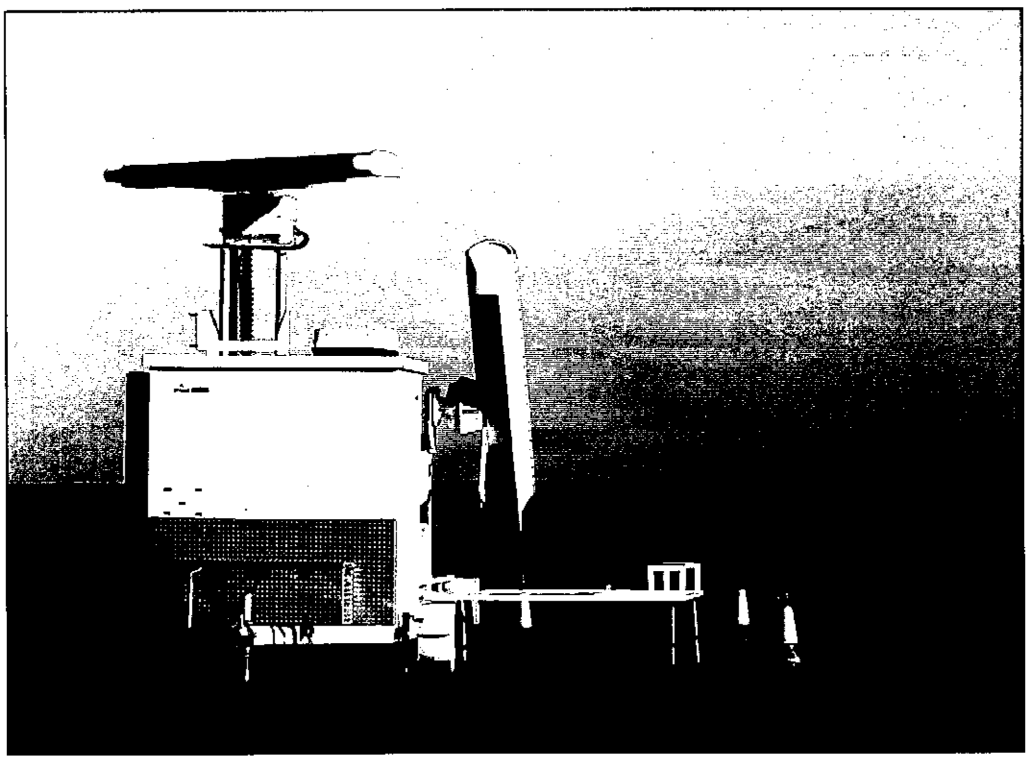
The remote monitoring of offshore avian movement using bird detection radar at Spurn Head, East Yorkshire.

Commissioned by Humber Wind Ltd.



Walls, R.J., Brown, M.B., Budgey, R., Parnell, M. & Thorpe, L.

Bird Management Unit
Central Science Laboratory (CSL)
Sand Hutton
York
YO41 1LZ

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1. Summary

- The Central Science Laboratory (CSL) Bird Detection Radar was commissioned by Humber Wind Limited to undertake a four-day monitoring exercise during 26.10.2004-29.10.2004 October 2004 into offshore avian flight activity in the vicinity of the proposed Humber Wind Farm (HWF).

- The radar successfully detected all birds at ranges in excess of 4km, but detection beyond 6km was less reliable. This means that the radar would need to be positioned on an offshore platform to fully monitor the proposed wind farm area.

- The radar detected bird migration patterns, including a night-time arrival of migrants on 27th October that would not have been detected by other methods.

- Changing weather conditions appeared to be associated with the migration event, but more data are needed to explore this phenomenon more fully.

- The radar provided accurate measurements of the altitude of birds moving through the study area, including migrants arriving at night. Altitudes measured are for birds within 1.4km of the radar. It is not possible to determine the altitude of birds passing through the actual wind farm area without an offshore deployment of the radar.

- The majority of birds were detected at altitudes of below 20m ASL but some were recorded as high as 3000m

- Bird altitudes changed during the arrival of nocturnal migrants when altitudes of 100-200m ASL became more frequent.

- Shore based observations provided valuable information on the species and flock sizes present. These observations, and those from boat based surveys are important to the interpretation of data gathered by radar and should be regarded as complimentary techniques in a comprehensive survey programme.

2. Introduction

Bird detection radar allows the remote monitoring of avian flight activity over greater temporal and spatial scales than the human observer is able to conduct. The radar unit gathers and records bird movement data continuously and during periods of bad visibility due to weather and darkness over an area covering tens of kilometres. For these reasons it provides a valuable technique with which to monitor and assess avian movement through a specific area of seascape. It is the quantity, continuity and objectivity of data gathering that makes radar remote sensing an ideal technique for ornithological assessment of large areas offshore.

2.1 Aims

- To provide a radar assessment of bird flight activity and direction within radar range from the coast out towards the Humber Wind Farm site.
- To describe the bird movement in relation to weather conditions.
- To evaluate the radar's ability to detect birds at night at this location
- To evaluate the radar's ability to detect falls of arriving migrants
- To compare boat-based and shore based observations with radar.

2.2 Study site

The radar unit was sited at a slightly elevated point in Clubley's field close to the sea-watching hide behind Spurn Bird Observatory on Spurn Head (GR: TA 41841 15526). This position on Spurn Head was chosen as it provided the best available propagation of the radar signal out across the seascape over approximately 180° from the North through East to the South. This gave best chance possible from a land-based location of detecting bird movement out at sea towards the proposed HWF. The radar was sited in the same location throughout the 84hrs of monitoring.

3. Methodology

3.1 Bird Detection Radar Unit

The CSL Bird Detection Radar System utilises two Furuno Marine radars. An S-Band surveillance antenna (FR-2135S-B) detects birds in the horizontal plane, and an X-Band (FR-2125-B) is mounted in the vertical plane (Figure 1). The S-Band radar has a 10 cm wavelength, with a peak pulse power of 30 kW, a pulse width of 0.3 μs, beam width of 25° in the vertical plane and 2.5° in the horizontal plane. The antenna head is positioned at a height of approximately 4 m above the ground. The X-Band radar has a 3 cm wavelength, with a peak pulse power of 25 kW, a pulse width of 0.07 μs, beam width of 20° in the vertical plane and 0.9° in the horizontal plane. The antenna head is positioned at a height of approximately 2 m above the ground.

The S-Band surveillance radar covers a circular area with a radius of 11.1 km (6 nautical miles) and the X-Band altitudinal radar measures target altitude over a distance of 1.4km either side of the radar unit. These ranges are thought to be the upper limits of this equipment in tracking bird movements and are based upon the known radar performance characteristics and the radar cross-sections of individual birds (Eastwood, 1967; Rinehart, 1996). Actual performance may vary from this depending on the altitude, distance and size of birds involved and on atmospheric conditions. Both antennae detect radar returns that are generated by birds, permanent landscape features ("clutter") and by randomly generated returns ("noise"). These returns are filtered, using specially developed algorithms, which differentiate between bird targets and other returns. Once clutter and other non-bird targets have been removed, the data are scripted to a Microsoft Access database. This process runs continuously. For every new 24 hr period the software creates a new database.

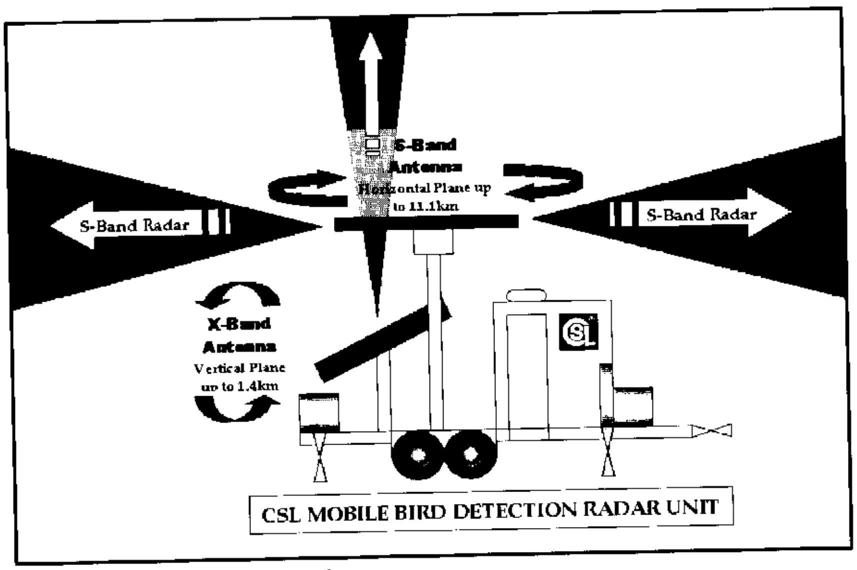


Figure 1. The CSL bird detection radar system

3.2 Data processing

Each database is then used to reconstruct bird movements in ArcGIS. The data are subjected to a number of additional clean up techniques that filter out any noise not removed by the initial radar processing. Following post processing, each bird track is represented as a straight-line vector showing the length of the track and it's bearing. This post processing also allows the data to be presented so that mass bird movements can be interpreted by eye and permits statistical analysis of these movements allowing comparison of changes in bird density and movement in time and space.

3.3 Ornithological field observations

In addition to the radar, both land-based observations (sea-watching) and ship-based observations were conducted to further sample the bird movements within the study area.

3.3.1 Sea watching

Sea watching was conducted by CSL ornithologists from TF 57180-64627 a point on the beach close to the radar looking out along a bearing of 087° (see Fig. 2). The optical equipment used was Swarovski 10x42 SLC Binoculars and a tripod mounted Kowa telescope TSN823M with 20-60x-zoom eyepiece. One individual carried out sea watching while a second noted the observations on field sheets to enable unhindered recording by the dedicated observer. During the 4 day period approximately 18 hours of sea watching observations were conducted leading to the observation of 440 flocks comprised of 3997 individuals.

3.3.2 Boat-based observations

The Institute of Estuarine & Coastal Studies (IECS) conducted boat-based observations. The boat based surveys were undertaken on the 26th and 29th of October 2004. The boat was anchored at a distance of approximately 6 kilometres from the coast at the following location (Ship position WGS 84 Longitude 0 Degrees 13.9384 Minutes East and Latitude 53 Degrees 37.5107 North) (see Fig. 2).

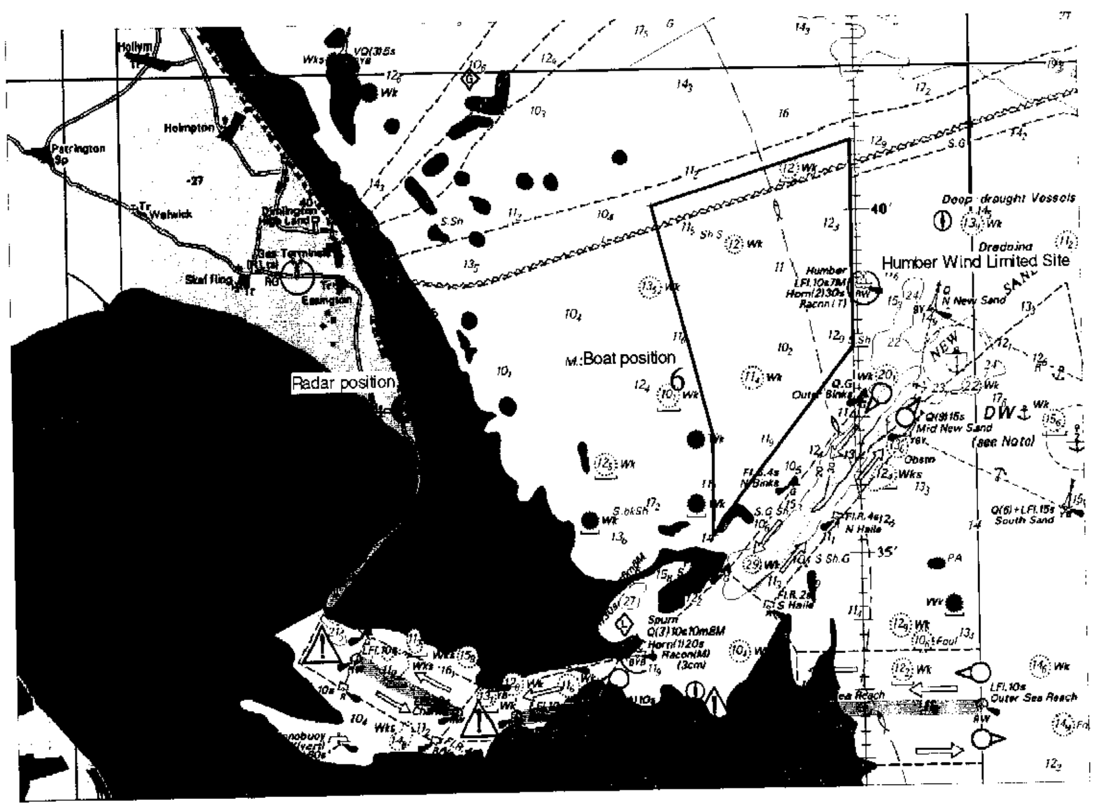


Figure 2. Map of the study site showing windfarm area, radar and boat locations

3.3.3 Weather conditions

Weather conditions during the study period were recorded for the radar location by the 10m met mast situated at Spurn Point. The variables presented in this study are wind direction (bearing), wind speed (ms^{-1}) (Figure 3) and temperature (°C) (Figure 10. in Appendix). These were sampled once every 10mins (144 per 24hrs).

In addition, Table 3 in the appendix illustrates the hours during which rainfall occurred and the radar's ability to function to its full capacity was compromised. Over the four-day period it was dry for 77.5% of the 84hrs and precipitation was detected in 22.5% (18hrs) of the time the radar unit was operational. Precipitation was evident on the 27th, 28th and 29th October. Precipitation only affects the S-Band radar system if the raindrop intensity is that of consistently heavy rainfall. Persistent heavy rainfall with densely packed reflective water droplets masks the ability of the radar to effectively detect and track birds. If the rainfall is patchy, the radar will continue to track bird targets wherever it is able to detect them, but will be blinded by the rainfall in other sectors of its scan. Weather conditions are crucial in determining the scale and timing of both seabird movement and autumn migration from across Scandinavia, Europe and the North Sea (Elkins, 1983 Gaston, 2004). Meteorological information is therefore essential to the interpretation of bird movements detected by the radar unit.

4. Results

4.1 Bird movement detected by radar

Over the four-day period, the radar detected and logged 21306 bird tracks (excluding those present within the Humber estuary). The number of tracks recorded per day ranged from 1721 to 7994. All tracks recorded are shown in the accompanying maps, which are presented in a separate appendix.

The data show clear differences between days both in the quantity and the direction of bird tracks recorded. The largest quantity of bird activity occurred on 27th, when a large nocturnal arrival of migrants occurred. Fig. 3 shows the variation in the number of bird tracks detected per hour by the radar over the 4 days of observation, and fig. 6 shows the total number of tracks detected per hour throughout the study. On 26th October the movement intensity was moderate with between 200 and 400 tracks per hour being recorded, and no particular pattern to the levels of activity. "7th October saw a marked increase in activity with two pronounced peaks at 04:00 and 11:00 hours when a maximum of around 1300 tracks per hour was recorded. Outside this period, however, activity on 27th was the lowest observed during the study with less than 50 tracks per hour recorded between 13:00and 23:00. 28th October saw consistently low levels of activity throughout the day, whilst 29th produced a similar, but smaller, nocturnal activity peak to the 27th. (see figs 3 and 4). It is important to note that rainfall on 27th 28th and 29th (see table 3 in the appendix) may have reduced the ability of the radar to detect birds.

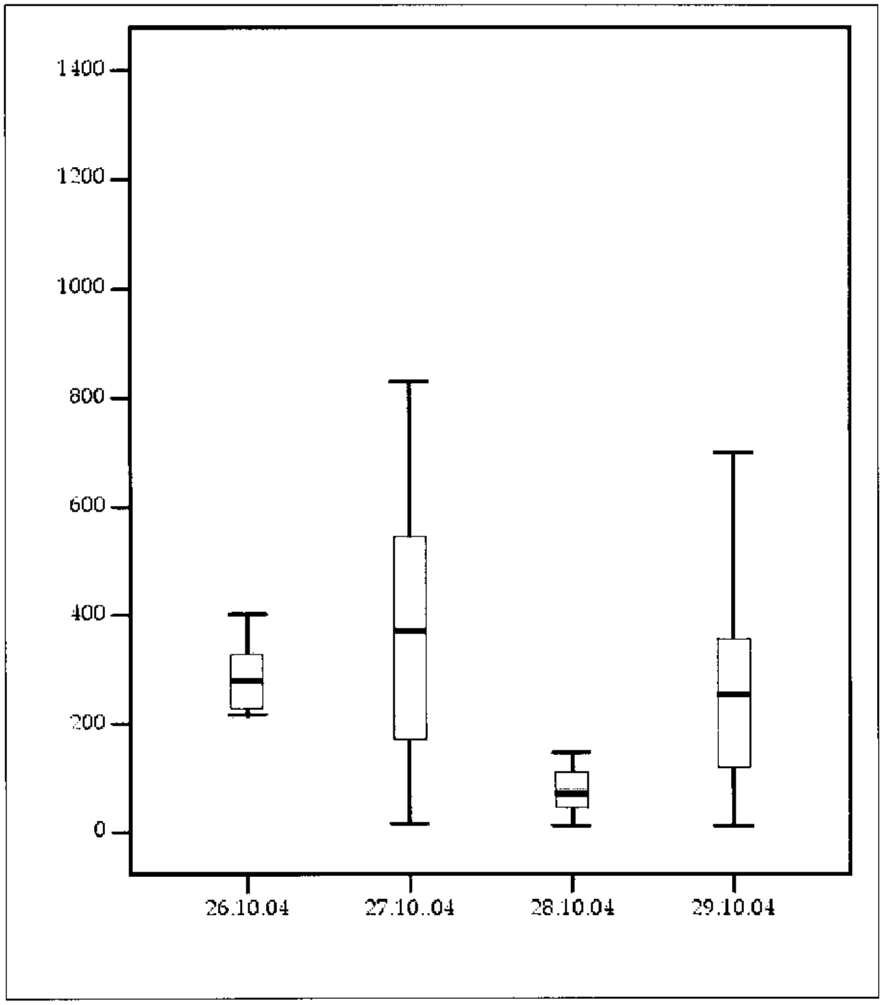


Figure 3. Mean number of bird tracks detected per hour on each of the four study days by S-Band radar, solid box refers to 50% confidence intervals (CI) and error bars refer to 95% CI.

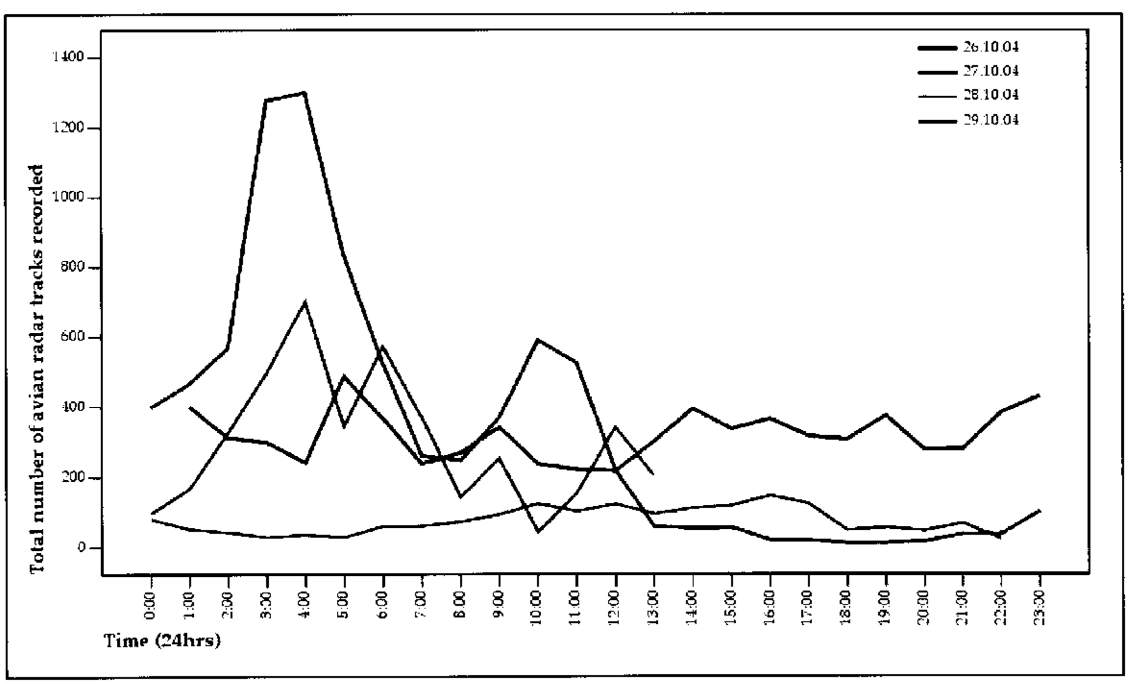
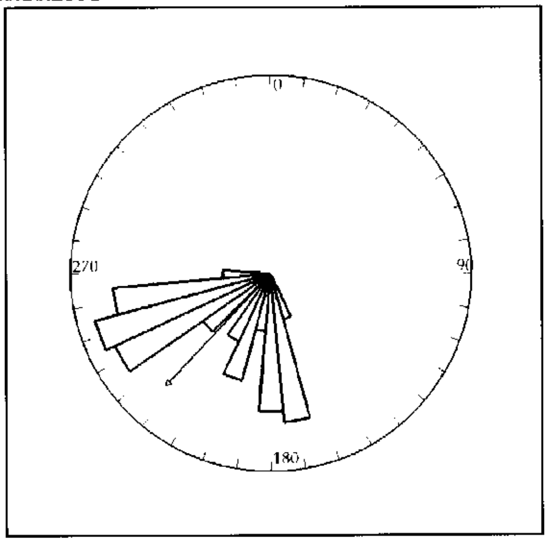


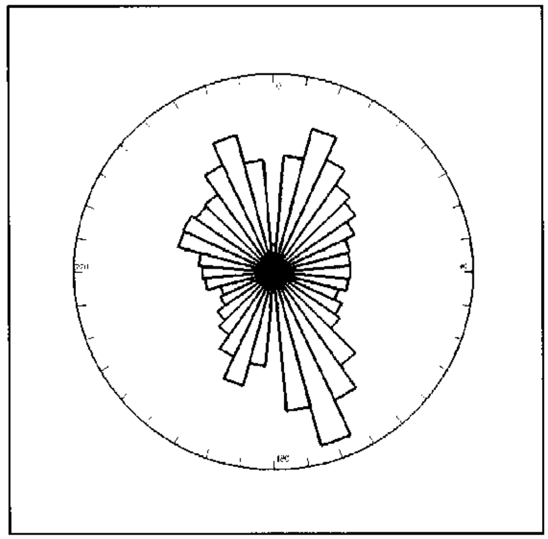
Figure 4. Total number of bird tracks detected per hour by S-Band radar during 26-29.10.2004.

The daily differences in bird activity levels are closely associated with changes in the weather during the study. Figs 5 and 6 show the wind direction and strength in relation to the track direction of birds in the study area. The predominantly SW wind on 26th was associated with birds moving on a NW-SE bearing i.e. parallel to the coast. On 27th the wind changed to a predominantly SE bearing and birds began to arrive from the continent on a westerly heading. The wind remained in the SE for the remainder of the study although the strength was reduced. Birds continued to arrive from the east on 28th but there was an increasing northward movement on 29th.

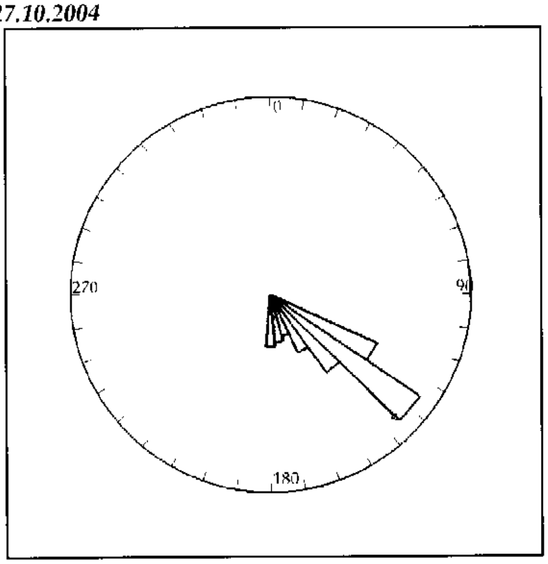
Wind Direction
26.10.2004



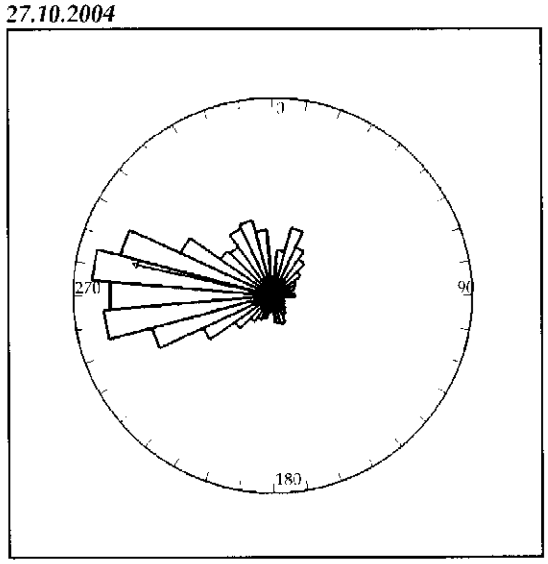
Bird Heading
26.10.2004



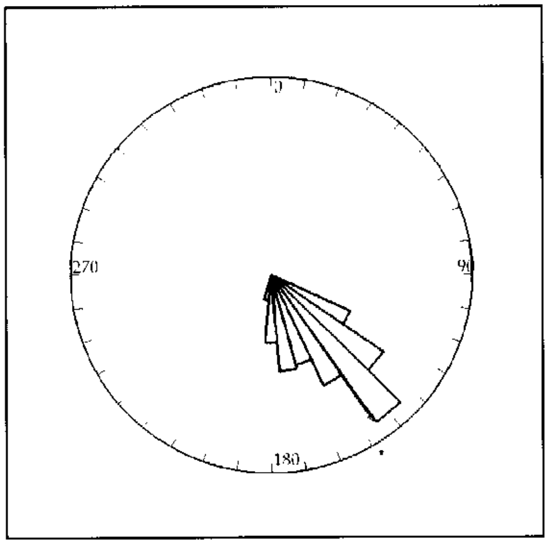
Wind Direction
27.10.2004



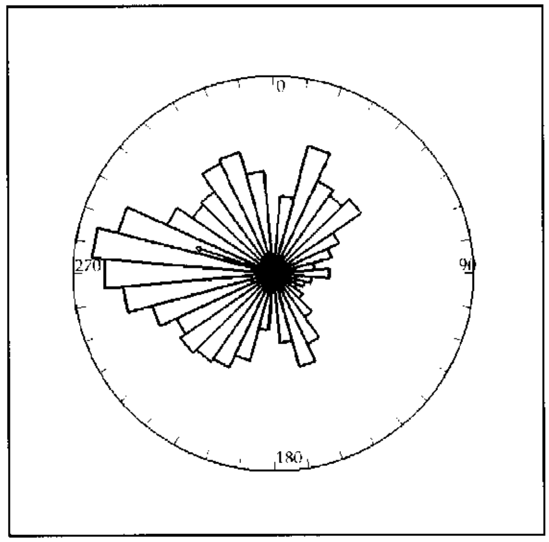
Bird Heading
27.10.2004



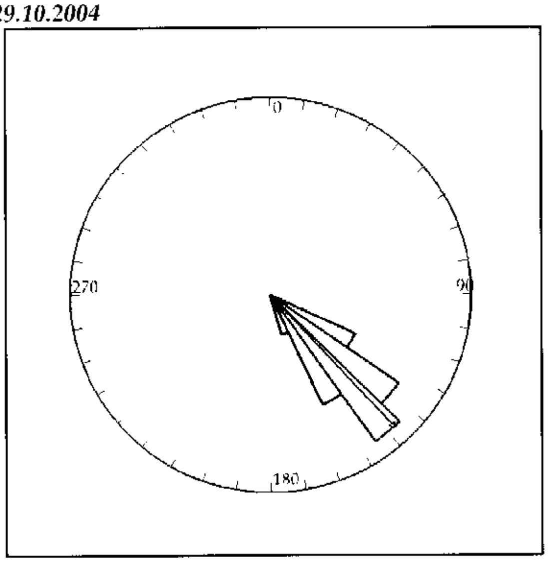
Wind Direction
28.10.2004



Bird Heading
28.10.2004



Wind Direction
29.10.2004



Bird Heading
29.10.2004

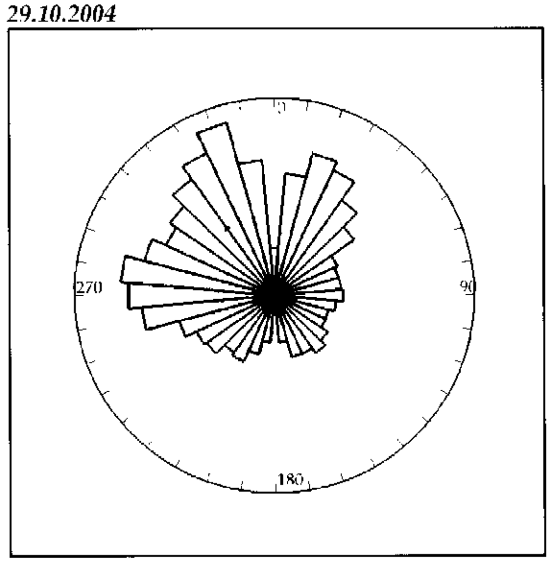


Figure 5. *The circular plots for each day indicating the daily wind direction and bird headings.* ***nb*** *Wind directions are shown conventionally and indicate the direction from which the wind was blowing. Bird headings show the direction in which the birds were flying. Each wind plot represents the direction from which the wind was blowing sampled every 10mins over 24hrs totalling 144 samples. The faint red arrow indicates the average wind direction. Values for both wind directions and bird headings are daily proportions.*

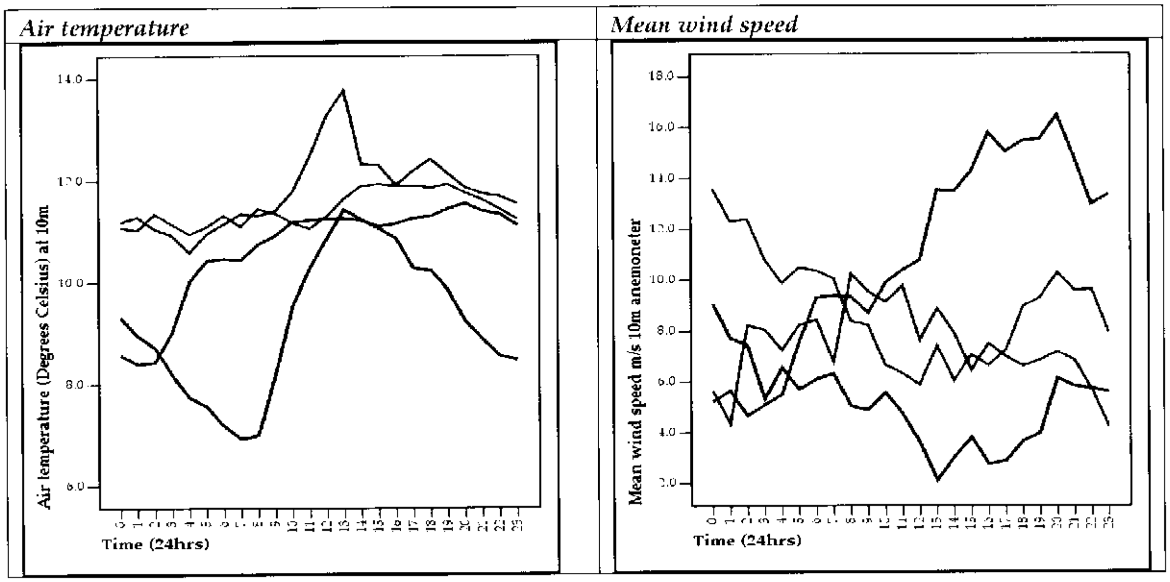


Figure 6. Mean temperatures at 10m agl and mean wind strength ms^{-1} as recorded by data loggers at the 10m anemometer every 10 minutes from 00:00-23:50. ***Black line = 26.10.2004, Red line = 27.10.2004,*** *Green line =* ***28.10.2004, Blue line = 29.10.2004.***

4.2 Activity beyond 6km offshore

During this study, bird targets were detected up to distances of 11km, but the majority of movement was recorded at less than 7km. The highest densities of tracks are always detected close to the radar due to its peak detection capability being approximately 1km away from the unit. The radar's physical properties mean that the signal strength returned by a target decreases with increasing distance. Smaller targets also reflect less energy than larger ones. It is therefore less likely to detect smaller targets at increasing distances. The targets recorded beyond 7km are likely to be either individuals of large bird species or flocks of smaller birds. It is best to take a precautionary view of the number of tracks detected at the high end of the radar range at >7km. Tracks detected at this distance do not constitute all of the bird movements occurring (as is shown by reference to the boat based observations below). They are likely to only represent the largest individuals and flocks, which make be only a small percentage of total bird activity at this distance offshore. Figure 7 illustrates this point. The boat based observations recorded significantly more bird flocks than the radar detected at distances beyond 6km. Figure 8, however, shows that on the following day, during the migration event that occurred on 27th, the radar detected far more tracks at distances over 6km. This may be because there were simply more birds present or that birds were larger, in larger flocks or at higher altitude, any or all of which would have made the birds more visible to the radar at long distances. Unfortunately there were no boat-based observations on 27th so it is impossible to determine which of these factors was most important.

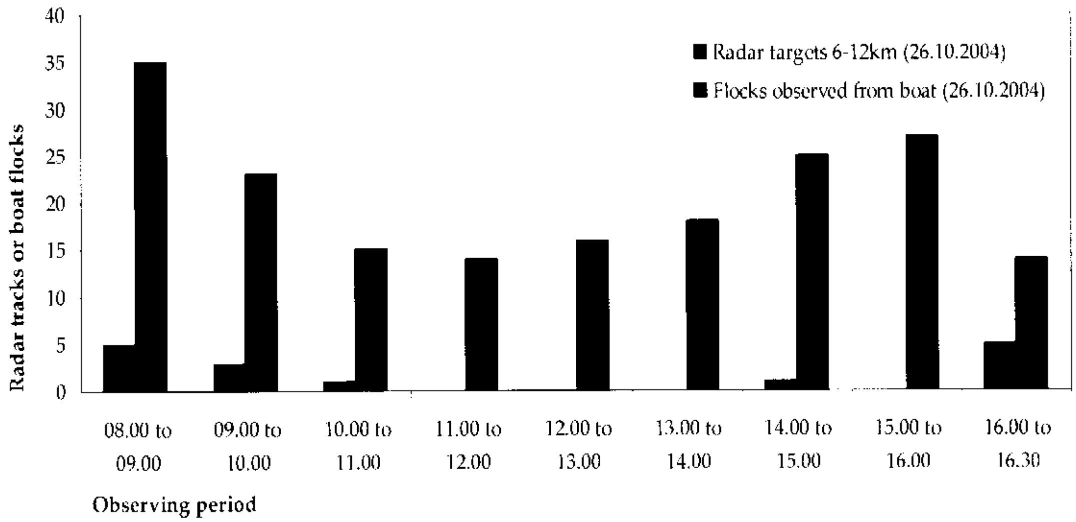


Figure 7. Radar tracks detected between 6km and 12km and flocks observed by boat-based observers on 26.10.2004 .

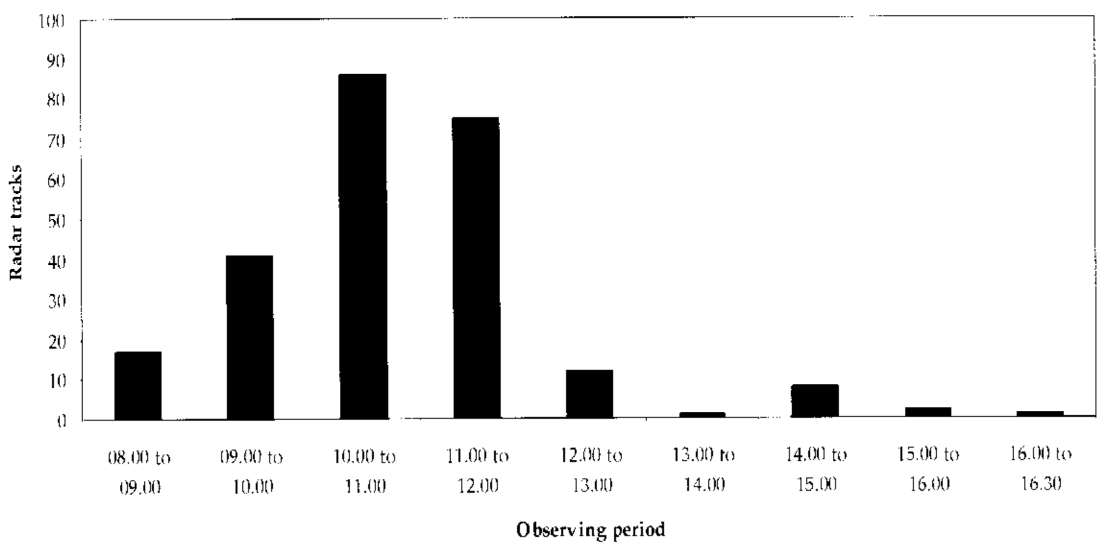


Figure 8. Radar tracks detected between 6km and 12km and flocks on 27.10.2004

Overall, during the four-day monitoring period, 253 bird tracks were detected between 6 – 8km offshore. This constitutes just 1.2% of the total tracks detected by the radar. The numbers detected varied according to study date, with 83.4% of detections at this range occurring on the 27th October. Within the 27th October, there was also a clumped pattern whereby 70% of these targets occurred in a 5 hour period (figure 9). 84.9% of the long range tracks were on a W or NW heading.

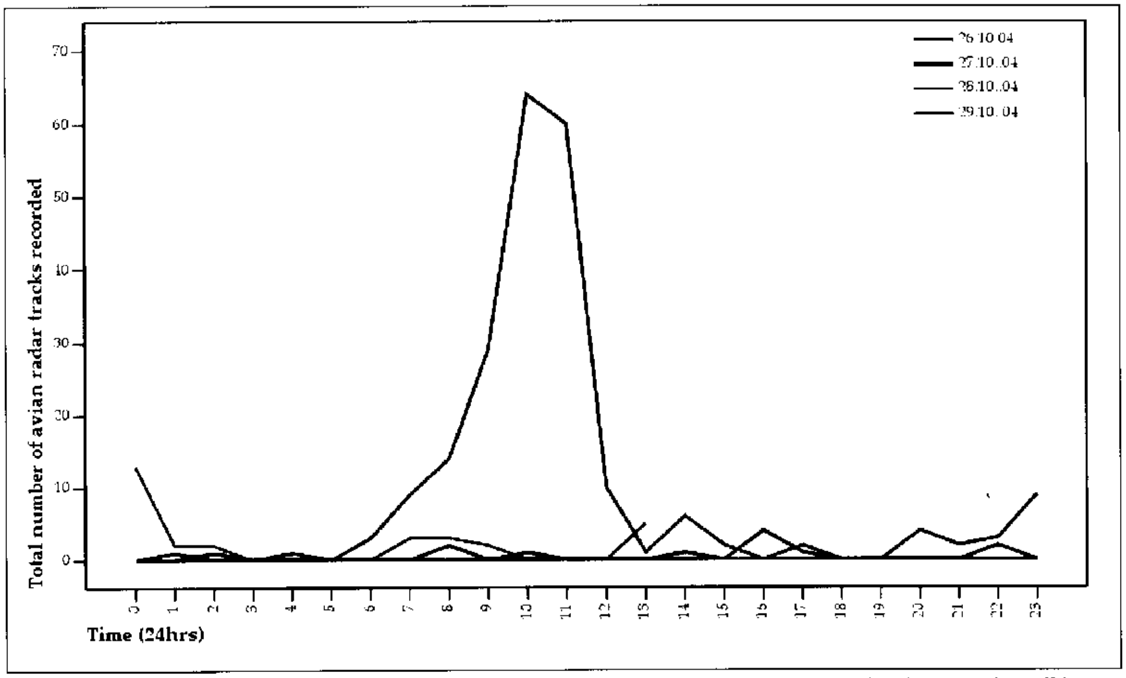


Figure 9. Total number of bird tracks detected per hour during 26-29.10.2004 by S-Band radar at 6-8km offshore.

4.3 Diurnal and nocturnal bird movement

A significant percentage of bird tracks recorded by radar occurred during the night (see table 1 below). However, three out of four days had more tracks detected during the day than the hours of darkness. The total tracks recorded over the 4 days (21306) were split 40.7% (8672) during the daytime and 59.3% (12634) during the night. Night is defined as 19:00-07:00hrs for this time of year in this study. On the 26th and 27th October 52% and 70% of the avian tracks respectively were recorded during the hours of darkness (Table 1). During the night on the 27th October, 68.2% of the tracks recorded were heading in a Westerly direction, whereas other study days experienced no such dominance in one heading. The night of the 27th October was also the most active 12-hour period within the whole study with 26.1% of activity being recorded therein.

[redacted]							
	7388	3538	3850	52	23	321	54
	7994	2428	5566	70	24	333	56
	1721	1206	515	30	23	75	12
	4203	2699	1504	36	14	300	50

Table 1.
Total bird radar tracks split between day and night.

4.4 Bird altitude

The X-Band radar provides information on the flight altitude of birds moving through the beam up to 1.4km out to sea. The X-band radar gathered data throughout the 4-day study. Because the radar was situated 6m above sea level and the radar head is 2m above the ground, targets below 8m above sea level (ASL) will not be detected. Flight altitude categories were constructed between 8-20m, 20.1-50m, 50.1-100m, 100.1-200, 200.1-300m, 300.1-400m, 400.1-500m, 500.1-1000m, 1000.1-1500m, 1500.1-2000m 2000.1-2500m and 2500.1-3000m. The following examples illustrate how the altitude of birds arriving at the coast changes between days as a migration event develops.

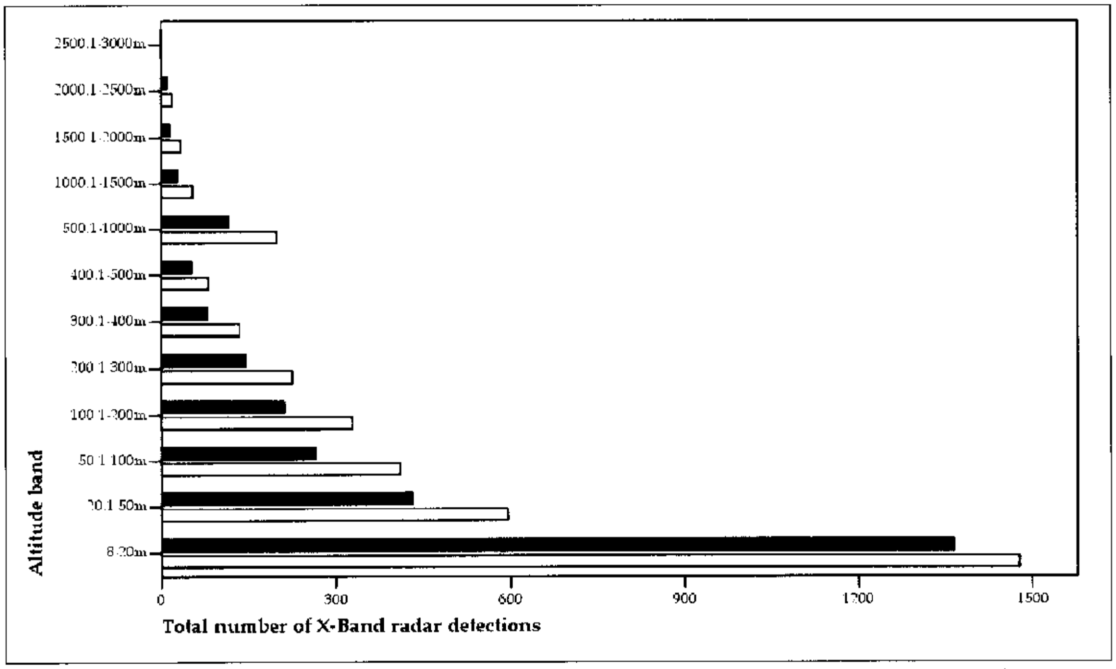


Figure 10. Total number of avian radar tracks detected by X-Band radar at dawn (07:00-09:00) (light grey) and dusk (17:00-19:00) (dark grey) on the 26th October.

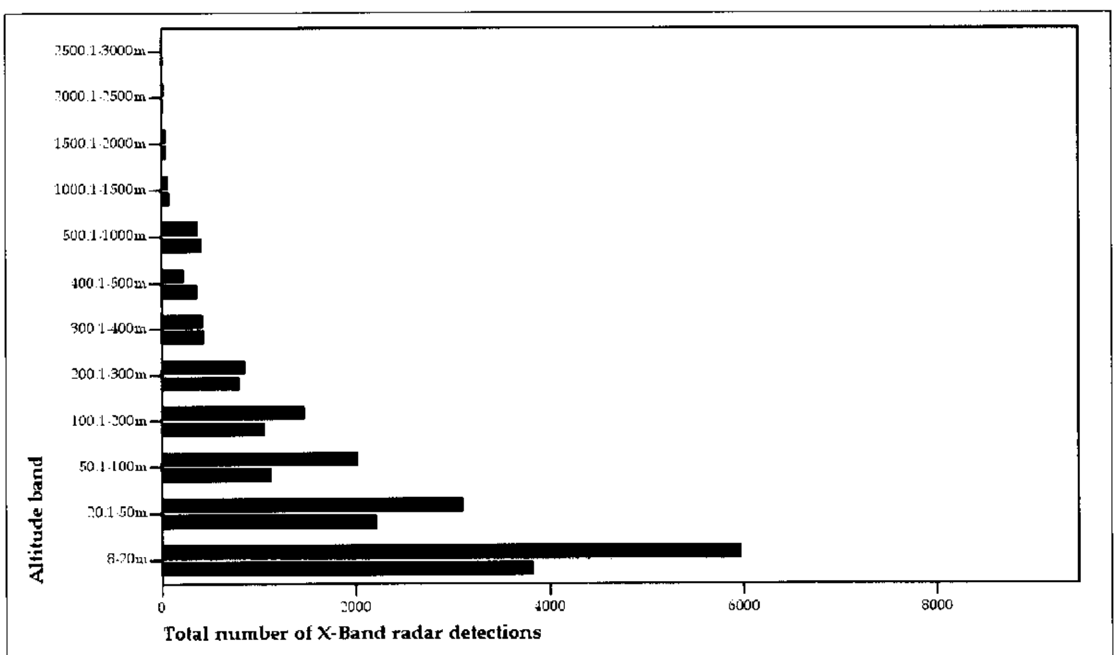


Figure 11. Total number of avian radar tracks detected by X-Band radar at night (01:00-05:00) (black) and during the day (11:00-15:00)(red) on the 26th October.

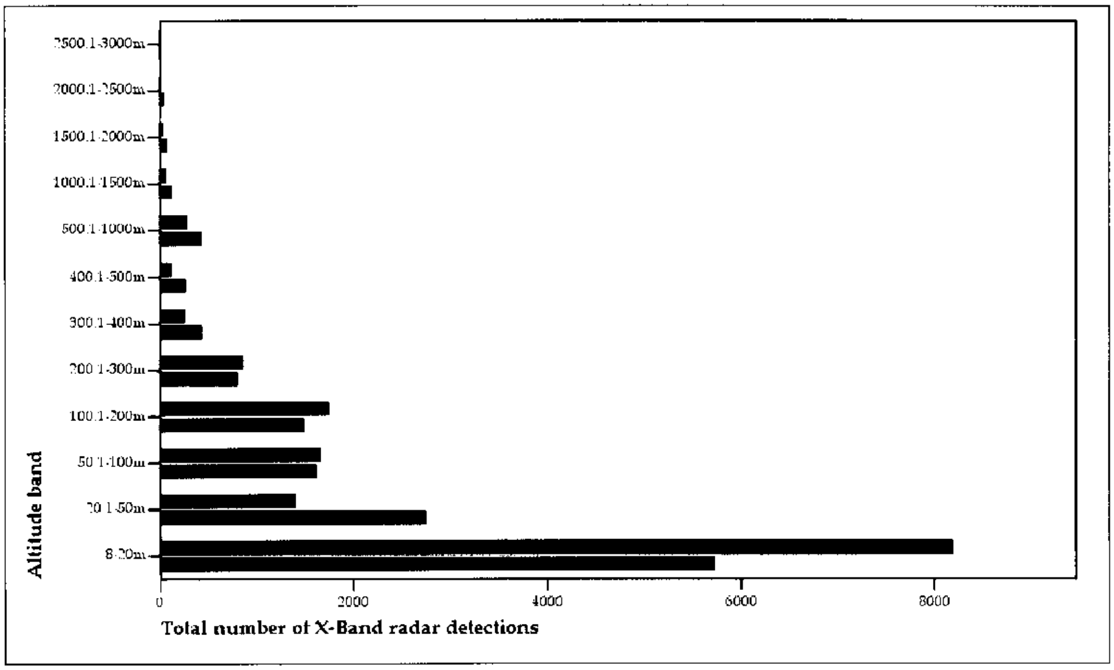


Figure 12. Total number of avian radar tracks detected by X-Band radar at night (01:00-05:00) (black) and during the day (11:00-15:00)(red) on the 27th October.

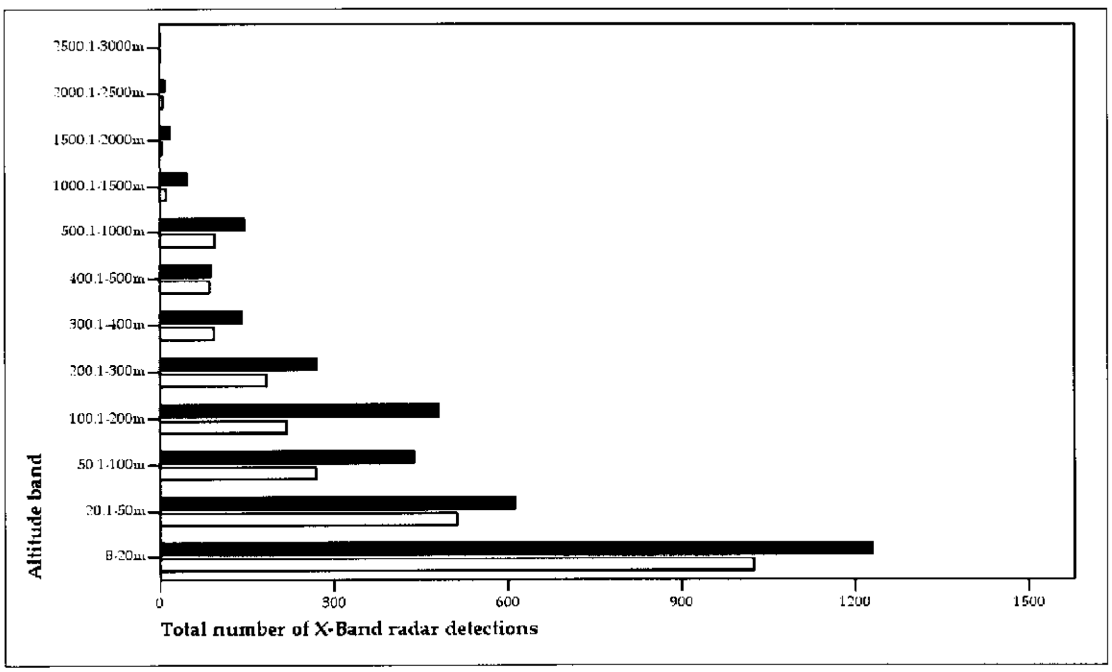


Figure 13. Total number of avian radar tracks detected by X-Band radar at 03:00-04:00on the 26th October (light grey) and 27th October (dark grey).

Figures 10 and 11 show the altitude of birds on 26th October. Whatever the diurnal period, day, night, dawn or dusk, the pattern is broadly the same with peak numbers between 8-20m asl. This reflects the altitude of the majority of gulls, sea-duck etc passing through the study area. On 27th October (Fig.12) a secondary peak in bird targets occurs in the 100-200m altitude band at night reflecting the migratory arrival. The difference in altitude of targets at night between days with and without nocturnal migration is especially apparent if the 03:00 to 04:00 time period is compared for 26th and 27th October (Fig. 13). The shift of the distribution to higher altitudes on 27^{th} can clearly be seen and the timing and direction of the movements (see Fig. 5) strongly suggest that the radar has detected a nocturnal arrival of migrating birds. The data also show a slight peak in numbers between 500 and 1000m ASL. Visual observations suggest that these may have been flocks of migrating Pink-footed Geese, but smaller species migrating at these altitudes would be undetectable by eye and so these data need to be interpreted with care.

4.5 Sea watching observations

Sea watching observations were conducted for approximately 18hrs over the 4-day period and ranged from 27mins – 1hr 57mins of observation, during which 3997 birds were identified, predominantly to species level. The success of observations was dependent on the weather conditions, visibility and species involved. Under the best light and weather conditions accurate observations of large gulls, sea-ducks, geese, swans and Gannets could be conducted up to 6km. Observations were only recorded where identification could be positively and confidently made. In addition, birds were assigned to species groups such as Auk sp or duck sp when identification to species was not possible.

During the 4-day period bird movement was predominantly in a southerly direction. This is as was to be expected because there are daily commuting flights associated with the tidal system at the Humber estuary. Corresponding northward movements are not as high as southward movements (Mann-Whitney U-test: U= 62.0; P=0.004), suggesting that there may also have been southward migration occurring along the coast. Approximately 80% of visually observed targets were moving in a southerly direction and only 11% Northerly. During the radar study, 52 bird species were observed. These are documented in Table 3 and 4 of the Appendix, including information on headings.

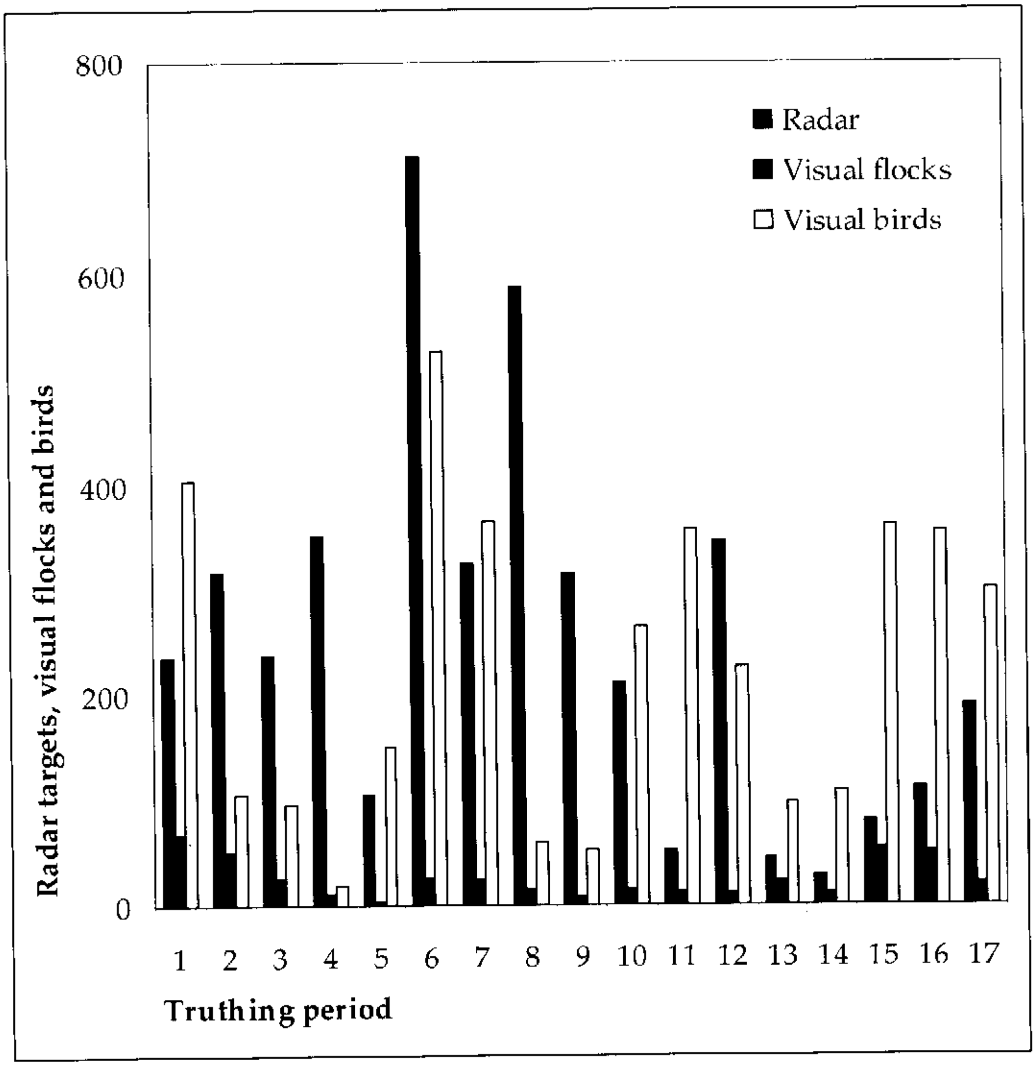


Figure 14. Total numbers of flocks and birds detected by visual observation and radar tracks detected during the same periods (See appendix 1, table 1; for dates and times of truthing periods)

The number of flocks seen by visual observation is consistently lower than the number of bird tracks detected by the radar. However, the number of individual birds seen by visual observation exceeded the number of radar tracks in 10 of the 17 observation periods. This situation occurs because the radar is unable to separate individual birds in very closely spaced flocks and will thus under count the number of individual birds in situations where large flocks of closely spaced birds are present. This occurred when flocks of sea duck and geese were present (see sections 4.5.1 and 4.5.2 below).

Visual verification of radar data provided valuable information on species composition that permitted more accurate inferences to be made about the daily commuting and migratory movements of the birds in the area. These observations may be biased by the proximity of birds moving close to the shore, which makes them easy to see and count. Therefore it might be expected that higher north and south movements would be recorded in visual observations at this location compared to the radar. There was, however, no significant difference between the proportions of birds heading in the four compass directions when visual observations were compared to radar (Wilcoxon signed rank test, N = 68, p = 0.590, Z = -.054) (Fig 13 a&b).

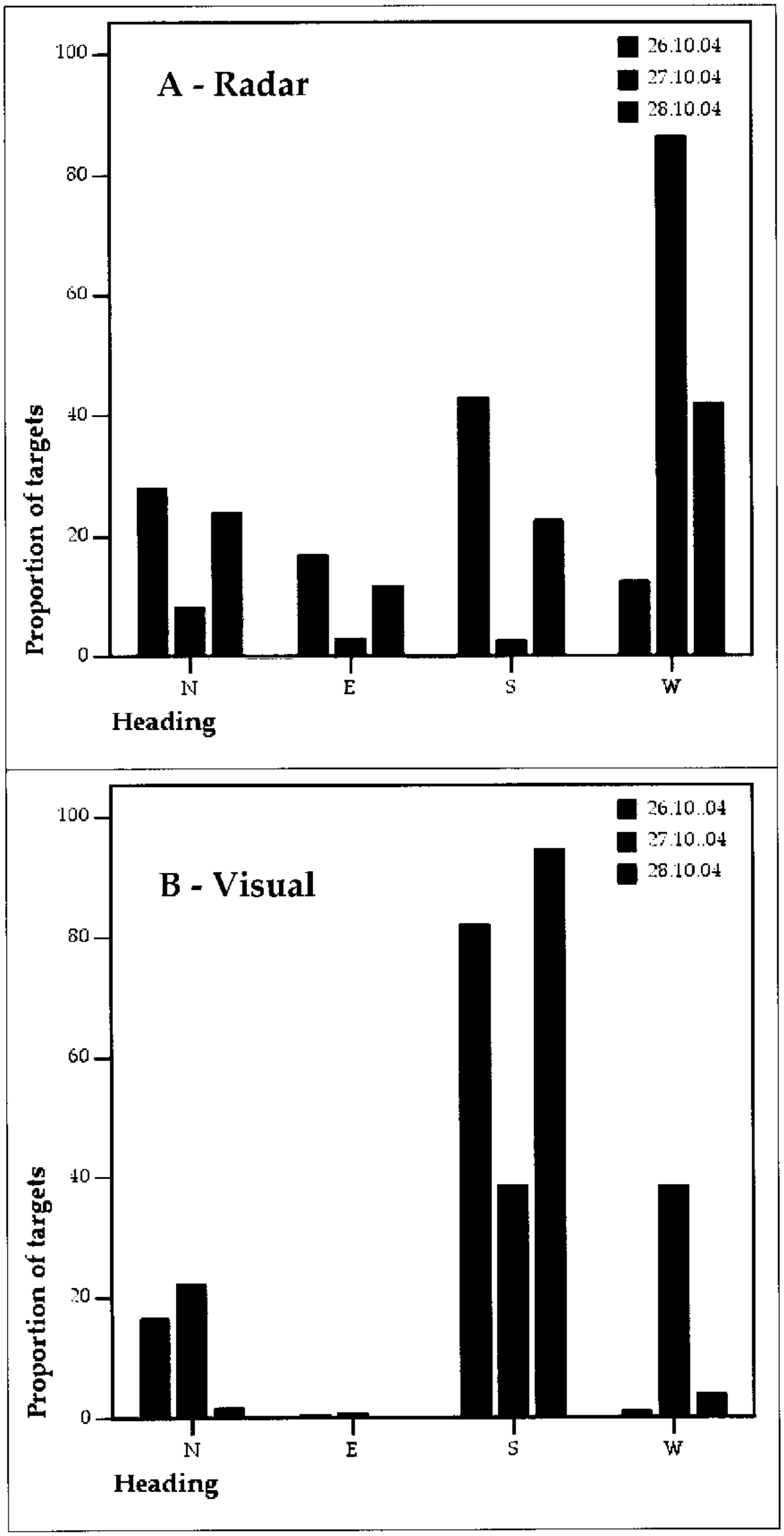


Figure 15. Proportions of avian targets observed by the radar (A) and identified by visual observation (B) heading on the four main cardinal points.

4.5.1 Seabird movement

Three hundred and fifteen Common Scoters, *Melanitta nigra* were observed in 25 flocks with the predominant heading being south (83%) and the remainder north (17%), flocks were seen at a range of 50-4500m and a height of 0-10m. Only four Cormorants, Phalacrocorax carbo were observed during the study with a 50-50 split between north and south. Eider, *Somateria mollissimia* were seen on 5 separate occasions, with a total of 18 individuals at a distance of between 0.2 – 3.5km and height of 1-3m. Fifteen Gannets, *Morus bassanus* were seen, thirteen heading north and two south at a range of 0.5-7.5km and height of 1-15m. Red-throated divers, *Gavia stellata* were recorded seven times at a distance of 150m-6km and height 1-20m, with five south and two north.

Arctic Skuas, *Stercorarius parasiticus* were seen on two occasions, both on the 27th October heading south. Only one Puffin, *Fratercula arctica* and two Shags, *Phalacrocorax aristotelis* was seen all of which were heading south.

Gulls were the most numerous seabirds observed in the system, with 466 individuals in total of which 90.6% were recorded as heading south. All of the Black-headed Gulls, *Larus ridibunus* were heading south at a distance of 50-750m offshore and 3-30m high on the 26th and 27th October only. Common Gulls, *Larus canus* were observed on ninety-three occasions all of which took place on the 26th October at distances of between 0.0-5.5km and altitudes of 60m. Twenty-six Great Black-backed Gulls, *Larus marinus* were observed at distances of 15-3500m with twenty-five heading south and one north. Herring Gulls, *Larus argentatus* were seen with seventy-four heading south and one north with 96.7% occurring on the 26th October at a distance of up to 1km and height of 100m.

4.5.2 Waterfowl species

The most abundant species were the Pink-footed Geese, *Anser brachyrhynchus* with a total of 610 individuals observed in only eight flocks, ranging from 27-185 individuals at a distance of 0.7-6km offshore. These movements took place on the 26th October, with 95% occurring between 15:00 –18:00. They were recorded flying at an altitude of 2-500m and all were heading south. The trend in activity amongst geese and swans in the system was for southward movement. Only Brent Goose, *Branta bernicla* did not have all individuals heading south, with twenty-four heading south and eight north at a distance of 50-500m and altitude of 1-60m. Canada Geese, *Branta canadensis* and Goosander, *Mergus merganser* were seen on two and three occasions respectively. Whooper Swan, *Cygnus Cygnus* was observed on 22 occasions in four flocks at a distance of 0-200m and a height of 2-30m.

Thirty-three Goldeneye, *Bucephala clangula* were seen moving south at a range of 0.2-3km and a height of 1-5m, with a mean flock size of 3. Forty-nine Mallard, *Anas platyrhynchos* were seen heading south in flock sizes ranging from 1-38, distances of 0-400m and heights between 1-20m. Eleven Shoveler, *Anas clypeata* were observed on the 28th October heading south on five separate occasions at a arrange of 250-300m.

Three hundred and thirty one Teal, *Anas crecca* were observed in 32 flocks of which 87% occurred on the 28th October, in flock sizes ranging from 1-40, distance of 100-450m and heights of between 1-50m. Four hundred and sixty-five Wigeon, *Anas Penelope* were seen, all of which were heading south with 95% occurring on the 28th October, at distances of between 15-1000m and heights of 1-100m and represented the second most frequently recorded species in the study area.

4.5.3 Passerine species

The headings of passerine species differ significantly from those observed in the other groupings because they contain numerous records of Westward flights. Altogether 12 passerine species were identified and they came to a total of 1049 individuals, of which a full list can be seen in Section 7 Table 4. Eighty-four Fieldfare, *Turdus pilaris* were observed on the 27th October at a distance of 0-500m approaching on a westerly heading. One hundred and one Meadow pipits, *Anthus pratensis* were recorded on the 27th and 28th October between 07:30-08:30 at distances of between 6-100m and altitudes of 15-50m. Redwing, *Turdus iliacus* migration was observed on the 27th and 28th October between 11:00-15:00 where thirty-nine birds were observed heading west and one north. One hundred and eighty-one Starlings, *Sturnus vulgaris* were observed heading south of which 92.3% occurred on the 27th and the remainder on the 28th October. In addition to this five hundred and thirty Thrushes, not to species level, were identified predominantly on the 27th October of which 93.8% were heading west.

4.5.4 Wader species

Bar-tailed godwit, *Limosa lapponica*; Curlew, *Numenius arquata*, Dunlin, *Calidris alpina*; Knot, *Calidris canutus*; Lapwing, *Vanellus vanellus*; Redshank, *Tringa tetanus*; Ringed plover, *Charadrius hiaticula* and Turnstone, *Arenaria interpes* were detected through visual observation. The most abundant wader species, based on observations was the Dunlin which were all recorded on the 27th October at a distance of 0-50m and height of 1-50m, the Dunlin showed the greatest variability in flight heading of all wader species with birds identified heading north (90), south (116) and west (19). Knot were also observed in significant numbers (51), on the 27th October. One hundred and twenty-one Redshank were seen on the 26th October with 99% observed heading west.

5. Discussion

This short term radar deployment was designed to investigate whether bird detection radar is capable of determining relationships between weather and bird movements in the Humber Estuary and to investigate the capability of radar to detect bird movements, and especially 'falls' of migrant birds during the hours of darkness.

Because of the limited period of the radar deployment, there was little opportunity to evaluate the effects of weather on bird migration. The change in wind direction between 26th and 27th October, when the SW wind backed to SE and increased in strength from 6 to 16 kts, did coincide with an arrival of migrating birds from the east, presumably from continental Europe, and visual observations during daylight suggested that these may have been thrush species and/or Starlings. More observations at different times of year and different weather conditions would be needed to produce a comprehensive analysis of this phenomenon.

The radar was able to detect arrivals of migrating birds at night and could clearly differentiate differing levels of migratory activity. Because of the very short period of radar deployment it is unclear whether the migration event detected on 27th October represents a routine nocturnal arrival of birds or a 'fall'. A longer period of radar surveys would be needed to obtain an estimate in the variability in the size and timing of migratory bird arrivals in the Humber Estuary area at night.

The majority of bird tracks were at altitudes below 20m ASL, which reflects the movements of seabirds, waterfowl etc. close to the water surface. During migratory arrivals there was a secondary peak in bird targets between 100 and 200mASL, which occurred principally at night. Without the use of radar this would have been impossible to record. It is important to note that the altitude records reflect birds within 1.4km of the radar unit. It is not possible to determine at what altitude birds passed through the wind farm area. For example, birds on nocturnal migration across the North Sea may begin to lose height as soon as they detect the coast, and may have passed through the wind farm area at a higher altitude than that detected by the radar. Deployment of the radar offshore would be the only way to obtain accurate altitude measurements of bird altitudes.

The radar detected broadly similar numbers of targets to the total number of birds seen by human observers during sea watching periods. The majority of birds detected by sea watching were single birds, which would be recorded by the radar as a single target. Some of the larger flocks detected by the sea watchers, of up to 200 birds are unlikely to register as 200 separate radar targets, as more than one individual bird in the same radar range bin will be recorded as a single target on the database. It is therefore likely that the radar under-records the numbers of birds in large flocks, but detects more flocks, especially at higher altitudes, thus arriving at a similar number of individual targets. The radar is thus likely to under-record bird numbers in cases where there are small numbers of large flocks present, but will out-perform human observers when large numbers of small flocks or single birds occur, especially at high altitude or in poor visibility when visual detection proves difficult. The radar should be seen as a complimentary technique for day-time observations, because human observers are able to add information on species composition and flock size that the radar cannot determine.

The boat-based observers detected more individual birds and flocks than the radar. This is unsurprising as the 6km range at which the boat transect was conducted is beyond the limit of the radar's ability to detect smaller bird species reliably. Interestingly, on 27th October, the radar detected far more targets at ranges in excess of 6km than it did on 26th. This may simply be because the migration event in progress meant that there were more birds present, but it was also the case that the birds were moving at higher altitudes on 27th and this may have made them more detectable to the radar at long distance. Whatever the true situation, it is clear that the radar, although capable of detecting birds at long distances, becomes increasingly less reliable at ranges of over 6km. In order for this equipment to provide comprehensive data collection for the proposed wind farm, locating it on a platform in or close to the wind farm site would be necessary.

6. Conclusion

The data obtained in this study clearly show the utility of radar for assessing bird movements through a potential wind farm area. Because the radar was stationed on the shore, it was not able to detect birds moving through the area of the wind farm with great reliability. However, the effective detection range of the radar means that were it to be situated on a platform in the wind farm area, it could monitor the entire site by day and night for as long as is required, detecting seabird and waterfowl passage and passerine migration. If supported by periodic visual observations to provide species identification and flock size data, bird radar offers objective, continuous, long range monitoring of large areas of seascape, providing accurate positional and altitude data on bird targets passing through the area thus facilitating an accurate assessment of the likely impact of a wind farm development.

7. References

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7. Appendix

Date	Start	End	Duration	N	E	S	W	N	E	S	W
26/10/2004	07:25	08:19	54	10	0	57	2	42	0	240	123
26/10/2004	09:30	10:29	59	3	1	48	0	4	1	100	0
26/10/2004	11:20	12:30	70	4	0	23	0	5	0	92	0
26/10/2004	13:34	14:35	61	6	0	6	0	8	0	10	0
26/10/2004	15:11	15:28	17	0	0	3	0	0	0	151	0
26/10/2004	15:49	17:46	117	8	0	18	0	45	0	482	0
27/10/2004	07:23	08:34	71	11	0	12	2	177	0	169	19
27/10/2004	10:19	11:18	59	4	0	8	3	19	0	28	13
27/10/2004	11:23	12:01	38	0	0	1	6	0	0	2	51
27/10/2004	12:01	12:59	58	0	0	1	14	0	0	2	262
27/10/2004	13:12	14:15	63	1	1	0	12	1	25	0	331
27/10/2004	14:17	15:18	61	2	0	4	5	9	0	93	125
27/10/2004	15:18	16:20	62	4	0	14	5	25	0	61	13
27/10/2004	16:23	18:00	97	5	0	7	0	16	0	94	0
28/10/2004	09:26	10:23	57	1	0	54	0	1	0	361	0
28/10/2004	10:30	11:27	57	1	0	47	3	10	0	339	6
28/10/2004	11:58	13:28	90	0	0	19	2	0	0	279	22

Table 1.
Periods of visual observation and the flight direction of birds observed.

TIME PERIOD	26/10/2004	27/10/2004	28/10/2004	29/10/2004
00:00 - 01:00				
01:00 - 02:00				
02:00 - 03:00				
03:00 - 04:00				
04:00 - 05:00				
05:00 - 06:00				
06:00 - 07:00				
07:00 - 08:00				
08:00 - 09:00				
09:00 - 10:00				
10:00 - 11:00				
11:00 - 12:00				
12:00 - 13:00				
13:00 - 14:00				
14:00 - 15:00				
15:00 - 16:00				
16:00 - 17:00				
17:00 - 18:00				
18:00 - 19:00				
19:00 - 20:00				
20:00 - 21:00				
21:00 - 22:00				
22:00 - 23:00				
23:00 - 00:00				

Table 2.
Table shows the hours of operation of the radar at Spurn over the 4-day period with grey indicating hours where the radar was not scanning and blue-hatched hours during periods when rainfall was detected.

Geese & Swans						
Brent Goose	*Branta bernicla*	BG	8	0	24	0
Canada Goose	*Branta canadensis*	CG	0	0	2	0
Goosander	*Mergus merganser*	GD	0	0	3	0
Pink-footed Goose	*Anser brachyrhynchus*	PG	0	0	610	0
Whooper Swan	*Cygnus cygnus*	WS	0	0	22	0
Swan sp.	~	Swan sp.	0	0	6	0
Waterfowl						
Common Scoter	*Melanitta nigra*	CX	52	0	263	0
Eider	*Somateria mollissima*	E.	1	0	8	0
Goldeneye	*Bucephala clangula*	GN	0	0	33	0
Long-tailed Duck	*Clangula hyemalis*	LN	0	0	1	0
Mallard	*Anas platyrhynchos*	MA	0	0	49	0
Pintail	*Anas acuta*	PT	0	0	6	0
Pochard	*Aythya ferina*	PO	0	0	3	0
Red-breasted Merganser	*Mergus serrator*	RM	0	0	7	0
Shelduck	*Tadorna tadorna*	SU	0	0	9	0
Shoveler	*Anas clypeata*	SV	0	0	11	0
Teal	*Anas crecca*	T.	0	0	331	0
Tufted Duck	*Aythya fuligula*	TU	0	0	7	0
Wigeon	*Anas penelope*	WN	0	0	465	0
Merganser sp.	~	Merganser sp.	0	0	9	0
Duck sp.	~	Duck sp.	13	0	41	0
Wader						
Bar-tailed Godwit	*Limosa lapponica*	BA	0	0	1	0
Curlew	*Numenius arquata*	CU	0	0	4	0
Dunlin	*Calidris alpina*	DN	90	0	116	19
Knot	*Calidris canutus*	KN	50	0	1	0
Lapwing	*Vanellus vanellus*	L.	0	0	10	0
Redshank	*Tringa totanus*	RK	1	0	0	120
Ringed Plover	*Charadrius hiaticula*	RP	5	0	0	0
Turnstone	*Arenaria interpres*	TT	0	0	10	0
Wader sp.	~	Wader sp.	0	0	17	0
Gulls						
Black-headed Gull	*Larus ridibundus*	BH	0	0	38	0
Common Gull	*Larus canus*	CM	6	0	87	0
Great Black-backed Gull	*Larus marinus*	GB	1	0	25	0
Herring Gull	*Larus argentatus*	HG	1	0	74	0
Little Gull	*Larus minutus*	LU	0	0	1	0
Gull sp.	~	Gull sp.	6	1	24	10

Table 3.
Species recorded visual observations undertaken on the 26th, 27th and 28th of October 2005.

Seabirds						
Arctic Skua	*Stercorarius parasiticus*	AC	0	0	2	0
Common Tern	*Sterna hirundo*	CN	0	0	3	0
Cormorant	*Phalacrocorax carbo*	CA	2	0	2	0
Gannet	*Morus bassanus*	GX	13	0	2	0
Puffin	*Fratercula arctica*	PU	0	0	1	0
Red-throated Diver	*Gavia stellata*	RH	2	0	5	0
Shag	*Phalacrocorax aristotelis*	SA	0	0	2	0
Auk sp.	–	Auk sp.	9	0	1	1
Passerine						
Blackbird	*Turdus merula*	B.	0	0	0	1
Brambling	*Fringilla montifringilla*	BL	1	0	0	0
Carrion Crow	*Corvus corone corone*	C.	1	0	6	0
Fieldfare	*Turdus pilaris*	FF	0	0	0	84
Grey Wagtail	*Motacilla cinerea*	GL	34	0	0	0
Meadow Pipit	*Anthus pratensis*	MP	13	0	88	0
Redwing	*Turdus iliacus*	RE	1	0	0	39
Robin	*Erithacus rubecula*	R.	0	0	1	0
Sky Lark	*Alauda arvensis*	S.	0	0	11	0
Song Thrush	*Turdus philomelos*	ST	0	0	0	3
Starling	*Sturnus vulgaris*	SG	10	0	3	180
Swallow	*Hirundo rustica*	SL	0	0	4	0
Finch sp.	–	Finch sp.	0	0	8	0
Thrush sp.	–	Thrush sp.	23	0	10	497
Passerine sp.	–	Passerine sp.	0	0	30	0
Other						
Merlin	*Falco columbarius*	ML	0	0	1	0
Woodcock	*Scolopax rusticola*	WK	0	0	0	2
Diver sp.	–	Diver sp.	1	0	0	0

Table 4.
Species recorded visual observations undertaken on the 26th, 27th and 28th of October 2005.

	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	DAILY TOTAL
N		23	8	16	19	24	13	9	3	3	1	3	0	5	15	10	10	25	16	13	15	13	20	13	277
NNE		69	62	43	37	101	41	20	12	23	12	9	28	34	45	49	55	40	37	18	37	28	50	41	891
NE		42	28	10	14	45	11	11	14	10	12	12	13	47	22	32	38	15	12	18	21	25	21	30	503
ENE		18	13	10	4	22	8	12	6	8	12	14	17	16	22	19	22	8	10	10	9	12	20	21	313
E		11	11	10	6	35	22	7	10	6	6	5	8	19	11	23	13	21	13	19	5	5	5	4	275
ESE		11	10	15	10	34	27	5	10	8	5	5	9	12	13	8	4	8	9	13	6	4	3	2	231
SE		37	18	24	17	32	45	35	34	35	15	22	12	8	17	13	23	10	14	24	11	5	3	3	457
SSE		107	89	78	52	77	76	57	72	140	85	66	58	42	29	26	60	33	28	29	13	37	25	9	1288
S		27	21	15	6	7	9	14	19	27	26	16	15	4	11	5	10	12	5	4	0	14	5	6	278
SSW		26	19	13	13	16	17	30	37	37	38	35	31	45	55	11	23	24	18	15	5	21	15	9	553
SW		2	4	5	1	11	10	5	13	12	8	12	8	25	27	6	21	14	14	15	9	10	3	11	246
WSW		1	3	6	4	5	4	1	4	5	3	4	5	13	18	3	3	8	18	17	13	4	5	8	155
W		2	1	4	4	8	12	1	8	6	5	4	2	7	26	12	13	9	19	28	17	16	20	28	252
WNW		1	0	2	9	13	7	2	2	5	3	2	0	1	27	17	11	18	17	34	27	19	74	126	417
NW		5	3	4	7	16	13	5	7	1	1	2	2	6	22	30	22	22	20	39	31	24	66	71	419
NNW		19	21	43	38	41	51	24	17	15	5	10	9	16	34	72	37	48	56	78	58	42	49	50	833
TOTAL		401	311	298	241	487	366	238	268	341	237	221	217	300	394	336	365	315	306	374	277	279	384	432	7388

Table 5.
All avian radar tracks from 26.10.2004 divided between the cardinal points of the compass throughout 24hrs detected from 0Km – 12Km out to sea.

	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	DAILY TOTAL
N	7	19	32	17	3	11	13	3	3	2	1	0	2	0	0	0	0	0	0	0	1	0	0	1	115
NNE	33	90	80	34	13	35	57	7	6	5	0	4	1	0	0	1	1	0	0	2	1	0	1	1	372
NE	22	30	26	15	2	13	23	3	1	2	0	2	0	0	0	0	0	0	1	2	0	0	1	1	144
ENE	8	14	5	5	0	2	9	1	1	0	0	0	0	0	0	0	0	1	2	0	0	2	0	0	50
E	3	5	2	1	0	1	0	2	0	0	1	6	0	0	4	0	0	4	0	0	0	0	0	0	29
ESE	2	2	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	9
SE	4	3	7	4	1	0	2	0	0	0	0	1	0	0	0	1	0	1	1	1	0	2	0	0	28
SSE	26	15	8	9	1	2	3	0	0	0	0	1	0	0	0	1	2	1	0	1	0	1	0	0	71
S	8	7	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
SSW	8	11	5	6	4	3	0	1	1	0	1	0	1	0	1	0	0	1	2	1	0	0	0	2	48
SW	10	12	17	27	60	24	3	3	0	0	2	2	0	0	0	0	2	2	3	0	1	1	1	0	170
WSW	11	17	29	328	502	246	30	9	4	5	11	7	16	8	9	16	5	1	1	1	0	1	8	19	1284
W	63	64	100	506	581	339	131	82	72	84	169	259	105	34	31	23	5	5	1	2	6	14	7	35	2718
WNW	121	81	61	108	87	96	137	115	141	243	377	227	82	14	8	6	3	0	0	2	5	12	12	33	1971
NW	33	28	64	67	16	25	40	18	7	16	22	13	8	1	0	3	1	1	1	0	2	3	3	5	377
NNW	40	68	131	148	28	33	73	16	11	13	6	3	4	0	1	4	1	2	0	0	0	0	3	4	589
TOTAL	399	466	568	1277	1299	831	523	260	247	370	590	525	219	57	54	55	20	19	12	12	16	37	37	101	7994

Table 6.
All avian radar tracks from 27.10.2004 divided between the cardinal points of the compass throughout 24hr detected from 0Km – 12Km out to seas.

	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	DAILY TOTAL
N	0	0	0	1	0	0	2	4	3	4	6	3	1	4	1	6	3	5	0	2	3	0	1		49
NNE	2	1	1	4	0	1	6	11	4	4	7	12	21	4	8	10	17	16	4	3	2	4	2		144
NE	2	1	0	1	2	2	7	3	5	10	11	14	13	7	7	4	9	2	0	2	2	2	1		107
ENE	1	0	0	0	2	0	1	3	4	1	3	4	4	8	3	1	1	1	1	0	0	0	1		39
E	0	0	2	0	0	1	0	1	1	2	1	2	0	2	6	1	2	0	3	0	3	0	0		27
ESE	0	0	1	0	0	0	0	0	1	0	1	0	1	0	2	1	1	1	0	0	1	0	0		10
SE	0	0	0	1	0	2	0	1	0	3	3	2	5	3	1	0	0	1	1	0	0	0	0		23
SSE	0	0	0	0	2	1	0	4	6	12	16	7	12	2	8	5	2	4	3	4	0	0	0		88
S	0	0	0	0	0	0	0	0	4	0	0	3	2	1	1	1	2	0	0	0	0	0	0		14
SSW	0	1	0	0	0	1	1	4	4	5	9	8	9	8	9	16	10	4	3	1	1	0	0		94
SW	1	0	0	2	2	0	2	0	4	8	8	5	9	8	23	17	17	8	8	10	3	0	0		135
WSW	8	1	4	0	2	6	2	3	3	5	18	8	13	9	10	20	28	5	6	7	1	8	1		168
W	45	22	12	7	7	3	10	5	15	16	13	14	10	12	11	14	16	12	3	11	6	18	9		291
WNW	18	20	14	9	13	6	8	7	14	13	13	8	17	12	8	4	10	11	1	1	10	28	4		249
NW	2	3	5	2	0	2	4	5	2	4	7	5	3	6	7	6	14	17	5	3	6	5	1		114
NNW	1	2	3	2	5	3	16	9	2	5	7	6	2	7	5	11	14	36	9	11	8	2	3		169
TOTAL	80	51	42	29	35	28	59	60	72	92	123	101	122	93	110	117	146	123	47	55	46	67	23		1721

Table 7.
All avian radar tracks from 28.10.2004 divided between the cardinal points of the compass throughout 24hr detected from 0Km – 12Km out to sea.

	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	DAILY TOTAL
N	1	3	17	21	41	8	38	28	8	13	0	5	5	7											195
NNE	5	14	37	64	83	41	122	62	13	30	4	17	26	8											526
NE	1	9	25	39	27	29	71	26	11	16	1	10	20	6											291
ENE	2	6	6	15	7	10	20	6	5	11	1	8	9	5											111
E	2	3	8	15	11	7	12	6	12	13	0	3	7	6											105
ESE	1	4	4	8	9	7	9	5	9	5	1	5	8	8											83
SE	1	5	14	10	10	11	10	8	7	10	0	6	9	11											112
SSE	4	7	11	9	10	4	12	9	6	7	0	4	12	6											101
S	1	3	3	3	0	0	5	1	1	3	0	2	3	2											27
SSW	10	11	6	6	9	11	18	7	2	2	3	4	7	9											105
SW	5	7	9	16	17	11	18	11	3	13	5	3	13	11											142
WSW	8	18	23	31	27	23	22	23	8	9	6	9	36	9											252
W	15	23	34	42	61	80	16	37	22	24	9	30	77	59											529
WNW	16	9	38	26	71	36	32	43	17	33	2	28	60	23											434
NW	14	14	37	57	133	26	47	38	12	34	3	12	22	14											463
NNW	9	30	53	135	184	40	120	60	7	30	7	7	27	18											727
TOTAL	95	166	325	497	700	344	572	370	143	253	42	153	341	202											4203

Table 8.
All avian radar tracks from 29.10.2004 divided between the cardinal points of the compass throughout 24hr detected from 0Km – 12Km out to sea.