# Analysis of Marine Ecology Monitoring Plan Data - Robin Rigg Offshore Wind Farm

## Operational Year Five Technical Report – Ornithological Monitoring

e·on | Climate & Renewables

18 December 2015
E.ON Climate & Renewables

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Document Reference:1101321

Planning & Development | Ecology & Hydrology | Technical Construction & Geotechnical | Asset Management | Due Diligence

natural power

# Document history


| | | |
|---|---|---|
| Author | Dr Emily Nelson, Dr Fiona Caryl & Dr Gillian Vallejo | 11 December 2015 |
| Checked | Dr Ross McGregor | 16 December 2015 |
| Approved | Dr Jane Lancaster | 17 December 2015 |


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| Issue | Date | Revision Details |
|---|---|---|
| A | 17 December 2015 | First issue to client |
| B | 22 August 2016 | Second issue to client |

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# List of abbreviations

| Abbreviation | Description |
|---|---|
| CEFAS | Centre for Environment, Fisheries and Aquaculture Science |
| COWRIE | Collaborative Offshore Wind Research into the Environment |
| CV | Coefficient of Variation |
| DECC | Department of Energy and Climate Change |
| E.ON | E.ON Climate & Renewables |
| EIA | Environmental Impact Assessment |
| ES | Environmental Statement |
| ESAS | European Seabirds at Sea |
| EU | European Union |
| FEPA | Food and Environment Protection Act |
| GPS | Global Positioning System |
| MEMP | Marine Environment Monitoring Programme |
| NNR | National Nature Reserve |
| OWF | Offshore Wind Farm |
| RRMG | Robin Rigg Management Group |
| SNCBs | Statutory Nature Conservation Bodies |
| SPA | Special Protection Area |
| SSSI | Site of Special Scientific Interest |
| WeBS | Wetland Bird Survey |
| ZIP GAMM | Zero-Inflated Poisson Generalised Additive Mixed Effects Model |

# Executive summary

**Introduction:** The Robin Rigg Offshore Wind Farm (OWF) in the Solway Firth is operated by E.ON Climate & Renewables (E.ON) and was the first commercial OWF in Scottish waters. The site is comprised of 60 x three megawatt Vestas turbines and an offshore sub-station. Construction of the OWF and its associated cabling began in December 2007 and the site became fully commercially operational in April 2010.

In accordance with the consent from Scottish Ministers under Section 36 of the Electricity Act 1989, a Marine Environment Monitoring Programme (MEMP) was developed to record any changes to the local physical and ecological environment as a result of the construction and operation of the OWF. This included monitoring requirements for a number of ecological receptors, including benthos, non-migratory and electro-sensitive fish, birds, and marine mammals. Monitoring was undertaken during pre-construction, construction and operational phases of the OWF. Over the course of the survey programme, MEMP monitoring requirements for all ecological receptors except birds have been met. Boat-based post-construction monitoring of birds continued across five years of operation, as required under the MEMP.

Analyses of pre-construction, construction and post-construction bird data have been undertaken every year during the first four years of operation at the Robin Rigg OWF (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). This report summarises the findings of these reports. **No significant negative effects from construction and operation of the Robin Rigg OWF on the 11 key avian receptors outlined in the MEMP have been detected, validating the predictions outlined in the ES.**

**Aims:** Since the MEMP monitoring requirements have been met for birds, this report consolidates the findings of the entire MEMP ornithological monitoring following completion of a full five years of operational survey, and answers a number of pertinent, species-specific questions regarding avoidance behaviour for six bird species frequently identified as a priority in OWF impact assessments.

**Results:** Both guillemots and razorbills were present within the wind farm footprint during construction (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014) and during all five years of operational monitoring. There was therefore evidence to suggest that razorbills and guillemots were not displaced from the Robin Rigg OWF during operation.

Modelled guillemot and razorbill abundance increased within the Robin Rigg OWF during the first three years of operation, indicating habituation to the Robin Rigg OWF following construction. Between operational year one and operational years four and five, statistically significant decreases in guillemot abundance was seen outside the Robin Rigg OWF, with a similar pattern observed for razorbills. These patterns appeared to be independent of the Robin Rigg OWF and it is likely that both species were following changes in prey distribution resulting from natural sedimentary movement.

Across the study area, modelled kittiwake abundance of both birds in flight and on sea was highest within and surrounding the Robin Rigg OWF, providing strong evidence that kittiwakes in flight did not exhibit macro-avoidance and were not displaced from the Robin Rigg OWF during operation. Whilst modelled abundance of herring gulls in flight were largest close to the Cumbrian coastline, flying herring gulls were not absent from the Robin Rigg OWF during operation and there is evidence of no macro-avoidance by flying herring gulls.

Data indicated that the majority (*c*. 94%) of gannets, kittiwakes, herring gulls and great black-backed gulls flew below turbine rotor height (35-125 m) across the entire study area. Therefore, collision risk for these four species is negligible at the Robin Rigg OWF.

Flying gannets were not recorded within the Robin Rigg OWF during any of the five operational years. Whilst this may indicate macro-avoidance of the Robin Rigg OWF by flying gannets, numbers were too low across all three development phases to test this statistically. As such, it is likely that any effects of the wind farm would be on very few individuals compared to the regional population, and therefore negligible.

Both kittiwakes and great black-backed gulls flew below the turbine rotor height (35-125 m) within the Robin Rigg OWF, with small numbers of both species recorded flying at higher altitudes outside the Robin Rigg OWF, indicating some level of meso-avoidance. However, sample sizes were too small to be able to test this difference statistically.

**Conclusion: This report provides further evidence of no significant negative effects from construction and operation of the Robin Rigg OWF on the Solway Firth bird community. As such, the MEMP requirements for ornithology have been met and it is recommended that further ornithological monitoring at the Robin Rigg OWF is not required.**

# 1. Introduction

The Robin Rigg Offshore Wind Farm (OWF) in the Solway Firth is operated by E.ON Climate & Renewables (E.ON) and represents E.ON's third UK OWF and the first commercial OWF in Scottish waters. The site comprises 60 x three megawatt Vestas turbines and two offshore substations, together with associated cabling, covering a total area of *c*. 13 km$^2$. Consent for the scheme was granted by the Scottish Executive in March 2003 under Section 36 of the Electricity Act 1989 following submission of an Environmental Statement (ES; Natural Power, 2002). Construction began in December 2007 and full commercial operation commenced in April 2010.

In accordance with the consent from Scottish Ministers, a Marine Environment Monitoring Programme (MEMP) was developed in conjunction with the Robin Rigg Management Group (RRMG)[1] prior to construction (MEMP, 2004). The purpose of the MEMP was to record potentially adverse impacts to the local physical and ecological environment resulting from construction and operation of the wind farm, allowing mitigation measures to be adopted in time to avoid irreversible significant impacts.

An extensive survey programme has been undertaken under the MEMP covering the pre-construction, construction and post-construction phases of the development. The programme has concentrated on a number of ecological receptors, including subtidal benthic habitats, intertidal habitats, non-migratory fish, electro-sensitive fish, marine mammals and birds. Over the course of the survey programme, MEMP monitoring requirements for benthic and intertidal habitats, non-migratory fish, electro-sensitive fish and marine mammals have been met and the results are presented in previous post-construction monitoring reports (Walls *et al.,* 2013a, 2013b and 2013c).

Boat-based post-construction monitoring of birds was undertaken across five years of operation, as required under the MEMP. This extensive dataset, spanning from May 2001 to February 2015, provides a valuable resource for examining the effects of OWF developments on birds; few other long-term datasets of this nature exist and those that do are restricted to the eastern North Sea (Petersen *et al*., 2006, 2011; Leopold *et al*., 2013; Vanermen *et al*., 2014). Detailed analyses of pre-construction, construction and post-construction bird data have been undertaken every year during the first four years of operation and the results of these analyses are well documented (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014).

This report consolidates the findings of the entire MEMP ornithological monitoring programme following completion of a full five years of operational survey, in order to determine the impacts of the Robin Rigg OWF on the Solway Firth bird community and validate the predictions made in the ES.

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[1] The RRMG is comprised of Marine Scotland, Scottish Natural Heritage, Natural England, the Royal Society for the Protection of Birds, Galloway Fisheries Trust, Scottish Environment Protection Agency, Environment Agency, the Scottish Government's Energy Consents Unit and E.ON.

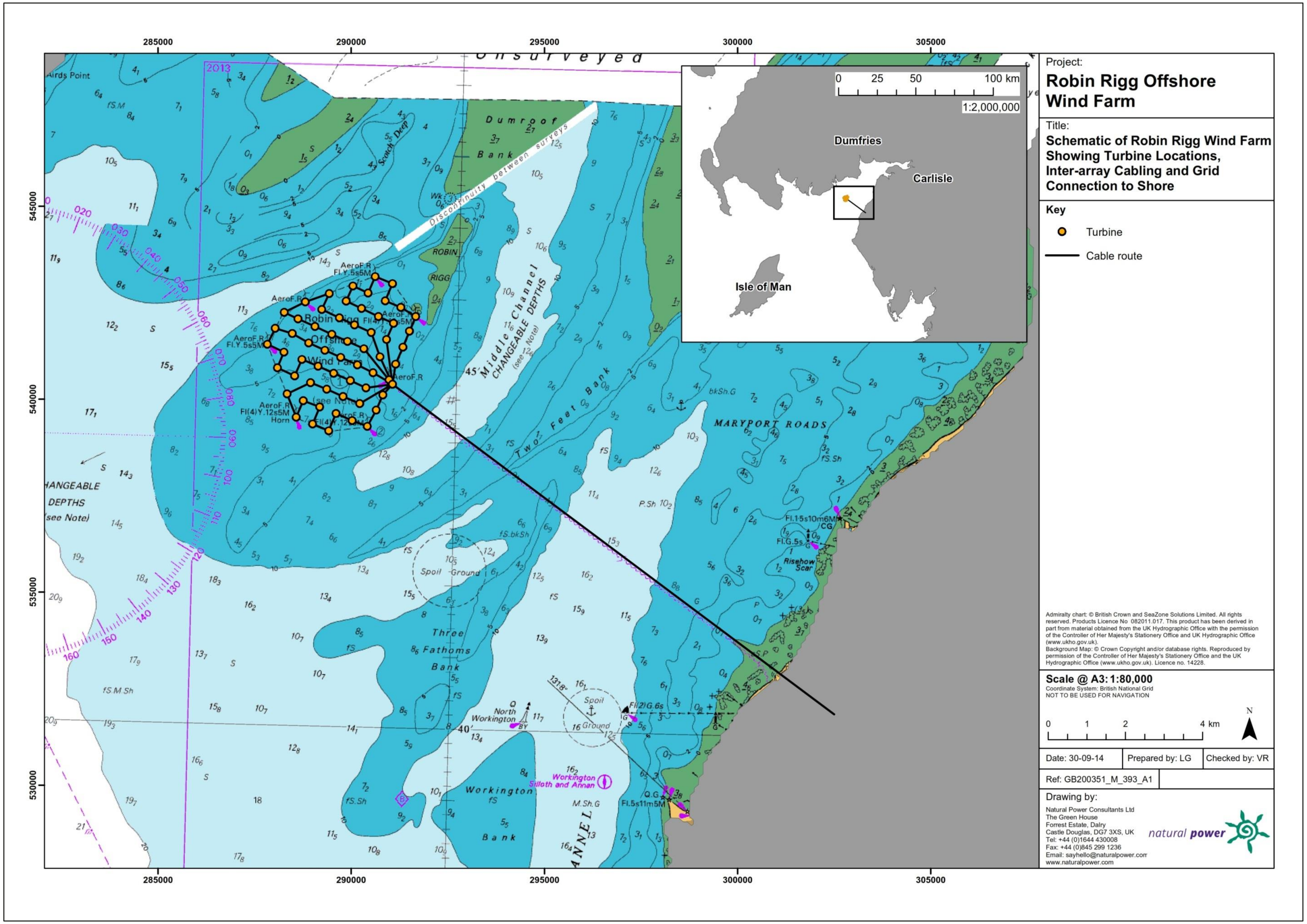


**Figure 1.1:** Location of Robin Rigg offshore wind farm showing turbine locations, inter-array cabling and grid connection to shore.

## 1.1. Background to Solway Firth bird populations

### 1.1.1. Designated sites

The Solway Firth is a shallow estuary and at low water much of the area of the Inner Solway dries out exposing extensive fringing beaches and sandbanks. The subtidal area within the Solway Firth has been described as being dominated by mobile sediments brought into the area from the Irish Sea with sedimentary movements resulting in a change of depth and sediment type. The OWF is located on one such sandbank, known as Robin Rigg, hence the OWF name.

This area of Robin Rigg is characterised by high wave exposure and moderate tidal currents, resulting in a highly dynamic environment. As such, the Solway Firth has long been recognised as being of environmental importance and several important areas for birds within the Firth are protected under national and international law, including:

- Protected sites established under national legislation such as Sites of Special Scientific Interest (SSSI) and National Nature Reserves (NNR);
- Protected sites established under European Union (EU) Directives such as the Natura 2000 network; and
- Protected sites established under international agreements such as Ramsar sites.

These protected sites are summarised in Table 1.1. In addition, there is a draft Special Protection Area (SPA) covering the Solway Firth proposed for populations of red-throated diver and common scoter.

### 1.1.2. Key receptors

Eleven bird species have been the focus of post-construction ornithological data exploration, as agreed by the RRMG. These include nine species which are listed as qualifying features at protected sites within the Solway Firth which were recorded in at least regionally important numbers during baseline surveys undertaken in 2001 and 2002 for the ES:

- Scaup (*Aythya marila*);
- Common scoter (*Melanitta nigra*);
- Red-throated diver (*Gavia stellata*);
- Manx shearwater (*Puffinus puffinus*);
- Gannet (*Morus bassanus*);
- Cormorant (*Phalacrocorax carbo*);
- Razorbill (*Alca torda*);
- Guillemot (*Uria aalge*); and
- Kittiwake (*Rissa tridactyla*).

The other two key species were recorded in relatively large abundance during the course of pre-construction and construction surveys, and include:

- Herring gull (*Larus argentatus*); and
- Great black-backed gull (*Larus marinus*).

Detailed accounts of general species ecology for all 11 key avian receptors are provided in previous post-construction monitoring reports (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014).

Table 1.1: Protected sites for birds within the Solway Firth.

| Site name | Designation | Distance from OWF (km) | Qualifying features |
|---|---|---|---|
| Upper Solway Flats and Marshes | Ramsar | 6.4 | **Non-breeding:** pink-footed goose, barnacle goose, pintail, scaup, oystercatcher, curlew, bar-tailed godwit and knot. |
| Upper Solway Flats and Marshes | SPA | 6.4 | **Non-breeding:** whooper swan, pink-footed goose, barnacle goose, shelduck, mallard, pintail, scaup, goldeneye, cormorant, great crested grebe, oystercatcher, golden plover, grey plover, lapwing, ringed plover, curlew, bar-tailed godwit, knot, dunlin, redshank.<br>**Passage:** ringed plover. |
| Upper Solway Flats and Marshes | SSSI | 6.4 | **Non-breeding**: barnacle goose, shelduck, pintail, scaup, oystercatcher, golden plover, ringed plover, curlew, bar-tailed godwit, knot, sanderling, dunlin and redshank.<br>**Breeding bird assemblage.** |
| Abbey Burn Foot to Balcary Point | SSSI | 8.5 | **Breeding:** cormorant, fulmar, kittiwake, guillemot and razorbill. |
| Borgue Coast | SSSI | 21.8 | **Breeding:** common gull and great black-backed gull. |
| St Bees Head | SSSI | 24.7 | **Breeding:** fulmar, shag, puffin, black guillemot, razorbill, guillemot, kittiwake and herring gull. |
| Cree Estuary | SSSI | 40.4 | **Non-breeding:** pink-footed goose |
| Scare Rocks | SSSI | 62.3 | **Breeding:** gannet, shag and guillemot. |
| Loch of Inch and Torrs Warren | Ramsar | 68.6 | **Non-breeding:** Greenland white-fronted goose. |
| Loch of Inch and Torrs Warren | SPA | 68.6 | **Non-breeding:** Greenland white-fronted goose and hen harrier. |
| Torrs Warren to Luce Sands | SSSI | 68.6 | **Non-breeding:** hen harrier |
| Mull of Galloway | SSSI | 73.2 | **Breeding:** fulmar, razorbill and kittiwake. |
| Ailsa Craig | SPA | 103.0 | **Breeding:** gannet, lesser black-backed gull, guillemot, kittiwake and herring gull. |

### 1.1.3. Predicted impacts

Ornithological monitoring undertaken as part of the MEMP allows exploration and validation of the potential impacts on birds resulting from construction and operation of the Robin Rigg OWF. Anticipated effects of offshore wind development on seabirds range from increased mortality caused by collision to habitat loss, habitat change and barrier-effects (Exo *et al*., 2003; Langston & Pullan 2003; Fox *et al*., 2006; Drewitt & Langston, 2006; Stienen *et al*., 2007). Three of these potential impacts were assessed the Robin Rigg OWF ES (Natural Power, 2002). No significant impact was predicted on any bird species in the assessment, as outlined below:

#### 1. Habitat loss

The direct loss of habitat for feeding and roosting birds through construction of turbine and substation foundations, together with associated cable laying, was considered to be relatively small, such that no significant impact on any bird species was predicted.

#### 2. Displacement

Displacement may lead indirectly to habitat loss if birds avoid the wind farm entirely (Langston & Pullan, 2003; Drewitt & Langston, 2006; Petersen *et al*., 2006). However, to date few seabirds have been found to avoid offshore wind farms entirely, even those considered to be highly susceptible to disturbance (Garthe & Huppop, 2004; Leopold & Dijkman, 2010). Only a single study has reported complete avoidance of an operational offshore wind farm by two species; red-throated diver and common scoter at Horns Rev in the eastern North Sea (Petersen *et al*., 2006). Common scoters, however, were later documented to be present within the wind farm in high numbers which was thought to be related to changes in in the distribution of their preferred prey, rather than the presence of the wind farm (Leonhard *et al*., 2013). Other studies have documented only partial avoidance in red-throated diver (Rexstad & Buckland, 2012), guillemot (Petersen *et al*., 2006; Vanermen *et al*., 2012, 2014), razorbill (Vanermen *et al*., 2014) and gannet (Krijgveld *et al*., 2011; Vanermen *et al*., 2012, 2014). The degree of displacement may therefore depend on a range of factors including species, abundance, behaviour, weather conditions or wind farm configuration (Beale & Monaghan, 2004; Petersen *et al*., 2004; MacArthur Green, 2013; Vanermen *et al*., 2014). Over time, birds which were initially displaced from an OWF may habituate to its presence and return to the area (Petersen & Fox, 2007). Furthermore, there is evidence that some species are attracted into offshore wind farms (Leopold *et al*., 2011, 2013; Vanermen *et al*., 2012, 2014).

At Robin Rigg OWF, displacement due to disturbance was predicted to be greatest during the construction period but with the potential to continue into operation. The potential impact as a result of disturbance was not considered to be significant for any species, with regionally important numbers of birds affected at most.

Displacement zones of 3 km and 5 km would be needed to affect nationally important numbers of common scoters and red-throated divers, respectively. This scale of disturbance was predicted to be unlikely given the maximum displacement distance recorded at an existing wind farm (at the time of submission) was 800 m (Pedersen & Poulsen, 1991).

A summary of key species sensitivities in and around Robin Rigg OWF is presented in Table 1.2. The magnitude of impact is that which would arise if birds were displaced from a zone of 1 km around the OWF.

**Table 1.2: Summary of displacement assessment at Robin Rigg Offshore Wind Farm, as outlined in the ES.**

| Species | Sensitivity of local population | Magnitude of effect | Significance | Significant impact? |
|---|---|---|---|---|
| Scaup | High | Low | Low | No |
| Common scoter | High | Low | Low | No |
| Red-throated diver | Medium | Negligible | Very low | No |
| Manx shearwater | Medium | Negligible | Very low | No |
| Gannet | Medium | Low | Low | No |
| Cormorant | Medium | Low | Low | No |
| Razorbill | Medium | Low | Low | No |
| Guillemot | Medium | Low | Low | No |
| Kittiwake | Medium | Low | Low | No |
| “Other” seabirds | Low | Low | Very low | No |

## 3. Collision risk

Mortality resulting from collision with rotating turbine blades depends upon a range of factors related to bird species, numbers and behaviour, weather conditions and the nature of the wind farm itself (Band *et al*., 2007; Band 2012).

A collision risk assessment was undertaken as part of the ES for two of the 11 key avian receptors present in the Solway Firth: common scoter and red-throated diver. Further assessment was undertaken for “other” seabirds recorded during baseline surveys.

For the majority of these species, the magnitude of collision risk was negligible with an increase of less than 1% on baseline mortality rates. Red-throated diver was the only species to exceed this, with a predicted increase of 22.8% on the baseline mortality rate. Whilst the predicted worst case collision mortality for red-throated diver was relatively low (3.3 birds per year), the increase in baseline mortality was thought to result from a combination of the species being long-lived and the small population size within the study area. Such high mortality was thought to be highly unrealistic since field data suggested that 98% of birds observed flew below rotor height.

A summary of predicted collision risk at the Robin Rigg OWF is presented in Table 1.3. The potential impact as a result of collision was not considered to be significant for any of the species assessed.

**Table 1.3: Summary of collision risks at Robin Rigg Offshore Wind Farm, as outlined in the ES.**

| Species | Sensitivity of local population | Magnitude of effect | Significance | Significant impact? |
|---|---|---|---|---|
| Common scoter | High | Negligible | Very low | No |
| Red-throated diver | High | Low | Low | No |
| “Other” seabirds | Medium | Low/negligible | Low/very low | No |

### 1.1.4. Validation of predicted impacts

Extensive analyses of pre-construction, construction and post-construction bird data have been undertaken every year during the first four years of operation and the results of these analyses have been presented to the RRMG in a number of post-construction monitoring reports (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). As such, a large volume of data is currently available to validate the predictions outlined in the ES for each of the 11 key avian receptors. The findings of the MEMP up to operational year four, together with remaining knowledge gaps, are summarised below and in Table 1.4.

#### Scaup

In the ES, scaup were identified as being present in the Solway Firth in regionally important numbers. However, only a single flock was recorded within 2 km of the Robin Rigg OWF during baseline monitoring, with the majority of birds recorded in shallow waters close to the Dumfries and Galloway coastline (Natural Power, 2002). The numbers and distribution of individual scaup recorded across the survey area remained similar during pre-construction and construction monitoring, but numbers in the north of the survey area were considerably larger during post-construction. However, as bird numbers in the offshore environment are subject to large fluctuations at any given location (Maclean *et al*., 2013), this is most likely due to the occasional sighting of a large flock rather than a positive effect of the wind farm. Whilst density (and hence statistical power) was too low during all three development phases to undertake further statistical examination of potential wind farm effects on scaup (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014), it is likely that any effects of the wind farm would be on very few individuals compared to the regional population. Furthermore, all scaup in flight were recorded close to the sea surface and were therefore not at risk of collision (Nelson *et al*., 2014). **Thus the finding of no significant impact on scaup in the ES has been validated during four years of post-construction monitoring.**

#### Common scoter

Common scoters were recorded in nationally important numbers in the Solway Firth during baseline monitoring for the ES. Numbers varied between surveys, reflecting the birds changing distribution during the tide cycle. The majority of birds were recorded in shallow waters along the north-western edge of the survey area, with very low numbers recorded within 2 km of the Robin Rigg OWF; indeed, numbers only reached national importance 2-3 km away from the wind farm footprint (Natural Power, 2002). Initial examination of the post-construction data indicated that the number of common scoter had declined between pre-construction surveys and surveys undertaken during the first two years of operation (Walls *et al*., 2013a and 2013b). Common scoters are known to be highly sensitive to disturbance including from OWF construction and operation (Garthe & Hüppop, 2004; Schwemmer *et al.,* 2011; Furness *et al*., 2013). However, data collected during operational years three and four showed an increase in the total number of common scoter recorded; indeed, both abundance and distribution had recovered to pre-construction levels by operational year four (Walls *et al*., 2013c; Nelson *et al*., 2014). Whilst this may indicate habituation of common scoters to the presence of the Robin Rigg OWF, the statistical significance of this increase could not be tested due to the highly aggregated distribution (large flocks) of common scoters preventing model convergence (Walls *et al*., 2013c; Nelson *et al*., 2014). Regardless, the increase in numbers during post-construction monitoring, together with the presence of common scoters within the Robin Rigg OWF footprint itself during operation, indicates no long-term displacement common scoters from the Robin Rigg OWF. Furthermore, all common scoter in flight were recorded between 0-25 m throughout operational monitoring, and were therefore not at risk of collision (Nelson *et al*., 2014). **Therefore, post-construction monitoring has validated the ES prediction of no significant impact on common scoter.**

#### Red-throated diver

The ES identified the Solway Firth as being of national importance for red-throated divers, although numbers within 5 km of the Robin Rigg OWF reached only regional importance. There was a tendency for red-throated divers to occur in shallow waters (5-10 m), moving further away from the coast with the ebb tide to maintain this depth. Wetlands Birds Scheme (WeBS) monitoring found a five year average count of 51 birds between 1995 and 2000, which is above the threshold of national importance of 50 birds. However, these WeBS counts were undertaken from the coast; boat-based surveys undertaken for the ES found a peak count of two birds within the Robin Rigg OWF footprint itself (Natural Power, 2002). Numbers were confirmed to be small during construction and post-construction monitoring (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Since red-throated divers are thought to be highly sensitive to disturbance, a decrease during the construction phase might have been expected (Garthe & Hüppop, 2004; Schwemmer *et al.,* 2011; Furness *et al*., 2013). Indeed, at other wind farms in the North Sea, strong displacement effects were found out to 4 km (e.g. Petersen *et al*., 2006). Whilst the statistical power to detect a change in red-throated diver abundance at the Robin Rigg OWF was low, it is clear that such large displacement effects have not occurred at the Robin Rigg OWF. As predicted in the ES, collision risk was negligible with only a very low percentage (<2%) of flying red-throated divers recorded at rotor swept height (35-125 m) during operational monitoring (Nelson *et al*., 2014). **As such, post-construction monitoring has validated the ES prediction of no significant impact on red-throated diver.**

### Manx shearwater

The Solway Firth was determined to be of regional importance for Manx shearwaters in the ES, although not within 2 km of the Robin Rigg OWF. A mean count of three Manx shearwaters was recorded within the wind farm footprint during baseline surveys; most Manx shearwaters were recorded to the south and west of the survey area, over deeper water, and only during the summer months (Natural Power, 2002). Post-construction analysis reports showed a slight indication of an increase in the number of Manx shearwaters recorded on the sea in the south-east of the survey area between pre-construction and construction (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014), although both birds in flight and on the sea showed a decline across the survey area during operation. Densities were too low to be able to test these changes statistically however, and it is likely that these patterns result from high levels of spatio-temporal variation in Manx shearwater flock presence (Maclean *et al.,* 2013), rather than being an effect of the Robin Rigg OWF. Manx shearwaters were recorded flying close to the sea surface throughout operational monitoring, and were therefore not at risk of collision with turbines (Nelson *et al*., 2014). **Thus changes in Manx shearwater abundance and distribution were not clearly attributable to the presence of the OWF and the ES prediction of the no significant impact of Manx shearwater is validated.**

### Cormorant

Cormorant numbers increased substantially within the wind farm area following construction of the wind farm. During baseline surveys for the ES, cormorants were recorded largely in the north-west of the survey area, close to breeding colonies between Port O'Warren and Balcary Point on the Dumfries and Galloway coastline. However, since construction of the Robin Rigg OWF, cormorant numbers increased by *c*.400% (260 individuals during pre-construction vs. 1,053 during operation; Nelson *et al*., 2014) across the survey area, with large concentrations within the wind farm footprint (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Anecdotal evidence from surveyors suggests cormorants are exploiting the OWF for foraging, using the turbine transition pieces for maintenance behaviours (Figure 1.2). The presence of above-water structures allows cormorants to dry out their plumage after foraging (Gaston, 2004), and similar behaviour at OWFs elsewhere in Europe has been recorded (Leopold *et al*., 2011, 2013). Measures were recently implemented by E.ON to try to modify this behaviour since fouling of the handrails poses a health and safety risk. It may be that these measures will lead to a reduction in the number of cormorants using the Robin Rigg OWF, although there is little evidence of this to date (Figure 1.2). Whilst cormorants were recorded flying within the Robin Rigg OWF, only a small percentage of flying birds (<3%) were recorded at rotor swept height (35-125 m) indicating that collision risk is very low. **Therefore, the conclusion of no significant *negative* effect presented in the ES was validated, but there was clearly an effect that was beneficial in nature**.

**Figure 1.2: Left: cormorants perching on the handrails of a Robin Rigg OWF turbine transition piece. Right: wires deployed on the handrails of a Robin Rigg OWF turbine transition piece to discourage cormorant perching.**

## Gannet

During baseline surveys undertaken for the ES, gannets were recorded in regionally important numbers across much of the Solway Firth, with the exception of the shallow waters in the north-west of the survey area (Natural Power, 2002). Few gannets were recorded within the wind farm footprint however, with a peak count of four individuals (Natural Power, 2002). There was evidence of a decrease in the number of gannets across the survey area between pre-construction and construction monitoring (17% reduction of birds in flight, 24% reduction of birds on the sea; Walls *et al*., 2013a). Furthermore, post-construction monitoring has shown further declines in gannet numbers across the survey area during successive operational years (Nelson *et al*., 2014). Despite these declines across the survey area,, small numbers (0.30 birds/$km^2$; Nelson *et al*., 2014) of gannets were present on the sea within the wind farm footprint throughout construction and operation, suggesting that declines across the survey area are related to wider changes in habitat use rather than the Robin Rigg OWF (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Low numbers of gannets were recorded in flight during operational monitoring, with none recorded within the Robin Rigg OWF, indicating that collision risk to this species is negligible (Nelson *et al*., 2014). **Therefore the conclusion of no significant effect on gannets presented in the ES was validated by post-construction monitoring.**

## Razorbill

In the ES, razorbills were identified as being present in the Solway Firth in regionally important numbers. However, only small numbers were recorded within the Robin Rigg OWF, with a peak count of 18 birds; the majority of razorbills were recorded in deeper waters towards the mouth of the Solway Firth (Natural Power, 2002). The predicted number of razorbills declined during the construction phase both within the Robin Rigg OWF and across the rest of the survey area. During post-construction, razorbill numbers increased with numbers within the OWF lower than across the rest of the survey area during all four operational years (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Whilst these results suggest some degree of wind farm avoidance, it is likely that any effects of the wind farm would be on very few individuals compared to the regional population. The majority (*c.*95%) of razorbills recorded in flight during operational monitoring were in height band one (0-5 m), with none at potential collision height (Nelson *et al*., 2014). **Therefore the conclusion of no significant effect on razorbills presented in the ES was validated by post-construction monitoring.**

## Guillemot

Guillemots were the most abundant seabird recorded during across all three development phases (Natural Power, 2002; Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Regionally important numbers were recorded during baseline monitoring for the ES, with a peak of 39 birds recorded within the wind farm footprint (Natural Power, 2002). Numbers increased across the survey area from pre- to post-construction both within and outside the Robin Rigg OWF (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). There was some evidence for a shift in distribution across development phases, with the largest densities of guillemots on the sea concentrated in the west of the survey area during pre-construction, moving to deeper waters in the south during operation (Nelson *et al.,* 2014). Given the guillemots were present within the wind farm footprint throughout construction and operation, these patterns appear to be independent of the Robin Rigg OWF, and may instead be linked sedimentary movement and depth changes across the Solway Firth during the course of the MEMP. As for razorbill, the majority (*c.*98%) of flying guillemots were recorded in height band one (0-5 m). Therefore collision risk for this species is negligible. **Therefore the conclusion of no significant effect on guillemots presented in the ES was validated by post-construction monitoring.**

### Kittiwake

Kittiwakes were present in regionally important numbers in the Solway Firth during baseline monitoring for the ES, although not within 2 km of the Robin Rigg OWF where numbers peaked at 46 individuals (Natural Power, 2002). In general, kittiwake numbers across the survey area were relatively similar across development phases (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). The number of both kittiwakes on the sea and in flight decreased within the Robin Rigg OWF during the construction phase, although this reduction was not statistically significant (Walls *et al*., 2013a, 2013b). Kittiwake numbers across four years of operation were similar with some evidence of an increase in kittiwakes on the sea within the wind farm footprint (Walls *et al*., 2013c; Nelson *et al*., 2014). Whilst there is some indication of wind farm avoidance, this was not found to be statistically significant. Furthermore, <3% of flying kittiwakes were at potential collision height (35-125 m) during operation, indicating that collision risk is very low for this species. **Therefore the conclusion of no significant effect on kittiwakes presented in the ES was validated by post-construction monitoring.**

### Herring gull

Herring gull was not considered to be a key receptor in the ES since this species was not present across the wider survey area in regionally important numbers (Natural Power, 2002). However, larger numbers of herring gulls were recorded during pre-construction and construction surveys, hence the species' inclusion in the MEMP. Indeed, data suggest that herring gull abundance on the sea increased slightly across all three development phases, with a large increase in numbers seen within the Robin Rigg OWF footprint. Herring gulls in flight have shown a decline across the survey area throughout monitoring, although again, an increase was detected within the Robin Rigg OWF during operation (Walls *et al*., 2013c). As with cormorants, it is likely that herring gulls are using the turbine transition pieces for maintenance behaviours. During post-construction monitoring, there was a rise in the number of herring gulls recorded flying at rotor height. However, it is likely that this is a result of an increase in surveyor recording accuracy due to the presence of turbines, rather than a change in behaviour. The absolute numbers of herring gulls recorded at rotor height was relatively small however, with only five birds recorded at rotor height within the Robin Rigg OWF throughout operational monitoring (this report). **The ES prediction of no significant impact on any bird species within the Solway Firth therefore is validated based on the MEMP results for herring gull.**

### Great black-backed gull

As for herring gull, great black-backed gull was not recorded in regionally important numbers during baseline monitoring for the ES and as such, was not considered in detail in the impact assessment (Natural Power, 2002). Great black-backed gulls were recorded in smaller numbers than herring gulls throughout the MEMP, preventing detailed analyses of changes in abundance and distribution to be undertaken due to low statistical power. However, data suggest an increase in numbers during construction and post-construction monitoring with similar numbers recorded during the first four years of operation (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Larger numbers of great black-backed gulls were recorded at rotor height during these phases, again, most likely resulting from increased accuracy in recording rather than behavioural change. However, collision risk is likely to be negligible since great black-backed gulls were not recorded at collision height within the Robin Rigg OWF itself during operational monitoring (this report). **The ES prediction of no significant impact on any bird species within the Solway Firth therefore is validated based on the MEMP results for great blacked-backed gull.**

Table 1.4: Summary of ES predictions and MEMP monitoring findings for 11 key avian receptors at Robin Rigg Offshore Wind Farm.

| Key avian receptors | Predicted Effect | Significant Impact? | Validated by MEMP? | Evidence |
|---|---|---|---|---|
| **Scaup** | Displacement | No | Yes | Density was too low during all three development phases to undertake statistical examination of potential displacement (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Therefore, any displacement effects would be on very few individuals compared to the regional population. |
| | Collision | No | Yes | All scaup in flight were recorded close to the sea surface and were therefore not at risk of collision (Nelson *et al*., 2014). |
| **Common scoter** | Displacement | No | Yes | Data indicated a decline between pre-construction and the first two years of operation (Walls *et al*., 2013a and 2013b), although data collected during operational years three and four showed an increase in the total number of individuals recorded; indeed, both abundance and distribution had recovered to pre-construction levels by operational year four (Walls *et al*., 2013c; Nelson *et al*., 2014). This, together with the presence of common scoters within the Robin Rigg OWF footprint itself during operation, indicates no long-term displacement. |
| | Collision | No | Yes | All common scoter in flight were recorded between 0-25 m throughout operational monitoring, and were therefore not at risk of collision (Nelson *et al*., 2014). |
| **Red-throated diver** | Displacement | No | Yes | Density was too low during all three development phases to undertake statistical examination of potential displacement (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Therefore, any displacement effects would be on very few individuals compared to the regional population. |
| | Collision | No | Yes | Collision risk was negligible with only a very low percentage (<2%) of flying red-throated divers recorded at rotor swept height (35-125 m) during operational monitoring (Nelson *et al*., 2014). |
| **Manx shearwater** | Displacement | No | Yes | Post-construction analysis has shown a slight increase in the number of individuals recorded on the sea in the south-east of the survey area between pre-construction and construction (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014), although both birds in flight and on the sea showed a decline across the survey area during operation. Densities were too low to be able to test these changes statistically. It is likely that these patterns result from high levels of spatio-temporal variation in flock presence (Maclean *et al.,* 2013), rather than being an effect of the Robin Rigg OWF |
| | Collision | No | Yes | Manx shearwaters were recorded flying close to the sea surface throughout operational monitoring, and were therefore not at risk of collision with turbines (Nelson *et al*., 2014). |
| **Cormorant** | Displacement | No | Yes | Cormorant numbers increased significantly within the wind farm area following construction as birds use the turbine transition pieces for maintenance behaviours Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Thus there is no evidence of a negative effect on this species. |
| | Collision | No | Yes | Whilst cormorants were recorded flying within the Robin Rigg OWF, only a small percentage of flying birds (<3%) were recorded at rotor swept height (35-125 m) indicating that collision risk is very low. |
| **Gannet** | Displacement | No | Yes | There was evidence of a decrease in gannets across the survey area between pre-construction and construction monitoring (Walls *et al*., 2013a), with further declines in gannet numbers across the survey area during successive operational years (Nelson *et al*., 2014). Despite these declines, small numbers (0.30 birds/km$^2$; Nelson *et al*., 2014) of gannets were present on the sea within the wind farm footprint throughout construction and operation, suggesting that declines across the survey area are related to wider changes in habitat use rather than the Robin Rigg OWF (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). |
| | Collision | No | Yes | Low numbers of gannets were recorded in flight during operational monitoring, with none recorded within the Robin Rigg OWF. Collision risk to this species is negligible (Nelson *et al*., 2014). |

| Key avian receptors | Predicted Effect | Significant Impact? | Validated by MEMP? | Evidence |
|---|---|---|---|---|
| **Razorbill** | Displacement | No | Yes | The predicted number of razorbills declined during construction across the survey area. During post-construction, razorbill numbers increased with numbers within the OWF lower than across the rest of the survey area during all four operational years (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Whilst these results suggest some degree of avoidance, it is likely that any effects of the wind farm would be on very few individuals compared to the regional population. |
| | Collision | No | Yes | The majority (*c.*95%) of razorbills recorded in flight during operational monitoring were in height band one (0-5 m), with none at potential collision height (Nelson *et al*., 2014). |
| **Guillemot** | Displacement | No | Yes | Numbers increased across the survey area from pre- to post-construction both within and outside the Robin Rigg OWF (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). There was some evidence for a shift in distribution across development phases (Nelson *et al.,* 2014). Given that guillemots were present within the wind farm footprint throughout construction and operation, these patterns appear to be independent of the Robin Rigg OWF. |
| | Collision | No | Yes | The majority (*c.*98%) of flying guillemots were recorded in height band one (0-5 m). Therefore collision risk for this species is negligible. |
| **Kittiwake** | Displacement | No | Yes | Kittiwakes on the sea and in flight decreased within the Robin Rigg OWF during construction, although this reduction was not statistically significant (Walls *et al*., 2013a, 2013b). Kittiwake numbers across four years of operation were similar with some evidence of an increase in kittiwakes on the sea within the wind farm footprint (Walls *et al*., 2013c; Nelson *et al*., 2014). |
| | Collision | No | Yes | Less than 3% of flying kittiwakes were at potential collision height (35-125 m) during operation, indicating that collision risk is very low for this species. |
| **Herring gull** | Displacement | Not considered in ES | Yes | Data suggest that herring gull abundance on the sea increased slightly across all three development phases, with a large increase in numbers seen within the Robin Rigg OWF footprint (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). Herring gulls in flight have shown a decline across the survey area throughout monitoring, although again, an increase was detected within the Robin Rigg OWF during operation (Walls *et al*., 2013c). As with cormorants, it is likely that herring gulls are using the turbine transition pieces for maintenance behaviours. |
| | Collision | Not considered in ES | Yes | Absolute numbers of herring gulls recorded at rotor height was relatively small, with only five birds recorded at rotor height within the Robin Rigg OWF throughout operational monitoring (this report). |
| **Great black-backed gull** | Displacement | Not considered in ES | Yes | Great black-backed gulls were recorded in smaller numbers than herring gulls throughout the MEMP, preventing detailed analyses of changes in abundance and distribution to be undertaken due to low statistical power. However, data suggest an increase in numbers during construction and post-construction monitoring with similar numbers recorded during the first four years of operation (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). |
| | Collision | Not considered in ES | Yes | Collision risk is negligible since great black-backed gulls were not recorded at collision height within the Robin Rigg OWF during operational monitoring (this report). |

## 1.2. Report aims

In accordance with the MEMP (MEMP, 2004), this report presents a summary of data collected for 11 key avian receptors across the full five years of operation. Data collected at the Robin Rigg OWF during pre-construction, construction and four years of post-construction monitoring have validated the predictions outlined in the ES. No significant negative effects from construction and operation of the Robin Rigg OWF on the 11 key avian receptors have been detected.

Assessment of potential impacts on seabirds is key for permission to develop OWFs and some projects have recently been cancelled, at substantial financial cost, due to predicted negative impacts (e.g. DECC 2012; Smith 2014). Improving the evidence base and reducing uncertainty surrounding these assessments will enable more informed decisions to be made about OWFs, benefitting both the renewable industry and statutory nature conservation bodies (SNCBs) and regulators. However, estimating the impacts of OWFs on seabirds is often difficult and imprecise, resulting in part from a lack of empirical data. Avoidance during OWF construction and operation may result in displacement from key habitat for seabirds (Furness *et al*., 2013). Displacement can lead to habitat loss if individuals OWFs completely or habitat degradation if they do so only partially. Monitoring at constructed OWFs in the eastern North Sea has shown that displacement may be both site- and species-specific (Petersen *et al*., 2006, 2011; Krijgsveld *et al*., 2011; Leopold *et al*., 2013; Vanermen *et al*., 2014), although there is a need for empirical data from other regions. Over time, individuals which were initially displaced may habituate to the presence of an offshore wind farm (Petersen & Fox 2007). However, few long-term empirical datasets exist to determine the extent of habituation to OWFs (Langston & Pullan 2003; Fox *et al*., 2006)

Since the MEMP monitoring requirements have been met for birds, and the predictions in the ES now validated, this report focusses on answering a number of pertinent, species-specific questions regarding avoidance behaviour, rather than repeating those phase comparisons presented in previous operational monitoring reports (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014).This approach has been agreed with Marine Scotland (Roger May, *pers. comm*.). The extensive monitoring programme undertaken at the Robin Rigg OWF provides a valuable empirical dataset to examine avoidance and displacement behaviour in detail, reinforcing the aim of the MEMP to record potentially adverse impacts on birds from construction and operation of the wind farm.

Specifically, this report aims to answer the following questions which relate to potential impacts of OWFs on birds, for six priority species (as defined by Furness *et al*., 2013) which have been recorded at the Robin Rigg OWF:

1. Have kittiwakes, razorbills and guillemots on the sea been displaced from Robin Rigg OWF during operation?
2. Have razorbills and guillemots habituated to the presence of Robin Rigg OWF during operation?
3. Do flying kittiwakes and herring gulls show macro-avoidance of Robin Rigg OWF?
4. Does the flight height of gannets, kittiwakes, herring gulls and great black-backed gulls change in response to the presence of Robin Rigg OWF (meso-avoidance)?

Many seabirds are thought to be particularly vulnerable to displacement effects during the breeding season as they are restricted to finding sufficient food within foraging range of their breeding colony (Burke & Montevecchi, 2009) During the non-breeding season, central-place foraging constraints are removed allowing seabirds to be more flexible in their habitat choice and less vulnerable to displacement from a given area (Stephens & Krebs, 1986). Therefore, the questions addressed in this report relate to breeding birds only, with the exception of herring gull where the UK wintering population is larger than the breeding population as migrants from Europe arrive to into the UK to overwinter (Wernham *et al*., 2002).

# 2. Methods

## 2.1. Surveys

### 2.1.1. Overview

Ecology Consulting Ltd. carried out boat-based baseline surveys across the Robin Rigg OWF in 2001 and 2002 to inform the Environmental Impact Assessment (EIA). Ecology Consulting Ltd. continued to undertake boat-based surveys until February 2012 to meet the requirements of the MEMP, after which surveys were undertaken by Natural Power. The timing of boat-based ornithological surveys is shown in Table 2.1 and described below:

**EIA baseline surveys**

- Boat-based surveys were undertaken twice per month between May 2001 and April 2002 (with the exception of May and October 2001 when only one survey was completed).
- Monthly baseline boat-based surveys continued to December 2002, but only data up to and including April 2002 were included in the EIA.

**MEMP monitoring surveys**

- Pre-construction surveys were undertaken once per month in April and May 2003 and between January and September 2004. An additional two surveys were carried out in July 2007, prior to construction commencing.
- Construction phase surveys began in January 2008 and continued twice per month until the end of construction in February 2010. Surveys were completed during all months in this period, with the exception of November 2009.
- Post-construction surveys have been undertaken once per month between March 2010 and February 2015 inclusive, to meet the requirements of the MEMP.

**Table 2.1: Timing of boat-based ornithological surveys at Robin Rigg OWF. Numbers refer to the number of surveys undertaken each month. Light grey = EIA baseline surveys (N.B only data collected up to and including April 2002 were included in the EIA); grey = pre-construction surveys; dark grey = construction surveys; hatched = post-construction surveys.**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | | | | | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |
| 2002 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2003 | | | | 1 | 1 | | | | | | | |
| 2004 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 2005 | | | | | | | | | | | | |
| 2006 | | | | | | | | | | | | |
| 2007 | | | | | | | 2 | | | | | |
| 2008 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 2009 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | 2 |
| 2010 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2011 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2012 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2013 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2014 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2015 | 1 | 1 | | | | | | | | | | |

### 2.1.2. Data collection

#### Recording methods

To ensure that a comparable dataset was collected across development phases, the survey method employed during EIA baseline surveys was followed throughout the MEMP. Consistency in data collection is important for statistical comparison of bird abundance and distribution across development phases.

During each boat-based survey, the vessel travelled along a total of ten parallel transects each approximately 18 km in length and spaced 2 km part (Figure 2.1). This separation distance was chosen to gather a representative sample of data for each key species, whilst minimising the risk of double-counting by displacing birds from one transect into another. Since access to shallow parts of the survey area was restricted at low tide, tidal conditions dictated whether surveys were undertaken in a single day or across two days.

Key components of the method are as follows:

- Bird detection was undertaken by eye, but high quality 7x50 binoculars were used to confirm identity and to occasionally look ahead for easily flushed species such as red-throated diver and common scoter;
- The survey was based on a line transect method with a strip width of 300 m;
- Birds were recorded as 'in flight' or 'on the sea' by two observers working simultaneously on either side of the vessel; each observed a 90° angle ahead and to the side of the vessel;
- The 300 m transect was sub-divided into the following five bands into which all birds on the sea surface were allocated: (A) 0-50 m; (B) 50-100 m; (C) 100-200 m; (D) 200-300 m; (E) >300 m. Distances were perpendicular to the transect line. Only birds within 300 m (bands A-D) were considered to be 'in transect';
- For each observation, species, number of individuals, transect number and time was recorded. Time was recorded to the nearest minute. The time piece used for recording sightings was matched to a hand-held Global Positioning System (GPS) unit used for recording transect tracks to allow the precise position of each observation to be determined; and
- Additional data were collected for each bird (where possible) including: age, plumage type and behaviour.

Environmental data were not recorded during baseline and pre-construction surveys. However, from 2007 onwards, a number of environmental variables were collected so that bird data could be compared against factors which might affect detectability. These environmental data were recorded at the start of each transect and then every 15 minutes (or more frequently if conditions changed). Data included:

- Wind speed and direction;
- Glare;
- Precipitation;
- Cloud cover;
- Visibility; and
- Sea state (recorded using the Beaufort scale for wind measurement).

#### Updating recording methods

Although a standardised method for collecting seabird data from boats was first proposed in 1984 (Tasker *et al.,* 1984), a standardised method for collecting seabird data at OWF developments was not produced until 2004 (Camphuysen *et al*., 2004), three years after surveys began at Robin Rigg OWF.

At the onset of operational year three in March 2012, survey methods were modified slightly by Natural Power to ensure compliance with current best practice European Seabirds at Sea (ESAS) methods as recommended by COWRIE (Camphuysen *et al.,* 2004; MacLean *et al*., 2009). All birds on the sea surface were recorded in the same way as previously. However, the way in which birds in flight were recorded was adjusted. Prior to March 2012, Ecology Consulting Ltd. estimated the height of all birds in flight by eye to the nearest metre. Natural Power modified this method to follow best practice guidance by allocating birds in flight into six height bands based on their height at first observation: (1) 0-5 m; (2) 6-25 m; (3) 26-34 m; (4) 35-125 m; (5) 126-200 m; (6) >200 m. The height bands were chosen to reduce observer error and to reflect the known rotor height of turbines at Robin Rigg OWF (35-125 m). Furthermore, whilst one Natural Power surveyor continued to collect flight data continuously on one side of the vessel to allow comparison with existing data, the second surveyor collected flight data using ‘snapshots’, as recommended by Camphuysen *et al*., (2004). ‘Snapshots’ involved recording the species and height band of flying birds every 300 m of travel (approximating to one snapshot every minute at a speed of 10 knots). A timed repeat alarm marked the location of the snapshots and was adjusted to the speed of the survey vessel. At the time of a snapshot, all birds in flight were recorded within a 300 m x 300 m ‘box’ extending 300 m to the front and 300 m perpendicular to the vessel. This method was intended to reduce the risk of double-counting birds in flight. Indeed, comparison of the differences in the number of flying birds recorded using the two methods has shown that fewer birds are recorded using the ‘snapshot’ method (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014).

## Vessels

A number of vessels were used throughout the MEMP ornithological monitoring programme, with viewing platforms ranging from 3.5-4.5 m above sea level (Table 2.2). Although slightly below the recommended 5 m (Camphuysen *et al*., 2004; MacLean *et al*., 2009), it was considered that these vessels provided suitable viewing platforms without restricting the survey area; larger vessels with higher viewing platforms were unable to navigate the sandbanks that run through the Solway Firth, potentially reducing the survey area.

**Table 2.2: Vessels used during ornithological surveys at Robin Rigg offshore wind farm between 2001 and 2015, including viewing platform height (in metres) above sea level.**

| Vessel name | Viewing platform height (m) | Number of survey days |
|---|---:|---:|
| *Solway Protector* | 4.5 | 101 |
| *P.V. Tiger* | 4.5 | 18 |
| *Catch Me II* | 4.5 | 2 |
| *Talisman of Wight* | 3.5 | 8 |
| *Pilgrim* | 4 | 5 |
| *Maid Good/Lady Moira* | 4.5 | 99 |

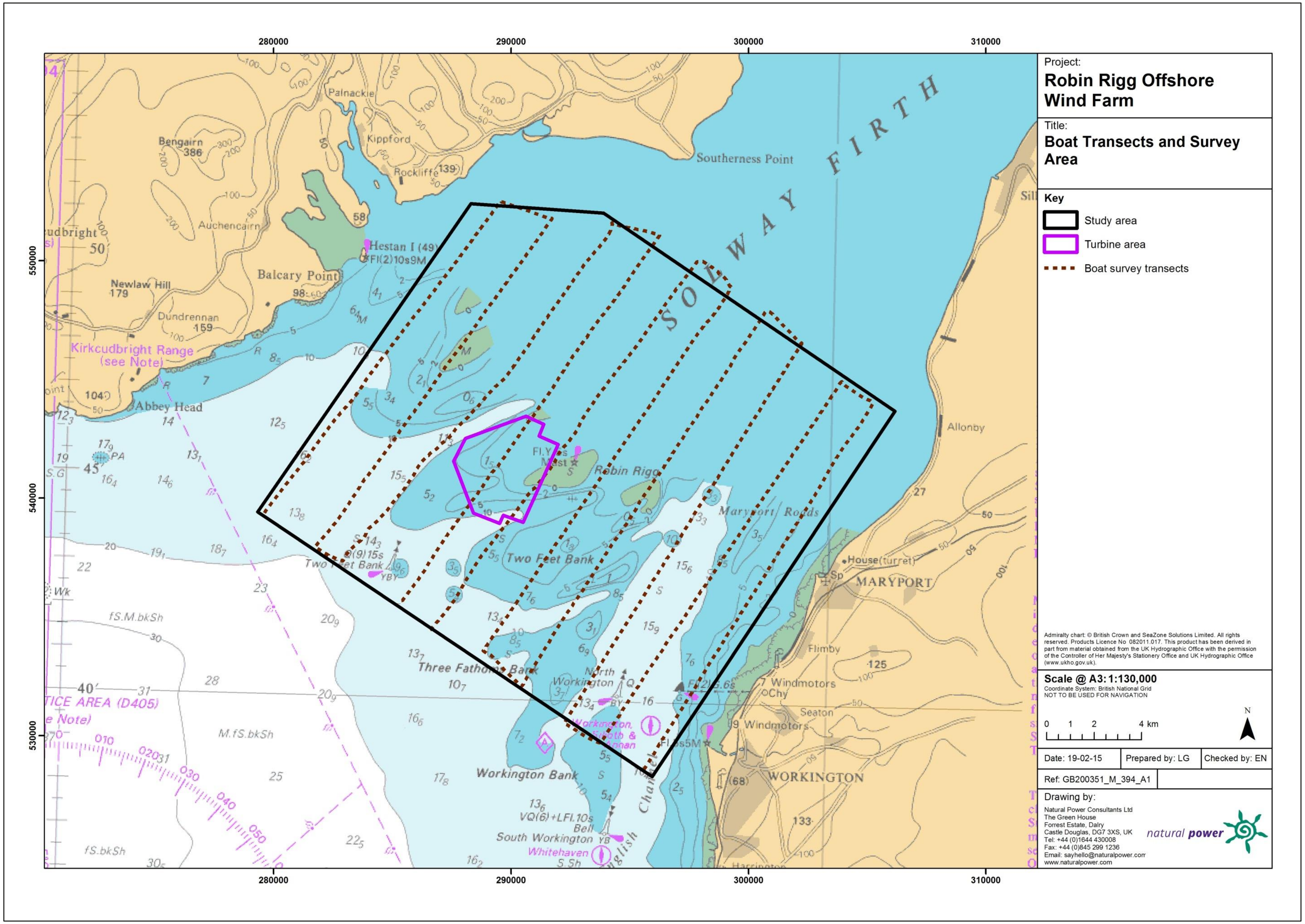


Figure 2.1: Survey transects used during ornithological surveys at Robin Rigg offshore wind farm between 2001 and 2015.

## 2.2. Analysis

### 2.2.1. Overview

The analytical methodology has been determined by the data available to Natural Power, collected as part of the MEMP before, during and after construction of the Robin Rigg OWF. The approach to analysis has been agreed with the RRMG and developed following review of the MEMP requirements, the Food and Environment Protection Act (FEPA) licence and a Centre for Environment, Fisheries and Aquaculture Science (CEFAS) review of OWF monitoring associated with FEPA licence conditions (Walker & Judd, 2010).

The Natural Power Ecology and Hydrology Department have undertaken all of the ornithological data analyses presented in this report with input from Dr Alain Zuur (Highland Statistics). Questions have been addressed as fully as possible within the limits imposed by the survey programme and methods, and the rigour and consistency of the data collected.

### 2.2.2. Data collation

All data, including that collected by Ecology Consulting Ltd., were collated and verified by Natural Power. Throughout this procedure, data were visually inspected and any concerns referred back to the surveyors so that any issues with the dataset could be resolved. All data were stored and managed using Microsoft Excel.

### 2.2.3. Data summary

For each of the 11 key bird species, the density (birds per km$^2$) of birds in flight and on the sea was calculated from raw observations per development phase and operational year. Raw observations across all five operational years were mapped to provide an overview of any changes in abundance and/or distribution within and surrounding the Robin Rigg OWF.

### 2.2.4. Modelling approach

Due to the highly mobile and aggregating (flocking) behaviour of many seabird species, ornithological data collected at Robin Rigg OWF are characterised by a high proportion of zeros and a minority of strongly varying positive numbers (Maclean *et al*., 2013; Leopold *et al*., 2013). This creates analytical challenges as statistical models are built on assumptions about the distribution of the response variable; response variables with lots of zeros and very high variance (e.g. seabird abundance) do not fit many of the distributions commonly used for this purpose. In addition, ornithological data are subject to spatial dependence and/or temporal autocorrelation (i.e. samples taken near each other in space and/or time tend to be more similar than those taken further apart) as a consequence of seabirds responding to variation over time in environmental factors (Pérez Lapeña *et al*., 2010). If spatio-temporal autocorrelation is not taken into account during statistical modelling, standard errors will be overestimated. The modelling approach used in this report accounts for these statistical challenges.

As species-specific datasets had very different properties, a species-by-species approach was adopted. Spatial models were produced for guillemot, razorbill, kittiwake and herring gull. Transect lines for all surveys were divided into 600 m x 600 m segments (Figure 2.2) using ArcGIS (version 10.2). The width of each segment was determined by transect width (300 m to either side of the survey vessel) and the same length was chosen to ensure that the resolution of spatial covariates was the same on both axes, i.e. covariates were averaged across each segment; if segment width was smaller than segment length then average covariate values will have less variation (higher resolution) along the width axis than the length axis.

Bird observations were extracted for kittiwake, razorbill and guillemot according to the following breeding seasons: April to September for kittiwake, April to August for razorbill and April to July for guillemot, as defined in the Walney Extension ES (NIRAS, 2013; thereby following a 'common currency' approach). Herring gull observations from all months were used. Bird observations were then assigned to segments. Multiple observations within a single segment were summed to give the total number of birds observed per segment. Data for potential covariates were extracted for each segment using ArcGIS (version 10.2). These included sea depth, distance to the nearest coastline, sediment type, longitude, latitude, time of day, tidal height and sea state. These were extracted for the mid-point of each segment.

Distance sampling is often used to convert the rate of observations along line transects into estimated abundances by constructing a detection function which can account for decreasing detectability of animals with increasing distance from the observer. However, this was not done here, as the aim of the model was to investigate changes in relative abundance (hereafter 'modelled abundance') of birds rather than absolute numbers. Therefore it was decided not to model detectability as this would add a further source of uncertainty to the modelling process.

Data exploration was undertaken to determine coverage and collinearity among covariates, potential outliers, possible spatial and temporal dependency structure and the distribution of the raw data. During this stage of the analysis, all covariates were found to be collinear, and as a result, only longitude and latitude were included in the final modelling process. These variables act as a proxy for the underlying environmental determinants of the spatial distribution of seabirds. Data exploration also indicated a spatio-temporal dependency structure which was incorporated into the modelling process using random effects. Finally, data exploration and initial modelling attempts indicated that the datasets contained an excess of zeros. This was accounted for by using a zero-inflated model structure (i.e. a probability distribution that allowed for frequent zero-valued observations).

The final models consisted of zero-inflated Poisson generalised additive mixed effects models (ZIP GAMM) with bird abundance per segment as the response variable. Explanatory variables for the Poisson (count) part of the model included operational year and a two-dimensional smooth of longitude and latitude which was allowed to vary by phase. An intercept only binary model was used to account for additional zeros resulting from "sampling error" (i.e. where birds were not encountered in a segment due to chance rather than as a result of segment occurring in an area that was unsuitable for the birds). The two-dimensional spatial smooth was allowed to vary among operational years for razorbill and guillemot, whilst a single smooth across all five operational years was produced for kittiwake and herring gull. Survey and transect within survey were incorporated into the Poisson part of the model as random effects to account for spatio-temporal dependency inherent within the data. The analysis was carried out within a Bayesian framework using the open source statistical packages JAGS (Plummer, 2003) and R version 3.2.1 (R Core Team, 2015).

Model validation was carried out to check the robustness of each model. This included investigation of the convergence for each of the parameters being estimated, the fit of the model to the raw data, and residual patterns in the data which would suggest that dependency structures were not being appropriately accounted for or that additional covariates should be included.

The outputs of the final models were used to produce density surfaces for each year of operation and uncertainty plots presenting the relative uncertainty of the model across the spatial range of the survey area. Uncertainty was expressed as the coefficient of variation (*CV*) which describes model fit in terms of the relative sizes of the squared residuals and outcome values. Higher certainty in model predictions is expressed as low *CV* values. Difference plots are also presented which show how modelled bird abundance for each year differed from that during the first year of operation.

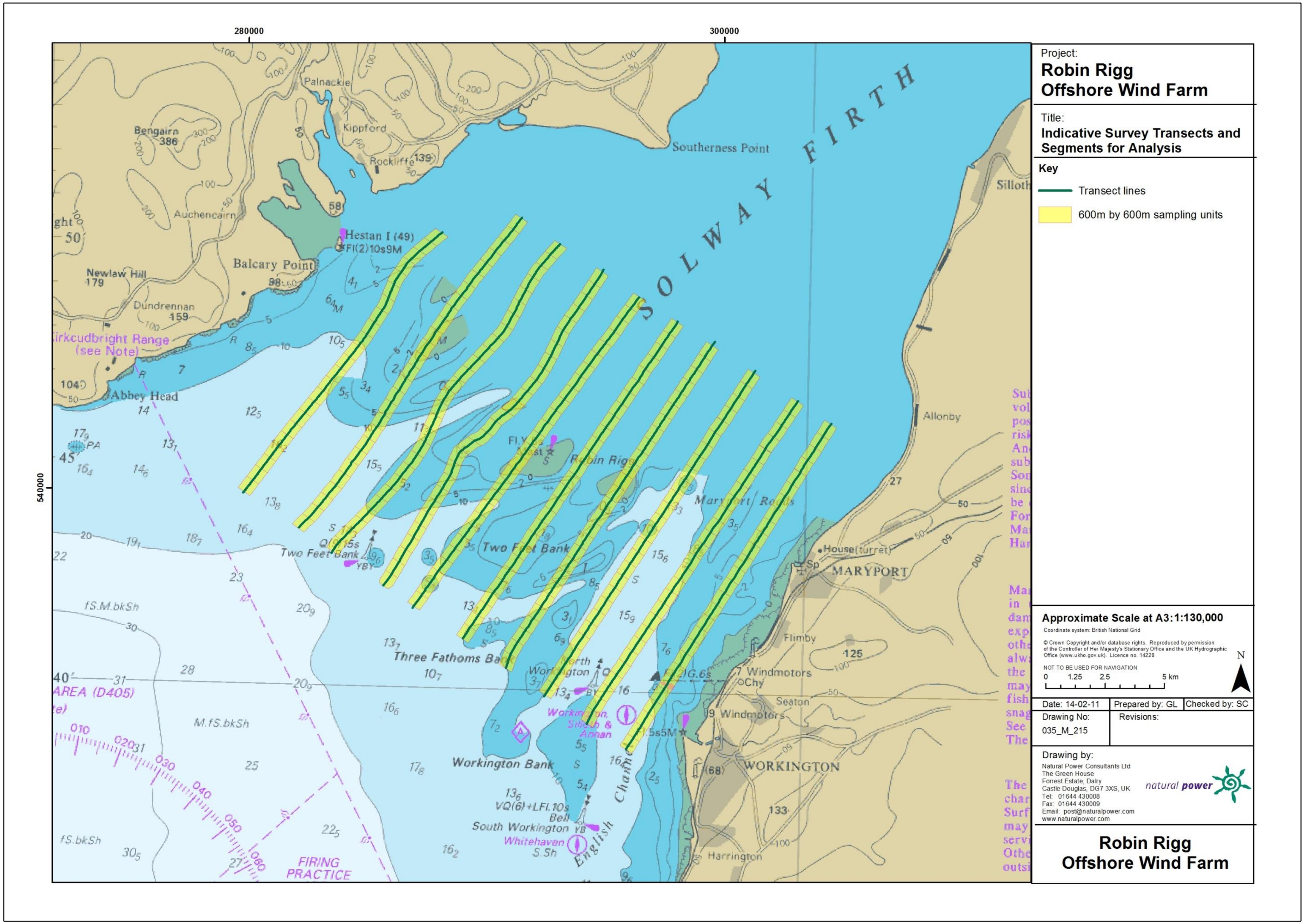


Figure 2.2: Example of 600 m x 600 m segments applied to survey transects for which data were extracted.

# 3. Results

## 3.1. Data summary

### 3.1.1. Across three development phases

**Birds in flight**

The densities (birds per $km^2$) of birds in flight across the three development phases are shown in Table 3.1. Densities are shown for birds in flight both within the Robin Rigg OWF and across the remainder of the survey area (i.e. excluding the OWF). The raw number of birds in flight across the three development phases, together with the areas ($km^2$) surveyed, are shown in Appendix A.

Densities of birds in flight were relatively low across all three development phases for all 11 key species within the Robin Rigg OWF, particularly for scaup, common scoter, red-throated diver, Manx Shearwater and great black-backed gull.

Densities indicate an increase in flying cormorants and herring gulls within the Robin Rigg OWF across the three development phases, and a decrease in flying gannets, razorbills and guillemots. The density of flying kittiwakes remained similar within the Robin Rigg OWF across the three development phases.

Across the remaining survey area, densities of common scoter in flight were the highest of all 11 key species across all three development phases. This is likely to result from a small number of large flocks of common scoter in flight.

**Table 3.1: Density (birds per $km^2$) of birds in flight within and outside the Robin Rigg offshore wind farm (OWF) during the three development phases. *Pre-construction includes EIA baseline surveys.**

| Species | Within Robin Rigg OWF | | | Within remainder of survey area | | |
|---|---|---|---|---|---|---|
| | Pre-construction* | Construction | Operation | Pre-construction* | Construction | Operation |
| Scaup | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Common scoter | 0.00 | 0.06 | 0.00 | 1.80 | 2.09 | 0.78 |
| Red-throated diver | 0.11 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 |
| Manx shearwater | 0.00 | 0.05 | 0.01 | 0.14 | 0.07 | 0.06 |
| Cormorant | 0.02 | 0.40 | 0.50 | 0.05 | 0.25 | 0.26 |
| Gannet | 0.12 | 0.03 | 0.00 | 0.10 | 0.05 | 0.06 |
| Razorbill | 0.31 | 0.03 | 0.03 | 0.31 | 0.05 | 0.07 |
| Guillemot | 0.25 | 0.10 | 0.08 | 0.12 | 0.10 | 0.12 |
| Kittiwake | 0.25 | 0.22 | 0.22 | 0.16 | 0.09 | 0.11 |
| Herring gull | 0.13 | 0.17 | 0.19 | 0.22 | 0.19 | 0.19 |
| Great black-backed gull | 0.01 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 |

### Birds on the sea

The densities (birds per km$^2$) of birds on the sea across the three development phases are shown in Table 3.2. Densities are shown for birds on the sea both within the Robin Rigg OWF and across the remainder of the survey area. The raw number of birds on the sea across the three development phases, together with the areas (km$^2$) surveyed, are shown in Appendix A.

For common scoter, razorbill and guillemot in particular, densities of birds on the sea were larger than densities of birds in flight across all three development phases both within and outside the Robin Rigg OWF. For scaup, red-throated diver, Manx shearwater and great black-backed gull, densities of birds on the sea were again relatively low in comparison to the other key species.

Densities indicate an increase in common scoter, cormorant, guillemot, kittiwake and herring gull on the sea within and outside the Robin Rigg OWF between construction and operational phases. The density of gannets and razorbills on the sea were similar between construction and operational phases.

Across the remaining survey area, densities of common scoter on the sea were highest of all 11 key species across all three development phases. Again, this is likely to result from a small number of large flocks of common scoter in flight.

**Table 3.2: Density (birds per km$^2$) of birds on the sea within and outside Robin Rigg offshore wind farm (OWF) during the three development phases. *Pre-construction includes EIA baseline surveys.**

| Species | Within Robin Rigg OWF | | | Within remainder of survey area | | |
|---|---|---|---|---|---|---|
| | Pre-construction* | Construction | Operation | Pre-construction* | Construction | Operation |
| Scaup | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.24 |
| Common scoter | 0.04 | 0.08 | 1.31 | 13.15 | 9.01 | 9.99 |
| Red-throated diver | 0.04 | 0.03 | 0.00 | 0.07 | 0.06 | 0.08 |
| Manx shearwater | 0.00 | 0.01 | 0.02 | 0.05 | 0.16 | 0.14 |
| Cormorant | 0.06 | 0.45 | 2.67 | 0.07 | 0.11 | 0.45 |
| Gannet | 0.05 | 0.00 | 0.01 | 0.05 | 0.03 | 0.03 |
| Razorbill | 1.94 | 0.49 | 0.36 | 0.57 | 0.56 | 0.57 |
| Guillemot | 2.19 | 0.84 | 1.55 | 1.54 | 1.08 | 1.23 |
| Kittiwake | 0.25 | 0.19 | 1.25 | 0.19 | 0.14 | 0.17 |
| Herring gull | 0.25 | 0.06 | 1.29 | 0.16 | 0.07 | 0.17 |
| Great black-backed gull | 0.09 | 0.04 | 0.06 | 0.02 | 0.04 | 0.10 |

### 3.1.2. Across five operational years

**Birds in flight**

The densities (birds per km$^2$) of birds in flight across each of the five operational years are shown in Table 3.3. Densities are shown for birds in flight both within the Robin Rigg OWF and across the remainder of the survey area. The raw number of birds in flight across each of the five operational years, together with the areas (km$^2$) surveyed, are shown in Appendix A.

Densities of birds in flight were relatively low across each of the five operational years for all 11 key species within the Robin Rigg OWF, particularly for scaup, common scoter, red-throated diver, Manx Shearwater, gannet and great black-backed gull.

Densities indicate a general increase in flying cormorants, guillemots and herring gulls within the Robin Rigg OWF between operational year one and operational year five, and a decrease in flying razorbills. The density of flying kittiwakes remained similar within the Robin Rigg OWF across all five operational years.

Across the remaining survey area, densities of all 11 key birds in flight were comparable across each of the five operational years. Densities of common scoter in flight were the highest of all 11 key species across all five operational years.

**Table 3.3: Density (birds per km$^2$) of birds in flight within and outside Robin Rigg offshore wind farm (OWF) during all five operational years.**

| Species | Within Robin Rigg OWF | | | | | Within remainder of survey area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Y1 | Y2 | Y3 | Y4 | Y5 | Y1 | Y2 | Y3 | Y4 | Y5 |
| Scaup | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Common scoter | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.77 | 0.88 | 1.06 | 0.66 | 0.42 |
| Red-throated diver | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.08 | 0.04 | 0.06 | 0.04 | 0.04 |
| Manx shearwater | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.06 | 0.05 | 0.04 | 0.13 | 0.02 |
| Cormorant | 0.09 | 0.17 | 0.04 | 0.97 | 1.92 | 0.24 | 0.18 | 0.23 | 0.54 | 0.20 |
| Gannet | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.06 | 0.06 | 0.09 | 0.04 |
| Razorbill | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.20 | 0.03 | 0.02 | 0.03 |
| Guillemot | 0.06 | 0.00 | 0.08 | 0.12 | 0.24 | 0.19 | 0.07 | 0.20 | 0.07 | 0.09 |
| Kittiwake | 0.06 | 0.48 | 0.19 | 0.24 | 0.04 | 0.11 | 0.13 | 0.12 | 0.09 | 0.08 |
| Herring gull | 0.09 | 0.23 | 0.27 | 0.28 | 0.16 | 0.19 | 0.08 | 0.52 | 0.12 | 0.11 |
| Great black-backed gull | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 0.03 | 0.04 | 0.08 | 0.06 | 0.07 |

### Birds on the sea

The densities (birds per km$^2$) of birds on the sea across each of the five operational years are shown in Table 3.4. Densities are shown for birds on the sea both within the Robin Rigg OWF and across the remainder of the survey area. The raw number of birds on the sea across each of the five operational years, together with the areas (km$^2$) surveyed, are shown in Appendix A.

For common scoter, razorbill, and guillemot, densities of birds on the sea were larger than densities of birds in flight across each of the five operational years both within and outside the Robin Rigg OWF. In contrast, densities of kittiwakes and herring gulls on the sea were generally larger than densities of kittiwakes and herring gulls in flight within the Robin Rigg OWF only. For scaup, red-throated diver, Manx shearwater and great black-backed gull, densities of birds on the sea were again relatively low in comparison to the other key species.

Densities indicate a general increase in common scoter, cormorant, guillemot, kittiwake and herring gull on the sea within the Robin Rigg OWF across operational years, with a possible decline in razorbills. The density of gannets on the sea was comparably low across operational years both within and outside the Robin Rigg OWF.

Across the remaining survey area, densities of common scoter on the sea were again the highest of all 11 key species across each of the five operational years.

**Table 3.4: Density (birds per km$^2$) of birds on the sea across Robin Rigg offshore wind farm (OWF) during all five operational years.**

| Species | Within Robin Rigg OWF | | | | | Within remainder of survey area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Y1 | Y2 | Y3 | Y4 | Y5 | Y1 | Y2 | Y3 | Y4 | Y5 |
| Scaup | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.26 | 0.00 | 0.08 | 0.00 | 0.00 |
| Common scoter | 0.22 | 0.25 | 0.00 | 6.04 | 0.00 | 8.67 | 9.79 | 10.58 | 13.53 | 7.15 |
| Red-throated diver | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.12 | 0.11 | 0.10 | 0.02 | 0.04 |
| Manx shearwater | 0.00 | 0.04 | 0.00 | 0.04 | 0.00 | 0.06 | 0.18 | 0.06 | 0.31 | 0.11 |
| Cormorant | 0.39 | 0.58 | 4.90 | 4.03 | 3.14 | 0.24 | 0.18 | 0.26 | 1.44 | 0.11 |
| Gannet | 0.00 | 0.02 | 0.04 | 0.00 | 0.00 | 0.01 | 0.04 | 0.05 | 0.03 | 0.01 |
| Razorbill | 0.71 | 0.40 | 0.23 | 0.26 | 0.22 | 0.45 | 0.71 | 0.92 | 0.47 | 0.29 |
| Guillemot | 1.03 | 1.92 | 1.38 | 1.37 | 2.04 | 1.30 | 1.44 | 1.40 | 1.05 | 0.97 |
| Kittiwake | 0.11 | 0.31 | 2.58 | 3.08 | 0.04 | 0.08 | 0.26 | 0.17 | 0.14 | 0.18 |
| Herring gull | 0.26 | 1.34 | 2.97 | 1.39 | 0.38 | 0.08 | 0.08 | 0.42 | 0.11 | 0.14 |
| Great black-backed gull | 0.00 | 0.02 | 0.14 | 0.14 | 0.00 | 0.08 | 0.08 | 0.13 | 0.10 | 0.09 |

### Distribution of observations

The spatial distributions of all 11 key bird species across all five operational years are shown in Figure 3.1 to Figure 3.3. Each panel within Figure 3.1 to Figure 3.3 shows the total number of raw observations of both birds in flight and on the sea.

All 11 key bird species were present within the OWF footprint during operation (except scaup which was absent across all three development phases), showing that these species did not avoid the operational Robin Rigg OWF entirely.

For species favouring shallow waters, including scaup and common scoter, observations are clustered towards the north of the study area, close to the Dumfries and Galloway coastline. Whilst red-throated diver and cormorant observations were recorded throughout much of the study area, larger numbers were recorded in coastal waters along both the northern and southern shores of the Solway Firth, again reflected species' habitat preferences. In contrast, Manx shearwater observations were clustered towards the south-west of the study area, towards the deeper waters in the mouth of the Solway Firth. Whilst guillemot and razorbill observations were recorded throughout all of the study area, the highest numbers were again clustered in deeper waters to the south-west during operation. Gannets did not show any clear patterns in distribution with clusters of observations recorded throughout the study area. As with gannets, all three species of gull were distributed across much of the study area across all five operational years. Kittiwakes and herring gulls were more highly clustered within the Robin Rigg OWF footprint compared to great black-backed gull, which instead showed a preference for the Cumbrian coastline.

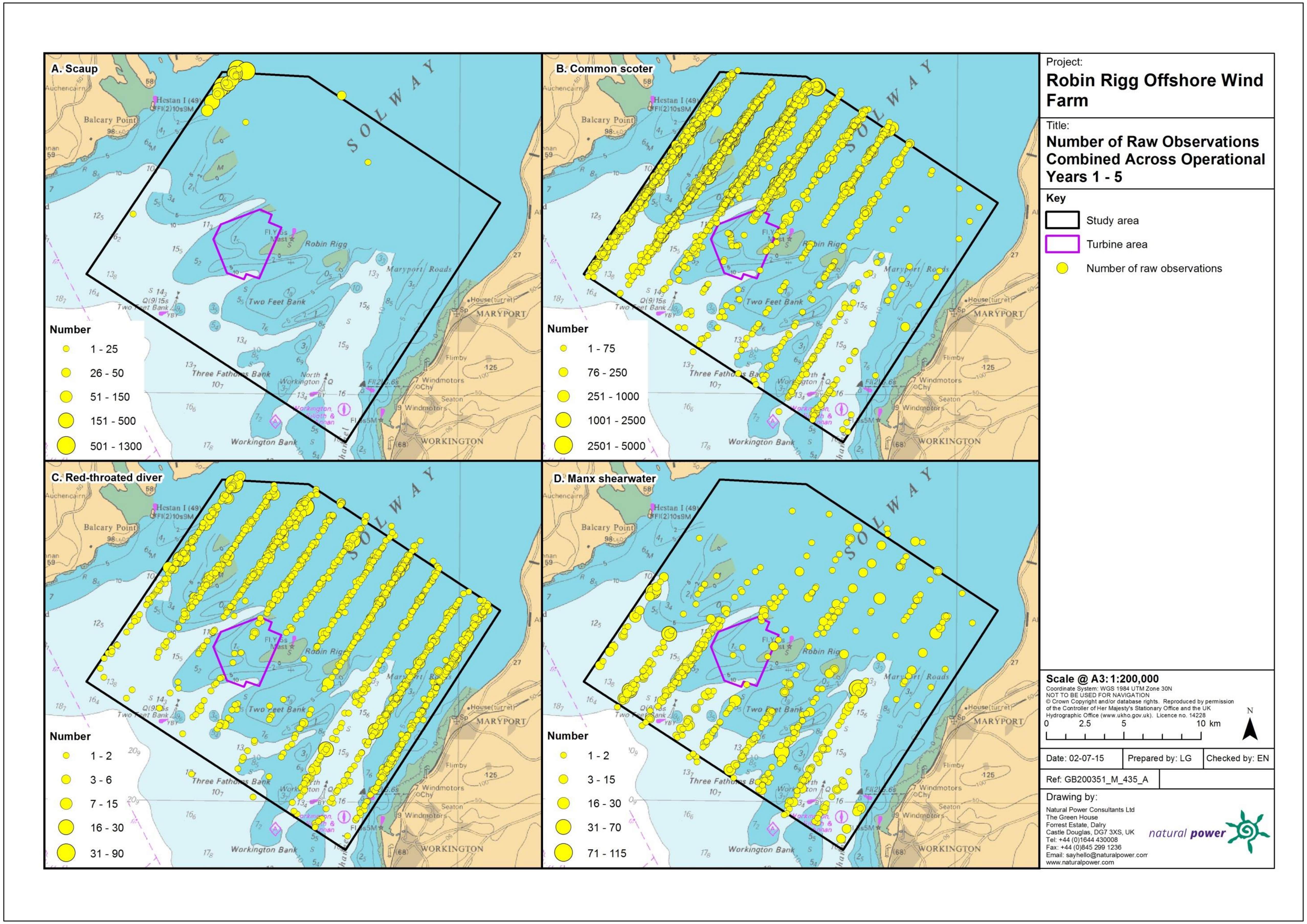


**Figure 3.1: Distribution of raw observations across all five operational years for a) scaup, b) common scoter, c) red-throated diver and d) Manx shearwater. Both birds in flight and on the sea are shown.**

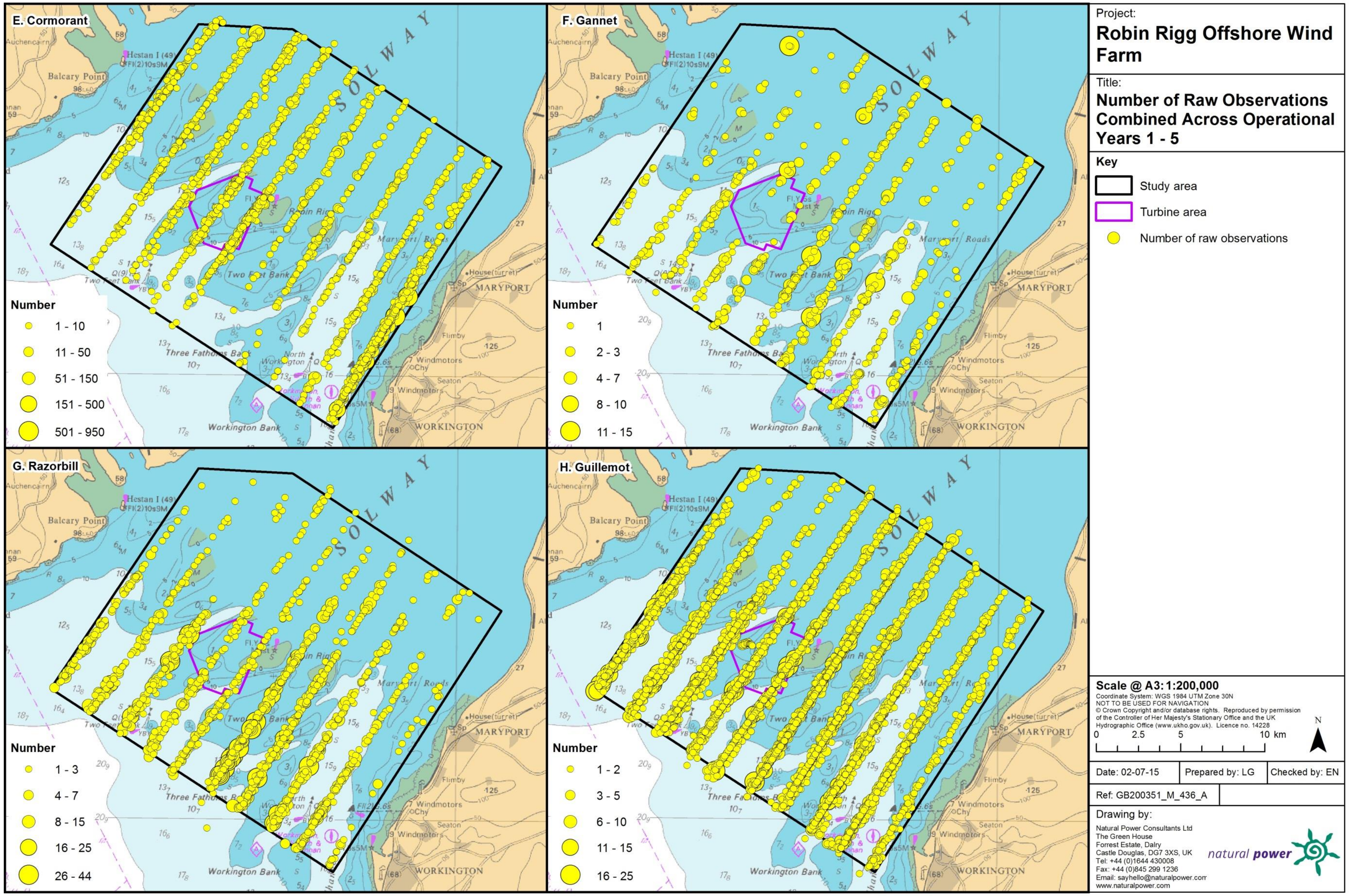


**Figure 3.2:** Distribution of raw observations across all five operational years for e) cormorant, f) gannet, g) razorbill and h) guillemot. Both birds in flight and on the sea are shown.

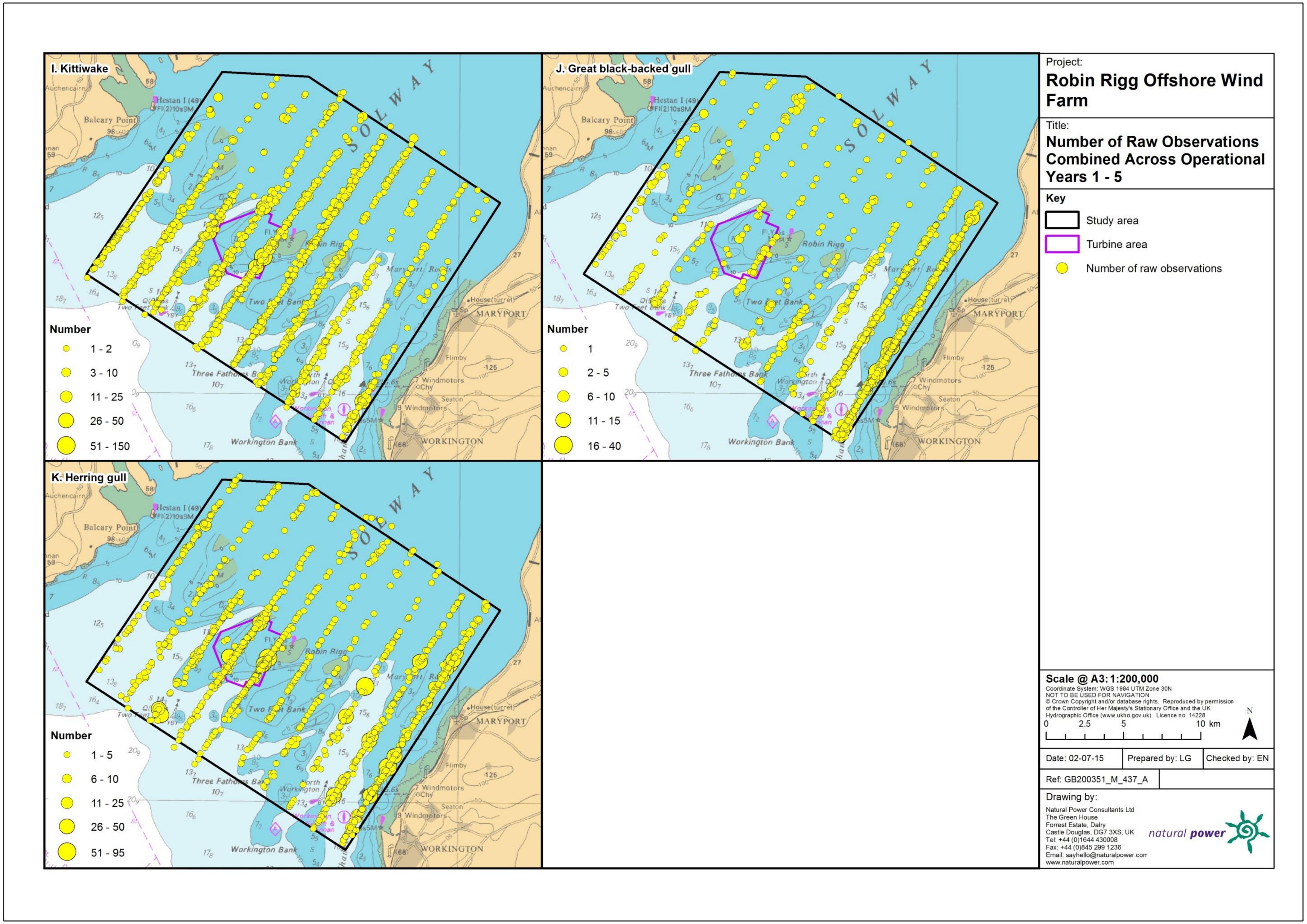


**Figure 3.3:** Distribution of raw observations across all five operational years for i) kittiwake, j) herring gull and k) great black-backed gull. Both birds in flight and on the sea are shown.

### Annual variation in density

Data across all five operational years were combined to show species presence across the entire Robin Rigg OWF survey area throughout the year (Table 3.5). Birds in flight and on the sea were combined to give a total density (birds per km$^2$) during each month.

Annual variation in species density across the five operational years followed that expected from all 11 key species' ecology. Scaup and red-throated diver were present in the study area during the winter months only, since both species migrate northwards to breed during the summer. In contrast, Manx shearwater and gannet were present in the summer months only since both species migrate southwards to overwinter. Common scoters were present in relatively higher densities compared to the other key species for most of the year, although the highest densities were recorded in late summer as birds gather in large numbers to moult before dispersing to overwinter elsewhere. The highest densities of razorbills, guillemots and kittiwakes were recorded during the breeding and post-breeding seasons since all three species disperse further offshore during the winter. Cormorants, herring gulls and great black-backed gulls were present in the study area year-round.

**Table 3.5: Monthly density (birds per km$^2$) aross all five operational years across the entire Robin Rigg OWF survey area. Both birds in flight and on the sea are included. Species-specific breeding seasons (as defined in the Walney Extension ES; NIRAS, 2013) are shaded.**

| Species | Density (birds/km$^2$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| Scaup | 2.69 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.20 |
| Common scoter | 4.91 | 8.86 | 8.10 | 1.61 | 10.05 | 18.42 | 23.73 | 15.65 | 9.66 | 7.45 | 7.75 | 6.32 |
| Red-throated diver | 0.13 | 0.12 | 0.16 | 0.21 | 0.20 | 0.01 | 0.00 | 0.00 | 0.10 | 0.16 | 0.08 | 0.18 |
| Manx shearwater | 0.00 | 0.00 | 0.00 | 0.27 | 0.23 | 1.01 | 0.62 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| Cormorant | 0.79 | 3.78 | 0.20 | 0.13 | 0.22 | 0.22 | 0.36 | 0.33 | 0.32 | 0.35 | 0.95 | 1.22 |
| Gannet | 0.00 | 0.00 | 0.04 | 0.04 | 0.10 | 0.20 | 0.27 | 0.05 | 0.02 | 0.13 | 0.01 | 0.00 |
| Razorbill | 0.08 | 0.10 | 1.06 | 1.18 | 0.36 | 0.24 | 0.12 | 0.09 | 0.32 | 1.67 | 2.02 | 0.14 |
| Guillemot | 0.68 | 1.02 | 0.91 | 1.46 | 1.30 | 1.43 | 1.81 | 1.91 | 1.54 | 1.87 | 1.16 | 0.85 |
| Kittiwake | 0.03 | 0.05 | 0.24 | 0.30 | 0.53 | 0.59 | 0.47 | 0.87 | 0.09 | 0.07 | 0.28 | 0.02 |
| Herring gull | 0.19 | 0.23 | 0.60 | 0.36 | 0.40 | 0.34 | 0.29 | 0.20 | 0.21 | 0.41 | 0.92 | 0.16 |
| Great black-backed gull | 0.23 | 0.12 | 0.14 | 0.04 | 0.05 | 0.03 | 0.08 | 0.06 | 0.11 | 0.32 | 0.24 | 0.28 |

## 3.2. Gannet

### Evidence for meso-avoidance

Gannet flight height data across all five operational years were combined to show species presence within the Robin Rigg OWF, within 500 m of the Robin Rigg OWF, within 1 km of the Robin Rigg OWF and across the rest of the study area during the breeding season. Data are presented in Figure 3.4.

Gannets in flight were not recorded within the Robin Rigg OWF during operation. Data indicate that gannets largely flew below turbine rotor height (35-125 m) throughout the entire study area, with <2% of all gannets in flight recorded in flight height band four. Evidence suggests that there was no change in gannet flight behaviour in response to the Robin Rigg OWF.

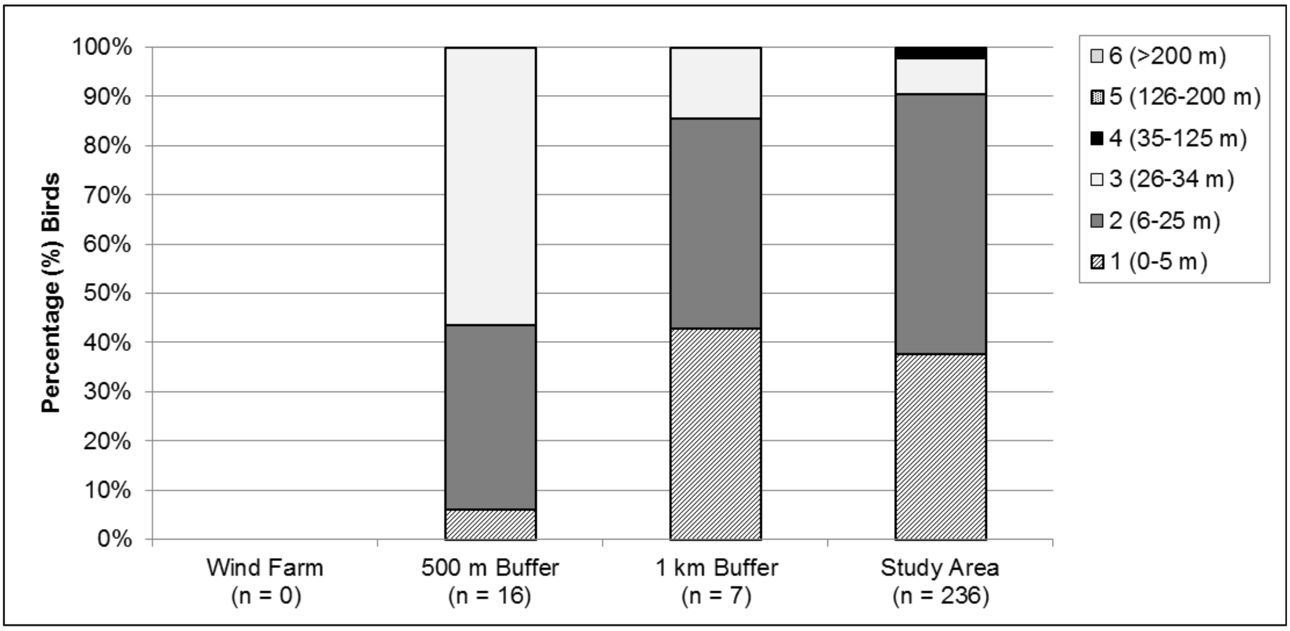


**Figure 3.4: Percentage of gannet recorded within six flight height bands across all five operational years during the breeding season.**

## 3.3. Razorbill

### Evidence for displacement and habituation

Razorbill abundance across the study area was modelled (as described in Section 2.2.4) for birds on the sea during the breeding season (April to August) for each of the five operational years. Model predictions are shown in Figure 3.5. Model parameter estimates are presented in Appendix B.

Model predictions of razorbill distribution during each of the five operational years are shown in the top row of Figure 3.5. Model predictions showed that razorbills were not entirely absent from the Robin Rigg OWF during any operational year. Modelled razorbill abundance within the Robin Rigg OWF during operational years two, three and four was higher than during operational years one and five.

Levels of uncertainty (*CV*) in modelled razorbill abundance are shown on the middle row of Figure 3.5. Uncertainty was highest around the edges of the study area, with increased levels of confidence in areas where modelled razorbill abundance was high.

The change in modelled razorbill abundance between operational years (with all years compared to operational year one) is shown on the bottom row of Figure 3.5. There was no statistically significant change in modelled razorbill abundance between operational year one and any subsequent operational year. The largest increase in modelled razorbill abundance was seen within the Robin Rigg OWF between operational year one and operational year three. Between operational year one and operational year five there was an indication of a slight shift in distribution with a cluster of birds moving from the east of the study area into deeper waters in the south-west of the study area.

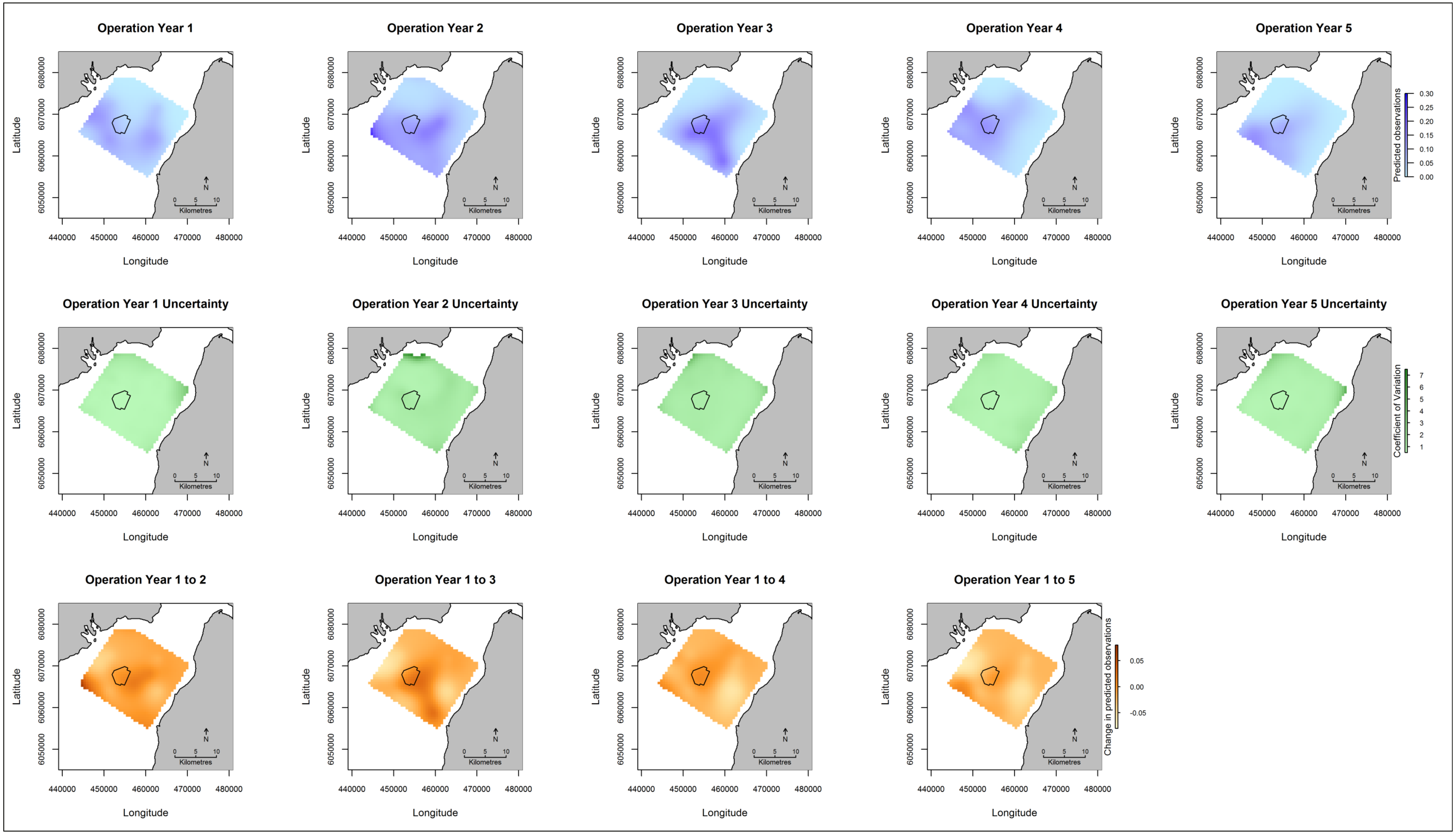


Figure 3.5: Top row: modelled razorbill abundance on the sea during the breeding season (April to August) for each operational year (1-5). Middle row: uncertainty (*CV*) in modelled razorbill abundance for each operational year (1-5). Bottom row: change in modelled razorbill abundance between operational years (all years compared to operational year one).

## 3.4. Guillemot

### Evidence for displacement and habituation

Guillemot abundance across the study area was modelled for birds on the sea during the breeding season (April to July) for each of the five operational years. Model predictions are shown in Figure 3.6. Model parameter estimates are presented in Appendix B.

Modelled guillemot abundance for each of the five operational years is shown on the top row of Figure 3.6. Model predictions showed that guillemots were not entirely absent from the Robin Rigg OWF during any operational year. As with razorbills, modelled guillemot abundance was higher within the Robin Rigg OWF during operational years two, three and four than during operational years one and five.

Levels of uncertainty (*CV*) in modelled guillemot abundance are shown on the middle row of Figure 3.6. Uncertainty was highest around the edges of the study area, with increased levels of confidence in areas where modelled razorbill abundance was larger.

The change in modelled guillemot abundance between operational years (with all years compared to operational year one) are shown on the bottom row of Figure 3.6. There was no statistically significant change in modelled guillemot abundance within the Robin Rigg OWF between operational year one and any other operational year.

A statistically significant increase in modelled guillemot abundance was predicted between operational year one and operational year two in the western corner of the study area. An increase in modelled guillemot abundance was predicted within and immediately south of the Robin Rigg OWF between operational year one and operational year three, although this was not statistically significant. Between operational year one and operational years four and five, statistically significant decreases in modelled guillemot abundance were predicted outside the Robin Rigg OWF, in shallow waters close to the northern and southern shores of the Solway Firth. These changes indicate a slight shift in distribution with birds moving into deeper waters in the south-west of the study area during operational year five.

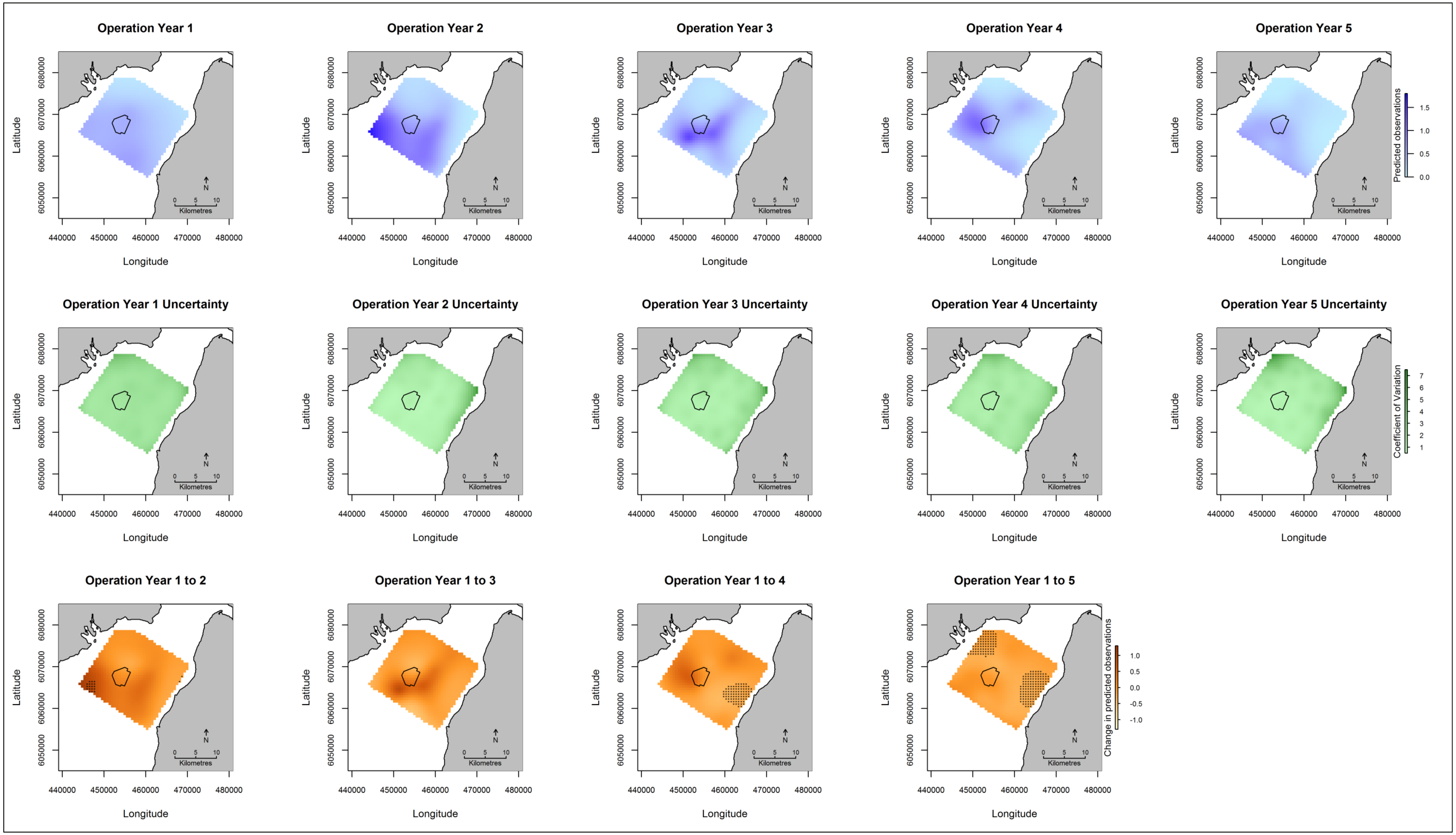


Figure 3.6: Top row: modelled guillemot abundance on the sea during the breeding season (April to July) for each operational year (1-5). Middle row: uncertainty (*CV*) in modelled guillemot abundance for each operational year (1-5). Bottom row: change in modelled guillemot abundance between operational years (all years compared to operational year one).

## 3.5. Kittiwake

### Evidence of meso-avoidance

Kittiwake flight height data across all five operational years were combined to show species presence within the Robin Rigg OWF, within 500 m of the Robin Rigg OWF, within 1 km of the Robin Rigg OWF and across the rest of the study area during the breeding season. Data are presented in Figure 3.7.

Kittiwakes in flight were recorded within the Robin Rigg OWF during operation. Data indicate that kittiwakes largely flew below turbine rotor height (35-125 m) throughout the entire study area, with 1.3% of all kittiwakes in flight recorded in flight height band four. No kittiwakes were recorded at turbine rotor height (35-125 m) within the Robin Rigg OWF.

This suggests that there was no change in kittiwake flight behaviour in response to the Robin Rigg OWF.

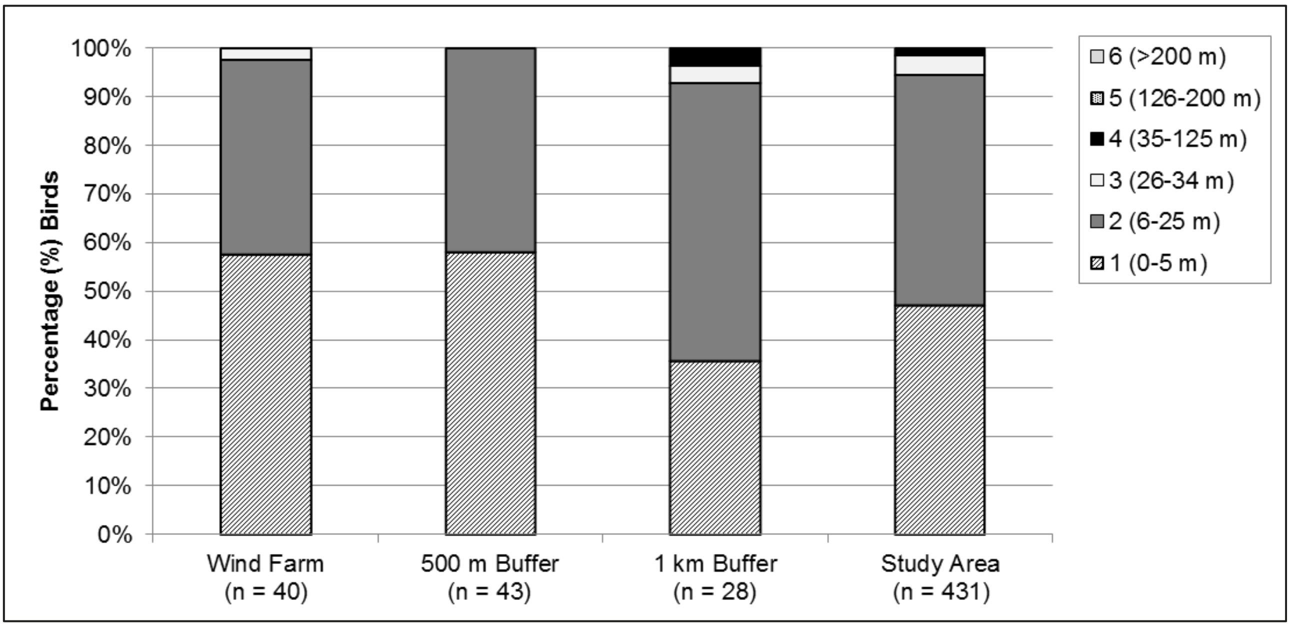


**Figure 3.7: Percentage of kittiwake recorded within six flight height bands across all five operational years during the breeding season.**

### Evidence for displacement

Kittiwake abundance across the study area was modelled for birds on the sea during the breeding season (April to September) across all five operational years. Model predictions are shown in Figure 3.8. Model parameter estimates are presented in Appendix B.

Modelled kittiwake abundance across all five operational years is shown on the left of Figure 3.8. Across the study area, modelled kittiwake abundance was largest within and immediately east and west of the Robin Rigg OWF. A cluster of kittiwakes on the sea was also predicted in the southern corner of the study area.

Levels of uncertainty (*CV*) in modelled kittiwake abundance are shown on the right of Figure 3.8. Uncertainty was largest around the edges of the study area, with a high level of confidence in modelled kittiwake abundance within and surrounding the Robin Rigg OWF.

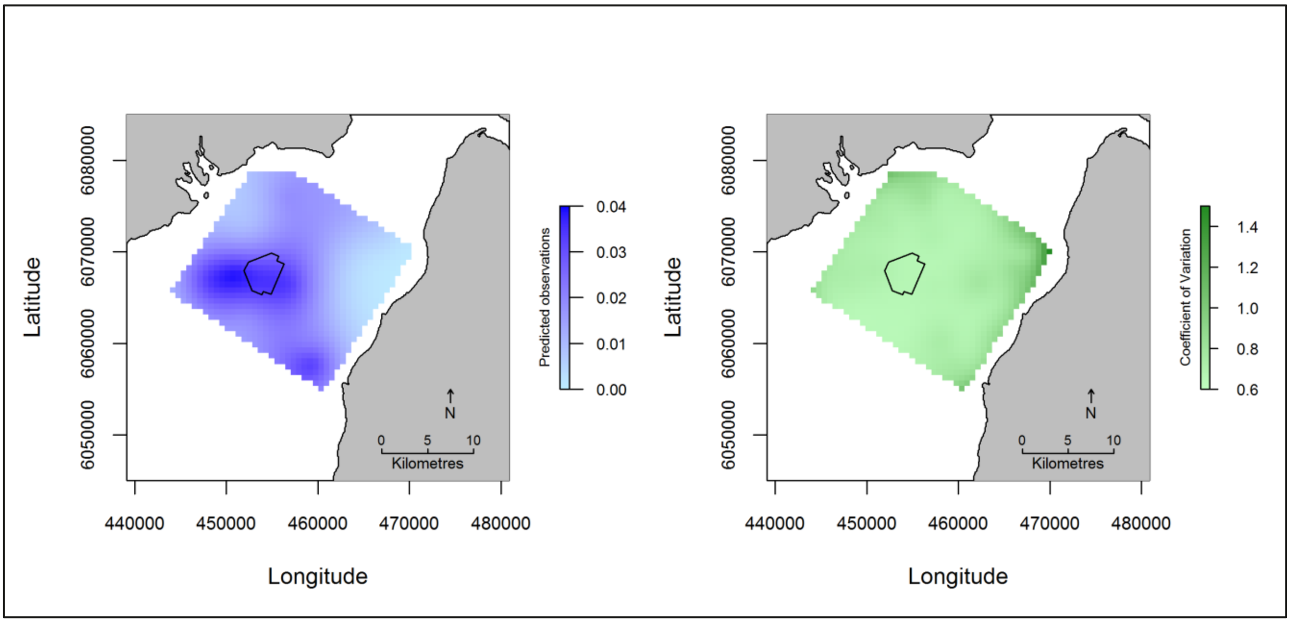


**Figure 3.8: Left: modelled kittiwake abundance on the sea during the breeding season (April to September) across all operational years (1-5). Right: uncertainty (*CV*) in modelled kittiwake abundance across all operational years (1-5).**

### Evidence for macro-avoidance

Kittiwake abundance across the study area was modelled for birds in flight during the breeding season (April to September) across all five operational years. Model predictions are shown in Figure 3.9. Model parameter estimates are presented in Appendix B.

Modelled kittiwake abundance across all five operational years is shown on the left of Figure 3.9. Across the study area, modelled kittiwake abundance of birds in flight was largest within and immediately north-west of the Robin Rigg OWF. Relatively large numbers of kittiwakes in flight were also predicted to occur to the south of the Robin Rigg OWF, towards deeper waters in the mouth of the Solway Firth.

Levels of uncertainty (*CV*) in modelled kittiwake abundance are shown on the right of Figure 3.9. Uncertainty was largest around the edges of the study area, particularly in the northern corner of the study area where few kittiwakes in flight were predicted to occur. There was a high level of confidence in modelled kittiwake abundance within and surrounding the Robin Rigg OWF.

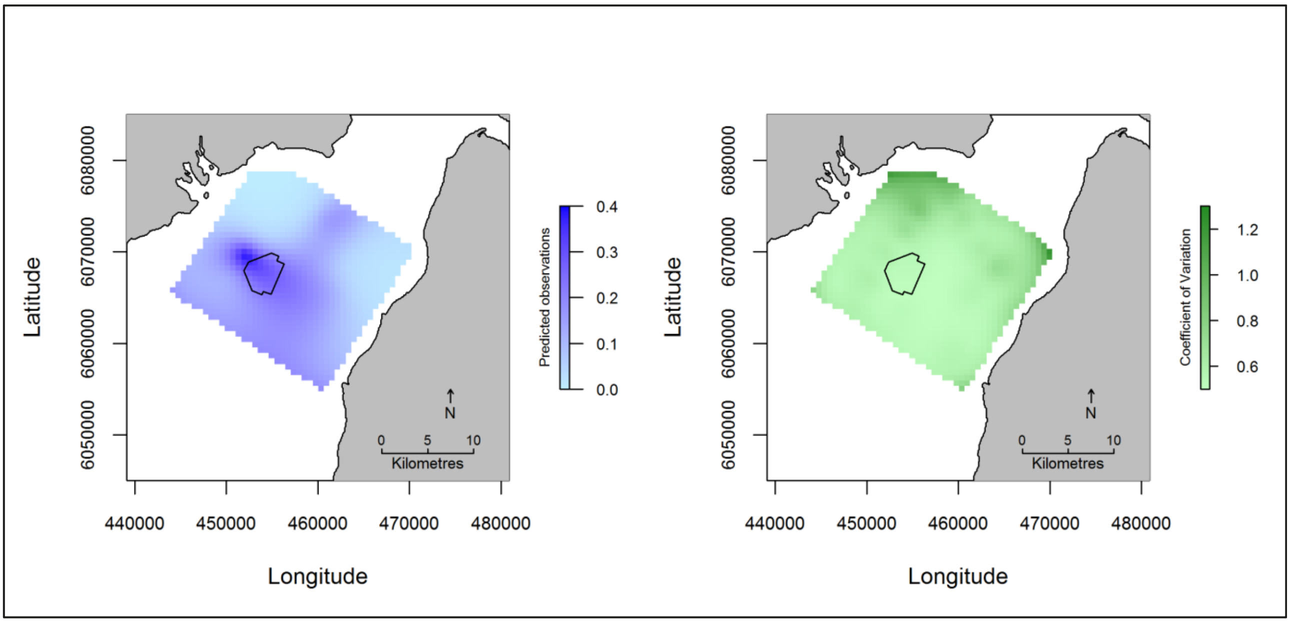


**Figure 3.9: Left: predicted kittiwake abundance in flight during the breeding season (April to September) across all operational years (1-5). Right: uncertainty (*CV*) in predicted kittiwake abundance across all operational years (1-5).**

## 3.6. Herring gull

### Evidence for meso-avoidance

Herring gull flight height data across all five operational years were combined to show species presence within the Robin Rigg OWF, within 500 m of the Robin Rigg OWF, within 1 km of the Robin Rigg OWF and across the rest of the study area during the breeding season. Data are presented in Figure 3.10. Model parameter estimates are presented in Appendix A.

Herring gulls in flight were recorded within the Robin Rigg OWF during operation. Compared to gannets and kittiwakes, a larger percentage of herring gulls were recorded at turbine rotor height (35-125 m) throughout the entire study area, with 5.6% of all herring gulls recorded in flight height band four. Overall, the majority of herring gulls within and outside the Robin Rigg OWF flew below turbine rotor height.

There was evidence for no change in herring gull flight behaviour in response to the Robin Rigg OWF.

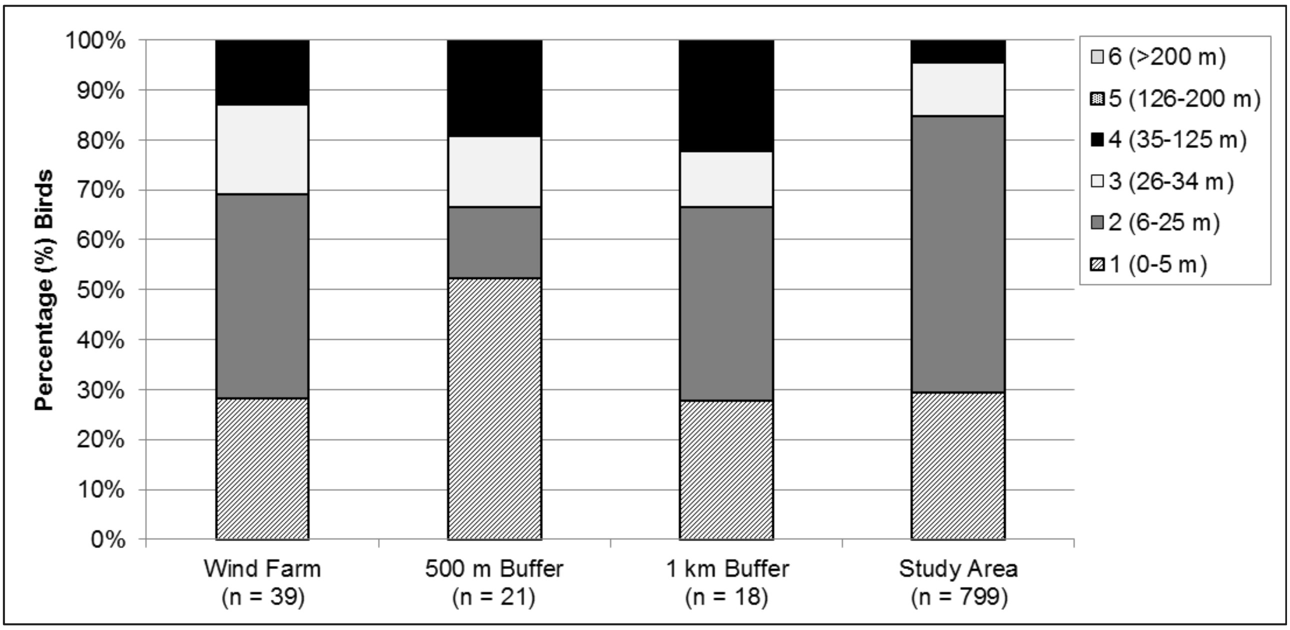


**Figure 3.10: Percentage of herring gull recorded within six flight height bands across all five operational years during the breeding season.**

### Evidence for macro-avoidance

Herring gull observations across the study area were modelled for birds in flight throughout the breeding (April to August) and non-breeding (September to March) seasons across all five operational years. Model predictions are shown in Figure 3.11. Model parameter estimates are presented in Appendix B.

Modelled herring gull abundance across all five operational years is shown on the left of Figure 3.11. Across the study area, the largest numbers of herring gulls in flight were predicted to occur close to the Cumbrian coastline. Although in smaller abundance, herring gulls in flight were also predicted to occur in a band heading out from the Cumbrian coastline and into the Robin Rigg OWF.

Levels of uncertainty (*CV*) in modelled herring gull abundance are shown on the right of Figure 3.11. Uncertainty was largest around the edges of the study area, and towards the north-east of the study area where few herring gulls in flight were predicted to occur. There was a higher level of confidence in modelled herring gull abundance close to the Cumbrian coastline and within the Robin Rigg OWF.

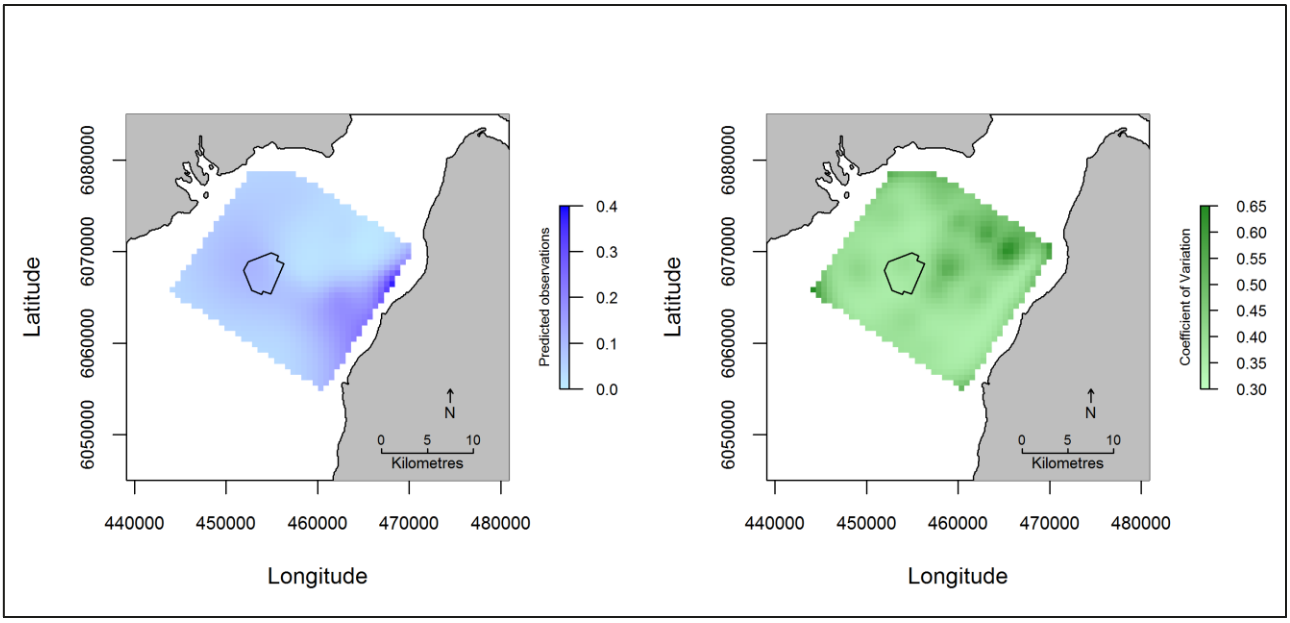


**Figure 3.11: Left: predicted herring gull abundance in flight throughout the breeding (April to August) and non-breeding seasons (September to March) across all operational years (1-5). Right: uncertainty (*CV*) in predicted herring gull abundance across all operational years (1-5).**

## 3.7. Great black-backed gull

### Evidence for meso-avoidance

Great black-backed gull flight height data across all five operational years were combined to show species presence within the Robin Rigg OWF, within 500 m of the Robin Rigg OWF, within 1 km of the Robin Rigg OWF and across the rest of the study area during the breeding season. Data are presented in Figure 3.12.

Great black-backed gulls in flight were recorded within the Robin Rigg OWF during operation. Compared to gannets, kittiwakes and herring gulls, a larger percentage of great black-backed gulls were recorded at turbine rotor height (35-125 m) outside the Robin Rigg OWF and surrounding buffers, with 21.8% of great black-backed gulls recorded in flight height band four in the remainder of the study area. A single great black-backed gull was recorded at turbine rotor height (35-125 m) within 500 m of the Robin Rigg OWF. Overall, the majority of great black-backed gulls within and outside the Robin Rigg OWF flew below turbine rotor height.

Evidence for a change in great black-backed gull flight behaviour in response to the Robin Rigg OWF was limited by small sample sizes. It appears from Figure 3.12 that fewer birds were flying at collision risk height within the OWF than outside the OWF. However, too few birds were recorded for this finding to be robust enough to conclude that meso-avoidance of birds in flight was occurring.

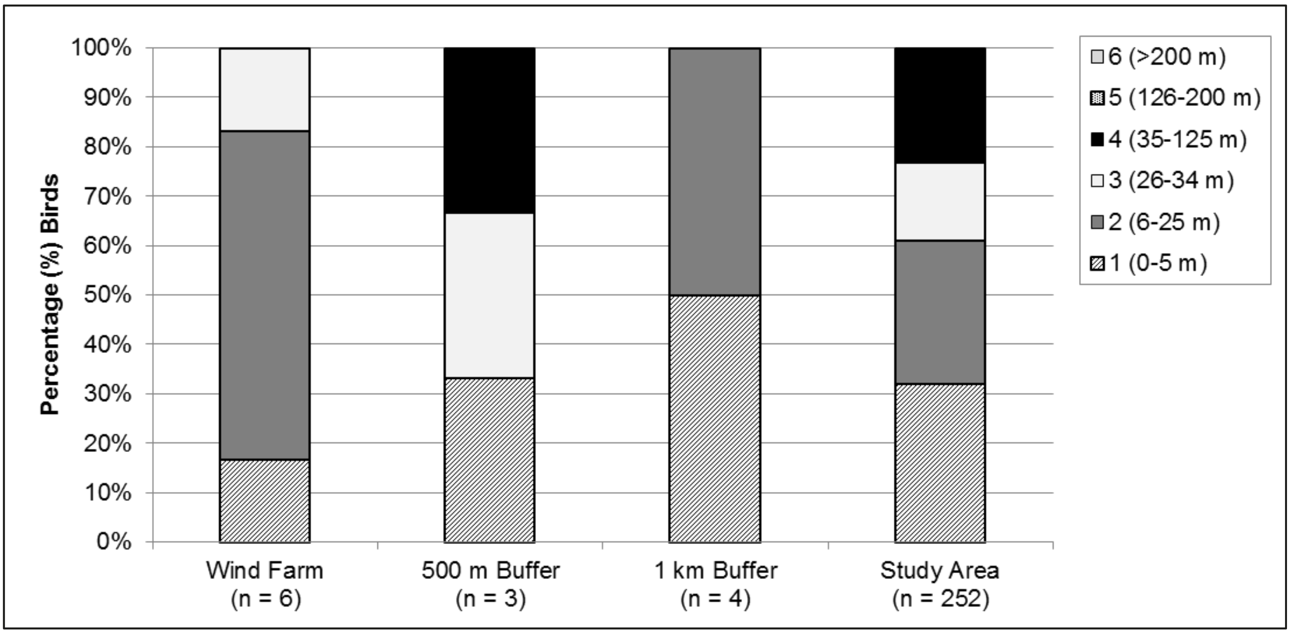


**Figure 3.12: Percentage of great black-backed gull recorded within six flight height bands across all five operational years during the breeding season.**

# 4. Discussion

In accordance with the consent from Scottish Ministers under Section 36 of the Electricity Act 1989 and the Robin Rigg MEMP (MEMP, 2004), this report consolidated the findings of the entire ornithological monitoring programme following completion of a full five years of operational survey, in order to determine any impact of construction and operation of the Robin Rigg OWF on 11 key avian receptors and to validate the predictions made in the ES.

Comprehensive analyses of pre-construction, construction and post-construction bird data have been undertaken every year during the first four years of operation and the results of these analyses have been presented to the RRMG in a number of post-construction monitoring reports (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). The large volume of data presented in these post-construction monitoring reports has validated the predictions outlined in the ES for each of the 11 key avian species outlined in the MEMP (MEMP, 2004). Few changes in abundance and distribution were directly attributable to the Robin Rigg OWF and no significant negative effects from construction and operation of the Robin Rigg OWF have been detected.

Quantifying and interpreting avoidance behaviour of seabirds both on the sea and in flight at offshore wind farms is crucial to reducing consenting risk yet little empirical data exists to do so (Hill & Arnold, 2012; Vanermen *et al*., 2014). Avoidance during OWF construction and operation may result in displacement from key habitat for seabirds, which may have fitness consequences in terms of individual survival and future productivity. Individual fitness may be affected by increased energy expenditure by moving to alternative foraging grounds or by reduced rates of energy acquisition if alternative foraging grounds are of lower quality (Masden *et al*., 2010b). Displacement can also cause intensified competition for resources within the remaining foraging habitat (e.g. Lewis *et al*., 2001; Burton *et al*., 2006). The sensitivity of seabird species to displacement may also vary depending upon the stage on their annual cycle. During the breeding season, seabirds become central-place foragers and are restricted to finding sufficient food within foraging range of their breeding colony (Burke & Montevecchi, 2009). As such, many seabirds are thought to be particularly vulnerable to displacement effects during the breeding season. Recent modelling of displacement effects on breeding guillemots off the east coast of Scotland concluded that displacement may result in changes to species time-energy budgets, with possible consequences for breeding performance and/or adult survival (Searle *et al*., 2014). During the non-breeding season, central-place foraging constraints are removed allowing seabirds to be more flexible in their habitat choice and less vulnerable to displacement from a given area (Stephens & Krebs, 1986). A key difficulty is identifying and defining the spatial scales at which avoidance behaviour of birds in flight occurs, which has consequences for collision risk (Cook *et al*., 2014). Birds may avoid an OWF in its entirety, (termed 'macro-avoidance'), or they may respond to individual turbines, avoiding passing close to them within a wind farm (termed 'meso-avoidance').

The extensive monitoring programme undertaken at the Robin Rigg OWF provides a valuable empirical dataset to examine avoidance behaviour in detail. Since the MEMP monitoring requirements have been met for birds, and the predictions in the ES largely validated, this report focussed on answering a number pertinent, species-specific questions regarding avoidance behaviour, adding to the evidence base and reducing uncertainty in consenting. This discussion focusses on answering these questions on the basis of the evidence presented in this report.

### Have razorbills, guillemots and kittiwakes been displaced from Robin Rigg OWF during operation?

Analyses presented in previous post-construction monitoring reports highlighted that the predicted number of razorbills and guillemots declined during the construction phase, both within the Robin Rigg OWF and across the rest of the survey area (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). However, razorbills and guillemots were present within the Robin Rigg OWF during all five years of operational monitoring. As such, there was evidence to suggest that razorbills and guillemots had not been displaced from the Robin Rigg OWF during operation.

This contrasts with findings at OWFs in the eastern North Sea. Leopold *et al*., (2013) found statistically significant displacement of both guillemots and razorbills at the Dutch Egmond aan Zee and Princess Amalia OWFs and there was also evidence for displacement of auks at the Horns Rev OWF off Denmark and the Bligh Bank OWF off Belgium (Petersen *et al*., 2006; Vanermen *et al*., 2014). Displacement at these OWFs was thought to be in response to specific stimuli, such as the presence of above-water rotating turbines in their usually open marine habitat, and/or the presence of maintenance vessels (Fox & Petersen, 2006). The results from the Robin Rigg

OWF highlight that there may be regional variation in species-specific displacement responses, which should be taken into account when assessing potential impacts of OWFs.

The number of kittiwakes on the sea decreased within the Robin Rigg OWF during the construction phase, although this reduction was not statistically significant (Walls *et al*., 2013a, 2013b). During operation, modelled kittiwake abundance across the study area was largest within and immediately east and west of the Robin Rigg OWF, providing clear evidence that kittiwakes sitting on the sea have not been displaced from the Robin Rigg OWF during operation. Evidence from other studies is inconsistent, with results from Alpha Ventus indicating that kittiwakes were displaced from the OWF (Mendel *et al*., 2014) whilst kittiwakes showed attraction at Egmond aan Zee (Leopold *et al*., 2011). Kittiwake results from Robin Rigg OWF add to this evidence base, and show that responses of broadly distributed species vary on a site-specific basis.

### Have razorbills and guillemots habituated to the presence of Robin Rigg OWF during operation?

Modelled guillemot and razorbill abundance increased within the Robin Rigg OWF during the first three years of operation, which may indicate a movement back into area following construction, as birds habituated to the presence of the OWF. However, between operational year one and operational years four and five, statistically significant decreases in guillemot abundance was predicted outside the Robin Rigg OWF, in shallow waters close to the northern and southern shores of the Solway Firth. These patterns appear to be independent of the Robin Rigg OWF with birds moving into deeper waters in the south-west of the study area during operational year five.

The Solway Firth is a shallow estuary and the subtidal area is dominated by mobile sediments brought into the area from the Irish Sea with sedimentary movements resulting in a change of depth and sediment type. The benthic infaunal communities, upon which guillemots and razorbills are ultimately reliant, are known to exhibit cyclic variations in distribution and abundance within these mobile sandbanks (Gray & Elliot 2009; Walls *et al.,* 2013a; Rutherford *et al*., in prep). It is therefore likely that changes in guillemot and razorbill abundance and distribution simply track this variation in benthic infauna resulting from sedimentary movement, rather than being an effect of the OWF (Maclean *et al*., 2013). This is supported by similar patterns in distribution being predicted for both razorbills and guillemots across the five operational years.

### Do kittiwakes and herring gulls show macro-avoidance of the Robin Rigg OWF during operation?

Across the study area, the largest numbers of kittiwakes in flight were predicted to occur within and immediately north-west of the Robin Rigg OWF, providing strong evidence that kittiwakes in flight did not exhibit macro-avoidance of the Robin Rigg OWF.

This is in contrast to findings at the Princess Amalia and Egmond aan Zee OWFs off the Netherlands, where a statistically significant negative effect was found for the Princess Amalia OWF, but not for Egmond aan Zee (Leopold *et al*., 2013). Leopold *et al*., (2013) hypothesise that this difference in avoidance may result from the higher density of turbines at the Princess Amalia OWF compared to Egmond aan Zee.

Whilst modelled abundance of herring gulls in flight was largest close to the Cumbrian coastline, flying herring gulls were not absent from the Robin Rigg OWF during operation. Therefore, there is evidence of no macro-avoidance of the Robin Rigg OWF by flying herring gulls.

Vanermen *et al*., (2014) reported a statistically significant increase of herring gulls within Bligh Bank wind farm following construction. This was against expectation since at-sea gull distribution has been shown to be strongly determined by the presence of fishing trawlers (e.g. Camphuysen & Leopold, 1994; Garthe, 1997). The main anticipated effect was therefore a decrease in gull density within the OWF resulting from the exclusion of trawlers. Gulls occurring inside Bligh Bank OWF were only observed resting on the water or on the turbine transition pieces, indicating that their presence was related to an increase in roosting opportunities. Analyses presented in previous post-construction monitoring reports for the Robin Rigg OWF have shown an increase of herring gulls on the sea surface within the OWF footprint during operation (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). It is therefore likely that herring gulls are exhibiting similar behaviour at OWFs both UK and Belgian waters. Indeed, a recent review by Cook *et al*., (2014) found no consistent evidence of macro-avoidance in gull species, and suggested a macro-avoidance rate of zero.

### Do gannets, kittiwakes, herring gulls and great black-backed gulls show meso-avoidance of the Robin Rigg OWF during operation?

Data indicated that all four species largely flew below turbine rotor height (35-125 m) throughout the entire study area, with *c*. 6% of all gannets, kittiwakes, herring gulls and great black-backed gulls in flight recorded in flight height band four. Within Robin Rigg OWF, only herring gulls were recorded at turbine height (35-125 m) but in small numbers; only five birds were recorded in flight height band four across five operational years. These data indicate that collision risk for these four species is negligible at the Robin Rigg OWF.

Flying gannets were not recorded within the Robin Rigg OWF during any of the five operational years. Gannets show evidence of a macro-avoidance response to OWFs in the eastern North Sea (e.g. Krijgsveld *et al*., 2011, Vanermen *et al*., 2013) and data from the Robin Rigg OWF appear to support this. However, sample sizes of flying gannets within the Robin Rigg OWF were relatively small during the pre-construction phase so the statistical significance of this potential macro-avoidance response cannot be tested.

Both kittiwakes and great black-backed gulls flew below the turbine rotor height (35-125 m) within the Robin Rigg OWF, with small numbers of both species recorded flying at higher altitudes outside the Robin Rigg OWF, which may indicate negative horizontal meso-avoidance. However, sample sizes were too small to be able to detect a quantifiable horizontal meso-response to the Robin Rigg OWF turbines. Studies of meso-avoidance at OWFs are limited. Data from Krijgsveld *et al*., (2011) appear to suggest moderate, negative horizontal meso-avoidance to turbines, with a further study finding no evidence of horizontal meso-avoidance (Skov *et al*., 2012). Cook *et al*., (2014) concluded in their review that all three of these studies had limitations and it is currently not possible to be confident about the magnitude of any horizontal meso-avoidance, particularly at a species-specific level.

# 5. Conclusions

- This report consolidates the findings of the entire MEMP ornithological monitoring programme following completion of a full five years of operational survey, in order to determine any impact of the Robin Rigg OWF on the Solway Firth bird community and validate the predictions made in the ES.
- Comprehensive analyses of pre-construction, construction and post-construction bird data have been undertaken every year during the first four years of operation at the Robin Rigg OWF (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014). No significant negative effects from construction and operation of the Robin Rigg OWF on the 11 key avian receptors outlined in the MEMP (MEMP, 2004) have been detected, validating the predictions outlined in the ES.
- The extensive monitoring programme undertaken at the Robin Rigg OWF (>10 years) provides a valuable empirical dataset to examine avoidance and displacement behaviour. Improving the evidence base and reducing uncertainty surrounding the assessment of potential impacts of OWFs on seabirds will enable more informed decisions to be made about future OWFs.
- Both guillemots and razorbills were present within the wind farm footprint during construction (Walls *et al.,* 2013a, 2013b and 2013c; Nelson *et al*., 2014) and during all five years of operational monitoring. There was therefore evidence to suggest that razorbills and guillemots were not displaced from the Robin Rigg OWF during operation.
- Modelled guillemot and razorbill abundance increased within the Robin Rigg OWF during the first three years of operation, indicating habituation to the Robin Rigg OWF following construction. However, between operational year one and operational years four and five, statistically significant decreases in guillemot abundance was predicted outside the Robin Rigg OWF, in shallow waters close to the northern and southern shores of the Solway Firth. Similar patterns were seen for razorbills. These patterns appear to be independent of the Robin Rigg OWF and it is likely that both species are tracking variation in prey distribution resulting from natural sedimentary movement.
- Across the study area, modelled kittiwakes abundance of birds in flight was largest within and immediately north-west of the Robin Rigg OWF, providing strong evidence that kittiwakes in flight do not exhibit macro-avoidance of the Robin Rigg OWF.
- Whilst modelled abundance of herring gulls in flight was largest close to the Cumbrian coastline, flying herring gulls were not absent from the Robin Rigg OWF during operation. Therefore, there is no evidence of macro-avoidance of the Robin Rigg OWF by flying herring gulls.
- Data indicated that gannets, kittiwakes, herring gulls and great black-backed gulls largely flew below turbine rotor height (35-125 m) throughout the entire study area, with *c*. 6% of birds in flight recorded in flight height band four; the collision risk zone. Therefore, collision risk for these four species is negligible at the Robin Rigg OWF.
- Flying gannets were not recorded within the Robin Rigg OWF during any of the five operational years. Whilst this may indicate macro-avoidance of the Robin Rigg OWF by flying gannets, numbers were too low across all three development phases to test this statistically. As such, it is likely that any effects of the wind farm would be on very few individuals compared to the regional population, and therefore negligible.
- Both kittiwakes and great black-backed gulls flew below the turbine rotor height (35-125 m) within the Robin Rigg OWF, with small numbers of both species recorded flying at higher altitudes outside the Robin Rigg OWF. This may indicate some level of meso-avoidance. However, sample sizes were too small to be able to test this difference statistically.
- Overall, all key avian receptors outlined in the MEMP (MEMP, 2004) were present within the OWF footprint during operation (except scaup which was absent across all three development phases), showing that these species did not avoid the operational Robin Rigg OWF entirely.

**This report consolidates the findings of the entire MEMP ornithological monitoring programme following completion of a full five years of operational survey, and provides further evidence of no significant negative effects from construction and operation of the Robin Rigg OWF on the Solway Firth bird community. As such, the MEMP requirements for ornithology have been met and it is recommended that further ornithological monitoring at the Robin Rigg OWF is not required.**

# 6. Recommendations

Monitoring requirements for the Robin Rigg OWF have now been met for all ecological receptors outlined in the MEMP (MEMP, 2004) including subtidal benthic habitats, intertidal habitats, non-migratory fish, electro-sensitive fish, marine mammals and now birds. Furthermore, the predictions in the ES have been validated with no significant negative impacts predicted for any of the 11 key avian receptors. As such, it is recommended that further ornithological monitoring at the Robin Rigg OWF is not required.

The extensive monitoring programme undertaken at the Robin Rigg OWF provides a valuable empirical dataset which can be used to improve the evidence base and reduce uncertainty surrounding impact assessment for OWFs, benefitting both the renewable industry and SNCBs and regulators. Publishing the findings of the Robin Rigg OWF monitoring programme in international, peer-reviewed journals is key to this and several manuscripts are currently in preparation.

The sensitivity of seabirds to displacement may vary in accordance with specific stages of their lifecycle, e.g. in relation to breeding, post-breeding and non-breeding seasons. As such, further comparison of avoidance behaviour between seasons would provide a valuable contribution to the evidence base since few studies have examined the effects of seasonality on OWF avoidance to date (Cook *et al*., 2014).

The introduction of turbine foundations as hard substrate in a soft-bottom marine ecosystem has been shown to result in a number of environmental changes, and several studies, including drop-down video surveys at the Robin Rigg OWF, have demonstrated the fast development of hard-bottom benthic communities and attraction of associated fish, in a process known as the ‘reef effect’ (Leonhard & Pedersen, 2006; Reubens *et al*., 2013; Natural Power, 2014). Whether such effects within the Robin Rigg OWF will result in enhanced feeding possibilities and subsequent attraction of seabirds is unknown and could be explored through focussed survey work in future years.

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# Appendices

## A. Raw observations and areas ($km^2$) surveyed

The following tables present the raw number of observations and area surveyed ($km^2$) within the Robin Rigg OWF and across the remainder of the study area across the three development phases (Tables A.1 and A.2), and during each of the five operational years (Tables A.3 and A.4). These were used to calculate the densities presented in Sections 3.1.1 and 3.1.2 of the report.

**Table A.1: Raw observations of birds in flight and areas surveyed across the three development phases.**

| | | Within Robin Rigg OWF | | Within remainder of survey area | |
|---|---|---|---|---|---|
| Species | Development Phase | Individuals | Area Surveyed ($km^2$) | Individuals | Area Surveyed ($km^2$) |
| Scaup | Pre-construction | 0 | 84.96 | 4 | 1,804.32 |
| | Construction | 0 | 156.24 | 0 | 4,163.04 |
| | Operation | 0 | 169.92 | 0 | 4,029.48 |
| Common scoter | Pre-construction | 0 | 84.96 | 3,251 | 1,804.32 |
| | Construction | 9 | 156.24 | 8,701 | 4,163.04 |
| | Operation | 0 | 169.92 | 3,135 | 4,029.48 |
| Red-throated diver | Pre-construction | 9 | 84.96 | 42 | 1,804.32 |
| | Construction | 1 | 156.24 | 153 | 4,163.04 |
| | Operation | 2 | 169.92 | 214 | 4,029.48 |
| Manx shearwater | Pre-construction | 0 | 84.96 | 247 | 1,804.32 |
| | Construction | 8 | 156.24 | 311 | 4,163.04 |
| | Operation | 1 | 169.92 | 239 | 4,029.48 |
| Cormorant | Pre-construction | 2 | 84.96 | 97 | 1,804.32 |
| | Construction | 62 | 156.24 | 1,059 | 4,163.04 |
| | Operation | 85 | 169.92 | 1,057 | 4,029.48 |
| Gannet | Pre-construction | 10 | 84.96 | 173 | 1,804.32 |
| | Construction | 5 | 156.24 | 211 | 4,163.04 |
| | Operation | 0 | 169.92 | 236 | 4,029.48 |
| Razorbill | Pre-construction | 26 | 84.96 | 554 | 1,804.32 |
| | Construction | 5 | 156.24 | 205 | 4,163.04 |
| | Operation | 5 | 169.92 | 297 | 4,029.48 |
| Guillemot | Pre-construction | 21 | 84.96 | 210 | 1,804.32 |
| | Construction | 15 | 156.24 | 413 | 4,163.04 |
| | Operation | 14 | 169.92 | 502 | 4,029.48 |
| Kittiwake | Pre-construction | 21 | 84.96 | 280 | 1,804.32 |
| | Construction | 34 | 156.24 | 388 | 4,163.04 |
| | Operation | 38 | 169.92 | 442 | 4,029.48 |
| Herring gull | Pre-construction | 11 | 84.96 | 396 | 1,804.32 |
| | Construction | 27 | 156.24 | 804 | 4,163.04 |
| | Operation | 33 | 169.92 | 753 | 4,029.48 |
| Great black-backed gull | Pre-construction | 1 | 84.96 | 61 | 1,804.32 |
| | Construction | 5 | 156.24 | 142 | 4,163.04 |
| | Operation | 5 | 169.92 | 214 | 4,029.48 |

Table A.2: Raw observations of birds on the sea and areas surveyed across the three development phases.

| | | Within Robin Rigg OWF | | Within remainder of survey area | |
|---|---|---|---|---|---|
| Species | Development Phase | Individuals | Area Surveyed (km$^2$) | Individuals | Area Surveyed (km$^2$) |
| Scaup | Pre-construction | 0 | 84.96 | 0 | 1,804.32 |
| | Construction | 0 | 156.24 | 350 | 4,163.04 |
| | Operation | 0 | 245.52 | 1,401 | 5,863.68 |
| Common scoter | Pre-construction | 3 | 84.96 | 23,732 | 1,804.32 |
| | Construction | 13 | 156.24 | 37,529 | 4,163.04 |
| | Operation | 322 | 245.52 | 58,572 | 5,863.68 |
| Red-throated diver | Pre-construction | 3 | 84.96 | 124 | 1,804.32 |
| | Construction | 5 | 156.24 | 245 | 4,163.04 |
| | Operation | 1 | 245.52 | 460 | 5,863.68 |
| Manx shearwater | Pre-construction | 0 | 84.96 | 97 | 1,804.32 |
| | Construction | 1 | 156.24 | 672 | 4,163.04 |
| | Operation | 4 | 245.52 | 849 | 5,863.68 |
| Cormorant | Pre-construction | 5 | 84.96 | 119 | 1,804.32 |
| | Construction | 71 | 156.24 | 465 | 4,163.04 |
| | Operation | 655 | 245.52 | 2,662 | 5,863.68 |
| Gannet | Pre-construction | 4 | 84.96 | 99 | 1,804.32 |
| | Construction | 0 | 156.24 | 138 | 4,163.04 |
| | Operation | 3 | 245.52 | 174 | 5,863.68 |
| Razorbill | Pre-construction | 165 | 84.96 | 1,037 | 1,804.32 |
| | Construction | 77 | 156.24 | 2,321 | 4,163.04 |
| | Operation | 88 | 245.52 | 3,348 | 5,863.68 |
| Guillemot | Pre-construction | 186 | 84.96 | 2,779 | 1,804.32 |
| | Construction | 132 | 156.24 | 4,497 | 4,163.04 |
| | Operation | 381 | 245.52 | 7,191 | 5,863.68 |
| Kittiwake | Pre-construction | 21 | 84.96 | 343 | 1,804.32 |
| | Construction | 30 | 156.24 | 567 | 4,163.04 |
| | Operation | 308 | 245.52 | 991 | 5,863.68 |
| Herring gull | Pre-construction | 21 | 84.96 | 297 | 1,804.32 |
| | Construction | 9 | 156.24 | 306 | 4,163.04 |
| | Operation | 317 | 245.52 | 997 | 5,863.68 |
| Great black-backed gull | Pre-construction | 8 | 84.96 | 44 | 1,804.32 |
| | Construction | 6 | 156.24 | 173 | 4,163.04 |
| | Operation | 15 | 245.52 | 563 | 5,863.68 |

**Table A.3: Raw observations of birds in flight and areas surveyed across the five operational years.**

| | | Within Robin Rigg OWF | | Within remainder of survey area | |
|---|---|---|---|---|---|
| Species | Operational Year | Individuals | Area Surveyed ($km^2$) | Individuals | Area Surveyed ($km^2$) |
| Scaup | 1 | 0 | 46.44 | 0 | 1,030.68 |
| | 2 | 0 | 47.88 | 0 | 1,164.60 |
| | 3 | 0 | 25.74 | 0 | 615.42 |
| | 4 | 0 | 24.84 | 0 | 610.20 |
| | 5 | 0 | 25.02 | 0 | 608.58 |
| Common scoter | 1 | 0 | 46.44 | 798 | 1,030.68 |
| | 2 | 0 | 47.88 | 1,028 | 1,164.60 |
| | 3 | 0 | 25.74 | 651 | 615.42 |
| | 4 | 0 | 24.84 | 402 | 610.20 |
| | 5 | 0 | 25.02 | 256 | 608.58 |
| Red-throated diver | 1 | 0 | 46.44 | 82 | 1,030.68 |
| | 2 | 2 | 47.88 | 45 | 1,164.60 |
| | 3 | 0 | 25.74 | 40 | 615.42 |
| | 4 | 0 | 24.84 | 24 | 610.20 |
| | 5 | 0 | 25.02 | 23 | 608.58 |
| Manx shearwater | 1 | 0 | 46.44 | 66 | 1,030.68 |
| | 2 | 1 | 47.88 | 54 | 1,164.60 |
| | 3 | 0 | 25.74 | 26 | 615.42 |
| | 4 | 0 | 24.84 | 81 | 610.20 |
| | 5 | 0 | 25.02 | 12 | 608.58 |
| Cormorant | 1 | 4 | 46.44 | 250 | 1,030.68 |
| | 2 | 8 | 47.88 | 211 | 1,164.60 |
| | 3 | 1 | 25.74 | 143 | 615.42 |
| | 4 | 24 | 24.84 | 331 | 610.20 |
| | 5 | 48 | 25.02 | 122 | 608.58 |
| Gannet | 1 | 0 | 46.44 | 54 | 1,030.68 |
| | 2 | 0 | 47.88 | 70 | 1,164.60 |
| | 3 | 0 | 25.74 | 35 | 615.42 |
| | 4 | 0 | 24.84 | 52 | 610.20 |
| | 5 | 0 | 25.02 | 25 | 608.58 |
| Razorbill | 1 | 5 | 46.44 | 15 | 1,030.68 |
| | 2 | 0 | 47.88 | 232 | 1,164.60 |
| | 3 | 0 | 25.74 | 19 | 615.42 |
| | 4 | 0 | 24.84 | 15 | 610.20 |
| | 5 | 0 | 25.02 | 16 | 608.58 |
| Guillemot | 1 | 3 | 46.44 | 200 | 1,030.68 |
| | 2 | 0 | 47.88 | 84 | 1,164.60 |
| | 3 | 2 | 25.74 | 122 | 615.42 |
| | 4 | 3 | 24.84 | 44 | 610.20 |
| | 5 | 6 | 25.02 | 52 | 608.58 |
| Kittiwake | 1 | 3 | 46.44 | 113 | 1,030.68 |
| | 2 | 23 | 47.88 | 154 | 1,164.60 |
| | 3 | 5 | 25.74 | 73 | 615.42 |
| | 4 | 6 | 24.84 | 56 | 610.20 |
| | 5 | 1 | 25.02 | 46 | 608.58 |
| Herring gull | 1 | 4 | 46.44 | 197 | 1,030.68 |

| Species | Operational Year | Within Robin Rigg OWF | | Within remainder of survey area | |
|---|---|---|---|---|---|
| | | Individuals | Area Surveyed (km$^2$) | Individuals | Area Surveyed (km$^2$) |
| | 2 | 11 | 47.88 | 96 | 1,164.60 |
| | 3 | 7 | 25.74 | 322 | 615.42 |
| | 4 | 7 | 24.84 | 73 | 610.20 |
| | 5 | 4 | 25.02 | 65 | 608.58 |
| Great black-backed gull | 1 | 0 | 46.44 | 35 | 1,030.68 |
| | 2 | 5 | 47.88 | 49 | 1,164.60 |
| | 3 | 0 | 25.74 | 51 | 615.42 |
| | 4 | 0 | 24.84 | 36 | 610.20 |
| | 5 | 0 | 25.02 | 43 | 608.58 |

Table A.4: Raw observations of birds on the sea and areas surveyed across the five operational years.

| | | Within Robin Rigg OWF | | Within remainder of survey area | |
|---|---|---|---|---|---|
| Species | Operational Year | Individuals | Area Surveyed (km$^2$) | Individuals | Area Surveyed (km$^2$) |
| Scaup | 1 | 0 | 46.44 | 1,301 | 1,030.68 |
| | 2 | 0 | 47.88 | 0 | 1,164.60 |
| | 3 | 0 | 51.48 | 100 | 1,230.84 |
| | 4 | 0 | 49.68 | 0 | 1,220.40 |
| | 5 | 0 | 50.04 | 0 | 1,217.16 |
| Common scoter | 1 | 10 | 46.44 | 8,933 | 1,030.68 |
| | 2 | 12 | 47.88 | 11,400 | 1,164.60 |
| | 3 | 0 | 51.48 | 13,019 | 1,230.84 |
| | 4 | 300 | 49.68 | 16,514 | 1,220.40 |
| | 5 | 0 | 50.04 | 8,706 | 1,217.16 |
| Red-throated diver | 1 | 0 | 46.44 | 122 | 1,030.68 |
| | 2 | 1 | 47.88 | 131 | 1,164.60 |
| | 3 | 0 | 51.48 | 123 | 1,230.84 |
| | 4 | 0 | 49.68 | 30 | 1,220.40 |
| | 5 | 0 | 50.04 | 54 | 1,217.16 |
| Manx shearwater | 1 | 0 | 46.44 | 57 | 1,030.68 |
| | 2 | 2 | 47.88 | 206 | 1,164.60 |
| | 3 | 0 | 51.48 | 75 | 1,230.84 |
| | 4 | 2 | 49.68 | 375 | 1,220.40 |
| | 5 | 0 | 50.04 | 136 | 1,217.16 |
| Cormorant | 1 | 18 | 46.44 | 249 | 1,030.68 |
| | 2 | 28 | 47.88 | 206 | 1,164.60 |
| | 3 | 252 | 51.48 | 319 | 1,230.84 |
| | 4 | 200 | 49.68 | 1,757 | 1,220.40 |
| | 5 | 157 | 50.04 | 131 | 1,217.16 |
| Gannet | 1 | 0 | 46.44 | 54 | 1,030.68 |
| | 2 | 0 | 47.88 | 70 | 1,164.60 |
| | 3 | 0 | 51.48 | 35 | 1,230.84 |
| | 4 | 0 | 49.68 | 52 | 1,220.40 |
| | 5 | 0 | 50.04 | 25 | 1,217.16 |
| Razorbill | 1 | 33 | 46.44 | 465 | 1,030.68 |
| | 2 | 19 | 47.88 | 828 | 1,164.60 |
| | 3 | 12 | 51.48 | 1,136 | 1,230.84 |
| | 4 | 13 | 49.68 | 571 | 1,220.40 |
| | 5 | 11 | 50.04 | 348 | 1,217.16 |
| Guillemot | 1 | 48 | 46.44 | 1,340 | 1,030.68 |
| | 2 | 92 | 47.88 | 1,672 | 1,164.60 |
| | 3 | 71 | 51.48 | 1,720 | 1,230.84 |
| | 4 | 68 | 49.68 | 1,281 | 1,220.40 |
| | 5 | 102 | 50.04 | 1,178 | 1,217.16 |
| Kittiwake | 1 | 5 | 46.44 | 84 | 1,030.68 |
| | 2 | 15 | 47.88 | 299 | 1,164.60 |
| | 3 | 133 | 51.48 | 207 | 1,230.84 |
| | 4 | 153 | 49.68 | 176 | 1,220.40 |
| | 5 | 2 | 50.04 | 225 | 1,217.16 |
| Herring gull | 1 | 12 | 46.44 | 80 | 1,030.68 |

| Species | Operational Year | Within Robin Rigg OWF | | Within remainder of survey area | |
|---|---|---|---|---|---|
| | | Individuals | Area Surveyed (km$^2$) | Individuals | Area Surveyed (km$^2$) |
| | 2 | 64 | 47.88 | 93 | 1,164.60 |
| | 3 | 153 | 51.48 | 515 | 1,230.84 |
| | 4 | 69 | 49.68 | 134 | 1,220.40 |
| | 5 | 19 | 50.04 | 175 | 1,217.16 |
| Great black-backed gull | 1 | 0 | 46.44 | 80 | 1,030.68 |
| | 2 | 1 | 47.88 | 97 | 1,164.60 |
| | 3 | 7 | 51.48 | 162 | 1,230.84 |
| | 4 | 7 | 49.68 | 117 | 1,220.40 |
| | 5 | 0 | 50.04 | 107 | 1,217.16 |

# B. Model parameter estimates

The following tables show parameter estimates for explanatory variables included in the model predictions shown in Sections 3.3 to 3.6 of this report.

Table B.1: Razorbill on sea model parameter estimates. Statistically significant parameters shown in bold.

| Model Parameter | Mean | Standard Error | Credible Intervals 2.5% | Credible Intervals 97.5% |
|---|---|---|---|---|
| Poisson intercept | -0.640 | 1.286 | -2.805 | 2.236 |
| Operation Year 2 | -0.472 | 1.400 | -3.196 | 2.248 |
| Operation Year 3 | -0.603 | 1.740 | -4.175 | 2.753 |
| Operation Year 4 | -0.970 | 1.640 | -4.203 | 2.119 |
| Operation Year 5 | -1.141 | 1.601 | -5.120 | 1.579 |
| **Binary intercept** | **1.430** | **0.077** | **1.283** | **1.578** |
| **Survey random effect** | **1.757** | **0.360** | **1.175** | **2.612** |
| **Transect random effect** | **1.253** | **0.136** | **0.997** | **1.536** |

Table B.2: Guillemot on sea model parameter estimates. Statistically significant parameters shown in bold.

| Model Parameter | Mean | Standard Error | Credible Intervals 2.5% | Credible Intervals 97.5% |
|---|---|---|---|---|
| Poisson intercept | -0.373 | 0.553 | -1.344 | 0.729 |
| Operation Year 2 | 0.477 | 0.716 | -0.766 | 1.827 |
| Operation Year 3 | 0.477 | 0.920 | -1.333 | 2.203 |
| Operation Year 4 | -0.551 | 0.900 | -2.098 | 1.329 |
| Operation Year 5 | -0.213 | 0.834 | -1.757 | 1.378 |
| **Binary intercept** | **-0.127** | **0.059** | **-0.245** | **-0.014** |
| **Survey random effect** | **0.608** | **0.146** | **0.383** | **0.943** |
| **Transect random effect** | **0.660** | **0.054** | **0.556** | **0.769** |

Table B.3: Kittiwake on sea model parameter estimates. Statistically significant parameters shown in bold.

| Model Parameter | Mean | Standard Error | Credible Intervals 2.5% | Credible Intervals 97.5% |
|---|---|---|---|---|
| **Poisson intercept** | **-2.458** | **0.699** | **-3.656** | **-0.728** |
| Operation Year 2 | 0.788 | 0.777 | -0.913 | 2.174 |
| Operation Year 3 | -0.137 | 0.715 | -1.616 | 1.258 |
| Operation Year 4 | 0.943 | 0.791 | -0.637 | 2.553 |
| Operation Year 5 | 0.857 | 0.710 | -0.534 | 2.249 |
| **Binary intercept** | **2.057** | **0.082** | **1.897** | **2.220** |
| **Survey random effect** | **1.165** | **0.289** | **0.679** | **1.792** |
| **Transect random effect** | **1.704** | **0.144** | **1.432** | **2.003** |

Table B.4: Kittiwake in flight model parameter estimates. Statistically significant parameters shown in bold.

| | | | Credible Intervals | |
|---|---|---|---|---|
| Model Parameter | Mean | Standard Error | 2.5% | 97.5% |
| Poisson intercept | 0.024 | 0.703 | -1.367 | 1.320 |
| Operation Year 2 | -0.494 | 0.687 | -1.856 | 0.918 |
| Operation Year 3 | -0.039 | 0.689 | -1.395 | 1.369 |
| Operation Year 4 | -0.127 | 0.679 | -1.467 | 1.215 |
| Operation Year 5 | -0.845 | 0.671 | -2.213 | 0.461 |
| **Binary intercept** | **1.530** | **0.134** | **1.269** | **1.786** |
| **Survey random effect** | **1.038** | **0.230** | **0.677** | **1.558** |
| **Transect random effect** | **0.946** | **0.134** | **0.684** | **1.204** |

Table B.5: Herring gull in flight model parameter estimates. Statistically significant parameters shown in bold.

| | | | Credible Intervals | |
|---|---|---|---|---|
| Model Parameter | Mean | Standard Error | 2.5% | 97.5% |
| Poisson intercept | -1.602 | 0.719 | -2.856 | 0.048 |
| Operation Year 2 | -0.450 | 0.424 | -1.289 | 0.377 |
| Operation Year 3 | 0.403 | 0.438 | -0.482 | 1.286 |
| Operation Year 4 | -0.308 | 0.436 | -1.156 | 0.538 |
| Operation Year 5 | -0.348 | 0.442 | -1.189 | 0.556 |
| **Binary intercept** | **1.768** | **0.104** | **1.565** | **1.971** |
| **Survey random effect** | **0.860** | **0.137** | **0.614** | **1.158** |
| **Transect random effect** | **1.002** | **0.094** | **0.821** | **1.195** |

# What We Do

Natural Power is a leading independent renewable energy consultancy and products provider. We offer proactive and integrated consultancy, management & due diligence services, backed by an innovative product range, across the onshore wind, offshore wind, wave, tidal, solar and bioenergy sectors, whilst maintaining a strong outlook on other new and emerging renewable energy sectors. Established in the mid-1990s, Natural Power has been at the heart of many ground-breaking projects, products and portfolios for close to two decades, assisting project developers, investors, manufacturers, finance houses and other consulting companies.

With its iconic Scottish headquarters, The Green House, Natural Power has expanded internationally employing 300 renewable energy experts across Europe and the Americas and operating globally. Providing Planning & Development, Ecology & Hydrology, Technical, Construction & Geotechnical, Asset Management and Due Diligence services, Natural Power is uniquely a full lifecycle consultancy – from feasibility to finance to repowering, and every project phase in between. We are a truly trailblazing consulting organisation; Natural Power has consistently invested in product development and technical research in order to progress certain key areas within the industry such as the operational management of wind farms, the design and assessment of wind farms in complex flow and the use of remote sensing for wind measurement. From award-winning consultancy and management services, through a string of technology world-firsts, Natural Power has a successful track record and the breadth of services and deep-rooted experience that provides a wealth of added value for our diverse client base.

**Natural Power – delivering your local renewable energy projects, globally.**

# Our Global Expertise

Natural Power delivers services and operates assets globally for our clients, with twelve offices across Europe and North America and agencies active in South America and AsiaPac.


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