Migration routes of Whooper Swans and geese in relation to wind farm footprints

Final Report

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Report to DECC

November 2011

Published by:

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This publication should be cited as:

Griffin, L., Rees, E. & Hughes, B. 2011. Migration routes of Whooper Swans and geese in relation to wind farm footprints: Final report. WWT, Slimbridge. 87 pp.

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1 Executive Summary and Recommendations

In March 2010, Hartley Anderson Ltd., on behalf of its client the Department of Energy and Climate Change (DECC) contracted the Wildfowl & Wetlands Trust (WWT) to undertake further analysis of Whooper Swan migration data initially collected for a study commissioned by COWRIE Ltd.

The original study reported on the routes and flight heights of 50 Whooper Swans fitted with GPS satellite transmitters, recorded during the swans' spring and autumn migrations between the UK and Iceland in 2009, in relation to offshore wind farm sites, particularly those in the East Irish Sea and Greater Wash areas.

This extension to the previous work includes analysis of new GPS data from swans that were still carrying transmitters by spring 2010, plus data for five birds fitted with newly refurbished transmitters in spring 2010. Analyses considered onshore as well as offshore wind farm sites. Variation between years in the swans' migration route is described. The current study also examines existing WWT satellite tracking data, in relation to wind farm location, for three goose species (the Svalbard Barnacle Goose, Greenland White-fronted Goose and East-Canadian Light-bellied Brent Goose) which winter in the UK but follow different migration routes to separate breeding areas.

Whooper Swan migration

Five adult male Whooper Swans caught at WWT Martin Mere, Lancashire, NW England in March 2010 were fitted with refurbished 70g solar GPS ARGOS PTT satellite transmitters. These, together with two swans from the earlier (COWRIE Ltd.) project wintering in western Britain (at Martin Mere and in Cumbria), provided data on the swans' migration along the west coast of Britain in spring 2010

Of the seven birds tracked from NW England in 2010, four (57%) crossed an offshore wind farm location (at Ormonde, Robin Rigg, Islay or the Argyll Array); rising to six (86%) if one of the withdrawn Scottish Territorial Waters (STW) sites (Solway Firth) is included. This supported results of the 2009 study, which found that a high proportion (75%) of swans tracked from NW England crossed at least one offshore wind farm footprint, compared with 7.1% of those tracked along the east coast from SE England (Griffin *et al.* 2010a).

Only two tags provided GPS locations for the birds immediately before and after crossing an operational wind farm or one under construction. In both cases the data indicated that the birds gained height to avoid the potential obstacle.

Consistency in the swans' migration routes

Whooper Swan tracked from NW England took a more westerly migration route in spring 2010 than in spring 2009. One individual tracked in two consecutive springs also took a more westerly route in 2010. Four autumn tracks were all more westerly than the spring migration routes recorded for the same birds. There was preliminary evidence for wind direction encountered during the long overseas crossing between Britain/Ireland and Iceland having some influence on the swans' migration routes.

Treatment of wind farm location data

Onshore wind farm datasets were obtained both from Scottish Natural Heritage (SNH) and from RenewableUK (RUK, formerly the British Wind Energy Association). Analysis of data provided in October 2010 for the Interim Report (Griffin *et al.* 2010b) found a large number of discrepancies in onshore wind farm locations recorded in the two datasets. The SNH data were considered more accurate for Scottish wind farm sites. Updated versions of the SNH and RUK onshore wind farm datasets were obtained and used for this Final Report. The data were treated in the same was as described in the Interim Report, with small wind farm sites (< 5 turbines) excluded.

The Crown Estate dataset on offshore wind farms recorded STW sites withdrawn from the planning process since the Interim Report was completed. Withdrawn STW sites were retained the analyses, as they may be reconsidered for future development, but are referred to as they occur in this Final Report.

Data on wind farm locations along the coast of Norway were obtained from the Norwegian Energy Directorate, for analysis in relation to the migration of the Svalbard Barnacle Goose population.

A total of 357 onshore sites in Scotland (SNH data), 222 onshore sites in England, Wales and Northern Ireland (RUK data), 48 UK offshore sites (Crown Estate data) and 47 onshore and offshore sites along the Norwegian coast (Norwegian Energy Directorate data) were imported into a GIS for analysis in relation to swan and goose migration routes.

Whooper Swan migration routes in relation to all (offshore and onshore) wind farm locations

Eleven offshore wind farms and 81 onshore wind farms were within 5km of the flight-lines for Whooper Swans tracked from NW England (Martin Mere), SE England (Welney) and SW Scotland (Caerlaverock) in 2009 and 2010, including three offshore wind farms (Kintyre, Wigtown Bay and Solway Firth) where the planning applications have recently been withdrawn.

Over 80% of the swans tracked in 2009 and 2010 passed over the footprint of at least one proposed or operational onshore site. Additionally, 20–30% of the birds tracked from SE England/SW Scotland passed within 5km of a proposed or operational offshore wind farm, rising to 70% of tracks for birds from NW England passing across these sites (80–90% within 3–5km of the offshore sites).

Most intensive Whooper Swan movement in the vicinity of wind farms was over the consented West Duddon offshore site, the withdrawn Solway Firth offshore site and the Dalmellington onshore site currently at the planning stage. Whooper Swan tracks passed over all four of the operational/consented Cumbrian R1/R2 offshore sites: West Duddon, Ormonde, Walney and Barrow, as well as the Robin Rigg wind farm (in operation) on the Solway Firth.

Of Whooper Swans tracked from Martin Mere and Welney, 39% and 21.5% respectively crossed three or more wind farm sites/footprints, emphasising the need for an assessment of the cumulative effects of the development of wind farm sites along migration routes.

The number of onshore wind farm sites crossed by the swans is substantially higher than the number of offshore sites, both at the constructed/consented and at the planning stage, as is the number of wind farms within 5km of the swans' flight-lines. Thus, in assessing the potential effects of wind farm development on migratory populations, onshore and offshore wind farms should be considered in combination rather than as separate entities.

Svalbard Barnacle Goose migration

Most of the Svalbard Barnacle Goose population winters on the Solway Firth, on the SW Scotland/NW England border. There was little indication from the small number of birds satellite-tracked during a four-winter study that the mid-winter movements of the geese crossed proposed and operational wind farm sites within the Solway Firth, though the Wigtown Bay STW site (now withdrawn) had the potential to be on the flight-lines of geese using this part of the Solway.

Svalbard Barnacle Geese migrate overland for a relatively short (100–110km) distance within the UK, heading from the Inner Solway (predominantly from Rockcliffe Marsh, Cumbria) to exit Britain along a stretch of coast extending ~90km from the Firth of Forth to just south of Lindisfarne. The migratory front is broadest across the North Sea, and also across the Barents Sea to Spitsbergen; the birds follow a very narrow migratory corridor along the Norwegian coast in spring.

Twenty-seven Barnacle Geese provided sufficiently detailed tracks on leaving the Solway for an assessment of departure times and dates, and also light conditions. Over half of these geese (16 birds) probably left the Solway Firth at night; six appeared to travel in near total darkness while 10 may have had the benefit from some moonlight, although for at least three of these there was extensive cloud cover (≥ 75%) on the nights they departed. The remainder all departed in daylight but during the evening, between 17:00 and 19:00 hours. The main offshore wind farm area potentially affecting this species in the UK, the Firth of Forth, is ~150km from the Solway, which the geese would typically reach in 1.5–2 hours. Thus at least 75% of the geese probably passed through this area at night, with half of these travelling in near total darkness.

Given the latitude of staging sites in Norway, and the dates on which the geese were there, only nine of 311 migratory flights recorded along the Norwegian coast (in either spring or autumn) could be classed as being in low light levels. Reduced visibility therefore seems less likely to pose a risk at this stage of migration except in poor weather conditions. No weather data were available for Norwegian coastal sites for the current analysis, but this may be considered in future, in collaboration with Norwegian scientists.

Of the 27 geese tracked for which UK weather data were available, 22 (81%) departed on southwest/westerly “tail” winds in spring, but five birds migrated into “head” winds. Most of the geese (78%) migrated during conditions of high and rising pressure or steady high pressure, a typical indicator of more stable and good weather conditions. Birds migrating in westerly winds tended to depart the UK coast further south than those in more southerly or easterly winds.

One Barnacle Goose (CPS) took an extremely odd diversion south (and nearly reached the Humber) during his spring 2007 migration, apparently due to a thick band of coastal fog or “haar” that had developed in the North Sea. A second bird (DAC) made an unprecedented climb to 461m and then 584 m above sea level on crossing the North Sea, to clear the same fog bank, reaching 4–5 times the altitude typical of geese flying in this area.

Barnacle Goose migration routes in relation to all (offshore and onshore) wind farm locations

Forty-two wind farms sites (8 UK offshore/inshore sites, 19 onshore sites and 15 sites in Norway) either had Barnacle Geese passing over the site, or were ≤5km from the flight-lines for at least 5 geese tracked on migration. A further 71 sites (62 in Britain; 9 in Norway) were within 5km for 1–4 geese tracked, but the birds did not pass directly over the wind farm footprints.

The most frequently crossed sites were the Round 3 offshore Firth of Forth site, currently at the planning stage (13 of 26 tracks passed over the site; 15 ≤ 5km of the site), the Beck Burn onshore site also at the planning stage (7 tracks over the site; 25 ≤ 5km of the site) and the Smøla (operational), Vardøya (consented) and Havsul I (consented) sites in Norway.

Almost all of the tracked geese passed within 2km of a proposed (planned, consented or under construction) or operational onshore wind farm sites in the UK and in Norway, with *c.* 50% and 60% predicted to pass across wind farms in the UK and Norway respectively. Between 40–50% of tracks passed across offshore wind farm sites.

Of 21 Barnacle Geese tracked from the UK to Svalbard, four (19%) passed across a wind farm footprint once, two (9.5%) passed over twice, one (5%) passed over on three occasions, seven (33%) on four occasions, three (14%) on five occasions and four (19%) passed over wind farm sites on six or more occasions. Additionally, noting that some geese provided more data than others, >10% of the movements recorded for 18 of 27 geese tracked from the Solway passed within 5km of a wind farm site.

The total number of wind farm sites passed through by Svalbard Barnacle Geese within the UK and Norway is predicted to be about four or more over the course of a year.

Between 60–80% of individually tagged geese flew across (a) onshore sites at the planning stage, (b) offshore (UK R3/STW) sites at the planning stage and (c) Norwegian sites where development has already been consented, rising to 100% of geese passing within 5km of planned onshore sites, >70% passing within 5km of planned offshore sites in the UK and >90% within 5km of consented and/or operational sites within Norway.

Whooper Swan and Barnacle Goose flight heights

Flight height estimates were subject to error because altitude data recorded by the transmitters were accurate only to within ± 22 m of true height.

Nevertheless, both Whooper Swans and Barnacle Geese were found to fly quite low. For Whooper Swans migrating overland, the mean flight height (± S.E.) was 8 m (±9 m) above ground level, median flight height was 42 m and the modal value was 10 m. Mean altitude of flight when flying over water was 31 m (±3 m) above sea level (a.s.l.), median flight height was 9 m and the modal value was again in the 0–10 m band.

For Barnacle Geese migrating across Scotland, the mean flight height (±S.E.) was 183 m (±65 m) above ground level, median flight height was 161 m and the modal value was up to 20 m. Mean altitude of flight when flying over water was 81 m (±8 m) a.s.l., median flight height was 16 m and modal flight height was again in the 0–20 m band.

Whooper swans generally flew at about half the Barnacle Goose migration flight height. In both species, flight heights over the open ocean were approximately half that typically recorded over land.

Whilst noting the errors in the altitude data, it still seems likely that Barnacle Geese migration over land is mainly above the maximum height of the rotors (~130 m). Offshore, the geese tend to fly within and below the rotor-swept zone. Whooper Swans, however, tend to fly at heights within or below the sweep of the rotors both onshore and offshore.

Light-bellied Brent Goose migration

Data for nine Light-bellied Brent Geese found little evidence for the geese passing across offshore wind farms, but the lower frequency and accuracy of the Doppler fixes recorded for these birds provides only a broad overview of their migration routes. The Kintyre, Islay and Argyll Array STW sites appear to have the greatest potential to occur on the Brent Goose flight path. Three birds were considered to have come within 20km of these proposed STW sites.

Greenland White-fronted Goose migration

Six Greenland White-fronted Geese were tracked from Loch Ken, SW Scotland; four in 2008 and two in 2010. The four birds tracked in spring 2008 were recorded at the same time and locations, indicating that they were migrating together. Tracking birds from a wider range of sites, including the internationally important wintering areas on Kintyre and Islay, is required to provide a more informed assessment of Greenland White-fronted Goose migration routes in relation to wind farm sites.

Disseminating the results of the study

Results of the study were disseminated through webpages on the WWT website, by preparing and circulating reports, publishing articles, and by giving talks at workshops and conferences.

RECOMMENDATIONS

That 39% of Whooper Swans tracked from Martin Mere and 21.5% of those tracked from Welney crossed three or more wind farm sites/footprints emphasises the importance of ensuring that potential cumulative effects of wind farm sites (both onshore and offshore) along migration routes are assessed prior to planning permission being granted.

The number of wind farms crossed by individual swans migrating from Martin Mere was notably higher than those migrating from Caerlaverock and Welney. Potential impacts of wind farm development therefore should be assessed in relation to the wintering sites and migration routes used by birds from different parts of the country. Assessing variation in Whooper Swan survival may help to determine whether there is a post-construction increase in mortality for swans wintering at Martin Mere, although it may prove difficult to control for other factors affecting variation in the swans' survival rates.

A high proportion of the Svalbard Barnacle Geese tracked crossed the offshore Firth of Forth Round 3 site, which is currently at the planning stage. This development therefore is of particular concern for the population, particularly in combination with wind farm development elsewhere (within and outside the UK). Further inspection of the tracks indicated that more than half of the spring tracks crossing the site were concentrated in the southern part of the footprint. Also, of 15 tracks (autumn and spring) that missed the site 13 (87%) were to the south compared with 2 to the north. Thus there is scope for positioning turbines within the footprint to minimise the impact on the birds. Radar studies in the northern and southern sections are strongly recommended to reinforce these findings, and to advise on the location and spacing of turbines, particularly given that the results are for the R3 zone as a whole and there's currently no information available on where wind farms may be positioned within the footprint.

There is a general lack of post-construction data, readily accessible in the public domain, on how birds move through UK wind farms, and on collision rates for birds at these sites. This is particularly important for larger sites, where birds are likely to encounter more turbines on changing their flight-line rather than being able to go around the site. Further radar and satellite-tracking studies, and also field-based observations of flight heights and avoidance, will help to analyse movement through (using radar) or over (satellite-tracking) constructed wind farms, and thus determine how the birds cope with these structures.

The high proportion of Barnacle Geese migrating at night emphasises the need for a separate assessment of collision risks for migrating birds flying in very poor light conditions. Current avoidance rates and collision risks, used for assessing the potential impact of UK wind farm sites, seem to be based mainly on a 24 h mortality assessment (search for corpses under turbines) used to determine collision risks for birds moving between feeding areas and the roost, which is predominately in the daytime (for movements between feeding sites) and at dusk (for movements to the roost). This is insufficient for assessing collisions where a high proportion of movements are in the dark, particularly if there's also cloud cover.

The high number of Norwegian wind farms along the Barnacle Goose migration route emphasises the importance of international collaborative studies and political agreements for determining cumulative impact and risk assessment for birds flying across wind farms from more than one country. The Svalbard Barnacle Goose population would provide a good case study, as it has a relatively restricted distribution and only two countries (the UK and Norway) developing wind farms along its flyway.

Noting that population viability analysis for the Svalbard Barnacle Goose has indicated that (assuming a goal of avoiding medium-term population decline) additional losses from the population exceeding approximately 350 geese annually should be avoided (Trinder *et al.* 2005), the allocation of allowable collision risk across countries needs to be determined as a matter of some urgency at the political level.

Satellite-tracks recorded for Light-bellied Brent Geese and for Greenland White-fronted Geese, which were developed for separate studies, were not specifically designed to determine migration routes in relation to wind farm sites. Thus although this report did not find substantial overlap of these species with wind farm footprints, more considered radar and satellite-tracking studies would be required to assess whether wind farms could affect a significant section of these populations. This is particularly true for Greenland White-fronted Geese, which winter mainly in Islay, Kintyre and Ireland. Loch Ken, where the tracked geese were marked, is a relatively small and discrete site for these birds. Tracking from Kintyre and/or Islay therefore would be more appropriate for assessing whether the Islay STW site and the Argyll Array are on the main migration route for this population.

Whilst movement of swan and goose populations along coastal Britain and through Scotland has been described by the satellite-tracking work, much less is known about flight-lines taken by birds (e.g. Bewick's Swans) moving between southeast England and continental Europe. Radar and satellite-tracking studies are recommended to clarify potential effects of wind farm development along these flyways.

2 Introduction

The installation of wind farms has increased rapidly across Europe over the last two decades, as governments seek to secure their energy supplies through increasing use of renewable resources and also to reduce the greenhouse gas emissions associated with climate change. More than 25,000 wind farms are now in operation across Europe, and the number of onshore and offshore wind farms operational or under construction in the UK are now put at 274 (2,137 turbines) and 14 (559 turbines), respectively (BWEA 2009). With 20% of EU energy to come from renewable sources by 2020, it is estimated that some 4,400 new turbines will be built at onshore sites in the UK alone (Devereux *et al.* 2008) and potentially 5,000 wind turbines built offshore (Rowena Langston pers. comm.). Moreover, the Committee on Climate Change proposed that the UK should adopt a significantly more ambitious target than the 60% objective set by the UK Government in the 2003 Energy White Paper, and aim to cut greenhouse gas emissions by at least 80% below 1990 levels by 2050. This target has now been adopted by the UK Government under the 2008 Climate Change Act (CCC 2008). A substantial uptake of renewable energy generation therefore is anticipated over the next decade. Wind power, as a proven form of low-carbon power generation, is considered likely to be a key contributor towards reaching the 2050 target (CCC 2008).

The environmental community, regulators, developers and interested members of the public therefore are being faced with a challenge: there is increasing evidence for climate change having a deleterious effect on wildlife populations (Parmesan & Yohe 2003; Root *et al.* 2003; Thomas *et al.* 2004, Bright *et al.* 2006, Bright *et al.* 2008), yet at the same time injudicious location of wind farms may have detrimental effects on some species, particularly bats (Hötker *et al.* 2006; Kerns *et al.* 2005; Brinkmann & Schauer-Weisshahn 2006; Sterner *et al.* 2007, from review in EEA 2009) and birds (Barrios & Rodriguez 2004; Garthe & Hüppop 2004; Langston & Pullan 2003, Bright *et al.* 2008). Possible negative effects include direct mortality due to collisions, habitat loss/degradation, displacement from feeding areas, decreased landscape functions (barrier effects), and disturbance (reviews in Langston & Pullan 2003; Drewitt & Langston 2006; Bright *et al.* 2006; Inger *et al.* 2009). The risk of colliding with the turbines seems to vary across species, and also with the location of the wind farm site, with potential for there being population-level effects in some cases (*e.g.* White-tailed Eagle in Scotland; Bright *et al.* 2008 provide a review).

In August 2008, COWRIE Ltd. awarded a research grant to WWT to assess the migration of Whooper Swans between breeding and wintering grounds with respect to strategic offshore wind farm areas. Whooper Swans were of particular concern because their large size makes them less manoeuvrable than other smaller species and flying accidents are known to be a major cause of death for these birds (Brown *et al.* 1992; Rees *et al.* 2002).The main objectives of the study were to (a) determine the migration routes and flight heights of Whooper Swans in relation to Round 3 offshore zones, particularly those in the East Irish Sea and Greater Wash areas (b) publish the results on a website to provide up to date information on the Whooper Swans' migration and easy access to all interested parties, including the public (c) assess potential impacts of weather during migration, particularly periods of poor or adverse weather conditions, and (d) assess the potential risk to Whooper Swans from offshore wind farms. Whooper Swans wintering in western England (WWT Martin Mere) and SE England (WWT Welney, on the Ouse Washes) were selected for tracking because these were most likely to migrate through the East Irish Sea and the Greater Wash, respectively, and also because they would additionally provide data on any movements by these birds through wind farms sites further north. Martin Mere and the Ouse Washes are both sites of international importance for the species; over 7,500 birds (c. 28% of the population) have been recorded wintering at these two sites in recent years. The study provided valuable information on the location of wind farm sites in relation to the migration routes of individual birds in spring 2009 (Griffin *et al.* 2010a) and the information was also disseminated to schools and the wider public via the WWT website (http://www.wwt.org.uk/flywiththeswans).

Whilst the data recorded as part of this project provided valuable information on the swans' migration routes in 2009, some transmitters continued transmitting into 2010, providing an opportunity to obtain further insights into the swans' migration routes and altitude of flight. Additionally, whilst the initial study described Whooper Swan migration routes in relation to offshore wind farm sites (Griffin *et al.* 2010a), the potential effect of the full series of wind farms located along the swans' migration routes has yet to be determined. This study therefore analysed migration routes in relation to onshore as well as offshore wind farm sites, and incorporated accurate digital terrain data (*i.e.* Ordnance Survey contour data) to clarify the altitude of swan flight when migrating overland, described variation in the altitude of flight in the vicinity of onshore compared with offshore wind farm sites, and determined the total number of wind farms traversed by Whooper Swans during migration.

Whereas the COWRIE-funded study focussed on Whooper Swan migration, WWT has also undertaken satellite-tracking studies for three UK-wintering goose populations: the Greenland White-fronted Goose, the East Canadian Light-bellied Brent Goose and the Svalbard Barnacle Goose. The Svalbard Barnacle Goose population is highly concentrated in its winter distribution; > 99% of the total population winters within 5km of the Solway coast (Madsen *et al.* 1998). The Greenland White-fronted Goose population is in decline (classed as "Red" in the list of Birds of Conservation Concern; Eaton *et al*. 2009), and is recognised as a priority species for conservation in Scotland. The East Canadian Light-bellied Brent Goose population makes an exceptional return migration from the UK via Iceland and Greenland to Canadian breeding grounds each year. Analysis of these satellite-tracks would provide information on several populations for which the UK has major conservation responsibilities (*i.e.* receives >25% of the population), and thus provide information towards identifying optimal and sub-optimal locations for offshore wind farm sites in Scottish waters. A comparison of the tracks for those species migrating between Britain and Iceland would also indicate whether the different species (Brent Geese, Greenland White-fronted Geese and Whooper Swans) follow the same, or similar, flight-paths. Altitudes of flight data are also available for some of the more recent tracks.

In March 2010, Hartley Anderson Ltd. contracted the Wildfowl & Wetlands Trust on behalf of its client the Department of Energy and Climate Change (DECC) to undertake further analysis of Whooper Swan migration data initially collected for the study commissioned by COWRIE Ltd. This analysis was to include new GPS data from swans still carrying transmitters, plus data for up to seven birds to be fitted with newly refurbished transmitters, in relation to onshore as well as offshore wind farm sites, and in relation to flight heights over land. The study was also to include analysis of existing satellite tracking data held by WWT for the Svalbard Barnacle Goose, Greenland White-fronted Goose and East Canadian Light-bellied Brent Goose in relation to wind farm locations.

3 Objectives

Five specific objectives were described under the terms of the DECC contract:

Objective 1: To incorporate Ordnance Survey contour data into analysis of Whooper Swan flight heights when migrating overland.

Objective 2: To continue downloads of satellite-transmitter data to the end of the autumn 2010 migration, and redeploy recovered transmitters, to provide additional data on the swans' migration. Analysis to include an assessment of the consistency of migration routes for individual Whooper Swans in relation to wind farm locations and the status (construction *versus* operational) of the wind farm sites.

Objective 3: To undertake an extended analysis of Whooper Swan flight paths in relation to both onshore and offshore wind farm locations to provide comprehensive information on the number of wind farms along the swans' flight paths from southern Britain.

Objective 4: To analyse existing satellite-tracking data for four key species (Svalbard Barnacle Geese, East Canadian Light-bellied Brent Geese, Greenland White-fronted Geese and Whooper Swans), in relation to wind farm locations (proposed and operational) along their migratory flyways.

Objective 5: Disseminate the results of the satellite-tracking study via the WWT website, and through presentations to conservation groups, stakeholders and policy makers, to help resolve any conflict between the UK's move towards green energy and the conservation of the Icelandic Whooper Swan population.

4 Specific Tasks

Specific work tasks were identified to achieve each of these objectives:

Objective 1: To incorporate Ordnance Survey contour data into analysis of Whooper Swan flight heights when migrating overland.

Work Task 1. Purchase Ordnance Survey contour data (DXF product) for Scotland and England to improve the accuracy of the swans' migration height assessment when flying over land. The DTM (digital terrain map), derived from 1:10,000 scale contour and spot height data gives elevation data to an accuracy of +/- 5m.

Work Task 2. Incorporate the DTM data into the GIS.

Work Task 3. Analyse and report on Whooper Swan flight heights when migrating overland.

Objective 2: To continue downloads of satellite-transmitter data to the end of the autumn 2010 migration, and redeploy recovered transmitters, to provide additional data on the swans' migration. Analysis to include an assessment of the consistency of migration routes for individual Whooper Swans in relation to wind farm locations and the status (construction *versus* operational) of the wind farm sites.

Work Task 4. Continue data downloading from the Argos satellite system from March 2010 to March 2011 inclusive.

Work Task 5. Recover, refurbish and redeploy up to seven satellite-transmitters.

Work Task 6. Analyse and report on Whooper Swan migration routes in relation to offshore wind farm footprints, with particular reference to the consistency of migration tracks for individual birds and any change in the status of wind farm sites between 2009 and 2010.

Objective 3: To undertake an extended analysis of Whooper Swan flight paths in relation to both onshore and offshore wind farm locations to provide comprehensive information on the number of wind farms along the swans' flight paths from southern Britain.

Work Task 7. Incorporate onshore wind farm locations into the GIS.

Work Task 8. Analyse and report on Whooper Swan migration routes and flight heights in relation to all (offshore and onshore) wind farm locations.

Objective 4: To analyse existing satellite-tracking data for four key species (Svalbard Barnacle Geese, East Canadian Light-bellied Brent Geese, Greenland White-fronted Geese and Whooper Swans), in relation to wind farm locations (proposed and operational) along their migratory flyways.

Work Task 9. Coordinate and verify satellite-tracking data for the four key species into a single GIS.

Work Task 10. Analyse and report on inter-specific variation in migration routes in relation to offshore wind farm locations.

Objective 5: Disseminate the results of the satellite-tracking study via the WWT website, and through presentations given to conservation groups, stakeholders and policy makers, to help resolve any conflict between the UK's move towards green energy and the conservation of the Icelandic Whooper Swan population.

Work Task 11. Continue to maintain and update the Whooper Swan satellite-tracking webpage on the WWT website to include:
- satellite telemetry maps, updated automatically on receipt of data from ARGOS.
- upload of news items, at least weekly during key migratory periods (autumn and spring).
- a prominent display of logos for WWT, the Funding Partner and any additional organisations sponsoring the work.

Work Task 12. Provide an interim report by 15th November 2010, a draft final report by 15th May 2011, and a final report by 1st July 2011.

Work Task 13. Report results of the study to relevant agencies (including DECC, DEFRA, JNCC, NE, SNH, Marine Scotland) for consideration.

Work Task 14. Produce articles in WWT's popular magazine "*Waterlife*" and its "*GooseNews*" publications, in which funding partners would be fully acknowledged. Produce scientific papers on the migration routes and altitude of flight of Whooper Swans, in relation to wind farm locations.

Work Task 15. Present findings with acknowledgement to funders to at least one international conference or workshop, such as the British Ecological Society.

The work tasks completed for this final report are summarised in the table below:

Milestones	Work Tasks	Dates
Redeployment of up to 7 satellite transmitters	5	31st March 2010
Additional Whooper Swan data downloaded and imported into GIS	4	March 2010 – March 2011
Super Whooper web pages updated and maintained	11	March 2010 – March 2011
Ordnance Survey contour data obtained and incorporated into GIS	1, 2	31st May 2010
Import, verify and analyse satellite tracks for other species	9, 10	31st October 2010
Incorporate onshore wind farms locations into GIS	7	31st October 2010
Production of interim report	3, 10, 12, 13	15th November 2010
Presentation of interim report to stakeholder review group	12, 13	1st December 2010
Information on project presented in general articles	14	1st January 2011
Analysis of additional Whooper Swan data	6, 8	April 2011
Production of draft report	12, 13	15th May 2011
Review	12, 13	1st June 2011
Production of final report	12, 13, 15	1st July 2011

5 Work Completed

5.1 Objective 1: To incorporate Ordnance Survey contour data into analysis of Whooper Swan flight heights when migrating overland.

Three work tasks were identified under this objective. The work completed for each is described below.

Work Tasks 1 and 2. Incorporate Ordnance Survey contour data (DXF product) for Scotland and England into a GIS to improve the accuracy of the swans' migration height assessment when flying over land.

Ordnance Survey data (based on the British National Grid) were provided both as DXF tiles (1:10,000 scale contour and spot height data) and as ASCII tiles (DTM gridded data; 50m cell size) for the whole of Britain. These data were imported into the ArcView GIS (ESRI) for further examination. Due to the large size of the datasets, the separate tiles were joined into two main shapefiles or GRIDs representing northern or southern Britain. The gridded (DTM) data provided a useful interpolation between the contour line and spot heights; this dataset therefore was used for further analysis.

Work Task 3. Analyse and report on Whooper Swan flight heights when migrating overland.

Whooper Swan flight heights were collected by the GPS tags at all times of the year. Not every GPS fix is successful in obtaining a good height estimate; some are "2-D fixes" (*i.e.* simply provide latitude and longitude data) and some fixes are defined as "neg alt", especially when birds are migrating or resting close to sea level. Microwave Telemetry Inc. (MTI) states that their satellite transmitters are accurate to within ± 22m of true height (with 75% of fixes considered to be ± 10m of true height), so "neg alt" (negative altitude) records may occur when the birds are at low altitude. Here we provide summary data on Whooper Swan flight heights over land firstly with the "neg alt" values recorded by the tag omitted and secondly with these values substituted by those drawn at random from a half-Normal distribution provided online at www.wessa.net ("Free Statistics and Forecasting Software" based on 'R' code routines), where the mean of the distribution was set = 0 with an SD = 10 and the distribution truncated from infinity to ± 22m.

"Neg alt" values recorded by the tag should not be confused, in the following analyses, with negative altitude values that are calculated by subtracting OS land height values from the altitude recorded by the tags which can result in nonsensical altitude values due to the error in the accuracy of the GPS fix in the vertical plane. These negative values are used in all calculations of mean (±S.D.) height.

Flight heights were analysed for the migration period as the swans are most likely to traverse both offshore and onshore wind farms during migration. The start of spring migration was defined as the bird moving >10km from its wintering site and continuing towards the breeding grounds. Ground speeds of > 8kph were taken as being birds in flight.

For Whooper Swans flying over land within the UK during spring migration, the mean flight height above ground was 90m in 2009 (S.D. ± 138m, n = 200 altitude records), 12m in 2010 (± 73m, n = 14) and 84m overall (± 136m, n = 214). The maximum flight height when flying over land was 649m in 2009 and 85m in 2010. A small number of negative height values were obtained on subtracting terrain elevation from the altitude recorded by the GPS transmitter (resulting in minimum heights of -312m in 2009 and -155m in 2010), due to error in GPS accuracy for a few altitude records (further information in the last bullet point in this section). The mean flight speed over land during spring migration was 63 kph (± 16kph, n = 203) in 2009, 61kph (± 15kph, n = 14) in 2010 and 63kph (± 15kph, n = 217) overall (maximum = 99kph).

For Whooper Swans flying over land within the UK during autumn migration, the mean flight height above ground was 7m (S.D. ± 66m, n = 12; a combination of 11 altitude records in 2009 and 1 record in 2010) at a mean speed of 61kph ± 20kph (maximum 88kph). The maximum flight height was 85m, with a minimum height of -180m due to error in GPS accuracy.

Overall, on combining data across seasons and across years, the mean flight height for Whooper Swan migration over land was 80m ± 134m, at ground speeds of 63kph ± 16kph (n = 226). Median flight height (*i.e.* the most frequently recorded altitude of flight) over land during migration was 40m in spring and 6m in autumn; 40m overall.

For Whooper Swans migrating over land in spring within the UK, at ground speeds greater than 8kph, where the "neg alt" values were replaced by those drawn randomly from a half-Normal distribution, this only made a slight difference to the spring data in 2009 where mean flight height became 88m ± 138m (n = 203). The overall median flight height decreased slightly to 38m and mean flight height overall (regardless of season or year) also decreased slightly to 79m ± 134m (n = 229).

Of the 229 flight height measures overall (including 3 "neg alt" replacements), 19 (8%) height values were found to be less than -25m on deducting terrain elevation from the swans' flight height, as recorded by the satellite transmitter. These 19 flight heights, which were outside the variation expected from established (± 22m) errors in GPS altitude measures, were nevertheless found to be due to GPS errors in the "tail" of the altitude distribution (*i.e.* at high and low flights) acknowledged by MTI. Inspection of each of these data points found that the discrepancy was not attributable to a sudden, short-distance change in terrain elevation (*e.g.* the bird flying over the edge of a cliff).

5.2 Objective 2: To continue downloads of satellite-transmitter data to the end of the autumn 2010 migration, and redeploy recovered transmitters, to provide additional data on the swans' migration. Analysis to include an assessment of the consistency of migration routes for individual Whooper Swans in relation to wind farm locations and the status (construction *versus* operational) of the wind farm sites.

Work Task 4. Continue data downloading from the Argos satellite system from March 2010 to March 2011 inclusive.

The WWT satellite tracking database has been set up so that it is updated with any new data uploaded to the CLS-ARGOS system every day via an automated Telnet connection. These data are immediately relayed to the WWT "Super Whooper" website (http://www.wwt.org.uk/flywiththeswans) and the WWT back site showing the satellite data collected for all species to date (http://www.wwt.org.uk/research/tracking/maps.asp).

Data were downloaded for nine Whooper Swans tracked in spring and summer 2010, including five swans fitted with refurbished transmitters in March 2010 as part of the current project (see Work Task 5 below). Detailed information on the migration of one bird (Y6K) was also recorded in autumn 2010 and into the 2010/11 winter. Y6K's transmitter provided data up to the time that the swan was sadly killed on colliding with power-lines near Newton Stewart, Dumfries & Galloway, on 1st February 2011.

Work Task 5. Recover, refurbish and redeploy up to seven satellite-transmitters.

Five adult males selected from a catch of 119 Whooper Swans at WWT Martin Mere on 16th March 2010 were fitted with refurbished 70g solar GPS ARGOS PTT satellite transmitters (Microwave Telemetry Inc.). Originally six birds were fitted with satellite tags at the catch, but pre-release observations found that one bird was not 100% fit, so the tag was removed before release. During the earlier (COWRIE Ltd.) satellite-tracking study, two types of plastic housing (Mark I and II), developed by an engineer in collaboration with WWT staff, were used to mount the transmitters (Griffin *et al.* 2010a). These rigid plastic housings showed signs of weathering when recovered from birds in 2009/2010, however, so a simpler design using a thin flexible plastic base plate on which to mount the transmitter was used in spring 2010.

The weight of the previously used housing, plus the satellite tag and elastic harness, was *c.* 124g, representing 1.5% of the typical body weight of an adult male Whooper Swan in winter. The new set-up typically weighed 15% less at *c.*106g.

The original housings and the newer base plates were both designed so that the satellite tags could be fitted to the swans without compromising their welfare whilst at the same time raising the solar panel above the feathers to enhance the charge rate. The housing or base plate also served to extend the length of the transmitter attachment points of the harness so that they matched the wing base width of the birds, thus ensuring that attachment did not interfere with the wing joint and the patagium membrane. The elastic harness therefore was fitted smoothly behind the back edge of the wing and in front of the thigh muscle in a continuous band so that the attachment would fall off if the harness broke in just one place. The original housings were curved in shape to improve aerodynamics in flight (*i.e.* ensure a smooth airflow over the back of the bird), white in colour to blend with the body feathers, and wide to spread the weight of the transmitter over the bird's back, with a view to minimising pressure points and feather damage. The base plate was lighter and also flat, so did not increase the level of drag on the tag.

For swans fitted with tags in Iceland in 2009, locations were recorded at one hour intervals from 5th March–5th May (spring migration) with data downloads every two days, and at one hour intervals from 18th October–25th November (autumn migration) when data downloads were made every four days (Table 1). Data downloads were less frequent from 6th May–17th October inclusive and during mid-winter to enhance solar-powered battery recharge and to reduce data download costs during non-migratory periods. Four of these tags remained functional after the COWRIE project.

The duty cycles of the tags recovered during 2009/2010 and redeployed on swans at WWT Martin Mere in March 2010 were similar to those of tags deployed in Iceland although they had a less intensive fix schedule during the autumn migration period with fixes requested every two hours instead of hourly (Table 2). Low light levels in autumn make it very difficult to obtain a high number of GPS fixes at this time of year, especially if the birds delay their departure from Iceland (where day-length is shortening rapidly) due to mild autumn conditions.

The origins of the satellite transmitters which provided data during the DECC-funded project are summarised in Table 3. Four birds were tagged in Iceland in summer 2009, and five birds at Martin Mere in March 2010.

Table 1. Seasonal duty cycles of the three satellite transmitters deployed on swans caught in Iceland in 2009 (as part of the COWRIE Ltd. study) that were still functional during the current study.

Season	Annual Start Date	Annual End Date	Receiver Start Hour (local time)	Receiver End Hour (local time)	Hour Step	TX Cycle (transmit every "x" days)
1	5th Mar	5th May	18	11	1	2
2	6th May	31st Aug	8	20	6	9
3	1st Sep	17th Oct	10	14	4	8
4	18th Oct	25th Nov	4	14	1	4
5	26th Nov	4th Mar	10	14	4	8

Table 2. Seasonal duty cycles of the five satellite transmitters deployed on swans at WWT Martin Mere in March 2010.

Season	Annual Start Date	Annual End Date	Receiver Start Hour (local time)	Receiver End Hour (local time)	Hour Step	TX Cycle (transmit every "x" days)
1	8th Mar	15th May	18	11	1	2
2	16th May	31st Aug	8	20	6	9
3	1st Sep	14th Oct	10	14	4	8
4	15th Oct	25th Nov	6	20	2	5
5	26th Nov	7th Mar	10	14	4	8

Table 3. Details of adult male Whooper Swans fitted with satellite transmitters on the breeding and moulting grounds in Iceland in August 2009, and those fitted with refurbished tags in March 2010 on the wintering grounds at WWT Martin Mere, which provided tracking data for the current project.

Catch site	Catch Date	PTT	Type of Harness	Ring	Final fix
Glaumbaer, Skagafjörður	01/08/2009	89285	Mark II	NA3	28/06/2010 [1]
Sandvatn, Mývatnsheiði	05/08/2009	89290	Mark II	Y5T	09/06/2010 [2]
Brennitjorn, Mývatnsheiði	05/08/2009	89292	Mark II	Y6K	31/01/2011 [3]
Kalfborgarvatn, Fljótsheiði	07/08/2009	78374	Mark II	BV5	17/02/2011 [4]
WWT Martin Mere	16/03/2010	89254	Flexible base plate	H6F	10/04/2010 [5]
WWT Martin Mere	16/03/2010	89261	Flexible base plate	C7V	24/08/2010 [6]
WWT Martin Mere	16/03/2010	89266	Flexible base plate	V3Z	03/08/2010 [7]
WWT Martin Mere	16/03/2010	89275	Flexible base plate	H5Z	07/07/2010 [8]
WWT Martin Mere	16/03/2010	89279	Flexible base plate	S3T	25/10/2010 [9]

[1] Tracked on migration in spring 2010; tag recovered in Iceland in August 2010; no sign of a carcass.

[2] Tag last gave a non-GPS fix from eastern Iceland on 9 June 2010; the fields in this area were checked in August 2010 but there was no evidence of a swan or the tag.

[3] Tracked on migration in both spring and autumn 2010; visited WWT Welney in the first part of the 2010/11 winter; died on colliding with power-lines near Newton Stewart, Dumfries & Galloway, on 1st February 2011.

[4] Over-summered on Coll & Tiree in 2010; tag transmitted until February 2011, but had been ditched by the bird earlier in the winter. BV5 was seen several times without a transmitter from 19th December 2010 onwards.

[5] Tracked as far as the Hebrides in spring 2010; tag recovered from Shetland in October 2010 after it started working again in August 2010; no sign of a carcass.

[6] Tracked on migration in spring 2010; swan was seen without its tag at WWT Martin Mere in November 2010.

[7] Tracked on migration in spring 2010; tag recovered in Iceland in August 2010; bird seen at WWT Martin Mere in November 2010. This bird was also tracked with a different tag (which it succeeded in removing in 2009) as part of the COWRIE project.

[8] Tracked on migration in spring 2010; swan was seen without its tag at WWT Martin Mere in October 2010.

[9] Tracked on migration in spring 2010; tag recovered in Iceland in November 2010; swan seen at WWT Martin Mere in October 2010.

Work Task 6. Analyse and report on Whooper Swan migration routes in relation to offshore wind farm footprints, with particular reference to the consistency of migration tracks for individual birds and any change in the status of wind farm sites between 2009 and 2010.

Detailed analysis of the migration routes of Whooper Swans tagged in 2009 in relation to offshore wind farms is described in the WWT report to COWRIE Ltd. (Griffin *et al*. 2010a; Executive Summary included here as Appendix 1). Here we consider the swans' migration routes in 2010 in relation to the 2009 data.

Only one swan that migrated (Y6K, tag no. 89292; Table 3) had a transmitter still functioning in both spring and autumn 2010. All five of the newly deployed tags were shed by the swans (four during the summer in Iceland; one during spring migration, the last GPS position coming from Lewis). The swans seemed to shed tags fitted in 2010 more easily, probably due to the elastic fraying where it passed through holes in the baseplate.

The five swans fitted with transmitters on 16 March 2010 at WWT Martin Mere departed on spring migration between 25 March and 8 April 2010 (Table 4). A sixth bird, NA3, which had been tagged in Iceland in August 2009 and wintered at Martin Mere in 2009/10, also migrated at this time. These birds migrated through the UK over a period of *c.* 3–6 days (Table 4), leaving the country over the Outer Hebrides (Uists and Lewis). The migration along the west coast of Britain was similar to tracks recorded for swans fitted with transmitters whilst wintering at Martin Mere and Caerlaverock in 2009 (Figure 1; COWRIE Report).

Table 4. Migration dates for eight adult male Whooper Swans tracked in spring 2010. The wintering sites include Martin Mere (MM), where five of the swans tracked in spring 2010 were caught and fitted with transmitters on 16 March 2010. Swans NA3, Y6K and Y5T were ringed in Iceland in August 2009. Swan names in bold indicate those followed by BBC Northwest. Location of the summer site in Iceland is based on fixes recorded from arrival in Iceland to 1st July 2010. Departure/arrival times and dates in *italics* indicate that extrapolation over a period of >3 hours between fixes was necessary.

PTT	Ring	Name	Winter site	Depart winter site	Depart UK	Arrive Iceland	Duration (days) UK migration	Duration (days) sea crossing	Land-fall Iceland	Summer site Iceland
89261	C7V	Gordon	MM	07:00 25/03/10	16:00 29/03/10	19:00 30/03/10	4.4	1.1	S	W
89266	V3Z	Tony	MM	23:00 28/03/10	05:00 02/04/10	12:00 04/04/10	4.3	2.3	SE	SE
89275	H5Z	H5Z	MM	06:00 30/03/10	01:00 02/04/10	11:00 04/04/10	2.8	2.4	S	W
89279	S3T	S3T	MM	03:00 30/03/10[1]	18:00 04/04/10	15:00 06/04/10	5.6	1.9	S	NW
89285	NA3	NA3	MM	23:00 02/04/10[2]	10:00 07/04/10	00:00 08/04/10	4.5	0.6	SE	SE
89254	H6F	H6F	MM	01:00 08/04/10	*08:00 11/04/10*[3]	n.a.	3.3	n.a.	n.a.	n.a.
89292	Y6K	Y6K	Cumbria	19:00 12/04/10	17:00 13/04/10	01:00 17/04/10	1.1	3.3	S	S
89290	Y5T	Y5T	Ireland	18:00 17/05/10	n.a.	*05:00 19/05/10*	n.a.	1.5	SE	E

[1] S3T visited WWT Caerlaverock for *c.* 2 days on its way north from Martin Mere from 08:00 h on 01/04/10 to 07:00 h on 03/04/10.

[2] NA3 originally departed WWT Martin Mere at 07:00 h on 07/03/10, but curtailed its northward migration at 18:00 h on 08/03/10 to return to WWT Caerlaverock, from whence it finally departed on migration at 23:00 h on 02/04/10.

[3] H6F migrated through UK as far as Lewis and remained there until 11:00 h on 10/04/10. The tag next gave positional fixes > 3 months later from the western shores of Shetland on 20/07/10. The tag was recovered but there was no sign of a carcass. It is believed the swan migrated at some point between 11:00 h on 10/04/10 and 05:00 h on 12/04/10, the time at which the tag would have uploaded if it had been in position on the swan's back. It seems likely either that the tag fell off whilst the swan was close to the UK, or that the swan perished during migration over the sea to Iceland. Either way, the extrapolated departure time from the UK for the swan is given as the midway point between those two times; *i.e.*, at 08:00 h on 11/04/10.

A seventh swan, Y6K, originally marked in August 2009 in Iceland departed its wintering site in Cumbria on 12 April 2010, passing not far from Caerlaverock. This bird migrated rapidly through the UK, taking just over one day to reach its exit point over South Uist (Table 4).

Five of the seven birds showed a tendency to take a more westerly route than reported for birds tracked in 2009 along western Britain, especially on the section of the journey beyond Coll & Tiree (Figure 1).

One swan (tag no. 89254; H6F) was tracked only as far as Lewis; the others continued to Iceland.

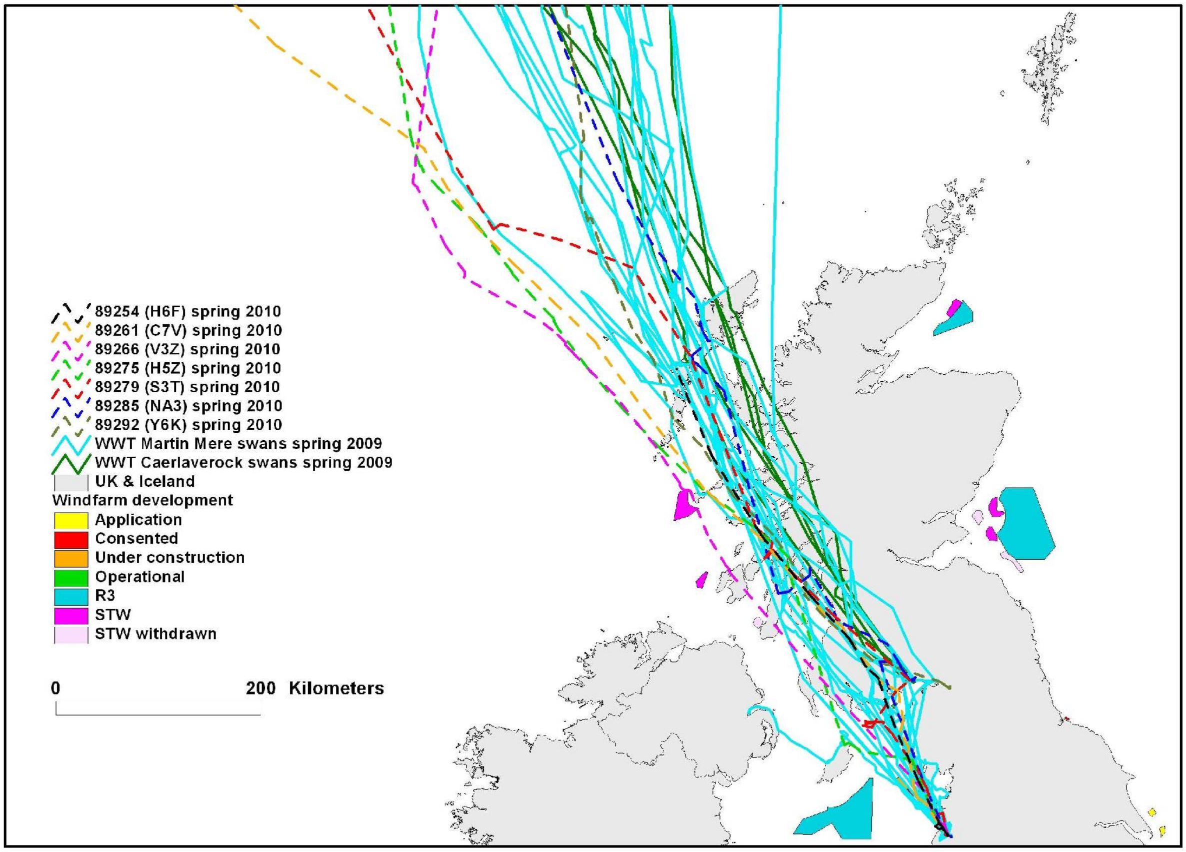


Figure 1. The migratory routes of seven adult male Whooper Swans tracked in spring 2010. Five birds (H6F, C7V, V3Z, H5Z and S3T) were fitted with satellite tags at WWT Martin Mere in spring 2010; the other two birds (NA3 and Y6K) were tagged in Iceland in August 2009. Although ringed in Iceland, NA3 showed an affinity to Martin Mere, spending the winter at the site. Similarly Y6K wintered east of Carlisle not far from Caerlaverock. Tracks for swan Y5T, which departed from western Ireland and flew direct to east Iceland in spring 2010, are not shown to improve the clarity of the map. The 2010 tracks are shown in relation to those recorded for Martin Mere and Caerlaverock birds in 2009. Departure points from the UK for swans wintering at Martin Mere were generally further west in 2010 than in 2009.

The seven birds took between half a day and just over three days to make the Atlantic Sea crossing from the UK to Iceland, with all birds making landfall over the south and southeast coasts of Iceland.

Departure patterns in 2010 were not directly (statistically) comparable with those recorded in 2009 due to differences in the capture dates – transmitters were not fitted until mid-March 2010, by which time some swans had started migration in 2009. Nevertheless, the date and timing of departure from the wintering sites appeared similar in the two years (Figures 2 & 3), as did the date and time of day for departure from the UK (Figures 4 & 5).

Five of the satellite tracked swans departed during a main migration of Whooper Swans from Martin Mere between 25th March and 2nd April, whilst the remaining two departed shortly afterwards in groups migrating on 8th and 12th April (Figure 2).

As in 2009, the swans tracked in 2010 all set off on their migration from Martin Mere in the evening, overnight or early in the morning; none of the 2010 birds departed in the main part of the day, from 08:00–18:00 h (Figure 3).

As in 2009, the timing of departure from the UK was relatively evenly spread over the 24 hours (in comparison with the evening–early morning departure from the wintering sites) in 2010, but with a tendency towards embarking on the overseas crossing during the morning and early evening (Figure 5).

Although only a few birds were tracked in 2010, the duration of migration through the UK and across the sea to Iceland were also similar in the two years (Figures 6 & 7). It is perhaps notable that one bird (swan Y6K), which had the most rapid migration through the UK, was at sea for about 80 hours, longer than any other bird tracked (Table 4).

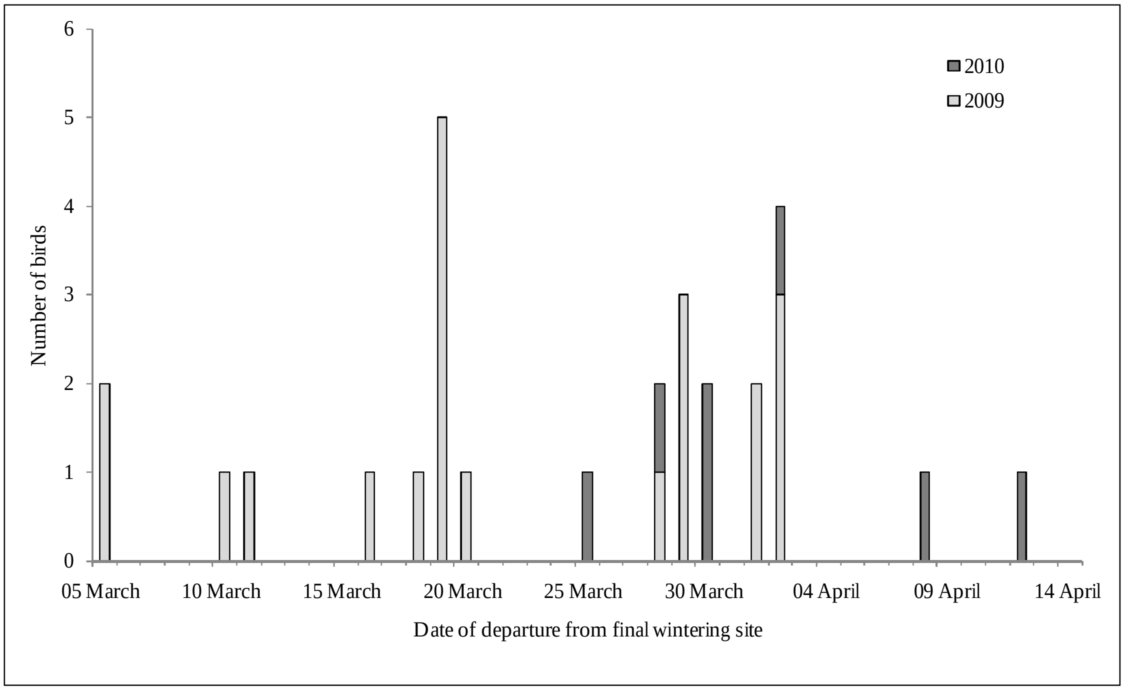


Figure 2. Dates of departure from the wintering sites for Whooper Swans tracked from Martin Mere (ringing date for five of the birds from Martin Mere was 16 March 2010) or Caerlaverock in 2010, in comparison with birds tracked from the same sites in 2009.

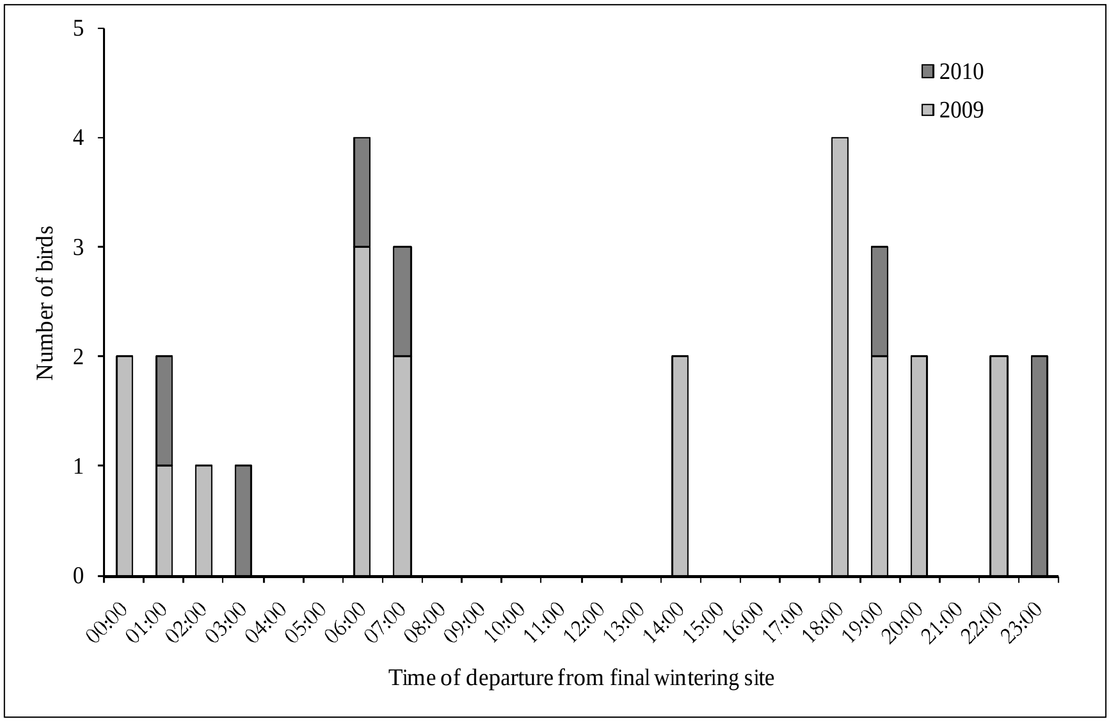


Figure 3. Timing of departure from wintering sites for Whooper Swans tracked from Martin Mere or Caerlaverock in 2010, in comparison with birds tracked from the same sites in 2009.

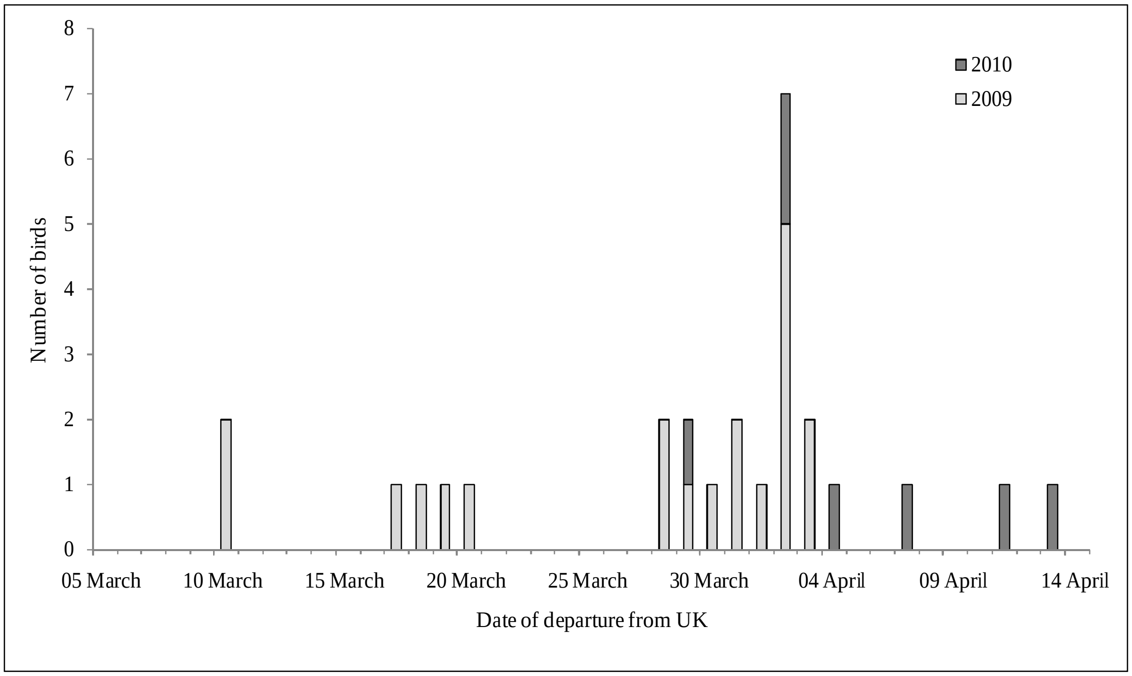


Figure 4. Dates of departure from the UK for Whooper Swans tracked from Martin Mere (ringing date for five of the birds from Martin Mere was 16 March 2010) or Caerlaverock in 2010, in comparison with birds tracked from the same sites in 2009.

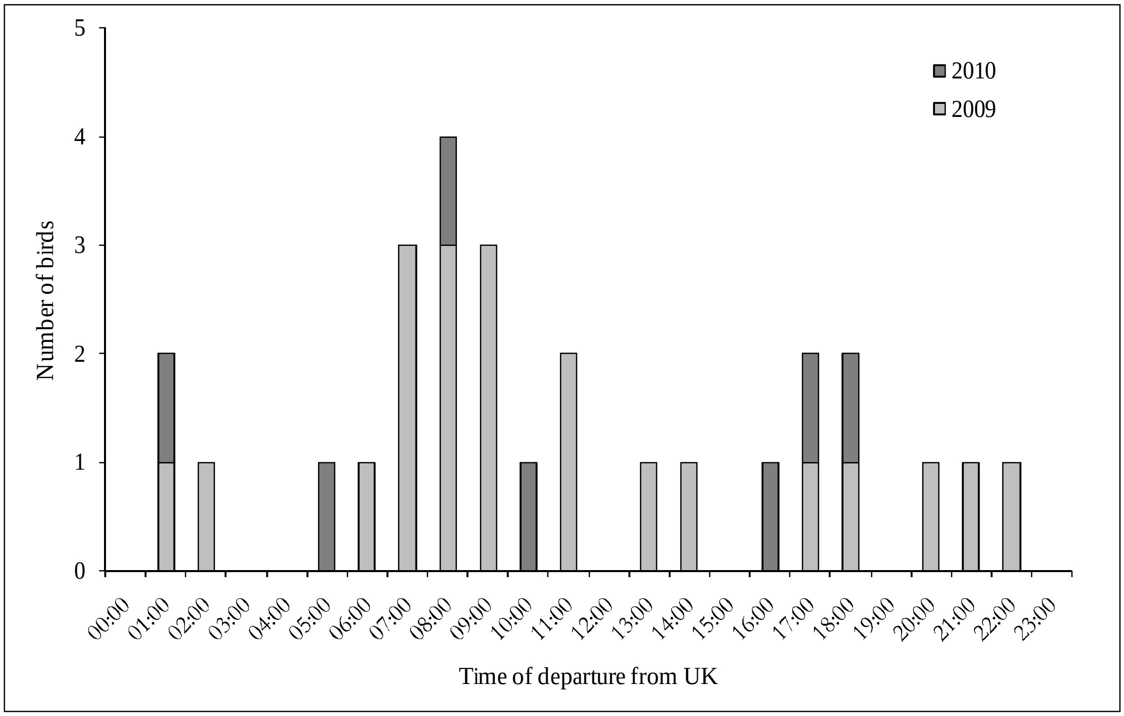


Figure 5. Timing of departure from the UK for Whooper Swans tracked from Martin Mere or Caerlaverock in 2010, in comparison with birds tracked from the same sites in 2009.

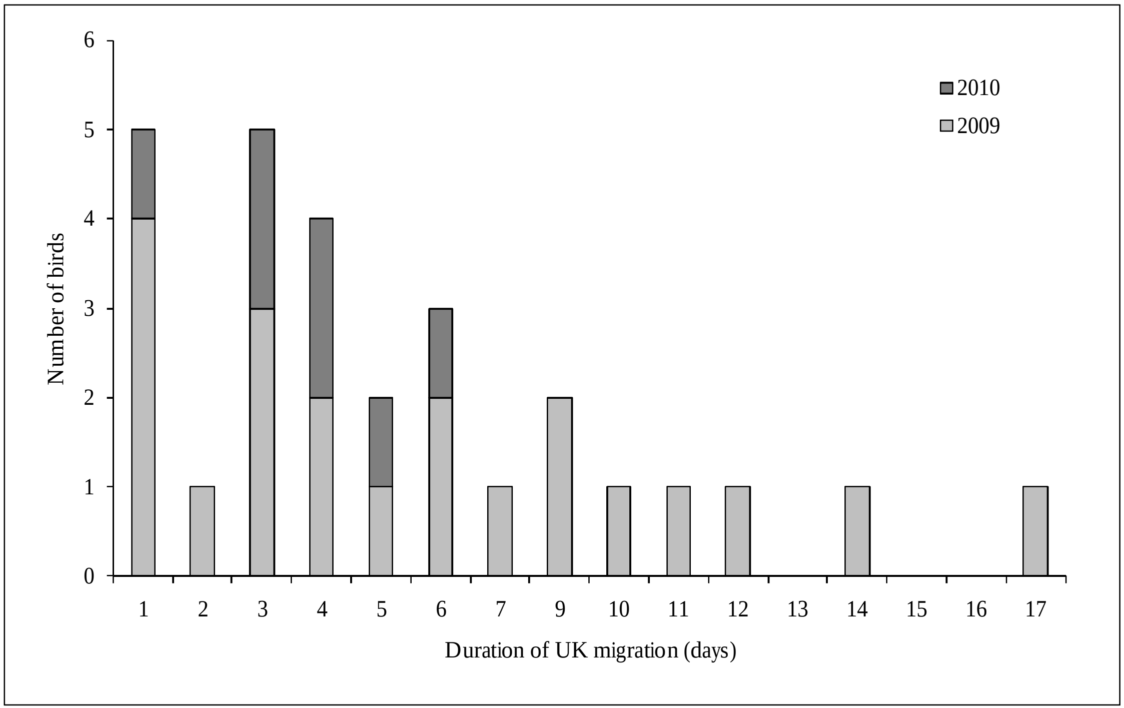


Figure 6. Duration of the UK migration for Whooper Swans tracked from their final wintering quarters at Martin Mere or Caerlaverock in 2010 compared to birds tracked from the same sites in 2009.

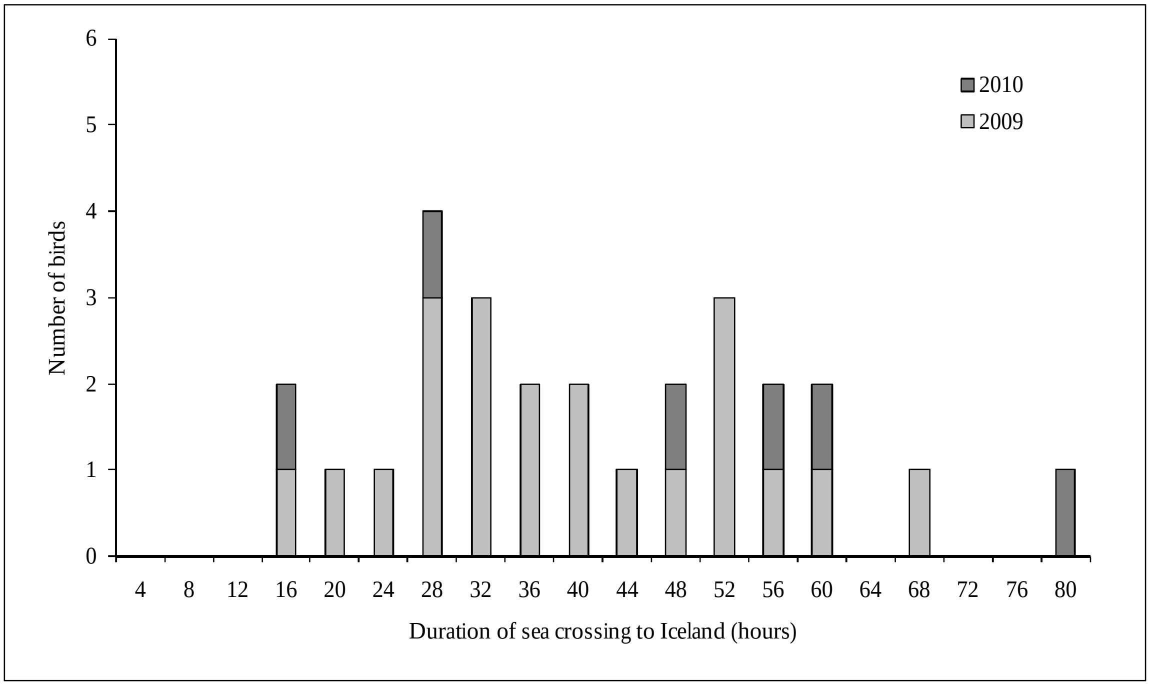


Figure 7. Duration of the sea crossing to Iceland for Whooper Swans tracked from their final wintering quarters at Martin Mere or Caerlaverock in 2010 compared to birds tracked from the same sites in 2009.

Given that swan migration is generally in a NNW direction (*i.e.* 337.5º) on heading through the UK towards Iceland in spring, winds of 271–360º and 0–45º are classed as head winds, 226–270º and 46–90º as side winds, and 91–225º as tail winds for the spring migration period.

As in 2009 (Griffin *et al.* 2010a), the Whooper Swans tracked in 2010 mostly commenced their migration from Martin Mere on south-easterly "tail" winds or slight south-westerly "side" winds (Figure 8).

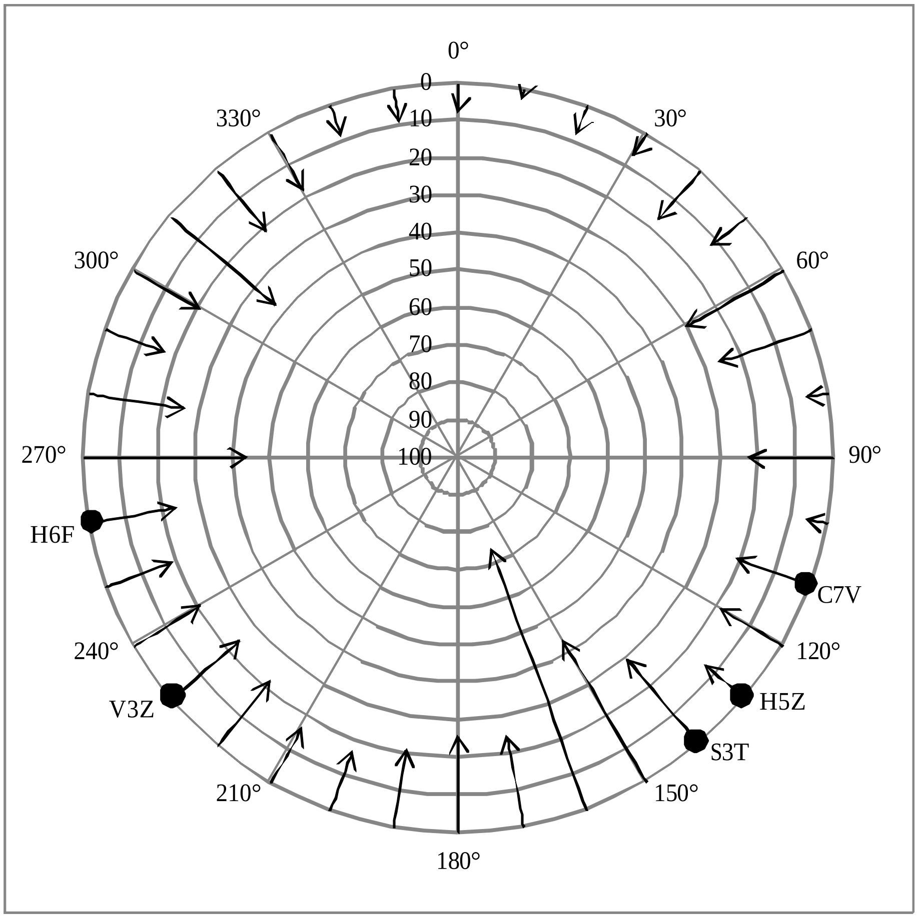


Figure 8. Wind direction recorded at Crosby Meteorological Station (18km from Martin Mere) at the time at which each of the five birds migrated from Martin Mere in 2010 (dot) in relation to the total number of hours (arrows) that winds were recorded from different directions over the period of the migration from the date of the catch to when the birds left the UK mainland. Wind direction of 90° = easterly wind, 180° = southerly, 270° = westerly and 360° = northerly.

Unlike 2009, however, some of the swans tracked in 2010 appear to have commenced and completed their migrations through the UK under conditions of decreasing and/or Low atmospheric pressure (Figure 9). These swans, migrating at the end of March, moved at the end of a period of >2 weeks of decreasing atmospheric pressure, 1–5 days before a period of *c.* 2 weeks of increasing and higher atmospheric pressure. Whether these swans were perhaps able to detect (see for example Kreithen & Keeton 1974) that the Low had bottomed out and was likely to be replaced in the short-term by High pressure conditions, or whether increasing day length (an indicator of the timing of spring migration for many species, including swans; Rees 1982) triggered their departure remains unclear. In 2009 nearly all swans migrated under conditions of increasing or high pressure within the UK (Griffin *et al.* 2010a).

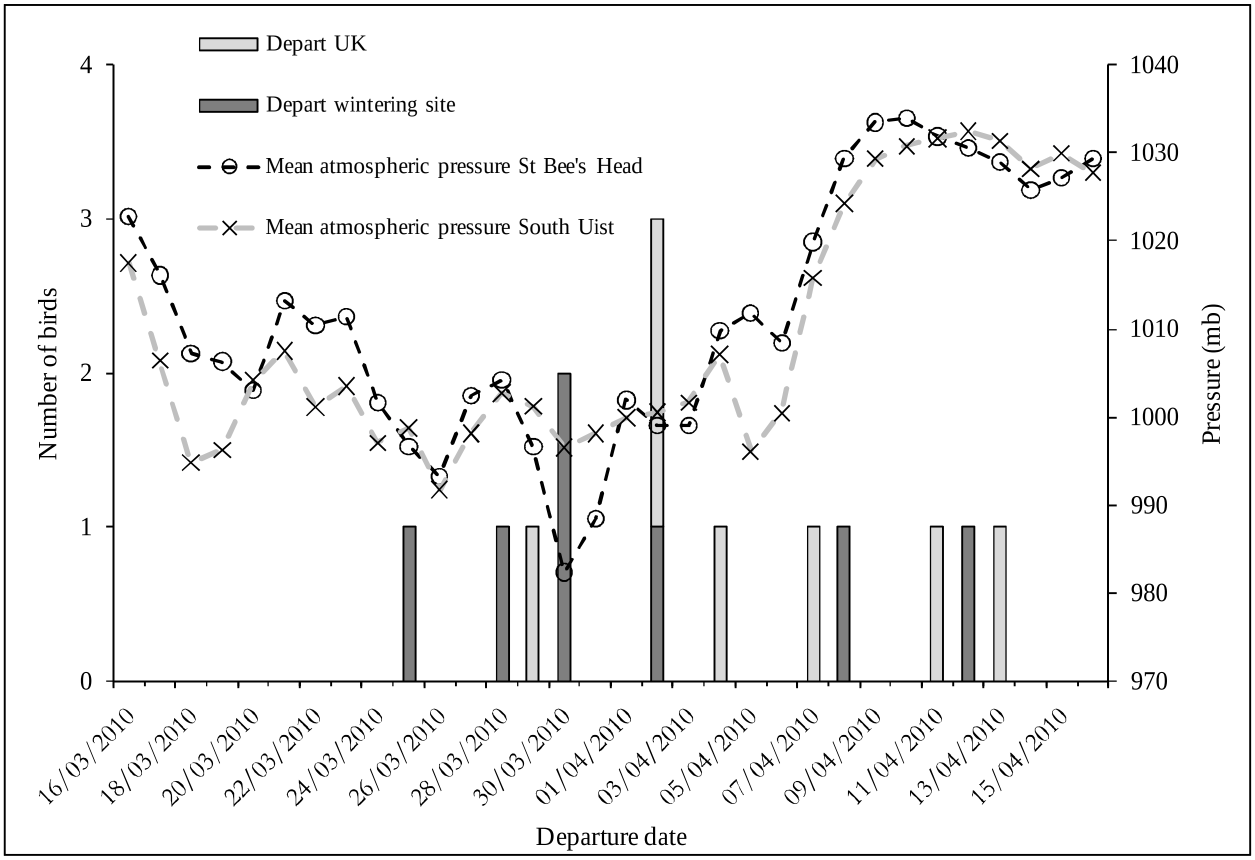


Figure 9. Dates of Whooper Swan departures in 2010, from their final wintering sites and also from the UK, in relation to the mean daily atmospheric pressure (adjusted to sea level) recorded at: (a) St. Bee’s Head (a central location 50, 65 and 110km from the swans departing Caerlaverock, Carlisle and Martin Mere respectively); and (b) South Uist (within 80km of all swan UK departure points).

Potential effect of weather conditions on the routes taken by migratory Whooper Swans.

The extent to which variation in weather conditions contribute to the differences in the tracks taken by Whooper Swans within the same or different years ("migratory drift") is being analysed separately in collaboration with Lund University, but some preliminary information is given here.

Whooper Swans (and also Barnacle Geese – see later) showed some variation between years in their broad migration routes (as illustrated in Figure 1), and swans migrating at much the same time (*i.e.* during a single spring or autumn), from the same starting points, take different routes between the UK and Iceland (Figure 10). Moreover, repeat tracks of the same individuals may differ between years (Figures 14 & 17 in the section on consistency of migration, later in this chapter).

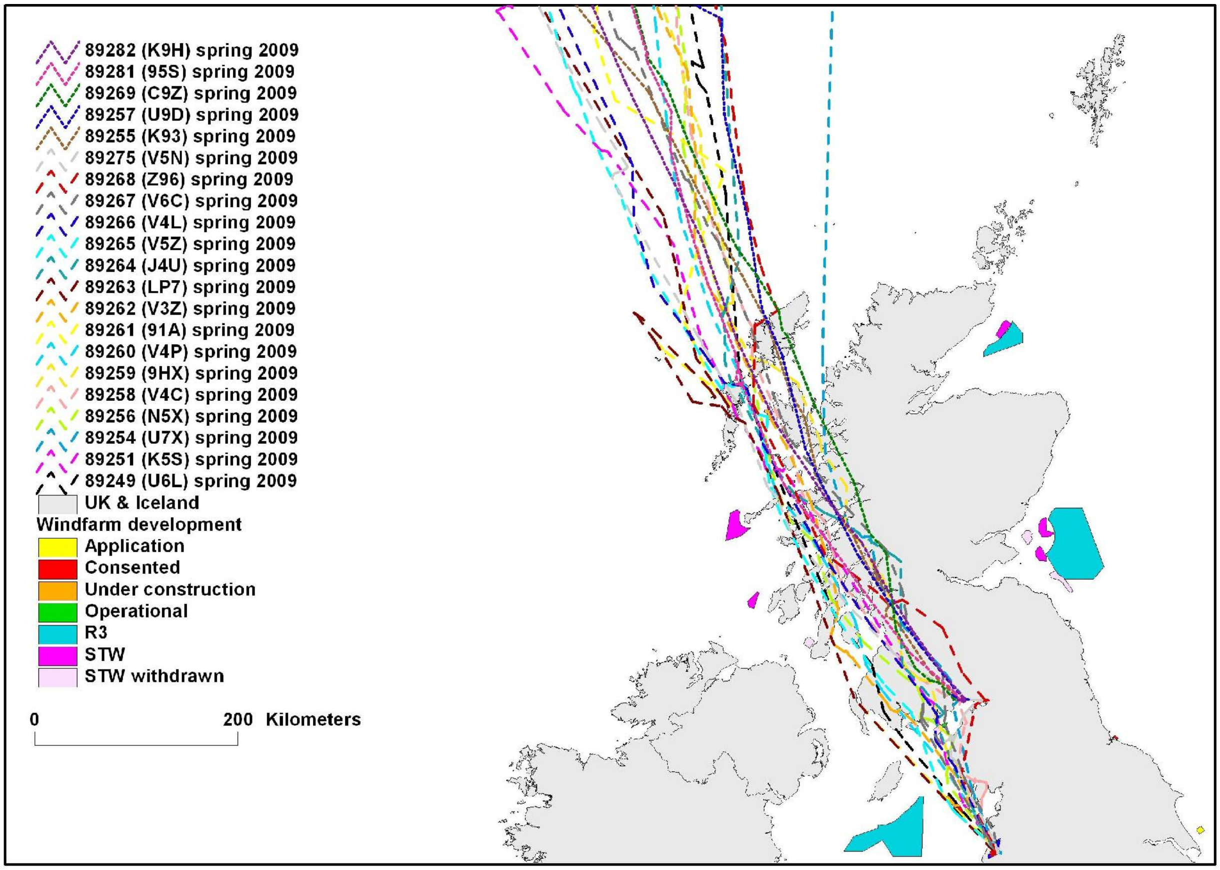


Figure 10. The migration routes of 21 adult male Whooper Swans tracked in spring 2009. These tracks were selected for birds that subsequently completed their migration to Iceland alive and with their tags intact from either WWT Caerlaverock (five birds - fine dotted lines) or WWT Martin Mere (16 birds – broader dotted lines).

In 2010, the five swans tracked from Martin Mere exited the UK across a migratory front of 100km, measured as how far west the birds were on leaving the country (V3Z = H5Z > C7V >H6F > S3T; Figure 1). Swans C7V, V3Z and H5Z probably encountered more periods of easterly winds during migration through the UK, which would have pushed them west, whereas H6F and S3T appear to have encountered more periods of side winds with a more westerly component (Figure 11). Y6K also migrated from Cumbria during a period of easterly winds and exited Britain just a little to the northwest of C7V/V3Z/ H5Z, whereas NA3 migrated from Caerlaverock on south/southwest side winds similar to those encountered by H6F and S3T.

In 2009, the exit routes of 21 swans tracked from Caerlaverock/Martin Mere to Iceland with their tags intact generally took a more easterly route (mostly departing over Lewis and the Uists) than the seven swans tracked in 2010, with those from Caerlaverock tending to be more easterly than those swans from Martin Mere, presumably because of their more easterly starting point (Figure 10). The reason for this broader difference between years is not clear from an examination of the prevailing wind directions during the respective migratory periods, although comparison of Figures 11 & 12 suggests a greater prevalence of easterly side winds in 2010, which will have tended to push the birds west in that year.

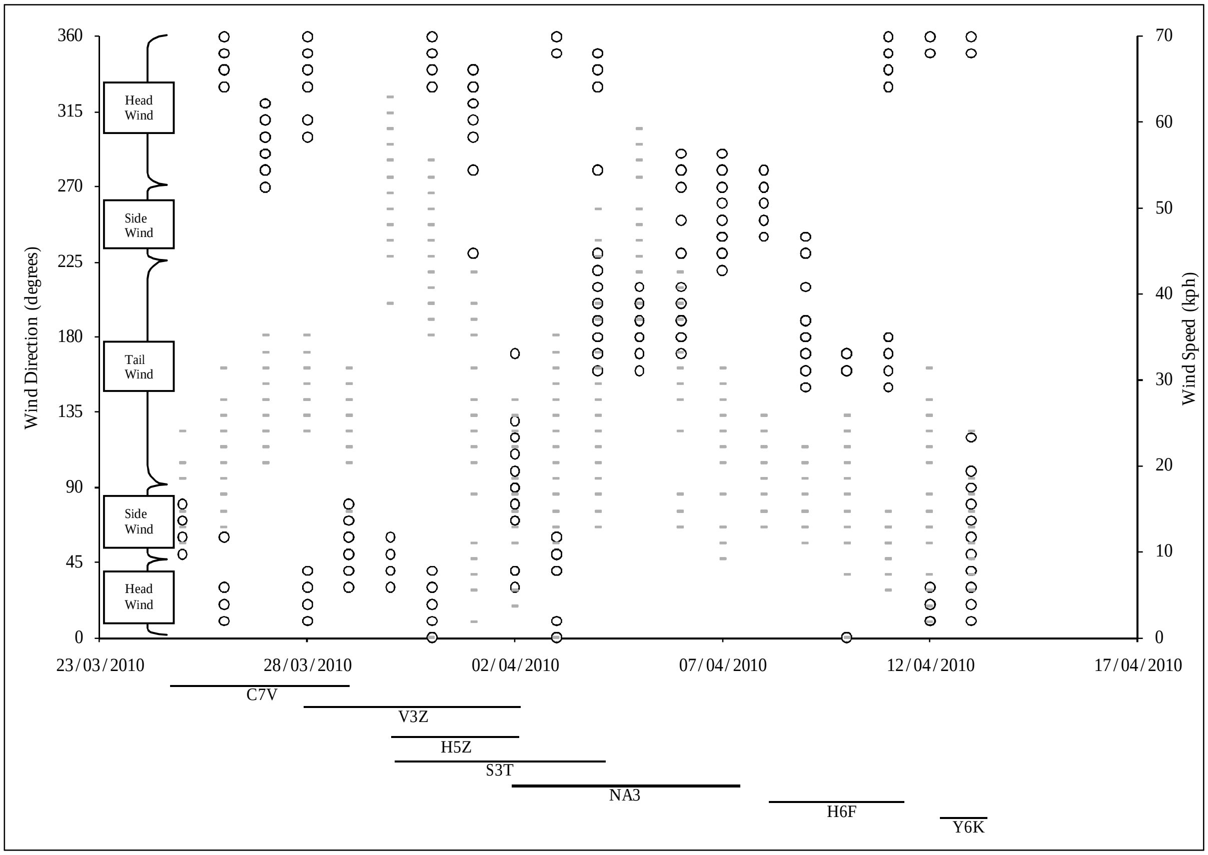


Figure 11. Hourly wind speeds (kph; dashes) and direction (to the nearest 10°; circles) recorded at the Tiree Meteorological Station in spring 2010, in relation to the migration of Whooper Swans tracked from Martin Mere and Caerlaverock. Ring codes plus lines represent the period during which the bird was migrating through mainland UK. Exit routes from the UK for these individual swans are illustrated in Figure 1. Wind direction: 90° = easterly wind, 180° = southerly, 270° = westerly and 360° = northerly; 28kph = Beaufort 4, a moderate breeze. Given that Whooper Swan spring migration is broadly NNW (*i.e.* 337.5°) for birds heading through the UK for Iceland, winds of 271–360° and 0–45° are classed as head winds, 226–270° and 46–90° as side winds, and 91–225° as tail winds.

Further consideration of individual tracks in relation to wind conditions in 2009 (by comparing Figures 10 & 12) suggests that the pattern seen in 2010 was not apparent in 2009, in that birds exiting the UK from more westerly positions did not necessarily encounter more easterly winds during their 2009 migration. Wind direction data available for 2009 did not have the resolution of that in 2010 (45° and 10° respectively), however, making it more difficult to determine accurately the wind conditions encountered by the birds in 2009.

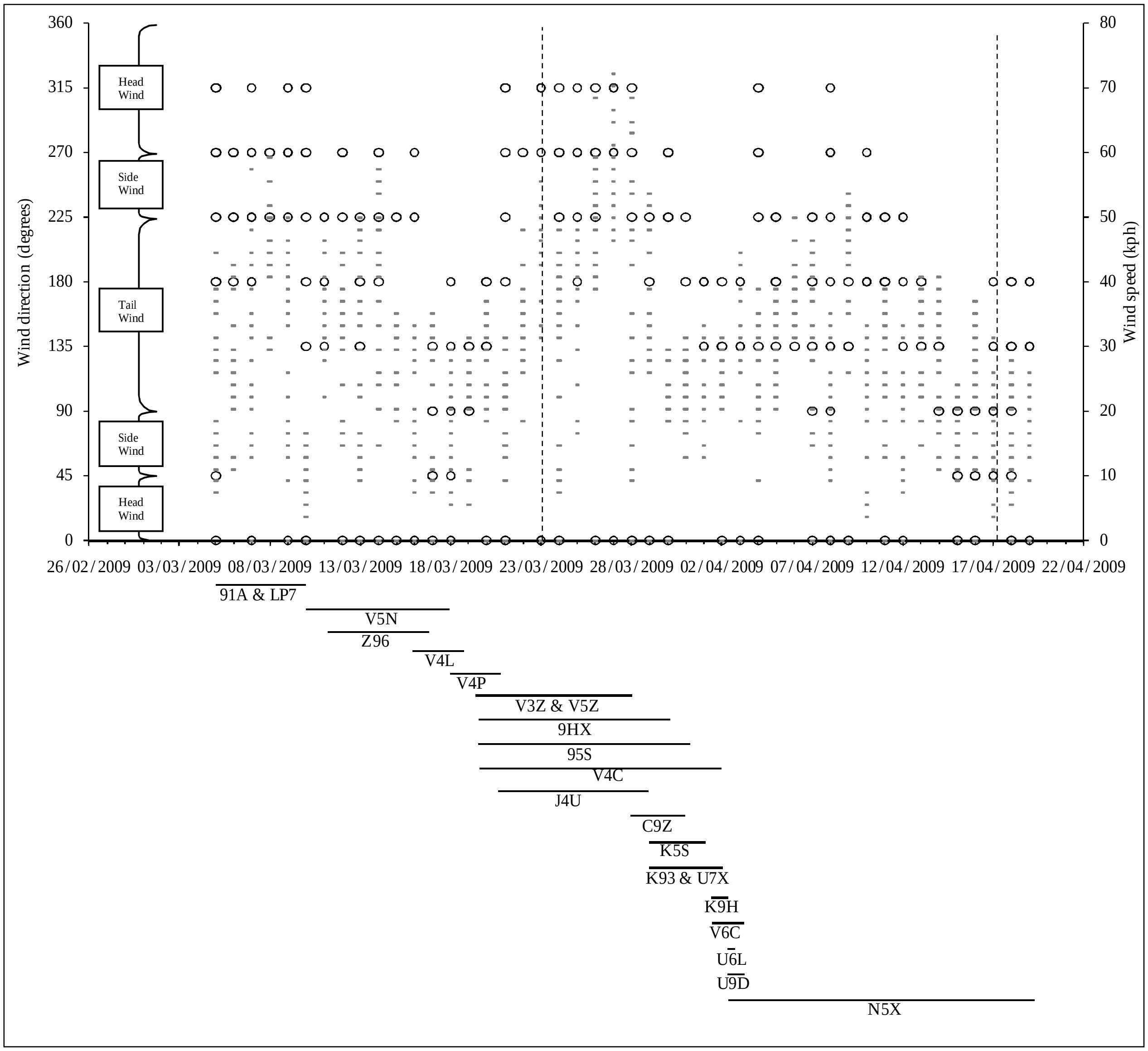


Figure 12. Hourly wind speeds (kph; dashes) and direction (to the nearest 45°; circles) recorded at the Tiree Meteorological Station in 2009, in relation to the migration of Whooper Swans tracked from Martin Mere and Caerlaverock in 2009. Ring codes plus lines represent the period during which the bird was migrating through mainland UK. Exit routes from the UK for these individual swans are illustrated in Figure 1. Wind direction: 90° = easterly wind, 180° = southerly, 270° = westerly and 360° = northerly; 28kph = Beaufort 4, a moderate breeze. Winds of 271–360° and 0–45° = head winds; 226–270° and 46–90° = side winds; 91–225° = tail winds.

Thus to conclude, wind direction particularly in the form of side winds (as swans are less likely to fly into head winds) may potentially influence the routes taken by Whooper Swans out of the UK. However, this examination of differences in wind directions over two springs, in relation to the routes taken by different individuals, is quite crude particularly given the narrow front (< 200km) over which all tagged swans in the western migratory corridor exited the UK. A full analysis of the potential effects of wind conditions on the swans' migration routes would need to integrate wind speed and direction at all stages of each individual's migration, from the meteorological stations closest to those legs of the route, at all times at which they were flying. These analyses are being taken forward through external collaborations. Such an analysis would help to tease out the extent to which the variation in the routes taken between years and by different individuals is attributable to prevailing weather conditions, as opposed to individuals following innate routes or diverting to visit temporary stopover sites to feed as necessary. For example in 2010, swan NA3 showed a clear intention to migrate from Martin Mere north, but aborted the migration and headed southeast to Caerlaverock (a site of which it is assumed the bird had prior knowledge), where it stayed to feed for nearly a month (Figure 1). Likewise, swan S3T visited Caerlaverock for nearly two days after leaving Martin Mere. It is likely that such diversions are based on the swans' prior knowledge of stopover sites, which individuals might weigh against prevailing weather conditions and in relation to feeding requirements.

Consistency in the migration routes of individual swans

The previous section provides a broad assessment of the weather conditions experienced by the tracked birds over the migration period; the current section considers in greater detail how weather (particularly wind conditions) influences consistency in the migration tracks of individual birds.

Four swans were tracked in both spring and autumn, or in two consecutive springs, in 2009 and 2010 (Figure 13).

Of these, swan 89292 (Y6K) migrated direct between Iceland and Ireland without passing through Britain.

All four migration tracks took a more westerly route in autumn than in spring (Figure 13).

Swan 89262/89266 (V3Z), tracked on migration from WWT Martin Mere in both springs (having originally been fitted with a transmitter in 2009, and receiving a new transmitter in March 2010), took a more easterly route in 2009 (via Mull, Skye and finally Lewis) than 2010 (heading via Islay, Tiree and Barra to Iceland). Although the ocean crossings from the UK to Iceland differed by up to 200km in the east-west trajectory between these two years, it is interesting to note that this swan navigated to the same entry point on the southeast coast of Iceland on each occasion.

Swan 89285 (NA3) flew from SW Iceland in autumn 2009, and took a westerly route south through Scotland (similar to that described for V3Z), but in spring 2010 he took a more easterly route north via WWT Caerlaverock and then inland passing close to Ayr, and exiting the UK via Mull, Skye and Lewis.

Swan 89290 (Y5T) also headed from the southwest coast of Iceland in autumn 2009, on his migration direct to Ireland. In spring 2010 he took a much more easterly route to arrive on the southeast coast of Iceland.

Swan 89292 (Y6K), marked in Iceland in August 2009, has provided three migratory tracks. He flew direct from SW Iceland to Ireland in autumn 2009, then moved east mid-winter via Kintyre and Arran to settle at a site just west of Carlisle, where he was seen looking fit and well with other swans during the winter months. In spring 2010 he migrated north passing close to WWT Caerlaverock and then via Arran, Mull and South Uist to cross the Atlantic 200–400km west of his autumn route, arriving over the southeast coast of Iceland. During the summer this non-breeding bird (again seen looking fit and well in a non-breeding flock in Iceland) gradually moved west along the coast to exit Iceland in autumn 2010 at exactly the same departure point as in 2009. The swan followed a very similar route south as in 2009 until about mid-Atlantic when it appeared to take a more easterly route to arrive near Stranraer before moving via the north Solway coast to the east side of the UK near Lindisfarne. After feeding on fields around the Tweed near Coldstream for a few days he moved to WWT Welney, but returned to SW Scotland during the cold snap in SE England in December 2010 and sadly died on colliding with power-lines near Newton Stewart, Dumfries & Galloway on 1st February 2011 (Figure 13).

Of 50 swans originally fitted with transmitters in the 2009 study, only two tags recorded GPS fixes an hour apart for positions immediately before and after crossing an operational wind farm or one under construction. In both cases, the data indicated that the birds gained height to avoid the potential obstacle. Changes in the status of wind farm sites since the COWRIE report are given as a footnote to Table 5.

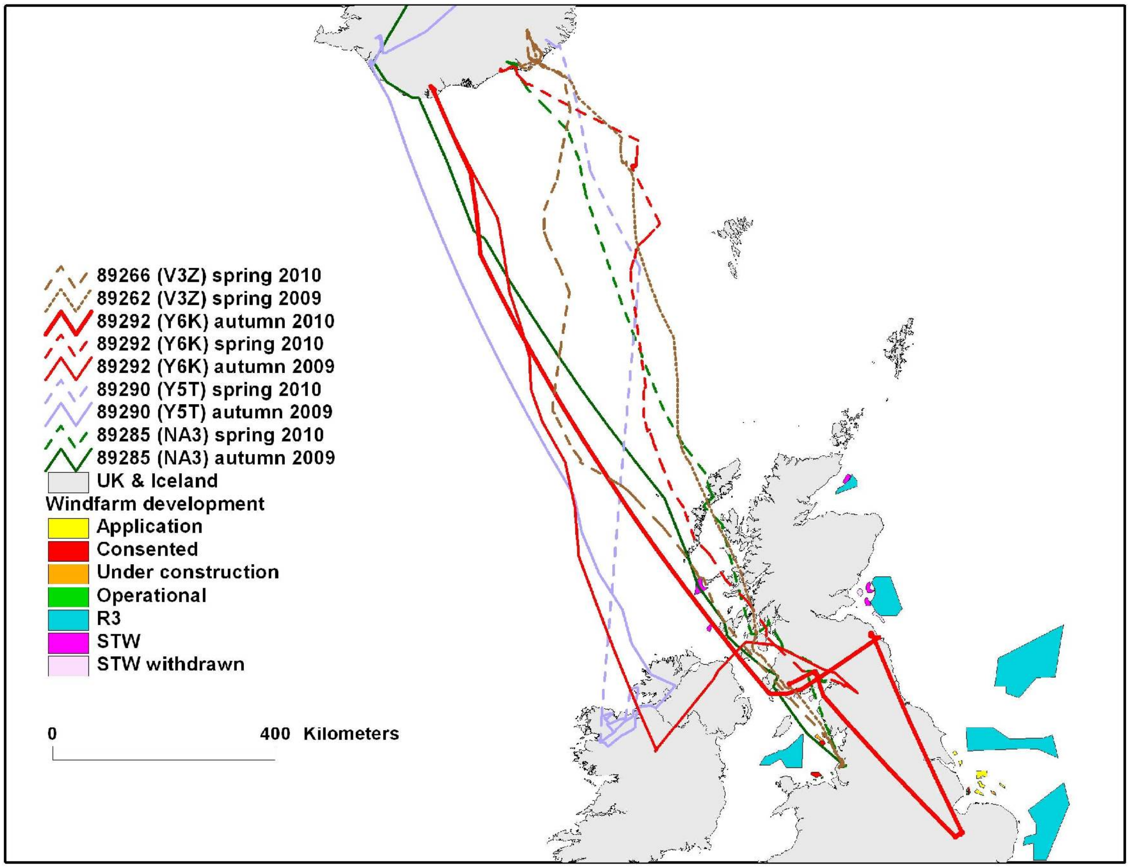


Figure 13. The full migratory return routes of Whooper Swans tracked between UK/Ireland and Iceland in 2009 and into 2010. Dashed lines show spring routes, solid lines show autumn routes, with different colours representing the different birds. Note: swan V3Z was fitted with two different tags in the two years. Only two birds were tracked in the same season in both years: swan V3Z from Martin Mere and swan Y6K from SE Iceland.

More detailed consideration of the two spring migration tracks recorded for swan V3Z ("Tony"), fitted with two different tags (89262 and 89266) at Martin Mere, showed that whilst information about the initial part of the migration was somewhat sparse in 2010 compared to 2009, the bird appeared to follow a similar route in both years as far north as the Kintyre peninsula (Figure 14). Thereafter the routes diverged rapidly, with the track being more easterly in 2009 (passing through Mull, Skye and finally Harris to the south of Lewis from 21–28 March), whereas the more rapidly flown seaward route taken in 2010 passed over Islay, Tiree and finally Barra to the south of the Uists from 1–2 April. Wind conditions from the 21–28 March 2009 generally were more westerly, whereas in 2010 (especially on 1st April) they appeared more easterly and were quite strong, for instance around Tiree. This could have led to the divergence of the tracks along more easterly and westerly flight-lines in these two years respectively. Moreover, pressure maps at the time of V3Z's departure from the UK for Iceland, indicated that the tracks should have continued to diverge, at least initially (Figures 15 & 16). Winds became calmer with progress towards Iceland on 3rd–4th April 2010, and V3Z was able to take a more northerly route to arrive in SE Iceland at exactly the same point (Lonfjordur) as in 2009 (Figure 13), despite the tracks having diverged by > 200km mid-Atlantic and V3Z having travelled ~50km further on its migration from Scotland in 2010 than in 2009.

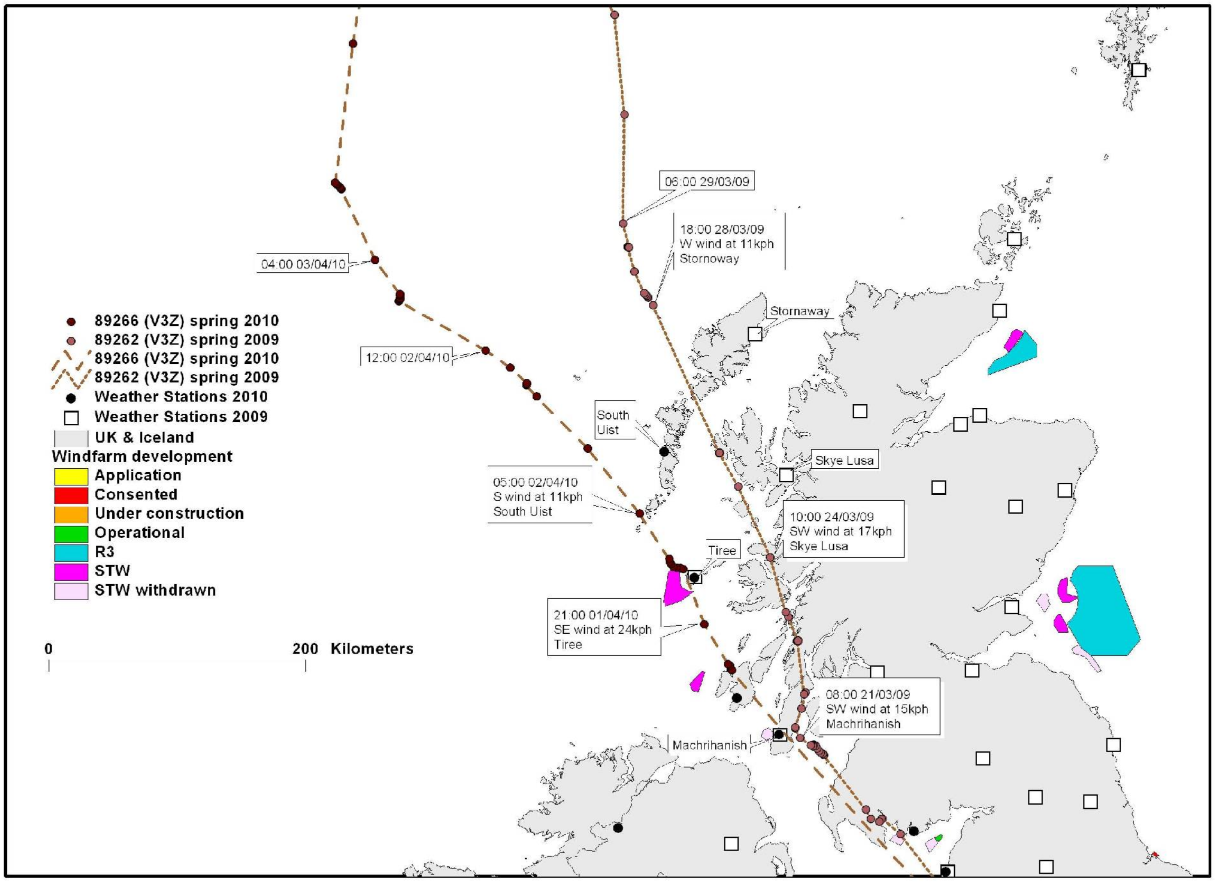


Figure 14. The two spring migration routes taken by Whooper Swan V3Z (Tony) from Martin Mere in 2009 and 2010. Fine dotted line = tag 89262 (fitted in 2009) and broad dashed line = tag 89266 (fitted in 2010). The times and dates of significant movements along the migratory route are shown in relation to wind observations made at the closest Meteorological Stations to those sections of the journey.

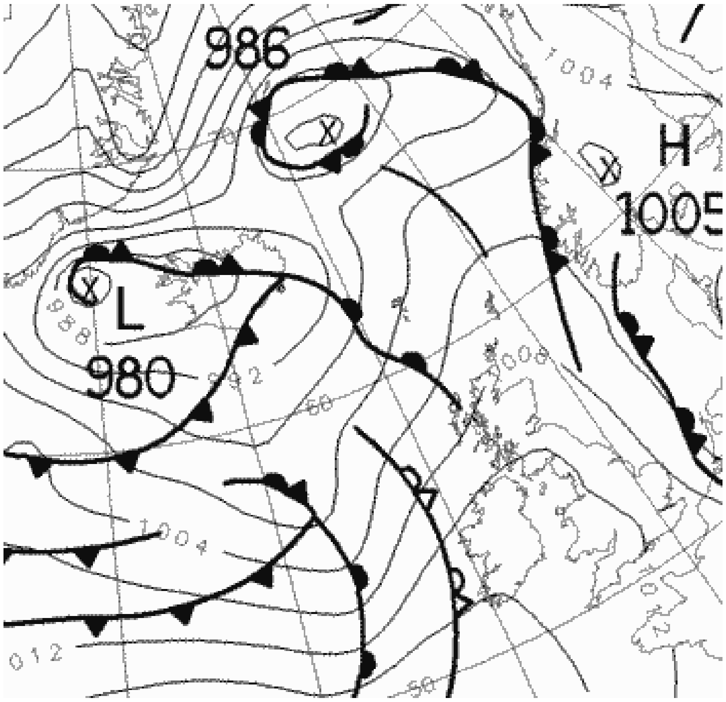


Figure 15. Meteorological chart for 00:00 h on 29 March 2009, showing the isobars and pressure systems when Whooper Swan V3Z ("Tony") exited the UK in spring 2009.
With the systems moving eastwards over time it can be seen that by 06:00 h the westerly winds will continue anti-clockwise around Low 980.

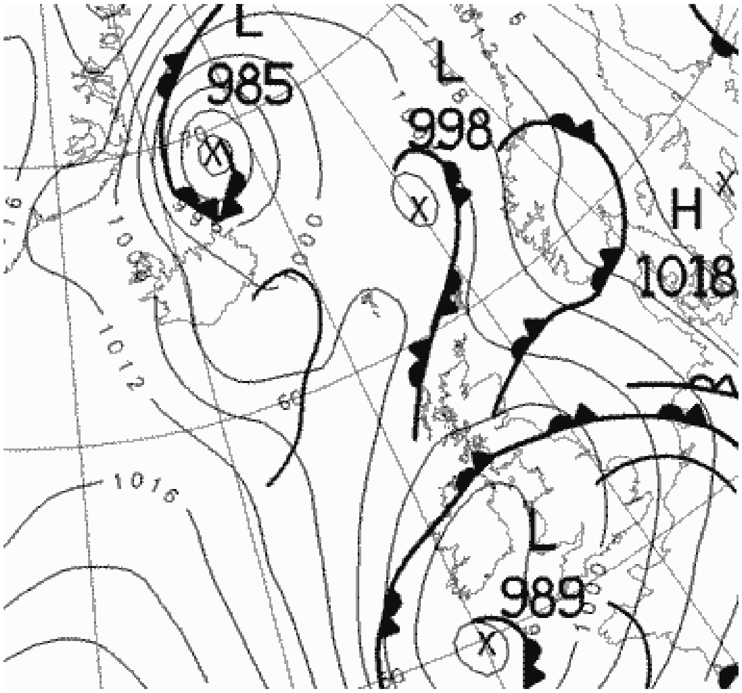


Figure 16. Meteorological chart for 00:00 h on 3 April 2010 showing the isobars and pressure systems when Whooper Swan V3Z ("Tony") exited the UK in spring 2010.
With Low 989 moving northeast the isobars become more tightly packed by 04:00 h, with a strengthening north/northeast wind with "slack" areas of calm conditions closer to Iceland.

Swan Y6K similarly provided detailed tracks for two consecutive autumn migrations, in 2009 and 2010, from the same exit point in SW Iceland. In 2009 the swan progressed rapidly from Iceland, probably leaving the Icelandic coast early in the morning of 1st November to arrive in NW Ireland early in the morning of 2nd November, after a journey of what seems likely to have been ~24 hours. Likewise in 2010, Y6K seems to have departed from Iceland early in the morning of 19th October and was in SW Scotland (at Stranraer) by 05:00 h the next day after a flight again of ~24 hours, or possibly less (Figure 17). Fewer locations were provided by the transmitter in 2010; probably because the shorter days reduced solar re-charge of the transmitter battery during the autumn. However, the 2010 migration clearly was more easterly than in 2009, and it seems that the routes diverged south of the half-way stage between Iceland and UK/Ireland. Data from the Stornoway Meteorological Station (the nearest station to the bird) indicates that Y6K encountered easterly winds from the afternoon of 1st November 2009 onwards, which may have caused him to drift west towards Ireland (see also Figure 18). By 05:00 h on 2nd November, when Y6K was stationary in NW Ireland, the winds were more westerly. In 2010 there is little data available on the bird's progress and so it is more appropriate to assess conditions from the pressure maps for that period (Figure 19); also, there are no detailed Meteorological Station data available for that period. Pressure maps for 19–20 October 2010 give little reason to expect any deflection in the swan's track as it migrated south, and the alignment of the high and low pressure systems at that time should have conveyed the bird rapidly south to Scotland, which appears to have been what happened.

The differences in the migration tracks recorded for swans V3Z and Y6K over two spring and two autumn migrations respectively serve to illustrate the extent to which the routes may differ between years in line with prevailing weather conditions.

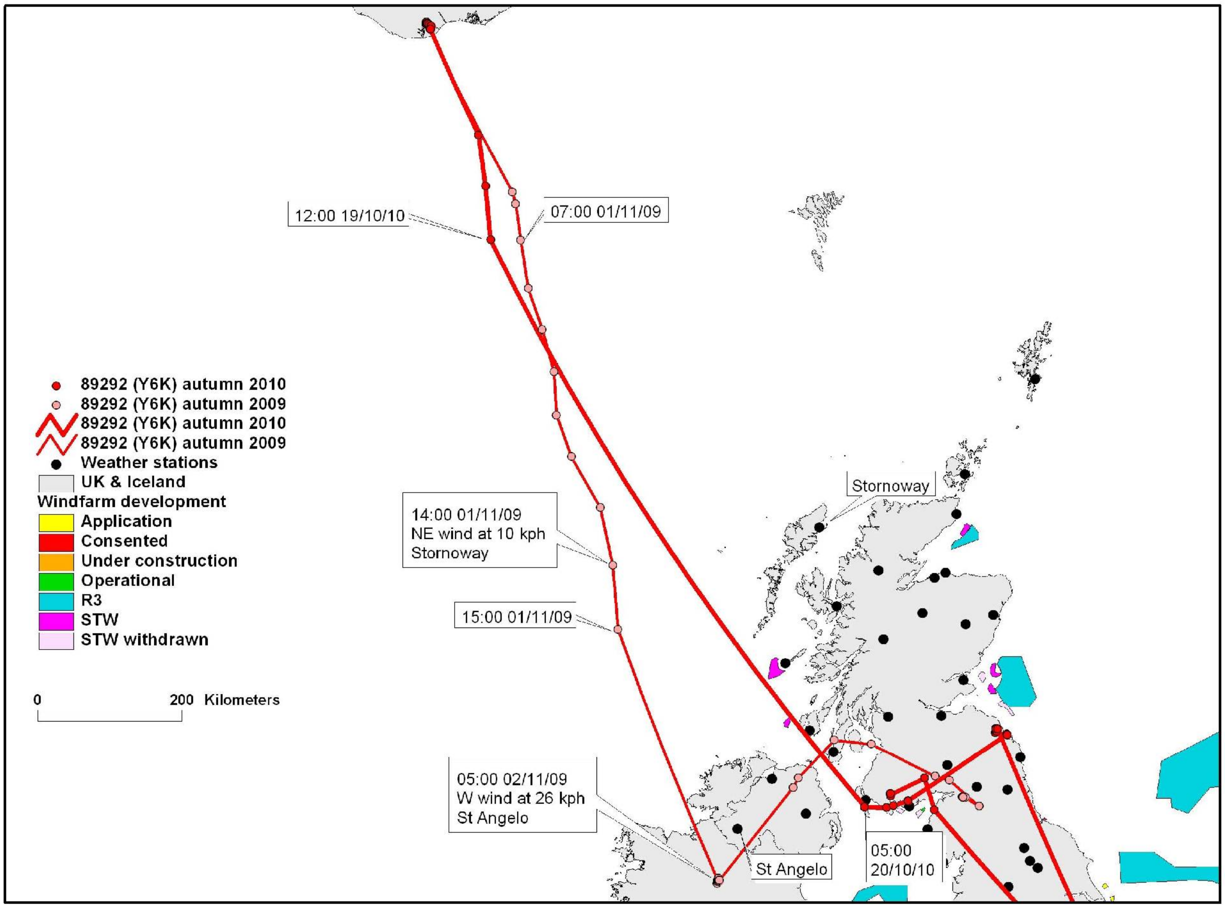


Figure 17. The two autumn migration routes taken Whooper Swan Y6K (tag 89292) from SW Iceland in 2009 (thin solid line) and 2010 (thick solid line) respectively. The times and dates of significant movements along the migratory route are shown in relation to wind observations made at the closest Meteorological Stations to those legs in the journey. Due to low light availability for solar charge of the tags in autumn, the 2010 route is not as detailed as in 2009 and the extrapolation across the North Atlantic between the GPS fix at 12:00 19/10/10 to the fix at 05:00 20/10/10 should be treated with caution.

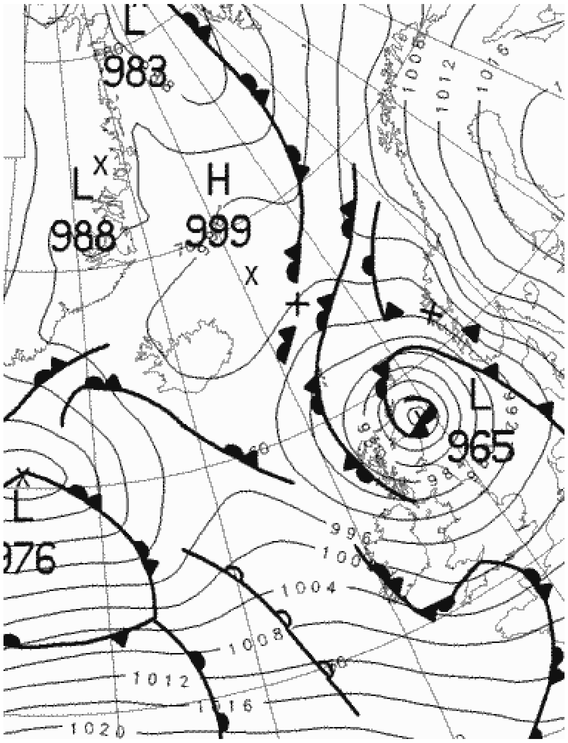


Figure 18. The meteorological chart for 00:00 h on 2nd November 2009, showing the isobars and pressure systems relevant to Whooper Swan Y6K when arriving in the UK/Ireland in autumn 2009.
With the Low 965 positioned over NE Scotland and moving east, this system with its fairly strong anti-clockwise winds will have deflected swan Y6K westwards if it was trying to approach Scotland at or before this time, which seems likely from the knowledge available for its track (see Figure 17).

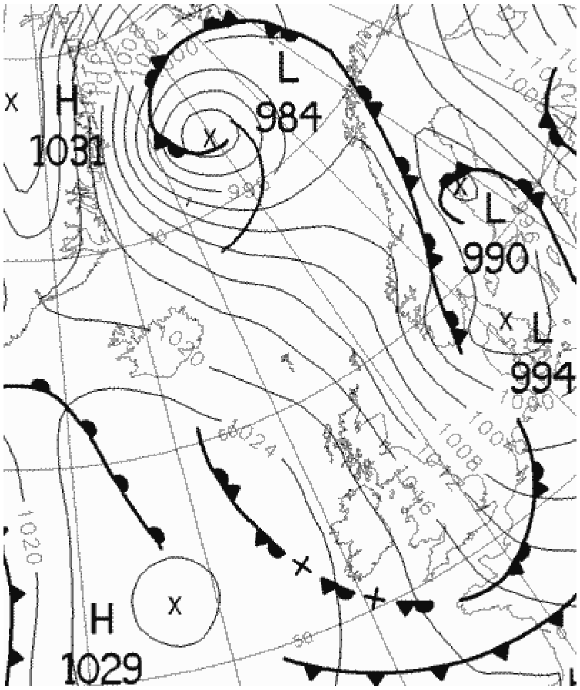


Figure 19. The meteorological chart for 00:00 h on 20th October 2010, showing the isobars and pressure systems relevant to Whooper Swan Y6K when arriving in the UK/Ireland in autumn 2010.
With Low 984 positioned to the northeast of Iceland and High 1029 to the west of Ireland for much of the 19th and 20th October, fairly strong northerly winds travelling along the isobars between these two pressure systems will have aided the rapid migration of Y6K south from Iceland (see Figure 17).

5.3 Objective 3: To undertake an extended analysis of Whooper Swan flight paths in relation to both onshore and offshore wind farm locations to provide comprehensive information on the number of wind farms along the swans' flight paths from southern Britain.

Work Task 7. Incorporate onshore wind farm locations into the GIS.

Onshore wind farm datasets were obtained both from Scottish Natural Heritage (SNH) and from RenewableUK (RUK, formerly the British Wind Energy Association). Analysis of data provided in October 2010 for the Interim Report found a large number of discrepancies in onshore wind farm locations recorded in the two datasets. Verification undertaken for sites in Scotland suggested that the SNH data were more accurate for Scottish wind farm sites (Griffin *et al*. 2010b).

The onshore and offshore wind farm location data analysed in this Final Report are derived from updated versions of the SNH and RUK wind farm datasets, and are considered to be as up-to-date as possible. Information on the Crown Estate offshore wind farm footprints was also updated to provide current information on any of the 48 sites that have changed their developmental status, for instance Scottish Territorial Waters (STW) sites that have withdrawn from the planning process since the Interim Report (Griffin *et al*. 2010b, Table 5) was completed. Withdrawn STW sites were nevertheless included the analyses, in case they are reconsidered for future development. The UK wind farm datasets therefore are believed to be valid up to 1st June 2011, and these were analysed in relation to all tracking data recorded for Whooper Swans and Barnacle Geese, including new data recorded for the geese in spring 2011 (*i.e.* not included in Griffin *et al.* 2010b), up to the end of May 2011.

Additionally, data on wind farm locations along the coast of Norway were obtained from the Norwegian Energy Directorate, for analysis in relation to the migration of the Svalbard Barnacle Goose population. These data are valid up to March 2011.

Treatment and verification of the newer SNH and RUK datasets followed a similar process to that described in the Interim Report (Griffin *et al.* 2010b), although the treatment of these newer versions of the datasets is repeated here (below) for future reference.

Treatment of SNH data:

A total of 1,517 onshore and offshore wind farms were included in the SNH Excel database. Sites classed as "Scoping", "Application", "Approved" or "Installed" or which were unclassified were retained for the analyses; those classed as "Lapsed pre-application", "Pre-application", "Refused", "Withdrawn" and "Decommissioned" were omitted. Thus 794 sites within Scotland were constructed or within the planning process. Of these, 387 wind farm sites with ≥ 5 turbines, or where the number of turbines was not stipulated were retained; smaller sites were not included because feedback on the Interim Report suggested a threshold size of wind farm should be considered for the analysis of overlap between migration routes and wind farm footprints. The error of the wind farm locations together with the positional error of the tags would make interpretation of overlap with small installations difficult (Rowena Langston, pers. comm.).

Of the 387 sites included, 90 did not have any information on the number of turbines present or planned. However, for 35 of these, information on the number of turbines present was implicit in the description given under the "Development Name" heading, for instance "Newton of Fortrie (3 turbines)" or "Little Hilton Farm Wind Turbine". This information was used to fill in some of the missing values, and where the number given was < 5 turbines (*i.e.* at 34 of the 35 sites), the sites were again deleted.

Of the 353 sites remaining, 10 were offshore sites more comprehensively covered by the Crown Estate database, developed in the GIS for the interim report. Entries for R3 and STW sites therefore were deleted, leaving just the “Aberdeen Offshore Wind Deployment Centre” and the “Methil – Offshore Wind Demonstrator Sites”. Thus there were now 345 sites from the SNH database being considered for the analysis.

Of the remaining 55 sites without direct information on the number of turbines present, 11 had information on the installed capacity which via a rearrangement of the equation developed in the interim report relating capacity to the number of turbines at a site allowed for the calculation of the likely number of turbines at these sites, *i.e.* $y/2.8677 = x$, where ‘y’= MW output and ‘x’ = the number of turbines.

Of these 11 sites, two were calculated to have < 5 turbines and so these sites were deleted. Of the 44 sites remaining without either turbine number or MW capacity information, the median turbine number of 9.5 rounded up to 10, as calculated in the interim report, was substituted. This included 32 “Scoping” sites, five “Application” sites, and two “Approved” sites plus five sites with unknown status.

Following this process, 343 sites remained in the SNH database. Of these sites 125 had no information on Mw capacity; this was calculated from knowledge of the number of turbines using the equation cited above. Of this total number of sites, nine were of unknown status, 143 were “Scoping”, 79 “Application”, 55 “Approved” and 57 “Installed”.

One of the nine sites of unknown status also had an unknown name and no grid reference; this site was deleted. The site names of the other eight sites were checked against the RUK dataset but they did not appear to be present in that dataset.

In addition to the Excel database of site details, SNH supplied an ESRI shapefile of wind farm footprints and turbine positions as polygon and point coverage respectively.

There were 24 turbine sites without matching polygons where the number of turbines was less than five and these were deleted.

The polygon footprints for 268 sites were exported into Excel, with the number of turbine locations in each footprint having been counted in the GIS. The number of turbines was then plotted against footprint area giving the equation: $y = 0.0135x + 9.1531$ where $r^2 = 0.55$ (with one outlier removed and zero values filtered out). This equation was used to predict the turbine numbers for 48 footprints where SNH did not have turbine positions in the GIS layer.

This dataset was then joined to the original Excel database via the site ID numbers to check whether there were any sites not represented in the original SNH database, or if further information was present in the GIS data.

When joined to the original Excel database of 342 sites there were 196 sites for which there was information in both datasets and 67 cases where wind farm sites were only present in the GIS layer and not in the original Excel file. Of these 67, 45 sites had < 5 turbines and were deleted.

One site classified as “Application” in the GIS layer was recorded as “Approved” in the original Excel database, the updated situation being accepted. The number of turbines recorded by the two datasets was mostly similar and in all cases where both datasets provided different numbers, the original Excel database was taken to represent the “true” situation (because there was some evidence of the double digitising of turbine points on the GIS layer and overlapping polygons for wind farm sites too).

For records that matched between the Excel file and the footprints file all that was retained from the GIS was the grid reference for the central location within the footprint area as derived from the polygons within the GIS or for centrally weighted location based on the distribution of the turbine locations.

For the other 146 wind farms in the original Excel database there was no corresponding record in the GIS layers and so the grid reference in the Excel database was used to generate the locations for these sites when importing back into the GIS. This process identified 10 records in the Excel file that had no proper recognised grid references. Two of these records were found to have a grid reference in the GIS layer that could be used. For the other eight sites it was noted that four had been given the median turbine number and another had only six turbines so these five sites were deleted (including three “Scoping” sites and two of unknown status) as they were small, probably being just larger than the threshold cut-off level of < 5 turbines and no further information was available for them. The grid references for the likely positions of the other three sites (all at the “Scoping” stage), containing 20, 29 and 50 turbines, were derived from the Ordnance Survey’s “Get-a-Map” website.

After the deletion of a couple of duplicate sites and Robin Rigg, and the correction of the grid reference for the Marbrack site in Dumfries & Galloway which was given a NY grid reference rather than a NX one, 357 sites remained in the final SNH dataset in the GIS.

Treatment of RUK data:

All RUK data on wind farms at the Operational”, “Construction”, “Consented” and “Planning” stages were copied from the RUK website on 6th June 2011. These data were pasted into an Excel spreadsheet, which indicated a total of 827 wind farm sites (including those within Scotland listed on the website, and also offshore wind farm sites).

‘Latitude’ and ‘Longitude’ values were filtered for nonsensical values, identifying five wind farms, including three “Consented” of ≤ 3 turbines (each of which were deleted) and two at the “Planning” stage (including one with 12 turbines in South Lanarkshire) which were also deleted.

‘Latitude’ and ‘Longitude’ were then filtered for missing values which gave 85 sites in total including 63 “Planning”, 16 “Consented”, 2 “Construction” and 4 “Operational”. Of these, 30 sites were in Northern Ireland and 6 in Wales and so not in areas key to the analyses in this report. A further 31 in Scotland were thought likely to be better covered by the SNH dataset, and two were offshore sites and so would be better covered by the Crown Estate dataset. The rest of the sites were scattered across England and because only 16 sites overall had > 15 turbines, and because they were mostly in areas that did not interact with the broad migratory corridors, this whole set of 85 wind farms was deleted.

The data were then filtered for those sites having zero turbines as an attribute. This identified a site in Scotland and an offshore site, both of which would be better covered in those other datasets; both therefore were deleted.

As a precursor to establishing a median ‘Power per Turbine’ value (necessary, as described below, for calculating a ‘Megawatt Capacity’ value for sites where the information was not listed in the database) all data available was considered. Twenty five sites had no ‘Power per Turbine (MW)’ record, but did have a ‘Number of Turbines’ value and a ‘Megawatt Capacity’ value; a ‘Power per Turbine (MW)’ value therefore was calculated from these values for these sites.

The 735 sites remaining in the RUK dataset were then added to the GIS where 318 sites with < 5 turbines were deleted before comparing the dataset visually with that created from the SNH data for Scotland. Thus there were 417 sites remaining in RUK dataset. When compared with the SNH dataset, visual inspection suggested sites with similar names and numbers of turbines were often up to a few kilometres apart, and even up to 12km apart, as shown in detail in the interim report (Griffin *et al*. 2010b). Thus 171 sites from the RUK database indicated as being in Scotland were deleted, it being assumed that the SNH database was more accurate in depicting wind farms within Scotland (as discussed in detail in the Interim Report, in which SNH data were compared with third party sources of wind farm information for the Sutherland and Caithness areas; Griffin *et al*. 2010b). Offshore sites were also deleted from this database leaving 222 records for England, Northern Ireland and Wales.

Norwegian data treatment:

The data provided by the Norwegian Energy Directorate was in Excel format and in Norwegian. Developmental status and other information were translated using Google and translations were also kindly provided by Paul Shimmings. The data were assembled for import into the GIS. In order to be able to model footprint sizes, the MW capacity values provided for each wind farm were used to predict wind farm footprint areas and thus buffer radii to be used in the GIS, using the equation relating the UK's R1/2 offshore footprint sizes to MW output: $y = 0.2038x - 11.214$, where $r^2 = 0.88$, y = footprint area and x = MW output.

A total of 47 Norwegian sites were imported into the GIS, including offshore and onshore sites along the Norwegian coast classed as "License granted", "Under construction" and "Operational".

Treatment applied to all datasets and GIS manipulations carried out:

The UK onshore wind farm dataset and the Norwegian dataset consisted of points within the GIS. These were then "buffered" within the GIS to create theoretical wind farm footprints, in line with the conservative approach described in the Interim Report (Griffin *et al.* 2010b). When assessing the spatial overlap of wind farms on peatland with sensitive areas for birds, Bright *et al.* (2010) produced a predictive relationship between the expected footprint of a wind farm in km^2 (F) and the MW output capacity (Z), where $F = (0.00007Z^2) + (0.0505Z) + 0.0295$. This equation was explored as a useful way of predicting the possible area of a wind farm, based on its potential output capacity in MW for sites where this information was known (or derived from the number of turbines), so that a realistic footprint might be described for predicting whether it overlapped with the birds' migratory tracks. However, it was felt that this footprint related better to the question for which it was intended, namely the ground covered by turbines and associated infrastructure, such as service tracks and buildings, and the "disturbance zone" they caused in the horizontal plane. The current project addresses the degree to which the turbines might actually represent a collision risk and it was felt the Bright *et al*. method could overestimate the potential wind farm area (by including infrastructure lower in height than the turbines) in this regard. A second method therefore was devised, based on the number of turbines at a site. Firstly the nearest neighbour distances between all of the turbines (except at single turbine sites) plotted in the SNH shapefile were calculated within the GIS, giving a mean value of 325m between turbines (n = 4,058 turbine locations). Then, for hypothetical square wind farm areas, the increase in area attributable to each additional turbine based on a 325m spacing and a 50m buffer at the edges of the site (rotors with up to 45m blades being specified on many websites describing the onshore turbines used) was calculated to formulate the polynomial equation $y = 0.0003x^2 + 0.0767x – 0.14$ where $r^2 = 0.9999$ (see Griffin *et al*. 2010b).

The distances of all Whooper Swan GPS fixes in relation to these onshore and offshore sites in the UK, and also for Svalbard Barnacle Geese in relation to Norwegian wind farms as well as sites in Scotland, were calculated in the GIS.

The distances of GPS fixes to the coastline of the UK and Norway or Iceland (as appropriate) was also calculated for the two species, as were the distances of GPS fixes to the nearest Meteorological Stations in the UK for which data had been obtained in the different years.

The GPS locations for both species were also overlaid on a 50m 1:10,000 land height Grid which was provided free by the O.S. under a new data agreement and the height values likely to be accurate to ±10m were extracted. For birds within the UK, these land heights were subtracted from the height values recorded by the satellite tags on the birds to give an estimate of the "true" flight height above ground level of the swans and geese.

In selecting observations that represented migratory flights, a flight speed of 15 kph or more was selected for geese and swans as this represents a cut-off in the statistical distribution of flight speeds, with most observations having speeds less than this or more than this, and with the least number of speed observations being around this level. Also, below this speed the number of successive distances between GPS fixes that are given as zero increases – *i.e.* the birds were stationary but the transmitter erroneously recorded a speed reading. This is known to happen occasionally at speeds of < 30 kph (MTI pers. comm.)

Work Task 8. Analyse and report on Whooper Swan migration routes and flight heights in relation to all (offshore and onshore) wind farm locations.

The Whooper Swans studied in 2010 provided eight detailed tracks (including one autumn track) of swan migration along the west coast of Britain. Of seven birds tracked from NW England (Martin Mere and Cumbria) in spring 2010, four (57%) crossed an operational or proposed offshore wind farm site (at Ormonde, Robin Rigg, Islay or the Argyll Array); rising to 86% (six birds) if one of the withdrawn Scottish Territorial Waters (STW) sites (Solway Firth) is included (Figure 20, Table 5, Table 6).

Table 5. UK offshore Round 1 (R1), Round 2 (R2), Round 3 (R3) and Scottish Territorial Water (STW) wind farm sites recorded in the Crown Estates database.

ID	Name	Turbines	Capacity (MW)	Status	Round	Area (km^2)
1	Barrow	30	90	Operational	R1	10
2	Gwynt Y Mor	250	750	Consented	R2	124
3	Westernmost Rough	80	240	Application	R2	35
4	West Duddon	140	500	Consented	R2	67
5	Walney	102	450	Under Construction [1]	R2	73
6	Triton Knoll	286	1,200	Application	R2	207
7	Thanet	60	300	Operational [2]	R2	35
8	Sheringham Shoal	108	315	Under Construction [1]	R2	35
9	Scroby Sands	30	60	Operational	R1	9
10	Robin Rigg	60	216	Operational [2]	R1	18
11	Rhyl Flats	30	100	Operational	R1	10
12	Race Bank	100	500	Application	R2	75
13	Ormonde	30	108	Under Construction [1]	R1	10
14	North Hoyle	30	60	Operational	R1	10
15	Lynn	27	90	Operational	R1	10
16	London Array	271 [3]	1,000	Under Construction [1]	R2	246
17	Lincs	120	250	Consented	R2	35
18	Kentish Flats	30	90	Operational	R1	10
19	Inner Dowsing	27	90	Operational	R1	10
20	Humber Gateway	70	300	Application	R2	35
21	Gunfleet Sands (2)	20	64	Operational [2]	R2	6
22	Gunfleet Sands (1)	30	108	Operational [2]	R1	10
23	Inner Gabbard	100	360	Under construction	R2	112
24	The Galloper	40	140	Under construction	R2	34
25	Dudgeon	60	300	Application	R2	35
26	Burbo Bank	25	90	Operational	R1	10
27	Teesside	30	90	Consented	R1	10
28	Scarweather Sands	30	108	Withdrawn	R1	10
29	Docking Shoal	100	500	Application	R2	75
30	Moray Firth				R3	522
31	Firth of Forth				R3	2,859

32	Dogger Bank				R3	8,551
33	Holderness				R3	4,741
34	Norfolk				R3	5,872
35	Hastings				R3	271
36	West Isle of Wight				R3	724
37	Bristol Channel				R3	950
38	Irish Sea				R3	2,161
39	Argyll Array		1,500	Planning	STW	361
40	Solway Firth		300	Withdrawn [4]	STW	61
41	Wigtown Bay		280	Withdrawn [4]	STW	51
42	Islay		680	Planning	STW	95
43	Kintyre		378	Withdrawn [4]	STW	69
44	Beatrice		920		STW	121
45	Bell Rock		700	Withdrawn [4]	STW	93
46	Neart na Gaoithe		360	Planning	STW	105
47	Inch Cape		905		STW	150
48	Forth Array		415	Withdrawn [4]	STW	128

[1] Change in status since COWRIE report (February 2010) from ‘Consented’ to ‘Under Construction’.

[2] Change in status since COWRIE report (February 2010) from ‘Under Construction’ to ‘Operational’.

[3] London Array has a ‘Grampian Condition’ which has to be met in order to enable phase 2 to proceed, so phase 1 currently under construction comprises substantially fewer turbines than given in the table.

[4] ‘Withdrawn’ since the preparation of the Interim Report

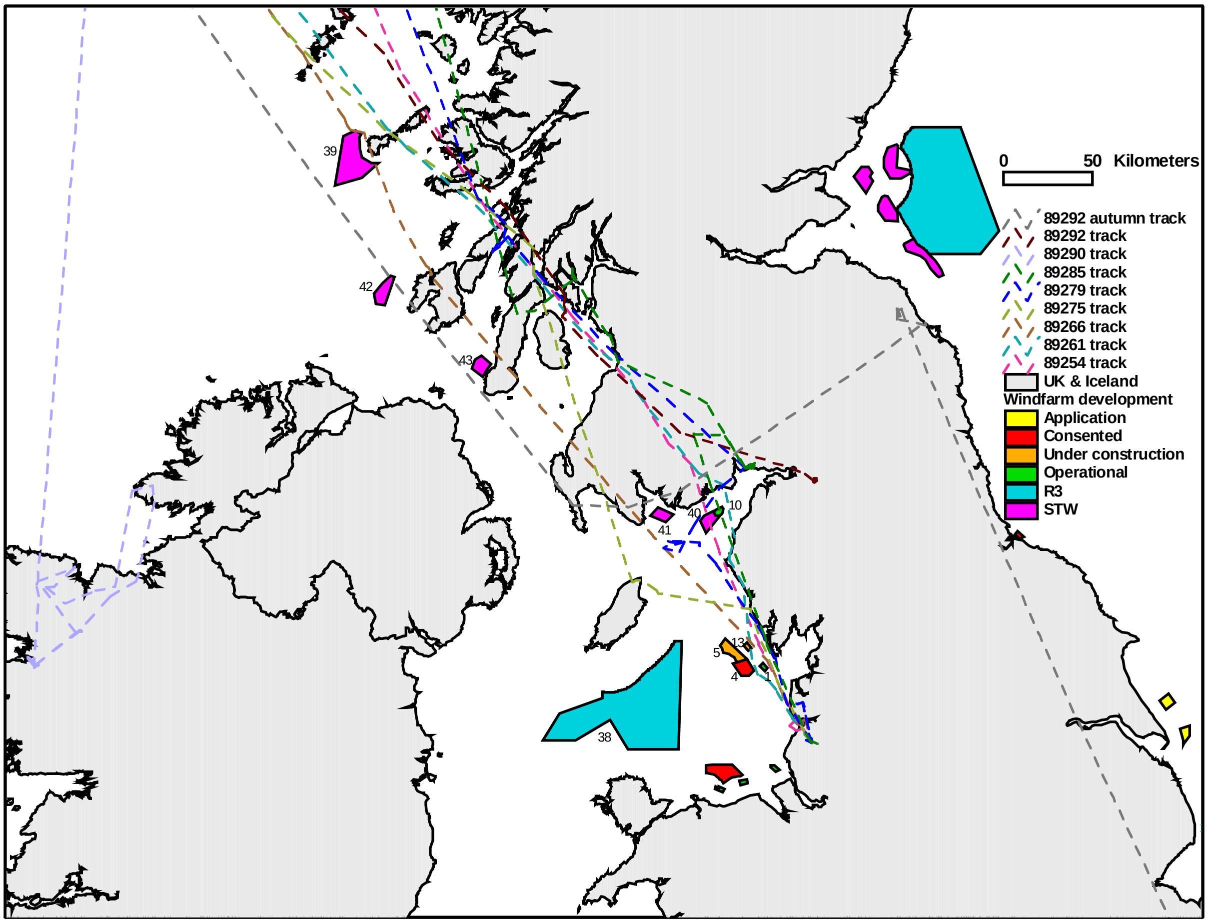


Figure 20. Detailed overview of the eight spring and single autumn migratory routes taken in 2010 by Whooper Swans first fitted with satellite transmitters either in Iceland in August 2009 (swans 89285, 89290 and 89292) or at WWT Martin Mere in March 2010 in relation to the operational and potential offshore wind farm sites (key as per Table 5).

Table 6. Whooper Swans fitted with GPS ARGOS PTT transmitters tracked in spring 2010 potentially passing within, or less than 20km from the nearest, operational, proposed or (in the case of the Solway Firth and Wigtown Bay) recently withdrawn offshore wind farm areas. Wind farm status and tranche is given in Table 5. The distance at which an extrapolated track passed to the nearest offshore wind farm is shown in bold typeface where six birds potentially passed within 1km of five operational, or potential, wind farm areas, and bold *italics* where birds potentially passed within 5km of such areas.

Tag	Ring code	Date	Time	Speed (kph)	Altitude (m)	Dist since last GPS fix (km)	Nearest wind farm	Distance (km)	2nd nearest wind farm	Distance (km)	3rd nearest wind farm	Distance (km)
89254	H6F	08/04/2010	06:00:00	55	1	49.79	Barrow	*1.75*	Ormonde	*5.00*	West Duddon	9.49
89254	H6F	08/04/2010	07:00:00	53	12	58.41	Ormonde	*5.00*	Barrow	10.37	Solway Firth	10.57
89254	H6F	08/04/2010	08:00:00	0	26 [1]	48.20	Solway Firth	0.00	Robin Rigg	*3.71*	Wigtown Bay	18.37
89261	C7V	25/03/2010	10:00:00	3	11	7.39	West Duddon	*3.36*	Barrow	*3.95*	Walney	11.06
89261	C7V	25/03/2010	11:00:00	3	9	9.52	West Duddon	*1.37*	Barrow	*2.45*	Walney	*3.44*
89261	C7V	25/03/2010	18:00:00	52	8	40.62	Ormonde	0.00	West Duddon	*2.92*	Walney	*3.42*
89261	C7V	26/03/2010	11:00:00	0	9 [2]	0.02	Solway Firth	13.83	Robin Rigg	14.39	Wigtown Bay	36.99
89261	C7V	26/03/2010	18:00:00	0	2 [3]	28.96	Robin Rigg	*3.15*	Solway Firth	6.03	Wigtown Bay	31.82
89261	C7V	29/03/2010	10:00:00	58	1	56.05	Argyll Array	18.39	Islay	59.16	Kintyre	78.18
89261	C7V	29/03/2010	11:00:00	1	1	15.65	Argyll Array	15.39	Islay	71.02	Kintyre	121.51
89261	C7V	29/03/2010	18:00:00	57	7	171.21	Argyll Array	13.77	Islay	81.03	Kintyre	135.66
89266	V3Z	29/03/2010	05:00:00	1	2	0.62	Barrow	16.92	West Duddon	21.36	Walney	28.80
89266	V3Z	29/03/2010	06:00:00	80	12	18.21	Barrow	*2.54*	West Duddon	10.44	Ormonde	14.30
89266	V3Z	29/03/2010	19:00:00	0	19 [4]	288.33	Ormonde	*1.95*	Barrow	*2.69*	Kintyre	5.98
89266	V3Z	01/04/2010	20:00:00	1	-	1.87	Islay	18.92	Kintyre	56.70	Argyll Array	61.13
89266	V3Z	01/04/2010	21:00:00	60	1	35.91	Islay	18.45	Argyll Array	25.53	Kintyre	58.42
89266	V3Z	01/04/2010	22:00:00	3	-	45.88	Argyll Array	0.00	Islay	36.34	Kintyre	94.33
89266	V3Z	01/04/2010	23:00:00	2	1	2.42	Argyll Array	*1.09*	Islay	80.46	Kintyre	139.68
89266	V3Z	02/04/2010	00:00:00	2	1	2.92	Argyll Array	0.00	Islay	81.57	Kintyre	141.38
89266	V3Z	02/04/2010	01:00:00	2	1	2.58	Argyll Array	0.00	Islay	82.52	Kintyre	143.08
89266	V3Z	02/04/2010	02:00:00	1	1	2.78	Argyll Array	*1.43*	Islay	83.97	Kintyre	145.04
89266	V3Z	02/04/2010	03:00:00	4	11	2.06	Argyll Array	*4.11*	Islay	86.46	Kintyre	147.77
89266	V3Z	02/04/2010	04:00:00	3	7	2.48	Argyll Array	6.17	Islay	88.45	Kintyre	149.83
89266	V3Z	02/04/2010	05:00:00	67	1	42.15	Argyll Array	8.48	Islay	90.89	Kintyre	152.08
89275	H5Z	30/03/2010	07:00:00	74	37	30.41	Barrow	12.72	West Duddon	17.65	Walney	24.83
89275	H5Z	30/03/2010	08:00:00	71	1	44.46	Barrow	*2.54*	Ormonde	6.89	West Duddon	10.42
89275	H5Z	30/03/2010	10:00:00	0	-	52.01	Walney	18.48	Ormonde	18.78	Irish Sea	23.59
89275	H5Z	02/04/2010	00:00:00	63	1	58.71	Argyll Array	14.04	Islay	62.09	Kintyre	89.67
89275	H5Z	02/04/2010	01:00:00	57	1	56.16	Argyll Array	11.21	Islay	80.39	Kintyre	135.53
89279	S3T	30/03/2010	04:00:00	2	1	25.52	Barrow	5.50	West Duddon	13.49	Ormonde	14.44
89279	S3T	30/03/2010	05:00:00	2	1	0.48	Barrow	6.40	West Duddon	13.52	Ormonde	14.07
89279	S3T	30/03/2010	06:00:00	0	1	15.02	Barrow	6.40	Ormonde	8.83	West Duddon	13.52
89279	S3T	30/03/2010	07:00:00	2	18	6.67	Ormonde	9.61	Barrow	15.75	Walney	16.03

89279	S3T	30/03/2010	08:00:00	1	-	11.64	Ormonde	12.21	Walney	18.41	West Duddon	20.52
89279	S3T	31/03/2010	10:00:00	17	10	9.65	Wigtown Bay	14.59	Solway Firth	18.28	Robin Rigg	28.15
89279	S3T	31/03/2010	11:00:00	32	6	16.83	Solway Firth	*4.06*	Robin Rigg	12.73	Wigtown Bay	13.87
89279	S3T	31/03/2010	18:00:00	0	7	25.94	Solway Firth	0.70	Robin Rigg	4.39	Wigtown Bay	13.88
89285	NA3	07/03/2010	08:00:00	74	11	61.35	Barrow	5.14	Ormonde	8.84	West Duddon	12.94
89285	NA3	07/03/2010	09:00:00	0	1	3.68	Ormonde	8.84	Barrow	11.62	Walney	14.48
89285	NA3	07/03/2010	10:00:00	0	4	0.02	Ormonde	10.29	Barrow	15.13	Walney	16.60
89285	NA3	07/03/2010	18:00:00	56	173 [6]	90.03	Robin Rigg	0.00	Solway Firth	*1.14*	Ormonde	10.29
89292	Y6K	20/10/2010	05:00:00	0	29 [7]	941.67	Islay	0.00	Kintyre	*4.30*	Argyll Array	6.10
89292	Y6K	20/10/2010	09:00:00	64	144 [8]	30.38	Wigtown Bay	13.65	Solway Firth	41.09	Robin Rigg	48.22
89292	Y6K	20/10/2010	10:00:00	2	5	9.81	Wigtown Bay	7.44	Solway Firth	32.59	Robin Rigg	39.11
89292	Y6K	20/10/2010	11:00:00	1	4	21.47	Wigtown Bay	5.02	Solway Firth	19.31	Robin Rigg	21.98

Notes with regard to the altitude recorded by the transmitters (no correction has been made for land height where the birds were not travelling over the sea):

[1] Land height 117m at this point; [2] land height 7m; [3] land height 4m; [4] land height 18m; [5] land height 6m; [6] land height 149m; [7] land height 33m; [8] land height 59m.

On considering both onshore and offshore wind farm sites, individual Whooper Swans were found to cross 1–2 currently consented onshore wind farms and 1 offshore STW site at the planning stage when migrating from Caerlaverock. Individuals migrating from Martin Mere cross 1–2 operational onshore sites, 1–3 consented onshore sites (with 1–5 more at the planning stage), 1–2 operational offshore (R1/2) sites, 1–2 R1/2 sites under construction, 1–2 R1/2 sites consented, and two offshore STW sites at the planning stage. Individuals tracked from Welney crossed 1–2 operational onshore sites, 1–2 consented onshore sites (with one more at the planning stage), and 1–2 offshore STW sites at the planning stage (Table 7).

Moreover, on considering wind farms close to (≤ 5km from) the Whooper Swans' migration route, the maximum number of wind farms recorded along an individual's flight line rose substantially to a maximum of 12 operational onshore wind farms, 4 operational offshore (R1/2) wind farms, 4 offshore (R1/2) sites under construction and three consented for Whooper Swans migrating from Martin Mere (Table 8). The number of wind farms crossed by swans migrating from Martin Mere was notably higher than those migrating from Caerlaverock and Welney, although the migration tracks of the Welney swans were close to (≤ 5km from) seven operational onshore wind farm sites, with two more under construction and 10 consented (Table 8).

Table 7. The mean number (±SE, min and max values) of wind farm areas in different categories that were passed across by the extrapolated tracks of the Whooper Swans (n = 43 tracks) from three different wintering sites. These summary data are based on the data presented in Figures 23, 25 & 27, but omit data from swan V3Z (from Martin Mere) and from swan Y6K (which showed an affinity for Welney) as both birds completed more than a single northward migration which would bias the mean values towards their tracks.

	Onshore Planning	Onshore Consented	Onshore Construction	Onshore Operational	Offshore R1/2 Planning	Offshore R1/2 Consented	Offshore R1/2 Construction	Offshore R1/2 Operational	Offshore R3 Planning	Offshore STW Planning	Offshore STW Withdrawn
Caerlaverock											
Mean	1.5	1.7	-	1.0	-	-	-	-	-	1.0	2.0
SE	0.5	0.3	-	0	-	-	-	-	-	0	0
Min	1	1	-	1	-	-	-	-	-	1	2
Max	2	2	-	1	-	-	-	-	-	1	2
Count	2	3	0	2	0	0	0	0	0	1	1
Martin Mere											
Mean	2.1	1.5	-	1.2	-	1.2	1.1	1.3	-	2.0	1.0
SE	0.4	0.5	-	0.2	-	0.2	0.1	0.3	-	0	0
Min	1	1	-	1	-	1	1	1	-	2	1
Max	5	3	-	2	-	2	2	2	-	2	1
Count	14	4	0	5	0	5	7	3	0	1	10
Welney											
Mean	1.0	1.3	-	1.1	-	-	-	-	-	1.5	-
SE	0	0.3	-	0.1	-	-	-	-	-	0.5	-
Min	1	1	-	1	-	-	-	-	-	1	-
Max	1	2	-	2	-	-	-	-	-	2	-
Count	7	4	0	7	0	0	0	0	0	2	0

Table 8. The mean number (±SE, min and max values) of wind farm areas in different categories that were at or within 5km of the extrapolated tracks of the Whooper Swans (n = 43 tracks) from three wintering sites. These summary data are based on the data presented in Figures 24, 26 & 28, but omit data from swan V3Z (from Martin Mere) and from swan Y6K (which showed an affinity for Welney) as both birds completed more than a single northward migration which would bias the mean values towards their tracks.

	Onshore Planning	Onshore Consented	Onshore Construction	Onshore Operational	Offshore R1/2 Planning	Offshore R1/2 Consented	Offshore R1/2 Construction	Offshore R1/2 Operational	Offshore R3 Planning	Offshore STW Planning	Offshore STW Withdrawn
Caerlaverock											
Mean	10.2	4.8	-	4.0	-	-	-	-	-	1.0	2.0
SE	1.8	0.9	-	0.6	-	-	-	-	-	0	0
Min	7	2	-	3	-	-	-	-	-	1	2
Max	17	7	-	6	-	-	-	-	-	1	2
Count	5	5	0	5	0	0	0	0	0	1	1
Martin Mere											
Mean	11.0	2.4	-	4.3	-	1.8	2.3	1.8	-	2.0	1.6
SE	1.5	0.4	-	0.8	-	0.3	0.4	0.2	-	0	0.3
Min	1	1	-	1	-	1	1	1	-	2	1
Max	27	6	-	12	-	3	4	4	-	2	4
Count	22	19	0	18	0	8	10	15	0	2	12
Welney											
Mean	14.4	6.9	1.3	4.1	1.0	-	-	-	1.0	2.0	2.3
SE	0.7	0.7	0.3	0.6	0	-	-	-	0	0	0.6
Min	9	3	1	1	1	-	-	-	1	2	1
Max	19	10	2	7	1	-	-	-	1	2	4
Count	14	14	4	14	1	0	0	0	2	2	4

Overall, 11 offshore and 81 onshore sites were within 5km of the swans' flight-lines for Whooper Swans tracked from Martin Mere, Caerlaverock and Welney, though three of the offshore wind farms (Kintyre, Wigtown Bay and Solway Firth) have recently been withdrawn (Table 9).

The most intensive flight paths were in the vicinity of the consented West Duddon offshore site (6 tracks over the site; 10 within 5km of the site) and the Dalmellington onshore site (120 turbines) which is currently at the planning stage (Table 9).

Most flights (7 tracks) were recorded across the Solway Firth offshore site, which has now been withdrawn (Table 9).

Table 9. Ninety onshore and offshore wind farm sites in Britain for which extrapolated Whooper Swan tracks indicates that at least one swan passed across the site (n= 67 sites), and/or at least 5 birds passed within 5km of the site. * For the sake of presentation clarity and because the sites appear to have lower levels of swan movement in the vicinity, the table does not include 215 sites registered as having 1–4 birds passing within 5km of the wind farms, where none of the extrapolated tracks passed directly across the sites.

Type	Stage	Name	Tur-bines	Tagged birds passing across wind farm	Tagged birds passing ≤ 5km of wind farm
Onshore	Consented	Arecleoch Wind Farm	10	0	6
Onshore	Consented	Luing	5	0	5
Onshore	Consented	Royal Oak	5	0	5
Onshore	Consented	The Grange	7	0	8
Onshore	Consented	Tween Bridge Moor	22	0	5
Onshore	Consented	Twin Rivers Wind Farm	14	0	6
Onshore	Consented	A'Chruach	24	1	3
Onshore	Consented	Allt Dearg 2	12	1	7
Onshore	Consented	Carraig Gheal	21	1	2
Onshore	Consented	Clyde Wind farm	173	1	1
Onshore	Consented	Eishken wind farm (Muaitheabhal)	53	1	2
Onshore	Consented	Green Rigg	18	1	3
Onshore	Consented	Keadby	34	1	6
Onshore	Consented	Millour Hill	6	1	2
Onshore	Consented	Windy Standard Extension	30	1	4
Onshore	Consented	Arecleoch	60	2	5
Onshore	Consented	Goole Fields	16	2	3
Onshore	Consented	Whiteside Hill	32	2	8
Onshore	Consented	Hare Hill Extn 2	39	3	4
Onshore	Operational	Dalswinton	16	0	6
Onshore	Operational	Fairfield Farm	5	0	7
Onshore	Operational	Oldside	16	0	6
Onshore	Operational	Wether Hill	14	0	5
Onshore	Operational	Winscales Moor	7	0	5
Onshore	Operational	Ardrossan	15	1	3
Onshore	Operational	Buolfruich	15	1	2
Onshore	Operational	Cruach Mhor	37	1	2
Onshore	Operational	Dalry Wind farm	6	1	2
Onshore	Operational	Deeping St Nicholas	8	1	1
Onshore	Operational	Dummuies (eight turbines)	8	1	1
Onshore	Operational	Earlsburn	14	1	1
Onshore	Operational	Lowca	7	1	6
Onshore	Operational	Hare Hill	47	2	5
Onshore	Operational	Paul's Hill	35	2	4
Onshore	Operational	Rusholme	12	2	2
Onshore	Operational	Beinn an Tuirc	46	3	5
Onshore	Planning	Afton	27	0	5
Onshore	Planning	Auchencairn	20	0	7
Onshore	Planning	Beinn Ghlas II	24	0	6
Onshore	Planning	Burnhead Wind Farm	20	0	10
Onshore	Planning	Dalleagles Wind farm	10	0	5
Onshore	Planning	Dersalloch Wind farm	24	0	7
Onshore	Planning	Dodd Hill	5	0	5
Onshore	Planning	Doon Hill	6	0	5
Onshore	Planning	Loch Hill Wind farm	21	0	7
Onshore	Planning	Marbrack	10	0	9
Onshore	Planning	Margree	30	0	6
Onshore	Planning	Meall Mhor	11	0	7
Onshore	Planning	Ackron Farm (Golval)	10	1	2
Onshore	Planning	Barmore	10	1	2
Onshore	Planning	Barmore Wind farm	17	1	3
Onshore	Planning	Blackcraigs	45	1	6
Onshore	Planning	Blary Hill	18	1	3
Onshore	Planning	Breaker Hill Wind farm	15	1	5
Onshore	Planning	Cairn Duhie	15	1	1
Onshore	Planning	Clach Liath	10	1	2

Onshore	Planning	Cour	13	1	5
Onshore	Planning	Cowans Law	25	1	5
Onshore	Planning	Cowans Law Community Wind farm	20	1	5
Onshore	Planning	Dorenell	59	1	1
Onshore	Planning	Ewe Hill Wind farm	6	1	2
Onshore	Planning	Frawney	7	1	5
Onshore	Planning	Gelston	9	1	7
Onshore	Planning	Gortfinbar	5	1	1
Onshore	Planning	Hare Hill Extension 2	39	1	5
Onshore	Planning	Harelaw Renewable Energy Park	39	1	5
Onshore	Planning	Lambdoughty	55	1	3
Onshore	Planning	Moorhouse Farmers Wind farm	18	1	3
Onshore	Planning	Shira	22	1	5
Onshore	Planning	Solwaybank	21	1	2
Onshore	Planning	Spaldington Common	7	1	4
Onshore	Planning	Ulzieside	15	1	6
Onshore	Planning	Assel Valley Wind farm	17	2	3
Onshore	Planning	Burnhead wind farm	19	2	9
Onshore	Planning	Kilgallioch	10	2	6
Onshore	Planning	Kilgallioch Wind farm (Arecleoch Part 2)	139	2	4
Onshore	Planning	Twentyshilling Hill	9	2	6
Onshore	Planning	Killgallioch Wind farm	132	3	6
Onshore	Planning	Dalmellington	120	6	10
Offshore	R1/2 Consented	Duddon West	140	5	8
Offshore	R1/2 Construction	Ormonde	30	3	7
Offshore	R1/2 Construction	Walney	102	4	8
Offshore	R1/2 Operational	Barrow	30	2	14
Offshore	R1/2 Operational	Robin Rigg	60	2	10
Offshore	STW Planning	Islay		1	2
Offshore	STW Planning	Neart na Gaoithe		2	2
Offshore	STW Planning	Argyll Array		3	3
Offshore	STW Withdrawn	Kintyre		3	3
Offshore	STW Withdrawn	Wigtown Bay		4	5
Offshore	STW Withdrawn	Solway Firth		7	10
Total turbines (excluding offshore R3 and STW sites) and sites			~2404	90	305 (=90+215*)

Almost all of the swans tracked from Caerlaverock, Martin Mere and Welney in 2009 and 2010 passed within 1km of a proposed or operational onshore wind farm; moreover, over 80% were predicted to pass across at least one onshore site (Figure 21).

Only 20-30% of the birds tracked from Caerlaverock and Welney passed within 5km of a proposed or operational offshore wind farm, whereas 70% of the bird tracks from Martin Mere passed through these areas and 80-90% within 3–5km of the offshore sites (Figure 22).

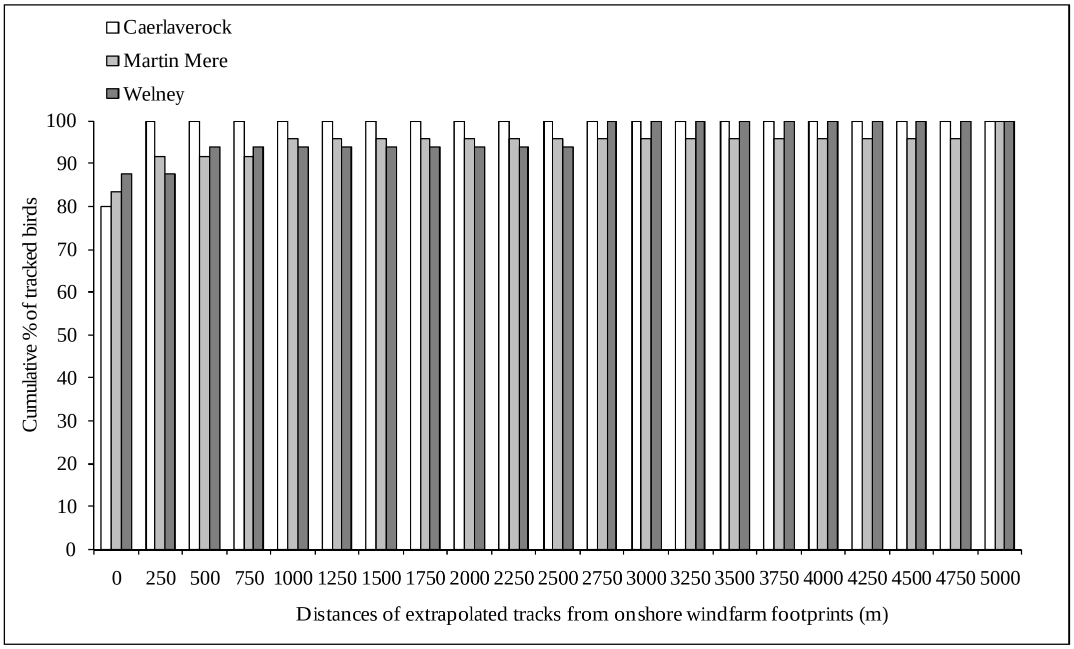


Figure 21. Cumulative % of Whooper Swans tracked from WWT Caerlaverock, Martin Mere and Welney, whose extrapolated migratory tracks passed within 0–5km of onshore wind farm sites in the UK.

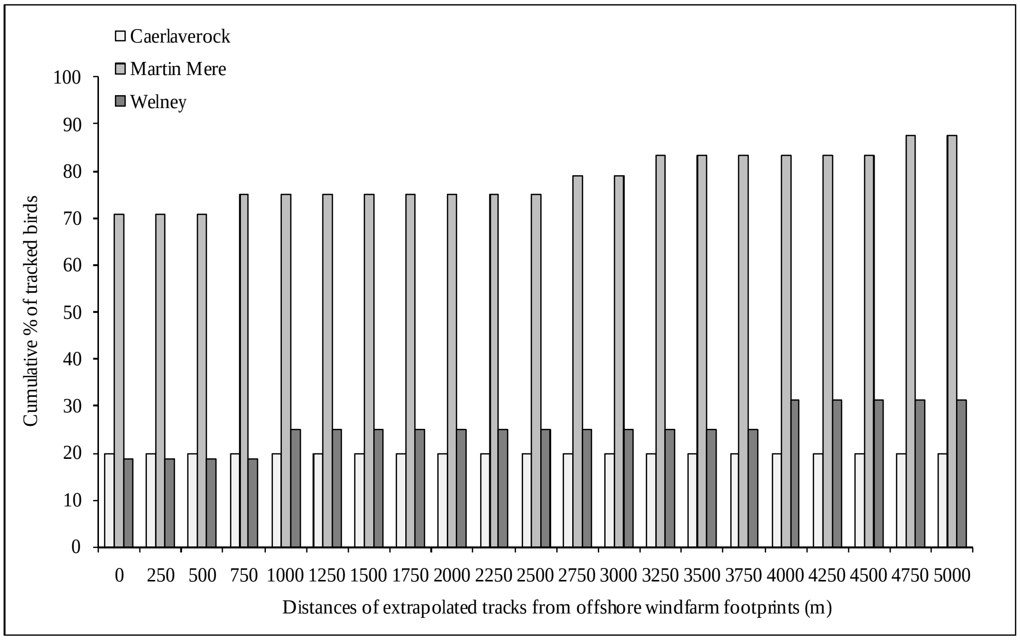


Figure 22. Cumulative % of Whooper Swans tracked from WWT Caerlaverock, Martin Mere and Welney, whose extrapolated migratory tracks passed within 0–5km of offshore wind farm sites in the UK.

Of the five Whooper Swans tracked from Caerlaverock, two (40%) passed across onshore sites on two occasions, two (40%) passed across onshore sites on three occasions and there was one track of one bird (C9Z; 20%) over an offshore STW site at the planning stage (Figure 23). Additionally, 16–26% of the tracks recorded for each individual passed within 5km of a wind farm site (Figure 24).

Of the 23 Whooper Swans tracked from Martin Mere, eight (35%) passed across one wind farm site, five (22%) passed across two sites, four (17%) across three sites and five (22%) across four or more sites (Figure 25). These figures did not include the withdrawn STW sites; inclusion of these sites would have added 11 tracks to the totals. One bird (V4P) did not cross any wind farms following the withdrawal of an STW offshore site (Figure 25). Additionally, 5–44% of the tracks recorded for each individual passed within 5km of a wind farm constructed, consented or still in the planning process (Figure 26).

Of the 14 Whooper Swans providing complete tracks through Britain from Welney, five (36%) passed across one wind farm site, six (43%) passed across two sites, two (12.5%) across three sites and one (Y6K; 6%) across four or more sites (Figure 27). Additionally (and on excluding swan Y6K which was tracked twice), 2–32% of the tracks recorded for each individual passed within 5km of a wind farm constructed, consented or still in the planning process (Figure 28).

That 39% of Whooper Swans tracked from Martin Mere and 21.5% of those tracked from Welney crossed three or more wind farm sites/footprints emphasises the need for an assessment of the cumulative effects of the development of wind farm sites along migration routes.

The number of onshore wind farm sites crossed by the swans was substantially higher than the number of offshore sites, both at the constructed/consented and at the planning stage (Figures 29 & 30), as is the number of wind farms within 5km of the flight-lines of the individual swans (Figures 31 & 32).

Thus, in assessing the potential effects of wind farm development on migratory populations, onshore and offshore wind farms should be considered in combination rather than as separate entities.

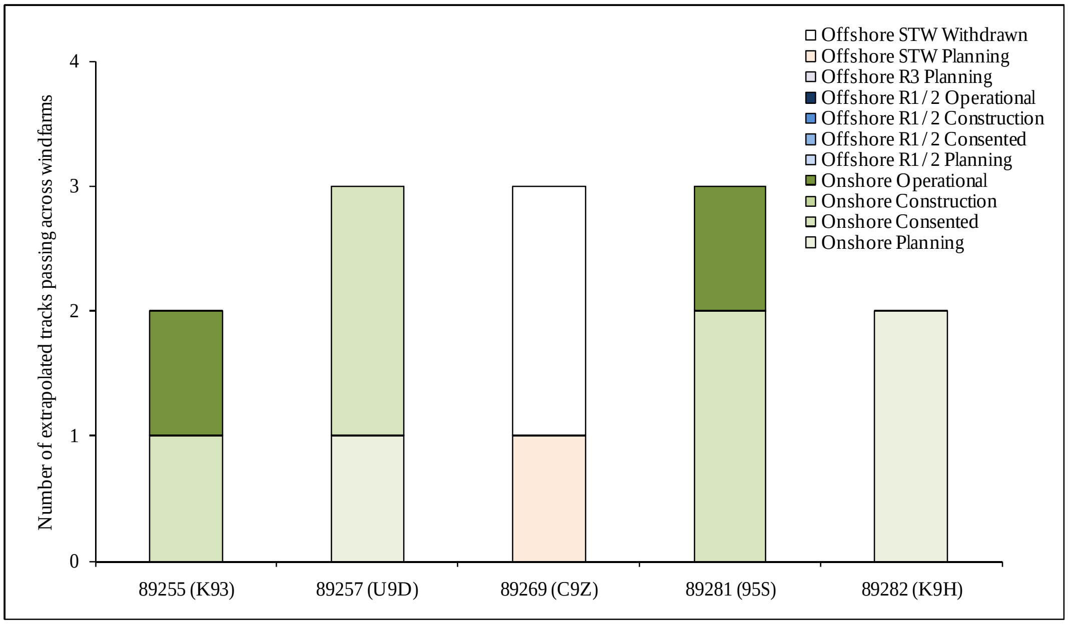


Figure 23. Cumulative number of extrapolated tracks for individual Whooper Swans from Caerlaverock that passed across onshore and offshore wind farms at various stages of development.

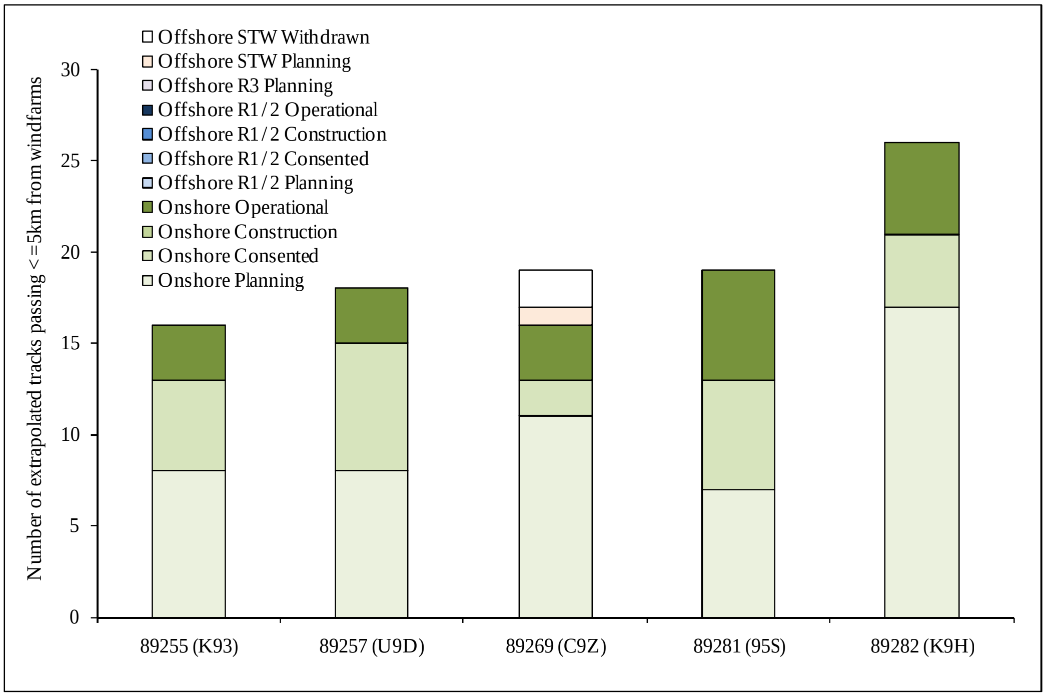


Figure 24. Cumulative number of extrapolated tracks for individual Whooper Swans from Caerlaverock that passed ≤ 5km from onshore and offshore wind farms at various stages of development.

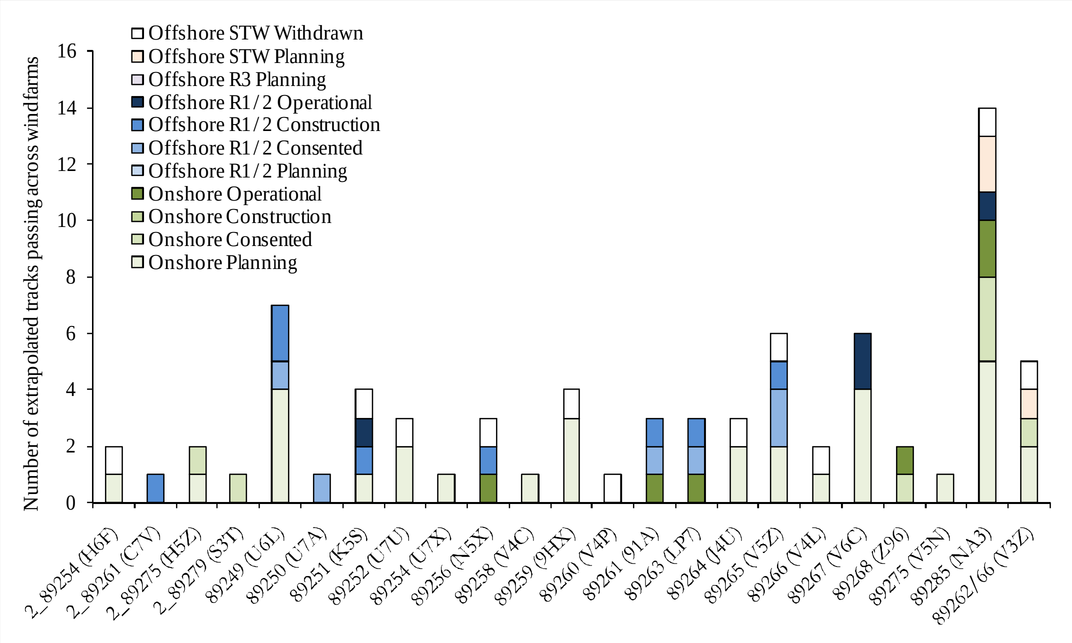


Figure 25. Cumulative number of extrapolated tracks for individual Whooper Swans from Martin Mere that passed across onshore and offshore wind farms at various stages of development. Note: V3Z completed a repeat spring migration and NA3 completed a full migration.

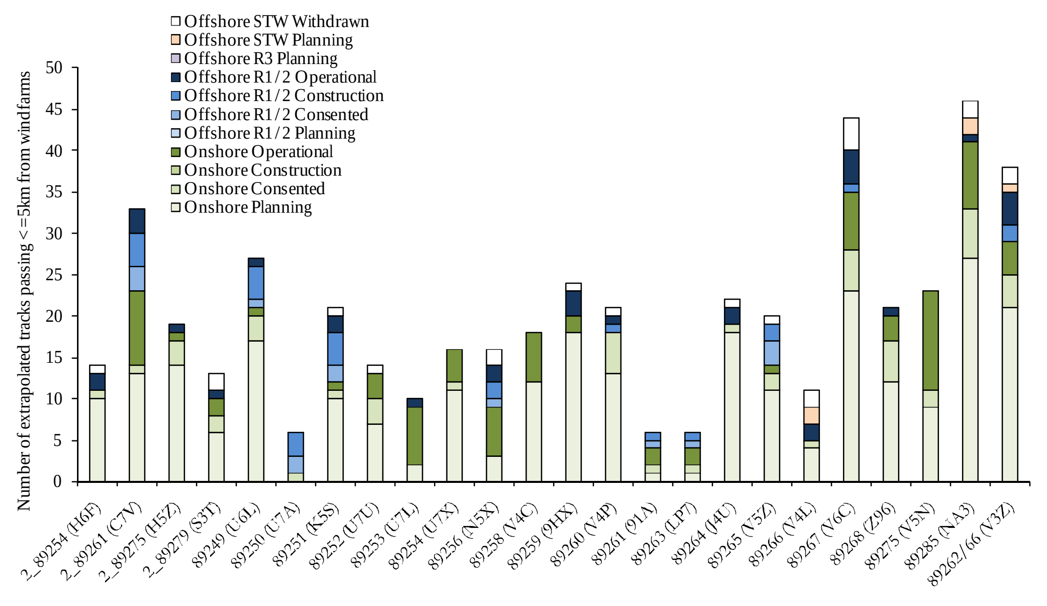


Figure 26. Cumulative number of extrapolated tracks for individual Whooper Swans from Martin Mere that passed ≤ 5km from onshore and offshore wind farms at various stages of development. Note: V3Z completed a repeat spring migration and NA3 completed a full migration.

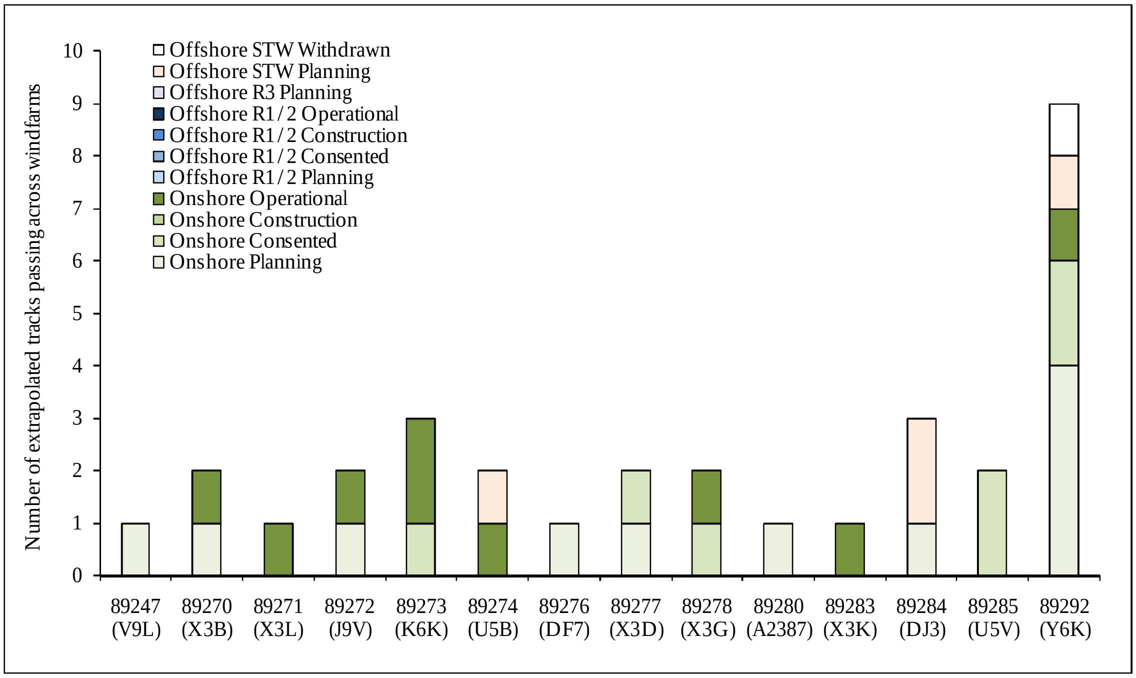


Figure 27. Cumulative number of extrapolated tracks for individual Whooper Swans from Welney that passed across onshore and offshore wind farms at various stages of development. Note: bird Y6K completed a second autumn migration.

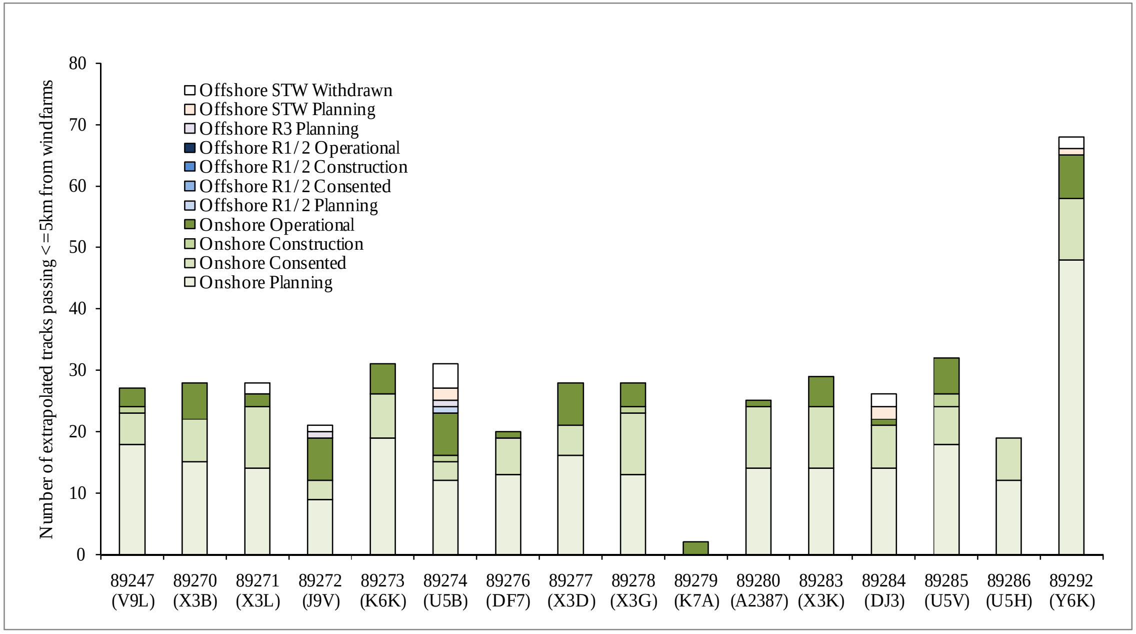


Figure 28. Cumulative number of extrapolated tracks for individual Whooper Swans from Welney that passed ≤ 5km from onshore and offshore wind farms at various stages of development. Note: bird Y6K completed a second autumn migration.

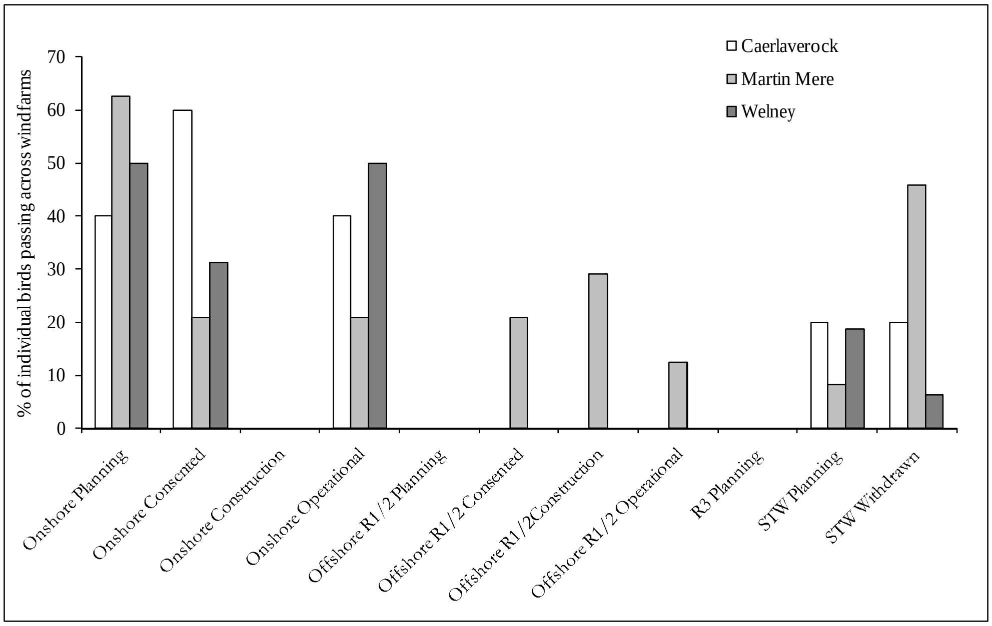


Figure 29. Percentage of individual Whooper Swans whose extrapolated tracks passed across onshore and offshore wind farms at various stages of development.

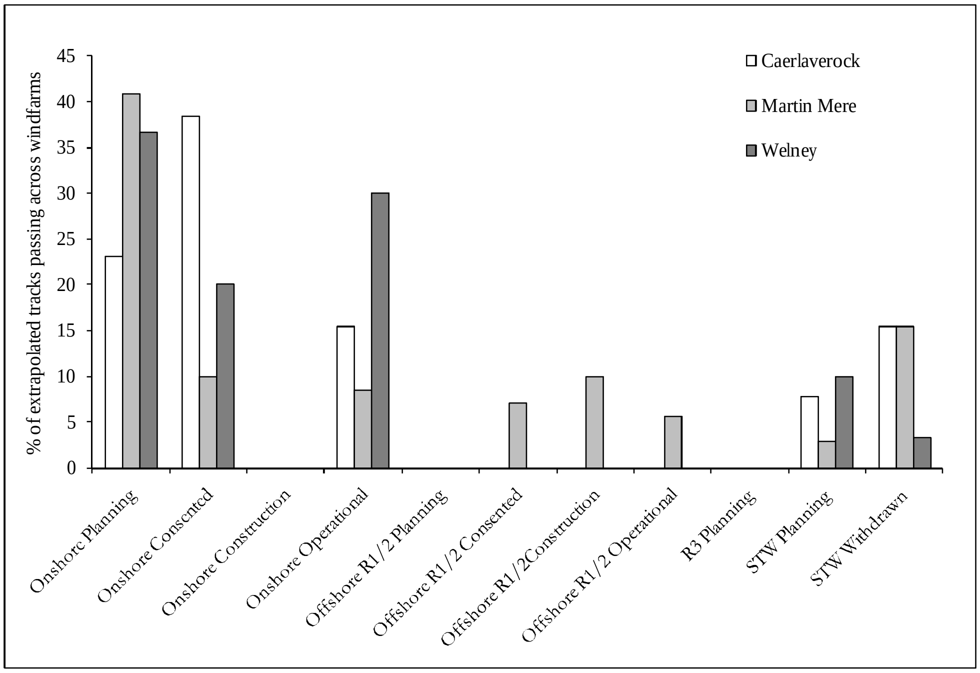


Figure 30. Percentage of extrapolated tracks for Whooper Swans from the three wintering sites that passed across onshore and offshore wind farms at various stages of development.

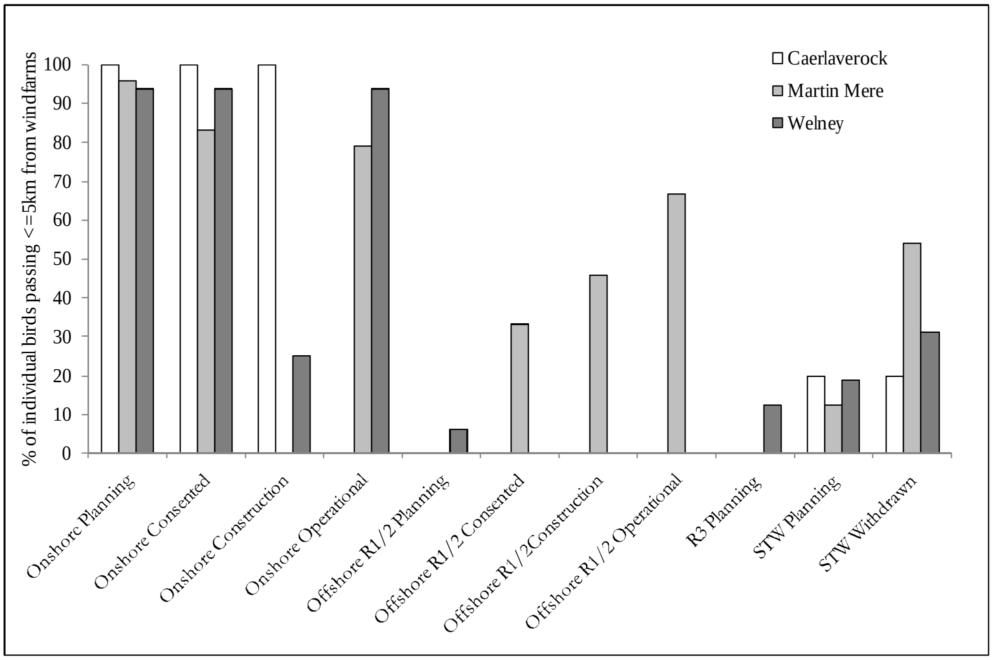


Figure 31. Percentage of individual Whooper Swans whose extrapolated tracks passed ≤ 5km from onshore and offshore wind farms at various stages of development.

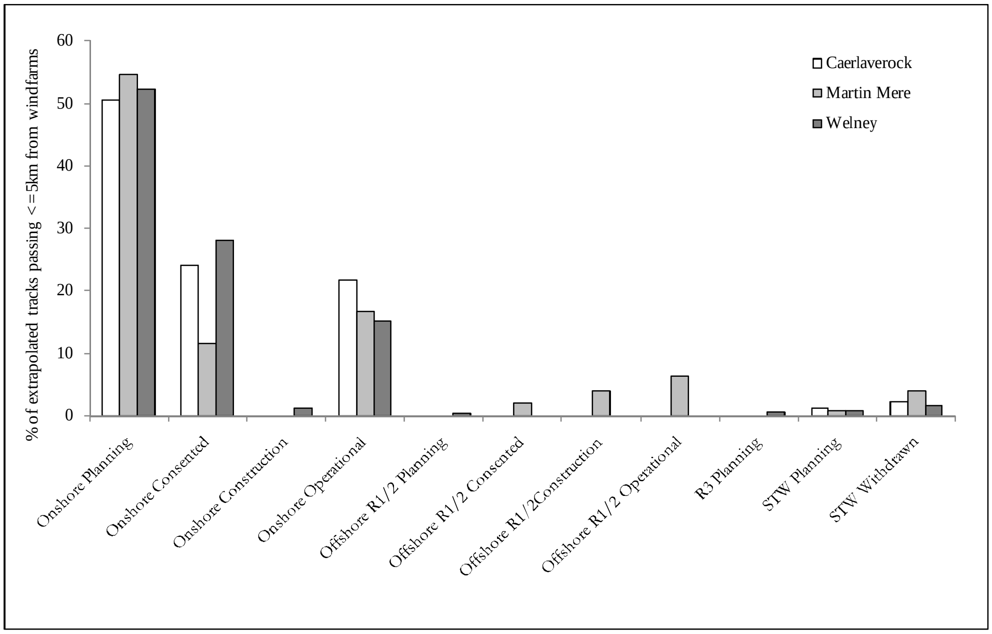


Figure 32. Percentage of the extrapolated tracks of Whooper Swans from the three wintering sites passing ≤ 5km from onshore and offshore wind farms at various stages of development.

Whooper Swan flight heights

Flight heights for Whooper Swans migrating overland within the UK were calculated within the GIS as described under point 3.1.2 (Work Task 3) above. This process resulted in some negative values being calculated, and these could be of considerable magnitude. Some inaccuracy in flight height estimates occur because the satellite transmitters themselves are only accurate to within ± 22 m of true height, although 75% of fixes are considered by Microwave Telemetry Inc. to be within 10 m of true height (MTI pers. comm.). Because the tags can record "*neg alt*" (negative altitude) for flight heights, on calculating mean and median flight heights the "*neg alt*" value was replaced by a negative value extracted at random from a half-Normal distribution provided online at www.wessa.net ("Free Statistics and Forecasting Software" based on 'R' code routines), where the mean of the distribution was set = 0 with an SD = 10 and the distribution truncated from infinity to ± 22m. This was preferred over simply deleting "*neg alt*" values, as it balanced any errors in tag height data which would have deviated towards the positive side of the error distribution. "*Neg alt*" values recorded by the tag should not be confused, in the following analyses, with negative altitude values that are calculated by subtracting O.S. land height values from the altitude recorded by the tags which can result in nonsensical altitude values due to the error in the accuracy of the GPS fix in the vertical plane. These negative values are used in all calculations of mean height (±S.E.).

A total of 220 GPS fixes with altitude data (range = -312 – 649 m) were recorded for Whooper Swans during their overland migratory flights. The mean flight height (±S.E.), above ground level, was 82 m (±9 m), with a median flight height of 42 m and a modal value of 10 m. A total of three "*neg alt*" values (in a total of 22 height values < -22m) were replaced for calculating the mean and median values. The height distribution data for overland flights are illustrated in Figure 33.

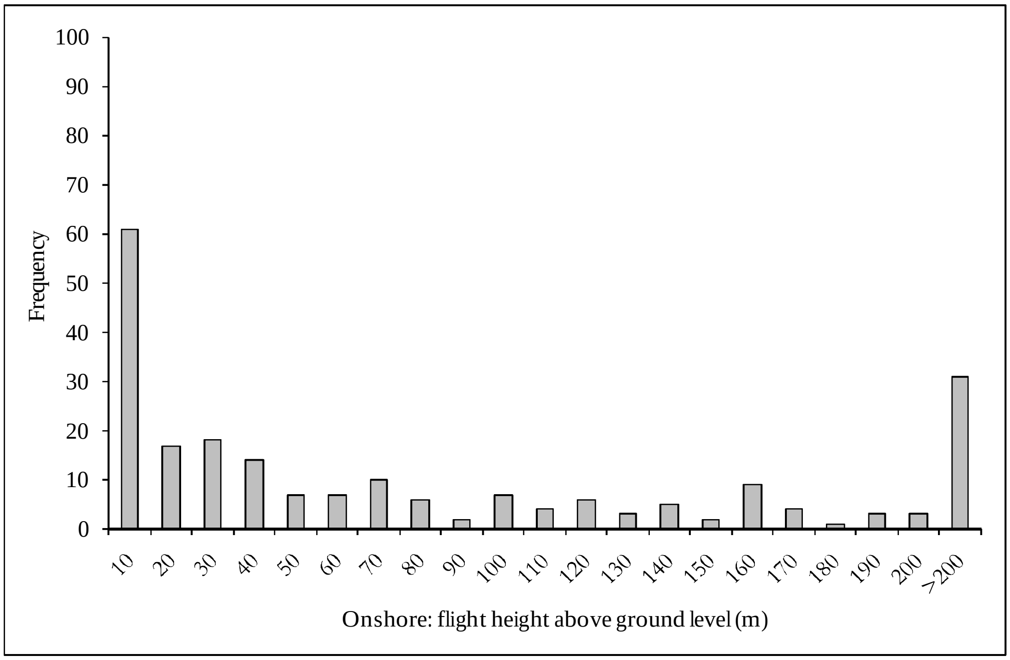


Figure 33. Onshore flight heights above ground level recorded for Whooper Swans during their spring and autumn migrations (n = 220). Of the flight heights recorded in the 10 m category, 34 were negative with 22 being less than -22m.

A total of 335 GPS fixes with altitude data (range = -22 – 471 m) were recorded for Whooper Swans during their migration over water. No height values were less than -22 m. Offshore values were filtered to be > 20km from the UK coastline and > 20km from the Icelandic coastline, to ensure that the flight heights were not confounded by movement from overland to overwater and *vice versa*. The mean flight height (± S.E.), above sea level, was 31 m (±3 m), with a median flight height of 9 m and a modal value also in the 0–10 m band. A total of 84 "*neg alt*" values were replaced for calculating the mean and median values. The height distribution data for the overseas flights are illustrated in Figure 34.

Noting that the error in the flight height data recorded by the transmitters is ± 22 m, it seems that Whooper Swan flight height is mostly near or at rotor level (assuming a sweep of 30–150 m) for the onshore wind farms, and also at or just below the lower reaches of the sweep of the rotors for the offshore sites.

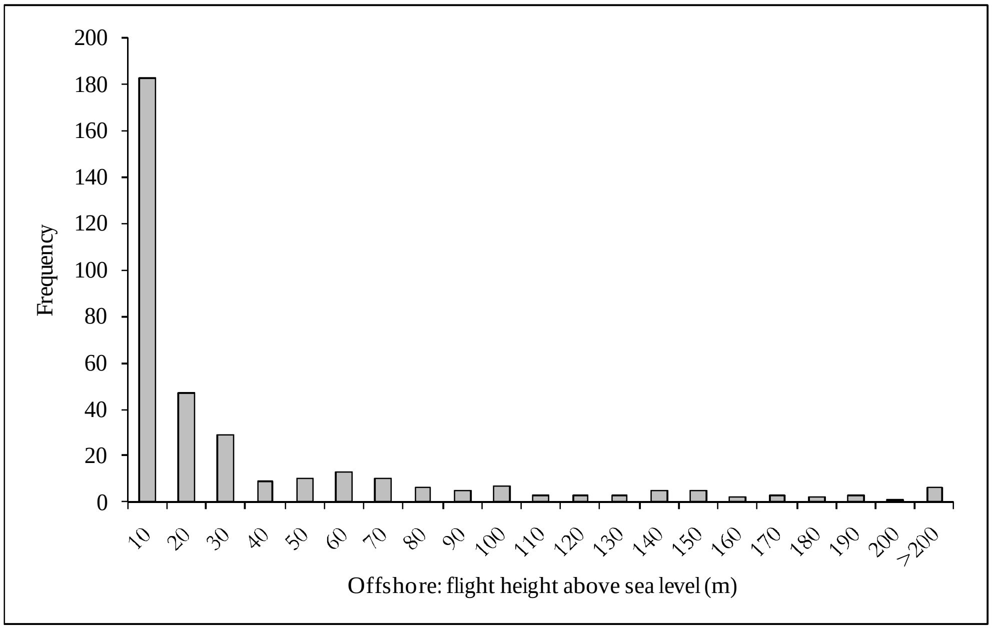


Figure 34. Offshore flight heights above sea level recorded for Whooper Swans during their spring and autumn migrations (n = 355). Of the flight heights recorded in the 10m category, 84 had "*neg alt*" heights and were given negative values.

5.4 Objective 4: To analyse existing satellite-tracking data for four key species (Svalbard Barnacle Geese, Light-bellied Brent Geese, Greenland White-fronted Geese and Whooper Swans), in relation to wind farm locations (proposed and operational) along their migratory flyways.

Work Task 9. Coordinate and verify satellite-tracking data for the four key species into a single GIS.

Since spring 2005, WWT and scientists at the Icelandic Institute for Natural History have tracked Light-bellied Brent Geese from Northern Ireland or Iceland to the Canadian High Arctic using a variety of small ~30g satellite transmitters, some of which have been conventional non-solar Doppler tags while others have been solar GPS tags like smaller versions of those used on the Whooper Swans. Often with the Doppler tags, only a few fixes per day of reasonable quality (*i.e.* Argos location classes 0, 1, 2 or 3, with no height information, whereby the radius of error for a class 3 fix is < 250 m, class 2 < 500 m, class 1 < 1,500 m and class 0 >1,500 m with an error estimate provided) were obtained for the migratory routes of these geese between the UK and Iceland. For the GPS tags up to eight fixes per day were obtained, again with little or no height information.

Since spring 2006, WWT has tracked 27 Svalbard Barnacle Geese from the Solway Firth to Norway and 22 birds provided good data from Norway to Svalbard. Fourteen were tagged with 30g solar GPS ARGOS PTTs and the remaining eight birds were tagged with 45g solar GPS ARGOS PTTs. Location data for both the 30g and the 45g GPS tags (supplied by Microwave Telemetry) were accurate to within 15m. The tags produced up to 12 GPS fixes per day (with associated height data) during Barnacle Goose migration.

Greenland White-fronted Geese caught at Loch Ken, Dumfries & Galloway in 2008 and 2010, in a sub-population of *c*. 200 birds that regularly winter at the site, were fitted with GPS tags. In 2008 four 45g solar GPS tags were used giving height and position information up to 12 times per day; in 2010 two non-solar 40g LC4 GPS tags were used which give only one fix per day and no height data.

All of the geese fitted with tags were adult males. A braided elastic harness was used to attach the tag in each case.

Location and any altitude data obtained from each project were downloaded from CLS-ARGOS to a single WWT database. These were imported along with the Whooper Swan data into the GIS.

Work Task 10. Analyse and report on inter-specific variation in migration routes in relation to offshore wind farm locations.

BRENT GEESE

Of the 32 Brent Geese tagged since 2005, the spring Doppler tracks for four birds in 2005, autumn Doppler tracks for three birds in 2005 and the spring GPS tracks for two birds in 2006, were of use to this report as they showed birds moving between Ireland and Iceland or vice versa (Figures 35 & 36). In general, the lower frequency and accuracy of the Doppler fixes give only a broad overview of the routes taken by the geese during migration. Nevertheless these, coupled with the more precise GPS tracks (± 15m horizontal accuracy), suggest that there is little overlap between the migratory routes taken by the Light-bellied Brent Geese and potential offshore wind farm sites. The Kintyre, Islay and Argyll Array STW sites appear to have the greatest potential to occur on the migration routes of Brent Geese leaving or arriving in NE Ireland, *e.g.* at the principal wintering site at Strangford Lough. Three birds possibly travelled within 20km of these proposed STW sites (20km being taken as a broad measure of proximity, given (a) the relatively low accuracy of Doppler fixes and (b) the lack of detailed information on the birds' movements between fixes), although for goose 34873 (in spring 2005) this was only after an aborted northward migration attempt, which may have been an aberrant movement.

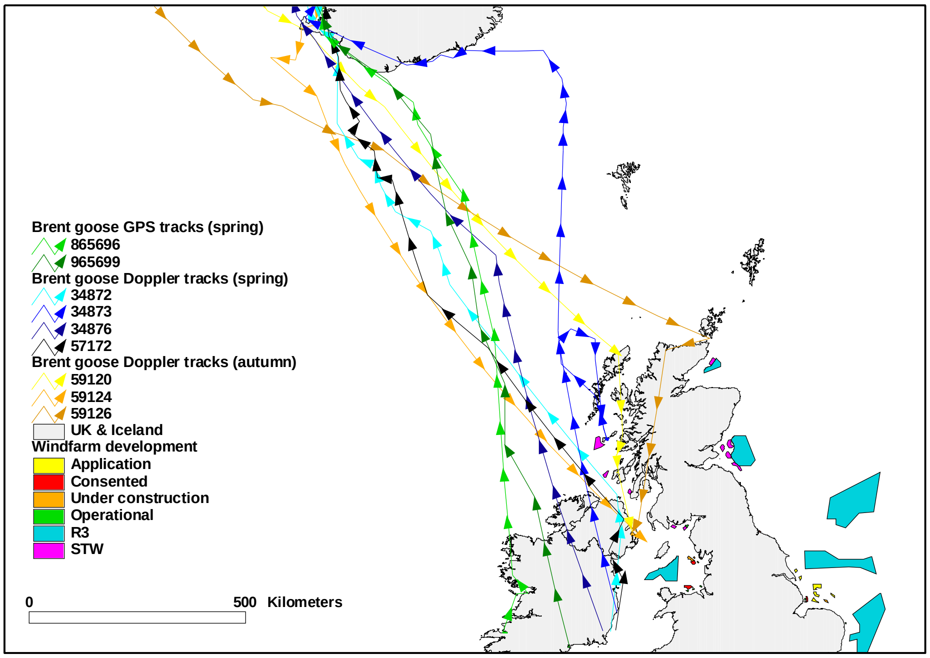


Figure 35. Overview of the migratory routes taken by Light-bellied Brent Geese fitted with conventional Doppler fix satellite transmitters in 2005 and solar GPS transmitters in 2006 – full migration route to Iceland.

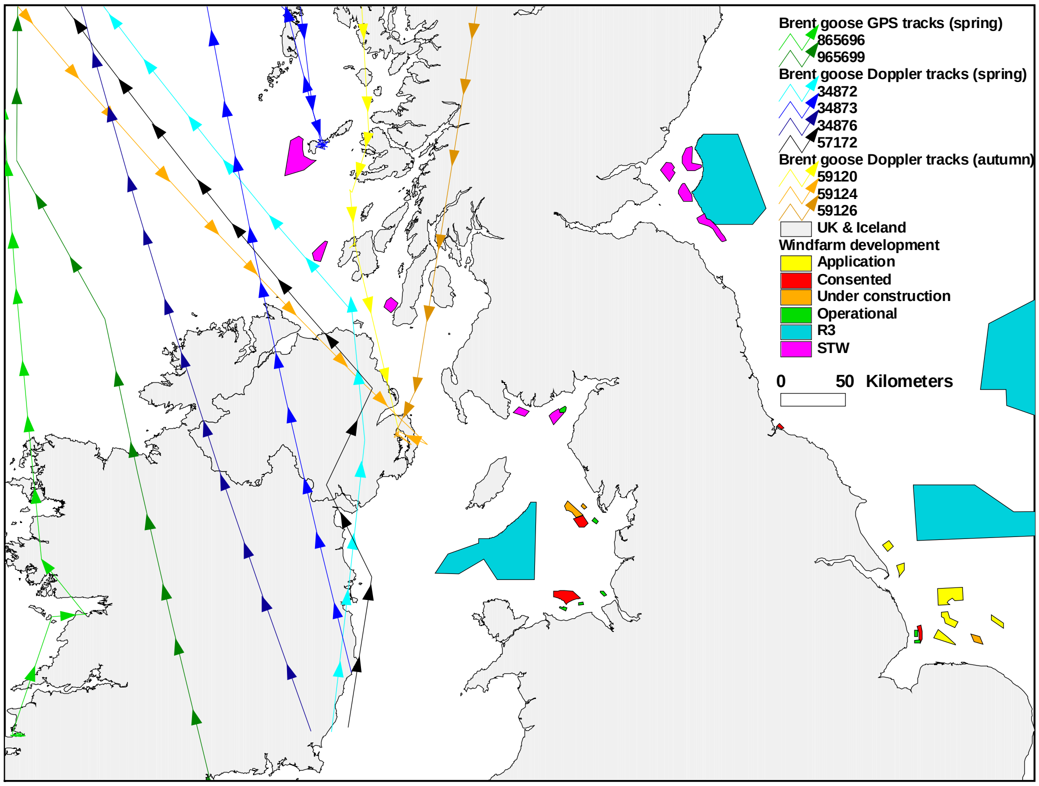


Figure 36. Migration routes within the UK of Light-bellied Brent Geese fitted with conventional Doppler fix satellite transmitters in 2005 and solar GPS transmitters in 2006.

BARNACLE GEESE

The Svalbard Barnacle Goose population winters mostly on the Solway Firth, on the border of SW Scotland with NW England, with geese occurring at the site from September to late May. Over six years of the satellite-tracking study (from 2006–2011), there was little indication that the daily movements of the Barnacle Geese during winter overlapped with the footprints of proposed and operational wind farms within the Solway Firth (Figure 37). However, this is a small sample size and up to 2,000 Svalbard Barnacle Geese are known to use Wigtown Bay, feeding on the saltmarshes in February and March. It seems likely that these are birds that move west from the Mersehead and Caerlaverock areas as food supplies become depleted. The proposed Wigtown Bay STW (41) footprint, now withdrawn, therefore had the potential to overlap with these movements.

The data from 26 adult male Barnacle Geese fitted with 30g or 45g solar GPS PTT-100 ARGOS transmitters either at WWT Caerlaverock or RSPB Mersehead (except goose DAV which was caught at Colvend *c*. 5km west of Mersehead) are presented. All extrapolations are based on the speed recorded by a tag before or after its arrival or departure respectively, and the distance yet to be covered or already covered by the bird. Arrival at or departure from Norway or Spitsbergen was defined by the bird being, or extrapolated to be, within or greater than 50 km respectively of the land masses or offshore islands associated with those territories (Table 10).

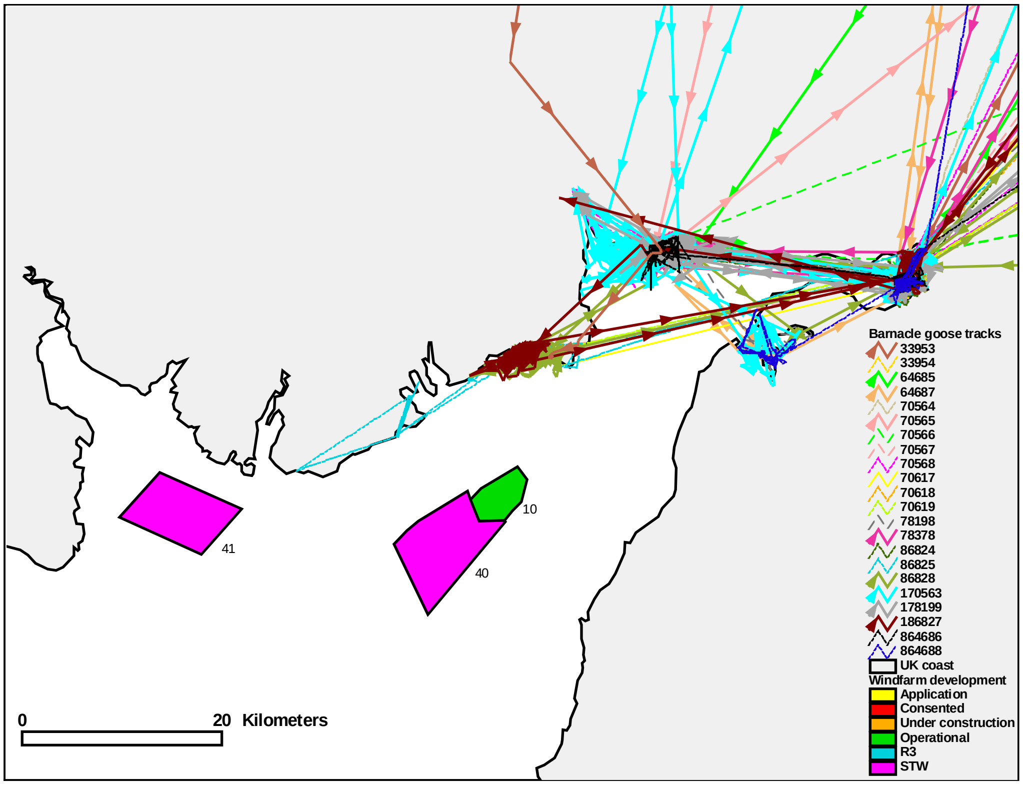


Figure 37. Within-winter movements for 22 Svalbard Barnacle Geese tracked on the Solway Firth between 2006– 2010. No daily movements passed close to the operational Robin Rigg wind farm (No. 10), nor to areas of the Inner Solway considered for STW sites (40 = Solway Firth; 41 = Wigtown Bay) which have now been withdrawn.

The Barnacle Geese generally depart on migration from late April to late May, after spending 1–4 weeks on saltmarsh at Rockcliffe Marsh, Cumbria, at the inner (east) end of the Solway. Most migrate northeast from the Inner Solway (predominantly from Rockcliffe Marsh, Cumbria) and fly 100–110km over land to exit the UK along a stretch of coast ~90km long between North Berwick and the area south of Lindisfarne and Holy Island.

The journey from the UK to Norway over the North Sea generally takes 7–24 hours, and that across the Barents Sea to Spitsbergen takes 11–50 hours, with stops for some birds of 1–124 hours on Bear Island (Figure 38, Table 10).

Table 10. Migration dates of the 26 adult male Barnacle Geese tracked from spring 2006 until spring 2011. Repeat spring migration details for three geese (CPS, DDT and DUC) are included. Departure/arrival times and dates in *italics* indicate where extrapolation over > 3 hours between fixes was necessary; details of these extrapolations are given in the footnotes. Where fixes were > 24 hours apart, no attempt at extrapolation was made. * Numbers in parentheses for the Barents Sea crossing indicate birds visiting Bjørnøya (Bear Island) in the Svalbard archipelago, with the time spent there in parentheses.

PTT	Ring	Date tag deployed	Depart Solway	Arrive Norway	Depart Norway	Arrive Spitsbergen	Journey UK to Norway (hrs)	Crossing Barents Sea (hrs)*
64685	DAD	07/04/06	19:00 29/04/06	19:00 30/04/06	05:00 19/05/06	08:00 20/05/06	24	27
64686	CUB	07/04/06	17:00 16/05/06	13:00 17/05/06	n.a.[13]	n.a.	20	n.a.
64687	CPS	07/04/06	18:00 29/04/06	13:00 30/04/06	*00:00 21/05/06*	19:00 21/05/06	19	19
			Insufficient data	18:00 05/05/07	09:00 18/05/07	21:00 18/05/07	20[16]	11
64688	CYD	07/04/06	02:00 17/05/06	n.a.[11]	n.a.	n.a.	n.a.	n.a.
70565	DAN	03/11/06	*22:00 18/04/07*[1]	05:00 19/04/07	11:00 14/05/07	16:00 15/05/07	7	29
70568	DAZ	03/11/06	*21:00 21/05/07*[2]	09:00 22/05/07	10:00 25/05/07	02:00 28/05/07[15]	12	24 (40)
70619	DAV	13/02/07	*20:00 25/04/07*[3]	09:00 26/04/07	20:00 17/05/07	16:00 18/05/07	13	20
70567	DAC	19/02/07	*00:00 03/05/07*[4]	13:00 03/05/07	07:00 22/05/07	22:00 22/05/07	13	15
70566	CHH	23/03/07	18:00 19/05/07	02:00 20/05/07	05:00 26/05/07	09:00 27/05/07	8	20
70618	DHL	23/03/07	*21:00 18/04/07*[5]	05:00 19/04/07	06:00 18/05/07	18:00 18/05/07	9	12
70563	DDT	04/04/07	Insufficient data	05:00 23/04/07	05:00 18/05/07	17:00 18/05/07	8[17]	12
			18:00 19/05/08	06:00 20/05/08	00:00 22/05/08	10:00 28/05/08	12	30 (124)
70564	DIP	04/04/07	18:00 18/05/07	*03:00 19/05/07*[12]	09:00 25/05/07	10:00 26/05/07	9	25
78198	DSS	14/11/07	*21:00 19/05/08*[6]	09:00 20/05/08	09:00 28/06/08[6]	*15:00 13/07/08*[6]	12	n.a.
78199	DLT	14/11/07	*01:00 25/04/08*[7]	09:00 25/04/08	07:00 19/05/08	23:00 19/05/08	8	16
78202	TZZ	20/03/08	*18:00 20/05/08*[8]	n.a.[8]	n.a.	n.a.	n.a.	n.a.
78378	DUC	20/03/08	*22:00 01/05/08*[9]	07:00 02/05/08	05:00 15/05/08	16:00 15/05/08	9	11
			21:00 30/04/09[10]	06:00 01/05/09	07:00 18/05/09	21:00 18/05/09	9	14
86824	DVY	24/11/08	22:00 02/05/09	06:00 03/05/09	05:00 16/05/09	11:00 17/05/09	8	24 (6)
86825	DVX	24/11/08	19:00 24/05/09	06:00 25/05/09	n.a.[14]	n.a.	11	n.a.
86827	CNV	23/01/09	20:00 01/05/09	03:00 02/05/09	16:00 16/05/09	21:00 17/05/09	7	29
86828	DXF	23/01/09	22:00 01/05/09	08:00 02/05/09	16:00 15/05/09	03:00 17/05/09	10	35
33953	FAJ	09/03/10	17:00 13/05/10	02:00 14/05/10	*11:00 01/06/10*	10:00 02/06/10	9	19 (4)
33954	FBI	09/03/10	18:00 15/05/10	05:00 16/05/10	08:00 27/05/10	10:00 29/05/10	11	50
33102	FDS	04/03/11	23:00 18/05/11	12:00 19/05/11	*12:00 21/05/11*	Insufficient data	13	n.a.
33103	FCS	04/03/11	22:00 13/05/11	09:00 14/05/11	00:00 24/05/11	22:00 25/05/11	11	46
33104	FDZ	04/03/11	23:00 18/05/11	06:00 19/05/11	18:00 21/05/11	*12:00 23/05/11*	7	39 (3)
33145	FCV	04/03/11	21:00 18/05/11	04:00 19/05/11	*11:00 20/05/11*	04:00 21/05/11	7	16 1)

Footnotes:

[1] Bird 70565 (DAN) departed the Solway between 20:00 18/04/07 and 04:00 19/04/07, the time given in the table is based on the bird's distance from the Solway of 575km and its speed of 95 kph at 04:00.

[2] Bird 70568 (DAZ) departed the Solway between 20:00 21/05/07 and 06:00 22/05/07, the time given in the table is based on the bird's distance from the Solway of 640km and its speed of 73kph at a position just 5km from where it was resting on the North Sea at 06:00.

[3] Bird 70619 (DAV) departed the Solway between 20:00 25/04/07 and 04:00 26/04/07, the time given in the table is based on the bird's distance from the Solway of 370km and its speed of 48 kph at 04:00. At this speed and distance it is likely that the bird departed not long after 20:00 25/04/07.

[4] Bird 70567 (DAC) departed the Solway between 20:00 02/05/07 and 04:00 03/05/07, the time given in the table is based on the bird's distance from the Solway of 215km and its speed of 53 kph at 04:00.

[5] Bird 70618 (DHL) departed the Solway between 20:00 18/04/07 and 04:00 19/4/07, the time given in the table is based on the bird's distance from the Solway of 580km and its speed of 82 kph at 04:00.

[6] Bird 78198 (DSS) departed the Solway between 21:00 19/05/08 and 05:00 20/05/08, the time given in the table is based on the bird's distance from the Solway of 430km and its speed of 46 kph at 05:00. At this speed and distance it would be predicted that the bird departed not long after 20:00 19/05/08, however the bird was still stationary on the Solway at 21:00 and so it will probably have departed close to that time. This bird returned to the Solway without its tag in winter 2008/09 and its aberrant behaviour in departing Norway and arriving on Svalbard suggest it was in the process of removing its tag/harness at that time.

[7] Bird 78199 (DLT) departed the Solway between 21:00 24/04/08 and 05:00 25/04/08, the time given in the table is based on the bird's distance from the Solway of 330km and its speed of 91 kph at 05:00.

[8] Bird 78202 (TZZ) started its migration on 20/05/08 heading at least 45km NE from the Solway by 19:00, but by 20:00 this bird was back on the Solway having aborted the migration attempt. The last fix from this bird was at 09:00 on 29/05/08 from the Solway.

[9] Bird 78378 (DUC) departed the Solway between 21:00 01/05/08 and 05:00 02/05/08, the time given in the table is based on the bird's distance from the Solway of 610km and its speed of 93 kph at 05:00.

[10] Bird 78378's (DUC) repeat spring migration departed the Solway between 21:00 30/04/09 and 05:00 01/05/09, the time given in the table is based on the bird's distance from the Solway of 780km and its speed of 104 kph at 05:00. At this speed and distance it is likely that the bird departed not long after 21:00 30/04/09.

[11] Bird 64688 (CYD) gave its last fix 120km NE of Aberdeen at 20:00 17/05/06.

[12] Bird 70564 (DIP) probably arrived in Norway at some point between 01:00 – 05:00 on 19/05/07 since it was stationary on the sea in the Firth of Forth at 20:00 18/05/07 with a 650km journey to Norway remaining. Therefore even assuming the maximum ground speed of ~130 kph recorded for a goose it would take five hours to reach Norway, *i.e.* 01:00 19/05/07. However the bird will likely have travelled slower than this and was recorded resting on a Norwegian island along the west coast at 06:00 19/05/07 and so it is likely to have arrived in Norway at some point between 01:00 and 05:00 19/05/07, the time given in the table being midway between these two times.

[13] Bird 64686 (CUB) got caught in an Atlantic depression; its last GPS fixes was from near Jan Mayen after five days at sea.

[14] Bird 86825 (DVX) gave its last GPS fix from the vicinity of a small Norwegian offshore island at 14:00 30/05/09.

[15] Bird 70568 (DAZ) gave its last GPS fix just 150km south of Spitsbergen at the time and date given in the table.

[16] Bird 64687 (CPS) did not upload GPS fixes for a 32 hour period between 20:00 02/05/07 and 04:00 04/05/07 and so its time and date of departure from the Solway could not be reliably estimated; the time given in the table for the sea crossing to Norway is given relative to its departure from the UK east coast, rather than the Solway, at 14:00 04/05/07.

[17] Bird 70563 (DDT) did not upload GPS fixes for a 38 hour period between 16:00 18/04/07 and 06:00 20/04/07, so its time and date of departure from the Solway could not be reliably estimated. The time given in the table for the sea crossing to Norway is given relative to its departure from the UK east coast, rather than the Solway, estimated at 21:00 22/04/07 from the bird's distance from the UK of 560km and its speed of 74 kph at 06:00 23/04/07 along the Norwegian coast.

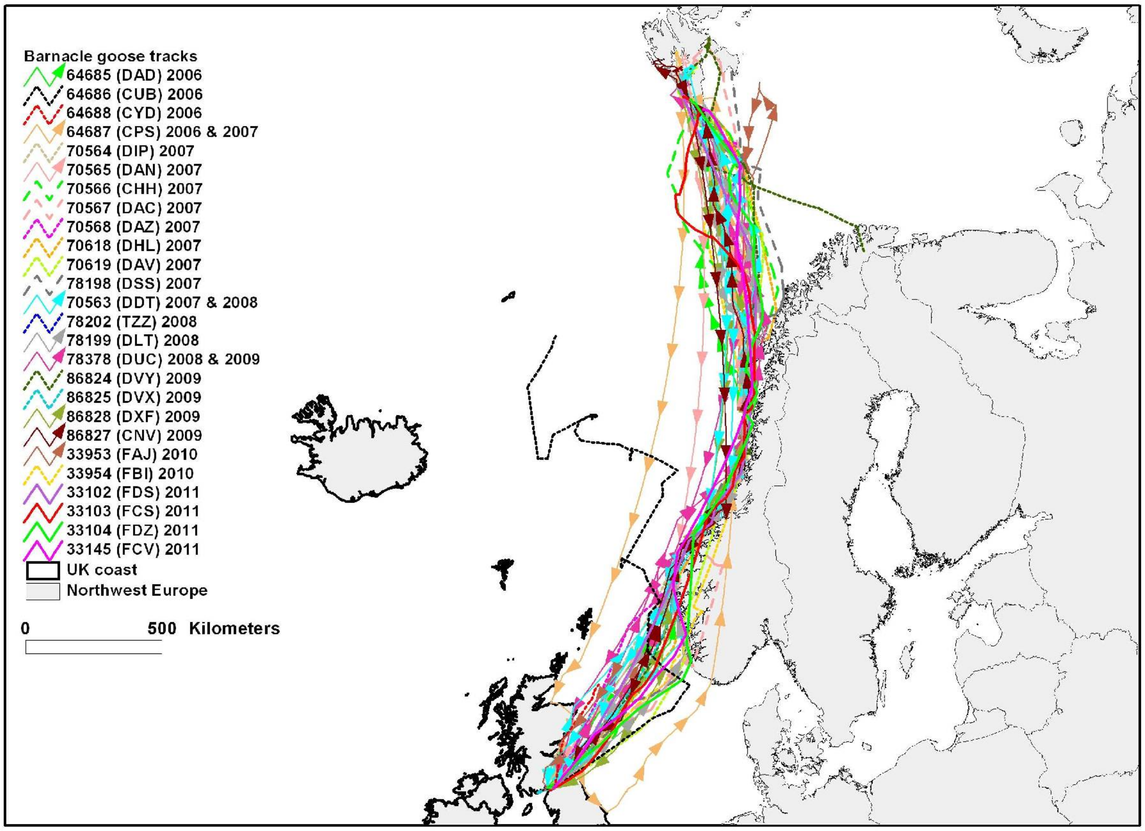


Figure 38. Overview of the migration route of 26 different Svalbard Barnacle Geese tracked from and to the Solway between 2006 and 2011. The migratory front is broadest across the North Sea and across the Barents Sea; the migratory corridor is very narrow along the Norwegian coast in spring. The autumn routes (indicated by southbound arrows) are likely to be inaccurate, due to extrapolations between GPS fixes that are often > 12 hours and large distances apart, due to the reduced frequency of fixes in lower light levels.

Of four Barnacle Geese tagged in 2011 for the specific purpose of identifying in greater detail their night-time overland routes, and whether or not the geese tend to rest on the sea in the Firth of Forth area or pass straight through the windfarm areas on spring migration, there was fairly strong evidence that two passed through the southern part of the R3 Firth of Forth site. The other two birds are likely to have passed to the south of this site.

Unlike previously tracked geese, the solar tags of these birds were programmed to take GPS fixes every hour throughout the night. We therefore can be fairly certain, on the basis of the speeds recorded by the tags and the distances between consecutive fixes, which these birds did not stop on the sea in the Firth of Forth area overnight. This cohort of tagged geese did however leave the Solway fairly late in May and three of the four did not stage in Norway. It is therefore possible that the rapid progress of these particular geese over the Firth of Forth is not representative of the broader population as a whole.

Of 27 Barnacle Geese providing sufficiently detailed tracks on leaving the Solway to allow for the extrapolation of departure times and dates, lighting conditions in relation to sun and moon altitude above the horizon and the percentage of the moon's disk that was illuminated were used to assess the likely lighting conditions at the time of migration. A freeware Excel macro "sunmoon.xls" (provided by Keith Burnett at http://www.bodmas.org/kepler) was revised so that the altitude of the sun and moon (in degrees relative to the horizon), and also the percentage of the moon's disk illuminated, could be determined for goose locations at specific dates and times of day. Light levels were grouped into three categories: daylight (when sun altitude was >-4º), moonlight (when moon altitude was >-4º and >40% of the moon's disk was illuminated) and darkness (sun and moon <-4º; or moon >-4º but moon disk <40%), thus giving an indication of the light levels available to geese for navigating during migration. Weather conditions recorded at the nearby Meteorological Station at Spadeadam (~30km due east from the Barnacle Goose departure point of Rockcliffe Marsh) were also assessed, with the station also providing data on cloud cover in Oktas from 2006–2010 (provided by the Met Office under contract), which if for example more than 25% of the sky was covered could indicate poorer light conditions if only moonlight was available for navigation (Figure 39). In 2011 weather data obtained from the Met Office website did not contain information on cloud cover, and wind direction was only assessed to the nearest 45º rather than 10º.

Over half the geese tracked (16) probably departed at night from the Solway, and of these birds, six probably travelled in near total darkness while ten would probably have been able to benefit from some lighting of the landscape by moonlight, although for three of these birds there was a lot of cloud cover (>=75%) on the nights they departed (Figure 39).

The main area of offshore wind farm development potentially affecting this species in the UK, the Firth of Forth, is ~150km from the Solway, a distance which would typically be covered in 1.5–2 hours by the geese. This would mean that 75% or more of the geese would probably be travelling through these sea areas at night, and half of these in near total darkness.

In contrast along the Norwegian coast, due to the latitude of the staging sites and the dates on which the geese are there, only nine out of 311 migratory flights in that area (observations having been filtered for flight speeds >=15kph and within 30km of the Norwegian coastline) in either spring or autumn could be considered to have occurred under low light levels with the sun more than four degrees below the horizon, and for half of these dates a moon with more than 40% of the disk illuminated would have been above the horizon. Therefore a lack of good visibility during migration along the Norwegian seems unlikely to be a factor unless it is due to poor weather conditions. No weather data were available for the current analysis for the Norwegian coastal sites from 2006 to 2011, but this is an aspect that could perhaps be pursued in the future with collaborators in that area.

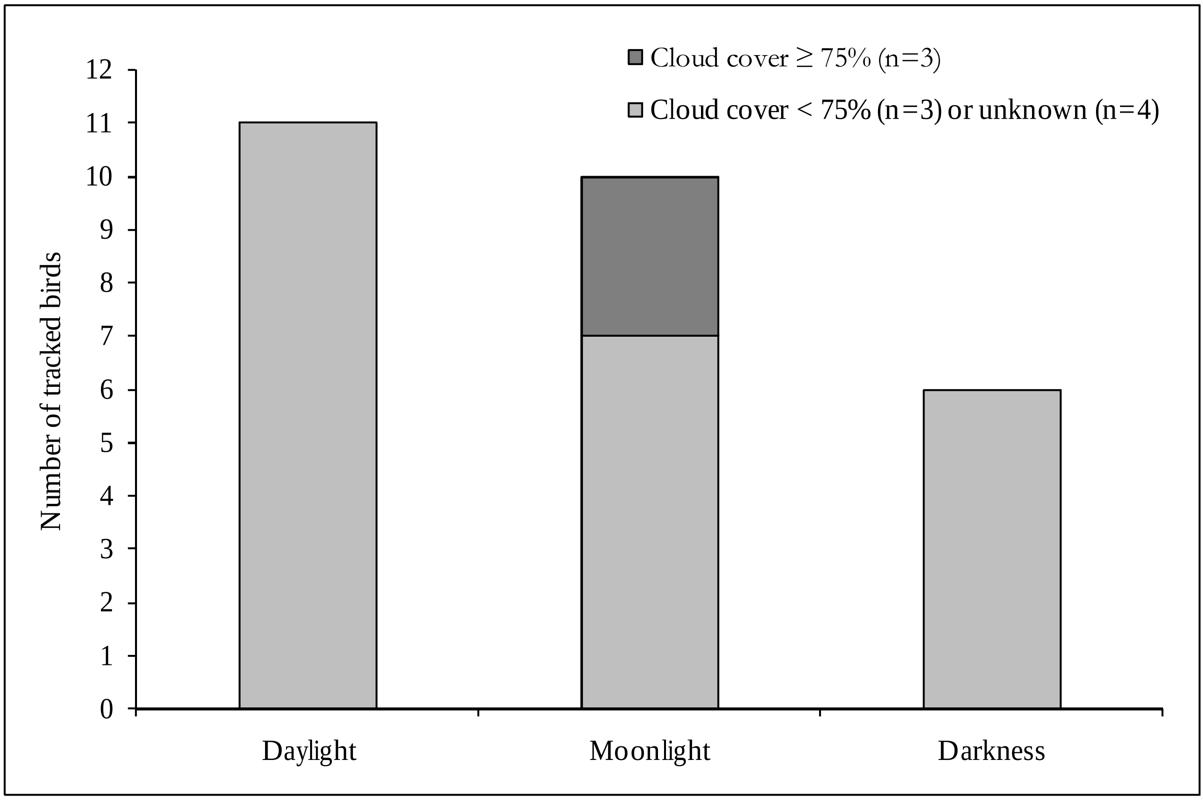


Figure 39. Diurnal lighting conditions under which tagged Svalbard Barnacle Geese migrated in spring 2006 to 2011. Light levels were grouped into three categories: daylight (when sun altitude was >-4º), moonlight (when moon altitude was >-4º and >40% of the moon's disk was illuminated) and darkness (sun and moon <-4º; or moon >-4º but moon disk <40%). Under moonlit conditions the likely percentage cloud cover was also assessed for 23 of the 27 tracks for which Meteorological Station data from Spadeadam were available. Four birds travelled in 2011 under moonlit conditions for which no cloud cover data were available. The breakdown of cloud cover (%) is given (where known) for the Moonlight category only.

Of the 27 tracks for which weather data were available, 22 (81%) departed on winds with a south-westerly or westerly component from 210-270 degrees, which if it is assumed that the geese are heading on a bearing of ~45 degrees for Norway, equates to tailwinds, with a slight westerly side wind component in some cases. Five birds however migrated on winds of between 60-90 degrees which represents quite a strong headwind component. All wind speeds at the start of migration were between 11-46 kph, whereby for reference 28kph = Beaufort 4, a moderate breeze.

Of the geese tracked 78% migrated during conditions of high and rising pressure or steady high pressure (if it is assumed "high" ≥ 1,000mb at sea level), a typical indicator of more stable and good weather conditions. Five birds (19%) departed under high but dropping pressure conditions and one bird departed under Low and falling pressure conditions (Figure 40). A summary of the weather data and diurnal light conditions associated with the commencement of migration for each track are shown in Table 11.

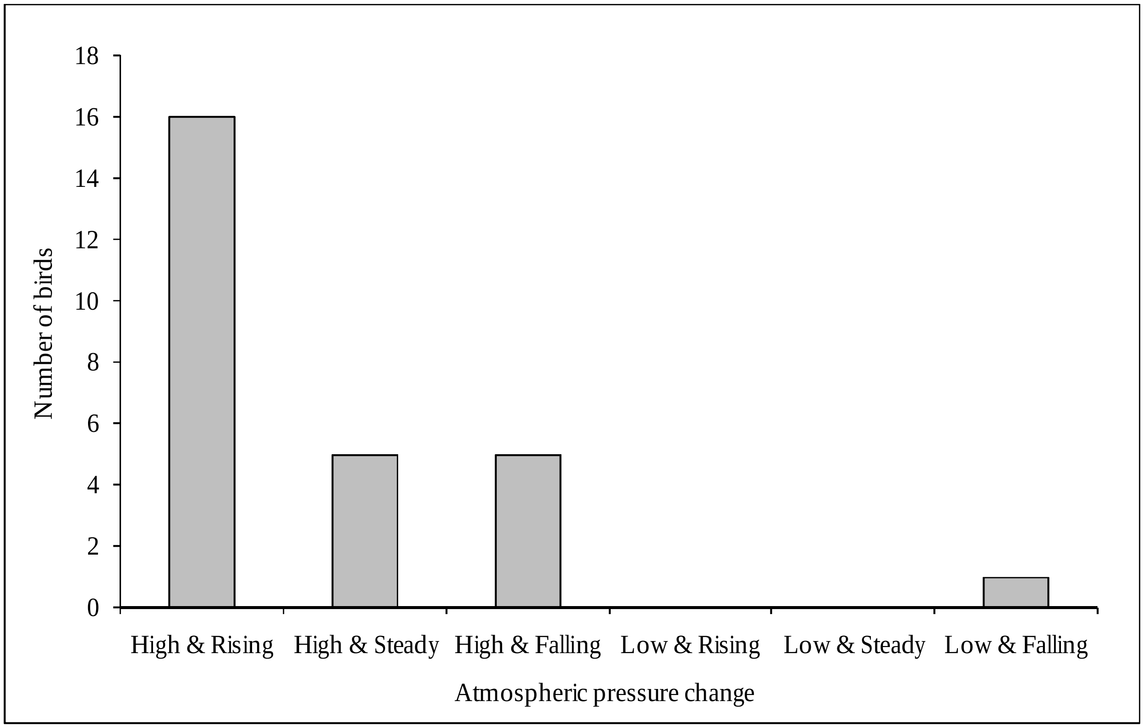


Figure 40. Atmospheric pressure conditions (at sea level) during which Svalbard Barnacle Geese commenced their migrations from the Solway. High pressure conditions were equated with readings of ≥ 1,000mb.

Table 11. Weather and light conditions on the Solway at the times and dates of Barnacle Goose departures. Weather data are from the Spadeadam Meteorological Station, ~20km east of the Solway.

Tag ID	Date of departure	Time of departure	Moon disk % illuminated	Sun alt (deg)	Moon alt (deg)	Light level	Wind speed (kph)	Wind direction	Cloud (oktas)[1]	Pressure at Mean Sea Level (mb)	Pressure change	Visibility (m)	Weather Description
64685	29/04/2006	19:00	5.2	4.9	27.2	daylight	16.7	260	4	1018	Falling	30000	
64686	16/05/2006	17:00	86.9	25.4	-57.4	daylight	27.8	260	8	1012	Rising	35000	
64687	29/04/2006	18:00	5.0	13.3	35.5	daylight	16.7	270	4	1019	Falling	30000	
64688	17/05/2006	02:00	84.0	-12.1	3.9	moonlight	13.0	220	7	1012	Steady	20000	
70565	*18/04/2007*	*22:00*	3.3	-18.5	-2.5	darkness	20.4	250	0	1020	Falling	30000	
70568	*21/05/2007*	*21:00*	30.5	-4.7	33.3	darkness	14.8	250	0	1017	Rising	60000	
70619	*25/04/2007*	*20:00*	65.6	-4.0	50.0	moonlight	29.6	260	7	1014	Rising	60000	
70567	*03/05/2007*	*00:00*	99.5	-19.5	12.2	moonlight	16.7	60	8	1021	Steady	500	Fog
70566	19/05/2007	18:00	12.0	17.3	47.4	daylight	44.4	250	6	1005	Rising	30000	Patchy rain
70618	*18/04/2007*	*21:00*	3.2	-12.9	3.9	darkness	24.1	250	5	1020	Falling	30000	
70564	18/05/2007	18:00	5.6	17.1	39.4	daylight	38.9	210	7	998	Falling	35000	
70563	19/05/2008	18:00	99.7	17.5	-18.5	daylight	14.8	90	7	1020	Rising	50000	
78198	*19/05/2008*	*21:00*	99.8	-5.0	1.6	moonlight	11.1	70	0	1021	Rising	40000	
78199	*25/04/2008*	*01:00*	81.9	-21.0	-0.3	darkness	13.0	250	8	1019	Rising	15000	
78202	*20/05/2008*	*18:00*	99.4	17.6	-27.0	daylight	20.4	90	1	1019	Rising	35000	
78378	*01/05/2008*	*22:00*	17.6	-14.5	-35.2	darkness	13.0	220	3	1009	Rising	30000	
78378	*30/04/2009*	*21:00*	38.9	-9.4	38.5	darkness	11.1	250	6	1018	Rising	50000	
86824	02/05/2009	22:00	61.8	-14.3	35.2	moonlight	14.8	230	5	1025	Falling	18000	
86825	24/05/2009	19:00	0.3	10.0	14.8	daylight	22.2	260	0	1019	Steady	40000	
86827	01/05/2009	20:00	49.7	-2.4	47.2	daylight	22.2	240	7	1019	Rising	15000	
86828	01/05/2009	22:00	50.7	-14.6	33.8	moonlight	18.5	230	5	1021	Rising	10000	
33953	13/05/2009	17:00	81.8	24.9	-56.9	daylight	46.3	80	0	1017	Steady	50000	
33954	15/05/2010	18:00	3.6	16.6	33.5	daylight	27.8	260	0	1013	Steady	20000	
33102	18/05/2011	23:00	97.0	-14.0	4.1	moonlight	24.1	225		1012	Rising	30000	
33103	13/05/2011	22:00	82.8	-11.6	26.4	moonlight	14.8	270		1015	Rising	19000	Mostly Cloudy
33104	18/05/2011	23:00	97.0	-14.0	4.1	moonlight	24.1	225		1012	Rising	30000	
33145	18/05/2011	21:00	97.3	-5.3	-7.9	moonlight	27.8	270		1011	Rising	35000	Rain

[1] Sky conditions are estimated by the Met Office in terms of how many eighths are obscured by cloud, ranging from completely clear, 0 oktas, to completely overcast, 8 oktas.

Potential weather effects on the routes taken by migratory Svalbard Barnacle Geese.

As with the Whooper Swans, it is possible to make a preliminary assessment of the possible effects of prevailing wind conditions on the routes taken across the UK by the Barnacle Geese, albeit that the migratory journey is much shorter over land than for the Whooper Swans. This comparison is possible between years for the routes taken by different geese, but unfortunately not between years for individual geese because of a lack of good quality GPS fixes in one of the years for the three individuals which completed two full migratory cycles (Figure 41).

Where Barnacle Geese gave GPS fixes for sites over land or over the sea during spring ≤ 50km from Meteorological Stations, and where the birds were recorded as flying, the bearing of their tracks from the Solway could be assessed in relation to the prevailing wind conditions at the time of their migration. This was not applicable to the three repeat spring migratory tracks because of a lack of GPS in one of the two spring years in each case. Even so, Figure 42 shows that birds subjected to more westerly winds during their migration tended to depart the UK coast further south than birds subjected to more southerly or easterly winds. Exceptions to this pattern such as CUB and CYD are probably due to: (a) CUB initially being subjected (as seems likely from a prediction of the time of departure) to westerly winds for possibly the first hour of its journey from the Solway; and likewise (b) CYD was already 180km from the Solway, and thus possibly four hours into its journey before the first comparison with weather data can be made. If CYD had been on the Solway 4–5 hours earlier it would have been subject to more southerly winds.

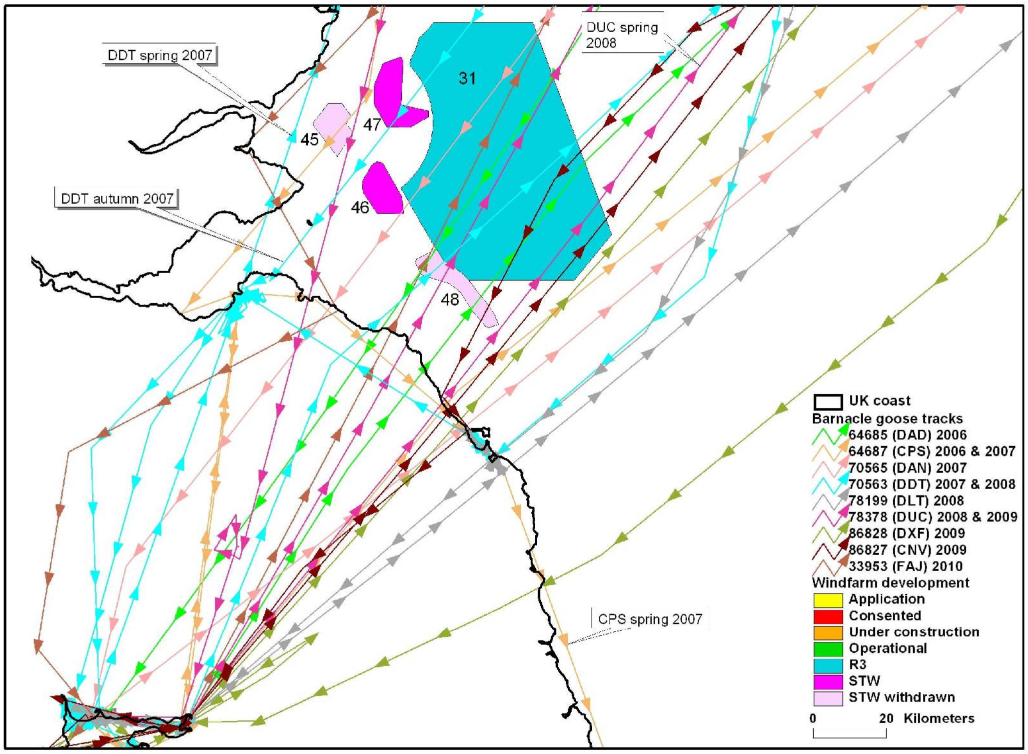


Figure 41. Full return migratory tracks of Svalbard Barnacle Geese, with repeat tracks for three birds being shown. One of these, DDT, completed two full migrations. Any repeat routes are labelled to distinguish them between years.

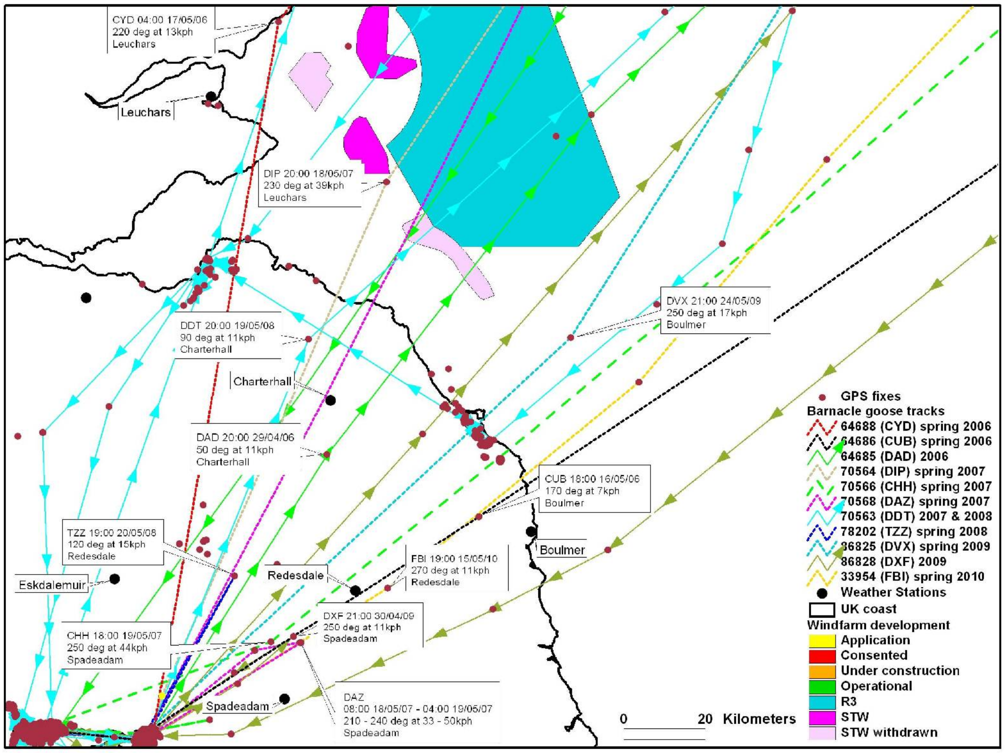
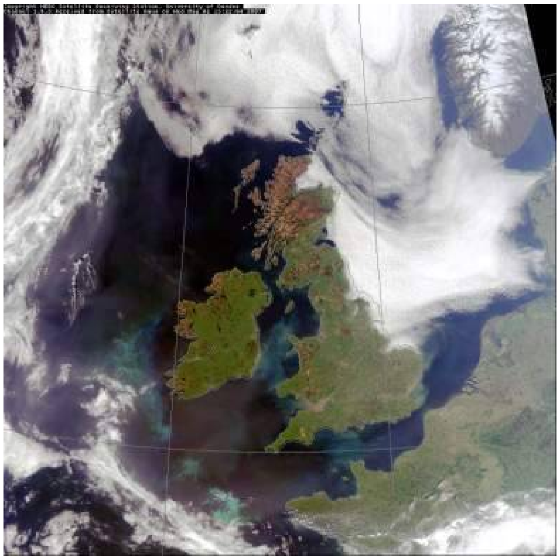


Figure 42. Variation in the spring migration routes taken by Svalbard Barnacle Geese on leaving the UK in relation to prevailing wind conditions.

Figures 41 & 42 illustrate an interesting anecdotal observation that was initially difficult to explain but which may have important implications for what strategies birds undertake when confronted by poor weather conditions. It can be seen that bird CPS in the year of his repeat spring migration in 2007 takes an extremely odd journey south on the morning of 4th May of more than 200km from his previous exit point from the UK in 2006. When the bird had almost reached the Humber by 14:00 h that day it then migrated directly across the North Sea to a landfall site in Norway approximately 350km south of the site it arrived at the previous year. It seems likely that this coastal migration south in the UK was a response to a thick band of coastal fog or "ha" that had developed along its previous migratory route in the North Sea from at least 2nd May 2007 until 4th May 2007 (Figures 43 & 44). As can be seen from Figure 44, the fog was thinning in the vicinity of the Humber in the afternoon of 4th May when bird CPS turned to migrate across the North Sea. Only one other bird, DAC, migrated to Norway during this period on 3rd May 2007 and its direct route through the typical migratory corridor to Norway appears to invalidate this theory. However, bird DAC made an unprecedented climb to 461m and then 584 m above sea level when crossing the North Sea, approximately four to five times the typical travel height of a goose across this area of sea. Thus this bird appears to have made the decision to go over the fog bank while the other, CPS, went around it.



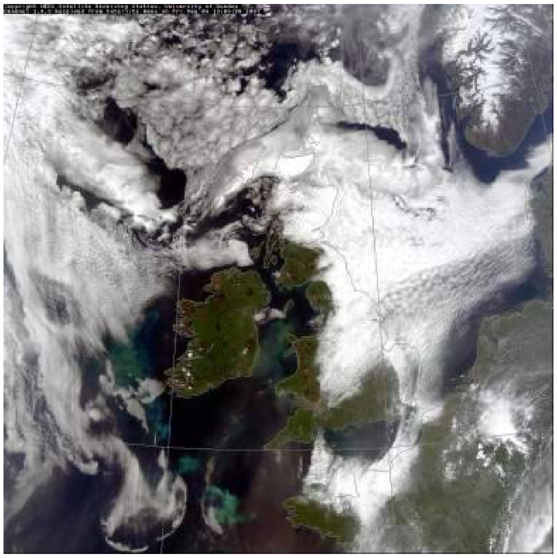


Figure 43. MODIS satellite imagery from Dundee University showing evidence of the formation of a sea "ha" or fog in the North Sea on 2nd May 2007 at a time when geese would typically be attempting to migrate to Norway.

Figure 44. MODIS satellite imagery from Dundee University showing the thick fog bank persisting at least until the afternoon of 4th May 2007, with the fog thinning close to the Humber Estuary, an area through which one of the geese eventually migrated well south of the usual spring migratory corridor.

The potential overlap between Barnacle Goose migratory routes and onshore and offshore wind farm footprints.

Overall, forty two wind farms sites (eight UK offshore/inshore sites, 19 onshore sites and 15 sites in Norway) either had Barnacle Geese passing over the site, or were ≤5km of flight-lines for at least 5 geese tracked on migration (Table 12). An additional 71 sites (62 in Britain; 9 in Norway) were within 5km for 1–4 geese tracked, but these birds did not pass directly over the wind farm footprints.

Table 12. Key onshore and offshore wind farm sites, in Britain and along the coast of Norway, in terms of the number of tracked Barnacle Geese (up to 27 passing across UK onshore areas, 26 offshore areas and 23 along the Norwegian coast) predicted to have passed across the sites based on the extrapolated straight line tracks between consecutive GPS fixes, and/or ≤ 5km of the sites (totals include those passing across the sites). * The table does not include 71 sites (of which nine were Norwegian) that registered less than five birds passing within 5km of the wind farms and had zero extrapolated tracks passing across the sites.

Type	Stage	Name	Tur-bines	Tagged birds passing across wind farm	Tagged birds passing ≤ 5km of wind farm
Onshore	Consented	Drone Hill (Coldingham Moor)	22	1	5
Onshore	Consented	Fallago Rig	48	1	2
Onshore	Operational	Crystal Rig I extension (5 turbines)	5	1	4
Onshore	Operational	Crystal Rig Phase II	52	1	2
Onshore	Planning	Hallburn Farm	6	0	14
Onshore	Planning	Monashee	17	0	5
Onshore	Planning	Whitton	6	0	8
Inshore	Planning	Aberdeen Wind Deployment Centre	35	1	2
Onshore	Planning	Barmoor Wind farm	10	1	10
Onshore	Planning	Barrel Law	10	1	3
Onshore	Planning	Buchan (Mintlaw)	15	1	1
Onshore	Planning	Cousland Limeworks	10	1	1
Onshore	Planning	Felkington	10	1	8
Onshore	Planning	Gilston	24	1	2
Onshore	Planning	Housebyres Community Wind Co-op	6	1	1
Onshore	Planning	Leithope	10	1	11
Onshore	Planning	Minch Moor	12	1	2
Onshore	Planning	Park Head	9	1	1
Onshore	Planning	Penmanshiel	19	1	6
Onshore	Planning	Beck Burn	9	7	25
Offshore	R3 Planning	Dogger Bank	-	1	1
Offshore	R3 Planning	Moray Firth	-	1	1
Offshore	R3 Planning	Firth of Forth	-	13	15
Offshore	STW Planning	Inch Cape	-	1	3
Offshore	STW Planning	Neart na Gaoithe	-	1	3
Offshore	STW Withdrawn	Bell Rock	-	2	4
Offshore	STW Withdrawn	Forth Array	-	7	9
Norwegian	Consented	TESTOMRÅDE STADT	3	0	8
Norwegian	Consented	ANDMYRAN	40	1	2
Norwegian	Consented	HARBAKFJELLET	33	1	3
Norwegian	Consented	SWAY KARMØY	1	1	3
Norwegian	Consented	HARAM	16	2	9
Norwegian	Consented	ROAN	66	2	4
Norwegian	Consented	SWAY KOLLSNES	1	2	5
Norwegian	Consented	SØRMARKSFJELLET	33	2	4
Norwegian	Consented	VARDØYA	2	4	19
Norwegian	Consented	YTRE VIKNA	83	4	8
Norwegian	Consented	HAVSUL I	44	6	15
Norwegian	Construction	MEHUKEN 2	5	1	7
Norwegian	Operational	MEHUKEN I	5	1	8
Norwegian	Operational	HARØY	5	3	8
Norwegian	Operational	SMØLA	68	3	10
Total turbines (excluding offshore R3 and STW sites) and sites			~740	42	113 (=42+71*)

Most tracks were over or near the Round 3 offshore Firth of Forth site, which is currently at the planning stage (13 of 26 tracks were over the site; 15 ≤ 5km of the site), the Beck Burn onshore site which is also at the planning stage (7 tracks over the site; 25 ≤ 5km of the site) and the Smøla (operational), Vardøya (consented) and Havsul I (consented; 44 turbines) sites in Norway (Table 12).

Further assessment of the extrapolated tracks for geese arriving and particularly those leaving Britain (which provided more detailed movement data) indicated that more than half of the spring tracks crossing the R3 Firth of Forth site were concentrated in the southern part of the footprint, and that of 15 spring tracks that missed the site 13 (87%) were to the south compared with 2 to the north (Figure 45).

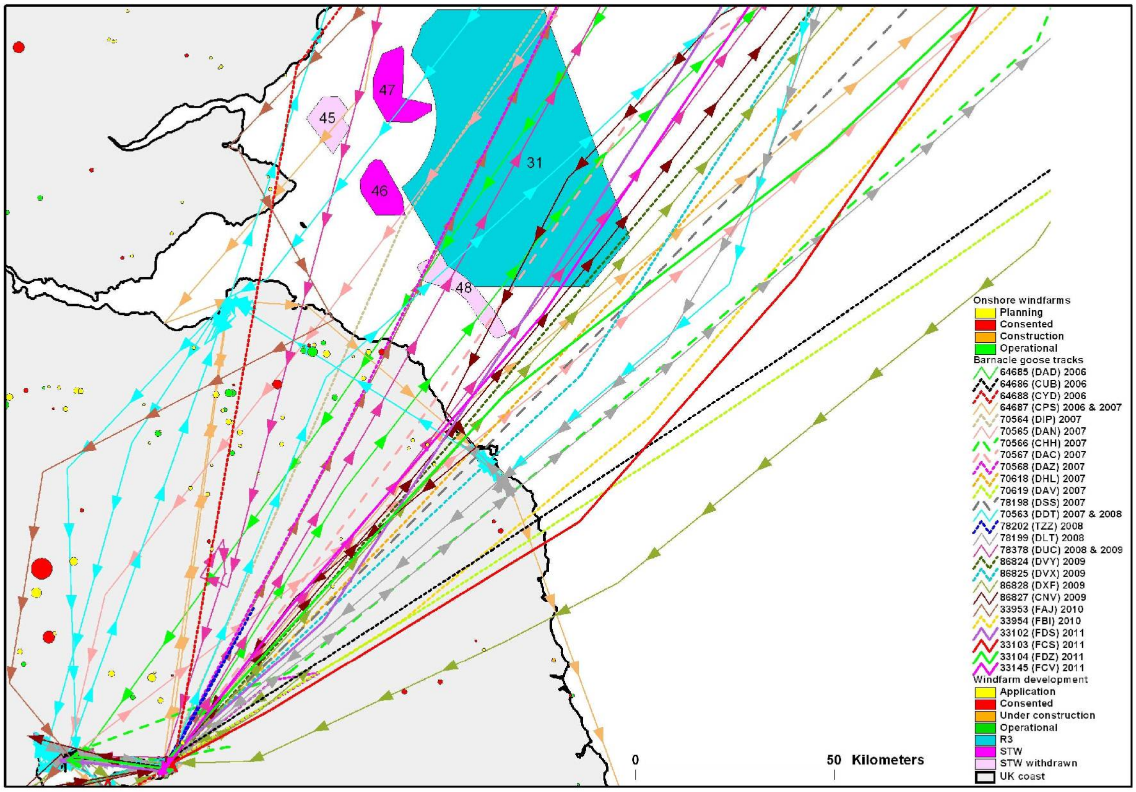


Figure 45. Extrapolated GPS tracks of Svalbard Barnacle Geese across UK onshore and offshore windfarm sites from 2006 to 2011. Developmental status of the windfarm sites up to June 2011 is given. Solid lines with arrows indicate birds that have made return migrations; dotted lines indicate those for which only spring data are available within a given year. Thick solid lines are given for those four birds tagged in 2011 for the specific purpose of identifying night-time overland routes and whether or not the birds tend to pass across the Firth of Forth R3 (see Table 5 for further details; 31 = Firth of Forth) and STW (45 = Bell Rock; 46 = Neart na Gaoithe; 47 = Inch Cape; 48 = Forth Array) offshore sites. Barnacle Goose tagged 70617 is omitted from the figure because there were no location data provided between a last fix from the Solway in May and the next transmission from Norway in July.

Almost all of the birds tracked passed within 2km of proposed or operational onshore wind farm sites in the UK and in Norway, with *c*. 50% and 60% predicted to pass across wind farms in the UK and Norway respectively (Figure 46). Between 40–50% of tracks passed across offshore wind farm sites (Figure 46).

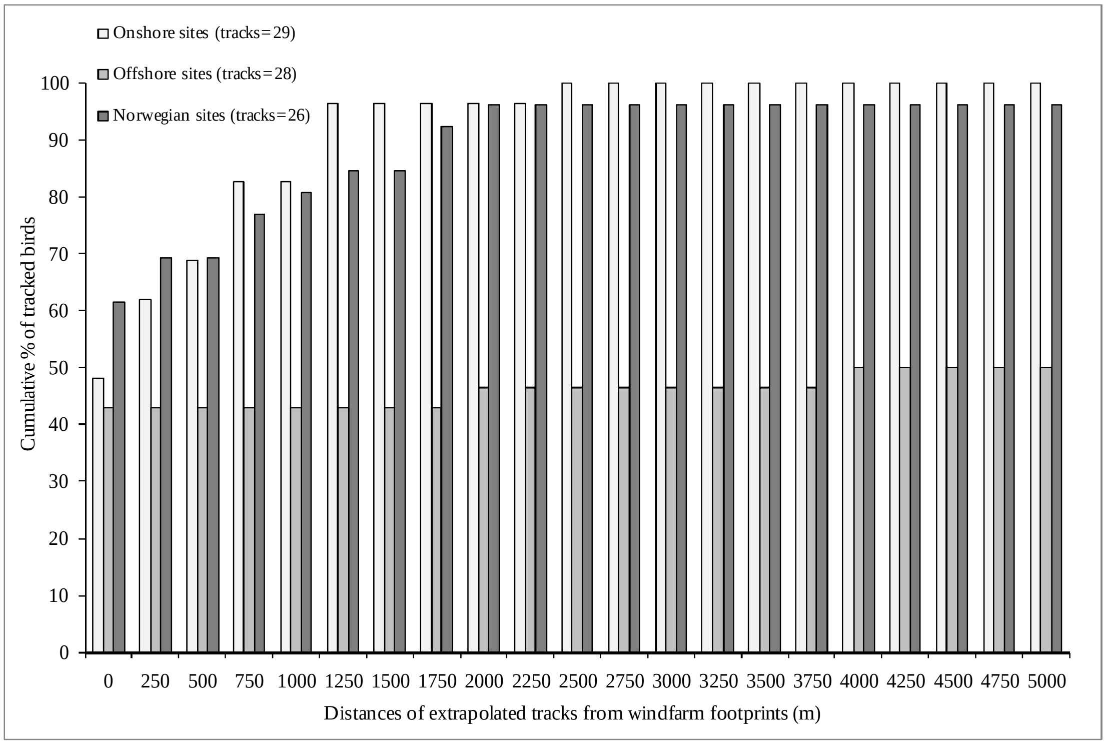


Figure 46. Cumulative percentage of tagged Barnacle Geese whose extrapolated spring migratory tracks passed within certain distance bands of onshore and offshore wind farm sites in the UK and Norway.

Of 21 Barnacle Geese migrating from the UK to Svalbard, four (19%) were tracked across a wind farm footprint once, two (9.5%) passed over twice, one (5%) passed over on three occasions, seven (33%) on four occasions, three (14%) on five occasions and four (19%; including 70563 which completed two return migrations and 78378 which completed a return migration plus a spring migration) passed over wind farm sites on six or more occasions (Figure 47). Additionally, noting that some geese provided more data than others, >10% of the tracks recorded for 18 of 27 geese tracked from the Solway passed within 5km of a wind farm site (Figure 48).

The total number of wind farm sites passed through by Svalbard Barnacle Geese within the UK and Norway is predicted to be about four or more over the course of a year.

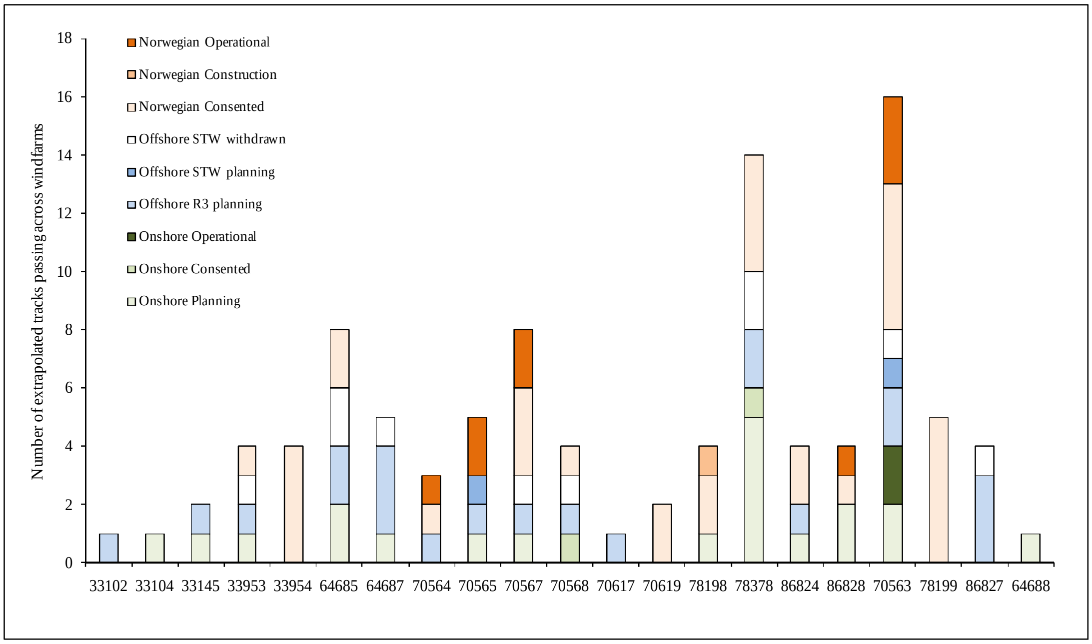


Figure 47. Cumulative number of extrapolated tracks for individual Barnacle Geese that passed across onshore and offshore wind farms at various stages of development in the UK and Norway. Note: bird 70563 completed two full migratory cycles; birds 78378 and 64687 completed a full migratory cycle and repeat spring migration; birds 33953, 64685, 70565, 86827 and 82828 each completed a full migratory cycle. Other birds shown only completed or part-completed their spring migrations north, with some part-completing the autumn migrations south.

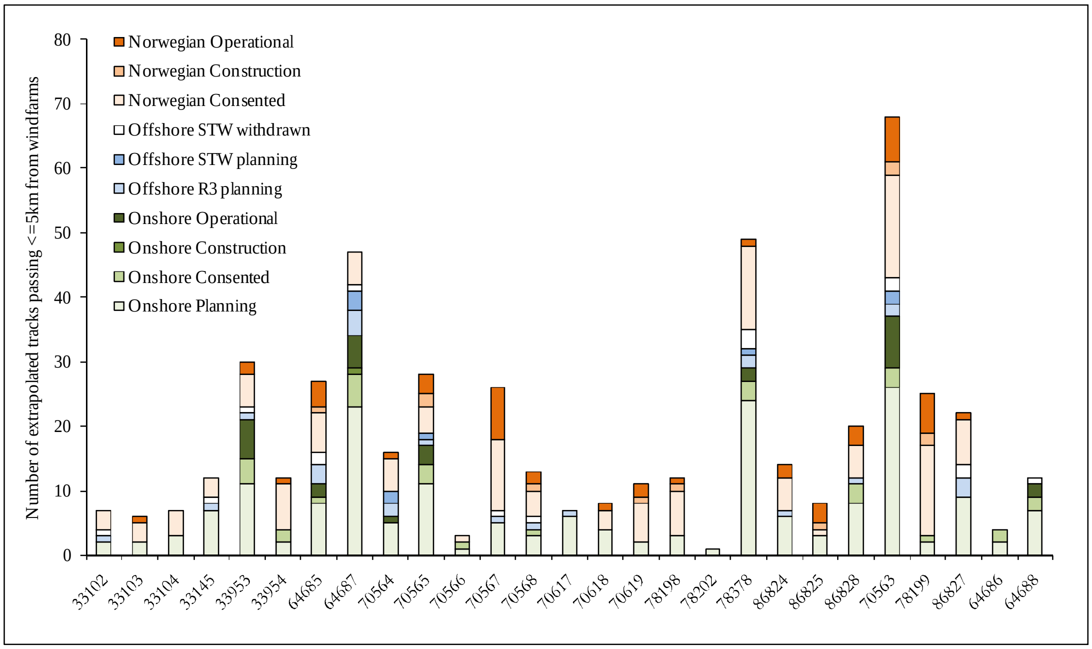


Figure 48. Cumulative number of extrapolated tracks for individual Barnacle Geese that passed ≤ 5km from onshore and offshore wind farms at various stages of development in the UK and Norway. Note: bird 70563 completed two full migratory cycles; birds 78378 and 64687 completed a full migratory cycle and repeat spring migration; birds 33953, 64685, 70565, 86827 and 82828 each completed a full migratory cycle. Other birds shown only completed or part-completed their spring migrations north, with some part-completing the autumn migrations south.

Between 60–80% of individually tagged geese passed across (a) onshore sites at the planning stage, (b) offshore (UK R3/STW) sites at the planning stage and (c) Norwegian sites where development has already been consented (Figure 49), rising to 100% of geese passing within 5km of planned onshore sites, >70% passing within 5km of planned offshore sites in the UK and >90% within 5km of consented and/or operational sites within Norway (Figures 50). The percentage of extrapolated tracks that crossed wind farm sites similarly indicated a high number of wind farms over-flown by the geese or occurring within 5km of their flight-lines (Figures 51 & 52).

The high number of Norwegian wind farms along the Svalbard Barnacle Goose migration route serves to emphasise the importance of international agreements for determining cumulative impact and risk assessment, and thus identifying which wind farm developments should be permitted within each country along the migration route of this species.

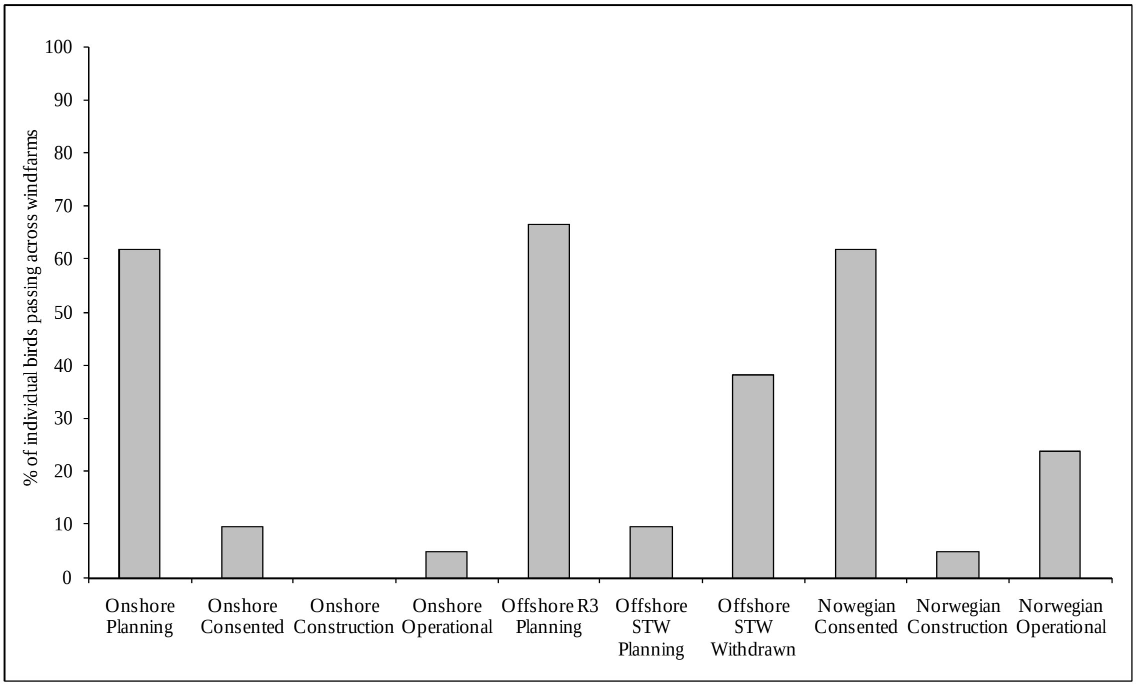


Figure 49. Percentage of individually tagged Barnacle Geese whose extrapolated tracks passed across onshore and offshore wind farms at various stages of development in the UK and Norway.

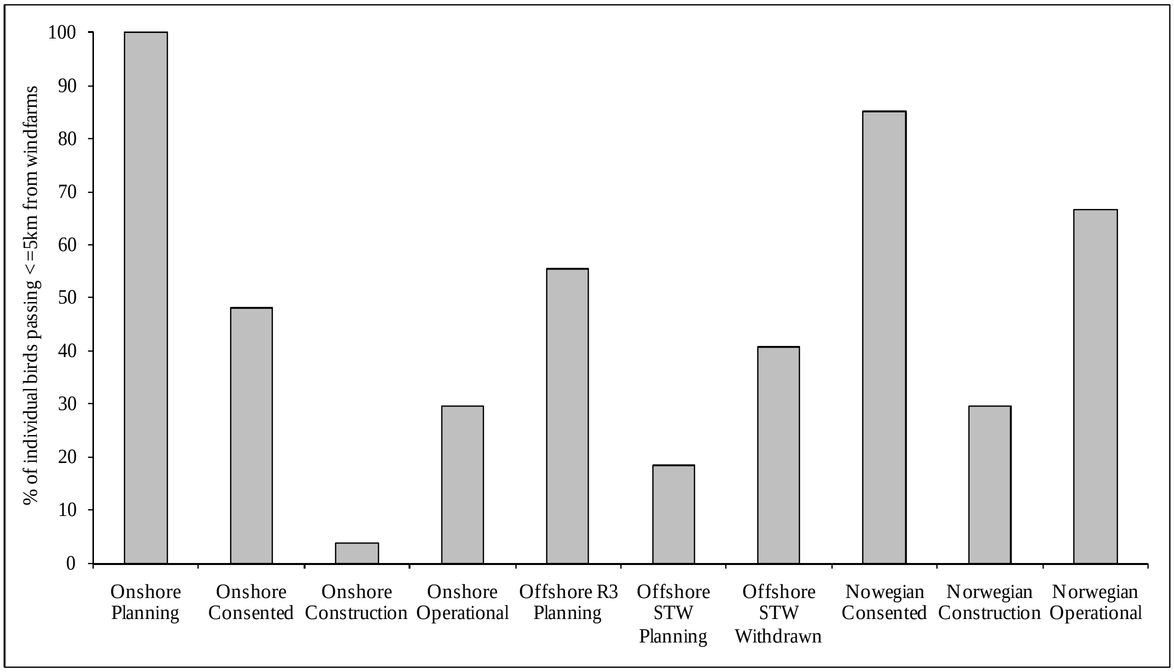


Figure 50. Percentage of individually tagged Barnacle Geese whose extrapolated tracks passed≤ 5km from onshore and offshore wind farms at various stages of development in the UK and Norway.

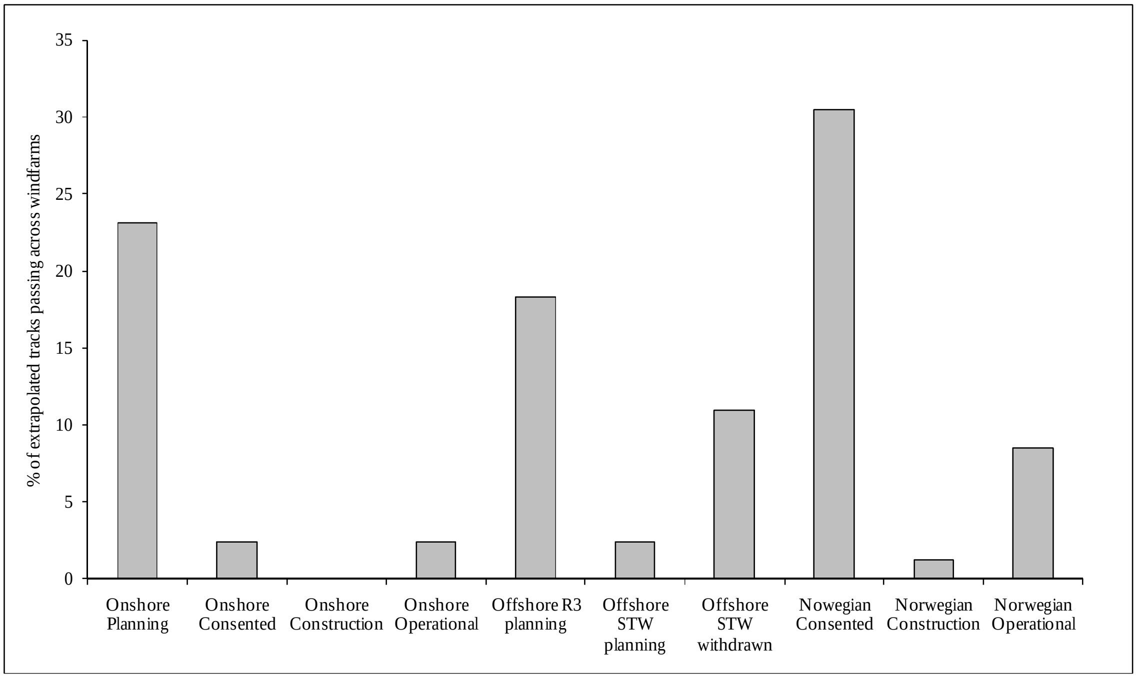


Figure 51. Percentage of the extrapolated tracks of Barnacle Geese passing across onshore and offshore wind farms at various stages of development in the UK and Norway.

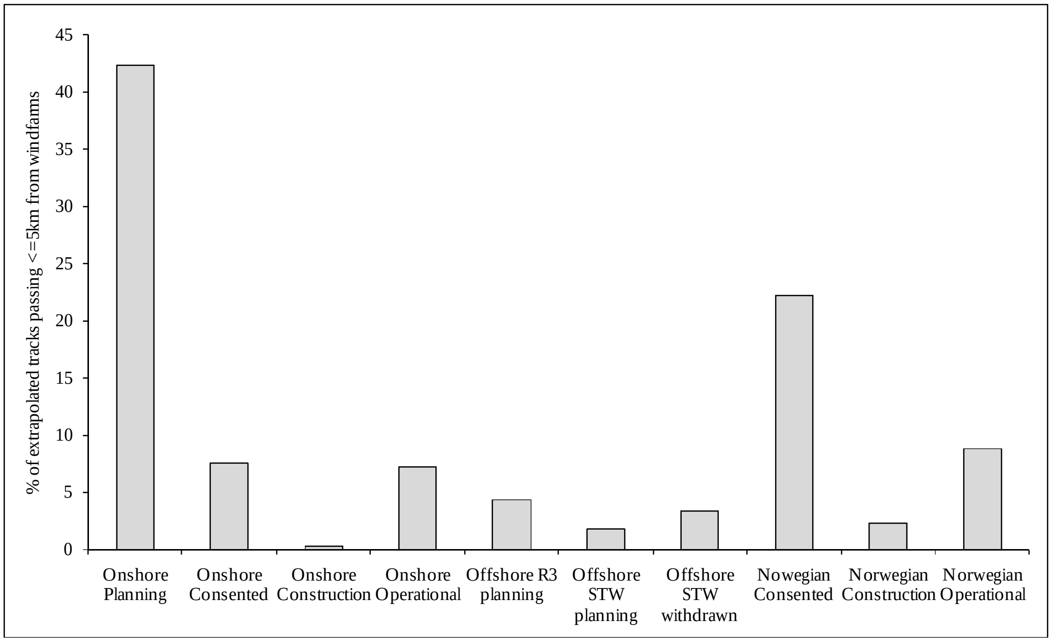


Figure 52. Percentage of the extrapolated tracks of Barnacle Geese passing ≤ 5km from onshore and offshore wind farms at various stages of development in the UK and Norway.

Onshore and offshore flight heights Barnacle Geese, and in comparison with Whooper Swans.

Flight heights for Barnacle Geese migrating overland within the UK were calculated within the GIS, as described in section 3.1.2 and also for Whooper Swans above.

A total of 23 GPS fixes with altitude data (range = -210 – 1,099 m) were recorded for Svalbard Barnacle Geese during their overland migratory flights. The mean flight height (± S.E.), above ground level, was 183 m (±65 m), with a median flight height of 161 m and a modal value of up to 20 m. One "*neg alt*" value (in a total of six height values < -22m) was replaced for calculating the mean and median values, as described under section 3.1.2 above. The height distribution data for overland flights are illustrated in Figure 53.

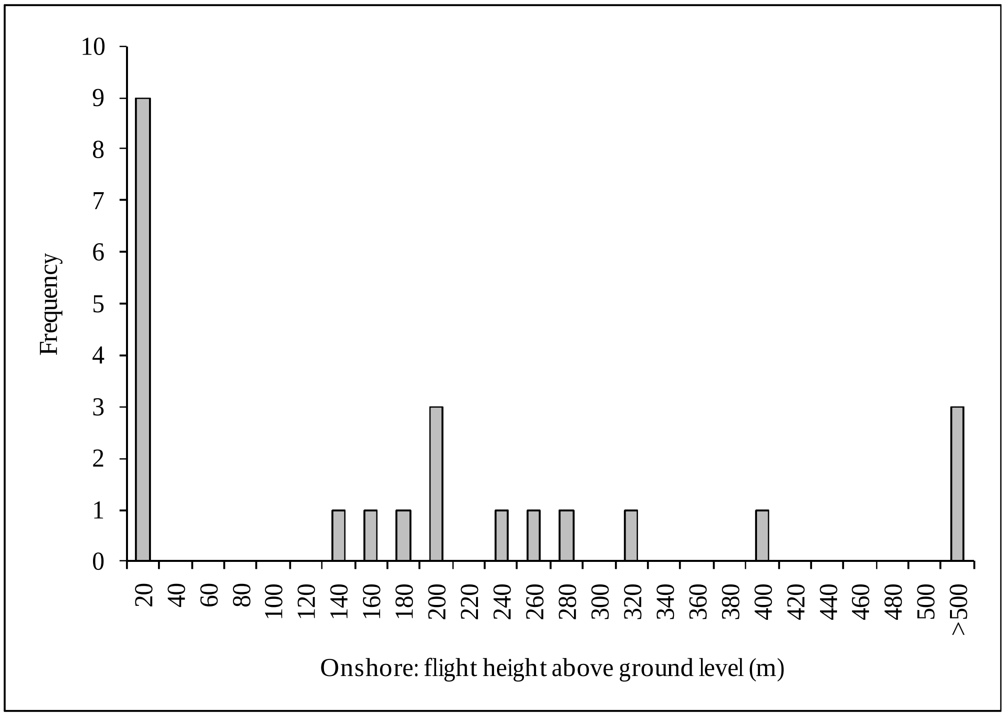


Figure 53. Onshore flight heights above ground level recorded for Svalbard Barnacle Geese during their spring and autumn migrations (n = 23). Eight of the flight heights recorded in the 20m category were negative, with six values being less than -22 m.

A total of 305 GPS fixes with altitude data (range = -21–677 m) were recorded for Svalbard Barnacle Geese during their migration over the sea. The mean flight height (± S.E.) above sea level, was 81 m (±8 m), with a median flight height of 16 m and a modal flight height in the 0–20 m band. Seventy seven "*neg alt*" values were replaced for calculating the mean and median values. The height distribution data for the overseas flights are illustrated in Figure 54. Offshore values were filtered to be more than 20km from the UK coastline and more than 20km from the Norwegian/Svalbard coastline.

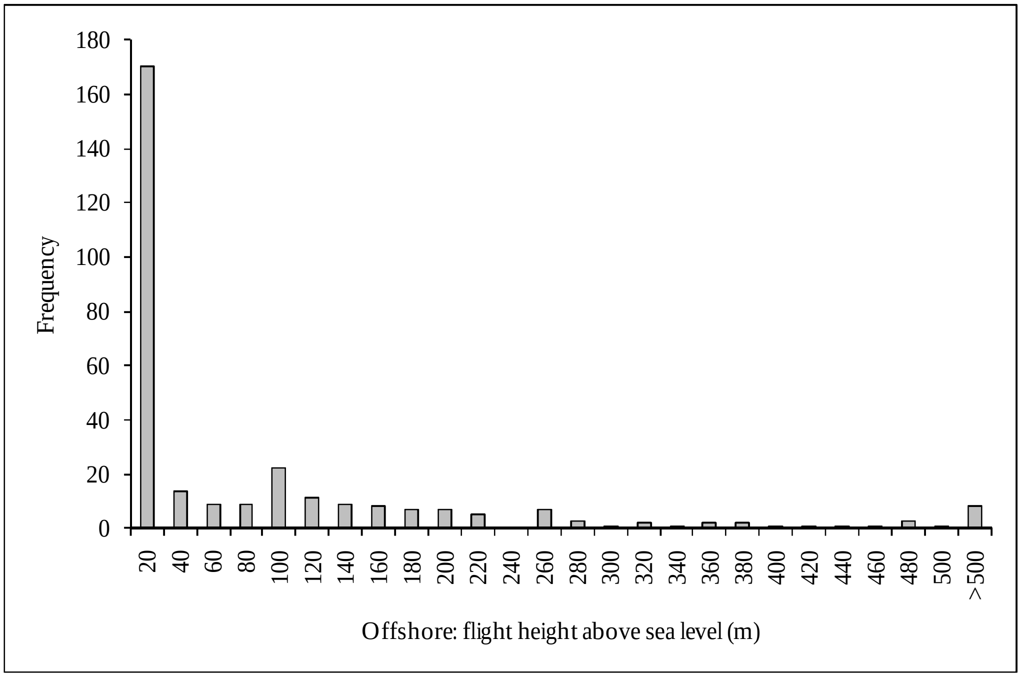


Figure 54. Offshore flight heights above sea level recorded for Svalbard Barnacle Geese during their spring and autumn migrations (n = 305). Of the flight heights recorded in the 20m category, 77 had "*neg alt*" heights and were given negative values.

On comparing the flight heights recorded for Barnacle Geese and Whooper Swans, it seems that the swans tend to fly at about half the Barnacle Goose migration flight height (Table 13).

In both species, flight heights over the open ocean are approximately half that typically recorded over the land.

Whilst noting the errors recorded by the GPS tags, it still seems likely that Barnacle Geese migrate over land the majority of the time at heights above a maximum rotor tip height of ~130m. Offshore, the geese tend to fly within the rotor swept zone and below. In terms of flight heights, Whooper Swans tend to fly within or below what would be the rotor swept zone both onshore and offshore (Table 13).

Table 13. Summary of the flight height characteristics of Svalbard Barnacle Geese and Whooper Swans migrating over land and over the sea.

Statistic	Whooper Swan flight height (m)		Svalbard Barnacle Goose flight height (m)	
	Onshore	Offshore	Onshore	Offshore
Mean (±SE)	82 (±9)	31 (±3)	183 (±65)	81 (±8)
Median	42	9	161	16
Minimum	-312	-22	-210	-21
Maximum	649	471	1,099	677
n	220	355	23	305

GREENLAND WHITE-FRONTED GEESE

Greenland White-fronted Goose migration was satellite-tracked by WWT in 2008 and 2010, but only for a very small number of birds from the small sub-population of around 200 birds that winters at Loch Ken, Dumfries & Galloway.

Few generalisations therefore can be made regarding the population at large and the limited data collected so far can be used only for an initial assessment of the possible migration route taken by this sub-population in spring. Six spring migration tracks were available (four from 2008 with frequent GPS fixes per day; two from 2010 with only 1 GPS fix per day). There are no tracks recorded for autumn to date. It could be argued that the four birds tracked in 2008 did not behave independently as they appeared to be part of the same migratory flock, at least as far as Iceland (Figure 14). These birds were fitted with transmitters following a catch of five adult male birds in February 2008 that were seen together throughout the rest of the winter at Loch Ken (*i.e.* they appeared to be related or otherwise closely associated).

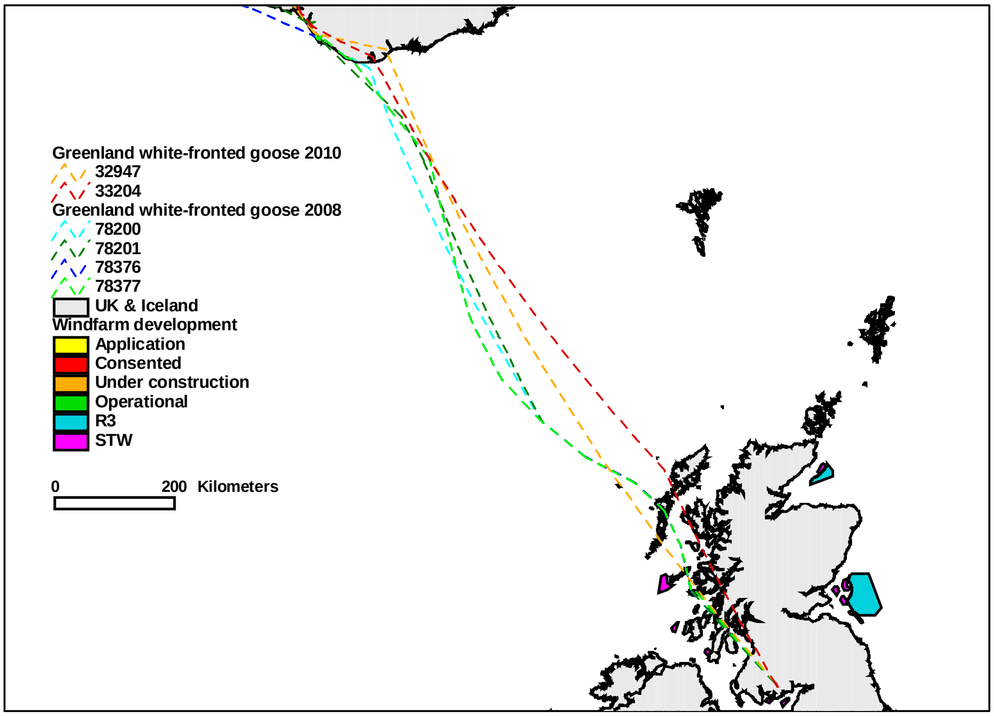


Figure 14. Spring migration routes for six Greenland White-fronted Geese tracked in 2008 and 2010 with solar GPS transmitters (up to 12 GPS fixes per day) and non-solar GPS transmitters (1 GPS fix per day with no height observations), respectively. The tracks of the 2008 cohort overlap as far as Iceland as the birds were in the same migratory flock.

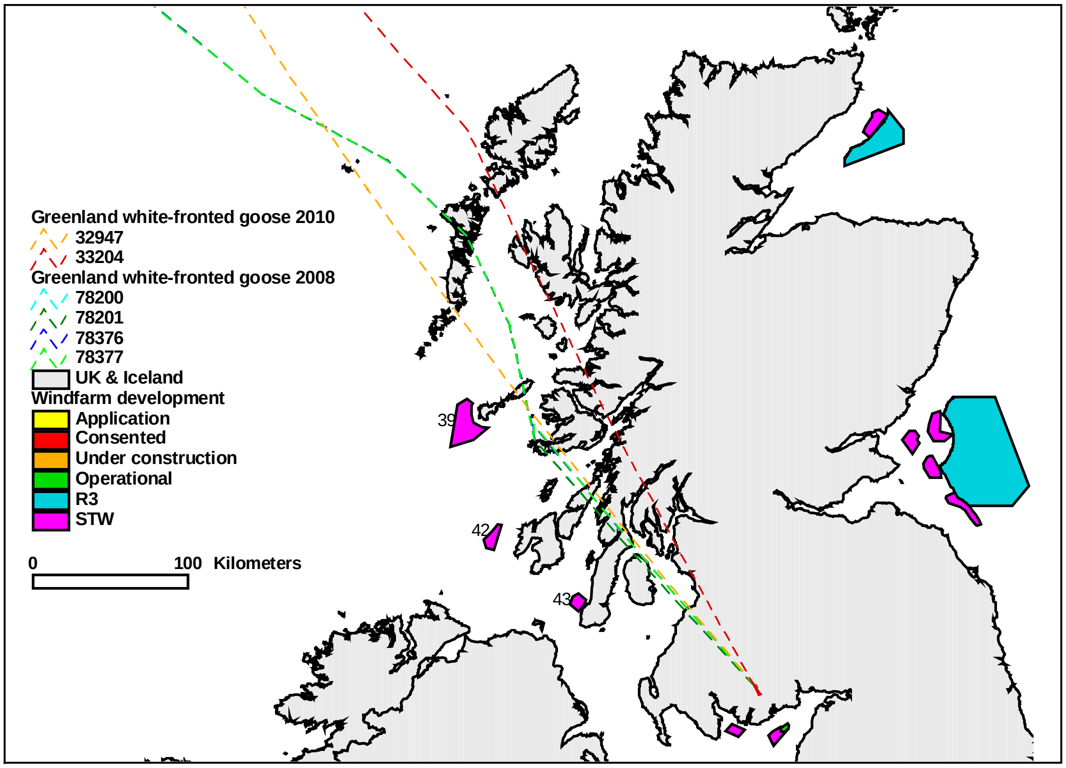


Figure 15. Spring migration routes taken by six Greenland White-fronted Geese from Loch Ken, Dumfries & Galloway, in 2008 and 2010. Key to the offshore wind farm sites is given in Table 5.

All birds probably exited the UK via the Uists or Lewis. The extrapolated tracks suggest that no birds from this very small sub-population passed within 20km of a proposed offshore wind farm site. However, this may not be the case for the much larger population of around 7,000 birds on Islay.

The tracks of the 2008 cohort of four tagged birds overlap to a large extent, suggesting that they were part of the same flock (*i.e.* the sample size of tracked birds could effectively be three). To determine whether the 2008 cohort is best seen as a group of birds making individual decisions during the spring migration, the details of their flight heights and speeds from UK inshore waters are described below (see also Figure 15).

As the geese passed west of Mull at 05:00 h on 8th April 2008, two birds were in loose association: bird 78377 (travelling at a speed of 57 kph at an altitude of 50m), and bird 78376 just 300m away (travelling at 59kph and 140m altitude). By 07:00 both birds appeared to have doubled back at least 10km to the tip of Iona, with bird 78376 then travelling at 39kph and 170m altitude and bird 78377 at 39kph and 150m altitude still 300m away.

In the same vicinity at 07:00 h, bird 78200 was similarly travelling at 39kph and 173m, and bird 78201 was flying at 32kph but at a lower altitude of 55m. This latter bird was 600m from the three others.

By 09:00 h, bird 78376 and 78200 were southwest of Canna travelling at 29 kph and 30 kph, respectively, with bird 78376 recording a "*neg alt*" value (*i.e.* it was likely to be close to sea level). These two birds were at the same location. 400 m north of them, bird 78201 was travelling at 31 kph and 39 m altitude; 450 m north of that, bird 78377 was travelling at 29 kph and 150 m. On passing over North Uist at 11:00 h, bird 78377 was travelling at 37 kph at 50 m, bird 78200 at 34 kph at 139 m and 78201 at 35 kph at 132 m with just 20 m between them. Bird 78376 was 400 m to the south of this group travelling at 16 kph at 120 m.

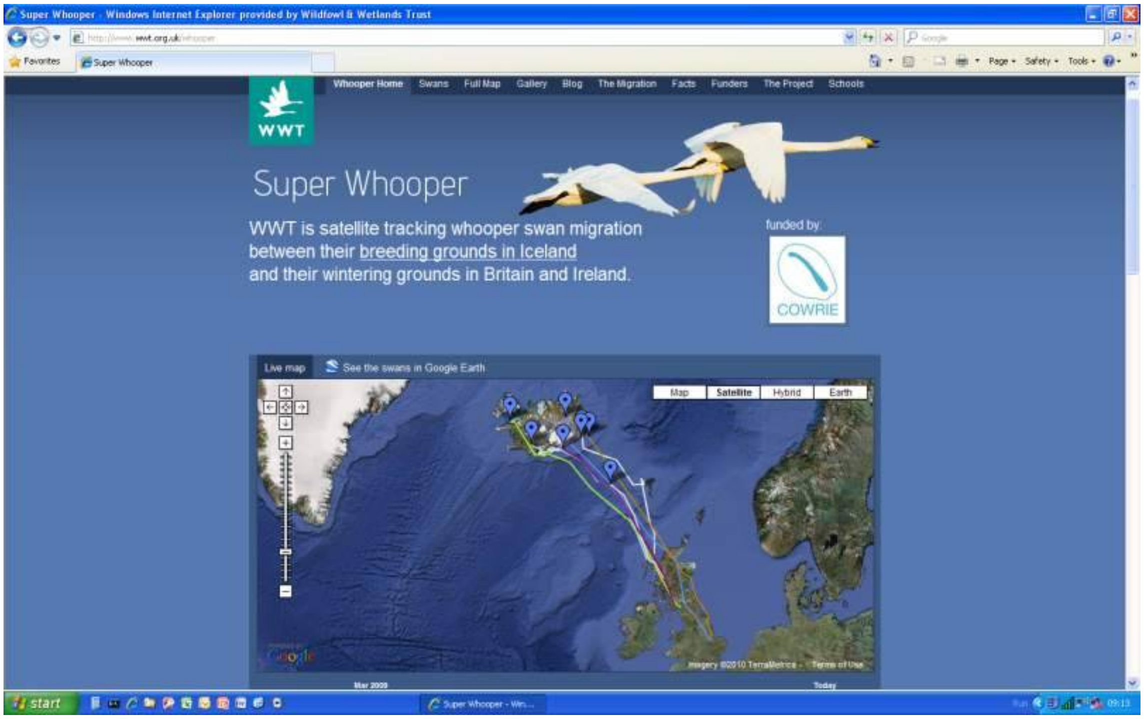
Over the next ten hours flying over the open ocean it seems likely that the birds remained part of the same loose flock and only recorded "*neg alt*" values suggesting that they were all flying at or very near sea level at a sustained 36–56 kph.

It therefore seems that these four birds were migrating as a group, which gives a preliminary indication that geese from Loch Ken may migrate together, but also emphasises the importance of tracking birds from a wider range of wintering sites to provide a fuller description of the migratory routes taken by Greenland White-fronted Geese. In particular the large population of 6,000–7,000 Greenland White-fronted Geese wintering on Islay, the most important site for this species outside of Wexford, Ireland, if taking a direct flight line for their spring staging areas in southern Iceland might well be expected to cross the STW Argyll Array site in spring in particular, perhaps coupled with the STW Kintyre site in autumn on return to Islay. The migratory routes of birds within the other large sub-populations on the Kintyre peninsula, at Rhunahaorine (typically up to 1,000 birds) and Machrihanish (typically up to 2,000 birds), might also be expected to overlap to an extent with these STW sites, suggesting further tracking and/or radar studies are needed to assess the risk for this threatened and declining species of conservation concern.

5.5 Objective 5: Disseminate the results of the satellite-tracking study via the WWT website, and through presentations given to conservation groups, stakeholders and policy makers, to help resolve any conflict between the UK's move towards green energy and the conservation of the Icelandic Whooper Swan population.

Work Task 11. Continue to maintain and update the Whooper Swan satellite-tracking webpage on the WWT website.

The Super Whooper website (http://www.wwt.org.uk/flywiththeswans), which was launched on the WWT website on 10th March 2009, continued to be updated with the progress of the tagged swans during 2010 and early 2011 (Figure 16).



WWT is satellite tracking whooper swan migration between their breeding grounds in Iceland and their wintering grounds in Britain and Ireland.

Figure 16. Homepage of the WWT "Super Whooper" website.

The tracks for the five new swans (*i.e.* those tagged in March 2010 at WWT Martin Mere) were added to the "Super Whooper" web pages, and were updated automatically along with the earlier tags still functioning. The tagging of the new swans under the DECC project received extensive coverage on BBC Northwest News as the BBC followed the migration of two of the swans (named "Gordon" and "Tony" after the presenters, rather than the politicians).

Blogs on the swans' migration were posted weekly in spring 2010. By autumn 2010 there was only one tag still functional and so the rate of news items declined throughout the year, although there were important updates from the trip to Iceland in August 2010 to recover tags shed by the swans. More general information about Whooper Swans wintering in Britain and Ireland was added during winter 2010/11 (focussing on satellite-tagged birds that had lost their transmitters but were identified by their ring codes), including details of the swans' departure on spring migration in March–April 2011.

Other pages within the "Super Whooper" website provide information on: (a) the aims of the study; (b) life-histories of the satellite-tagged swans; (c) information on COWRIE Ltd.; (d) a Google Earth map of the swans' movements; (e) information about Whooper Swans and their migration; (f) a blog providing regular descriptive updates on the swans' progress.

During the COWRIE project, nine of the satellite-tagged swans were followed closely by local schools (three each at Caerlaverock, Martin Mere and Welney) and WWT Education Officers also used the study to illustrate swan migration to other schools visiting WWT Centres. School visitor statistics recorded by WWT suggest that the project was described to at least 7,000 children, teachers, and parent helpers at WWT Welney, Martin Mere and Caerlaverock over the course of the initial COWRIE study (March 2009–February 2010), and to a similar number since during the period of the DECC contract. The Caerlaverock primary school that championed the swan "Rocky" continued to be updated on his progress throughout 2010. Since his tag has now been recovered from Iceland with no sign of a dead bird, it is hoped he will visit WWT Caerlaverock again this winter.

The public also became involved by using the 'Flickr', 'Twitter' and 'RSS' links on the website, and by posting comments on the blog. Numerous blogs have been posted to date and many positive comments have been received. Some examples of comments on the website are as follows:

> *Well done Y6K. Wildfowl and Icelandic volcanoes have coexisted for millions of years. Not sure about 7 billion people and a complex interconnected modern world, that may be a bit more fragile?* By: Phil Rhodes on 22/04/10.
>
> *Migratory birds are close to the heart of New Zealanders, we have also tracked Godwits to Siberia & Alaska; your data is good journalism also thanks very much.* By: Suzanne Vaassen on 26/04/10.
>
> *There are 150 of these swans on my local lake in Co Sligo, West Ireland. Strange as they have not been here before.* By: Thomas James Feeney on 08/11/10.
>
> *20 Whoopers asleep in the middle of Kirk Loch, Lochmaben. Warming in the sunshine we had on Monday.* By: Suzanne Storm on 26/10/10.
>
> *Thirty + Whoopers passing over and between Mullagh Lake & Lough Ramor, Co Cavan on October 23rd at 11.00 am approx. Welcome back!* By: Daphne Shackleton on 26/10/10.
>
> *Hundreds of swans flying between Lough Swilly towards Lough Foyle on 23 October at around 8.30.* By: Brian Baker on 24/10/10.
>
> *Lytham Moss Lancashire Family group of 5 whooper 21st and 30 whooper today 23rd Oct on grazing grass.* By: Adrian Fielding on 23/10/10.
>
> *On Sunday, 31st October, I came upon a huge gathering of Whoopers at Myroe, on the flat lands near Lough Foyle, just outside Limavady. I had never witnessed such a huge gathering before. Circumstances did not allow me to*

> *photograph them or to take an estimate, but people had stopped their cars to witness the spectacle, so I'm sure someone did*. By: Ella Swan on 12/11/10.

Work Task 12. Provide an interim report by 15th November 2010, a draft final report by 15th May 2011, and a final report by 1st July 2011.

The Interim Report (Griffin *et al.* 2010b) was submitted to Hartley Anderson on 19th November 2010. This, the Final Report, was submitted in August 2011.

Work Task 13. Report results of the study to relevant agencies (including DECC, DEFRA, JNCC, NE, SNH, Marine Scotland).

The results of this work will be reported to the relevant agencies and to stakeholder groups in 2011 – 2012, through circulation of the Final Report and through discussions at meetings.

Work Task 14. Prepare articles for WWT's popular magazine "*Waterlife*" and its "*GooseNews*" publications, and scientific papers on the migration routes and altitude of flight of Whooper Swans, in relation to wind farm locations.

An extended abstract describing the results of 2009 satellite-tracking study has been published online in the *BOU Proceedings – Climate Change and Birds*. http://www.bou.org.uk/ccb/griffin-etal.pdf.

The study featured as the "big issue" article, entitled "*Wings of Change*", in WWT's *Waterlife* magazine (Issue 177) in summer 2011.

A paper on Whooper Swan migration in relation to offshore wind farm sites is in preparation and will be submitted for publication in *Ibis*. A second paper, on the extent to which Whooper Swans drift from the migration route, in relation to wind strength and direction, is being prepared in collaboration with the University of Lund.

An article will also be prepared for WWT's *GooseNews* once the Final Report has been approved by DECC.

Work Task 15. Present findings with acknowledgement to funders to at least one international conference or workshop, such as the British Ecological Society.

Preliminary results were presented at the workshop on "Ecological Monitoring for Marine Renewables: Fixed Platforms and their application to strategic renewables development" which was organised by Natural Power and hosted by FERA in May 2010.

Results of the Whooper Swan satellite-tracking programme were also presented at the British Ecological Society annual meeting at Leeds University in September 2010.

A talk on Whooper Swan ecology, including its migration in relation to wind farm footprints, was given at the Society of Biology AGM in March 2011.

A talk on the satellite tracking of swan and goose populations was also given the UK Swan Study Group meeting in March 2011.

The results of the study were presented at the European Ornithologists' Union symposium being held near Riga, Latvia, in August 2011.

6 Acknowledgements

This study was undertaken for the Department of Energy and Climate Change under contract to Hartley Anderson Ltd. We are particularly grateful to Philip Bloor for advocating the extension to the original work (undertaken for COWRIE Ltd.) and to John Hartley not only for facilitating the study but for helpful comments on an earlier draft of this document. We thank Scottish Natural Heritage and RenewableUK for kindly providing data on wind farm and turbine locations, and Ordnance Survey for supplying the digital terrain data. We are also most grateful to Paul Shimmings for kindly providing an English translation of information on wind farms given in the Norwegian Energy Directorate website. Catching and ringing Whooper Swans and geese would not have been possible without the support of the North Solway Ringing Group, Arthur and Margaret Thirlwell, Keith Kirk and Karl Munday, and WWT colleagues including Robin Allen, Kendrew Colhoun, Richard Hearn, Richard Hesketh, Kerry Mackie, Leigh Marshall, Carl Mitchell, Julia Newth, James Robinson, Jon Smith, Chris Tomlinson, Robin Ward, and all those participating in the swan and goose catches. Particular thanks are due to Richard Hesketh for his skill in fitting many of the transmitters with due attention to the welfare of the birds. Fitting transmitters to Whooper Swans and Brent Geese in Iceland would not have been possible without collaborative support from Ólafur Einarsson and Sverrir Thorstensen (for Whooper Swans), Gudmundur Gudmundsson (for Brent Geese), and the help of those participating in the swan catches. Permission to undertake the work in Iceland was granted by the Icelandic Post- and Telecom Administration, the Icelandic Science Council and the Icelandic Bird Ringing Scheme (notably Aevar Petersen); we are grateful for their kind cooperation.

The cost of purchasing satellite-transmitters to track Whooper Swan migration was possible through an earlier contract from COWRIE Ltd. and we are grateful to COWRIE for the opportunity to undertake the work. The substantial cost of satellite tracking Barnacle Geese and Greenland White-fronted Geese has been supported primarily by the Solway Coast Area of Outstanding Natural Beauty Sustainable Development Fund, the BBC, the Heritage Lottery Fund, Scottish Natural Heritage and the National Trust for Scotland, with contributions from the Scottish Environment Protection Agency. Satellite-tracking of Brent Geese was funded by generous grants from Quarry Products Association, BBC Natural History Unit, Action Renewables, Northern Ireland Environment Agency, Canadian Wildlife Service, NERI, Coillte, National Parks & Wildlife Service, the Heritage Council and the Icelandic Institute of Natural History and was also supported by WWT. We are also most grateful for the key contributions made by James Robinson, Sean Boyd, Gudmundur Gudmundsson, Alyn Walsh, Stuart Bearhop, Richard Inger, Graham McElwaine and Kendrew Colhoun to the Light-bellied Brent Goose study.

We are grateful to Chris Whitehead (WWT Martin Mere), Emma Brand (WWT Welney) and Brian Morrell (WWT Caerlaverock) for disseminating the results of the study through education programmes at WWT Centres, and to Andrew Parker, Sarah Gill and Ruth Seymour for arranging the development and management of the “Super Whooper” webpages on the WWT website. The site was designed, constructed and operated by Sheldon Els and Gareth Brown at One Black Bear. We are also indebted to Alison Bloor, Kane Brides, Steve Heaven, Ailsa Hurst, Graham McElwaine, Richard Smith and Dave and Estelle Walsh for their significant contributions to the study. As always, we give special thanks to Robin Jones for his major contribution to the work in synthesising and mapping the satellite-tracking data. Phil Bloor, Jack Farnham, John Hartley, Rowena Langston, Kevin O’Carroll and Christine Urquhart made helpful comments of a draft of the report.

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8 Appendix 1

Executive Summary from the WWT Report to COWRIE Ltd. (Griffin *et al.* 2010a).

Of the 40 Whooper Swans tagged in winter 2008/09, 35 (88%) were tracked to Iceland in spring 2009: 17 from Martin Mere, 13 from Welney and all 5 birds from Caerlaverock.

The first two satellite-tagged birds to depart on spring migration, LP7 (Sigrunn) and 91A (Finnur), left Martin Mere on 4–5 March 2009; the precise timing of their departure is not known because frequent (hourly) data downloads did not commence until 8 March. The last bird to migrate, V9L, flew to Iceland on 14 May after spending six weeks staging at Loch Eye in NE Scotland. The three main departure periods thereafter were 10 – 13 March (5 birds, 12.5% departed), 16 – 20 March (17 birds, 42.5% departed) and 28 March – 2 April (14 birds, 35% departed). The main timing of arrival in Iceland was 18 – 22 March when eight birds (23%) made landfall and 30 March – 6 April when 22 birds (63%) reached Iceland.

Swans migrating from SE England (Welney) generally migrated north along the east coast of Britain whereas those from NW England and SW Scotland (Martin Mere and Caerlaverock) followed the western coastline.

As distance from the ringing site increased, the spread of the migration tracks (and thus the width of the migratory front followed by the satellite-tagged birds) also increased from 50 – 100km when <150km of the ringing site to about 200km on passing the Outer Hebrides. Areas of higher ground (*e.g.* the North York Moors or the Scottish Highlands) represented “pinch points” where the migratory front narrowed as the birds funnelled along lower-lying corridors. Of the 35 birds tracked to Iceland, there was no significant overlap between the migratory corridors of the east coast (Welney) and west coast (Martin Mere/Caerlaverock) birds until a distance of 900km from Welney, at >100km from the NW coast of Scotland. Two exceptions to this were of a single Welney bird intersecting the Martin Mere/Caerlaverock tracks and a single Martin Mere bird intersecting the Welney tracks.

The east coast *versus* west coast split in migration routes continued as the swans made landfall in Iceland, and also appeared to influence their summer distribution up until 1 July 2009. Welney birds tended to visit breeding areas in the east whereas Martin Mere birds tended to use more northerly, southerly or western areas with greatest overlap with the Caerlaverock birds. The area of greatest overlap between the Martin Mere and Welney birds was in the northeast.

Most birds tended to begin their migrations from their wintering sites from 05:00 – 08:00 or from 17:00 - 24:00, although with the tags being off for charging during the period from 11:01 to 17:59 it is not possible to assess whether there was truly a bi-modal distribution.

Most of the tagged birds completed their migration through the UK within 14 days, although one bird from Welney, V9L, staged for up to six weeks at Loch Eye before completing the migration to Iceland in 1.25 days. Once the birds had left the UK coast for Iceland, the 800km (500 mile) sea crossing was completed in under three days, with two Welney birds completing the flight in just eight hours at speeds of 90-100 kph.

Swan location data and weather data were downloaded from the ARGOS satellite and UK meteorological weather stations, respectively, and imported into a GIS. Data on the swans’ migration patterns (*i.e.* the timing, altitude and direction of flight) at specific locations were then extracted for analysis in relation to the weather data that most closely matched the swans’ location (derived from the satellite fixes) in time and space.

A digital terrain model (DTM) of the migratory flyway for the Icelandic Whooper Swan population was constructed within the GIS from GTOPO30 data, a high resolution orographic dataset derived from satellite measurements supplied by the U.S. Geological Survey. This DTM dataset, which has a resolution of approximately 1km and an altitude error of ± 30 m, was found to be insufficiently fine enough resolution for an accurate assessment of Whooper Swan flight heights when flying over land. More precise estimates of terrain elevation (and thus flight height over land) therefore were calculated from Ordnance Survey data for a small number of satellite fixes in the vicinity of onshore wind farm areas. Some inaccuracy in flight height estimates remained for these areas because the satellite transmitters were only accurate to within ± 22 m of true height, although 75% of fixes are considered by Microwave within 10 m of true height.

Generalized linear mixed models (GLMMs) were developed in Genstat 12 to determine which environmental variables (particularly weather conditions) had a significant influence on the Whooper Swans' migration between the UK and Iceland. Data recorded from the swans' departure from their wintering sites to their making land fall in Iceland were used in the analysis. Whether the bird was moving or not moving for each of its satellite tag transmissions was included as a binary response variable (1 = move; 0 = not move). GLMMs with binomial error distributions and logit link functions therefore were used to assess how environmental factors and covariates affected the swans' onward movements from the ringing sites to Iceland. Pending more sophisticated statistical analysis of the data, bird identity was included as a random effect to control for heterogeneity in the data from individual birds. As a further measure to control for pseudoreplication, the analyses were also run on a sub-sample of data points, with every 10th location for each bird selected for inclusion in the analysis. Explanatory weather variables included in the initial analyses were: wind direction (classed as head, side or tail winds), wind speed, visibility, pressure and pressure change. In addition to the weather variables, the identity of each bird, light levels (*i.e.* whether daylight, moonlit or dark), whether migration was over land or water, and also the stage of migration (*i.e.* whether the swans were migrating along the British coast or heading over the ocean for Iceland) were included as potential explanatory variables in the models.

The final models showed that, once migration had commenced, the swans' onward movement was influenced by light conditions (*i.e.* whether daytime, moonlight or dark), wind direction, atmospheric pressure and the interaction of wind speed with wind direction. These variables were significant in all of the final fitted models. The swans were significantly less likely to continue migration under moonlit or dark conditions than during the day and they were more likely to continue migration with side winds or particularly tail winds, than when experiencing head winds. There was also a significant positive association between swan movement and atmospheric pressure.

On including rainfall, cloud cover and the presence/absence of fog/mist in the model, only cloud cover proved significant, in addition to the variables mentioned in the previous paragraph. The swans seemed more likely to continue their migration under light cloud cover and to stop moving in overcast conditions, but this requires further investigation taking into account the distance from the meteorological stations from the swans' actual position (those up to 50km from the bird's locations were included in the analyses).

A negative association between onward movement and both the time since an individual started migration and migration stage (*i.e.* whether within Britain or crossing to Iceland), may reflect a tendency for the swans to continue moving shortly after leaving the wintering site then to spend more time resting during the later stages of migration.

Analysis of the effect of weather conditions on the altitude of swan flight were limited by (1) the swans' tendency to migrate at low altitudes (within the ± 22 m accuracy of altitude measures which resulted in "negative altitude" records for swans known from flight speed to be airborne), and (2) insufficient resolution (altitude error of ± 30 m with a resolution of 1km) in the digital terrain model developed from GTOPO30 data. Flights over land therefore were excluded from the analysis of the altitude of flight presented in this report. Ground clearance by swans migrating over both land and water will be analysed in further detail as part of a DECC-funded 1-year extension to the project, for which Ordnance Survey digital terrain data are being purchased.

Mean altitude of flight was 9 m (s.d. ± 16.2, n = 140) for swans migrating over water along the British coast and 32 m (s.d. ± 55, n = 560) when crossing from Britain to Iceland (overall mean = 27 m, s.d. ± 50.7, n = 700), with an additional margin of error of ± 22 m attributable to the accuracy of the altitude data recorded by the satellite tags. Flight altitude was higher for flights over land (mean altitude = 74 m, s.d. ± 123, n=1,016), but this did not control for variation in the terrain. There was no evidence for an association between weather conditions and the altitude of flight.

The swans' satellite tracks were inspected in relation to the distribution of the potential and actual footprint areas of individual wind farms in six key overlapping areas: the East Irish Sea, the Solway Firth, the North Channel/Inner Hebrides, the Greater Wash/North Sea, the Firth of Forth and the Moray Firth. A total of 48 Round 1 (R1), Round 2 (R2), Round 3 (R3) and Scottish Territorial Water (STW) offshore sites were considered in the analysis.

Of 19 swans tagged at Martin Mere that flew across the East Irish Sea, up to seven flight lines (37% of birds tagged at Martin Mere) passed across or immediately adjacent to the existing or proposed R1 and R2 wind farm sites of Barrow, Ormonde, Walney and West Duddon, with another eight tracks (42%) passing within 5km of these sites. The remaining four tracks across the East Irish Sea were >5km from the wind farm sites. No birds (except for the aberrant track of U7A that over-summered in Ireland) passed within 10km of the Irish Sea (R3) site.

Of 19 swans tagged at Martin Mere, for which 20 tracks were recorded crossing the Solway Firth (one bird having returned south), up to ten flight lines (50% of tracks recorded) passed across or immediately adjacent to the existing or proposed R1 or STW wind farm sites of Robin Rigg, Solway Firth and Wigtown, with another two (10%) passing within 5km of these sites. Eight other tracks (40%) that crossed the Solway were not likely to have been within 5km of the sites.

Of 17 swans tagged at Martin Mere passing through the North Channel/Inner Hebrides area, mostly over land, no birds were likely to have flown within 50km of the Islay (STW) site and none were likely to have come within 15km of the Kintyre (STW) site. One bird came within 10km of the Argyll Array (STW) although this bird had behaved aberrantly since departing Martin Mere and failed to complete the crossing to Iceland.

All five Caerlaverock birds and 16 out of 17 Martin Mere birds were confined to a relatively narrow migratory corridor of c. 70km wide on passing Coll and Skye and heading out to sea via either the southern half of Lewis or predominantly North Uist/Benbecula. Four Welney birds exited the UK via the northern half of Lewis with a further nine leaving from the northwest coast of mainland Scotland.

Of 15 swans tagged at Welney, no birds flew within 30km of any of the proposed R3 sites in the Greater Wash area, and it is unlikely that any of the flight paths crossed existing or proposed R1 or R2 sites either. The closest a track came was 4km to the site proposed at Westermost Rough (R2).

Of the 14 swans tagged at Welney reaching the Firth of Forth only one bird stopped and flew across a proposed wind farm area at Neart na Gaoithe (STW); no birds passed within 10km of the Firth of Forth (R3) site.

Of the 12 swans tagged at Welney reaching the Moray Firth (one bird took a more westerly route through Scotland), it is likely that only two birds came within 10km of the Moray Firth (R3) site, one of which was possibly within 1km of the site, and none came within 20km of the Beatrice (STW) site.

Most Whooper Swans from Martin Mere and Caerlaverock travelled during the day rather than the night by the time they reached the North Channel area; within the Irish Sea and the Solway Firth travel was conducted equally under day and night and often without the aid of moonlight. Of 6,525 satellite fixes recorded throughout the migration period, the swans were flying on 17.6% of 2,960 day-time fixes, 13.4% of 1,239 moonlight fixes and 7.6% of 2,326 locations in the dark.

Birds travelled predominantly through the wind farm areas of the west coast under tailwind conditions mainly at speeds of <30 kph.

Birds travelled in visibility conditions as limited as 2km, but it should be noted that fog is very localised and that visibility can be excellent at just a few metres of altitude.

The swans mostly travelled under conditions of high and rising atmospheric pressure, probably due to its association with better general weather conditions and lighter winds. Few birds made offshore migratory movements through the west coast wind farm areas during conditions of less than 1,010 hPa.

For Martin Mere birds flying within the Irish Sea area, proximal to the wind farm sites, the median flight height was 12 m a.s.l. (n = 16) with 94% at or below 50 m and 63% at or below 20 m. Similarly in the Solway Firth area median flight height was 13 m (n = 11) with 91% at or below 50 m and 64% at or below 20 m. In the North Channel area, the median flight height increased to 100m (n=14), with 43% at or below 50m and 29% at or below 20m. The increase in flight height over water in this area is likely to be due to the nature of the landscape, with the swan's flight paths often intersecting the higher land areas of the Argyll and Inner Hebrides region.

These altitude statistics exclude two outliers - birds 89251 and 89267. With the rotors of offshore wind farms generally sweeping the area from 20–120 m a.s.l., these two swans recorded flight heights of 172 m and 160 m at 8.9km and 3.8km north of Barrow and Robin Rigg, respectively. The flight heights of these birds one hour previously had been 40 m above land of height c. 3 m and 55 m above land of height c.10 m, respectively. Albeit a small sample size, these two birds may have shown an avoidance response by ascending over the operational R1 wind farm site at Barrow, and the R1 site at Robin Rigg which was under construction at the time of the spring 2009 migration, with many of the turbines in place. The Barrow crossing was at dawn whereas the Robin Rigg crossing was at night under moonlit, although possibly cloudy, conditions. Although this suggests that Whooper Swans may fly over operational wind farms, because of the very small sample size it is recommended that radar studies should be carried out to confirm this finding particularly in an area such as the Solway Firth where for a period covering the first week in March to the first week in April a relatively large sample of radar observations could be gathered.

Many more birds from Welney compared to Martin Mere chose to migrate through offshore areas during daylight hours. Migrations through offshore areas, as with west coast birds, were conducted predominantly under tail wind conditions or those with a side wind component, with all crossings being made under relatively calm conditions. As with west coast birds, Welney birds travelled under relatively low visibility conditions although this was possibly associated with the hazy conditions characteristic of high pressure systems with no birds travelling from Welney under prevailing atmospheric pressures of less than 1,010 hPa, with pressures generally high or falling slightly.

In the Greater Wash/North Sea area the median offshore flight height was 30 m, with 89% at or below 50 m. In the Firth of Forth area the median was 1 m (n = 5) with 100% at or below 50 m with the same for the Moray Firth (n = 6). The median value for the Firth of Forth excludes an outlying flight height of 365 m. As seen with the North Channel offshore passage on the west coast, this increased flight height is likely to be due to the preceding position of the bird over an area of relatively high land with the bird at 315 m above land of c. 280 m height one hour earlier.

The birds from all areas appeared to travel under a variety of weather conditions, although many of these can be localised and may thus not represent the actual conditions at the location of the swan.

Because of the southerly nature of key sites within the Whooper Swan's wintering range, the birds tracked from the three WWT centres tended to stop off at or overfly other sites of national or international importance further north. These sites held from 57 to 1,673 swans on average in the peak winter periods from 1995/1996-1999/2000. Thus it is suspected that the tagged birds provide a good representation of the routes likely to be used by other Whooper Swans from the main UK wintering sites during migration.

Of eight birds producing reasonably detailed tracks during the autumn migration, four made landfall in Ireland (after a brief pause for one in the Outer Hebrides) and thus birds appeared to arrive across a broader front than was apparent in the spring. Six of these birds passed within 10km of offshore wind farm sites with five birds passing across or immediately adjacent to planned sites. One bird out of the two returning to Caerlaverock probably passed through three potential offshore STW sites of Argyll Array, Kintyre and Wigtown. The only bird returning to Martin Mere with a fully functional tag passed through the Argyll Array and Kintyre sites and 1km from Walney/West Duddon (R2). Of the only two birds heading for Welney, one passed across the proposed Neart na Gaoithe (STW) site and the other moving from Ireland in late December passed across the proposed Kintyre (STW) site. Thus despite the very small sample sizes, the swans could be more likely to pass across proposed wind farm sites, and to traverse a series of these sites in succession, during autumn migration.

A "Super Whooper" website which described the project and provided live updates of maps showing the swans' movements was launched on 10th March 2009. A total of 23,300 pages were viewed up to February 2010 in 16,535 unique visits to the site (3% of all unique visits to the WWT website). Peaks in visitation to the site coincided with the swans' migration period and also with PR coverage, such as WWT featuring on the BBC's SpringWatch series in late March–early April 2009. The site features a "Home Page", which provides an overview of the aims of the project and information on COWRIE with links to the COWRIE website. Other pages provided information on: (a) the aims of the study; (b) the life-histories of the satellite-tagged swans; (c) further information on COWRIE; (d) a Google Earth map of the swans' movements; (e) information about Whooper Swans and their migration; (f) YouTube videos about the project; (g) a blog that provides regular descriptive updates of the swans' progress. The public became involved by using the 'Flickr', 'Twitter' and 'RSS' links on the website, and by posting comments on the blog. A total of 60 blogs have been posted to date and many positive comments have been received.

Nine of the satellite-tagged swans were followed closely, and named, by local schools; three each at Caerlaverock, Martin Mere and Welney. Information about the schools was provided on the website, together with contact details for the WWT Education Officers to enable other schools to become involved in the project.

Information on the project has been disseminated via four articles in magazines and newsletters: one in *Tracking News* (Microwave Telemetry's (MTI's) Newsletter), two in WWT's *Waterlife* magazine and one in *GooseNews*. It will also feature in WWT's Conservation Report, due to be published in 2010. Results of the study are to be presented at the British Ornithologists' Union (BOU) meeting at the University of Leicester in April 2010, and a paper will be submitted for publication in *Ibis* thereafter.

Recommendations from the earlier WWT Report to COWRIE Ltd. (Griffin *et al.* 2010a)

Satellite tracking studies are generally limited by sample size, largely due to the cost of purchasing the satellite transmitters. The current study was exceptional in that it provided detailed information on the movements for 50 birds, of which 35 provided completed spring migration tracks and seven provided complete autumn migration tracks. The study described the migration routes for Whooper Swans along the east and west coasts of Britain, but obtaining detailed data on bird movement within or adjacent to wind farm sites remained difficult. The shortest duration between fixes provided by the tags is one hour; thus whether Whooper Swans flying at 60 kph pass around, through or over wind farm areas remains unclear. It is therefore recommended that MTI and other tag manufacturers adjust their software so that half hourly intervals at least can be specified. This will give the tags even greater application to fine-scale research projects, and ensure that their temporal resolution matches the exceptional spatial resolution provided by the GPS ability of the tags.

Despite this limitation, the current study found that the potential for overlap between Whooper Swan migration routes and proposed offshore wind farm sites is greater for swans migrating along the west coast of Britain (*e.g.* to/from the Martin Mere SPA) than for those migrating along the east coast of Britain (*e.g.* to/from the Ouse Washes SPA, which includes WWT Welney). Potential differences in collision risk arising from the installation of wind farms within these two migratory corridors could be assessed by continuing the long-term study of Whooper Swan survival rates for birds wintering at these WWT Wetland Centres over the next 5-10 years, during which time many of the proposed wind farms will become operational. An assessment could be made of any change in survival for birds that traditionally winter at Martin Mere, Welney and Caerlaverock over the next five years or more, in relation to the 20+ years prior to the construction of these wind farms. This longer-term, indirect approach to the study of potential collision risk could not only feed into the medium-term developmental decision making process but also into the longer-term decommissioning process in 20-25 years time.

We recommend that the information this study has provided on the Whooper Swans' migration routes be used to provide a focus for more detailed localised studies, including radar studies, at current and proposed wind farm locations which fall within the swans' migratory flyway. Priority areas for radar studies should include the potential "pinch points" described in the current study, where migratory corridors are relatively narrow and where birds are most likely to cross wind farm footprints in greatest numbers. For instance, a high proportion of Whooper Swans migrate along the islands off the west coast of Scotland, so environmental assessments undertaken for any large-scale wind farm proposals in these areas should be particularly rigorous. Depending on the capabilities of the radar equipment used, it would be useful to establish monitoring from at least the first week in March to the first week in April in the Irish Sea area encompassing the R1/R2 Barrow, West Duddon, Walney and Ormonde complex and/or in the Solway Firth to encompass the R1 Robin Rigg and STW Solway Firth sites. If coupled with detailed weather observations at those locations, this should provide a much larger sample size of observations describing how the birds actually respond to the presence of turbines.

Whilst the study to date has provided valuable information on Whooper Swan migration routes in relation to offshore wind farm sites, the potential effect of the full series of wind farms (terrestrial as well as offshore) located along the swans' migration routes has yet to be determined. Incorporating existing data on the location of onshore wind farm sites into the analysis would serve to provide a comprehensive assessment of the total number of wind farms potentially over-flown by Whooper Swans during their migration between the UK and Iceland, and thus increase the information available for environmental impact assessments for future wind farm developments. Purchase of Ordnance Survey contour data, which gives terrain elevation to an accuracy of +/- 5m would be beneficial both for the present study (for including flight heights over land as well as over water) and for a more detailed assessment of swan migration routes and flight heights in relation to all British wind farm sites. The inclusion of onshore as well as offshore wind farm sites in the analyses, together with Ordnance Survey contour data, will now be taken forward in a DECC-funded study to be completed in April 2011.

The study focussed on Whooper Swans migrating to and from Iceland because of concern that their large body size would make them less manoeuvrable than other smaller species, especially as flying accidents is known to be the major cause of death for these birds. Yet the UK is the main wintering ground for a range of other migratory populations for which the UK has international responsibility and which can be tracked in the same way. These include protected goose populations (Greenland Barnacle Goose, Greenland White-fronted Goose, and Light-bellied Brent Goose) and quarry species (Pink-footed Goose and Icelandic Greylag Goose) which migrate to Iceland. A comparison of the tracks for those species migrating between Britain and Iceland would indicate whether the different species follow the same flight-paths, and thus the importance of these routes for a range of species. Other migration routes should also be investigated in greater detail, for instance for species arriving in SE Britain from mainland Europe (*e.g.* Bewick's Swan) and those arriving in Scotland from Norway (*e.g.* the Svalbard Barnacle Goose). WWT has previously collected data from GPS tags fitted to Svalbard Barnacle Geese, identifying the key migratory corridors for this flyway population, the main UK spring departure point for this population being the Firth of Forth. It is suggested that data already collected should be analysed to determine any overlap between flight paths and proposed offshore wind farm sites in that area, with particular reference to the STW Forth Array and the R3 Firth of Forth sites. More tags fitted to the geese would help to elucidate the flight paths taken across the Firth of Forth by this relatively vulnerable population, which winters almost entirely within the Solway Firth. Such a study could be a useful precursor to detailed radar observations in that area.