the vertical radar, most bird groups were recorded in the evening and a small peak in the morning (fig. 12.2). These were gulls coming from the roosting areas. In the evening gulls flew towards the roosting areas and some migration of landbirds and waders was seen. In the evening birds tended to fly higher at less risky altitudes compared to the morning. In general, the lowest numbers of flying birds were recorded in the period after midnight and at midday (9:00–11:00 GMT = 11:00–13:00 local time).

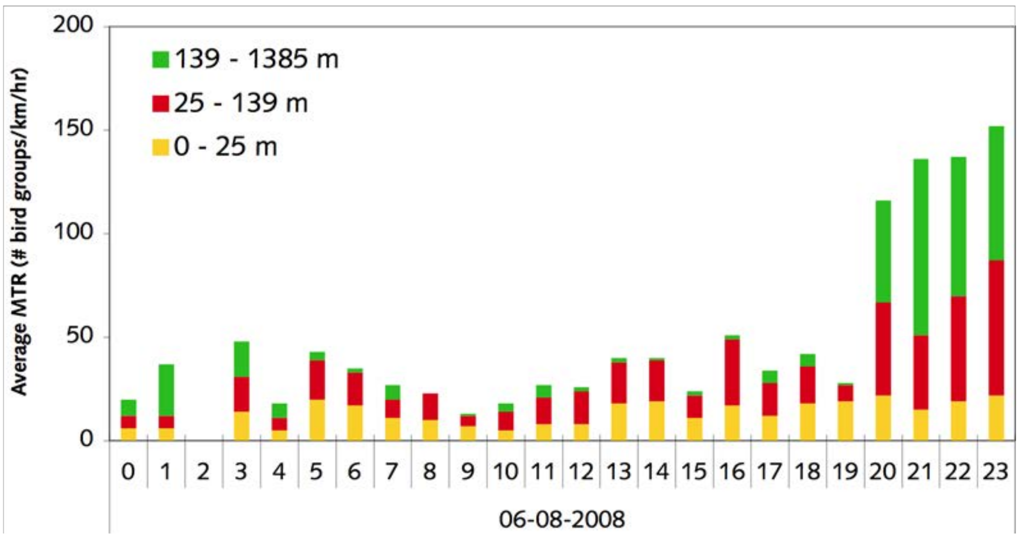


Figure 12.2 Mean traffic rates on 6 August 2008. Data are separated into 3 risk classes.

12.2 Winter

In winter, fluxes were relatively low (fig. 12.1), reflecting mainly local flight movements of gulls and cormorants. Instead of the lesser black-backed gulls, that are present in summer but migrate south in winter, common gulls were found in a much higher abundance. Other species likely to be encountered were gannets, guillemots and smaller numbers of razorbills. Winter is also the main period for passing divers and scoters around the OWEZ wind farm.

A typical winter day was the observation day of the 11th of February 2008 with SE 2 Bft wind and clear sunny skies (8°C). At noon a clear dip in numbers of tracks was observed.

On this day some groups of geese (brent and bean geese), ducks (scoters and eider), red-throated divers and alcids (guillemots and razorbills) were visually recorded. Some passerine migration included small groups of starlings. A similar species composition of local seabirds and migrants was also seen from the coast according to the results on www.trektellen.nl. Looking at the vertical radar data, highest numbers occurred in the morning (fig. 12.3).

In the morning flight activity was highest with the majority of bird groups flying in the lowest altitude band just above the sea surface. Flight activity decreased during the day and slightly increased towards the evening (GMT 14:00 – 16:00), just before darkness. Lowest numbers of birds were recorded in the afternoon. Typically in winter and also during this day, high altitude movements were sporadically found.

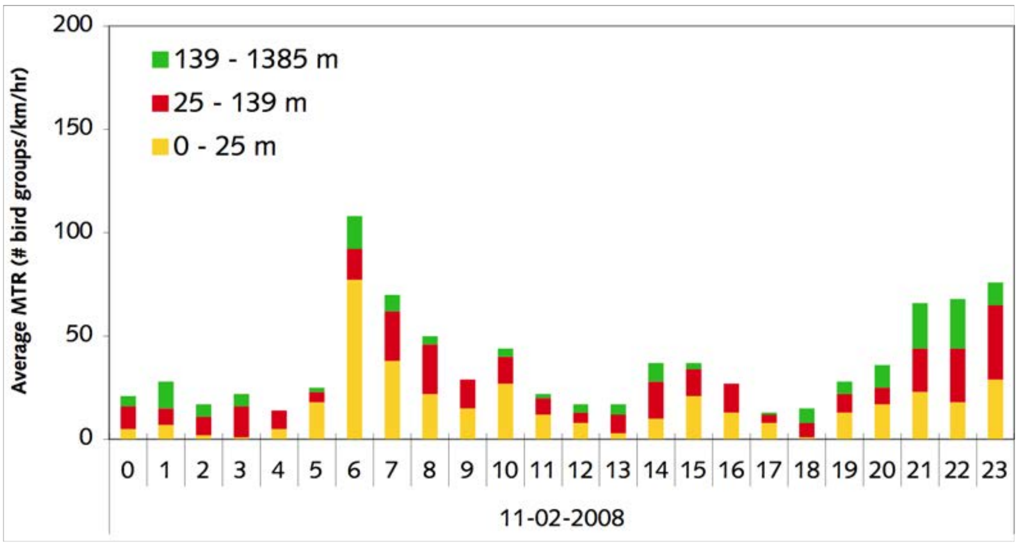


Figure 12.3 Mean fluxes on 11 February 2008. Data are separated into 3 risk classes.

12.3 Spring

In spring, MTRs were elevated (fig. 12.1) but less high than in autumn. A good example of a spring migration day/night was the observation day of the 23rd to the 24th of April 2008 when fieldwork was carried out on the metmast. On these days a variable wind (SE – SW) of 1-3 Bft and a temperature up to 10°C was measured. Short periods of drizzle occurred during the evening. Throughout the day but especially in the evening, large groups of little gull were visually observed with in addition large numbers of large gulls flying west. High numbers of migratory birds started to fly after 0:00 GMT. Almost no sounds were audible but some songbirds and gulls were recorded.

The vertical data showed that the night of the 22nd had high numbers of high altitude (low-risk) passage (fig. 12.4). In the night that fieldwork was carried out, more movements occurred at lower (high and intermediate risk) altitudes. Trackplots of these two nights showed migration at all altitudes but with a distinct difference in 2D direction on the screen (fig. 12.5). Both displayed long tracks so in this case flight direction must be very different and might indicate different cohorts from different origins or maybe different species.

Differences in wind were distinct between the two nights with a westerly 5 Bft. during the night of 22nd to 23rd of April and a north westerly wind 3-4 Bft. during the night of the 23rd tot 24th of April. Probably these differences in wind direction and speed might have influenced the chosen flight altitude and flight direction and flight intensity.

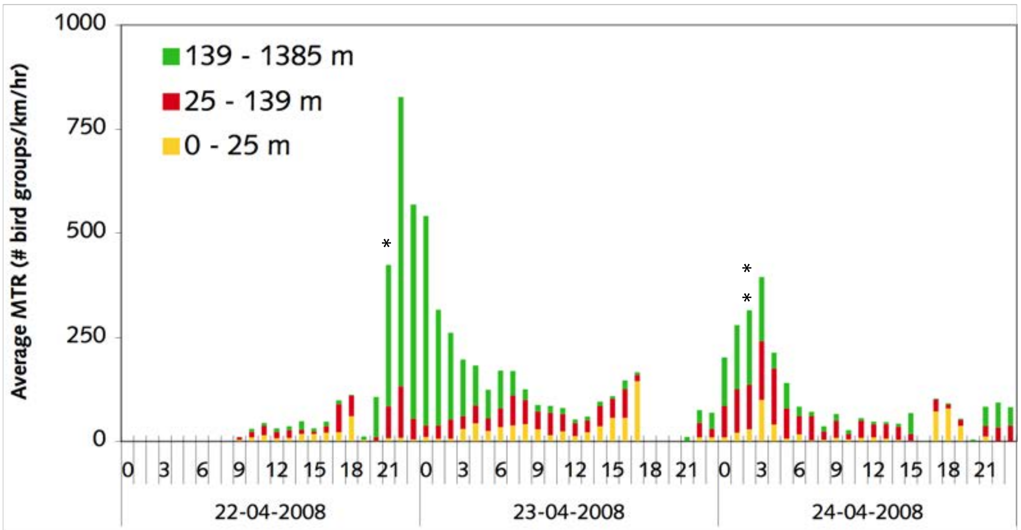


*Figure 12.4 Mean fluxes during 22 until 24 April 2008. Data are separated into 3 risk classes. * is the upper trackplot and ** the lower trackplot in fig. 12.5.*

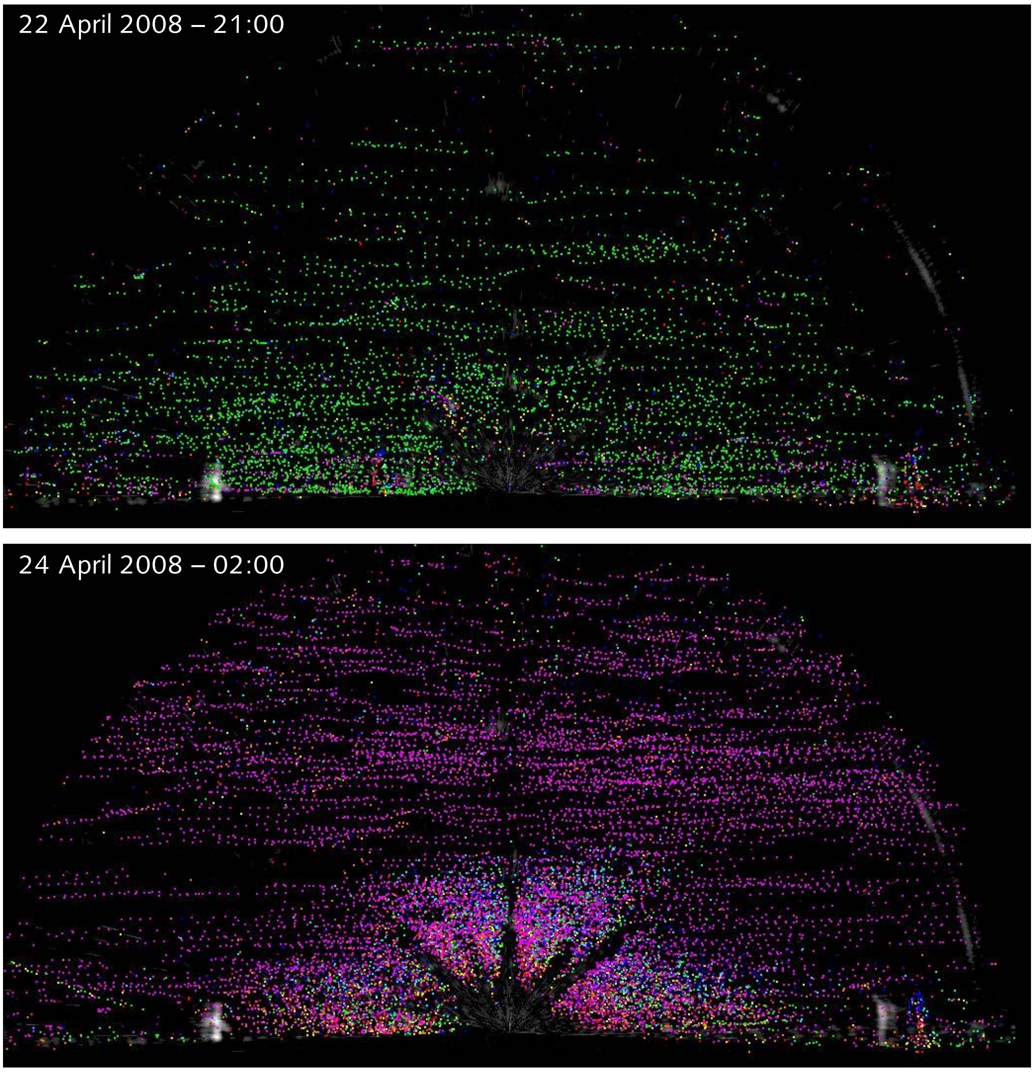


Figure 12.5 Two trackplots of different migration nights in spring with a distinct difference in flight altitude and flight direction.

In the previous example, from a later period in the spring migration season (end of April), diurnal and nocturnal migration was more evenly distributed. Earlier in spring often days occurred with almost no movements during the day and migration peaks in the night (fig. 12.6). This type of nocturnal migration is typical for species such as thrushes and waders. These species tend to migrate earlier in the season, at higher altitudes than other species, and to migrate strictly nocturnal. Later in spring more (smaller) songbirds and high-arctic waders migrate to the breeding areas, which travel more during daytime as well (e.g. Lensink *et al.* 2002).

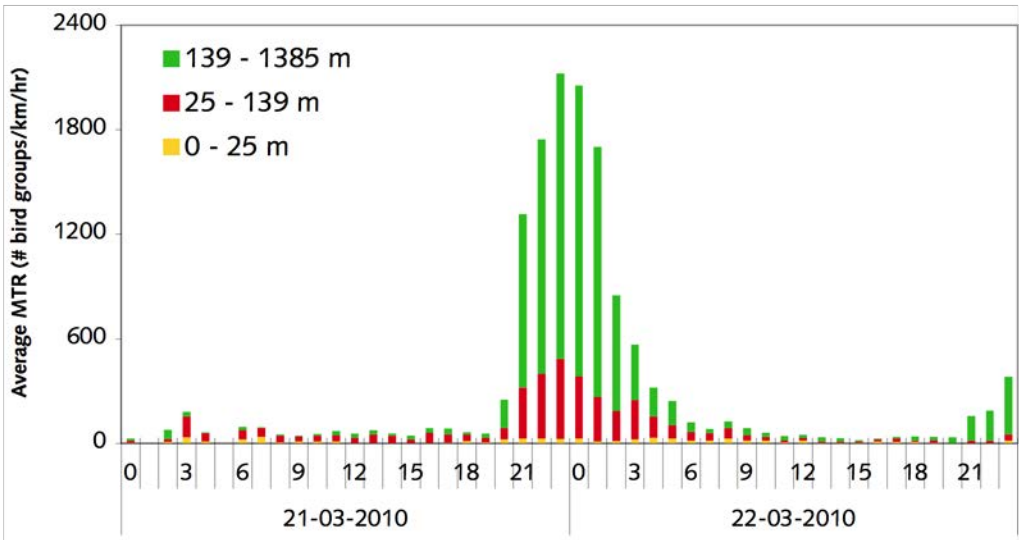


Figure 12.6 Mean fluxes during 21 until 22 March 2010. Data are separated into 3 risk classes.

12.4 Autumn

In autumn, MTRs were the highest of all seasons (fig. 12.1). Mainly during north easterly and easterly wind numbers of migratory birds were high in this season. The majority of these birds were coming from north-easterly directions (Scandinavia) flying south-west and west to the wintering grounds in southern Europe and Great Britain.

One of these autumn migration days/nights in which fieldwork was carried out was the observation night of 6 to 7 November 2008. However, in this night bird numbers were quite low. In order to get detailed insight in an autumn migration night, the night of 29 and 30 October was taken for analysis (fig. 12.7). Unfortunately no fieldwork data for the night exist, as weather conditions did not allow accessing the metmast that night.

Based on timing of year, weather conditions and field reports from various birding websites this night probably followed a pattern more or less similar to the night of 6 November 2008 in which high numbers of thrushes such as redwing, blackbird and song thrush were heard throughout the night. These birds all started to fly immediately after dusk. In the course of the night, flux decreased as reflected on the vertical radar. On the 30st of October we were able to visit the metmast and observed a lot of goose (brent geese) and passerine (thrushes, starling) migration in the area. Locally large groups of kittiwakes were present as well. These caused elevated flight activity during the day as well.

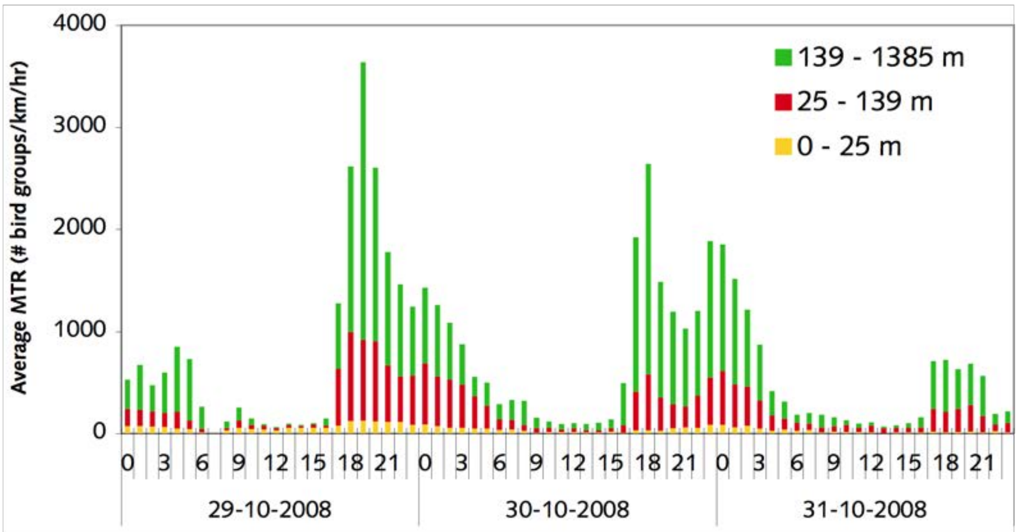


Figure 12.7 Mean fluxes during 29 until 31 October 2008. Data are separated into 3 risk classes.

Trackplots for the night of 30 October 2008 showed that distinct directional patterns occurred that night (fig. 12.8). Although the exact migration directions of the targets could not be traced back, birds were initially migrating predominantly in north-westerly directions (left on the radar; pink tracks). Later in the night migration activity decreased (with the dip around 20:00) but increased again around 22:00, at which time the main flight direction was south-easterly (right on the radar; green tracks). This shift clearly indicates a change in flight direction within cohorts of birds or the presence of two different migration waves from either different origin or different species. At 0:00 two different direction bands at separate altitudes were visible. These indicated possibly species-specific but at least altitude-specific migration with different dominating flight directions.

At the end of the summer, the first migratory activity was expected to pass the OWEZ wind farm with arctic waders and swifts (often seen already in July). Also sandwich terns passed the OWEZ wind farm in this period (as was observed visually as well). Later on, in August, seabirds such as shearwaters, gannets, alcids, as well as landbirds such as pipits, larks and swallows follow towards the wintering grounds (e.g., Lensink *et al.* 2002). These birds are mainly diurnal migrants flying at lower altitudes, which was recorded on the vertical radar as well, for example around 29 August 2009 (fig. 12.9). The majority of migrants on 29 August 2009 flew below 25 m.

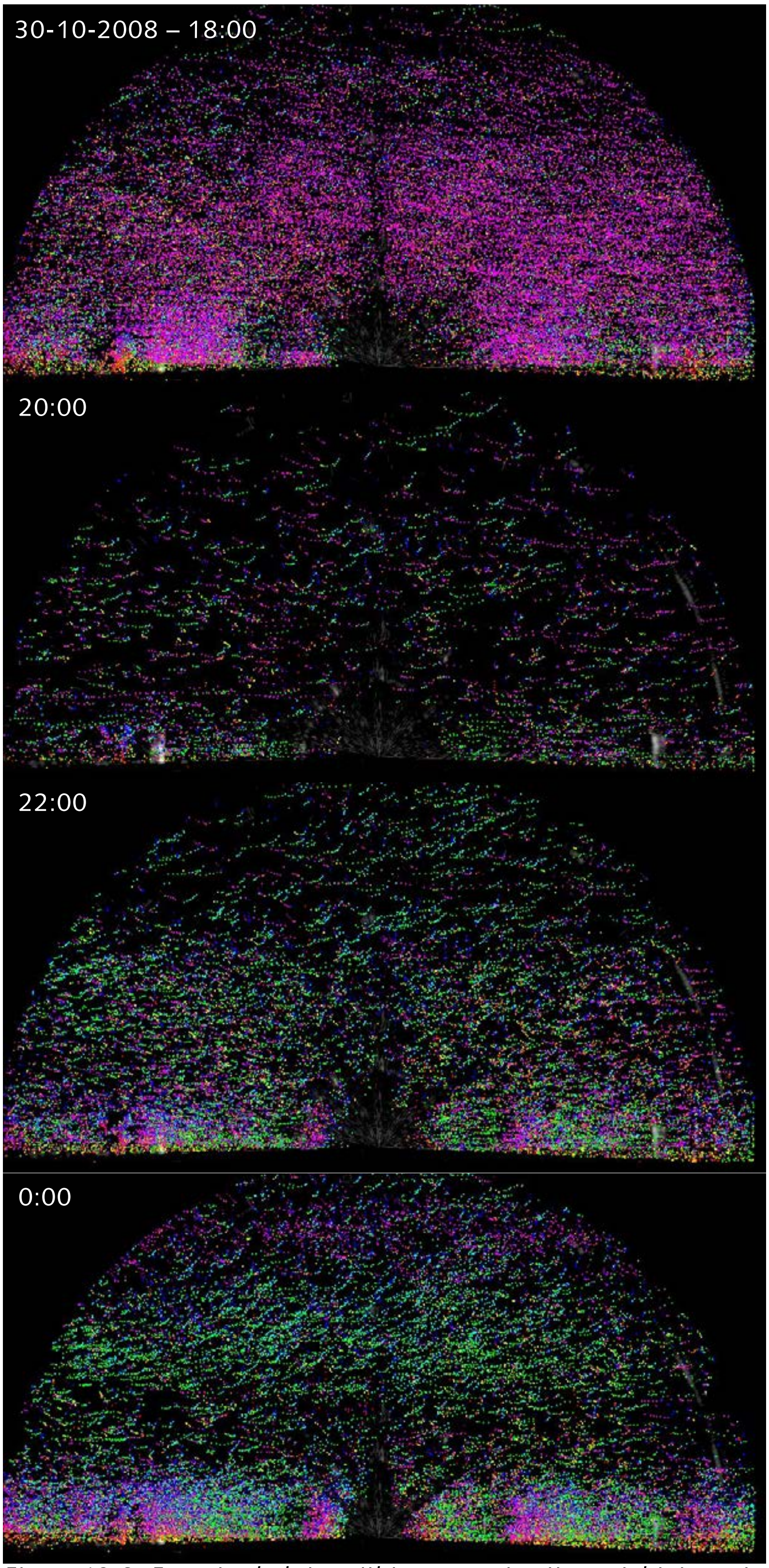


Figure 12.8 Four trackplots within one migration night in autumn with a distinct segregation in flight altitude and flight direction (colour).

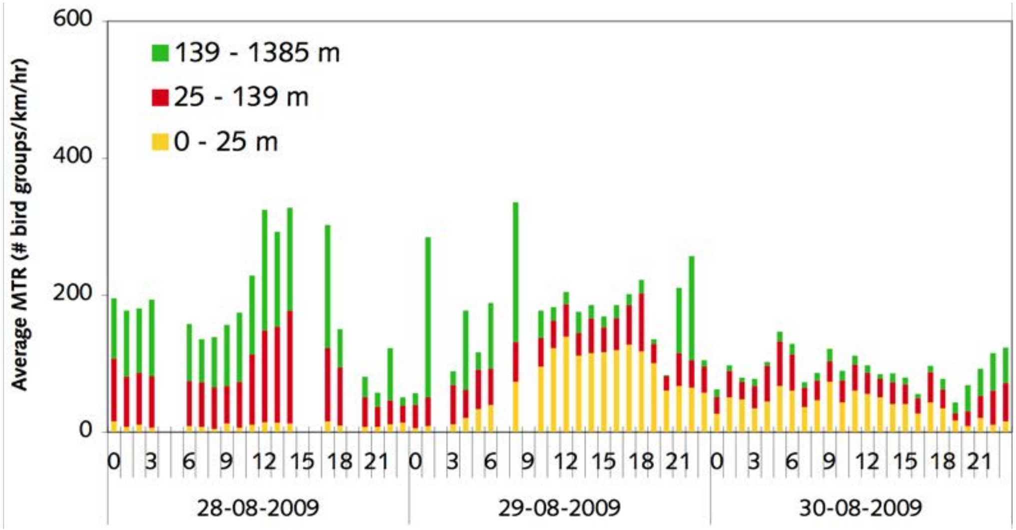


Figure 12.9 Mean fluxes during 28 until 30 August 2009. Data are separated into three risk classes. Figure shows low-altitude daytime migration of waders and terns.

In September and October the vast majority of migrants passed the OWEZ wind farm (fig. 10.2). A more detailed look at these waves revealed that numbers increased rapidly just after dark and gradually decrease in the course of the night (fig. 12.7 and 12.10). Many waterbirds and passerines such as thrushes migrated through the area mainly during the night. The highest proportion at high altitude flew in the beginning of the night and at lower altitudes after midnight.

The last migratory birds passed OWEZ in November. In this month higher numbers of geese and swans migrated through the OWEZ wind farm at lower altitude during the day. In the night thrushes such as redwing and black bird dominated the higher altitudes (fig 12.11). This example is also the night when the influence of fog on flight altitude was clearly noted (fig 11.13).

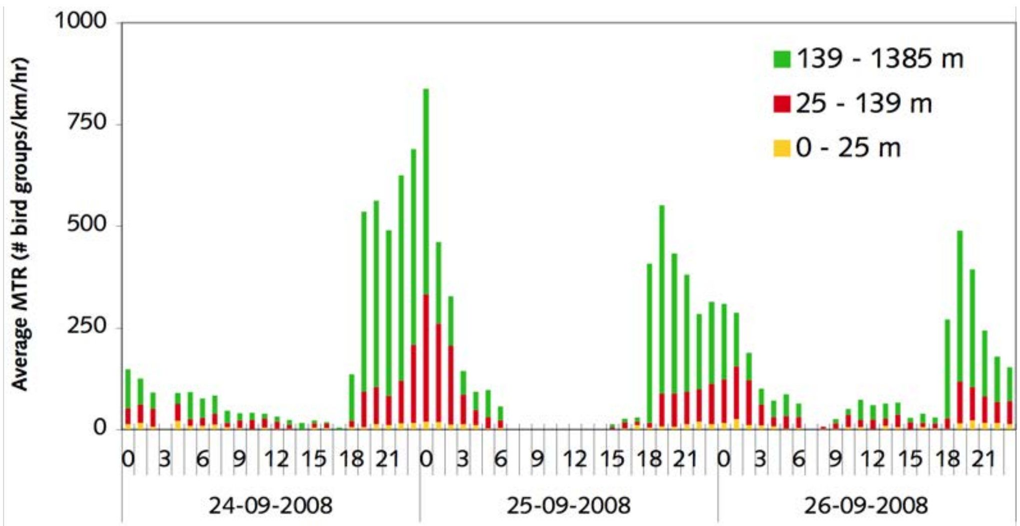


Figure 12.10 Mean fluxes during 24 until 26 September 2008. Data are separated into three risk classes.

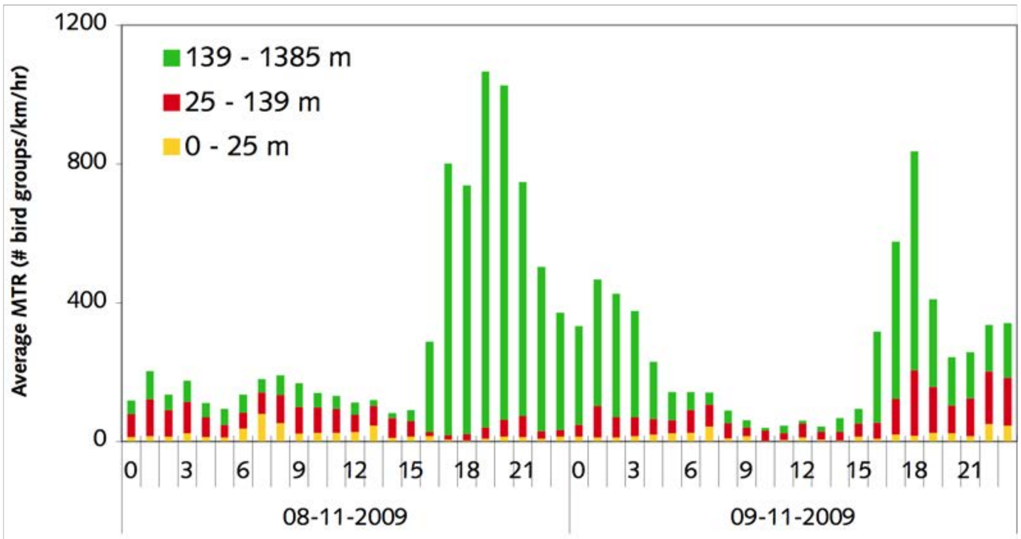


Figure 12.11 Mean fluxes on 8 and 9 November 2009. Data are separated into three risk classes.

13 Results: Micro-avoidance of birds approaching individual turbines

Bird mortality as a result of collisions with wind turbines has been estimated through both empirical studies and modelling approaches (Winkelman 1992; Grünkorn *et al.* 2005; Krijgsveld *et al.* 2009a). The latter has been more typically applied in situations where empirical data are lacking, such as pre-construction, or are difficult to obtain, such as in offshore areas. A number of models for assessing the potential number of collisions with wind turbines have been proposed (Tucker 1996; Bolker *et al.* 2006; Band *et al.* 2007), of which the 'Band' model is the most typically used (Madders & Whitfield 2006). This model relies on a number of measured or estimated parameters in order to calculate the collision rate for specific bird species within specific wind farm scenarios. Parameters used in the models, such as flux, bird size, flight speed and turbine size are known from published literature or can be directly measured. However, key assumptions, namely that birds fly evenly within the wind farm and that they take no avoiding action, greatly influence the outcome of the model (Chamberlain *et al.* 2005; Chamberlain *et al.* 2006; Band *et al.* 2007).

Studies employing the Band-model commonly apply an avoidance factor, which has by far the largest influence on the calculated mortality (Chamberlain *et al.* 2005, 2006). Despite its importance in determining the number of collisions, few figures for avoidance rates exist (Chamberlain *et al.* 2006), particularly for offshore areas (Drewitt & Langston 2006). Consequently, values based on standard default values have been suggested (SNH 2010). However, these values are often derived from non-analogous studies or represent pure estimates. Avoidance rates can be described as either avoidance of the entire wind farm (macro-avoidance) (discussed in ch. 9) or, for those birds entering the wind farm, avoidance of individual turbines (micro-avoidance).

Here we used a combination of horizontal radar and visual observations to specifically investigate how birds that were flying within the wind farm, responded when they approached individual turbines. The range of the radar was reduced to 0.75 NM to increase sensitivity (see §5.4 for details on radar methods and §6.7 for details on radar limitations). The data collected by the radar have the advantage that they can be collected continuously during both day and night, they can cover a larger area than can be covered visually, and lastly, they provide accurate information on the flight paths, such as absolute distance from the turbines. These radar data, however, do not allow the identification of species or numbers of individuals. Therefore visual observations were carried out as well (see §4.7). These served to quantify behaviour of individual species in close proximity to the turbines. In addition, the behavioural respons of individual birds to turbines was observed (e.g., horizontal or vertical deflection, as well as how the birds passed the rotor blades).

The resolution and potential detection loss of the radar are discussed in §6.7.1. With reference to radar data in this chapter the term 'birds' is used to indicate bird groups.

13.1 Summary

- Micro-avoidance (responses of birds to individual turbines) was studied from mid-July 2009 through until mid-March 2010. A combination of visual and radar observations was used, that was focussed on quantifying bird behaviour when they flew in close proximity of the turbines. For this purpose, the range of the horizontal radar was reduced from 3 to 0.75 NM to increase resolution around the turbines, and visual observation protocols were adjusted.
- Less than one bird per hour passed within 50 horizontal meters of each turbine, with the highest numbers recorded in October and December.
- 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).
- 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 the turbine, very few (7%) came within 45m; which was the horizontal reach of the rotors of the turbine. From visual observations it was established that these birds passed the turbines mostly in the area behind or in front of the rotor blades.
- The overall micro-avoidance rate (*i.e.* avoidance of individual turbines by birds that do enter the wind farm), based on radar and visual observations, was 0.976.

13.2 Measuring avoidance of individual turbines

Most estimates of avoidance are determined by estimating alterations in flight paths in order to prevent collision with individual turbines. For birds making abrupt changes in their flight path at close proximity to a turbine these avoidance actions may be clearly detectible. The question remains, however, whether these movements represent true avoidance or reflect the birds´ general patterns of flight. The same is true for other types of movements. Birds flying on a direct course may make subtle changes in their heading in order to avoid a turbine, which may be difficult to detect or determine as avoidance action. At 50 m from a turbine a bird on a direct course to the centre of a rotor would need to change heading by over 65° in order to fly around a 45 m rotor blade. At 100 m the required deviation is 24°, at 200 m 12° and at 500 m 5°. The effect of drift due to wind would further add to the problem, meaning that a bird may simply stop compensating for drift rather than making any discernable change in heading. In order to assess avoidance within OWEZ, an approach was adopted that eliminated the uncertainty associated with the assessment of deviations in flight

trajectories. This approach examined the distribution of flying birds within the wind farm to assess whether any avoidance of the turbines was evident.
Birds can only be deemed at risk of collision if flying within the reach of the rotors or associated turbulence, while outside of this area birds are at no risk of collision. Although it is possible that collisions may occur with the tower of a turbine, compared to collisions with the rotors these are considered negligible; due to the static state of the tower and its relatively small area in comparison to the area swept by the rotors (Petersen *et al.* 2006).

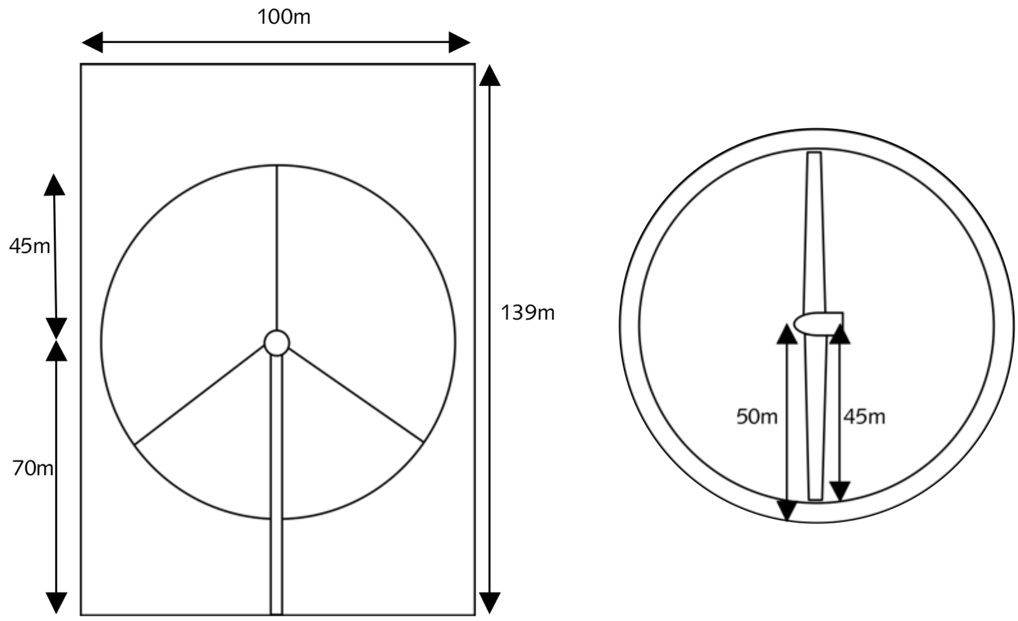


Figure 13.1 Area close to the turbines in which birds are considered as being at risk of collision, in cross-section (left) and from above (right). The area covers a 50 m radius around the turbine (5 m beyond the horizontal reach of the rotor tips) to a height of 139 m (i.e. 24 m above the rotor tips).

Birds that flew within an area of 50 m horizontally and 139 m vertically of the location of a wind turbine were considered as being close enough to the turbine to be at risk of collision, while birds outside of this area were considered not to be at risk of collision (fig. 13.1). A distance of 5 m beyond the horizontal reach of the rotors (45 m) was chosen to represent the area in which birds were at risk of collision to provide a maximum estimate and would include possible turbulence associated with the tips of the rotors. The height of 139 m, although it is 24 m above the tips of the rotors, necessarily follows the classification as defined and used in chapter 11. The actual blade surface occupies less than 3% of the space around the turbine (fig. 13.1). Not all birds, therefore, flying within this area encounter the rotors or associated turbulence. In particular, birds flying parallel to, or above or below the reach of, the rotors will also not be at risk of collision.

In order to assess whether birds were avoiding the areas close to the turbines, the numbers of birds flying within the area close to the turbines, as observed with horizontal radar set at close range, were compared to those further away from the turbines. The level of avoidance was assessed during different periods of the day and for whether turbines were in operation or not. Visual observations collected during the same period were used to validate the radar method and provided additional information into the species involved. Finally, results were set in context for use in a collision risk model.

13.3 Numbers of birds passing close to turbines

Birds were passing within 50 horizontal metres of the turbine locations in all months and during day, night, dawn and dusk (as recorded with horizontal radar). Between August 2009 and March 2010 an average of 0.95 birds passed within 50 horizontal metres of each turbine per hour. The highest numbers were recorded in October and December, and the lowest in August, January and February. This pattern largely reflected the numbers of birds passing the wind farm as recorded with the vertical radar, but at a much lower level (fig. 13.2).

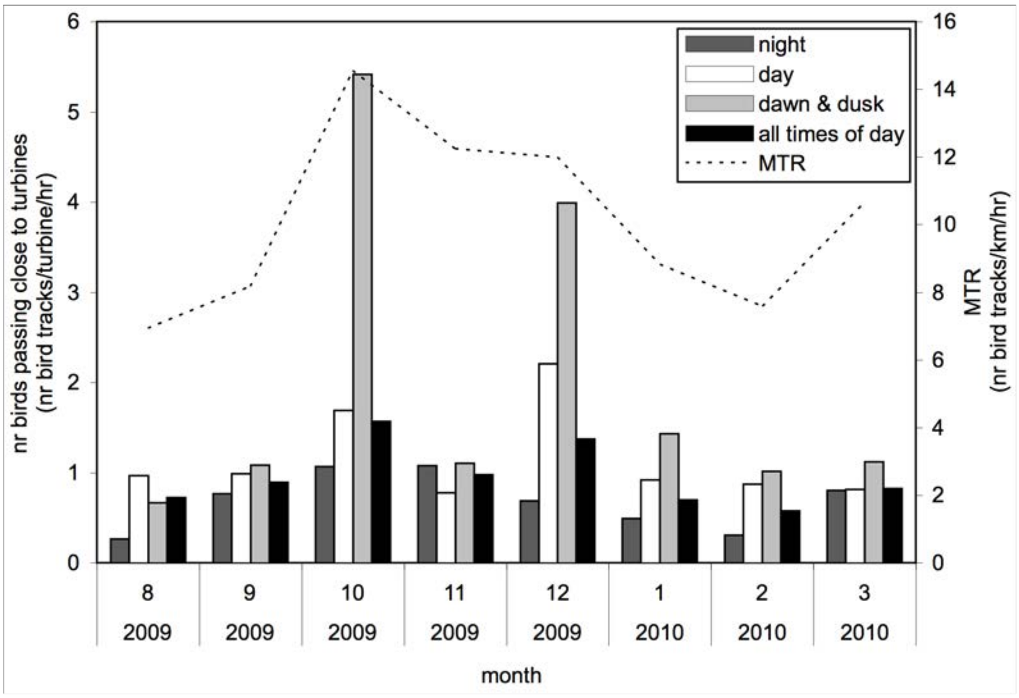


Figure 13.2 Mean number of bird tracks passing within 50 horizontal m of a turbine per hour (bars), as recorded with horizontal radar set at close range. Numbers reflect birds flying at all altitudes within horizontal radar range (0-165 m). For comparison, monthly MTR is given as well (dashed line), as measured with vertical radar at turbine height and as detailed in chapter 10.

The high numbers of birds passing close to the horizontal locations of the turbines during dawn/dusk in October and December reflect the pattern seen across the wind farm as a whole (see ch. 11) and is possibly explained by migrating birds passing at lower altitudes over the area during dawn, or by movements of local birds such as gulls. Figure 13.2 refers to birds at all heights recorded by the horizontal radar. Below, a correction is made to exclude those birds flying above the height of the rotors.

The altitudes of birds flying in the vicinity of the wind farm were derived from data collected by vertical radar (see chapter 11). Tracks were assigned to one of two altitude groups: between 0-139 m (the lowest altitude band on the vertical radar) or between 140-270 m (the approximate height of the horizontal radar beam operating at 0.75 NM was 165 m at max; so these two altitude bands together cover more than the flight paths measured with the horizontal radar at close range).

Between August 2009 and March 2010 a greater proportion of birds was recorded between 0-139 m altitudes than above (fig. 13.3). Proportions below 140 m were lowest during the night in October, November and March, probably due to migrant species passing over the wind farm at higher altitudes (see §8.3 & 11.2). The proportions of birds flying below 140 m were highest in August, December, January and February. This is likely to be a result of the low-altitude movements of local species such as gulls and cormorants (see §8.3 & 11.2).

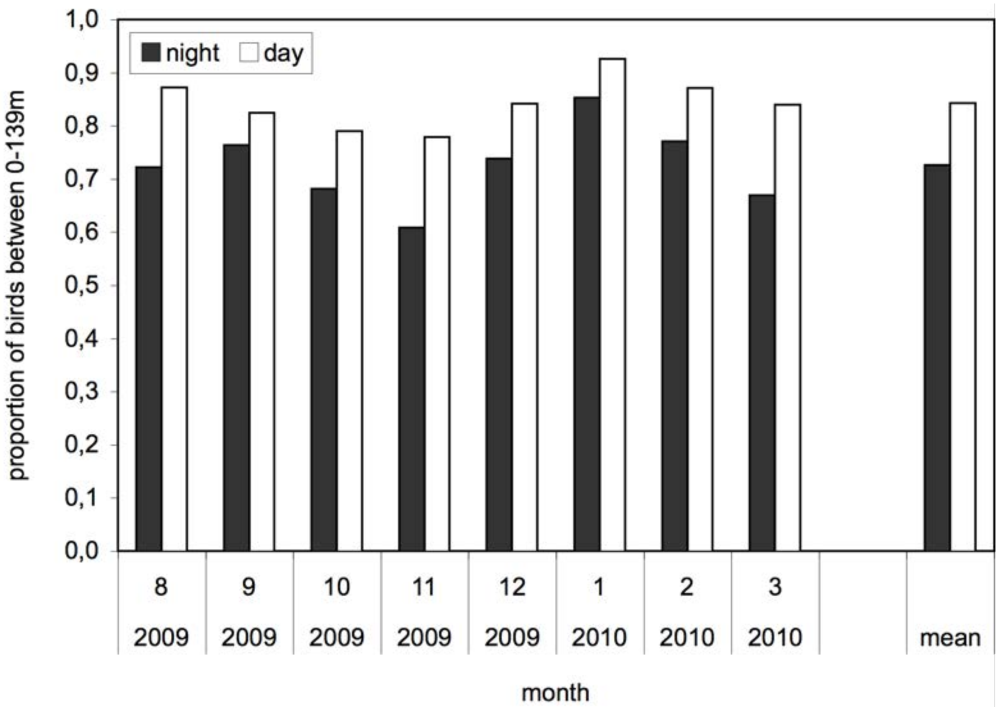


Figure 13.3 Proportion of birds flying at altitudes between 0-139 m, from a total range of up to ca. 270 m, during night (black bars) and day (white bars) between August 2009 and March 2010.

Those birds flying above 140 m are above the reach of the rotors and can, therefore, be considered at no risk of collision with the turbines. The numbers of birds passing at rotor height within the area close to the turbines (fig. 13.1) between August 2009 and

March 2010 are given in figure 13.4; proportions of birds below 140 m during dawn/dusk are based on mean figures of day and night.

The numbers of birds passing close to the turbines varied between 0.19 birds/turbine/hr during night in August and 3.99 birds/turbine/hr during dawn and dusk in October (fig. 13.4). In general, lower numbers were recorded during night than during the day. Highest numbers were recorded during dawn/dusk (see §10.2). These patterns reflect those of birds passing the area of the wind farm (fig. 13.4; also see chapter 10).

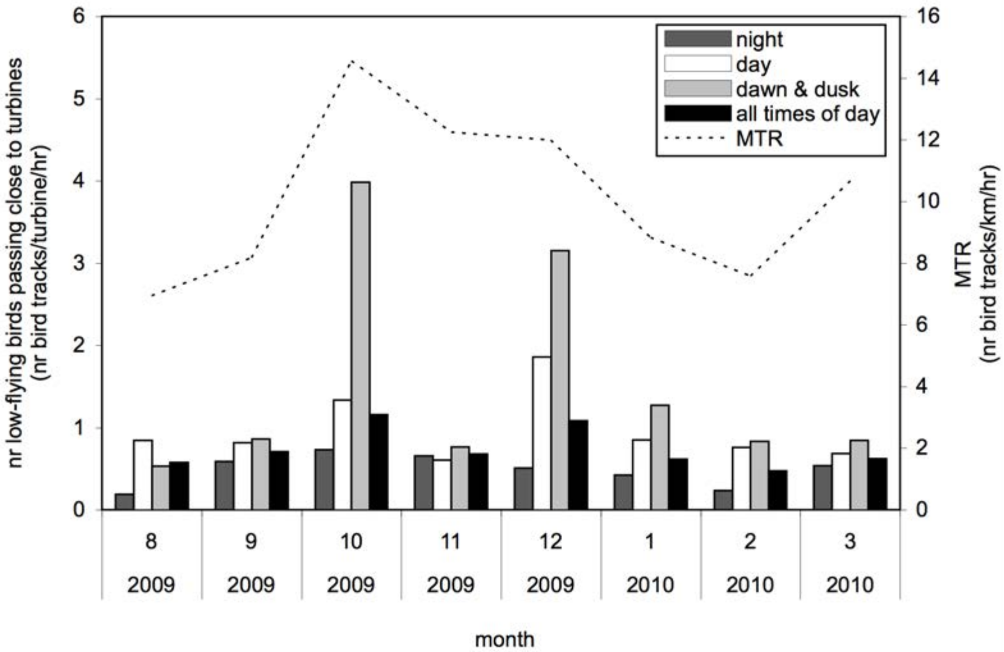


Figure 13.4 Mean number of tracks of low-flying birds, passing within 50 horizontal m of a turbine per hour (bars), as recorded with horizontal radar. Numbers reflect birds flying at turbine height, up to 140 m. For comparison, monthly mean traffic rate is given as well (dashed line, turbine height), as recorded with vertical radar and detailed in ch. 10. The graph shows that fluxes measured with the horizontal radar at close range are lower than fluxes measured with the vertical radar, but do show the same pattern and thus properly reflect the actual local situation.

13.4 Avoidance of individual wind turbines

In order to assess whether and to what extent birds flying within the wind farm avoided the individual turbines (*i.e.* micro-avoidance), the numbers of tracks close to the turbines were compared with those in other areas of the wind farm during the same periods. Fewer birds were found close to the turbines than in other areas of the wind farm compared to what would be expected if birds were distributed evenly (one-sample *T*-test; mean=0.27, sd=0.15, *T*=34, *p*<0.001). This avoidance of individual turbines is visualized in figure 13.5 for migrating passerines flying west in October

2009. The number of birds within the areas close to the turbines was less than one-third of that in other areas within the wind farm. This indicates that birds avoided the areas close to the turbines at a rate of 0.66. As previously stated, this number represents the maximum number of birds at risk of collision, as it includes those passing above, below or parallel to the area of the rotors. To further define micro-avoidance rate, we tackled the above aspect in §3.7 (behaviour), and §3.8 (overall micro-avoidance rate).

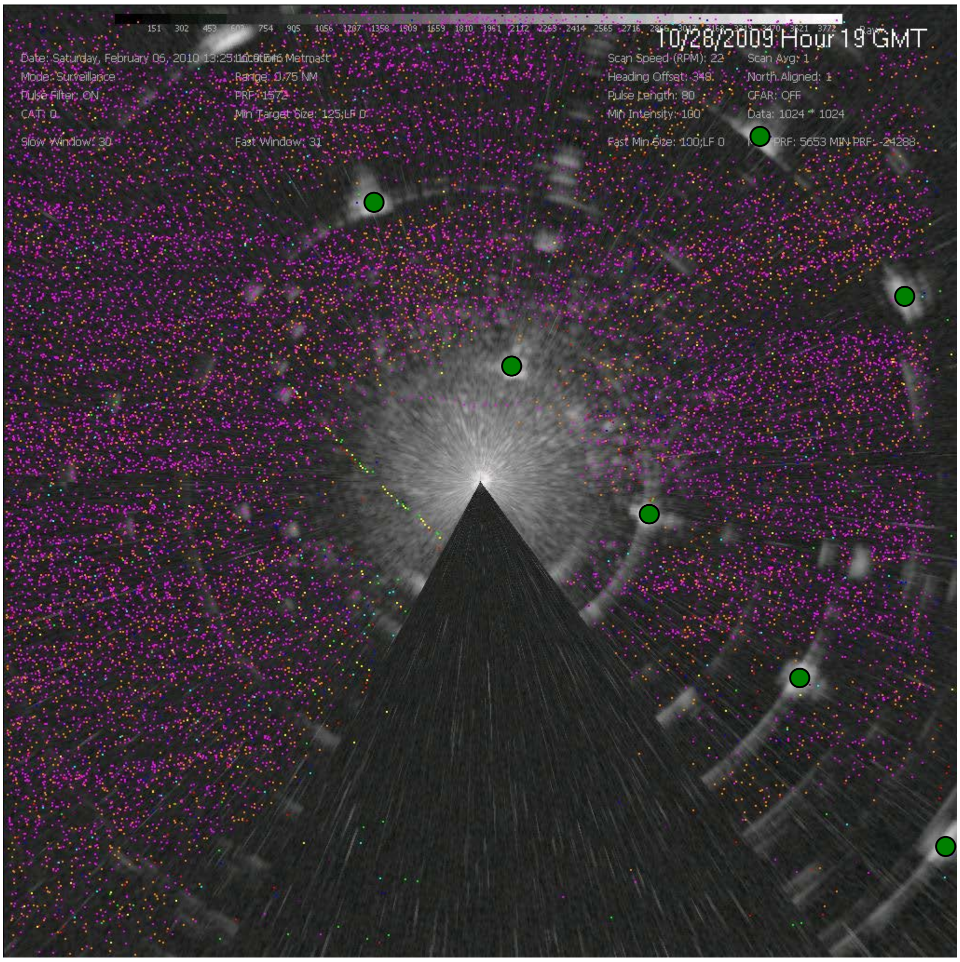


Figure 13.5 Trackplot showing flight paths of passerines migrating east on October 28 2009, between 19:00-20:00 h. Birds are marked purple (and orange), turbines are marked green. For an explanation of trackplots see box I in §5.2. The birds avoided flying in the proximity of the turbines.

13.5 Effect of time of day

At night, fewer of the birds within the wind farm passed close to the turbines compared to both daytime and dawn/dusk (Kruskal Wallis; H=34.19, df=2, p<0.001, night=22%, day=29%, dawn/dusk=31%). These findings are analogous with the results obtained on macro-avoidance (§9.3), and with those from the Horns Rev offshore wind farm in Denmark (Desholm & Kahlert 2005), and suggest that birds account for poorer visibility during darkness by maintaining a greater distance from the turbines.

13.6 Avoidance of turbines that are in operation or down

If birds were indeed avoiding the turbines it might be expected that this response was lower when the turbines were not in operation. The proportions of birds within a horizontal distance of 250 m from the turbines, that passed within a horizontal distance of 50 m from the turbine were compared for those turbines that were in operation and those that were not. This analysis revealed that a smaller proportion of the birds within 250 m of a turbine passed closer than 50 m while the turbine was in operation than while off (in operation median=0.04, off median=0.06, Mann-Whitney U; U=11003, n=341, p<0.005). This greater level of avoidance for turbines in operation was less visible during the day than at night (day; in operation median=0.06, off median=0.07, night; in operation median=0.03, off median=0.05, Mann-Whitney U; night, U=2566, n=176, p<0.005; day, U=2770, n=165, p>0.05). This suggests that birds maintained a greater distance from turbines during periods of poorer visibility, even while the turbines are off. These results are in line with results found for the entire wind farm, as described in §9.3.5.

13.7 Comparison with visual observations

To quantify flight behaviour in relation to the location of the wind turbines, we visually recorded flight paths of birds flying within the wind farm as well, in relation to the location of turbines. This was done during eight separate days of visual observations, carried out between July 14 and December 16 2009, in a subsection of the wind farm area containing six turbines (see §4.7). The observations were carried out during daylight hours and, due to restrictions in accessing the metmast, in periods of good weather (§4.2)..

A total of 1610 birds in 409 groups were recorded (table 13.1). Mean group size was 3.9 birds, the mode 1 and the maximum 122 (starling). Maximum flock size was greater than 10 in five species (groups): cormorant, black-headed gull, skylark, starling and unidentified passerines.

Table 13.1 Overview of the number and species of birds observed visually within a specified section of the wind farm between 14th July and 16th December 2009. These observations were used to quantify behaviour close to turbines in detail.

	Jul	Aug	Sep	Oct	Dec
fulmar		15			
gannet	1		3		
cormorant	22	17	13	50	9
greylag goose		2			
mallard				1	
common scoter				8	
spotted redshank	1				
whimbrel	5				
turnstone	2				
pomarine skua			1		
large gull spec.		6	1	1	
great black-backed gull		3	7	14	1
lesser black-backed gull	94	36	13	3	
yellow-legged gull		1			
herring gull	7	3	1	1	2
kittiwake					4
black-headed gull	69		3	5	
common gull	1			6	22
little gull				2	
common tern	5				
sandwich tern	7	3			
guillemot				1	12
skylark				203	
blackbird				1	
starling				840	
passerine spec.				77	
unidentified spec.			4	1	
total	214	86	46	1214	50

Very few of these birds approached the turbines closely. A total of 115 birds in 52 groups were recorded as passing within 50 horizontal m from the turbine hub (out of the total 1610 birds/409 groups). And of these 52, only eight groups flew at rotor height (*i.e.* 20-120 m altitude, taken as altitude at which flying birds were at potential risk of collision, 5 m beyond the vertical reach of the rotors). This means that 98% of the birds that entered the wind farm, avoided the proximity of the turbines. The eight groups within 50 m consisted of single individuals of lesser (n=2) or greater (n=4) black-backed gulls, a group of 2 starlings and a group of 28 skylarks. None of these birds were seen crossing the area swept by the rotor, all passed either in front or behind the rotors.

For birds flying between 20-120 m high, fewer birds were recorded within 45 m from the turbine (the maximum reach of the rotors), than would be expected with an even distribution across a section between two turbines (fig. 13.6, based on 213 birds between 20-120 m high, with known distance to the turbine). For birds between 20-120 m altitude while at their closest point to a turbine, less than one-fifth of the expected numbers were present within 45 m from the turbines. In contrast, over twice as many birds as expected were recorded flying just beyond the reach of the rotors (between 46-50 m from the hub, in the plane of the rotors). It is important to note in this respect that when recording distances from turbines, birds were assigned to distance categories. For birds seen flying within 5 m of the rotor tips these were assigned in the 50 m category. These observations suggest that although birds fly close to the turbines, very few actually fly within reach of the rotors. Of those birds recorded within 50 m of a turbine, as many as 92.6% were recorded as being beyond the reach of the rotors. Furthermore, not all birds within 45 m of the turbine encounter the rotors, as those flying parallel to the rotors will not necessarily be at risk of collision.

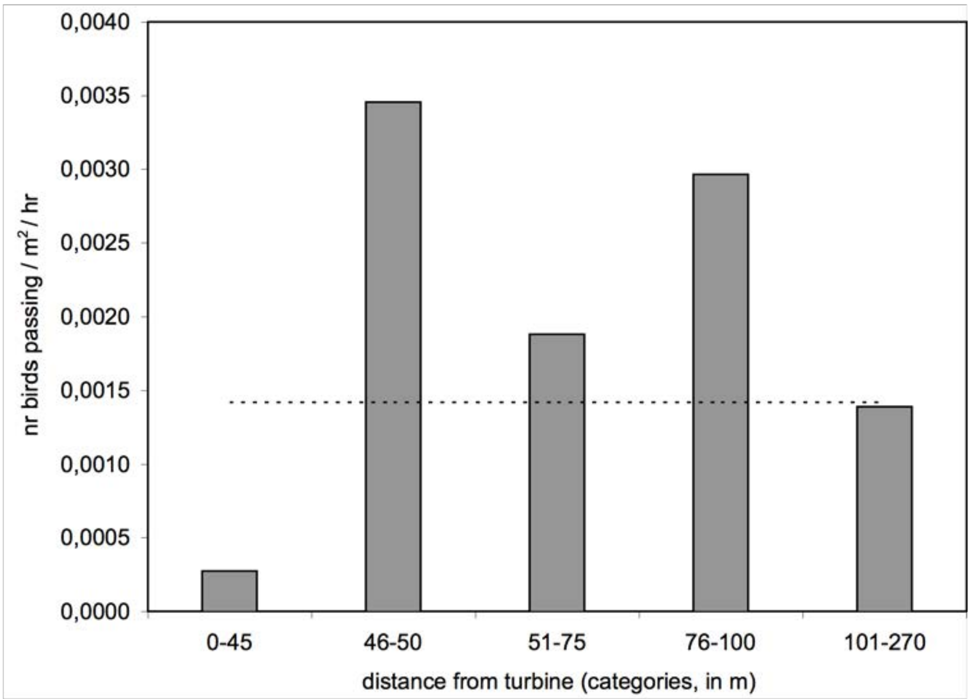


Figure 13.6 The number of birds passing per distance category within a section between two turbines within the wind farm, as observed visually (bars). Numbers are given per m^2 per hour, to correct for the difference in surface area. Given as well is the mean number that is expected when assuming an even distribution (dashed line). Data based on a sample size of 213 birds. Substantially fewer birds than expected were flying within rotor range (0-45).

13.8 Application of avoidance rate

Understanding the responses of birds flying in the vicinity of the turbines is essential for the assessment of the likelihood of collisions. Outcomes of collision risk models that use an avoidance factor can be largely influenced by the avoidance rate used (Chamberlain *et al.* 2005). Actual avoidance rates have seldom been measured under field conditions. If these have been measured they have mostly involved observers, large species and terrestrial locations (Chamberlain *et al.* 2006; Pendelbury 2006; Whitfield & Madders 2006). Using both radar and visual observation we have been able to show that birds not only show avoidance of areas close to the turbines within an offshore wind farm, but that birds flying close to the turbines also actively avoid the rotor-swept area.

The minimum micro-avoidance rate, or the rate of avoidance of individual turbines by birds flying within the wind farm, of 0.976 was determined for birds flying within the boundary of the wind farm. This was calculated by combining both the rates of avoidance for the area up to 50 m from the turbines, and - for those birds flying within 50 m from the turbine - the avoidance of the area within 45 m of the turbines. The first was assessed by means of radar data (§13.4, 0.66), the second by means of visual observations of flight paths (§13.7, 0.926). Micro-avoidance rate was calculated as 1 minus the fraction that did not avoid, or 1-(1*(1-0.66)*(1-0.926)) = 0.976. Actual avoidance rate will be even higher than this estimate, because of those birds that were flying within 45 m from the turbine hub, very few will pass through the rotor-swept zone. The figure of 0.66 is fairly reliable as it is based on 8 months worth of radar data in combination with flight paths obtained during visual observations. The figure of 0.926 may change when more data are collected on flight behaviour in the rotor-swept zone, as it is based on a very limited number of visual observations. This is the first time that micro-avoidance rates have been determined based on actual measurements of displacement behaviour of birds offshore.

14 The OWEZ results in the light of the baseline study and nearby locations

In this chapter a comparison is made between the results of the study at hand and studies at other locations relevant to the understanding and implications of this report. First, a comparison is made between the effect study (this report) and the baseline study (Krijgsveld *et al.* 2005; §14.2). Second, data of some studies further offshore are discussed (§14.3) and in addition also flight patterns of birds along the coast close to the OWEZ wind farm are examined (§14.4). Third, although this is not at a different but at the same location, flight altitude is compared between the data recorded during seabirds at sea (ESAS) counts (Leopold *et al.* 2011) and the data presented in this report (§14.5). In all paragraphs similarities and differences will be discussed within the main themes of this report: species composition, flight intensity, flight altitude and flight paths.

14.1 Summary

In general, species composition was found to be similar between OWEZ and the baseline study around Meetpost Noordwijk (MpN) but some species-specific differences occurred. Species composition determined in this study was similar to observations done from the coast (www.trektellen.nl) and during boat surveys in the area. Fluxes were generally comparable in both the baseline study as well as the effect study although MTRs around OWEZ were substantially higher than around MpN. Only in spring fluxes higher MTRs were measured at MpN. Flight altitudes were similar in both studies with flight movements. Fluxes were in the same order of magnitude of fluxes found in other studies along the coast and at inland locations.

14.2 Baseline study

Data on offshore flight patterns of birds within the MEP-NSW framework were collected at two different locations (see fig. 3.1). During the baseline study, the only available offshore observation platform that was comparable to the OWEZ site, was Meetpost Noordwijk (MpN). Therefore visual and radar observations were carried out on MpN, which was 30 km to the south of OWEZ and a few km nearer to the coast. As the methodology used was almost identical, the flight patterns of birds in these two areas in the North Sea could be compared. In the baseline study (Krijgsveld *et al.* 2005) a paragraph was written on the expected differences in flight activity between MpN and OWEZ. The proposed hypotheses on species and fluxes in that report are discussed in this paragraph.

Species
Quite a similar species abundance and composition was found in the baseline study compared to OWEZ (see also §8.3). This was unexpected as most species groups were expected to be more abundant in the OWEZ area compared to the MpN area (Krijgsveld *et al.* 2005; Leopold *et al.* 2011). This assumption made by Krijgsveld *et al.* (2005) was mainly based on sea watching data from coastal sites (Camphuysen & van Dijk 1983; Platteeuw *et al.* 1994).

Especially for the pelagic seabirds, such as *tubenoses, marine ducks, divers, gannets and alcids* abundance was expected to be more than twice as high in OWEZ area compared to MpN (Krijgsveld *et al.* 2005). Indeed, the abundance of some of these groups turned out to be higher in the OWEZ area but not to the supposed extent. Whether this discrepancy is due to the presence of the OWEZ wind farm or due to the use of data from coastal sea watching sites instead of offshore data is unknown.

Densities of *gannets* were often higher around OWEZ compared to the baseline study, especially during spring and autumn migration (baseline study: max. 0.025 birds per km2; OWEZ: max. 0.15). Moreover, cormorants rather than the pelagic seabirds were showing the largest change. Compared with the baseline study the numbers of flying birds were higher in OWEZ (maximum numbers in baseline and currently in OWEZ are respectively ca. 0.1 and 0.28 birds per km2). This was due to the previously unexpected presence of a (almost) resident group of cormorants. These birds mainly originated from the recently increasing colonies in Noord-Holland. The timing of highest numbers was comparable in both studies, with maximum numbers in June in OWEZ and maximum numbers in May during the baseline study. Also during the breeding season and in winter many of these cormorants were found within OWEZ. The turbines and metmast provided the necessary resting platforms, and it is likely that food availability for cormorants was good both within and outside the wind farm area. Despite the fact that MpN was closer to the coast, and also had a breeding colony nearby (The Hague), it was not used as a resting place by foraging cormorants. Birds seen in the baseline study were commonly associated with fishing vessels.

In contrast to the above-mentioned groups other species groups were much less abundant in OWEZ during the panorama scans compared to the baseline study. For example, the numbers of *divers* were much lower in the wind farm area than at MpN. Also the numbers of *alcids* were lower in the panorama scans of the effect study compared to the baseline study. During the effect study, peak numbers were observed three months later than during the baseline study (November in baseline study). Occurrence and numbers of alcids are highly variable, related to local weather and food conditions.

Similar numbers of *terns, waders and large migrating landbirds* were expected at OWEZ compared to MpN. Numbers and timing of these species groups did correspond between the two sites. On the contrary, *skuas* were not regularly encountered during fieldwork at the OWEZ metmast whereas at MpN skuas were more often seen.

Smaller numbers of *geese and swans, grebes and ducks* were expected at OWEZ and this was confirmed by the results found in this study. Apart from the peak season, average monthly densities were slightly lower. Incidental observations of geese concern mainly dark-bellied brent geese. In October 2008 five groups passed the area of OWEZ (maximum group size 55 birds). During the panorama scans no swans were observed and apart from the panorama scans only one swan was seen at a large distance (species unknown). The lower numbers are probably due to the location of MpN. MpN is situated in the vicinity of a major wildfowl flyway through the interior of the Netherlands (IJsselmeergebied, IJssel Valley) to the Delta area and Belgium. This route largely bypasses Noord-Holland (and thus the OWEZ wind farm) and reaches the coastline further south. An example species for this phenomenon could be swans. However, there is also a cohort of Bewick's swans that fly via Noord-Holland towards the UK which are more likely to cross at OWEZ than at MpN. Migration towards the UK of geese is only found during severe winter conditions and does not occur each year.

Also smaller numbers of foraging *gulls* were expected during the breeding season, because MpN was within the foraging range of gulls breeding at the Maasvlakte while OWEZ was further away from the large colonies. However, gulls breeding in the colonies in various towns such as IJmuiden easily reached the OWEZ area, and obvious differences between numbers of foraging gulls were not observed during the effect study. Given the fact that the number of fishing vessels was expected to be lower at OWEZ as well, this is unforeseen as gull abundance is highly correlated with the presence of fishing vessels (Camphuysen *et al.* 1995). The area around the OWEZ wind farm turned out to be a good foraging area for breeding gulls (lesser black-backed gull and to a lesser extent herring gull) from the coastal colonies. Also in autumn and winter the expected difference between OWEZ and MpN was not present. In this time of year increasing numbers of common gull and kittwakes were found. In winter great black-baked gull and herring gull were common. In OWEZ, the local food availability (and thus trawler distribution around OWEZ) was also the main driver of gull distribution, and the occurrence of fishing vessel in the areas around the park was high (mainly spring and summer, fig. 8.4).

Migrating *landbirds* (mostly *passerines,* and excluding large ones such as raptors and herons) passed MpN in autumn from three different source locations. The first are birds that cross the North Sea in a westerly direction in autumn in order to winter in the British Isles. These different sources of landbirds were not as clearly visible at OWEZ. Birds cutting off the bend were not likely to occur but from the flight paths in spring and autumn coast parallel migration did occur out at sea within the OWEZ area. The assumption that the abundance of landbirds migrating over sea parallel to the coastline was likely to be much smaller at OWEZ than at MpN, was not confirmed. On the contrary, average densities of landbirds were higher in the effect study compared to the baseline study. The second consists of birds on autumn migration towards SW Europe that have started crossing the North Sea in a SW direction during the night, but at dawn find themselves far out at sea and then reorient towards the coast in a SE direction. The third are birds that travel over sea parallel to the coastline either to intentionally cut off the ‘bend’ in the mainland coastline when conditions are good, or after being blown somewhat off course during eastern winds.

Fluxes

In general, the order of magnitude of MTRs was found to be similar between the baseline study at Meetpost Noordwijk and the effect study at OWEZ (fig. 14.1). Also similar patterns in diurnal variation were found with migration peaks concentrated at night and the majority of movements of local seabirds during the day. The influence of weather was also similar in both studies, with most birds flying when wind speeds were around 3-4 Bft.

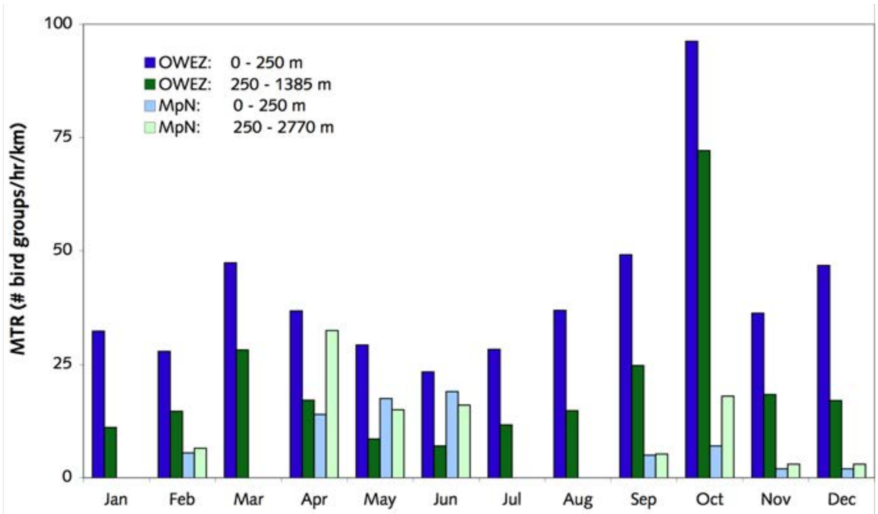


Figure 14.1 Mean traffic rates in OWEZ (dark blue and dark green) and in the baseline study (light blue and light green) as determined by vertical radar at two different altitude classes (0-250 m: blue; above 250 m: green). Altitude classification was in conformity with the reported results in the baseline study. Overall, fluxes were comparable, but autumn migration was better covered in OWEZ.

In May and June (roughly the last part of spring migration), fluxes were highly comparable taking into account that the ‘high altitude’ class is 1385 m higher during the baseline study (MpN: 250 – 2770 m, OWEZ: 250-1385 m). In April, MTRs at low altitude in OWEZ were substantially higher, which is expected for March as well, although MpN data lack for this month. There are no explicit causes for the differences in MTRs between the two studies.

On the contrary in autumn MTRs were very different between the two locations. Much higher MTRs were found in OWEZ compared to the baseline study. The reason for this was that the vertical radar was predominantly off during autumn migration in the baseline study. This was caused by radar failure and due maintenance and therefore a lower radar effort was realised. Unfortunately many migration peaks were missed because of this. MTRs during the baseline study were therefore also higher in spring than in autumn in contrast to OWEZ where the highest MTRs were found in autumn. As the availability of the vertical radar during the effect study was far better, the OWEZ results are expected to be a better representative of the actual flux over the

North Sea than the results shown in the baseline study (assuming OWEZ has no effect on the measured fluxes).

In the baseline study high altitude movements were mostly found in April (and October, although here data are unreliable as most migration peaks were missed). In OWEZ this was true for March and especially October. However baseline data lack for March and it is unknown to what extent the higher altitudes were used by migratory birds at that time.

14.3 OWEZ results in relation to other offshore studies

Offshore bird migration in the Dutch North Sea has not been extensively studied in the past. Detailed studies have been done in the past by Lack (1959-1963) and Buurma (1987) but these studies were all with radars from the coast. In 2006 a study was published on fluxes and flight altitudes of migratory birds around the FINO platform in the German Bight in 2003 and 2004 (Hüppop *et al.* 2006). Similar seasonal and diurnal migration patterns were found but the MTRs found by vertical radar was, similarly to the MpN study, more profound in spring than in autumn in contrast to the situation found for OWEZ. However also on the FINO platform major radar breakdowns in October (the month with the highest MTRs in autumn) did bias the findings for autumn migration. At the FINO platform, migration was also found at all altitudes throughout the year, including summer and winter. The highest numbers of movements were found below 200 m but also at high altitudes substantial numbers of migratory birds were found. Fluxes are not one to one comparable between the FINO based research and the findings in the OWEZ wind farm as the German results are just the total numbers of bird per hour and not in a stretch of one km. Also in the Dutch North Sea studies on bird migration have been done using radar (Buurma 1987; van Gasteren *et al.* 2002). Unfortunately a different type of radars were used and on different ranges. However timing of migration peaks was fairly similar to the results found in OWEZ with highest migration intensities found during the nights and in October (Buurma 1987).

14.4 OWEZ results in relation to studies on the coast

Fluxes of migrating birds show peak levels in the coastal region (Lensink *et al.* 2002). Further out at sea, fluxes decrease again (van Gasteren *et al.* 2002). In the OWEZ effect study it was expected that species composition and abundance would follow similar patterns along the coast and further offshore. Therefore species composition and fluxes of birds within the OWEZ wind farm were compared to findings of standardized multi-year research of migration at sea done from the coast. Several relevant sea watching posts are scattered along the coast adjacent to the OWEZ wind farm. Findings of these counts are published in several sea watching reports (Camphuysen & van Dijk 1983; Platteeuw *et al.* 1994). Also up-to-date information and counts can be found at www.trektellen.nl. Note that most of these studies involve visual observations that are limited to the daylight period and only cover the migration flux flying at lower altitudes.

On the Dutch North Sea coast several studies on bird migration have been done using radar (Buurma 1987; van Gasteren *et al.* 2002). Unfortunately often different types of radars were used and on different ranges. However, flight altitude was fairly similar with the majority of birds flying below 100 m and very small numbers of birds flying at higher altitudes during the day (van Gasteren *et al.* 2002). Fluxes are difficult to compare as MTRs in these studies were expressed as numbers of bird groups per cubic km. Nevertheless, seasonal and diurnal patterns in fluxes were comparable (van Gasteren *et al.* 2002).

Flight intensity during migration was slightly lower at sea than on land. In this study, an exceptional peak MTR of 3,638 bird groups/km/hr was found. In general, the average numbers during peak hours on migration days/nights were less (in the order of 500-1,000 birds/km/hr). These figures were slightly less compared to migration peaks on the coast, however exceptions occur as shown by Krijgsveld *et al.* (2005). Incidentally, migration intensity was higher at MpN than on the coast.

In general, the intensity of bird migration is highest on the coast and lower inland and at sea (Lensink *et al.* 2002). In recent studies along the Dutch coast peak MTRs were found to be 1,600 bird groups/km/hr (headwind conditions) in Eemshaven (Poot & Lensink 2007) and 3,500 bird groups/km/hr in Antwerpen (Poot & Lensink 2008; Poot *et al.* 2008). To place these numbers in perspective, up to 9,000 bird groups/km/hr have been recorded in Israel during peak migration nights (Bruderer & Liechti 1995; Bruderer 2001). However, Israel is one of the major migration hotspots in the world. Millions of migratory birds travelling from Eurasia to Africa pass this point and numbers are very high due to a 'bottleneck-effect'. Also, the radar used in that study had a much wider range compared to the OWEZ radar and higher MTRs were expected. Remarkably thus, these peak figures are not extraordinary far from the situation on the Dutch coast.

Flight altitude along the coast and within the OWEZ wind farm is difficult to compare as in general, altitude is not recorded during sea watching counts. Some references in literature suggest that passerine migration at sea is higher than along the coast both during day and night (Klomp 1956; Jellmann 1979). Most pelagic seabirds will only fly at sea so differences cannot be studied (e.g. divers, tubenoses, gannets, marine ducks, skuas, alcids). They are generally thought to fly low above sea level (Camphuysen & van Dijk 1983; Platteeuw *et al.* 1994) however terns and skuas were found migrating at higher altitudes.

Obviously, *species composition* was different between land and sea. However, species-specific peaks in migration could be picked up both during fieldwork and on the sea watching posts. This was found for species such as divers, ducks and passerines (starlings).

The species spectrum during coastal sea watching is wider as more different species are recorded from the same species groups. This was not caused by a difference in species occurrence but more likely due to a difference in observation conditions. In general, sea watching on the coast is most popular during adverse weather. Strong westerly winds attract high numbers of birders to the coast. More 'eyes' see more birds and the difference in observation effort between fieldwork at the metmast and on the coast is high. Also under these weather conditions several pelagic species, that live/migrate further offshore, tend to get blown towards the coast ('leading line effect'). Under these conditions observations from the metmast were not possible due to safety reasons and therefore these species were often missed during fieldwork. Shearwaters, storm petrels, skuas and high abundance events of species such as kittiwakes and fulmars are missed in this way. On the other hand, ship-based surveys have learned that during these conditions at open sea, flight activity and densities of seabirds are generally low.

Leading line effects of bird migration along the coast are probably confined to the first 0-5 km from the coast. Therefore higher numbers of birds are expected in this range from the coast. As OWEZ is further offshore these leading line effects will not play an important role in the results on fluxes found in this study. However, comparing results from the metmast, the boat surveys and coastal sea watching these leading line effects need to be taken into account.

The numbers of *divers and grebes* were higher on the coast than noted from the OWEZ metmast. Certainly grebes are more bound to the coast but also divers seemed to prefer the shallow coastal zone (Leopold *et al.* 2011).

Along the coast *tubenoses and gannets* were virtually absent outside periods with strong westerly winds. During the boat surveys tubenoses and gannets were observed more pelagic as well.

Cormorant abundance will be more or less similar between coast and OWEZ due to the attractive nature of the park for feeding and resting cormorants. Cormorants were also mainly confined to the wind farm area and the coast during the boat surveys.

Migration of *geese, swans and ducks* (both marine and freshwater) was higher along the coast than from our findings in OWEZ. Also during the boat surveys only incidentally geese, swans and freshwater ducks were encountered. On the other hand marine ducks were more numerously encountered during the boat surveys with migration of for example common scoter closer to the coast. Raptors were also seen from the coast and during the boat surveys but similar to our findings in very low numbers.

Most observations of *waders* were made during spring, although waders were also recorded in summer, autumn and winter. The observations of groups of golden plovers and dunlin coincide with the peak observations of migrating birds along the Dutch coast (Lensink *et al.* 2002). Fewer waders than might be expected compared to numbers of migrating birds along the Dutch North Sea coast, were seen in OWEZ. This suggests that, during daytime, waders possibly migrate relatively close to the coast.

Skuas were sighted more commonly during the boat surveys than from the metmast. Also on coastal watches bigger fluxes of skuas were observed. These differences are due to difference in observation effort due to weather conditions, as mentioned previously.

Differentiation between *gull* abundance along the coast and in the OWEZ wind farm is difficult to estimate, as gulls are not always noted during coastal sea watching. Distribution of local birds was highly dependent on the distribution of fishing vessels. From the boat surveys some distinct patterns in gull distribution could be concluded. Little gull were found in the OWEZ wind farm as well as outside whereas black-headed gull was more confined to the coast. Observations from the metmast are limited for the latter species as well. Common gulls were virtually absent in summer and autumn and present in winter and spring. Lesser black-backed gulls are the most numerous species and confined to spring, summer and to a lesser extent autumn. Herring gulls were mostly found along the coast but also within the wind farms. Kittiwakes were absent in summer but found inside and outside the wind farm.

Terns were primarily found on the coast. They were only recorded during spring and summer, reflecting the seasonal movements of these species. Sandwich tern was the only species recorded during spring; all species recorded were observed in summer. Sandwich terns are recorded throughout the summer along the Dutch coast, although peak numbers are recorded in early September (Lensink *et al.* 2002). Sandwich terns mainly forage within 5-10 km of the coast (up to 30km), although most are found within 5 km from the coast (Camphuysen & Leopold 1994; Garthe & Flore 2007). Peak numbers of common terns were recorded in the area during summer, both along the Dutch coast and inland (Lensink *et al.* 2002). Birds recorded from the metmast are likely to refer to birds not actively breeding as common terns typically have a maximum foraging distance of 6.3 km (Becker *et al.* 1993). Observations in the OWEZ wind farm were mainly during migration.

Distribution of *alcids* in the Dutch North Sea area is unknown, but varies largely with food availability and weather conditions. Results from boat surveys suggest that avoidance of the wind farm by guillemots and razorbills did occur (Leopold *et al*. 2011).

A total of 32 *landbird species* were identified from the metmast. The large majority was recorded in highest densities during autumn rather than spring. Starlings and thrushes were recorded in highest densities during the panorama scans and in addition skylarks and meadow pipits were also recorded in relatively high numbers. Peak numbers of starlings were recorded during autumn, reflecting the peak of migration along the Dutch coast and inland (Lensink *et al.* 2002). Along the Dutch coast the numbers of most thrush species peak during the end of October and beginning of November (Lensink *et al.* 2002). During this period most thrushes were observed on the metmast. Migrating passerines, especially the individuals flying at higher altitudes, were often missed during the seabird surveys. Observation done during these surveys revealed a similar species-spectrum as from the metmast. Also incidental observations of passerines (e.g. redwing and blackbirds) on deck and circling the anchored ship during the night confirm these findings.

Another reason for differences between observations in the OWEZ wind farm and coastal sea watching is caused by the location of the wind farm. From the results described by Leopold *et al.* (2011) on local birds we know that the OWEZ wind farm however, seemed to be located in a relatively 'bird-poor' area with increased abundance on either sides of the park to the coast and further offshore.

14.5 Flight altitude of local birds determined during the baseline study and the ship-based surveys

Effect study versus baseline study

In the baseline study at MpN less movements at high altitude were found throughout the year. Except at night in spring when high numbers of birds passed MpN as well. Possibly this difference was due to detection limitations of the vertical radar and a lower radar effort (similar to with the fluxes). In the baseline study most migratory movements occurred above 150 m during favourable conditions whereas in OWEZ, migration was also found in the lower regions.

Some species groups (e.g. divers, cormorants, and passerines) on average flew higher during the effect study compared to the baseline study (fig. 14.2). Other species groups (e.g. grebes, tubenoses, gannets, terns and alcids) flew lower on average in the effect study.

Some species groups showed large differences in flight altitude between the T0 and T1 seabird surveys as well (e.g. geese and swans) or between the metmast and ship surveys (e.g. geese and swans, raptors and owls, skuas, other ducks). For both categories the total number of observations within these groups was very small and therefore the standard deviation was high.

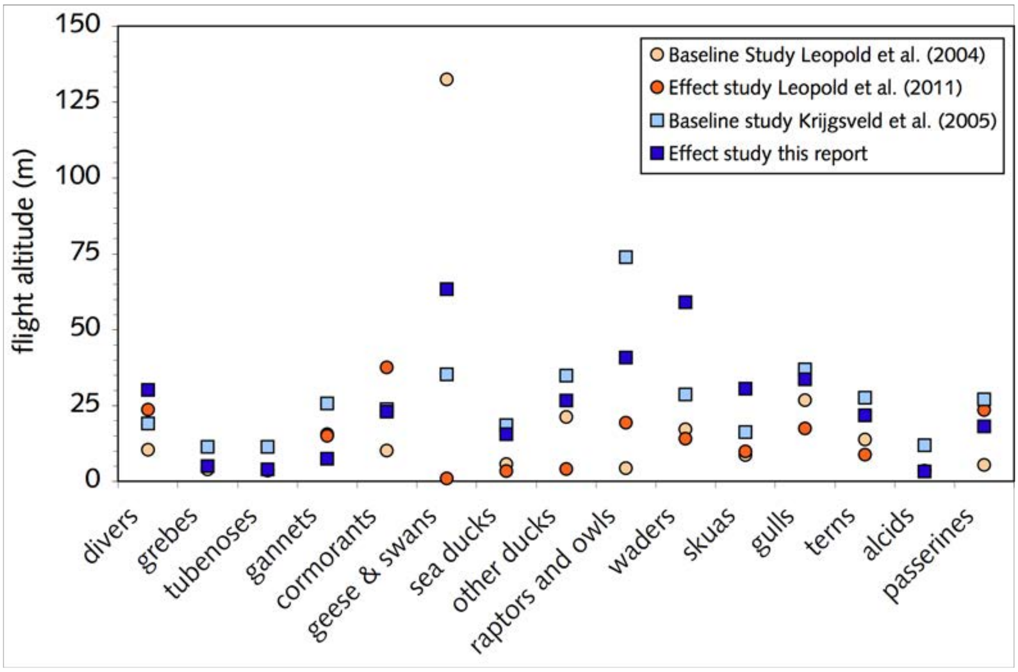


Figure 14.2 Average flight altitude per species group as determined by boat surveys reported in Leopold et al. (2004; 2011) and as determined from observations from the metmast on indifvidual flight paths reported in Krijgsveld et al. (this study). Flight heights from the baseline study from Krijgsveld et al. 2005 are based on panorama scans are higher because they reflect averages from larger altitude classes. The large difference in flight altitude of geese & swans, raptors & owls and other ducks is due to small sample sizes.

Platform-based versus ship-based surveys

The results on species-specific flight altitudes (based on additional observations on individual flight paths) in the report at hand can be compared to the altitude findings of the seabird surveys carried out to determine disturbance . Flight altitude was recorded for all species observed during the boat surveys of the baseline study (Leopold *et al.* 2004) as well as of the effect study (Leopold *et al.* 2011), although the latter data were not complete for all surveys. Note that these data have several limitations, as during the boat surveys passerines and high altitude movements will have been underestimated. This was due to the fact that the search effort of the observers aboard was concentrated on the stretch of sea in front of the boat and not the sky above. The results found during the seabird surveys however, are mainly collected outside the wind farm as most of the transects were outside the wind farm vicinity. Therefore the recorded altitudes give an indication of the flight altitude in the area regardless of the presence of turbines.

In figure 11.14 the altitudes recorded during visual observations are shown. These average flight altitudes for the difference species groups showed many similarities with the results obtained from visual observations during the boat surveys, shown in figure 14.2. In many cases birds flew higher during the platform-based surveys compared to the ship-based surveys. Probably this had something to do with the above-mentioned difference in observation technique and search-window rather than actual differences in overall flight altitudes. This is best illustrated by the waders and the geese & swans. These groups observed from the ship flew much lower than those observed from the metmast. This is due to the fact that higher altitude movement of waders is often missed from the ship.

The most remarkable difference between the two methods was the flight altitude of gannets. During the ship surveys, gannets flew on average much higher than observed from the metmast. This might be due to the higher proportion of searching and foraging gannets observed from the ship in contrast to the gannets seen from the metmast who were mainly in transit. Gannets in transit fly much lower above the water compared to feeding and searching gannets (Nelson 1978).

15 Conclusions

In this chapter the results as presented in the previous chapters, are brought back to the research questions of this study. In the first three paragraphs we discuss what the effects are on birds of the OWEZ wind farm. Barrier effects are discussed in §15.1, collision risks are discussed in §15.2, and disturbance is briefly discussed in §15.3. Performance of radars is discussed in §15.4. In §15.5 we discuss what the research has and has not yielded in terms of species-specific flight patterns.

15.1 Barrier effects

Macro-avoidance
Overall, between 18-34% less birds flew within the OWEZ wind farm compared to outside the wind farm (28% on average). In winter, when mainly local seabirds were present in the area, avoidance was lowest with only 18% less birds within the wind farm, in autumn avoidance was highest with 34% fewer birds in the wind farm than outside. Avoidance was higher at night than during the day. The difference is hard to quantify, but at night the proportion of birds in the wind farm was roughly half to two thirds of the proportion during daytime. Flight paths were generally adjusted 1-2 km before the wind farm, and after leaving the wind farm within 3-4 km from the wind farm.

Micro-avoidance
Birds actively avoided turbines. Flight paths did hardly come within 45 m from the turbines, and when they did, birds flew mostly only in the area where rotors were not sweeping, behind or in front of the rotor blades. Birds were not seen to pass directly through the rotor-swept area. Especially at night, close proximity of turbines was avoided.

Of those birds that entered the wind farm, 66% avoided the turbines up to 50 m distance. Of the birds that did come within reach of the rotor blades (45 m from the turbine), very few (7%) came within the rotor-swept area of the turbine. Combining these two figures, results in an overall micro-avoidance, *i.e.* avoidance of individual turbines by birds that do enter the wind farm, of 97.6%.

Species-specific avoidance
Avoidance varied largely between species. In general, avoidance was largest in seabirds such as gannets, divers, auks and guillemots, and scoters (fig. 15.1). No avoidance and possibly even attraction was observed for cormorants and most species of gulls. Of the migrating landbirds, geese and swans showed strongest avoidance. Most other migrating species showed little to no avoidance. At night, migrating passerines showed stronger avoidance than during the day.

Because observations on flight paths were limited to 3 NM (5.5 km) at maximum, it is possible that avoidance may have occurred at distances larger than the observed 5.5 km. At such large distances it is also difficult to evaluate whether a flight path is affected by the wind farm and thus whether avoidance did occur. This could for instance be the case in the alcids, that were scarce in the wind farm area, and were at times seen flying by at large distances (>5 km). Observations on distribution of local birds reported in Leopold *et al.* (2011) give insight in occurrence of such effects. Their results indicate that such disturbance did occur in this species group.

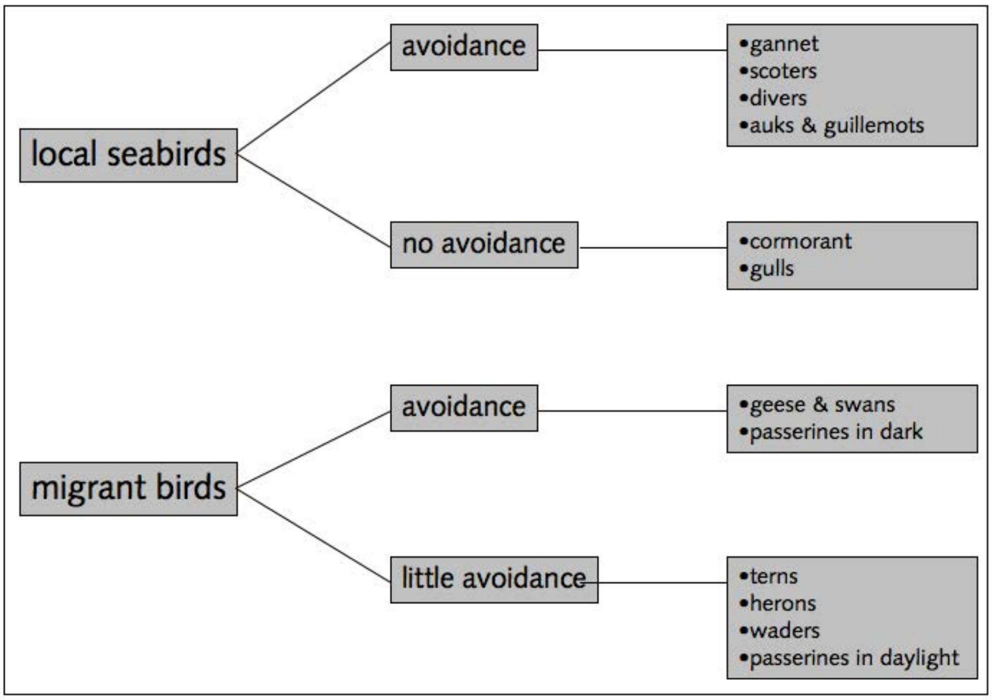


Figure 15.1 Schematic overview of species that did or did not avoid the wind farm, separated into (mostly local) seabird species and migrating landbirds. Observed visually for individual species, and additionally with radar for the passerines.

Avoidance rates

Based on the spatial distribution per species group in the wind farm area (table 9.3) and the avoidance behaviour of individual species (§9.7), we calculated the overall avoidance levels of species groups (table 15.1).

Based on panorama scans, macro-avoidance rates could be assessed for the majority of species groups. 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 gannets and 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 (see §9.7, fig 9.37). 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%).

Overall micro-avoidance by birds of individual turbines was determined at 97.6%, based on general fluxes at altitudes within the risk-zone of the rotor-area. Overall avoidance behaviour around the turbines is further determined by species-specific flight altitudes as well as species-specific behaviour in response to the turbines.

Species-specific flight altitudes

When calculating collision risks, overall avoidance levels play a significant role. Horizontal avoidance is included in the calculated macro-avoidance levels. Flight altitude also plays a significant role in collisions risk, but this aspect is accounted for in the overall flux of birds through the rotor-area. Because many species have very specific flight altitudes, this significantly reduces the collision risk for those species flying consistently above or below rotor height, and therefore has to be accounted for when determining avoidance and flux through the wind farm. Thus, this flux was further specified by accounting for species-specific flight altitudes (see §11.4, fig. 11.14). This aspect is included in table 15.1 as well.

Tubenoses and alcids virtually always fly only a few meters above sea-level. Based on observed flight altitdudes, we estimate that of every 50 birds flying into the wind farm, a maximum of one may have flown up to rotor height (98% avoidance). Gannets and sea-ducks and also grebes generally flew well below rotor height, while waders and passerines flew above rotor height, but these species may reach rotor heights during migration, when disturbed or (for waders and passerines) during headwinds. Based on observations, we estimate that half of the birds of these species will have flown at rotor height at maximum (50% avoidance). 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% avoidance).

In conclusion

Deflection of flight paths consisted of 18-34% of the birds in the area avoiding the entire wind farm in general, this number being larger or smaller depending on the species. Many birds chose to fly around the wind farm rather than entering it. Of the birds entering the wind farm, at least 97.6 % avoided flying in the rotor-swept area (micro-avoidance). This results in a reduced collision risk of course, 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).

The cumulative effects of the total number of wind farms that are currently planned in the Dutch North Sea are quantified by Poot *et al.* (2011).

Table 15.1 Overall 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 (macro-avoidance) or that did not come within the rotor-swept area (micro-avoidance). Shown are macro-avoidance rate, micro-avoidance rate (value=0,976), resulting overall avoidance rate, and avoidance rate based on species-specific flight altitude, which can be accounted for in the calculation of species-specific fluxes through the rotor area. Data in the first three columns are calculated from the results. Data in the final column were estimated based on visual observations.

species	macro-avoidance	micro-avoidance	overall horizontal avoidance	prop. not flying at rotor height
divers	0,68	0,976	0,992	
grebes	0,28	0,976	0,983	0,98
tubenoses	0,28	0,976	0,983	0,50
gannets	0,64	0,976	0,991	
cormorants	0,18	0,976	0,980	0,50
geese & swans*	0,68	0,976	0,992	0,50
sea ducks*	0,71	0,976	0,993	
other ducks	0,28	0,976	0,983	0,50
waders	0,28	0,976	0,983	
skuas	0,28	0,976	0,983	
gulls	0,18	0,976	0,980	
terns*	0,28	0,976	0,983	
alcids	0,68	0,976	0,992	0,98
raptors	0,28	0,976	0,983	
small passerines	0,28	0,976	0,983	0,50

*values for species group based on mostly one species: geese&swans: brent geese; seaducks: common scoter; terns: sandwich tern

15.2 Collision risk

Flight intensity

Mean traffic rate in the wind farm area was 80 bird groups/km/hr, with peaks up to 3600. Overall flux through and over the entire wind farm area was approximately 5,201,000 bird groups per year (table 10.3; 743,036 bird groups x 7 km). MTR was highest during the migratory seasons, especially in autumn. During migration, fluxes were highest at night, reflecting migrating birds, whereas in summer and winter fluxes of locally foraging birds were highest during daytime.

Flight altitudes

Flight altitudes varied from 0 m to the maximum measured altitude of 1385 m. In winter and summer, more birds flew in the lowest altitude band up to 70 m above sea level, while in the migratory seasons the number at higher altitudes increased. However, in all months movements were recorded at high altitudes. The higher number of birds flying at night were found at all altitudes except at the lowest. This reflects the presence of local seabirds in the lowest altitude bands, these birds being less active at night. The highest-flying birds were passerines and waders. Particularly low-flying birds were the alcids.

When approaching the wind farm, birds generally increased their flight altitude, but altitudes mostly still were within the range of the rotor blades. Of birds that flew within the risk zone of the turbines, most species groups were represented, including divers, grebes, gannets, cormorants, all waterbirds, marine ducks, raptors and owls, skuas, gulls, terns and passerines.

Collision risk
Of the birds flying though and over the wind farm area, 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 1,866,000 bird groups were at risk of colliding with the rotors (data from table 11.1, high-risk altitude class, fluxes/km multiplied by 7 km).

To determine how many bird groups of specific species or species groups flew through the wind farm, the total flux was attributed to the various species groups visually observed in the area. This was calculated using the proportional species composition (table 10.5). The resulting species-specific annual flux is presented in table 16.1.

15.3 Disturbance

Disturbance effects on local seabirds are being reported by Leopold *et al.* (2011). They found a low abundance of local sea birds in the wider wind farm area. This low abundance was related to the location of the wind farm rather than the presence of the wind farm itself: nearshore species remained closer to the coast, while the more pelagic species were low in abundance and showed no difference in abundance in the wind farm area versus further away from it. They found the strongest indications of disturbance in alcids, which showed clear avoidance, and occurred in somewhat higher numbers in the area. However, numbers were still too low to statistically determine whether disturbance occurred.

Our results show that pelagic seabird species had the highest avoidance levels. This indicates that these species will avoid the OWEZ wind farm, which 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 probably limited. Gannets, alcids and marine ducks were all seen foraging within or near the wind farm on rare occasion.

15.4 Performance of radars

The radars operated consistently throughout the study period, with little down-time due to hardware problems. During strong winds the radars needed to be turned off, potentially leading to a bias in flight patterns, but the results have shown that fluxes were considerably lower during strong winds, and enough variation in weather conditions exists in the data to interpret effects of wind on flight patterns. Compared to the baseline study, where the vertical radar suffered frequent fall-outs in strong winds, performance was good.

As can be expected when trying to watch bird echoes over sea, the amount of clutter generated in the horizontal database was extremely large (ca. 95%). The software was not able to distinguish birds from sea clutter very well, because sea clutter turned out to have very much the same echo characteristics as birds. This affected tracking of birds as well, because echoes of waves were included in tracks of birds to some extent. However, based on behavioural characteristics of tracks of birds versus those of echoes, clutter could be removed successfully to a large extent, resulting in a reliable database with clear flight patterns of birds.

In the vertical radar data, clutter originated mainly from interference from the metmast and the turbines. By selecting two areas with relatively little clutter, the proportion of clutter to be removed from the data was already significantly reduced. The subsequent filtering process was successful, although to a small extent clutter will have remained in the database and bird tracks will have been thrown out. Overall fluxes do however closely reflect the actual fluxes of birds flying over the wind farm area.

The Merlin radar system that was used proved to be a successful means to measure flight patterns of birds in the offshore location of the OWEZ wind farm. Given the remote offshore conditions and the research questions, the system was able to provide us with the required data.

15.5 Limitations in assessment of species composition

Because with the radars that were used we could not discern between species, an alternative approach needed to be used to assess species-specific flight patterns. During daylight hours this was achieved with visual observations. These provided insight in species abundance in the wind farm area, avoidance behaviour of individual species as well as species-specific fluxes and flight altitudes. This approach worked well in obtaining insight in flight patterns, but had a number of drawbacks.

First, visual observations were limited to days with calm weather conditions. This was due to the study location at the metmast, that has no accomodation. Noordzeewind safety policy prescribed transfer of staff from the crew tender to the metmast at low sea state only (max 1 m significant wave height). Species that are present in the area during other conditions, such as fulmars coming in with stronger winds from northwesterly directions, were therefore underrepresented in the database. Comparisons with coastal observations and the observations carried out to study disturbance (Leopold *et al*. 2011) do however show similar results with regard to species composition and presence. This indicated that the bias due to weather conditions was limited.

Second, visual observations were limited to ca. 3 km. This distance is required to obtain sufficient information on abundance and distribution, and also to limit effects from the presence of the platform. For smaller species such as passerines, this distance is considerably less. As a result, of small to medium-sized passerines, only those birds were detected visually that flew within ca. 500-1000 m from the metmast. Abundance of these smaller species was thus underestimated in the visual observations. To correct for this the vertical radar data were used, by evaluating the proportion of tracks likely to be of passerines versus of locally foraging birds. Thus, the proportional abundance of species groups flying during daytime could be determined with a fair accuracy. In combination with the continuously measured flux through the area, numbers per species group flying through the area were obtained.

Third, observations during the hours of darkness were limited to radar observations and to a limited number of data obtained from auditory methods and moonwatching. Radar data did not provide information on species group level, while auditory observations were limited to species that call during flight. This means that during dark, although overall flight patterns could be assessed in detail, information on what species these flight patterns consisted of was very limited. Based on flight behaviour and timing of flight activity, nocturnal radar data could be interpreted to a large extent as belonging to either local seabirds or migrating songbirds. With existent knowledge about the behaviour of local seabirds we were even able to assess to what species the majority of flight paths of local birds belonged to. However, it was not possible to determine the abundance of individual species of songbirds migrating though the wind farm area. This aspect was limited to an insight in the species that were migrating through the area, which will not have been the full range of passerine species migrating at night through the area. It was clear however that during nights with strong migratory activity, a large proportion of birds consisted of thrushes (redwing, blackbird, song thrush).

In conclusion

Overall, flight patterns of local and migrating seabirds in the area were assessed in detail at species level. Flight patterns of larger landbirds flying during daytime were similarly determined, although numbers were so low that information is less detailed. Flight patterns of migrating songbirds could not be determined to species level, but overall flight patterns of this group were obtained in detail with the horizontal and vertical radar observations, and these contribute significantly in the insights needed to assess the effects of offshore wind farms on this group. Flight patterns at night were measured with radar, and could be interpreted to a considerable extent for local and migrating seabirds. Flight patterns in relation to the wind farm were also assessed for the entire group of passerines, including flight altitudes and avoidance behaviour, but it was not possible to determine species-specific fluxes for this group.

15.6 In conclusion

The results presented in this report show fluxes, flight altitudes and avoidance rates of birds flying in the area around the Offshore Wind farm Egmond aan Zee. The main results are:

- Overall the density of species flying in the area was low (ch. 8). Flight activity in the area was limited, because of the location of the wind farm, as reported by Leopold *et al.* (2011). He found that coast-related flight activity was reduced at the location of the wind farm, while the more pelagic species still occurred in relatively low abundance.
- Patterns in fluxes as measured with the vertical radar reflected seasonal and diurnal flight patterns of birds (ch. 10). Large numbers of migrating songbirds passed through and over the wind farm in spring and autumn, while during summer and winter flight activity was much lower, reflecting local seabirds that were mostly active during daytime.
- Local seabirds flew mostly at altitudes up to 70 m, which is at turbine height (ch. 11). Migrating species such as waders and passerines flew at all altitudes that we observed, up to 1.4 km high, and thus a large proportion flew above turbine-height. Altitudes of these birds varied largely however, depending on environmental conditions.
- Species varied largely in how much they avoided the wind farm (ch. 9). The gulls showed no avoidance at all, and the cormorants were drawn to the wind farm from the coast. More pelagic species however mostly avoided the wind farm entirely, by deflecting their flight paths around it. This concerns species such as gannets, scoters, divers, auks and guillemots.
- Of the birds entering the wind farm, the vast majority (97.6%) avoided the direct vicinity of the turbines (ch. 13). These data on micro-avoidance rates are the first actual measurements of displacement behaviour of birds around turbines offshore.

This study is among the first to present flight patterns of birds in relation to wind farms in the offshore environment.

16 Collision risk: an attempt to estimate the number of collisions

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 (Dirksen 2006, 2009). To date, actual collisions risks have not been measured for any offshore wind farm, so no collision risks are available from comparable offshore situations to estimate the number of victims. To obtain a crude estimate of numbers of victims, we followed two ways to calculate this. 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 Band-model (Chamberlain *et al*. 2006, Band *et al.* 2007). This second route is explained extensively in the report on cumulative effects (Poot *et al.* 2011), and the number of collisions reported in table 16.1 was taken from that report.

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. 2009a*). Based on this percentage, number of collisions were estimated for each species (- group). Flux was determined as the species-specific flux in the area (see §15.2), which was adjusted to give flux through the wind farm at rotor height by correcting for macro-avoidance and flight altitude as shown in table 15.1.

Interpretation

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, as observed with the radar, which also has positive consequences for the number of collisions. Collision victims occur among all types of birds, and during various types of behaviour. Migrating birds at night are known to be prone to collision, but also birds foraging during daytime and only paying attention to potential prey and the areas where prey can be found. 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 very limited due to the low abundance of local seabirds in the area, the relatively high avoidance level of pelagic seabirds such as gannets, divers, alcids and scoters, and also the high level of both macro-and micro-avoidance of these species. Gulls 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.

Table 16.1 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 on estimated using the Band-model (as calculated in Poot et al. 2011). Fluxes rounded off 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	1130	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	17160	0.64	0	6090	8.5	1.6
cormorants	4.20	78430	0.18	0.5	32160	45.0	30.2
geese & swans	0.35	6500	0.68	0.5	1040	1.5	0.9
sea ducks	0.41	7590	0.71	0	2170	3.0	0.1
other ducks	0.19	3520	0.28	0.5	1270	1.8	0.6
raptors & owls	0.02	360	0.28	0	260	0.4	0.1
waders	0.12	2300	0.28	0	1660	2.3	0.4
skuas	0.00	90	0.28	0	70	0.1	0.1
gulls	32.75	611120	0.18	0	501120	701.6	234.3
terns	0.57	10660	0.28	0	7670	10.7	2.9
alcids	0.38	7000	0.68	0.98	50	0.1	0.0
passerines	60.00	1119600	0.28	0.5	403050	564.3	309.9
total in OWEZ / year		1866000			957160	1340	581
est. nr of victims / wind turbine / year						37	16

Assuming a collision risk that is 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.

The onshore collision risk however is probably higher than offshore. Landbirds, that continuously face man-made and natural structures such as buildings, powerlines and trees, generally seem to show a more risky behaviour around wind farms, based on observations of flight behaviour around turbines onshore (Akershoek *et al.* 2005, Fijn *et al*. 2007). In contrast, the offshore species that were active in and around OWEZ avoided the wind farm, except for gulls, cormorants and diurnal migrants.

Calculations with the Band-model suggest half of the number of victims as estimated based on onshore collision risks (Poot *et al*. 2011). This is mainly due to the fact that the Band-model accounts for the actual macro- and micro-avoidance of the birds as measured in OWEZ in the study at hand, and is therefore thought to more closely approach actual numbers of collisions.

Furthermore, the macro and micro avoidance figures presented here must be regarded as conservative. We found higher avoidance rates than those assumed in the Band-model for some species (SNH 2010), and we feel that for most species avoidance will in reality be even higher, due to limitations in the spatial resolution of the radar data and the difficulty of species identification of individual radar targets, which has neccessitated cautious interpretation of the results. With a better resolution in the analysis of micro avoidance, more birds can be positively identified as flying outside the rotor area. We therefore think with technical innovations in radar ornithology or alternative studies on individual flight paths, future estimates of avoidance rates will be higher, and therewith result in a lower collision rate than presented here.

Migrating songbirds passing the area reached high numbers during spring - and autumn migration. The majority of these birds passed through the wind farm area well above rotor height. A considerable number, approximately one million bird groups, still passed the area at rotor height. Because of this high passage rate, and because of the high level of variation in flight altitude, the highest number of collisions is expected to fall among the migrating passerines. Among passerines, rough estimates suggests 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.

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- Visual observations: Camiel Heunks (panorama scans); Mark Collier (moon watching and nocturnal calls); Martin Poot, Daniël Beuker, Robert Jan Jonkvorst, Thijs Schrama, Hans Slabbekoorn (the latter two of Leiden University, Behavioural Biology Department) and Magnus Robb (Sound Approach) (automated registration of calls); Peter van Horssen, Daniel Beuker and Karen Krijgsveld (visual flight paths);
- Vertical radar data: Ruben Fijn (data processing, analysis and reporting), Maarten Japink (data processing), Karen Krijgsveld and Martin Poot;
- Horizontal radar data: Karen Krijgsveld (data processing, validation, analysis and reporting), Maarten Japink and Peter van Horssen (data processing), Jim de Fouw (validation) and Mark Collier (analysis and reporting of micro-avoidance data).

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Appendix I Species names

List of species seen in the wind farm area, with their scientific and Dutch name, sorted by species group. Ongedet. stands for ongedetermineerd.

group / subgroup	English name	scientific name	Dutch name
divers	black-throated diver	*Gavia arctica*	parelduiker
	red-throated diver	*G. stellata*	roodkeelduiker
grebes	great crested grebe	*Podiceps cristatus*	fuut
tubenoses	northern fulmar	*Fulmarus glacialis*	noordse stormvogel
	shearwater spec.	*Puffinus spec.*	ongedet. pijlstormvogel
gannets	northern gannet	*Morus bassanus*	jan-van-gent
cormorants	great cormorant	*Phalacrocorax carbo*	aalscholver
	European shag	*P. aristotelis*	kuifaalscholver
herons	grey heron	*Ardea cinerea*	blauwe reiger
	Eurasian spoonbill	*Platalea leucorodia*	lepelaar
geese & swans			
anser geese	greylag goose	*Anser anser*	grauwe gans
	white-fronted goose	*A. albifrons*	kolgans
	bean goose	*A. fabalis*	rietgans
branta geese	dark-bellied brent goose	*Branta bernicla*	rotgans
	barnacle goose	*B. leucopsis*	brandgans
	greater Canada goose	*B. canadensis*	grote canadese gans
other ducks			
diving ducks	scaup	*Aythya marila*	toppereend
mergansers	goosander	*Mergus merganser*	grote zaagbek
	red-breasted merganser	*M. serrator*	middelste zaagbek
swimming ducks	Eurasian wigeon	*Anas penelope*	smient
	northern pintail	*A. acuta*	pijlstaart
	teal	*A. crecca*	wintertaling
	mallard	*A. platyrhynchos*	wilde eend
	northern shoveler	*A. clypeata*	slobeend
sea ducks	common scoter	*Melanitta nigra*	zwarte zee-eend
	velvet scoter	*M. fusca*	grote zee-eend
	common eider	*Somateria mollissima*	eider
raptors	northern goshawk	*Accipiter gentilis*	havik
	sparrowhawk	*A. nisus*	sperwer
	kestrel	*Falco tinnunculus*	torenvalk
	marsh harrier	*Circus aeruginosus*	bruine kiekendief
	hen harrier	*C. cyaneus*	blauwe kiekendief
	merlin	*Falco columbarius*	smelleken
	peregrine falcon	*F. peregrinus*	slechtvalk

Continued on next page.

Appendix I *Continued.*

group / subgroup	English name	scientific name	Dutch name
coots	Eurasian coot	*Fulica atra*	meerkoet
waders	red knot	*Calidris canutus*	kanoet
	dunlin	*C. alpina*	bonte strandloper
	little stint	*C. minuta*	kleine strandloper
	purple sandpiper	*C. maritima*	paarse strandloper
	sanderling	*C. alba*	drieteenstrandloper
	Eurasian curlew	*Numenius arquata*	wulp
	Eurasian golden plover	*Pluvialis apricaria*	goudplevier
	grey plover	*P. squatarola*	zilverplevier
	lapwing	*Vanellus vanellus*	kievit
	common ringed plover	*Charadrius hiaticula*	bontbekplevier
	dotterel	*C. morinellus*	morinelplevier
	Eur. oystercatcher	*Haematopus ostralegus*	scholekster
	black-tailed godwit	*Limosa limosa*	grutto
	bar-tailed godwit	*L. lapponica*	rosse grutto
	whimbrel	*Numenius phaeopus*	regenwulp
	ruddy turnstone	*Arenaria interpres*	steenloper
	spotted redshank	*Tringa erythropus*	zwarte ruiter
	greenshank	*T. nebularia*	groenpootruiter
	woodcock	*Scolopax rusticola*	houtsnip
	jack snipe	*Lymnocryptes minimus*	bokje
skuas	arctic skua	*Stercorarius parasiticus*	kleine jager
	pomarine skua	*S. pomarinus*	middelste jager
	great skua	*S. skua*	grote jager
gulls			
large gulls	lesser black-backed gull	*Larus fuscus*	kleine mantelmeeuw
	great black-backed gull	*L. marinus*	grote mantelmeeuw
	black-backed gull spec.	*L. marinus/fuscus*	ongedet. mantelmeeuw
	herring gull	*L. argentatus*	zilvermeeuw
	yellow-legged gull	*L. michahellis*	geelpootmeeuw
	large gull		ongedet. grote meeuw
small gulls	little gull	*L. minutus*	dwergmeeuw
	black-headed gull	*L. ridibundus*	kokmeeuw
	common gull	*L. canus*	stormmeeuw
	kittiwake	*Rissa tridactyla*	drieteenmeeuw
	Sabine's gull	*L. sabini*	vorkstaartmeeuw
	small gull		ongedet. kleine meeuw
terns	arctic tern	*Sterna paradisaea*	noordse stern
	common tern	*S. hirundo*	visdief
	sandwich tern	*S. sandvicensis*	grote stern
	black tern	*Chlidonias niger*	zwarte stern
alcids	guillemot	*Uria aalge*	zeekoet
	razorbill	*Alca torda*	alk

Continued on next page.

Appendix I *Continued.*

group / subgroup	English name	scientific name	Dutch name
passerines			
large passerines	carrion crow	*Corvus corone corone*	zwarte kraai
	jackdaw	*C. monedula*	kauw
	collared dove	*Streptopelia decaocto*	turkse tortel
	wood pigeon	*C. palumbus*	houtduif
	homing pigeon	*C. livia domestica*	postduif
	pigeon spec.	*C. spec.*	ongedetermineerde duif
medium passerines	blackbird	*Turdus merula*	merel
	redwing	*T. iliacus*	koperwiek
	fieldfare	*T. pilaris*	kramsvogel
	song thrush	*T. philomelos*	zanglijster
	thrush spec.	*Turdus spec.*	ongedet. lijster
	waxwing	*Bombycilla garrulus*	pestvogel
	starling	*Sturnus vulgaris*	spreeuw
small passerines	redpoll	*Carduelis flammea*	barmsijs
	chaffinch	*Fringilla coelebs*	vink
	house martin	*Delichon urbica*	huiszwaluw
	swallow	*Hirundo rustica*	boerenzwaluw
	swift	*Apus apus*	gierzwaluw
	pied wagtail	*Motacilla alba yarrellii*	witte kwikstaart
	yellow wagtail	*M. flava flavissima*	gele kwikstaart
	grey wagtail	*M. cinerea*	grote gele kwikstaart
	meadow pipit	*Anthus pratensis*	graspieper
	skylark	*Alauda arvensis*	veldleeuwerik
	robin	*Erithacus rubecula*	roodborst
	black redstart	*Phoenicurus ochruros*	zwarte roodstaart
	chiffchaff	*Phylloscopus collybita*	tjiftjaf
	willow warbler/chiffchaff	*P.trochilus/P.collybita*	fitis/tjiftjaf
	blackcap	*Sylvia atricapilla*	zwartkop
	gold crest	*Regulus regulus*	goudhaan
	siskin	*Carduelis spinus*	sijs
	northern wheatear	*Oenanthe oenanthe*	tapuit
	stonechat	*Saxicola torquata*	roodborsttapuit
marine mammals	grey seal	*Halichoerus grypus*	grijze zeehond
	harbour seal	*Phoca vitulina*	gewone zeehond
	harbour porpoise	*Phocoena phocoena*	bruinvis

Appendix II List of Merlin echo characteristics

List of echo characteristics registered and logged by the Merlin system of DeTect Inc., as well as parameters derived by Bureau Waardenburg, for both the horizontal S-band and the vertical X-band radar.

S-band Data	X-band Data	Definitions
DBASE ID	DBASE ID	Unique database identification number for each echo identified in the radar data. These are supposed to be birds, but may also be boats, airplanes, waves, or other clutter.
Period	Period	Link to Session Metadata with this field. This is a Unique ID for the Session
Date	Date	Date and Time - dd/mmm/yyyy hh:mm:ss.
Scan Index	Scan Index	How many seconds into the current hour the scan is made (max 3600)
Target Index	Target Index	The number assigned to the echo in the current scan, echoes in the same scan are numbered from top left to bottom right of the display
Track ID	Track ID	Unique identifying number for each track. At least 3 echoes are required to make a track. If a track is broken for two or more scans but then reappears, then a new track is started
Track Type	Track Type	Consistency with which a track is recorded by Merlin. Higher value indicates the object was missed more often in the previous scans, lower value indicates the object was seen in up to all previous scans.
Area	Area	Area of the target (in pixels)
Max Segment	Max Segment	Longest length across the target
Perimeter	Perimeter	Perimeter of the echo measured (in pixels)
Orientation	Orientation	The angle of the longest axis of a target with respect to the horizontal axis. This value is between 0 - 180 degrees.
Ellipse Major	Ellipse Major	Length of the major axis of an ellipse that has the same area and perimeter as the target
Ellipse Minor	Ellipse Minor	Length of the minor axis of an ellipse that has the same area and perimeter as the target
Ellipse Ratio	Ellipse Ratio	Ratio of Ellipse Major to Ellipse Minor
Elongation	Elongation	A measure of the elongation of a echo, the higher the value the more elongated the echo
Compactness	Compactness	Ratio of the echoes area to the area of the smallest rectangle that contains the echo
Heywood	Heywood	Ratio of the perimeter of the echo to a circle with the same area as the echo
Hydro Radius	Hydro Radius	Ratio of echo area to it's perimeter
Waddel Disk	Waddel Disk	Diameter of a circle with the same area as the echo
Mean Intercept	Mean Intercept	The mean length of segments along the length of a echo
Max Intercept	Max Intercept	The length of the longest segment of an echo, in any direction
Type Factor	Type Factor	-
Mean Chord X	Mean Chord X	The mean length, in pixels, of the horizontal segments of a echo
Mean Chord Y	Mean Chord Y	The mean length, in pixels, of the vertical segments of a echo
Av Reflectivity	Av Reflectivity	Average reflectivity over the entire echo area (Max 4096)
Max Reflectivity	Max Reflectivity	Maximum reflectivity over the entire echo area (Max 4096)
Min Reflectivity	Min Reflectivity	Minimum reflectivity over the entire echo area (Max 4096)
Std Dev Reflectivity	Std Dev Reflectivity	Standard deviation in reflectivity over the entire echo area (Max 4096)
Range Reflectivity	Range Reflectivity	Range in reflectivity over the entire echo area (Max 4096)
Target X1	Target X1	X-coordinate of the centre of the current echo in a track (pixels) (recalculated)
Target Y1	Target Y1	Y-coordinate of the centre of the current echo in a track (pixels) (recalculated)
Target X2	Target X2	X-coordinate of the centre of the echo from the previous scan in this track (pixels)
Target Y2	Target Y2	Y-coordinate of the centre of the echo from the previous scan in this track (pixels)
Target X3	Target X3	X-coordinate of the centre of the echo from the 3rd oldest scan in this track (pixels)
Target Y3	Target Y3	Y-coordinate of the centre of the echo from the 3rd oldest scan in this track (pixels)
Target X4	Target X4	X-coordinate of the centre of the echo from the 4th oldest scan in this track (pixels)
Target Y4	Target Y4	Y-coordinate of the centre of the echo from the 4th oldest scan in this track (pixels)
Lat 1	-	Latitude of the centre of the current echo in a track (not used)
Long 1	-	Longitude of the centre of the current echo in a track (not used)
Lat 2	-	Latitude of the centre of the echo from the previous scan in this track
Long 2	-	Longitude of the centre of the echo from the previous scan in this track

Appendix II Continued.

S-band Data	X-band Data	Definitions
Lat 3	-	Latitude of the centre of the echo from the 3rd oldest scan in this track
Long 3	-	Longitude of the centre of the echo from the 3rd oldest scan in this track
Lat 4	-	Latitude of the centre of the echo from the 4th oldest scan in this track
Long 4	-	Longitude of the centre of the echo from the 4th oldest scan in this track
Class	Class	-
-	AGL	Altitude Above Ground Level of an echo – this is altitude above the X-band radar (m) (recalculated)
-	Cross Track_m	Distance along the surface of the water or ground that an echo is away from the radar (m) (recalculated)
Range_m	Range_m	Distance from the radar to the echo in a direct line (m) (recalculated)
Bearing	Bearing	Bearing from the radar to the echo, *i.e.* position of the echo relative to the radar (degrees) (recalculated)
Distance	-	Distance that the echo is away from the S-band radar location
Track distance	-	Distance from the current location to the furthest point used to correlate the track (C or D) in units defined by SPEED UNITS field in Metadata table (m)
Heading_nw	Heading_nw	Azimuth heading of a tracked echo (0 - 359 degrees), *i.e.* direction the target has moved from previous to current echo (degrees) (recalculated)
Speed	Speed	Goundspeed of a tracked echo, *i.e.* speed of the target from previous to current echo. In the units specified in the Metadata table of the database (km/h) (recalculated)
		Derived parameters:
longdist	longdist	Distance from previous to current echo in pixels.
tracklength	tracklength	Number of echoes that have the same trackID, *i.e.* the number of echoes within a track.
trackquality	trackquality	Sum of tracktype-values of all echoes within a track, divided by the tracklength. A lower value counter-intuitively indicates higher quality, as the object was seen in more previous scans and/or was seen in more scans.
trackheading	trackheading	Heading of the entire track, calculated as the median of all headings of the individual signals within that track (degrees)
trackbearing	trackbearing	Bearing of the entire track, calculated as the median of all bearings of the individual signals within that track (degrees)
short distance	short distance	Distance from the first to the last echo recorded in a track, measured in a straight line in pixels
total distance	total distance	Distance of the entire track, measured as the sum of all distances within a track from one echo to the next (pixels)
angdevheading	angdevheading	Angular deviation in heading for the total track in degrees. This is a circular measure of the variation in heading within a track (Brookes 2009). SQRT(2*(1-sqrt((sinheadmean*sinheadmean)+ (cosheadmean * cosheadmean))))
turnangle	turnangle	Difference in heading between the current and the previous echo within a track (degrees)
fractal dimension	fractal dimension	log (tracklength – 1) divided by (log(tracklength-1) + log(straightdistance / totaldistance)
distanceratio	distanceratio	Totaldistance divided by the straightdistance
pointratio	pointratio	Totaldistance divided by tracklength
airspeed	airspeed	Airspeed of the echo. This is the groundspeed corrected for wind speed and wind direction. Calculated as $\sqrt{}$(groundspeed^2 + windspeed^2 – 2 x groundspeed x windspeed x cos (heading target-winddirection)), where heading and direction are in radians and wind direction is entered as the direction that the wind is blowing to rather than from (km/h)
deltarange	deltarange	Difference in range between the current and the previous echo within a track (m)
	Delta_AGL	Difference in AGL between the current and the previous echo within a track (m)
	Delta_Cross_track	Difference in Cross_track between the current and the previous echo within a track (m)
deltarangemean	deltarangemean	total deltarange divided by tracklength
deltaspeed	deltaspeed	Difference in speed between the current and the previous echo within a track (km/h)
turnanglemean	-	Mean of turnangle per track (tam)
pointratioxtam	-	Pointratio divided by turnanglemean
minreflectivity	-	Totalminreflectivity divided by tracklength

Appendix III Horizontal VTS radar trial

Objective
Birds flying on the north side of the wind farm could potentially be invisible to the radars used in this study due to the location of the metmast (south west of the wind farm). This invisibility was caused by interference from the wind turbines standing in between the radars and the targets. Another possibility is that birds approaching the wind farm from northerly directions, would have started to avoid the wind farm before their flight paths were picked up by radar. This would mean that avoidance would remain undetected. To gain insight in the flight paths of birds in this sector of the wind farm, a marine VTS radar system positioned on wind turbine nr. 21 was adapted to record flight paths of birds. This is a radar used as a backup in monitoring movements of vessels to the west of the wind farm. The radar is in use by IJmuiden Port Control, and operates as part of the VTS system that monitors ship movements. Merlin was added to enable us to record bird movements. Since the radar was located in a good position to measure flight paths of birds from the north, and since the radar was already present on the wind turbine, we opted to use this radar for additional measurements.

Technical specifications and effective range
The VTS radar on turbine 21 was an X-band radar operating in the standard horizontal position to support vessel tracking by the port of IJmuiden. The radar was a 25 kW JRC radar, type JMA-5320. Beam width was 20°, rotation speed ca. 24 rpm. Range of the radar was set in Merlin at 3 NM. The range of the radar itself was much larger, but Merlin was detecting up to 3 NM. Merlin was installed on the VTS radar system, in a similar way as on the metmast. The data were stored on a second computer in the turbine. The system could not be accessed other than by visits to the turbine, and occasional remote checks by HITT. Therefore settings could not be adjusted during the process of data collection.

Higher-frequency X-band radars are more sensitive to pick up echoes. Over land or in a vertical position this helps in picking up the small bird echoes, but when recording in a horizontal plane over sea, it is very sensitive to echoes from waves as well, which results in high levels of clutter. The sensitivity of the system could not be reduced much, because of the need to record small echoes of birds. This resulted in a trade off between monitoring flight paths of birds versus reducing the amount of clutter detected. The settings were thus that on calm days larger bird flocks would be detected, while during days with somewhat higher waves, the level of clutter was too high to obtain flight paths of birds. During the measurements, it turned out that there often was so much clutter that the Merlin processor could not keep up with the radar, and stalled, resulting in loss of data.

Dates of data collection and volume of database
Data were collected during two seasons of autumn migration. Data collection started in October 2008 and finished at the end of October 2009. In January 2009 the system

stalled, and was only rebooted by June 2009 due to log-in and settings problems. The Merlin system was in place for a total of 378 days, but could only record data during 152 days (40%). Each day up to two MS-Access-files were stored from the VTS radar. Each file was in between 1.5 and 500 MB in size. By May 2010, the entire vertical database consisted of 172 files or 79,000,000 records or ca. 44 GB. The majority of the days when data were recorded, were filtered from the database because of high clutter levels and detection limitations.

Data processing
It was intended to process and analyse the data in the same way as the long-range dataset, described in §6.3. However looking at the trackplots of the raw radar data already made clear that the detection of the X-band VTS radar was limited to very calm (seastate 0) weather and that bird movements were only tracked at relatively small range (fig. III.2). Due to a lack of remote access to the Merlin computer at turbine 21, no instantaneous adjustments to the settings could be performed and looking back Merlin was not able to record the overload of radar data properly on days with wind speed over 1 or 2 Bft. Ships were tracked very well but the VTS radar did not track birds to a sufficient extent that Merlin was able to recognize these tracks as birds.

Clutter filtering rules
Clutter filtering was not performed and only trackplots were used during analysis. Data availability was limited too much to perform a complete analysis as was done for the data of the horizontal radar.

Outcomes
From the trackplots made from the data collected with the VTS radar, no additional information on flight paths and numbers of birds was extracted. Recorded bird tracks were limited and most of the track plots were full of clutter (similar to but mostly worse than the bottom trackplot in figure III.2). Only a couple of hours showed obvious bird migration such as the hour 9:00-10:00 on the 14th of October 2009 (fig. III.1). Therefore these images could not be used to estimate numbers of birds or study flight patterns

All in all, the X-band radar was not capable of recording birds in the horizontal plane and unfortunately, the VTS radar trial must be regarded as a failure.

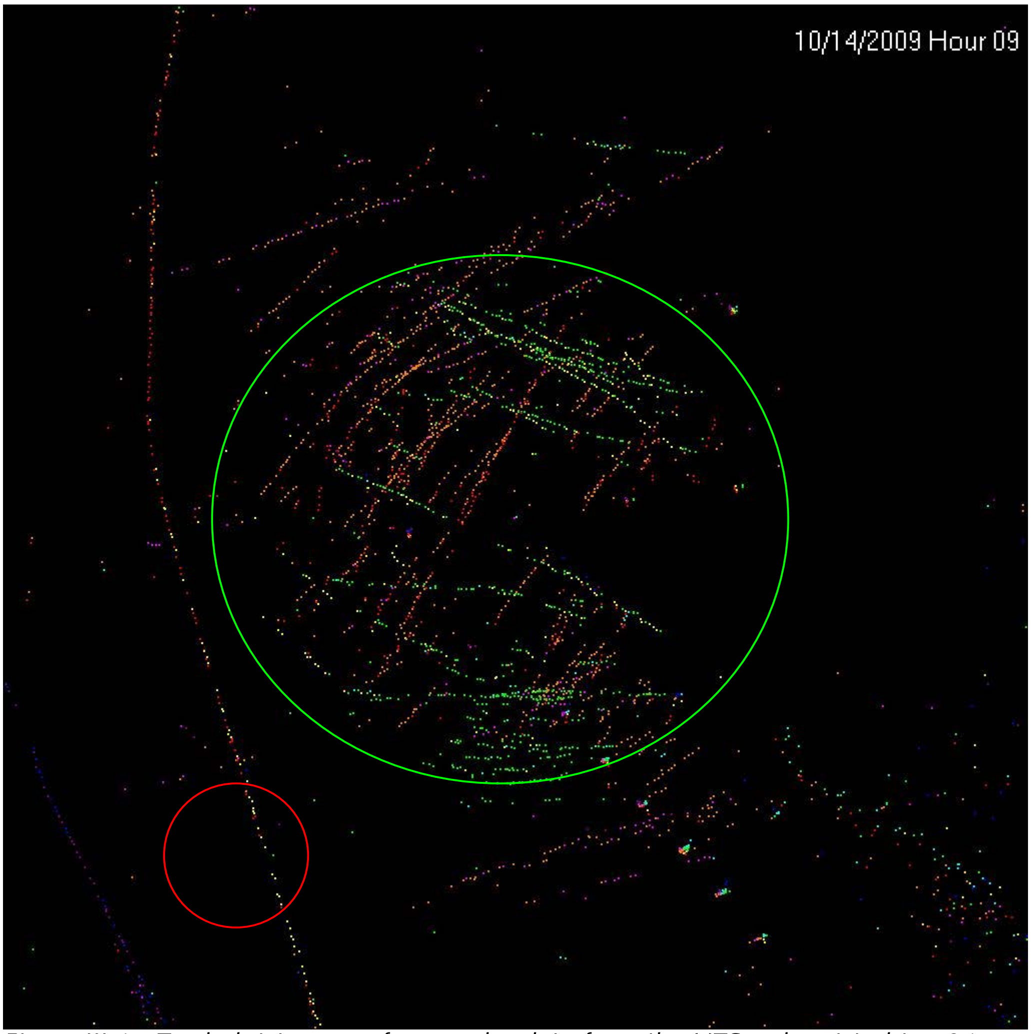


Figure III.1 Trackplot images of raw radar data from the VTS radar at turbine 21 on the 14th of October 2009. Bird tracks (green circle) as well as the track of a ship (red circle) can be seen.

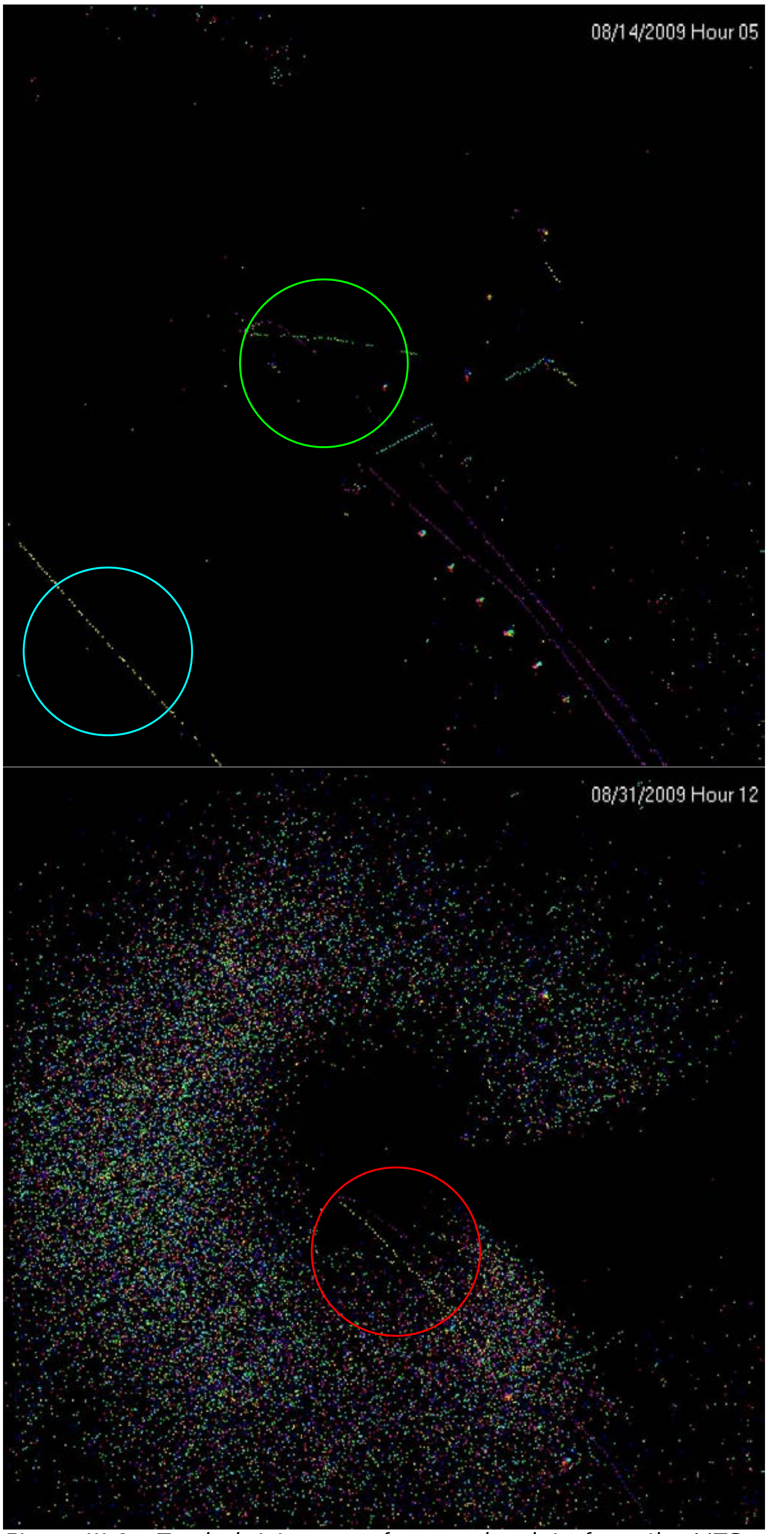
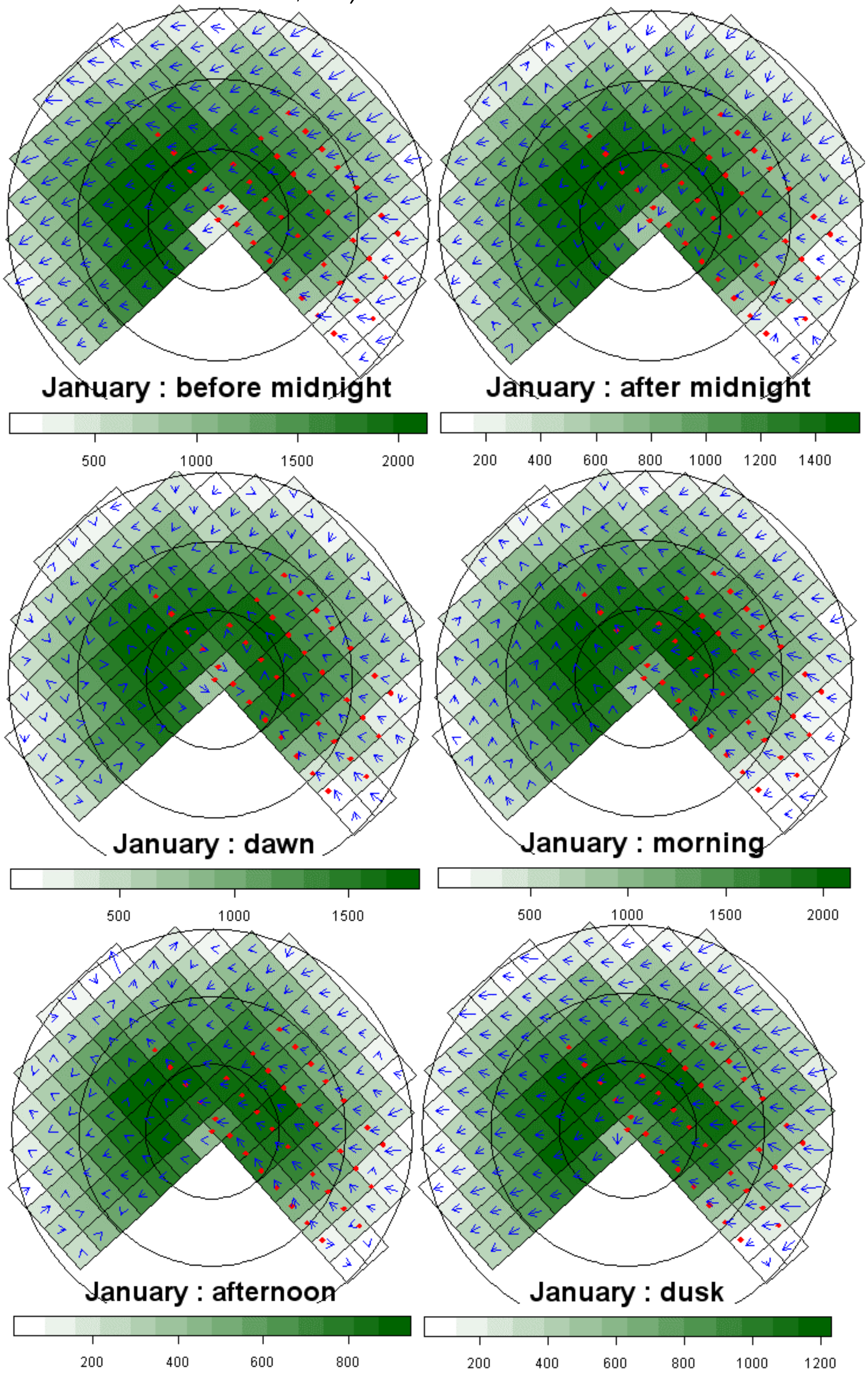


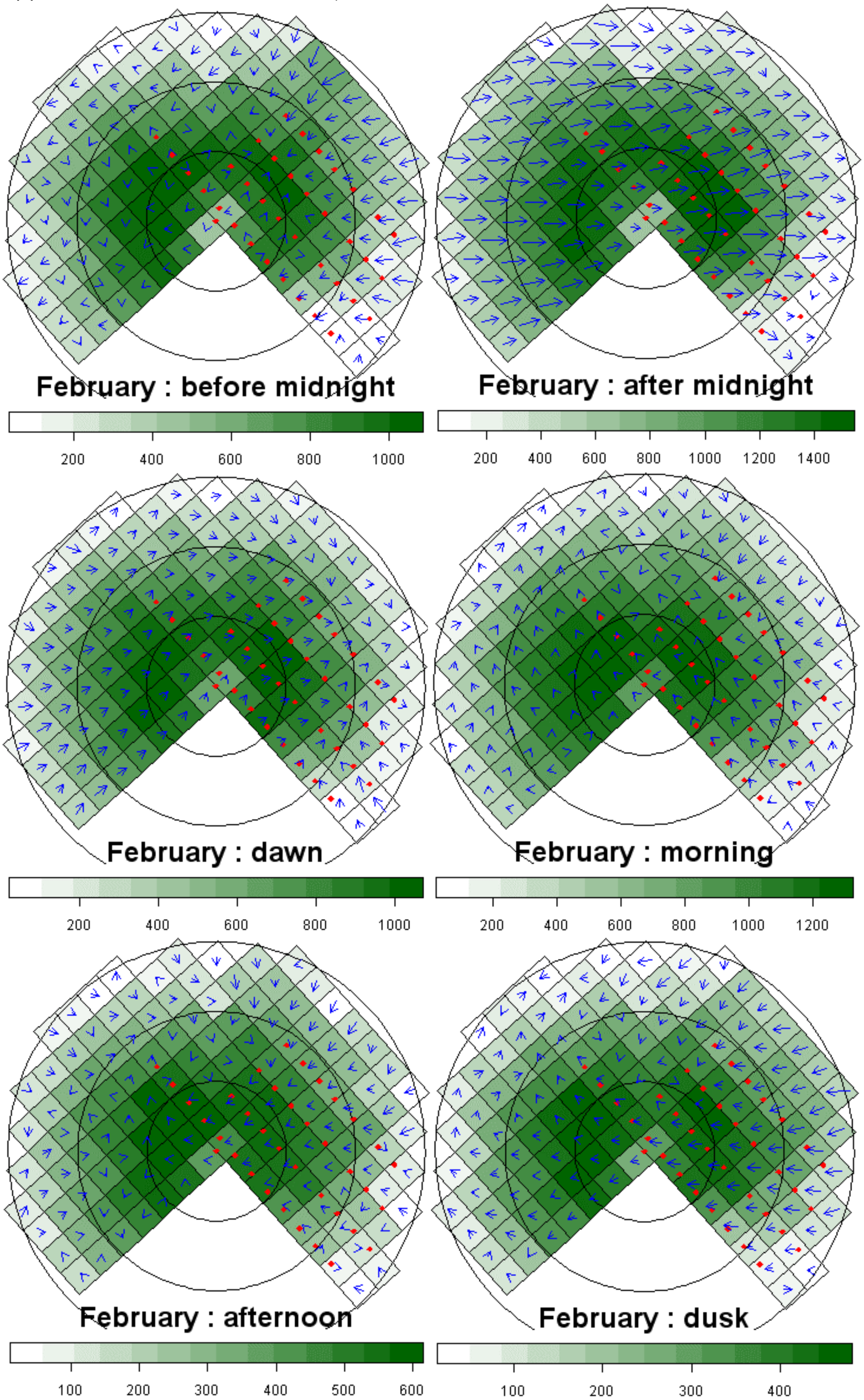
Figure III.2 *Trackplot images of raw radar data from the VTS radar at turbine 21 on the 8th of August 2009 (wind: east 4 Bft. & 31st of August 2009 (wind: south 4 Bft). A supply vessel arriving and departing a turbine is visible (red circle) as well as a ship leaving IJmuiden harbour (blue circle). Some bird tracks were also visible (green circle).*

Appendix IV Overview of flight directions

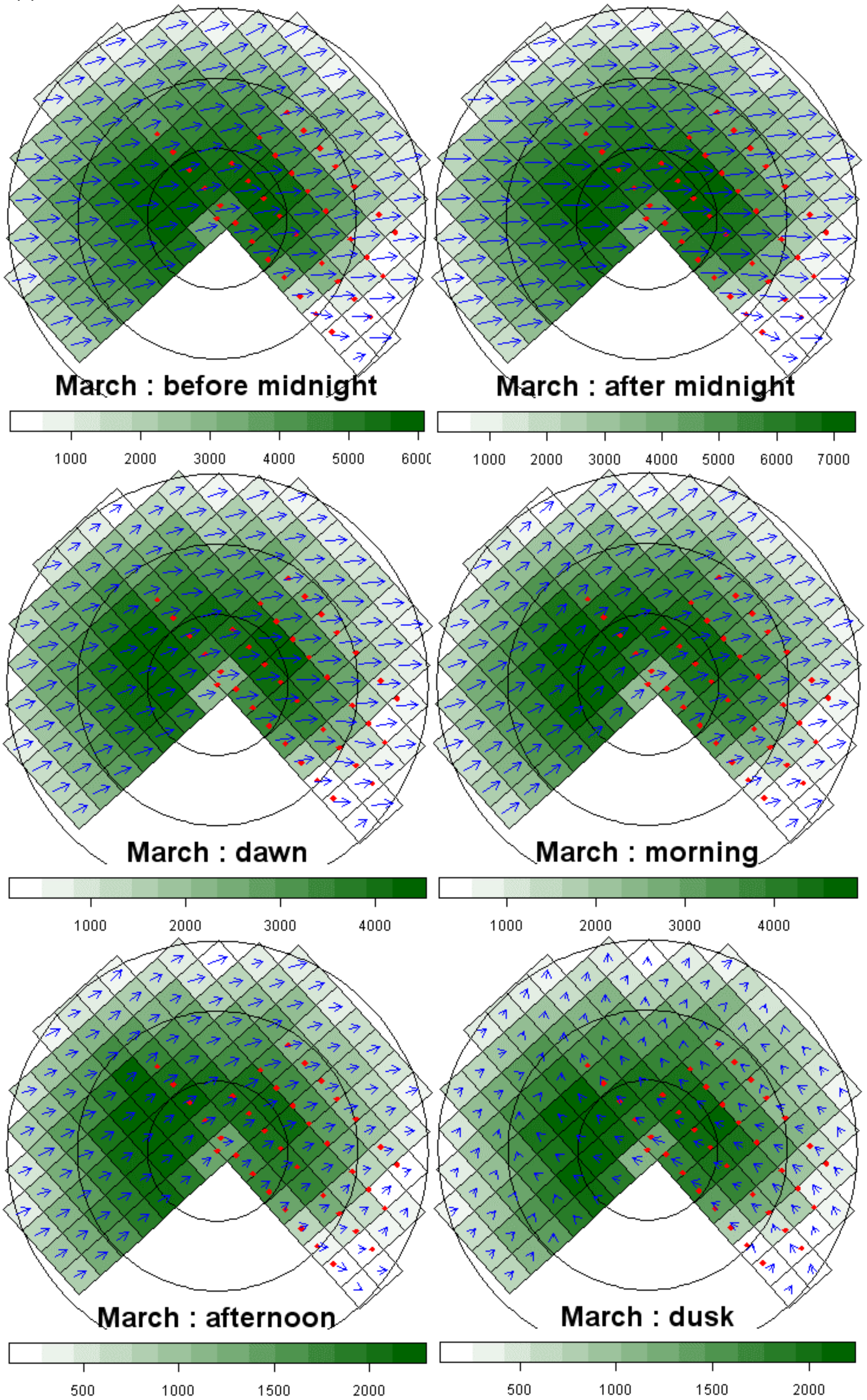
Flight directions of bird tracks per month combined over all years, and shown per grid cell to illustrate differences between different areas of the wind farm area. Directions are shown as arrows. Variation in direction is shown in the length of the arrow: the longer the arrow, the more birds flew in the same direction. Number of tracks per cell is the sum of all tracks in that period, indicated in green colours and scaled at the bottom of each graph. Note the differences in scale. Data from horizontal radar, May 2007-June 2010.



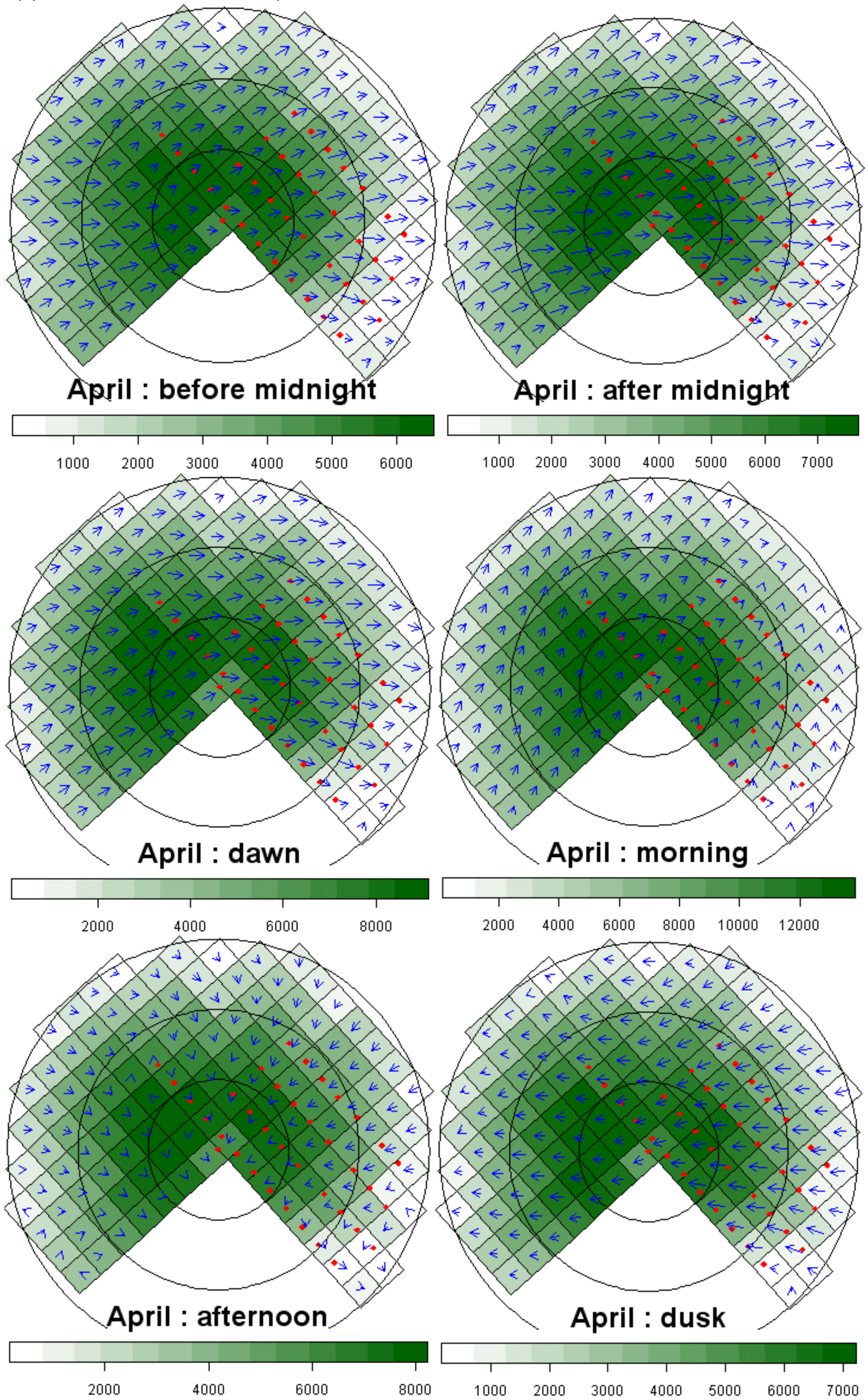
Appendix IV Continued. February.



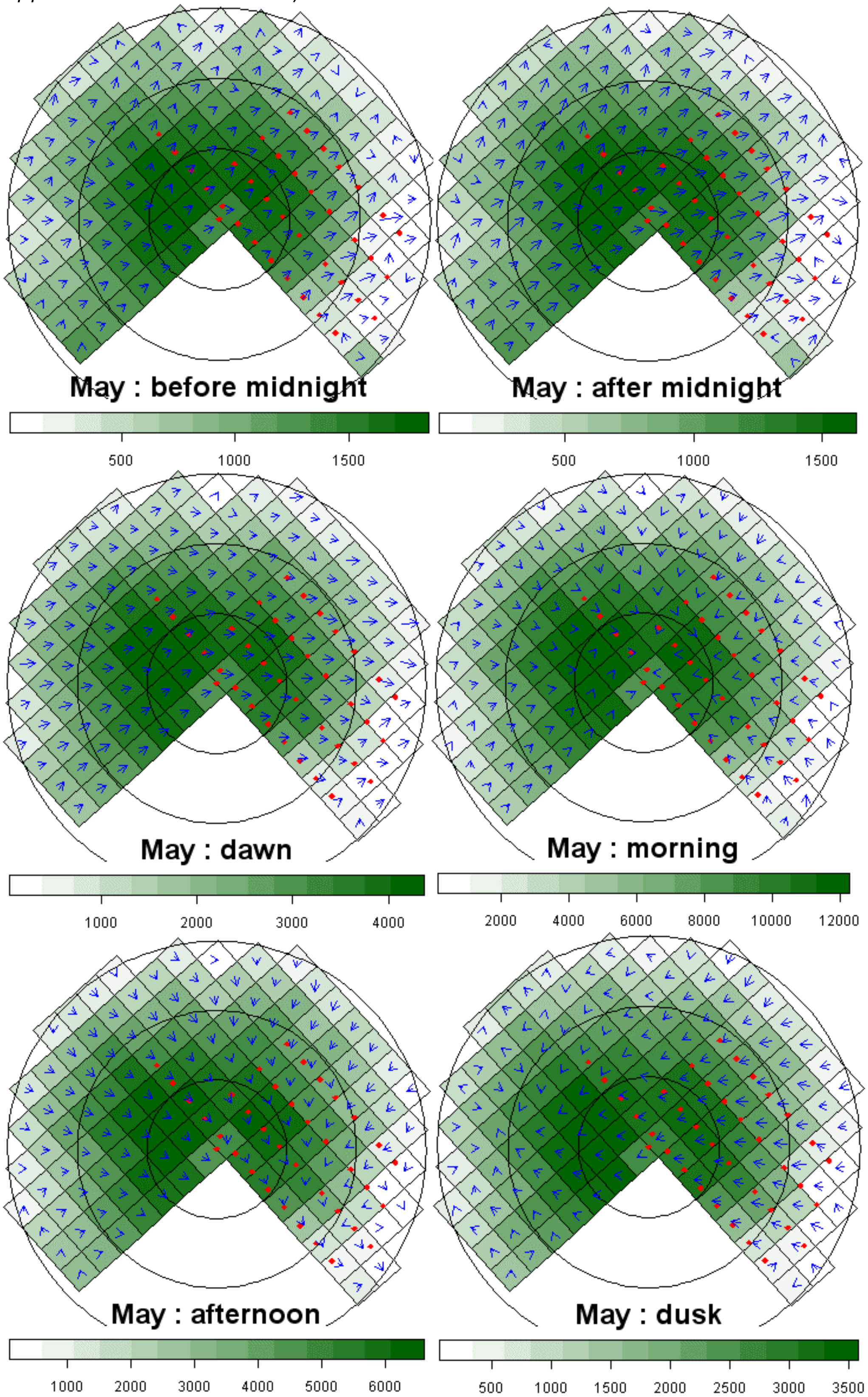
Appendix IV Continued. March.



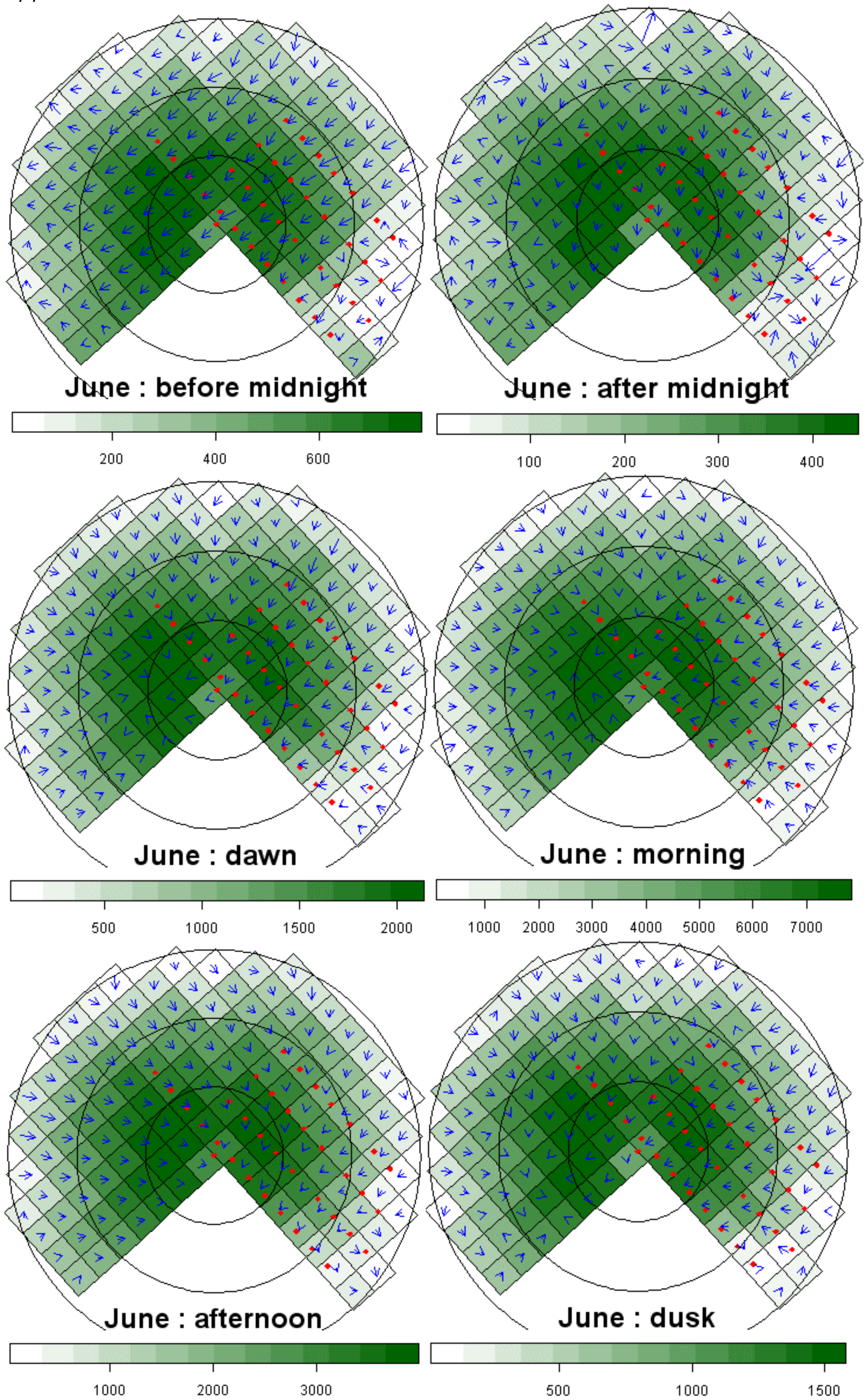
Appendix IV Continued. April.



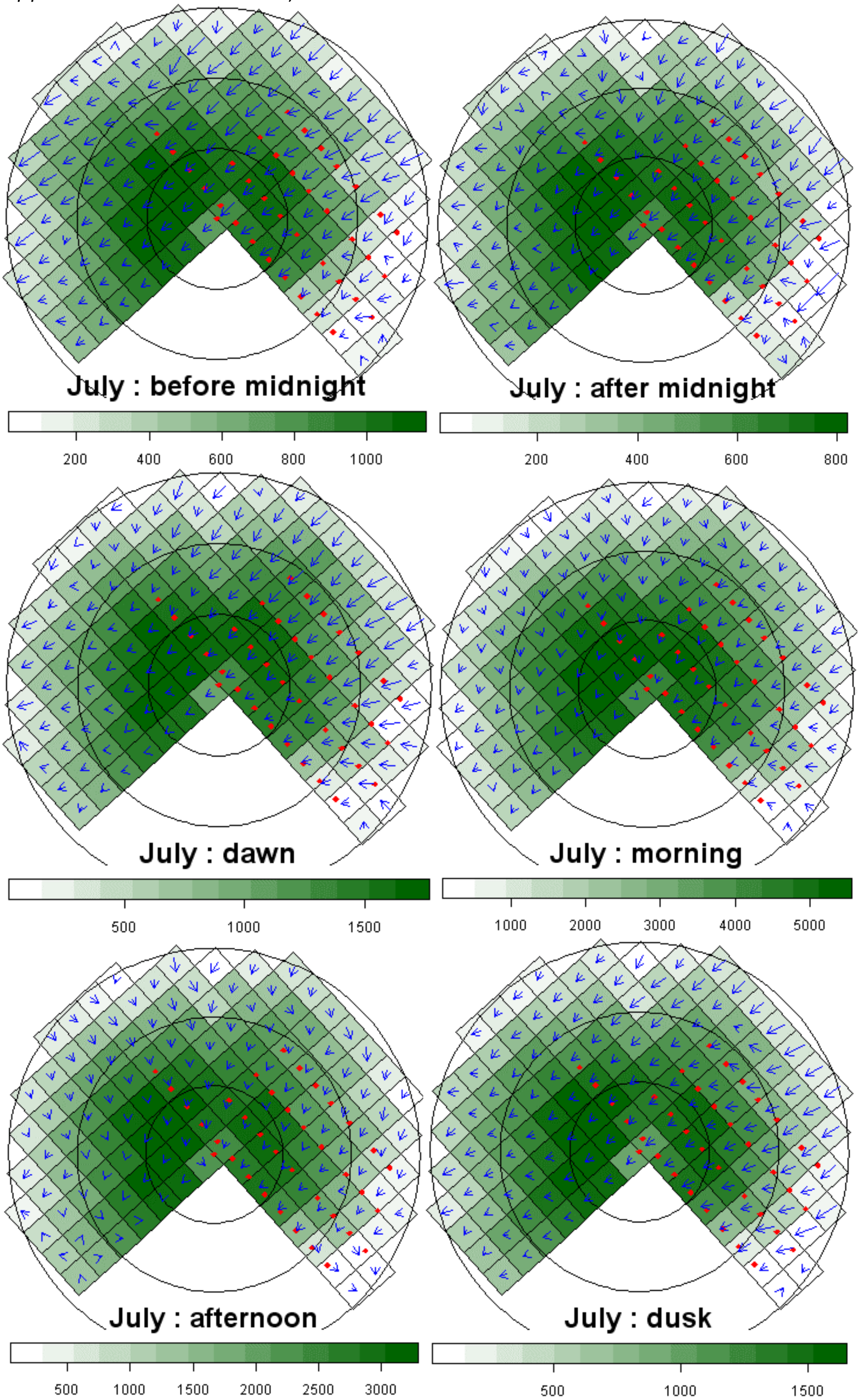
Appendix IV Continued. May.



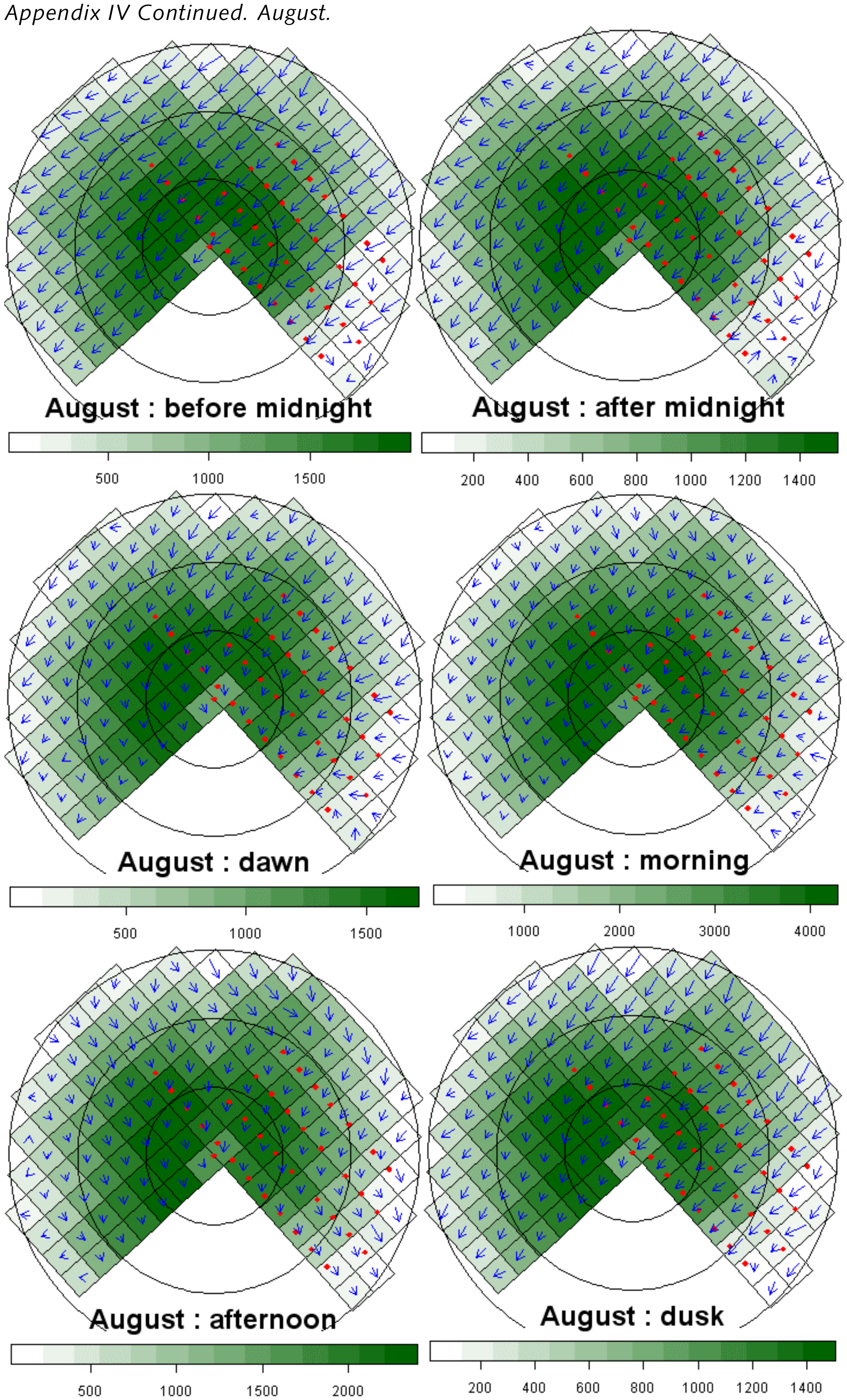
Appendix IV Continued. June.



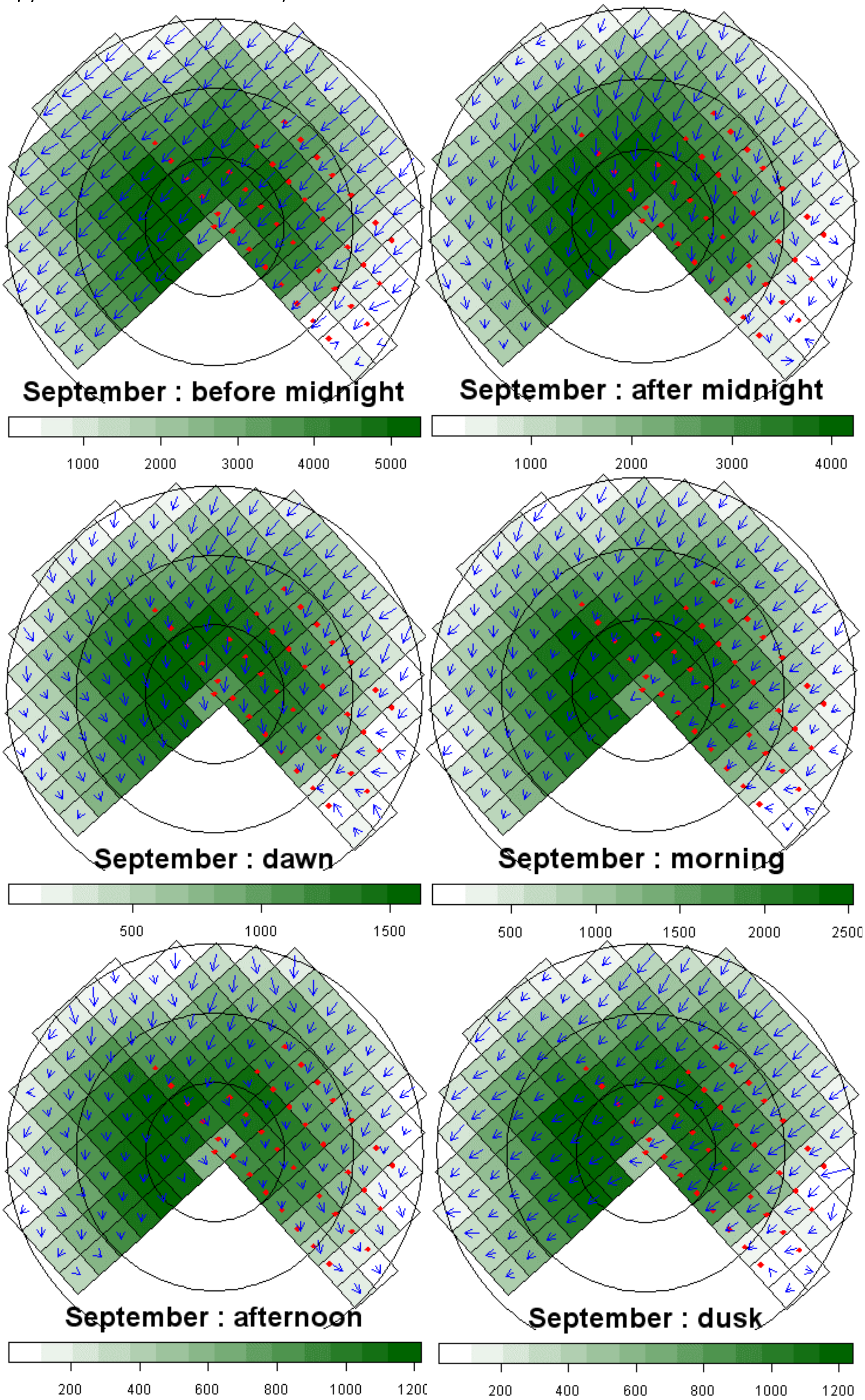
Appendix IV Continued. July.



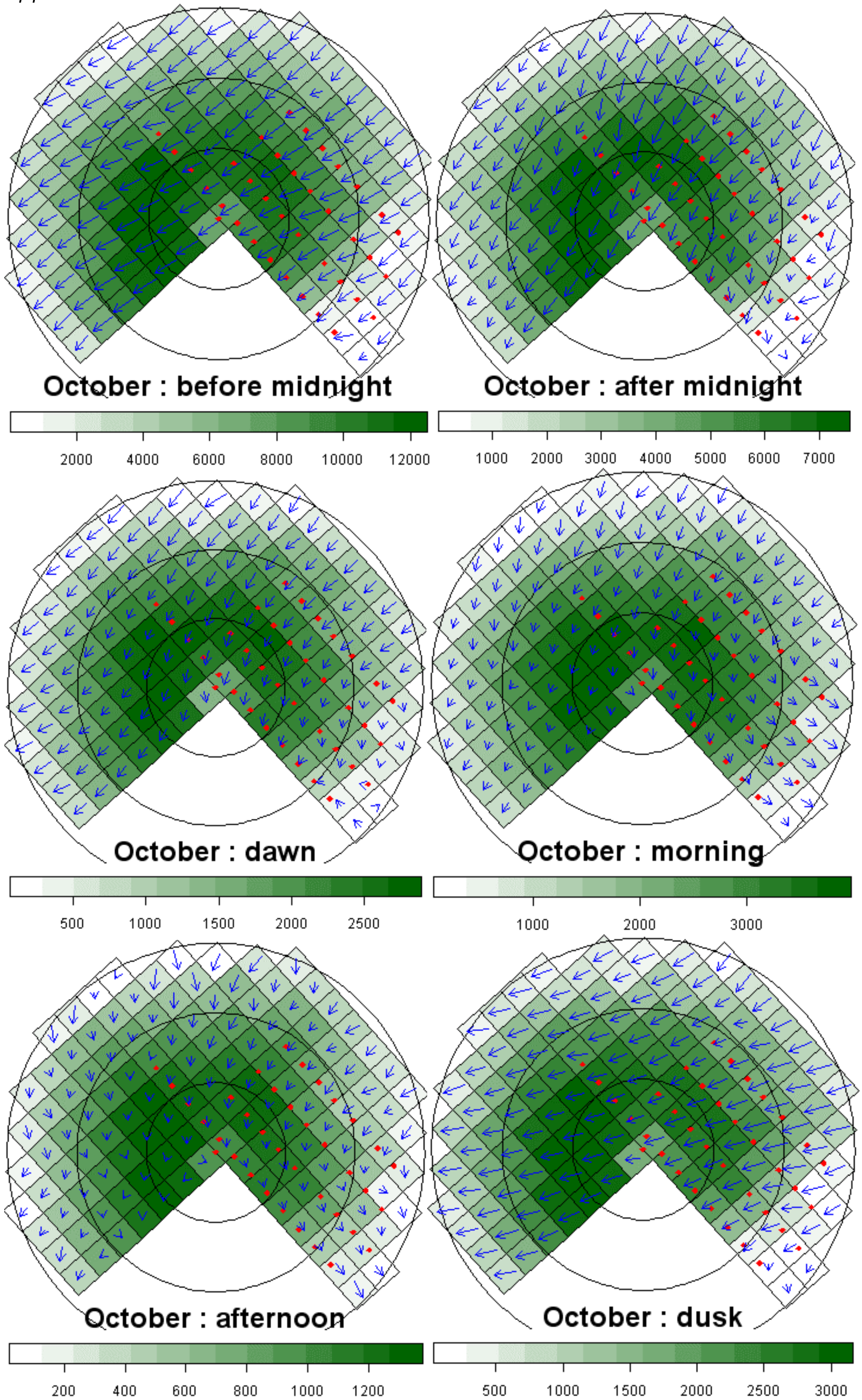
Appendix IV Continued. August.



Appendix IV Continued. September.



Appendix IV Continued. October.



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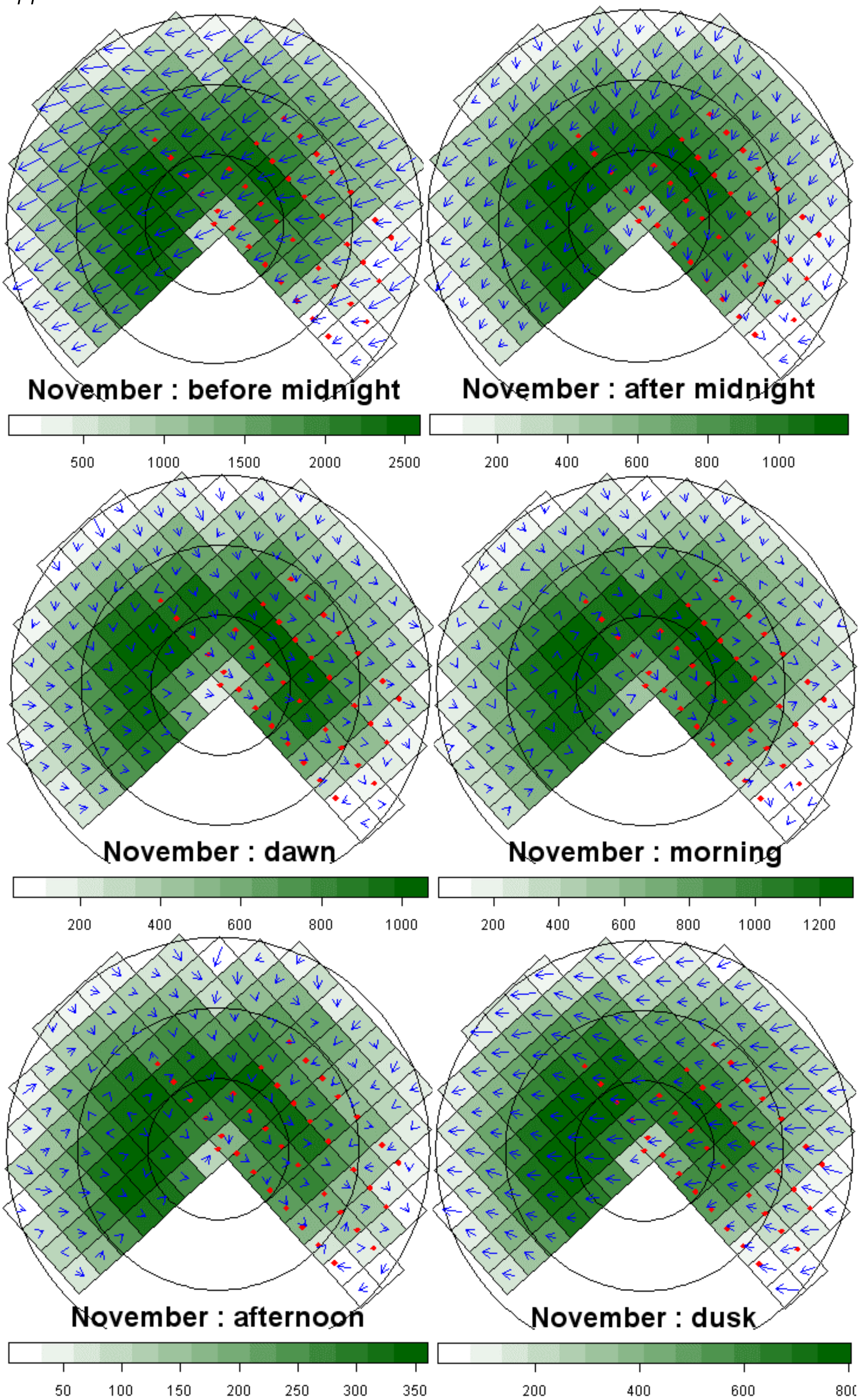
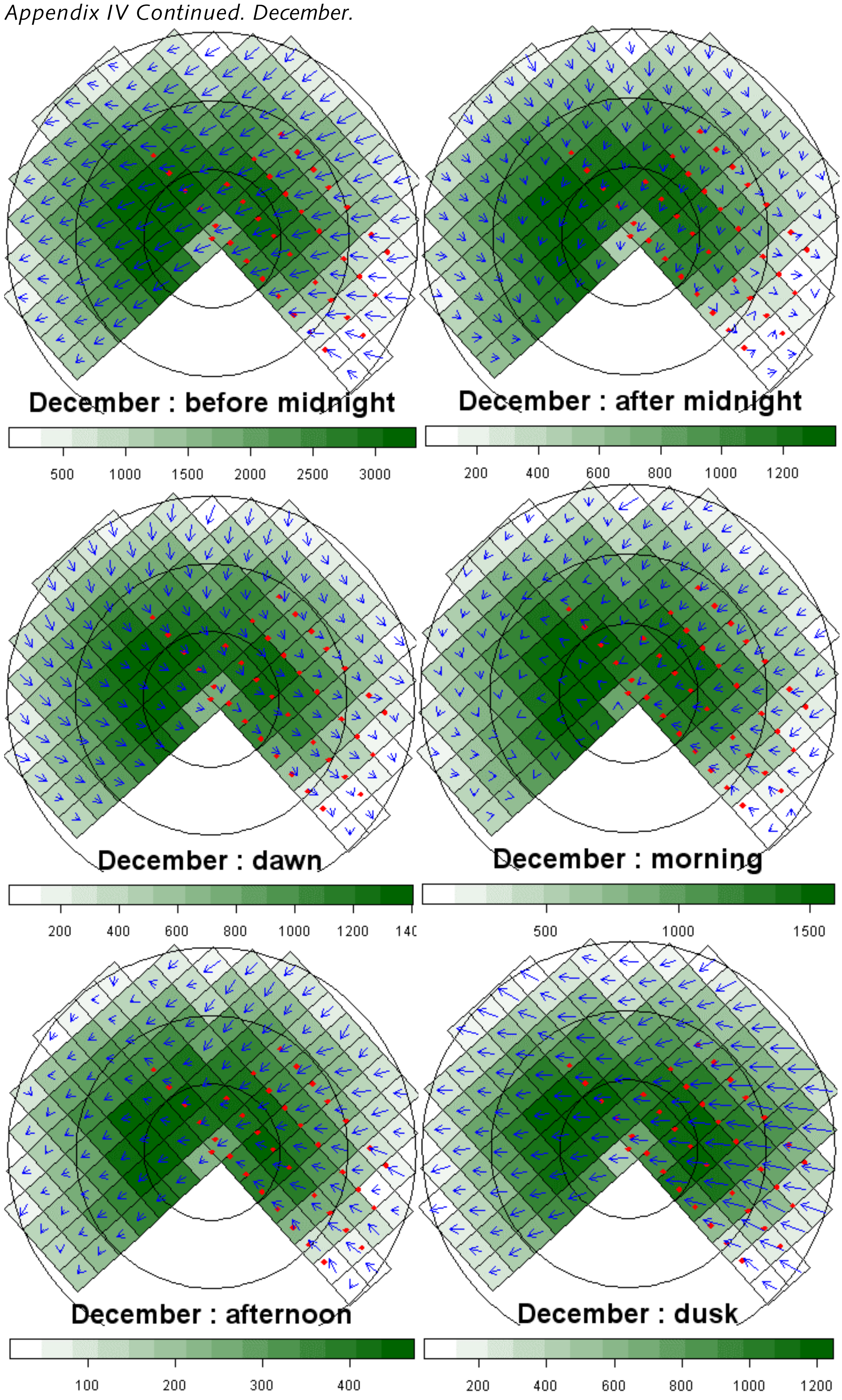


Appendix IV Continued. December.



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