Dong Energy A/S

Horns Rev 2 Offshore Wind Farm
Bird Monitoring Program
2010-2012

BIRD MIGRATION

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Project ID	1321000072
Document	1321000075-03-003
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Checked by	Bo Svenning Pedersen
Version	3
Approved by	Lars Sloth
Issued date	December 2012

Data sheet

Title: Horns Rev 2 Monitoring 2010-2012. Migrating Birds.

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Publisher: Horns Rev II A/S. Kraftværksvej 53, DK-7000 Fredericia, Denmark.

Year: 2012

Version: 3

Report to be cited: Skov H.; Leonhard, S.B.; Heinänen, S.; Zydelis, R.; Jensen, N.E.; Durinck, J.; Johansen, T.W.; Jensen, B.P.; Hansen, B.L.; Piper, W.; Grøn, P.N. 2012. Horns Rev 2 Monitoring 2010-2012. Migrating Birds. Orbicon, DHI, Marine Observers and Biola. Report commissioned by DONG Energy.

Summary: Offshore wind development may have an impact on bird migration especially in areas with dense flyway corridors. Avoidance response and collisions may affect populations of migrating birds which may be subsequently increased in areas with more wind farms. Studies at Horns Rev, which is an important corridor and resting area for migrating water- and seabirds as well as for migrating landbirds, showed significant increased migration intensity coast wards from wind farms 20-30 km offshore. Local activities from foraging seabirds dominated radar data and only occasionally high activities were recorded for other migrating birds in wind farm areas.

Key words: Offshore wind farms, bird migration, Horns Rev 2, Horns Rev 1, avoidance response, barrier effect, collision risk, cumulative effects, Potential Biological Removal (PBR).

Photos ©: Thomas W. Johansen, Graeme Pegram, Jens Christensen and Per N. Grøn. Cover photo ©: Greylag geese flying over turbines at Horns Rev. Graeme Pegram. Appendices: Common Scoter Thomas W. Johansen.

Arctic Skua close by Horns Rev 1 Offshore Wind Farm © Graeme Pegram

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1 SUMMARY

As part of its license conditions for the Horns Rev 2 offshore wind farm (HR2) DONG Energy A/S is obliged to undertake post-construction monitoring of bird migration. This report contains the results of the monitoring on bird migration carried out during September 2010 to May 2012. The post-construction monitoring followed up on the baseline program during 2008. The purpose of the post-construction monitoring was to monitor possible impacts of the operation of Horns Rev 2 on bird migration, including collision risk, barrier effects and cumulative effects as a consequence of Horns Rev 1(HR1) and Horns Rev 2 being located in the same marine region. The methods applied in the post-construction monitoring have as far as possible been based on the same field methods as used during the baseline, which again were based on the methods developed and applied during the PSO [1] monitoring program for the HR1 wind farm and the investigations carried out as part of the EIA for HR2.

This implied using horizontal radar at HR1 and HR2 with the same technology as during the baseline, while the species-specific monitoring has been based on radar- and rangefinder-based tracking methods capable of collecting species-specific data on behavioural reactions of migrating birds to HR2 and HR1 for the calculation of avoidance and collision rates. In order to assess the relative importance of migration intensities offshore visual observations were also undertaken at Blåvandshuk during the same observation periods as on HR1 and HR2.

In total 1,785 species-specific tracks were recorded, of which 1,047 were 3D tracks made by laser rangefinder and 738 were 2D tracks made by radar. The majority of the tracks recorded by both devices were of Common Scoter (55.1 %). With these data, the data collected during the baseline in 2008 and the investigations related to HR1 the knowledge of spatio-temporal and directional trends in the movements of birds along Horns Rev has now reached a level which enables generalisations concerning bird migration to be made for the whole region. These generalisations include differences and similarities in the composition of species and functional groups along Horns Rev.

In an attempt to generalise the flight patterns and behavioural reactions to the wind farms of different bird species altitude and flight regression models were developed using a generalised additive mixed model design. The models successfully incorporated weather-induced variation in flight patterns and species-specific responses to the wind farms, and made it possible to assess and predict likely effects in terms of collision risks and barrier effects, including cumulative effects, for the main species of birds occurring in the region. The models and the predictions show general flight patterns in relation to weather, wind and distance to the turbines which can be extrapolated beyond the sites of data collection. However, it is important to note that due to

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[1] PSO is an abbreviation for Public Service Obligation. PSO is charges as a tariff by the consumer payment for electricity, which by law is used for e.g. subsidies for renewable energy projects and support to research and development projects that aim to secure environmentally friendly electricity.

the sensitivity of the radar devices to wind induced sea clutter the data was collected during calm weather conditions, and is therefore biased towards these conditions. The response to e.g. wind speeds might therefore change at higher wind speeds.

The flight directions (both specific-specific tracks and the automated radar recordings) corroborated earlier findings indicating the dominance of 'local'[2] seabirds at the two wind farms, and in comparison to the situation on the coast of Blåvandshuk movements of birds on long-distance migration constituted a small proportion of the total number of movements. Movements of one species, Common Scoter, outnumbered those of other species, which was reflected in the 55% of all recorded tracks, and the large number of radar signals recorded between November and March. Due to the higher abundance of Common Scoter at HR2 as compared to HR1 the highest densities of species-specific tracks and radar signals were recorded at HR2. Compared to the baseline the post-construction monitoring documented the presence of events of migrating passerines on Horns Rev, especially Meadow Pipits during autumn. Yet, these events were also noted on Blåvandshuk at an even larger scale. Thus, the occurrence of large numbers of passerines offshore on Horns Rev seems to be related to mass migration during autumn rather than specific offshore corridors. The visual recordings of terns showed that some movements of terns are noted on HR1 but not at the coast, indicating the presence of an offshore corridor.

Prominent barrier effects and a reduced risk of colliding with the turbines of HR1 and HR2 could be determined for most key species. Gannets were seen in the HR2 wind farm despite the fact that the species has not previously been recorded in the HR1 wind farm. Accordingly, for all main species the barrier effect could be judged as partial as no species completely abandoned the wind farms. An avoidance corridor where densities of flying birds peaked was determined for Common Scoter to be 1,500-2,500 meter distance from the wind farm, and at HR1 at 1,000-2,000 m distance. The probability of the Common Scoter to fly towards a wind turbine decreased more steeply at a distance of 1.5 km, with a tendency for a delayed response during spring as compared to autumn, possibly as a result of habituation during the staging period. These results are in line with the findings during the PSO program, and it can be safely concluded that due to the limited spatial scale of the barrier effect of local seabirds at HR1 and HR2 no cumulative barrier effect exists between the two wind farms.

The altitude profiles of the majority of species showed a preference for low altitude flights, particularly for the seabird species which all predominantly were recorded flying below the rotors when they approached the two wind farms. Only large gull species (Herring Gull, Lesser Black-backed Gull, Great Black-backed Gull), Gannets,

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[2] The term 'local' seabirds refers to non-breeding seabirds which unlike seabirds which pass the Horns Rev area during migration use the area during shorter or longer periods of time.

raptors, pigeons and passerines were often recorded flying at rotor height close to the wind farms. The flight models indicated that most species flew higher in tail and side winds in comparison to head winds although the variable was not always significant. Common Scoters and large gull species flew, according to the models, at higher altitudes closer to the turbines. Gannets and Common Scoters increased altitude with increasing wind speeds while large gulls, passerines and pigeons increased flight height with decreasing wind speed. According to the models the species flying closer to the rotor swept area were Gannets and large gulls, whereas Common Scoters and terns flew well below the rotor swept area in all weather situations. The risk for the Gannets and large gull species of potentially colliding with the rotors increased when the birds were flying in tail or side winds and for the Gannets at intermediate wind speeds and for large gull species at low wind speeds. The risk was higher at Horns Rev 2 than at Horns Rev I as the rotor swept area reaches 10 m closer to the sea surface at Horns Rev 2. The modelled average flight altitudes for passerines and pigeons were based on a small sample size and included a range of different species which consequently increased the uncertainties of the results.

A higher collision rate was seen across all assessed species, except small gulls, for HR2 than for HR1. Thus, the height of the lower tip of the rotor over the sea surface (10 m higher for HR1 than HR2) seems to constitute an important design parameter in relation to mitigating collision risks to seabirds. The specific macro avoidance rates were lower than those recorded at offshore wind farms in the Netherlands and Belgium, and those recorded earlier during the monitoring at HR1. This fact together with higher tendency to fly at rotor height at HR2 compared to these other wind farms increased the risk of collision of seabirds at HR2. These differences may be caused by movements on Horns Rev being dominated by local feeding or resting seabirds which may have a higher tendency to habituate to the wind farm than birds on long-distance migration. The worst case estimated total mortality of seabirds per ‘winter’ season was 553 at HR2 and 415 at HR1, of which Common Scoter and large gulls comprised the vast majority of potential victims. The large number of estimated collisions by Common Scoter was mainly driven by the large abundance of birds at HR2. Although only a minority entered the wind farm perimeter at rotor height the flux of birds was sufficiently large to cause regular collisions with the rotor blades. The high estimated collision rates for large gulls were mainly driven by a combination of low avoidance rates and high proportions flying at rotor height. Despite the relatively high number of estimated collisions the toll of the species concerned was estimated to lead to insignificant impacts at the population level. Thus, the estimated level of in-combination collisions by seabirds for HR2 and HR1 should be seen as less problematic than those reported for raptors at the Nysted and Rødsand 2 offshore wind farms.

The collision models have provided detailed estimates of collisions using a deterministic approach, and a methodology for which most parameters can be safely set using the field data at hand from radar and rangefinder tracks. However, for two of the model parameters very few data are available, and as they represent the within wind farm behaviour of birds and interactions with the rotor blades the estimated collisions should only be regarded as approximations; proportion trying to cross the swept area without showing avoidance and the probability of being hit by the rotor-blades. To establish realistic micro-avoidance rates it is recommended exploring the possibility for applying surveillance networks comprising a combination of tracking in the periphery and inside the wind farm.

Flock of migrating knot passing Horns Rev Offshore Wind Farm in spring 2011 © Thomas W. Johansen

2 DANSK RESUMÉ

Som en del af licensbetingelserne for Horns Rev 2 havmøllepark (HR2) er DONG Energy A/S forpligtet til at foretage overvågning af fugletrækket efter anlægsfasen. Denne rapport indeholder resultaterne af overvågningen af fugletrækket efter etableringen af HR2. Overvågningen blev gennemført i perioden september 2010 til maj 2012. Overvågningen fulgte op på baselineundersøgelserne, der blev gennemført i 2008, og havde til formål at dokumentere eventuelle konsekvenser af driften af Horns Rev 2 på fugletræk, herunder kollisionsrisiko, barriereeffekter og kumulative effekter som følge af at Horns Rev 1 (HR1) og Horns Rev 2 er placeret i samme havområde. De metoder, der blev anvendt har så vidt muligt været baseret på de samme feltmetoder, som blev anvendt under baseline, som igen var baseret på de metoder, der blev udviklet og anvendt i det såkaldte PSO[3] overvågningsprogram for HR1vindmøllepark og undersøgelser gennemført i forbindelse med VVMen for Horns Rev 2.

Dette indebar anvendelse af horisontal radar ved HR1 og HR2 med den samme teknologi som under baseline, mens artsspecifikke data på adfærdsmæssige reaktioner af trækfugle på HR1 og HR2 blev indsamlet til beregning af undvigelses- og kollisionsrater. For at vurdere den relative betydning af de registrerede trækintensiteter offshore blev der også foretaget visuelle observationer ved Blåvandshuk i de samme observationsperioder som på HR1 og HR2.

I alt 1.785 artsspecifikke spor blev registreret, hvoraf 1.047 var 3D spor fra laserkikkert og 738 var 2D spor fra radar. De fleste af de registrerede spor var af sortand (55,1%). Med disse data, med de data der blev indsamlet data i forbindelse med baseline i 2008, og undersøgelser relateret til HR1 har den tilgængelige viden om de rumlige, tidslige og retningsbestemte tendenser i bevægelserne af fugle langs Horns Rev nu nået et niveau, der gør det muligt at generalisere fugletrækket for hele regionen. Disse generaliseringer omfatter forskelle og ligheder i sammensætningen af arter og funktionelle grupper langs Horns Rev.

I et forsøg på at generalisere bevægelsesmønstre og adfærdsmæssige reaktioner på vindmølleparkerne hos de forskellige fuglearter blev der udviklet regressionsmodeller til beskrivelse af fuglenes flyvehøjde og trækbevægelser ved brug af ”Generalised Additiv Mixed Model” designs. Modellerne integrerede både den vejrafhængige variation i trækmønstret og de artsspecifikke reaktioner på vindmølleparkerne, og de gjorde det muligt at vurdere og forudsige de sandsynlige virkninger i form af kollisionsrisici og barriereeffekter, herunder kumulative effekter, for de vigtigste fuglearter i regionen. De udviklede modeller viser generelle trækmønstre i forhold til vejr, vind og afstand til

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[3] PSO står for Public Service Obligations, dvs. offentlige serviceforpligtigelser. PSO opkræves som en tarif på forbrugernes elregning og skal efter loven anvendes til eks. som tilskud til vedvarende energi projekter samt til forsknings- og udviklingsprojekter der har til formål at sikre miljøvenlig energi.

møllerne, der kan ekstrapoleres ud over de stationer, hvor dataindsamlingen fandt sted. Det er imidlertid vigtigt at bemærke, at der på grund af radarudstyrets følsomhed overfor bølgestøj blev de fleste data indsamlet under rolige vejrforhold, hvorfor en bias i forhold til disse vejrbetingelser ikke kan udelukkes. Fuglenes reaktioner på f.eks. vindhastigheder kan derfor ændre sig ved højere vindhastigheder.

De registrerede trækretninger (både artsspecifikke spor og de automatiserede radardata) bekræftede tidligere observationer, der indikerer at 'lokale'[4] havfugle dominere fuglebevægelserne ved de to havmølleparker, og i sammenligning med situationen på kysten af Blåvandshuk udgør langdistancetrækkerne en lille andel af det samlede antal bevægelser. Én art, sortand, dominerede bevægelserne af fugle, hvilket bl.a. blev afspejlet i at sortand udgjorde 55% af alle registrerede spor, og i det store antal radarsignaler optaget mellem november og marts. På grund af den højere forekomst af sortand på HR2 sammenlignet med HR1 blev de højeste tætheder af artsspecifikke spor og radarsignaler registreret ved HR2.

Sammenlignet med baseline dokumenterede disse undersøgelser tilstedeværelsen af ’events’ med større trækbevægelser af spurvefugle om efteråret, især engpibere. Disse trækbevægelser blev dog også bemærket ved Blåvandshuk i endnu større målestok. Således synes forekomsten af større bevægelser af småfugle offshore på Horns Rev at være relateret til massebevægelser om efteråret snarere end til specifikke offshore korridorer. De visuelle observationer af terner viser, at nogle trækbevægelser hos terner blev noteret ved HR1 men ikke ved kysten, hvilket indikerer tilstedeværelsen af en offshore korridor for terner.

Markante barriereeffekter og en reduceret risiko for kollisioner med møllerne på HR1 og HR2 blev bestemt for hovedparten af de vigtigere arter. Sulerne blev observeret i HR2 vindmøllepark til trods for, at arten ikke tidligere er blevet registreret i HR1 vindmølleparken. Følgelig er der for alle de vigtigste arter tale om en barriereeffekt, der kan vurderes som delvis da ingen af arterne fuldstændig undgår vindmølleparkerne. En undvigelseskorridor, hvor tæthederne af flyvende fugle toppede, blev for sortand bestemt til at være i 1.500-2.500 meters afstand fra HR2 vindmølleparken, og ved HR1 i 1.000-2.000 meters afstand. Sandsynligheden for at sortænder vil flyve i retning mod en vindmølle falder drastisk når afstanden til vindmøllen er mindre end ca. 1,5 km. Der er endvidere en tendens til, at der er en forsinket respons i foråret i forhold til efteråret, hvilket muligvis er et resultat af tilvænning i løbet af overvintringsperioden. Disse resultater er i overensstemmelse med resultaterne opnået under PSO-programmet, og det kan konkluderes, at der på grund af den begrænsede rumlige skala af barriereeffekten på ”lokale” havfugle på HR1 og HR2 ikke er tale om kumulativ barriereeffekter mellem de to vindmølleparker.

Højdeprofiler viste for de fleste arter en præference for at flyve i lav højde, især for de havfuglearter, som alle overvejende blev registreret flyvende under rotorerne, når de nærmede sig de to havmølleparker. Kun store mågearter (sølvmåge, sildemåge,

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[4] Termen ’lokale’ havfugle dækker her over ikke-ynglende havfugle, der i modsætning til havfugle der blot passerer Horns Rev undertrækket, udnytter området gennem kortere eller længere tid.

svartbag), rovfugle, duer og småfugle blev ofte registreret flyvende i rotorhøjde tæt på vindmølleparkerne. Trækmodeller viste, at de fleste arter fløj højere ved rygvind og sidevind i forhold til modvind, selvom denne variabel ikke altid var signifikant. Sortænder og store mågearter fløj ifølge modellerne højere over vandoverfladen tættere på møllerne. Suler og sortænder øgede flyvehøjden med stigende vindhastigheder, mens store måger, spurvefugle og duer øgede flyvehøjden med faldende vindhastighed. Ifølge modellerne var suler og store måger de arter, der fløj tættest på rotorzonen, hvorimod sortænder og terner fløj et godt stykke under rotoren i alle vejrsituationer. Risikoen for at sule og store mågearter kolliderer med rotorerne øges, når fuglene flyver i ryg- eller sidevind og for suler ved mellemhøje vindhastigheder og for store mågearter ved lave vindhastigheder. Risikoen var højere på Horns Rev 2 end ved Horns Rev I, da rotorzonen når 10 m tættere på havoverfladen ved Horns Rev 2. Den modellerede gennemsnitlige flyvehøjde for spurvefugle og duer var baseret på en forholdsvis lille stikprøve, og omfattede en række forskellige arter, som dermed øgede usikkerheden yderligere.

En højere kollisionsrate blev estimeret på tværs af alle de vurderede arter for HR2 end for HR1, og det synes således, at højden af den nedre spids af rotoren over havoverfladen (10 m højere for HR1 end HR2) er et vigtigt designparameter i forhold til afværgeforanstaltninger til reduktion af kollisionsrisikoen hos havfugle. De specifikke observerede makroundvigelsesrater var lavere end registreret ved offshore vindmølleparker i Holland og Belgien, og under overvågningsprogrammet for HR1. Dette faktum sammen med den højere tendens til at flyve ved rotorhøjde ved HR2 øgede risikoen for kollision af havfugle her. Disse forskelle kan være forårsaget af at bevægelserne på Horns Rev var domineret af lokale fouragerende og rastende havfugle, som kan have en højere tendens til at vænne sig til vindmølleparken end fugle på langdistancetræk. Den samlede ’worst case’ dødelighed for havfugle pr 'vinter' sæson blev estimeret til553 for HR2 og 415 for HR1, hvoraf sortand og store måger omfattede langt størstedelen af de potentielle ofre. Det store antal af estimerede kollisioner for sortand var primært drevet af den store forekomst af fugle ved HR2. Selv om få fugle fløj ind i vindmølleparken i rotorhøjde var tæthederne af sortænder tilstrækkeligt høj til at forårsage regelmæssige kollisioner med rotorbladene. De høje estimerede kollisionsrater for store måger blev primært drevet af en kombination af lave undvigelsesrater og en høj andel flyvende i rotorhøjde. Trods det forholdsvis store antal af kollisioner ved de to mølleparker vurderes effekten på bestandsniveau for de involverede arter at være ubetydelig.

Kollisionsmodellerne har givet detaljerede estimater af kollisioner ved de to mølleparker ved hjælp af en deterministisk metode, hvor de enkelte parametre kan fastsættes ud fra sporingsdata indsamlet med radar og afstandsmåler. Men for to af modelparametrene er der meget få data til rådighed, og da de samtidigt repræsenterer fuglenes adfærd indenfor vindmølleparken og responsen på rotorbladene bør de anslåede kollisioner kun betragtes som tilnærmelser; andelen af fugle der forsøger at krydse rotorzonen uden at undvige, og sandsynligheden for at blive ramt af rotor-bladene. For at etablere realistiske mikro-undvigelsesrater anbefales det, at undersøge muligheden for at anvende overvågningsnetværk, der omfatter en kombination af sporing af fuglebevægelser i periferien af og indenfor mølleparken.

3 INTRODUCTION

3.1 Objective

This report contains the results of the post-construction baseline monitoring on bird migration carried out in relation to the Horns Rev 2 Offshore Wind Farm (HR2) undertaken from September 2010 to May 2012. The post-construction monitoring followed up on the baseline program undertaken during 2008. The purpose of the post-construction monitoring is to monitor for possible impacts of the operation of the wind farm on migratory birds, including collision risk, barrier effects and cumulative effects as a consequence of two large-scale offshore wind farms Horns Rev 1(HR1) and Horns Rev 2 (HR2) being located in the same marine territory.

3.2 Background

The methods applied in the post-construction baseline have as far as possible been based on the same field methods as used during the baseline (Piper et al., 2008; Skov et al., 2009), which again were based on the methods developed and applied during the PSO monitoring programme for the HR1 wind farm and the investigations carried out as part of the EIA for HR2 (Petersen et al., 2006). The statistical design for the post-construction monitoring has been based on a combination of species-specific effect monitoring (barrier effects and collisions) and automated monitoring based on a BACI approach (Before-After-Control-Impact statistical analysis). The latter implied using horizontal radar at HR1 and HR2 with the same technology as during the baseline, while the species-specific monitoring has been based on radar- and rangefinder-based tracking methods capable of collecting species-specific data on behavioural reactions of migrating birds to HR2 and HR1 for the calculation of avoidance rates and collision rates. In order to assess the relative importance of migration intensities offshore, visual observations were also undertaken at Blåvandshuk during the same observation periods as on HR1 and HR2. The location of the observation points at the Poseidon platform (HR2), at the transformer station Alpha (HR1) and at Blåvandshuk is depicted in Figure 3-1, and the radar installations are shown in Figure 3-2.

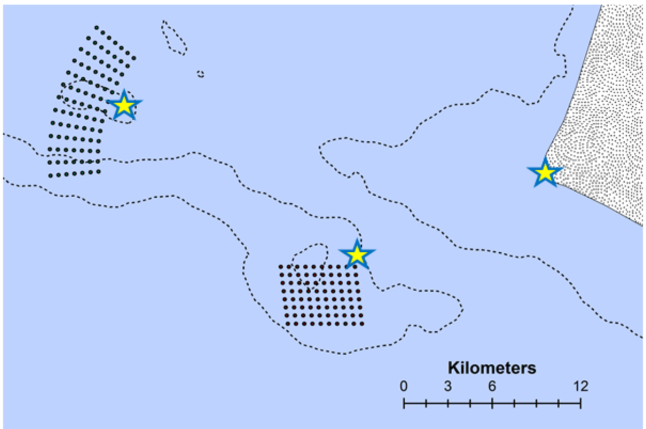


Figure 3-1. Location of observation stations at Horns Rev 2, HR1and Blåvandshuk. The turbines and substations of the HR1and HR2 offshore wind farms are indicated.

During the later part of the baseline monitoring programme, data on migration intensities along and across Horns Rev were collected from HR2, HR1 and Båvandshuk during autumn 2008. The data from the three stations in combination with visual calibration observations resulted in a comprehensive database on bird migration along the Horns Rev area. The collected data were judged sufficient to establish a baseline for future monitoring of bird migration. The data allowed trends and profiles of migration intensities of the major bird groups to be mapped, and revealed no indications of large-scale migrations occurring at HR2 in autumn. Additionally, no short-term events were noted at the site. The trends in flight intensities at HR1 OWF indicated avoidance response by the three bird classes: ‘large waterbirds’, ‘ducks’ and ‘passerines’.

Figure 3-2. The observation platforms and mounted radars at the two locations at the Poseidon platform (HR2, upper panel) and the transformer station Alpha (HR1, lower panel).

The spatial patterns of flight intensities recorded during the baseline at HR1 show that the reduced flight intensities were completely related to the wind farm and the surrounding area to a distance of approximately 1.5 km, and there were no indications of e.g. shading effects on the southern fringe of the wind farm (Skov et al., 2009). Thus, a local avoidance effect at HR1 as well as HR2 was expected to impact the southbound migration of a wide range of species, albeit the effect in terms of modified flight paths and energetic costs seemed to be minor for long-distance migrants. Further, the results from the baseline studies showed that HR1 lies at the western margin of the migration corridor in autumn, and so the effects are most likely to cause long-distance migrants moving towards the Wadden Sea to adjust eastwards and migrants with a south and southwesterly course to temporarily split paths when passing the wind farm. The post-construction activities were intended to gain more knowledge of the dominance of migration corridors east of the Horns Rev 2 and close to shore, and the scale of cumulative effects of the two wind farms during both spring and autumn migration. In order to collect as precise data as possible at the species level, the automated radar recordings were supplemented with species-specific track data.

The collection of information on behavioural reactions of birds to HR2 and HR1 for the estimation of collision risks is in accordance with the methods used during the PSO programme at HR1. Compared to the recordings during the PSO programme, the species-specific tracks during the post-construction programme included recordings of migration altitude using rangefinders.

Horns Rev 1 Offshore wind farm

4 METHODS

4.1 Species-specific monitoring

4.1.1 Tracking by rangefinder

Laser rangefinders (Vectronix 21 Aero®) were used to collect species-specific data on migrating birds. Laser rangefinders (LRF) were operated permanently at the observation points on HR2 and HR1 with a minimum of 15 minutes per hour allocated for tracking.

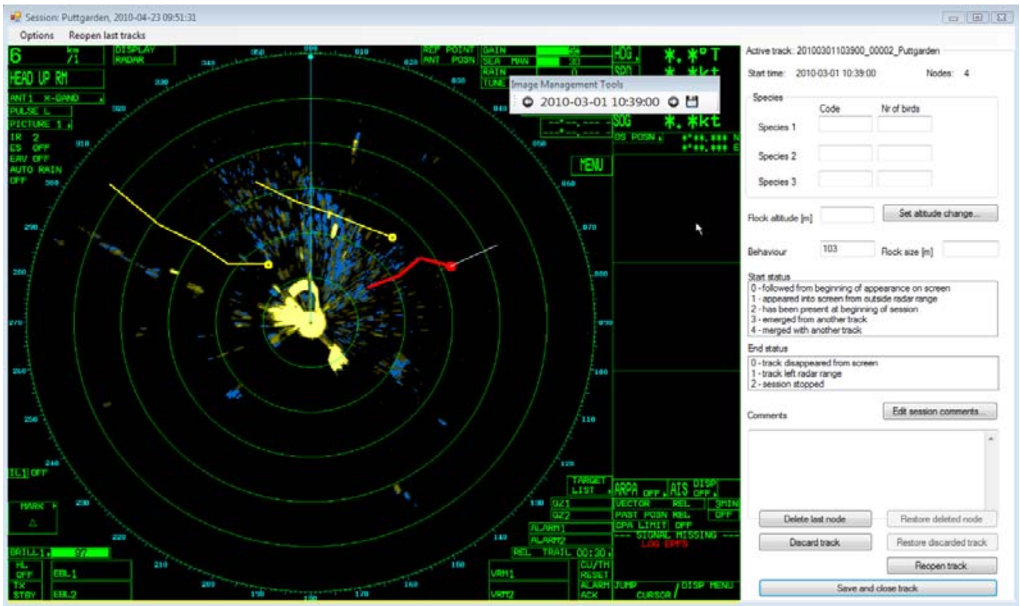
The laser rangefinder is comparable to a handheld binocular, but is equipped with a build-in, battery driven laser system, that's allow recordings of distance, altitude and direction to a given object. Thus operated at known geographical positions and elevations, the laser rangefinders were used to obtain three-dimensional data on the migratory birds. Under optimal conditions, laser rangefinders can be used out to a distance of between 2 and 3 km for the largest bird species, depending on the angle of view and on bird flight behaviour (gliding, soaring or flapping). LRF's can be operated or "fired" with approximately 10-15 sec. intervals and positions and altitudes logged automatically via GPS, and can provide long series of recordings for an individual focal bird or bird flock. The data from the laser rangefinder supplemented data collected by the horizontal radar. The recorded number of tracks of individual birds/bird flocks is shown in Appendix 3 .

Large amounts of metal on the two platforms interfered with the geo-positioning of the recorded data regularly. To account for this, calibration data were collected at each wind farm once per hour by measuring the individual distances to three turbines in the wind farm using the rangefinder. The calibration points which were located at each end centrally in the wind farms were used to spatially adjust the location of records (see section 4.1.3).

4.1.2 Tracking by radar

Tracking of individual species by horizontal radar was undertaken at the stations on HR2 and HR1. Using the horizontal radar, but adding species information was accomplished by a so-called "Real-time tracking" procedure, in which a dedicated software program "BirdTracker" made it possible to draw/follow tracks of individual birds or flocks on background images, i.e. real-time videos from the horizontal surveillance radar. The videos were produced using a frame grabber connected to the surveillance radar and tailor-made software provided the video as a background image on the PC-screen with the radar position in the centre. A radar range of 6.0 km was used. During tracking the PC screen was divided into two parts, the radar video and the window to record data, including number of birds, flock altitude, flock size (dimension), behaviour, status when start tracking, status when end tracking, comments per track or per session; start and end time, number of nodes and coordinates per node were added automatically.

Two observers were involved in the real-time radar-tracking. One followed the tracks on the screen and recorded the information into a database. The second observer attempted to find the objects in the field, using binoculars or telescope, and provided species names, number of birds and flying altitude. For each observation interval (15 minutes per hour during daytime) a separate session was started. Several tracks plus data could be recorded in parallel (at the same time) on the screen, one of them active. Each track had several nodes, representing the different locations of the track. In addition to the start and the end-point, directions were calculated for all tracks, Figure 4-1.



Session: Puttgarden, 2010-04-23 09:51:31

Image Management Tools: 2010-03-01 10:39:00

Active track: 20100301103900_00002_Puttgarden

Start time: 2010-03-01 10:39:00

Nodes: 4

Behaviour: 103

Start status
0 - followed from beginning of appearance on screen
1 - appeared into screen from outside radar range
2 - has been present at beginning of session
3 - emerged from another track
4 - merged with another track

End status
0 - track disappeared from screen
1 - track left radar range
2 - session stopped

Figure 4-1. Screenshot of "BirdTracker" view with radar screen as background image on the left and editing sheet on the right. One active (red) and two inactive tracks (yellow) are shown from the same session. The white line on the right end of the active track indicates where to place the next node. Dots at one end of the track indicate the last active signal.

The purpose of the tracking session was to track and identify as many birds/flocks as possible. It is important to stress that the bird tracks identified may well constitute only a proportion of the total number of birds or bird flocks moving through the area investigated. This is a result of the sampling frequency combined with the number of bird tracks that is possible to identify by observers on the radar screen, which is an underestimation of the actual tracks. However, as no selective tracking was applied the obtained sample of tracks is considered representative. Also, during very busy situations it has not always been possible to provide identifications for all tracks.

4.1.3 Processing of track data

The data collected using rangefinder and radars were further processed before used in the statistical analyses. Obvious outliers, wrongly located points within tracks, were removed by visually inspecting the tracks. Other errors, test tracks etc. were also removed from the data files. The rangefinder data also needed to be corrected for distortion due to the massive metal constructions of the observer platforms. The corrections were made with the help of fixed calibration points with known positions. Three or two wind turbines were used as calibration points. The spatial corrections were made in

ArcGIS 10 using the spatial adjustment tool. If three calibration points were available the points were adjusted with the “affine” method and if only two points were available the “similarity” method was used.

The track data were further integrated with the weather data (Appendix 1) by using an integration tool made by DHI which is designed for extracting data from MIKE by DHI model files based on temporal (date and time) and spatial (coordinates) information. The integration was made by linear interpolation between time steps (1 hour) in the weather time series data. The wind components U (m/s in W-E direction) and V (m/s in S-N direction), air pressure, clearness, relative humidity, total precipitation and air temperature were thus added as new columns to the track data files by using the integration tool. The U and V wind components were further converted to wind speed (m/s) and wind directions (0-360°). A variable defining the flight direction in relation to wind direction was also created. The variable defined in other words whether the bird was flying in head wind (within a range of 90 degrees), tail wind (within 90 degrees) or side winds (within 90 degrees from either side).

Finally a raster layer was created defining the distance to the nearest wind turbine by using the “Euclidean Distance tool” in the “Spatial Analyst Toolbox” in ArcGIS 10. The distance layer, with a resolution of 50x50 m, was also integrated with the track data, as a static variable.

4.1.4 Prediction of bird movement and migration behaviour

For the assessment of general patterns in the migration behaviour regarding flight altitude statistical models were developed. These models are suitable for explaining the differences in flight altitude related to wind and weather conditions (wind speed at 10 m, air pressure, relative humidity, clearness and temperature) and distance to the nearest wind turbine. Statistical models would potentially assess the probability for collision risk for staging and wintering seabirds approaching HR2 and HR1 during migration as well as during local (foraging) movements. The general patterns of flight altitude were used in the estimation of the flight altitude relative to the height of the rotors of the two wind farms. Design parameters of the turbines are listed in Table 4-1.

As the relationships between the response variable (altitude) and the predictor variables in many cases were non-linear and the error structure of the data was non-normally distributed a generalized additive modelling framework was used. This modelling framework is a semi-parametric and data driven approach capable of dealing with these issues (Zuur et al., 2009). A generalized additive mixed model (GAMM) with a correlation structure (corAR1), was used to account for the spatial and temporal autocorrelation of the rangefinder data. This is because one of the assumptions of the method, that samples within a rangefinder track shall be independent of each other, was not fulfilled.

Table 4-1. Design parameters for the turbines in Horns Rev 2 and Horns Rev 1 wind farms.

Design parameter	Horns Rev 2	Horns Rev 1
Total height	114.5 m	110 m
Rotor diameter	93 m	80 m
Height of lowest tip of rotor	21.5 m	30 m
Height of nacelle	68 m	70 m

The models were applied using R version 2.13.0 (R Development Core Team, 2004) and the “mgcv” package (Wood, 2006). The GAMMs were fitted with altitude (m) as the dependent variable and the predictor variables mentioned above as smooth terms (using thin plate regression splines). Flock size was also considered as a smooth term in addition to the variable mentioned above. Flight direction in relation to wind (head, tail or side winds), besides location (either Horns Rev 1 or Horns Rev 2), season and season plus location were included as categorical variables in the models. To fit the models the most appropriate error distribution was used (the one which resulted in the best fit), either a gamma distribution with a log link, a Gaussian distribution or a quasipoisson distribution. The degree of smoothing (how closely the model fits the data) is chosen “automatically” by cross validation in the “mgcv” package (Wood, 2006). The default maximum degree of smoothing (degrees of freedom) is 10 (k=10). The maximum degree of smoothing was restricted to 5 and if the model fitted a too complex curve (after visual assessment) the degree of smoothing was restricted to 3 (k=3). The correlation structure called “corAR1” was used for the random part (lme) of the GAMM (Zuur et al., 2009). The “track ID” was used as a grouping factor, thus accounting for the autocorrelation within the tracks. At first a model was fitted including all variables, and next the variables not contributing to the model fit were eliminated. Ecological irrelevant predictor variables were eliminated too. The residuals were assessed using a correlogram with 10 lags (1 = lag was the defined nearest neighbourhood of 250 m) to inspect whether the model was suitable for displaying the spatial autocorrelation in the residuals of the model. For calculating the “Moran’s I” (measure of spatial autocorrelation) the R package “spdep” (Bivand, 2009) was used.

The predictive accuracy of the models was evaluated by splitting the data into two data sets, a calibration set (70%) and an evaluation set (30%). The model was fitted on the calibration data and predicted on the evaluation set. Thereafter the agreement between observed and predicted altitudes was checked by plotting the predicted values against the observed and the Spearman’s correlation coefficient was estimated (Potts & Elith, 2006).

The models were used for predicting the average flight altitude of birds entering both the HR2 and the HR1 wind farm areas. The predicted area was defined as a 5 km buffer around the observer platform. For visualisation of the predicted altitudes across the 5 km buffer zones two transects were applied as cross sections (Figure 4-2). The transects should not be interpreted as flight tracks (directions), but were used in the calibration of the model of flight altitudes, depending on the distance to the nearest wind turbine and the relationships to the other predictor variables included in the species-specific (or species group) model. The wind and weather parameters were set to mean conditions of the collected data.

4.1.5 Collision models

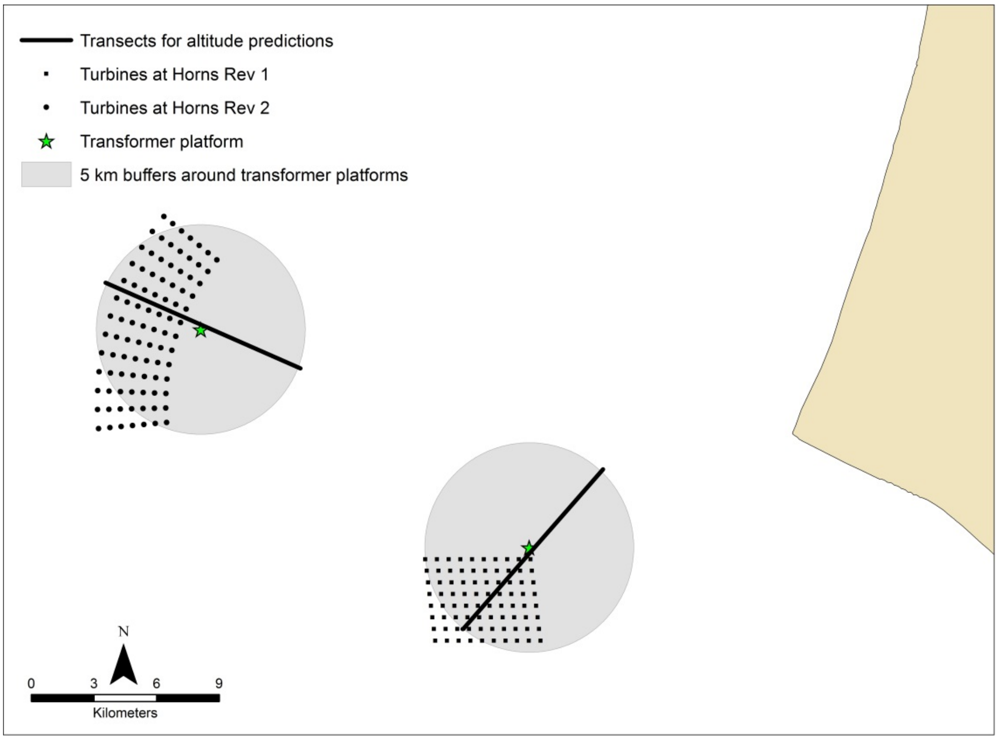


Figure 4-2. Transects (or cross section) through the predicted areas (5 km buffer around transformer platforms) used for displaying predicted altitudes in relation to both wind farm sites.

The detailed flight trajectories obtained by combined radar and rangefinder techniques enabled the estimation of collision risks for selected species, including migrating landbirds and resident seabirds. Assessment of the risk imposed by the HR1 and HR2 wind farms on birds requires a good definition and subsequent estimation of the number of collisions likely to occur for the different species. We used a modified version of the collision model developed by Band et al. (2000), Band et al. (2007) for migrating birds and by Band et al. (2012) for staging/wintering seabirds. As separation of short-distance movements and long-distance migration could not be safely determined in the field, all tracks of seabirds were classified as short-distance movements of staging birds, and all tracks of landbirds were classified as long-distance migration.

A collision is here defined as the proportion of birds/flocks exposing themselves to a collision by crossing a scale-specific collision conflict window. To calculate collision risks, several parameters need to be considered. Technical parameters are in this case the measurements/dimensions of rotor structures and wind farm design. Given these, the number of birds flying within the collision risk area, defined by the design of the wind farm can be estimated from the measured 2- and 3-dimensional flight trajectories and tallies of birds in the horizontal and the vertical plane..

4.1.5.1 Assessment of the collision risk of migrating landbirds

The collision model for landbirds on long-distance migration (Band et al. 2000; Band et al., 2007) is based on the assumption of single transits of the same individual. The model was applied using bird crossings of 10 (HR1) and 7 (HR2) turbine rows. As estimates of the total numbers of landbirds on long-distance migration crossing Horns Rev during spring and autumn are not available, the adjusted model was used to calculate the proportion of birds that could potentially get killed by the rotors. The model is based on the availability of the following data for the target species or species groups:

a) The proportion of birds entering the wind farm, calculated from horizontal radar and range finder data;

b) Proportion within horizontal reach of rotor-blades in each turbine row. The value of this parameter corresponded to the proportion that the sweep area comprised relative to the area of the so-called risk window in each turbine row (Band et al., 2000; Band et al., 2007). Mathematically, this can be formulated as:
$N * (\pi * r^2) / (H * L)$, where N = number of turbines in a row in the western section of the wind farm, r = radius of the rotor, H = difference between the maximum and minimum altitudes of the rotor and L = length of a turbine row;

c) Proportion of birds within vertical reach of rotor-blades at closest range from the turbines, calculated from the rangefinder data;

d) Proportion of birds trying to cross the swept area without showing avoidance. A value of 92% was derived from (Winkelman, 1992);

e) Probability of being hit by the rotor-blades. The approach used by Band et al. (2000) and Band et al. (2007) was adopted. Here the wing span, body length and flight speed was incorporated. Biometric measurements were obtained from http://www.dofbasen.dk/ART/ and flight speeds from (Alerstam et al., 2007).

The proportion of birds colliding with the blades could then be calculated for each crossing of a turbine row as: a * b * c * d * e

4.1.5.2 Assessment of the collision risk of staging seabirds

The collision risk of resident birds was calculated using the modelling framework elaborated by Band et al. (2012), which represent further development of earlier collision risk models (Band et al., 2000; Band et al., 2007). Detailed description of the model design and underlying assumptions could be found in Band et al.(2012), and here we present only the basic principles of the model and the data used for model parameterisation.

The model is based on the availability of the following data for the target species and wind farm in question:

a) The density of flying birds per km^2. The densities of flying birds were estimated from numbers of each species staging/wintering in wind farm areas and 3 km buffer surrounding them. Average numbers of wintering birds of each species were estimated from aerial surveys (Petersen I., 2012). As concurrent survey data from the investigation period was not available, monthly data collected in February-April 2006 and January-April 2007 were used. As the difference in abundance of seabirds between 2006-2007 and 2009-2010 was not known at the time of the analyses the estimated number of collisions should be taken as representative for the former period. It should be noted that although the HR2 offshore wind farm was not established during 2006-2007 the estimated number of collisions still provides a useful indication of the annual number of casualties due to collision with HR2 and HR1. Numbers of birds observed during aerial surveys were corrected to account for distance detection bias using detection functions calculated from analogous surveys conducted elsewhere (the southern Baltic), as no distance detection functions were available for the Horns Rev aerial survey dataset. Further, densities of flying individuals were then estimated from the total bird density using species-specific proportions of birds in flight, which have been extracted from the European Seabird at Sea Database (ESAS v. 4). Only ship-based survey records were used from this database, as ship platform allows more reliable determination of bird behaviour. Once corrected, results of all aerial surveys in Horns Rev were used to calculate mean density of wintering birds within each wind farm. Wintering period was considered to represent a period lasting from November until April, although no surveys were available from Horns Rev in November and December. Since no data about seabird densities were available for other seasons, other months (May – October) were not considered in the calculations.

b) Bird flux is further calculated form density of flying birds and species flying speed. The bird flux represents mean species traffic rate through the area and is calculated by

$$F_L = D_A \times v / (\pi/2)$$

Where F_L is total bird flux expressed in birds/sec per meter of baseline, D_A is bird density per square meter, v is speed of birds in m/sec and $(\pi/2)$ is directional element as flux is directional metric.

c) Proportion of flying birds within vertical reach of rotor-blades (i.e., potential 'danger zone') was calculated from the rangefinder data.

d) Daylight hours and nocturnal activity. Because bird activities usually differ by day and night, the model calculates day and night lengths based on latitude of a wind farm. Entered density of flying birds (step 'a' above) usually refers to daylight hours. Further, nocturnal activity code is entered for each species, which ranges from 1 to 5 and refers to nocturnal activity with reference to observers daytime activity of a species. A rating of 1 represents hardly any flight activity at night, and 5 much flight activity at night, and could roughly be translated in respectively 0%, 25%, 50%, 75% and 100% of daytime activity. Rankings of the most common seabird species were introduced by Garthe & Hüppop (2004) and later refined by Furness & Wade (2012). For the majority of species we used nocturnal activity rankings from Furness & Wade (2012).

Only for Common Scoters we down-scaled the suggested nocturnal activity factor from 3 to 1, as literature on behaviour of sea ducks indicates very little activity at night (Guillemette et al., 2007; Lewis et al., 2005).

e) Estimating numbers of birds flying through rotors. Calculations are done using several simplifying assumptions that birds fly perpendicular to the rotor, at constant speed, that rotor is facing wind at all times and that equal number of birds fly upwind and downwind (the collision risk flying upwind is greater). Total number of bird transits through turbines is calculated using the following equation, which multiplies overall bird flux proportion of birds flying at risk height:

$$v * DA/2R * (T\pi R2) * (t_{day} + f_{nigh}\ t_{night}) \times Q_{2R}$$

where v is bird speed, D_A – density of flying birds, 2R – rotor diameter, T – number of turbines, πR^2 – area of the rotor, t_{day} – total daylight time (in seconds), f_{night} – species nocturnal activity factor, t_{night} – total night time, Q_{2R} – proportion of birds flying at risk height.

f) Probability of collision for a single rotor transit is calculated applying the approach developed in earlier version of collision models (Band et al., 2000; Band et al., 2007). This approach incorporates dimensions and speed of turbines and bird species wing span, body length and flight speed. Biometric measurements of birds were obtained from (DOF, 2012) or (BTO, 2012) online databases and flight speeds from (Alerstam et al., 2007).

g) Proportion of time that wind farm operates. We received actual monthly percentages of operational time of HR2 wind farm during January 2011 – July 2012, which on average exceeded 90%. This information was used to represent operational time of HR2 and was assumed to be the same for HR1.

h) Finally, wind farm avoidance rates were applied for a bird flux in rotor swept area. By reviewing available publications to date on offshore wind farms and seabirds, (Cook et al., 2012) suggested that most seabird species have overall avoidance rate (consisting of macro- and micro-avoidance) of 99-99.5%. In our estimates we offer two figures: one representing pessimistic scenario with overall avoidance rate of 98% and the other one representing optimistic scenario with overall avoidance rate of 99.5%.

The final figure of possible collision rates consists by multiplying the bird flux through the rotor height (‘e’ above), collision probability (‘f’), proportion of wind farm operational time (‘g’), and avoidance rates (‘h’):

$$e \times f \times g \times h.$$

4.1.6 Population risk models

An assessment of the in combination impact of collisions at HR2 and HR1 on population levels was undertaken. This was undertaken by estimating the significance of collision numbers at both wind farms as compared with thresholds for sustainable removal from the relevant bio-geographic bird populations concerned. These assessments are conservative, and follow the so-called PBR (Potential Biological Removal) concept. The main advantage of this approach is that it relies on those demographic parameters which are easiest to obtain for the species.

The PBR approach is widely used to guide conservation and management of long-lived species like marine mammals (Wade, 1998) and has been demonstrated as a useful tool to assess impacts of fisheries by-catch mortality on birds. The PBR is a threshold of additional annual mortality, which could be sustained by a population. PBR is a conservative metric and accounts for potential bias due to density dependence, uncertainty in estimates of the population size and stochasticity (Wade, 1998; Taylor et al., 2000; Milner-Gulland & Akcakaya, 2001). Additive mortality exceeding PBR would indicate potentially overexploited populations.

Recently, PBR has become increasingly used in studies analysing effects of additive mortality on waterbird populations (Niel & Lebreton, 2005; Dillingham & Fletcher, 2008; Bellebaum et al. (2010) calculated PBR for a number of bird species, including waders and passerines, aiming to assess thresholds of collisions with offshore wind parks in the German Baltic Sea that bird populations can sustain. However, the PBR concept has been developed and sufficiently tested only for birds with K-strategic life histories, i.e. long-lived and slow reproducing species like raptors.

PBR is calculated using the following general equation (Wade, 1998):

$$PBR = \frac{1}{2} R_{\max} N_{\min} f$$

where R_{max} is maximum recruitment rate, N_{min} is minimum population size, and f is recovery factor used to account for uncertainty in population growth rate and population size. Maximum recruitment rate is calculated considering maximum annual population growth rate:

$$R_{max} = \lambda_{max} - 1$$

where λ_{max} is maximum annual population growth rate, which is solved using the equation suggested by Niel & Lebreton (2005), which requires only adult bird annual survival probability (S_{ad}) and age of first reproduction (α):

$$\lambda_{\max} = \exp\left(\left(\alpha + \frac{S_{ad}}{\lambda_{\max} - S_{ad}}\right)^{-1}\right)$$

For minimum population size (N_{min}) Wade (1998) suggested using the lower bound of the 60% confidence interval of a given population estimate. However, a majority of available bird population estimates lack measures of uncertainty and provide either one figure for population estimate, or the upper and lower bound between which the actual population size is expected to lie. In the latter situation, the lower bound was used as an approximation representing N_{min}. If only one number was provided as population estimate, following Dillingham & Fletcher (2008) we estimated N_{min} as the 20th percentile of the population estimate assuming coefficient of variation $CV_{\bar{N}} = 0.05$.

The population recovery factor f, used to account for uncertainty in population growth rate and population size, ranges between 0.1 and 1. Dillingham & Fletcher (2008) suggested a recovery factor *f* = 0.5 for stable populations, *f* = 0.3 for declining, *f* = 0.1 for rapidly declining. These *f* values were accepted in our assessment, and we additionally used *f* = 0.7 for species with increasing population trend.

The estimates of the number of bird passing the study area in autumn as well as the entire bio-geographic population were used as reference populations for the PBR. Obviously, the reference populations are much larger, however by also using the regional total numbers as reference points the calculated thresholds demonstrate the range of extra mortality which the regional and total populations may sustain.

4.1.7 Assessment of barrier effects

Barrier effects on movements and long-distance migration of seabirds resulting in a change of migration or flight routes and altitudes and thus in energetic costs to the birds have been well-described from existing offshore wind farms (Masden et al., 2009; Masden et al., 2010). Monitoring at existing offshore wind farms has involved combined visual and radar-based observations of behavioural responses of migrating birds to the turbine structures. Experiences related to species-specific responses in the Baltic Sea have been gathered at the Nysted wind farm. Waterbirds reacted at distances of 5 km from the turbines, and generally deflected at a distance of 3 km from the wind farm (Petersen et al., 2006). Within a range of 1-2 km more than 50 % of birds heading for the wind farm avoided passing within it. Waterbirds entering the wind farm minimised their risk of collision by re-orientating to fly down between turbine rows, frequently keeping equidistance between turbines and by reducing their flight altitude below rotor height and by readjusting flight orientation once within the wind farm to take the shortest exit route.

Studies at the Nysted and HR1 wind farms have shown that the wind farm site is avoided and detoured to a greater extent by migratory birds than by resident birds (Blew et al., 2008). Seaduck species, particularly Common Scoter at Horns Rev and Common Eider at Nysted were registered in high numbers in the vicinity of the wind farms. Although, the seaducks were showing a general avoidance to enter the wind farm areas, individuals and groups of those species were found within the wind farm areas. Likewise, it has been found that scoters seem to exhibit avoidance behaviour of turbines in a Dutch offshore wind farm area (Leopold, et al., 2010). Extreme reactions such as turning back on encountering the wind farm were not observed. The avoidance of the offshore wind farms occurred by birds flying around it as well as above it (Blew et al., 2008).

Due to potential bias from the turbines and rotor blades (Blew et al., 2008) found it difficult to interpret the lower flight intensities recorded in the HR1 wind farm as a barrier effect. The spatial patterns of flight intensities recorded during the baseline investigations in 2008 showed that the reduced flight intensities were completely related to the wind farm and the surrounding area to a distance of approximately 1.5 km, and there were no indications of e.g. shading effects on the southern fringe of the wind farm (Skov et al., 2009; Petersen et al., 2006) also documented avoidance response at the scale of 0.5-1.5 km from the wind farm. (Skov et al., 2009) demonstrated that

HR1 is at the western margin of the migration corridor in autumn which may cause long-distance migrants moving towards the Wadden Sea to adjust eastwards. The baseline investigations also showed that due to the short scale of the avoidance effect it is not likely that the moderate displacement of migrants at HR1 would affect the migrants en-route to HR2, and the avoidance effect at HR2 is therefore most likely to be non-cumulative (Skov et al., 2009). The recorded migration intensity of waterbirds was slightly higher on the eastern than on the western side of HR2, and thus, the avoidance effect at HR2 was predicted to display a concentration of waterbirds on the eastern side of the wind farm.

The barrier effect of offshore wind farms on waterbirds typically results in movements along the periphery of the wind farm site and as a consequence a concentration of flying birds just outside the wind farm (Durinck & Skov, 2006; Petersen et al., 2006).

In order to assess the degree and nature of barrier effect of the HR2 and HR1 wind farms on various seabird species we analysed the gradients in densities of flying birds deduced from the radar tracks. Gradients in the densities of flying birds associated with the wind farms was explored by analysing recorded track density in a 100 m grid within the radius of 6 km around the horizontal radars. We fitted GAM models with a Tweedie distribution using both, all recorded bird tracks and only tracks of common scoters as response variables, and distance to the radar and distance to the wind farm as predictor variables. Distance to the radar was included as predictor variable to ensure that the estimated response to the wind farm took account of the response of the birds to the observer platform.

One of the key results from the analyses of gradients in the density of radar tracks was the finding of a concentration of flying Common Scoter at the periphery of the two wind farms. We further assessed the barrier effect of scoters by analysing whether there was a difference in flight direction in relation to the distance to the closest wind turbine. We wanted to know whether there is a change in direction (probability of flying towards or not) when the birds are closer to the wind farm (nearest turbine) or not? For assessing this we used the same GAMM approach as used in the altitude models (described above), however we did not restrict the degrees of freedom of the smooth terms (as we wanted to look at the response in the data). As the response variable we fitted a binomial variable describing flight direction of scoters in relation to the direction to the closest wind turbine (1=flying towards the nearest turbine within the range of 45 degrees, 0 = not flying towards the nearest turbine). The results reveal whether the probability of flying towards a wind farm changes with distance to the nearest turbine, when also accounting for other influential variables. We assessed the influence of the same variables as in the altitude models with the addition of Y-coordinates.

4.1.8 Changes in species composition

A qualitative assessment of changes in the composition of species at HR2 and HR1 was carried out using the visual observations and tracks obtained during the PSO programme, during the HR2 baseline investigation in 2008 and during the HR2 post-construction program.

4.2 Automated monitoring

4.2.1 Automated recordings by radar

The radar installations on HR2 and HR1 were based on DHI's LAWR (Local Area Weather Radar) system design, which was applied during the 2008 baseline (Skov, et al., 2009). The radars were operated during the periods when bird observations were undertaken. The software was developed by DHI for high-resolution LAWR signals processing, data extraction, automatic classification and GIS-interfacing. The LAWR is based on X-band technology, using a standard marine radar, type FR2127 from Furuno designed for 24/7 operation under harsh conditions. The data acquisition hardware developed by DHI allows sampling of up to 24 images per minute, which facilitates object tracking. All radar equipment includes ancillary hardware linked to the systems, allowing 24 hour operation and remote control, Figure 4-3,
Table 4-2.

The radar software package is subdivided into RadCtrl2, a radar control software, and PolScan, software for acquisition of radar data. PolScan software is DOS based, while RadCtrl2 is run under the WINDOWS-XP operating system. Additionally, the Bird Tracker software (see description above) for real-time tracking in GIS of birds recorded on the screen has been integrated with the radar software package.

Table 4-2. *Specifications of radar devices used.*

Brand	Furuno
Type	FAR2127
Power output	25kW
Frequency	9.4 GHz (X-band)
Horizontal angle of radar beam	1 degree
Vertical angle of radar beam	10 degree
Rotational speed	24 rpm
Antenna length	2400 mm
Range	8 km

RadCtrl2 is the radar control software and PolScan is program controlling the 20 MHz data scanning. The software package is responsible for archiving the collected data and for automatic restart of the radar system, in case of e.g. power failure. The software can be operated remotely via its internet connection. All sites are connected using wireless 3G internet. Based on the radar site coordinates and the orientation of the radar, the observations can be extracted with UTM coordinates. With the use of wireless Internet/wireless LAN, the software makes it possible to use the tracking and other tools away from radar site.

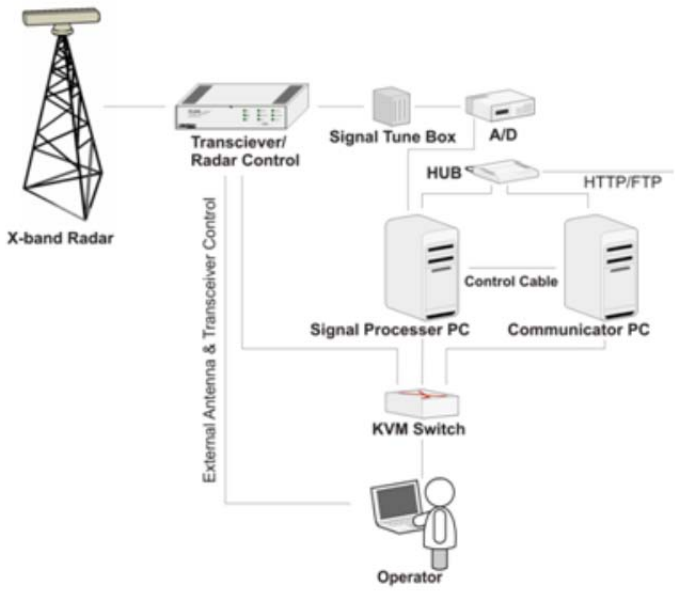


Figure 4-3. *Setup of the radar system including ancillary equipment.*

4.2.2 Processing of automated radar recordings

The integrated wind and automated radar track data were used to convert the speed of bird tracks “over ground” to flight speed through air. In addition to the wind information, the presence of rainfall in the radar coverage area was estimated as the average reflectivity over the entire radar image.

The echo signals received by the Furuno radar sensor were extracted directly from the receiver circuit before any of the traditional marine radar processing was done. This raw signal, which was sampled at 20 MHz at 10 bit resolution (1,023 levels) and collected in “bins” each covering a radial distance of 120 m and 1 degree tangentially, were then processed to obtain mean, peak and variance characteristics of the radar signals. These radar statistics were produced instantaneously at the data collection computer, and the scanning was performed continuously. Thus, signal characteristics could be integrated over freely chosen time and spatial scales.

The volume- and en-route correction of the echo, i.e. compensation for a larger scan volume as a function of distance and attenuation of the signal as a result of other echoes like rain, was handled using the standard correction scheme which has been successfully used on the LAWR during the last 12 years (Thorndahl et al., 2009). The tracking algorithm operates on a buffer of 120 successive radar images where each pixel is tagged for potential track content (corresponding to 2 hrs recording). Starting from the oldest image each tagged pixel forms the starting point for a volume search +/- two cells in the same and succeeding images. From the recorded wind-speed and wind-direction and the corresponding data for the track (speed and direction over ground), the object (bird) heading and velocity (speed through air) is calculated. The process is repeated for every successive one minute data.

Due to the presence of substantial noise in the recordings generated by ground- and sea clutter and echoes from other radars, a variety of filters were used to discriminate between this noise and echoes generated by birds. The filters are:

- Classification: Intervals for the mean, maximum and variance reflectivity are used for the classification of targets
- Persistence: When the same pixel records echo for more than 10 minutes, the pixel is tagged as being affected by clutter. If the same pixel changes to “no echo” the pixel is active again. This could happen when wind generated waves creates sea-clutter (turns off the pixels) and the cells are re-activated when the wind stops.
- Presence of 4 or more radial points within one minute (same image). Echoes generated by other radars or waves coming towards the radar have a tendency to generate this form of echoes.
- Track with no heading. Due to the one minute averaging, it is not possible to determine the direction of an identified track that only exists in the minute of integration (there is no way of telling the order of the points).
- Short tracks: Ignoring tracks composed of 3 or two classified cells.
- Regression fit: Since the cells have a size of 120 m by 1 degree tangentially, the tracks may display a zigzag nature. In addition to this, points recorded within one minute have no “order”. The regression filter places these points in the Cartesian coordinate system and finds the best fitted line thru the points to establish the direction of the track.
- Non-bird tracks: Tracks with a bird speed below 40 km/h or a ground speed exceeding 100 km/h are unlikely to be birds.
- Rain clutter: Periods with an average reflectivity over the entire radar image above 170 are heavily contaminated by rain clutter.
- Wave clutter: Periods with wind speeds above 6 m/s are generally contaminated by wave clutter.

Subsequently, the filtered horizontal data were extracted from within a distance of 500 m to 6000 m from the radars, thus covering the maximum detection range and avoiding the area close to the radars, which is typically infested by ground clutter. Statistics on the horizontal radar data were processed as counts of the number of tracks recorded per day in the control areas.

4.3 Visual observations

The recording routines during the visual observations at all three stations included observations of all movements of birds (Figure 4-2). The observations provided descriptions of the migration intensity, spatial distribution and orientation of birds in relan to the position of the offshore wind farm. Due to the general low density of migrating birds at the two offshore locations counts were undertaken continuously. The observers used binoculars and telescope and recorded species, flock size, flight altitude (25 m categories) and direction (8 categories).

4.4 Weather data

For the purpose of analysing the influence of weather conditions on the migratory behaviour of birds modelled wind data from the regional model (WRF) by StormGeo were applied (www.storm.no). The regional weather model is based on the global weather model run by the European Centre for Medium-Range Weather Forecasts (UK). The spatial resolution of the WRF model is 0.1 x 0.1 degree, and the temporal resolution is one hour. Wind speed (m/s, at 10 m) and direction (as U and V wind components) as well as air pressure (hPa, at 10 m) were integrated with the radar and rangefinder track data. Clearness (% at 10 m, based on total cloudiness), relative humidity (% at 10 m) and air temperature (°C at 2 m) were additionally integrated with the track data. Clearness and humidity should here be seen as proxies for visibility (humidity inversely correlated with visibility).

In addition, wind measurements recorded from the M8 mast in the western part of HR2 and the M7 mast east of HR1 were received and used to get an overview of the local wind conditions.

5 RESULTS

Approximately 159,000 birds of a total of 195 different species were observed during the visual observations from the three observations sites in the Horns rev area (Appendix 2). The majority of the migrating birds both in numbers (94%) and species were observed at Blåvandshuk and only few species occasionally observed in the wind farm areas were not seen at Blåvandshuk, Table 5-1. It should be noted that local concentrations of seaducks staging and wintering at the wind farms were not recorded, and thus the difference in abundance between Blåvandshuk and the wind farms may not reflect the true difference for this species group.

Table 5-1. Species exclusively recorded in the wind farm areas.

Common name	***Scientific name***
Gargany	*Anas querquedula*
Surf Scoter	*Melanitta perspicillata*
Lapwing	*Vanellus vanellus*
Long-tailed Skua	*Stercorarius longicaudus*
Long-eared Owl	*Asio otus*
Wren	*Troglodytes troglodytes*
Goldcrest	*Regulus regulus*
Pied Flycatcher	*Ficedula hypoleuca*
Long-tailed Tit	*Aegithalos caudatus*

The most numerous groups, Figure 5-1, represented more than 92% of all birds observed. The groups were characterised by high dominance of very few species representing up to 95% of all individuals in the group, Table 5-2, Figure 5-2 .

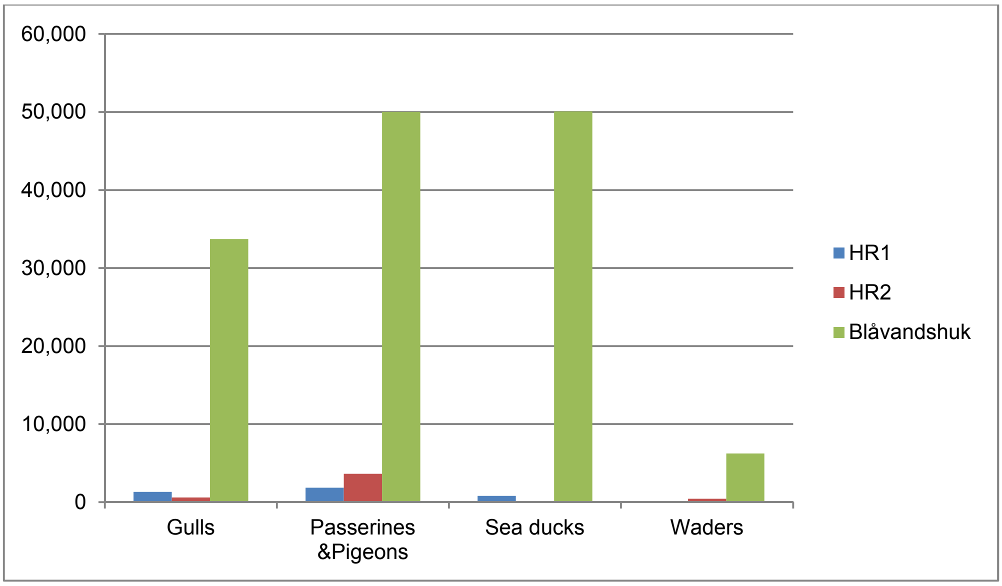


Figure 5-1. The most numerous birds grouped for each observation site

Table 5-2. Relative dominance of species in total of species observed within each group from autumn 2010 – spring 2012.

Group	Common name	Scientific name	%
Sea ducs	Common Scoter	*Melanitta nigra*	95
	Eider	*Somateria mollissima*	4
Waders	Dunlin	*Calidris alpina*	26
	Oystercatcher	*Haematopus ostralegus*	25
	Sanderling	*Calidris alba*	16
	Knot	*Calidris canutus*	15
	Golden Plover	*Pluvialis apricaria*	4
Gulls	Herring Gull	*Larus argentatus*	33
	Sandwich Tern	*Sterna sandvicensis*	21
	Common gull	*Larus canus*	11
	Black-headed Gull	*Larus ridibundus*	8
	Arctic tern	*Sterna paradisaea*	7
Passerines	Meadow pipit	*Anthus pratensis*	39
	Chaffinch	*Fringilla coelebs*	31
	Starling	*Sturnus vulgaris*	6

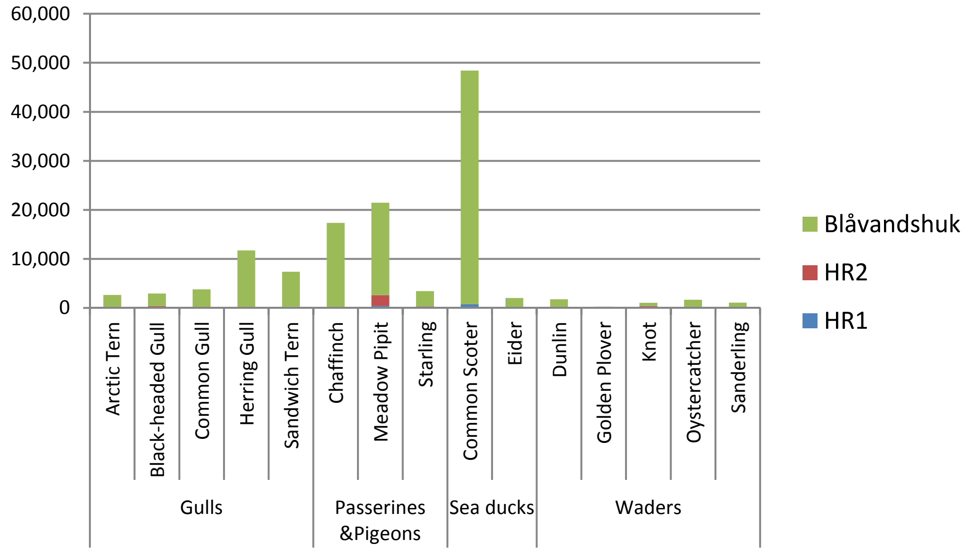


Figure 5-2. Total numbers of the most numerous migrating birds observed at Horns Rev from autumn 2010 - spring 2012.

5.1 Effort, data and weather overview

The strategy for the monitoring program was to undertake parallel observations from the Poseidon platform, from the transformer station on HR1 and from Blåvandshuk. In total, 68 days of observations were undertaken, of which parallel observations were made during 33 days. Despite logistic issues with transport to both offshore platforms, poor-moderate conditions were only encountered on seven days, and hence the overall effort achieved was satisfactory.

Appendices (Appendix 1, 2, 3) list the daily weather conditions, visual observations and radar- and rangefinder based tracks obtained during the two-year monitoring program. Compared to the monitoring data obtained during autumn 2008, this monitoring period gave a large number of detailed species-specific tracks. In total, 1,785 species-specific tracks across a wide range of species were recorded. At HR1 141 tracks were recorded by radar and 323 tracks by rangefinder, while 597 tracks were recorded by radar and 724 by rangefinder at HR2. 55 % of all species-specific tracks were of Common Scoter, reflecting the dominance of this species on Horns Rev during the period.

The observations corroborated earlier findings from Horns Rev of gradients in migration intensities from the coast and offshore (Petersen et al., 2006; Skov et al., 2009), and during the period a large number of Common Scoters were recorded feeding and resting on Horns Rev. Compared to the autumn, the abundance of diurnal migrants at Blåvandshuk was an order of magnitude lower, without any spectacular migration events. New information was received on quantities of passerines migrating offshore. This was especially noted at HR2 where large numbers of Meadow Pipit (*Anthus pratensis*) were recorded during the two autumn seasons. Still, numbers of most long-distance migrants observed at HR2 and HR1 were much lower than those recorded at Blåvandshuk. In particular, it is worth noting the very low migration intensities of raptors at HR1 and HR2. In addition, the number of species involved was also clearly higher at the coast.

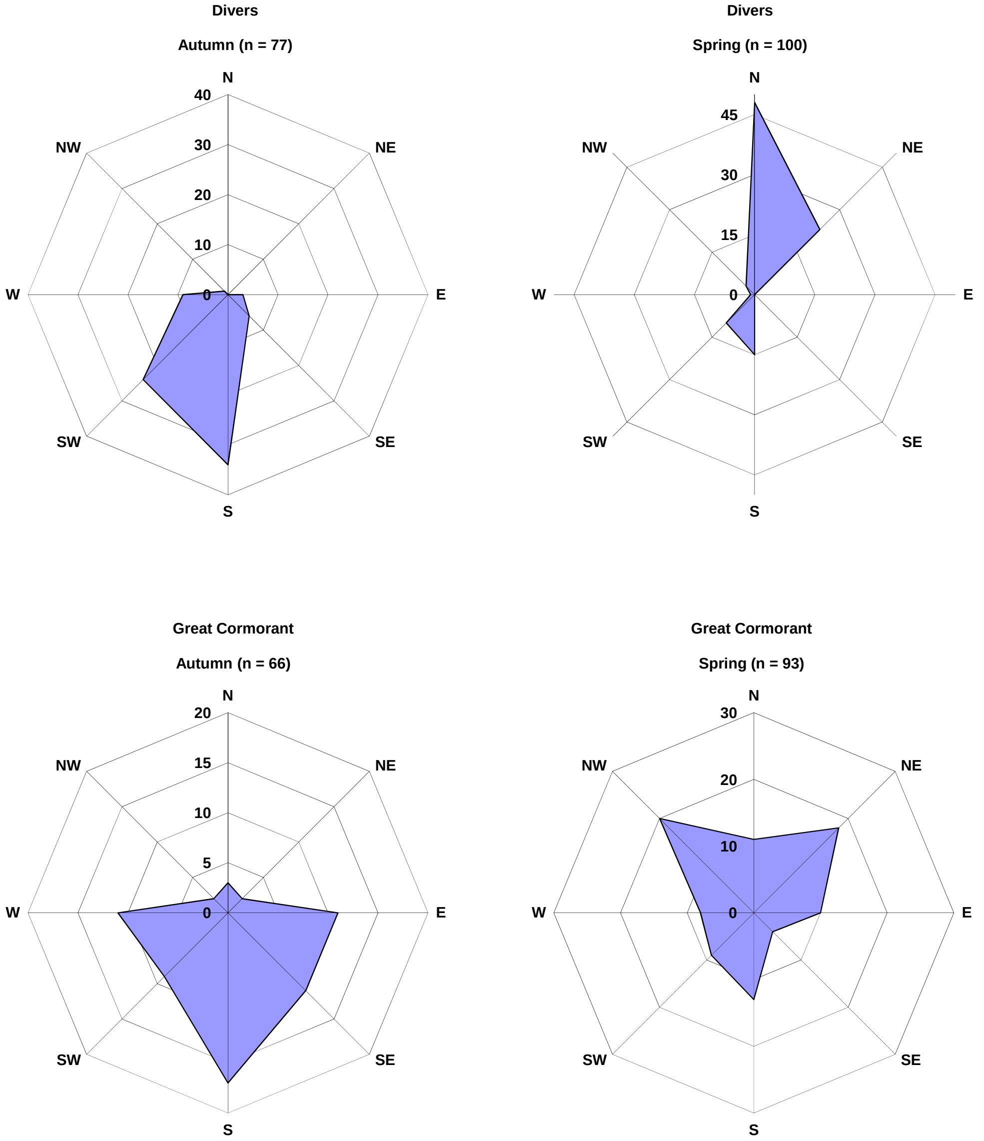
During early autumn, some migration events of terns (*Sternidae*) were mainly recorded at HR1 indicating a migration corridor for this species group located at some distance from the coast. During spring, the passage of Little Gulls (*Larus minutus*) was noticeably larger offshore compared to at Blåvandshuk, a situation which may be typical as moderate to large numbers of this species are seen regularly on Horns Rev during spring (Petersen et al., 2006).

5.2 Migration directions

The combined radar and rangefinder tracks showed that divers, small gulls, waders, terns, raptors, pigeons and passerines generally moved between southeast and southwest during autumn and between north and northeast during spring Figure 5 1. However, some variation in these patterns can be observed. During spring, most waders were recorded moving south-southeast, possibly cross North Sea migrants arriving Horns Rev from wintering areas in Great Britain. Also during spring, terns had a main migration direction towards NW, - a direction which may indicate birds crossing of the North Sea to breeding areas in the North Atlantic.

Cormorants *Phalacrocorax carbo*, Gannets *Sula bassana*, Common Scoter *Melanitta nigra*, large gulls and Kittiwakes (*Rissa tridactyla*) all displayed patterns with limited directional trend, thus indicating birds which use the HR1 and HR2 areas for feeding and resting during the non-breeding season. During spring, it should be noted that a large number of tracks of Common Scoter was recorded moving in north-westerly direction along the main axis of Horns Rev.

Merlin at Horns Rev 2



Divers

Autumn (n = 77)

Divers

Spring (n = 100)

Great Cormorant

Autumn (n = 66)

Great Cormorant

Spring (n = 93)

Figure 5-3. Mean migration direction of radar- and rangefinder-based recordings of bird species during autumn 2010 – spring 2012. The graphs demonstrate movement and migration types which may be summarised as patterns typical for the long-distance migrants and local, foraging waterbirds (Continued)

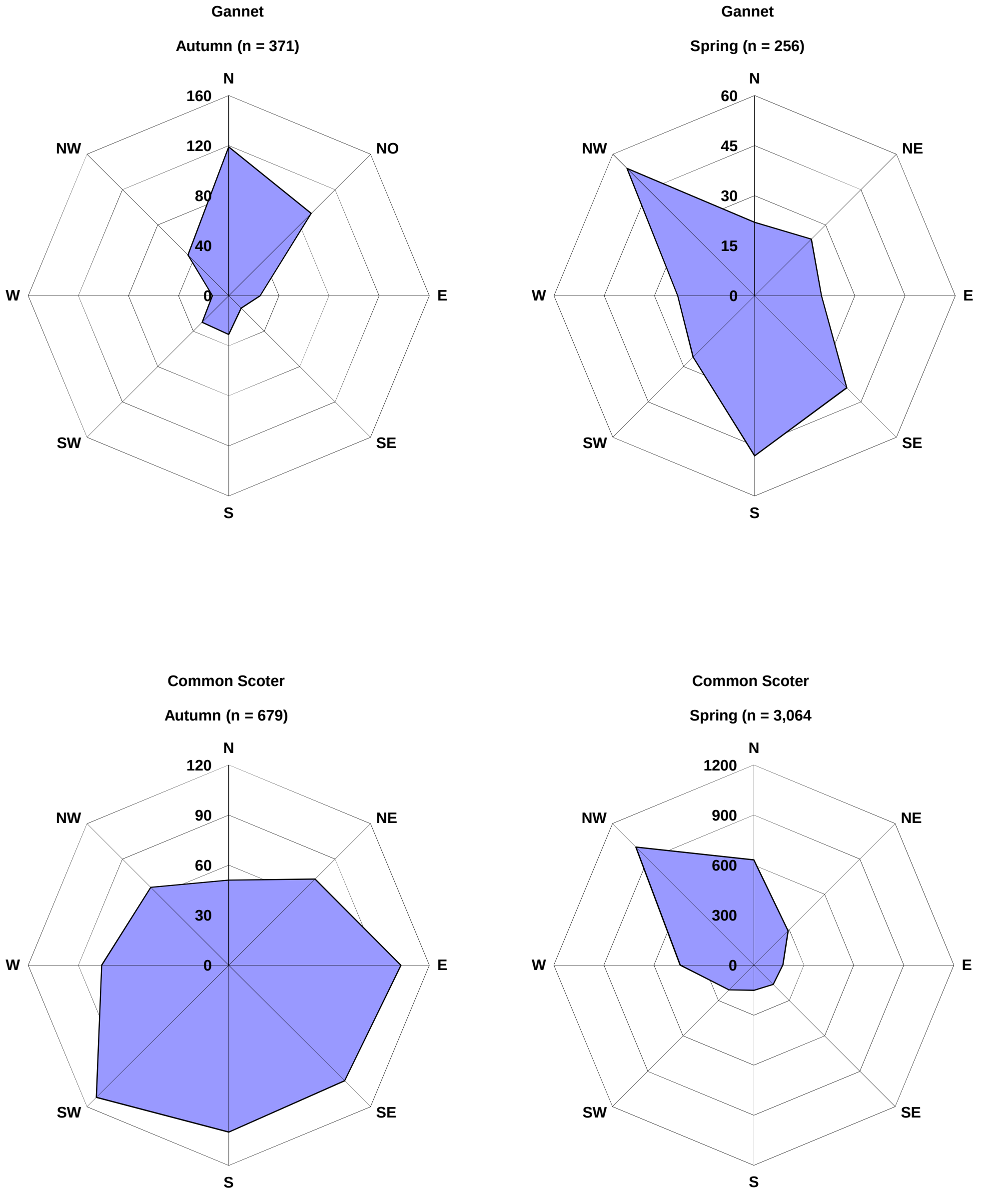


Figure 5-4. Continued. Mean migration direction of radar- and rangefinder-based recordings of bird species during autumn 2010 – spring 2012. The graphs demonstrate movement and migration types which may be summarised as patterns typical for the long-distance migrants and local, foraging waterbirds (Continued)

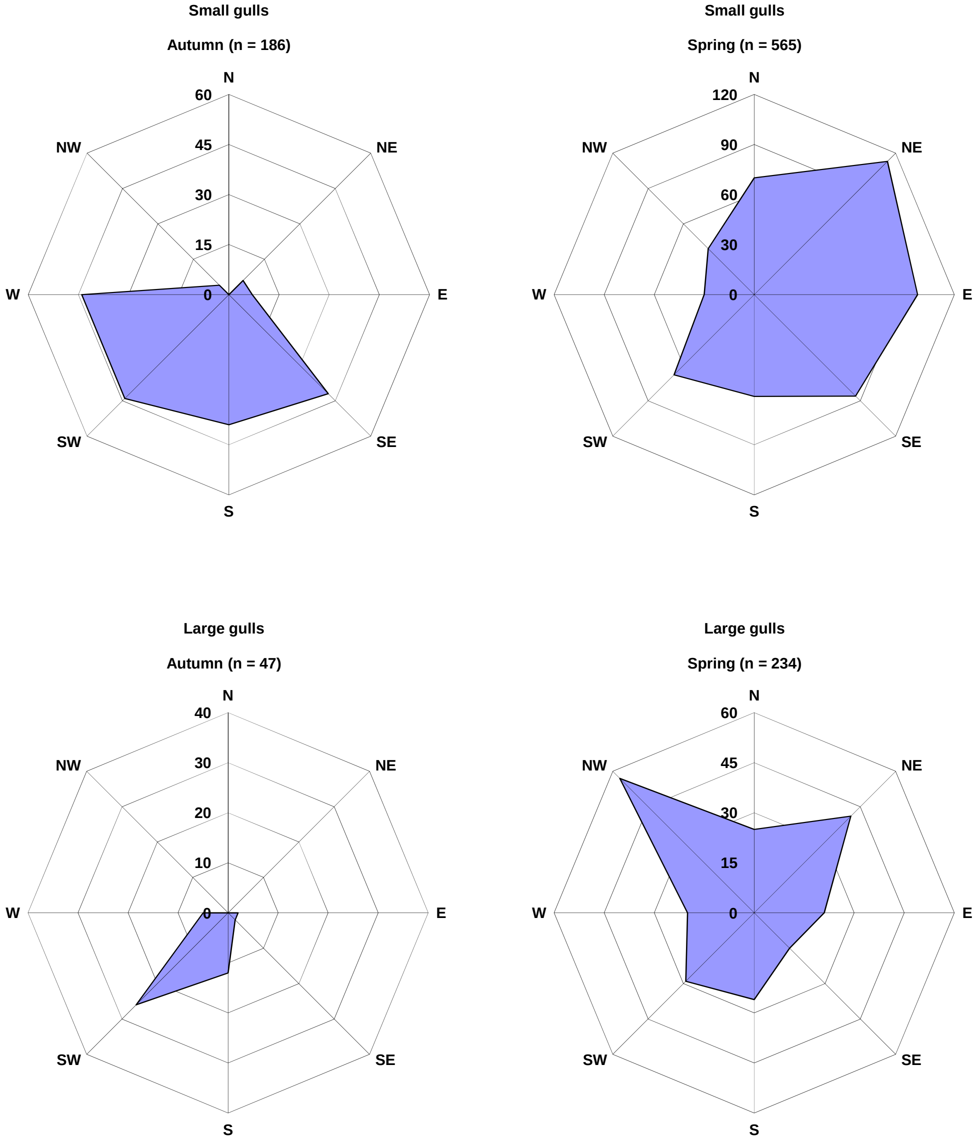


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Figure 5-5. Continued. Mean migration direction of radar- and rangefinder-based recordings of bird species during autumn 2010 – spring 2012. The graphs demonstrate movement and migration types which may be summarised as patterns typical for the long-distance migrants and local, foraging waterbirds (Continued

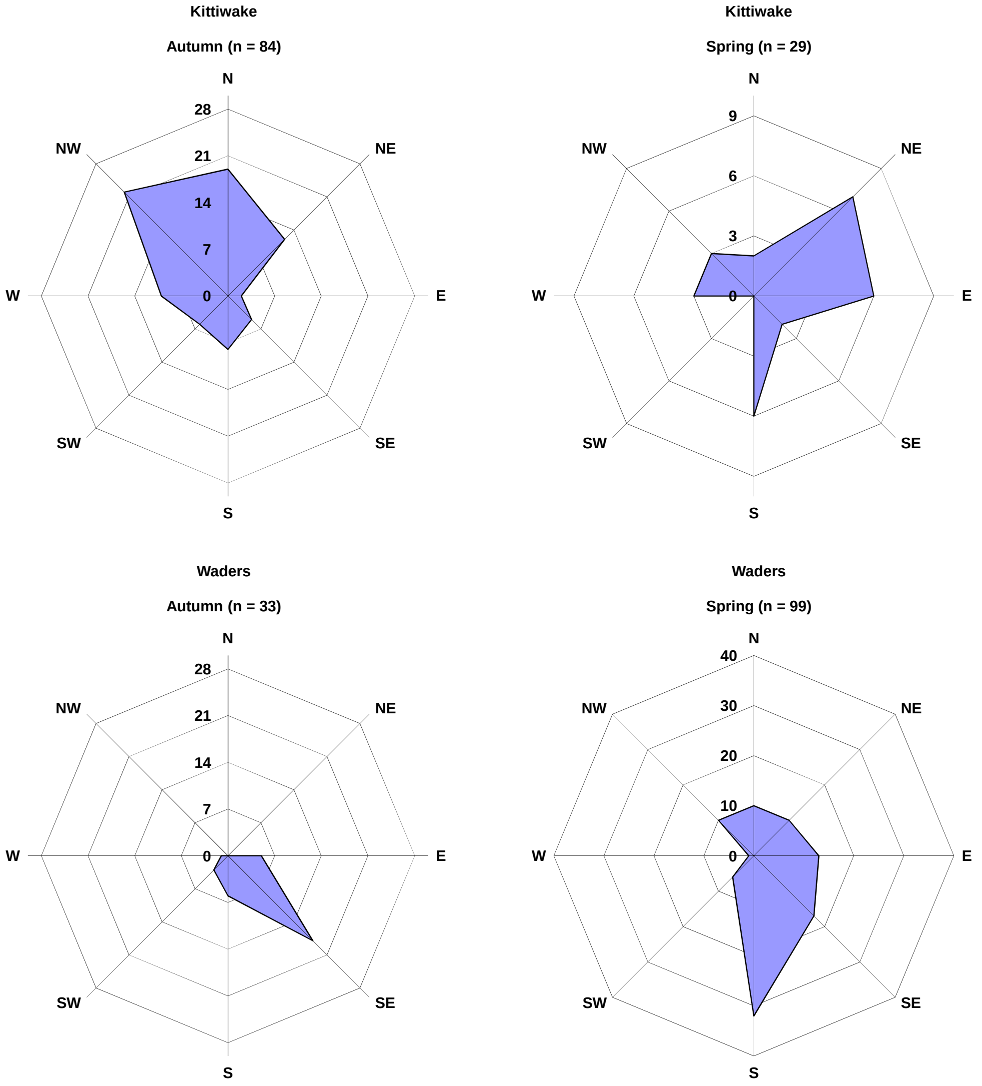


Figure 5-6. Continued. Mean migration direction of radar- and rangefinder-based recordings of bird species during autumn 2010 – spring 2012. The graphs demonstrate movement and migration types which may be summarised as patterns typical for the long-distance migrants and local, foraging waterbirds (Continued)

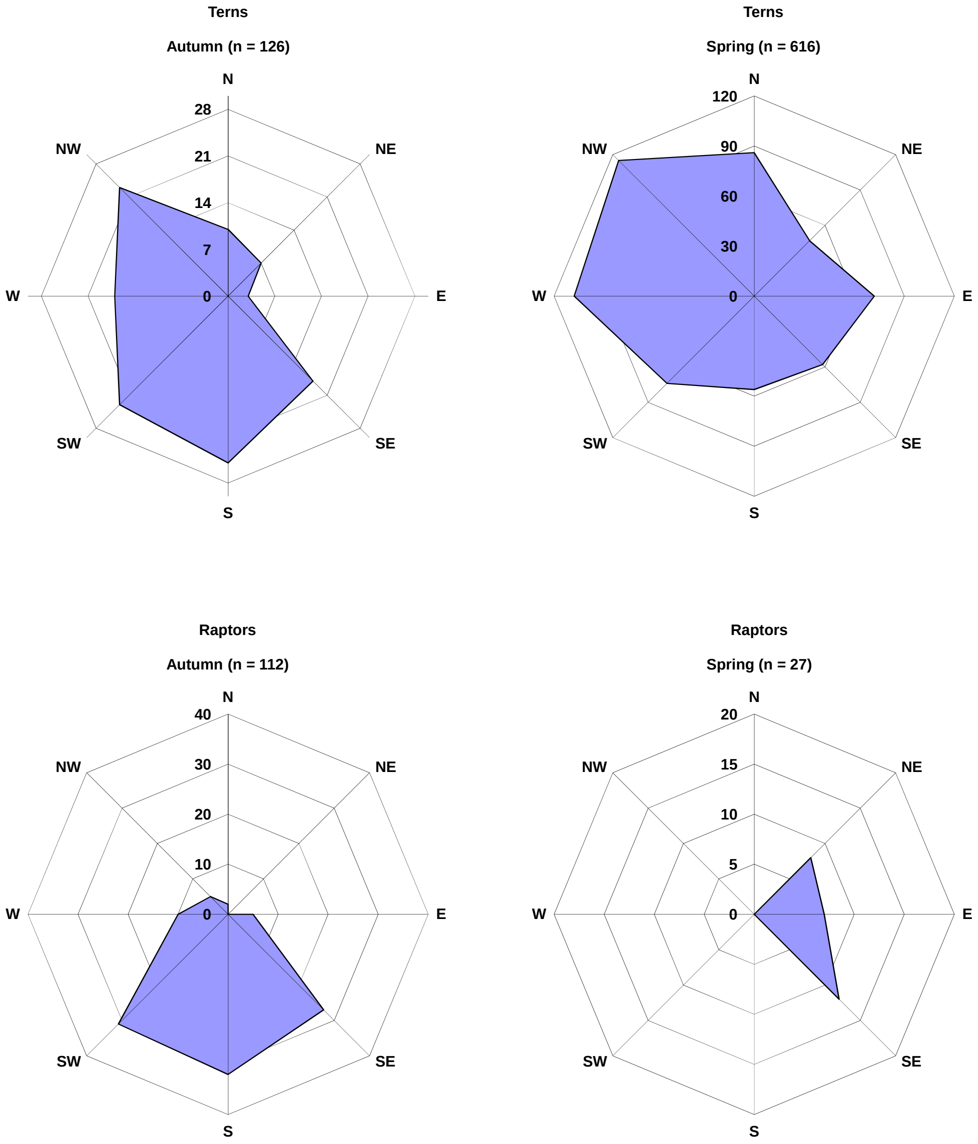


Figure 5-7. Continued. Mean migration direction of radar- and rangefinder-based recordings of bird species during autumn 2010 – spring 2012. The graphs demonstrate movement and migration types which may be summarised as patterns typical for the long-distance migrants and local, foraging waterbirds (Continued)

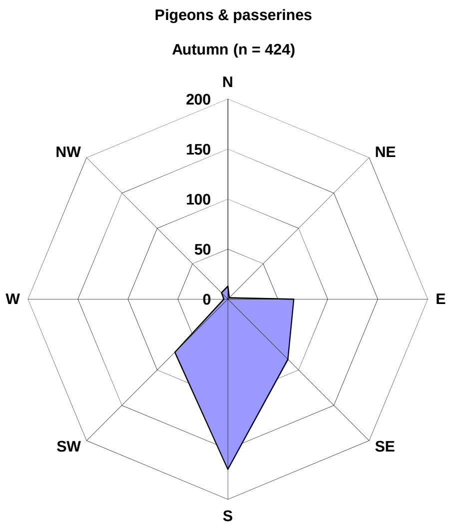


Figure 5-8. Continued. Mean migration direction of radar- and rangefinder-based recordings of bird species during autumn 2010 – spring 2012. The graphs demonstrate movement and migration types which may be summarised as patterns typical for the long-distance migrants and local, foraging waterbirds.

5.2.1 Blåvandshuk

Based on the visually observed data from Blåvandshuk the main migration for all groups followed the generally expected migration towards north in the spring and towards south in the autumn Figure 5-9. Gannets and sea ducks - mainly Common Scoter – displayed a less distinct migration patterns more reflecting foraging behaviour in the wintering area.

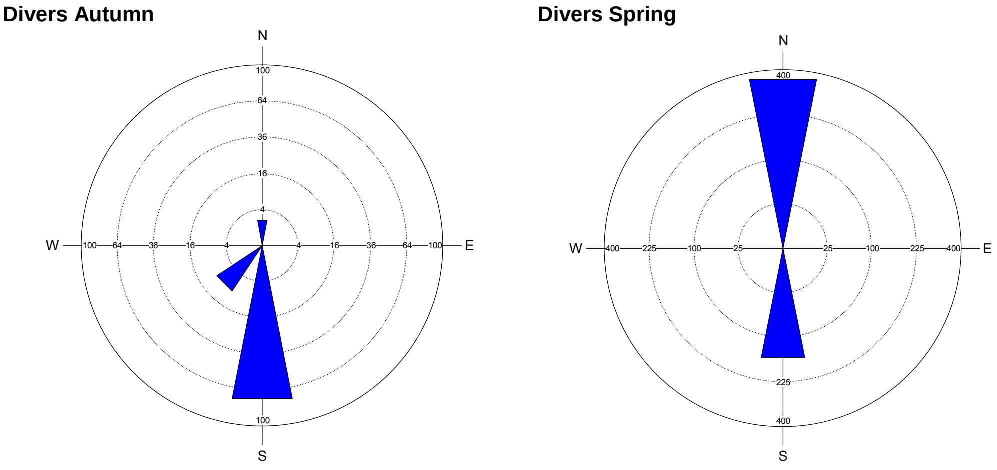
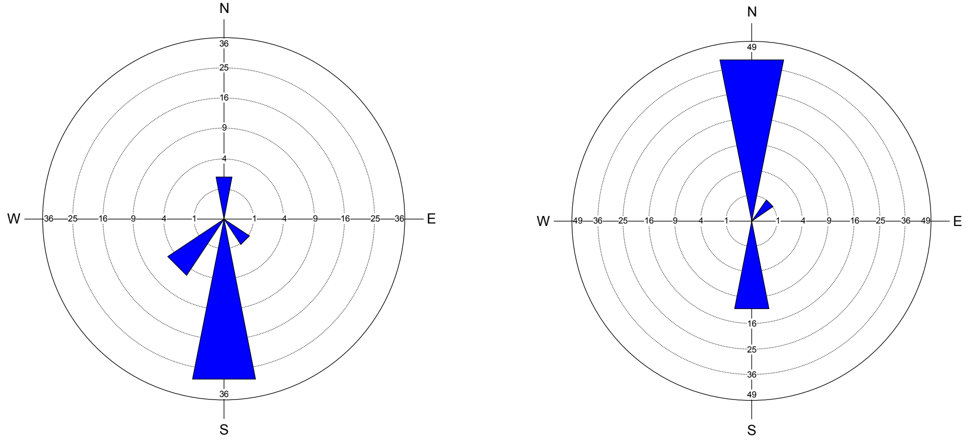
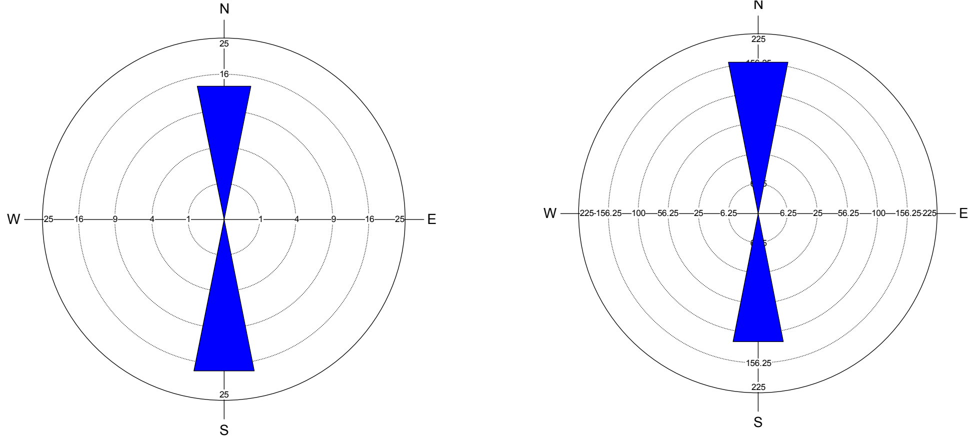


Figure 5-9. Main migration of visual based observations of bird species at Blåvandshuk during autumn 2010 – spring 2012 (Continued).



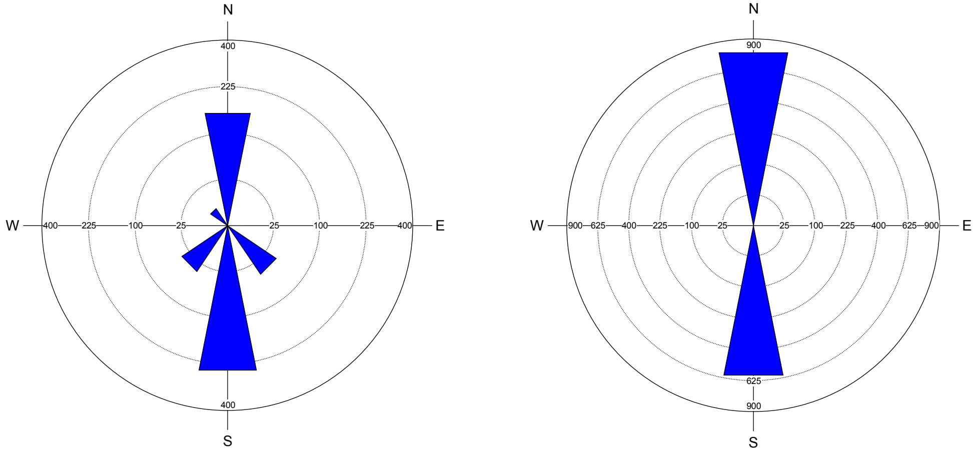
Cormorant Autumn

Cormorant Spring



Gannet Autumn

Gannet Spring

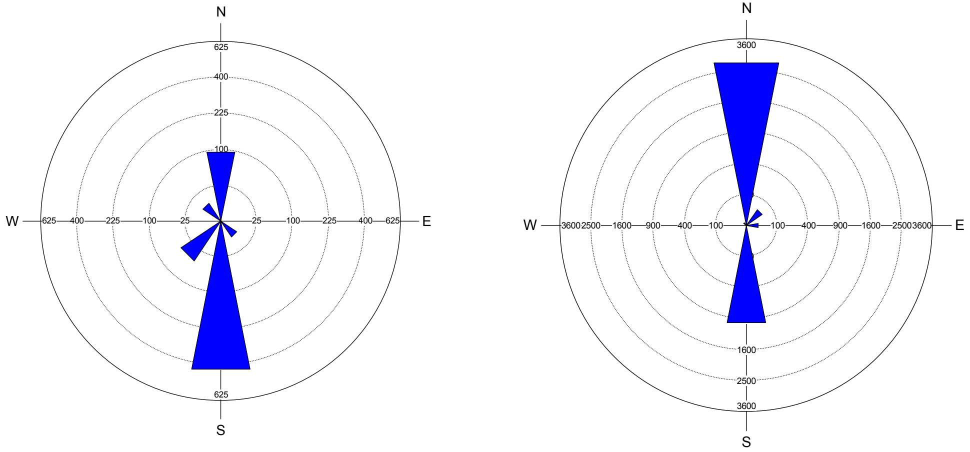


Sea ducks Autumn

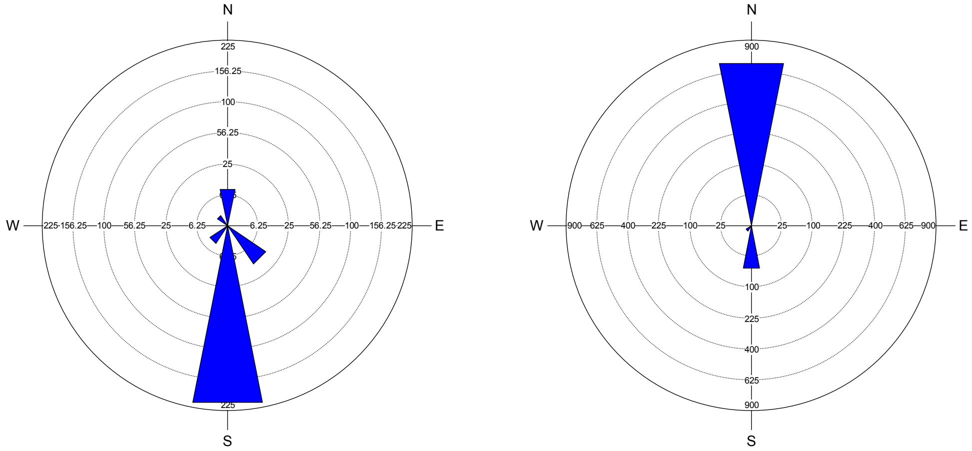
Sea ducks Spring

Figure 5-10.Continued. Main migration of visual based observations of bird species at Blåvandshuk during autumn 2010 – spring 2012 (Continued).

Gulls Autumn **Gulls Spring**



Waders Autumn **Waders Spring**



Passerines Autumn **Passerines Spring**

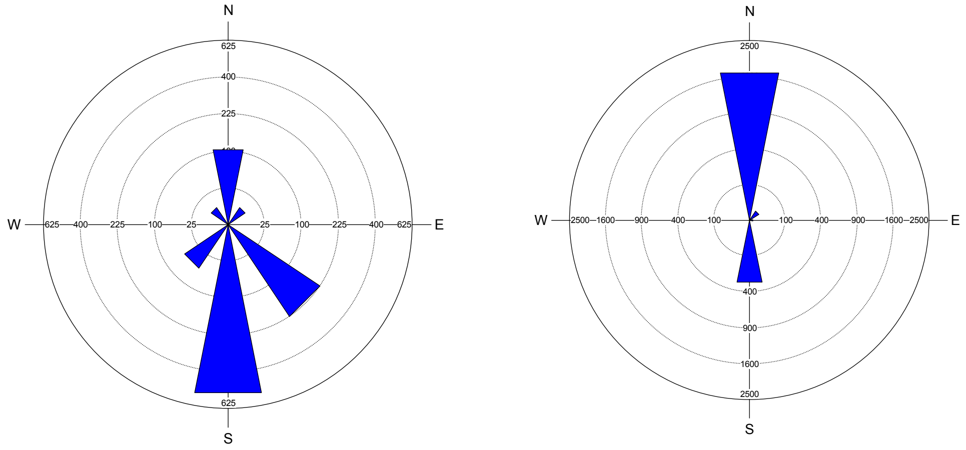


Figure 5-11. Continued. Main migration of visual based observations of bird species at Blåvandshuk during autumn 2010 – spring 2012.

5.3 Movements patterns

The spatial patterns of the recorded radar and rangefinder tracks in relation to the geometry of hr1 and hr2 are visualised for the key species (groups) in Figure 5-12 - Figure 5-22. all key species were recorded (albeit some rarely) moving into the wind farm area, yet with the exception of Cormorants, large gulls and terns they only seemed to enter the wind farms irregularly, and judged from the plots they showed movements which indicate barrier effects and a reduced risk of colliding with the turbines.

For divers, Gannets and Common Scoters the wind farms seem to give rise to movement corridors along the periphery of the wind farms. This effect is most clearly seen at HR2 which N-S movements of the three species were noted along the eastern boundary of the wind farm. In spite of the dominance of movements of these three species outside the wind farms, some complex movements of Common Scoters were recorded at HR2. These movements include birds penetrating the wind farm in the central sector, where the water depth is less than 10 m.

Figure 5-12. Recorded tracks of Red-throated/Black-throated Diver in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.. .

Figure 5-13. Recorded tracks of Great Cormorant in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares..

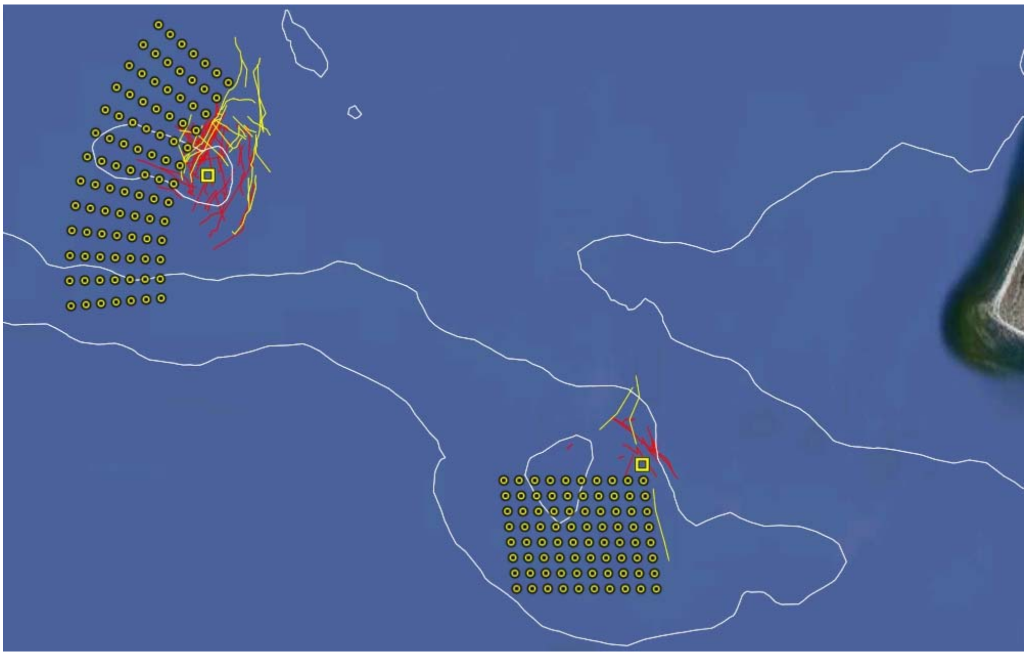


Figure 5-14. Recorded tracks of Gannet in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares..

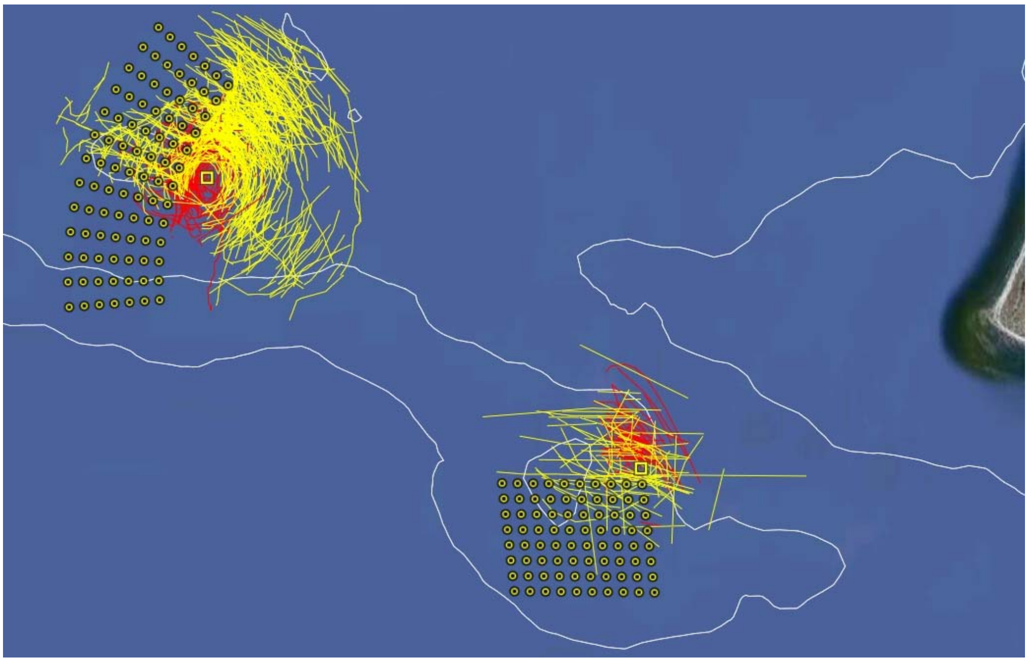


Figure 5-15. Recorded tracks of Common Scoter in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.

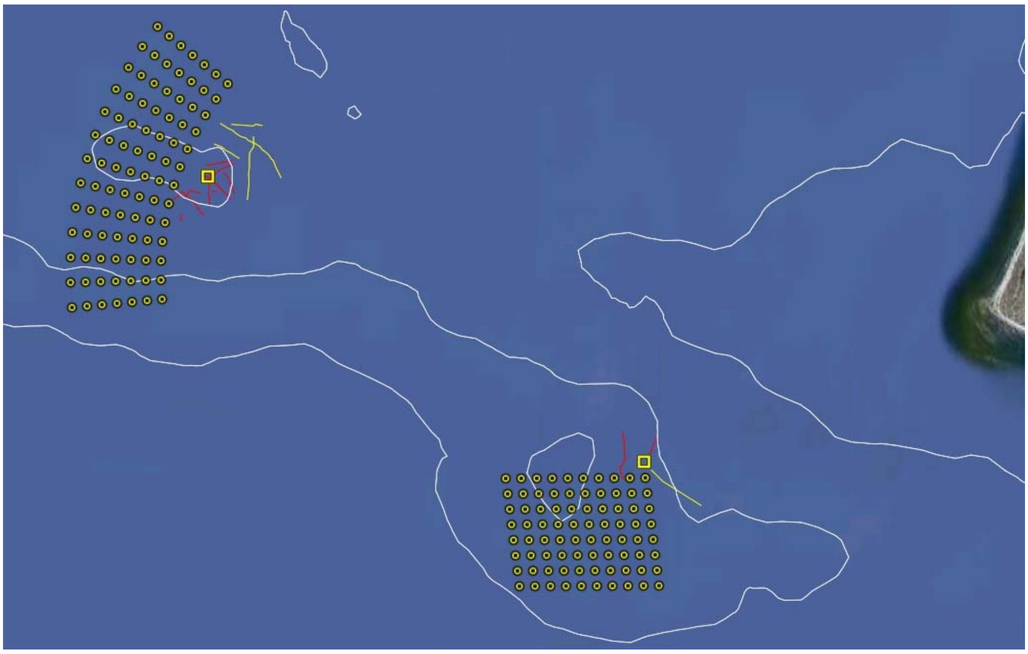


Figure 5-16. Recorded tracks of waders in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares..

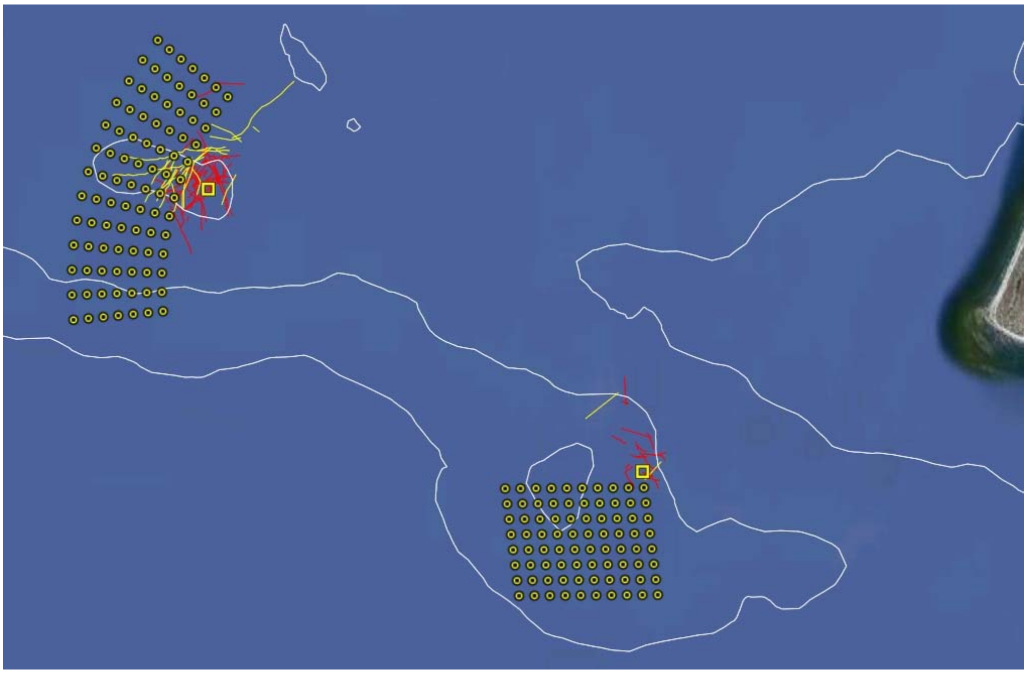


Figure 5-17. Recorded tracks of small gull species in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.

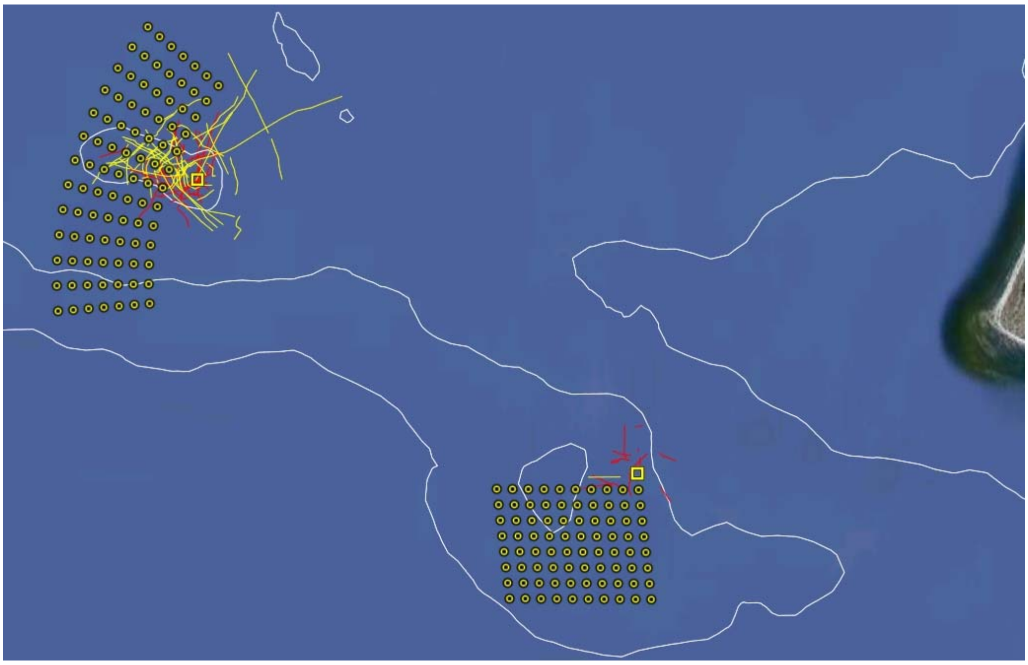


Figure 5-18. Recorded tracks of large gull species in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.

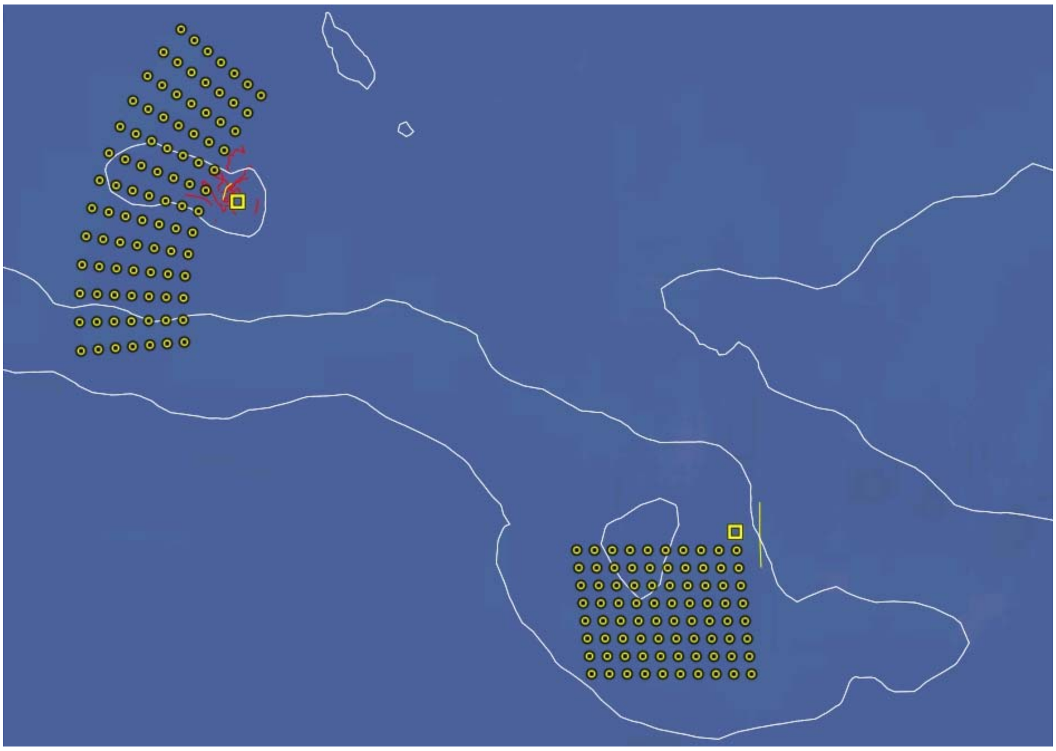


Figure 5-19. Recorded tracks of Black-legged Kittiwake in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.

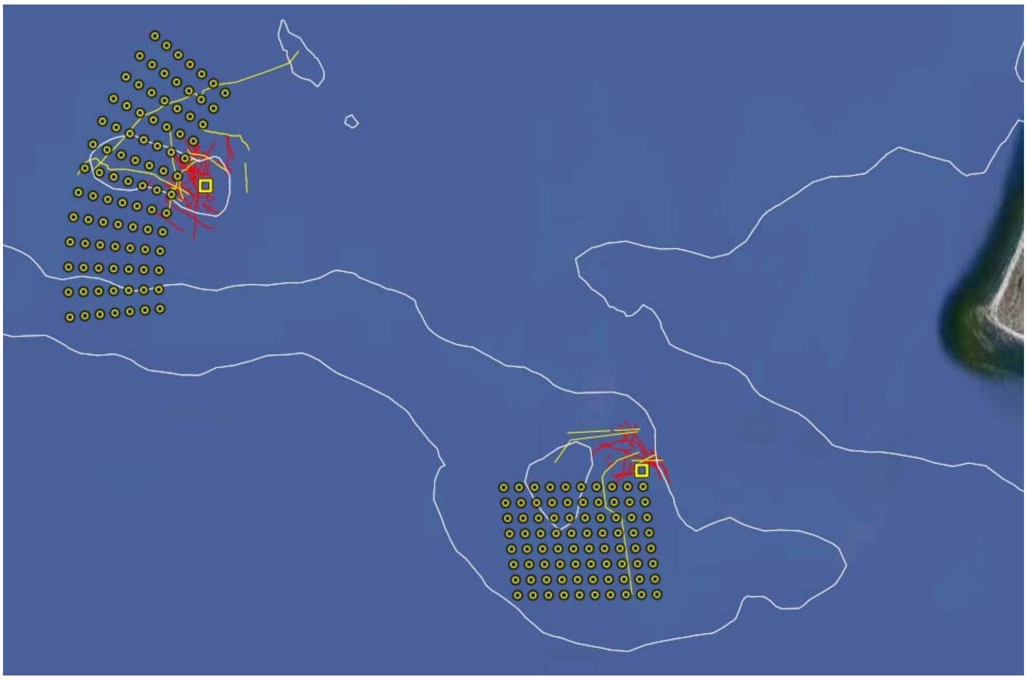


Figure 5-20. Recorded tracks of terns in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.

Figure 5-21. Recorded tracks of raptors in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.

Figure 5-22. Recorded tracks of pigeons and passerines in the study area autumn 2010 – spring 2012. Radar-based tracks are marked by yellow lines, and rangefinder-based tracks by red lines. The 10 m depth curve is indicated. Map source: Google Earth. Observation platforms – the “Alpha” HR1 and “Poseidon” HR2 transformer platform - are indicated by yellow squares.

5.4 Barrier effects

The obvious tendency for birds to align their movements along the periphery of HR1 and HR2 as seen in the previous chapter was quantified for each site in terms of gradients in density and changes in flight directions using multiple regression techniques. A barrier effect would be established provided both an increase in density and change in flight direction with decreasing distance from the wind farm were identified.

5.4.1 HR2

Predictor variables 'distance to radar' and 'distance to wind farm' turned out being significant in both models, when response variable was 'tracks of all birds' and 'tracks of Common Scoters', Table 5-3. Response curves were of similar shape in both models (Figure 5-23), which is not surprising since Common Scoters made a substantial proportion of all bird tracks. The models showed that track count peaked at about 1500-2500 meters from the radar and declined further out. Lower recordings of birds closer to the radar could indicate disturbance effect of the observation platform (Poseidon) together with limitations of the radar to record bird tracks in close proximity due to suppression filters for ground clutter. In relation to the wind farm, bird tracks peaked at the distance of 1500-2500 meters, and that was especially pronounced for the Common Scoter tracks (Figure 5-23). This could be interpreted as a barrier effect, when birds stop and/or change their flight paths after approaching the wind farm. This is also visible in maps when plotting recorded tracks density (Figure 5-24, Figure 5-25).

Table 5-3. Significance and F-values of predictor variables in GAMs for all bird tracks and Common Scoter tracks only as recorded by the radar at HR2 wind farm. Adjusted R-square values and variance explained by the models are also provided.

Parameter	Response: all bird tracks		Response: Common Scoter tracks	
	F-value	p-value	F-value	p-value
Distance to radar	321.5	<0.01	434.4	<0.01
Distance to wind farm	286.4	<0.01	191.4	<0.01
R-sq. (adj)	0.11		0.19	
Deviance explained	18.6%		21.9%	

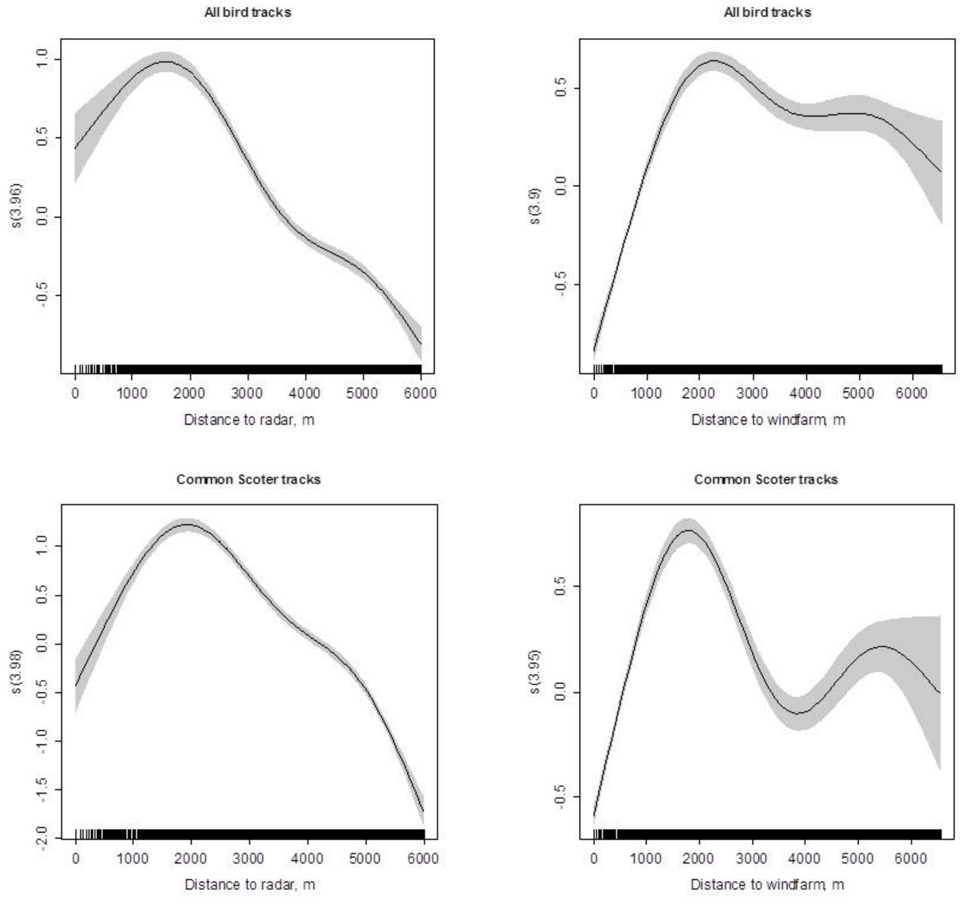


Figure 5-23. Response curves of the GAMs displaying the relationship between density of all bird tracks (upper two charts) with distance to the radar and distance to the HR2 wind farm, and the same for the Common Scoter tracks only (lower two charts). The values of the predictors are shown on the X-axis and the probability on the Y-axis in log scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas show the 95% confidence intervals.

Chiffchaff roosting at Horns Rev 1

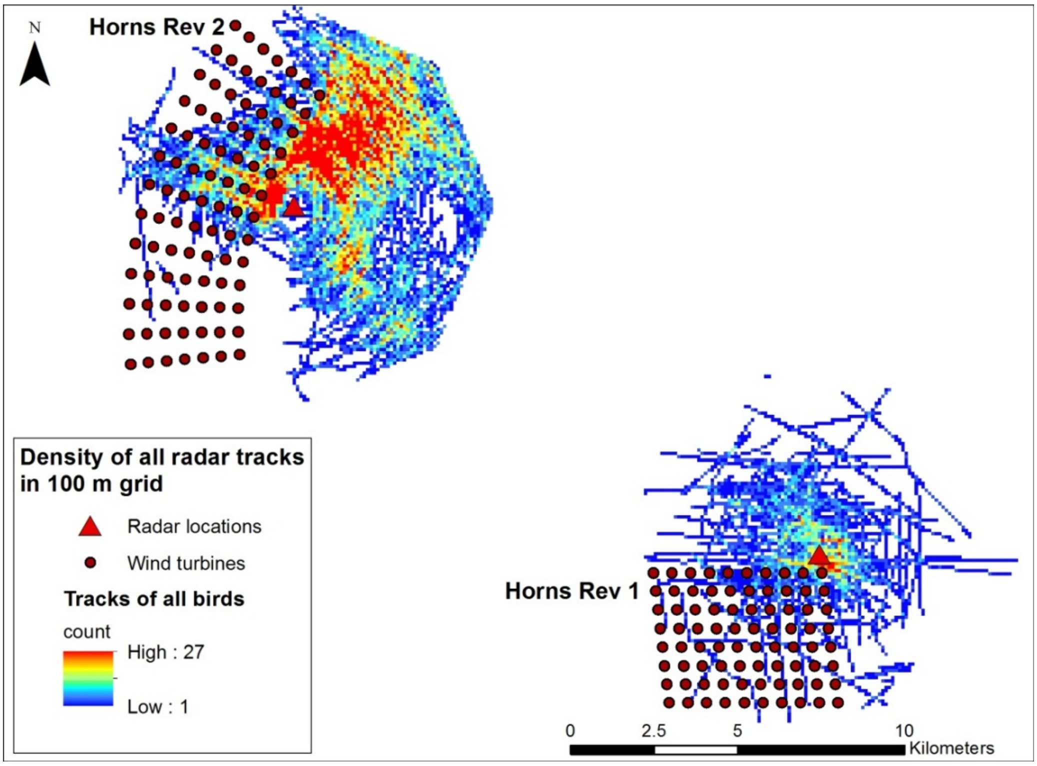


Figure 5-24. Mapped density of all bird tracks recorded by radars at HR1and HR2 wind farms.

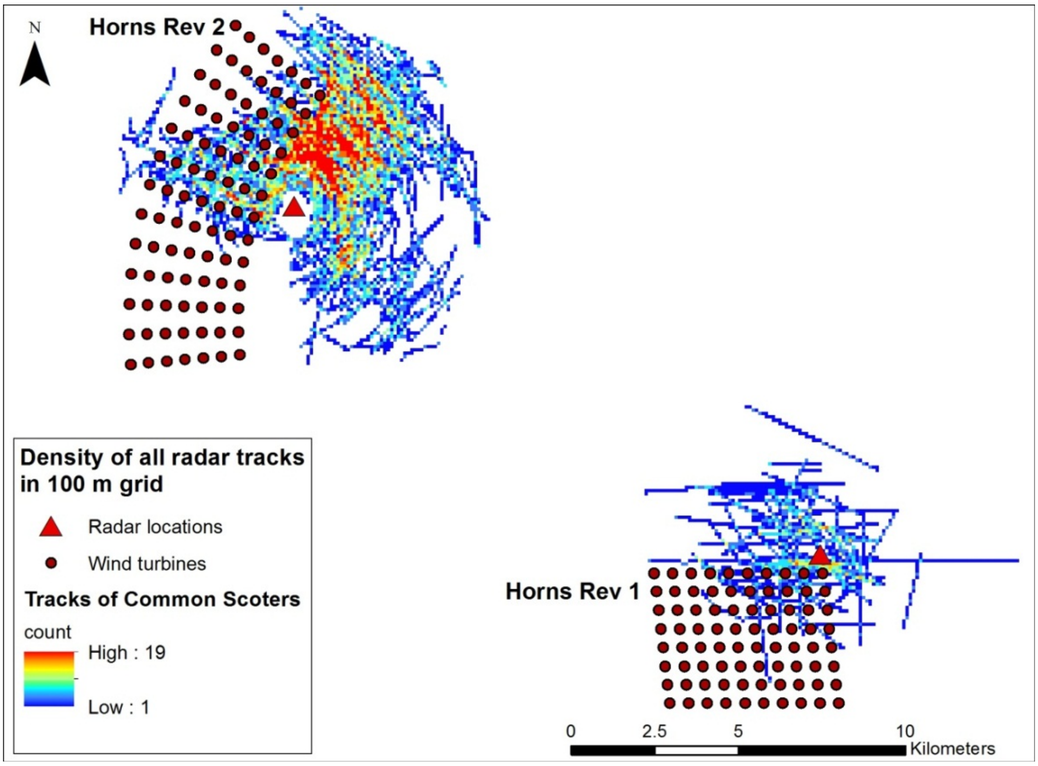


Figure 5-25. Mapped density of all Common Scoter tracks recorded by radars at HR1and HR2 wind farms.

5.4.2 HR1

Predictor variables ‘distance to radar’ and ‘distance to wind farm’ were also significant in both models, when response variable was ‘tracks of all birds’ and ‘tracks of Common Scoters’ at HR1 (Table 5-4). Also, response curves were of similar shape in both models (Figure 5-26), which is not surprising since Common Scoters made a substantial proportion of all bird tracks. Differently from the model fitted for HR2 wind farm, HR1 models showed that track count gradually declined with increasing distance from the radar fitted on the transformer platform. In relation to the wind farm, tracks of all birds together peaked at the distance of 2,000-3,000 m from the wind farm, and the peak of Common Scoter tracks alone was somewhat closer – at 1,000-2,000 m from the wind farm (Figure 5-24, Figure 5-25).

Table 5-4. Significance and F-values of predictor variables in GAMs for all bird tracks and Common Scoter tracks only as recorded by the radar at HR1wind farm. Adjusted R-square values and variance explained by the models are also provided.

Parameter	Response: all bird tracks		Response: Common Scoter tracks	
	F-value	p-value	F-value	p-value
Distance to radar	643.9	<0.01	668.2	<0.01
Distance to wind farm	22.4	<0.01	14.5	<0.01
R-sq. (adj)	0.50		0.32	
Deviance explained	35.5%		36.7%	

The tests of the change in flight direction with distance to the wind farms were focused on Common Scoter. The probability of the Common Scoter, according to the model, to fly towards a wind turbine decreased with decreasing distance to the turbines. The probability decreased more steeply after about ca. 1.5 km (Figure 5-27, Figure 5-28). The probability of flying towards a turbine was also higher in both spring seasons in comparison to the autumn. The probability was further higher in head winds, than in side and tail winds (tail wind was not significantly different from headwinds). We included the Y-coordinates as a predictor as the birds seemed to fly towards the turbines (as defined in the response variable) in the NE part of the wind farm when they were actually rounding the wind farm. The Y-coordinates, at least partly accounted for this as the variable was highly significant (Figure 5-27, Table 5-5

The model explained 20 % of the variance in the data. In conclusion, barrier effect to birds by HR1 and HR2 was detected in both track datasets, and the models showed bird track densities peaking at distances of 1,000-2,500 m to the wind farm perimeter, and the probability to fly towards the wind farm decreased steeply at 1,500 m distance.

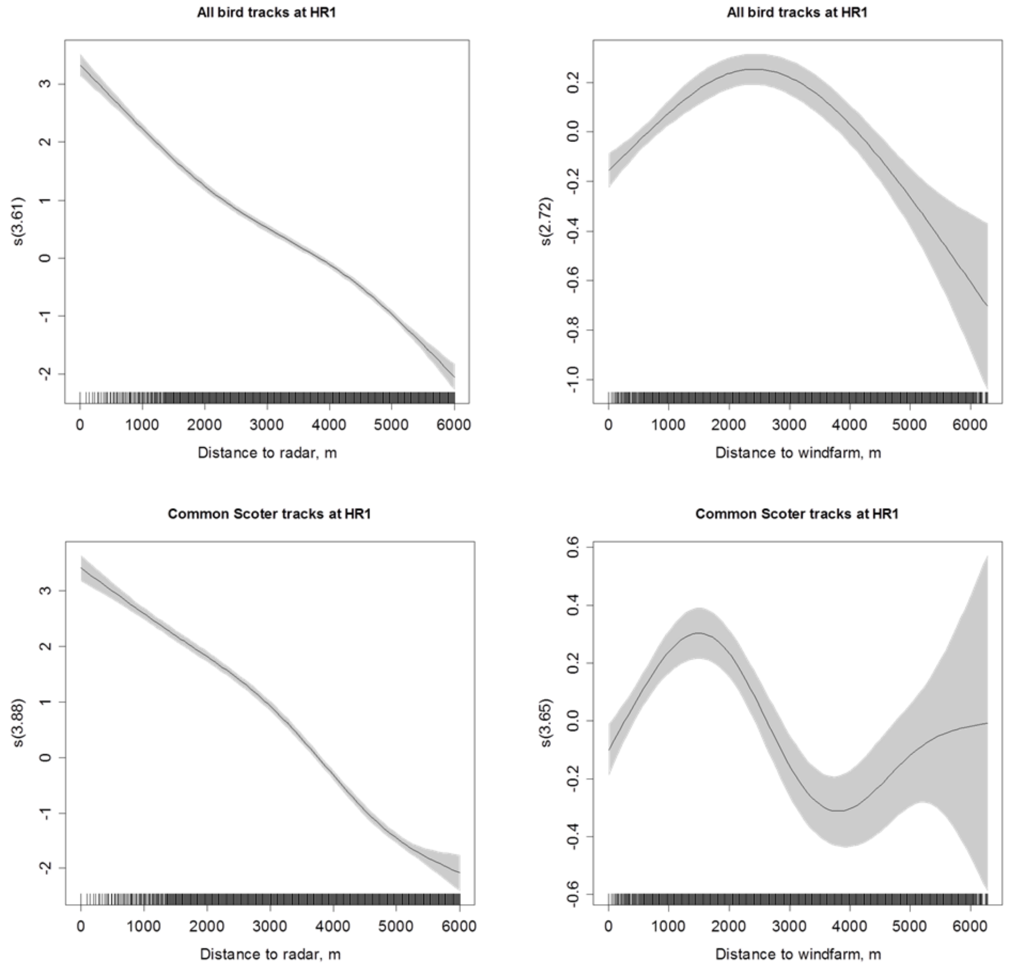


Figure 5-26. Response curves of the GAMs displaying the relationship between density of all bird tracks (upper two charts) with distance to the radar and distance to the HR1wind farm, and the same Common Scoter tracks only (lower two charts). The values of the predictors are shown on the X-axis and the probability on the Y-axis in log scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas show the 95% confidence intervals.

Roosting Grey Plower

Table 5-5. Significance and t- and F-values for the fixed parametric (wind directions, wind farm and survey year) and smooth terms included in the GAMM for the Common Scoter. The model was evaluated by fitting the model on 70% and testing the predictive accuracy on 30% by estimating Spearman's rank correlation between observed and predicted altitudes. Adjusted R-square value is given as an indication of variance explained by the model.

		t-value	**p-value**
Parametric	Tail wind	-3.520	0.08
	Side wind	-1.702	<0.01
	Season 2	2.403	0.02
	Season 3	-1.935	0.05
	Season 4	1.897	0.06
Smooth		**F-value**	**p-value**
	Dist. to turbine	13.18	<0.01
	Y-coordinates	20.45	<0.01
R-sq. (adj)		0.20	
Sample size		2,862	

Observers platform at Horns Rev 1

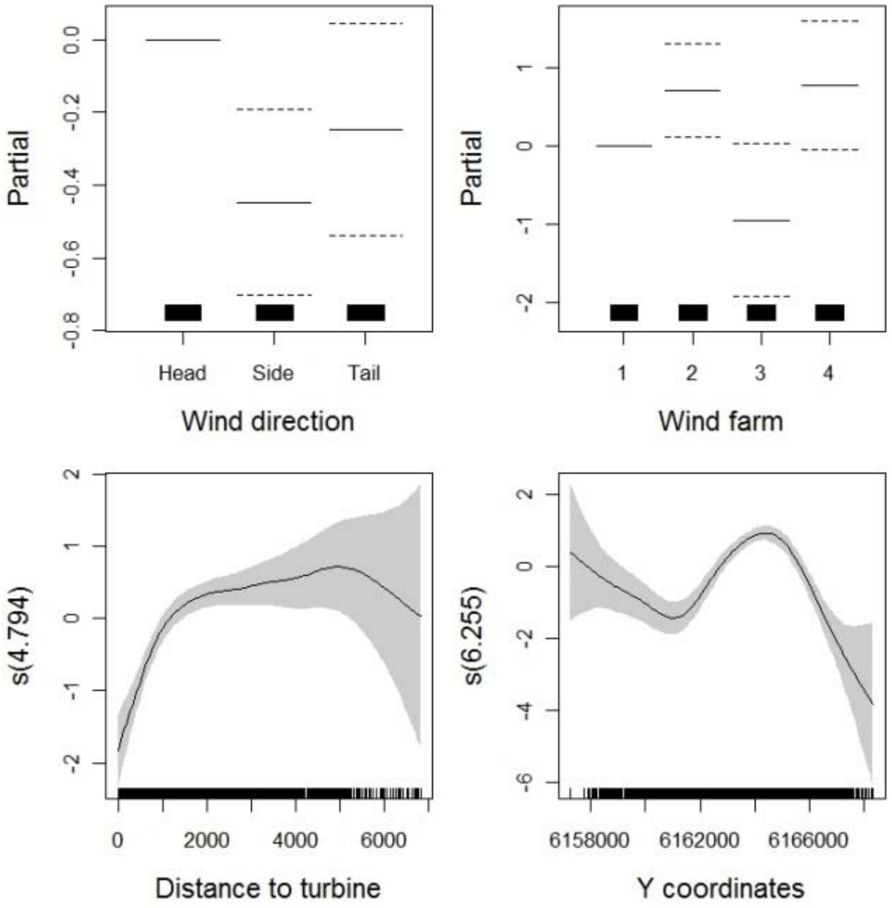


Figure 5-27. Response curves of the GAMM for the Common Scoter displaying the relationship between flight direction and predictor variables. The values of the environmental predictors are shown on the X-axis and the probability on the Y-axis in logit scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas and the dotted lines show the 95% Bayesian confidence intervals

Chaffinch roosting at Horns Rev 1

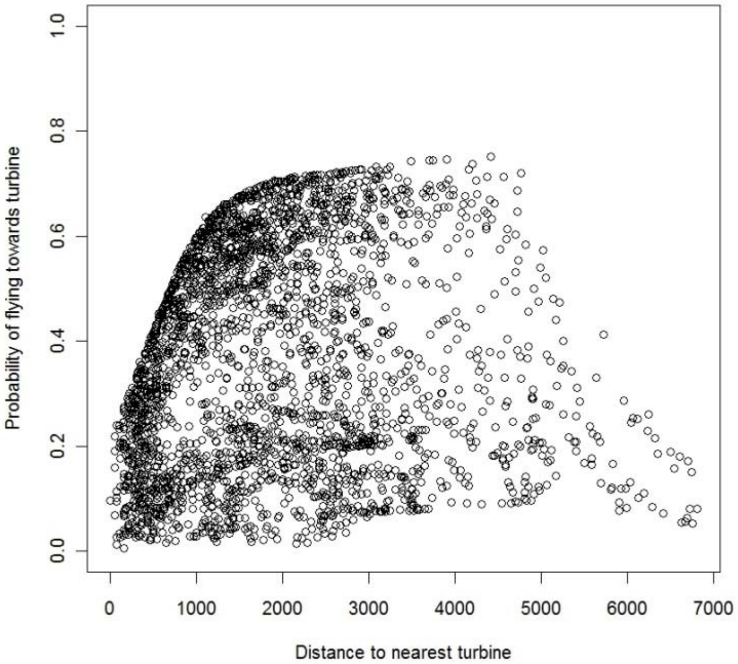
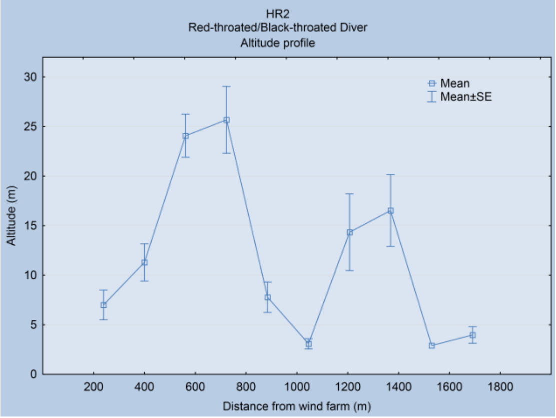


Figure 5-28. The predicted probability (when accounting for the other influential variables in the GAMM) of Common Scoter flying towards the wind turbines plotted against the distance to the closest wind turbine. The probability of flying towards a turbine decreases with decreasing distance to the closest turbine.

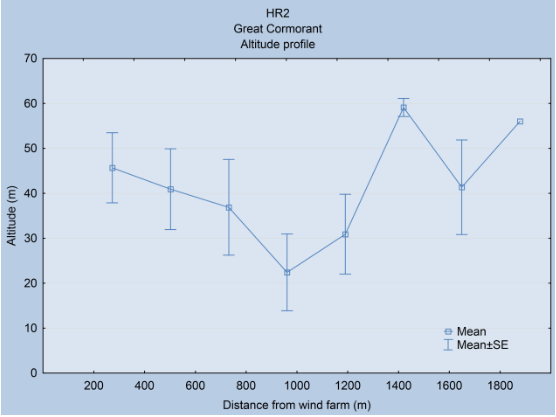
5.5 Flight altitude

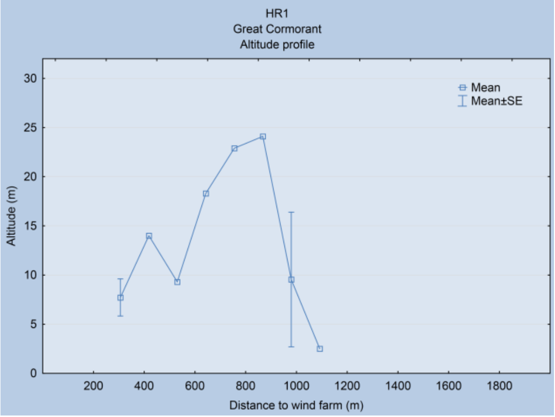
The altitude data recorded by the laser rangefinders have been summarised in Figure 5-29, as profiles related to the distance to HR1/HR2. The altitude profiles of the majority of species show a preference for low altitude flights, particularly for the seabird species which all predominantly fly below the rotors when they approach the two wind farms. Only large gull species (Herring Gull, Lesser Black-backed Gull, Great Black-backed Gull), raptors, pigeons and passerines generally fly at rotor height close to the wind farms. On approach to HR1, large gulls seemingly increase mean altitude from just above sea surface to rotor height, while at HR2 this is only evident in birds flying in side winds. Landbird tracks recorded at HR2 indicate raptors, pigeons and passerines increasing altitude close to the wind farm, yet may fail to gain sufficient height to be above the rotors if they cross the wind farm.

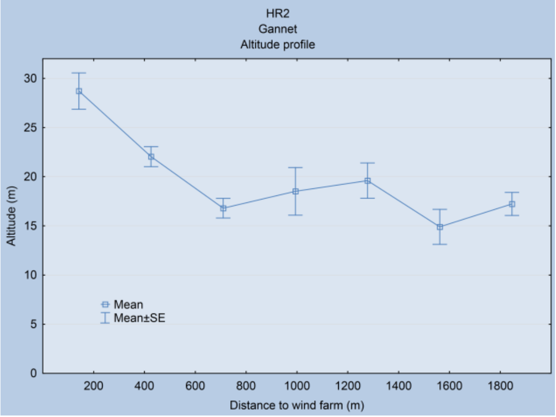
Most seabird species display much variation in flight altitude both in relation to distance to wind farm and between the two sets of data from each wind farm. Thus, any generalisation of flight patterns related both to weather conditions and wind farm requires the application of altitude models which take account of the variation in these parameters.



Red-throated Diver at Horns Rev 2







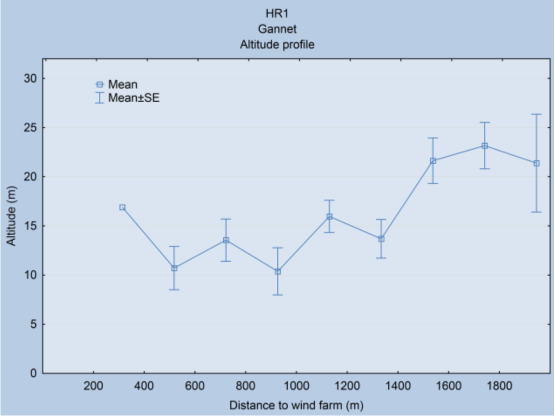


Figure 5-29. Altitude profiles of key species recorded by rangefinder at HR1 and HR2 showing the mean and SE altitude as a function of distance from the turbines in the two wind farms. Depending on the sample obtained, the measured altitude during different wind conditions is shown. Lowest tip of rotor above sea level HR2 (21.5 m) HR1 (30 M). (Continued).

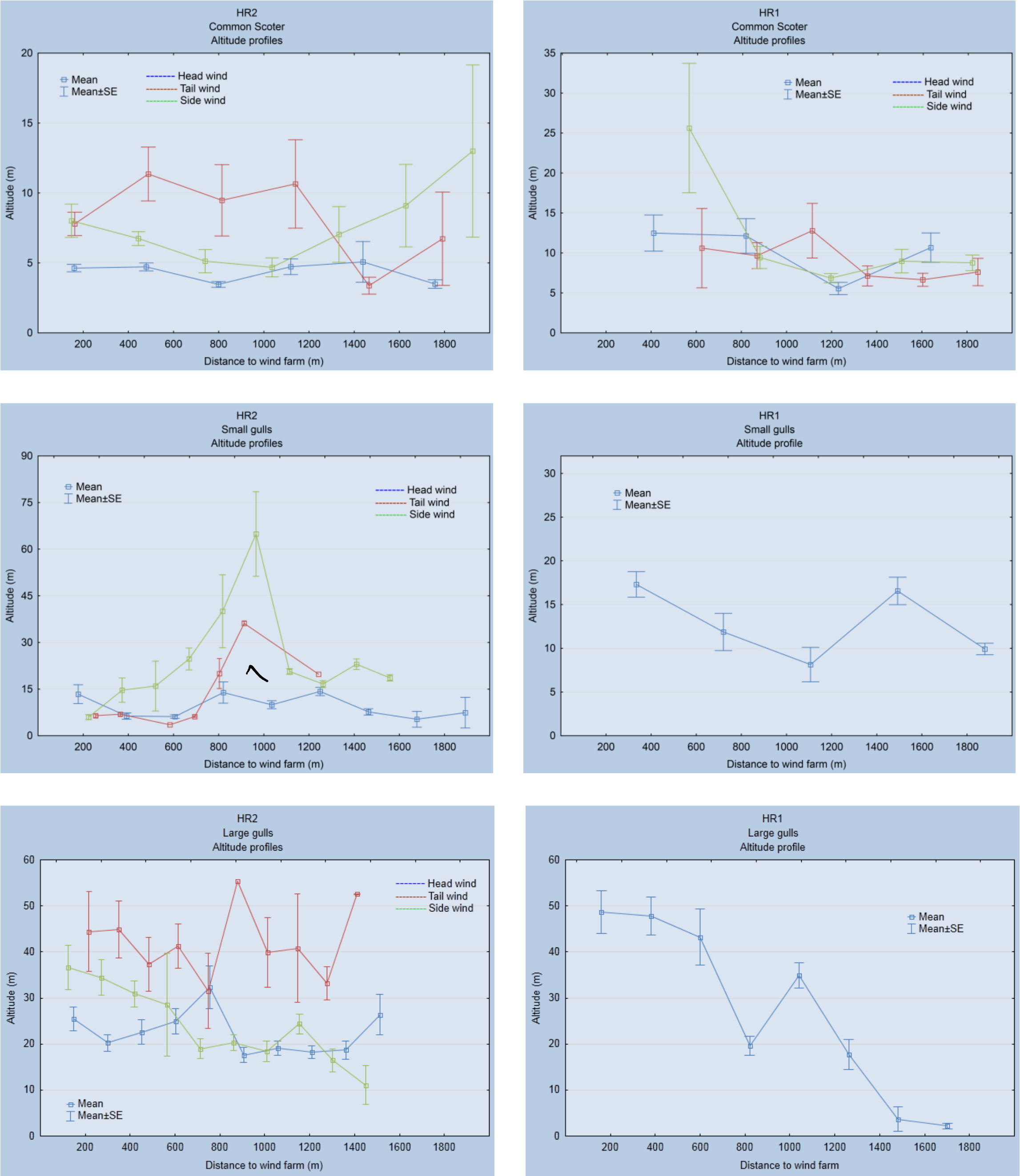
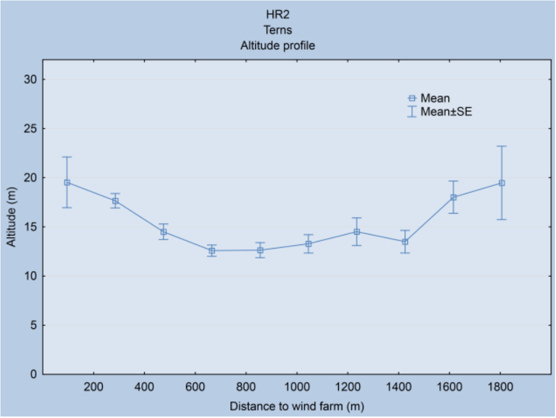
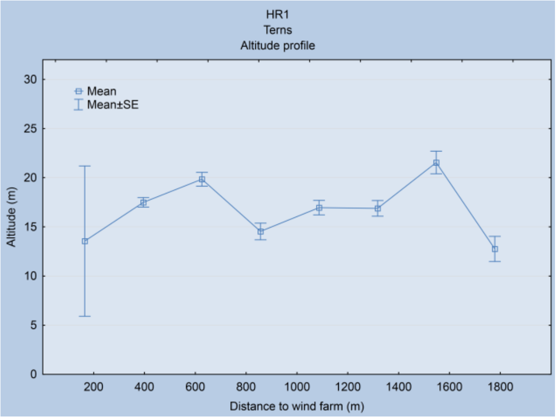
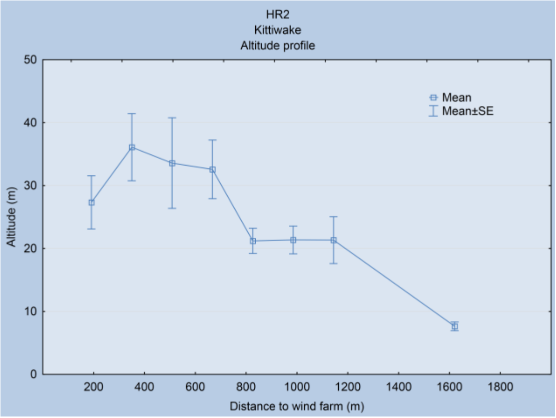
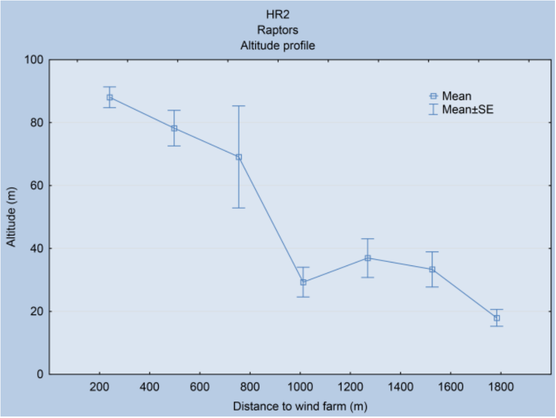


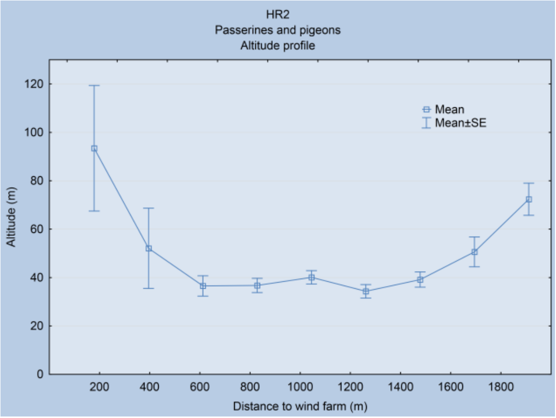
Figure 5-30.Continued Altitude profiles of key species recorded by rangefinder at HR1 and HR2 showing the mean and SE altitude as a function of distance from the turbines in the two wind farms. Depending on the sample obtained, the measured altitude during different wind conditions is shown. Lowest tip of rotor above sea level HR2 (21.5 m) HR1 (30 M). (Continued).











Goldcrest on rangefinder Horns Rev 2

Figure 5-31.Continued Altitude profiles of key species recorded by rangefinder at HR1 and HR2 showing the mean and SE altitude as a function of distance from the turbines in the two wind farms. Depending on the sample obtained, the measured altitude during different wind conditions is shown. Lowest tip of rotor above sea level HR2 (21.5 m) HR1 (30 M).

5.6 Collision risks

Despite the fact that the majority of seabirds on Horns Rev, including Common Scoter, fly at a mean altitude below the lower tip of the rotors of HR1 and HR2 the birds may still collide either coincidently or on account of specific weather conditions. The probability of collision was determined using two model approaches; a multiple regression model generalising the flight altitude as a function of weather and distance to wind farm and a collision risk model which estimated the potential number of casualties due to collision with the two wind farms on Horns Rev.

5.6.1 Red- & Black-throated Diver

5.6.1.1 Prediction of migration altitude at the wind farm sites

We were able to spatially adjust and use 15 rangefinder tracks of Red- and Black-throated Divers *Gavia stellate/arctica.* The number of tracks was too low for constructing reliable altitude models. Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-32-Figure 5-34.

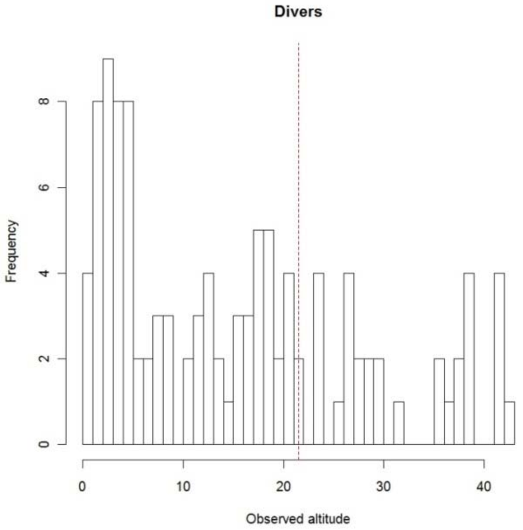


Figure 5-32. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

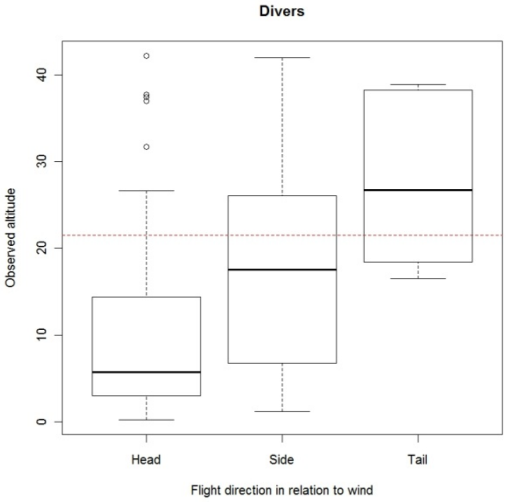
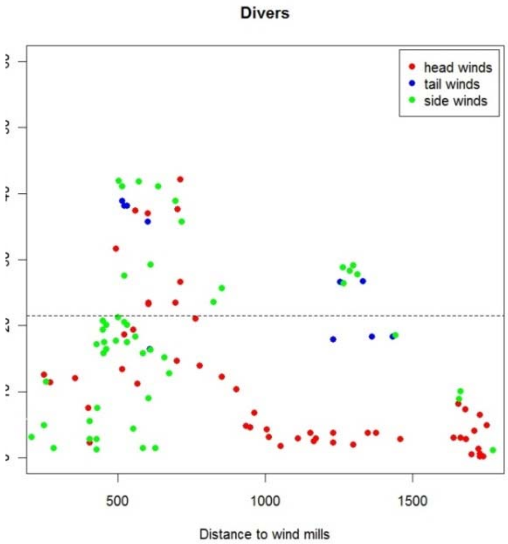


Figure 5-33. . Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.



Black throated Diver migrating at Blåvandshuk

Figure 5-34. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed lack line.

5.6.1.2 Estimates of collisions with HR1and HR2 offshore wind farms

Red- and Black-throated Divers are relatively common but not numerous wintering water birds in the Horns Rev area. All divers observed at HR1 and HR2 were considered as resident staging birds, although the flight directions did indicate some migration of the divers through the offshore parts. Aerial surveys conducted in winters 2006-2007 revealed low densities of divers within wind farm areas including a 3 km buffer zone (Table 5-6). There is no reliable information about the proportion of birds in flight, as aerial or ship survey results cannot be used for this question. E.g., ship survey results indicated that about 20% of all divers were recorded in flight (n = 2,390). This corresponds to 1.5-2 hours that each bird would be in flight every day, which is extremely unlikely for these species. We therefore assumed that proportion of time spent in flight by divers is similar to that of sea ducks, i.e. about 2%.

In total 10 diver tracks were observed using the radar and 15 with the rangefinder. Of these, one bird entered the wind farm area (perimeter) resulting in 96% macro-avoidance rate. Following rangefinder altitude measurements of diver tracks, 20% of birds were recorded flying at rotor height of HR1 and 33.3% at rotor height of HR2 (Table 5-6), when considering bird track locations that were the most proximate to wind turbines.

Collision risk estimates for wintering birds indicated that no or very few divers are expected to collide with the HR1 and HR2 wind farms (Table 5-6). Although both species of divers are listed on the Annex I to the EC Birds Directive a collision rate of 1-5 birds would be significantly below any critical level in relation to the bio-geographic populations involved, as the PBR (Potential Biological Removal) threshold for both species is 13,400 birds.

Table 5-6. Collision risk estimates for wintering Red- and Black-throated Divers at HR1and HR2 offshore wind farms, along with species-specific values of key input parameters. Collision risk calculated for pessimistic (98% avoidance rate) and optimistic (99.5 % avoidance rate) scenarios.

	Horns Rev 1	**Horns Rev 2**
Red- and Black-throated Divers		
Mean density of all wintering birds), ind./km^2	0.05	0.65
% of birds flying (assumption)	2%	2%
Mean density of flying birds in winter (Nov-Apr), ind./km^2	0.001	0.013
% of bird flying at rotor height	20%	33.3%
Collision risk (98% avoidance), number of birds colliding	0	5
Collision risk (99.5% avoidance), number of birds colliding	0	1

5.6.2 Gannet

5.6.2.1 Prediction of migration altitude

We were able to spatially adjust and use 46 rangefinder tracks of Gannets (*Morus bassanus*). Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-35-Figure 5-37.

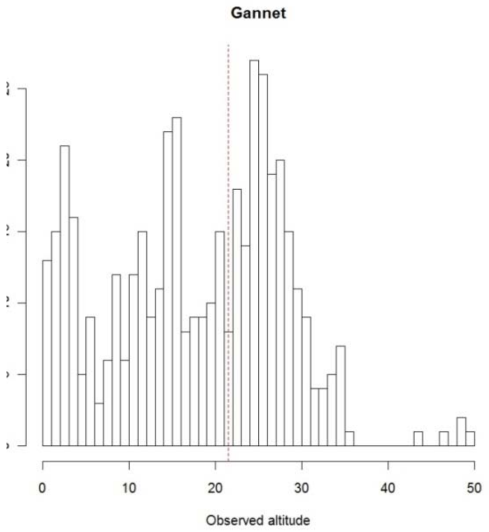


Figure 5-35. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line

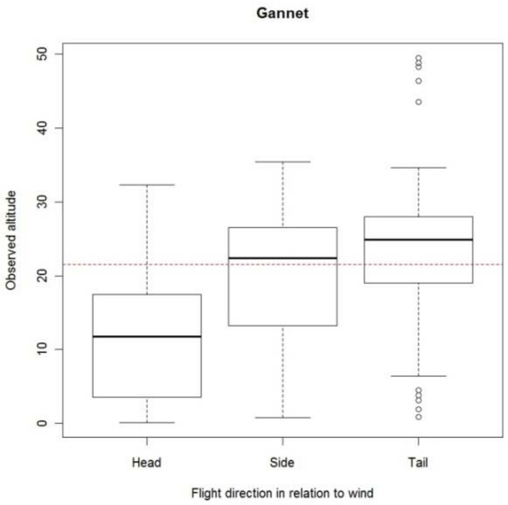
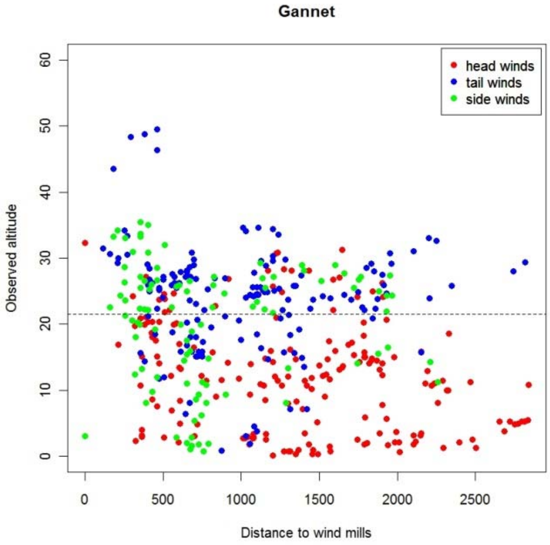


Figure 5-36. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

The GAMM for the Gannet, indicated that the birds fly higher in tail and side winds in comparison to head winds. They also seem to increase flight height with increasing wind speed and air pressure and also with decreasing relative humidity. The variable distance to closest wind turbine was not significant. There was not a significant difference between birds tracked at HR2 in comparison with birds tracked at HR1. Birds tracked in the autumn 2011 and spring 2012 flew significantly higher than during the two first seasons (Figure 5-38, Table 5-7). The model had a good predictive ability with a Spearman’s correlation coefficient of 0.70 when the model was fitted on 70% of the data and evaluated on 30%. The relationship between observed and predicted altitudes is visualised in Figure 5-39. The adjusted R-squared value indicated that the model explains 35 % of the variability in the data set. We did not find spatial autocorrelation in the model residuals of the “lme” model part, which indicated that the GAMM model was able to account for the spatial autocorrelation in the data.



Gannets observed migrating between Blåvands Huk and Horns Rev 1

Figure 5-37. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

Gannet flying close by Horns Rev 2 Offshore Wind Farm

Table 5-7. Significance and t- and F-values for the fixed parametric (wind directions, wind farm and survey year) and smooth terms included in the GAMM for the Gannet. The model was evaluated by fitting the model on 70% and testing the predictive accuracy on 30% by estimating Spearman's rank correlation between observed and predicted altitudes. Adjusted R-square value is given as an indication of variance explained by the model.

		t-value	p-value
Parametric	Tail wind	3.326	<0.01
	Side wind	2.928	<0.01
	HR2	1.262	0.208
	Season 2	1.257	0.210
	Season 3	3.242	<0.01
	Season 4	3.019	<0.01
Smooth		F-value	p-value
	Dist. to turbine	-	-
	Wind speed	8.106	<0.01
	Humidity	7.001	<0.01
	Pressure	13.295	<0.01
R-sq. (adj)		0.35	
Spearman's correlation		0.70	
Sample size		442	

We used the model for predicting the average flight altitudes during autumn 2011 (when most tracks were recorded). The weather parameters were set to mean values (within the collected data, Table 5-8). We made separate predictions for head winds, tail winds and side winds. According to the predictions the Gannets fly at rotor height during tail winds and side winds and barely below in headwinds (Figure 5-40). However, as they according to the model fly higher in "better weather conditions", with decreasing humidity and higher air pressure, they can also at certain conditions fly at rotor height during head winds. As the rotor height is higher at HR1 the risk of collision is lower there compared to at HR2 as the Gannets in average seem to fly below rotor height in all wind directions.

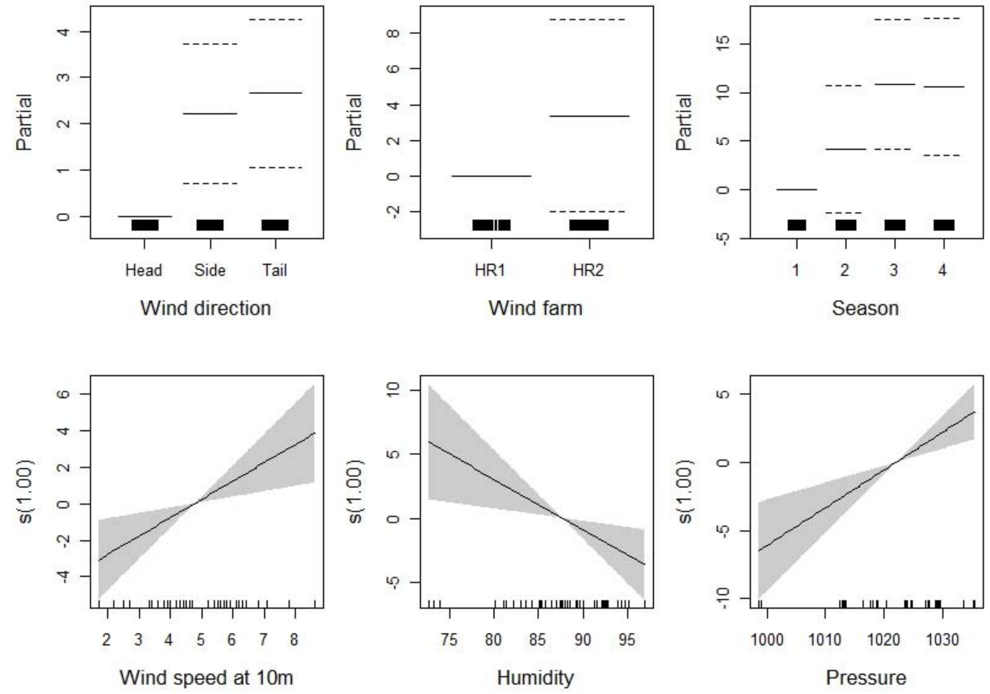
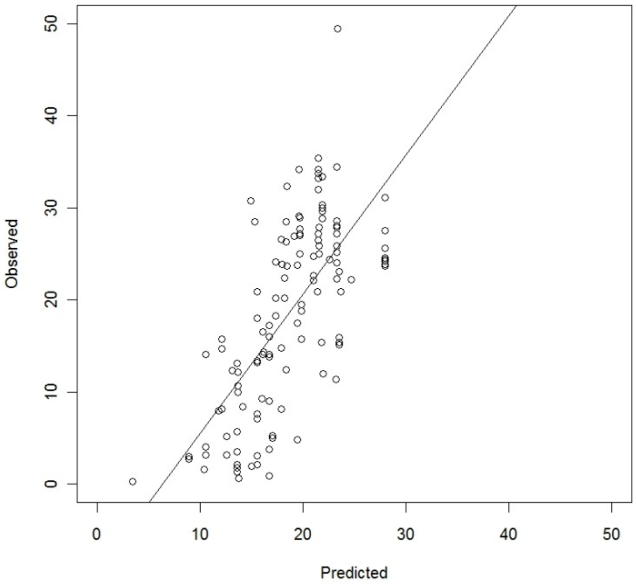


Figure 5-38. Response curves of the GAMM for the Gannet displaying the relationship between the flight altitude and predictor variables. The values of the environmental predictors are shown on the X-axis and the probability on the Y-axis in logit scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas and the dotted lines show the 95% Bayesian confidence intervals.



Gannets at Horns Rev 2

Figure 5-39. Predicted Gannet flight altitudes displayed against observed altitudes (not used in model construction). The model was fitted on 70% of the data and tested on 30%. The black line is a regression line (linear regression) between observed and predicted altitudes (intercept = -9.52, slope = 1.51).

Table 5-8. Mean, minimum and maximum values of the response and predictor variables, as well as sample size at either wind farm site as well as number of observations during head wind, tail wind and side winds.

Variables	Mean value	Min. value	Max value
Altitude	17.9	0.1	49.5
Distance to turbine	1,119	0.0	2,840
Wind speed (m/s)	4.8	1.7	8.6
Humidity (%)	87.7	72.7	96.9
Clearness	79.7	0.0	100.0
Pressure	1,022.1	998.6	1,035.5
Temperature (°C)	12.7	4.1	15.9
	Head wind	Tail wind	Side wind
No. of samples	192	151	99
	HR 1	HR 2	
No. of samples	88	354	

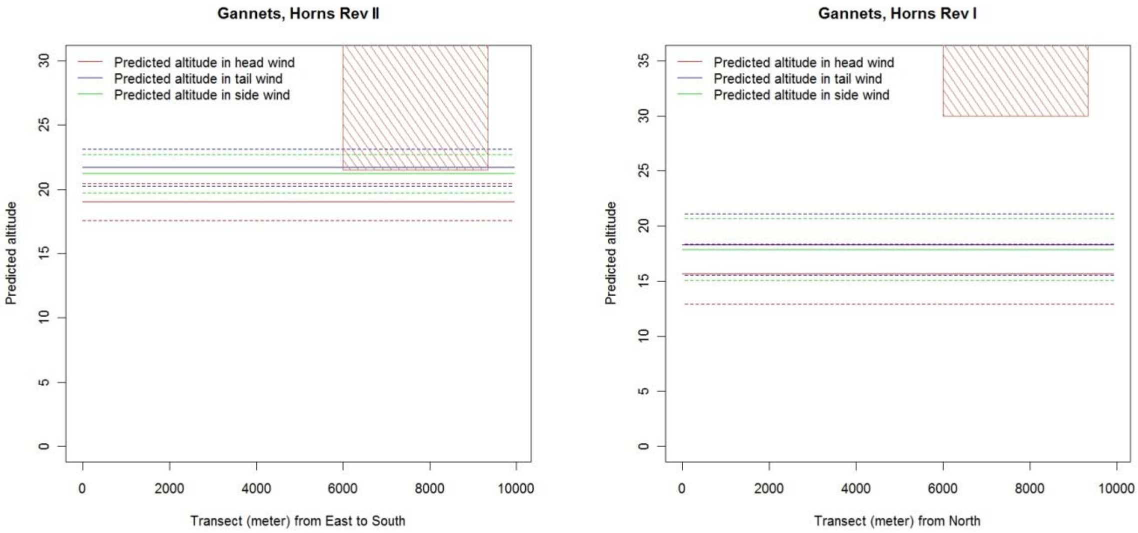


Figure 5-40. Predicted altitude at HR2 (upper) and at HR1 (lower), along a “theoretical” transect trough the investigated area in autumn 2011 for the Gannet during head winds, tail winds and side winds, with all other predictor variables set to mean conditions. The dashed lines around the predictions indicate the standard errors. The rotor swept area is defined by the rectangle with shading red lines.

5.6.2.2 Estimates of collisions with HR1and HR2 offshore wind farms

Gannets are rather uncommon wintering birds in the Horns Rev area, although they occur commonly in the area during late summer and autumn (Petersen et al., 2006). All gannets observed at HR1 and HR2 were considered as resident staging birds. The flight directions collected during the program indicated a low level migration activity through the wind farm areas, therefore possible collision risk of migrating gannets was not assessed. In total 26 gannet tracks were observed using the radar and 46 using the rangefinder. Of these, 10 birds entered the wind farm area (perimeter) resulting in 86% macro-avoidance rate.

Aerial surveys conducted in winters 2006 and 2007 revealed low densities of Gannets within wind farm areas including a 3 km buffer zone (Table 5-9). Ship survey results indicated that about 64% of all gannets were recorded in flight (n = 42,568).

Relatively high proportion of all Gannets was recorded flying at rotor altitude at Horns Rev wind farms. Following rangefinder altitude measurements, 8.7% of birds were recorded flying at rotor height of HR1 and 39.1% at rotor height of HR2 (Table 5-9), when considering bird track locations that were the most proximate to wind turbines.

Collision risk estimates for wintering birds indicated that no or very few Gannets are expected to collide with the HR1 and HR2 wind farms (Table 5-9). In Europe, the breeding population is estimated to number 900,000-930,000 individuals (BirdLife-International, 2004). Thus, the estimated mortality rate will have no impact at the population level. It should be noted, however, that the collision rate would be higher during late summer and autumn. Yet, due to the lack of estimates of the number of Gannets on Horns Rev during this period the collision rate has not been assessed.

Table 5-9. Collision risk estimates for wintering Northern Gannets at HR1and HR2 offshore wind farms, along with species-specific values of key input parameters. Collision risk calculated for pessimistic (98% avoidance rate) and optimistic (99.5 % avoidance rate) scenarios.

	Horns Rev 1	**Horns Rev 2**
Northern Gannet		
Mean density of all wintering birds), ind/km^2	0.006	0.018
% of birds flying (estimated from ship surveys)	64%	64%
Mean density of flying birds in winter (Nov-Apr), ind/km^2	0.004	0.012
% of bird flying at rotor height	8.7%	39.1%
Collision risk (98% avoidance), number of birds colliding	0	7
Collision risk (99.5% avoidance), number of birds colliding	0	2

5.6.3 Common Scoter

5.6.3.1 Prediction of migration altitude

A total of 344 rangefinder tracks of Common Scoter (*Melanitta nigra*) were spatially adjusted and used in the analysis. Three tracks were deleted as outliers, before altitude modelling. Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-41-Figure 5-43.

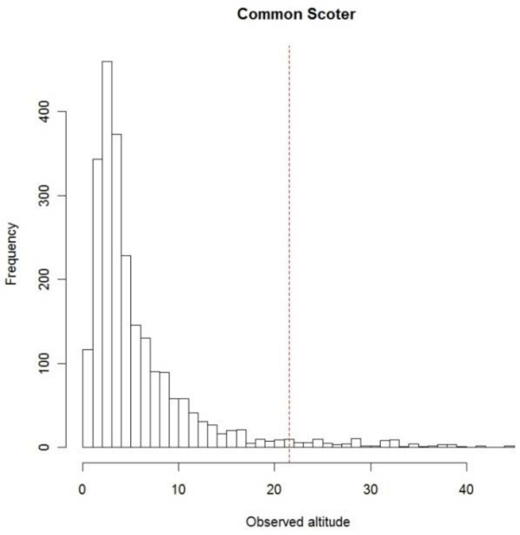


Figure 5-41. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

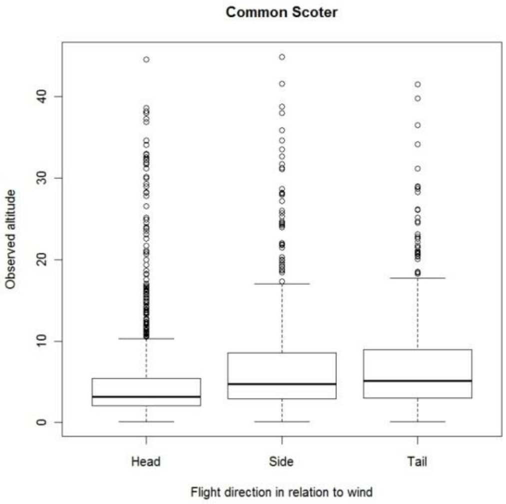


Figure 5-42. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

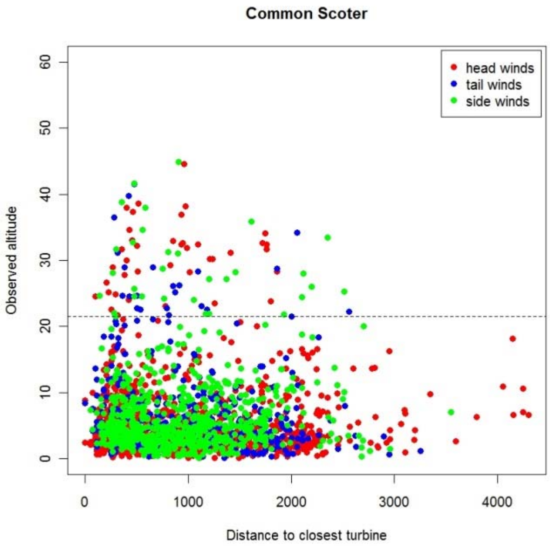


Figure 5-43. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

Foraging scoters at Horns Rev 2

The GAMM for the Common Scoter, indicated that the birds fly higher in tail and side winds in comparison to head winds. They also seem to increase flight height closer to the wind turbines, as well as with increasing wind speed and relative humidity. The

Common Scoter tracked at HR1 flew significantly higher than those tracked at HR2, according to the model (Figure 5-44, Table 5-10). The model had a reasonable predictive ability with a Spearman's correlation coefficient of 0.30 when the model was fitted on 70% of the data and evaluated on 30%. The relationship between observed and predicted altitude is visualised in Figure 5-45. The adjusted R-squared value indicated that the model explains 10 % of the variability in the data set. No spatial autocorrelation was found in the model residuals of the "lme" model part, which indicated that the GAMM model was able to account for the spatial autocorrelation in the data.

We used the model for predicting the average flight altitudes of the Common Scoters. The weather parameters were set to mean values (within the collected data, Table 5-11). We made separate predictions for head winds, tail winds and side winds.

According to the predictions the Common Scoters flew in mean conditions well below rotor height during all wind directions. The flight height was slightly higher at HR1 than at HR2 and also slightly higher in tail winds in comparison to head winds (Figure 5-46, Figure 5-47).

Table 5-10. Significance and t- and F-values for the fixed parametric (wind directions, wind farm and survey year) and smooth terms included in the GAMM for the Common Scoter. The model was evaluated by fitting the model on 70% and testing the predictive accuracy on 30% by estimating Spearman's rank correlation between observed and predicted altitudes. Adjusted R-square value is given as an indication of variance explained by the model.

		t-value	p-value
Parametric	Tail wind	4.825	<0.01
	Side wind	5.481	<0.01
	HR2	-7.043	<0.01
Smooth		**F-value**	**p-value**
	Dist. to turbine	7.092	<0.01
	Wind speed	3.068	0.08
	Humidity	13.832	<0.01
R-sq. (adj)		0.10	
Spearman's correlation		0.30	
Sample size		2,374	

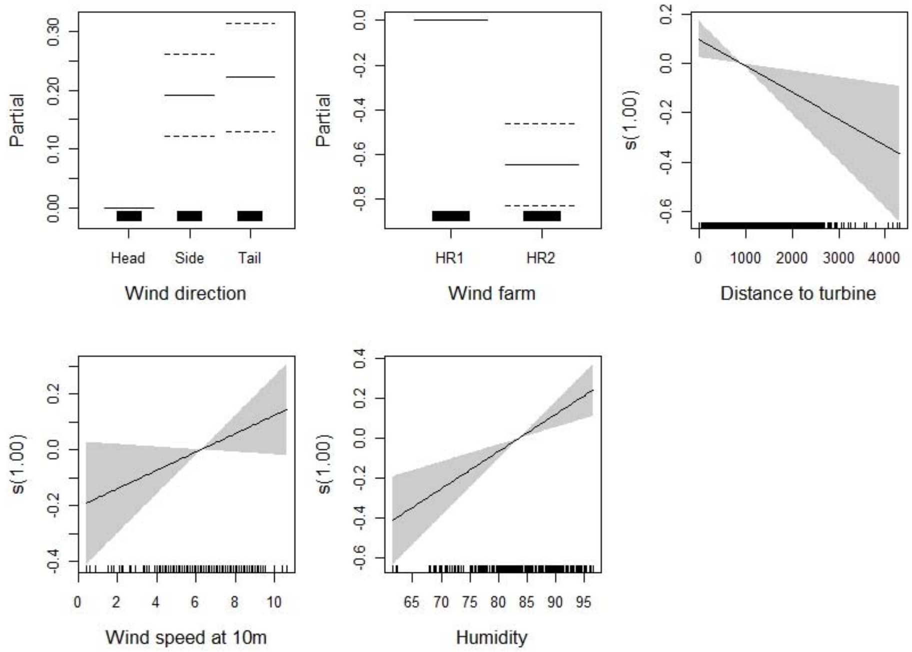
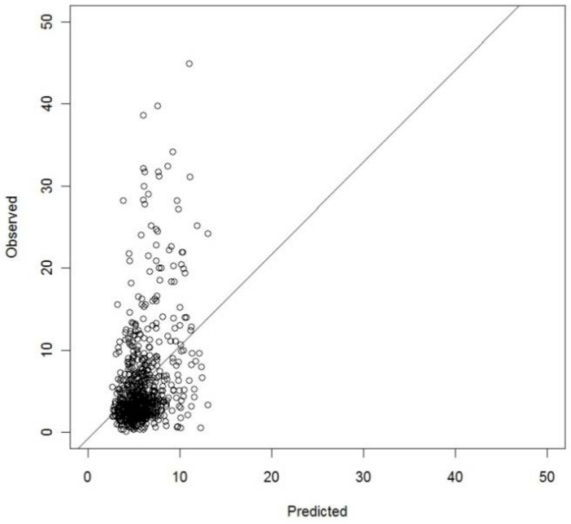


Figure 5-44. Response curves of the GAMM for the Common Scoter displaying the relationship between the flight altitude and predictor variables. The values of the environmental predictors are shown on the X-axis and the probability on the Y-axis in logit scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas and the dotted lines show the 95% Bayesian confidence intervals.



Common Scoter

Figure 5-45. Predicted Common Scoter flight altitudes displayed against observed altitudes (not used in model construction). The model was fitted on 70% of the data and tested on 30%. The black line is a regression line (linear regression) between observed and predicted altitudes (intercept = -0.701, slope = 1.12).

Table 5-11. Mean, minimum and maximum values of the response and predictor variables, as well as sample size at either wind farm site as well as number of observations during head wind, tail wind and side winds.

Variables	Mean value	Min. value	Max value
Altitude	5.8	0.1	44.9
Distance to turbine	921	0	4,302
Wind speed (m/s)	6.2	0.4	10.6
Humidity (%)	83.6	61.5	96.6
Clearness	72.8	0.0	100.0
Pressure	1,021.7	998.2	1,043.5
Temperature (°C)	8.1	-0.4	16.0
	Head wind	Tail wind	Side wind
No. of samples	1,328	371	675
	HR 1	HR 2	
No. of samples	543	1,831	

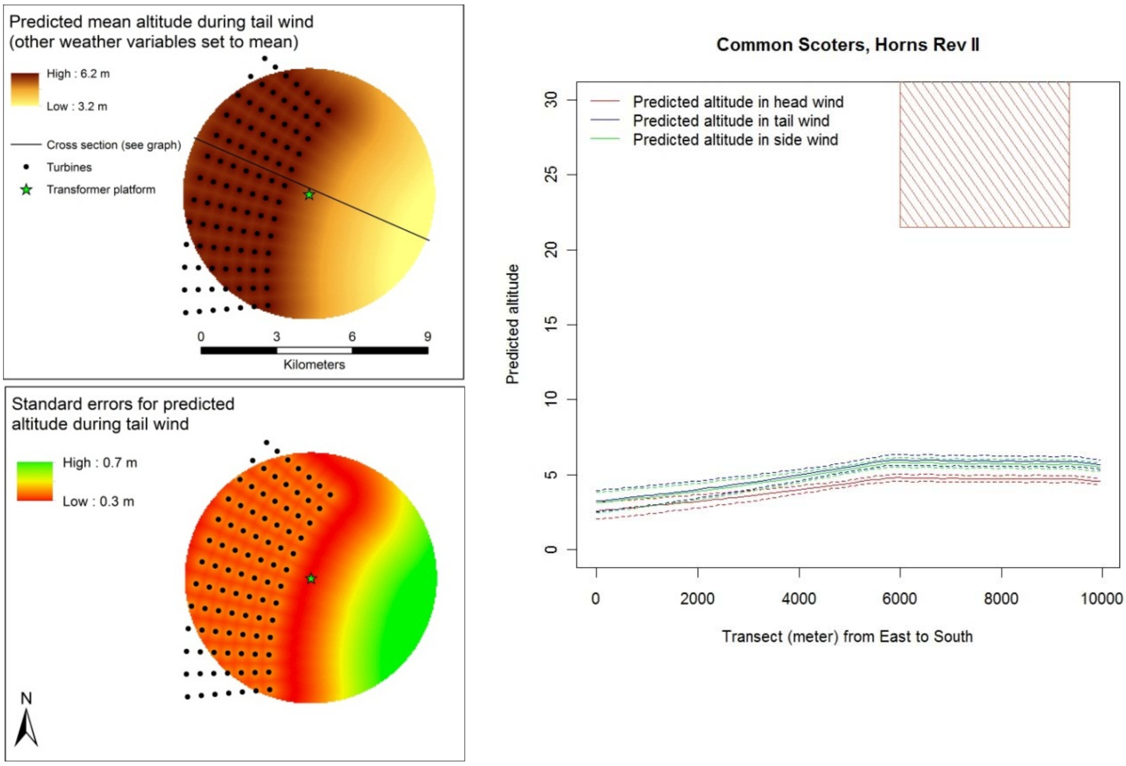


Figure 5-46. Mapped predicted altitudes of Common Scoters at HR2 during tail wind (upper left) with associated model standard errors (lower left). The same predictions are visualised along a transect trough the investigated area (see upper left) during head winds, tail winds and side winds, with all other predictor variables set to mean conditions. The dashed lines around the predictions indicate the standard errors. The rotor swept area is defined by the rectangle with shading red lines.

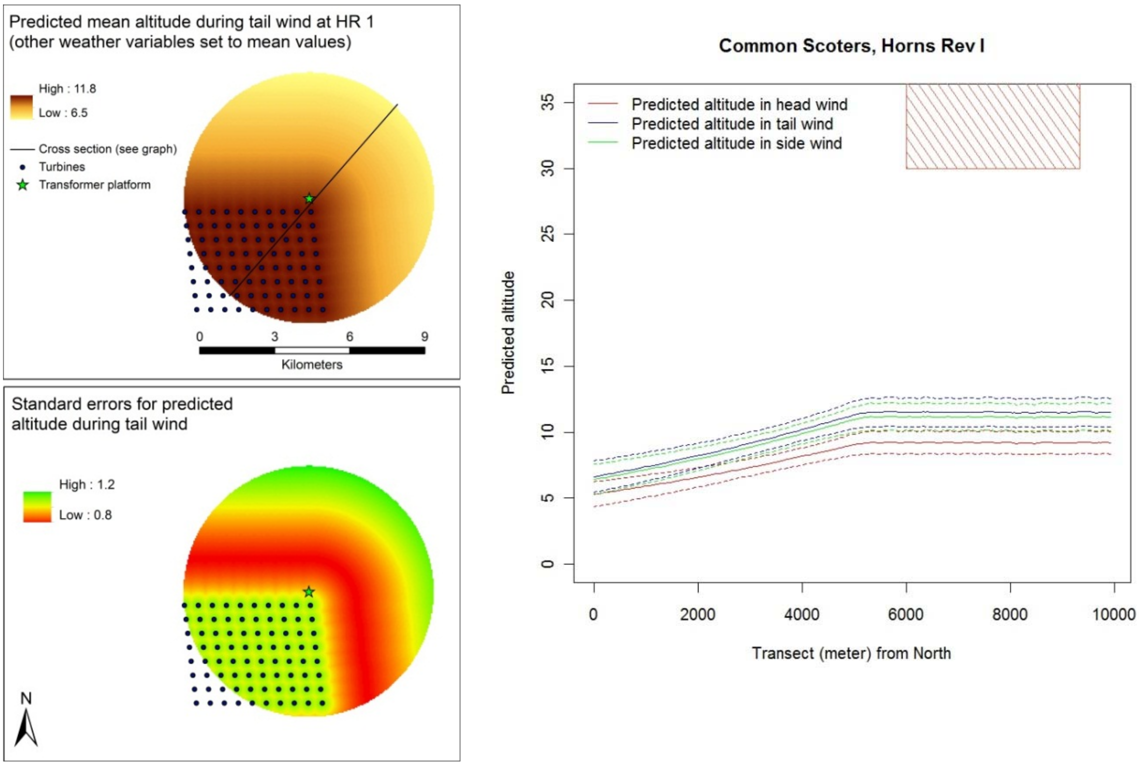


Figure 5-47. Mapped predicted altitudes of Common Scoters at Horns Rev 1during tail wind (upper left) with associated model standard errors (lower left). The same predictions are visualised along a transect trough the investigated area (see upper left) during head winds, tail winds and side winds, with all other predictor variables set to mean conditions. The dashed lines around the predictions indicate the standard errors. The rotor swept area is defined by the rectangle with shading red lines.

Raft of Common Scoter staging at HR2

5.6.3.2 Estimates of collisions with HR1 and HR2 offshore wind farms

Common Scoter is the most numerous bird species that is resident in Horns Rev area during the winter period. The collected flight directions did not indicate seasonal long-distance migrations through the wind farm areas, therefore possible collision risk of migrating scoters was not assessed. Aerial surveys conducted in winters 2006 and 2007 revealed very high densities of Common Scoters within wind farm areas including a 3 km buffer zone (Table 5-12). Ship survey results indicated that about 1% of all Common Scoters were recorded in flight (n = 11,948).

In total 434 Common Scoter tracks were observed using the radar and 344 with the rangefinder. Of these, 184 birds entered the wind farm area (perimeter) resulting in 76% avoidance rate.

Relatively low proportion of all scoters was recorded flying at rotor altitude at Horns Rev wind farms (Table 5-12), when considering bird track locations that were the most proximate to wind turbines.

Although, the majority of birds usually fly at low altitudes and only a small proportion is in flight at any given time, constant presence of high densities result in a high flux of birds through the wind farms. The estimated collision rates would only constitute an insignificant number of birds, when evaluated at the population level Table 5-12. The PBR threshold for the population wintering in NW Europe is 37,000 birds.

Table 5-12. Collision risk estimates for wintering Common Scoters at HR1 and HR2 offshore wind farms, along with species-specific values of key input parameters. Collision risk calculated for pessimistic (98% avoidance rate) and optimistic (99.5 % avoidance rate) scenarios.

	Horns Rev 1	**Horns Rev 2**
Common Scoter		
Mean density of all wintering birds), ind/km^2	156.05	274.05
% of birds flying (from ship surveys)	1%	1%
Mean density of flying birds in winter (Nov-Apr), ind/km^2	1.56	2.74
% of bird flying at rotor height	2.3%	6.1%
Collision risk (98% avoidance), number of birds colliding	31	178
Collision risk (99.5% avoidance), number of birds colliding	8	45

5.6.4 Geese and swans

We were able to spatially adjust and use 5 rangefinder tracks of geese, four Greylag Geese *Anser anser* and 1 Pink-footed Goose *Anser brachyrhynchus.* The number of tracks was too few for constructing reliable altitude models and estimate collision rates.

5.6.5 Waders

5.6.5.1 Prediction of migration altitude

We were able to spatially adjust and use 12 rangefinder tracks of Waders. The number of tracks was too few for constructing reliable altitude models. Summary graphs of the rangefinder data are shown in Figure 5-48 - Figure 5-50.

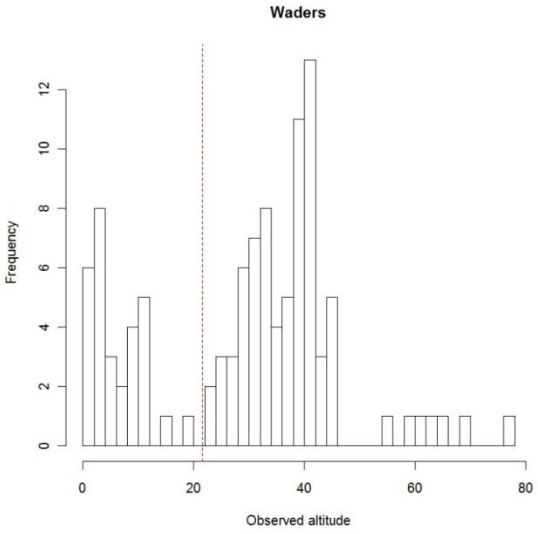


Figure 5-48. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line

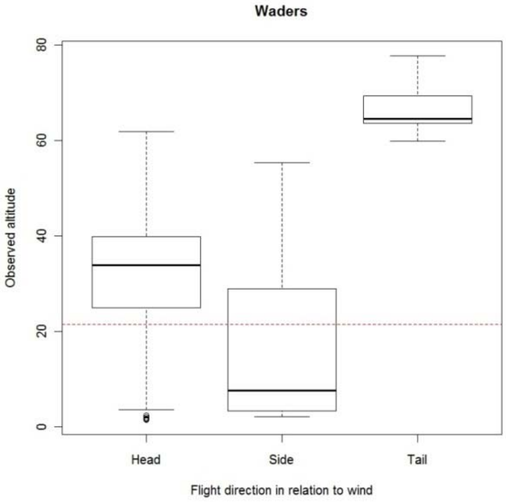
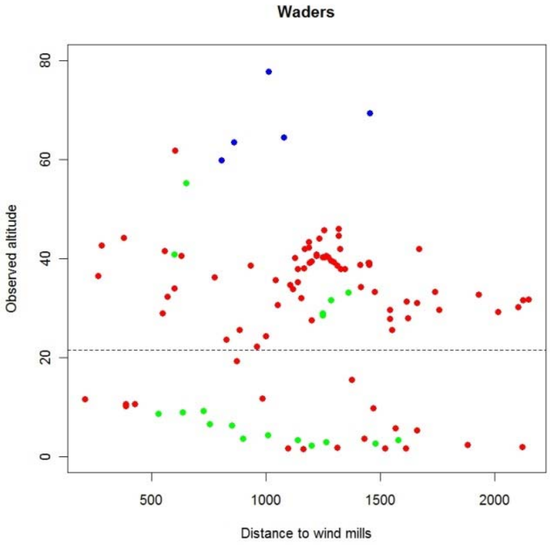


Figure 5-49. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line



Resting and foraging Sanderlings at Blåvandshuk

Figure 5-50. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

5.6.5.2 Estimates of collisions with HR1 and HR2 offshore wind farms

As shown by the visual observations (Appendix 2) the migration intensity of waders is rather low at HR1 and HR2, and the main migration of waders takes place closer to the coast during both spring and autumn. Three tracks were registered using the radar and 12 with the rangefinder covering a wide range of species with Oystercatcher, Golden Plover *Pluvialis apricaria* and Lapwing *Vanellus vanellus* being registered more than once (Table 5-13).

Table 5-13. Species composition of waders tracked using radar and rangefinder at HR1 and HR2 wind farms.

	Radar observations		Rangefinder observations	
Species	HR1	HR2	HR1	HR2
Oystercatcher		1	2	
Golden Plover	1			2
Grey Plover				1
Lapwing		1		1
Woodcock				1
Common Ringed Plover				1
Whimbrel				1
Common Redshank				1
Red Knot				1
Dunlin				1

Only one out of 15 observed waders entered a wind farm perimeter, resulting in 93% macro-avoidance rate. Considering flight altitude in the nearest proximity to a wind turbine, 83% of observed waders flew above 30 m (rotor height in HR1) and 92% above 21.5 m (rotor height in HR2). Using these parameters it was estimated that collision risk of waders crossing one wind turbine row would be 0.055% at HR1 and 0.05% at HR2. Assuming east-west crossing of wind farms, i.e. 10 and 7 turbine rows at HR1 and HR2 respectively, the overall collision risk was estimated being 0.55% at HR1 and 0.35% at HR2.

5.6.6 Small gull species

5.6.6.1 Prediction of migration altitude

We were able to spatially adjust and use 48 rangefinder tracks of small gulls, including Common Gull *Larus canus*, Black-headed Gull *Larus ridibundus* and Little Gull *Larus minutus*. Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-51 - Figure 5-53.

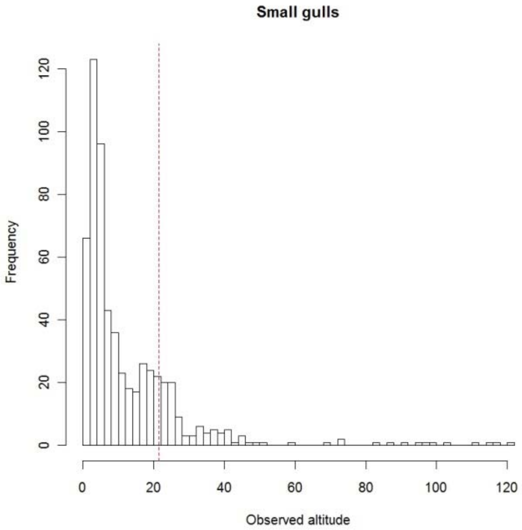


Figure 5-51. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

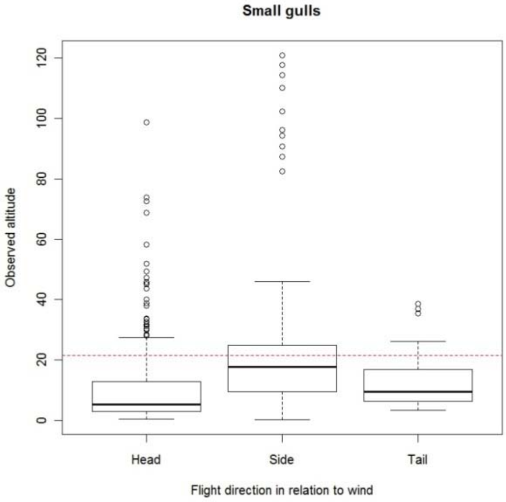


Figure 5-52. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

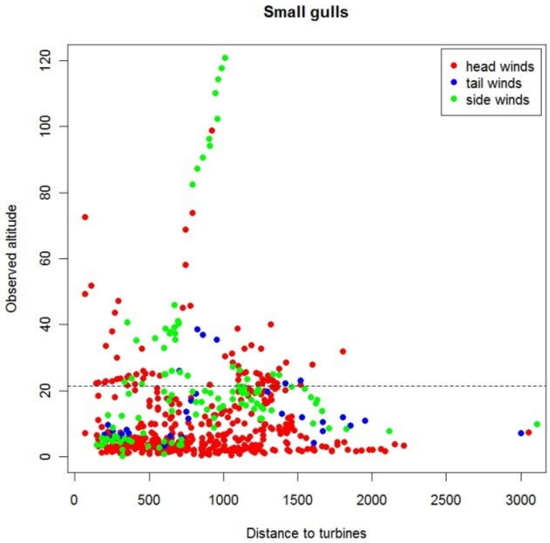


Figure 5-53. Observed altitude plotted against distance to closest wind turbine, with different colours for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

Little Gull

We attempted to model the flight altitude of the small gulls, however no reasonable fit was achieved. This indicates that based on our data the flight altitudes cannot be described by weather and wind farm variables. However, when looking at the observed altitude we can say that most birds fly below rotor height and there does not seem to be a difference between different wind and weather conditions.

5.6.6.2 Estimates of collisions with HR1and HR2 offshore wind farms

Small gull species are rather common wintering birds in Horns Rev area. All small gulls observed at HR1 and HR2 were considered as resident staging birds, although the obtained flight directions did indicate the presence of some long-distance migrations through the wind farm areas. Aerial surveys conducted in winters 2006 and 2007 revealed relatively low densities of small gulls within wind farm areas and 3 km buffer around them (Table 5-14). Ship survey results indicated that about 41% of all small gulls were recorded in flight (n = 1077).

In total 24 small gull tracks were observed using the radar and 48 with the rangefinder. Of these, 21 birds entered the wind farm area (perimeter) resulting in 71% macro-avoidance rate.

Relatively high proportion of all small gulls was recorded flying at rotor altitude at Horns Rev wind farms, when considering bird track locations that were the most proximate to wind turbines Table 5-14.

Although the densities of wintering small gulls were not high, relatively high proportion of birds in flight and flying at rotor altitude result in a high flux of birds through the wind farms and blade-swept area and estimates suggest that 2-18 birds could collide with turbines at HR1 and HR2 respectively (Table 5-14). The Little Gull is listed on the Annex I to the EC Birds Directive. Yet, the PBR threshold for the European population is 7,300 birds, and the estimated mortality at HR1 and HR2 are therefore unlikely to be significant at the population level.

Table 5-14. Collision risk estimates for wintering small gull species at HR1and HR2 offshore wind farms, along with species-specific values of key input parameters. Collision risk calculated for pessimistic (98% avoidance rate) and optimistic (99.5 % avoidance rate) scenarios.

	Horns Rev 1	**Horns Rev 2**
Small gull species		
Mean density of all wintering birds), ind/km^2	0.409	0.095
% of birds flying (estimated from ship surveys)	41%	41%
Mean density of flying birds in winter (Nov-Apr), ind/km^2	0.168	0.039
% of bird flying at rotor height	12.5%	22.9%
Collision risk (98% avoidance), number of birds colliding	18	10
Collision risk (99.5% avoidance), number of birds colliding	4	2

5.6.7 Large gull species

5.6.7.1 Prediction of migration altitude

We were able to spatially adjust and use 44 rangefinder tracks of large gulls, including Herring Gull *Larus argentatus*, Great Black-backed Gull *Larus marinus* and Lesser Black-backed Gull *Larus fuscus*. Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-54 - Figure 5-56.

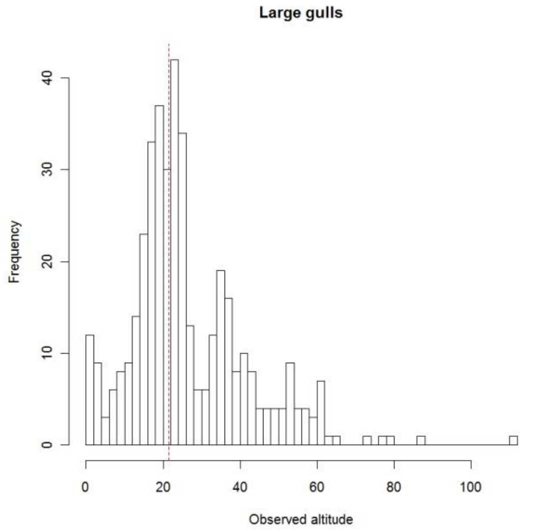


Figure 5-54. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

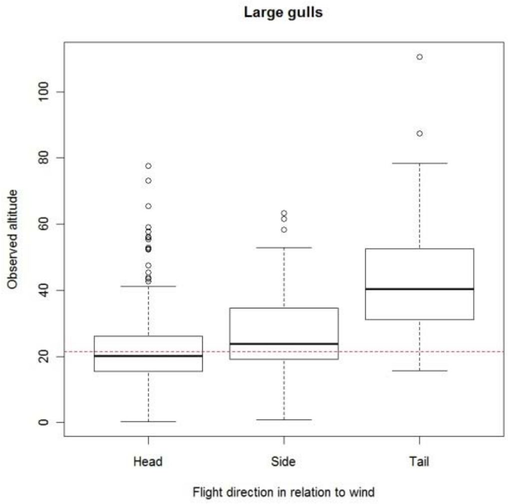
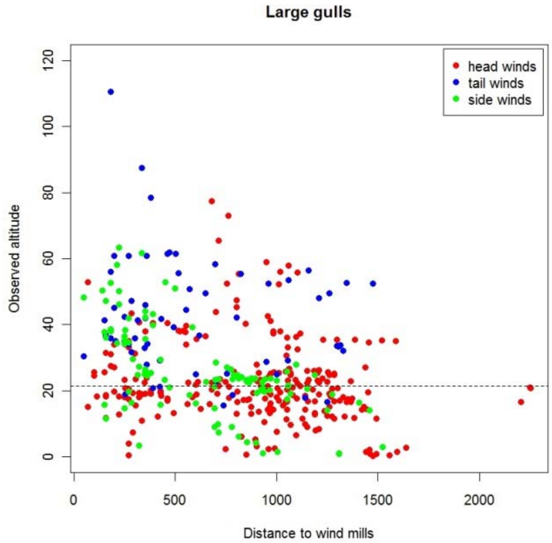


Figure 5-55. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.



Lesser Black-backed Gull at Horns Rev 2

Figure 5-56. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

The GAMM for the large gull species, indicated no significant difference in flight altitudes depending on wind direction. However, according to the model the gulls increase flight height with decreasing wind speed and decreasing distance to wind turbines. There was not a significant difference between birds tracked at HR2 in comparison with birds tracked at HR1 (Figure 5-57, Table 5-15). The model had a good predictive ability with a Spearman's correlation coefficient of 0.70 when the model was fitted on 70 % of the data and evaluated on 30 %. The relationship between observed and predicted altitude is visualised in Figure 5-58. The adjusted R-squared value indicated that the model explains 27 % of the variability in the data set. We did not find spatial autocorrelation in the model residuals of the "lme" model part, which indicated that the GAMM model was able to account for the spatial autocorrelation in the data.

We used the model for predicting the average flight altitudes of large gulls during head winds, tail winds and side winds, while setting the variable wind speed at mean value. According to the predictions the large gulls fly on average at rotor height during all wind directions (Figure 5-59). However, as they according to the model fly lower with increasing wind speeds they might fly below rotor height at higher wind speeds.

Table 5-15. Significance and t- and F-values for the fixed parametric (wind directions, wind farm and survey year) and smooth terms included in the GAMM for the large gulls. The model was evaluated by fitting the model on 70% and testing the predictive accuracy on 30% by estimating Spearman's rank correlation between observed and predicted altitudes. Adjusted R-square value is given as an indication of variance explained by the model.

		t-value	p-value
Parametric	Tail wind	1.263	0.207
	Side wind	1.525	0.128
	HR2	-0.200	0.842
Smooth		F-value	p-value
	Dist. to turbine	25.6	<0.01
	Wind speed	76.98	<0.01
R-sq. (adj)		0.27	
Spearman's correlation		0.51	
Sample size		408	

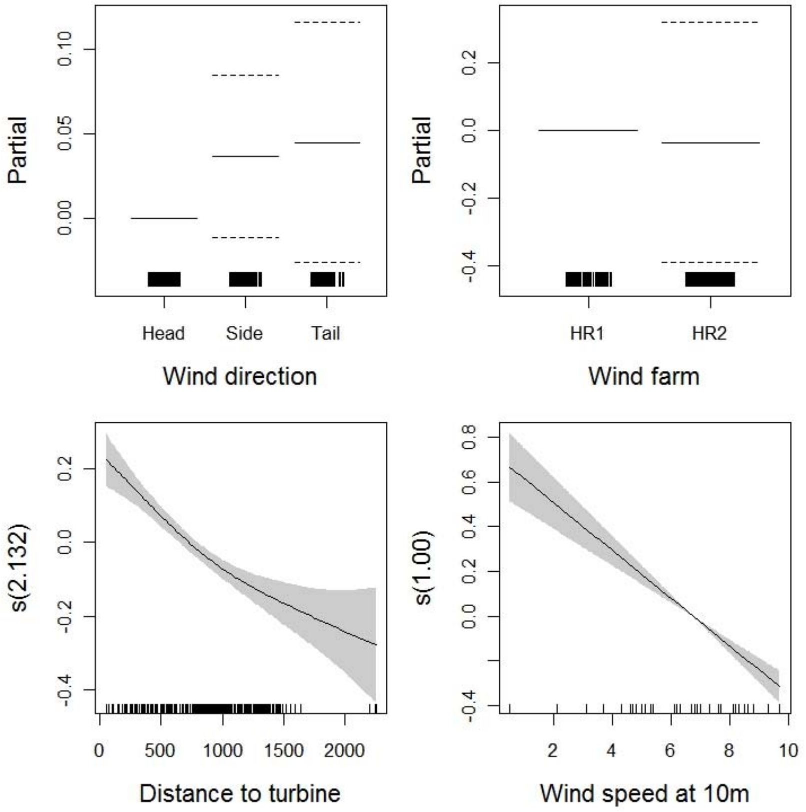
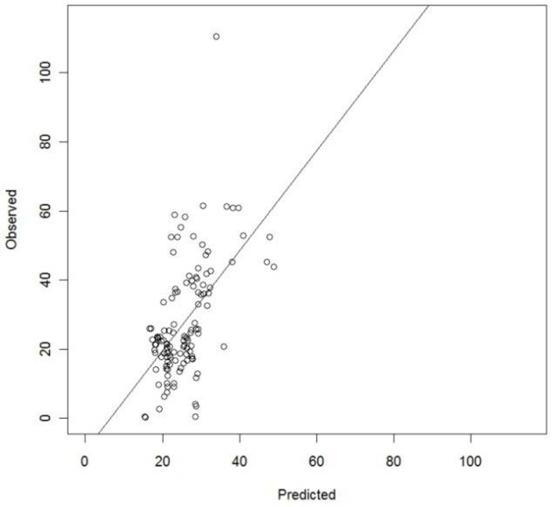


Figure 5-57. Response curves of the GAMM for large gulls displaying the relationship between the flight altitude and predictor variables. The values of the environmental predictors are shown on the X-axis and the probability on the Y-axis in logit scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas and the dotted lines show the 95% Bayesian confidence intervals.

Gulll foraging on passerines at Horns Rev 1



Lesser Black-backed Gull at Horns Rev 1

Figure 5-58. Predicted flight altitudes for large gulls displayed against observed altitudes (not used in model construction). The model was fitted on 70% of the data and tested on 30%. The black line is a regression line (linear regression) between observed and predicted altitudes (intercept = -9.28, slope = 1.45).

Table 5-16. Mean, minimum and maximum values of the response and predictor variables, as well as sample size at either wind farm site as well as number of observations during head wind, tail wind and side winds.

Variables	Mean value	Min. value	Max value
Altitude	26.5	0.2	110.6
Distance to turbine	783	50	2,252
Wind speed (m/s)	6.7	0.5	9.7
Humidity (%)	84.3	68.8	94.1
Clearness	72.3	0.0	100.0
Pressure	1,014.5	998.8	1,039.3
Temperature (°C)	9.1	0.5	15.4
	Head wind	Tail wind	Side wind
No. of samples	241	64	103
	HR 1	HR 2	
No. of samples	70	338	

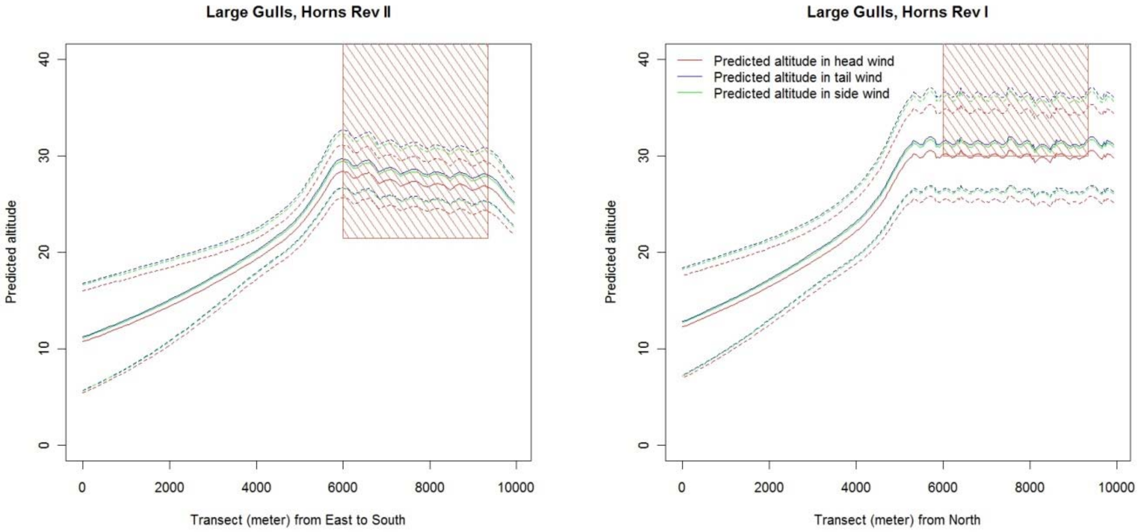


Figure 5-59. Predicted altitude at HR2 (upper) and at HR1 (lower), along a “theoretical” transect trough the investigated area in autumn 2011 for large gulls during head winds, tail winds and side winds, with all other predictor variables set to mean conditions. The dashed lines around the predictions indicate the standard errors. The rotor swept area is defined by the rectangle with shading red lines.

5.6.7.2 Estimates of collisions with HR1 and HR2 offshore wind farms

Large gull species are common wintering birds in Horns Rev area. All large gulls observed at HR1 and HR2 were considered as resident staging birds. The directions recorded during the project did not indicate seasonal long-distance migrations through the wind farm areas, therefore possible collision risk of migrating large gulls was not assessed. Aerial surveys conducted in winters 2006 and 2007 revealed medium densities of large gulls within wind farm areas including a 3 km buffer zone (Table 5-17). Ship survey results indicated that about 43% of all large gulls were recorded in flight (n = 1818).

In total 40 large gull tracks were observed using the radar and 44 with the rangefinder. Of these, 37 birds entered the wind farm area (perimeter) resulting in 56% macro-avoidance rate.

High proportion of all large gulls was recorded flying at rotor altitude at Horns Rev wind farms. Following rangefinder altitude measurements, 39.5% of birds were recorded flying at rotor height of HR1 and 55.8% at rotor height of HR2 (Table 5-17), when considering bird track locations that were the most proximate to wind turbines.

Although the densities of wintering gull were not very high, relatively high proportion of birds in flight and flying at rotor altitude result in a high flux of birds through the wind farms and blade-swept height and estimates suggest that 90-378 birds would collide with turbines at HR1 and HR2 during winter (Table 5-17).

Table 5-17. Collision risk estimates for wintering large gull species at HR1 and HR2 offshore wind farms, along with species-specific values of key input parameters. Collision risk calculated for pessimistic (98% avoidance rate) and optimistic (99.5 % avoidance rate) scenarios.

	Horns Rev 1	Horns Rev 2
Large gull species		
Mean density of all wintering birds), ind/km^2	1.754	0.920
% of birds flying (estimated from ship surveys)	43%	43%
Mean density of flying birds in winter (Nov-Apr), ind/km^2	0.754	0.396
% of bird flying at rotor height	39.5%	55.8%
Collision risk (98% avoidance), number of birds colliding	378	360
Collision risk (99.5% avoidance), number of birds colliding	95	90

5.6.8 Kittiwake

5.6.8.1 Prediction of migration altitude

We were able to spatially adjust and use 11 rangefinder tracks of kittiwakes. The number of tracks was too few for constructing reliable altitude models. Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-60-Figure 5-62.

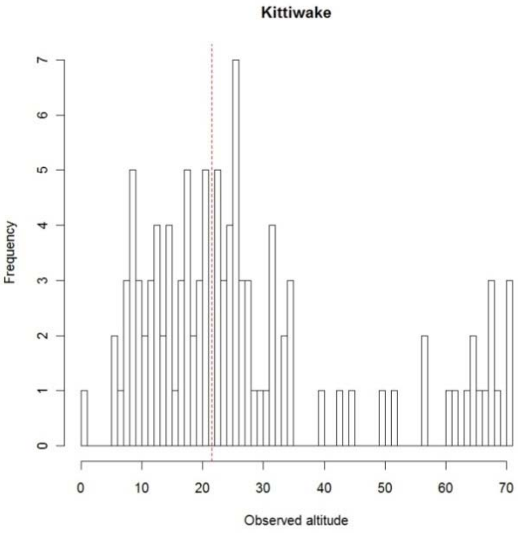


Figure 5-60. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

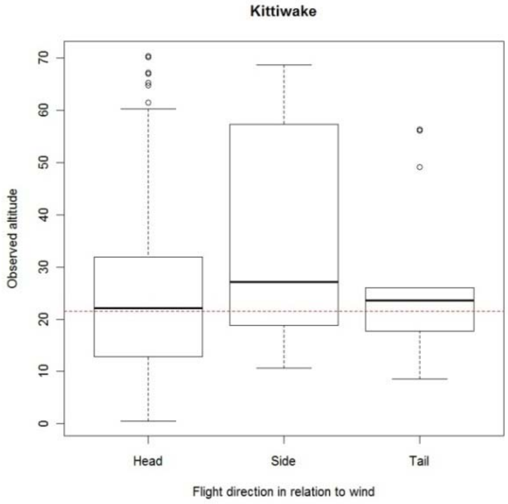


Figure 5-61. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

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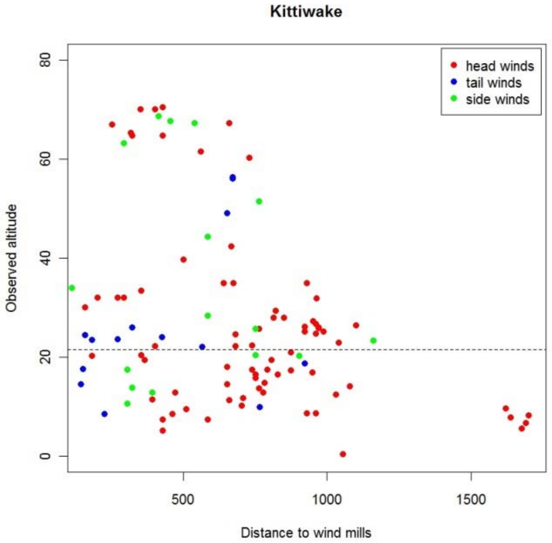


Kittiwake © Graeme Pegram

Figure 5-62. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

5.6.8.2 Estimates of collisions with HR1 and HR2 offshore wind farms

Kittiwakes are rather uncommon wintering birds in Horns Rev area. All kittiwakes observed at wind farms HR1 and HR2 were considered as resident staging birds. The obtained flight directions did not indicate seasonal long-distance migrations through the wind farm areas, therefore possible collision risk of migrating kittiwakes was not assessed. In total 2 kittiwake tracks were observed using the radar and 11 with the rangefinder. Of these, 4 birds entered the wind farm area (perimeter) resulting in 69% macro-avoidance rate

Aerial surveys conducted in winters 2006 and 2007 revealed low densities of kittiwakes within wind farm areas and 3 km buffer around them. Ship survey results indicated that about 56% of all kittiwakes were recorded in flight (n = 65,691).

Relatively high proportion of all kittiwakes was recorded flying at rotor altitude at the two wind farms, when considering bird track locations that were the most proximate to wind turbines (Table 5-18). Although the densities of wintering kittiwakes were low, relatively high proportion of birds in flight and flying at rotor altitude result in a high flux of birds through the wind farms and blade-swept area and estimates suggest that 1-8 birds would collide with turbines at HR1 and HR2 (Table 5-18).

Table 5-18. Collision risk estimates for wintering Kittiwakes at HR1 and HR2 offshore wind farms, along with species-specific values of key input parameters. Collision risk calculated for *pessimistic* (98% avoidance rate) and *optimistic* (99.5 % avoidance rate) scenarios.

	Horns Rev 1	**Horns Rev 2**
Kittiwake		
Mean density of all wintering birds), ind/km^2	0.050	0.029
% of birds flying (estimated from ship surveys)	56%	56%
Mean density of flying birds in winter (Nov-Apr), ind/km^2	0.028	0.016
% of bird flying at rotor height	18.2%	36.4%
Collision risk (98% avoidance), number of birds colliding	6	8
Collision risk (99.5% avoidance), number of birds colliding	1	2

5.6.9 Terns

5.6.9.1 Prediction of migration altitude

A total of 79 rangefinder tracks of terns, including Sandwich Tern *Sterna sandvicensis*, were spatially adjusted and used in the analysis. Common Tern *Sterna hirundo* and Arctic Tern *Sterna paradisaea*. Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-63 - Figure 5-65.

The GAMM for the terns indicated that the birds fly higher in higher air pressure and decreasing relative humidity. Larger flocks also fly significantly lower than smaller flocks according to the model. The variable distance to closest wind turbine was not significant. There was not a significant difference between birds tracked at HR2 in comparison with birds tracked at HR1 and the wind direction was not significant either. Birds tracked in the autumn 2011 and spring 2012 flew significantly higher than during the second season (no terns were tracked during the first season (Figure 5-66, Table 5-19). The model had a good predictive ability with a Spearman's correlation coefficient of 0.51 when the model was fitted on 70% of the data and evaluated on 30%. The relationship between observed and predicted altitude is visualised in Figure 5-67. The adjusted R-squared value indicated that the model explains 18 % of the variability in the data set. No spatial autocorrelation was found in the model residuals of the ”lme” model part, which indicated that the GAMM model was able to account for the spatial autocorrelation in the data.

We used the model for predicting the average flight altitudes during spring 2011 (when most tracks were recorded). The weather parameters were set to mean values within the collected data (Table 5-20). We made separate predictions for head winds, tail winds and side winds. According to the predictions the terns flew clearly below rotor height during all wind directions (Figure 5-68). However, as they according to the model flew higher in season 3 and 4, they can also during certain time fly closer to the turbines.

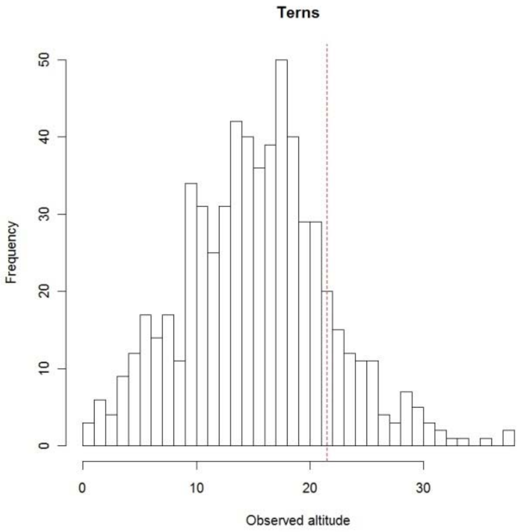


Figure 5-63. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

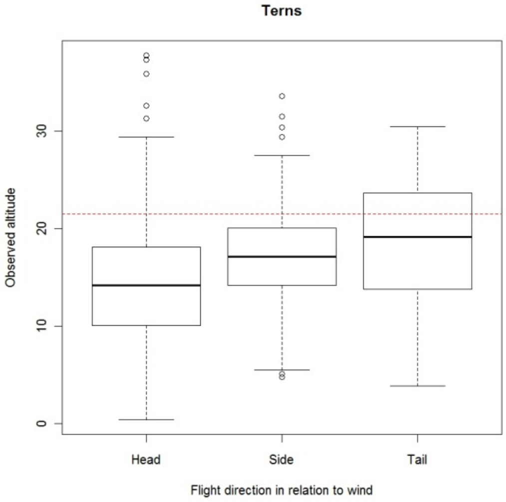


Figure 5-64. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

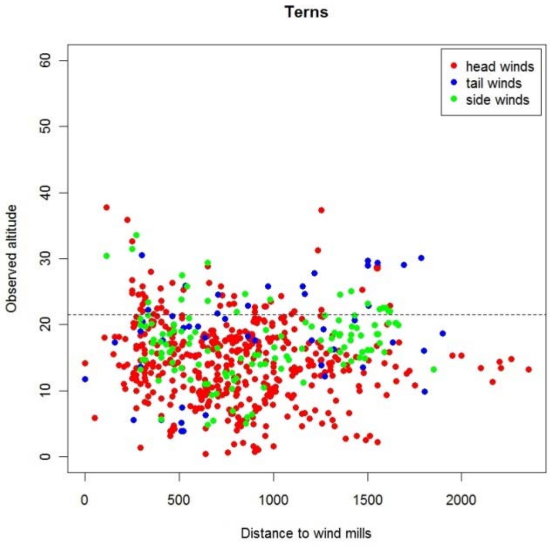


Figure 5-65. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

Sandwich tern © Thomas W. Johansen

Table 5-19. Significance and t- and F-values for the fixed parametric (wind directions, wind farm and survey year) and smooth terms included in the GAMM for the terns. The model was evaluated by fitting the model on 70% and testing the predictive accuracy on 30% by estimating Spearman's rank correlation between observed and predicted altitudes. Adjusted R-square value is given as an indication of variance explained by the model.

		t-value	p-value
Parametric	Tail wind	1.019	<0.31
	Side wind	2.268	0.02
	HR2	-0.654	0.51
	Season 3	3.256	<0.01
	Season 4	4.450	<0.01
Smooth		F-value	p-value
	Dist. to turbine	-	-
	Wind speed	-	-
	Humidity	6.927	<0.01
	Pressure	16.578	<0.01
	Flock size	21.864	<0.01
R-sq. (adj)		0.18	
Spearman's correlation		0.51	
Sample size		617	

Sandwich tern © Thomas W. Johansen

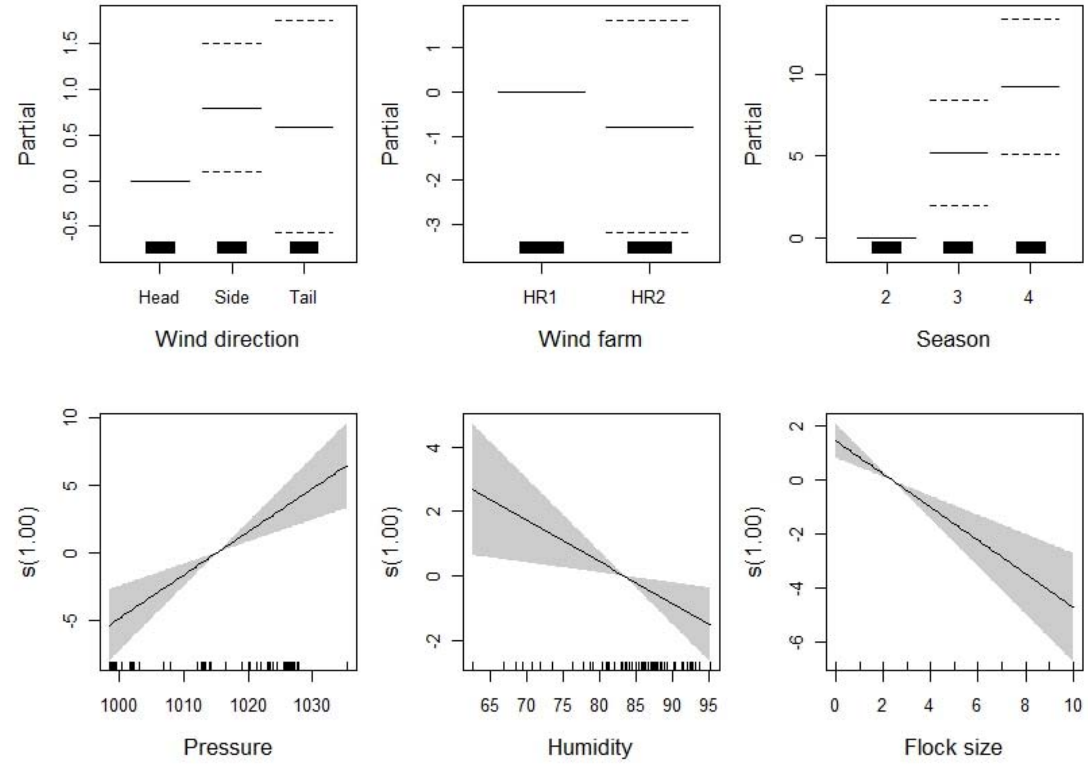


Figure 5-66. Response curves of the GAMM for the terns displaying the relationship between the flight altitude and predictor variables. The values of the environmental predictors are shown on the X-axis and the probability on the Y-axis in logit scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas and the dotted lines show the 95% Bayesian confidence intervals.

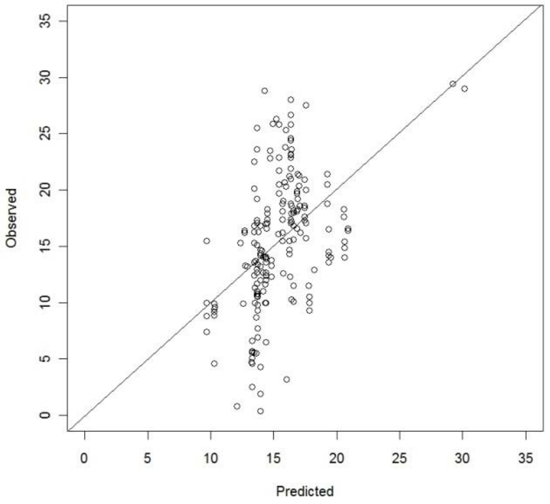


Figure 5-67. Predicted flight altitudes for terns displayed against observed altitudes (not used in model construction). The model was fitted on 70% of the data and tested on 30%. The black line is a regression line (linear regression) between observed and predicted altitudes (intercept = -0.04, slope = 1.01).

Table 5-20. Mean, minimum and maximum values of the response and predictor variables, as well as sample size at either wind farm site as well as number of observations during head wind, tail wind and side winds.

Variables	Mean value	Min. value	Max value
Altitude	15.3	0.4	37.8
Distance to turbine	840	0	2,355
Wind speed (m/s)	5.7	0.4	8.7
Humidity (%)	83.5	62.5	95.1
Clearness	72.4	0.0	100.0
Pressure	1,015.3	998.5	1,035.3
Temperature (°C)	9.1	4.3	16.3
	Head wind	Tail wind	Side wind
No. of samples	445	48	124
	HR 1	HR 2	
No. of samples	187	430	

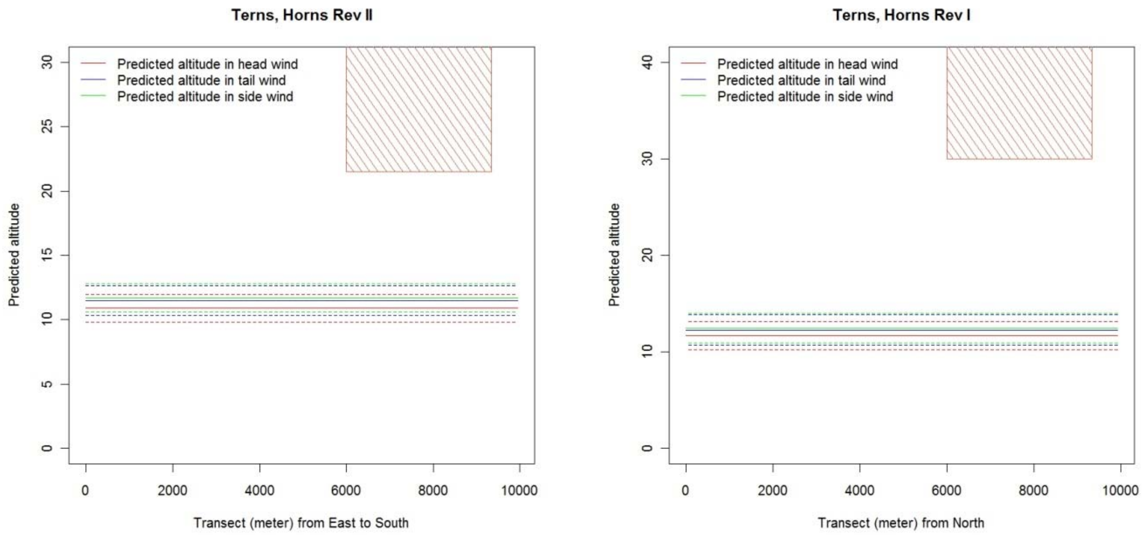


Figure 5-68. Predicted altitude at HR2 (upper) and at HR1 (lower), along a "theoretical" transect trough the investigated area in autumn 2011 for terns during head winds, tail winds and side winds, with all other predictor variables set to mean conditions. The dashed lines around the predictions indicate the standard errors. The rotor swept area is defined by the rectangle with shading red lines.

5.6.9.2 Estimates of collisions with HR1 and HR2 offshore wind farms

Tern densities are rather low during the season for which density estimates are available. All terns observed at wind farms HR1 and HR2 were considered as resident staging birds, although the obtained flight direction did indicate the presence of seasonal long-distance migrations through the wind farm areas.

Aerial surveys conducted in winters (and early springs) 2006-2007 revealed low densities of terns within wind farm areas inclusive a 3 km buffer zone (Table 5-21). Ship survey results indicated that about 70% of all terns were recorded in flight (n = 3,151).

In total 13 tern tracks were observed using the radar and 74 with the rangefinder. Of these, 20 birds entered the wind farm area (perimeter) resulting in 77% macro-avoidance rate.

Few terns were recorded flying at rotor altitude at Horns Rev wind farms (Table 5-21), when considering bird track locations that were the most proximate to wind turbines.

Collision risk estimates for wintering birds were very low (Table 5-21). The combined PBR threshold for the European population of the three tern species is 90,000 birds, thus the estimated mortality should be considered as insignificant at the population level.

Table 5-21. Collision risk estimates for wintering terns at HR1 and HR2 offshore wind farms, along with species-specific values of key input parameters. Collision risk calculated for pessimistic (98% avoidance rate) and optimistic (99.5 % avoidance rate) scenarios.

	Horns Rev 1	**Horns Rev 2**
Terns		
Mean density of all wintering birds), ind/km^2	0.006	0.021
% of birds flying (from ship surveys)	70%	70%
Mean density of flying birds in winter (Nov-Apr), ind/km^2	0.004	0.014
% of bird flying at rotor height	6.8%	16.4%
Collision risk (98% avoidance), number of birds colliding	0	2
Collision risk (99.5% avoidance), number of birds colliding	0	0

5.6.10 Raptors

We were able to spatially adjust and use 11 rangefinder tracks of raptors, including six species. The number of tracks was too low for constructing reliable altitude models. Summary graphs of the rangefinder data used in the altitude models are shown in Figure 5-69 - Figure 5-71.

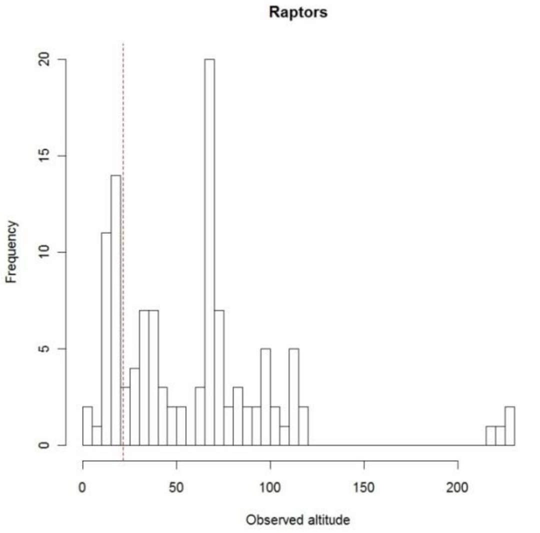


Figure 5-69. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

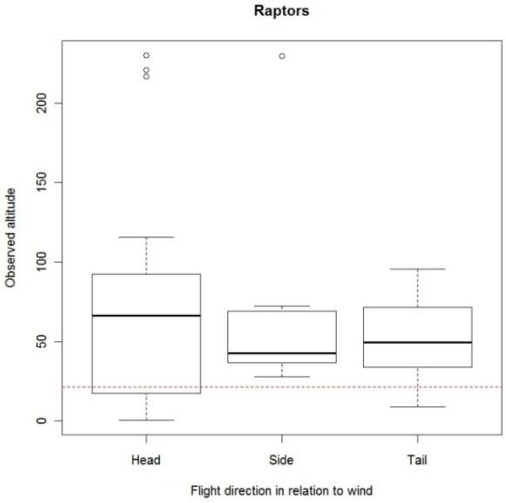


Figure 5-70. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

Migrating Short Eared Owl at Horns Rev 2

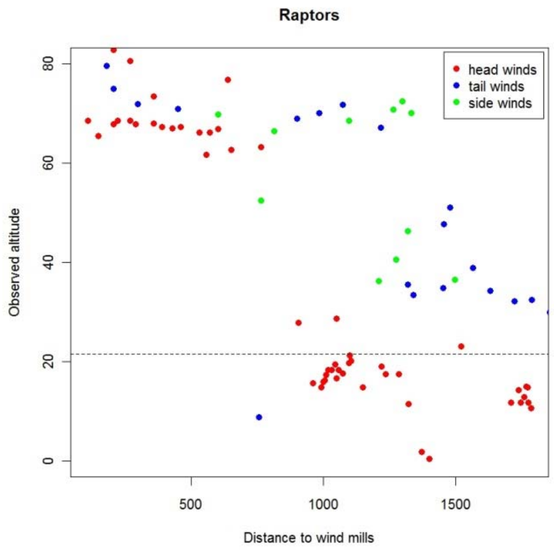


Figure 5-71. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

Kestrel resting on the Poseidon Platform, Horns Rev 2

5.6.10.1 Estimates of collisions with HR1 and HR2 offshore wind farms

Migrating raptors are rare at HR1 and HR2. In total, only 15 migrating raptor tracks were recorded, 4 using the radar and 11 with the rangefinder. Of these birds, 5 individuals entered the wind farm area (perimeter) resulting in 67% macro-avoidance rate. Kestrel *Falco tinnunculus* was the most frequently recorded species (Table 5-22).

Table 5-22. Species composition of raptors tracked using radar and rangefinder at HR1 and HR2 wind farms.

	Radar observations		Rangefinder observations	
Species	HR1	HR2	HR1	HR2
Marsh Harrier				1
Hen Harrier			1	
Sparrowhawk	1			1
Kestrel		1		4
Merlin	1			1
Peregrine Falcon		1		3

High proportions of raptors tracked using rangefinder flew at rotor height: 55% of birds were recorded flying at rotor height of HR1, and 73% at rotor height of HR2, when considering bird track locations that were the most proximate to wind turbines.

Using morphometric parameters of Kestrel, the most frequently recorded raptor species, it was estimated that the collision risk of crossing HR1 wind farm east to west (10 turbine rows) is 2.29%, and the collision risk of crossing HR2 wind farm at the same direction (7 turbine rows) is 1.89%.

5.6.11 Passerines and pigeons

5.6.11.1 Prediction of migration altitude

We were able to spatially adjust and use 67 rangefinder tracks of passerines and pigeons, including 16 different species. Only seven tracks were recorded at HR1, and were not included in the statistical analyses. Summary graphs of the rangefinder data used in the altitude models are shown in Figures 64-66.

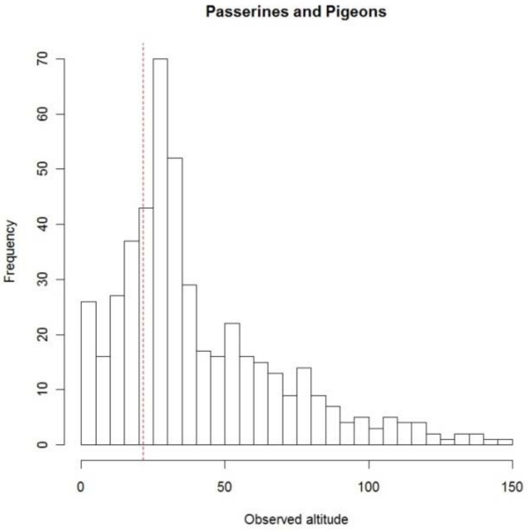


Figure 5-72. Histogram of observed altitudes, the rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

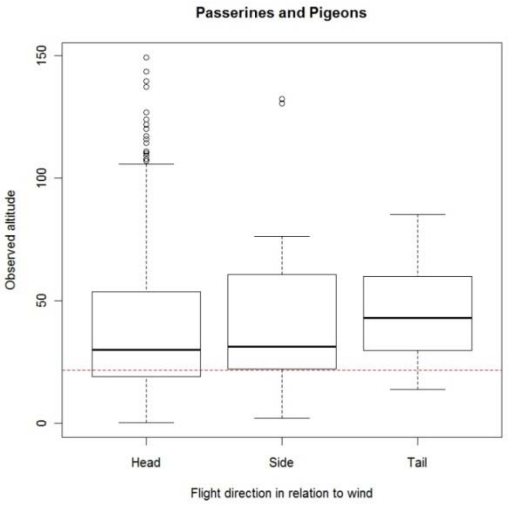
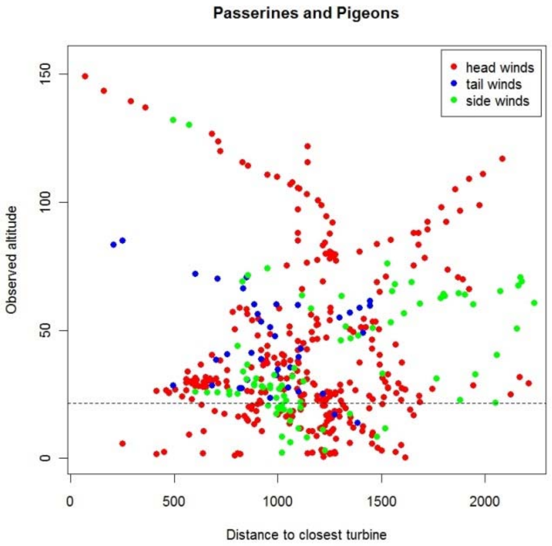


Figure 5-73. Boxplot of observed altitudes during head winds, side winds and tail winds, showing the range of the data (thin black lines), upper an lower quartiles (box), the median (thick black line) and potential outliers (open circles).The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed red line.

Hunting Great Grey Shrike at Horns Rev 1



Meadow Pipit at Horns Rev 1

Figure 5-74. Observed altitude plotted against distance to closest wind turbine, with different colors for head winds, side winds and tail winds. The rotor height (lowest tip) of the turbines at HR2 is indicated with a dashed black line.

The GAMM for the passerines and pigeons, indicated that the birds fly higher both close to the wind turbines and further away. They also seem to fly higher in decreasing wind speed, increasing clearness and increasing relative humidity. There was not a significant difference between different wind directions (Table 5-23, Figure 5-75). We did not include HR1 in the analyses as too few tracks were recorded. The model had a reasonable predictive ability with a Spearman’s correlation coefficient of 0.46 when the model was fitted on 70 % of the data and evaluated on 30 %. The relationship between observed and predicted altitude is visualised in Figure 5-76. The adjusted R-squared value indicated that the model explains 20 % of the variability in the dataset. We did not find spatial autocorrelation in the model residuals of the ”lme” model part, which indicated that the GAMM model was able to account for the spatial autocorrelation in the data.

We used the model for predicting the average flight altitudes of passerines and pigeons at the HR2 wind farm. The weather parameters were set to mean values (within the collected data, Table 5-24). We made separate predictions for head winds, tail winds and side winds. According to the predictions the passerines fly in mean conditions at rotor height during all wind directions (Table 5-23, Figure 5-77).

Table 5-23. Significance and t- and F-values for the fixed parametric (wind directions, wind farm and survey year) and smooth terms included in the GAMM for the passerines and pigeons. The model was evaluated by fitting the model on 70% and testing the predictive accuracy on 30% by estimating Spearman's rank correlation between observed and predicted altitudes. Adjusted R-square value is given as an indication of variance explained by the model.

		t-value	p-value
Parametric	Tail wind	-0.437	0.66
	Side wind	-0.448	0.66
Smooth		F-value	p-value
	Dist. to turbine	15.684	<0.01
	Wind speed	3.971	0.05
	Clear	17.137	<0.01
	Humidity	55.514	<0.01
R-sq. (adj)		0.20	
Spearman's correlation		0.46	
Sample size		439	

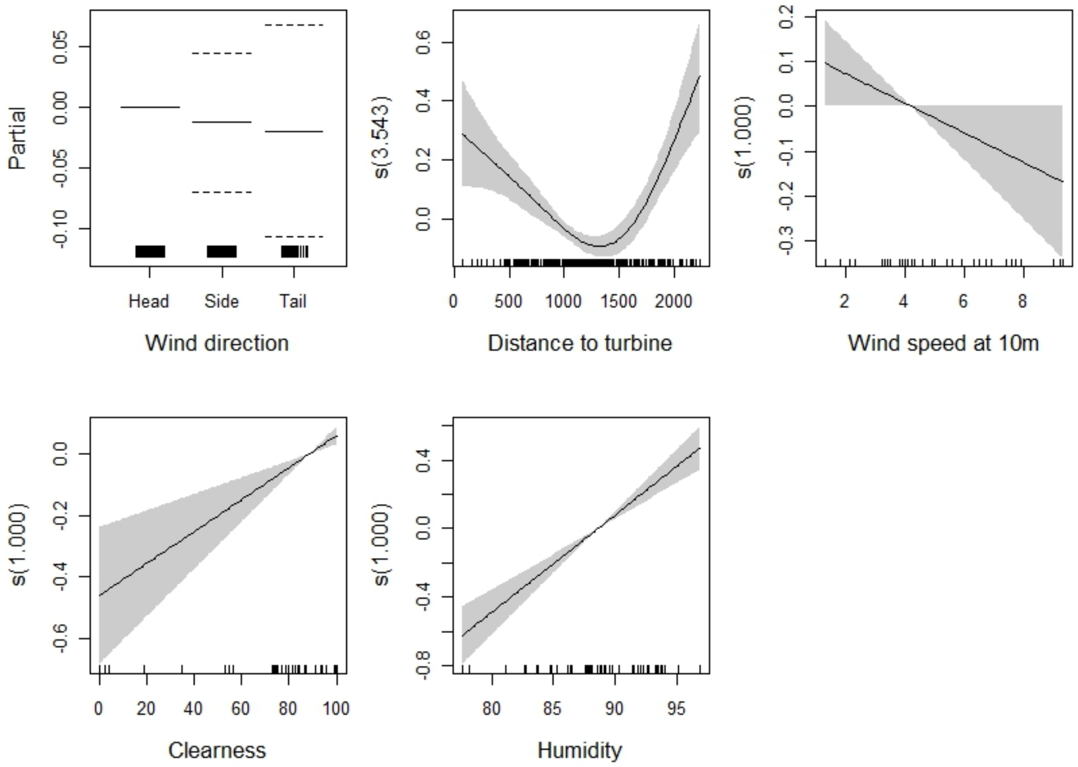


Figure 5-75. Response curves of the GAMM for the passerines and pigeons displaying the relationship between the flight altitude and predictor variables. The values of the environmental predictors are shown on the X-axis and the probability on the Y-axis in logit scale. The degree of smoothing is indicated in the title of the Y-axis. The shaded areas and the dotted lines show the 95% Bayesian confidence intervals.

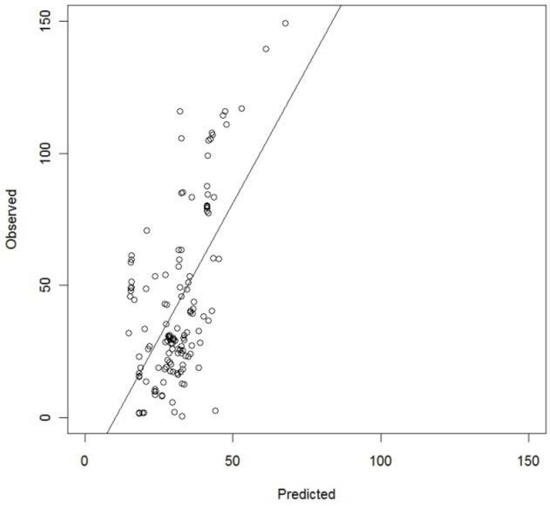
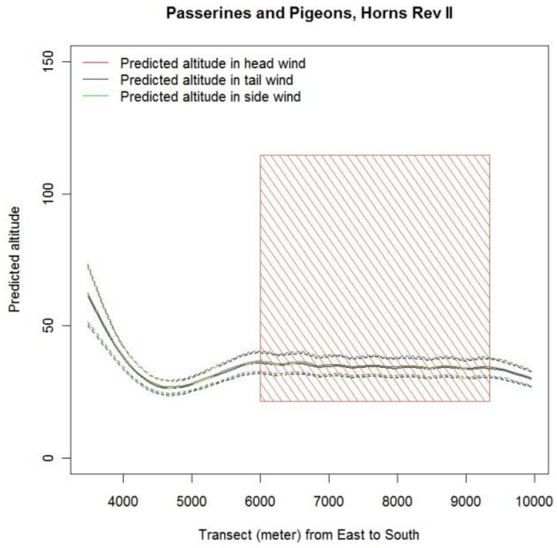


Figure 5-76. Predicted flight altitudes for passerines and pigeons displayed against observed altitudes (not used in model construction). The model was fitted on 70% of the data and tested on 30%. The black line is a regression line (linear regression) between observed and predicted altitudes (intercept = -20.63, slope = 2.04).

Redstart and Chaffinches resting on the Poseidon platform, Horns Rev 2

Table 5-24. Mean, minimum and maximum values of the response and predictor variables, as well as sample size at either wind farm site as well as number of observations during head wind, tail wind and side winds.

Variables	Mean value	Min. value	Max value
Altitude	40.9	0.2	149.2
Distance to turbine	1,149	71	2,236
Wind speed (m/s)	4.2	1.3	9.3
Humidity (%)	88.6	77.6	96.8
Clearness	88.6	0.0	100.0
Pressure	1,025	1,002	1,043
Temperature (°C)	11.0	-0.1	16.3
	Head wind	Tail wind	Side wind
No. of samples	316	39	84
	HR 1	HR 2	
No. of samples	(33) not used	439	



Chifchaff at Horns Rev 1

Figure 5-77. Predicted altitude at HR2, along a “theoretical” transect trough the investigated area in autumn 2011 for the passerines during head winds, tail winds and side winds, with all other predictor variables set to mean conditions. The dashed lines around the predictions indicate the standard errors. The rotor swept area is defined by the rectangle with shading red lines.

5.6.11.2 Estimates of collisions with HR1 and HR2 offshore wind farms

Despite the wind farms being offshore and not on any major migration route of land-birds, migrating passerines were relatively frequently observed at HR2. In total, 67 passerine tracks were recorded at both wind farms using the radar and 67 with the rangefinder.

Meadow Pipit *Anthus pratensis* was the most frequently recorded passerine species, accounting for a total of 57% tracks recorded by the radar and 30% recorded with the rangefinder. Four out of 58 recorded tracks entered wind farm perimeter, resulting in the macro-avoidance rate of 93%. Considering flight altitude in the nearest proximity to a wind turbine, 20% of Meadow Pipits flew above 30 m (rotor height in HR1) and 50% above 21.5 m (rotor height in HR2). Using these parameters it was subsequently estimated that collision risk of Meadow Pipits crossing one wind turbine row would be 0.015% at HR1 and 0.032% at HR2. Assuming east-west crossing of wind farms, i.e. 10 and 7 turbine rows at HR1 and HR2 respectively, the overall collision risk is estimated being 0.15% at HR1 and 0.23% at HR2.

5.1 Automated radar recordings

During both spring periods the automated radar recordings showed higher intensities of movements at HR2 than at HR1, while the intensities were at the same level during autumn (Figure 5-78, Figure 5-79). The temporal distribution during autumn at HR1 indicated higher intensities here during the late part of the autumn season. Similarly, at HR2 high intensities were recorded during October and November, as well as during late September. Even in August, relatively high intensities of movements were recorded at both platforms.

During the two spring seasons, quite different temporal trends were recorded at HR1 and HR2. At HR2 in spring 2011 high intensities were recorded throughout March and again around 20 May, whereas in spring 2012 high intensities were only recorded in March. At HR1 recordings during spring were highest in late April and mid May.

Given the dominance of 'local' birds it is likely that the temporal patterns at the two sites reflect variations in the abundance and distribution of feeding seabirds on Horns Rev during the investigations. However, events of long-distance migration as were recorded on HR2 during the peak migration of Meadow Pipits in late September (both years) may also be reflected (Figure 5-79). The large number of Common Scoter may largely have determined recorded intensities between September and April, while the recordings during May and August most likely reflect movements of terns and gulls. The two months constitute the main period of migration for Common, Sandwich and Arctic Terns, - a migration which was especially noted by the visual observations at HR1.

The mean directions of the recorded radar data show a dominance of directions along the axis of Horns Rev at HR1 and a multitude of directions at HR2, including the directions (NW-SE) along the axis of Horns Rev and the main directions expected for long-distance migrants (Figure 5-80, Figure 5-81).

Song trust at Horns Rev 1

Red breasted flycatcher at Horns Rev 1

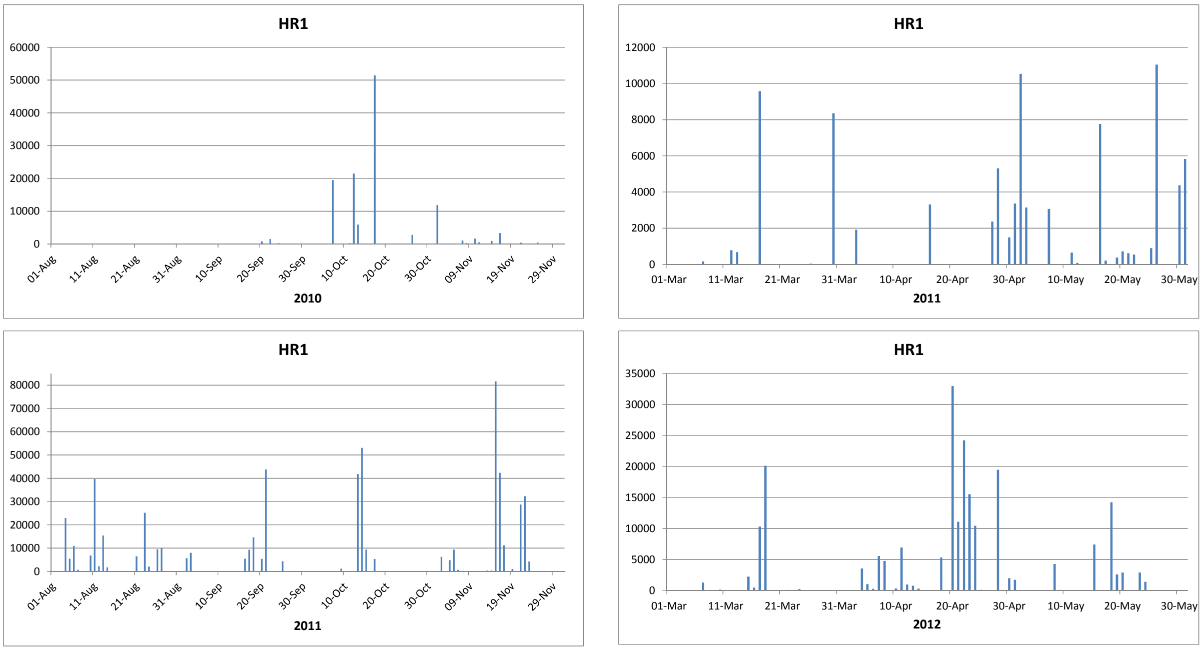


Figure 5-78. Daily relative migration intensities at HR1during periods of calm weather (< wind speed 6 m/s). The relative intensities represent an index of the total number of bird tracks recorded per day in the control area.

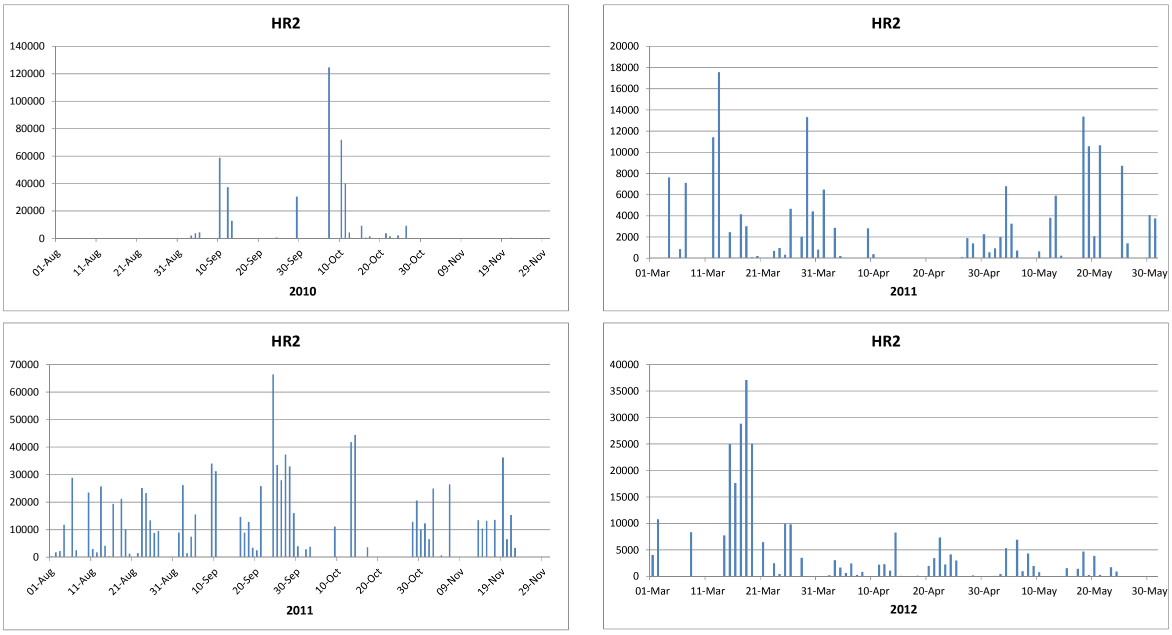


Figure 5-79. Daily relative migration intensities at HR2 during periods of calm weather (< wind speed 6 m/s). Daily relative migration intensities at HR2. The relative intensities represent an index of the total number of bird tracks recorded per day

in the control area.

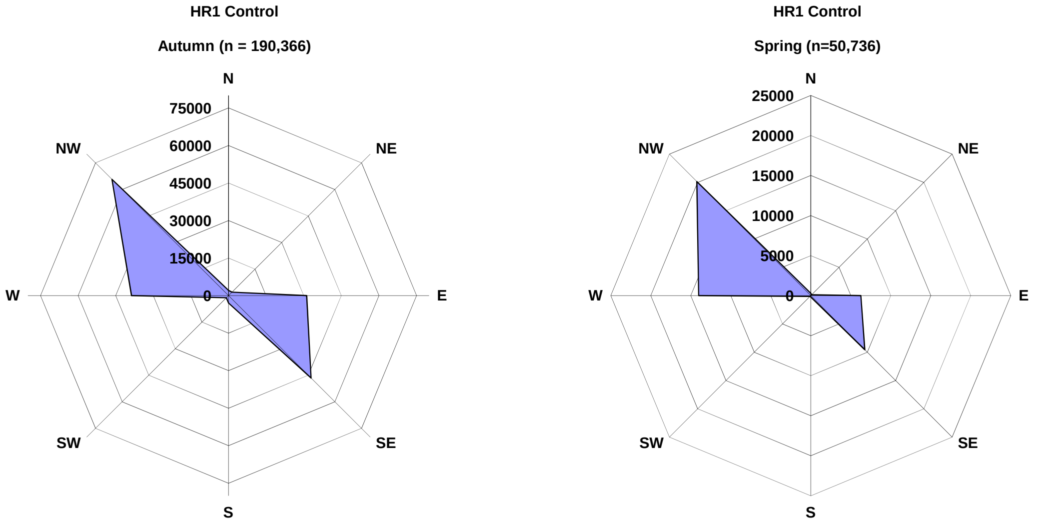


Figure 5-80. Mean migration direction of all bird tracks recorded by the radar in the control area at Horns Rev 1.

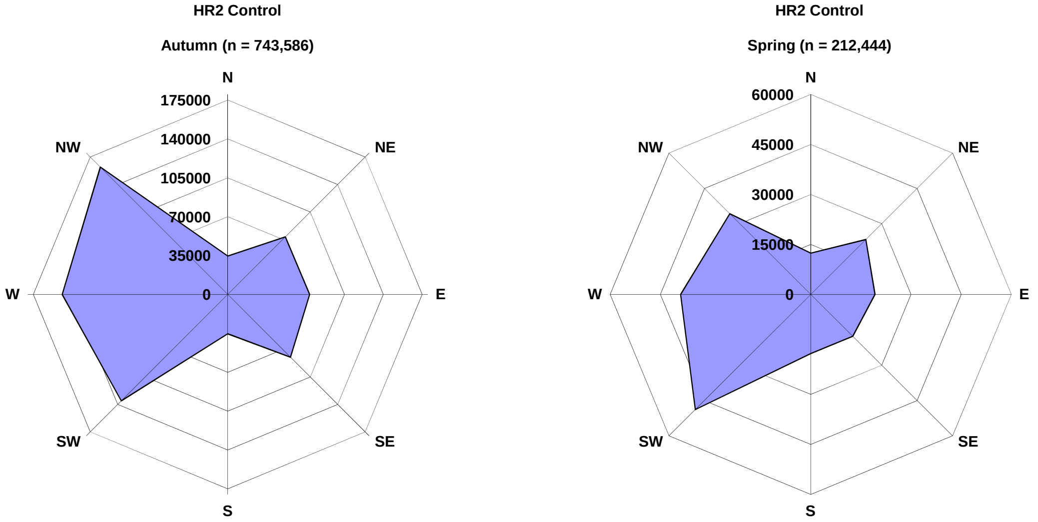


Figure 5-81. Mean migration direction of all bird tracks recorded by the radar in the control area at HR2.

6 DISCUSSION

6.1 Study design and data

The two-year post-construction study on bird movements and migration related to HR2 provided both a quantitative basis for estimation of species-specific barrier effects and collision risks and for comparing overall migration intensities between baseline and post-construction periods by use of automated monitoring by radar. Despite the exposed location of both radar stations on the Poseidon platform at HR2 and the transformer station at HR1 the planned effort was accomplished, and the total number of species-specific tracks and radar data was satisfactory. In total 1,785 species-specific tracks were recorded, of which 1,047 were 3D tracks made by rangefinder and 738 were 2D tracks made by radar (Appendix 3). The majority of the tracks recorded by both devices were of Common Scoter (55.1 %). With these data, the data collected during the baseline in 2008 (Piper et al., 2008; Skov et al., 2009) and the investigations related to HR1 (Petersen et al., 2006; Blew et al., 2008) the knowledge of spatio-temporal and directional trends in the movements of birds along Horns Rev has now reached a level which enables generalisations concerning bird migration to be made for the whole region. These generalisations include differences and similarities in the composition of species and functional groups along Horns Rev.

Most importantly in relation to the establishment of wind energy on Horns Rev, the altitude and flight models developed on species-specific behaviour at the two wind farms during this program make it possible to assess and predict likely effects for the main species of birds occurring in the region. There is little documented quantitative knowledge on the flight behaviour of birds offshore. Previously, flight altitudes of particularly raptors have been modelled in relation to distance to the coast and meteorological variables (Skov et al., 1212a; Skov, et al., 2012b). However, there are no prior studies that have tried to statistically model the flight height of birds flying in offshore areas (not influenced by distance to the coast). There is, however, a general knowledge about the influence of weather and wind on flight altitudes of birds (Richardson, 1978; Alerstam et al., 1978). The laser rangefinder data and the GAMM modelling approach made it possible to statistically assess the flight behaviour, in terms of altitudes, in the vicinity of the wind farms (for the species or species groups with a sufficient sample size). The models and the predictions show general flight patterns in relation to weather, wind and distance to the turbines which can be extrapolated beyond the sites of data collection. However, it is important to note that due to the sensitivity of the radar devices to wind induced sea clutter the data was collected during calm weather conditions, and is therefore biased towards these conditions. The response to e.g. wind speeds might therefore change at higher wind speeds. (Skov et al., 1212a) showed for example that the probability of birds flying higher increased up to around 7 m/s, were after it decreased again, for a few species of raptors. If the data would cover the whole range of weather and wind conditions the models would therefore most likely be improved.

6.2 Barrier effects

Prominent barrier effects and a reduced risk of colliding with the turbines of HR1 and HR2 could be determined for most of the key species. Gannets were seen in the HR2 wind farm despite the fact that the species has not previously or during this project been recorded in the HR1 wind farm. Accordingly, for all main species the barrier effect could be judged as partial as no species completely abandoned the wind farms.

Quantitative judgements of the strength of the barrier effects by the use of multivariate (GAM) models documented a concentration of flight paths around the wind farms and a significant decreasing tendency for the birds to fly towards the wind farms at closer distances. For Common Scoter the peak density at HR2 was determined to be 1,500-2,500 m distance from the wind farm, and at HR1 at 1,000-2,000 m distance. The probability of the Common Scoter to fly towards a wind turbine decreased more steeply at a distance of 1.5 km, with a tendency for a delayed response during spring as compared to autumn. The latter finding could potentially be due to that the scoters get used to the turbines during the winter and therefore do not react as strongly to the turbines in the spring as in the autumn.

These results are in accordance with the findings of Petersen et al. (2006) and Skov et al. (2009) who showed that more than 50% of the birds avoided the wind farm when being within 1-2 km from it. Along these lines it can be safely concluded that due to the limited spatial scale of the barrier effect of local seabirds at HR1 and HR2 no cumulative barrier effect exists between the two wind farms. Likewise, cumulative barrier effects on seabirds caused by the future expansion of wind farms planned for the Horns Rev region are likely to be rather limited.

6.3 Collision risks

The altitude profiles of the majority of species showed a preference for low altitude flights, particularly for the seabird species which all predominantly were recorded flying below the rotors when they approached the two wind farms. Only large gull species (Herring Gull, Lesser Black-backed Gull, Great Black-backed Gull), raptors, pigeons and passerines were often recorded flying at rotor height close to the wind farms.

Although most tracks were recorded during calm conditions, the weather and wind parameters as well as distance to the closest rotor were nevertheless shown to be influential in describing the flight altitudes, and the variance explained by the altitude models varied between 0.10 for Common Scoters and 0.35 for Gannets. However, the response differed between the species. Most species flew higher in tail and side winds in comparison to head winds although the variable was not always significant. For Common Scoter this was also noted by Blew et al. (2008). Common Scoters and large gull species flew, according to the models, at higher altitudes closer to the turbines. Gannets and Common Scoters increased altitude with increasing wind speeds while large gulls, passerines and pigeons increased flight height with decreasing wind speed. Increasing pressure explained partly the increasing flight altitude of terns and Gannets. Decreasing humidity was influential in describing an increase in altitude for Gannets and terns while increasing humidity was influential for Common Scoters, passerines and pigeons.

According to the models the species flying closer to the rotor swept area were Gannets and large gulls, whereas Common Scoters and terns flew well below the rotor swept area in all weather situations. The risk for the Gannets and large gull species of potentially colliding with the rotors increased when the birds were flying in tail or side winds and for the Gannets in intermediate wind speeds and for large gull species at low wind speeds. The risk was higher at HR2 than at HR1 as the rotor swept area reaches nearly 10 m closer to the sea surface at HR2. The modelled average flight altitudes for passerines and pigeons were based on a small sample size and included a range of different species which consequently increased the uncertainties to the results.

The estimated collision rates largely followed the predictions from the altitude models, yet the large abundance of Common Scoter resulted in a larger number of collisions than expected. A higher collision rate was seen across all assessed species for HR2 than for HR1. Thus, the height of the lower tip of the rotor over the sea surface (10 m higher for HR1 than HR2) seems to constitute an important design parameter in relation to mitigating collision risks to seabirds. The worst case estimated total mortality of seabirds per ‘winter’ season was 553 at HR2 and 415 at HR1, of which Common Scoter and large gulls comprised the vast majority of victims. The large number of estimated collisions by Common Scoter was mainly driven by the large abundance of birds at HR2. Although only a minority entered the wind farm perimeter at rotor height the flux of birds was sufficiently large to cause regular collisions with the rotor blades. The high estimated collision rates for large gulls were mainly driven by a combination of a high proportion of flying birds and high proportions flying at rotor height.

The specific macro avoidance rates were lower than those recorded at the Egmond aan Zee offshore wind farm in the Netherlands (Krijgsveld et al., 2011), and those recorded earlier during the monitoring at HR1, and for terns at the Zeebrugge wind farm in Belgium (Everaert & Stienen, 2007). The reason for this may be the fact that the movements on Horns Rev were more dominated by local feeding or resting seabirds which may have a higher tendency to habituate to the wind farm than birds on long-distance migration. The avoidance rate for Common Scoter was 76%. For comparison, an avoidance rate of 90% by Common Scoter was found during the monitoring at HR1 (Christensen et al., 2004). This may be a result of habituation since early 2000, as a gradual reduction in responses has been noted (Petersen et al., 2006). Other examples of the possible habituation of seabirds at Horns Rev wind farms are 86% avoidance in Gannets compared 99.1% at Egmond aan Zee and 71%/56% avoidance in small/large gulls compared to 76% recorded during the monitoring at HR1 (Petersen et al., 2006). For terns we recorded an avoidance rate of 77%. For comparison, overall avoidance rate of over 99% by terns was found at the Zeebrugge wind farm (Everaert & Stienen, 2007).

Rather low avoidance rates of migrating raptors were recorded. A macro-avoidance rate of 67% was recorded in raptors which may be comparable to the rates reported by Skov et al. (2012b) at Rødsand 2; Sparrowhawk 72%, Honey Buzzard 69%, Common Buzzard 94%, Red Kite 58% and Marsh Harrier 54%. For raptors a high proportion or 55% of birds were also recorded flying at rotor height at HR1, and 73% at HR2. These figures are comparable to those recorded for raptors at Rødsand 2 (Skov et al., 2012b).

The issue of habituation of local seabirds may also be the reason why a higher proportion of birds for all assessed species were flying at rotor height at HR2 than expected from the models of Cook et al. (2012), which used a minimum rotor blade height of 20 m and a maximum rotor blade height of 150 m. At HR1, probably on account of the higher lower tip of the rotor blades, the proportion flying at rotor height was only higher than reported by Cook et al. (2012) for divers. The height distributions of Red-throated Divers by Cook et al. (2012) indicated that only 2% of birds would be flying at rotor height compared to 20% at HR1 and 33.3% at HR2. For Gannets the proportion recorded by Cook et al. (2012) was 9.6% compared to 8.7% at HR1 and 39.1% at HR2. For Common Scoter Cook et al. (2012) recorded 1% at rotor height compared to 1.3% at HR1 and 6.6% at HR2. For the smaller gull species Cook et al. (2012) recorded that 7.9% of Black-headed Gulls, 5.5% of Little Gulls and 22.9% of Common Gulls would be flying at rotor height, while the average height recorded during this study indicated 12.5% at rotor height at HR1 and 22.9% at HR2. For the large gulls we recorded 39.5% flying at rotor height at HR1 and 55.8% at HR2, while Cook et al. (2012) recorded the following specific proportions: 25.2% of Lesser Black-backed Gulls, 33.1% of Greater Black-backed Gulls and 28.4% of Herring Gulls. For the Kittiwake 18.2% were recorded to fly at rotor height at HR1 and 36.4% at HR2 compared to 15.7% by Cook et al. (2012). For terns 6.8% were recorded flying at rotor height at HR1 and 16.4% at HR2 compared to the following specific proportions by Cook et al. (2012) 3.6% of Sandwich Terns, 12.7% of Common Terns and 2.8% of Arctic Terns.

The modelled flight altitudes for local seabirds provide a new basis for assessing cumulative collision risks caused by the planned expansion of offshore wind farms in the Horns Rev region. Although the abundance of the different species which regularly use Horns Rev will change as compared to the situation in 2006-2007 which was the basis for the collision models applied here, the avoidance rates would still be useful to assess collisions beyond the investigated areas at HR1 and HR2. Obviously, the design parameters, and here especially the lower height of the rotor should be taken into account when extrapolating the findings from this study to the entire development region on Horns Rev. Of the studied species improved collision models may be developed for the Gannet if more data on flight patterns were collected during situations with strong winds. Wind speed had a significant effect on the estimated collision risk for Gannets, however during the period when Gannets were mainly observed calm wind conditions prevailed. Thus, the flight altitude of the birds during strong wind situations is uncertain. Adding to this, the abundance of Gannets in the Horns Rev area is known to be highly variable from year to year (Petersen et al. 2006), and the years 2008-2010 were characterised by a low abundance of Gannets.

With respect to the collision model for migrating birds two of the model parameters are based on very few data, and as they represent the within wind farm behaviour of birds and interactions with the rotor blades the estimated collisions should only be regarded as approximations; proportion trying to cross the swept area without showing avoidance and the probability of being hit by the rotor-blades. The proportion trying to cross the swept area without showing avoidance was set to 92 % following Winkelman (1992). Despite several wind farm monitoring programs (see review of within wind farm monitoring methods in Collier et al. (2011) no data on micro-avoidance of different species have yet been published. However, the actual collision rate depends largely on this parameter, and variations of 10 % in the parameter would result in 20-fold differences in the resulting collision risk. Thus, the collection of real species-specific avoidance rates must be regarded as a priority if robust estimates of collisions are to be established. Last second avoidances are difficult to register, and estimations based on monitoring at individual turbines based on single Thermal Animal Detection Systems (TADS) or digital cameras have proven inadequate due to low sample sizes.

The probability of being hit by the rotor-blades depends on the size of the bird (both length and wingspan), the breadth and pitch of the turbine blades, the rotation speed of the turbine, and of course the flight speed of the bird. To facilitate calculation, many simplifications have been made. For example the bird is assumed to be of simple cruciform shape, with the wings at the halfway point between nose and tail. The turbine blade is assumed to have a width and a pitch angle, but to have no thickness, and it is assumed that a bird's flight will be unaffected by a near miss, despite the slipstream around a turbine blade. Most uncertainty seems to be related to the assumption that birds always cross the turbine at 90 degrees, even for birds which approach the rotor obliquely. The logic behind this, which is not founded on field observations, is that the reduction in crossed area and increase in time it takes for the bird to cross the rotor plane during oblique approaches probably cancel each other out. Certainly, empirical data are needed to enable comparisons of collision rates during perpendicular and oblique crossings. These may, conveniently, be collected from land-based wind farms.

It should also be noted that alternative approaches and modifications of both collision models may be useful in establishing the uncertainty of collision estimates. Moving from deterministic to probabilistic analysis could be undertaken using bootstrapping or Monte Carlo methods (Manly, 2006). Such analysis uses not one value per parameter, but includes the whole uncertainty range around it. For each parameter, this uncertainty range is based on all observed values and the frequency with which they occur. A random generator will then pick one value per parameter from their frequency distributions, thus leading to a large number of sets of random parameter values. For all of these sets the collision probability is then calculated by the deterministic model. Together, the collision probabilities resulting from these randomly combined sets will lead to a probability density function, which shows the probability that a certain collision probability will occur. This function thus provides insight in the range of potential outcomes, but also shows which uncertainties contribute most to the variability of the final result. A probability analysis is specifically useful in case many parameters are involved and their uncertainty ranges ‘accumulate’, such that the worst-case scenario will always result in a relatively large collision probability.

6.4 Species composition

As found by Piper et al. (2008) and Skov et al. (2009) the flight directions (both specific-specific tracks and the automated radar recordings) documented the dominance of local seabirds at the two wind farms, and in comparison to the situation on the coast of Blåvandshuk movements of birds on long-distance migration constituted a small proportion of the total number of movements. Movements of one species, Common Scoter, outnumbered those of other species, which was reflected in the 55% of all recorded tracks, and the large number of radar signals recorded between November and March. Due to the higher abundance of Common Scoter at HR2 as compared to HR1 the highest densities of species-specific tracks and radar signals were recorded at HR2. Since the observation of birds started at Blåvandshuk in 1963 the Common Scoter has been found to be the far most numerous species observed (Jakobsen, 2008). Flocks of more than 200.000 has been observed on the water, and the number wintering at Horns Rev makes up a high proportion of the total north-western population of Common Scoters. The majority of species found during the observations at Blåvandshuk from 1963 to 1992 (Jakobsen, 2008) were also found during the investigations from autumn 2010 to spring 2012 and no major changes in the phenology or overall dominance in the species composition of the most numerous species seems to be evident during the last 20 years.

Compared to the baseline the post-construction monitoring documented the presence of events of passerines, especially Meadow Pipits. Yet, these events were also noted on Blåvandshuk at an even larger scale. Thus, the occurrence of large numbers of passerines offshore on Horns Rev seems to be related to mass migration rather than specific offshore corridors. The visual recordings of terns indicate that some movements of terns are noted on HR1 but not at the coast, indicating the presence of an offshore corridor.

Sabine’s Gull at Blåvand

7 ACKNOWLEDGEMENTS

The observers who carried out the recordings at the two platforms and at Blåvandshuk are thanked for their great efforts and their great photos. The collaboration from DONG and Vattenfall staff at the platforms and with respect to transportation to and from the platforms was an important prerequisite for fulfilling the planned surveys.

Peregrine resting at Horns Rev 2

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MIGRATING BIRDS

Appendices

Marine Observers

biola

APPENDIX 1 OBSERVATION EFFORT AND WEATHER

Overview of daily weather conditions at the station at Blåvandshuk.

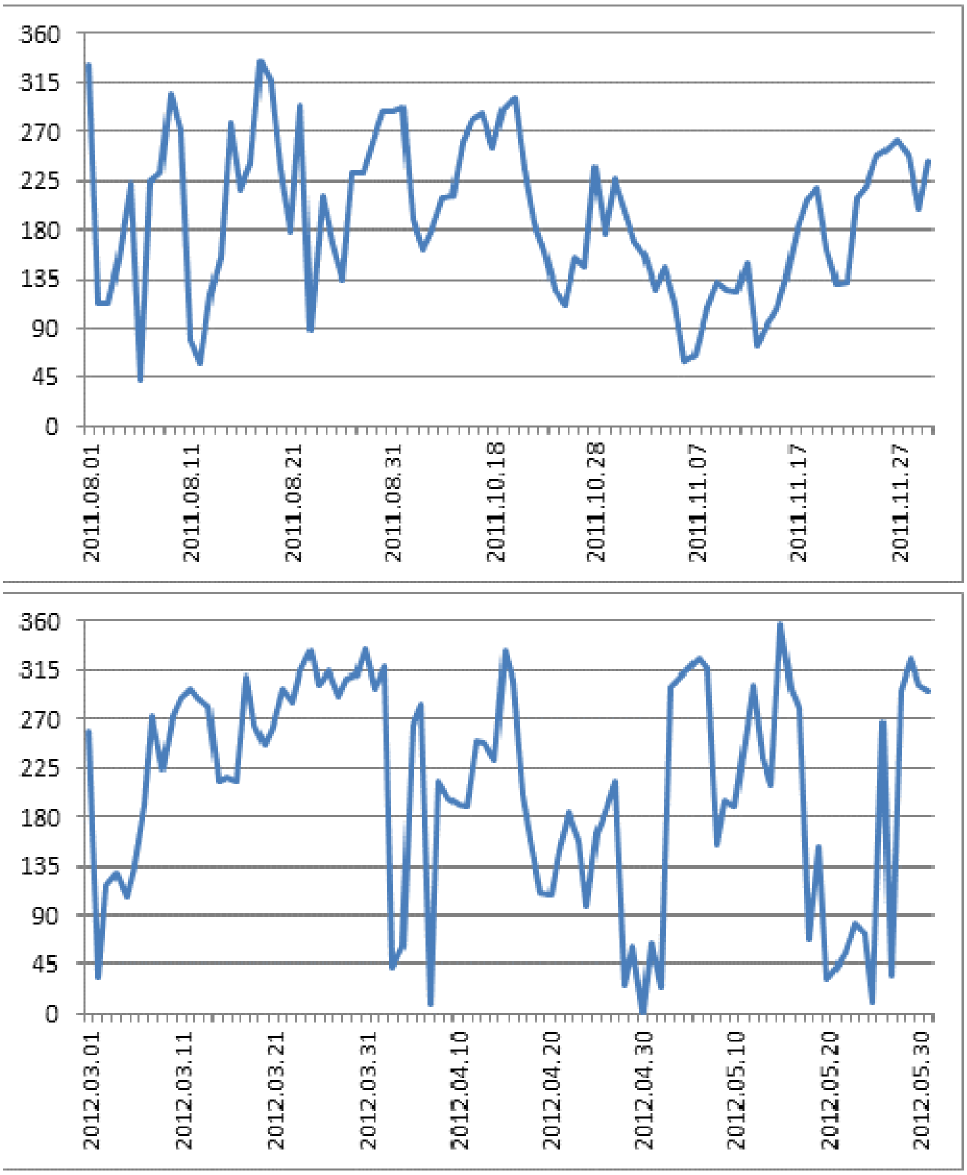
Date	Visibility (km)	Clouds (0-8/8)	Wind direction (Degrees)	Wind speed (m/s)	Rain (% day)	Effort (hours)
Autumn 2010						
23/09/2010	5	0	180	5	0	9.75
24/09/2010	3.5	4	45	3	10	9.75
25/09/2010	10	2	225	8	0	9.25
26/09/2010	8	8	45	6	30	8.25
27/09/2010	10	8	45	7	0	9.75
28/09/2010	40	1	45	8	0	9.75
12/10/2010	40	2	315	2	0	8.25
13/10/2010	2	8	90	2	0	8.25
20/11/2010	4.5	8	45	5	0	8.5
21/11/2010	3.5	8	45	6	0	8.5
Total						90
Spring 2011						
29/03/2011	5.5	8	270	9	0	14
30/03/2011	5	7	193	2	0	15
31/03/2011	1	8	180	8	0	15
24/04/2011	8	0	136	5	0	15
25/04/2011	7	0	193	2	0	15
26/04/2011	7.5	5	315	8	0	15
03/05/2011	10.5	3	139	3	0	12
04/05/2011	11.5	1	143	3	0	12
05/05/2011	11.5	2	292	6	0	12
Total						125
Autumn 2011						
16/08/2011	9.5	6	90	6	20	12.5
17/08/2011	11	4	74	8	0	12.5
18/08/2011	11	5	119	4	0	11.5
30/09/2011	7	0	5	4	0	10
01/10/2011	5	0	6	2	0	10
02/10/2011	1.5	4	7	4	0	7
06/11/2011	0.3	8	3	4	0	10
07/11/2011	1.5	8	3	5	0	9.5
Total						83
Spring 2012						
23/03/2012	9	0	135	3	0	13.25
24/03/2012	3	8	135	3	0	13.25
25/03/2012	9	0	135	5	0	11.25
21/04/2012	7	5	9	3	0	13.25
22/04/2012	11	4	45	6	0	13.25
23/04/2012	10	5	45	7	0	12.25
19/05/2012	8.5	7	130	3	40	13.25
20/05/2012	7.5	2	259	3	0	13.25
21/05/2012	10.5	2	270	4	0	13.25
Total						116.25
Total 2010-2012						344

Overview of daily weather conditions at the station at Horns Rev 1.

Date	Waves (m)	Visibility (km)	Clouds (0-8/8)	direction (De	Wind speed (m/s)	Rain (0-7)	Effort Visual (hours)	Effort radar	Effort rangefinder
Autumn 2010									
23/09/2010	0.5	3	7	180	4	1	9.5	1	
24/09/2010	0.4	8	8	225	6	1	9.5	11.5	11
25/09/2010	1.3	20	4	180	3	0	11.5	11.5	11
26/09/2010	1.6	6	8	45	5	3	11	11	10.5
27/09/2010	1.1	16	8	45	4	0	11.5	11.5	11
28/09/2010	0.9	20	3	45	5	0	11.5	11.5	11
12/10/2010	0.5	20	5	315	1	0	7	7	7
13/10/2010	0.3	5	7	180	1	2	10	10	10
20/11/2010	0.7	13	8	45	3	1	7	7	3
21/11/2010	0.8	7	8	90	3	2	8	8	7
Total							96.5	90	81.5
Spring 2011									
30/03/2011	0	6	8	127	3	0	10	0	10
31/03/2011	1	0.5	8	180	4	Rain	0	0	0
24/04/2011	0	20	0	120	4	0	10	0	10
25/04/2011	0	20	0	203	2	0	13	13	13
26/04/2011	1	15	4	360	4	Rain	7.5	0	7.5
03/05/2011	1	16	6	315	4	Rain	10	3	10
04/05/2011	0	20	2	255	3	0	12	5	12
05/05/2011	1	20	2	270	4	0	9	0	9
Total							71.5	111	153
Autumn 2011									
16/08/2011	0.7	11	7	225	4	2	12	0	12
17/08/2011	0.9	11	4	230	5	0	15	0	15
18/08/2011	0.5	15	4	290	3	0	15	0	15
30/09/2011	0.2	4	0	170	2	2	10	0	10
01/10/2011	0.2	4	0	135	2	2	9	9	9
14/10/2011	0.4	15	3	160	2	0	9.5	9.5	9.5
15/10/2011	1	15	4	180	5	0	10.5	0	10.5
16/10/2011	1	12	3	180	5	1	10.5	0	10.5
17/10/2011	0.6	11	5	200	3	1	4	0	4
06/11/2011	0.5	1	8	35	3	2	8	0	8
07/11/2011	0.8	2	8	45	4	2	7.5	0	7.5
Total	0.6	10	4	170	4	1	111	18.5	111
Spring 2012									
23/03/2012									
24/03/2012									
25/03/2012									
21/04/2012	0.2	4	6	145	2	0	11		11
22/04/2012	0.5	12	6	180	4	0	14		14
23/04/2012	1.2	5	6	165	5	0	9		9
19/05/2012	0.4	4	6	170	3	0	11.75	4	11.75
20/05/2012	0.5	5	3	20	4	0	11		11
24/05/2012	0.3	30	0	90	4	0	6.5		6.5
Total							63.25	4	63.25
Total 2010-2012							342.25	223.5	408.75

Overview of daily weather conditions at the station at Horns Rev 2

Date	Waves (m)	Visibility (km)	Clouds (0-8/8)	Wind directio	Wind speed (m/s)	Rain (0-7)	Effort Visual (hours)	Effort radar	Effort rangefinder
Autumn 2010									
12/09/2010	-	-	-	-	-	-	0	0	0
13/09/2010	-	-	-	-	-	-	3	0	0
23/09/2010	0.5	3	7	6	4	1	0	0	0
24/09/2010	0.4	8	8	7	6	1	0.5	3	3
25/09/2010	1.3	20	4	6	3	0	11	11	11
26/09/2010	1.6	6	8	3	5	3	0	0	0
27/09/2010	1.1	16	8	3	4	0	9	0	9
28/09/2010	0.9	20	3	3	5	0	7.5	0	7.5
12/10/2010	0.5	20	5	9	1	0	8	8	8
13/10/2010	0.3	5	7	6	1	2	8	6	8
20/11/2010	0.7	13	8	3	3	1	5	5	5
21/11/2010	0.8	7	8	4	3	2	3.25	0	3.25
Total							55.25	33	54.75
Spring 2011									
02/03/2011	0	5.3	8	90	3.5		8.5	8.5	8.5
03/03/2011	0	2.7	8	185	1		8.5	8.5	8.5
29/03/2011	2	10	8	260	10.5		11.5	11.5	11.5
30/03/2011	0.5	14.4	8	135	4.5	Rain	6	6	0
31/03/2011	1.33	0.1	8	180	9.3	Rain	2	0	0
22/04/2011	1	18.5	0	110	7.5		8.33	0	8.33
23/04/2011	1.2	14.6	3.4	90	9.4		12	0	12
24/04/2011	0.8	12.8	0	130	5.8		12	2.5	12
25/04/2011	0.25	12	0.2	171	3.2		5.5	5.5	5.5
26/04/2011	1.25	11	4	360	8		5.5	0	5.5
04/05/2011	0.67	45	2	345	4.7		11.5	10.5	11.5
05/05/2011	1	45	1	270	7.3		10.5	0	10.5
06/05/2011	0.95	15.6	4	140	5.2		8	8	8
Total							109.83	61	101.83
Autumn 2011									
13/08/2011	1.17	38	6	4	7		9.5		9.5
14/08/2011	1.5	4	8	5	10	1	12		12
15/08/2011	1	45	6	8	8		9		9
17/08/2011	1.67	45	4	8	11		10		10
18/08/2011	0.88	43	6	7	6		10		10
30/09/2011	0.25	5	0	6	4		6.5	6.5	6.5
01/10/2011	0.19	4	0	6	4		13	11.5	11.5
02/10/2011	0.25	3	5	7	5		7	4.5	4.5
27/10/2011	1.31	15	7	5	11		7.5		7.5
28/10/2011	1.09	25	7	8	8	1	10		5.5
06/11/2011	1	2	8	3	6		8		8
07/11/2011	1.5	3	8	3	9		4		1
Total							106.5	22.5	95
Spring 2012									
23/03/2012							8	0	8
24/03/2012	0.3	0.9	7.6	8	2.9		13.5	0	1.75
25/03/2012	0.7	7.4	3	9	8		9	0	9
21/04/2012	0.7	4.6	6.9	5.2	6.1		8.3	0	8.3
22/04/2012	0.6	12.9	4.9	6	6.9	1	11.5	0	11.5
23/04/2012	0.9	7.9	7.3	5.1	9.6		12.5	0	12
24/04/2012	0.8	9.8	8	4	9.3	1	12.5	0	11.8
25/04/2012	0.3	4.7	5	6	3.3		10	8	9.5
19/05/2012	0.4	3.3	6.6	5.4	4.4	0.2	10.5	6	10.5
20/05/2012	0.5	3.5	4.2	2	5.6	0	13.3	13.3	13.3
21/05/2012	0.9	10.3	3.9	3	8.7	0	12.3	0	12.3
22/05/2012	0.7	6.9	5.6	3	7.5	0	13.3	0	13.3
23/05/2012	0.7	10.2	0.1	3.2	7.2	0	12	0	12
Total							146.5	27.25	133.1
Total 2010-2012							418.08	143.75	384.68



Daily mean wind directions (at 35 m) based on data recorded at HR2 wind farm during the periods 1 August to 31 October 2011 and March 1 to May 30 2012.

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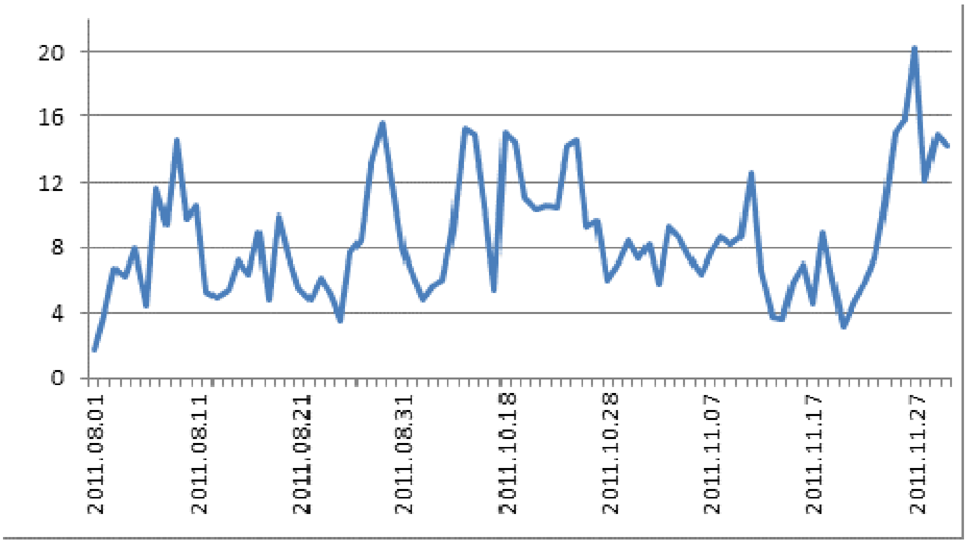
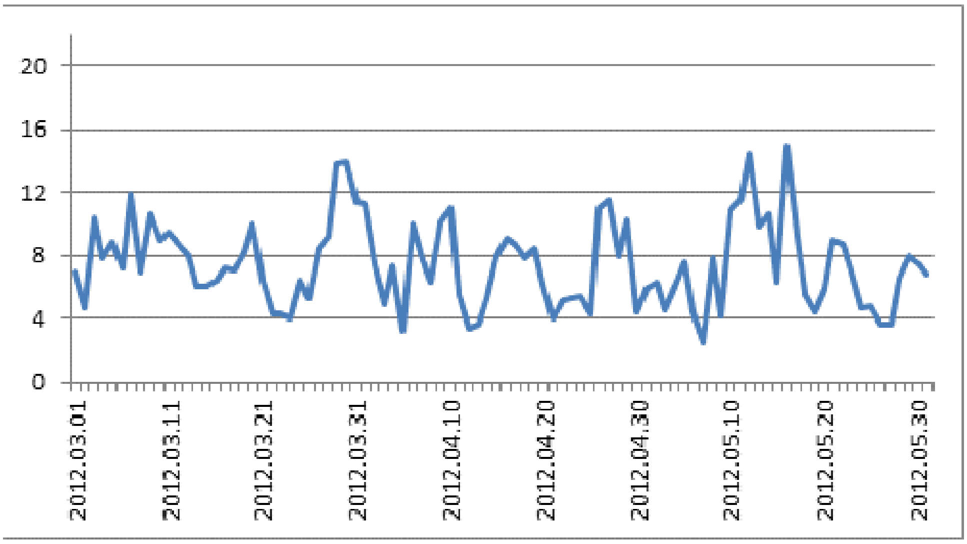




Daily mean wind speed (at 27 m) based on data recorded at HR2 wind farm area during the periods 1 August to 31 October 2011 and March 1 to May 31 2012

APPENDIX 2 SPECIES LIST. VISUAL OBSERVATIONS

Number of visually observed birds at the three observations sites at Horns Rev autumn 2010 – spring 2012. Numbers represent campaign totals (Continued).

					Autumn 2010			Spring 2011			Autumn 2011			Spring 2012			Total
Group	**Subgroup**	**Common name**	**Scientific name**	**Danish name**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	
Divers		Black-throated Diver	*Gavia arctica*	Sortstrubet Lom	2			5			1	3		12		1	**24**
		Great Northern Diver	*Gavia immer*	Islom				2						1			**3**
		Red-throated Diver	*Gavia stellata*	Rødstrubet Lom	262	3	3	788		14	27	19		1,030		4	**2,150**
		Unid diver	*Gaviidae indet.*	Uidentificeret lom			2			3	1	1				4	**11**
Grebes		Great Crested Grebe	*Podiceps cristatus*	Toppet Lappedykker	6			9		1	1			3			**20**
		Red-necked Grebe	*Podiceps grisegena*	Gråstrubet Lappedykker	4						1			1			**6**
		Unid Grebe	*Podicipedidae indet.*	Uidenficeret Lappedykker						1							**1**
Tubenoses		Fulmar	*Fulmarus glacialis*	Mallemuk				1					1				**2**
		Sooty Shearwater	*Puffinus griseus*	Sodfarvet Skråpe							2						**2**
Gannets		Gannet	*Morus bassanus*	Sule	25	4	6	97	2	19	27	12	25	405	4	38	**664**
Cormorants		Cormorant	*Phalacrocorax carbo*	Skarv	732	5	38	59	1	15	227	15	14	52	13	6	**1,177**
Herons		Grey Heron	*Ardea cinerea*	Fiskehejre	4			1		1	6			13		1	**26**
Geese & swans	Anser geese	Greylag Goose	*Anser anser*	Grågås	657	38	46	31	13	4	593			14			**1,396**
		Pink-footed Goose	*Anser brachyrhynchus*	Kortnæbbet Gås	250		92	186			50			32			**610**
		White-fronted Goose	*Anser albifrons*	Blisgås	3									1			**4**
	Branta geese	Barnacle Goose	*Branta leucopsis*	Bramgås	411			142			193			660			**1,406**
		Brent Goose	*Branta bernicla*	Knortegås	1,361			146			12			114			**1,633**
	Swans	Mute Swan	*Cygnus olor*	Knopsvane										7			**7**
		Unid Swan	*Cygnidae indet.*	Uidenficeret Svane		2											**2**
		Unid goose	*Anserini indet.*	Uidentificeret gås		1	16				61						**78**
Other ducks	Diving ducks	Greater Scaup	*Aythya marila*	Bjergand				1						4			**5**
		Tufted Duck	*Aythya fuligula*	Troldand	21			9						5			**35**
	Mergansers	Goosander	*Mergus merganser*	Stor Skallesluger							1						**1**
		Red-breasted Merganser	*Mergus serrator*	Toppet Skallesluger	29			39			5			54			**127**
	Sheldgeese	Egyptian Goose	*Alopochen aegyptiacus*	Nilgås										2			**2**
		Shelduck	*Tadorna tadorna*	Gravand		15		17			3			86			**121**
	Swimming ducks	Garganey	*Anas querquedula*	Atlingand		15											**15**
		Mallard	*Anas platyrhynchos*	Gråand	2	2	21	19		2	2		1	14			**63**
		Pintail	*Anas acuta*	Spidsand	59			4			7			8			**78**
		Shoveler	*Anas clypeata*	Skeand										1			**1**
		Teal	*Anas crecca*	Krikand	88			114	2		31			204		2	**441**
		Unid duck	*Anatinae indet.*	Uidentificeret and							2				4		**6**
		Wigeon	*Anas penelope*	Pibeand	545			14			23			17			**599**
Sea ducks		Common Scoter	*Melanitta nigra*	Sortand	10,291	285		10,152	95		2,310	283		24,902	97		**48,415**
		Eider	*Somateria mollissima*	Ederfugl	1,212			652			25			141		9	**2,039**
		Goldeneye	*Bucephala clangula*	Hvinand	18			17			10			53			**98**
		Long-tailed Duck	*Clangula hyemalis*	Havlit	2			39			2	41		13			**97**
		Surf Scoter	*Melanitta perspicillata*	Brilleand		1											**1**
		Velvet Scoter	*Melanitta fusca*	Fløjlsand	75		2	24			20			119			**240**
Raptors	Eagles	White-tailed Sea-eagle	*Haliaeetus albicilla*	Havørn	2												**2**
	Hawks	Buzzard	*Buteo buteo*	Musvåge	5			11		1	10			21			**48**
		Hen Harrier	*Circus cyaneus*	Blå Kærhøg	8			3	1		8	1		4			**25**
		Honey Buzzard	*Pernis apivorus*	Hvepsevåge										1			**1**
		Marsh Harrier	*Circus aeruginosus*	Rørhøg	1			2			2		2	3			**10**
		Pallid Harrier	*Circus macrourus*	Steppehøg				1			5						**6**
		Red Kite	*Milvus milvus*	Rød Glente							2						**2**
		Rough-legged Buzzard	*Buteo lagopus*	Fjeldvåge				1			4			3			**8**
		Sparrowhawk	*Accipiter nisus*	Spurvehøg	49	1	3	20		1	28	1	1	12			**116**
	Ospreys	Osprey	*Pandion haliaetus*	Fiskeørn	1			1									**2**
	Falcons	Hobby	*Falco subbuteo*	Lærkefalk										1		1	**2**
		Kestrel	*Falco tinnunculus*	Tårnfalk	15			2		1	22	3	2	6		4	**55**
		Merlin	*Falco columbarius*	Dværgfalk	10		2	2			4		1	6		1	**26**
		Peregrine	*Falco peregrinus*	Vandrefalk	3	1	3	2		2	1	2	2	3			**19**

Continued. Number of visually observed birds at the three observations sites at Horns Rev autumn 2010 – spring 2012. Numbers represent campaign totals (Continued).

					Autumn 2010			Spring 2011			Autumn 2011			Spring 2012			Total
Group	**Subgroup**	**Common name**	**Scientific name**	**Danish name**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	
Landfowls	Quails	Quail	*Coturnix coturnix*	Vagtel						1							**1**
Waders	Oystercatchers	Oystercatcher	*Haematopus ostralegus*	Strandskade	42			356		2	831	1		432			**1,664**
	Stilts & avocets	Avocet	*Recurvirostra avosetta*	Klyde				2				1		2			**5**
	Plovers & lapwings	Lapwing	*Vanellus vanellus*	Vibe						4							**4**
		Golden Plover	*Pluvialis apricaria*	Hjejle	3		1	97		2	66		6	94		1	**270**
		Grey Plover	*Pluvialis squatarola*	Strandhjejle	7			5		1	7			10			**30**
		Ringed Plover	*Charadrius hiaticula*	Stor Præstekrave	3			42		1	36		2	47			**131**
	Godwits, curlews and other sandpipers	Bar-tailed Godwit	*Limosa lapponica*	Lille Kobbersneppe				19			5			100			**124**
		Black-tailed Godwit	*Limosa limosa*	Stor Kobbersneppe				6			2			5			**13**
		Common Sandpiper	*Actitis hypoleucos*	Mudderklire				2		1	2			6		1	**12**
		Curlew	*Numenius arquata*	Stor Regnspove				76	2		33		3	72			**186**
		Green Sandpiper	*Tringa ochropus*	Svaleklire				4						2			**6**
		Greenshank	*Tringa nebularia*	Hvidklire				14			8			19			**41**
		Redshank	*Tringa totanus*	Rødben	15			33			32		1	42	2		**125**
		Spotted Redshank	*Tringa erythropus*	Sortklire				8			1			4			**13**
		Unid Wader	*Limicolae indet.*	Uidenficeret vadefugl			3					1	1				**5**
		Whimbrel	*Numenius phaeopus*	Lille Regnspove				19			31		4	26		1	**81**
	Sandpipers	Curlew Sandpiper	*Calidris ferruginea*	Krumnæbbet Ryle				2						2			**4**
		Dunlin	*Calidris alpina*	Almindelig Ryle	255		2	350		1	410	2	1	744			**1,765**
		Knot	*Calidris canutus*	Islandsk Ryle	5			4		375	375		3	263		2	**1,027**
		Little Stint	*Calidris minuta*	Dværgryle				3			2			4			**9**
		Purple Sandpiper	*Calidris maritima*	Sortgrå Ryle	10			2									**12**
		Sanderling	*Calidris alba*	Sandløber	45			269			27			738			**1,079**
		Temminck's Stint	*Calidris temminckii*	Temmincksryle										1			**1**
		Unid. Sandpipers	*Calidris indet.*	uid Ryle	8												**8**
	Snipes	Snipe	*Gallinago gallinago*	Dobbeltbekkasin	2	2		11		1	4	1		7			**28**
	Turnstones	Turnstone	*Arenaria interpres*	Stenvender	2	2		3			4		10	4			**25**
	Woodcocks	Woodcock	*Scolopax rusticola*	Skovsneppe				4		2				1			**7**
Skuas		Arctic Skua	*Stercorarius parasiticus*	Almindelig Kjove	1			3		3	9		7	34	3	6	**66**
		Great Skua	*Stercorarius skua*	Storkjove				1				1					**2**
		Long-tailed Skua	*Stercorarius longicaudus*	Lille Kjove					1								**1**
		Pomarine Skua	*Stercorarius pomarinus*	Mellemkjove	1											1	**2**
		Unid Skua	*Stercorariidae indet.*	Uidenficeret Kjove								5					**5**
Gulls	Large gulls	Glaucous Gull	*Larus hyperboreus*	Gråmåge				1			1			3			**5**
		Great Black-backed Gull	*Larus marinus*	Svartbag	103			717	2		477	23		1,208	9		**2,539**
		Herring Gull	*Larus argentatus*	Sølvmåge	951	58		6,414	20		1,205	19		3,060		4	**11,731**
		Lesser Black-backed Gull	*Larus fuscus*	Sildemåge	35	3		137	16	16	152	99		134	21	8	**621**
	Small gulls	Black-headed Gull	*Larus ridibundus*	Hættemåge	269			931	34	124	538	43	118	834	18	45	**2,954**
		Common Gull	*Larus canus*	Stormmåge	515	8		1,314	13	6	126	16		1,711	13	74	**3,796**
		Kittiwake	*Rissa tridactyla*	Ride	5						10	69		7		6	**97**
		Little Gull	*Larus minutus*	Dværgmåge	11		7	43	71	105	4	3	5	88	11	12	**360**
		Sabine's Gull	*Larus sabini*	Sabinemåge	1												**1**
	Terns	Arctic Tern	*Sterna paradisaea*	Havterne		1		1,483			151	3		1,007			**2,645**
		Black Tern	*Chlidonias niger*	Sortterne				3				51		1			**55**
		Caspian Tern	*Sterna caspia*	Rovterne										1			**1**
		Common Tern	*Sterna hirundo*	Fjordterne	1			633	16	6	31	7	12	639			**1,345**
		Common/Arctic Tern	*Sterna hirundo / paradisaea*	Fjordterne / Havterne	1			321				400		1,037	14	24	**1,797**
		Little Tern	*Sterna albifrons*	Dværgterne				153			1			121			**275**
		Sandwich Tern	*Sterna sandvicensis*	Splitterne	76	3		2,582	33	10	778	182		3,685	12	17	**7,378**
		Sandwich Tern/Little Gull	*Sterna sandvicensis/Larus minutus*	Splitterne/Dværgmåge											1		**1**
		Unid Tern	*Sterninae indet.*	Uidenficeret Terne								1			1		**2**
		Common Gull/Herring Gull	*Larus canus/Larus fuscus*	Stormmåge/Sildemåge					1								**1**
		Lesser/Greater Black-backed Gull	*Larus fuscus / marinus*	Sildemåge / Svartbag											6		**6**
		Unid Gull	*Laridae indet.*	Uidenficeret Måge											10		**10**

Continued. Number of visually observed birds at the three observations sites at Horns Rev autumn 2010 – spring 2012. Numbers represent campaign totals (Continued).

					Autumn 2010			Spring 2011			Autumn 2011			Spring 2012			Total
Group	**Subgroup**	**Common name**	**Scientific name**	**Danish name**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	**BV**	**HR1**	**HR2**	
Alcids		Guillemot	*Uria aalge*	Lomvie	7	1		7				32		4		1	**52**
		Guillemot/Razorbill	*Uria aalge/Alca torda*	Lomvie/Alk											1		**1**
		Little Auk	*Alle alle*	Søkonge		1					8	1	1				**11**
		Razorbill	*Alca torda*	Alk	2			2						2		1	**7**
		Razorbill/Guilimot	*Alca torda / Uria aalge*	Lomvie / Alk	6			21						4			**31**
Owls		Long-/Short-eared Owl	*Asio otus/Asio flammeus*	Skov-Mosehornhgle												1	**1**
		Long-eared Owl	*Asio otus*	Skovhornugle												1	**1**
		Short-eared Owl	*Asio flammeus*	Mosehornugle	1	2	1				5	2	5				**16**
Nightjars		Nightjar	*Caprimulgus europaeus*	Natravn				1									**1**
Passerines & Pigeons	Pigeons & doves	Collared Dove	*Streptopelia decaocto*	Tyrkerdue	2			8	2					18			**30**
		Stock Dove	*Columba oenas*	Huldue				4		2							**6**
		Turtle Dove	*Streptopelia turtur*	Turteldue										1			**1**
		Woodpigeon	*Columba palumbus*	Ringdue	95	54	178	27	2	6	3	2	2	45	1	2	**417**
	Cuckoos	Cuckoo	*Cuculus canorus*	Gøg							3			5			**8**
	Swifts	Swift	*Apus apus*	Mursejler				1			1		41	31	1	13	**88**
	Woodpeckers	Wryneck	*Jynx torquilla*	Vendehals				1									**1**
	Larks	Shore Lark	*Eremophila alpestris*	Bjerglærke	3			1			1		1	1			**7**
		Skylark	*Alauda arvensis*	Sanglærke	9		5	27	1	14	38		10	8	2	2	**116**
		Woodlark	*Lullula arborea*	Hedelærke	3			1			12			17			**33**
	Swallows and martins	House Martin	*Delichon urbica*	Bysvale	1			20			487			47	3	5	**563**
		Sand Martin	*Riparia riparia*	Digesvale				70		3	15			15		3	**106**
		Swallow	*Hirundo rustica*	Landsvale	195	1	3	345	11	19	1,045	10		578	39	41	**2,287**
Passerines &Pigeons	Wagtails and pipits	Grey Wagtail	*Motacilla cinerea*	Bjergvipstjert	9		4				3			1			**17**
		Meadow Pipit	*Anthus pratensis*	Engpiber	10,318	65	967	395	36	66	7,951	257	1,008	185	80	142	**21,470**
		Pied Wagtail	*Motacilla alba*	Hvid Vipstjert	65	1	6	126	6	7	55	5	4	175	20	12	**482**
		Rock Pipit	*Anthus petrosus*	Skærpiber	20		4							3			**27**
		Tree Pipit	*Anthus trivialis*	Skovpiber	4			27		9	10	1	1	22			**74**
		Yellow Wagtail	*Motacilla flava*	Gul Vipstjert	6			5	1	4	6		2	10		5	**39**
	Shrikes	Red-backed Shrike	*Lanius collurio*	Rødrygget Tornskade				2									**2**
		Woodchat Shrike	*Lanius senator*	Rødhovedet Tornskade										1			**1**
	Waxwings	Waxwing	*Bombycilla garrulus*	Silkehale	16												**16**
	Wrens	Wren	*Troglodytes troglodytes*	Gærdesmutte		1						2					**3**
	Accentors	Dunnock	*Prunella modularis*	Jernspurv	4		8	11			103		6	15			**147**
	Chats & Thrushes	Black Redstart	*Phoenicurus ochruros*	Husrødstjert										2	3		**5**
		Blackbird	*Turdus merula*	Solsort	4				8	3	49	65	137				**266**
		Fieldfare	*Turdus pilaris*	Sjagger	146	1		20		1	24	25	109	11			**337**
		Mistle Thrush	*Turdus viscivorus*	Misteldrossel							1		1	2			**4**
		Redstart	*Phoenicurus phoenicurus*	Rødstjert				1				1		1	1	2	**6**
		Redwing	*Turdus iliacus*	Vindrossel	45			17			181	50	37	47			**377**
		Ring Ouzel	*Turdus torquatus*	Ringdrossel	1						10			1			**12**
		Robin	*Erithacus rubecula*	Rødhals	2	1	1					2		9	4	1	**20**
		Song Thrush	*Turdus philomelos*	Sangdrossel	42	8	1	3	1	1	413	11	16	2		4	**502**
		Stonechat	*Saxicola torquata*	Sortstrubet Bynkefugl				4			1			4			**9**
		Unid Thrush	*Turdidae indet.*	Uidentificeret Drossel									1				**1**
		Wheatear	*Oenanthe oenanthe*	Stenpikker				40	4	2	10	1	1	19		1	**78**
		Whinchat	*Saxicola rubetra*	Bynkefugl				1			1			3			**5**

Continued. Number of visually observed birds at the three observations sites at Horns Rev autumn 2010 – spring 2012. Numbers represent campaign totals.

Group	Subgroup	Common name	Scientific name	Danish name	Autumn 2010			Spring 2011			Autumn 2011			Spring 2012			Total
					BV	HR1	HR2	BV	HR1	HR2	BV	HR1	HR2	BV	HR1	HR2	
	Warblers	Blackcap	*Sylvia atricapilla*	Munk								3		1		1	**5**
		Chiffchaff	*Phylloscopus collybita*	Gransanger					3		2			4			**9**
		Firecrest	*Regulus ignicapillus*	Rødtoppet Fuglekonge										1			**1**
		Garden Warbler	*Sylvia borin*	Havesanger										3			**3**
		Goldcrest	*Regulus regulus*	Fuglekonge		1				1							**2**
		Grasshopper Warbler	*Locustella naevia*	Græshoppesanger										3			**3**
		Lesser Whitethroat	*Sylvia curruca*	Gærdesanger				3						3			**6**
		Whitethroat	*Sylvia communis*	Tornsanger				4			3			6			**13**
		Willow Warbler	*Phylloscopus trochilus*	Løvsanger				1	1		1			8			**11**
	Flycatchers	Pied Flycatcher	*Ficedula hypoleuca*	Broget Fluesnapper						1							**1**
		Spotted Flycatcher	*Muscicapa striata*	Grå Fluesnapper										3		1	**4**
	Long-tailed tits	Long-tailed Tit	*Aegithalos caudatus*	Halemejse		11											**11**
	Tits	Great Tit	*Parus major*	Musvit							1						**1**
	Buntings	Corn Bunting	*Miliaria calandra*	Bomlærke				1									**1**
		Lapland Bunting	*Calcarius lapponicus*	Laplandsværling	10			6			3			6			**25**
		Reed Bunting	*Emberiza schoeniclus*	Rørspurv	126	1	1	42		1	175		7	36			**389**
		Snow Bunting	*Plectrophenax nivalis*	Snespurv	10	1	1	2			13		1				**28**
		Yellowhammer	*Emberiza citrinella*	Gulspurv	29			15			10		1	17	1		**73**
	Finches	Brambling	*Fringilla montifringilla*	Kvækerfinke	486	2	8	58	6	2		6		38		1	**607**
		Bullfinch	*Pyrrhula pyrrhula*	Dompap	1			2						2			**5**
		Chaffinch	*Fringilla coelebs*	Bogfinke	5,476	65	48	831	6	2	10,110	7	83	703		2	**17,333**
		Chaffinch/Brambling	*Fringilla coelebschnig/Fringilla montifringilla*	Bogfinke/Kvækerfinke			175					1				4	**180**
		Common Crossbill	*Loxia curvirostra*	Lille Korsnæb	26			27						12			**65**
		Common Rosefinch	*Carpodacus erythrinus*	Karmindompap				1						1			**2**
		Goldfinch	*Carduelis carduelis*	Stillits	7	7		47			7			48		1	**117**
		Greenfinch	*Carduelis chloris*	Grønirisk	48	3		87		1	30	1	2	75		1	**248**
		Lesser Redpoll	*Carduelis flammea*	Gråsisken	186	1		508			2			538			**1,235**
		Linnet	*Carduelis cannabina*	Tornirisk	19		3	642	31	1	45	2	2	429	2		**1,176**
		Serin	*Serinus serinus*	Gulirisk					1					1			**2**
		Siskin	*Carduelis spinus*	Grønsisken	276		31	124			262		8	82			**783**
		Twite	*Carduelis flavirostris*	Bjergirisk							5			7			**12**
		Unid finch	*Fringilla indet.*	Uidentificeret finke							40			20			**60**
	Sparrows	House Sparrow	*Passer domesticus*	Gråspurv							1						**1**
		Tree Sparrow	*Passer montanus*	Skovspurv	4						30						**34**
		Unid Passerine	*Passeriformes indet.*	Uidentificeret sangfugl		36	161			12			53		2	3	**267**
	Starlings	Starling	*Sturnus vulgaris*	Stær	337	7	1	83		43	2,434	244	20	249	3	6	**3,427**
	Crows	Crow	*Corvus corone cornix*	Gråkrage	35			102			53			182			**372**
			Corvus corone corone	Sortkrage	3			48	12	5	10			45	2		**125**
		Jackdaw	*Corvus monedula*	Allike	194			50	14		4	556		358	8	5	**1,189**
		Jay	*Garrulus glandarius*	Skovskade	45												**45**
		Magpie	*Pica pica*	Husskade	4			4						19			**27**
		Raven	*Corvus corax*	Ravn				1						2			**3**
		Rook	*Corvus frugilegus*	Råge										10	2		**12**
Total					**36,848**	**721**	**1,854**	**32,557**	**469**	**932**	**32,765**	**2,596**	**1,782**	**48,424**	**414**	**535**	**159,897**

APPENDIX 3 RECORDED RANGEFINDER AND RADAR TRACKS

Number of radar-based tracks recorded at the radar station at Horns Rev 1 and Horns Rev 2.

					Autumn 2010		**Spring 2011**		**Autumn 2011**		**Spring 2012**		**Total**	**Total**	**Total**
Group	**Subgroup**	**Common name**	**Scientific name**	**Danish name**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	
Divers		Red-throated Diver	*Gavia stellata*	Rødstrubet Lom	3			1				2	3	3	**6**
		Unid diver	*Gaviidae indet.*	Uidentificeret lom				5					0	5	**5**
Grebes		Red-necked Grebe	*Podiceps grisegena*	Gråstrubet Lappedykker				1					0	1	**1**
Tubenoses		Fulmar	*Fulmarus glacialis*	Mallemuk						1			0	1	**1**
Gannets		Gannet	*Morus bassanus*	Sule	4	1				15		5	4	21	**25**
Cormorants		Cormorant	*Phalacrocorax carbo*	Skarv	1		2	4		2		1	3	7	**10**
Geese & swans	Anser geese	Greylag Goose	*Anser anser*	Grågås	2	1	2			1			4	2	**6**
		Pink-footed Goose	*Anser brachyrhynchus*	Kortnæbbet Gås		1							0	1	**1**
		Unid goose	*Anserini indet.*	Uidentificeret gås		1							0	1	**1**
Other ducks	Sheldgeese	Shelduck	*Tadorna tadorna*	Gravand				1					0	1	**1**
Sea ducks		Common Scoter	*Melanitta nigra*	Sortand	40	48	36	339	1	26		21	77	434	**511**
		Eider	*Somateria mollissima*	Ederfugl			1					1	1	1	
		Velvet Scoter	*Melanitta fusca*	Fløjlsand				1					0	1	
Raptors	Hawks	Sparrowhawk	*Accipiter nisus*	Spurvehøg			3						3	0	**3**
		Kestrel	*Falco tinnunculus*	Tårnfalk						1			0	1	**1**
	Falcons	Peregrine	*Falco peregrinus*	Vandrefalk	1					1			1	1	**2**
Waders	Oystercatchers	Oystercatcher	*Haematopus ostralegus*	Strandskade				1					0	1	**1**
	Plovers & lapwings	Lapwing	*Vanellus vanellus*	Vibe				1					0	1	**1**
		Golden Plover	*Pluvialis apricaria*	Hjejle				1					0	1	**1**
	Godwits, curlews and other sandpipers	Unid Wader	*Limicolae indet.*	Uidenficeret vadefugl				1					0	1	**1**
	Snipes	Snipe	*Gallinago gallinago*	Dobbeltbekkasin	1								1	0	**1**
Gulls	Large gulls	Great Black-backed Gull	*Larus marinus*	Svartbag				5		1		3	0	9	**9**
		Herring Gull	*Larus argentatus*	Sølvmåge	3			10		7		2	3	19	**22**
		Lesser Black-backed Gull	*Larus fuscus*	Sildemåge			1	10					1	10	**11**
	Small gulls	Black-headed Gull	*Larus ridibundus*	Hættemåge	1					11			1	11	**12**
		Common Gull	*Larus canus*	Stormmåge				10					0	10	**10**
		Kittiwake	*Rissa tridactyla*	Ride								1	0	1	**1**
		Little Gull	*Larus minutus*	Dværgmåge				1			1		1	1	**2**
	Terns	Arctic Tern	*Sterna paradisaea*	Havterne	1								1	0	**1**
		Common Tern	*Sterna hirundo*	Fjordterne				1					0	1	**1**
		Common/Arctic Tern	*Sterna hirundo / paradisaea*	Fjordterne / Havterne			1			1			1	1	**2**
		Sandwich Tern	*Sterna sandvicensis*	Splitterne	2		5	4		1		3	7	8	**15**
		Common Gull/Herring Gull	*Larus canus/Larus fuscus*	Stormmåge/Sildemåge		1							0	1	**1**
		Unid Gull	*Laridae indet.*	Uidenficeret Måge		2		1	1	3		2	1	8	**9**
Alcids		Guillemot	*Uria aalge*	Lomvie						1			0	1	**1**
		Guillemot/Razorbill	*Uria aalge/Alca torda*	Lomvie/Alk		1							0	1	**1**
		Razorbill	*Alca torda*	Alk		1				1			0	2	**2**
Owls		Short-eared Owl	*Asio flammeus*	Mosehornugle	1								1	0	**1**
Passerines & Pigeons		Woodpigeon	*Columba palumbus*	Ringdue						1			0	1	**1**
	Larks	Skylark	*Alauda arvensis*	Sanglærke				1					0	1	**1**
	Wagtails and pipits	Meadow Pipit	*Anthus pratensis*	Engpiber	10					21			10	21	**31**
	Chats & Thrushes	Blackbird	*Turdus merula*	Solsort				1					0	1	**1**
		Song Thrush	*Turdus philomelos*	Sangdrossel	2								2	0	**2**
	Buntings	Corn Bunting	*Miliaria calandra*	Bomlærke	1								1	0	**1**
	Finches	Chaffinch	*Fringilla coelebs*	Bogfinke	5					1			5	1	**6**
		Greenfinch	*Carduelis chloris*	Grønirisk	1								1	0	**1**
		Unid Passerine	*Passeriformes indet.*	Uidentificeret sangfugl	8					3			8	3	**11**
Total					**87**	**57**	**51**	**400**	**2**	**99**	**1**	**41**	**141**	**597**	**735**

Number of rangefinder-based tracks recorded at the radar stations at Horns Rev 1 and Horns Rev 2. The tracks in autumn 2010 for Horns Rev 1 were recorded by optical rangefinder (Continued).

					Autumn 2010		**Spring 2011**		**Autumn 2011**		**Spring 2012**		**Total**	**Total**	**Total**
Group	**Subgroup**	**Common name**	**Scientific name**	**Danish name**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	
Divers		Black-throated Diver	*Gavia arctica*	Sortstrubet Lom								1	0	1	**1**
		Red-throated Diver	*Gavia stellata*	Rødstrubet Lom	1	7		2	2	6		1	3	16	**19**
		Unid diver	*Gaviidae indet.*	Uidentificeret lom				1					0	1	**1**
Grebes		Red-necked Grebe	*Podiceps grisegena*	Gråstrubet Lappedykker				1					0	1	**1**
Gannets		Gannet	*Morus bassanus*	Sule	1	12	9	5	1	26	5	14	16	57	**73**
Cormorants		Cormorant	*Phalacrocorax carbo*	Skarv		7	3	6	1	3	1	2	5	18	**23**
Herons		Grey Heron	*Ardea cinerea*	Fiskehejre				1				1	0	2	**2**
Geese & swans	Anser geese	Greylag Goose	*Anser anser*	Grågås	1	2		4			1		2	6	**8**
		Pink-footed Goose	*Anser brachyrhynchus*	Kortnæbbet Gås		4			1				1	4	**5**
	Branta geese	Brent Goose	*Branta bernicla*	Knortegås		1							0	1	**1**
	Swans	Unid Swan	*Cygnidae indet.*	Uidenficeret Svane	1								1	0	**1**
		Unid goose	*Anserini indet.*	Uidentificeret gås					1				1	0	**1**
Other ducks	Sheldgeese	Shelduck	*Tadorna tadorna*	Gravand	1								1	0	**1**
	Swimming ducks	Mallard	*Anas platyrhynchos*	Gråand				1					0	1	**1**
		Teal	*Anas crecca*	Krikand							2		2	0	**2**
		Unid duck	*Anatinae indet.*	Uidentificeret and		1							0	1	**1**
Sea ducks		Common Scoter	*Melanitta nigra*	Sortand	14	75	37	155	94	51	25	22	170	303	**473**
		Eider	*Somateria mollissima*	Ederfugl		1							0	1	**1**
		Long-tailed Duck	*Clangula hyemalis*	Havlit					1				1	0	**1**
		Velvet Scoter	*Melanitta fusca*	Fløjlsand		1	1						1	1	**2**
Raptors	Hawks	Hen Harrier	*Circus cyaneus*	Blå Kærhøg		1			1				1	1	**2**
		Marsh Harrier	*Circus aeruginosus*	Rørhøg						1			0	1	**1**
		Sparrowhawk	*Accipiter nisus*	Spurvehøg		2				1			0	3	**3**
	Falcons	Kestrel	*Falco tinnunculus*	Tårnfalk				1		2		1	0	4	**4**
		Merlin	*Falco columbarius*	Dværgfalk		2				1			0	3	**3**
		Peregrine	*Falco peregrinus*	Vandrefalk		1		1		2			0	4	**4**
Landfowls	Quails	Quail	*Coturnix coturnix*	Vagtel				1					0	1	**1**
Waders	Oystercatchers	Oystercatcher	*Haematopus ostralegus*	Strandskade			1				1		2	0	**2**
	Plovers & lapwings	Lapwing	*Vanellus vanellus*	Vibe				1					0	1	**1**
		Golden Plover	*Pluvialis apricaria*	Hjejle						3			0	3	**3**
		Grey Plover	*Pluvialis squatarola*	Strandhjejle				1					0	1	**1**
		Ringed Plover	*Charadrius hiaticula*	Stor Præstekrave				1					0	1	**1**
	Godwits, curlews and other sandpipers	Common Sandpiper	*Actitis hypoleucos*	Mudderklire								1	0	1	**1**
		Redshank	*Tringa totanus*	Rødben						1			0	1	**1**
		Unid Wader	*Limicolae indet.*	Uidenficeret vadefugl		1							0	1	**1**
		Whimbrel	*Numenius phaeopus*	Lille Regnspove				1		1			0	2	**2**
	Sandpipers	Dunlin	*Calidris alpina*	Almindelig Ryle						1			0	1	**1**
		Knot	*Calidris canutus*	Islandsk Ryle						1			0	1	**1**
	Snipes	Snipe	*Gallinago gallinago*	Dobbeltbekkasin						1			0	1	**1**
	Woodcocks	Woodcock	*Scolopax rusticola*	Skovsneppe				1					0	1	**1**
Skuas		Arctic Skua	*Stercorarius parasiticus*	Almindelig Kjove				1		6		3	0	10	**10**
		Unid Skua	*Stercorariidae indet.*	Uidenficeret Kjove					1				1	0	**1**

Continued. Number of rangefinder-based tracks recorded at the radar stations at Horns Rev 1 and Horns Rev 2. The tracks in autumn 2010 for Horns Rev 1 were recorded by optical rangefinder.

					Autumn 2010		Spring 2011		Autumn 2011		Spring 2012		Total	Total	Total
Group	**Subgroup**	**Common name**	**Scientific name**	**Danish name**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	**HR1**	**HR2**	
Gulls	Large gulls	Great Black-backed Gull	*Larus marinus*	Svartbag		2	1				4	1	5	3	**8**
		Herring Gull	*Larus argentatus*	Sølvmåge			9	1				1	9	2	**11**
		Lesser Black-backed Gull	*Larus fuscus*	Sildemåge			8	10	1	1	2	19	11	30	**41**
	Small gulls	Black-headed Gull	*Larus ridibundus*	Hættemåge			3	10	2	4	3	7	8	21	**29**
		Common Gull	*Larus canus*	Stormmåge			1	2	1		4	2	6	4	**10**
		Kittiwake	*Rissa tridactyla*	Ride		4				5		7	0	16	**16**
		Little Gull	*Larus minutus*	Dværgmåge		1	9	7	4		3	2	16	10	**26**
	Terns	Arctic Tern	*Sterna paradisaea*	Havterne				1					0	1	**1**
		Common Tern	*Sterna hirundo*	Fjordterne			5	1	4	10		11	9	22	**31**
		Common/Arctic Tern	*Sterna hirundo / paradisaea*	Fjordterne / Havterne				2				1	0	3	**3**
		Sandwich Tern	*Sterna sandvicensis*	Splitterne		3	15	24	3	5	20		38	32	**70**
		Common Gull/Herring Gull	*Larus canus/Larus fuscus*	Stormmåge/Sildemåge		1							0	1	**1**
		Lesser/Greater Black-backed Gull	*Larus fuscus / marinus*	Sildemåge / Svartbag							1		1	0	**1**
Alcids		Guillemot	*Uria aalge*	Lomvie		2			3	2			3	4	**7**
		Guillemot/Razorbill	*Uria aalge/Alca torda*	Lomvie/Alk		1							0	1	**1**
		Razorbill	*Alca torda*	Alk		1				4		1	0	6	**6**
Owls		Long-/Short-eared Owl	*Asio otus/Asio flammeus*	Skov-Mosehornhgle						1			0	1	**1**
		Short-eared Owl	*Asio flammeus*	Mosehornugle		1				6			0	7	**7**
Passerines & Pigeons	Pigeons & doves	Woodpigeon	*Columba palumbus*	Ringdue		2		1		2		1	0	6	**6**
	Swifts	Swift	*Apus apus*	Mursejler						5		4	0	9	**9**
		Skylark	*Alauda arvensis*	Sanglærke						2			0	2	**2**
	Swallows and martins	House Martin	*Delichon urbica*	Bysvale							2	3	2	3	**5**
		Sand Martin	*Riparia riparia*	Digesvale								1	0	1	**1**
		Swallow	*Hirundo rustica*	Landsvale		1		2			3	7	3	10	**13**
	Wagtails and pipits	Meadow Pipit	*Anthus pratensis*	Engpiber	1	6		8		13	1		2	27	**29**
		Pied Wagtail	*Motacilla alba*	Hvid Vipstjert		1		1			1		1	2	**3**
		Tree Pipit	*Anthus trivialis*	Skovpiber				1					0	1	**1**
	Accentors	Dunnock	*Prunella modularis*	Jernspurv						1			0	1	**1**
	Chats & Thrushes	Blackbird	*Turdus merula*	Solsort				1		9			0	10	**10**
		Fieldfare	*Turdus pilaris*	Sjagger						4			0	4	**4**
		Redwing	*Turdus iliacus*	Vindrossel						2			0	2	**2**
		Robin	*Erithacus rubecula*	Rødhals						1			0	1	**1**
		Song Thrush	*Turdus philomelos*	Sangdrossel						10			0	10	**10**
	Warblers	Blackcap	*Sylvia atricapilla*	Munk								1	0	1	**1**
		Goldcrest	*Regulus regulus*	Fuglekonge						1			0	1	**1**
	Flycatchers	Spotted Flycatcher	*Muscicapa striata*	Grå Fluesnapper								1	0	1	**1**
	Finches	Brambling	*Fringilla montifringilla*	Kvækerfinke		1							0	1	**1**
		Chaffinch	*Fringilla coelebs*	Bogfinke						1			0	1	**1**
		Chaffinch/Brambling	*Fringilla coelebschnig/Fringilla montifringilla*	Bogfinke/Kvækerfinke	1								1	0	**1**
		Siskin	*Carduelis spinus*	Grønsisken						1			0	1	**1**
		Unid Passerine	*Passeriformes indet.*	Uidentificeret sangfugl				1				1	0	2	**2**
	Starlings	Starling	*Sturnus vulgaris*	Stær		1		4					0	5	**5**
	Crows		*Corvus corone corone*	Sortkrage								1	0	1	**1**
		Jackdaw	*Corvus monedula*	Allike								1	0	1	**1**
Total					**21**	**146**	**102**	**262**	**121**	**197**	**79**	**119**	**323**	**724**	**1,047**

APPENDIX 4 SAMPLED RADAR DATA

Aberrations for good data and image quality for a total of 454 days of data recordings at HR1

Date	Data	Image	Notes
15/09/2010	Missing	Missing	
16/09/2010	Missing	Missing	
17/09/2010	Missing	Missing	
18/09/2010	Missing	Missing	
19/09/2010	Good	Missing	
20/09/2010	Missing	Missing	
21/09/2010	Missing	Missing	
22/09/2010	Some data is missing	Missing	
23/09/2010	Missing	Some data is missing	Frame grabber installation
24/09/2010	Some data is missing	Good	
25/09/2010	Missing	Good	
26/09/2010	Missing	Good	
27/09/2010	Missing	Good	
29/09/2010	Missing	Good	
30/09/2010	Missing	Good	
13/10/2010	Some data is missing	Some data is missing	Change of hard drive
29/03/2011	Some data is missing	Good	
30/03/2011	Some data is missing	Good	
31/03/2011	Some data is missing	Good	
26/04/2011	Good	Good	from 6 to 5 files!
03/05/2011	Some data is missing	Good	
04/05/2011	Some data is missing	Good	
05/05/2011	Missing	Good	
06/05/2011	Some data is missing	Good	
11/07/2011	Some data is missing	Good	
12/07/2011	Some data is missing	Good	
15/07/2011	Some data is missing	Some data is missing	
16/08/2011	Some data is missing	Good	
17/08/2011	Missing	Good	
18/08/2011	Missing	Good	
19/08/2011	Some data is missing	Good	
03/09/2011	Good	Some data is missing	
04/09/2011	Some data is missing	Missing	
05/09/2011	Missing	Missing	
06/09/2011	Missing	Missing	
07/09/2011	Missing	Missing	
08/09/2011	Missing	Missing	
09/09/2011	Missing	Missing	
10/09/2011	Some data is missing	Some data is missing	
02/10/2011	Some data is missing	Good	
03/10/2011	Some data is missing	Good	
16/10/2011	Some data is missing	Good	
27/11/2011	Some data is missing	Some data is missing	
28/11/2011	Some data is missing	Some data is missing	
01/03/2012	Some data is missing	Some data is missing	
23/03/2012	Some data is missing	Good	
25/03/2012	Some data is missing	Good	
24/05/2012	Some data is missing	Good	
25/05/2012	Some data is missing	Good	
26/05/2012	Some data is missing	Good	
27/05/2012	Some data is missing	Good	
28/05/2012	Some data is missing	Good	
29/05/2012	Missing	Good	
30/05/2012	Missing	Good	
31/05/2012	Missing	Good	

Aberrations for good data and image quality for a total of 552 days of data recordings at HR2 (Continued).

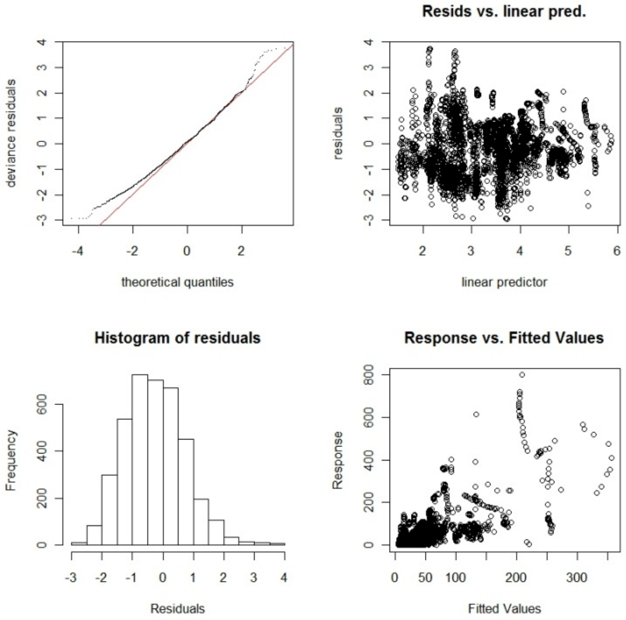
Date	Data	Image	Notes
17/08/2010	Some data is missing		
18/08/2010	Missing		
19/08/2010	Missing		
20/08/2010	Missing		
21/08/2010	Missing		
22/08/2010	Missing		
23/08/2010	Some data is missing		
15/09/2010	Good	Missing	Radar error
16/09/2010	Missing	Missing	
17/09/2010	Missing	Missing	
18/09/2010	Missing	Missing	
19/09/2010	Missing	Missing	
20/09/2010	Missing	Missing	
21/09/2010	Missing	Missing	
22/09/2010	Missing	Missing	
23/09/2010	Missing	Missing	
24/09/2010	Good	Missing	
25/09/2010	Missing	Missing	
26/09/2010	Some data is missing	Some data is missing	Frame grabber installation
27/09/2010	Good	Some data is missing	
17/10/2010	Some data is missing	Good	
18/10/2010	Missing	Good	
19/10/2010	Missing	Good	
20/10/2010	Some data is missing	Good	
26/10/2010	Some data is missing	Good	
27/10/2010	Missing	Some data is missing	
28/10/2010	Missing	Some data is missing	Change of hard drive (gear broken)
29/10/2010	Missing	Missing	
30/10/2010	Missing	Missing	
31/10/2010	Missing	Missing	
01/11/2010	Missing	Missing	
02/11/2010	Missing	Missing	
03/11/2010	Missing	Missing	
04/11/2010	Missing	Missing	
05/11/2010	Missing	Missing	
06/11/2010	Missing	Missing	
07/11/2010	Missing	Missing	
08/11/2010	Missing	Missing	
09/11/2010	Missing	Missing	
10/11/2010	Missing	Missing	
11/11/2010	Missing	Missing	
12/11/2010	Missing	Missing	
13/11/2010	Missing	Missing	
14/11/2010	Missing	Missing	
15/11/2010	Missing	Missing	
16/11/2010	Missing	Missing	
17/11/2010	Some data is missing	Good	
18/11/2010	Missing	Good	
19/11/2010	Missing	Good	
20/11/2010	Some data is missing	Good	
15/04/2011	Some data is missing	Some data is missing	
16/04/2011	Missing	Good	
17/04/2011	Missing	Good	
18/04/2011	Missing	Good	
19/04/2011	Some data is missing	Good	
21/05/2011	Some data is missing	Some data is missing	
22/05/2011	Some data is missing	Some data is missing	
30/05/2011	Good	Some data is missing	

Continued. Aberrations for good data and image quality for a total of 552 days of data recordings at HR2.

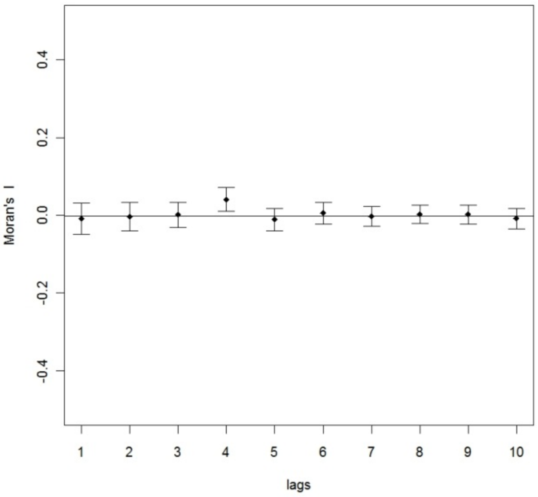
Date	Data	Image	Notes
20/08/2011	Some data is missing	Some data is missing	
21/08/2011	Some data is missing	Some data is missing	
22/08/2011	Some data is missing	Good	
02/11/2011	Good	Some data is missing	
03/11/2011	Good	Some data is missing	
09/03/2012	Some data is missing	Good	
11/03/2012	Some data is missing	Good	
12/03/2012	Some data is missing	Some data is missing	
13/03/2012	Good	Missing	
14/03/2012	Good	Some data is missing	
24/03/2012	Some data is missing	Good	
25/03/2012	Some data is missing	Good	
26/03/2012	Some data is missing	Some data is missing	
27/03/2012	Missing	Missing	
28/03/2012	Some data is missing	Some data is missing	
08/04/2012	Good	Missing	
09/04/2012	Missing	Missing	
10/04/2012	Missing	Missing	
11/04/2012	Some data is missing	Some data is missing	
12/04/2012	Some data is missing	Good	
13/04/2012	Some data is missing	Good	
15/04/2012	Good	Some data is missing	
16/04/2012	Good	Missing	
17/04/2012	Good	Missing	
18/04/2012	Good	Missing	
19/04/2012	Good	Missing	
20/04/2012	Good	Some data is missing	
01/05/2012	Good	Some data is missing	
02/05/2012	Good	Missing	
03/05/2012	Good	Missing	
04/05/2012	Good	Missing	
05/05/2012	Good	Some data is missing	
29/05/2012	Good	Some data is missing	
30/05/2012	Good	Missing	
31/05/2012	Good	Missing	
01/06/2012	Good	Missing	
02/06/2012	Good	Missing	
03/06/2012	Good	Missing	
04/06/2012	Good	Missing	
05/06/2012	Good	Missing	
06/06/2012	Good	Missing	
07/06/2012	Good	Missing	
08/06/2012	Good	Missing	
09/06/2012	Good	Missing	
10/06/2012	Good	Missing	
11/06/2012	Good	Missing	
12/06/2012	Good	Missing	
13/06/2012	Good	Missing	
14/06/2012	Good	Missing	
15/06/2012	Good	Missing	
16/06/2012	Good	Missing	
17/06/2012	Good	Missing	
18/06/2012	Good	Missing	
19/06/2012	Good	Missing	

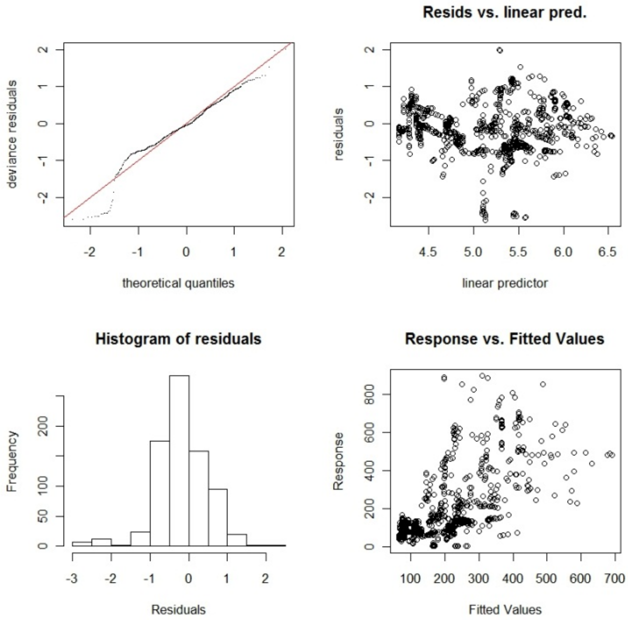
APPENDIX 5 ALTITUDE PREDICTION MODELS – DIAGNOSTICS

Sparrowhawk

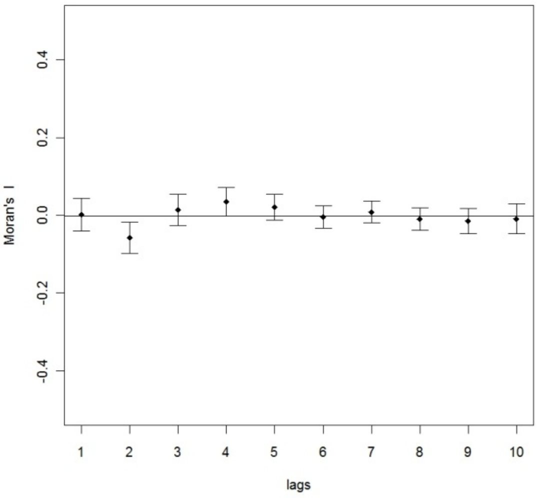


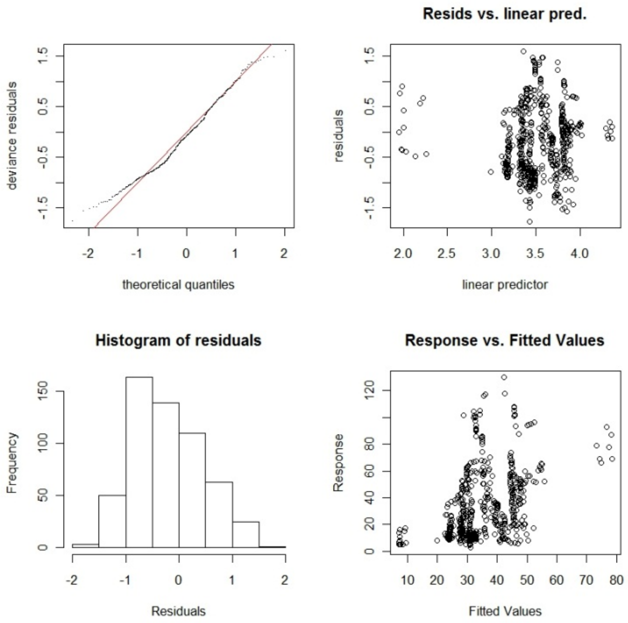
Common Buzzard



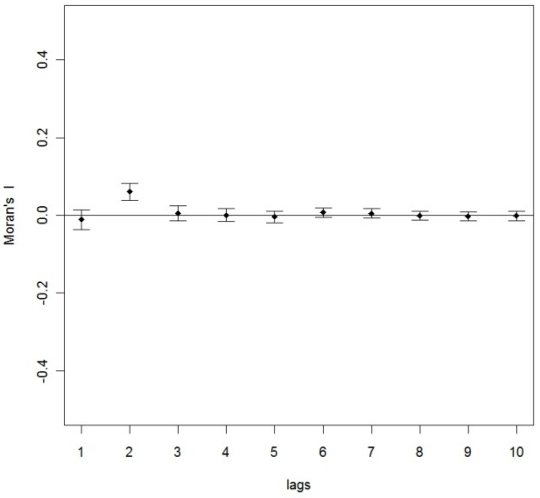


Honey Buzzard

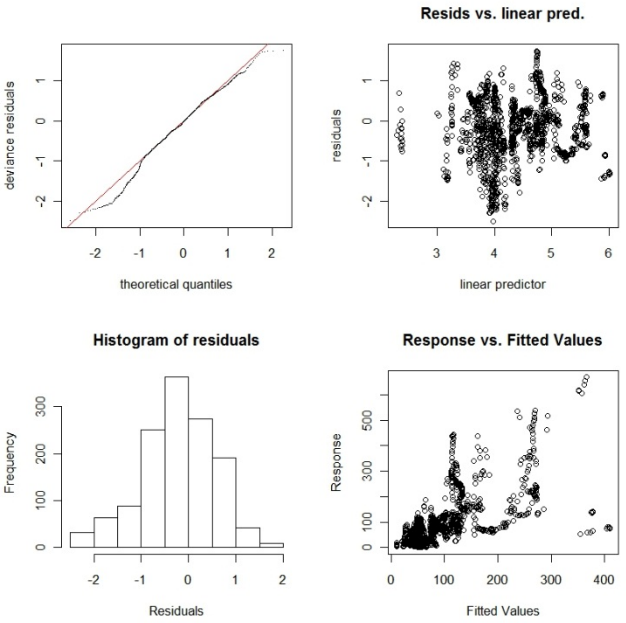




Red Kite

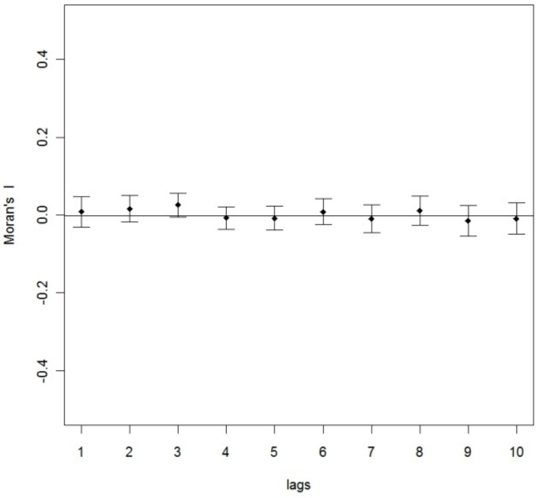


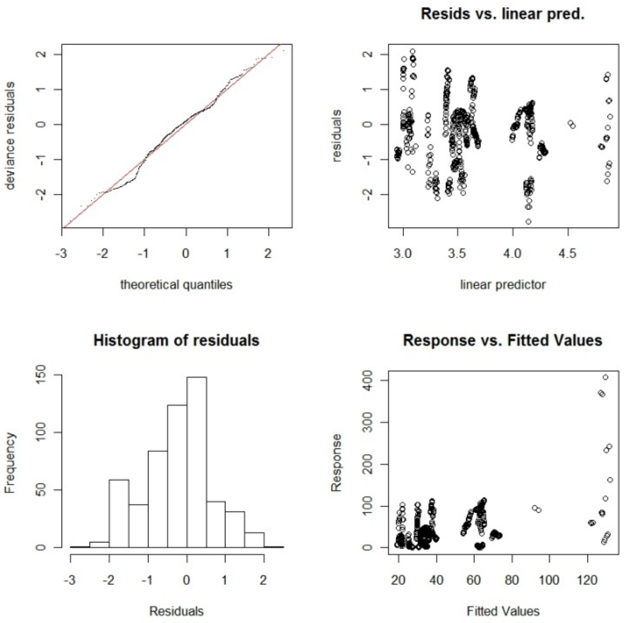
Moran's I
0.4
0.2
0.0
-0.2
-0.4
1
2
3
4
5
6
7
8
9
10
lags



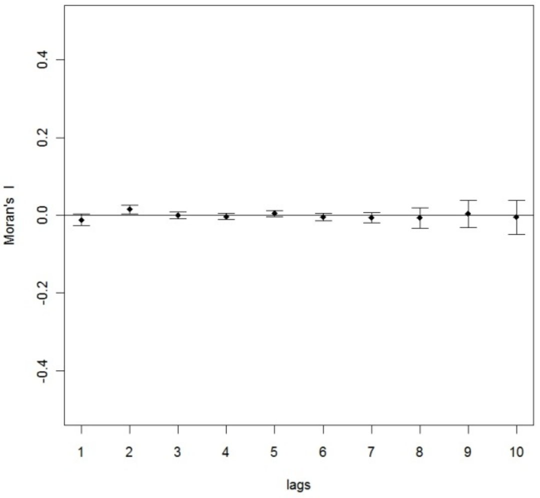
deviance residuals
theoretical quantiles
Resids vs. linear pred.
residuals
linear predictor
Histogram of residuals
Frequency
Residuals
Response vs. Fitted Values
Response
Fitted Values

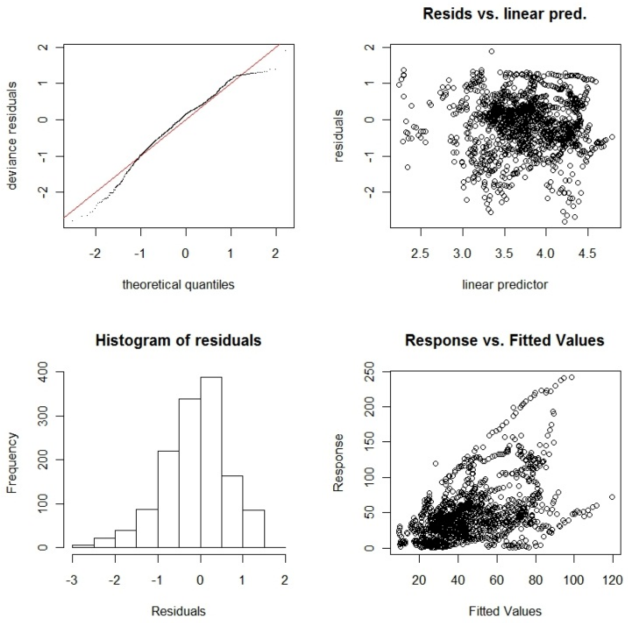
Marsh Harrier





Kestrel


Moran's I
0.4
0.2
0.0
-0.2
-0.4
1
2
3
4
5
6
7
8
9
10
lags


deviance residuals
2
1
0
-1
-2
-2
-1
0
1
2
theoretical quantiles
Resids vs. linear pred.
residuals
2
1
0
-1
-2
2.5
3.0
3.5
4.0
4.5
linear predictor
Histogram of residuals
Frequency
400
300
200
100
0
-3
-2
-1
0
1
2
Residuals
Response vs. Fitted Values
Response
250
200
150
100
50
0
20
40
60
80
100
120
Fitted Values