DONG
energy

Horns Rev **II**
Offshore Wind Farm
Monitoring of Bird Migration

Pseudo Baseline Studies 2008

DHI
WATER & ENVIRONMENT

Orbicon

CONTENTS

1   SUMMARY

This report contains the results of the extended baseline monitoring on bird migration in relation to the planned Horns Rev 2 offshore wind farm (HR2 OWF) undertaken September-November 2008. The extended baseline on bird migration followed up on baseline monitoring activities undertaken during spring 2008 to boost the cumulative database on bird migration across Horns Rev which was judged insufficient for the baseline of the HR2 monitoring programme. The insufficient data available on long-distance migration of waterbirds across Horns Rev is largely due to the methodological constraints and limitations using visual observations and radar screen analyses for quantifying bird migration and the inherently low samples obtainable from ship-based radar installations. Additionally, the monitoring programme for Horns Rev 1 (HR1) OWF did not cover the central and western areas of Horns Rev. Thus, an extended monitoring programme was established during autumn 2008 using fixed radar installations at Horns Rev 2 (foundation), the Horns Rev 1 Transformer Station and at Blåvands Huk. Visual observations were carried out from the HR1 transformer station and from Blåvands Huk, and were intended to provide calibration data for classification of the radar data into bird species groups. A total of 824 bird observations were made at HR1 and 2,554 at Blåvands Huk.

The three installations were based on the LAWR system design, which use software developed by DHI for high-resolution signal processing, data extraction, automatic classification and GIS-interfacing. The LAWR is based on X-band technology, using standard marine radars, type FR2127 from Furuno. The data acquisition hardware 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. The radar software is subdivided into 3 parts: RadCtrl2/PolScan (radar control and acquisition), BirdWatch/BirdWatchShow (on-line ground truth data collection) and BirdTrack (classification and extraction of bird tracks). Wind information and the presence of rainfall in the radar coverage area have been estimated and included in the radar image database. The echoes were 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. The sample time for one image was one minute. For further processing the mean, peak and variance of the radar signals were calculated "on-the-fly" at the data collection computer at each radar station. Volume- and en-route correction of the echo was handled using the standard correction scheme used on the LAWR during the last 10 years. Identification of tracks was made using algorithms operating on 120 successive radar images. From the recorded wind-speed and wind-direction and the corresponding data for the track bird heading and velocity (speed through air) was calculated. Filtering procedures were established which efficiently distinguishes echoes from potential birds from other echoes like ships, rain and wind-induced clutter.

A post-classification routine was developed to estimate the statistical probability for a trajectory belonging to a certain class of birds, which was made by applying a classification tree model, which was established based on the calibration data set. The classification tree compared classification potentials of bird classes separated by expected air speed, size and flight characteristics of the track. The selected classification tree model was deployed on the combined radar tracks resulting in the additions of estimated bird

classes to each track. They were subsequently used to generate spatial trends and time series profiles of flight intensities (frequency of tracks) for each bird class.

The sample size of potential bird flight trajectories was 535,482 of which 145,918 were from the radar at Blåvands Huk, 278,078 from HR1 and 111,486 from HR2. The classification tree analysis generated a 'simple' tree with only two splits resulting in three terminal nodes dominated by large waterbirds, ducks and passerines. The variance of the echo reflectance was the most important factor separating the three bird classes, followed by the speed through air. The modelled flight intensities showed similar trends across the three bird classes. The flight intensities of both waterbirds and landbirds strongly indicated higher passage rates of birds in the eastern-most sector of Horns Rev, significantly lower rates at the HR1 OWF and rather low rates at HR2; the area to the east of the planned HR2 wind farm had slightly higher rates than the area to the west of the planned wind farm. These results point at the existence of a marked migration corridor in autumn of approximately 10 km width at the inner Horns Rev – Blåvands Huk area.

Although no information on altitudes were collected during this study the information collected on flight intensities reveal potentials for avoidance behaviour of sea birds and collision risks associated with the construction of the HR2 OWF. Given the results of the trends and profiles of migration intensities of the three major bird groups there are no indications of large-scale migration 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 all three bird classes: 'large waterbirds', 'ducks' and 'passerines'. The spatial patterns of flight intensities recorded during this investigation show that the reduced flight intensities are completely related to the wind farm and the surrounding area to a distance of approximately 1.5 km, and there are no indications of e.g. shading effects on the southern fringe of the wind farm. Thus, a local avoidance effect at HR1 OWF must be expected to impact the southbound migration of a wide range of species, albeit the effect in terms of modified flight paths and energetic costs are deemed to be minor for long-distance migrants. As the results show that HR1 OWF is at the western margin of the migration corridor in autumn the effects is 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. Due to the short and local scale of avoidance effect it is not likely that the moderate displacement of migrants at HR1 will affect the migrants en-route to HR2 OWF, and the effect of avoidance at HR2 OWF is therefore most likely to be local (non-cumulative). The recorded migration intensity of the two bird classes 'large waterbirds' and 'ducks' was slightly higher on the eastern than on the western side of HR2 OWF, while the intensities of 'passerines' were equal on both sides. Thus, the avoidance effect at HR2 is likely to display both a concentration of birds (non-passerines) on the eastern side and a split of migrating passerines around the wind farm.

The application of automated recordings from fixed radar installations at Horns Rev 2, the Horns Rev 1 Transformer Station and Blåvands Huk in combination with visual calibration observations has resulted in a vastly increased database on bird migration along the Horns Rev area. The collected data are judged sufficient to establish a baseline for future monitoring of bird migration during the autumn season.

2 *DANSK RESUME*

Denne rapport indeholder resultaterne af det udvidede baseline overvågningsprogram i relation til DONG's planlagte havmøllepark Horns Rev 2 (HR2), som blev gennemført september-november 2008. Det udvidede baselineprogram på fugletræk var en opfølgning på aktiviteter gennemført under foråret 2008, og havde til formål at styrke den samlede database på fugletrækket over Horns Rev, som blev vurderet som utilstrækkelig til at etablere en baseline for fremtidig overvågning. At data på langdistancetrækket af vandfugle over Horns Rev bedømmes som utilstrækkelige skyldes især de metodiske problemer og begrænsninger ved brugen af visuelle observationer og radarskærmsanalyser til kvantificering af fugletræk, og de små stikprøvestørrelser der kan opnås ved brug af skibsbaserede radarundersøgelser. Derudover dækkede de tidligere fugletræksundersøgelser i relation til Horns Rev 1 havmølleparken (HR1) ikke de centrale og vestlige dele af Horns Rev. Der blev derfor igangsat et udvidet overvågningsprogram i efteråret 2008 med brug af tre radarinstallationer ved henholdsvis HR2 (fundament), HR1 Transformer Station og Blåvands Huk. Visuelle observationer blev gennemført fra HR1 transformer stationen og Blåvands Huk med det formål at levere kalbreringsdata til brug ved klassifikationen af fuglegrupper ud fra de indsamlede radardata. Totalt blev der indsamlet 824 observationer fra HR1 og 2,554 fra Blåvands Huk.

De tre installationer var baseret på LAWR-designet, der anvender software udviklet af DHI til signalprocessering i høj opløsning, overførsel af data, automatisk klassifikation og opkobling til GIS. LAWR er baseret på X-båndsteknologi, og anvender standard marine radarer, type FR2127 fra Furuno. Dataopsamlingen tillader processering af 24 billeder pr. minut, hvilket muliggør tracking af objekter. Radarudstyret giver mulighed for 24 timers drift og fjernbetjening. Radar-softwaren er delt i tre dele: RadCtrl2/PolScan (radarkontrol and dataoverførsel), BirdWatch/BirdWatchShow (on-line ground truth dataindsamling) og BirdTrack (identifikation og klassifikation af fugletracks). Information om vindforhold og regn blev estimeret og inkluderet i radarbillederne. Ekkoerne indsamledes ved 20 MHz i 10 bit opløsning (1023 niveauer) og blev aggregeret i "bins", som hver dækkede en radial afstand på 120 m og 1 grad tangentielt. Stikprøvetiden for et billede er et minut. Den videre processering af billederne I form af beregning af middel, maksimum og varians af registrerede reflektansværdier foregik "on-the-fly" på dataindsamlingscomputeren på hver radarstation. Volumen- retningskorrektion af ekkoer blev udført ved brug af standardmetoden anvendt for LAWR gennem de sidste 10 år. Identifikationen af tracks skete ved brug af algoritmer, der bearbejdede 120 successive radarbilleder. Ud fra de målte vindhastigheder- og retninger og de tilknyttede værdier for tracket blev fuglenes trækretning og hastighed gennem luften udregnet. Filtreringsprocedurer blev udviklet til effektiv adskillelse af potentielle fugleekkoer fra andre ekkoer som skibe, regn og vindrelateret støj.

Den statistiske sandsynlighed for at tracks tilhører bestemte grupper af fugle blev estimeret ved brug af klassifikationstræ-analyse, der blev baseret på resultaterne af kalibreringsobservationerne. Klassifikationstræet sammenlignede klassifikationspotentialet for forskellige grupper af fugle adskilt ved hastighed gennem luften og karakteristika fra de registrerede radartracks. Baseret på det udvalgte klassifikationstræ blev de estimerede fugleklasser tilføjet databasen med radardata, og derefter anvendt til beregning af rumlige profiler og tidsserier i trækintensiteten for de klassificerede fuglegrupper. Stikprøve-

størrelsen for de potentielle fugletrack var 535.482 hvoraf 145.918 var fra Blåvands Huk, 278.078 fra HR1 og 111.486 fra HR2. Klassifikationstræ-analysen resulterede i et 'simpelt' træ med kun to forgreninger og tre terminalpunkter domineret af store vandfugle, ænder og småfugle. Variansen i radarsignalet udgjorde den vigtigste faktor til adskillelse af de tre fugleklasser, fulgt af fuglenes hastighed gennem luften. De modellerede trækintensiteter udviste relativt ensartede tendenser på tværs af de tre klasser. Trækintensiteten hos bade landfugle og vandfugle indikerede kraftigere trækbevægelser i den østligste sektor af Horns Rev, signifikant lavere intensitet ved HR1 OWF og endnu lavere intensitet ved HR2; området øst for den planlagte HR2-møllepark havde moderat højere trækintensitet end området vest for mølleparken. Disse resultater peger på eksistensen af en markant trækkorridor om efteråret på omtrent 10 km's bredde ved det indre Horns Rev – Blåvands Huk.

Selvom der ikke blev indsamlet information om fuglenes trækhøjder under denne undersøgelse kan de indsamlede data på trækintensiteten afdække potentialet for havfugles undvigelsesadfærd og kollisionsrisici associeret med anlægget af HR2 OWF. Trækintensiteterne for de tre overordnede fuglegrupper antydede ikke forekomsten af storskala trækbevægelser ved HR2 om efteråret. I øvrigt blev der ikke noteret begivenheder af kortere varighed i området. Tendenserne i trækintensiteterne ved HR1 OWF indikerede eksistensen af undvigelsesadfærd for alle tre fugleklasser; store vandfugle, ænder og småfugle. De registrerede mønstre i trækintensiteterne under denne undersøgelse viser, at de reducerede intensiteter i radartracks helt kan relateres til mølleparken og det omkringliggende område til en afstand på omkring 1,5 km, og der var ingen indikationer på fænomener som skyggeeffekter langs den sydlige kant af mølleparken. Det må derfor forventes, at effekten af en lokalt ændret trækadfærd ved HR1 OWF påvirker en bred vifte af arter på sydgående træk, selvom påvirkningen på langdistancetrækkerne, i form af modificerede trækruter og energitab, med stor sandsynlighed vil være minimal. Som resultaterne viser, er HR1 OWF beliggende på den vestlige grænse af trækkorridoren om efteråret, og effekten vil derfor formodentlig bevirke, at langdistancetrækkerne der bevæger sig mod Vadehavet justerer trækruten mod øst, medens trækfugle med mere sydlig og sydvestlig kurs kortvarigt justerer i begge retninger omkring mølleparken. På grund af at der kun er tale om en lokal ændring i trækadfærd, er det ikke sandsynligt, at den moderate justering af trækket vil påvirke fuglene på vej mod HR2 OWF, og effekten ved HR2 OWF vil derfor sandsynligvis også kun blive lokal (non-kumulativ). Den registrerede trækintensitet af de to fugleklasser 'store vandfugle' og 'ænder' var en anelse højere på østsiden end på vestsiden af HR2 OWF, hvorimod intensiteten af 'småfugle' var ret ens på begge sider af mølleparken. Effekten af fuglenes undvigelsesadfærd ved HR2 vil derfor formodentlig resultere i både en koncentration af trækkende fugle (ikke-småfugle) på den østlige side og fordeling af småfugle på begge sider af mølleparken.

Anvendelsen af automatiske registreringer fra faste installationer ved Horns Rev 2, Horns Rev 1 Transformer Station og Blåvands Huk kombineret med visuelle kalibreringsobservationer resulterede i en væsentlig forøgelse af mængden af data på fugletrækket over Horns Rev. Det vurderes, at de indsamlede data er tilstrækkelige til etablering af baseline for fugletrækket under efterårssæsonen.

3 INTRODUCTION

3.1 Background

DONG Energy has commissioned a consortium of Orbicon, DHI and BIOLA to under-take baseline investigations and monitoring of migratory birds as part of the monitoring program for the planned Horns Rev 2 offshore wind farm (HR2 OWF). The establish-ment of the HR2 OWF was granted by the Department of Energy on the 19th March 2007 on the basis of DONG Energy's application of 13th October 2006.

This report contains the results of the extended baseline monitoring on bird migration undertaken September-November 2008. The extended baseline on bird migration fol-lowed up on baseline monitoring activities undertaken during spring 2008 (Piper et al. 2008), and implemented the recommendations from these activities. The baseline activi-ties recommended the application of advanced radar installations on fixed platforms at HR2, HR1 and onshore (Blåvands Huk) to boost the cumulative database on bird migra-tion across Horns Rev which was judged insufficient for the baseline of the HR2 moni-toring programme. The insufficient data available on long-distance migration of water-birds across Horns Rev is largely due to the methodological constraints and limitations using visual observations and radar screen analyses for quantifying bird migration and the inherently low samples obtainable from ship-based radar installations. Additionally, the PSO programme did not cover the central and western areas of Horns Rev. Thus, an extended monitoring programme was established during autumn 2008 using fixed radar installations at Horns Rev 2 (foundation), the Horns Rev 1 Transformer Station and Blåvands Huk. It was further expected that a larger volume of birds would pass the Horns Rev area during autumn as compared to spring.

The extended monitoring programme has been based on an advanced radar system, the Local Area Weather Radar (LAWR) system operated by DHI, which allowed radar sig-nal processing with enhanced clutter suppression capacities and a number of further analysis options including distance corrections, corrections for clutter and disturbances.

3.2 The Horns Rev 2 Project

3.2.1 Location

The location of the HR2 OWF is planned for the outer part of Horns Rev, a sand bank which stretches from the coast of Denmark (Blåvands Huk) and 40 km westwards, see Figure 3.1. The distance of the HR2 OWF to Blåvands Huk is 30 km. The minimum distance between the existing OWF on Horns Rev and the planned HR2 OWF is 14 km. The water depth at the site of the HR2 OWF varies between 6 and 18 m. The HR2 OWF has been designed as an arc north of the shallow VovVov on the western Horn Rev.

The HR2 OWF consists of a total of 91 turbines, each 2.3 MW which are placed with 13 e-w oriented rows of 7 turbines. Due to the design of the OWF the distance between the rows will vary from 700 m in the eastern part to 900 m in the western part, see Figure 3.1. The distance between individual turbines is 550 m.

Figure 3.1 and Figure 3.2 also show the proposed placement of three test turbines. The transformer station will be located 1 km east of the wind farm. 16-20 m northeast of the transformer station an accommodation platform will be installed with a gangway connecting the two platforms.

The turbines will be connected by e-w running 34 kV cables, which will be collated into a single cable in the eastern part of the OWF, which then is connected to the transformer station, see Figure 3.2.
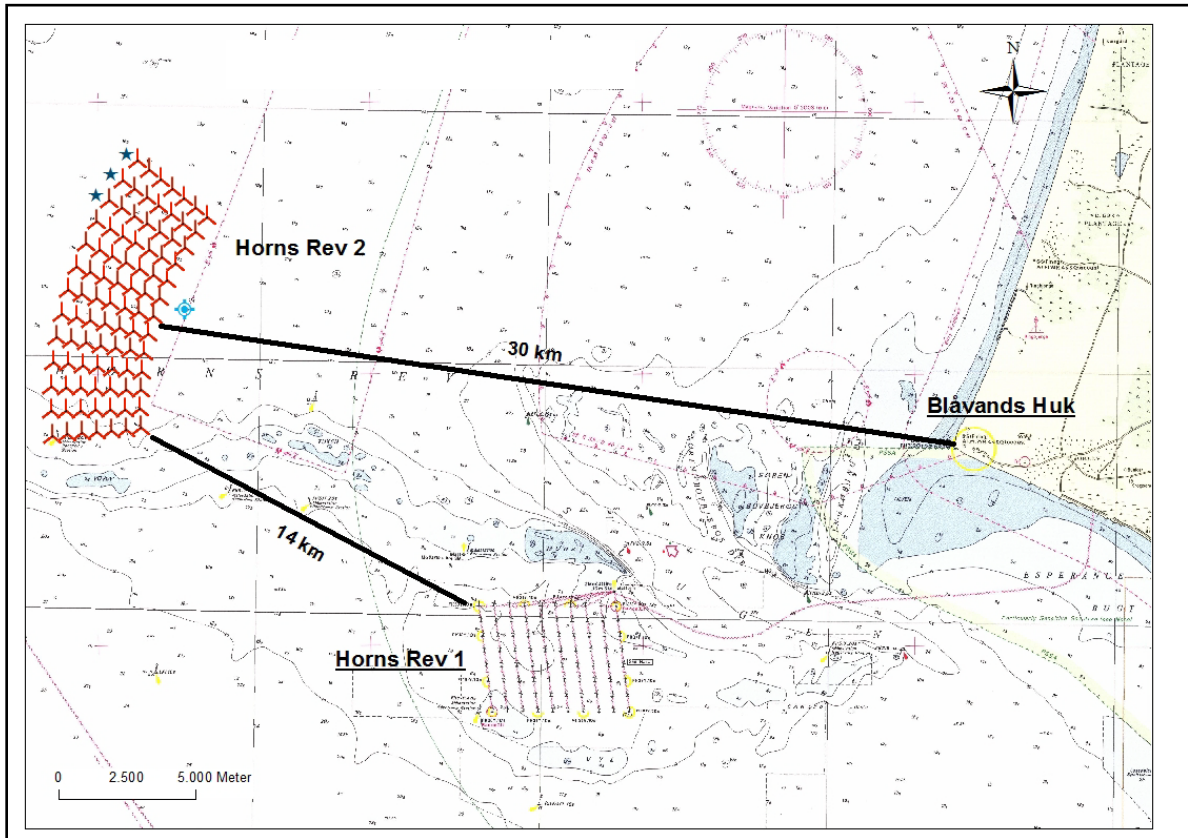

Figure 3.1.   The location of the HR2 OWF relative to Blåvands Huk and the Horns Rev 1 OWF.
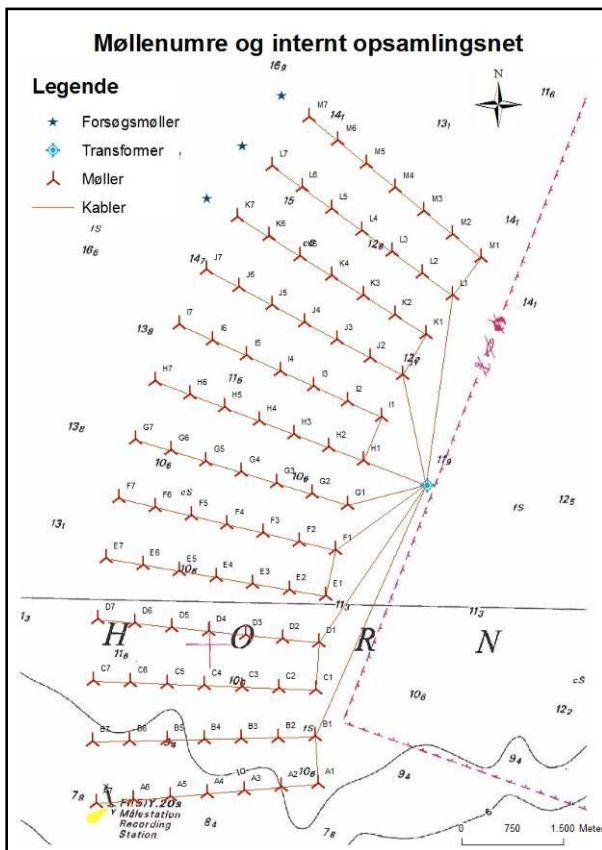
Figure 3.2.   Turbine numbers and planned cables for the HR2 OWF.

3.2.2   Free zone

A free zone of 4 km towards the south and west and 2 km towards the north and east has been granted to DONG Energy for this OWF.

3.3   Monitoring requirements and targets in relation to bird migration

The requirements for the monitoring programme for Horns Rev 2 state that the methodologies should as far as possible been based on the same field methods as used in relation to the PSO monitoring programme for the HR1 OWF and in the investigations carried out as part of the EIA for the HR2 OWF. Thus, the monitoring of bird migration has been based on application of horizontal ship radar to measure lateral changes in migration routes. The study focused on the long-distance migration of waterbirds across and along Horns Rev during spring and autumn 2008 in order to establish a baseline which would enable future assessments of effects of the construction of the HR2 OWF on migratory birds, including potential barrier effects as a consequence of both HR1 and HR2 OWFs. Due to insufficient data on waterbird migration at Horns Rev collected during the PSO monitoring programme and during spring 2008 it was decided to extend the monitoring of bird migration into autumn 2008 in an attempt to increase the sample of available data by using automated 24 h radar recordings from fixed installations at HR2 OWF, HR1 OWF and Blåvands Huk. The statistical design of the monitoring program is based on the BACI approach. As all radar recordings have been stored in a raster GIS analyses can be designed to compare before/after construction scenarios for freely chosen areas around the two wind farms. The impact and control sites will be se-

lected so that the recordings obtained during the PSO monitoring programme can be integrated into the analyses.

4   METHODS

4.1   Study area and coverage with radar and diurnal observations

The location of the three fixed radar stations is depicted in Figure 4.1 and the installation design for each station is shown in Figure 4.2. The radar in HR2 was installed at an altitude of 13 m on foundation number M4 located centrally in the northernmost row of the OWF. The radar in HR1 was installed at an altitude of 14 m on the transformer station located just northeast of the OWF and the radar on Blåvands Huk was installed at an altitude of 1.5 m in the dunes southeast of Blåvands Huk lighthouse.

With a potential detection range of 10 km the combined survey range of the three radars spanned the entire length of Horns Rev from the area west of HR2 OWF to the area around Blåvands Huk. Only the area just east of HR1 OWF was not covered. For safety reasons a 45 degree 'blind sector' was applied on the radar on Blåvands Huk. Due to the transformer station the blind sector at HR1 covered 100 degrees from NNV to S, and due to other installed equipment on the M4 foundation the sector north of the radar on HR2 OWF was blind. The blind sectors were set without jeopardising the coverage of the Horns Rev area for flocks of waterbirds, Figure 4.1.
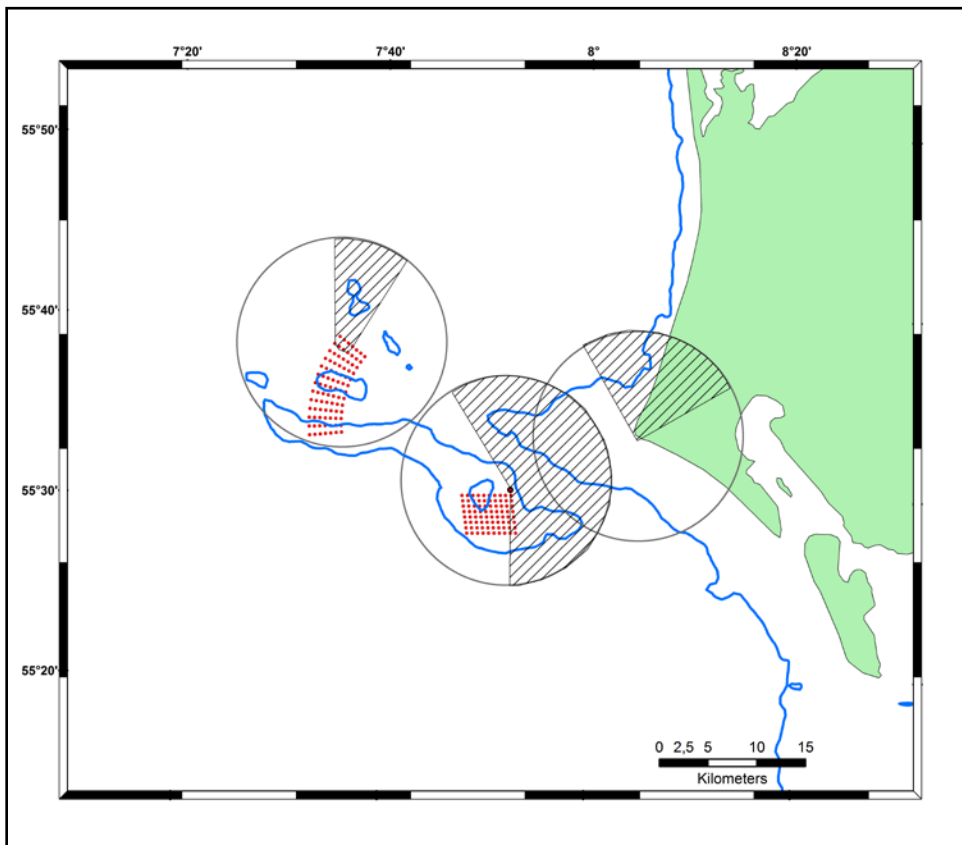

Figure 4.1.   Location of the three radar/observation stations showing 10 km radius of radar coverage including blind sectors (hatched area).
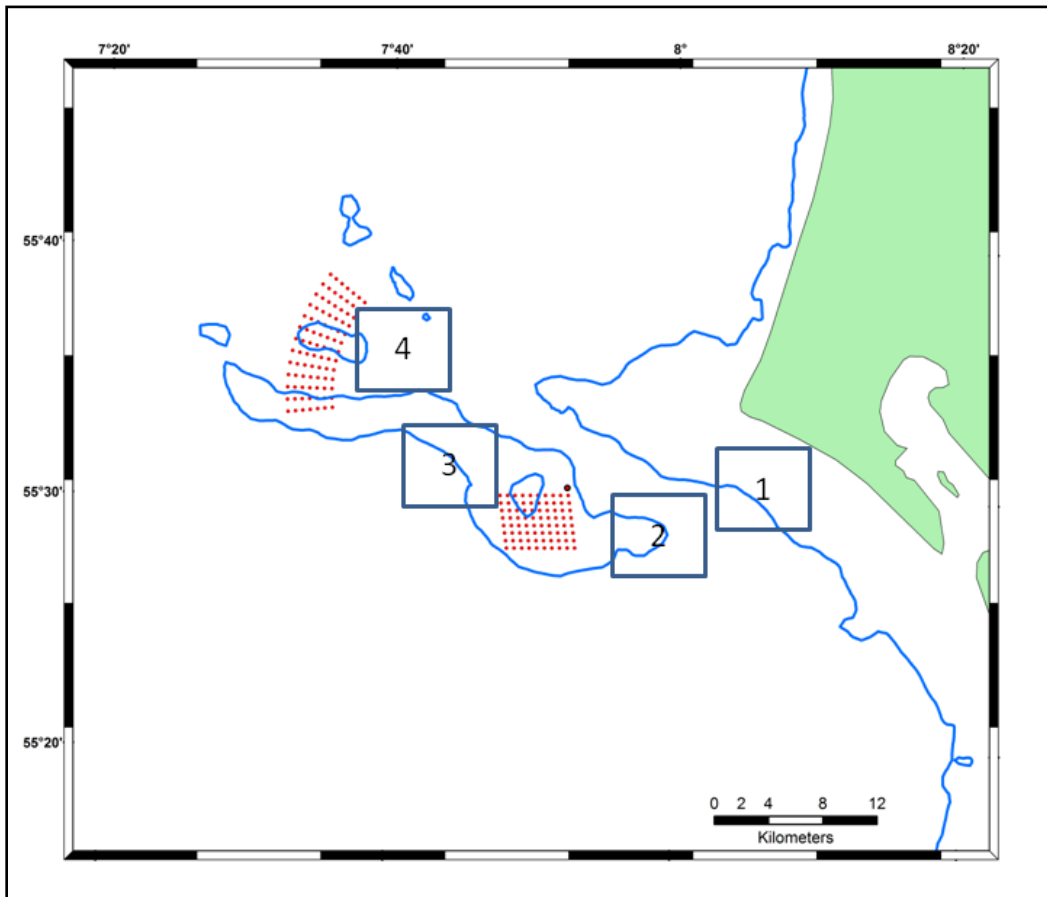
Figure 4.2.   Four zones used for analyses of the profiles of flight analyses.

Due to the large amount of data recorded analyses of profiles of flight intensities have been made by analysing mean values for four statistical zones, which were selected to obtain information along the entire length of Horns Rev. The four zones which are depicted in Figure 4.2 are not located in or near shipping lanes or in areas potentially affected by clutter or shading from wind farm installations:

1. Area south of Blåvands Huk;
2. Cancer;
3. West of Horns Rev 1 OWF;
4. East of Horns Rev 2 OWF.

HR2 – foundation M14

Figure 4.3. The observation platform and mounted radar at the three locations at Horns Rev 2 foundation M4, Horns Rev 1 Transformer Station and Blåvands Huk.

HR1 – transformer platform

Blåvands Huk

The data availability from the three radars is shown in Figure 4.4.
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Figure ´4-4. Data coverage from the three radars. All three radars were running with 24 hr coverage. Unfortunately, due to weather and logistical constraints the installation of the HR2 radar had to be postponed until 27 October, while the installation at Blåvands Huk was finalised 16 September and at HR1 at the 19 September. However, due to the coverage from HR1 of the area between HR1 and HR2 OWFs the major part of the waterbird migration between the two wind farms could be covered until the end of the migration in late November. The coverage at Blåvands Huk was broken by shorter drop-outs between 11 and 28 October. The reason for these drop-outs was the fact that the computer equipment was installed in the same room that was used by the army for different exercises, and the various army personnel accidentally switched off the power every now and then.

The visual observations were carried out from the HR1 transformer station and from Blåvands Huk, and were intended to provide calibration data for classification of the radar data into bird species groups. Due to weather constraints only 7 days with visual ob-

servations were made at HR1, while a total of 34 days were made at Blåvands Huk (Table 4.1). A total of 824 bird observations were made at HR1 and 2,554 at Blåvands Huk.

Table 4.1: Observation periods and effort days of visual observations at Horns Rev I and Blåvands Huk

Date	HR1	Blåvands Huk	Date	HR1	Blåvands Huk	Date	HR1	Blåvands Huk
16-sep			14-Oct		X	11-nov		
17-sep		X	15-Oct			12-nov		
18-sep		X	16-Oct		X	13-nov		
19-sep		X	17-Oct		X	14-nov		
20-sep			18-Oct		X	15-nov		
21-sep			19-Oct		X	16-nov		
22-sep			20-Oct		X	17-nov		
23-sep			21-Oct		X	18-nov		
24-sep			22-Oct		X	19-nov		
25-sep	X	X	23-Oct		X	20-nov		
26-sep		X	24-Oct		X	21-nov		
27-sep			25-Oct			22-nov		
28-sep		X	26-Oct		X	23-nov		
29-sep		X	27-Oct		X	24-nov		
30-sep			28-Oct		X	25-nov		X
1-Oct			29-Oct			26-nov		
2-Oct			30-Oct	X	X	27-nov		
3-Oct			31-Oct	X	X	28-nov		
4-Oct			01-nov	X	X	29-nov		
5-Oct			02-nov	X	X			
6-Oct			03-nov	X	X			
7-Oct		X	04-nov		X			
8-Oct			05-nov		X			
9-Oct			06-nov					
10-Oct			07-nov	X				
11-Oct		X	08-nov		X			
12-Oct		X	09-nov					
13-Oct		X	10-nov					

4.2 The LAWR system design

The three installations were based on the LAWR system design, which use software 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 4.4.

Table 4.2. Specifications of radar devices used .

Brand	Furuno
Type	FAR2127
Power output [kW]	25kW
Frequency [MHz]/wavelength [mm]	9.4 GHz (X-band)
Horizontal angle of radar beam [°]	1 degree
Vertical angle of radar beam [°]	10 degree
Rotational speed [min^{-1}]	24 rpm

Antenna length [mm]	2400

A mechanical clutter fence was used at the radar installation at Blåvands Huk to eliminate problems related to clutter (undesired echoes from waves, structures etc.). A major benefit is a well-defined scan area allowing beams to come close to sea surface without picking up sea-clutter. Dependent on the elevation of the radar antenna and the clutter-fence it is expected that reasonable data can be collected up to sea state 4.

The radar software was subdivided into 3 parts:
- RadCtrl2/PolScan. Radar control and acquisition software;
- BirdWatch/BirdWatchShow. On-line ground truth data collection system;
- BirdTrack. Software for classification and extraction of bird tracks.

Apart from the PolScan software which is DOS based, the rest of the software runs under the WINDOWS-XP operating system.

4.2.1 RadCtrl2 - PolScan

RadCtrl2 is the radar site software and PolScan is the control radar hardware. This software 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 were connected using wireless 3G internet. This software is a modified version of the well-proven software that has been used on DHI LAWR radars during the last 10 years, Figure 4.5.
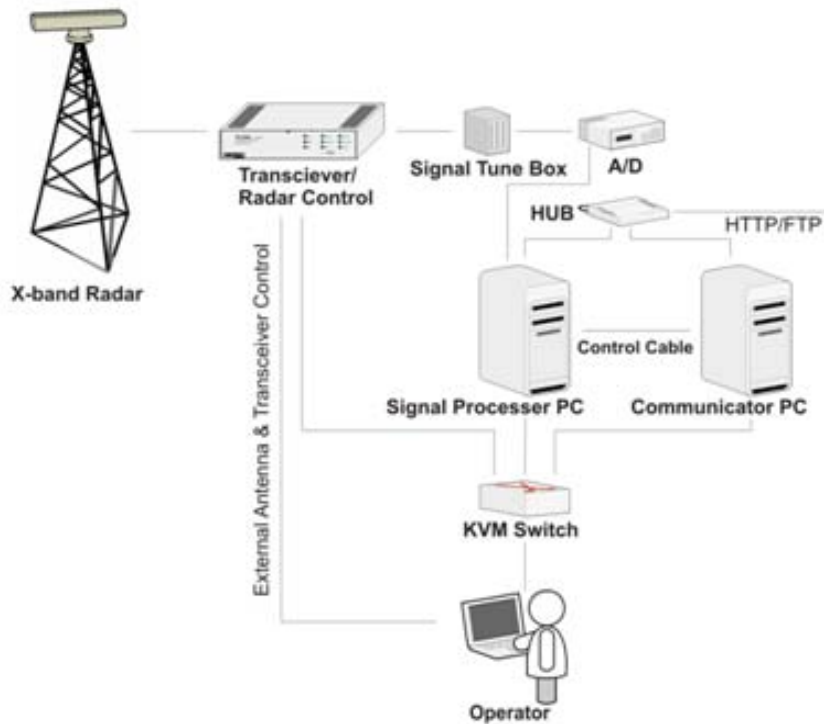
Figure 4.5.   LAWR system hardware design.

4.2.2   BirdWatch - BirdWatchShow

BirdWatch is data entry software package that allows visual observations to be entered directly on top of a live radar image simply by clicking on the echo identified as birds. This approach guarantees accurate positioning of the observation when both visual and radar detection is present. The BirdWatchShow is a tool that allows easy access to data and the corresponding bitmap dump of the radar image. 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 can be used away from radar site. Data are stored comma separated in an ASCII file, and the radar images are stored as BMP files.

4.2.3   BirdTrack

The BirdTrack software is used to classify the data in the radar images followed by a tracking system that extracts tracks from a set of images. The software is a post-processing software and is not available at the radar site.

Figure 4.6.   Database of visual observations in BirdWatch.
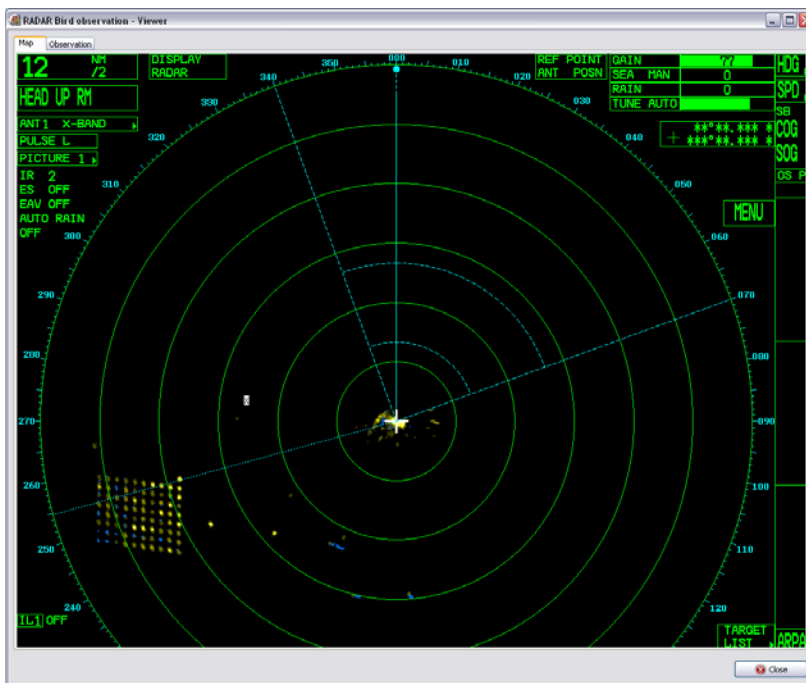

Figure 4.7.   Visual observation marked on radar image in BirdWatchShow.

4.3   Collation and integration of weather data

Wind direction, wind velocity and air pressure at the three radar stations has been collected from Vejr2's ETA model at a temporal resolution of hour. This information was used together with the radar-extracted flight tracks "over ground" to calculate the corresponding bird heading and flight speed through air.

In addition to the wind information, the presence of rainfall in the radar coverage area has been estimated as the average reflectivity over the entire radar image.

4.4   Echo detection

The echo received by the Furuno radar was extracted directly from the receiver circuit before any of the traditional marine radar processing was done. This raw signal 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. The sample time for one image was one minute. For further processing the mean, peak and variance of the radar signals (named L, M, V) were calculated for each bin every minute. This processing was performed "on-the-fly" at the data collection computer at each radar station. The scanning was performed continuously. For each time step three files were generated (the L,M and V files). All radar data were stored in polar format.

4.4.1   Correction for distance bias

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 used on the LAWR during the last 10 years. The correction follows the following equations that are applied to each raw scan line.

Volume correction:

$$Z_{rv} = \frac{1}{C_2 \cdot \exp(r \cdot C_3)} \quad (1)$$

Where:

       Zrv: Volume-corrected reflectivity at range r
       r: range
       C2, C3: Empirical constants that are location dependent.

En-route correction:

$$Z_r = Z_{g,r} \left(1 + \frac{\propto \sum_{i=0}^{i=r-1} Z_i}{C_1 \cdot 8000} \right) \quad (2)$$

Where:

       Zr: Adjusted reflectivity value at range r
       Zg,r: Uncorrected reflectivity at range r
       α, C1: Empirical Constants where typical values are 1.5 and 200 respectively

The actual setting of these parameters was stored in each radar image.

4.4.2 *Echo identification and mapping of flight trajectories*

The tracking algorithm operates on 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. The candidates for continued track are ranked according to shortest Euclidean distance from the track-start candidate in the L, M, V space. The selected candidates are tagged "used" and cannot appear in another track. For each step along the track, track-length and track-time are updated. When no more continuation candidates are found, the track is recorded. 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 track database includes the following elements:

```
TrackID                 : String starting with the radars 4 letter prefix
DateTime    : Date and time of the track start
From PosN               : (m),
From PosE : (m),
To PosE     : (m),
To PosN                 : (m),
Day or night            : N(ight)/D(ay),
Track Direction         : degree (towards),
Wind direction          : degree (towards)
Bird direction          : degree (towards)
Wind Velocity           : km/h,
Track length            : (m),
Track Time : (s)
Track Velocity          : (km/h),
Bird Velocity           : (km/h),
Start point of track:
Average reflectivity   0-1023
Max reflectivity               0-1023
Reflectivity variance 0-32767
Rain level   : 0-1023
Dist from radar           : (m)
```

4.4.3 *Filtering, incl. removal of noise*

Based on visual and statistical analyses of the recorded M, L and V values of each pixel in the polar image, a set of threshold values has been identified that will help distinguish echoes from potential birds from other echoes. The following parameters for this filtering process have been identified:

- M values in the interval $350 <= M <= 1024$
- L values in the interval $5 <= L <= 1024$
- V values in the interval $0 <= V <= 7000$

A physical way to interpret the data is for example that the echo from a large object like a ship will display similar (and high) average (L) and peak (M) values and small variance (V) values, while a bird will display much larger M than L values, and a bigger variance V.

In order to further remaining ship tracks, rain and wind-induced clutter from the data the following exclusion filters were applied to the radar data:

- Track velocity < 30 km/h
- Rain level > 10
- Wind velocity > 50 km/h.

4.4.4 Visual observations

Visual observations of flying birds with a focus on migration took place during daylight hours from before sunrise until after sunset. The focus of the visual observations was set on recording long-distance flight movements of waterbirds. In addition, during a period of intense nocturnal migration of passerines (mainly thrushes) acoustic observations were carried out at Blåvands Huk two hours following sunset.

As the objective of the visual observations was to obtain calibration data counts of birds were not undertaken. Instead migrating birds were tracked and the observations recorded either on-line using the BirdWatch software described in 4.4.2 or in a database with information on flight height, direction and distance. When recording on-line into BirdWatch positions and time of the corresponding radar echo was stored with details from the observation of bird species, number of bird, distance to the observer, direction of flight, estimated altitude and behavioural details. In addition, the observer noted whether the observed birds could actually be seen on the remote radar screen. Optics used by the observers were binoculars with 10x magnification and telescopes 25x magnification.

4.5 Data analyses

4.5.1 Classification of bird species groups

The in-situ pairs of calibration observations and identified trajectories made it possible to post-classify the radar data into bird classes on the basis of the echo characteristics (M, L, V) and the air and (over ground) speeds of the target. The radar trajectories were linked to the observations in BirdWatch by using a GIS-based search with the following criteria:
- Distance to track < 1000 m
- Time difference to start of track < 10 minutes

In cases where the search resulted in more than 1 candidate trajectory for an observation the final selection was made manually on the basis of the direction and speed of the trajectory as well as on the M, L and V values.

The post-classification routine is an estimation of the statistical probability for a trajectory belonging to a certain class of birds, which was made by applying a classification tree model, which was established based on the calibration data set. Classification trees are not commonly applied in ornithology, but have been used extensively in applied medicine (diagnosis) and in botany (classification). Classification trees are used to predict membership of cases or objects in the classes of a categorical dependent variable from their measurements on one or more predictor variables (Breiman et al. 1984, Ripley 1996). The goal of classification trees is to predict or explain responses on the categorical dependent variable, and as such, the technique resembles statistical techniques used in the more traditional methods such as discriminant analysis and cluster analysis.

Classification trees employ a hierarchy of predictions, with many predictions sometimes being applied to particular cases, to sort the cases into predicted classes. Traditional methods use simultaneous techniques to make one and only one class membership prediction for each and every case. Compared with the traditional methods classification trees are more flexible, and more successful in cases where no linear relationship exists between predictors and the dependent variable. Hence, because the univariate splits of classification trees are not restricted to a single linear combination of predictors, they have the ability to find the "cut points" on the predictor dimensions that allow the best possible classification. In addition, tree models can deal better with interactions between explanatory variables than regression, GLM, GAM or discriminant analysis.

We built the classification tree to compare classification potentials of bird classes separated by expected air speed, size and flight characteristics of target. The tree is constructed by repeatedly splitting the data; at each split the data are partitioned into two mutually exclusive groups, each of which is as homogeneous as possible. Splitting is continued until an overly large tree is grown, which is then pruned back to the desired size. The classification tree tries to assign each observation to one of the predefined groups based on a specific value from one of the variables, thereby maximizing the variation between the groups while minimizing the variation within each group.

Cross-validation was performed using cost-complexity cross-validation pruning (Breiman et. al., 1984). The costs needed to perform cost-complexity pruning are computed as the tree is being grown, starting with the split at the root node up to its maximum size. The learning sample costs are computed as each split is added to the tree, so that a sequence of generally decreasing costs (reflecting better classification) are obtained corresponding to the number of splits in the tree. As the complexity parameter is increased, larger trees are penalized for their complexity more and more, until a discrete threshold is reached at which a smaller-sized tree's higher costs are outweighed by the largest tree's higher complexity). The tree selection procedure was validated with global cross-validation, by which the entire analysis was replicated three times holding out a fraction of the cases to use as a test sample to cross-validate the selected classification tree. The selected classification tree model was deployed on the combined radar tracks resulting in the additions of estimated bird classes to each track.

4.5.2 Estimation of flight intensities

The classified tracks were transferred from vector to raster using a grid with the resolution of 1 km. The gridded track data, which were total frequencies, were split into bird classes. They were subsequently used to generate spatial trends and time series profiles of flight intensities (frequency of tracks) for each bird class. In addition, the flight directions of the classified tracks were summarised for the area around HR1 OWF.

4.6 Quality control

General quality assurance and management were conducted and documented in accordance with internationally accepted principles for quality and environmental management as described in the DS/EN ISO 9001 standard.

5 RESULTS

5.1 Filtering

The filtering procedure effectively reduced the amount of atmospheric and seaborne noise, Figure 5.1. The resulting sample size of potential bird flight trajectories was 535,482 of which 145,918 were from the radar at Blåvands Huk, 278,078 from HR1 and 111,486 from HR2.
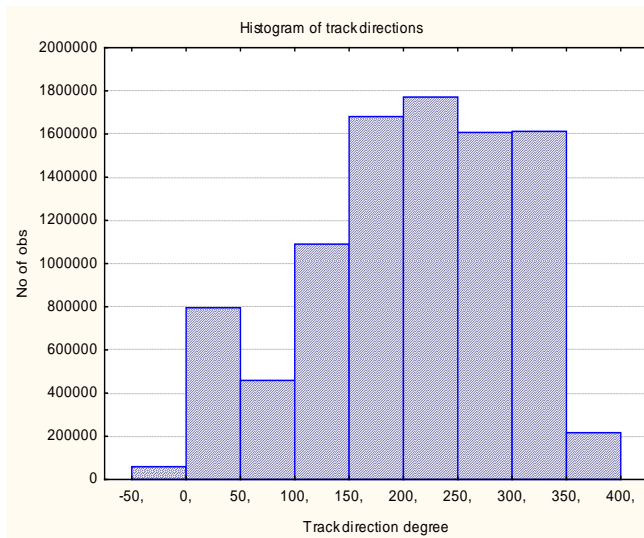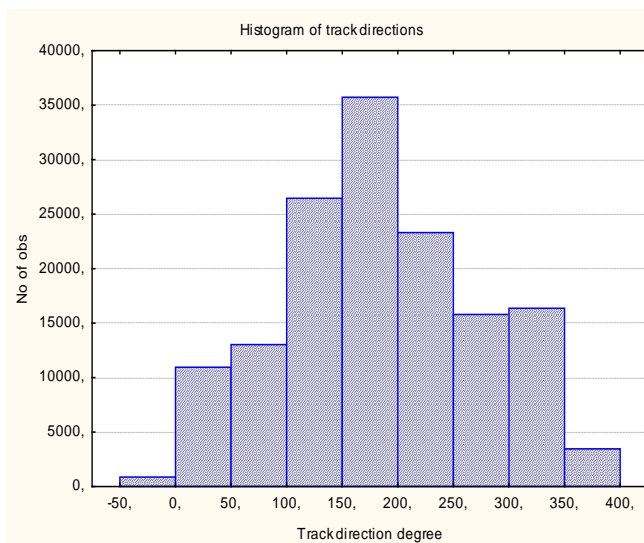

Figure 5.1. Example of the result of the filtering procedure showing track directions for unfiltered and filtered radar data from Blåvands Huk. The filtered data display the expected concentration of bird flight directions towards the south.

5.2 Species classification

The calibration data which could be linked to tracks consisted of 154 cases. The characteristics of the radar signals in terms of air speed, mean,peak and variance values of the identified tracks are shown in Figure 5.2 for six different bird groups: divers, geese+cormorants, gannets, seaducks, gulls and passerines. Air speed is often used as a classifier of bird groups, however with the exception of passerines which have markedly lower air speeds there is a great deal of overlap in the measured speeds between the different species groups. The highest speeds were measured for seaducks (primarily common scoters *Melanitta nigra*) with a mean speed of 65 km/h. The mean radar signals overlapped greatly between groups with passerines having the smallest and gannets the largest mean values. With respect to the maximum values both passerines and gulls had the smallest and gannets the largest values. The variance values separated

the species more with gannets and geese+cormorants having large values with narrow confidence intervals and passerines and seaducks having small and well-defined values.
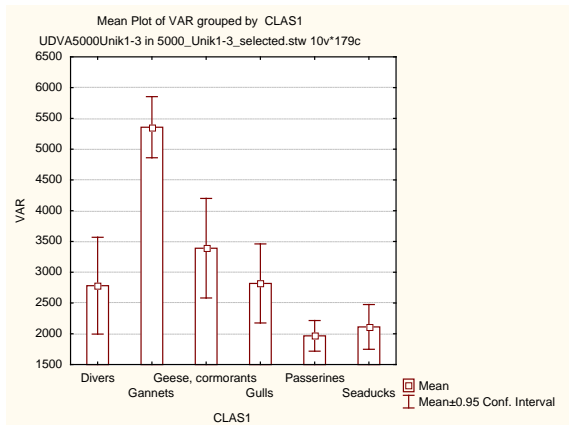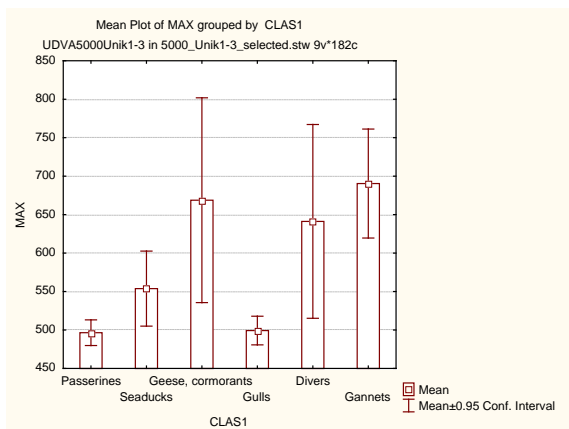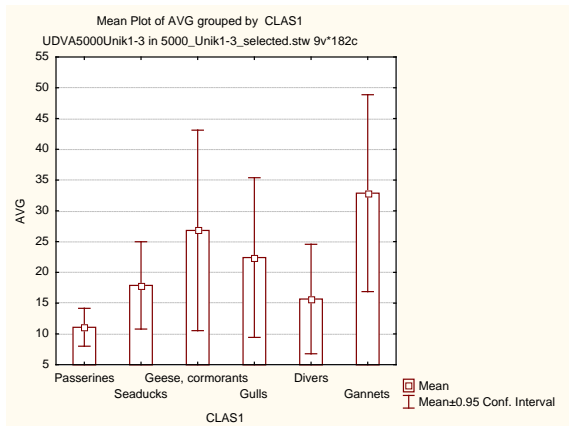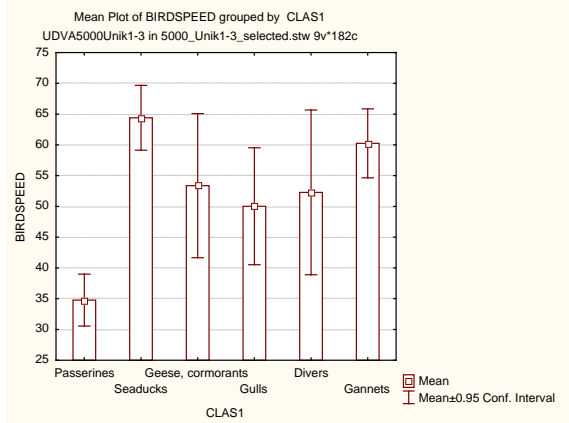
Based on these three broad classes were grouped and selected for the classification tree analysis with dissimilar characteristics:

- Large waterbirds – divers, gannets, cormorants, geese
- Ducks - seaducks
- Passerines - passerines

The classification tree analysis generated a 'simple' tree with only two splits resulting in three terminal nodes dominated by each of the broad bird classes, Figure 5.3. The first split was based on variance values with values higher than 2,990 being classed as the terminal node 'large waterbirds' as it was definitely dominated by this class. Variance values below 2,990 were classed as 'ducks' and was subsequently split into terminal nodes 'ducks' and 'passerines' based on air speed ($<>$ 44.21 km/h). Both nodes were dominated by the two respective species classes, but also contained tracks representing the other classes. The cross-validation indicated that a tree with two splits would be the best size of tree. Little predictive accuracy would be gained from a tree with more splits.

Figure 5.2. Radar signal characteristics (air speed, mean, peak and variance reflecatnce) of identified tracks for the calibration data (n=154). The graphs show mean and 95% confidence intervals for six groups of birds.
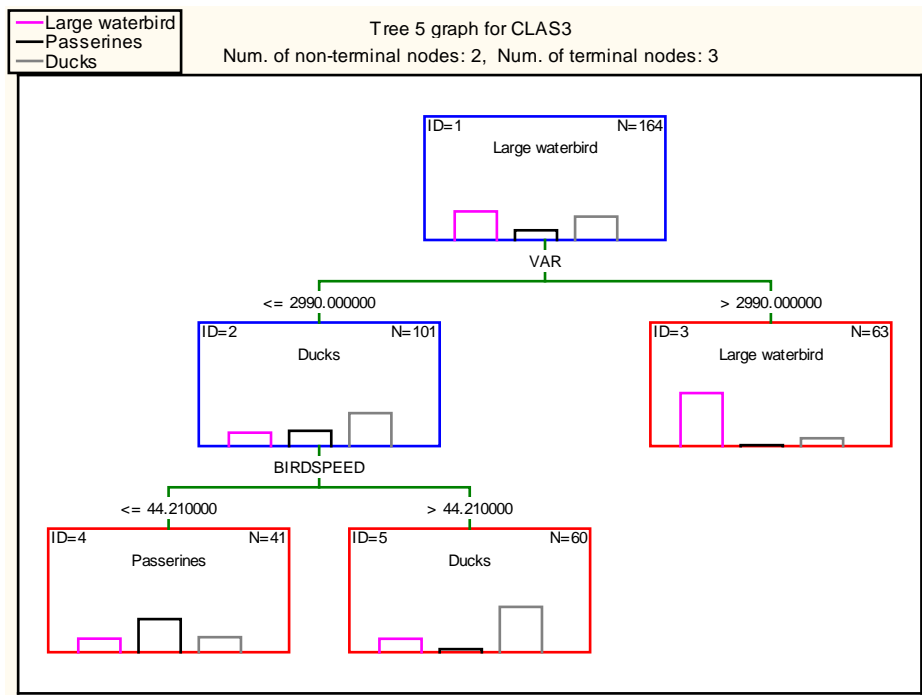
Figure 5.3.   Classification tree for the first level of bird classes. Terminal nodes are outlined with red lines, while the remaining decision nodes or split nodes are outlined with blue lines. The tree starts with the root node which is labelled as node 1 in its top-left corner. For each node the dominant bird class is mentioned and the proportion of each of the three classes is given as bars.
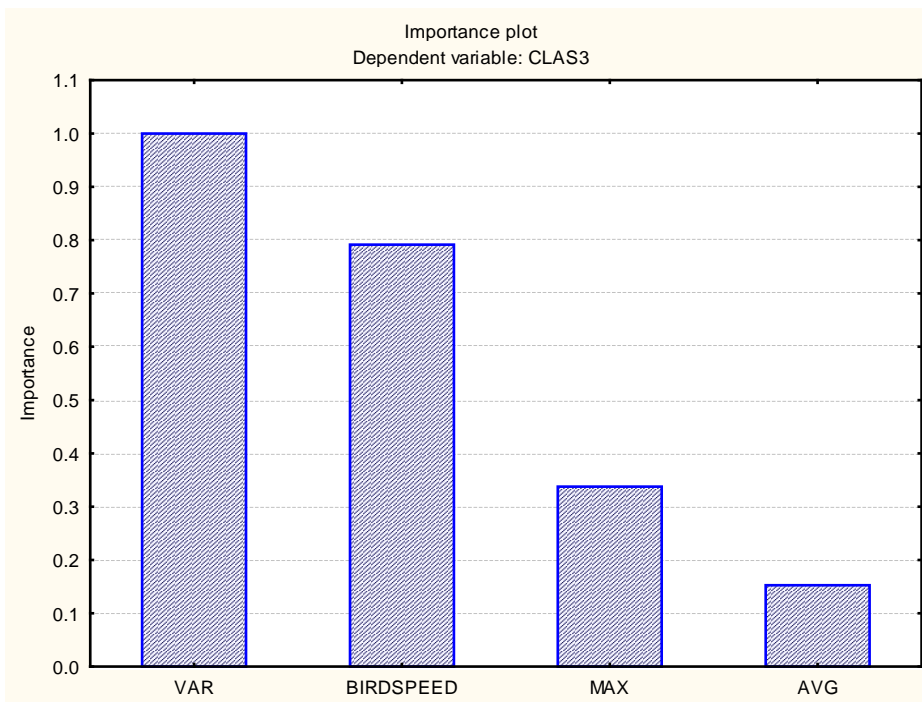
Figure 5.4.   The relative importance of each of the four predictor variables for the classification tree.

5.3   Migration intensity

In order to estimate profiles and spatial gradients of migration intensity along Horns Rev the classification tree model was implemented on the complete database of filtered radar tracks. Figures 5.5 – 5.10 summarise the spatial trends in the estimated flight intensities of the three bird classes 'large waterbirds', 'ducks' and 'passerines'. Several similar trends can be identified across these three groups. In general, flight intensities were much higher (at least a factor of 5) in the easternmost 10 km covered by the radar at Blåvands Huk as compared to the intensities recorded by the radars on HR1 and HR2 OWFs. A corridor of higher migration intensities was clearly identified, being narrower for the class 'large waterbirds' than for 'ducks' and 'passerines', and being most prominent in November as compared to September-October.

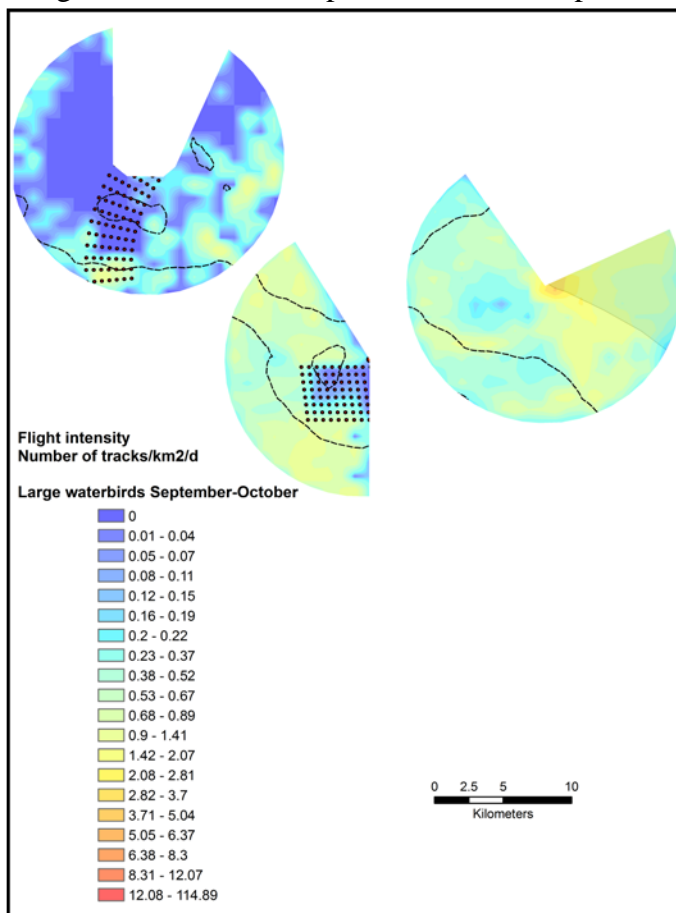Average flight intensities in the coastal corridor were clearly higher in November than in September-October for all three classified species groups, while the intensities of the groups large waterbirds and passerines were similar in the two periods. During November, high flight intensities of 'large waterbirds' (> 10 tracks/km^2/d) were recorded in the region southeast of Blåvands Huk, including the Esperanca Bugt. During the same period, high intensities of 'ducks' were recorded across the whole radar zone west and south of Blåvands Huk. The area around the HR1 OWF had medium intensities of 'ducks' in November. Flight intensities of 'passerines' were also high in November in the sector southeast of Blåvands Huk, and medium intensities were recorded south of HR1.

The area around the planned HR2 wind farm had relatively higher flight intensities of 'large waterbirds' and 'passerines' as compared to 'ducks. Flight intensities of 'large waterbirds' and 'ducks' were generally lower west of HR2 OWF compared to the area east of the planned wind farm, while intensities of passerines were at the same level on both sides of the planned wind farm. Flight intensities of all three bird classes were generally lower around HR2 OWF as compared to the area west of HR1 OWF. However, flight intensities for all three bird classes were markedly lower within the HR1 OWF than in the surrounding area.

Figure 5.5. Spatial trends in the mean flight intensity for the class 'large waterbirds' during September-October in the zones covered by the three radars (10 km radius). Flight intensity is measured as the average frequency of flight tracks per km^2 per day. The colour range has been designed to resolve the lower end of the values typically recorded in the western part of Horns Rev.

Flight intensity
Number of tracks/km2/d

Large waterbirds November

- 0
- 0.01 - 0.04
- 0.05 - 0.07
- 0.08 - 0.11
- 0.12 - 0.15
- 0.16 - 0.19
- 0.2 - 0.22
- 0.23 - 0.37
- 0.38 - 0.52
- 0.53 - 0.67
- 0.68 - 0.89
- 0.9 - 1.41
- 1.42 - 2.07
- 2.08 - 2.81
- 2.82 - 3.7
- 3.71 - 5.04
- 5.05 - 6.37
- 6.38 - 8.3
- 8.31 - 12.07
- 12.08 - 114.89

Figure 5.6. Spatial trends in the mean flight intensity for the class 'large waterbirds' during November in the zones covered by the three radars (10 km radius). Flight intensity is measured as the average frequency of flight tracks per km^2 per day. The colour range has been designed to resolve the lower end of the values typically recorded in the western part of Horns Rev.

Flight intensity
Number of tracks/km2/d

Ducks September-October

- 0
- 0.01 - 0.04
- 0.05 - 0.07
- 0.08 - 0.15
- 0.16 - 0.22
- 0.23 - 0.33
- 0.34 - 0.63
- 0.64 - 1.37
- 1.38 - 1.93
- 1.94 - 2.37
- 2.38 - 2.85
- 2.86 - 3.48
- 3.49 - 4.07
- 4.08 - 4.78
- 4.79 - 5.85
- 5.86 - 7.15
- 7.16 - 8.41
- 8.42 - 9.19
- 9.2 - 10.04
- 10.05 - 26.44

Figure 5.7. Spatial trends in the mean flight intensity for the class 'ducks' during September-October in the zones covered by the three radars (10 km radius). Flight intensity is measured as the average frequency of flight tracks per km^2 per day. The colour range has been designed to resolve the lower end of the values typically recorded in the western part of Horns Rev.

Figure 5.8. Spatial trends in the mean flight intensity for the class 'ducks' during November in the zones covered by the three radars (10 km radius). Flight intensity is measured as the average frequency of flight tracks per km[2] per day. The colour range has been designed to resolve the lower end of the values typically recorded in the western part of Horns Rev.
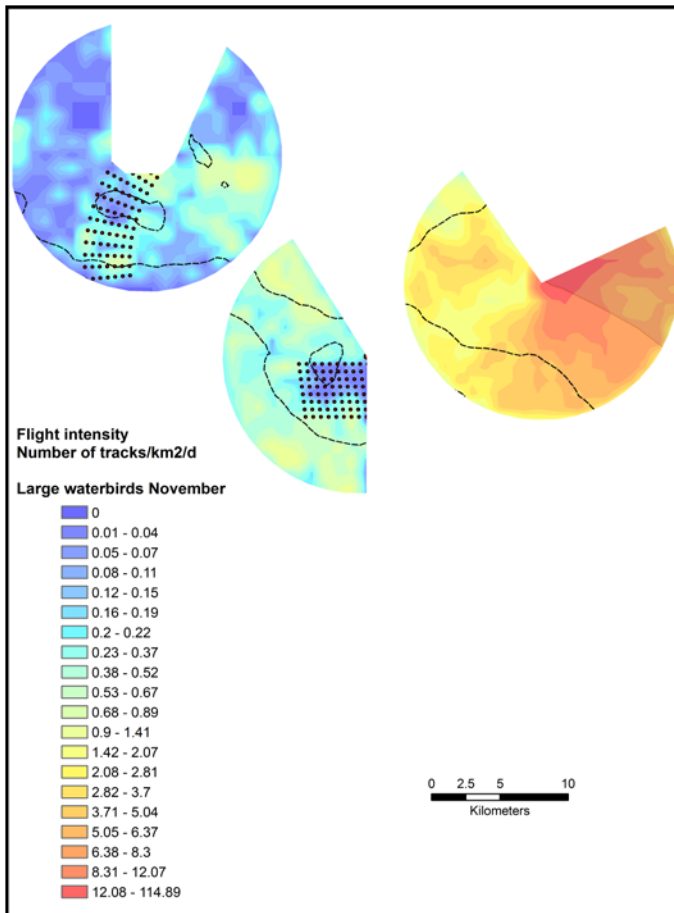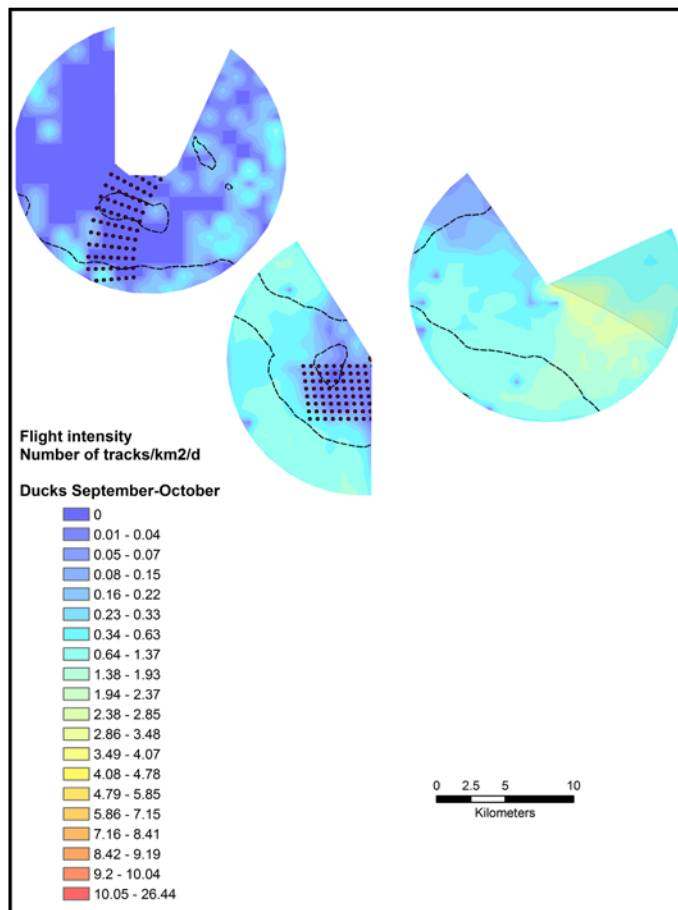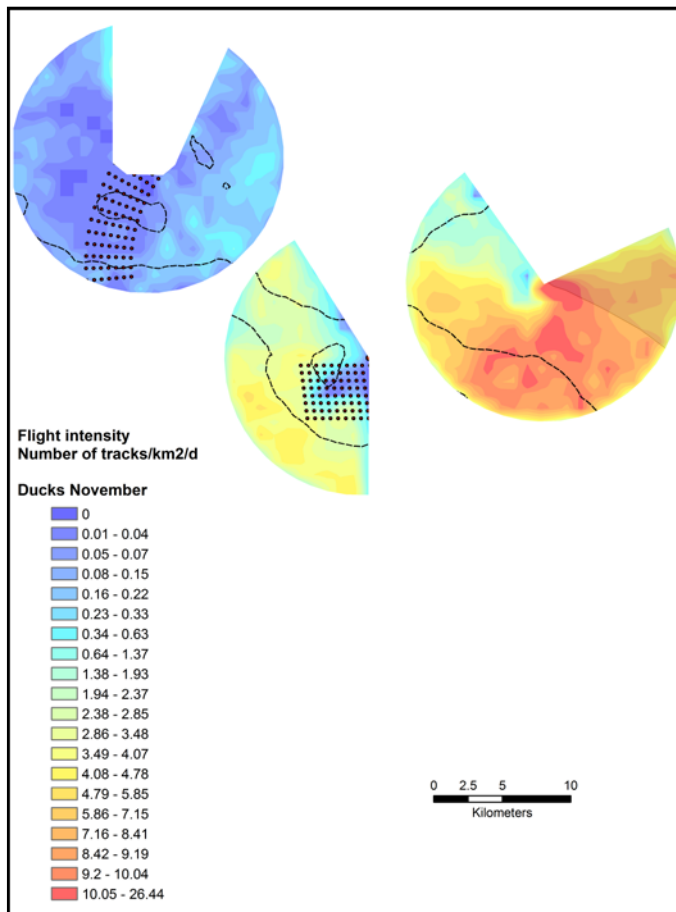
Flight intensity
Number of tracks/km2/d

Ducks November

- 0
- 0.01 - 0.04
- 0.05 - 0.07
- 0.08 - 0.15
- 0.16 - 0.22
- 0.23 - 0.33
- 0.34 - 0.63
- 0.64 - 1.37
- 1.38 - 1.93
- 1.94 - 2.37
- 2.38 - 2.85
- 2.86 - 3.48
- 3.49 - 4.07
- 4.08 - 4.78
- 4.79 - 5.85
- 5.86 - 7.15
- 7.16 - 8.41
- 8.42 - 9.19
- 9.2 - 10.04
- 10.05 - 26.44

0 2.5 5 10
Kilometers

Figure 5.9. Spatial trends in the mean flight intensity for the class 'passerines' during September-October in the zones covered by the three radars (10 km radius). Flight intensity is measured as the average frequency of flight tracks per km[2] per day. The colour range has been designed to resolve the lower end of the values typically recorded in the western part of Horns Rev.

Flight intensity
Number of tracks/km2/d

Passerines September-October

- 0
- 0.01 - 0.04
- 0.05 - 0.07
- 0.08 - 0.11
- 0.12 - 0.15
- 0.16 - 0.19
- 0.2 - 0.22
- 0.23 - 0.37
- 0.38 - 0.52
- 0.53 - 0.67
- 0.68 - 0.89
- 0.9 - 1.41
- 1.42 - 2.07
- 2.08 - 2.81
- 2.82 - 3.7
- 3.71 - 5.04
- 5.05 - 6.37
- 6.38 - 8.3
- 8.31 - 12.07
- 12.08 - 114.89

0 2.5 5 10
Kilometers

Figure 5.10. Spatial trends in the mean flight intensity for the class 'passerines' during November in the zones covered by the three radars (10 km radius). Flight intensity is measured as the average frequency of flight tracks per km² per day. The colour range has been designed to resolve the lower end of the values typically recorded in the western part of Horns Rev.
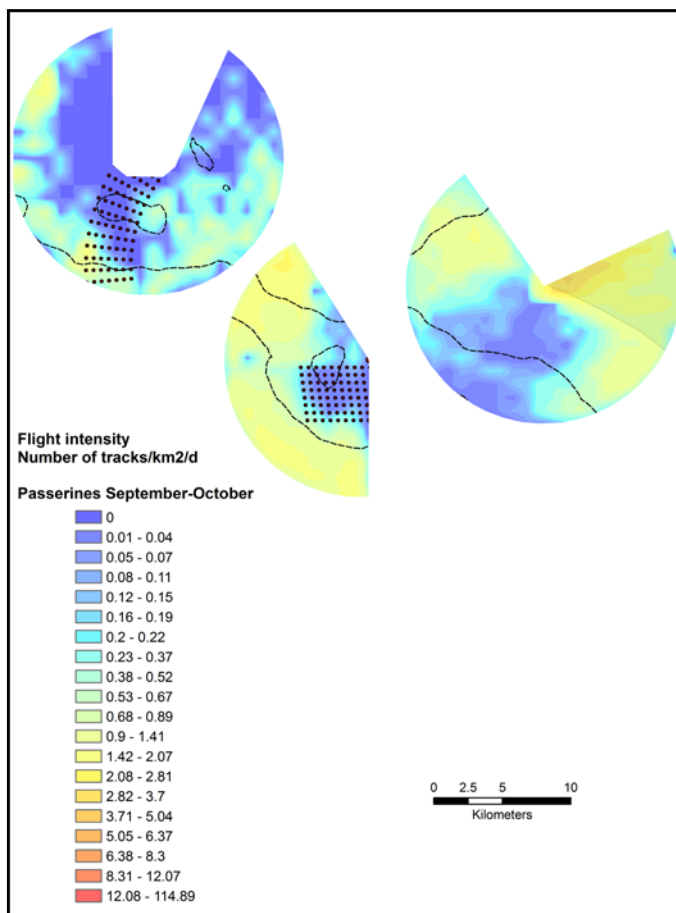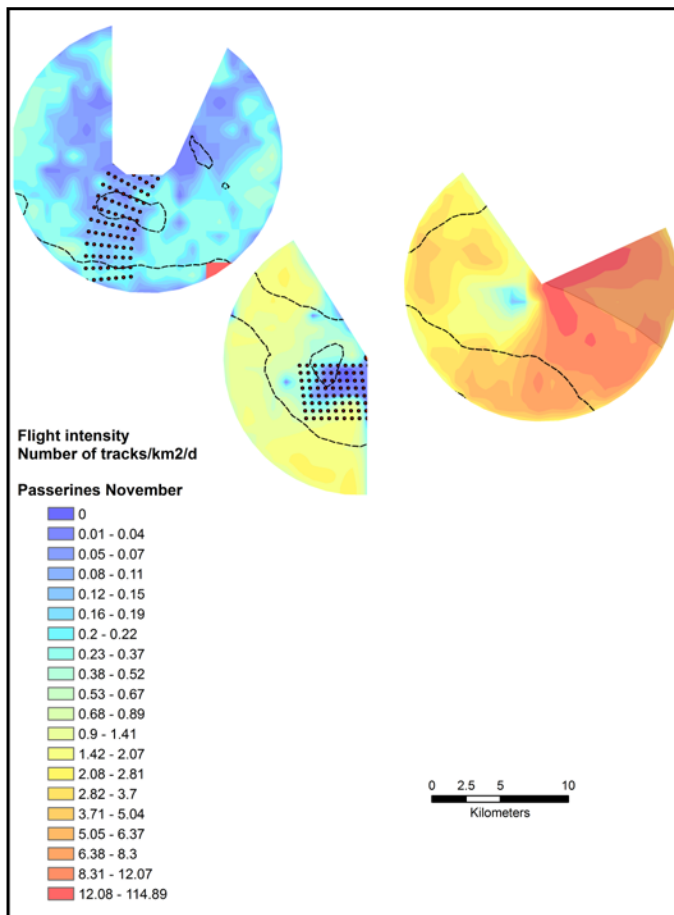
Temporal profiles of track frequencies were estimated for each of the four statistical zones over periods of 5 days, Figures 5.11, 5.12, 5.13. The four zones, Figure 4.2, were labelled from east to west as Blåvands Huk, Cancer, HR1 and HR2. The group 'large waterbirds' displayed two temporal patterns for the two eastern-most zones; one at medium intensity stretched over the entire period from the onset of the monitoring campaign in mid September until end of October, and another at higher intensity (mean values up to 45 tracks/km² at Blåvands Huk) in early and mid November. In both periods the intensities at Blåvands Huk were slightly higher than at Cancer. East of Horns Rev 1 irregular medium intensities were estimated for the first period and very low rates during the second period. At Horns Rev 2 only very low migration intensities were estimated for this group and only during the first period.

The group 'ducks' also displayed two temporal patterns for the two eastern-most zones; one at medium intensity during mid and late October and another at higher intensity mean values up to 140 tracks/km² at both Blåvands Huk and Cancer during the central part of November. The flight intensities of 'ducks' estimated for the zone east of HR1 was 85% lower than at Blåvands Huk and Cancer, but coincided with the temporal pattern at these zones. Only very low rates were estimated for this bird group for HR2.

As seen in the spatial trends described above the estimated flight intensities for the group 'passerines' were also much higher in the eastern sector of Horns Rev (mean values up to 180 tracks/km² at both Blåvands Huk and 135 tracks/km² at Cancer) as compared to the central area where medium intensities were estimated for HR1 and the western area where only very low intensities were estimated for HR2. The migration of 'passerines' in the eastern sector mainly took place between mid October and mid November with the peak occurring at the end of the period.
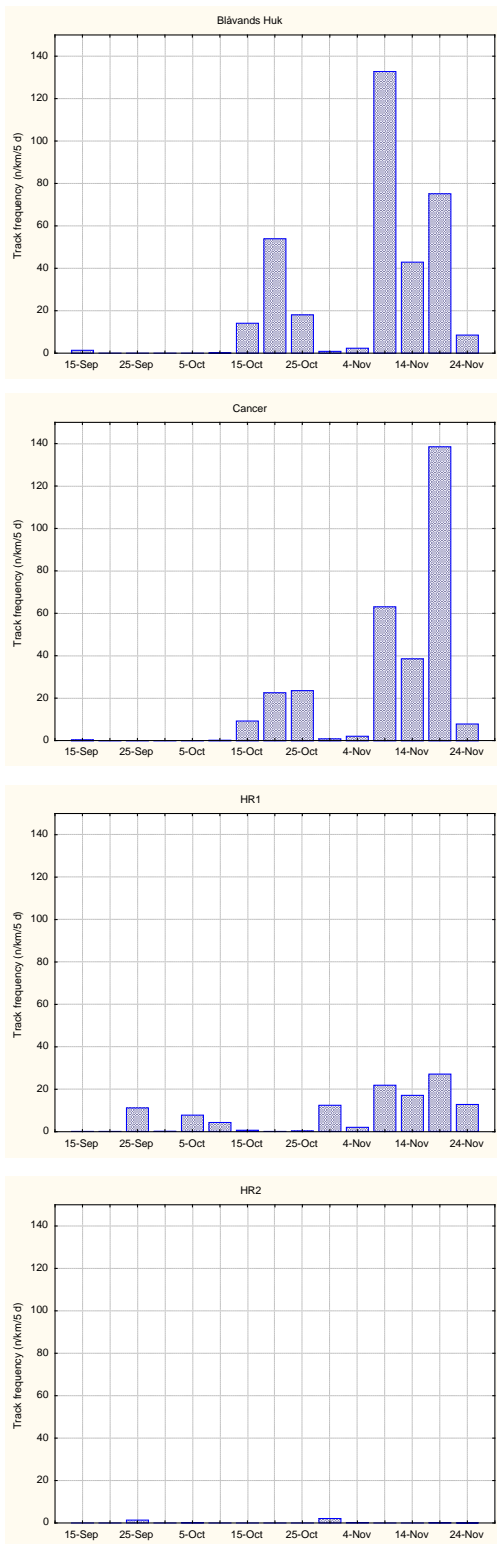
Figure 5.11. Profiles of flight intensity for the class 'large waterbird' in the four statistical zones. Flight intensity is measured as the average frequency of flight tracks per km over a period of 5 days.

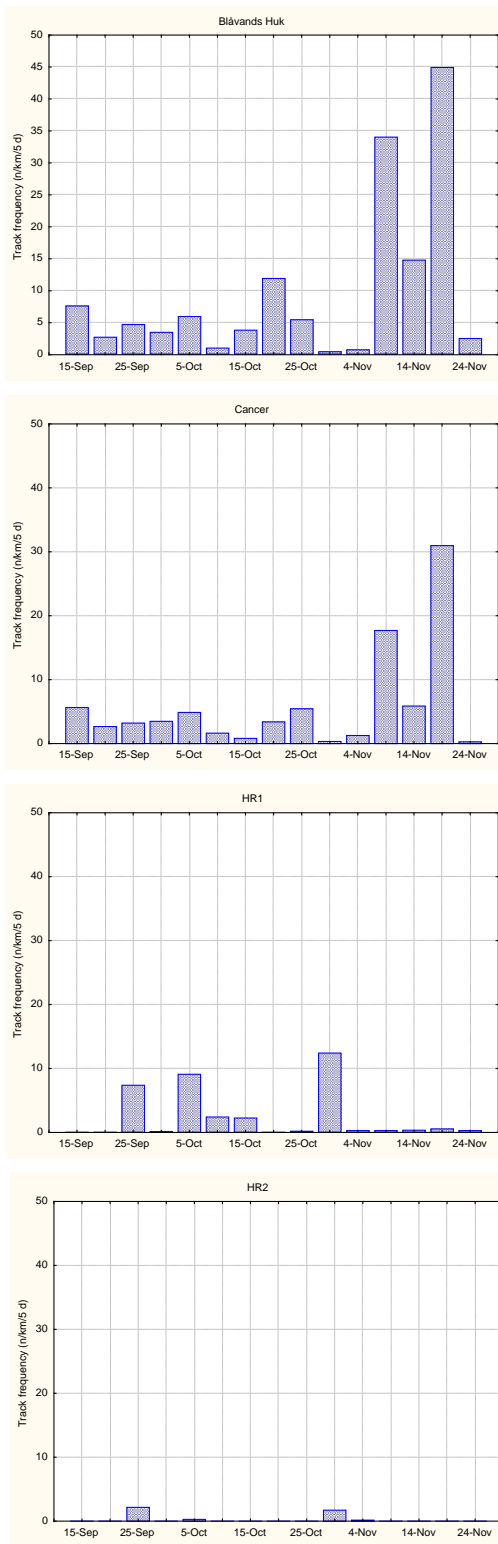Figure 5.12. Profiles of flight intensity for the class 'ducks' in the four statistical zones. Flight intensity is measured as the average frequency of flight tracks per km over a period of 5 days.
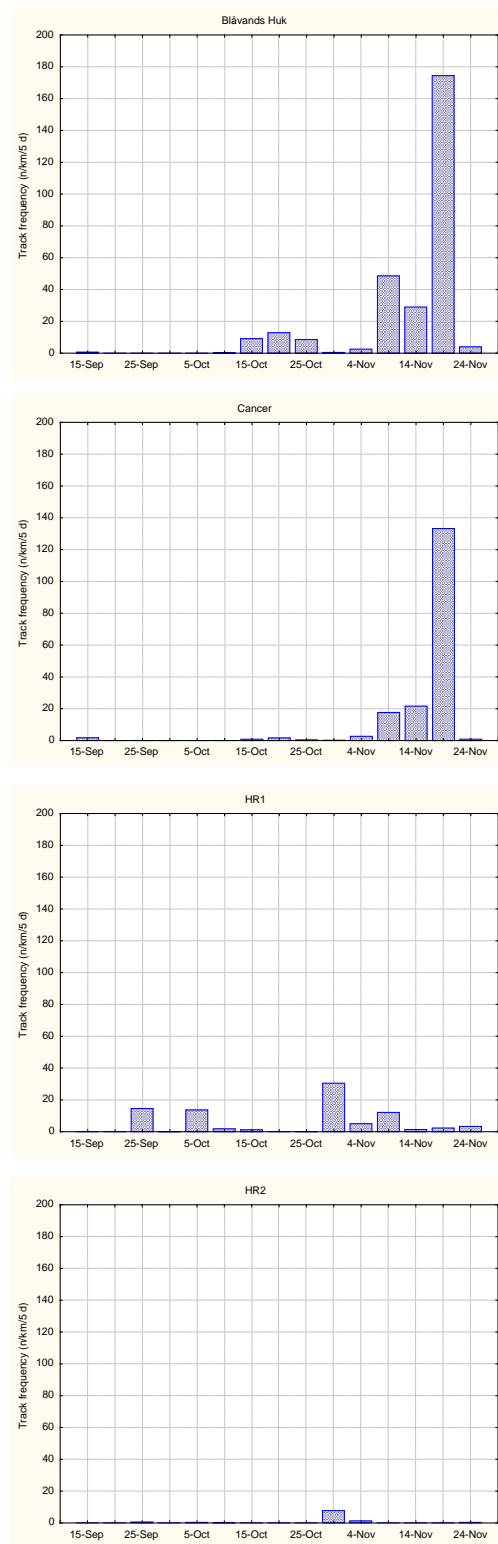
Figure 5.13. Profiles of flight intensity for the class 'passerine' in the four statistical zones. Flight intensity is measured as the average frequency of flight tracks per km over a period of 5 day.

6   DISCUSSION

As the investigation using automated 24 hr recordings with fixed X-band radars is the first to be applied in the Danish part of the North Sea it is not possible directly to compare the recorded temporal and spatial patterns in migration intensities directly with the data obtained during the PSO monitoring programme (Petersen et al. 2006) and the German investigations of bird collision risks near HR1 OWF (Blew et al. 2008). It is, however, well-documented from long-term investigations at the bird observatory at Blåvands Huk that a larger volume of birds pass the Horns Rev area during autumn as compared to spring. During the PSO programme quantitative data collection focused on visual transects at HR1 OWF. These transects showed that in terms of individuals common scoters, gulls and terns dominated the movements around HR1; scoters mainly in spring, the larger species of gulls mainly in autumn and terns both in autumn and spring. The German migration studies at HR1 during 2005-2006 obtained more information on the flight intensities of passerines and revealed larger movements in autumn than spring and large year-to-year differences at the site.

The primary goal of the study using automated radar recordings was to establish a baseline for monitoring of bird migration at Horns Rev, which would provide sufficient quantitative information on migration intensities of waterbirds adequate for future assessments of effects of the construction of the HR2 OWF on migratory birds, including assessment of potential cumulative avoidance effects of the existence of both HR1 and HR2 OWFs. The spatial coverage should be sufficient to allow for the estimation of profiles of the intensity of waterbird migration along Horns Rev from the coast to the western part of the HR2 OWF site. This goal was achieved, and it was possible to estimate spatial trends and time series for different species groups based on statistical probabilities derived through classification trees trained on the visual calibration data. The flight intensities of both waterbirds and landbirds strongly indicated higher passage rates of birds in the eastern-most sector of Horns Rev, significantly lower rates at the HR1 OWF and rather low rates at HR2; the area to the east of the planned HR2 had slightly higher rates than the area to the west of the planned wind farm. These results point at the existence of a marked migration corridor in autumn of approximately 10 km width at the inner Horns Rev – Blåvands Huk area.

Although no information on altitudes were collected during this study the information collected on flight intensities shed new light on the potential for barrier effects and collision risks associated with the construction of the HR2 OWF. Given the results of the trends and profiles of migration intensities of the three major bird groups there are no indications of large-scale migration occurring at HR2 in autumn. Additionally, no short-term events were noted at the site. The trends in flight intensities at HR1 OWF indicated the existence of avoidance response for all three bird classes: 'large waterbirds', 'ducks' and 'passerines'. Avoidance response for long-distance migration at the site was also shown by Petersen et al. (2006). However, 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 wind farm as a barrier effect. The spatial patterns of flight intensities recorded during this investigation show that the reduced flight intensities are completely related to the wind farm and the surrounding area to a distance of approximately 1.5 km, and there are no indications of e.g. shading effects on the southern fringe of the wind farm. Petersen et al. (2006) also documented avoidance response at the scale of 0.5-1.5

km from the wind farm. Thus, the avoidance effect at HR1 OWF must be expected to impact the southbound migration of a wide range of species, albeit the effect in terms of modified flight paths and energetic costs are deemed to be minor for long-distance migrants. As our results show that HR1 OWF is at the western margin of the migration corridor in autumn the effects is 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. Due to the local and short scale of the avoidance effect it is not likely that the moderate displacement of migrants at HR1 will affect the migrants en-route to HR2 OWF, and the avoidance effect at HR2 OWF is therefore most likely to be local (non-cumulative). This was clearly indicated by the analysis of spatial trends which showed no signs of a link between flight intensities east of HR1 OWF and the area around HR2. The recorded migration intensity of the two bird classes 'large waterbirds' and 'ducks' was slightly higher on the eastern than on the western side of HR2 OWF, while the intensities of 'passerines' were equal on both sides. Thus, the avoidance effect at HR2 is likely to display both a concentration of birds (non-passerines) on the eastern side and a split of migrating passerines around the wind farm.

The achieved coverage was acceptable, as the detection range of the three radars demonstrated effective detection of larger bird echoes at least to 10 km. Bird echoes were recorded frequently to a distance of 20 km. Due to the late installation of the radar at HR2 the area west of the planned OWF was poorly covered during this study. However, the area to the east of HR2 was covered during the whole period by the radar at HR1, and in the light of the unambiguous decreasing trends in flight intensities of all classified bird species groups it is not likely that the lack of data from the North Sea west of HR2 will significantly impair on the monitoring programme. Based on the available data the focus of the monitoring of bird migration related to the operation of HR2 OWF should be on the sector between HR2 and Blåvands Huk covered during this autumn.

6.1   Methods

The hardware set-up was based on the established LAWR design. However, due to the remote locations, and the experience with data out-falls due to power failures, automatic remote alarms, e.g. *sms* alarms, should be applied in future set-ups. The clutter fence was designed to reflect rather than absorb clutter. Given the relatively large amount of clutter collected close to the radar it is recommended to change this design, as it is expected that an absorbing fence will reduce clutter more efficiently.

The post-processing routines developed for establishment of tracks from single echoes seemed to work satisfactorily, which is important as the classification tree analysis used assumes that samples are independent. We did not come across indications that many bird flocks were lost during several rotations of the radar, for example, due to a sudden movement of the bird flock, or because they landed on the water, they may have been recorded in a second track as well. We therefore assume that this would generally be the exception in our data and that records (i.e., tracks) were uncorrelated and were from different birds/flocks.

The filtering procedures efficiently removed a lot of the atmospheric and seaborne clutter. However, some sea- and airborne clutter remained in the data, and obviously ships

moving at speeds exceeding 30 km/h (en-route passage and fast service boats at HR1 and HR2 OWFs) were recorded. Although the classification tree models classified bird groups correctly we may still have erroneously classified boats as slower moving birds (essentially passerines). An improved classification of landbirds would be possible by collecting more calibration data on different types of boats.

This radar methodology described is a significant improvement as compared to the radar applications for monitoring bird migration used during the PSO programme. This is particularly so because of the 24 hrs coverage, the unbiased (raw) radar data and statistical estimations of the probability for different species groups based on links between radar and visual observations.

7   CONCLUSION

The application of fixed radar installations at Horns Rev 2 (foundation), the Horns Rev 1 Transformer Station and Blåvands Huk in combination with visual calibration observations has resulted in a vastly increased database on bird migration along the Horns

Rev area. The collected data are sufficient to establish a baseline for the autumn season. The data document the width of the migration corridor with high flight intensities of most bird species as approximately 10 km, stretching from the coast to the western side of Slugen. The migration intensities from the eastern corridor to the North Sea display a pronounced decreasing trend, with slightly higher flight intensities recorded east than west of the planned HR2 OWF. The data collected provide further supportive documentation of avoidance response from HR1 OWF across a wide range of species. The effect has a local scale, and cause significant reductions in flight intensities within 1.5 km distance from the wind farm. The effect of avoidance at HR2 OWF is likely to be unrelated to the avoidance effect at HR1 OWF, but at a similar scale, and will most likely affect the migration of lower numbers of birds than the HR1 OWF.

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