E.ON Climate & Renewables

Analysis of Marine Environmental Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 1)

Technical Report

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EXECUTIVE SUMMARY

Robin Rigg Offshore Wind Farm is E.ON Climate and Renewables' (E.ON) third offshore wind farm and the first commercial offshore wind farm in Scottish waters. The site is comprised of 60 three megawatt Vestas turbines and an offshore sub-station and is situated within the central part of the Solway Firth, immediately to the north of the English/Scottish boundary which roughly bisects the firth. The centre of the turbine layout lies some 11 km from the Dumfries and Galloway coastline within Scotland and 13.5 km from the Cumbrian coastline in England.

Prior to the construction of the wind farm, a Marine Environment Monitoring Programme (MEMP) was developed in conjunction with the Robin Rigg Management Group (RRMG), covering the pre-, during and post construction stages of development in accordance with consent from Scottish Ministers under Section 36 of the Electricity Act 1989.

The remit of the MEMP was to record any changes to the physical and ecological environment that may be caused by the construction and operation of the wind farm, complying with condition 6.4 of Section Consent 36 conditions. The programme concentrated on areas where there was uncertainty on the effects of the offshore wind farm and where those effects may cause potential impacts on the marine ecology. This included benthos, fish, birds and marine mammals.

The purpose of this report is to assess data collected as part of the MEMP prior to the construction of the Robin Rigg Offshore Wind Farm (defined as baseline/pre-construction, 2001 - 2007) with that collected during its construction (December 2007 – February 2010) and during operational year one (March 2010 – February 2011). These data will form a basis from which to assess any impacts from the operational phase of Robin Rigg for E.ON, the RRMG and Scottish Government (Marine Scotland). A summary of reports completed to date can be found in Table 1 below. Reports examining operational years two, three, four and five will follow.

Table 1: Summary of reports completed examining ecological data collected as part of the MEMP for the Robin Rigg Offshore Wind Farm.

Report Number	Report Title	Version
035_R_NPC_EON_1	Analysis of MEMP ecological data: pre-construction & construction phases. Technical report.	Final
035_R_NPC_EON_2	Analysis of MEMP ecological data: pre-construction & construction phases. Non-technical report.	Final
1022189	Analysis of Marine Environmental Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 1) –Excutive Summary and Non-technical report.	Final
1022038	Analysis of Marine Environmental Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 1) – Technical Report	Final

Benthic ecology

Predictions made in the environmental statement relating to the potential impacts of the construction and operation of the Robin Rigg Offshore Wind Farm were supported by the data collected. There is no evidence, to date, that the construction and operation of the Robin Rigg Offshore Wind Farm has had any significant or permanent impact upon the benthic fauna in the immediate or surrounding area.

The predominant biotope in the area, *Nephtys cirrosa and Bathyporeia spp. in infralittoral sand* (SS.SSa.IFiSa.NcirBat), is characteristic of naturally high energy environments, and has been the predominant biotope since the baseline survey. Over the construction years there appears to have been spatial shift in biotopes, with *Abra prismatica, Bathyporeia elegans and polychaetes in circalittoral fine sand* (SS.SSa.CFiSa.ApriBatPo) biotope found however returning to SS.SSa.IFiSa.NcirBat during the operational year.

Non-migratory fish

Predictions made in the environmental statement relating to the potential impacts of the construction and operation of the Robin Rigg Offshore Wind Farm were supported by the data collected. There is no evidence, to date, that the construction and operation of the Robin Rigg Offshore Wind Farm has had any significant or permanent impact upon the fish and epibenthic communities in the immediate or surrounding area.

Fish and, to an extent, epibenthic abundances, did vary across the construction periods, with the largest abundance caught during the baseline survey. This, however, is thought to be due to the shifting of channels so that the trawls are no longer in the channel but on top of the sand bank where there is naturally less fish and epibenthos. The fish and epibenthic community assemblage, however, did not show any considerable change throughout the construction periods compared to the baseline.

Electro-sensitive fish

The majority of electro-sensitive fish (thornback rays and dogfish) were not found in the vicinity of the cable route, but on the Scottish side of the Solway Firth to the north of the wind farm site. As so few elasmobranch species were found around the cable route, it is possible to conclude that the area is not of critical importance to the thornback ray and dogfish populations in the Solway Firth. Any potential effects as a result of EMF from the electrified cable are likely to be of minimal significance to their populations as a whole.

Birds

As predicted by the environmental statement, little indication of a significant effect on the abundance of common scoter and red-throated diver was found between the three phases of the development. An increase in cormorant and large gull species abundance was observed in operational year one.

Marine mammals

As predicted by the environmental statement, no evidence in a decline in harbour porpoise or grey seal abundance was found between the three development phases.

Possible avoidance of wind farm area during the construction period by harbour porpoise was suggested by the density maps. This will be investigated further at the next stage of the analysis.

1. INTRODUCTION

Robin Rigg Offshore Wind Farm is E.ON Climate and Renewables' (E.ON) third offshore wind farm and the first commercial offshore wind farm in Scottish waters. The site is comprised of 60 three megawatt Vestas turbines and an offshore sub-station. Turbines began full commercial operation/generation 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 of the wind farm.

This report represents the analysis performed on data collected before construction, during construction and during the first year of operation (March 2010-March 2011).

These data will form a basis from which to assess any impacts from the operational phase of Robin Rigg for E.ON, by the Robin Rigg Management Group (RRMG) and Scottish Government.

1.1. Site description

The Robin Rigg Offshore Wind Farm (Figure 1.1, 1.2 and 1.3) is situated within the central part of the Solway Firth, immediately to the north of the English/Scottish boundary which roughly bisects the firth. The centre of the turbine layout lies some 11 km from the Dumfries and Galloway coastline within Scotland and 13.5 km from the Cumbrian coastline in England. The nearest towns are Dalbeattie in Scotland, 21 km to the north-northwest and Maryport in England, 14 km to the southeast.

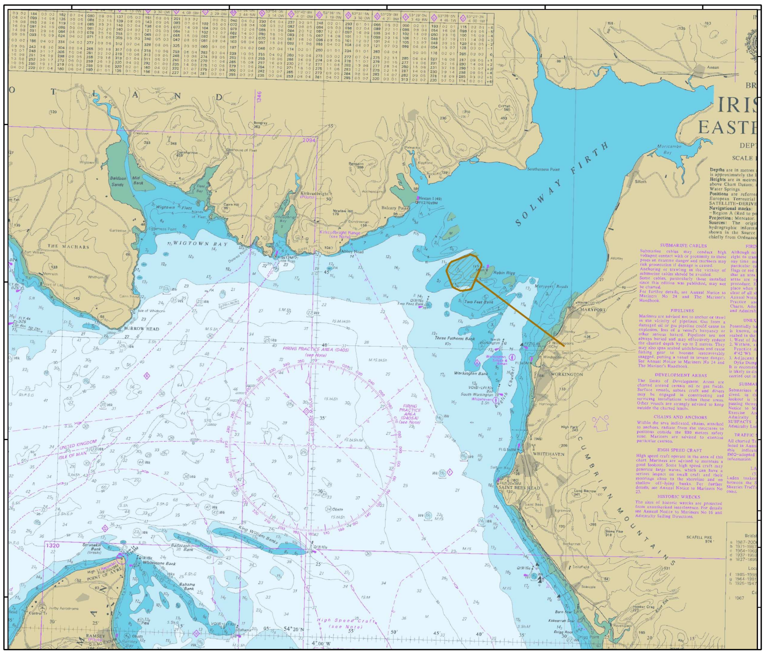

Figure 1.1: Map of Solway Firth showing the location of the Robin Rigg Offshore Wind Farm.

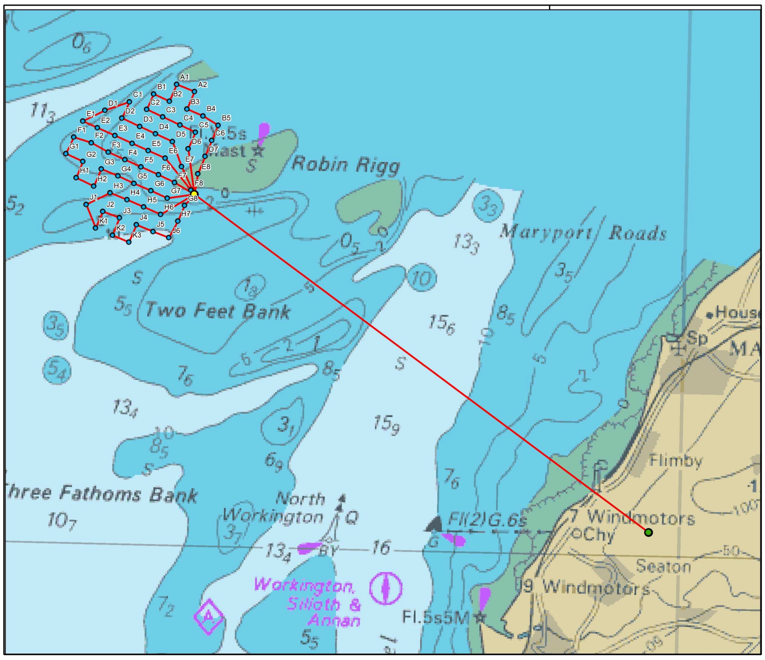

Figure 1.2: Schematic of Robin Rigg Offshore Wind Farm showing turbine locations (blue dots), inter-array cabling and grid connection to shore (red lines).

Figure 1.3: Photograph of Robin Rigg Offshore Wind Farm during the construction phase.

The foundations are a monopole design, with a transition piece which provides boat fendering, access ladders and cable conduits. The monopole and transition piece are connected with a grouted joint.

The installation of turbines foundations occurred between December 2007 and February 2009, with a gap in construction between February and August 2008 (see Table 1.1). The number of foundations installed each month can be found in Figure 1.4.

*Table 1.1: Schematic timetable of construction activities for the Robin Rigg Offshore Wind Farm. Pink = foundation installation; blue = turbine construction; purple = turbine commissioning; green = installation of wind farm cables; * = installation of export cable.*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009												
					*				*			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010												

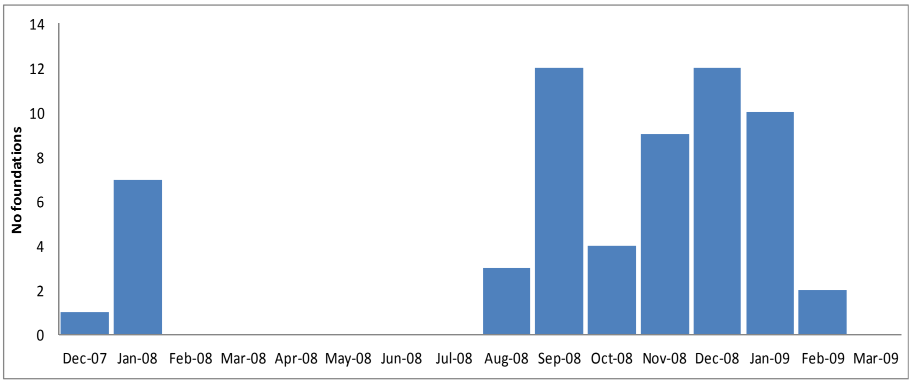

Figure 1.4: Number of foundations piled each month between December 2007 and March 2009.

Installation of the turbines commenced in November 2009 (see Table 1.1). These activities involved the use of large jack-up barges either towed or self propelled. The turbine towers are 80 m high and each of the three blades, 44 m long. Turbines are positioned approximately 500 m apart.

Cables were installed from July 2008 into early 2010 (see Table 1.1) and two different methods were used; a “lay and bury” technique and also a “surface lay and later bury” technique. The two export cables were laid in May and September 2009. The last turbine was installed during August 2009 and the first turbine operated briefly in August 2009 with main commissioning commencing in September 2009 and completed in April 2010 (see Figure 1.5). A variety of ports were used during construction including Belfast, Mostyn, Newcastle, Workington, Whitehaven and Barrow.

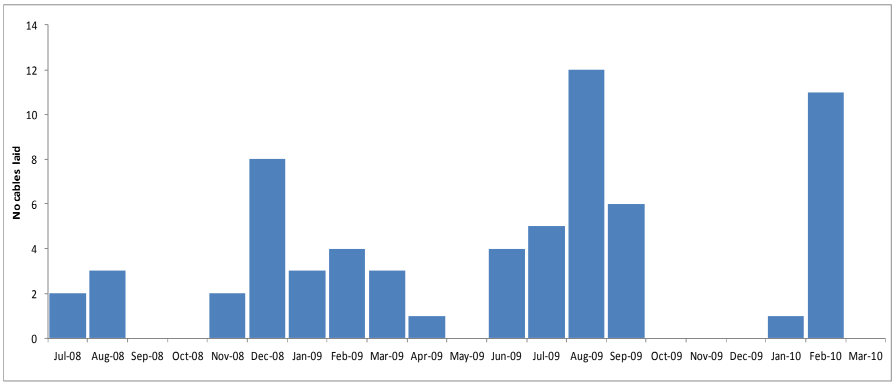

Figure 1.5: Number of cables installed each month between July 2008 and February 2010.

The turbines are connected in 4 loops, each containing 15 turbines, by 33 kV submarine cables with an embedded fibre optic link (Figure 1.2). There are 64 inter-array power cables installed between the wind turbine generators of the wind farm. The 8 ends of these array cable loops are received by the 2 offshore substations. The array cables have 2 different cross-sections, varying with location; 150 mm² conductors are used close to the end points and 300 mm² conductors are used in the middle of the loop and close to the offshore sub-station.

The wind farm is connected via an offshore sub-station using two export cables which operate at 132 kV. These cables come ashore near Seaton, Cumbria and continue for approximately 2 km inland to an onshore substation. There are 2 submarine high voltage AC power cables connecting the offshore substation to the onshore network. These 132 kV XLPe insulated 300 mm² Cu submarine composite export cables contain 3-phase power cable and one fibre optic element with double wire armour and single wire armour throughout the remainder of the route.

Turbine commissioning began in August 2009 and was completed in February 2010. The number of turbines commissioned each month is illustrated in Figure 1.6.

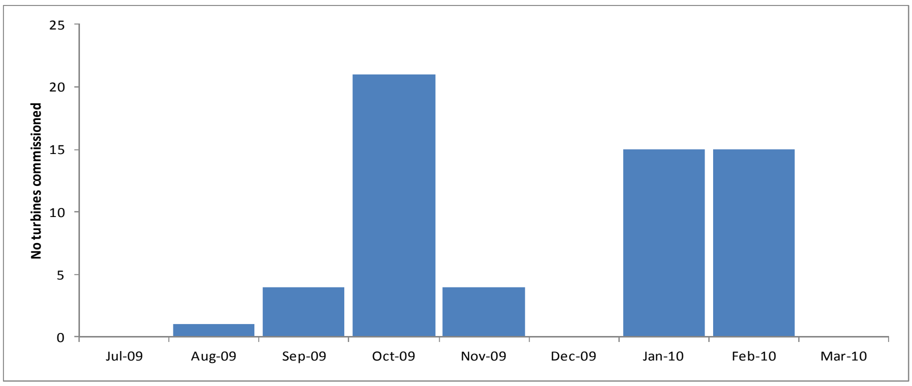

Figure 1.6: Number of turbines commissioned each month between August 2009 and February 2010.

In March 2011, the 132 kV export cables were sold by E.ON to a private transmission company "Transmission Capital" under the government's new OFTO regime. E.ON has been retained by the OFTO as their O & M contractor and this includes managing the environmental monitoring aspects of the export cable.

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2. ECOLOGICAL MONITORING AT ROBIN RIGG

An Environmental Statement was prepared for the Scottish Executive Energy Division under Section 36 of the Electricity Act (Scotland) 1989; a Private Bill for the Scottish Parliament; the Scottish Executive - Transport Division under Section 34 of the Coastal Protection Act 1949 and the Scottish Executive – Rural Affairs Department under the Food and Environment Protection Act 1985; and in accordance with the statutory procedures set out in The Environmental Assessment (Scotland) Regulations 1988 and the Environmental Impact Assessment (Scotland) Regulations 1999, in support of an application for an offshore wind farm at Robin Rigg in the Solway Firth.

Prior to the construction of the Robin Rigg Offshore Wind Farm, a MEMP was developed in conjunction with the RRMG, covering the pre-, during and post construction stages of development in accordance with consent from Scottish Ministers under Section 36 of the Electricity Act 1989.

The remit of the MEMP was to record any changes to the physical and ecological environment that may be caused by the construction and operation of the wind farm, complying with condition 6.4 of Section 36 Consent conditions. The programme concentrated on areas where there was uncertainty on the effects of the wind farm and where those effects may cause potential impacts on the marine ecology. This included benthos, fish, birds and marine mammals.

Below is a summary of the data available for analysis to Natural Power. All data collected during construction of the Robin Rigg Offshore Wind Farm was undertaken as part of the requirements for the MEMP and agreed by the RRMG. This included benthos, fish, birds and marine mammals. Intertidal surveys were also required and conducted, however the results of these surveys are not included in this report has the data has already been presented in a separate report.

2.1. Benthic Surveys

- Marenco Ltd was commissioned in 2001 by Solway Offshore LTD and Offshore Energy Resources to assess the like impacts of the development on benthic flora and fauna as part of the EIA process.
- Amec E & I UK Ltd (formerly Entec UK Ltd) have been contracted by NPC since July 2007 to undertake post EIA ecology benthic monitoring.

EIA baseline surveys

- Day grab samples were collected from a total of 100 stations, within and adjacent to the perimeter of the proposed wind farm development area during October 2001 and February 2002 by Marenco Ltd.
- Samples were also collected at five additional sites to the north and northwest of the main development area during February 2002 by Solenvo Marine Environmental Consultants.
- These additional surveys were undertaken in order to provide information on possible food sources for common scoters, which were found to be feeding in these areas.
- As the location of the cable route had not been finalised at this stage, no surveys of this area were undertaken.

MEMP monitoring

- Bi-annual benthic surveys were conducted throughout the pre-construction and construction phases on both the cable route and wind farm site (generally in the spring and autumn).
- Post construction: annual surveys for two years.
- Samples were collected from six stations within the site and three from outside the development area. All sampling stations surveyed correspond with ones sampled during the EIA baseline survey.
- For the cable route, sampling was conducted at eight stations along the cable route.

Table 2.1: Summary of when benthic surveys were conducted. WFS = wind farm site; CR = cable route; Light blue = baseline/EIA; Orange = pre-construction; Purple = construction; Green = operation.

Benthic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001										Benthic	Benthic	Benthic
2002		Benthic	Benthic									
2003												
2004												
2005			Inter-tidal									
2006												
2007							Benthic WFS				Benthic CR	
2008			Benthic WFS; Inter-tidal		Benthic CR						Benthic WFS/CR	
2009			Inter-tidal			Benthic WFS/CR			Inter-tidal			
2010			Inter-tidal		Benthic WFS/CR				Inter-tidal			Inter-tidal
2011	Inter-tidal	Inter-tidal	Inter-tidal	Benthic WFS/CR					Inter-tidal			

2.2. Fish Surveys

- Baseline data for the EIA was collected by Solenvo Marine Environmental Consultants.
- Amec E & I UK Ltd (formerly Entec UK Ltd) have been contracted by NPC since July 2007 to undertake post EIA ecology fish monitoring relating to non-migratory and electro-sensitive fish species (excluding migratory fish).

EIA baseline surveys

- Monthly trawls of 31 sampling stations in and around the area of the proposed wind farm were conducted from November 2001 to April 2002 by Solenvo Marine Environmental Consultants.
- As the location of the cable route had not been finalised at this stage, no surveys of this area were undertaken.

MEMP monitoring

- In accordance with FEPA requirements, fish surveys for non-migratory species were not undertaken during pre-construction.
- During the construction phase (December 2007 - February 2010), non-migratory fish surveys were originally performed monthly for the first three months, after which survey frequency reduced to quarterly.
- Non-migratory fish post construction – biannual surveys for three years (assuming no significant change in numbers of distribution observed during construction phase).
- Non-migratory fish surveys were performed at the same 31 sampling stations surveyed during the baseline EIA process.
- As no electro-sensitive fish survey of the cable route was undertaken during the EIA process, they were performed biannually during the first year of pre-construction, reducing to annually after February 2009.
- Electro-sensitive fish post construction – quarterly for 1 year assuming that the benthic community has recovered.

Table 2.2: Summary of when fish surveys were conducted. NM = non-migratory fish; ES = electro-sensitive fish; WFS = wind farm site; CR = cable route; Light blue = baseline/EIA; Orange = pre-construction; Purple = construction; Green = operation.

Benthic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001										NM Fish	NM Fish	NM Fish
2002		NM Fish	NM Fish	NM Fish	NM Fish	NM Fish	NM Fish	NM Fish	NM Fish			
2003												
2004												
2005												
2006												
2007								ES Fish			ES Fish	
2008		NM Fish	ES/NM Fish	NM Fish		ES Fish	NM Fish		ES Fish		NM Fish	
2009		ES/NM Fish				NM Fish		NM Fish				NM Fish
2010		NM Fish		ES/NM Fish			ES/NM Fish			ES/NM Fish		
2011			ES/NM Fish									

2.3. Bird Surveys

- Ecology Consulting completed the assessment of potential impacts of the development on birds from 2001 onwards as part of the EIA process and continued to conduct boat-based surveys required under the MEMP.

EIA baseline surveys

- Boat-based surveys consisting of ten transects were conducted on a bi-monthly basis between May 2001 and April 2002 (with exception of May and October 2001 when only one survey was completed).
- Each transect was about 18 km in length with 2 km intervals between.

MEMP monitoring

- Monthly boat-based surveys were conducted in April/May 2003 and bi-monthly surveys between January and September 2004 with an additional survey performed in July 2007, just prior to construction commencing.
- Construction phase surveys began in January 2008 and continued on a bi-monthly basis until the end of the phase in February 2010. Surveys were completed in all months of the construction phase except November 2009.
- Post construction – one survey per month for five years with review after three to establish if further surveys still required.

Table 2.3: Summary of when bird and marine mammal boat surveys were conducted. MM = marine mammals; B = birds; Light blue = baseline/EIA; Orange = pre-construction; Purple = construction; Green = operation.

Benthic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001					Birds	Birds	Birds	Birds	Birds	Birds	Birds	Birds
2002	Birds	Birds	Birds	Birds	Birds	Birds	Birds	Birds	Birds	Birds	Birds	Birds
2003				Birds	Birds							
2004	Birds	B/MM	B/MM		B/MM		B/MM	B/MM	B/MM	MM	MM	MM
2005	MM											
2006												
2007							B/MM					
2008	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM
2009	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM		B/MM
2010	Birds	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM
2011	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM	B/MM
2012	B/MM	B/MM										

2.4. Marine Mammal Surveys

- Information collected for the EIA on marine mammals took the form of a desk-based literature review with no additional surveys performed.
- Peter Ulrich has been involved with the mammal surveys required under the MEMP since 2004, both independently and in conjunction with the Centre for Marine and Coastal Studies Ltd.
- All surveys were performed in conjunction with the ornithology surveys.

EIA baseline surveys

- No surveys for marine mammals were conducted as part of the EIA process.

MEMP monitoring

- Boat-based surveys were conducted on a monthly basis between February 2004 and January 2005 with an additional survey performed in July 2007, just prior to construction commencing.
- Construction phase surveys began in January 2008 and continued on a bi-monthly basis until the end of the phase in February 2010.
- Surveys were completed in all months of the construction phase except November 2009.
- Post construction – one survey per month for two years (complete February 2012).
- In addition to the boat-based surveys, a marine mammal observer was required under Disturbance Licence conditions (Scottish Government, DEROG 068A/2007), to observe for marine mammals at least 30 minutes prior to the commencement of piling activities. An acoustic deterrent device was also deployed for the same period. These activities were conducted from the installation vessel.

3. ECOLOGICAL ANALYSIS RATIONALE

The analytical methodology has been determined by the data available to Natural Power Consultants, collected in both the EIA extended baseline / pre-construction period and as part of the MEMP during construction and operation.

The approach to the ecological analysis has been developed after reviewing the requirements of the MEMP, FEPA licensing requirements and the recent CEFAS document, "Strategic review of offshore wind farm monitoring data associated with FEPA licence conditions" (Walker *et al.,* 2010). As part of this process, consultation with Marine Scotland and SNH identified key questions or concerns for specific focus.

Data analysis was specifically tailored to the predictions made in the EIA and addresses the licence monitoring conditions. The analysis is focused on key areas highlighted by the RRMG and where data was available and appropriate, to address uncertainties as outlined in the aims of the MEMP.

Specific key questions have been identified by E.ON (with NPC) and the RRMG for the data analysis. These relate to:

- Disturbance/displacement of specific species;
- Changes in patterns of abundance and distribution with distance from the wind farm; and
- Identifying any predicted impacts/sensitivities from the EIA process.

Analysis of the Bird and Marine Mammal data has been undertaken by the NPC Ecology & Hydrology Department. This has only been possible where these data, the survey program, the survey methods and the rigour and consistency of the data collected by 3rd party consultants allowed for the analysis to be undertaken.

Amec Environment & Infrastructure UK Ltd (previously Entec UK Ltd) was contracted by NPC to conduct the analysis of the benthic and non-migratory fish data (Amec, 2011) collected throughout the construction phases of the wind farm.

4. BENTHOS

4.1. Benthic Surveys and analysis methodology

4.1.1. Grab Sample Methodology

Benthic infauna samples were recovered using a 0.1 m^2 Day Grab. The baseline survey was carried out by Marenco Ltd. The FEPA requirement surveys were conducted from the Amec E & I UK Ltd using the *Solway Protector*.

The time and location of each grab was recorded using the vessel's Global Positioning System (GPS). Depth was measured using the vessel's depth sounder and temperature was measured by the vessel's in-built thermometer. Surface water salinity was measured using a hand-held refractometer and turbidity was measured using a Secchi disc. A visual assessment of sediment type in each grab sample was made and a sample of sediment from the first grab sample was retained for particle size analysis (PSA) and Total Organic Carbon (TOC) analysis. The sediment from each grab sample was sieved using a 1 mm mesh and the fauna retained in the sieve were preserved in 5% formaldehyde.

During the baseline survey triplicate samples were collected. There was a large degree of similarity between replicate samples obtained in terms of both sediment and benthos characteristics over the survey area. As a result, following consultation with the Robin Rigg Monitoring Group, only duplicate grab samples during pre-construction and construction phase monitoring were required.

4.1.2. Survey Timing and Location

Day grab samples were collected from within and surrounding the wind farm site and along the cable route from during the baseline, pre-construction, construction and operational phases. Table 4.1 below lists the survey data and the corresponding period. The data collected was also sorted by season, with the winter months as January – March, spring months as April - June, summer months as July - September, and autumn months as October - December.

Table 4.1: Benthic grab sampling undertaken.

Location	Date of Survey	Period
Wind farm site and cable route	2001/2002	Baseline
Wind farm site	13/07/2007	Pre-Construction
Cable route	13/11/2007	Pre-Construction
Wind farm site	31/03/2008	Construction
Cable route	20/05/2008	Construction
Wind farm site and cable route	06/11/2008	Construction
Wind farm site and cable route	23/06/2009	Construction
Wind farm site and cable route	10/05/2010	Operational Year 1

The baseline survey had a total of 113 sampling stations within and adjacent to the perimeter of the proposed wind farm development area and along the cable route (Figure 4.1). In addition, an additional five sampling stations were added during February 2002, to the north and north-west of the main development area in order to provide benthic information on possible Common Scoter feeding grounds.

For the pre-construction, construction and operational phases of the wind farm (FEPA monitoring requirements) six sampling stations were surveyed within the wind farm site itself and three reference (control) sampling stations just outside the wind farm area (Figure 4.2). An additional eight sampling stations were located along the cable route.

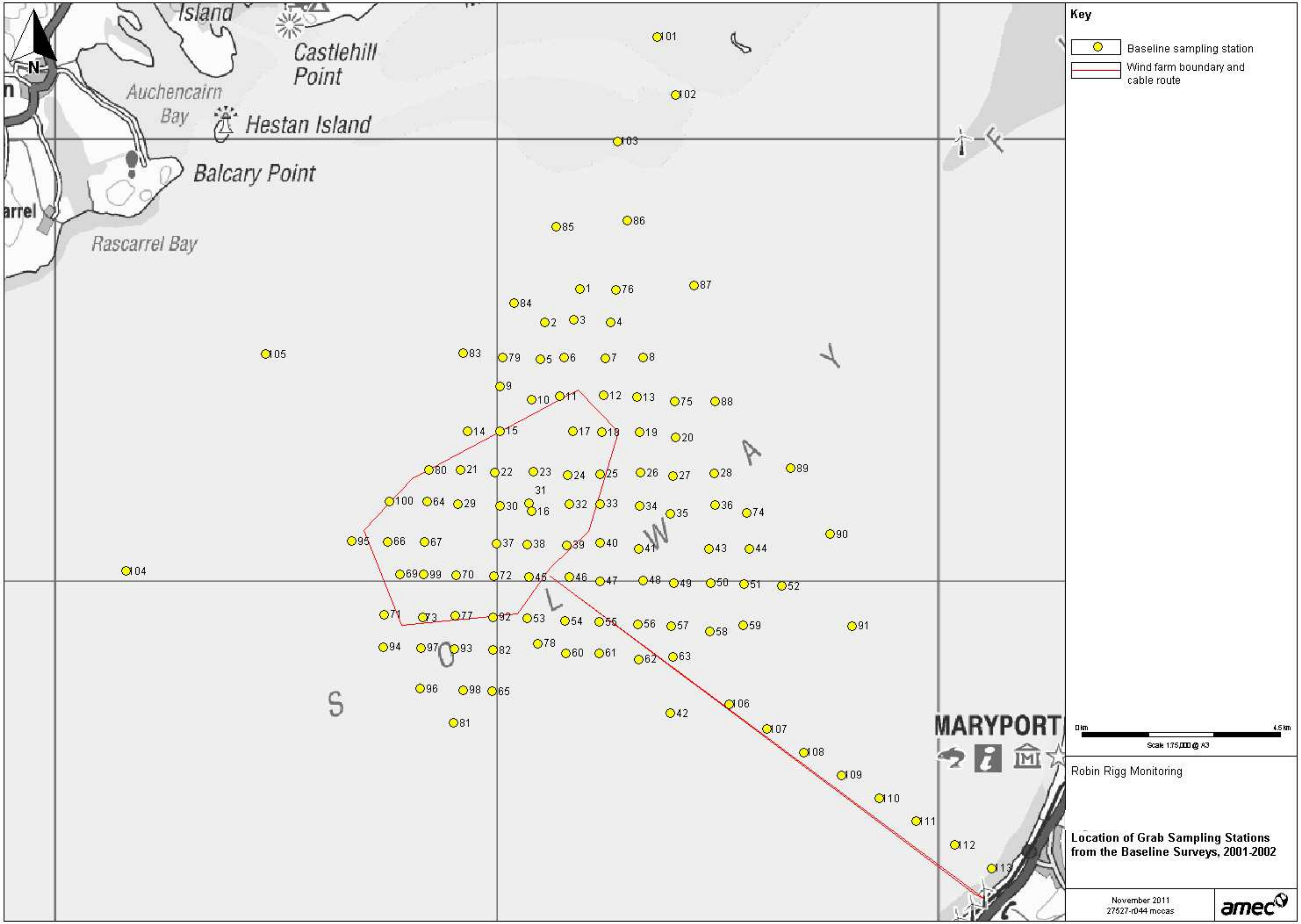


Figure 4.1: Location of grab-sampling stations from the baseline surveys, 2001-2002.

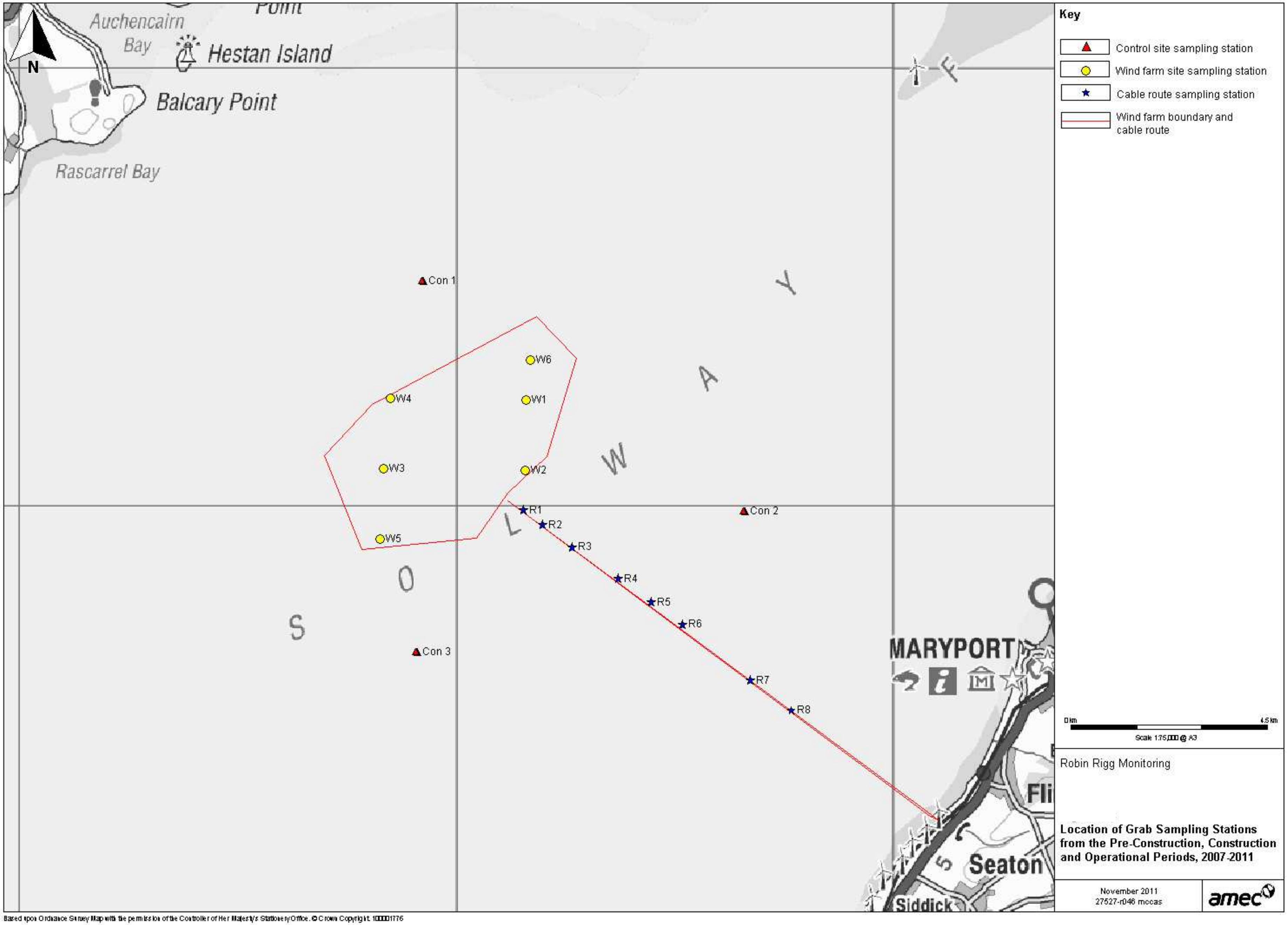


Figure 4.2: Location of grab-sampling stations from the pre-construction, construction and operational periods, 2007-2011.

4.2. Data Analysis

Data analysis was carried out by Amec E & I UK Ltd (formerly Entec) a summary of the results (Amec, 2011) is provided in this report. Cable route and wind farm survey data from pre-construction and construction phase work was combined for the purpose of the data analysis.

In the baseline sampling period, 113 grab sampling stations were surveyed, however many of these were quite far from the wind farm site and not near the FEPA monitoring stations. Therefore, only baseline sampling stations in the vicinity of the wind farm, cable route and control stations were used (representing a total of 18 out of 113; Table 4.2, Figure 4.3).

Table 4.2: Equivalent baseline and pre/construction period sampling stations.

Area	Pre/Construction period sampling station no.	Baseline survey sampling station no.
Wind farm site	Win 1	24
	Win 2	39
	Win 3	67
	Win 4	80
	Win 5	73
	Win 6	17
Control sites	Con 1	83
	Con 2	52, 90, 89
	Con 3	81
Cable route	1	46
	2	47
	3	56
	4	63
	5	No equivalent
	6	106
	7	108
	8	109

All statistical analysis was undertaken using the statistical package PRIMER v6[1] and XLSTAT[2].

4.2.1. Multivariate Statistics

All analysis was based on a Bray-Curtis similarity index. As the raw data consisted of sparse faunal abundance and species richness, with the odd high abundance of one or two species, square root or fourth root transformation was applied. Statistical tests used are non-metric Multidimensional Scaling (MDS) ordinations, Analysis of Similarities (ANOSIM), Species Contributions (SIMPER), PERMANOVA+ and hierarchical clustering. A more in-depth explanation of each test is given below.

[1] Clarke, K.R., Gorley, R.N. 2006. *PRIMER v6: User Manual/Tutorial.* PRIMER-E, Plymouth.
[2] Software developed by Addinsoft: www.xlstat.com.

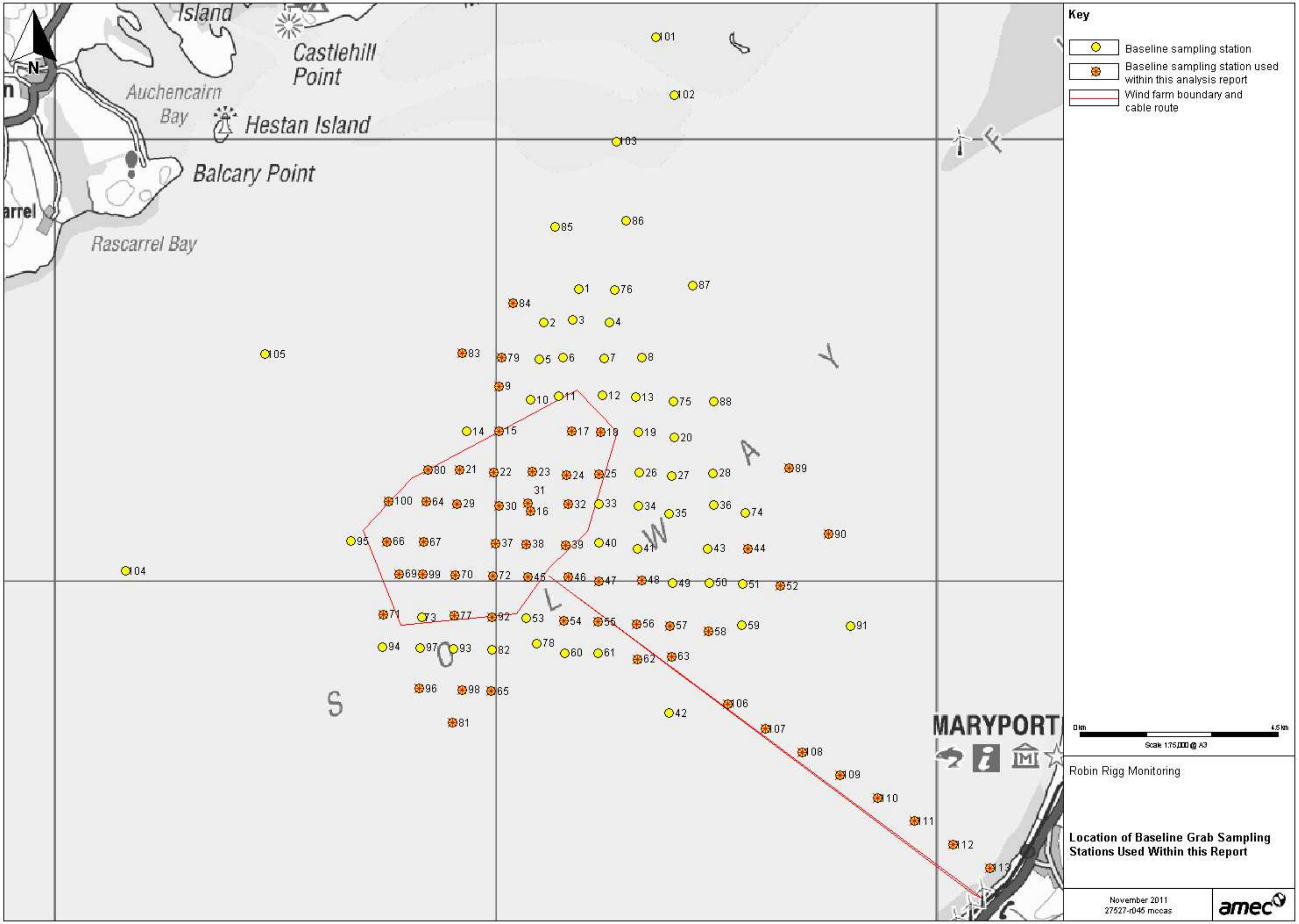


Figure 4.3: Location of baseline grab-sampling stations used within this report

Hierarchical Clustering
Cluster analysis aims to find "natural groupings" of samples such that samples within a group are more similar to each other, generally, than samples in different groups. The most commonly used clustering techniques are hierarchical agglomerative methods. These take a similarity matrix (Bray-Curtis in this instance) and successively fuse the samples into groups and the groups into larger clusters, starting with the highest mutual similarities, and then gradually lowering the similarity level at which groups are formed. The process ends with a single cluster classification.

ANOSIM
ANOSIM was used to determine whether there was a difference in benthic invertebrate community/composition between the survey years/construction phases. ANOSIM is a simple non-parametric permutation procedure applied to a similarity matrix underlying the ordination, or classification, or samples. It works by using a null hypothesis (H_o) which states that there is no difference in benthic invertebrate community/composition across the survey years/construction phases. ANOSIM calculates an R value that is between -1 and +1, although normally the R value lies between 0 and 1. If R is approximately zero then the H_o is accepted. If R equals 1 then the H_o is rejected. R will usually fall between 0 and 1 indicating some degree of discrimination between sites. The R value itself is a useful comparative measure of the degree of separation of sites, and its value is at least as important as its statistical significance. Statistical significance was chosen at $p \leq 0.05$. If the value of R is significant, you can conclude that there is evidence that the samples within groups are more similar than would be expected by chance.

SIMPER
SIMPER (similarity percentages) analysis looks at the role of individual species in contributing to the separation between two groups of samples, or the closeness of samples within a group. SIMPER was used to determine the main species contributing to the groups identified during the cluster analysis, thus aiding in determining the biotope. Average Bray-Curtis dissimilarity was used between all pairs of samples, and percentage contributions from each species were placed in decreasing order of contribution. The species that cumulatively made up 90% of the samples were used.

PERMANOVA+
PERMANOVA+ is a recent (2008) add-on package to the main PRIMER v6 programme, which extends the resemblance-based methods of PRIMER and allows the analysis of more complex sampling structures, experimental designs and models (Anderson *et al.,* 2008).

There are two essential differences between ANOSIM and PERMANOVA. Firstly, ANOSIM ranks the values before proceeding with the analysis, and is consistent with the philosophy of non-metric MDS ordination. PERMANOVA is a semi-parametric (permutation-based) analysis of the data, where the information of interest is in the dissimilarity values themselves. The second essential difference is in the construction of the test statistic. ANOSIM uses the R statistic with a scale from -1 to +1, and it is possible to interpret the R statistic directly as an absolute measure of the strength of the difference between the groups. It is also comparable between different studies. PERMANOVA uses the pseudo-F statistic, which is reliant on the degrees of freedom of the analysis, so it cannot necessarily be compared across studies. For example, a pseudo-F value of 2 will generally provide much stronger evidence against the null hypothesis if the residual degrees of freedom are 98 than if they are 5.

As with ANOSIM, the H_o for PERMANOVA analysis is that there is no difference in benthic invertebrate community/composition across the survey years/construction phases.

4.2.2. Univariate Statistics

There are a variety of different, single number statistics that can be used as measures of some attribute of community structure in a sample, all labelled as species diversity indices. The main aim of species diversity indices is to reduce the multivariate complexity of the data into a single index, which can then be handled statistically by univariate analysis.

Species diversity indices were calculated to determine how diverse the wind farm and cable route area is each year, and whether the diversity has changed over the years. There are a number of diversity indices available and for the purpose of this report, those most frequently used in literature have been adopted and calculated.

The diversity indices were analysed using the non-parametric Kruskal-Wallis test to determine if there was any significance between the construction periods. The H_o states that there is no difference between the construction periods. Bonferroni correction was also calculated so that if the H_o is rejected, we may identify which construction periods are different.

Statistical significance was chosen at $p \leq 0.05$. PRIMER v6 was used to calculate the species diversity indices. XLSTAT was used to calculate the Kruskal-Wallis test. Species diversity indices used in this report are:

- **Species richness** (S): the number of species present in an ecosystem, with no indication of relative abundances.
- **Number of individuals** (N): total number of individuals counted.
- Margalef's indexes (d): a measure of the number of species present for a given number of individuals. The higher the index, the greater the diversity.
- **Pielou's evenness** (J'): shows how equally the individuals in a population are distributed. J' = 0 – 1. The less variation in the samples, the higher J' is.
- **Shannon-Wiener index** (H'log2): measures the uncertainty of being able to predict the identity of the next species withdrawn from a sample (like picking lottery balls). H' = 1.2 – 7.0 (approximately). The higher the index the greater the diversity.
- **Simpson's indexes** (1-λ): a measure of the probability of choosing two individuals from a sample that are different species. D = 0 (minimum diversity) – 1.0 (maximum diversity).

4.3. Results

4.3.1. Species and habitats present

Since 2001, 109 species and a total of 3,527 individuals have been collected in the benthic grab sampling undertaken throughout the site and on the cable route. The predominant species found were *Bathyporeia elegans* and *Nepthys cirrosa*. *Scalibregma inflatum* had the third highest abundance however this resulted from a single grab (Table 4.3). A full list of species recorded can be found in Appendix 13.1.

Table 4.3: Top 20 most common species found in grab samples around the Robin Rigg Offshore Wind Farm, 2001 - 2011.

Species	Total numbers
Bathyporeia elegans	1048
Nephtys cirrosa	507
Scalibregma inflatum	258
Tellina fabula	166
Mysella bidentata	159
Magelona johnstoni	144
Pseudocuma longicornis	144
Scolelepis mesnili	110
Pomatoceros lamarcki	76
Bathyporeia nana	72
Nucula nitidosa	69
Abra alba	63
Gastrosaccus spinifer	61
Echinocardium cordatum	49
Donax vittatus	34
Nemertea	29
Bathyporeia sarsi	28
Ophelia borealis	28
Glycera tridactyla	24
Nephtys hombergii	24

Biotope classification

Biotope classification was undertaken using the Marine Habitat Classification for Britain and Ireland (Conner *et al.,* 2004). Biotope classification is a good way of describing the environment surrounding the wind farm, and identifying any changes occurring across the years.

Biotopes were identified for each construction period in Primer using the benthic infauna data. First a cluster analysis was undertaken to group the samples together by likeness. These groups are labelled alphabetically for ease of identification. For each group, characterising species were determined using the SIMPER routine in Primer. For a given set of records, SIMPER indicates and ranks the individual contribution of each species to the overall similarity within the data set. Normally the top three to four species identified in the analysis are used, as they generally represent the largest percentage of species in the group (all based on the cumulative percentage). The most dominant species in each group is one of the key factors determining the biotope classification.

Benthic infauna and particle size analysis results were used as the basis for biotope identification. Additional information on the epibenthos from the trawl survey was also consulted in order to confirm the biotope. Other factors used to aid the classification are location, exposure and other general area information. It should be noted that although no infaunal data were available in order to assign biotope type to the majority of the trawl survey sampling stations (where no grab sampling occurred), where specific epibenthic communities were found, these have also been mapped (Figures 4.4 – 4.7). This refers specifically to the brittlestar beds found to the north west of the site in the vicinity of Heston Island). Table 4.4 lists all the biotopes identified for each construction period with a description for each found below.

Table 4.4: Biotope classification of the study area per construction period.

ES Baseline Survey*	Pre-construction	Construction Year 1	Construction Year 2	Operational Year
SS.SSa.IFiSa.NcirBat	SS.SSa.IFiSa.NcirBat	SS.SSa.IFiSa.NcirBat	SS.SSa.IFiSa.NcirBat	SS.SSa.IFiSa.NcirBat
SS.SSa.IFiSa.IMoSa	SS.SSa.IFiSa.IMoSa	SS.SSa.CFiSa.ApriBatPo	SS.SSa.CFiSa.ApriBatPo	SS.SSa.IFiSa.IMoSa
SS.SSa.IMuSa			SS.SSa.IFiSa.IMoSa	
* The biotopes in the ES were classified to version 97.06 and 03.02, which has now been superseded by version 04.05. To allow comparison between the biotopes the baseline biotopes have been converted to version 04.05 using the translation tables provided by the MNCR.				

SS.SSa.IFiSa.NcirBat - *Nephtys cirrosa* and *Bathyporeia spp*. in infralittoral sand.
This is the predominant biotope in the Solway Firth and has not changed since the baseline survey. This biotope is characterised by well-sorted medium and fine sands and *Nephtys cirrosa* and *Bathyporeia* spp. (and sometimes *Pontocrates* spp.) which occur in the shallow sublittoral to at least 30 m depth. This biotope occurs in sediments subject to physical disturbance, as a result of wave action (and occasionally strong tidal streams).

SS.SSa.IFiSa.IMoSa - Infralittoral mobile clean sand with sparse fauna.
This is also another dominant biotope in the Solway Firth. This biotope is characterised by medium to fine sandy sediment in shallow water, often formed into dunes, on exposed or tide-swept coasts. It often contains very little infauna due to the mobility of the substratum. Some opportunistic populations of infaunal amphipods may occur, particularly in less mobile examples, in conjunction with low numbers of mysids such as *Gastrosaccus spinifer*, the polychaete *Nephtys cirrosa* and the isopod *Eurydice pulchra*. Sand eels (*Ammodytes* sp.), may occasionally be observed in association with this biotope.

SS.SSa.CFiSa.ApriBatPo - *Abra prismatica*, *Bathyporeia elegans* and polychaetes in circalittoral fine sand.
This biotope was only observed in 2008 and 2009. This biotope is characterised by circalittoral and offshore medium to fine sands between 25 m and 100 m depth, a community characterised by the bivalve *Abra prismatica*, the amphipod *Bathyporeia elegans* and polychaetes such as *Scoloplos armiger, Spiophanes bombyx, Aonides paucibranchiata, Chaetozone setosa, Ophelia borealis* and *Nephtys longosetosa*. Crustacea such as the cumacean *Eudorellopsis deformis* and the opheliid polychaetes such as *Ophelia borealis, Travisia forbesii* or *Ophelina neglecta* are often present in this biotope, and the brittlestar *Amphiura filiformis* may also be common at some sites.

In the 2008 and 2009 surveys, *Abra prismatica* is replaced by *Tellina fabula*, another type of venerid bivalve.

SS.SSa.IMuSa - Infralittoral muddy sand.
This biotope was observed during the baseline survey. According to the baseline data, this biotope was found in the more inshore part of the original cable route. The 2007-2011 surveys did not survey in this same area, therefore there no comparison can be made.

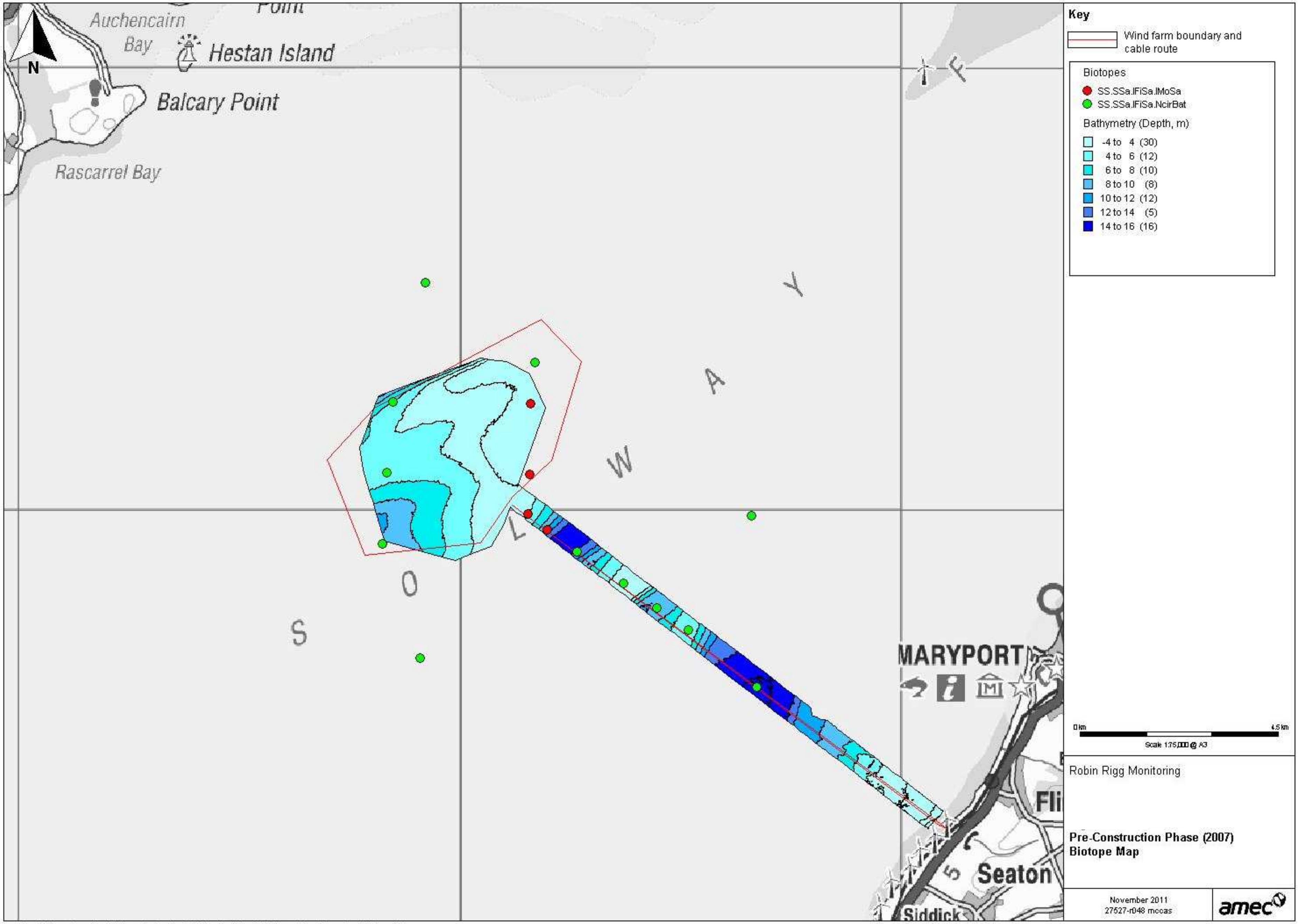


Figure 4.4: Pre-construction phase (2007) biotope map.

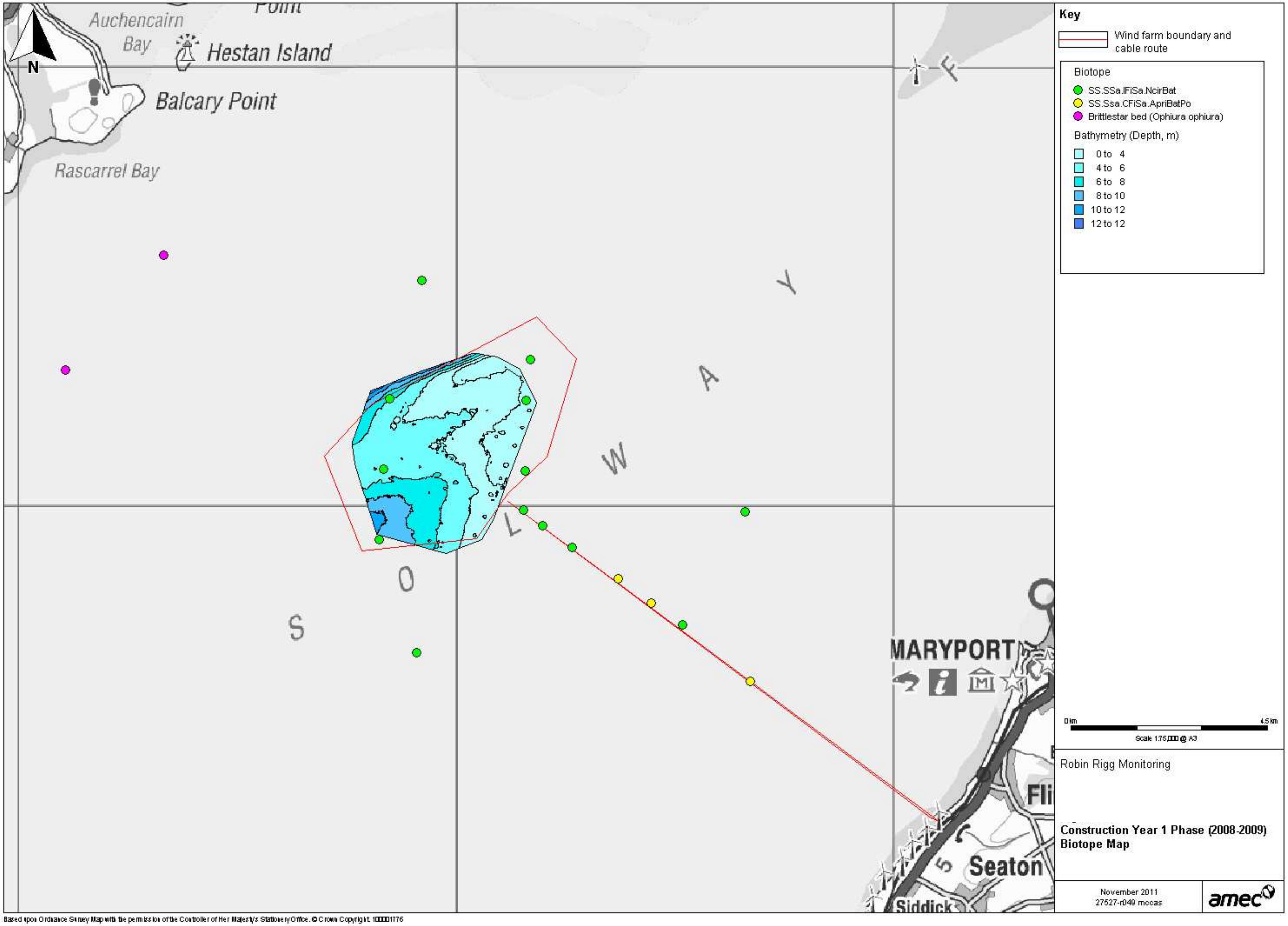


Figure 4:5.Construction year 1 phase (2008-2009) biotope map.

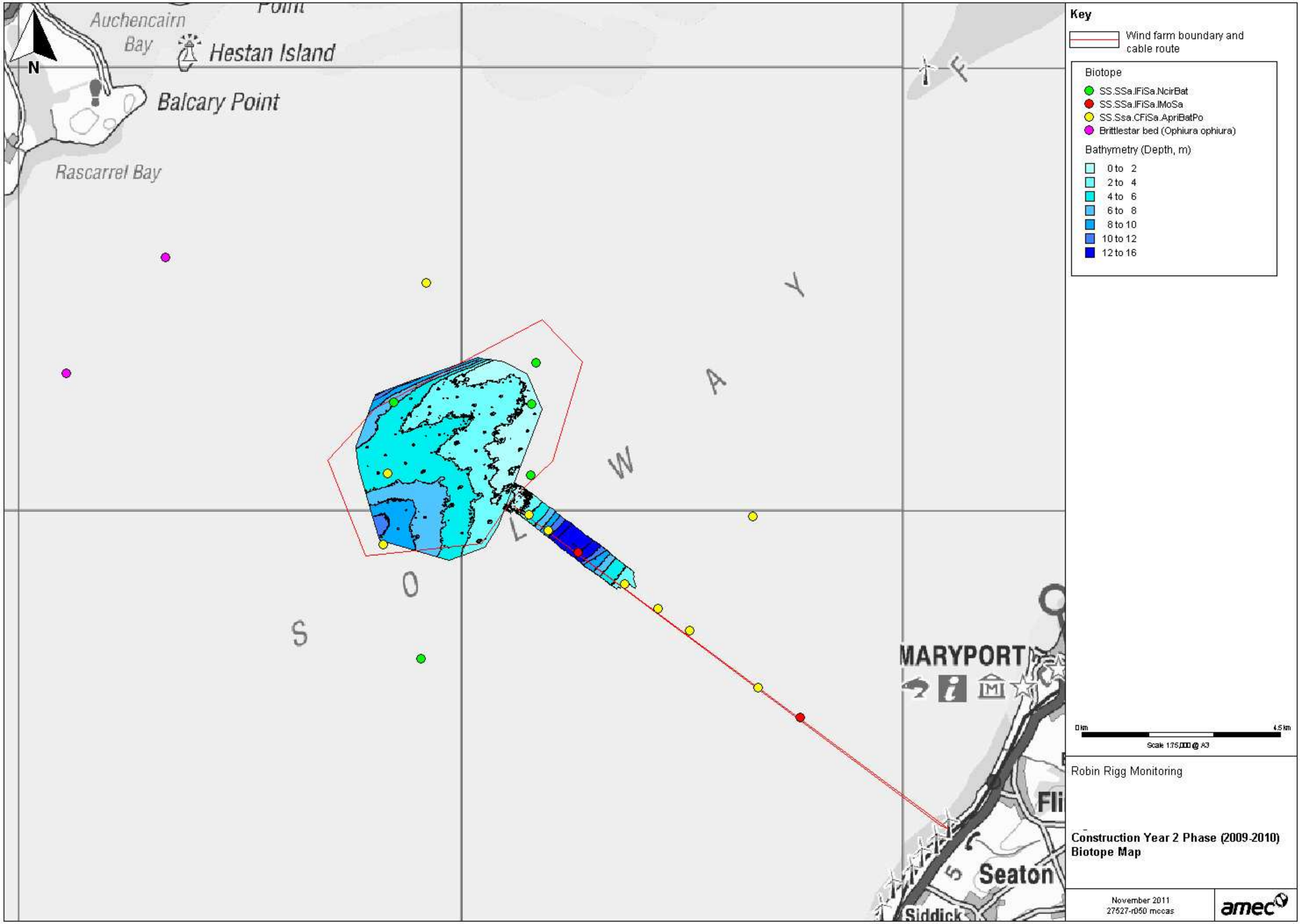


Figure 4.6: Construction year 2 phase (2009-2010) biotope map.

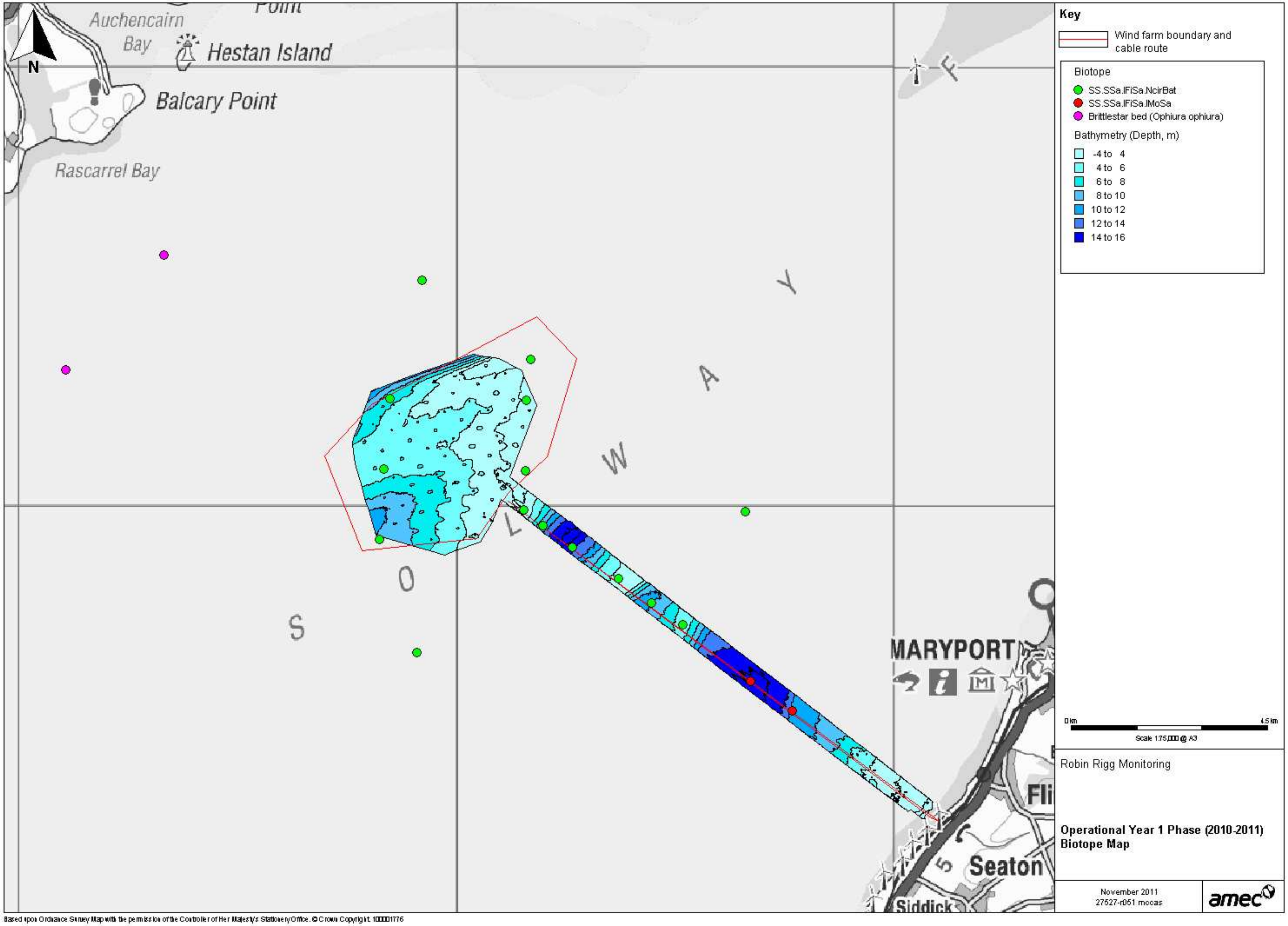


Figure 4.7: Operational year phase (2010-2011) biotope map.

4.3.2. Changes in benthic infauna community

Variation in community structure

Multivariate analysis was undertaken to determine if there have been any changes in the community structure surrounding the wind farm as a result of the construction and operation of the wind farm. Factors used in the analysis were construction period, year, and location (wind farm, cable route, or control). Seasonal effects were also examined.

Analysis undertaken was the creation of MDS plots using 4th root transformed data and Bray Curtis similarity with a dummy variable added, ANOSIM and SIMPER. Statistical significance was set at $p \leq 0.05$ (5%).

The relative similarity, or difference, between the samples is illustrated by the MDS plots by construction period (Figure 4.8) and year (Figure 4.9). Looking at both figures, there does not appear to be any particular separation of samples by construction period or year and the samples from each year are intermingled with each other. There does appear to be some slight clustering of the operational year (2010), however, the predominant outcome of these plots is the overlapping and intermingling of each factor.

ANOSIM analysis was also undertaken to determine whether there were any statistical differences between the construction periods or years. A significant relationship was detected between the construction periods ($p = 0.001$, $R = 0.171$) and years ($p = 0.0001$, $R = 0.174$), however the small R value suggests this represents a high level of similarity between construction periods in terms of community structure and composition (see Section 2.4.1 for a more in-depth explanation of the test).

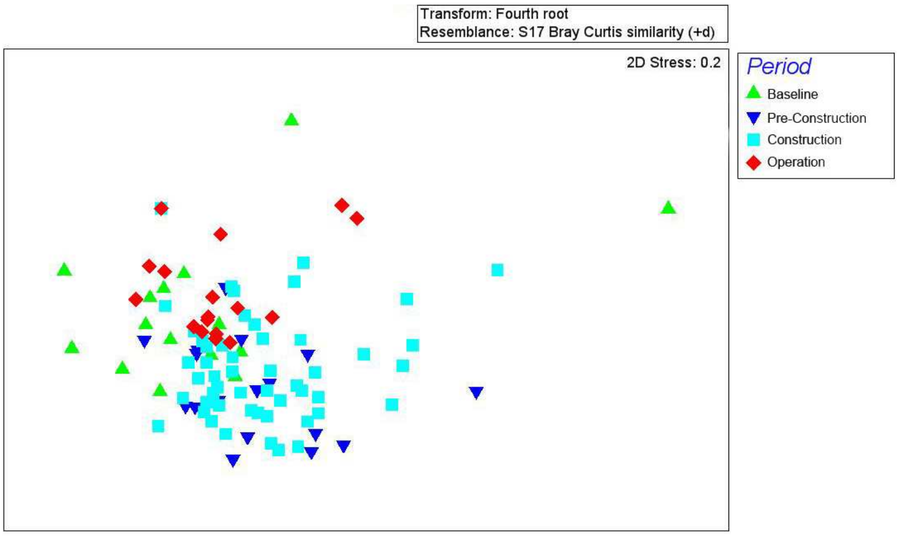


Figure 4.8: Non-parametric MDS plot of infauna samples, colour coded by survey period, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

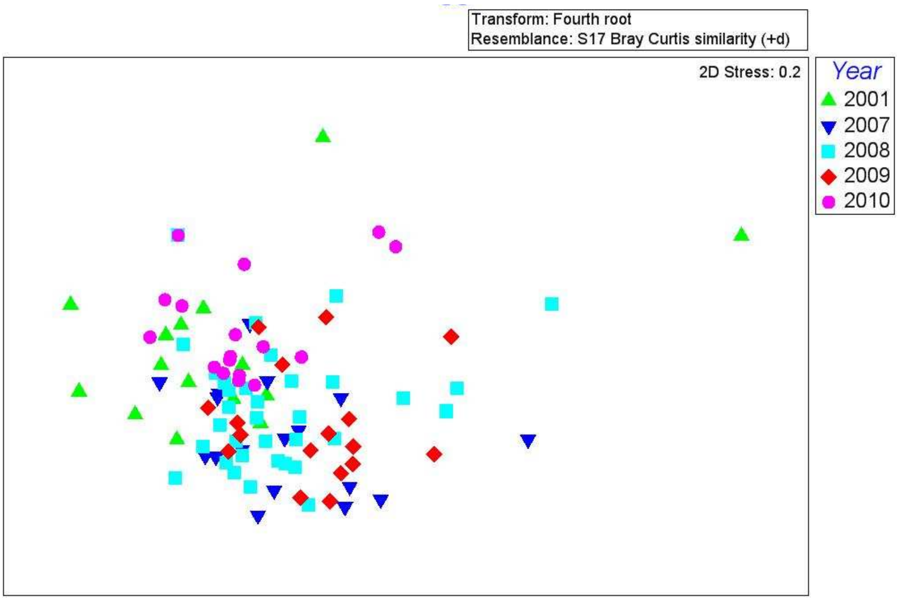


Figure 4.9: Non-parametric MDS plot of infauna samples, colour coded by year, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

Differences were also examined between the locations of the sampling stations, i.e. between those collected in the wind farm area, those collected along the cable route and those taken from the control site (Figure 4.10). Again, the MDS plots reveal no discernible differences or separation/clustering between the different areas, and the ANOSIM results show no significant differences or similarities between the areas (p = 0.361).

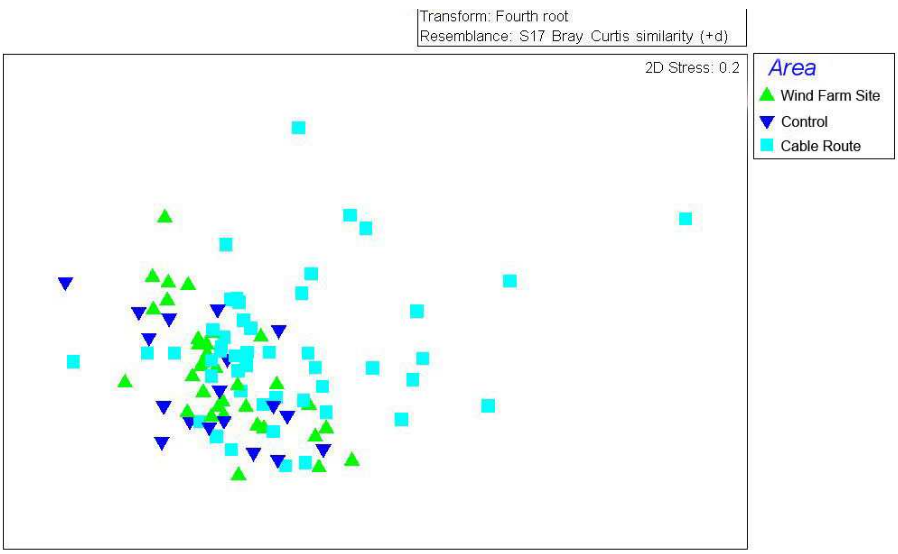


Figure 4.10: Non-parametric MDS plot of infauna samples, colour coded by area, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

Seasonal differences were also examined and again, there does not appear to be any separation between the seasons (Figure 4.11). ANOSIM results support this, showing no significant differences or similarities between seasons (p = 0.427)

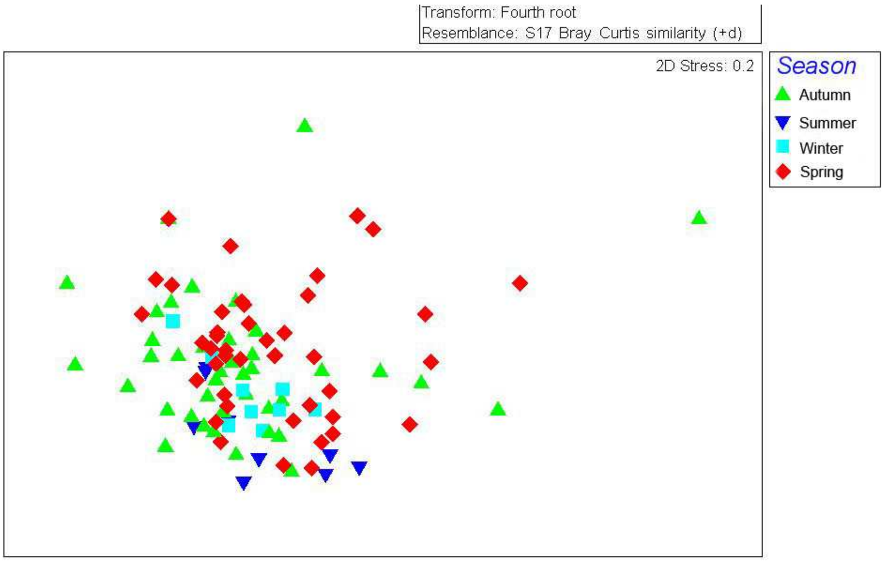


Figure 4.11: Non-parametric MDS plot of infauna samples, colour coded by season, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

Further Analysis

The initial analysis examined the raw data from all the surveys, checking for any patterns or groupings within the data. The ANOSIM results suggest no differences are present in the benthic community between construction periods, although the MDS plots suggest there might be some differences between the operational period and the rest of the survey periods. However, the monitoring conducted at Robin Rigg can be considered an unbalanced design, resulting from different surveyors, adverse weather conditions etc. The use of PERMANOVA+ for Primer**Error! Bookmark not defined.** enables the incorporation of the experimental design into the statistical analysis. Use of PERMANOVA may show patterns that may otherwise go unseen if relying solely on ANOSIM (see Section 2.4.1).

A design was set up for PERMANOVA with the construction period, year, area and season as fixed factors, and survey site as a random factor nested within the area factor. Significance value was set at $p \leq 0.05$. The PERMANOVA results showed the survey period ($p = 0.0001$, pseudo-F = 5.52), area ($p = 0.017$, pseudo-F = 2.32), and year ($p = 0.036$, pseudo-F = 2.04) all had a significant difference and a relatively strong pseudo-F value. Therefore it is worth looking at these factors in further detail. Season also showed a significant difference ($p = 0.003$), but a pseudo-F value of 1.66, which is not as strong as the other pseudo-F values mentioned above.

The values for survey period and area were averaged out to obtain mean values for each data set (Figure 4.12) in order to makes it easier to read the MDS plot and identify any separation or groupings. Using this analytical method, the operation period and baseline periods were clustered separately. The one baseline average which was not closely clustered was for the cable route samples. As stated in the introduction, the baseline cable route samples were taken from more inshore locations where the sedimentary environment is not as dynamic as in the middle of the Solway Firth and sediments contained a higher silt fraction. The pre-construction and construction periods for the cable route are clustered together and there does not seem to be any separation between the two periods.

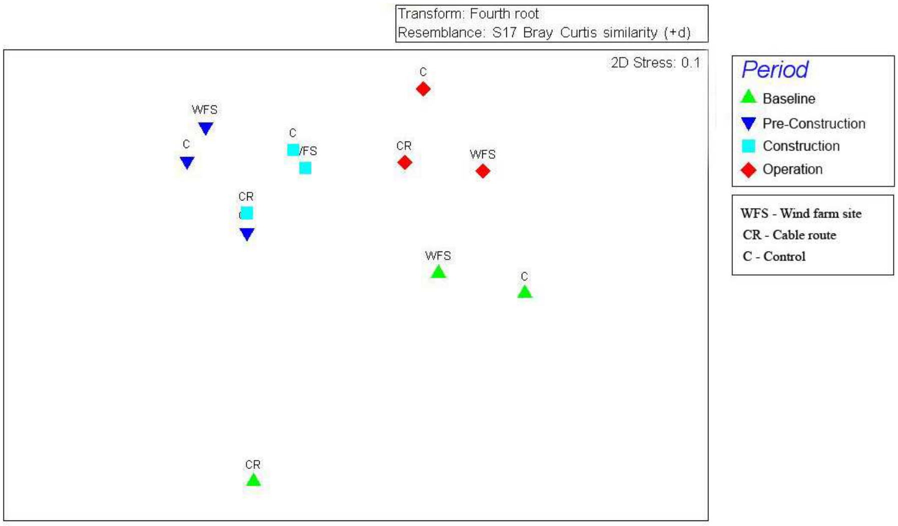


Figure 4.12: MDS plot of infauna samples with the survey period and area averaged to obtain the means; 4th root transformation and Bray Curtis similarity applied.

The baseline and pre-construction survey periods were compared against each other in order to detect any background changes arising prior to wind farm activity (Figure 4.13). This revealed some separation between the baseline and pre-construction survey periods, with three outliers belonging to the close inshore stations along the cable route. The low significance level and R value in the ANOSIM results indicates a significant relationship of very little change in the benthic community between the baseline and pre-construction periods ($p = 0.0001$, $R = 0.248$).

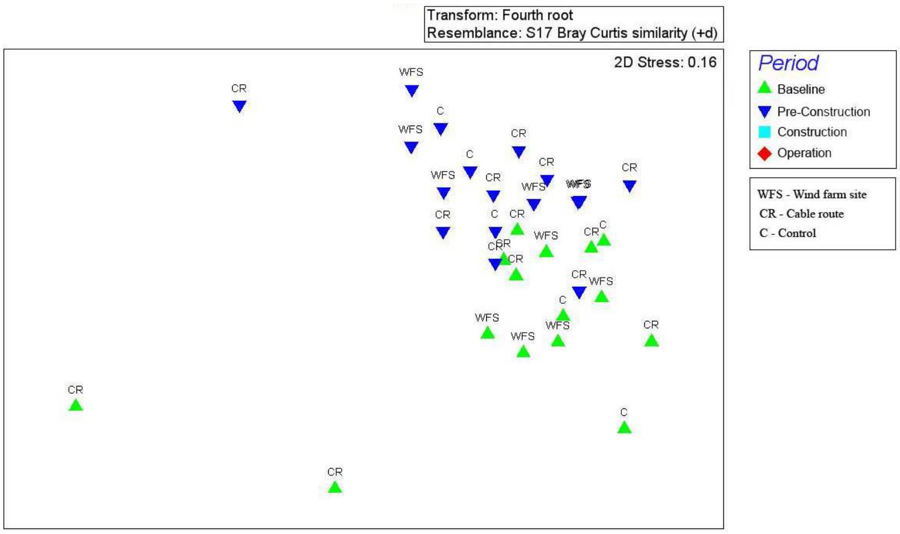


Figure 4.13: Non-parametric MDS plot of infauna samples for the baseline and pre-construction periods, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

In order to assess the impact on the benthos from construction, the pre-construction and construction survey periods were compared against each other (Figure 4.14). The MDS plot does not reveal any particular clustering or separation between these two survey periods. This is supported by the ANOSIM results which indicated no significant differences ($p = 0.299$).

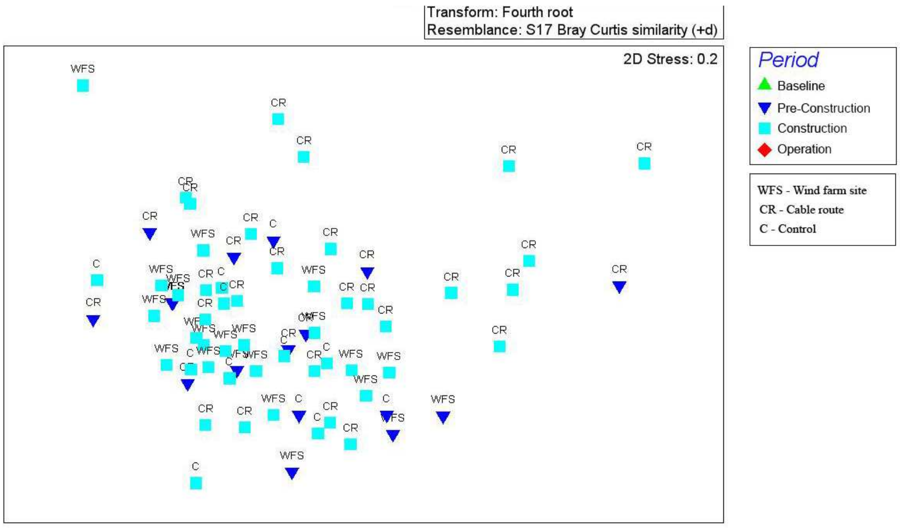


Figure 4.14: Non-parametric MDS plot of infauna samples for the pre-construction and construction periods, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

Finally, the potential impact on benthic communities from the operation of the wind farm was assessed. Operational benthic data were compared to both baseline and pre-construction data separately, due to the significant difference found between baseline and pre-construction data (see above).

The MDS plot of the pre-construction and operation survey periods (Figure 4.15) shows separation between the two periods. The ANOSIM results showed a significant relationship between the two periods, which the R value suggests is one of small changes, with a large degree of overlap in the benthic community between the construction periods ($p = 0.0001$, $R = 0.316$). When the operation year is compared against the baseline period (Figure 4.16), there still appears to be some separation between the two periods, however there is more intermingling between the samples than compared to Figure 4.15. It should be noted that the two outliers for baseline are the inshore samples along the cable route and these stations were not surveyed during the operational phase. The ANOSIM results again show a significant relationship between these two periods, however the R value suggests that this relationship is one of similarity in the benthic infaunal community between the first operational year and the baseline years ($p = 0.0004$, $R = 0.145$). Only further monitoring during the operational years would confirm this. It is worth noting that overall there is very little change in biotopes and diversity throughout the years.

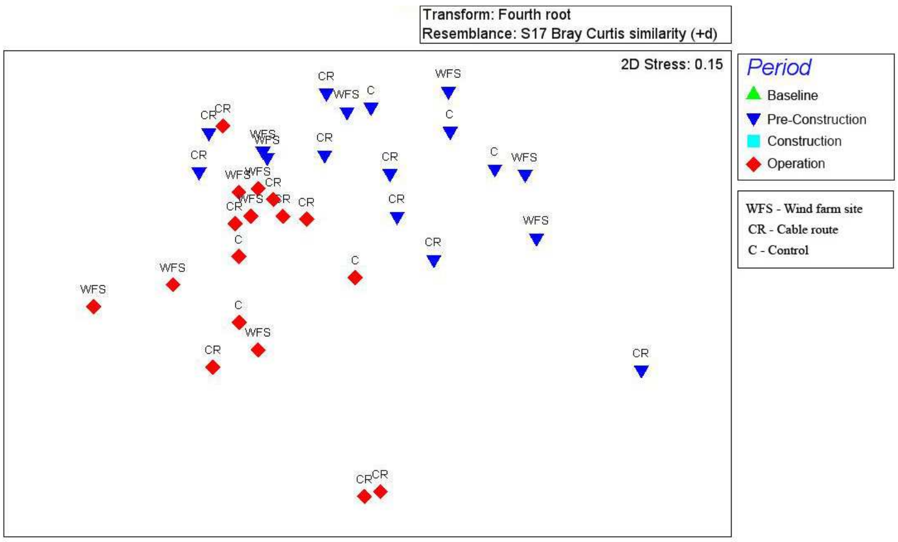


Figure 4.15: Non-parametric MDS plot of infauna samples for the pre-construction and operation periods, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

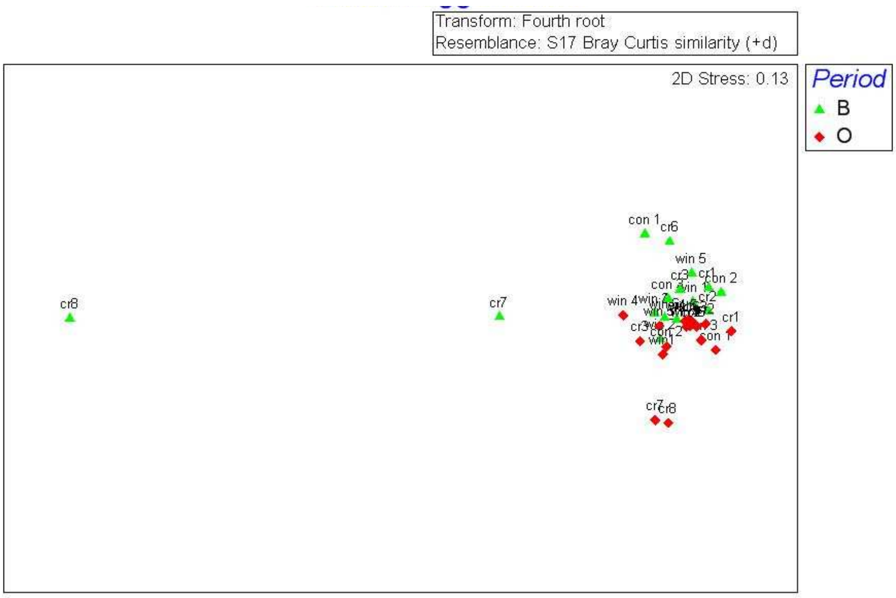


Figure 4.16: Non-parametric MDS plot of infauna samples for the baseline and operation periods, with 4th root transformation and Bray Curtis resemblance (dummy variable added).

Species diversity

The diversity indices are all very low throughout the years showing the area of the Solway Firth to be an area that has poor biodiversity. This is expected, as the Solway Firth can be classified as a highly stressed environment with a macro-tidal system, and continuously shifting sub-tidal sandbanks made up of fine to medium size grains of sand. Table 4.5 summarises the results obtained by the Kruskal-Wallis test and the Bonferroni Correction.

Table 4.5: p-values indicating significance between diversity indices (results in red indicate the tests are significantly different).

Diversity index	Kruskal-Wallis	Bonferroni Correction
Margalef (d)	0.0003	No discernible significant difference observed between periods.
Pielou' eveness (J')	0.092	N/A
Shannon index (H'log_2)	0.0002	No discernible significant difference observed between periods.
Simpson's index (1-λ)	0.09	N/A

Out of the four diversity index tests, only two tests showed any significant differences between the periods: Margalef's Index, and Shannon's Index. However, the Bonferroni Correction test did not identify which particular periods are different from each other.

Variations in species abundance

Although the initial analysis shows a significant, but small, difference between the construction periods, the further analysis (PERMAOVA+) shows a change or trend throughout the construction periods. SIMPER analysis was undertaken to determine what species are driving these changes between the construction periods. The results of the grab data reveal a shifting around of species for each construction period (Table 4.6), although *Nephtys cirrosa* and *Bathyporeia elegans* are the predominant species throughout.

Table 4.6: SIMPER analysis results of contributing species per construction period.

Construction Period	Species	Contribution %	Cumulative Contribution %
Baseline	*Nephtys cirrosa*	59.06	59.06
	Gastrosaccus spinifer	18.64	77.70
	Bathyporeia elegans	8.59	86.29
	Magelona johnstoni	4.25	90.54
Pre-Construction	*Bathyporeia elegans*	30.43	30.43
	Nephtys cirrosa	26.10	56.53
	Scolelepis mesnili	9.83	66.36
	Gastrosaccus spinifer	9.41	75.77
	Magelona johnstoni	6.79	82.56
	Tellina fabula	2.76	85.32
	Pseudocuma longicornis	2.61	87.93
	Bathyporeia sarsi	2.09	90.01
Construction	*Bathyporeia elegans*	44.41	44.41
	Nephtys cirrosa	25.77	70.18
	Pseudocuma longicornis	4.94	75.12
	Tellina fabula	4.67	79.79
	Bathyporeia nana	3.65	83.44
	Magelona johnstoni	3.47	86.91
	Scolelepis mesnili	3.26	90.17
Operation	*Nephtys cirrosa*	54.50	54.50
	Bathyporeia elegans	33.19	87.68
	Echinocardium cordatum	3.29	90.98

During the baseline surveys, the polychaete *Nephtys cirrosa* and the crustacean *Gastrosaccus spinifer* comprised over 77% of the infaunal community. During the pre-construction phase *Nephtys cirrosa*, the amphipod *Bathyporeia elegans* and the polychaete *Scolelepis mesnili* comprised up to 56% of the infaunal community, with *Gastrosaccus spinifer* responsible for up to 10% of the community. During the construction and operational years, it was again *N. cirrosa* and *B. elegans* that comprised up to 70% and up to 87% respectively of the infaunal community.

During pre-construction the main biotope present was *Nephtys cirrosa and Bathyporeia spp. in infralittoral sand* (SS.SSa.IFiSa.NcirBat) with a patch of *Infralittoral mobile clean sand with sparse fauna* (SS.SSa.IFiSa.IMoSa) at the export cable and wind farm interface. *Bathyporeia elegans* and *Nephtys cirrosa* accounted for 62% of the infaunal community, with *Nephtys cirrosa* alone accounting for up to 60% of the mobile clean sand area.

During the first year of construction the mobile, clean sands were replaced by the SS.SSa.IFiSa.NcirBat biotope, and *Abra prismatica, Bathyporeia elegans and polychaetes in circalittoral fine sand* (SS.SSa.CFiSa.ApriBatPo) was found along the cable route. The main infaunal community for this biotope comprised of *Bathyporeia elegans*, *Nephtys cirrosa*, *Tellina fabula* and *Magelona johnstoni*. They accounted for 63% of the infaunal community.

During the second year of construction this biotope was still found along the cable route and also inside the wind farm itself, replacing some of the area previously identified as the SS.SSa.IFiSa.NcirBat.

Moving from the second year of construction into the operational year there was again another shift in community with the SS.SSa.CFiSa.ApriBatPo being replaced by SS.SSa.IFiSa.NcirBat. The biotope map of the operational year is very similar to the pre-construction phase suggesting a return to the community found in the pre-construction phase.

5. FISH AND EPIBENTHOS

5.1. Fish and Epibenthos Sampling

5.1.1. Survey Timing and Location

For the EIA baseline, monthly marine fish and epibenthos trawls were carried out at 31 sampling stations within, and in the vicinity of the proposed wind farm site. These took place between November 2001 and September 2002, excluding January 2002, with a total of 10 surveys undertaken. No trawls were undertaken along the cable route as at the time of the EIA, the precise location of the cable route was not known.

In order to comply with the MEMP and FEPA licence requirements of the Robin Rigg Offshore Wind Farm, these surveys were repeated during the construction and operational period (Figure 5.1). For the purposes of the FEPA licence they were referred to as non-migratory (NM) fish surveys. **In accordance with the MEMP, no pre-construction non-migratory fish surveys were undertaken as it was felt that the available baseline data was sufficient.**

During the first year of construction (February 2008 - February 2009) trawl surveys were initially carried out monthly (for the first 3 months) and then its frequency was reduced to quarterly (a total of six surveys). For the second year of construction (June 2009 - February 2010) the surveys were simply carried out on a quarterly basis (Table 5.1).

For the first three surveys, all 31 sites were sampled however, after July 2008, this was not possible due to the presence of either the jack up barge or turbine bases. From July 2008 onwards only 28 sampling stations have been surveyed.

Trawl surveys along the cable route were also undertaken during the pre-construction and construction periods, primarily to monitor the presence of electro-sensitive fish (see Section 5.4). These were performed at eight sites along the cable route. During the pre-construction period of the wind farm (August - November 2007) these took place on two sampling occasions. During construction year one and operational year one, these electro-sensitive surveys were carried out quarterly. **In accordance with the MEMP, no electro-sensitive surveys were carried out in construction year 2** (Table 5.1).

It should be noted that during 2008, construction activity was suspended for a period of time. This resulted in a difference in the intensity of construction activity, with the majority of activity in 2008 involving trenching along the cable route. Only three monopiles were installed in 2008, with the remaining turbines and cables installed during 2009/2010. As a result, for the purpose of this analysis, the construction period was split into construction year one (February 2008 - February 2009) and construction year two (June 2009- February 2010).

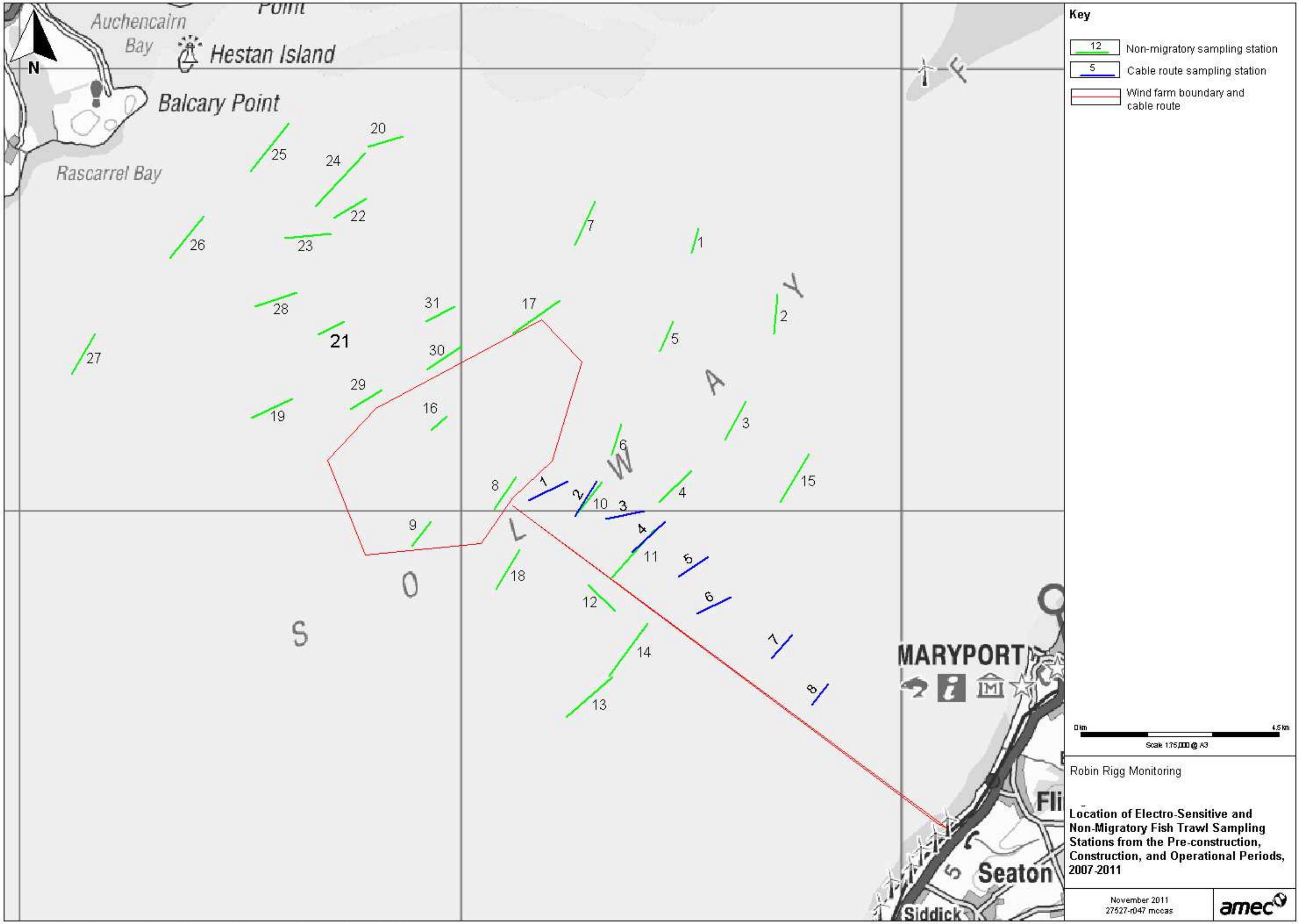


Figure 5.1: Location of electro-sensitive and non-migratory trawl sampling stations from the pre-construction, construction and operational periods, 2007-2011.

Table 5.1: Non-migratory and electro-sensitive fish (cable route) surveys undertaken. Note that no electro-sensitive fish surveys were only conducted in construction year one as per MEMP.

Survey type	Period	Frequency	Dates undertaken	No. sampling station per survey
Fish survey (non-migratory)	Baseline	Monthly	November 2001 – September 2002 (excluding January 2002)	31
Fish survey (non-migratory)	Construction Year 1	Monthly for first 3 months, then quarterly	February 2008	31
			March 2008	31
			April 2008	31
			July 2008	28
			November 2008	28
			February 2009	28
Fish survey (non-migratory)	Construction Year 2	Quarterly	June 2009	28
			August 2009	28
			December 2009	28
			February 2010	28
Electro-sensitive surveys (Cable route)	Pre-construction	Biannual	August 2007	8
			November 2007	8
Electro-sensitive surveys (Cable route)	Construction Year 1	Quarterly	March 2008	8
			June 2008	8
			September 2008	8
			February 2009	8
Electro-sensitive surveys (Cable route)	Operational year 1	Quarterly	April 2010	8
			July 2010	8
			October 2010	8
			March 2010	8

5.1.2. Trawl Methodology

The baseline survey was conducted by Solenvo using the vessel FV *Boy Tom* and for the FEPA monitoring surveys by Amec E&I UK Ltd using the patrol vessel *Solway Protector*.

- Samples for both fish and epibenthos for both baseline and FEPA monitoring were collected using a 2 m steel beam trawl with approximately 50 cm steel shoes and fitted with an iron tickler chain. The mesh size of the main body of the net was 24 mm, with a 24 mm mesh cod-end. Tow duration at each station was 15 minutes. During some of the winter surveys, 15 minute tows were not possible (due to short daylight hours) therefore 7.5 minute tows were undertaken and the catch quantity standardised to 15 minutes. Start and finishing times and positions were noted using the vessel's Global Positioning System (GPS), depth was measured using the vessel's depth sounder and temperature was measured using the vessel's in-built thermometer. Surface water salinity was measured using a hand held refractometer and turbidity was measured using a Secchi disc. Prevailing weather conditions and sea state were also noted.
- After each trawl, the number and size (total length[3]) of all large fish (including electro-sensitive elasmobranch species – see Section 5.4) was recorded, prior to being returned to the sea.
- For the non-migratory fish survey only, the remainder of the catch (small fish and epibenthic fauna) was weighed and a 1 kg sub-sample taken for further sorting and analysis in the laboratory. These samples were stored in labelled bags in a cool box and immediately frozen on return to shore. The frozen samples were stored in a freezer prior to further processing. After thawing, the catch was separated into individual species. The number and

[3] The length of skates and rays was ascertained by measuring the width across the wings.

length of fish of each species was recorded and the total wet weight recorded. The total number and total weight of each species of macro-invertebrate captured was also recorded. Following this, the sub-sample catch was raised to the size of the catch.

5.2. Data Analysis

Data analysis was carried out by Amec E & I UK Ltd (formerly Entec) a summary of the results (Amec, 2011) is provided in this report.

As both non-migratory and electro-sensitive trawls were carried out using the same equipment (2 m beam trawl), all data were amalgamated for the purpose of this analysis. This provides a more complete picture of the fish and epibenthic community in the Solway Firth around the wind farm site. Since all the data were collected using the same methodology the data is directly comparable. Specific analysis of electro-sensitive species can be found in Section 5.4.

Data sampling periods were defined as baseline, pre-construction, construction and operation. It should be noted when interpreting results that no non-migratory fish surveys were conduction immediately prior to construction (as per MEMP) and no electro-sensitive fish surveys along the cable route were conducted during the baseline period, resulting in an uneven distribution of sampling effort between sampling periods.

All statistical analysis was undertaken using the statistical package PRIMER v6[1] and XLSTAT[2].

5.2.1. Multivariate Statistics

All analysis was based on a Bray-Curtis similarity index. As the raw data consisted of sparse faunal abundance and species richness with very high abundances of certain species (e.g. *Crangon crangon*) severe transformations of 4th root and log(x+1) was applied to the raw data. Statistical tests used are non-metric Multidimensional Scaling (MDS) ordinations and Analysis of Similarities (ANOSIM), see Section 2.4.1 for an explanation of each test.

5.2.2. Univariate Statistics

Diversity indices were calculated for the fish and epibenthos and the Kruskal-Wallis test with Bonferroni correction used to determine if there were any significance differences between the construction periods. ANOVA was used to determine if the mean abundance of fish and epibenthos across all construction periods differed.

5.3. Results

5.3.1. Species and habitats present

Since 2001, 38 species of fish and 53 types of invertebrate have been captured during the non-migratory fish and cable route electro-sensitive fish surveys (Tables 5.2 and 5.3). The most commonly encountered fish species were plaice (*Pleuronectes platessa*), dab (*Limanda limanda*) and whiting (*Merlangius melangus*) with brown shrimps (*Crangon crangon*), brittle stars (*Ophiura ophiura*) and hermit crabs (*Pagurus bernhardus*) representing the most abundant invertebrate species. A full list of species recorded can be found in Appendix 13.2.

Table 5.2: The top 20 most common fish species found in the beam trawls around the Robin Rigg Offshore Wind Farm 2001-2011.

Common Name	Scientific Name	Total catch
Plaice	*Pleuronectes platessa*	21,935
Dab	*Limanda limanda*	19,621
Whiting	*Merlangius merlangus*	12,392
Lesser weever	*Echiichthys vipera*	4,704
Sprat	*Sprattus sprattus*	2,534
Solenette	*Buglossidium luteum*	2,488
Pogge	*Agonus cataphractus*	2,136
Sand goby	*Pomatoschistus minitus*	1,465
Sole	*Solea solea*	1,024
Scald fish	*Arnoglossus laterna*	926
Pipefish	*Syngnathus acus*	248
Bib	*Trisopterus luscus*	156
Dragonet	*Callionymus lyra*	150
Red gurnard	*Aspitriglia cuculus*	137
Grey gurnard	*Eutrigla gurnardus*	132
Lesser spotted dogfish	*Scyliorhinus caniculus*	76
Seasnail	*Liparis liparis*	76
Thornback ray	*Raja clavata*	69
Five barbed rockling	*Gaidropsarus vulgaris*	45
Flounder	*Platichthys flesus*	40

Table 5.3: The top 20 most common invertebrate species found in the beam trawls around the Robin Rigg Offshore Wind Farm 2001-2011.

Common Name	Scientific Name	Total catch
Brown shrimps	*Crangon crangon*	97,794
Brittle stars	*Ophiura ophiura*	20,007
Hermit crabs	*Pagurus bernhardus*	2,388
Harbour crabs	*Liocarcinus depurator*	2,079
Starfish	*Asteruis rubens*	1,248
Prawn	*Palaemon adspersus*	358
Pink shrimp	*Pandalus montagui*	277
Plumose anemone	*Metridium senile*	276
Moon jelly	*Aurelia aurita*	242
Masked crab	*Corystes cassivelaunus*	170
Spider crabs	*Macropodia rostrata*	128
Small shrimps	*Philocheras trispinus*	125

Barrel jellyfish	*Rhizostoma octopus*	115
Comb jellies	*Pleurobrachia pileus*	93
Sea mouse	*Aphrodita aculeata*	86
Lions mane jellyfish	*Cyanea capillata*	83
Shore crab	*Carcinus maenas*	75
Isopod	*Idotea lineanis*	66
Spotted crabs	*Portumnus latipes*	63
Common whelks	*Buccinum undatum*	56

5.3.2. Variations in fish and epibenthic community

Variation between development periods

Fish and invertebrate catch varied between construction periods (Figure 5.2). Significant differences were found in the mean fish catch between construction periods (data standardised to a 15 minute tow; Anova $F_{4,29} = 5.4$, $P < 0.05$), however no significant differences were recorded for epibenthic invertebrates (Anova $F_{4,29} = 2.4$, $P > 0.05$). These results, however, should be treated with caution as survey design varied considerably between each year; most notably in the pre-construction year when, in accordance with the MEMP, surveying only occurred at eight sampling stations along the cable route and not at the 31 non-migratory fish sampling stations.

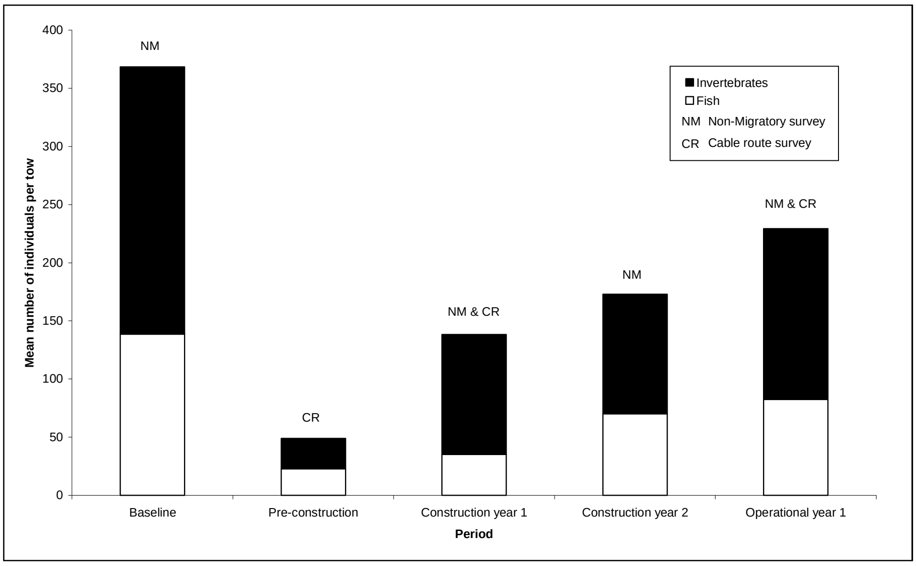


Figure 5.2: Mean number of individual fish and invertebrates caught per construction period across all sites, standardised to a 15 minute tow per survey.

The number of fish caught per sampling station declined from the baseline during the pre-construction year but since then has steadily increased during the construction and operational years. During the baseline survey, the lowest numbers of fish were caught inside and immediately surrounding the wind farm site (Figure 5.3) with this trend continuing throughout all the construction periods, with the lowest numbers of fish caught in and around the Robin Rigg sand bank (i.e. the development site). No data were available at the sampling stations inside the wind farm site from the second year of construction onwards, due to the presence of turbine bases preventing sampling trawls being undertaken.

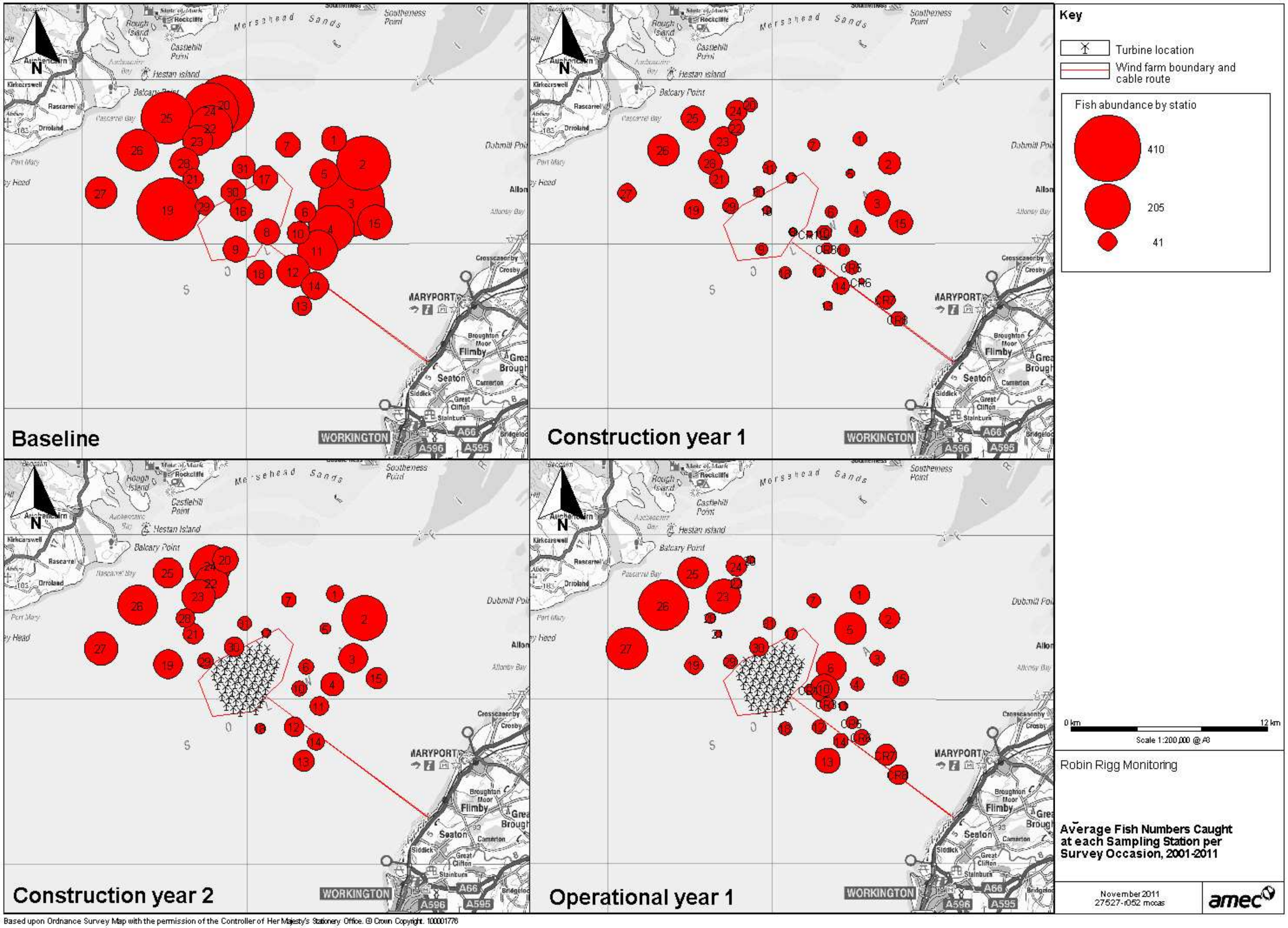


Figure 5.3: Average fish numbers caught at each sampling station per survey occasion, 2001-2011.

The invertebrate catches also showed a decline between construction and pre-construction years, although numbers increased again during construction year 1 and have remained fairly constant since (Figure 5.2). The distribution of invertebrates across the site has also changed during this time (Figure 5.4). During the baseline surveys invertebrate abundance was fairly uniform across the site although numbers were greatest at those sampling stations nearest to the Scottish coastline. However, although invertebrates decreased at all sampling stations during construction years, the abundance of invertebrates increased considerably at the sampling stations nearest the Scottish coastline due to a large catch of brittle stars *(Ophiura ophuira)* (Figure 5.4). During construction year one, construction year two, and operational year one, a large number of these brittle stars were captured at two trawl locations near the Scottish coastline. Of these, operational year one showed the largest catches (Figure 5.5), although when tested statistically the changes were not found to be significantly different across the different periods (Anova $F_{3,20} = 2.8$, $P > 0.05$). (It should be note that during pre-construction surveying only occurred on the cable route and no brittle stars have been found on the cable route in any construction period).

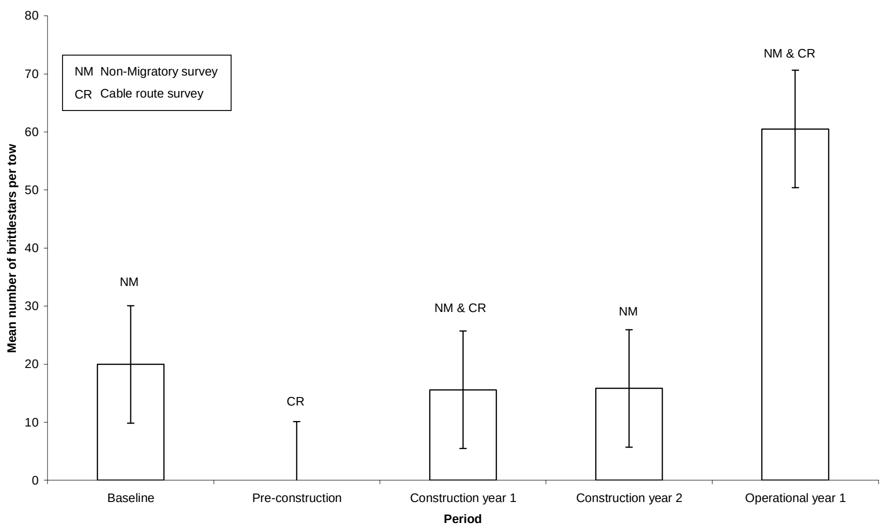


Figure 5.5: Mean number of brittle stars (<u>Ophiura ophuira</u>) per construction period (standardised per tow per survey). Error bars = Standard Error.

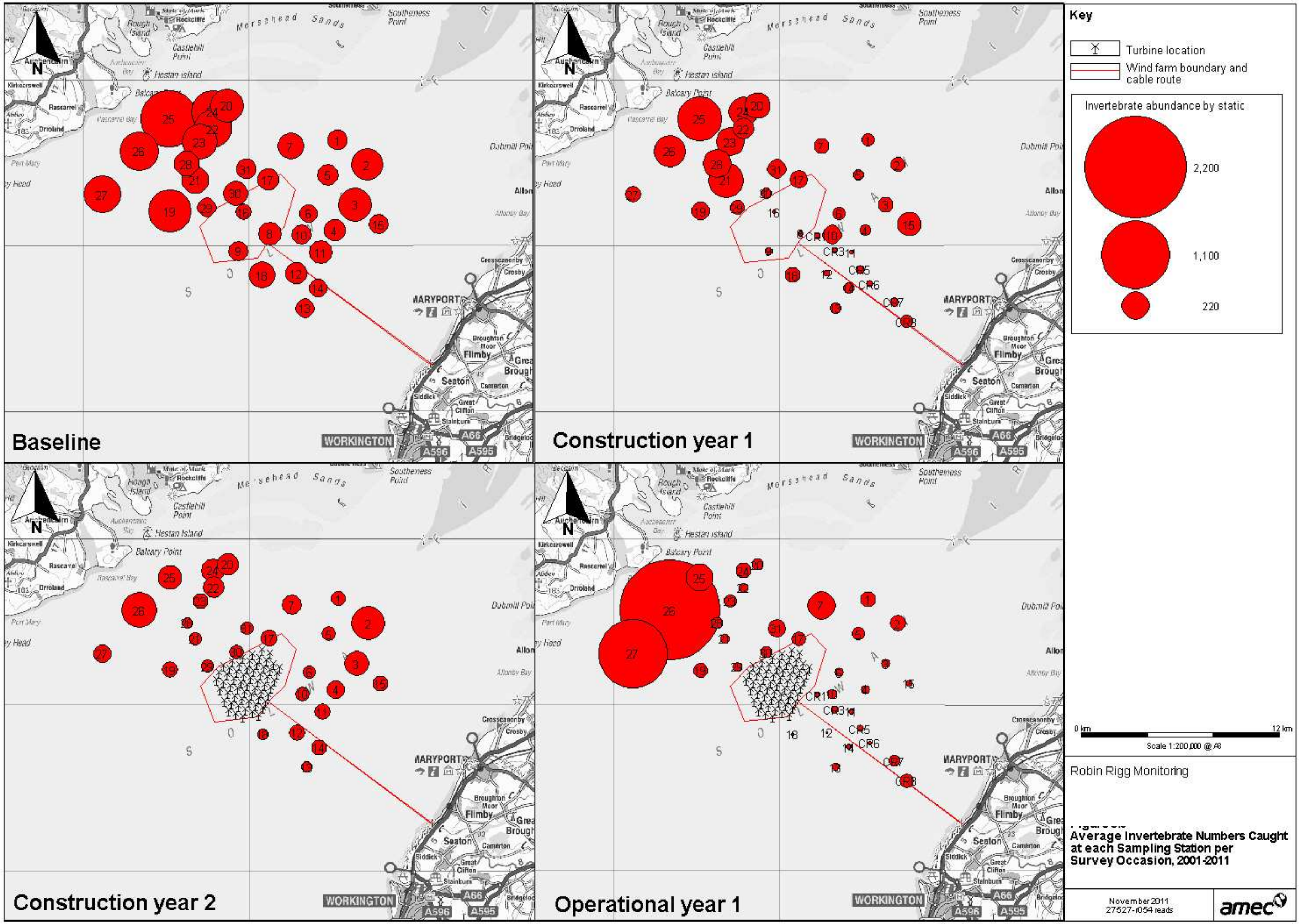


Figure 5.4: Average invertebrate numbers caught at each sampling station per survey occasion, 2001-2011.

Catch numbers of brown shrimp (*Crangon crangon*), an important local fishery species, were highest during the baseline surveys, and after a minimum catch recorded during the pre-construction period, have remained fairly consistent between construction and operational years (Figure 5.6). These differences in mean numbers of the brown shrimp catch (standardised to 15 minute tow) were found to be statistically significant between construction periods (Anova $F_{4,29} = 3.1$, $P < 0.05$).

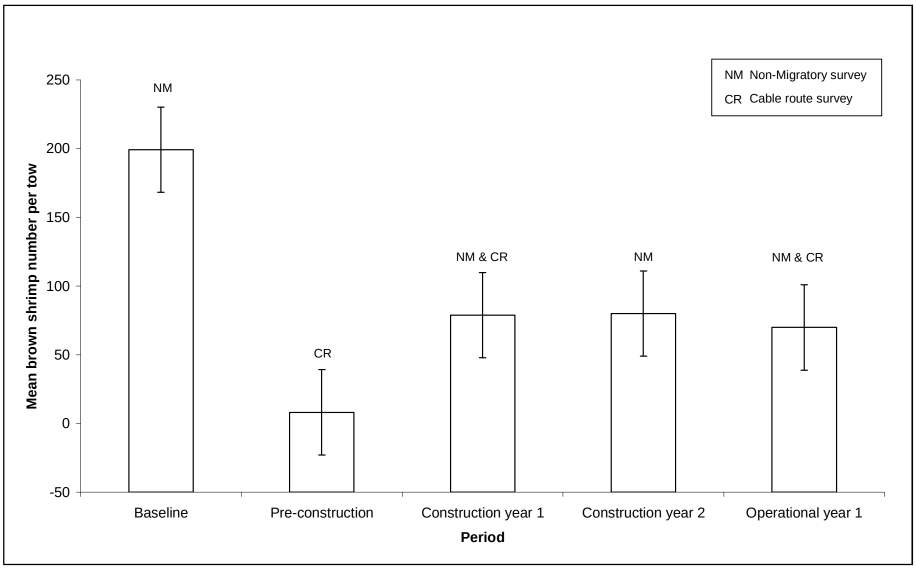


Figure 5.6: Mean number of brown shrimp (Crangon crangon) per construction period (standardised per tow per survey). Error bars = Standard Error

Catches of brown shrimp during the baseline were greatest at those sampling stations nearest to the Scottish coastline, but declined over construction years 1 and 2 (Figure 5.7). Operational year catches showed an increase again in those stations nearest the Scottish coastline, however catches across the rest of the site have continued to decline.

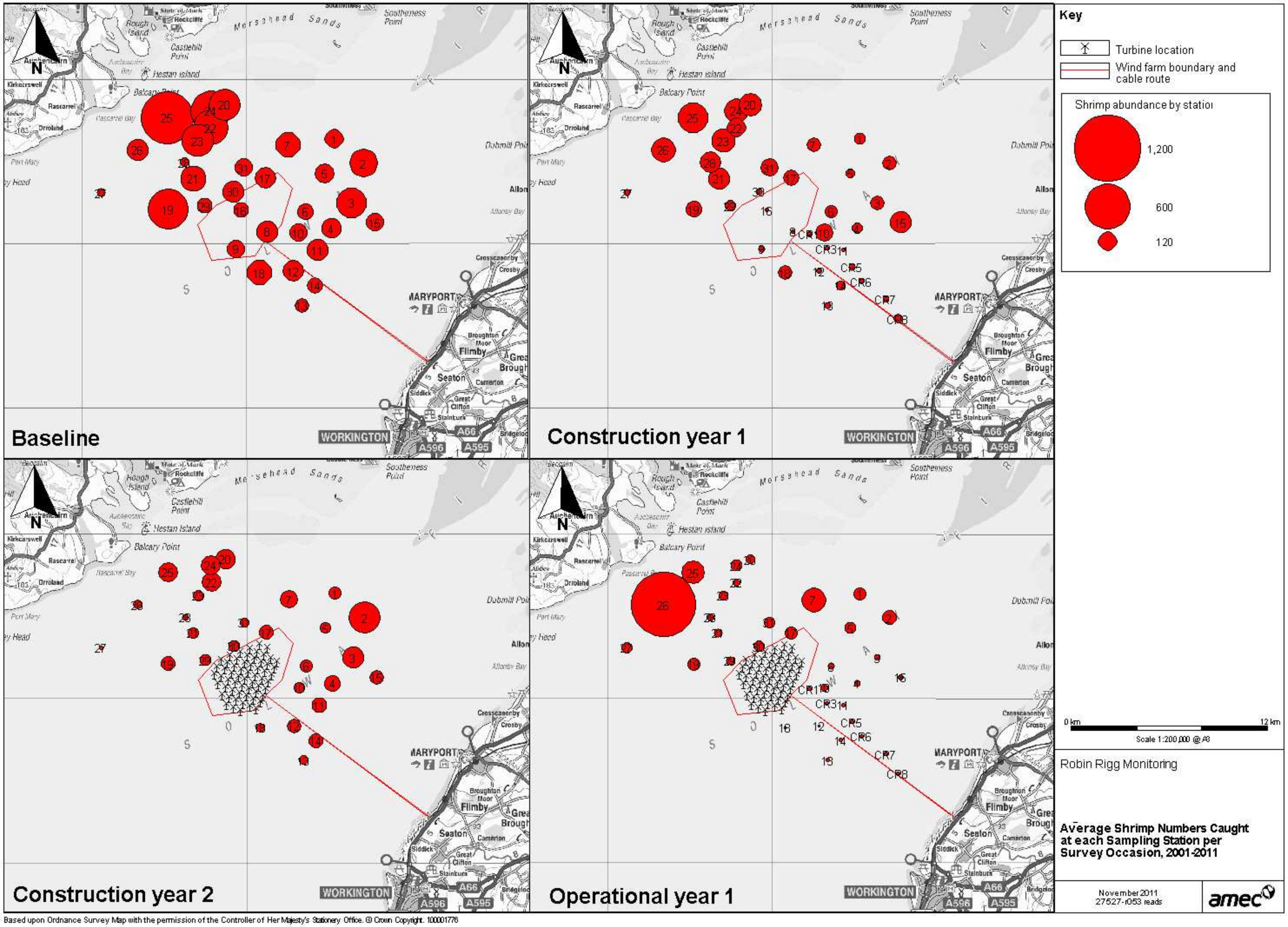


Figure 5.7: Average brown shrimp (Crangon crangon) numbers caught at each sampling station per survey occasion, 2001-2011.

Variation between seasons

Fish and invertebrate catches varied seasonally (Figure 5.8) with the lowest number of fish caught during the spring, and numbers increasing through the summer, peaking during the autumn months before decreasing again through the winter. The same trend was observed for mean numbers of all invertebrates. Numbers of fish and invertebrates (standardised to a 15 minute tow) were found not to be statistically different between seasons (Anova; fish: $F_{3,30} = 2.3$, $P > 0.05$; invertebrates: $F_{3,30} = 1.8$, $P > 0.05$).

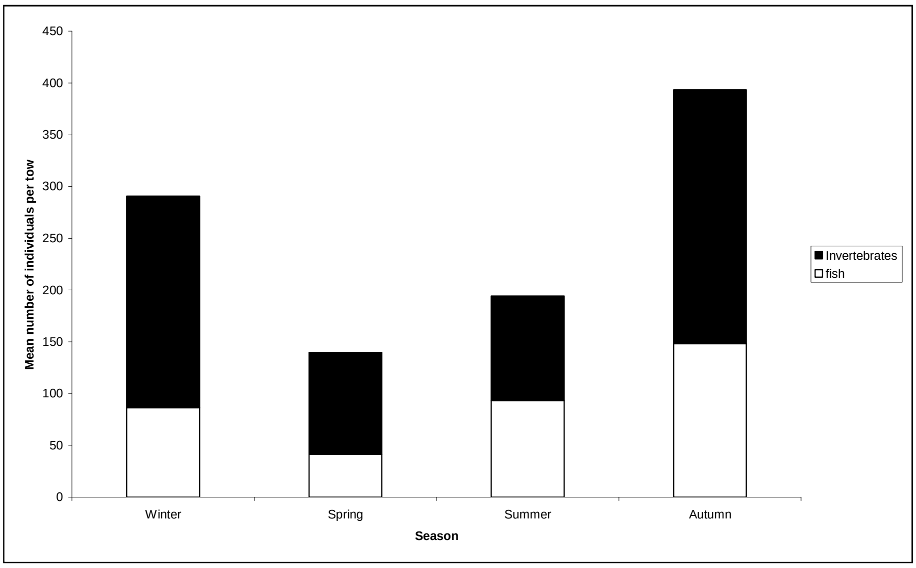


Figure 5.8: Mean number of fish & invertebrates per season (standardised per tow per survey).

Seasonal variations in the abundance of the brown shrimp were also observed (Figure 5.9) with the lowest numbers per sampling station recorded in the summer months, and numbers peaking to a maximum during the autumn and winter (Figure 5.9). Despite these visible changes in abundance, mean numbers of brown shrimp (standardised to a 15 minute tow) were found not to differ significantly between seasons (Anova $F_{3,30} = 2.7$, $P > 0.05$).

5.4. Electro-sensitive species

Electro-sensitive species can detect two types of electric fields (E-fields), which are localized polar and larger scale uniform E-fields. Species sensitive to electromagnetic fields can be categorised into two groups based upon their mode of detection: those which can detect induced electrical currents; and those which can directly detect the magnetic field. Elasmobranchs (sharks, rays and skates) are the major group of organisms which are electro-sensitive. This is due to the Ampullae of Lorenzie (AoL), a group of pores on the surface of the skin that conduct electricity with a similar resistance to seawater. Using these structures, elasmobranchs can detect very weak voltage gradients of 0.5 µV/m to 5 nV/cm (Gill *et al,* 2005). All elasmobranchs, as well as some teleosts (bony fish such as plaice), are able to detect magnetic fields, (Gill *et al,* 2005).

Whilst all electro and/or magneto sensitive species are acknowledged in this report, as per both COWRIE and FEPA guidance, the focal species are the elasmobranch. The reason for this being that shielding and burial are likely to attenuate much of the EMF from the cable, therefore only the most sensitive of species, i.e. the elasmobranches, are likely to be affected.

There were only three elasmobranch species caught in the vicinity of the Robin Rigg Offshore Wind Farm: thornback ray (*Raja clavata*); blond ray (*Raja brachyura*); and lesser-spotted dogfish

(*Scyliorhinus canicula*). These species were found in both the electro-sensitive fish surveys (along the cable route), as well as the non-migratory fish surveys (Table 5.4).

Table 5.4 Numbers of elasmobranch species caught during the trawl surveys. (CR = Cable Route)

Construction period	**Total numbers of elasmobranch**	**Thornback ray (*Raja clavata*)**	**Blond ray (*Raja brachyuran)***	**Lesser-spotted dogfish (*Scyliorhinus canicula*)**
Baseline	Total (inc. CR)	27	0	44
	CR only	Not surveyed		
Pre-construction	Total (inc. CR)	Not surveyed		
	CR only	2	0	0
Construction year 1	Total (inc. CR)	16	0	9
	CR only	3	0	1
Construction year 2	Total (inc. CR)	13	1	3
	CR only	Not surveyed		
Operation	Total (inc. CR)	11	1	24
	CR only	4	0	14

No significant differences were found between total elasmobranch catches across the construction periods (ANOVA, F=0.82, p=0.52). Catches of elasmobranchs were low when compared to other species, average abundance per tow ranged from 0.125 to 0.225, making any conclusions drawn from statistical analysis less certain. Despite this, when catch data was examined per tow, patterns of abundance were evident, with pre-construction and construction years showing a decrease in overall abundance from the baseline, and numbers increasing again during the operational year (Figure 5.9).

Comparisons of catch data between the cable route and non-migratory surveys shows a slightly different pattern (Figure 5.10). Elasmobranch catches during the non-migratory surveys do not differ by much between periods, and follow the general pattern seen in other fish species during the surveys, i.e. a decrease after the baseline followed by a steady increase in abundance. No significant difference was found in the elasmobranch catches of the non-migratory fish surveys between periods (ANOVA, F=1.19, p=0.34).

The cable route surveys, undertaken in the pre-construction, construction year 1, and the operational period, show average catches per tow of 0.125 individuals during the pre-construction and construction years, followed by an increased catch rate of 0.563 individuals per tow during the operational phase. This increase in the average catch was however the result of a single survey and as such no significant differences were found between periods (ANOVA, F=0.75, p=0.51).

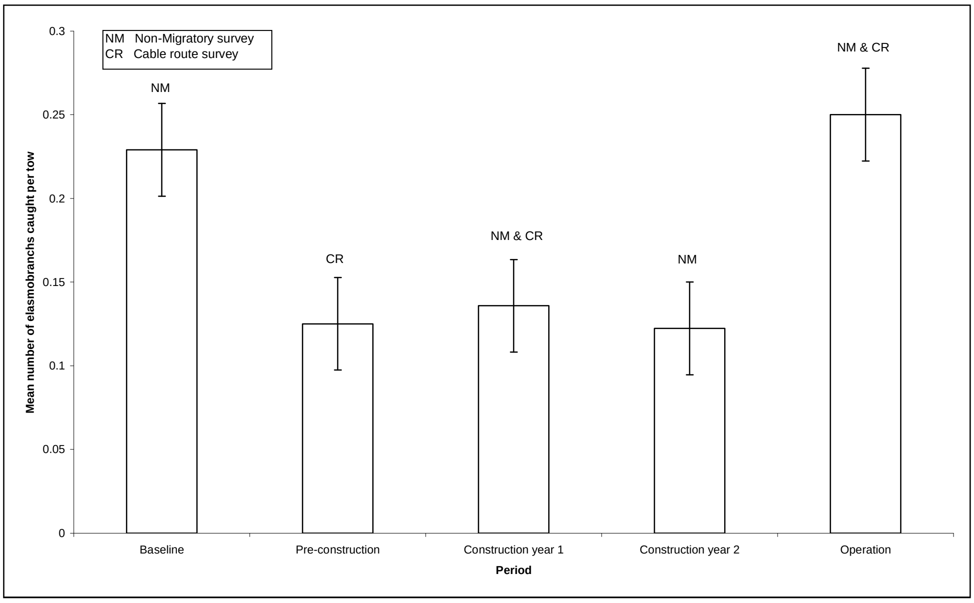


Figure 5.9: Mean number of elasmobranches per construction period (standardised per tow per survey). Error bars = Standard Error.

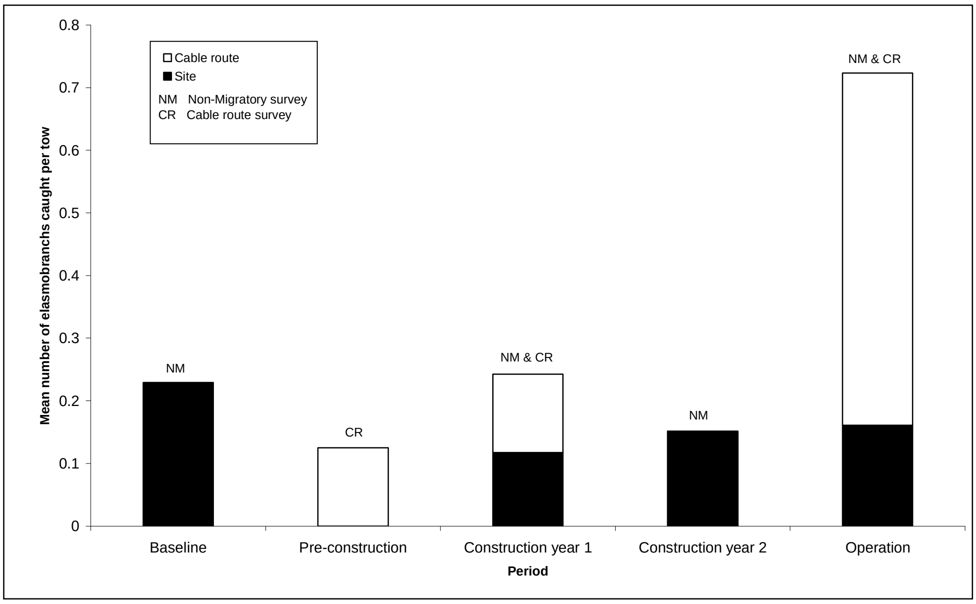


Figure 5.10: Mean number of elasmobranches per construction period (standardised per tow per survey) at the cable route and wind farm site. Error bars = standard error.

6. BIRDS

6.1. Analysis methodology

Analysis targeted key species of seabird as defined during RRMG liaison. The stages of ecological analysis for birds are identified below. Seven bird species (common scoter, diver species {red-throated, black-throated and great northern}, Manx shearwater, gannet, cormorant, kittiwake and guillemot) were initially targeted for analysis (see Report No 035_R_NPC_EON_2). For this second phase of analysis, diver species was singled down to red-throated diver and razorbill, auk species (razorbill, guillemot and auk species combined) and large gulls (herring, great black-backed, lesser black-backed and large gull combined) were also examined.

To ensure a robust approach was undertaken, the following steps were followed:

i) All counts available from the sub-consultants (Ecology Consulting) since 2001 have been collated by NPC, to ensure a complete dataset is available to E.ON and the RRMG. Data spreadsheets were converted to a standardised format and combined. Survey routes and observations were then visualised using ArcGIS.

Throughout these two procedures, data were checked visually and any concerns were referred back to the 3rd party surveyors and errors were either corrected or data removed from the analysis if no information was available as to where mistakes had been made or errors existed.

ii) Raw data were plotted in ArcGIS with circles of differing sizes representing the number of individuals constituting each observation. Colour was used to distinguish between animals observed during the different construction periods.

iii) Boat survey transects were segmented by distance (600 m) to produce replicate sampling blocks of equal effort. The number of observations was calculated for each block for both birds on the water and in flight. The depth and sediment type for each sampling block was also extracted using ArcGIS[4]. Depth was adjusted for tidal state using tidal measurements recorded at Workington[5].

All data was divided into three phases:

- Pre-construction (baseline) - 2001-2007;
- Construction - January 2008-February 2010; and
- Operational year 1 - March 2010-March 2011.

All statistical analysis was performed using R 2.13.1.

iv) As in the previous analysis report (Report No: 035_R_NPC_EON_2), simple General Linear Models (GLM), accounting for month and effort were applied to data for birds on the water and in the air separately, to investigate changes in numbers of observations among the three development phases.

It should be noted that the outputs will differ slightly from those previously reported as the method of defining sampling block has been improved and made more robust (previously time was used to define sampling effort not distance) and month was not included in the previous analysis.

v) Birds on the sea:
For each species in each phase of the development, detection functions were applied to the data to take into account imperfect detection of animals by surveyors. Hazard rate and half normal detection

[4] SeaZone Solutions Limited
[5] Data supplied by the British Oceanographic Data Centre as part of the function of the National Tidal & Sea Level Facility, hosted by the Proudman Oceanographic Laboratory and funded by the Environment Agency and the Natural Environment Research Council

functions were applied to the data sets and the best model chosen based on the lowest AIC[6] and best goodness of fit.

General Additive Models (GAMs) were fitted, incorporating the calculated detection function and a variety of covariate combinations (depth, sediment type, month, distance to coast, xy position). Sea state was not used as this information was not available for bird data prior to 2004. The final model was chosen based on GCV[7] score.

For all species, the final models included month and xy position as this provided the best fit to the data without including variables exhibiting co-linerality. The GAMs were then used to predict distribution in 600 by 600 m grid cells across the whole survey area, producing density surfaces and abundance estimates for the entire survey and turbine area in each phase of the development.

For each prediction grid cell, the difference in value between the three phases of the development was calculated (difference plots). A parametric bootstrap methodology was used to calculate standard errors around overall predictions for the turbine and survey areas and for each individual grid cell in order to assess statistical significance of any changes observed. The standard errors were converted to standard Z scores[8] in order to assess significance of changes in individual prediction grid cells.

vi) Birds in flight:
ESAS methodology incorporates recording flying birds at regular intervals as a "snapshot". This method was not applied to the data collection methods for Robin Rigg, limiting the analysis options available for birds in flight. Specifically, distance sampling techniques used for birds on the water could not be applied. As a result, available flight height data were grouped into six bands (0-5 m; 6-25 m; 26-34 m; 35-125 m; 126-200 m and 200 m plus).These bands were chosen based on the known rotor height (35-125 m), bird behaviour and known practicalities of collecting data. When sufficient data were available, the proportion of birds flying in each band for each construction phase was calculated and compared using Chi-square tests. To aid this analysis and interpretation, all data above and below rotor height were combined into single bands (i.e. 0-34 m; 35-125 m and 126 m plus).

For all analysis except the density surface models, data from the entire survey area was combined. For density estimates calculated from the density surface models, a boundary was drawn around the outer edge of the wind farm in order to produce separate estimates for the wind farm area and the survey area as a whole.

[6] Akaike Information Criteria: measure of goodness of fit and model complexity.
[7] Generalised Cross Validation: used as a measure of predicted error within model.
[8] The number of standard deviations the count is from the mean of the distribution.

6.2. Results

Table 6.1 below presents a summary of the data available for the analysis under discussion. A full list of species recorded can be found in Appendix 13.3.

Table 6.1: Summary of available data for birds, expressed as total number recorded in each phase (Total) and the number of sightings per unit survey effort (SPUE). Effort is defined as the total number of segments surveyed for each phase.

	Pre-construction		Construction		Operation year 1	
	Total	SPUE	Total	SPUE	Total	SPUE
Common scoter	70660	11.69	87910	7.05	19547	6.39
All diver species	1046	0.17	2182	0.17	794	0.26
Red-throated diver	550	0.09	562	0.05	506	0.17
Manx shearwater	1566	0.26	1672	0.13	160	0.05
Gannet	476	0.08	845	0.07	132	0.04
Cormorant	454	0.08	3266	0.26	1225	0.40
Kittiwake	922	0.15	1794	0.14	286	0.09
Herring gull	1294	0.21	1837	0.15	255	0.08
Great black-backed gull	207	0.03	287	0.05	224	0.07
Large gulls	5076	0.84	17503	1.40	3949	1.29
Guillemot	4157	0.69	5840	0.47	1736	0.57
Razorbill	2199	0.36	2956	0.24	608	0.20
All auks	6095	1.01	10721	0.86	3106	1.02
Scaup	705	0.12	391	0.03	2031	0.66

6.2.1. Simple GLMs

Table 6.2 below summarises the outputs from the simple GLMs in the form of p-values. Data is divided into birds on the water and birds in flight. A value of 0.05 or less was used to define significance.

Table 6.2a: Summary of simple GLM outputs for birds recorded on the water. Pink = significant decrease in numbers between periods; Green = significant increase in numbers between periods.

On Sea	Preconstruction to construction	Construction to operation	Preconstruction to operation
Common scoter	0.026	0.795	0.087
All divers	0.446	0.178	0.532
Red-throated diver	0.002	<0.001	0.335
Manx shearwater	0.081	0.019	0.443
Gannet	0.793	0.007	0.013
Cormorant	0.003	0.474	0.002
Kittiwake	0.366	0.010	0.004
Herring gull	0.157	0.361	0.130
Greater black-backed gull	0.023	0.040	<0.001
Large gulls	0.251	0.168	0.043
Guillemot	0.010	0.795	0.118
Razorbill	0.523	0.737	0.463
All auks	0.140	0.821	0.407

Table 6.2b: Summary of simple GLM outputs for birds recorded in flight. Pink = significant decrease in numbers between periods; Green = significant increase in numbers between periods.

Flying	Preconstruction to construction	Construction to operation	Preconstruction to operation
Common scoter	0.135	0.096	0.021
All divers	0.578	0.038	0.030
Red-throated diver	0.056	<0.001	0.003
Manx shearwater	0.006	0.502	0.047
Gannet	0.491	0.224	0.118
Cormorant	<0.001	0.013	<0.001
Kittiwake	0.673	0.452	0.336
Herring gull	0.022	0.606	0.074
Greater black-backed gull	0.876	0.034	0.082
All large gulls	0.058	0.338	0.656
Guillemot	0.421	0.073	0.362
Razorbill	<0.001	0.646	0.003
All auks	<0.001	0.040	0.188

6.2.2. Scaup

Scaup were highlighted in the ES as being present within the Solway Firth in regionally important numbers although not within 2 km of the wind farm area. The numbers recorded are included in Table 6.1.

As can be seen from Figure 6.1 below, all sightings (in flight and on the sea) occurred during the winter months (November-January). The mean number of scaup recorded per sampling block through the different construction periods can be seen in Figure 6.2 and the location of the sightings in Figure 6.3.

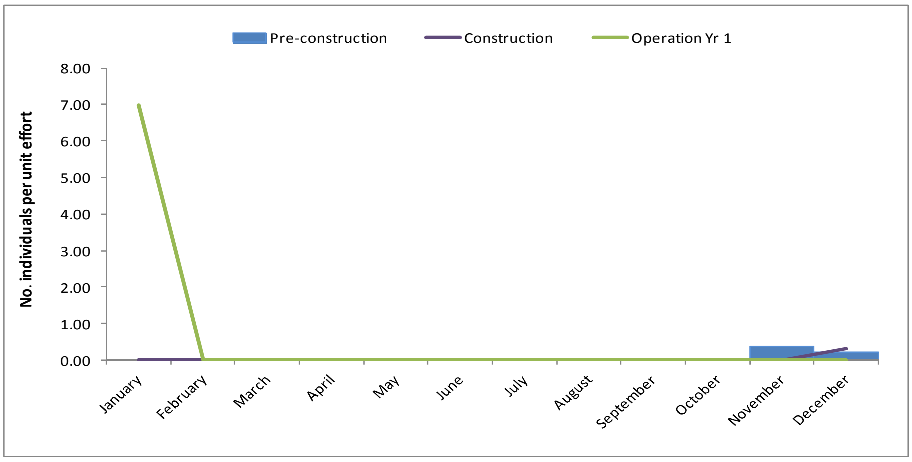


Figure 6.1a: Mean number of scaup observed on the sea per month during the pre-construction, construction and operational phases

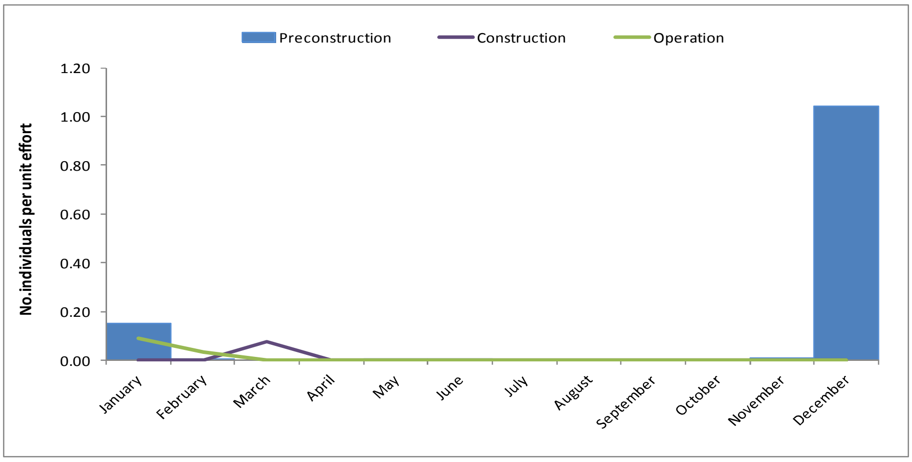


Figure 6.1b: Mean number of scaup observed in flight per month during the pre-construction, construction and operational phases

(a) (b)

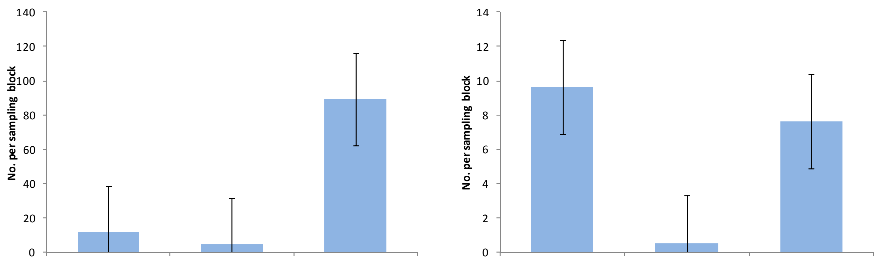


Figure 6.2: Mean number of scaup observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error)

- Birds on the sea

Only 20 sightings were recorded through the entire study period, totalling 3127 individuals. Of these, 1107 were recorded in band E (and would therefore be removed from any statistical analysis) and a further 518 were in flight. This resulted in only seven sightings on the water being available for analysis. Therefore, birds on the water could not be analysed due to the small sample size.

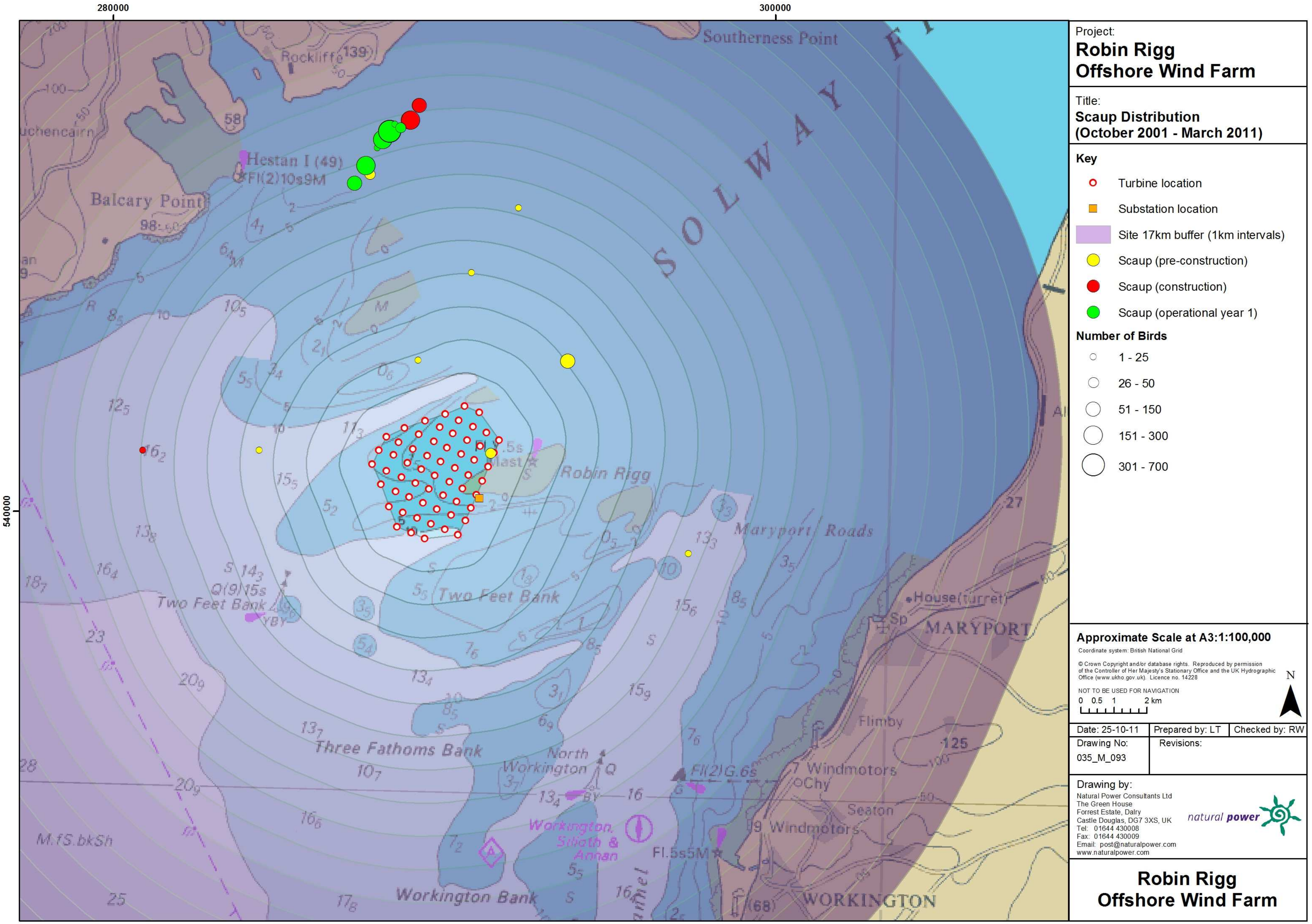


Figure 6.3: Locations of raw observations of scaup during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed.

- Birds in flight

The percentage of birds recorded in different height bands are illustrated in Figure 6.4 below. No birds were observed flying at rotor height (therefore no Chi-square test conducted).

Figure 6.4: The percentage of scaup recorded at different height bands relative to rotor height during the different phases of development. No Chi-squared test was performed as no birds were recorded at rotor height.

6.2.3. Common scoter

Common scoter were recorded predominantly to the northwest of the survey area (north-west of the wind farm site) throughout the year with large numbers recorded during the summer and autumn (Figure 6.5). The raw data indicate a decline in numbers compared to pre-construction (Figure 6.6 and 6.7).

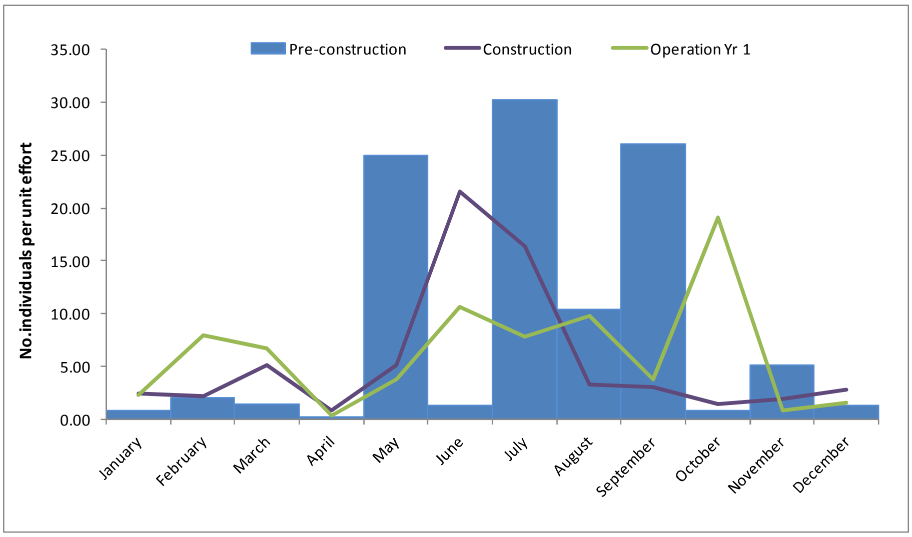


Figure 6.5a: Mean number of common scoter observed on the sea per month during the pre-construction, construction and operational phases

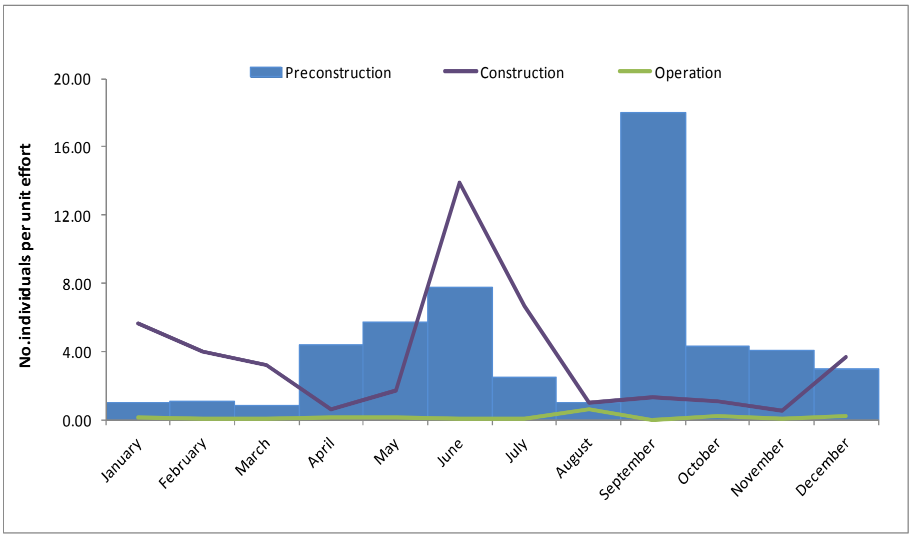


Figure 6.5b: Mean number of common scoter observed in flight per month during the pre-construction, construction and operational phases

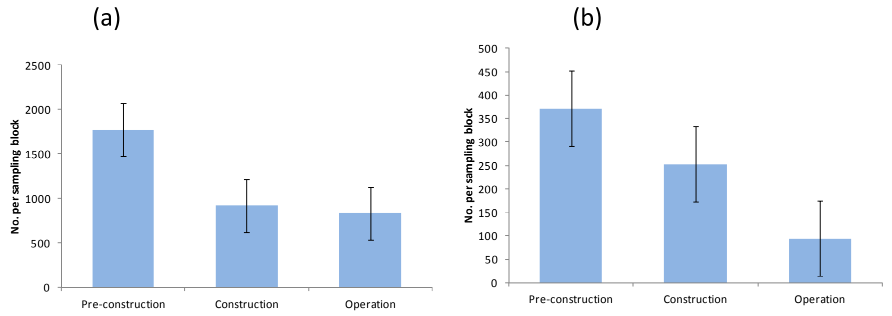


Figure 6.6: Mean number of common scoter observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error)

Results from the simple GLM also suggest a decline in numbers; on the water between pre-construction and construction and for birds in flight between preconstruction and operation (Table 6.3).

Table 6.3: Results from simple GLM for number of common scoter observed in flight and on the sea. Pink indicates a significant decline.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.026	0.795	0.087
In flight	0.135	0.096	0.021

- Birds on the sea

A half normal detection function was used for this analysis and the month of June used to estimate abundance. Due to the large group sizes recorded, cluster size was included as an additional covariate when calculating the detection function. The predicted number of scoter for each construction phase can be found in Figure 6.8 below.

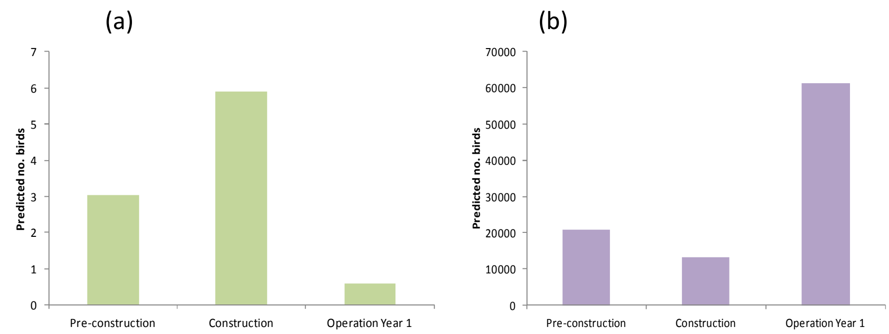


Figure 6.8: Predicted number of common scoter using (a) the turbine area and (b) the survey area (including the survey area) during the pre-construction, construction and operational phases.

Standard errors are not included in these figures due to the large size of the values. These figures are presented for completeness but we have little confidence in these results and advise that raw observations and simple GLM results should be used to draw conclusions regarding changes in common scoter usage of the survey area.

Density surface maps based on these predictions can be found in Figure 6.9 and the differences between the phases in Figure 6.10.

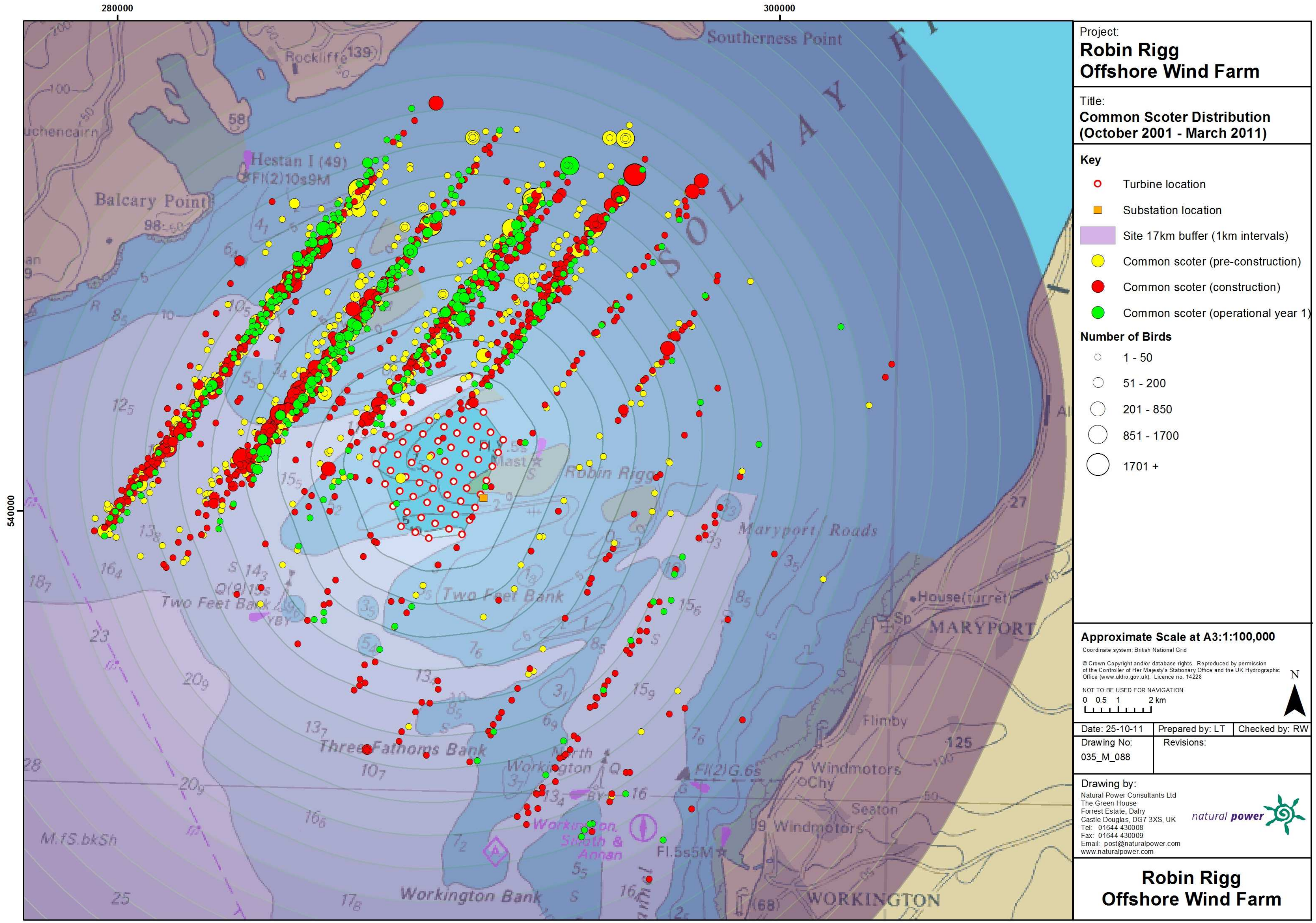


Figure 6.7: Locations of raw observations of common scoter during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed

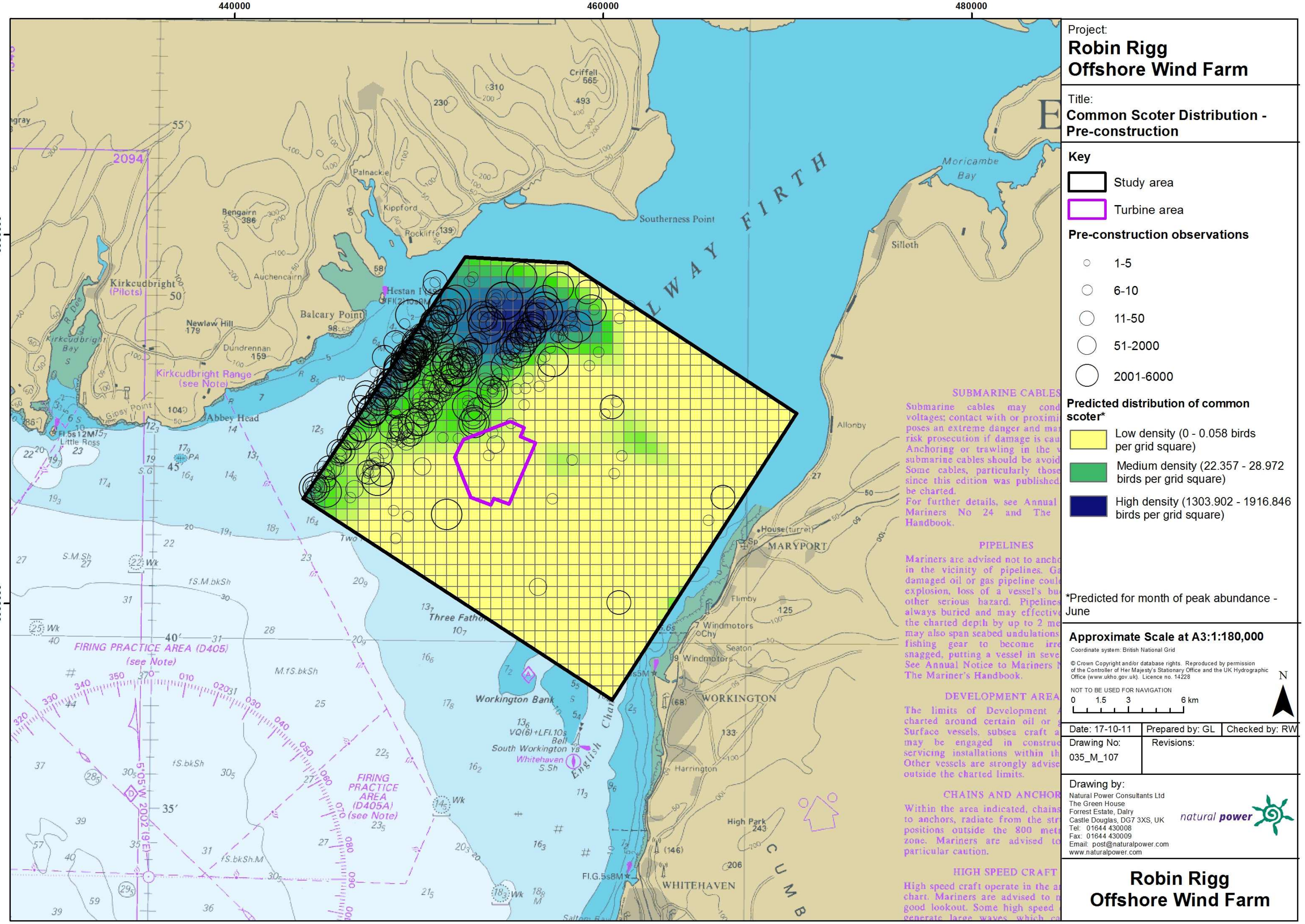


Figure 6.9a: Density surface map of the predicted density of common scoter across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

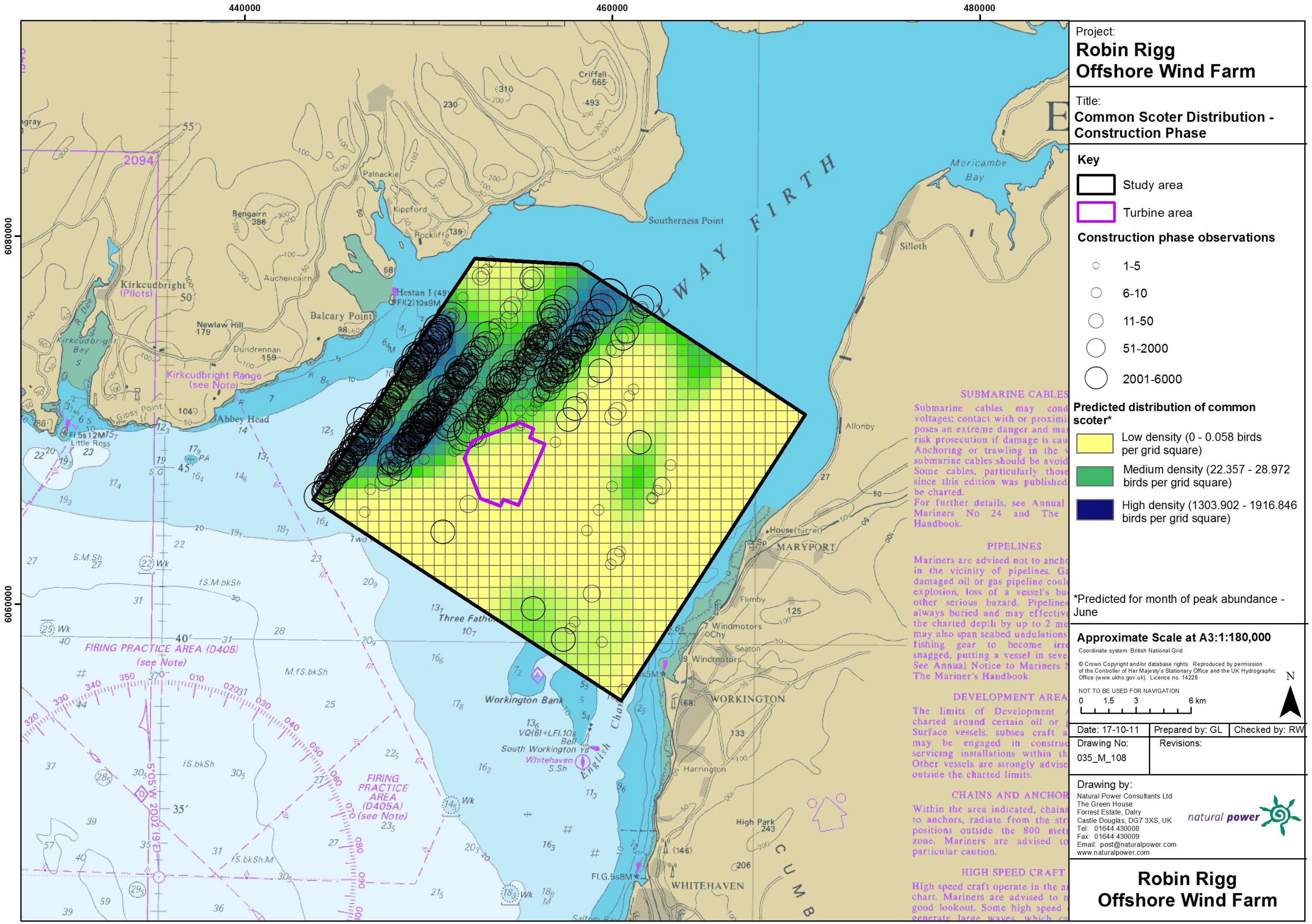


Figure 6.9b: Density surface map of the predicted density of common scoter across the survey area during the construction phase. Open circles show the locations of the raw observations

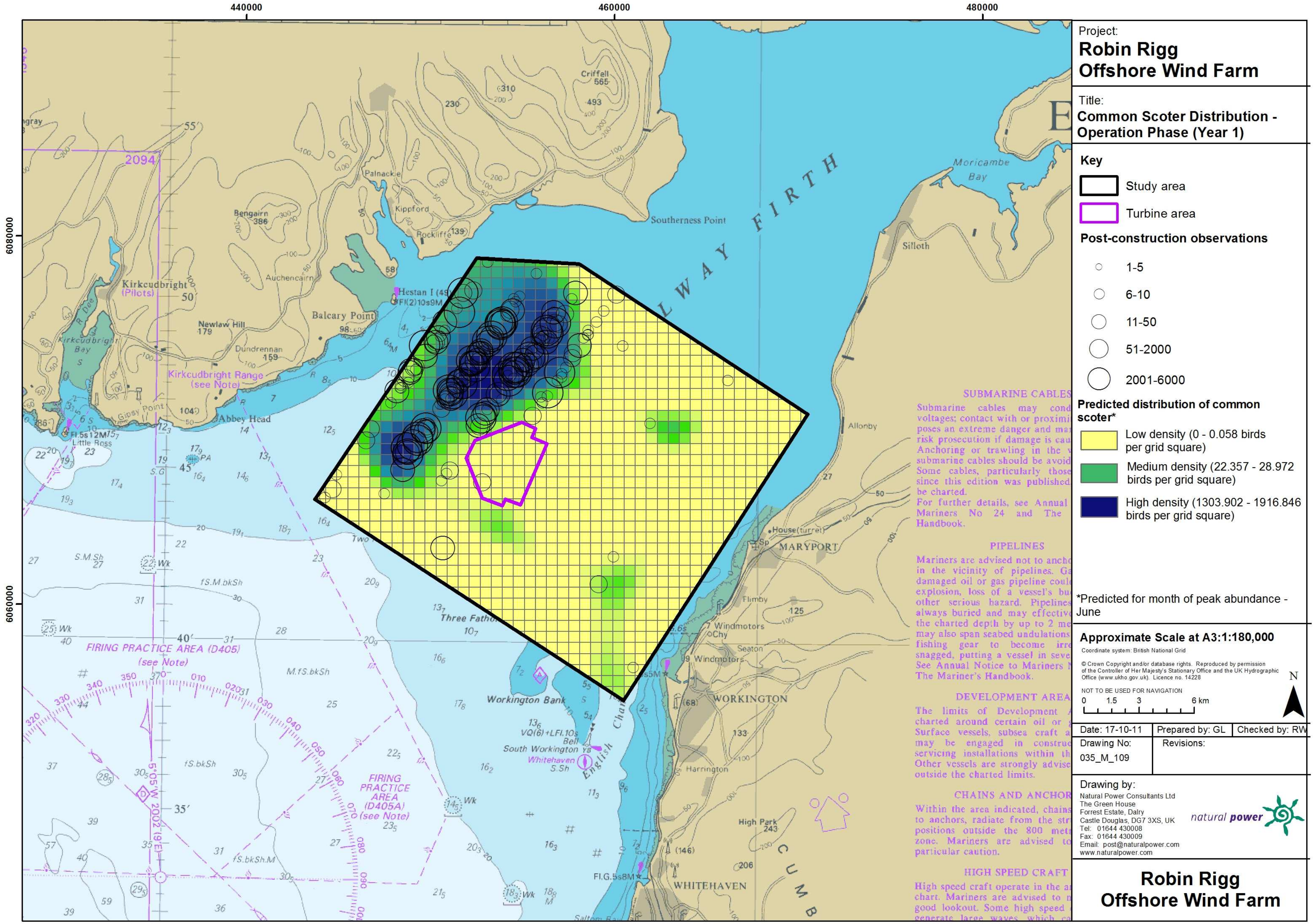


Figure 6.9c: Density surface map of the predicted density of common scoter across the survey area during the operational phase. Open circles show the locations of the raw observations.

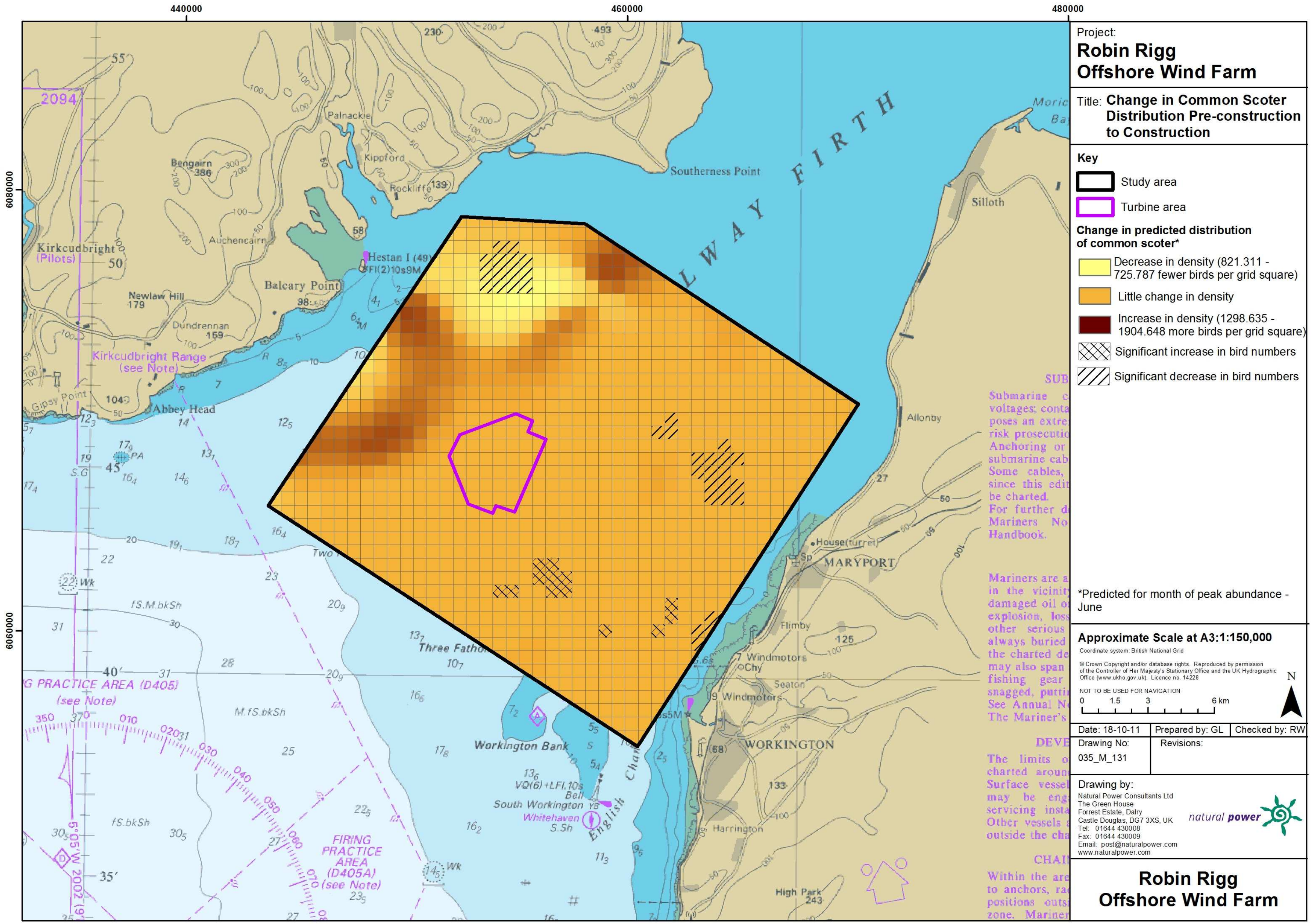


Figure 6.10a: Difference plot of the change in predicted density of common scoter between the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

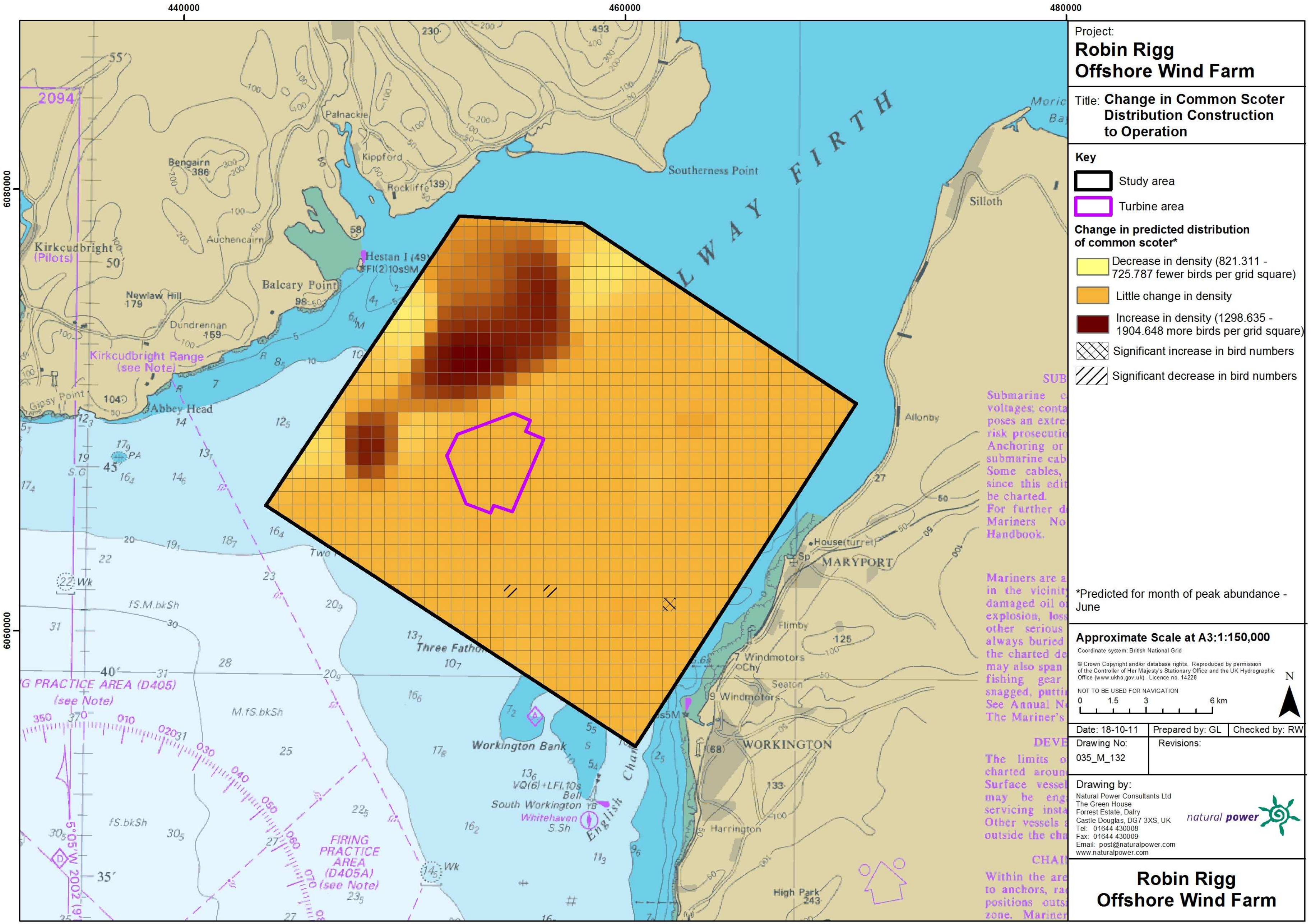


Figure 6.10b: Difference plot of the change in predicted density of common scoter between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

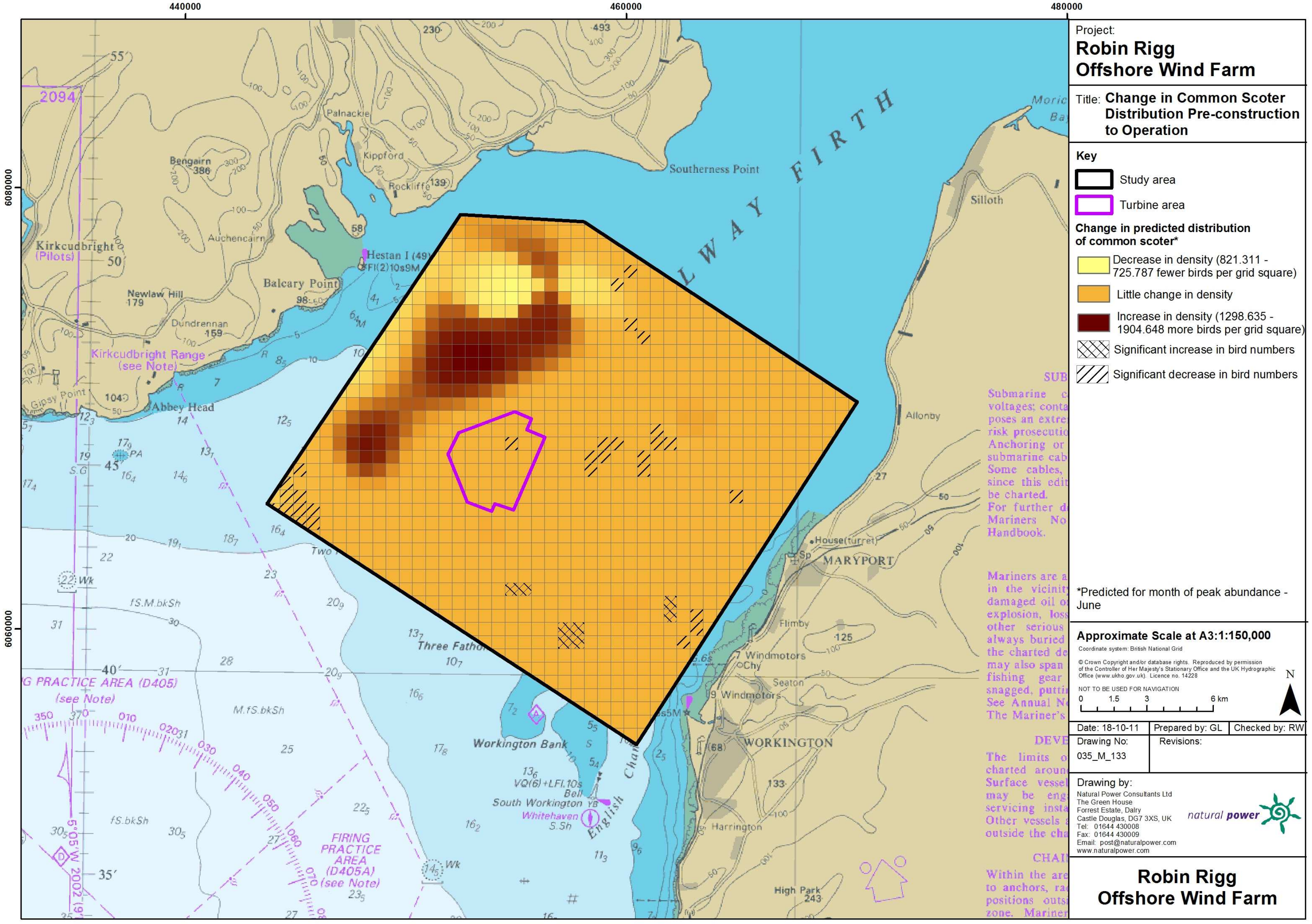


Figure 6.1ca: Difference plot of the change in predicted density of common scoter between the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines.

- Birds in flight

The percentage of common scoter recorded in different height bands relative to rotor height can be found in Table 6.4 and Figure 6.11a. The band 35-125 represents rotor height. The majority of scoter were observed flying at less than 25 m height, resulting in less than 0.5% observed flying at rotor height. Data were combined for Chi-squared analysis (Figure 6.11b) and a significant difference was found between flight bands (χ^2 = 47.81, p = <0.0001, 2 df).

Table 6.4: Percentage of common scoter recorded in different height bands. Rotor height = 35-125 m.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	61.0	38.8	0	0.06	0	0.08
Construction	60.5	38.9	0.05	0.5	0	0
Operation Yr. 1	75.3	24.4	0.2	0.2	0	0

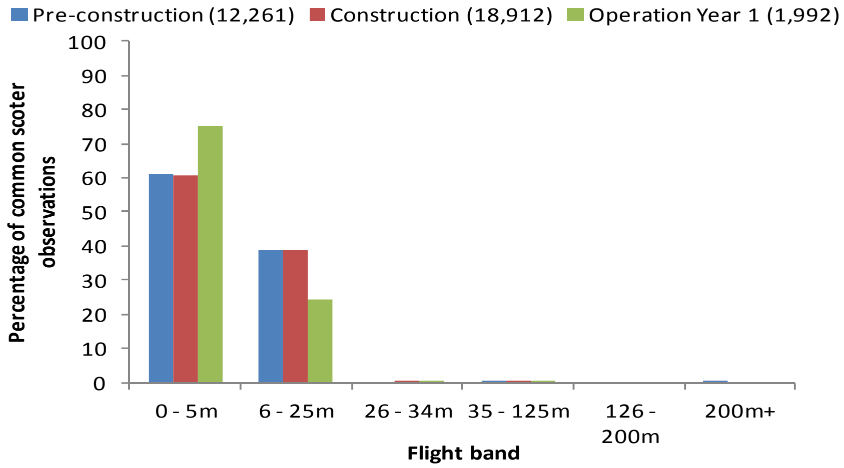


Figure 6.11a: Percentage of common scoter recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

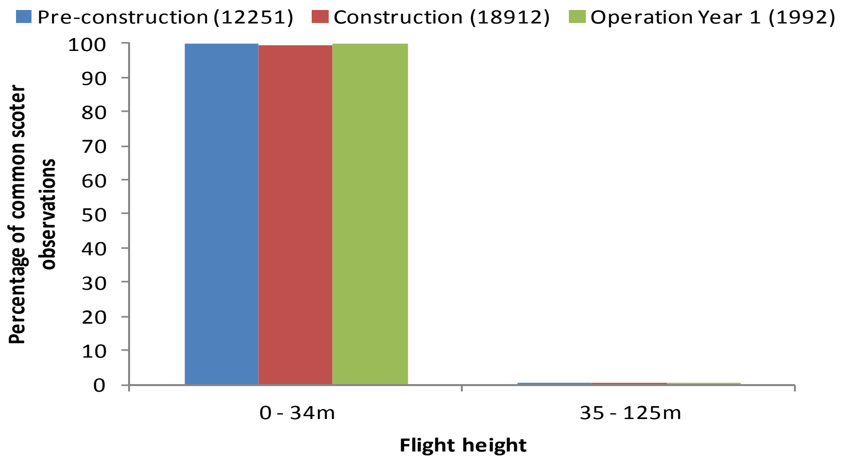


Figure 6.11b: Percentage of common scoter recorded in the combined flight bands used in the Chi-squared analysis. Figures in brackets represent total number.

6.2.4. Red-throated diver

Red-throated diver were recorded throughout the year with the greatest numbers, both on the water and in flight, observed in September during pre-construction although a similar peak was not observed in later phases (Figure 6.12). The raw data indicate a decline during construction for birds on the sea, while the pattern for birds in flight is less clear (Figures 6.13 and 6.14) although a decline for birds in flight could also be indicated.

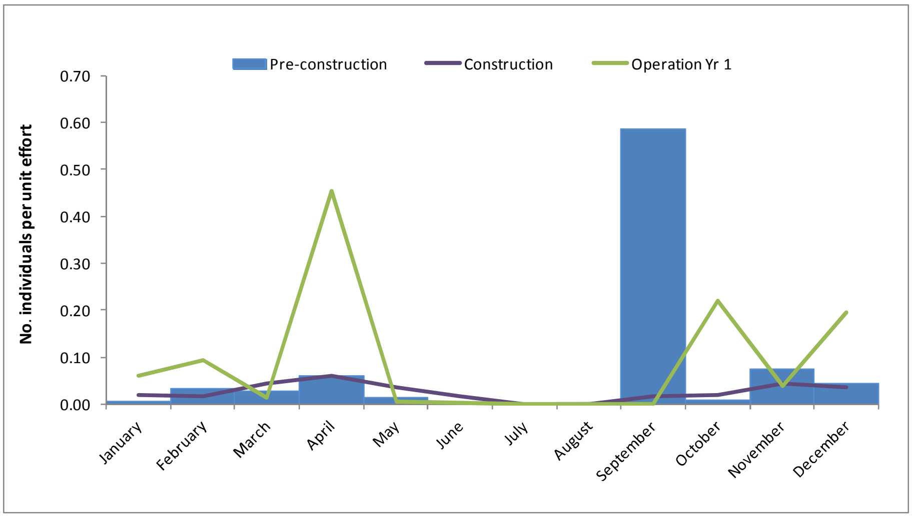


Figure 6.12a: Mean number of red-throated diver observed on the sea per month during the pre-construction, construction and operational phases.

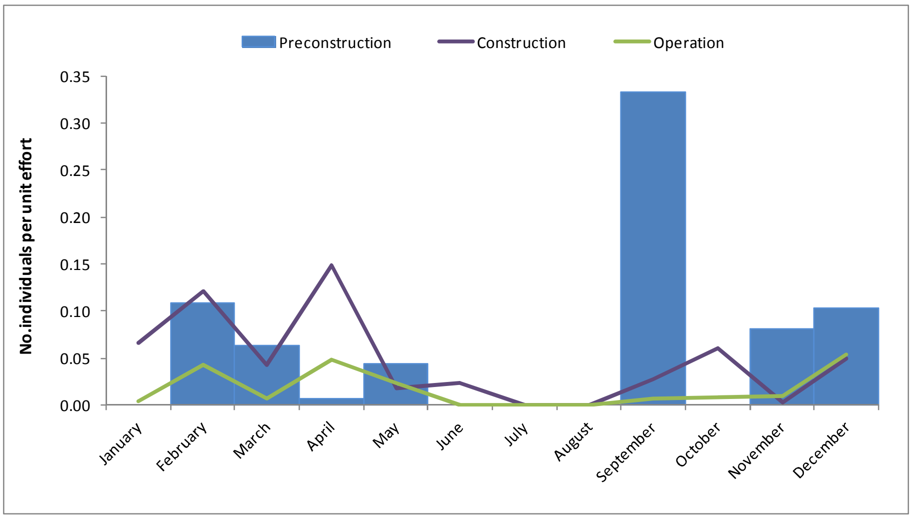


Figure 6.12b: Mean number of red-throated diver observed in flight per month during the pre-construction, construction and operational phases.

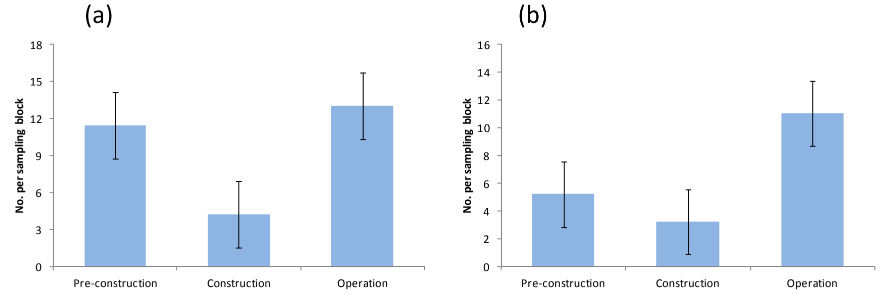


Figure 6.13: Mean number of red-throated diver observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error)

Results from the simple GLM also suggest a decline in numbers on the water between pre-construction and construction, followed by an increase between construction and operation (Table 6.5). Significant differences between phases for birds in flight were also found although trends were not clear. Examination of the raw data could suggest an increase in flying birds during operation year one but cannot be confirmed at this stage. This may become more apparent once more data has been collected at the end of operation year two.

Table 6.5: Results from simple GLM for number of red-throated diver observed in flight and on the sea. Pink indicates a significant decline between periods, and green a significant increase.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.002	<0.001	0.335
In flight	0.056	<0.001	0.003

- Birds on the sea

A half normal detection function was used for this analysis and the month of April used to estimate abundance. There is some evidence for reduction in numbers overall during construction period but no evidence for this to be specifically related to construction activities (Figure 6.15). The results also suggest a drop in numbers in the turbine area during operational year one but as the numbers originally observed in this area are very small, this decline will be of no ecological significance (i.e. bird numbers went from 1 to 0.3) across the study area.

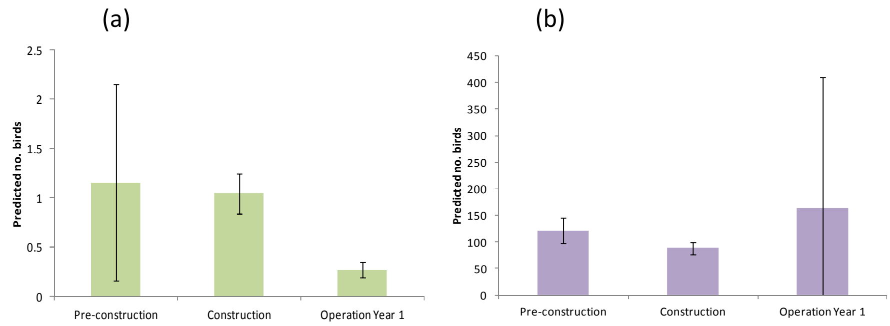


Figure 6.15: Predicted number of red-throated diver using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction, construction and operational phases (±standard error)

Density surface maps based on these predictions can be found in Figure 6.16 and the differences between the phases in Figure 6.17.

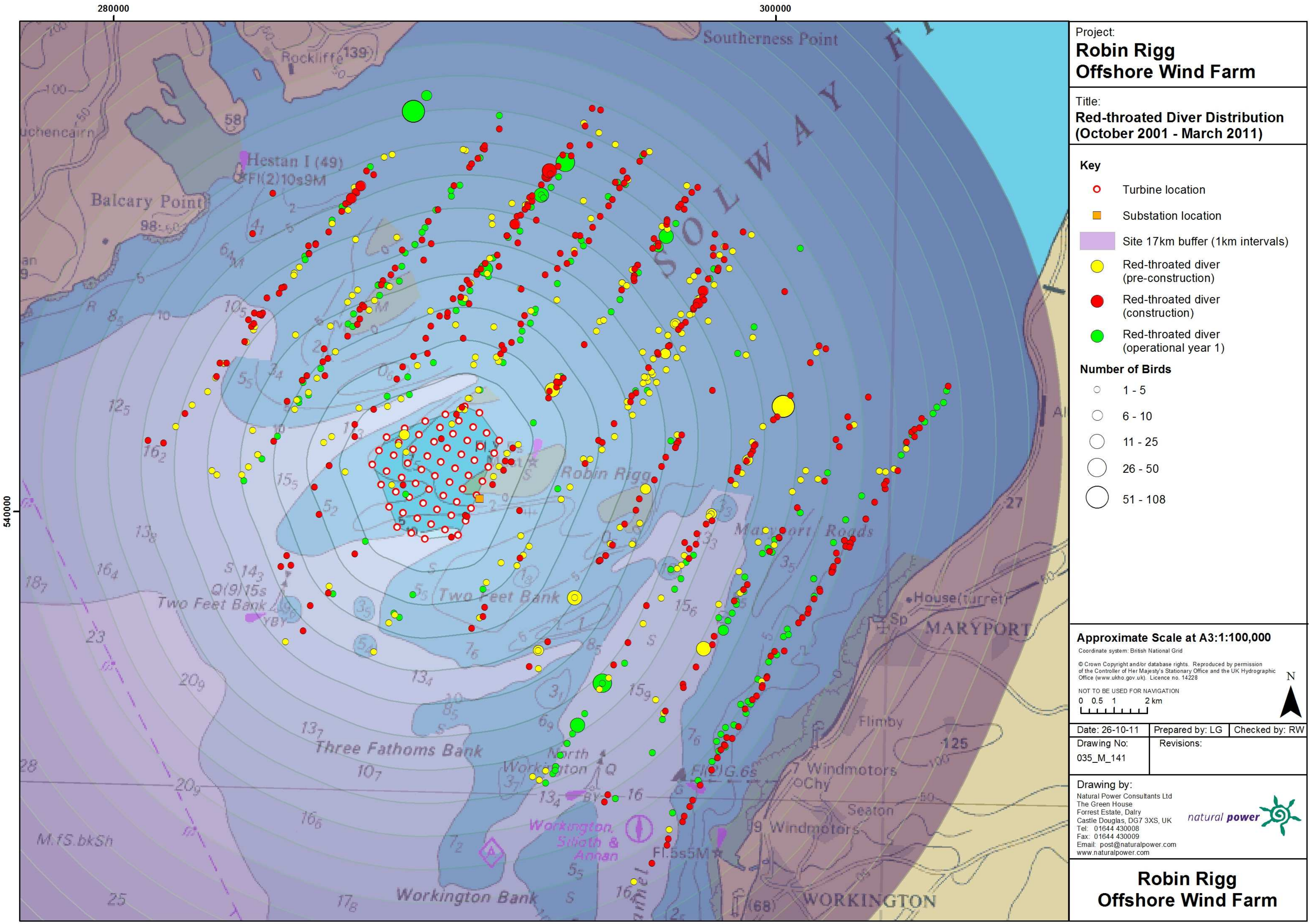


Figure 6.14: Locations of raw observations of red-throated diver during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed.

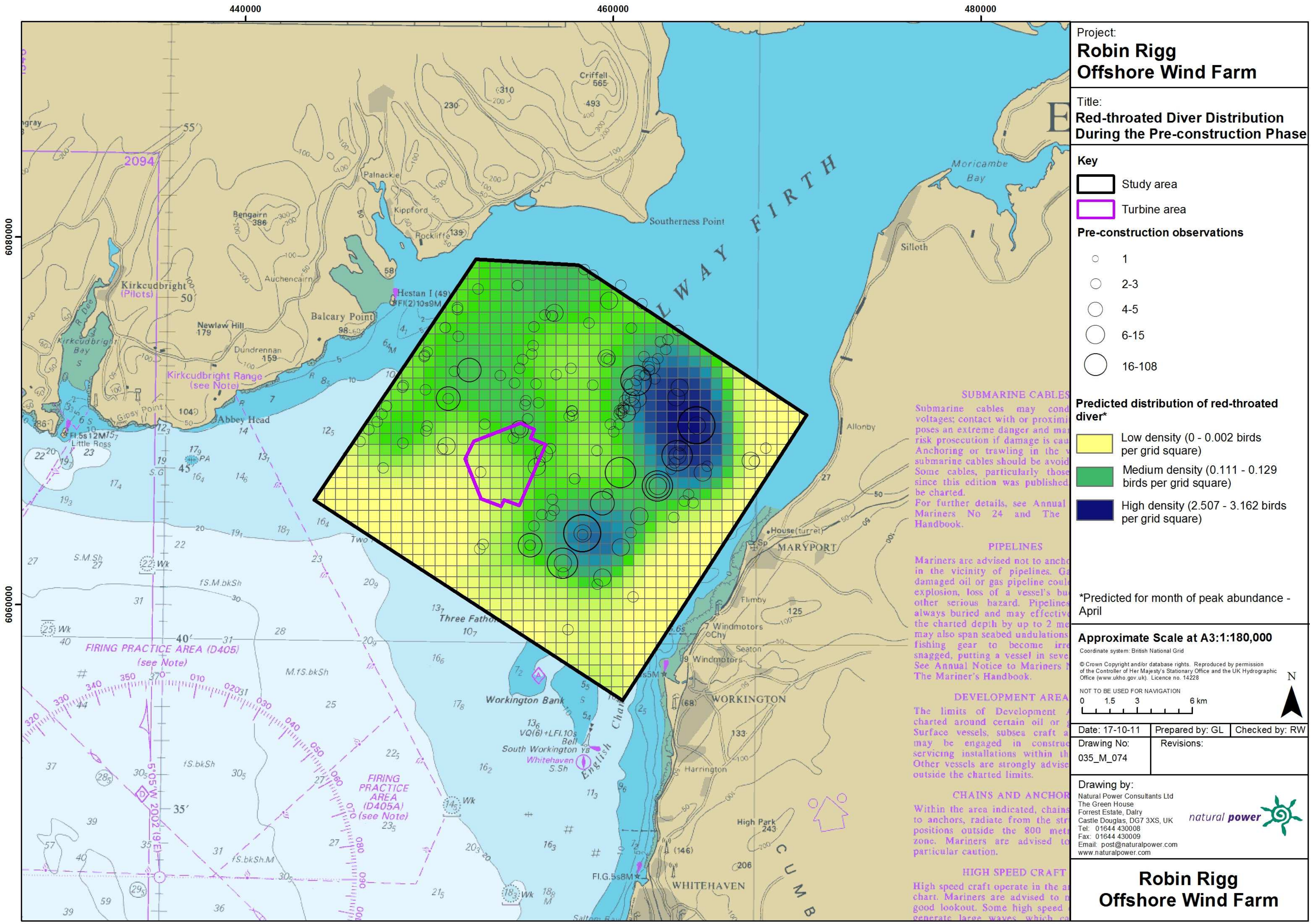


Figure 6.16a: Density surface map of the predicted density of red-throated diver across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

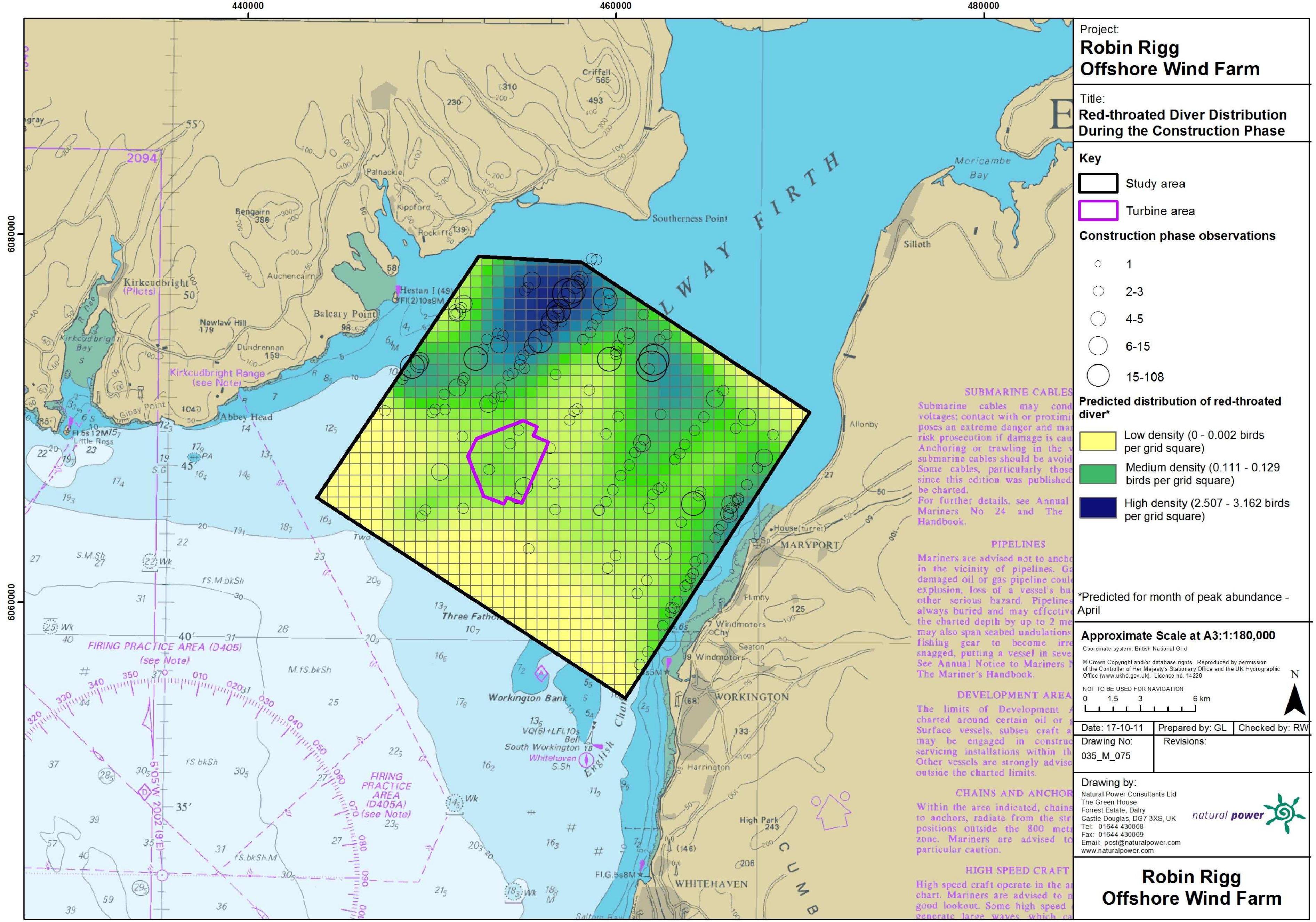


Figure 6.16b: Density surface map of the predicted density of red-throated diver across the survey area during the construction phase. Open circles show the locations of the raw observations.

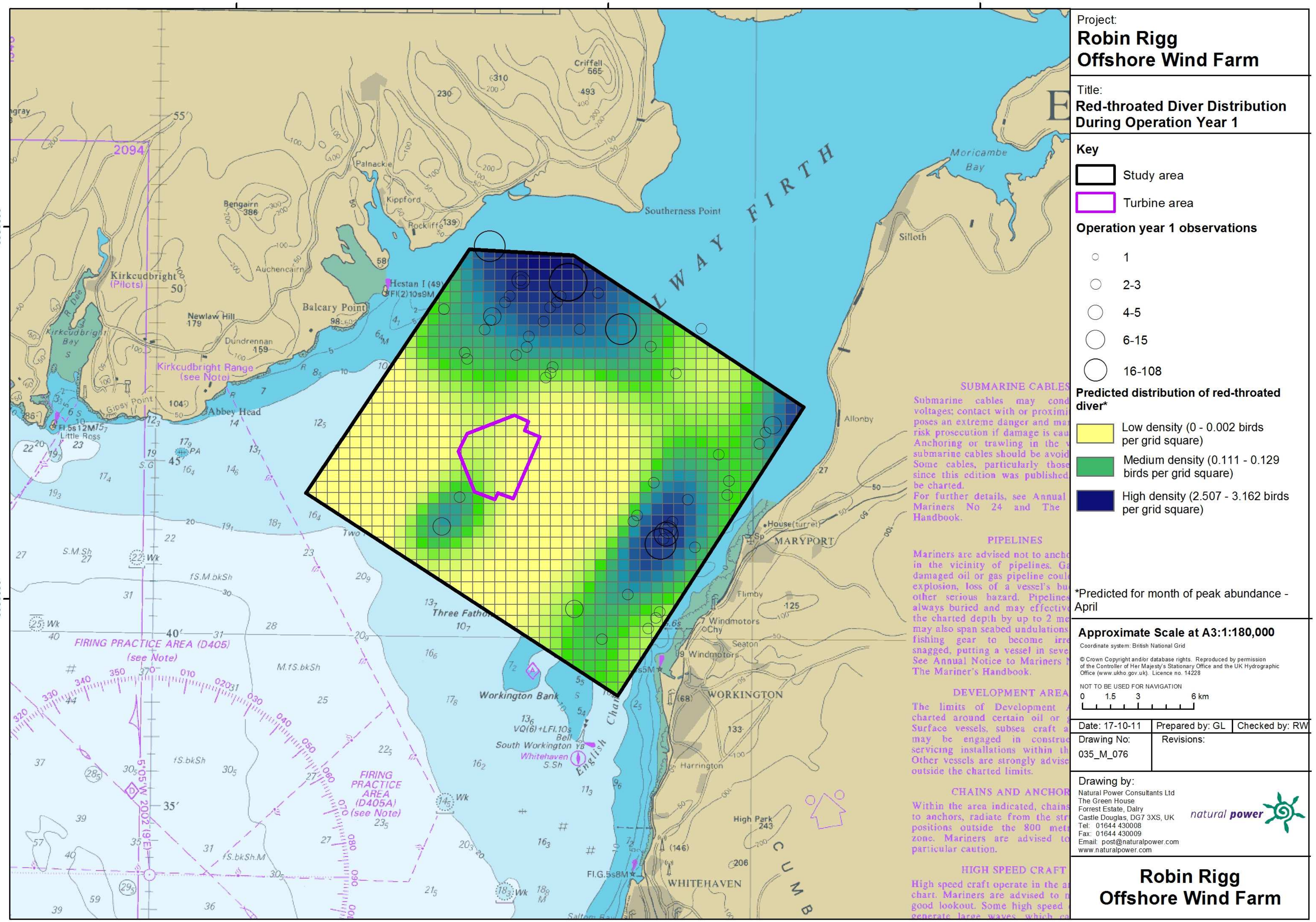


Figure 6.16c: Density surface map of the predicted density of red-throated diver across the survey area during the operational phase. Open circles show the locations of the raw observations.

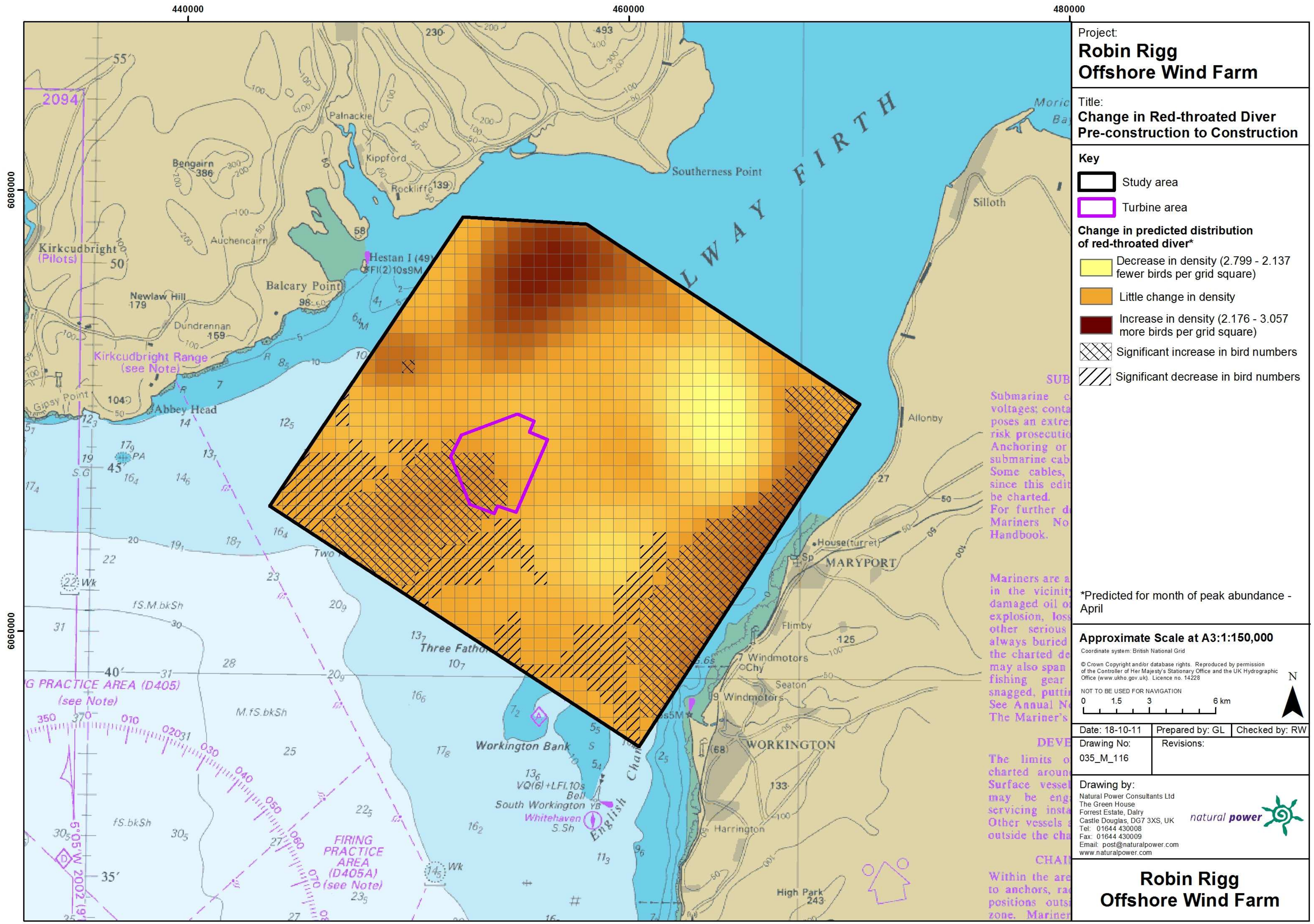


Figure 6.17a: Difference plot of the change in predicted density of red-throated diver between (a) the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

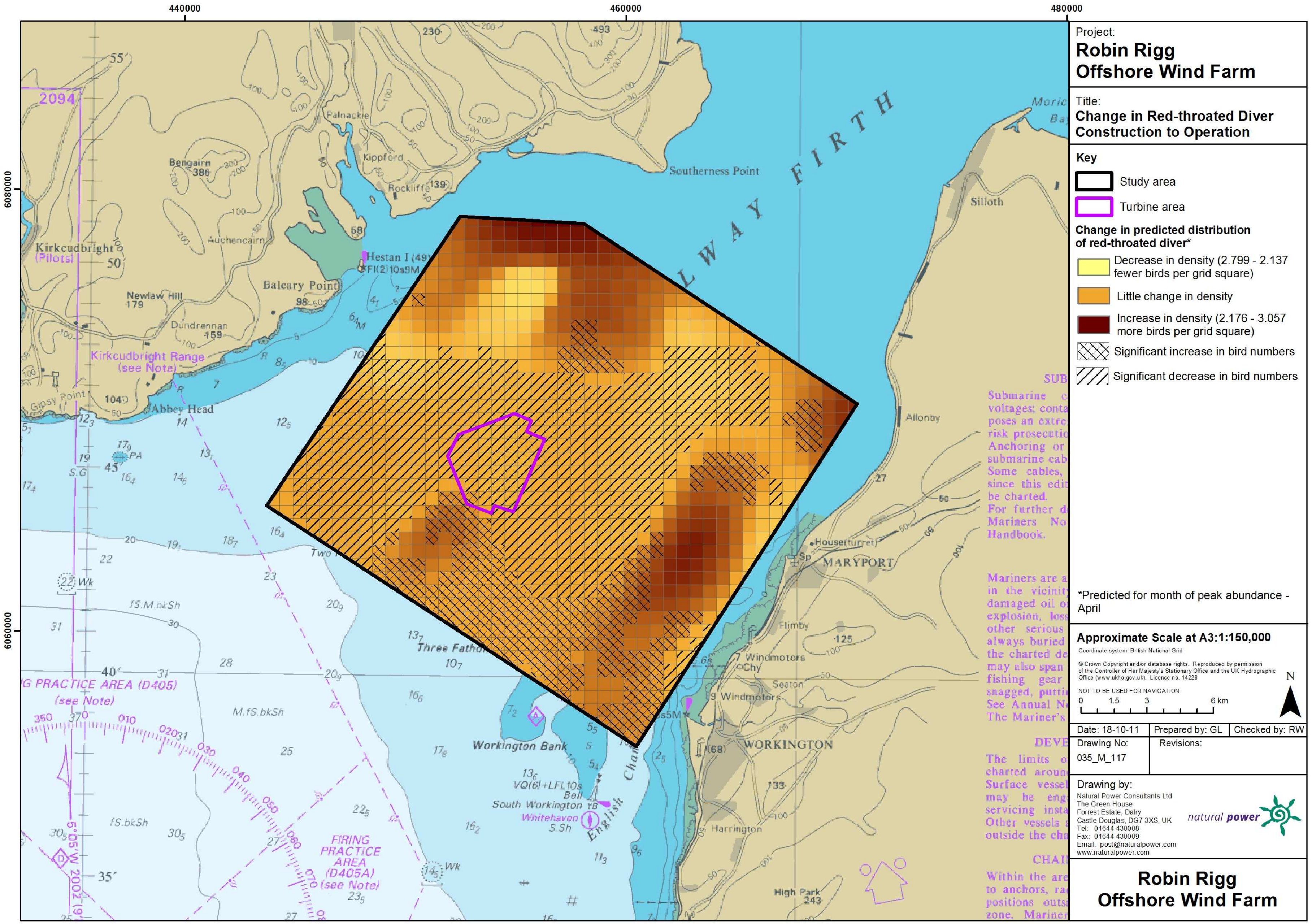


Figure 6.17b: Difference plot of the change in predicted density of red-throated diver between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

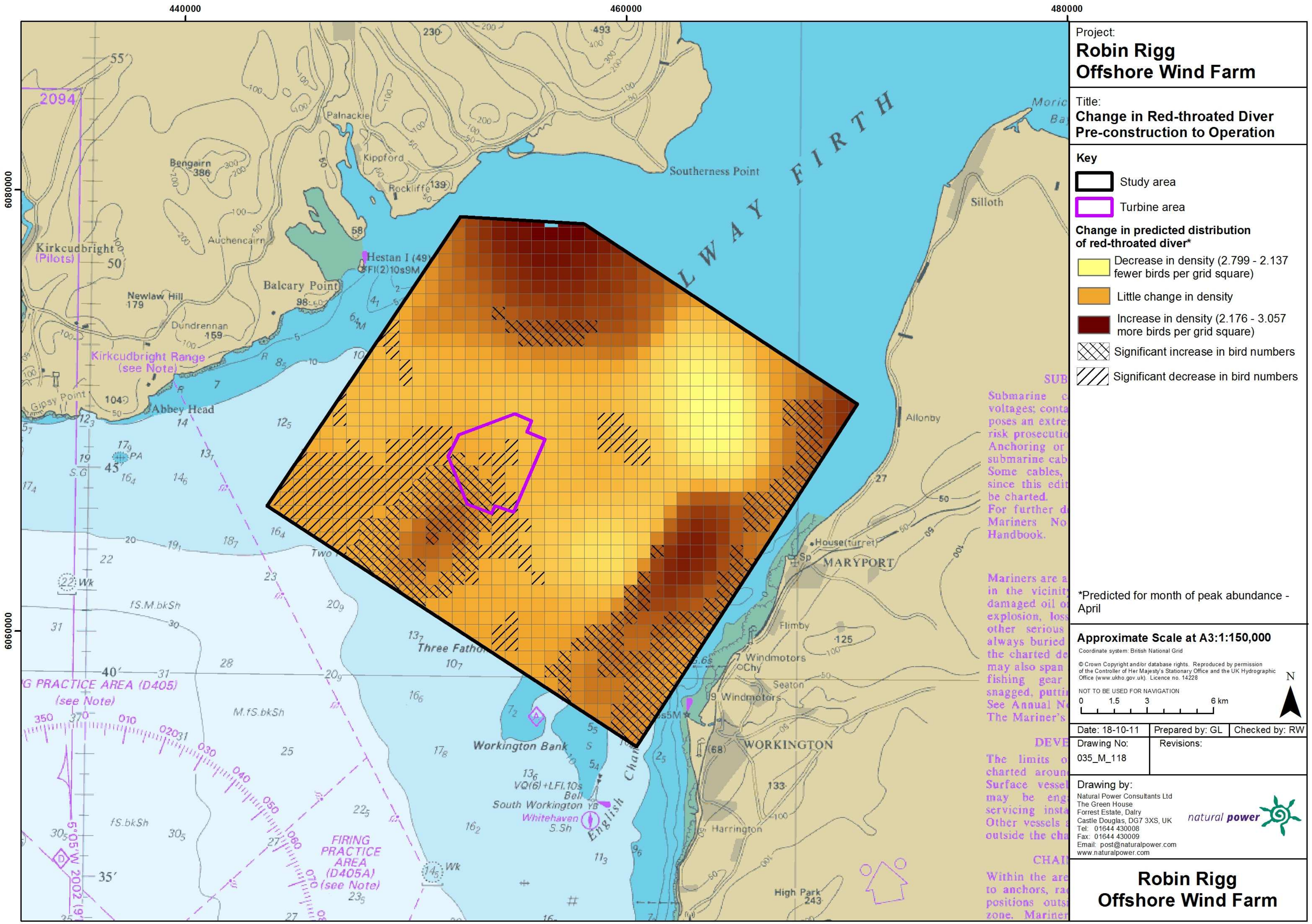


Figure 6.17: Difference plot of the change in predicted density of red-throated diver between the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines.

- Birds in flight

The percentage of red-throated diver recorded in different height bands relative to rotor height can be found in Table 6.6 and Figure 6.18a. The band 35-125 represents rotor height. Data were combined for Chi-squared analysis (Figure 6.18b) and no significant difference was found between flight bands during the different construction periods ($\chi^2 = 4.25$, $p = 0.1194$, 2 df). A greater number of red throated diver do appear to be flying at rotor height post construction although the reasons for this are unclear at this stage.

Table 6.6: Proportion of red-throated diver recorded in different height bands through the different stages of the development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	82.0	18	0	0	0	0
Construction	64.2	31.7	2.1	2.1	0	0
Operation Yr. 1	42.7	40.1	14.7	2.6	0	0

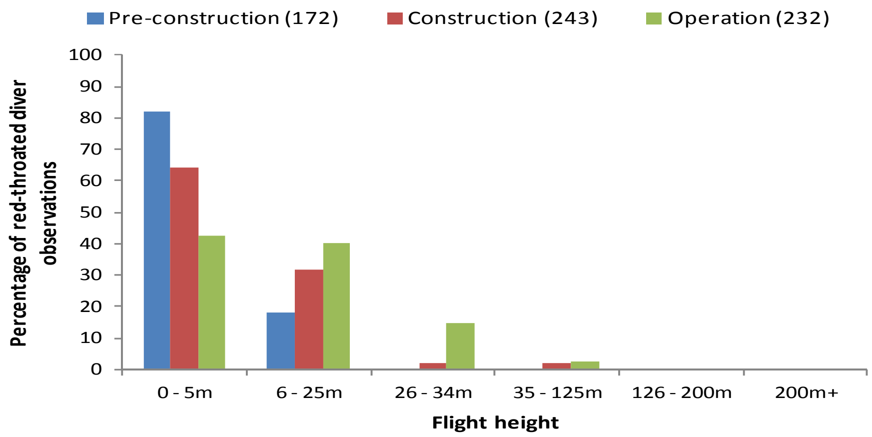


Figure 6.18a: Percentage of red-throated diver recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

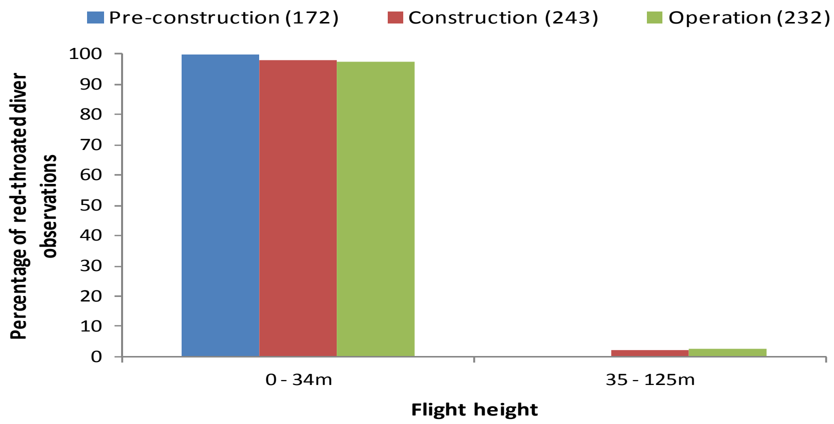


Figure 6.18b: Percentage of red-throated diver recorded in the combined flight bands used in the Chi-squared analysis. Figures in brackets represent total number.

6.2.5. Manx shearwater

Manx shearwater were rarely seen on site, and those that were sighted were predominantly during July, August and September (Figure 6.19). The raw data indicate an increase in numbers from the pre-construction to the construction phase for birds on the sea, followed by a decrease again from construction to operation. For birds in flight there was a decline in numbers for all phases compared to pre-construction (Figure 6.20). A map displaying the raw data can be found in Figure 6.21.

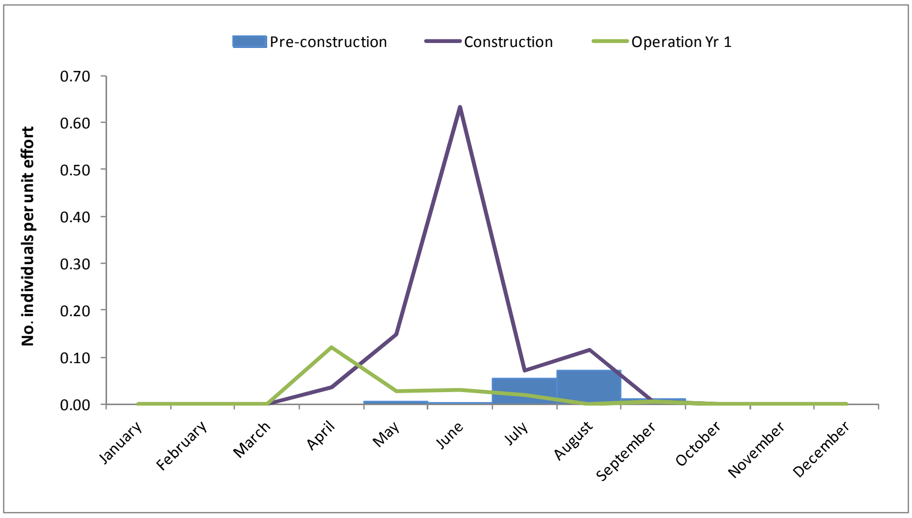


Figure 6.19a: Mean number of Manx shearwater observed on the sea per month during the pre-construction, construction and operational phases.

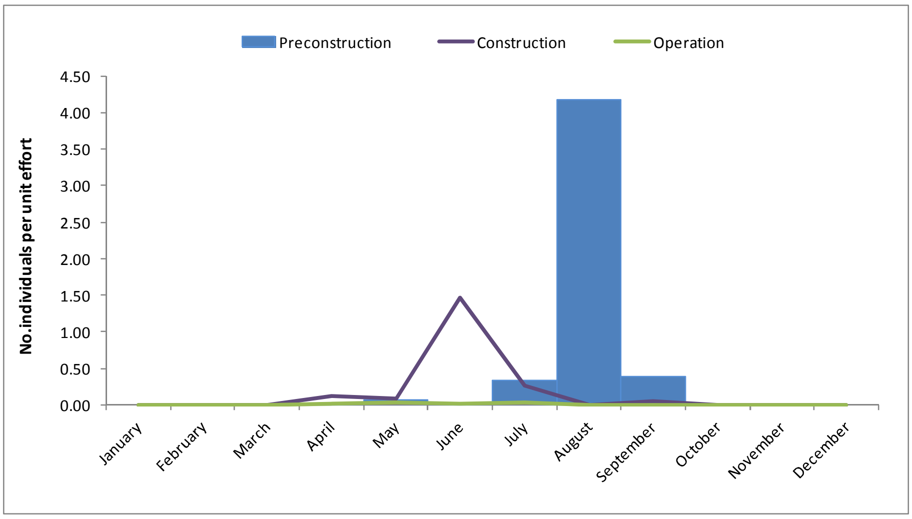


Figure 6.19b: Mean number of Manx shearwater observed in flight per month during the pre-construction, construction and operational phases.

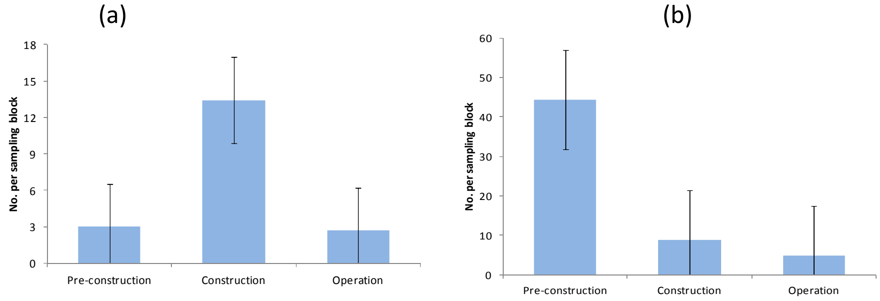


Figure 6.20: Mean number of Manx shearweater observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error)

Results from the simple GLM also suggest a decline in numbers on the water between construction and operation, and in flight between pre-construction and construction, and pre-construction and operation (Table 6.7).

Table 6.7: Results from simple GLM for number of Manx shearwater observed in flight and on the sea. Pink indicates a significant decline between periods.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.081	0.019	0.443
In flight	0.006	0.502	0.047

- Birds on the sea

There were insufficient sightings to do the full analysis for this species.

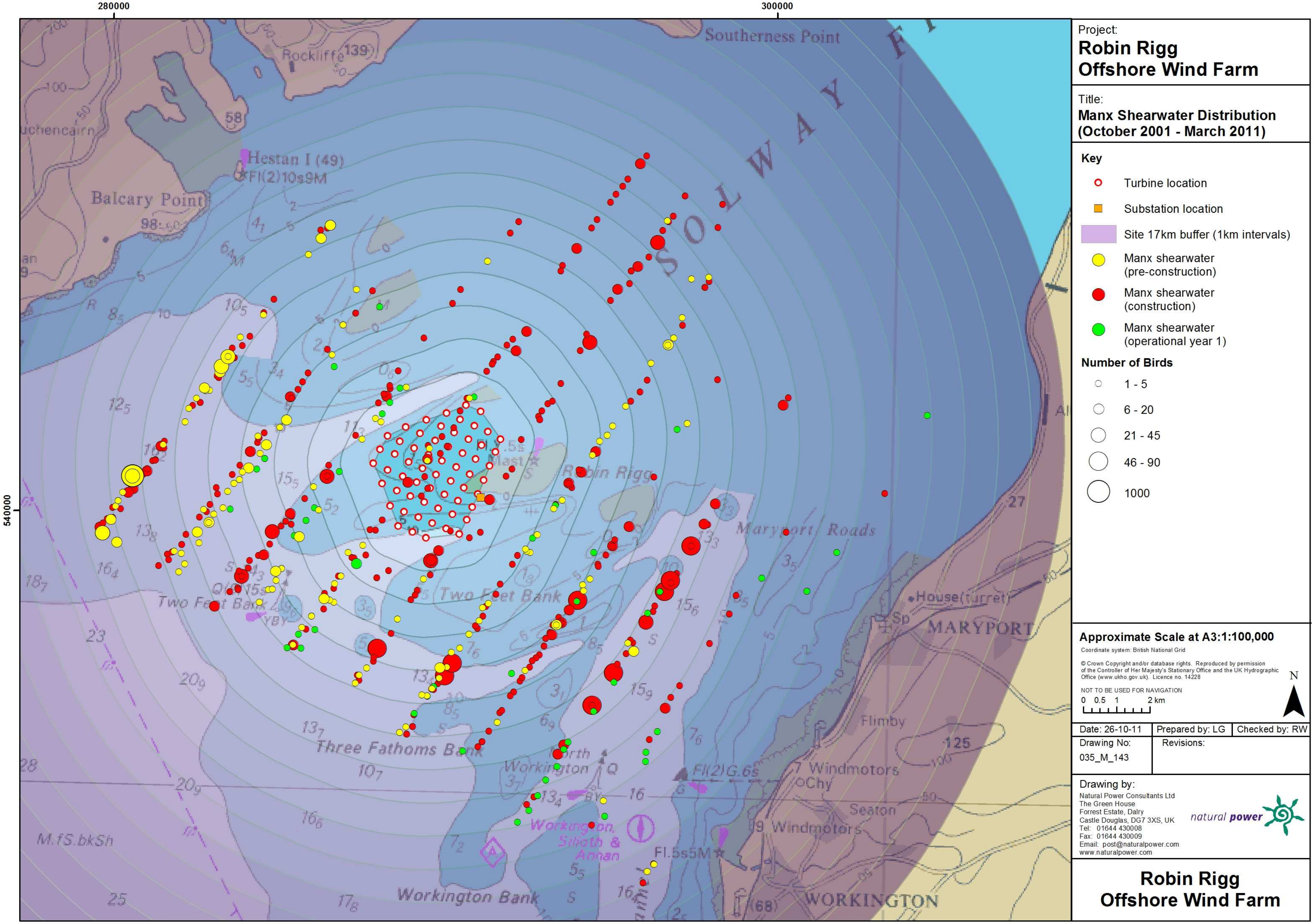


Figure 6.21: Locations of raw observations of Manx shearwater during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed.

- Birds in flight

The percentage of Manx shearwater recorded in different height bands relative to rotor height can be found in Table 6.8 and Figure 6.22. The band 35-125 represents rotor height. No Chi-square test was carried out for this species as no flights were observed at turbine rotor height. A greater proportion of Manx shearwater were recorded in height band 2 (6-25) during the construction period but the reasons for this are unclear and they are still below rotor height.

Table 6.8: Proportion of Manx shearwater recorded at different flight bands through the spate stages of the development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	100	0	0	0	0	0
Construction	81.8	18.2	0	0	0	0
Operation Yr. 1	98.1	1.9	0	0	0	0

Figure 6.22: Percentage of Manx shearwater recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

6.2.6. Gannet

Gannet were recorded throughout the spring, summer and autumn, with a peak in numbers in June/July (Figure 6.23). The raw data indicate a decline in numbers compared to pre-construction (Figures 6.24 and 6.25).

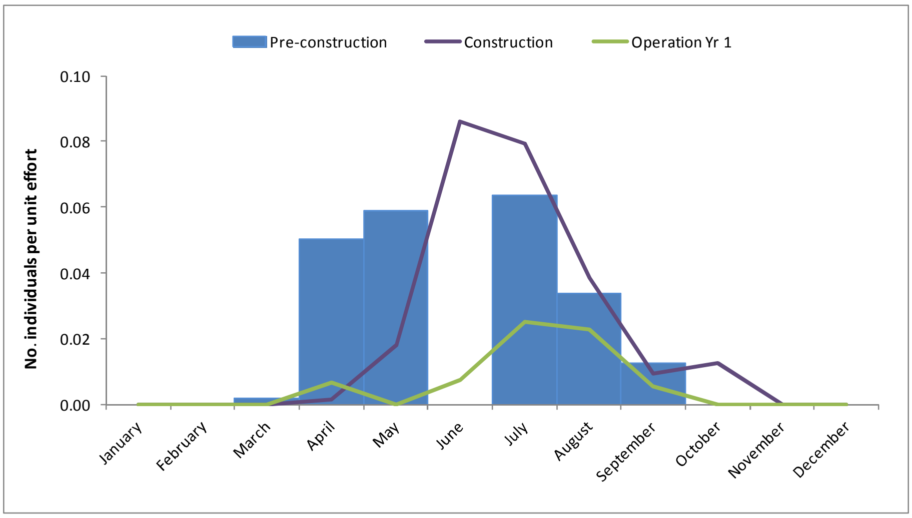


Figure 6.23a: Mean number of gannet observed on the sea per month during the pre-construction, construction and operational phases.

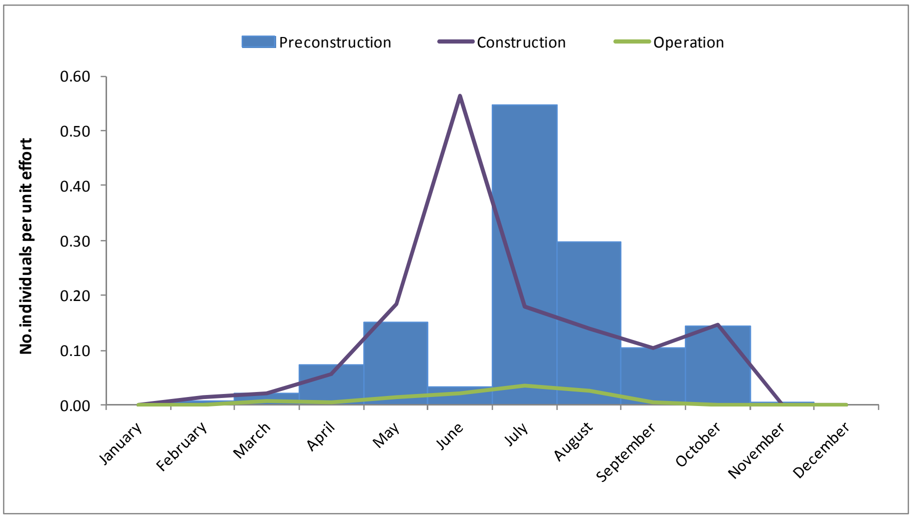


Figure 6.23b: Mean number of gannet observed in flight per month during the pre-construction, construction and operational phases.

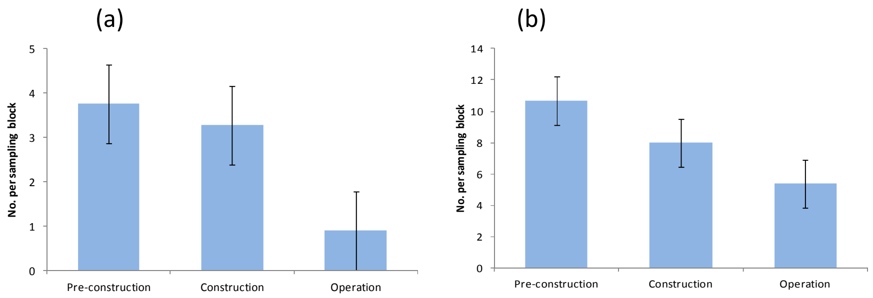


Figure 6.24: Mean number of gannet observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error).

Results from the simple GLM also suggest a decline in numbers on the water between construction and operation, and overall from preconstruction to operation. There were no significant differences observed for birds in flight (Table 6.9).

Table 6.9: Results from the simple GLM for number of gannet observed in flight and on the sea. Pink indicates a significant decline between time periods.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.793	0.007	0.013
In flight	0.491	0.224	0.118

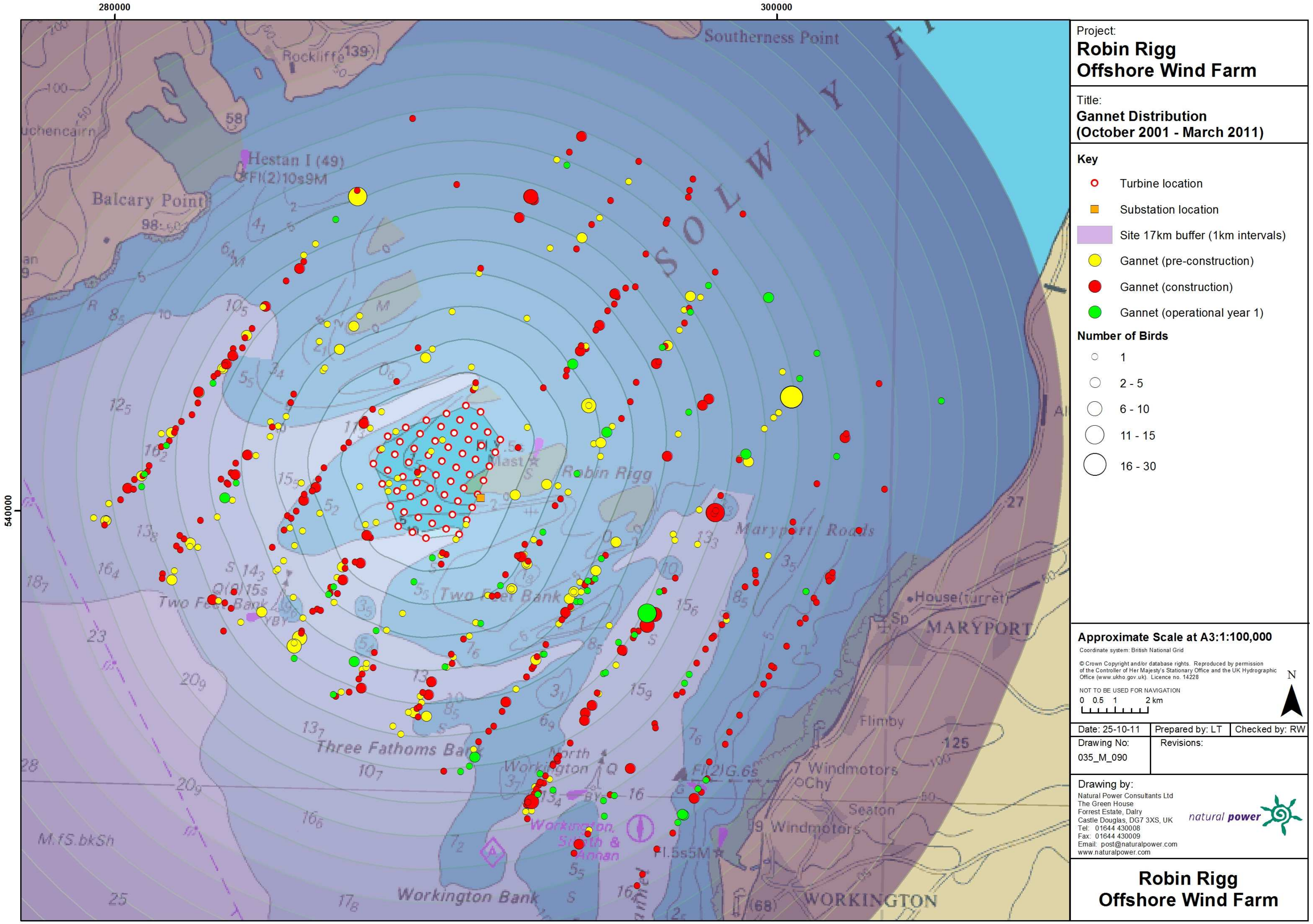


Figure 6.25: Locations of raw observations of gannet during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed

- Birds on the sea

A half normal detection function was used for this analysis and the month of July used to estimate abundance. The predicted number of gannet for each construction phase can be found in Figure 6.26 below. Note: there was insufficient data to complete the analysis for operational year one.

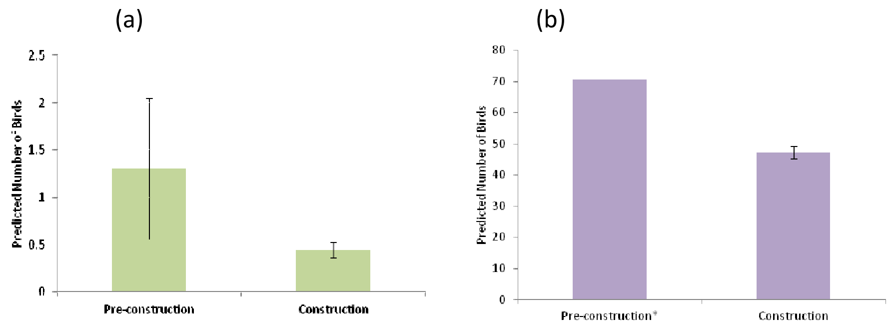


*Figure 6.26: Predicted number of gannet using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction and construction phases (±standard error) *Standard error too large to display (3490)*

Numbers for gannet have dropped from each phase to the next and analysis shows some evidence of avoidance behaviour. This is in keeping with behaviour observed at Hornsrev and Nysted offshore wind farms in Denmark (Petersen *et al.,* 2006). It will be important to determine if gannet numbers in operational year two and beyond remain low and if this is related to the presence of the wind farm of a more general decline in the regional population. See Section 9.3 for further discussion.

Density surface maps based on these predictions can be found in Figure 6.27 and the differences between the phases in Figure 6.28.

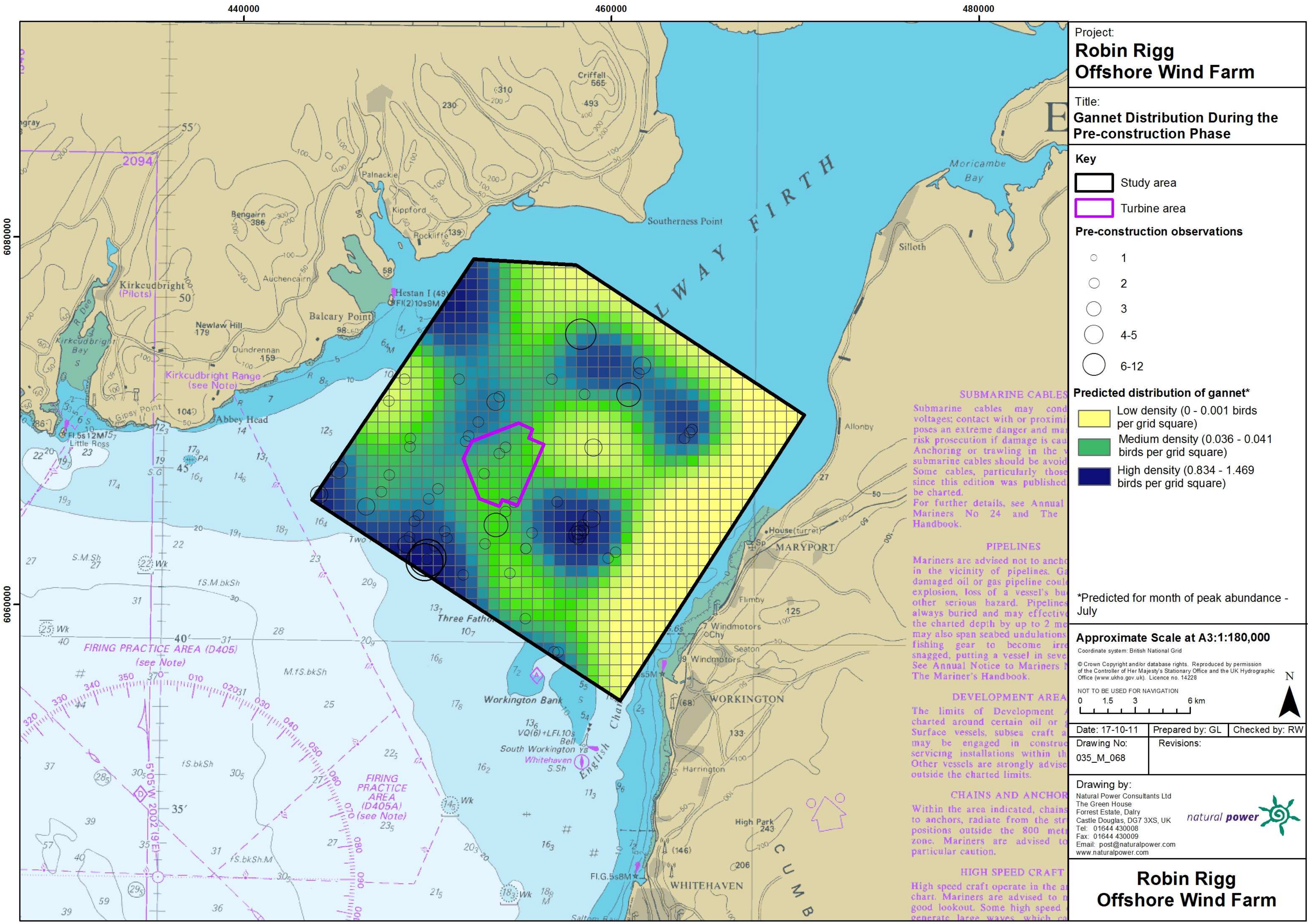


Figure 6.27a: Density surface map of the predicted density of gannet across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

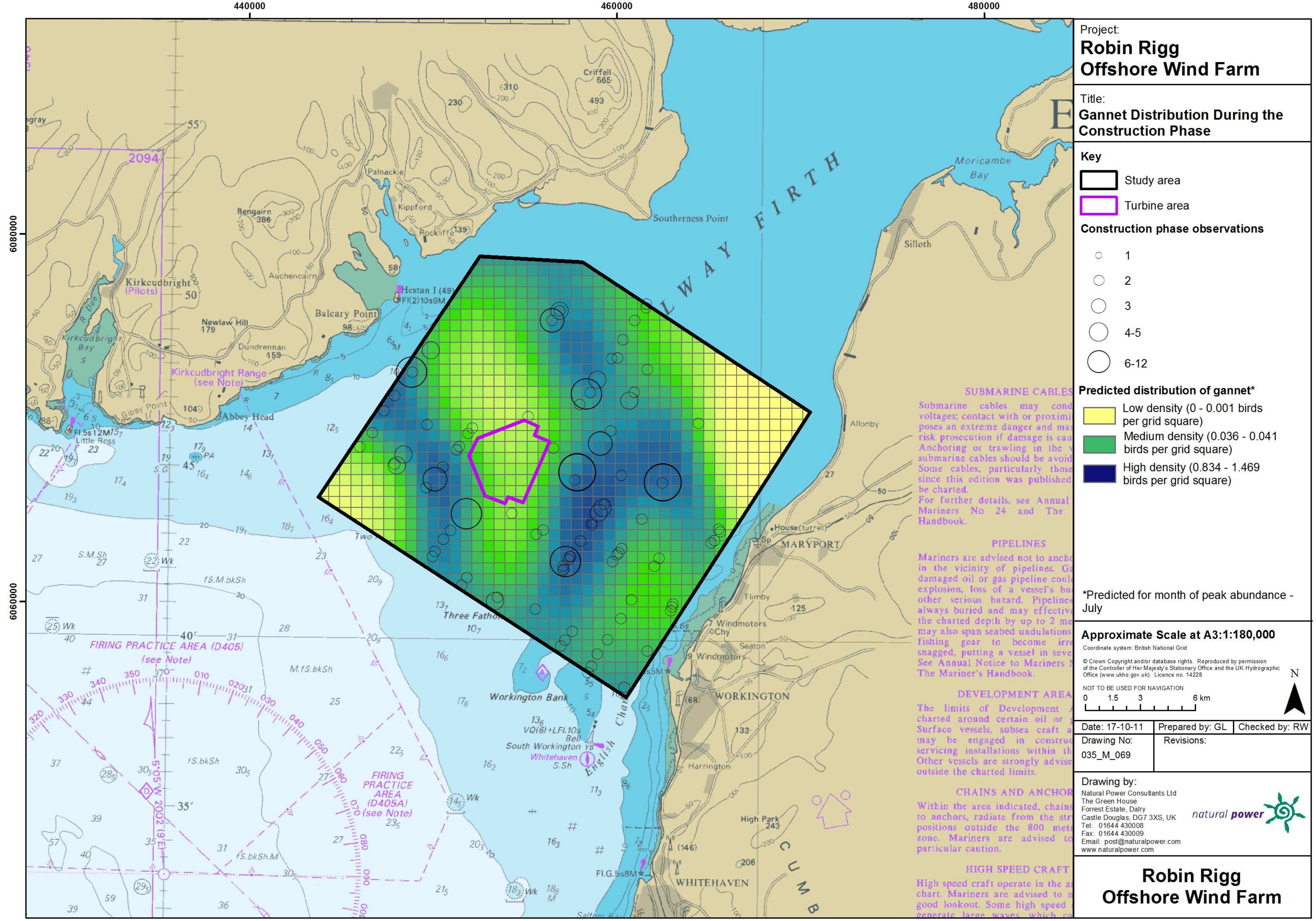


Figure 6.27b: Density surface map of the predicted density of gannet across the survey area during the construction phase. Open circles show the locations of the raw observations.

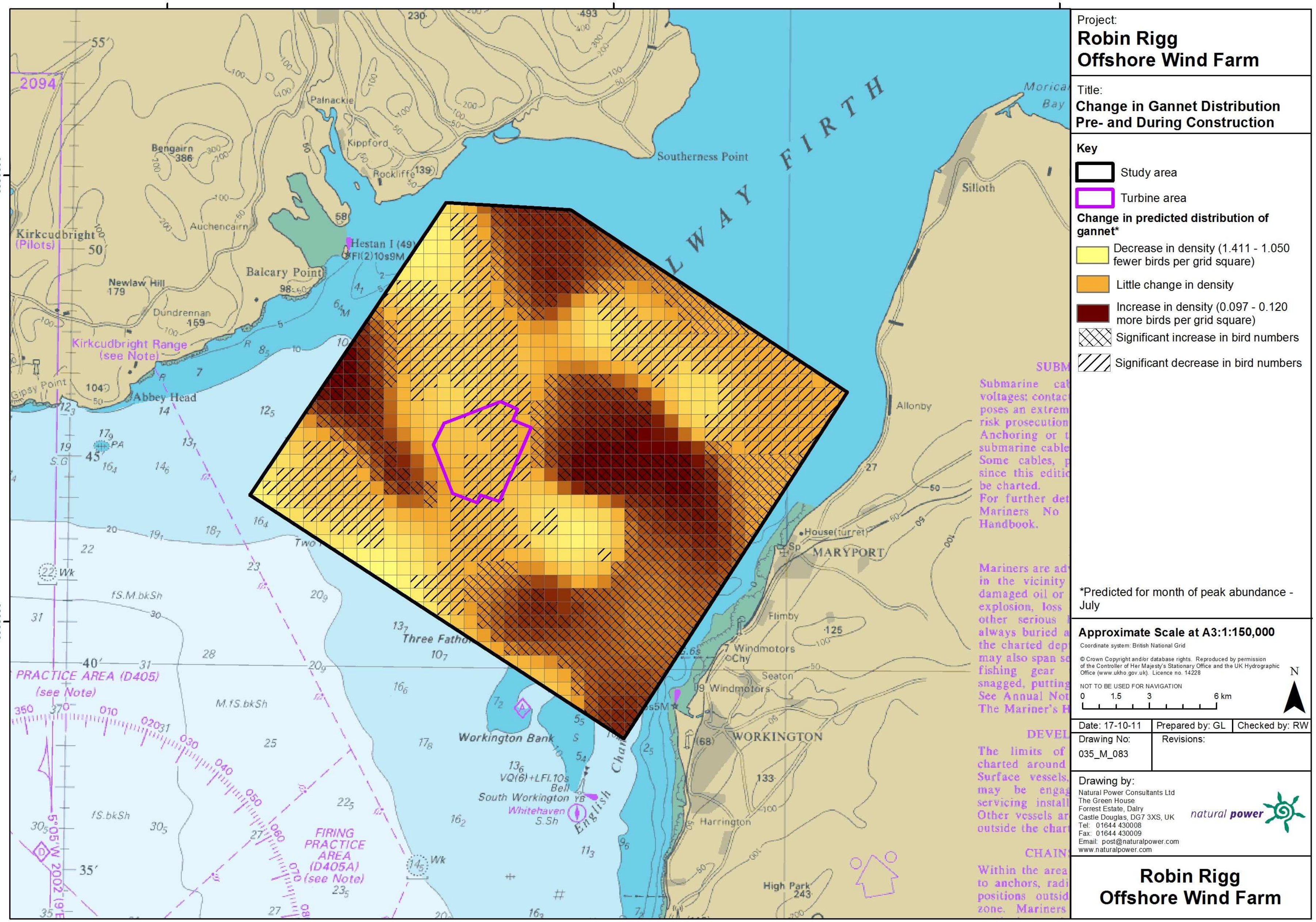


Figure 6.28: Difference plot of the change in predicted density of gannet between the pre-construction and construction phases

- Birds in flight

The percentage of gannet recorded in different height bands relative to rotor height can be found in Table 6.10 and Figure 6.29a. The band 35-125 represents rotor height. Data were combined for Chi-squared analysis (Figure 6.27b) and a significant difference was found between flight bands (χ^2 = 14.40, p = 0.0007, 2 df). These results should be treated with caution as one expected value was less than the recommended value for this test of 5. This value was for the operational year one data set so it is assumed that once more data becomes available (i.e. at the end of operational year two) a more robust analysis can be performed.

Table 6.10: Proportion of gannet recorded at different flight height bands through the different stages of the development. No birds were recorded above rotor height.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	33.0	65.1	2.0	0	0	0
Construction	26.9	60.9	8.2	4.0	0	0
Operation Yr. 1	35.4	56.6	5.3	2.7	0	0

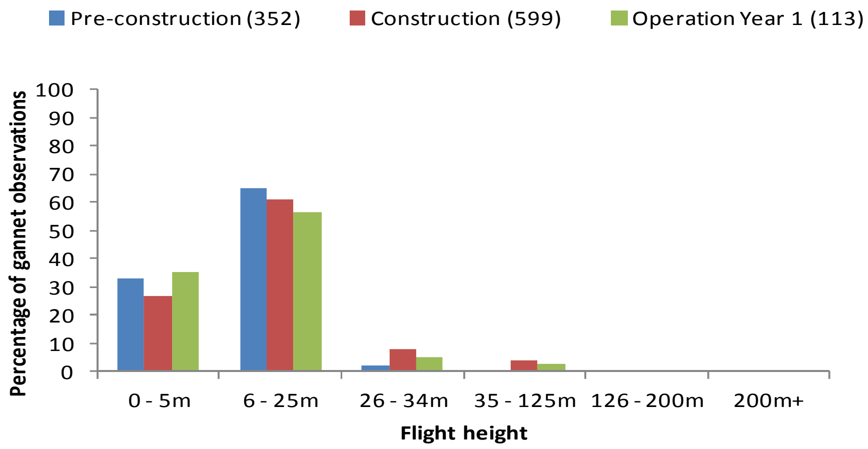


Figure 6.29a: Percentage of gannet recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

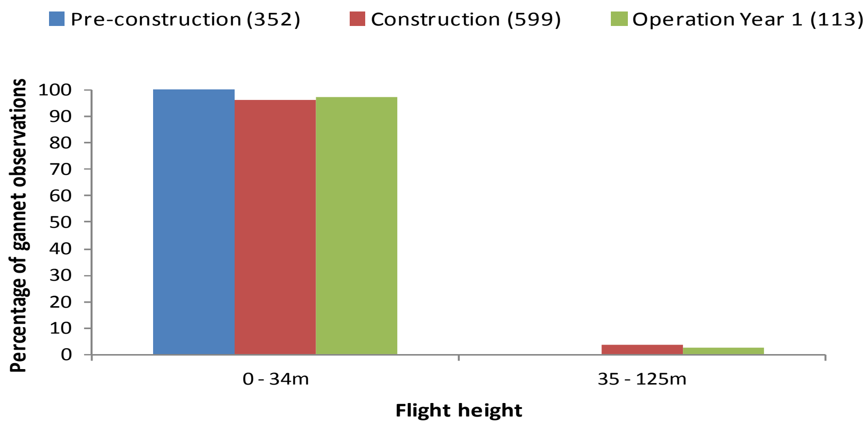


Figure 6.29b: Percentage of gannet recorded in the combined flight bands used in the Chi-squared analysis. Figures in brackets represent total number.

6.2.7. Cormorant

Cormorant were recorded throughout the year with the greatest numbers, both on the water and in flight, observed in July pre-construction (Figure 6.30). The raw data indicate an increasing number across the site through the different phases of the project; particularly during the construction period (see Figure 6.31 and 6.32).

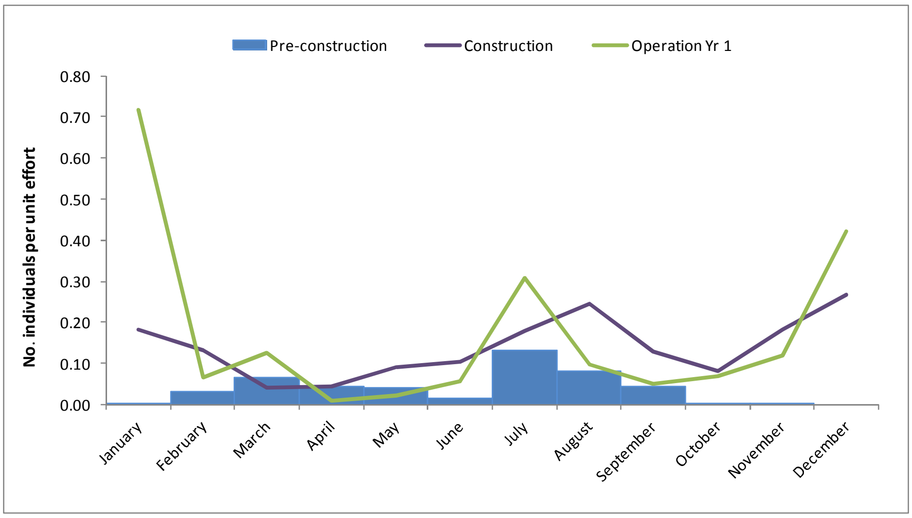


Figure 6.30a: Mean number of cormorant observed on the sea per month during the pre-construction, construction and operational phases.

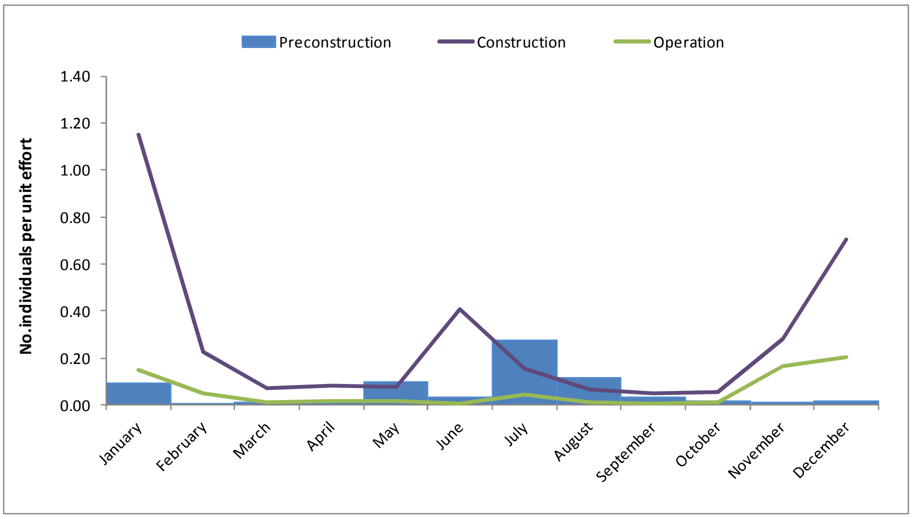


Figure 6.30b: Mean number of cormorant observed in flight per month during the pre-construction, construction and operational phases.

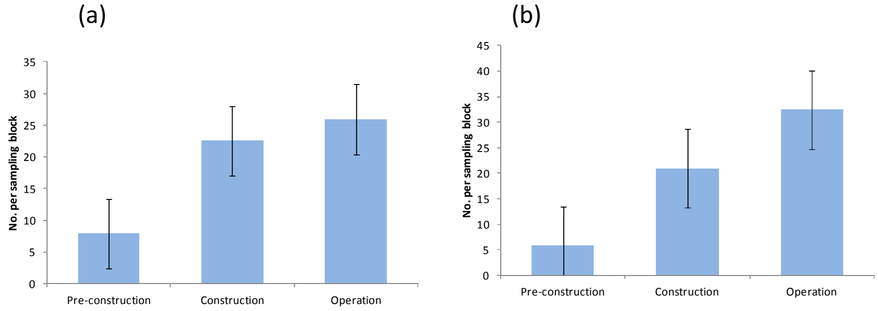


Figure 6.31: Mean number of cormorant observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error).

Results from the simple GLM also suggest an increase in numbers both on the water (pre-construction and construction pre-construction to operation) and in flight across all phases of the project (Table 6.11).

Table 6.11: Results from simple GLM for number of cormorant observed in flight and on the sea. Green indicates a significant increase between periods.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.003	0.474	0.002
In flight	<0.001	0.013	<0.001

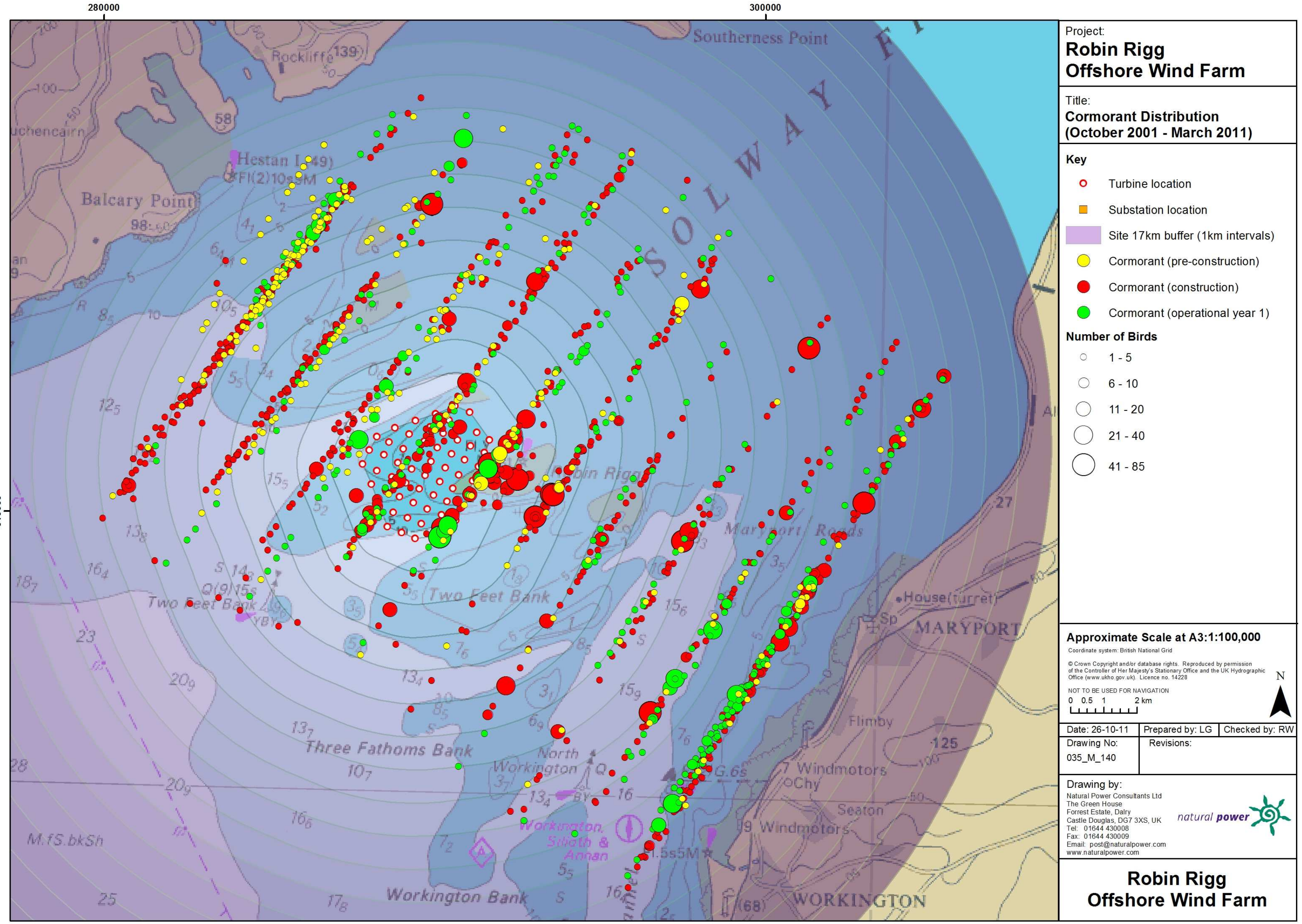


Figure 6.32: Locations of raw observations of cormorant during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed

- Birds on the sea

A half normal detection function was used for this analysis and the month of July used to estimate abundance. The predicted number of cormorant on site for each construction phase can be found in Figure 6.33 below.

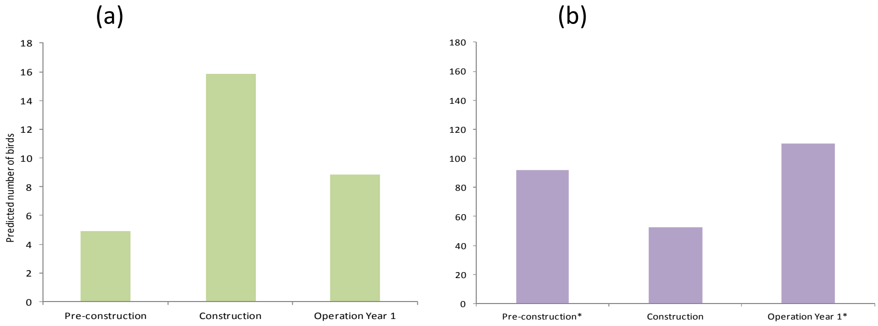


Figure 6.33: Predicted number of cormorant using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction, construction and operational phases. Note: Standard errors too large to display.

Standard errors are not included here (Figure 6.33) due to the large size of these values, particularly for the construction phase data. The figures are presented for completeness but we have little confidence in these results and advise that raw observations and simple GLM results should be used to draw conclusions regarding changes in cormorant usage of the survey area. Birds observed sitting on turbines are counted as being "on the sea" and therefore included in this dataset. Cormorant are regularly observed resting on turbines and show no signs of changing this behaviour (see Image 6.1 below).

Density surface maps based on these predictions can be found in Figure 6.34 and the differences between the phases in Figure 6.35.

Image 6.1: Cormorant sitting on hand rails at Robin Rigg.

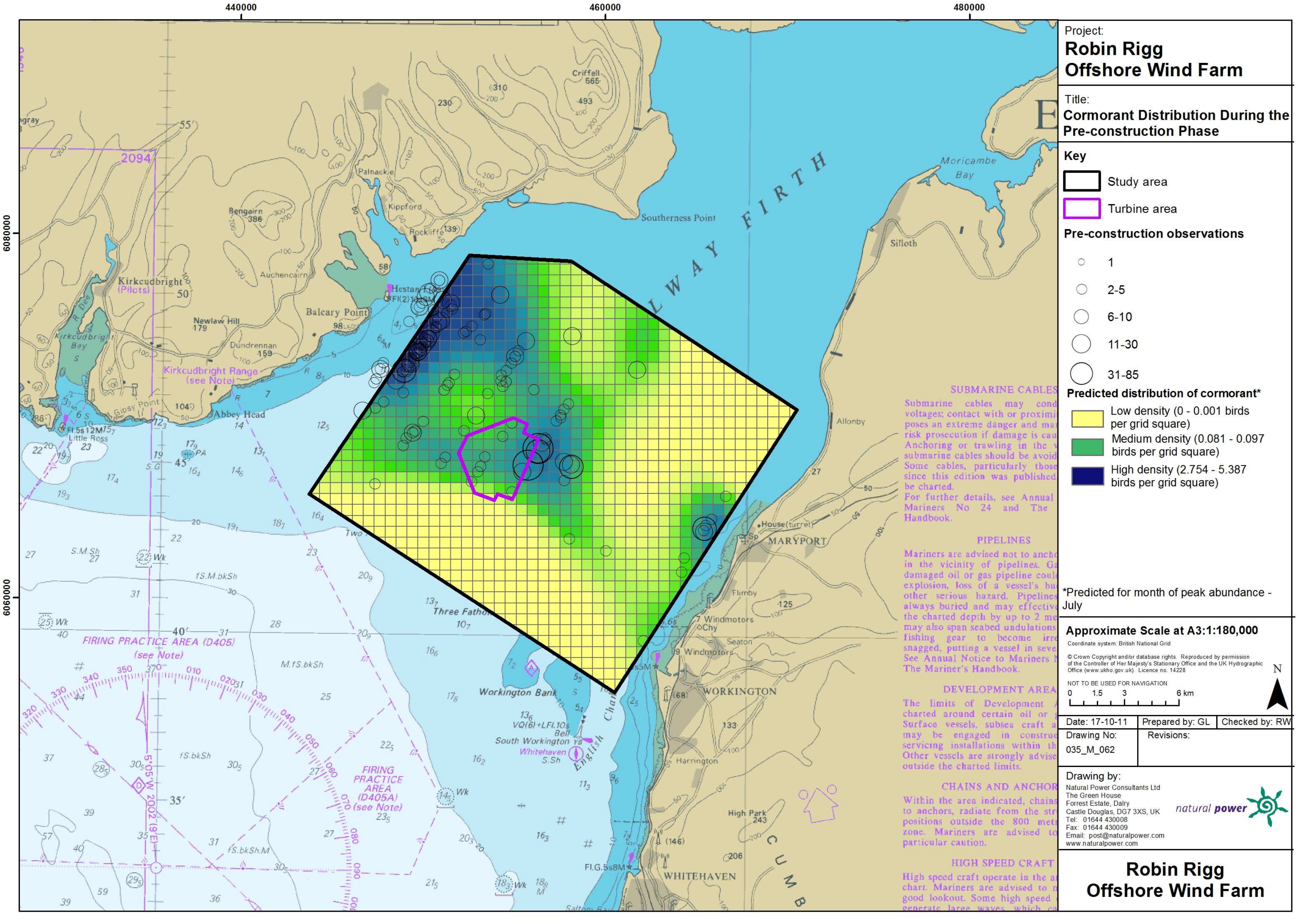


Figure 6.34a: Density surface map of the predicted density of cormorant across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

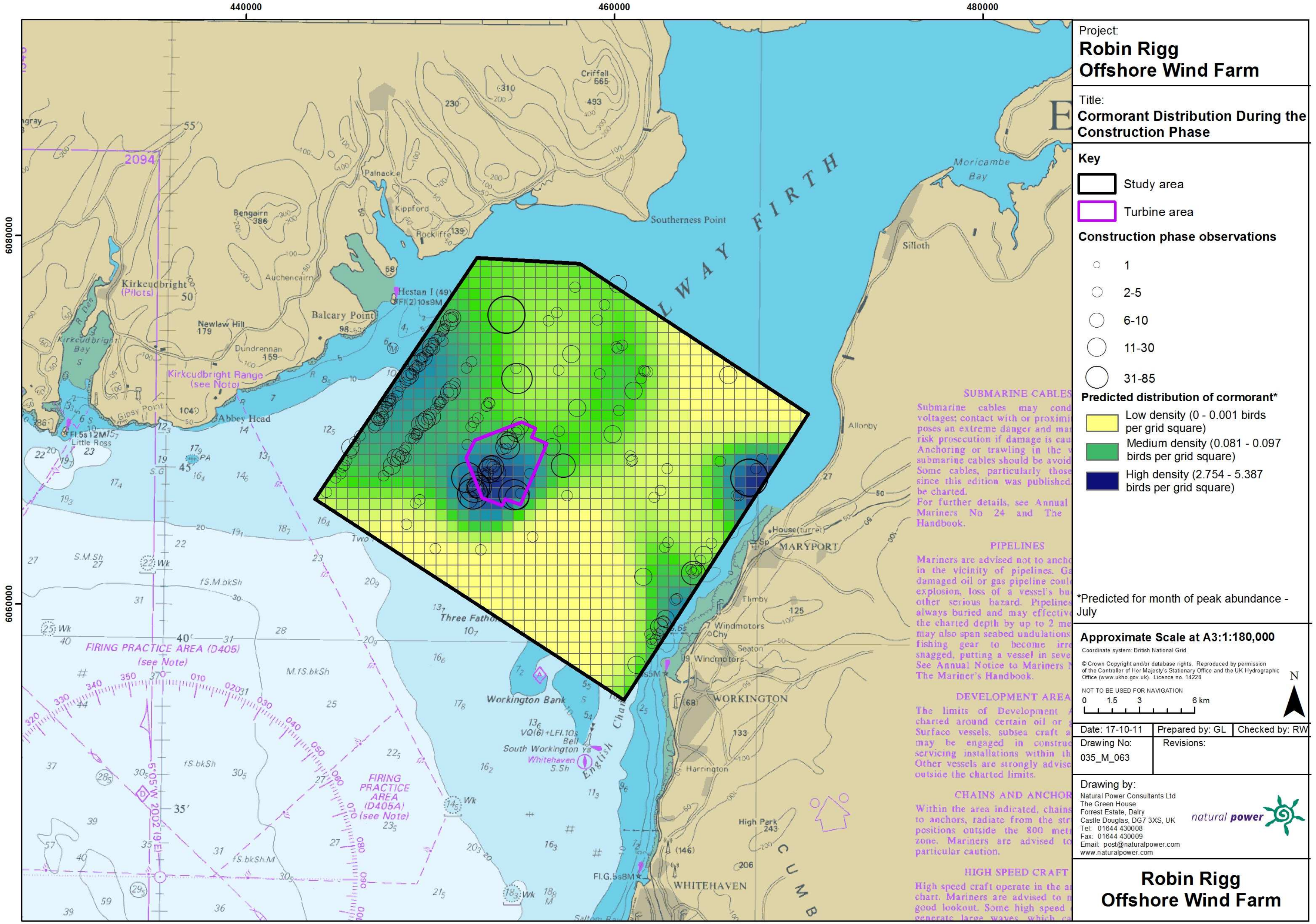


Figure 6.34b: Density surface map of the predicted density of cormorant across the survey area during the construction phase. Open circles show the locations of the raw observations.

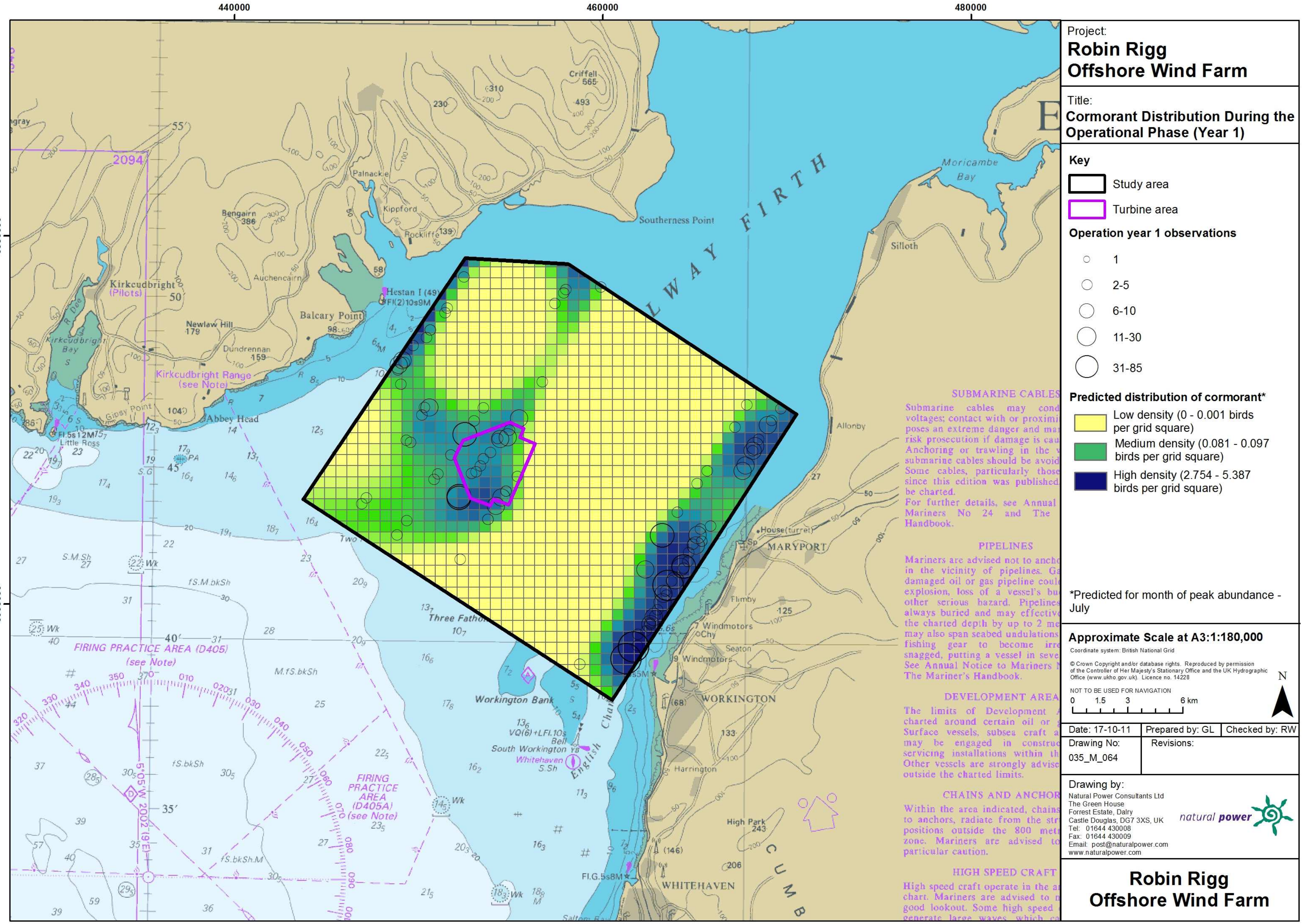


Figure 6.34c: Density surface map of the predicted density of cormorant across the survey area during the operational phase. Open circles show the locations of the raw observations.

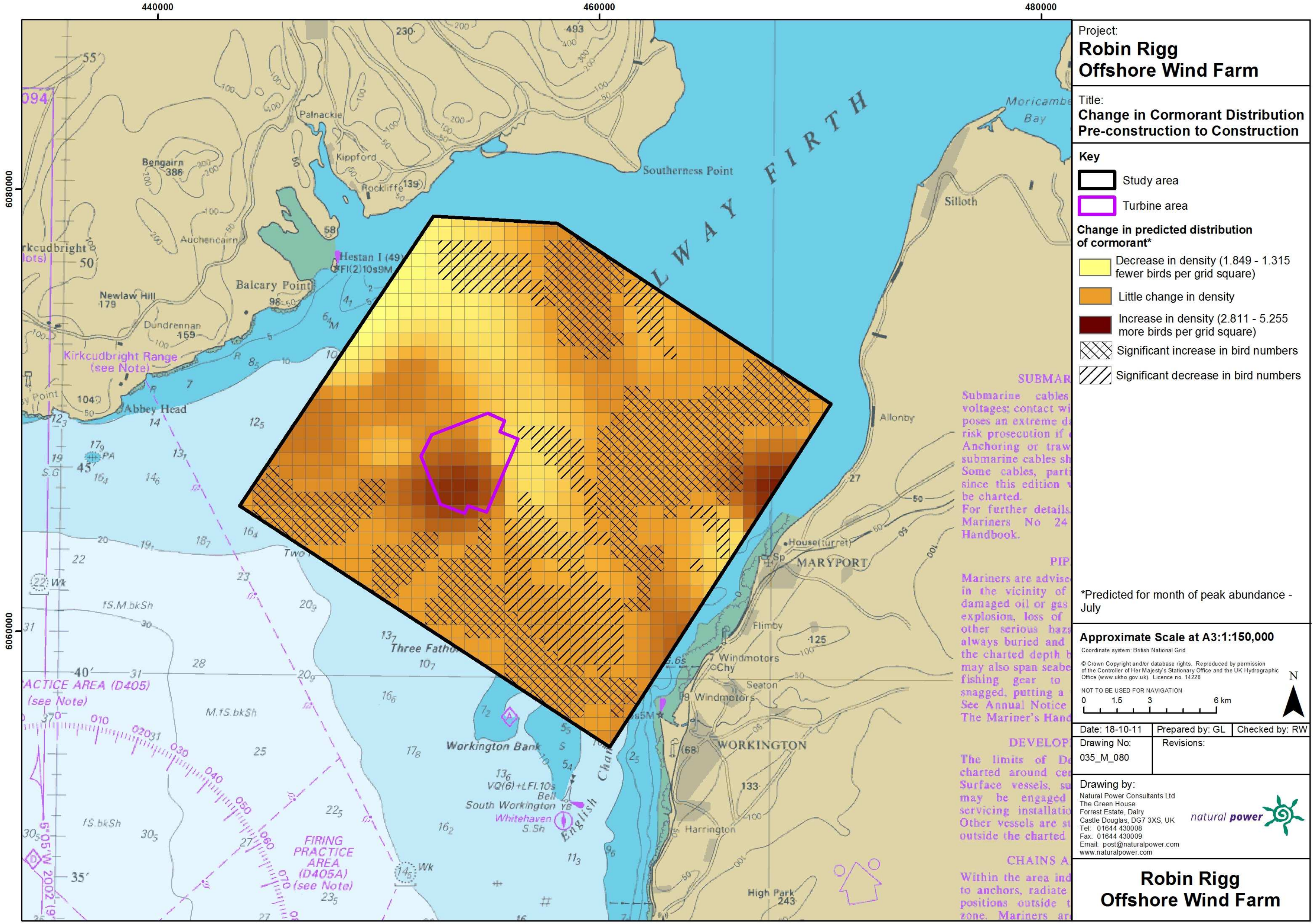


Figure 6.35: Difference plot of the change in predicted density of cormorant between the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

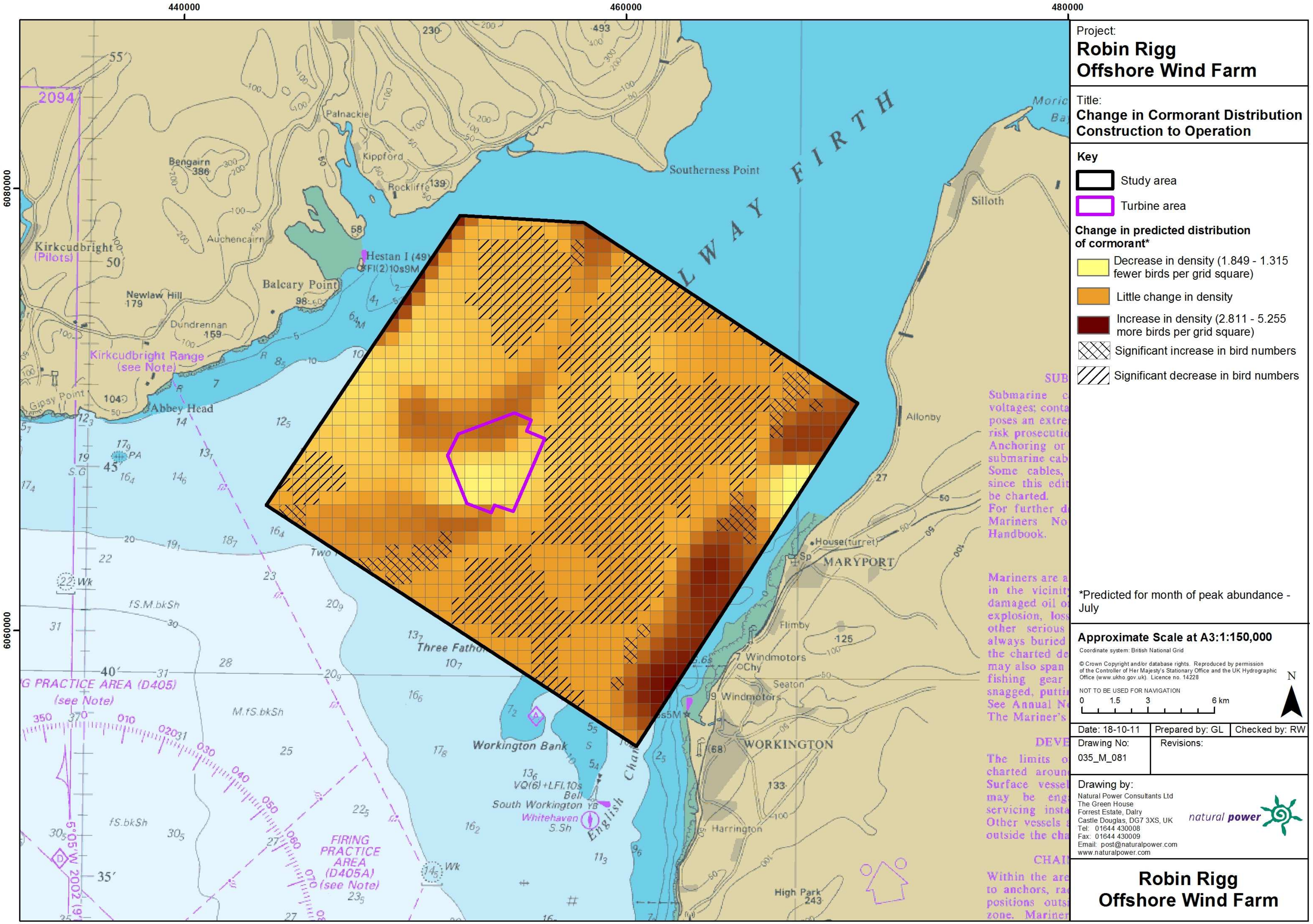


Figure 6.35: Difference plot of the change in predicted density of cormorant between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

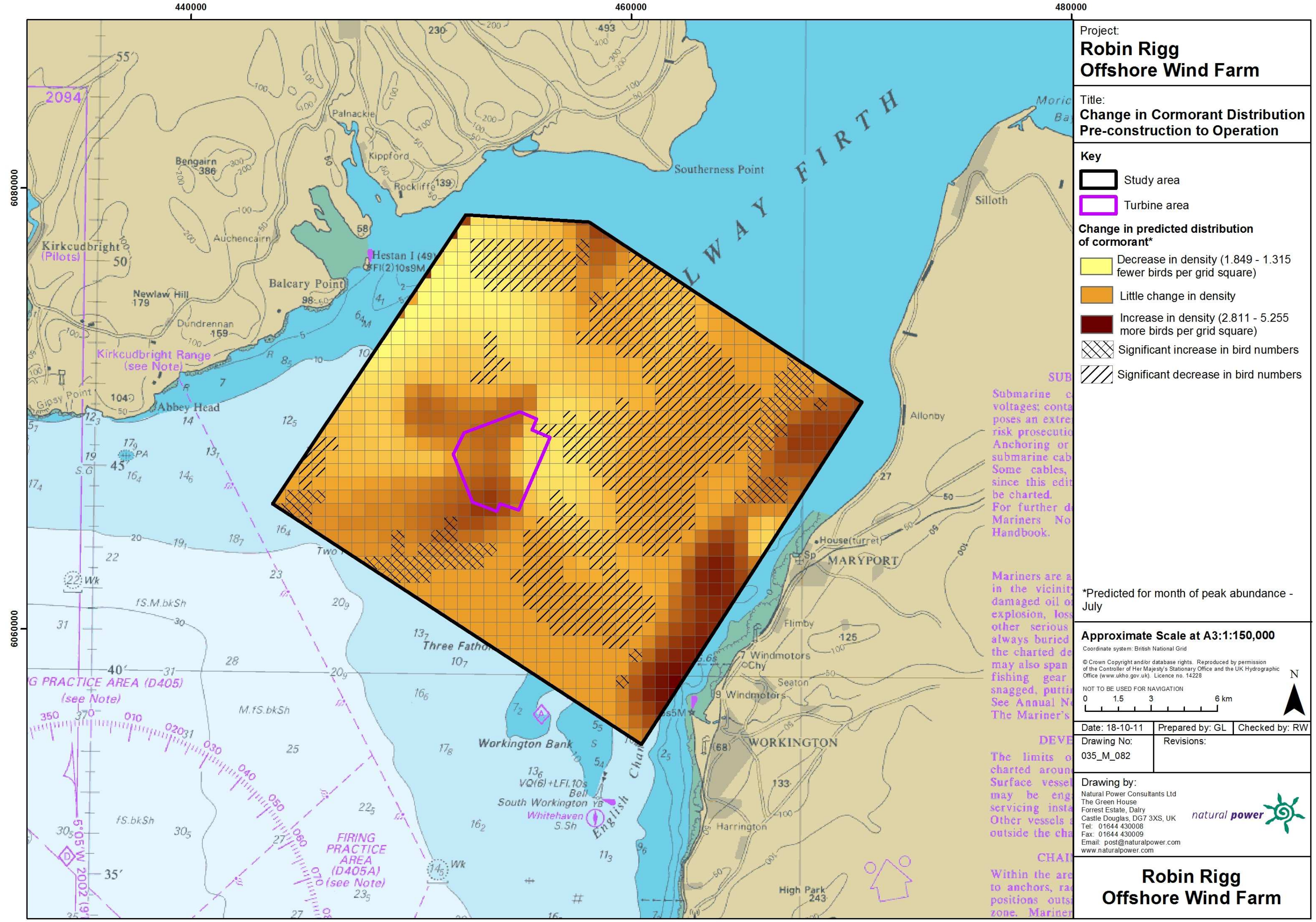


Figure 6.35: Difference plot of the change in predicted density of cormorant between the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines.

- Birds in flight

The percentage of cormorant recorded in different height bands relative to rotor height can be found in Table 6.12 and Figure 6.36a. The band 35-125 represents rotor height. Data were combined for Chi-squared analysis (Figure 6.32b) and a significant difference was found between flight bands (χ^2 = 17.79, p = 0.0001, 2 df). More birds than expected were observed flying at rotor height during the construction phase, with fewer at this height before and after.

Table 6.12: Proportion of cormorant observed flying in different height bands through the three stages of the development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	75.1	24.4	0.5	0	0	0
Construction	64.7	32.5	1.6	1.2	0	0
Operation Yr. 1	65.3	22.3	9.0	3.4	0	0

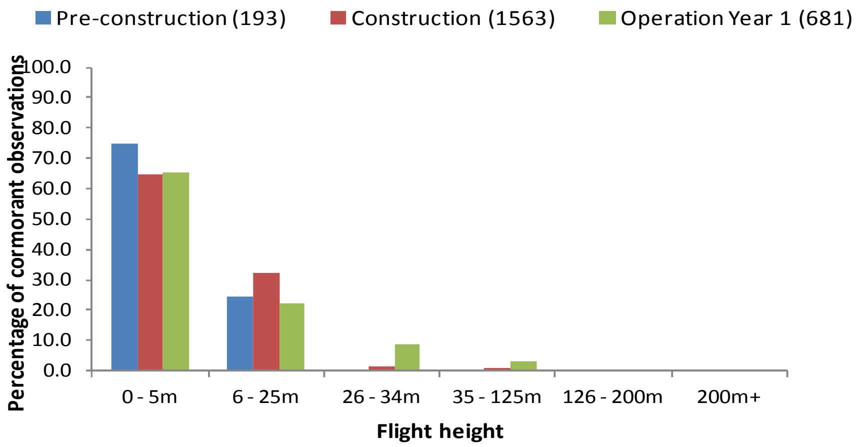


Figure 6.36a: Percentage of cormorant recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

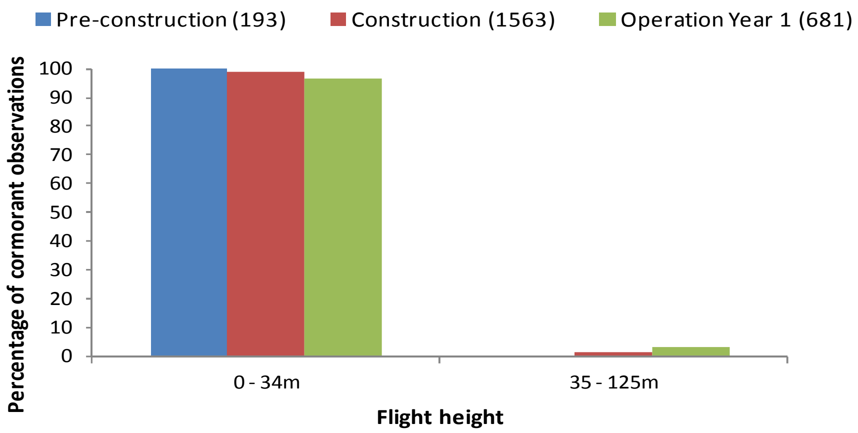


Figure 6.36b: Percentage of cormorant recorded in the combined flight bands used in the Chi-squared analysis. Figures in brackets represent total number.

6.2.8. Kittiwake

Kittiwake were recorded throughout the year with the greatest numbers, both on the water and in flight, observed in April and May pre-construction (Figure 6.37). The raw data indicate a decline in numbers through the three phases of the project compared to pre-construction (Figure 6.38 and 6.39).

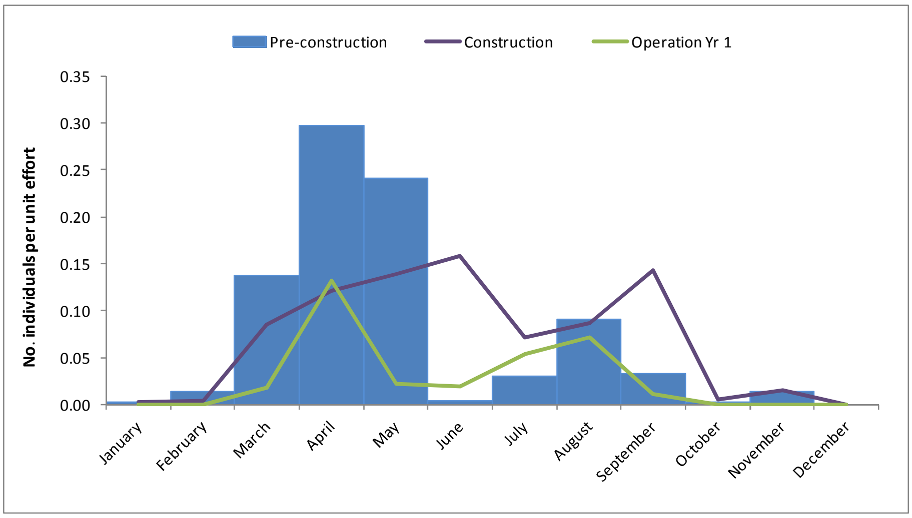


Figure 6.37a: Mean number of kittiwake observed on the sea per month during the pre-construction, construction and operational phases.

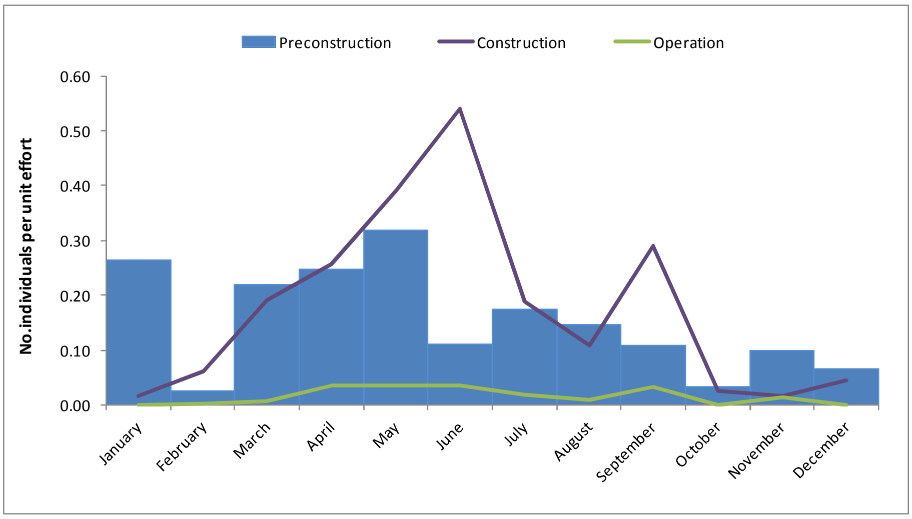


Figure 6.37b: Mean number of kittiwake observed in flight per month during the pre-construction, construction and operational phases.

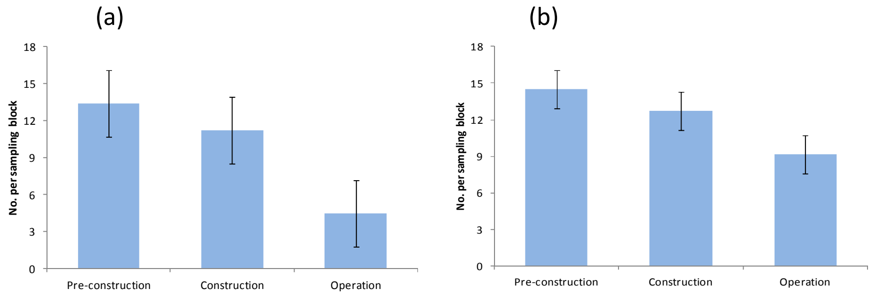


Figure 6.38: Mean number of kittiwake observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error)

Results from the simple GLM also suggest a decline in numbers on the water during the operational year one. There were no significant results for birds in flight (Table 6.13).

Table 6.13: Results from simple GLM for number of kittiwake observed in flight and on the sea. Pink indicates a significant decline between periods.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.366	0.010	0.004
In flight	0.673	0.452	0.336

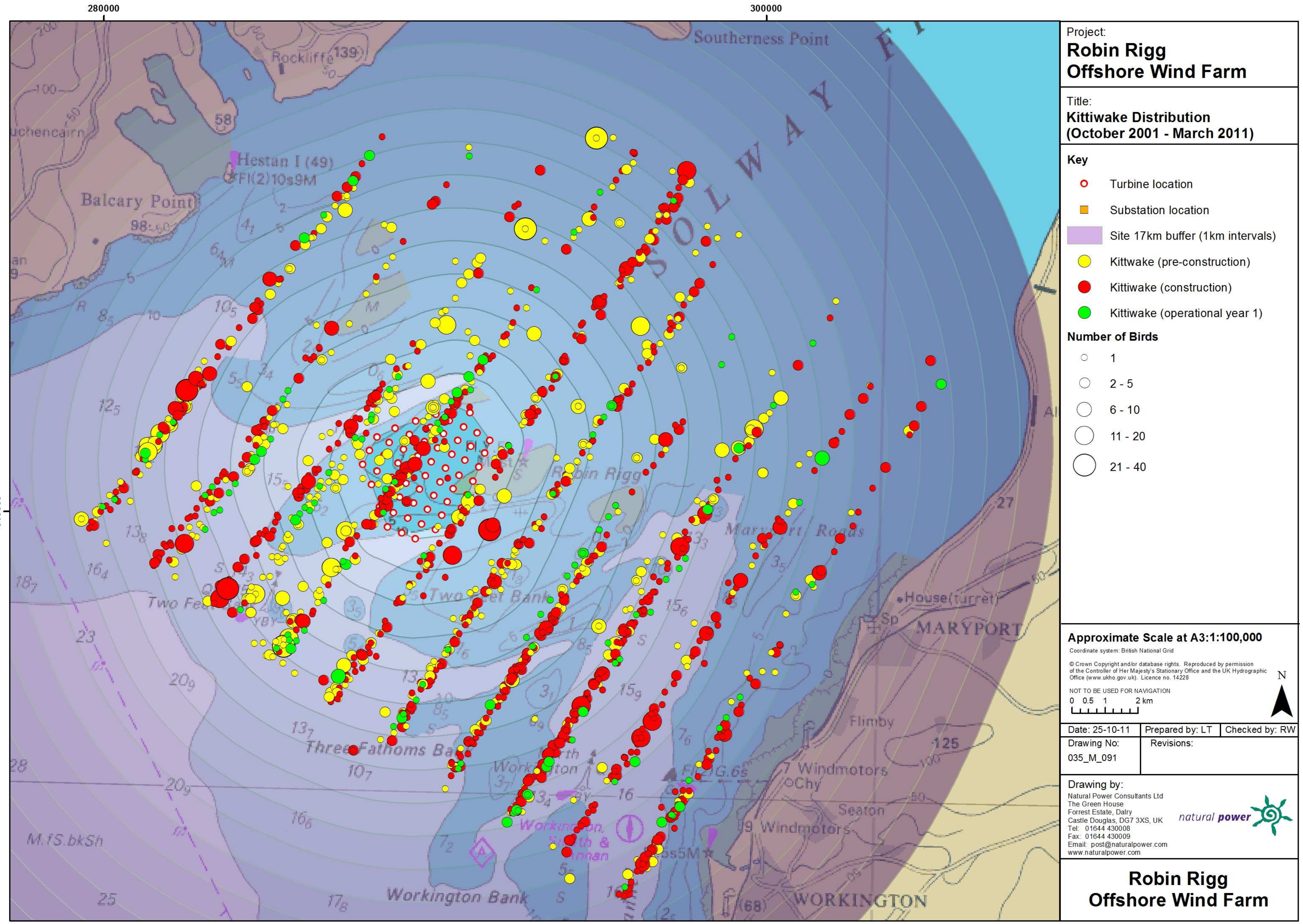


Figure 6.39: Locations of raw observations of kittiwake during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed

- Birds on the sea

A half normal detection function was used for this analysis and the month of April used to estimate abundance. Distance bands A and B were combined to obtain a satisfactory detection function. The predicted number of kittiwake for each construction phase can be found in Figure 6.40 below.

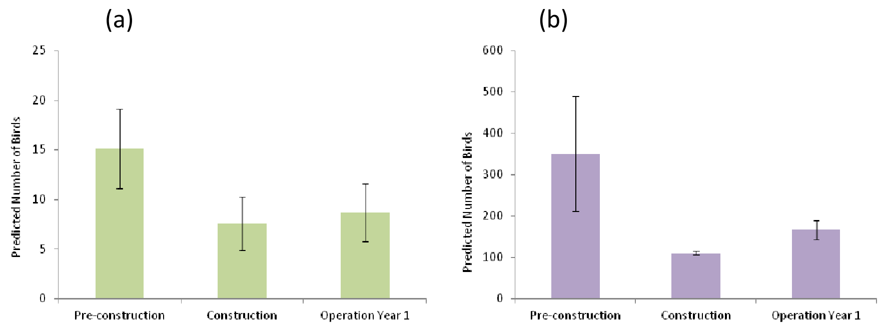


Figure 6.40: Predicted number of kittiwake using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction, construction and operational phases.

Kittiwake numbers do appear to have gone down during the construction phase and to an extent in operation year one (compared to pre-construction values) but this pattern is no more pronounced within the turbine area than compared to the entire site and could be regarded as reflecting inter-annual variation.

Density surface maps based on these predictions can be found in Figure 6.41 and the differences between the phases in Figure 6.42.

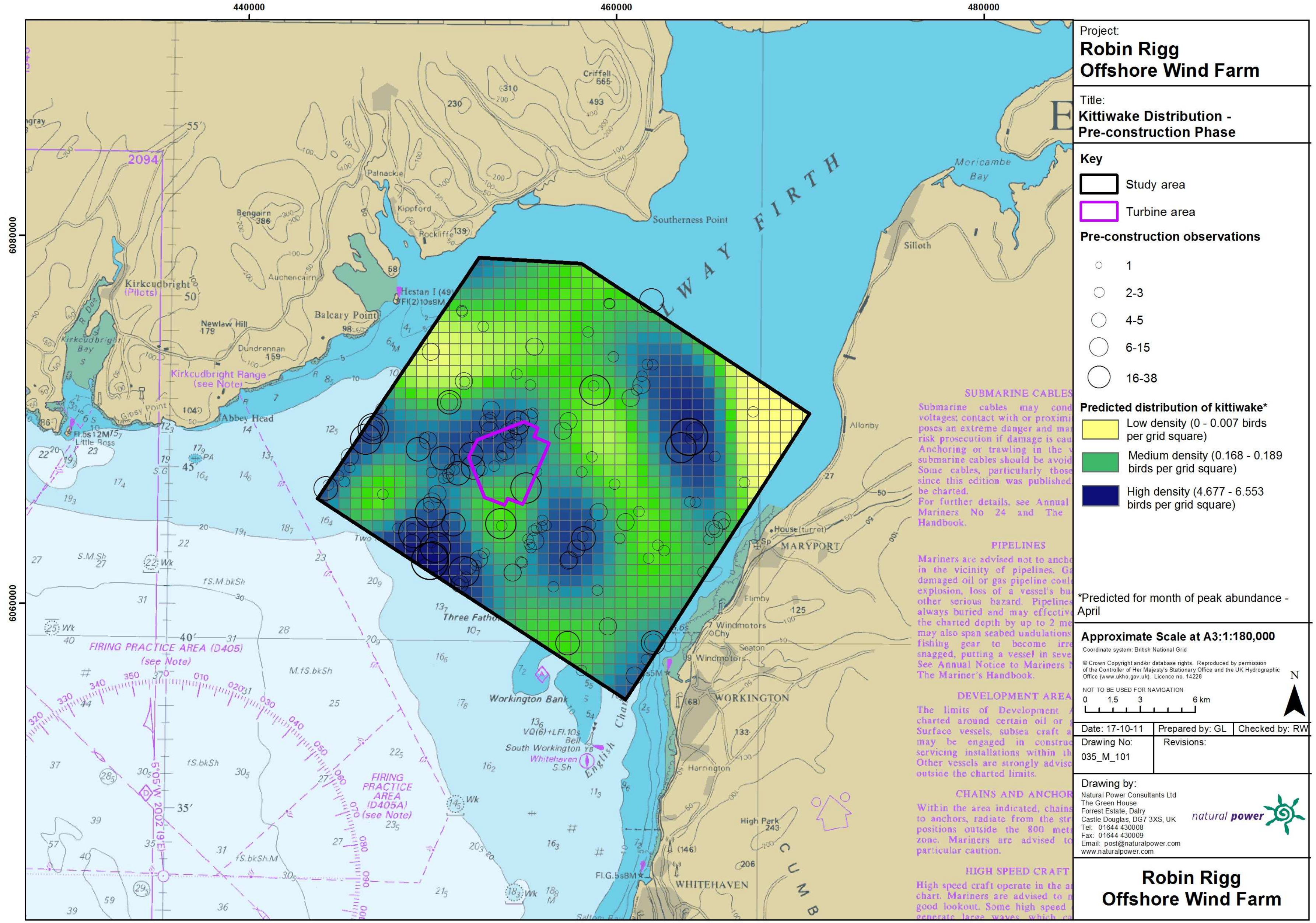


Figure 6.41a: Density surface map of the predicted density of kittiwake across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

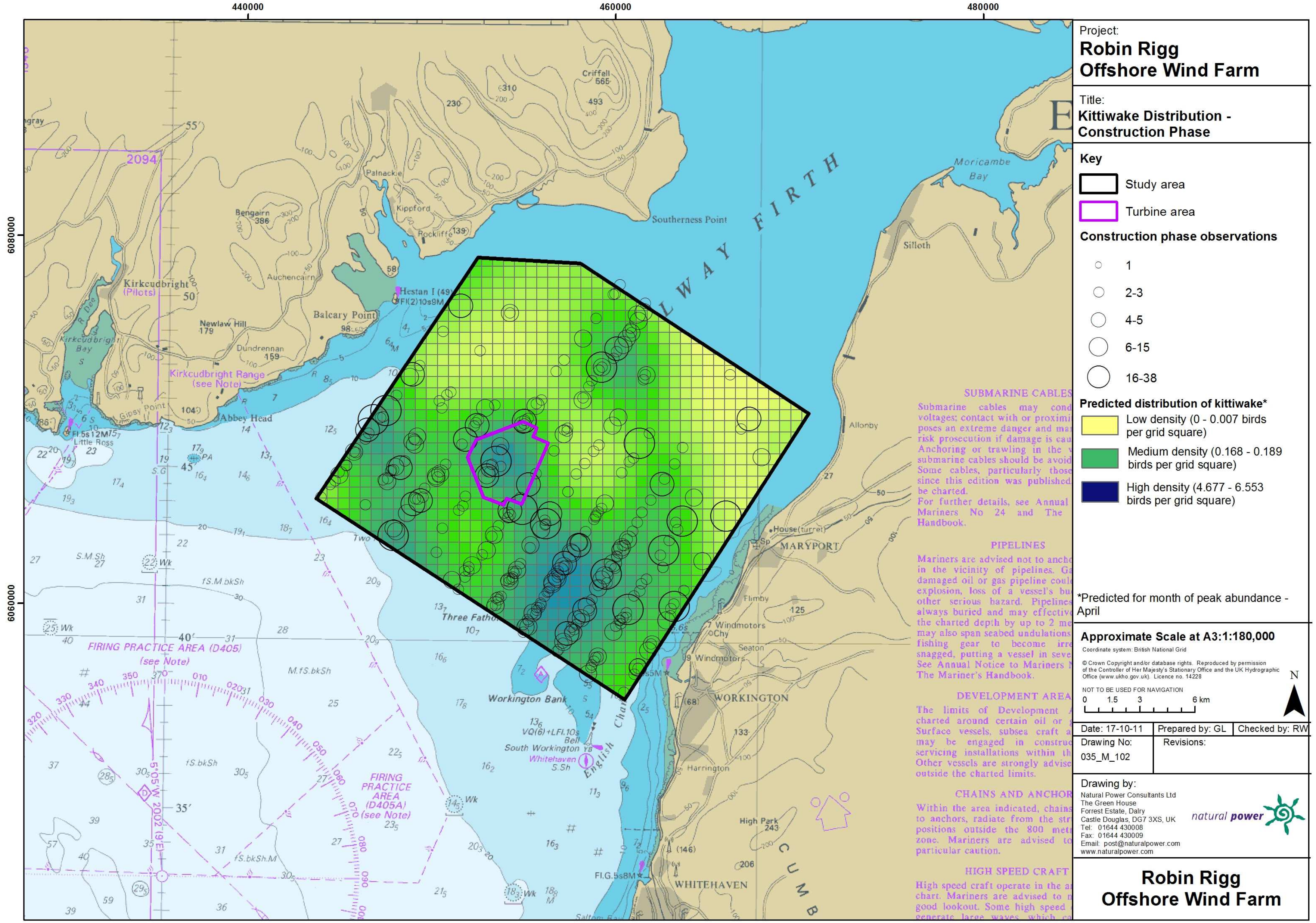


Figure 6.41b: Density surface map of the predicted density of kittiwake across the survey area during the construction phase. Open circles show the locations of the raw observations.

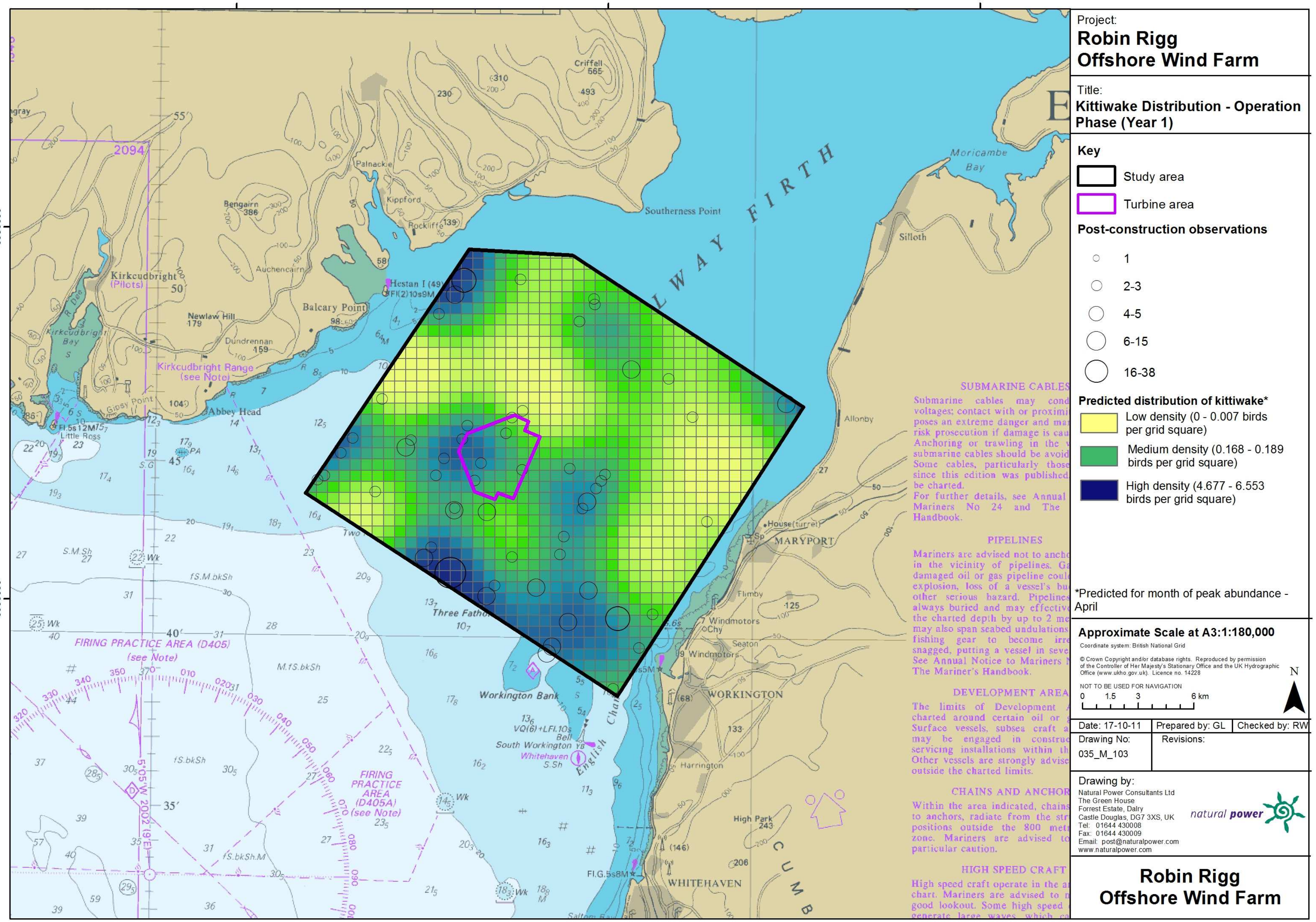


Figure 6.41c: Density surface map of the predicted density of kittiwake across the survey area during the operational phase. Open circles show the locations of the raw observations.

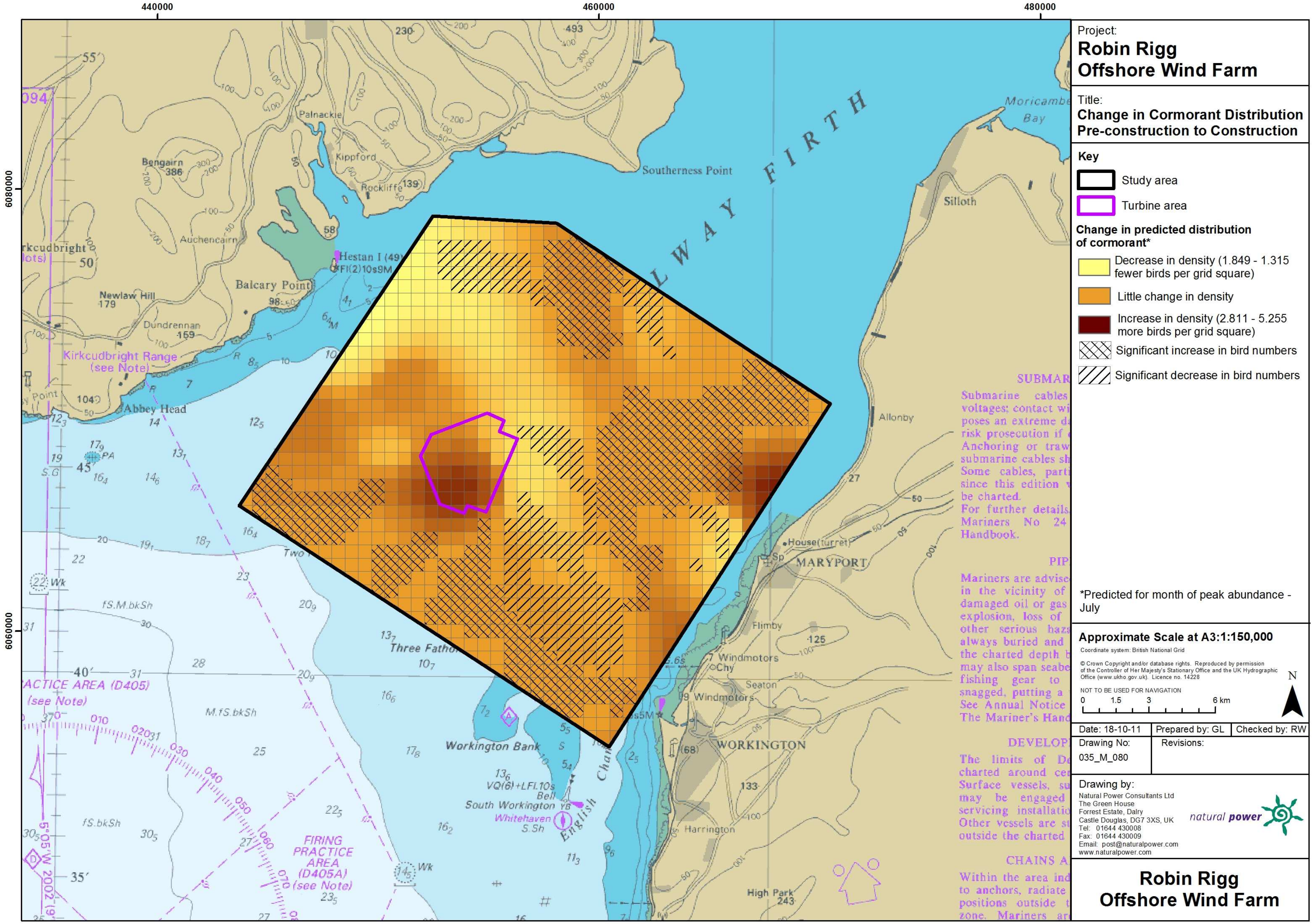


Figure 6.42a: Difference plot of the change in predicted density of kittiwake between the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

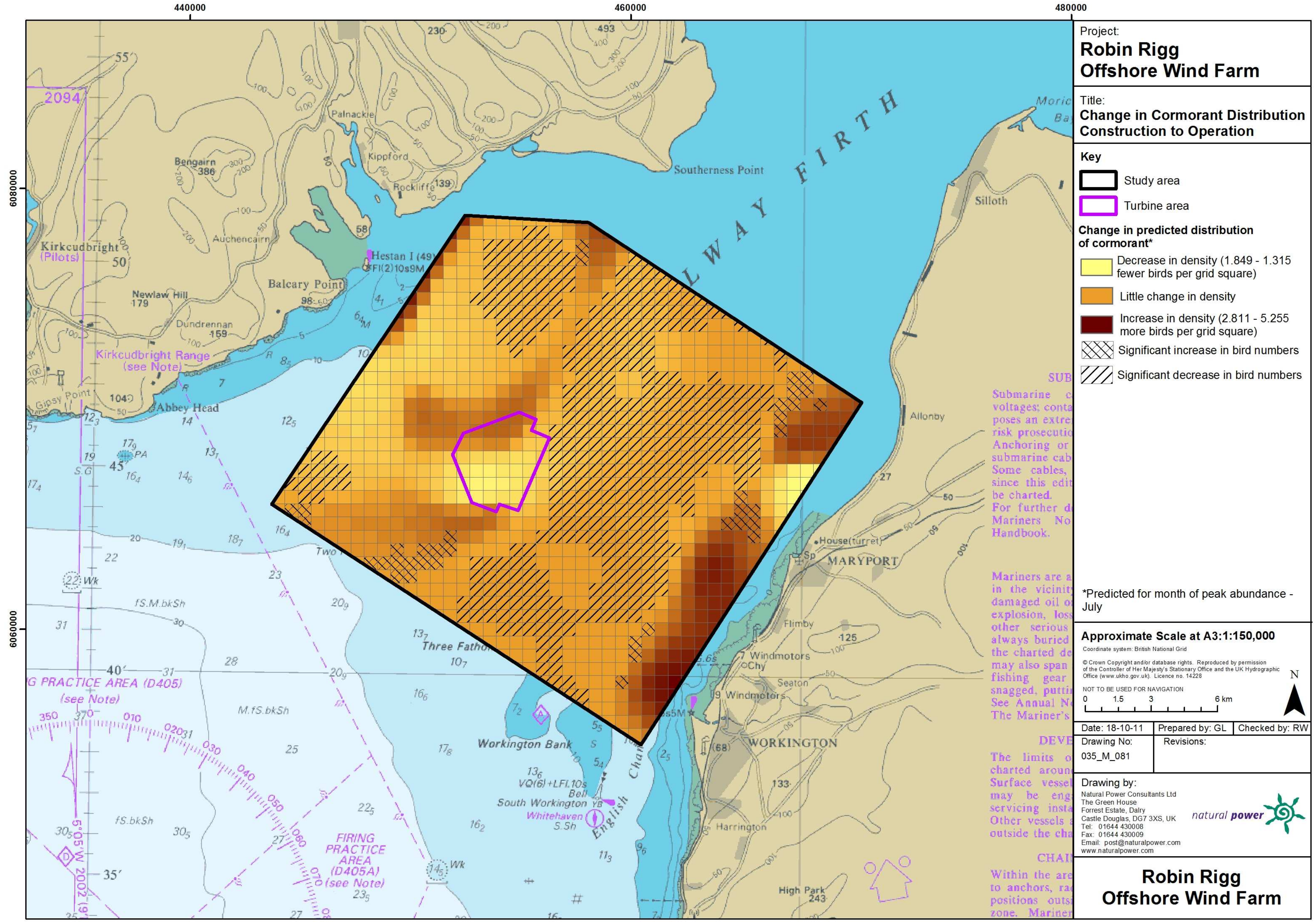


Figure 6.42b: Difference plot of the change in predicted density of kittiwake between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

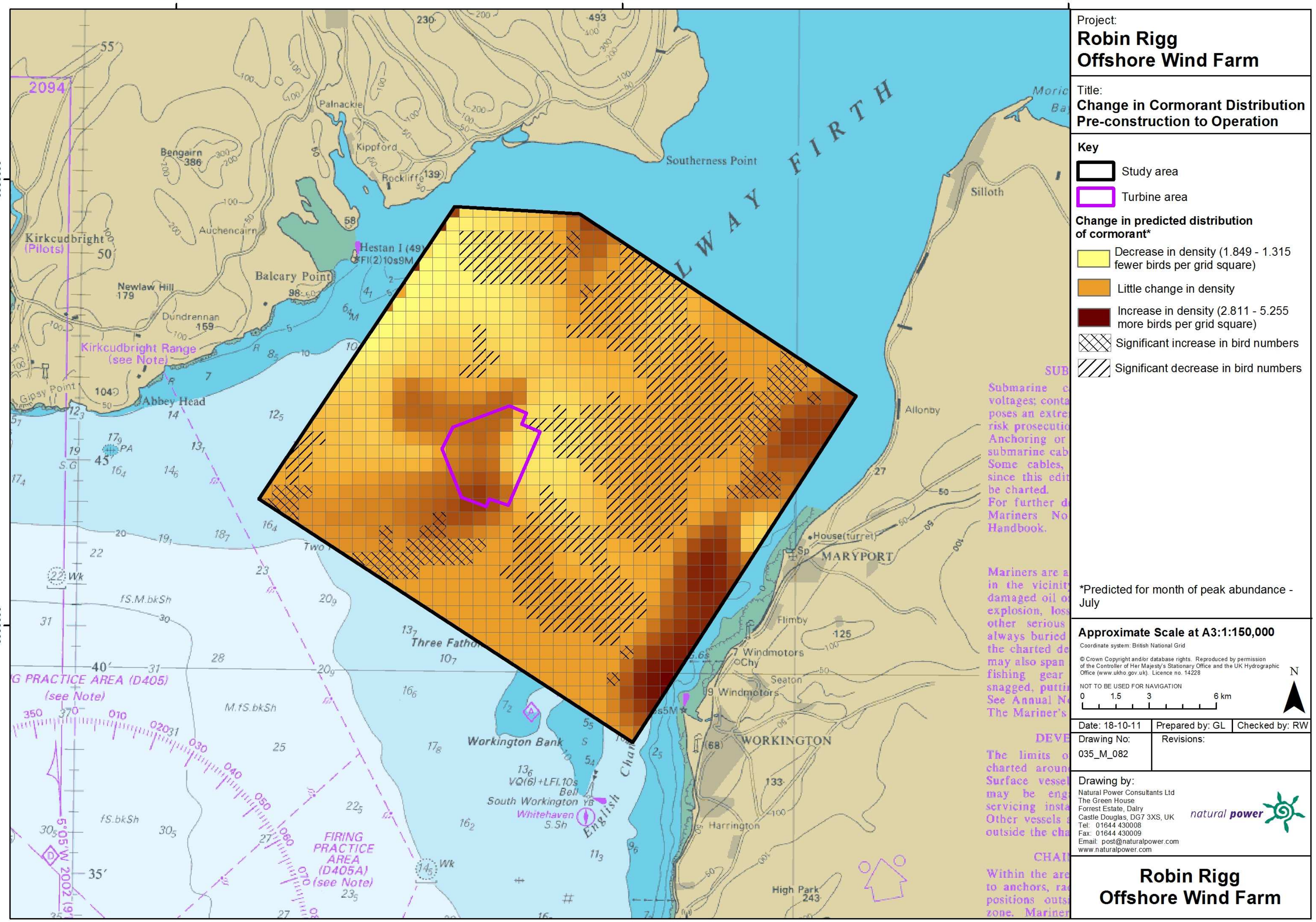


Figure 6.4c: Difference plot of the change in predicted density of kittiwake between the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines

- Birds in flight

The percentage of kittiwake recorded in different height bands relative to rotor height can be found in Table 6.14 and Figure 6.43a. The band 35-125 represents rotor height. Data were combined for Chi-squared analysis (Figure 6.39b) and a significant difference was found between flight bands ($\chi^2 = 8.19$, $p = 0.0167$, 2 df). Fewer birds than expected were observed flying at rotor height during the operational phase but it should be noted that the expected value was below the recommended five, making this result unreliable. It is assumed that once more data has been collected at the end of operation year two, a more robust analysis can be conducted.

Table 6.14: Proportion of kittiwake observed flying at different height bands during the three stages of development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	49.7	48.4	0.8	1.0	0	0
Construction	25.9	70.4	2.1	1.6	0	0
Operation Yr. 1	25.0	68.2	2.6	4.2	0	0

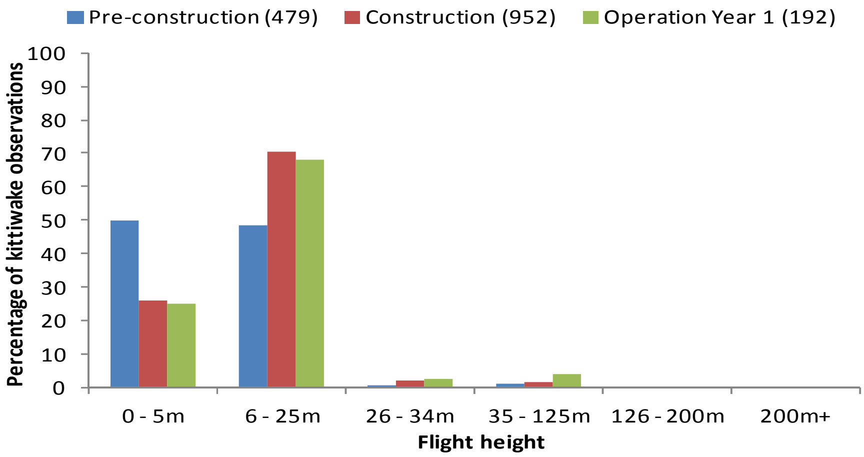


Figure 6.43a: Percentage of kittiwake recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

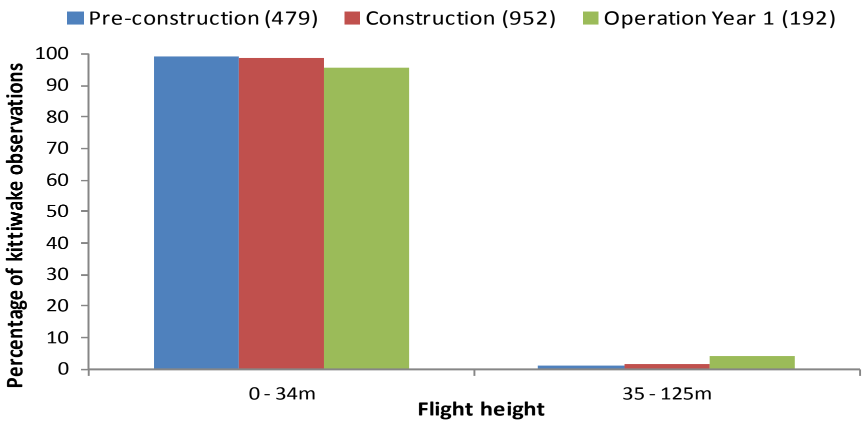


Figure 6.43b: Percentage of kittiwake recorded in the combined flight bands used in the Chi-squared analysis. Figures in brackets represent total number.

6.2.9. Large gulls

For the purpose of this analysis, herring gull, lesser black-backed and greater black-backed gulls have been combined into a single group and from herein are referred to as "large gulls". Supplementary analysis on herring gull and greater black-backed gull observations individually can be found in Appendix 13.4. Should the data during operation year two be sufficient, these species will be analysed independently in the next report.

Large gulls were recorded throughout the year with the greatest numbers observed on the water in spring (Figure 6.44). The raw data indicate an increase across all phases of the project for birds on the sea, while birds in flight increased during the construction phase before decreasing again during operation (Figures 6.45 and 6.46). Species differences were observed, with herring gull numbers declining across the survey area through all phases of the project (both on the sea and in flight); while greater black-backed gull showed the opposite trend (see Appendix 13.4).

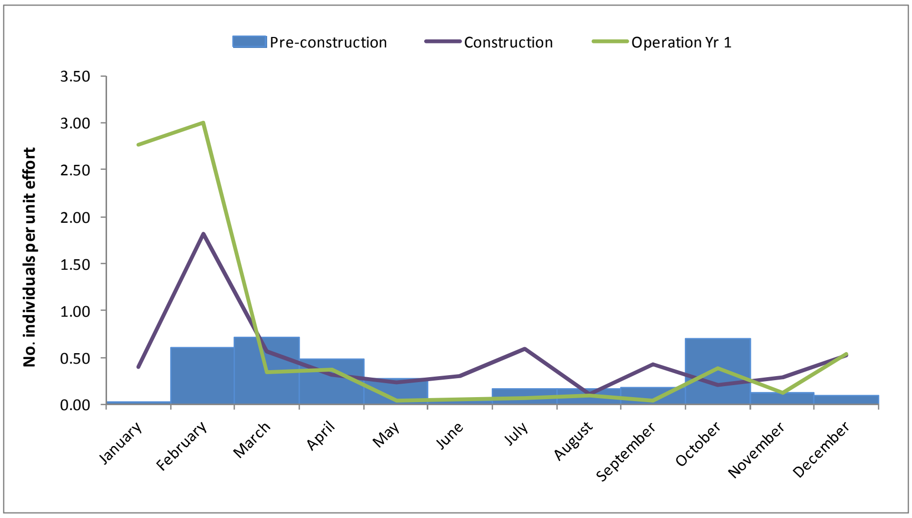


Figure 6.44a Mean number of large gulls observed on the sea per month during the pre-construction, construction and operational phases.

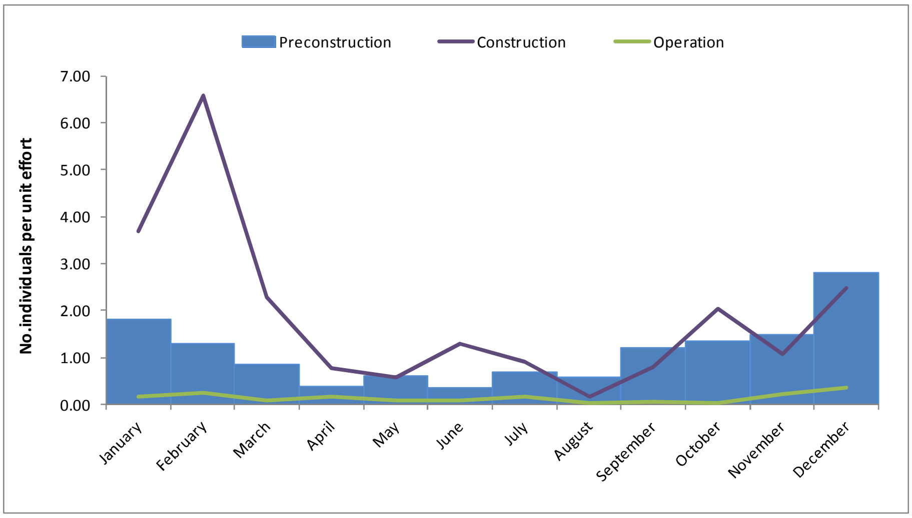


Figure 6.44b Mean number of large gulls observed in flight per month during the pre-construction, construction and operational phases.

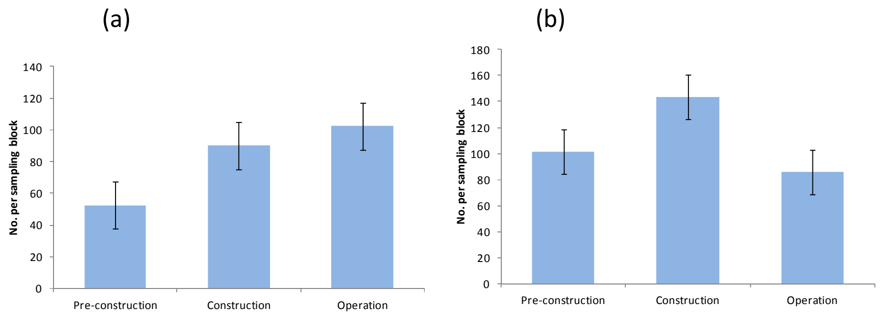


Figure 6.45: Mean number of large gulls observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error).

Results from the simple GLM also suggest an increase in numbers of large gulls on the water (pre-construction and operation) and an increase for birds in flight during operational year one (Table 6.15). Separate results for herring gull and great black-backed gull can be found in Table 6.2.

Table 6.15: Results from simple GLM for number of large gulls observed in flight and on the sea. Green indicates a significant increase between periods.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.251	0.168	0.043
In flight	0.058	0.338	0.656

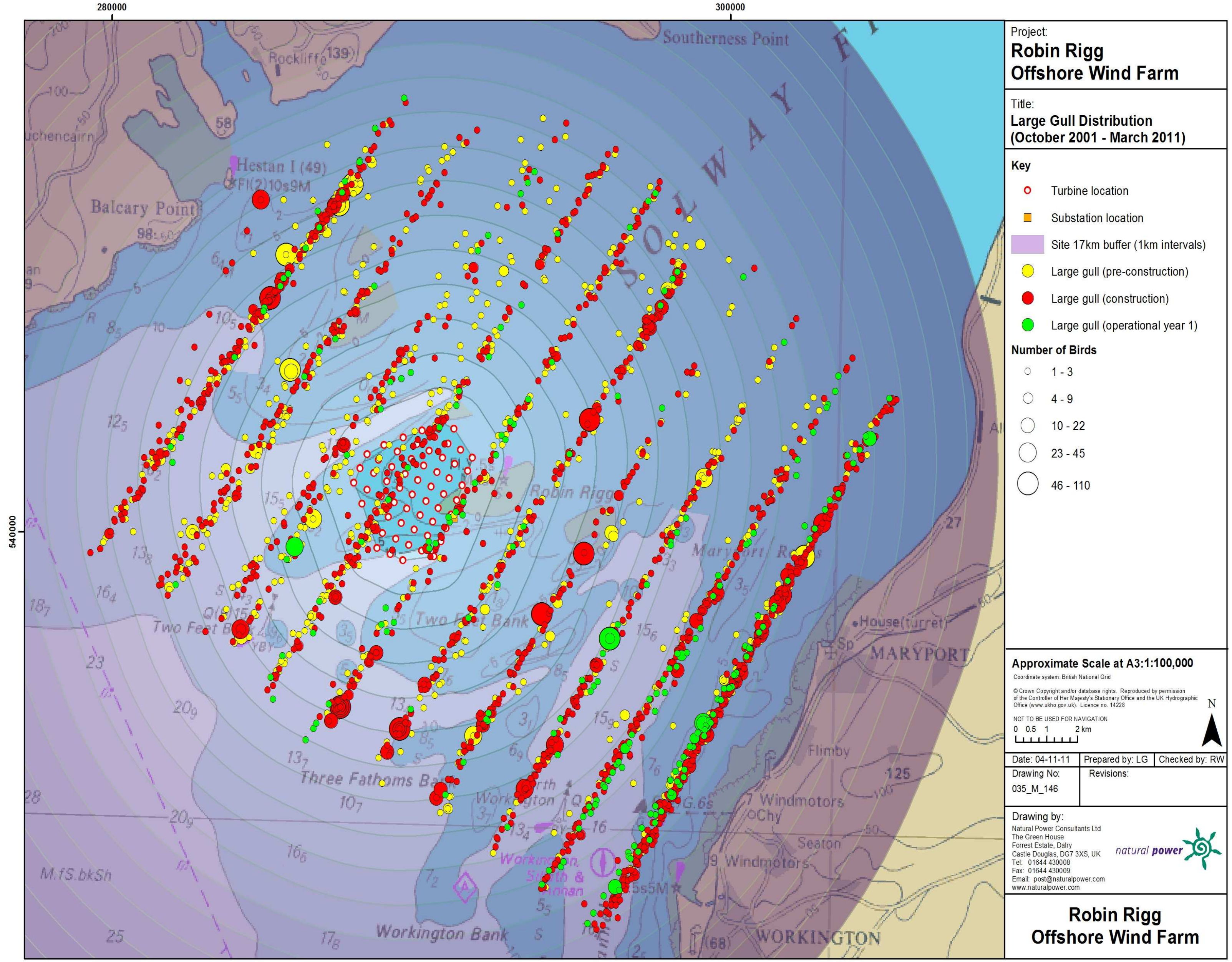
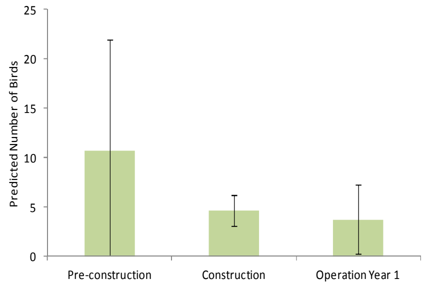


Figure 6.46: Locations of raw observations of large gulls during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed

- Birds on the sea

A half normal detection function was used for this analysis and the month of February to estimate abundances. Distance bands A and B were combined for the analysis to improve the detection function. The predicted number of large gulls for each construction phase can be found in Figure 6.47 below.

(a)



(b)

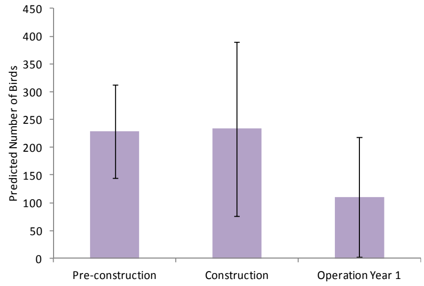


Figure 6.47: Predicted number of large gulls using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction, construction and operational phases.

The data suggest a possible decline in numbers during operational year one but the large error bars makes interpretation difficult. A clearer pattern may become apparent after more data has been collected at the end of operational year two.

Density surface maps based on these predictions can be found in Figure 6.48 and the differences between the phases in Figure 6.49.

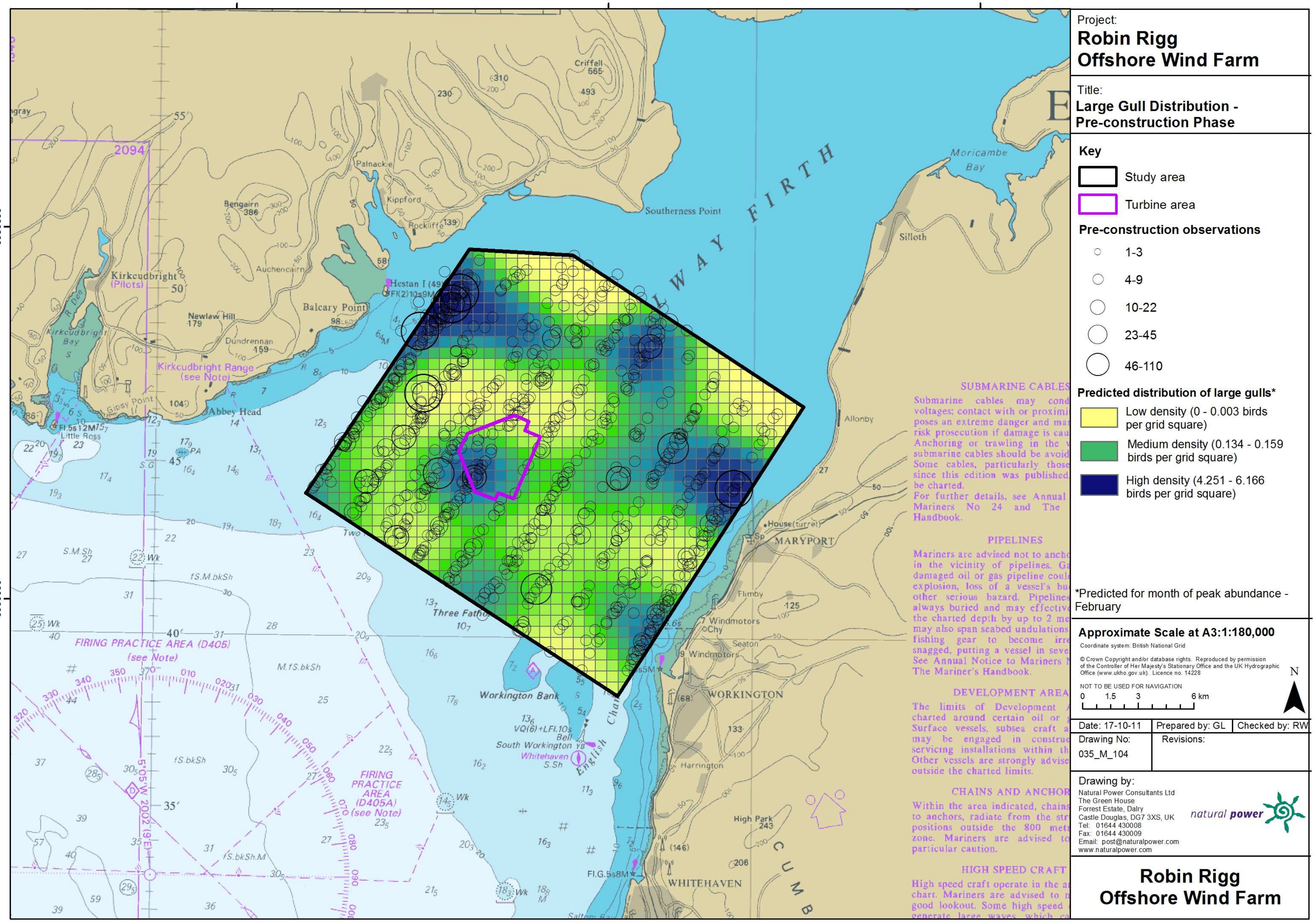


Figure 6.48a: Density surface map of the predicted density of large gulls across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

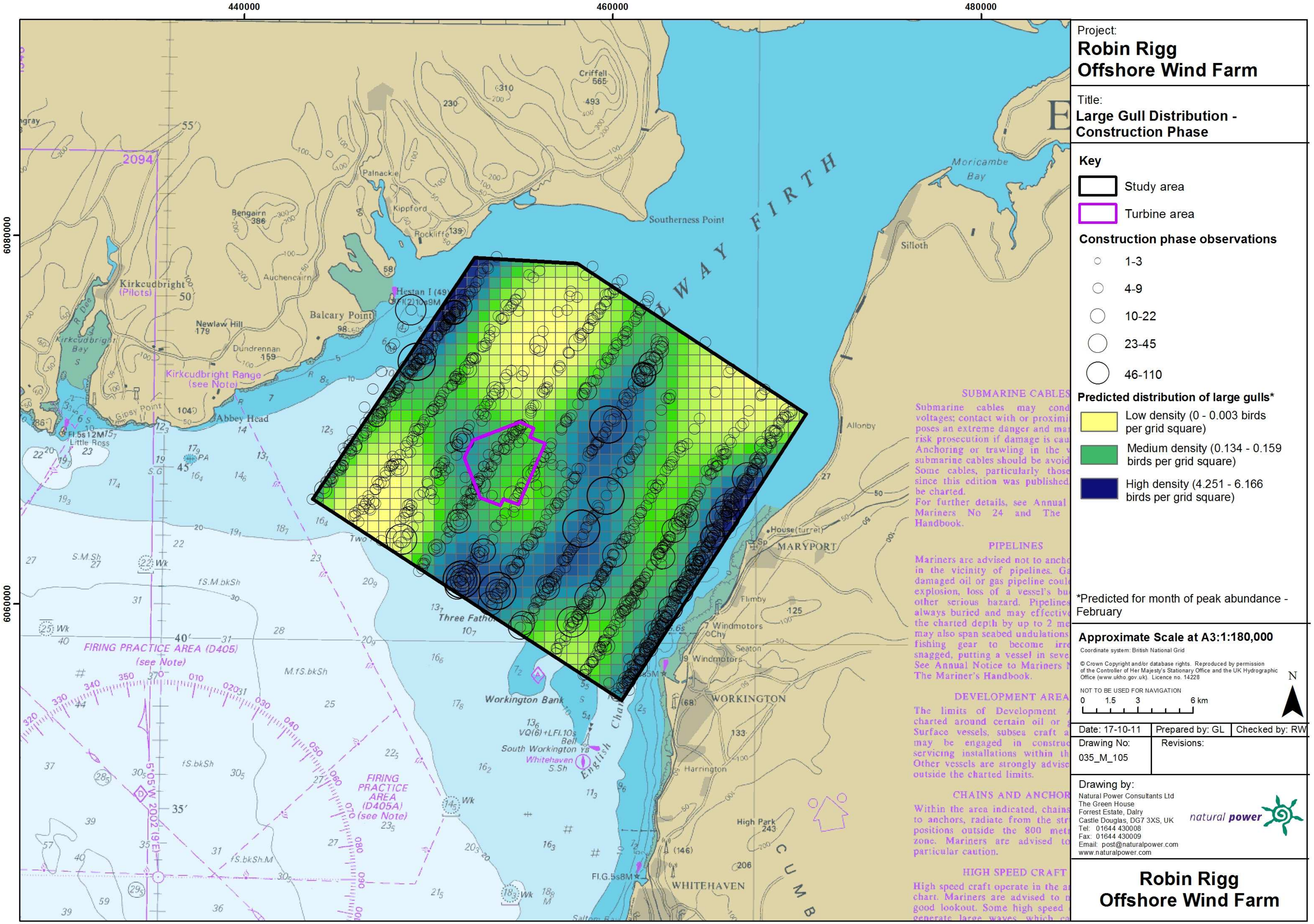


Figure 6.48b: Density surface map of the predicted density of large gulls across the survey area during the construction phase. Open circles show the locations of the raw observations.

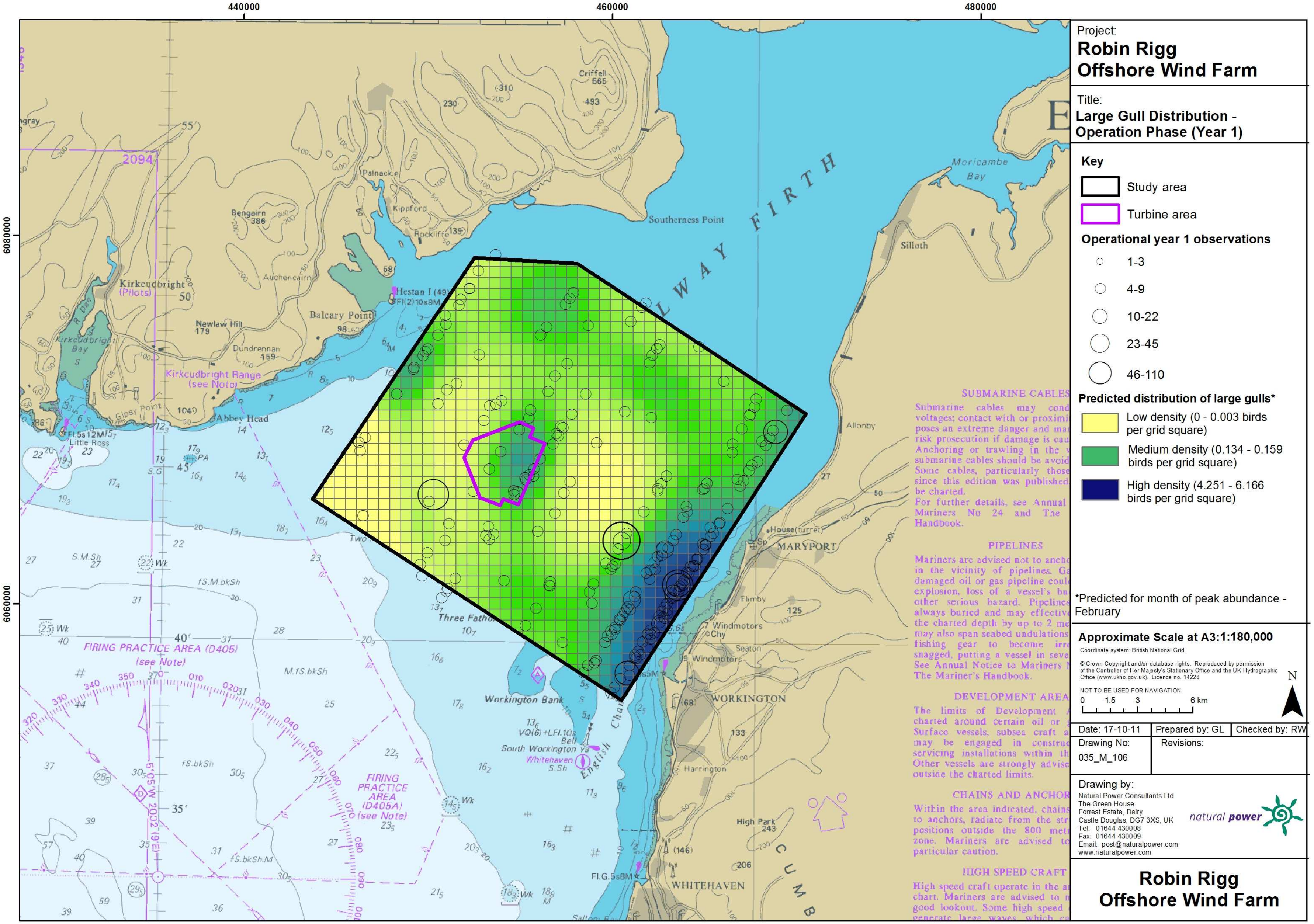


Figure 6.48c: Density surface map of the predicted density of large gulls across the survey area during the operational phase. Open circles show the locations of the raw observations.

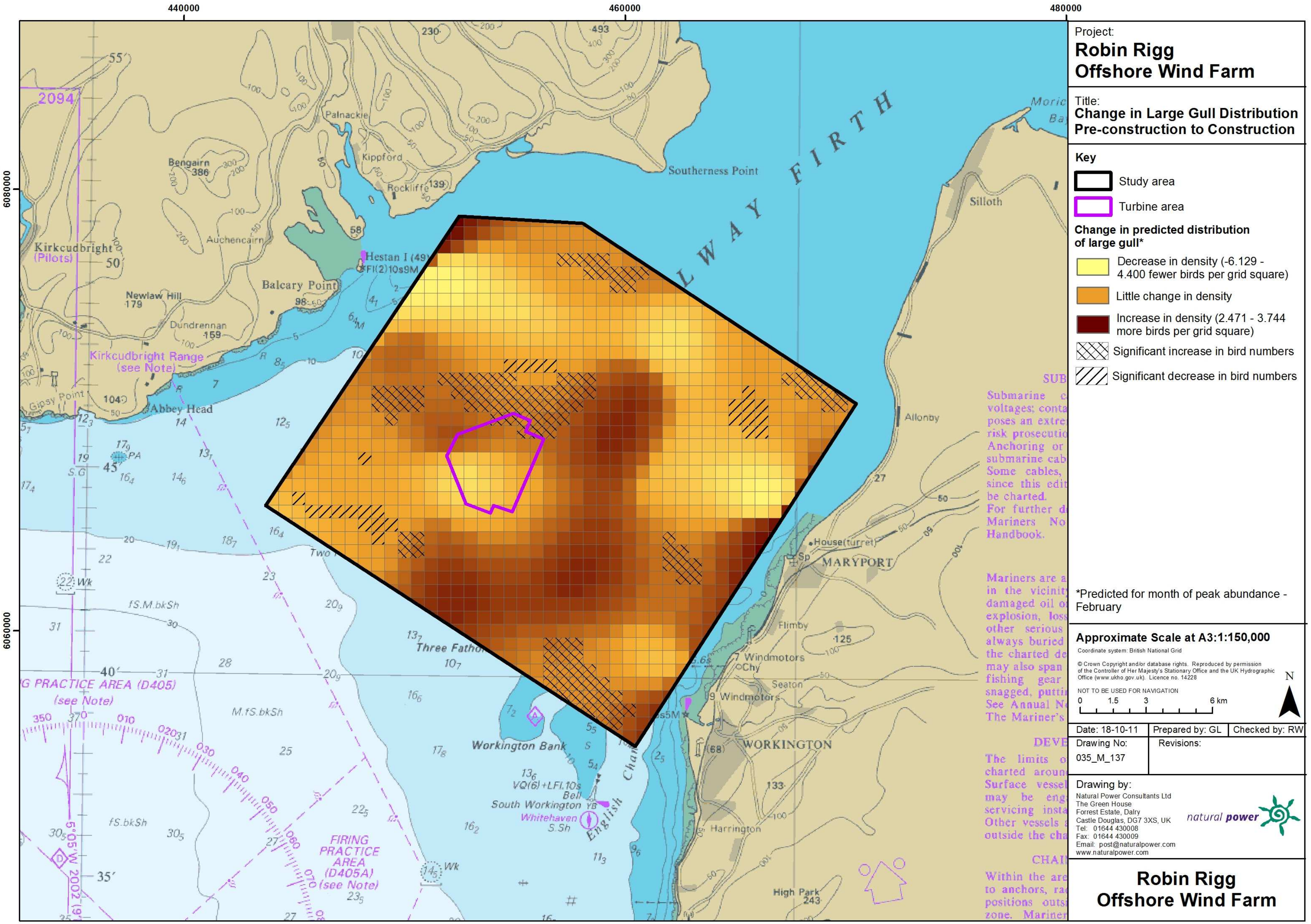


Figure 6.49a: Difference plot of the change in predicted density of large gulls between the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

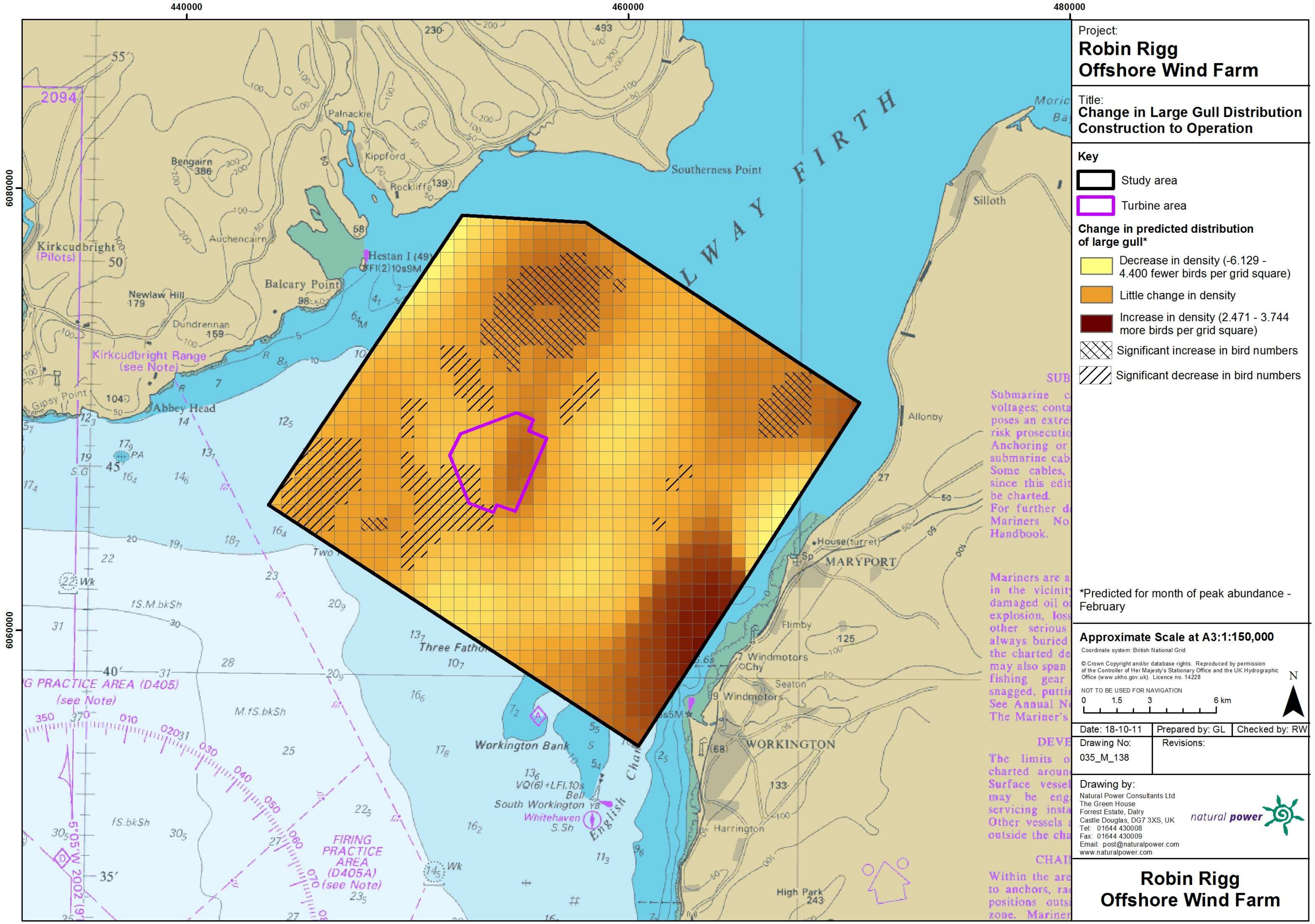


Figure 6.49b: Difference plot of the change in predicted density of large gulls between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

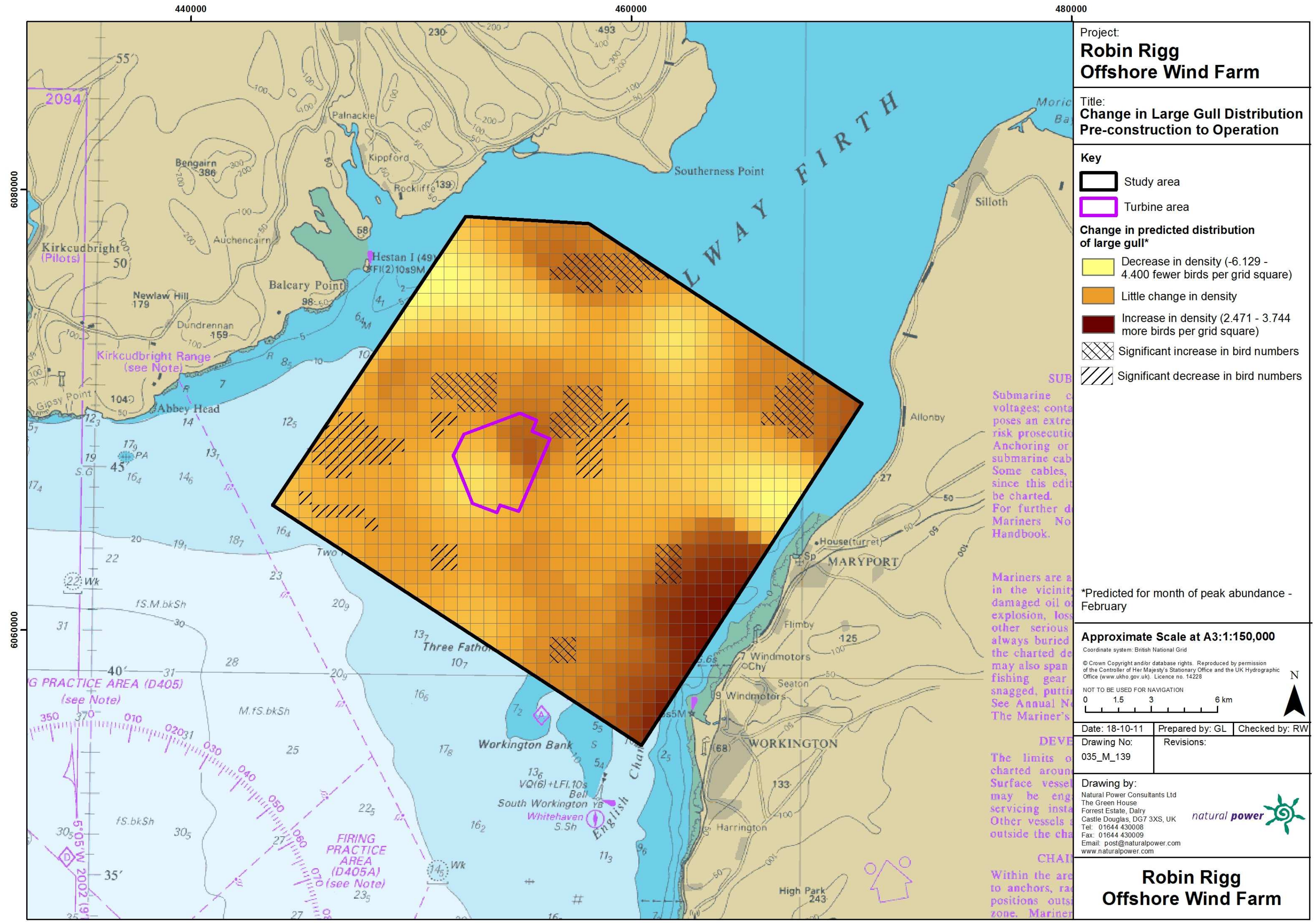


Figure 6.49c: Difference plot of the change in predicted density of large gulls between the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines

- Birds in flight

The percentage of large gulls recorded in different height bands relative to rotor height can be found in Table 6.16 and Figure 6.50a. The band 35-125 represents rotor height. Data were combined for Chi-squared analysis (Figure 6.48b) and a significant difference was found between flight bands (χ^2 = 130.04, $p < 0.0001$, 2 df). Fewer large gulls than expected were observed flying at rotor height pre-construction, while more than expected during the construction and operation phases, potentially increasing their risk of collision (see Section 9 for further discussion).

Table 6.16: Proportion of large gulls observed at different height bands through the three phases of the development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	28.7	66.1	3.8	1.4	0	0
Construction	18.5	61.4	10.4	9.7	0	0
Operation Yr. 1	16.1	52.0	18.7	13.1	0	0

Figure 6.50a: Percentage of large gulls recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

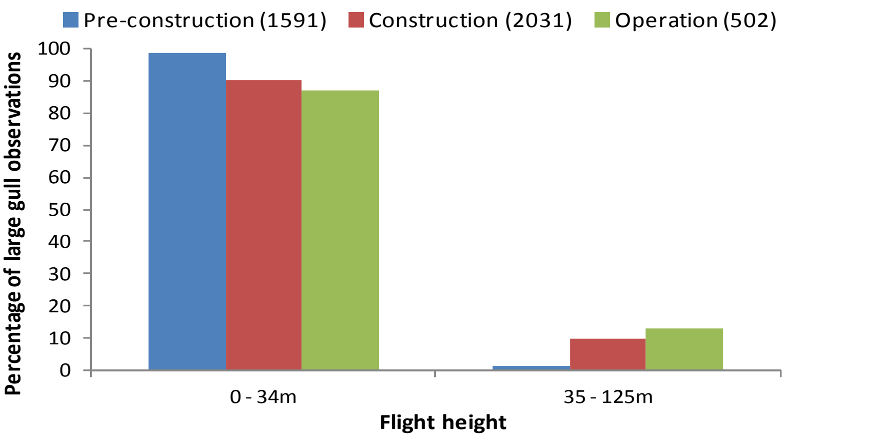


Figure 6.50b: Percentage of large gulls recorded in the combined flight bands used in the Chi-squared analysis. Figures in brackets represent total number.

6.2.10. Guillemot

Guillemot were recorded throughout the year with no clear seasonal peaks (Figure 6.51). The raw data indicate a decline during construction for birds on the sea, which is not followed by a return to pre-construction levels during the operational phase, while the pattern for birds in flight suggests an increase in numbers compared to pre-construction (Figure 6.52 and 6.53).

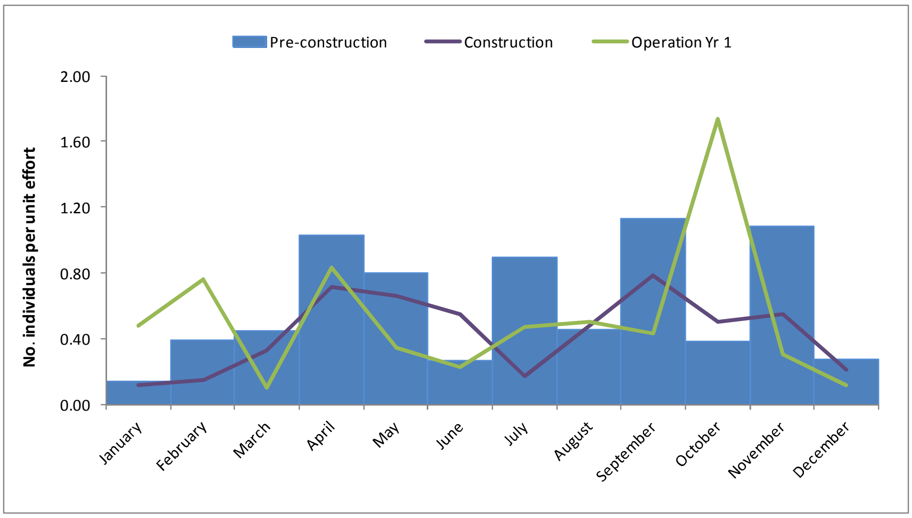


Figure 6.51a: Mean number of guillemot observed on the sea per month during the pre-construction, construction and operational phases.

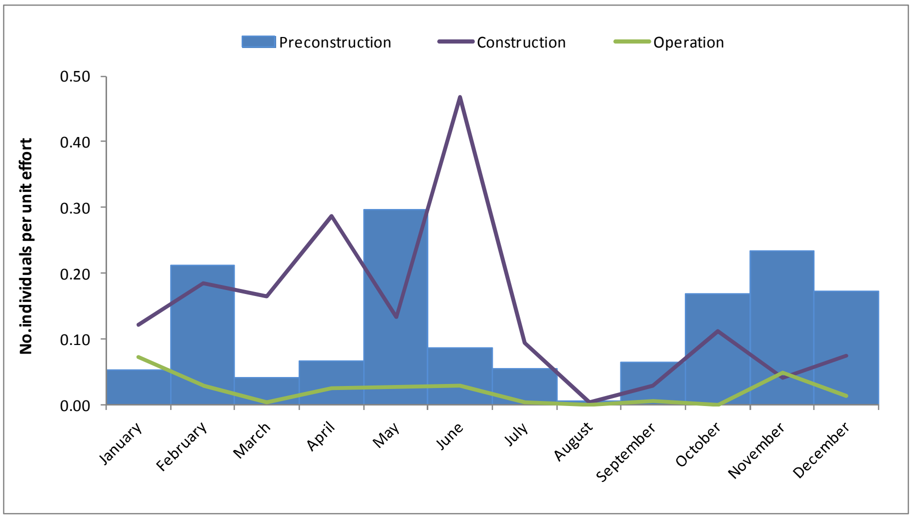


Figure 6.51b: Mean number of guillemot observed in flight per month during the pre-construction, construction and operational phases.

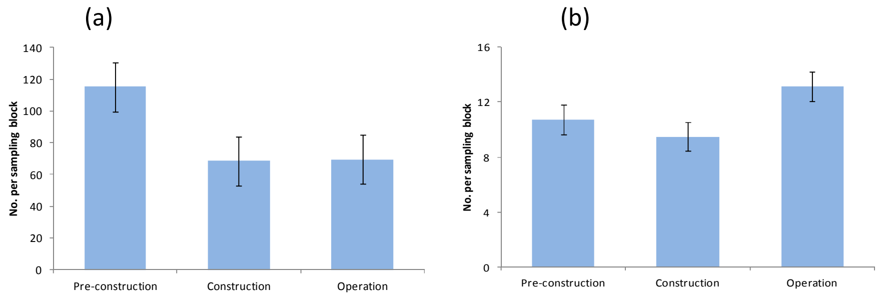


Figure 6.52: Mean number of guillemot observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error).

Results from the simple GLM also suggest a decline in numbers on the water between pre-construction and construction. There were no significant results for birds in flight (Table 6.17).

Table 6.17: Results from simple GLM for number of guillemot observed in flight and on the sea. Pink indicates a significant decline between periods.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.010	0.795	0.118
In flight	0.421	0.073	0.362

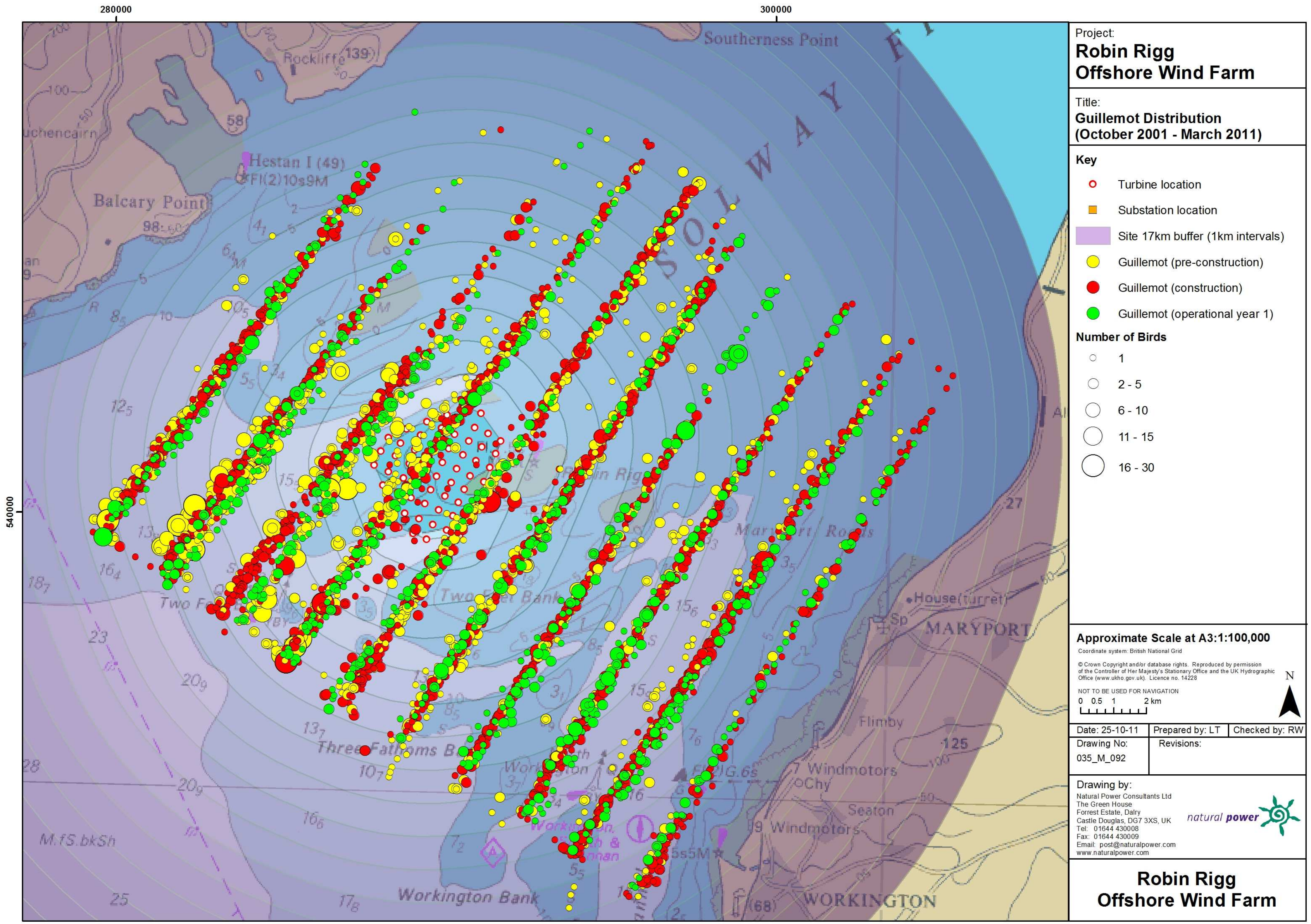


Figure 6.53: Locations of raw observations of guillemot during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed

- Birds on the sea

A hazard rate detection function was used for this analysis and the month of April used to predict abundance. The predicted number of guillemot for each construction phase can be found in Figure 6.54 below.

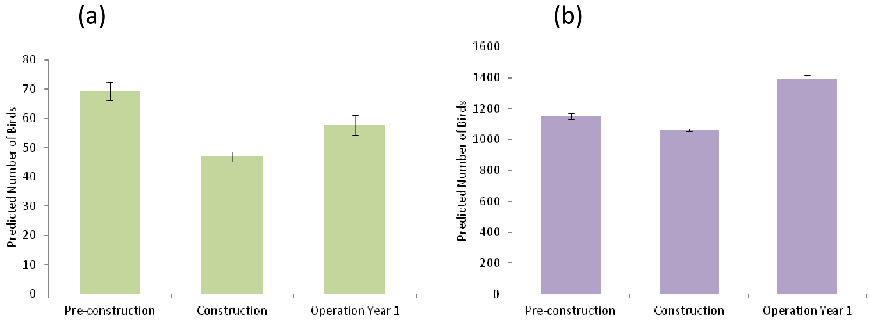


Figure 6.54: Predicted number of guillemot using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction, construction and operational phases.

Data suggests a decline in abundance during the construction phase with numbers increasing again during operational year one, although a smaller increase is observed within the turbine area indicating potential displacement.

Density surface maps based on these predictions can be found in Figure 6.55 and the differences between the phases in Figure 6.56.

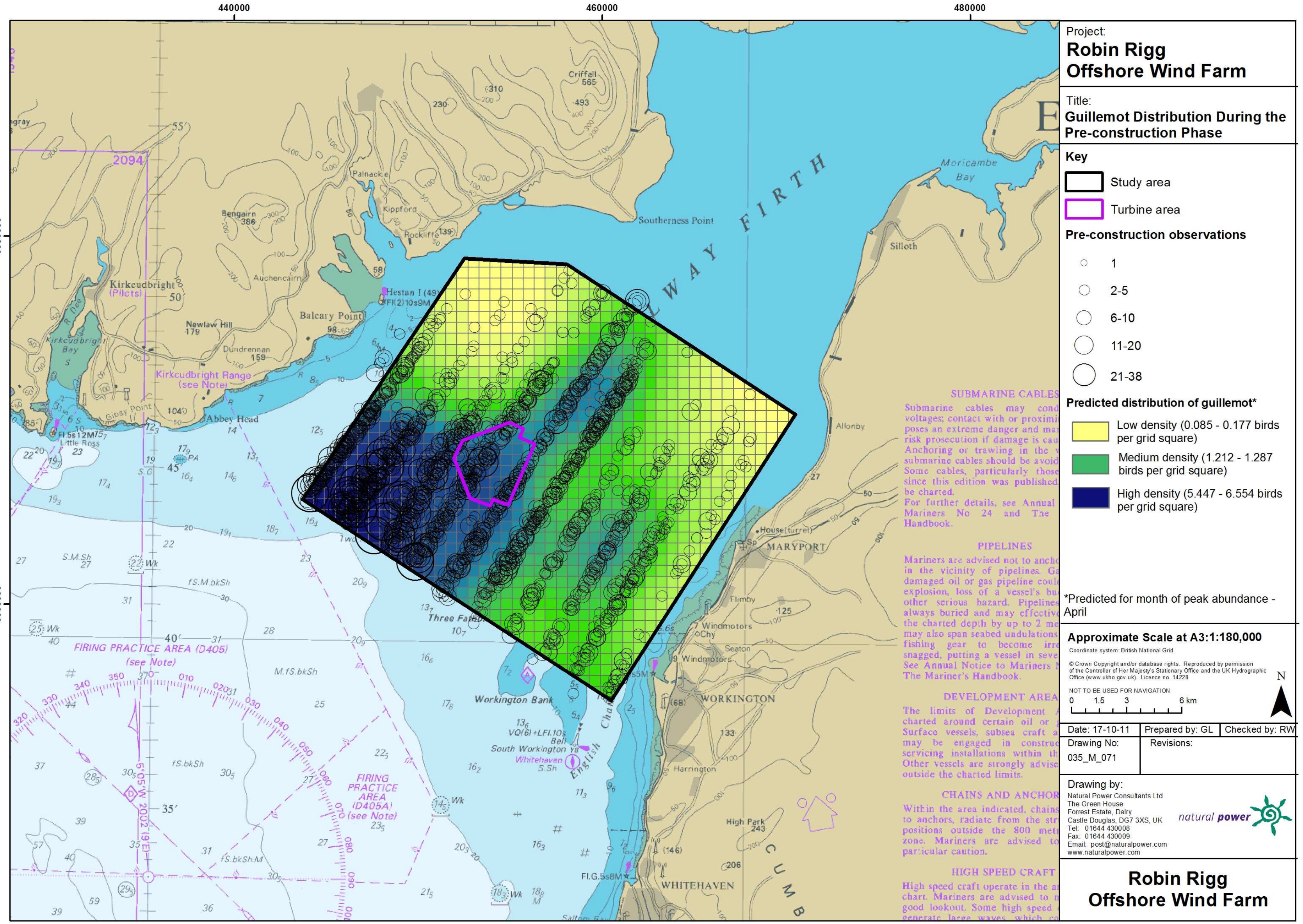


Figure 6.55a: Density surface map of the predicted density of guillemot across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

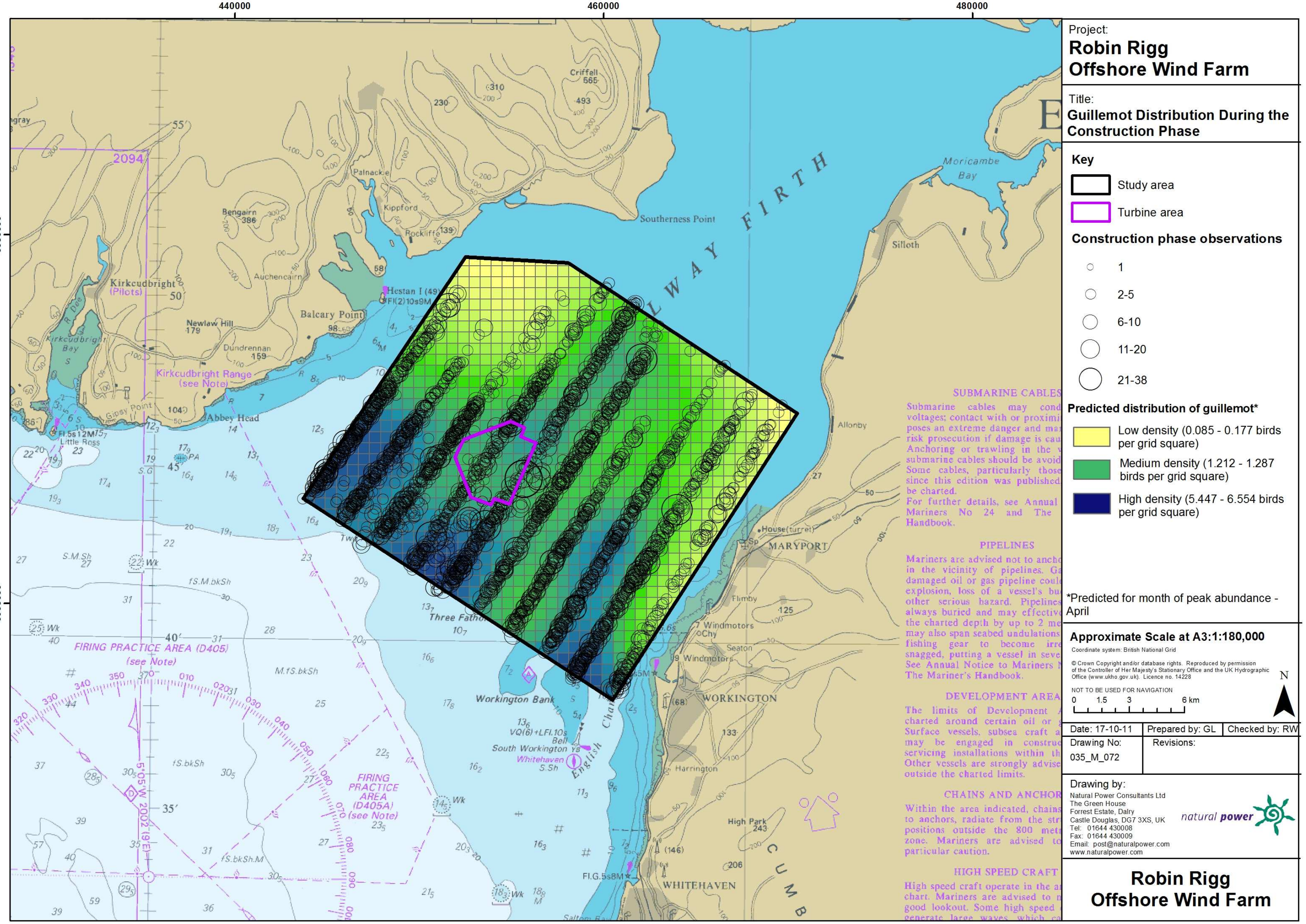


Figure 6.55b: Density surface map of the predicted density of guillemot across the survey area during the construction phase. Open circles show the locations of the raw observations.

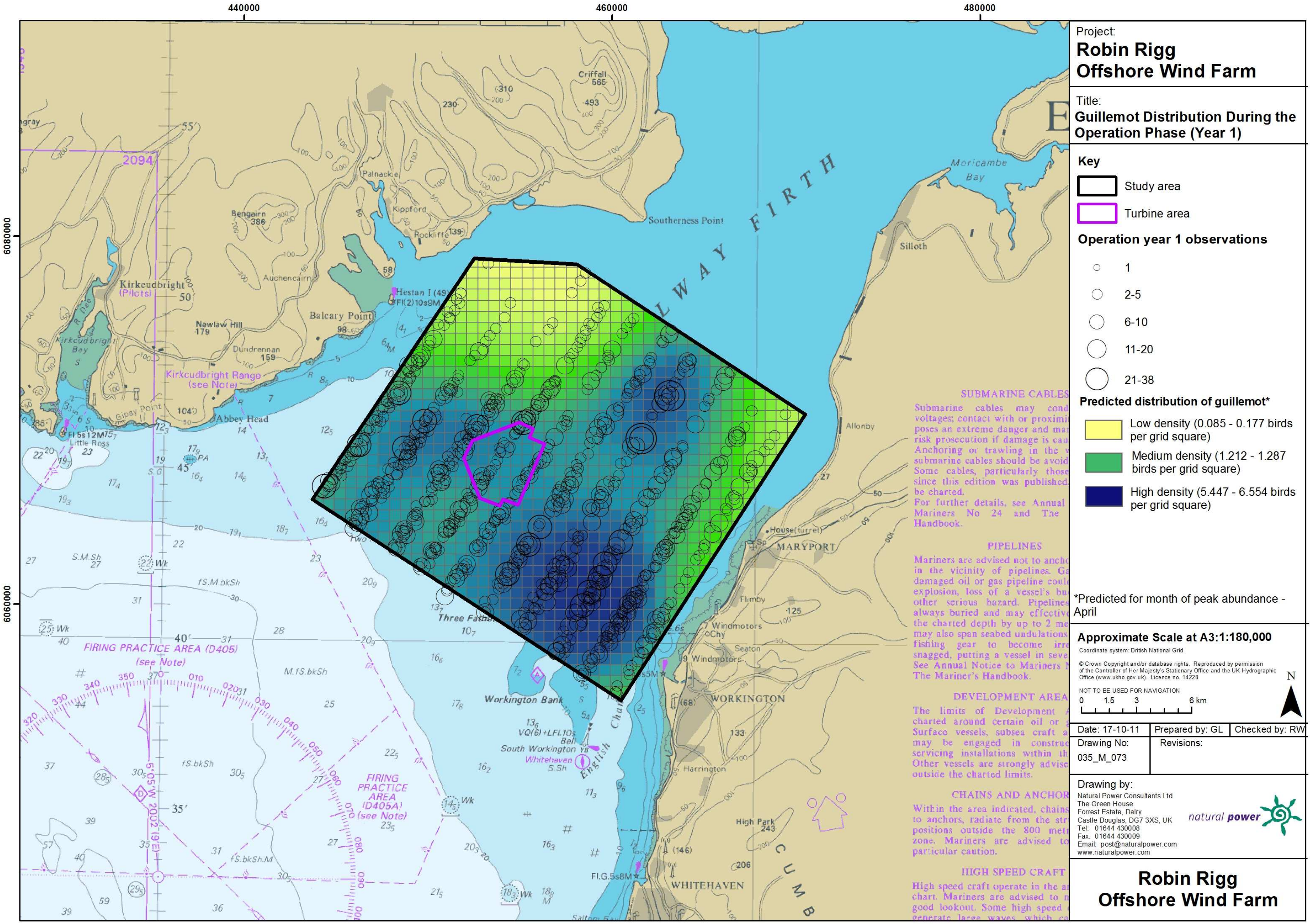


Figure 6.55c: Density surface map of the predicted density of guillemot across the survey area during the operational phase. Open circles show the locations of the raw observations.

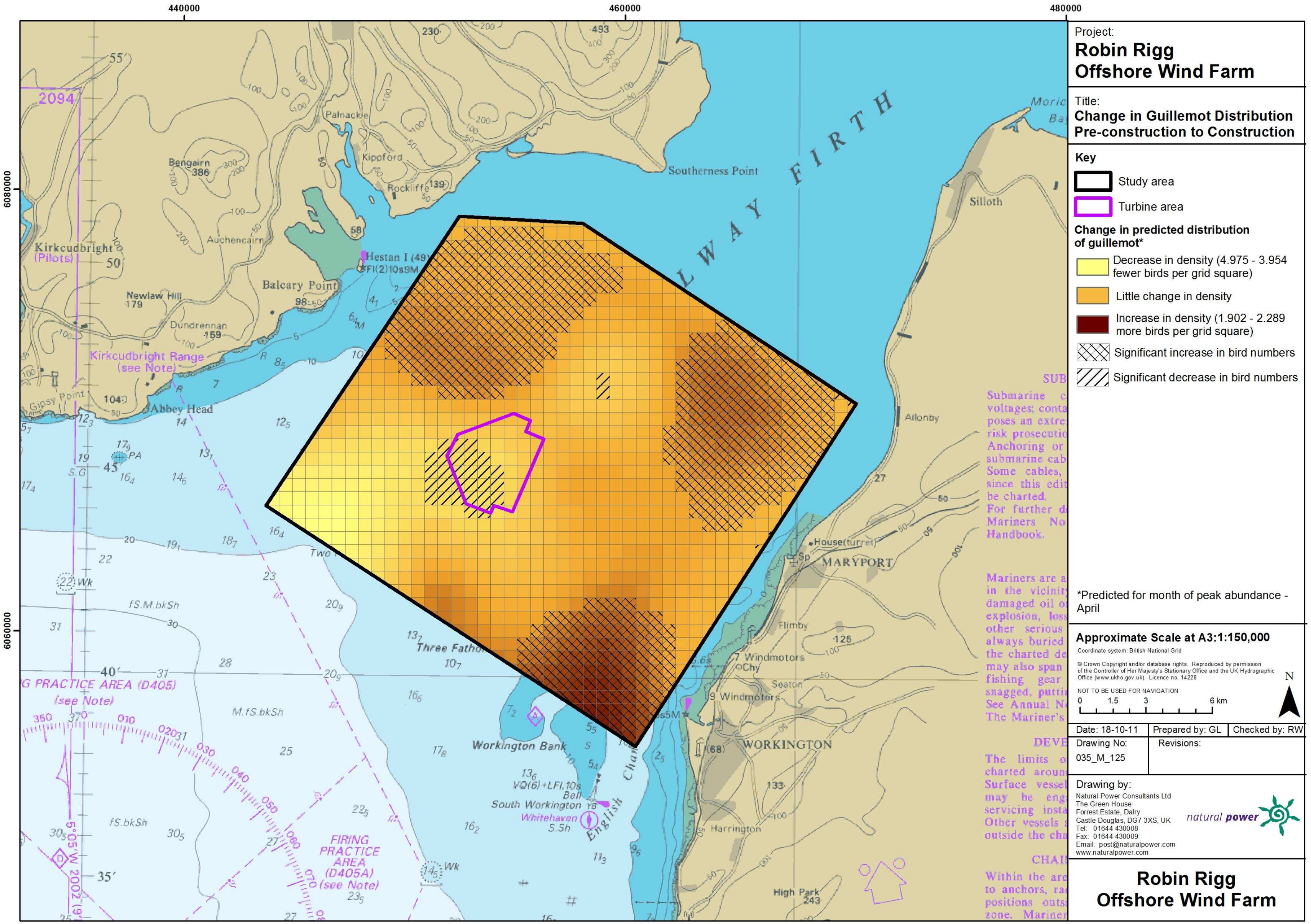


Figure 6.56a: Difference plot of the change in predicted density of guillemot between the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

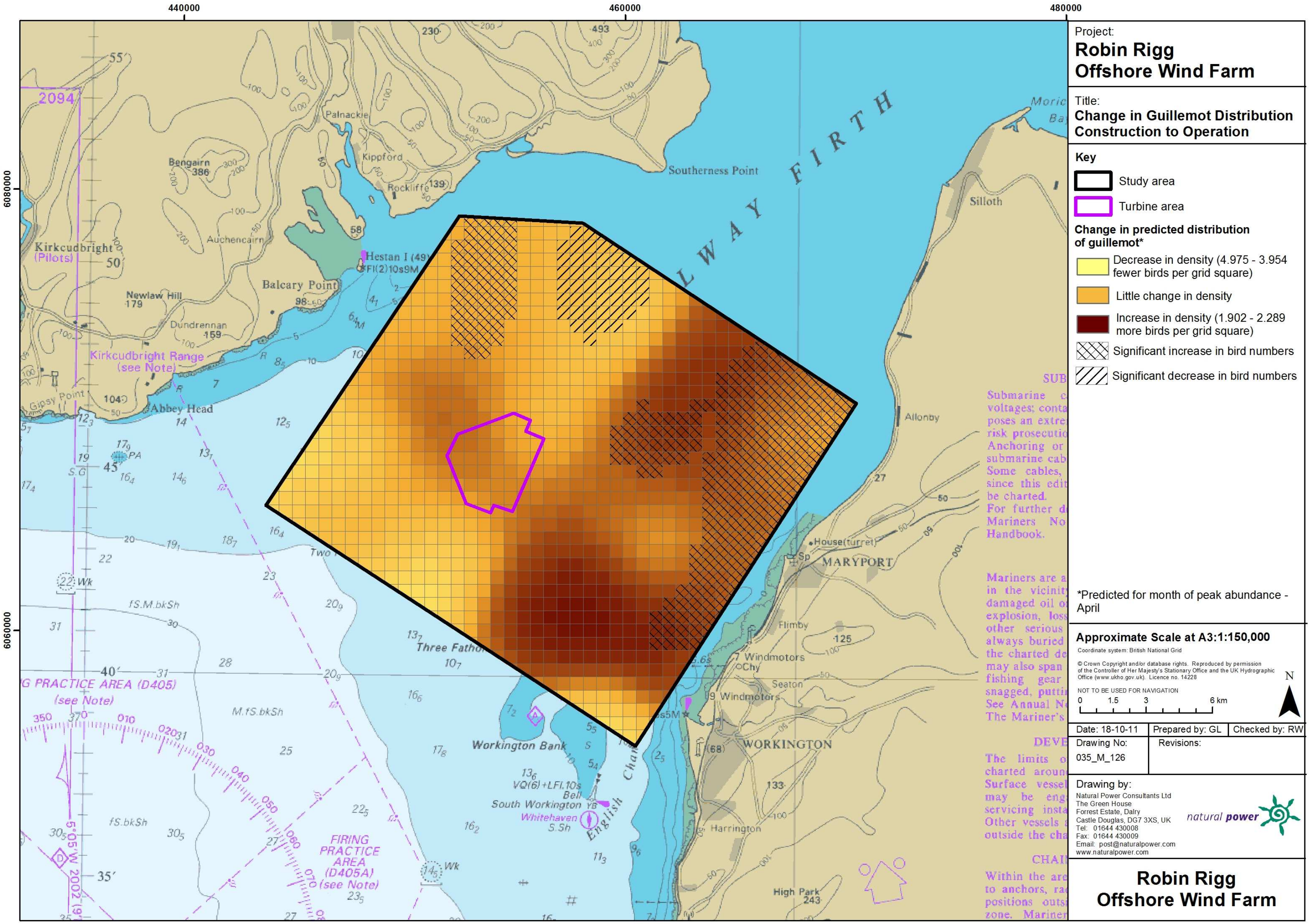


Figure 6.56b: Difference plot of the change in predicted density of guillemot between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

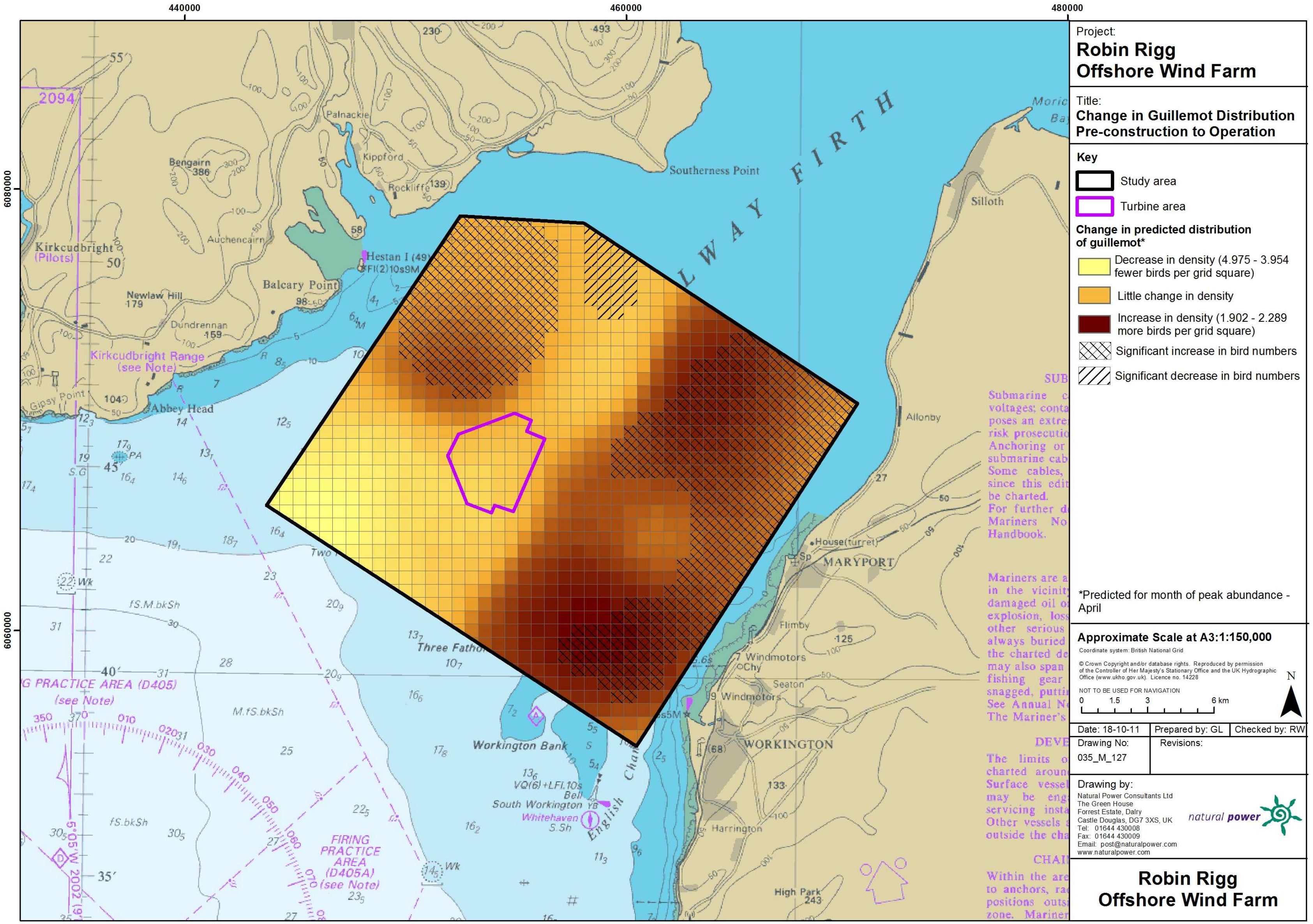


Figure 6.56c: Difference plot of the change in predicted density of guillemot the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines

- Birds in flight

The percentage of guillemot recorded in different height bands relative to rotor height can be found in Table 6.18 and Figure 6.57. The band 35-125 represents rotor height. No Chi-square test was carried out for this species as less than 1% of observed flights were at turbine rotor height.

Table 6.18: Proportion of guillemot recorded at different height bands through the three phases of development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	98.6	1.4	0	0	0	0
Construction	91.0	8.0	0.7	0.3	0	0
Operation Yr. 1	91.3	8.3	0.4	0	0	0

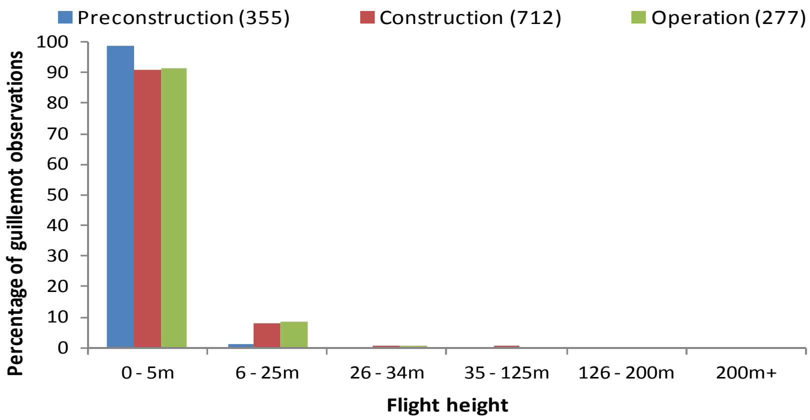


Figure 6.57: Percentage of guillemot recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

6.2.11. Razorbill

Razorbill were recorded throughout the year with the greatest numbers, both on the water and in flight, observed in October pre-construction and operation (Figure 6.58). The raw data indicate a decline during construction for birds on the sea, but the pattern for birds in flight is less clear (Figures 6.59 and 6.60).

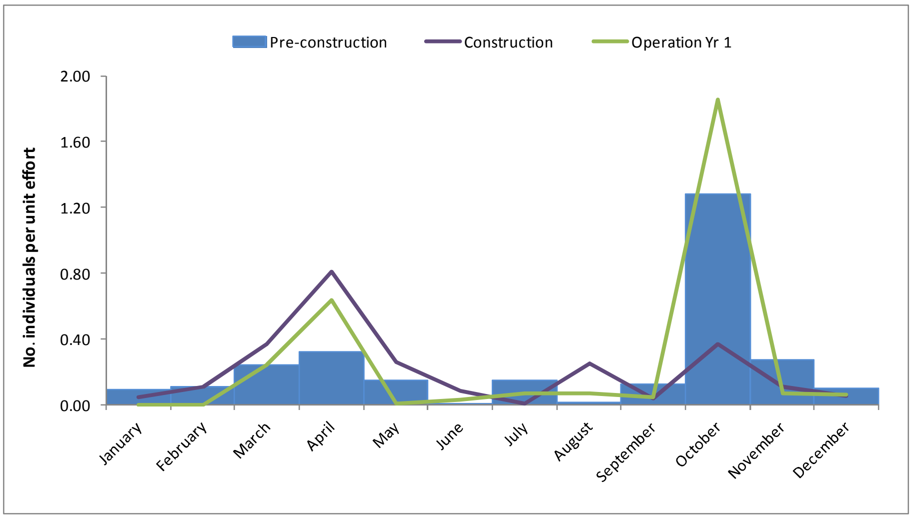


Figure 6.58a: Mean number of razorbill observed on the sea per month during the pre-construction, construction and operational phases

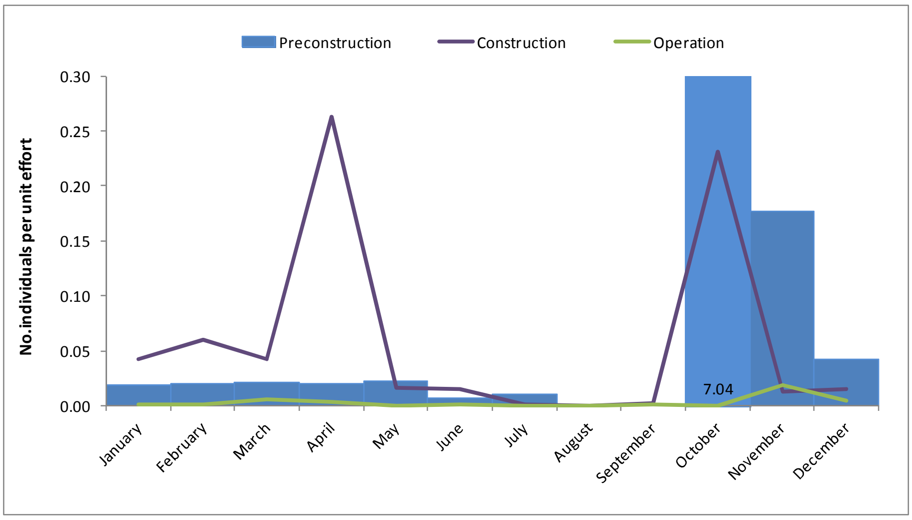


Figure 6.58b: Mean number of razorbill observed in flight per month during the pre-construction, construction and operational phases. Note: the vertical axis has been reduced to 0.3 to allow better representation of all of the data. The average number of razorbill observed per sampling block during October pre-construction was seven.

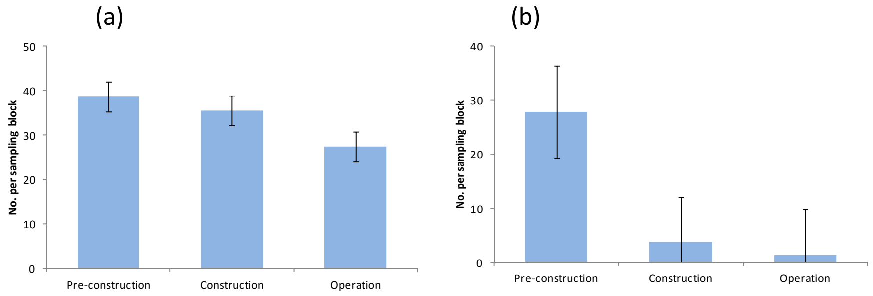


Figure 6.59: Mean number of razorbill observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error)

Results from the simple GLM suggest a decline in numbers of birds in flight compared to pre-construction values. There were no significant results for birds in on the sea (Table 6.19).

Table 6.19: Results from simple GLM for number of razorbill observed in flight and on the sea. Pink indicates a significant decline between periods.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.523	0.737	0.463
In flight	<0.001	0.646	0.003

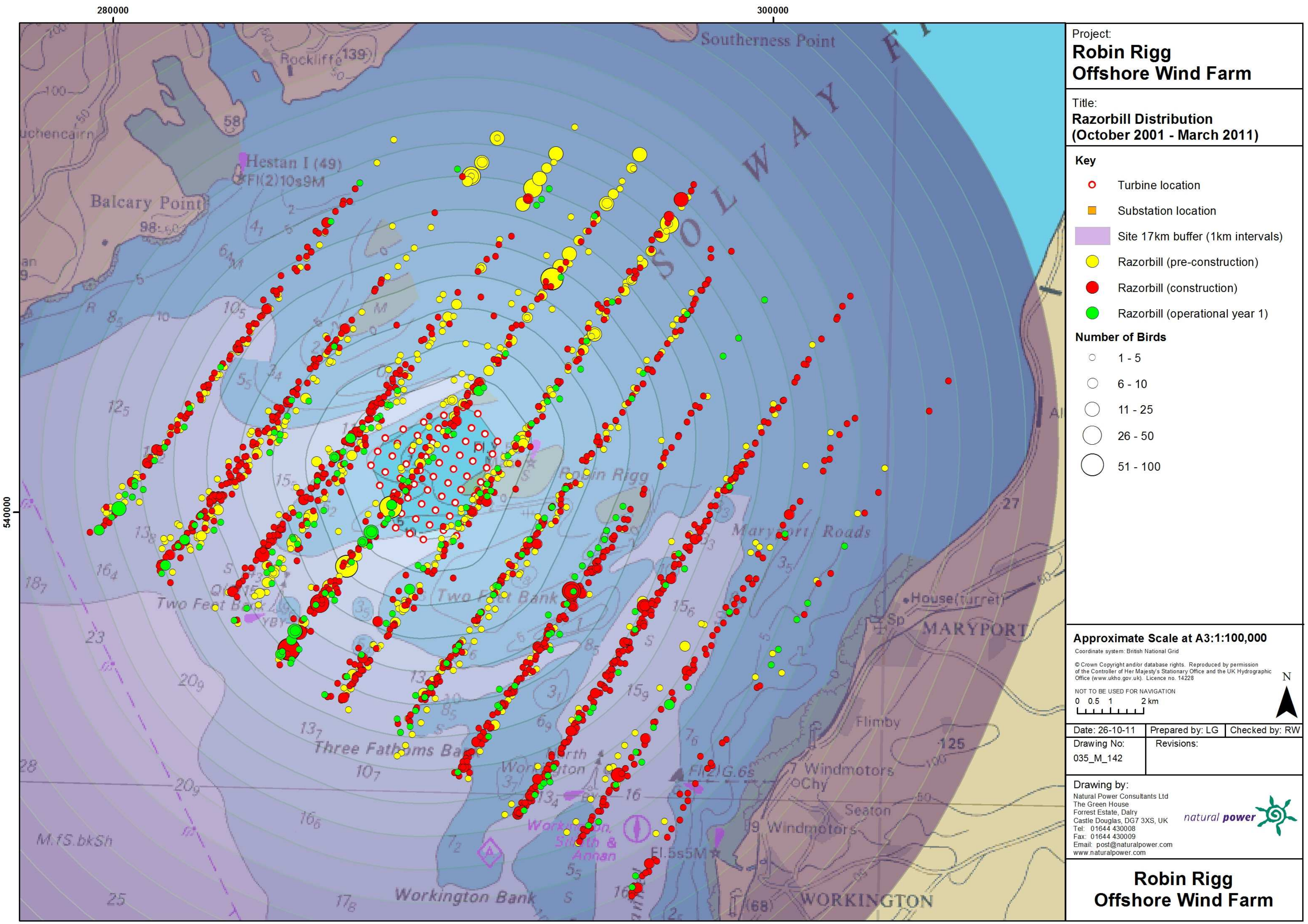


Figure 6.60: Locations of raw observations of razorbill during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed

- Birds on the sea

A hazard rate detection function was used for this analysis and the month of September used to estimate abundance. The predicted number of razorbill for each construction phase can be found in Figure 6.61 below.

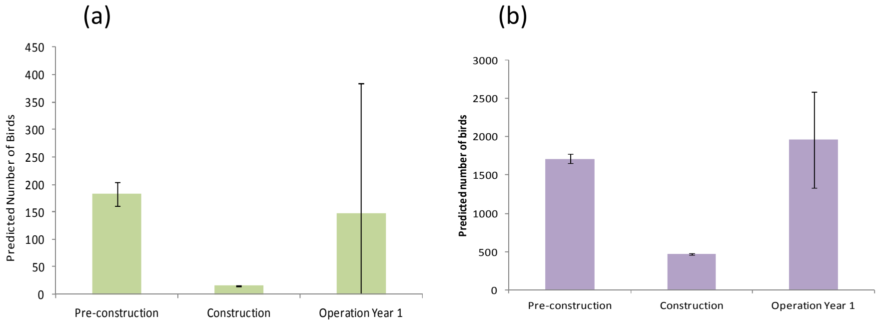


Figure 6.61: Predicted number of razorbill using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction, construction and operational phases.

Data suggest a decline in numbers during the construction phase, both within the turbine area and across the site as a whole. Numbers appear to have increased again post construction with numbers within the site lower than across the site as a whole, although the standard error for this is large. Re-analysis including operational year two data should help clarify these results.

Density surface maps based on these predictions can be found in Figure 6.62 and the differences between the phases in Figure 6.63.

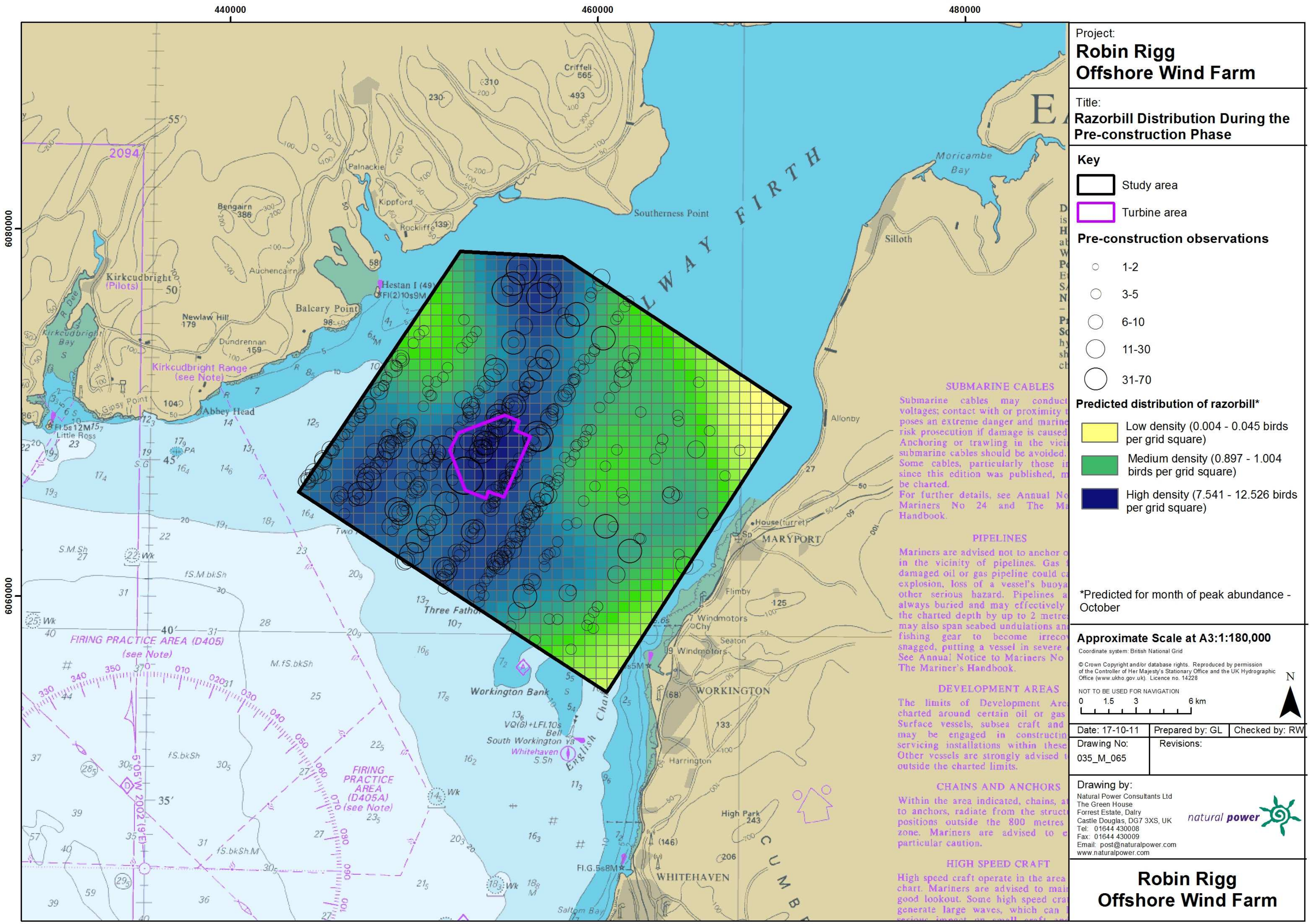


Figure 6.62a: Density surface map of the predicted density of razorbill across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

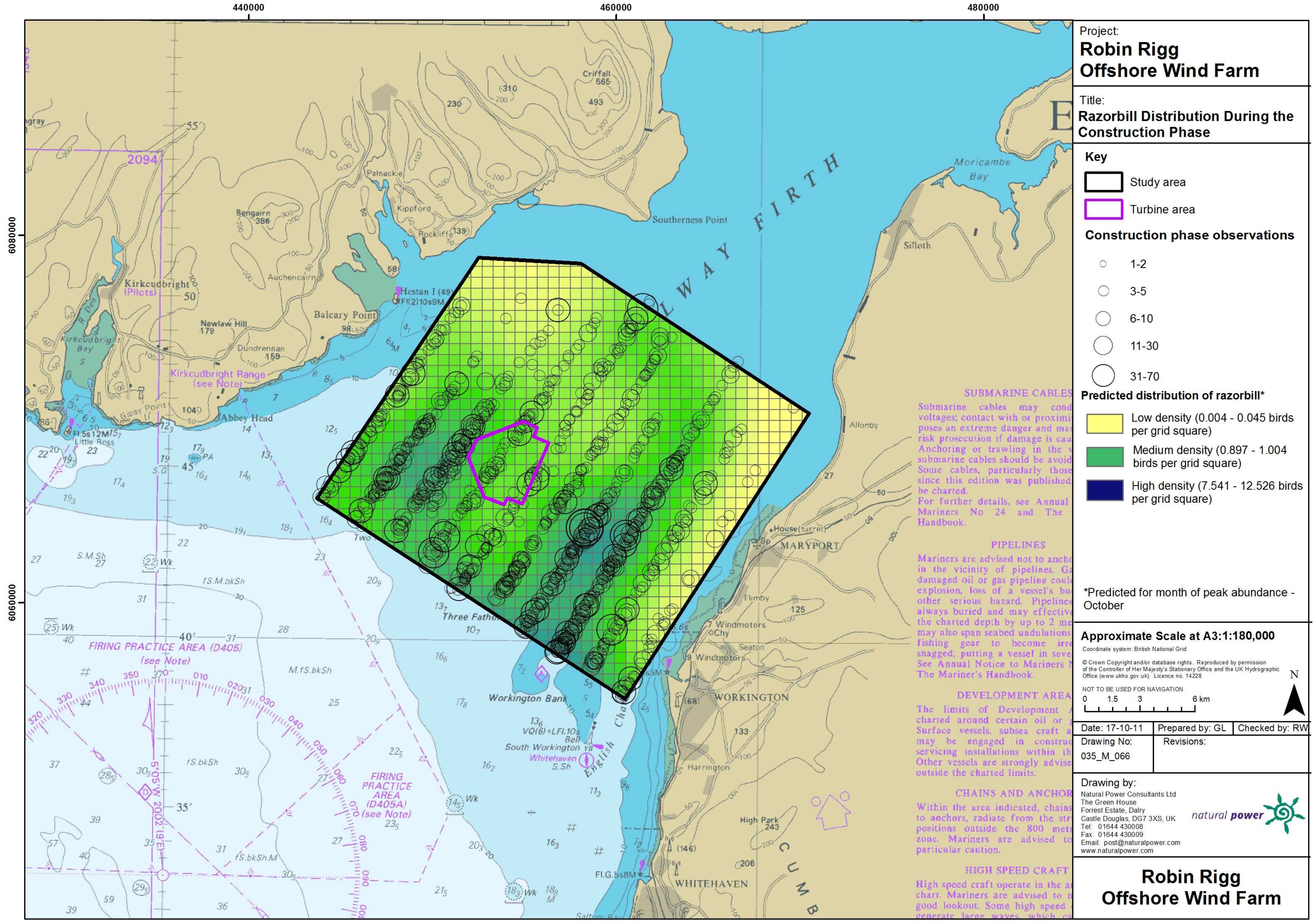


Figure 6.62b: Density surface map of the predicted density of razorbill across the survey area during the construction phase. Open circles show the locations of the raw observations.

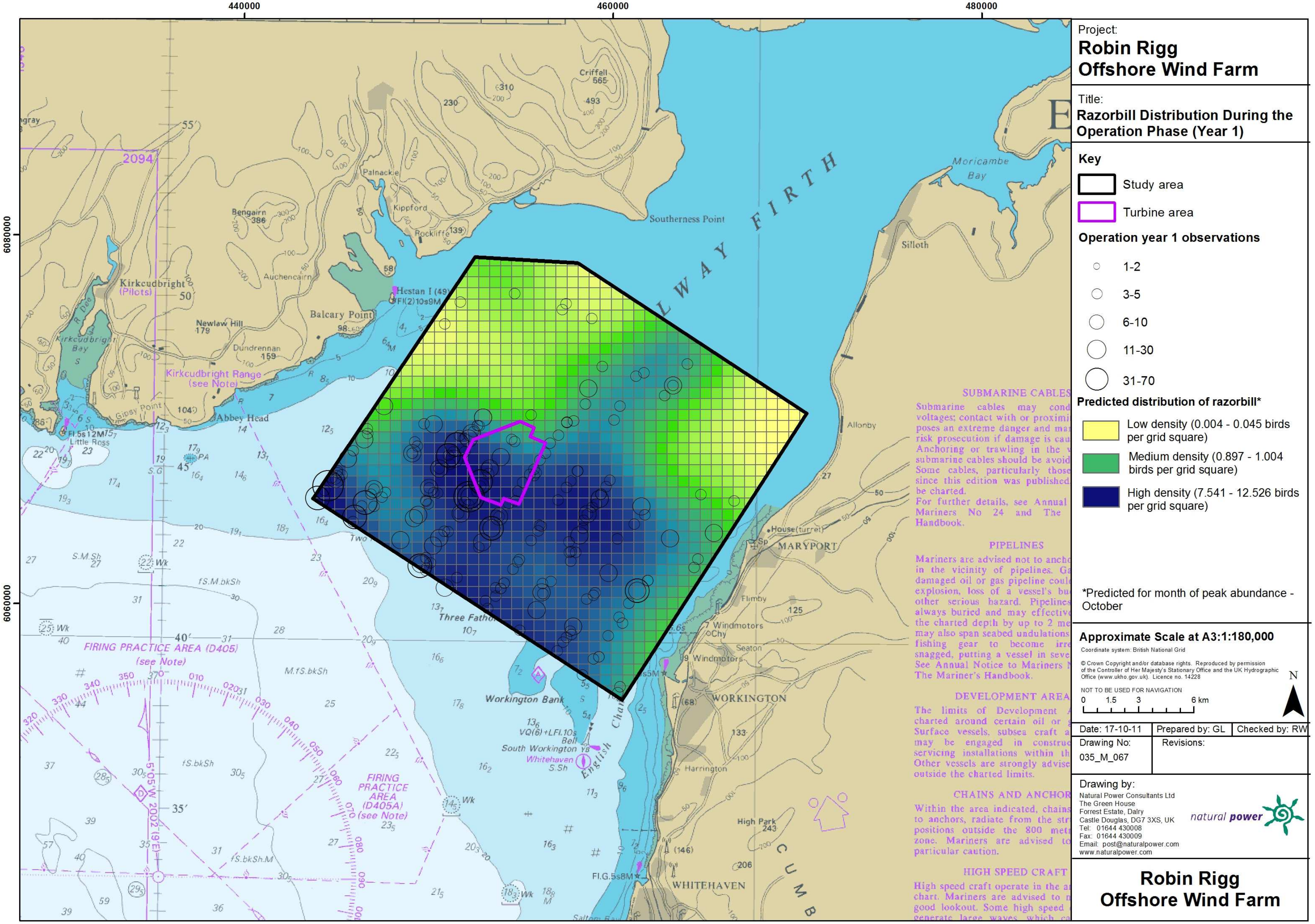


Figure 6.62c: Density surface map of the predicted density of razorbill across the survey area during the operational phase. Open circles show the locations of the raw observations.

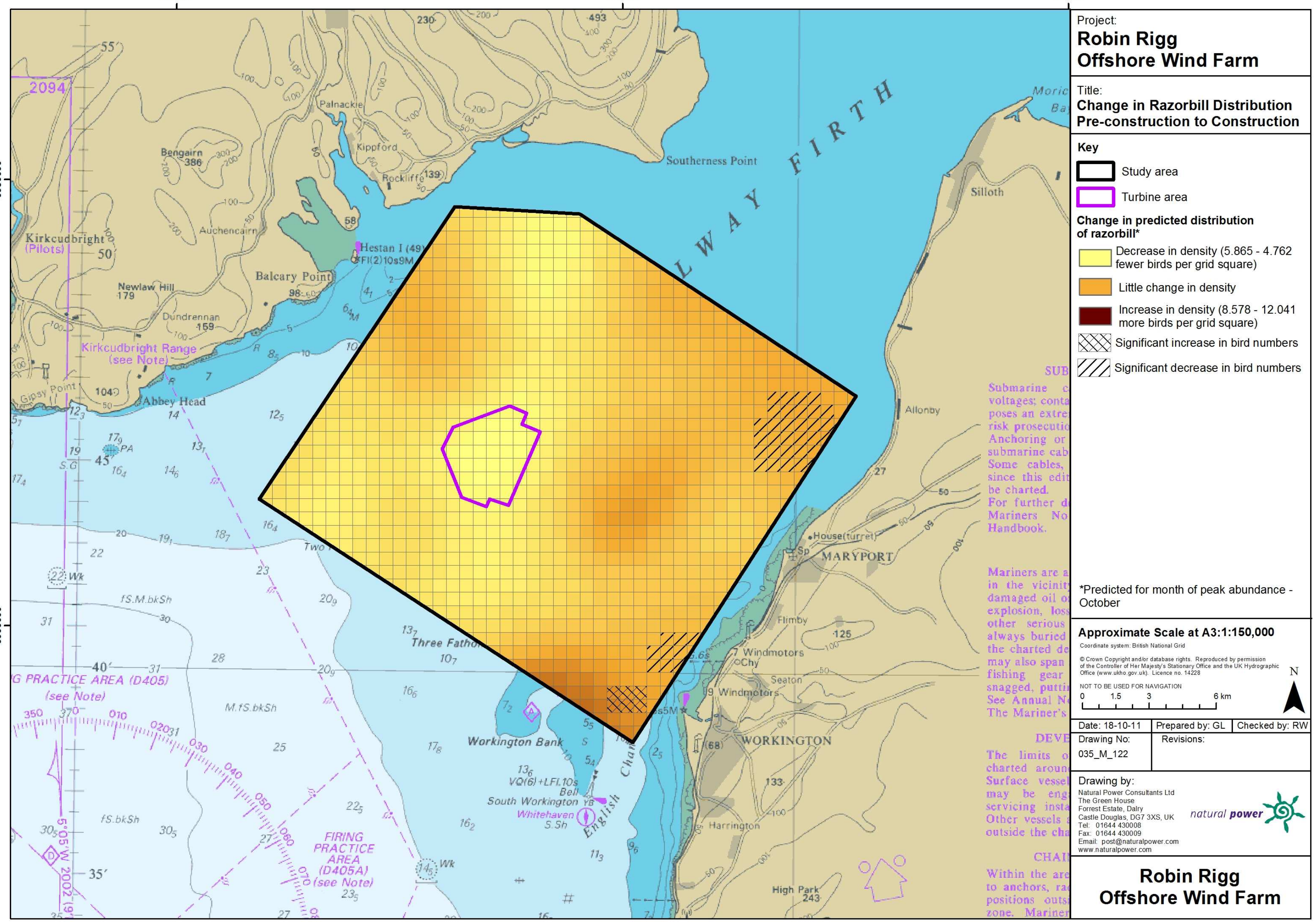


Figure 6.63a: Difference plot of the change in predicted density of razorbill between the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

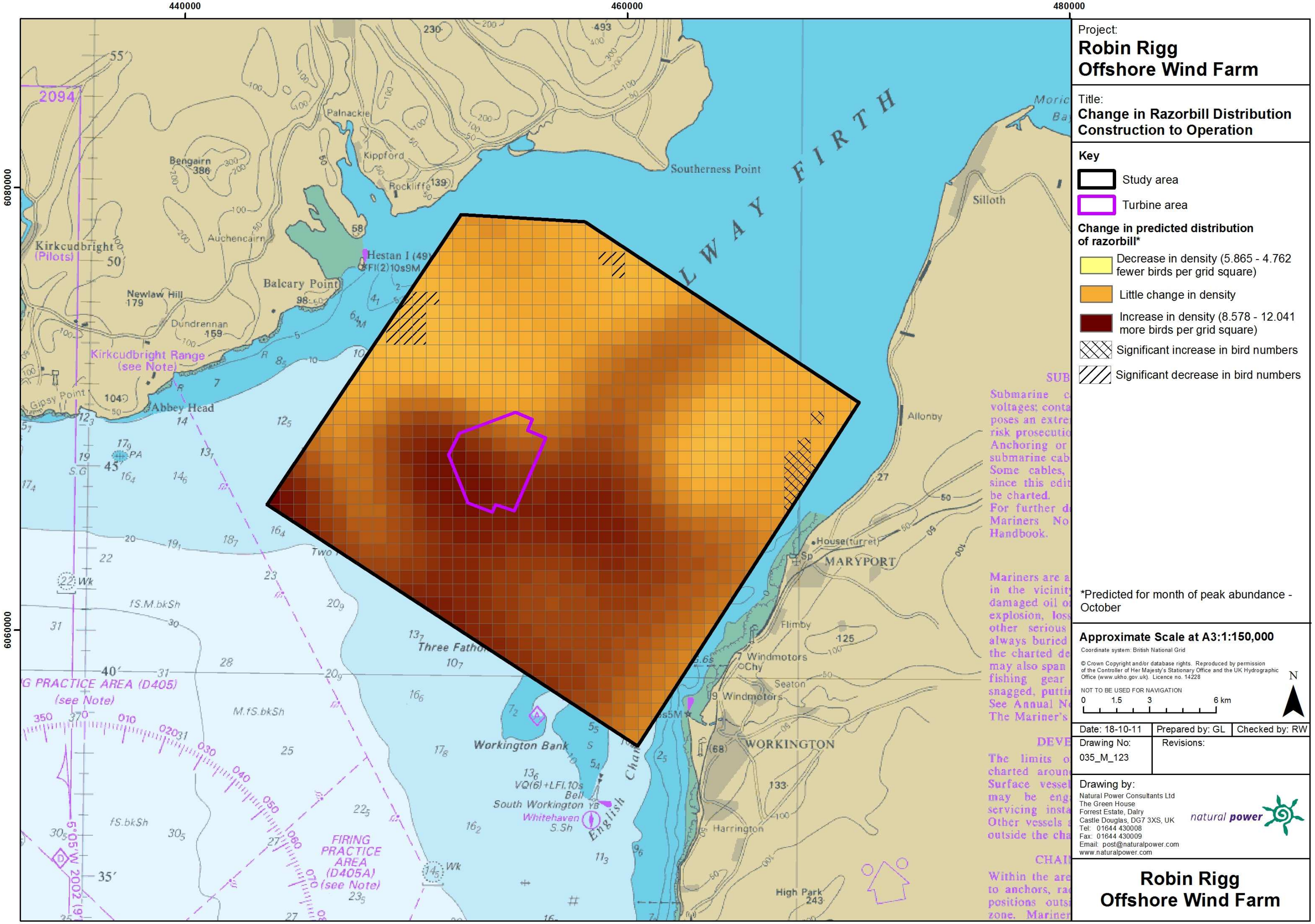


Figure 6.63b: Difference plot of the change in predicted density of razorbill between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

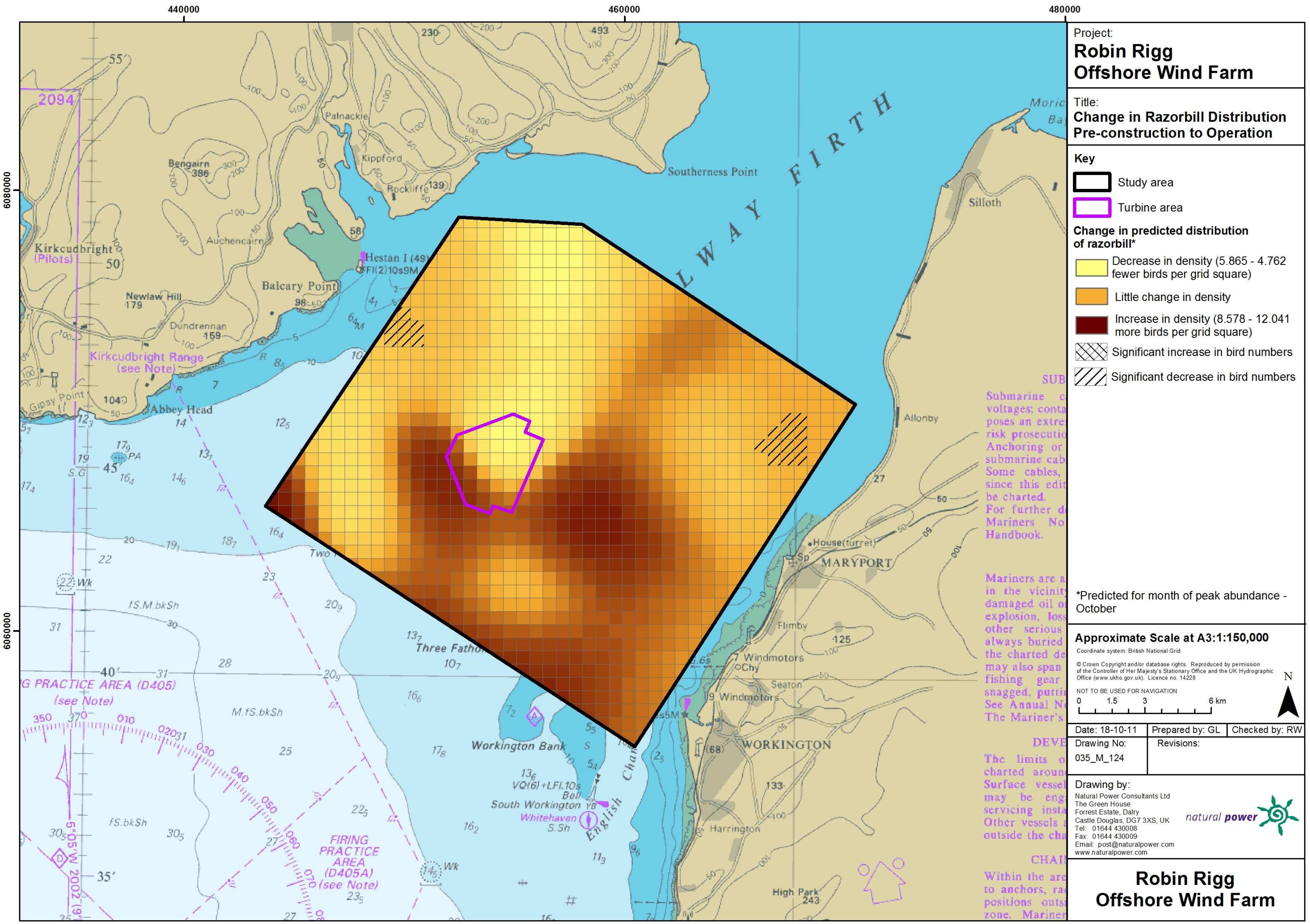


Figure 6.63c: Difference plot of the change in predicted density of razorbill between the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines.

- Birds in flight

The percentage of razorbill recorded in different height bands relative to rotor height can be found in Table 6.20 and Figure 6.64. The band 35-125 represents rotor height. No Chi-square test was carried out for this species as no flights were recorded at turbine rotor height.

Table 6.20: Proportion of razorbill recorded in different flight height bands through the three phases of the development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	99.6	0.4	0	0	0	0
Construction	92.2	7.8	0	0	0	0
Operation Yr. 1	100.0	0	0	0	0	0

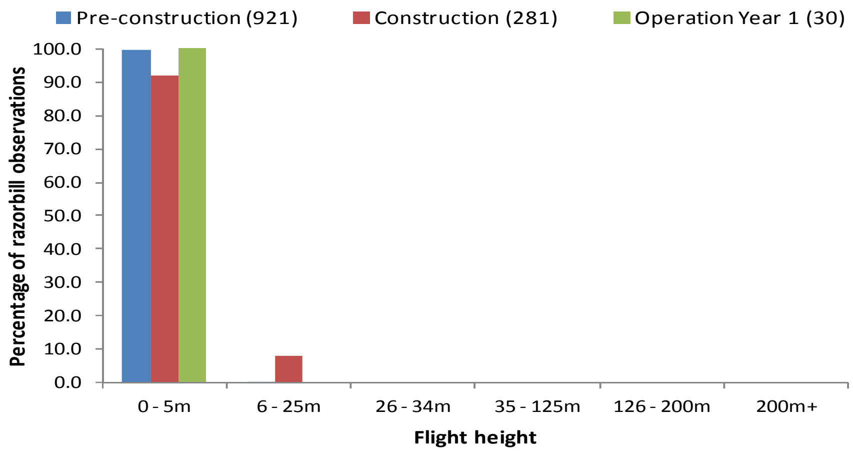


Figure 6.64: Percentage of razorbill recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

6.2.12. Auk species

“Auk species” were included in the analysis because many observations were only identified only as auk species, such that much of the data available are not used when analysing guillemot or razorbill individually. Therefore the results presented here are for razorbill, guillemot and those identified as auk species combined.

Auks were recorded throughout the year with no clear seasonal peaks for birds on the sea, but a pre-construction peak for birds in flight in October pre-construction (Figure 6.65). The raw data indicate a decline in numbers during the construction phase with a possibility of recovery during operational year one (Figure 6.66 and 6.67).

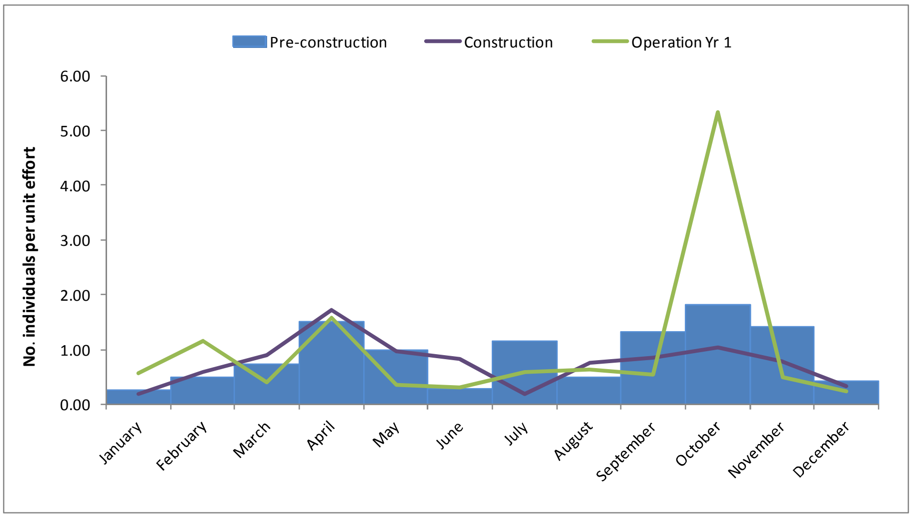


Figure 6.65a: Mean number of auks observed on the sea per month during the pre-construction, construction and operational phases.

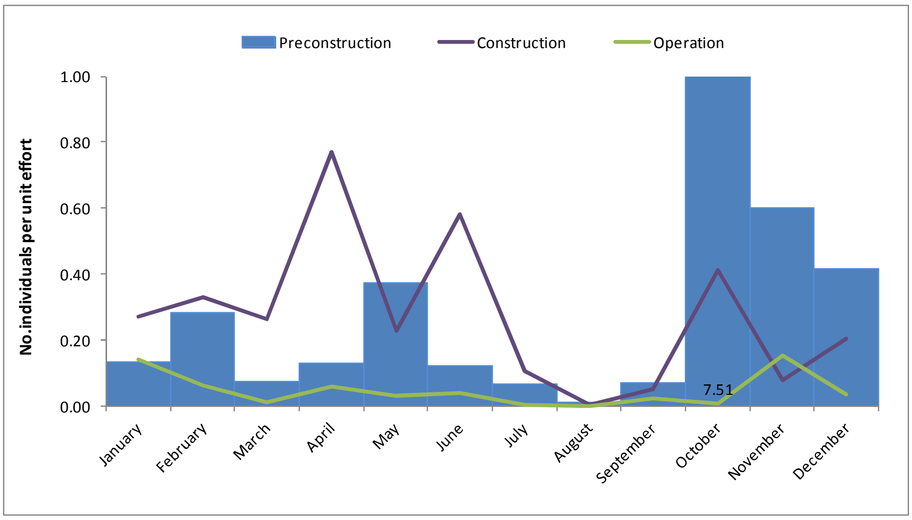


Figure 6.65b: Mean number of auks observed in flight per month during the pre-construction, construction and operational phases. Note the vertical axis has been restricted at 1 to allow better representation of the data. The pre-construction average value for October is 7.5 birds.

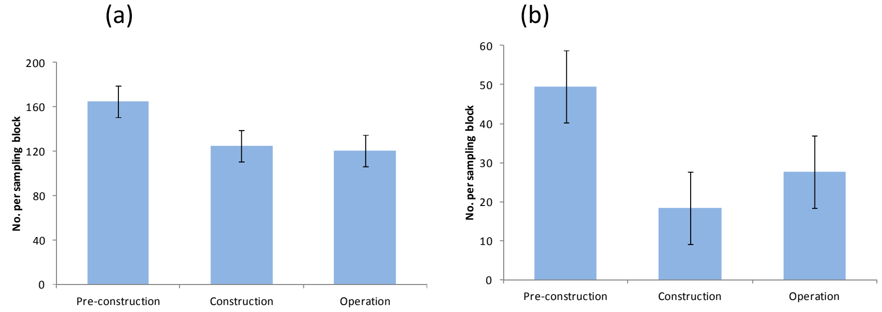


Figure 6.66: Mean number of auks observed per sampling block (a) on the sea and (b) in flight during the pre-construction, construction and operational phases (±standard error).

Results from the simple GLM suggest a decline in numbers of birds in flight between pre-construction and construction, followed by an increase between construction and operation. There were no significant results for birds on the water (Table 6.21).

Table 6.21: Results from simple GLM for number of auks observed in flight and on the sea. Pink indicates a significant decline between periods, and green a significant increase.

	Pre-construction to construction	Construction to operation	Preconstruction to operation
On sea	0.140	0.821	0.407
In flight	<0.001	0.040	0.188

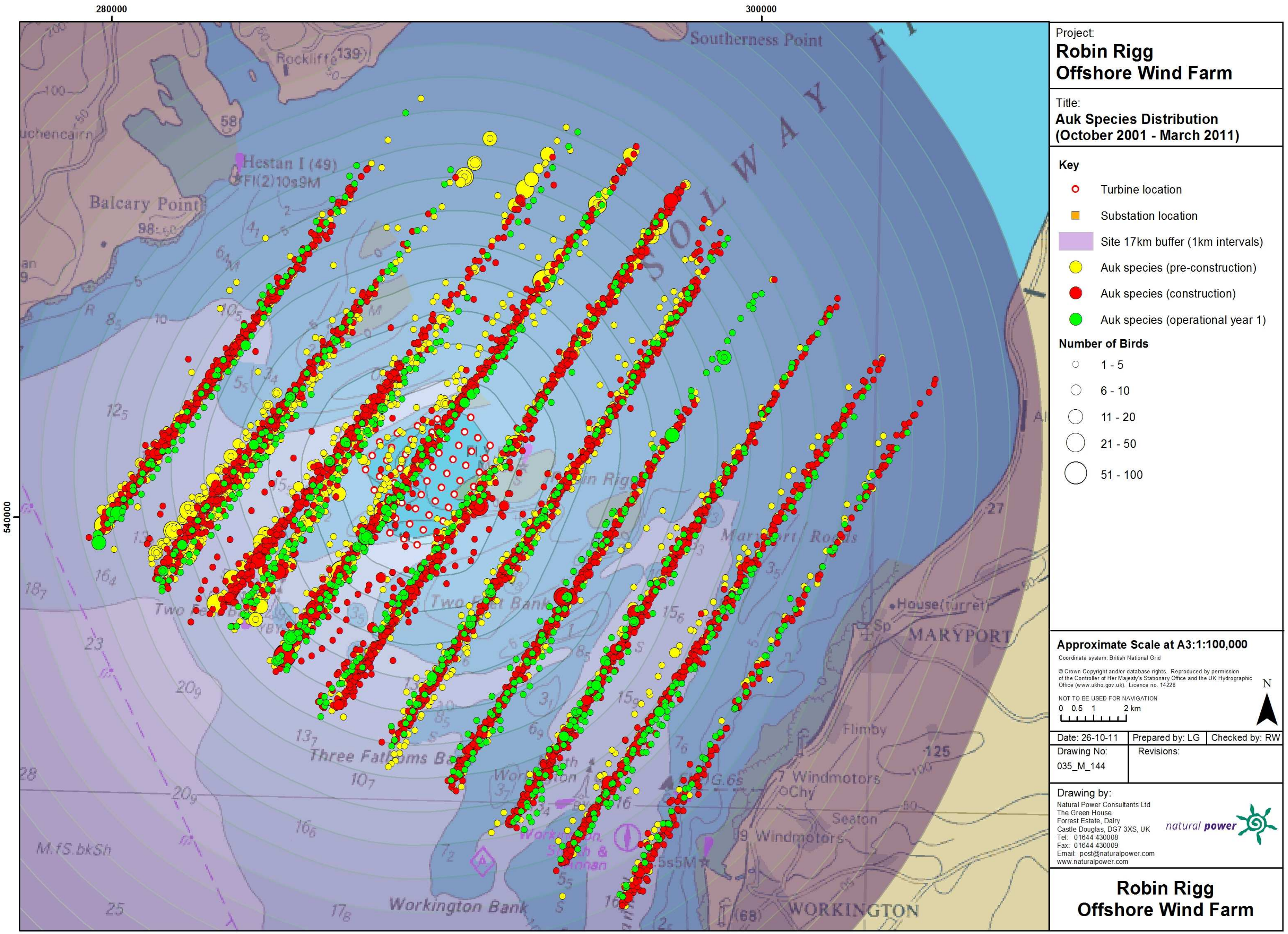


Figure 6.67: Locations of raw observations of auks during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group of animals observed.

- Birds on the sea

A hazard rate detection function was used for this analysis and the month of September used to estimate abundance. The predicted number of auks for each construction phase can be found in Figure 6.68 below.

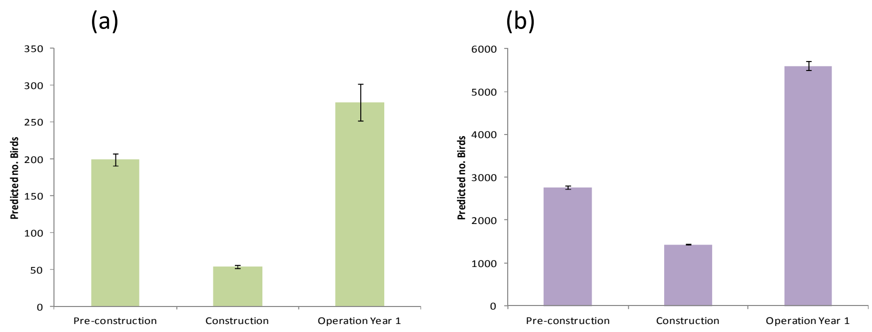


Figure 6.68: Predicted number of auks using (a) the turbine area and (b) the survey area (including the turbine area) during the pre-construction, construction and operational phases.

The results indicate a decline in numbers during the construction phase, both within the turbine area and throughout the site as a whole, with numbers recovering to values greater than those observed pre-construction, although recovery within the turbine area was to a lesser extent (than the survey area as a whole).

Density surface maps based on these predictions can be found in Figure 6.69 and the differences between the phases in Figure 6.70.

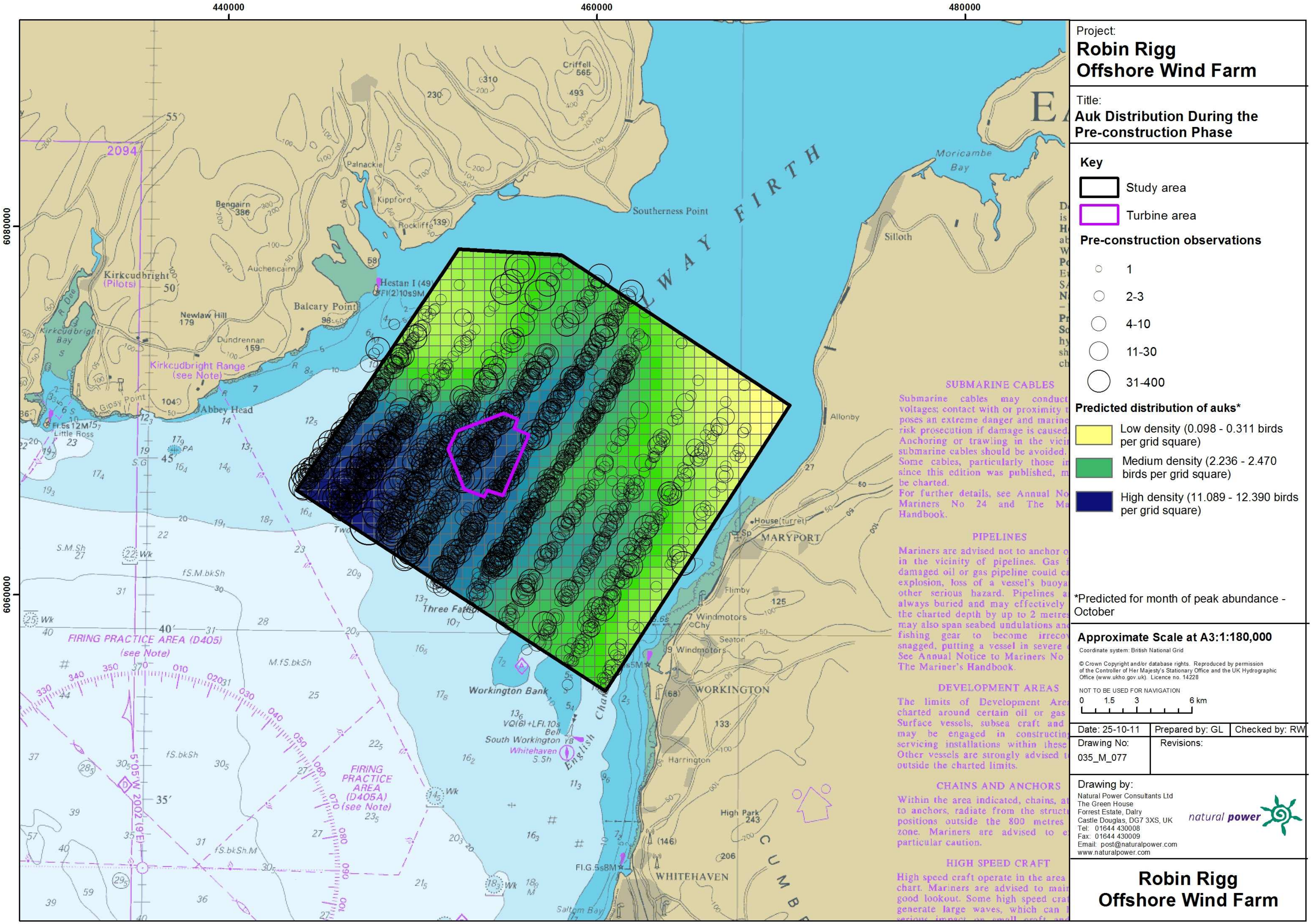


Figure 6.69a: Density surface map of the predicted density of auks across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

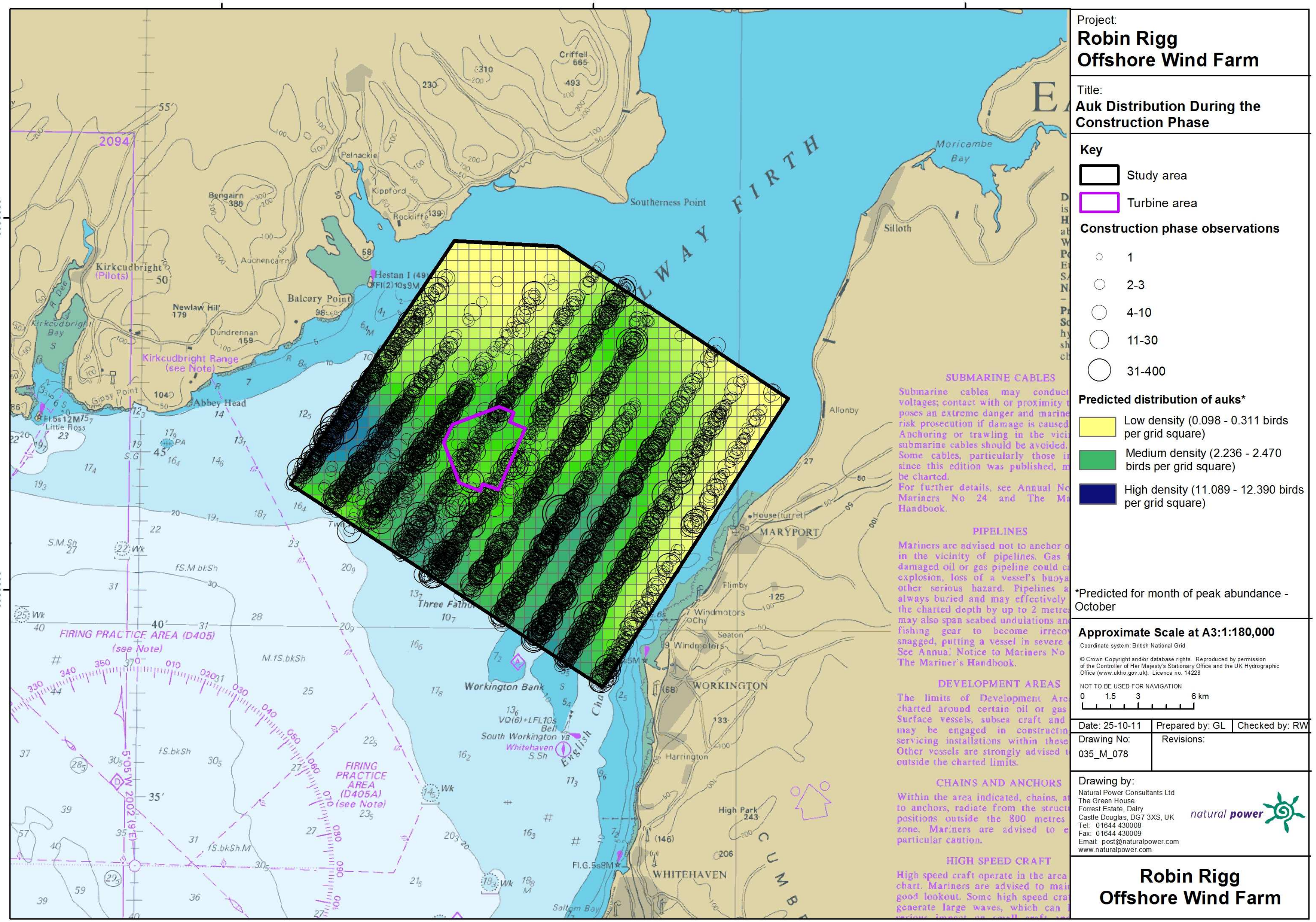


Figure 6.69b: Density surface map of the predicted density of auks across the survey area during the construction phase. Open circles show the locations of the raw observations.

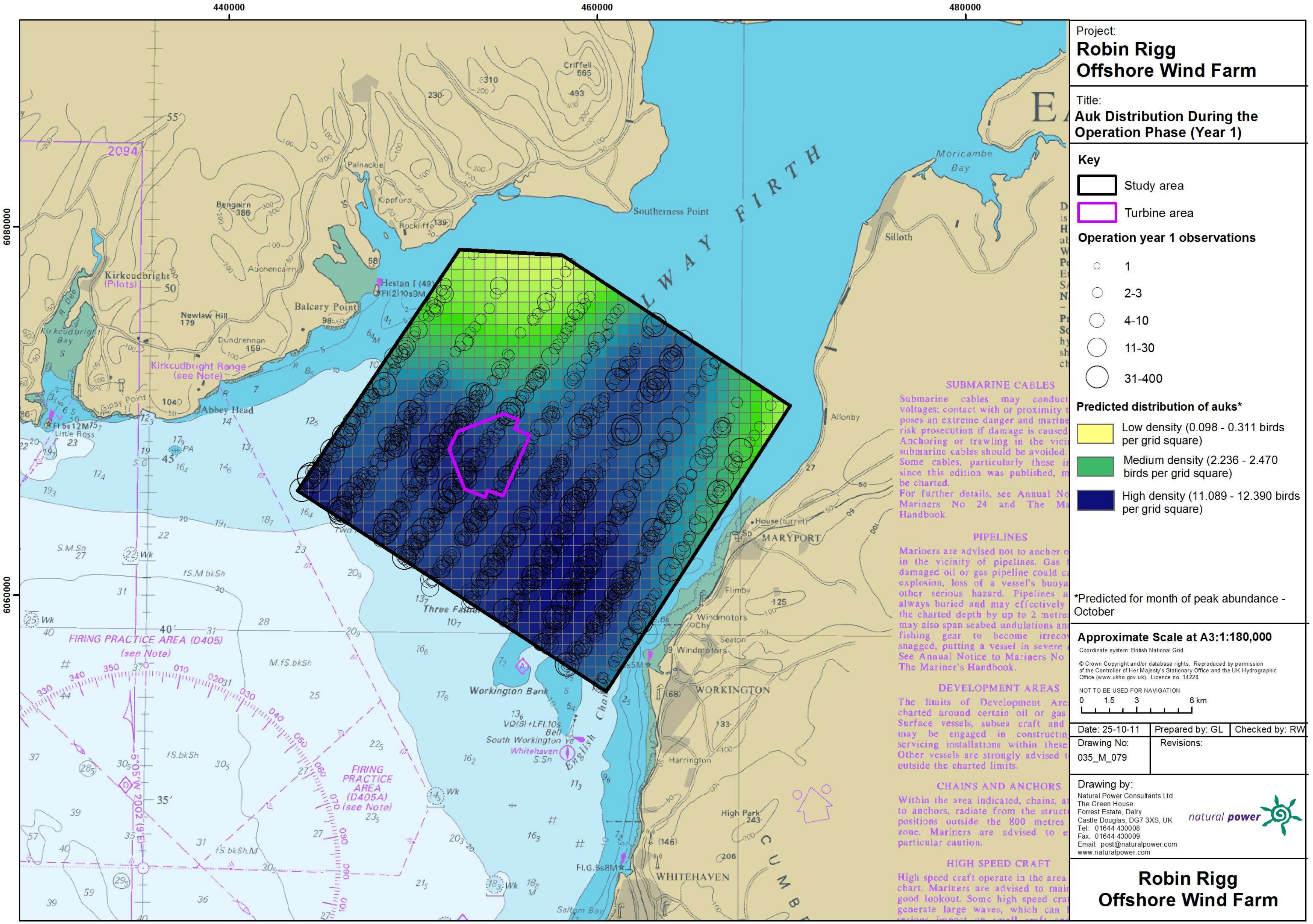


Figure 6.69c: Density surface map of the predicted density of auks across the survey area during the operational phase. Open circles show the locations of the raw observations.

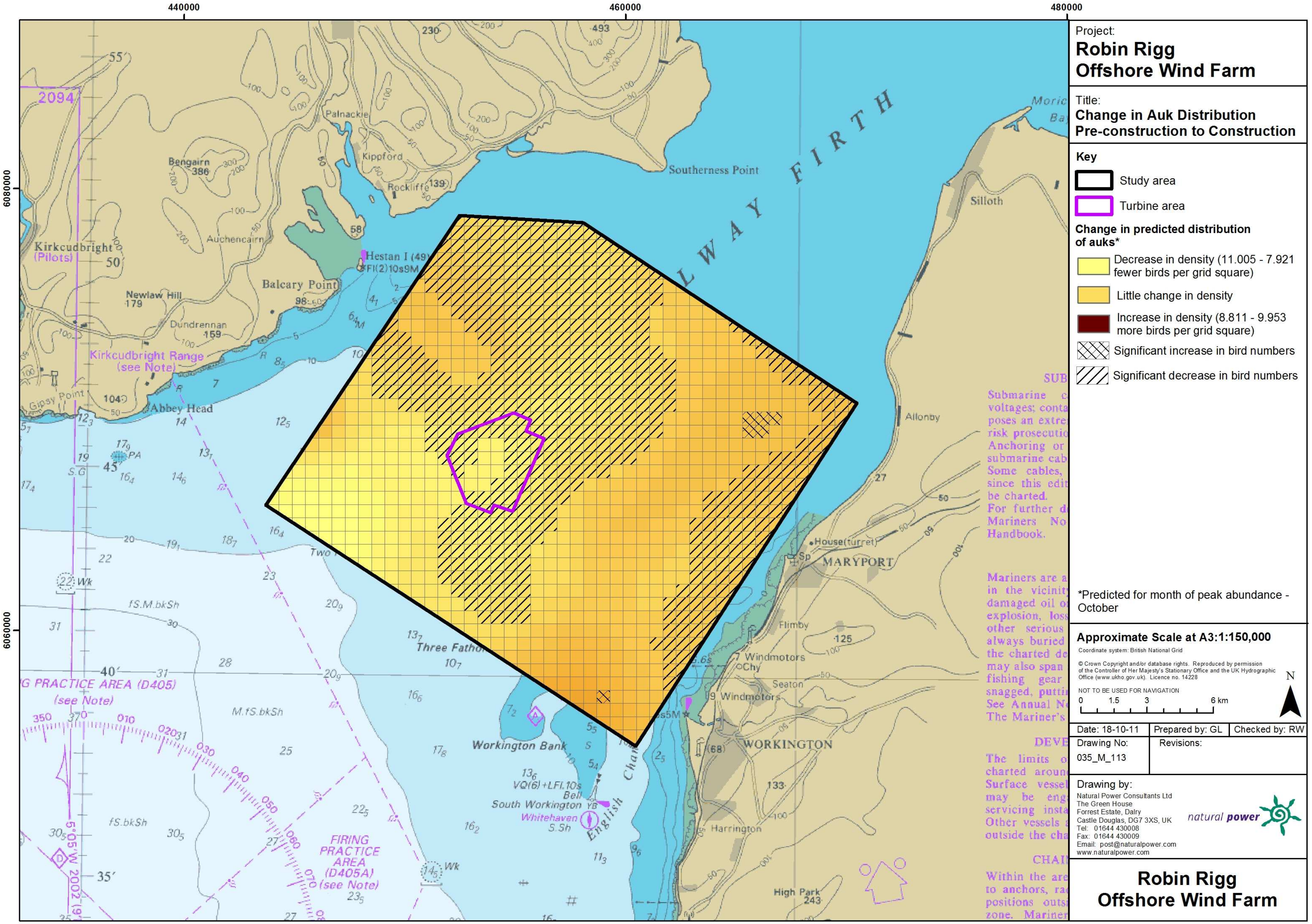


Figure 6.70a: Difference plot of the change in predicted density of auks between the pre-construction and construction phases. Significant differences are marked with diagonal or hashed lines.

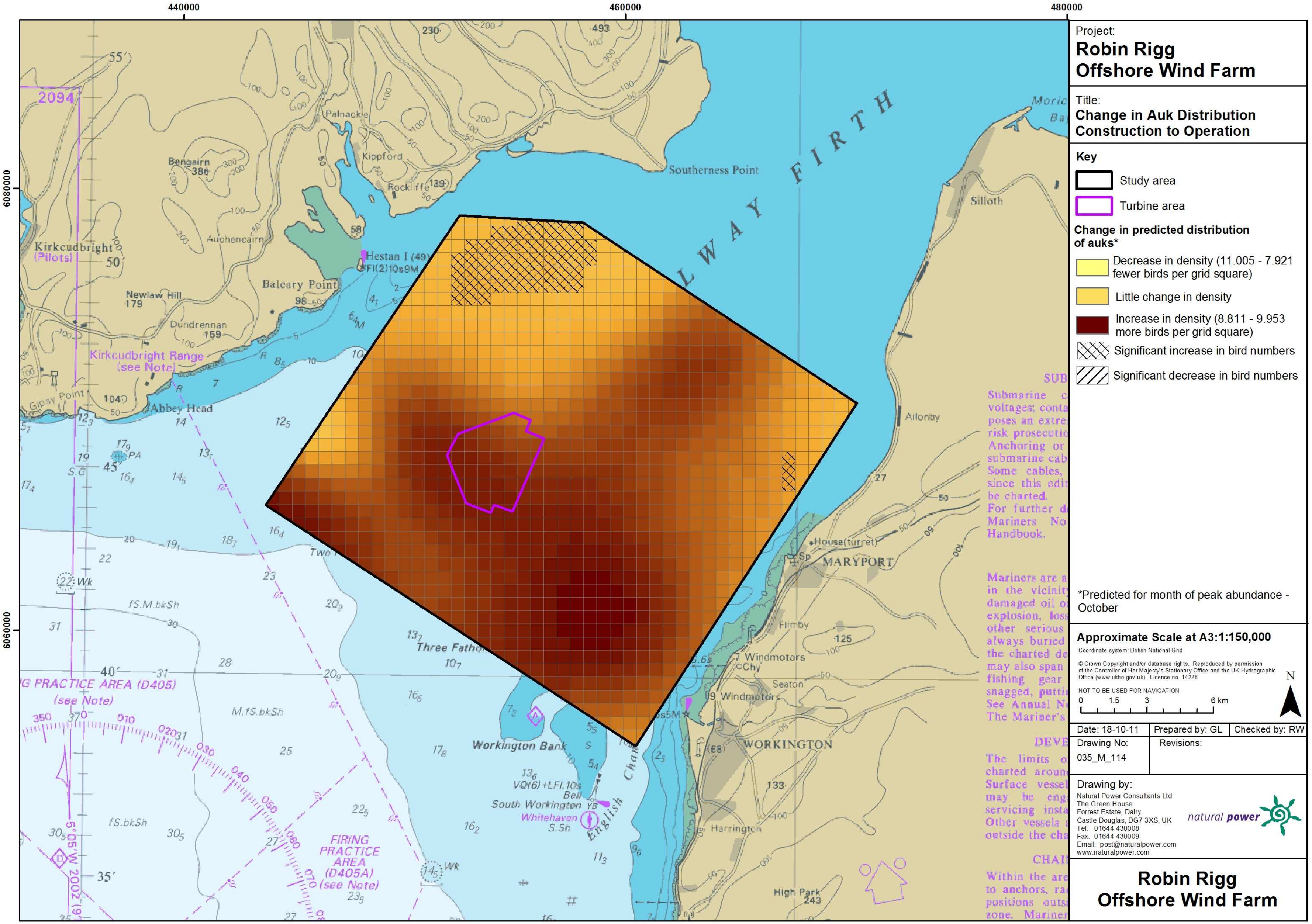


Figure 6.70b: Difference plot of the change in predicted density of auks between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

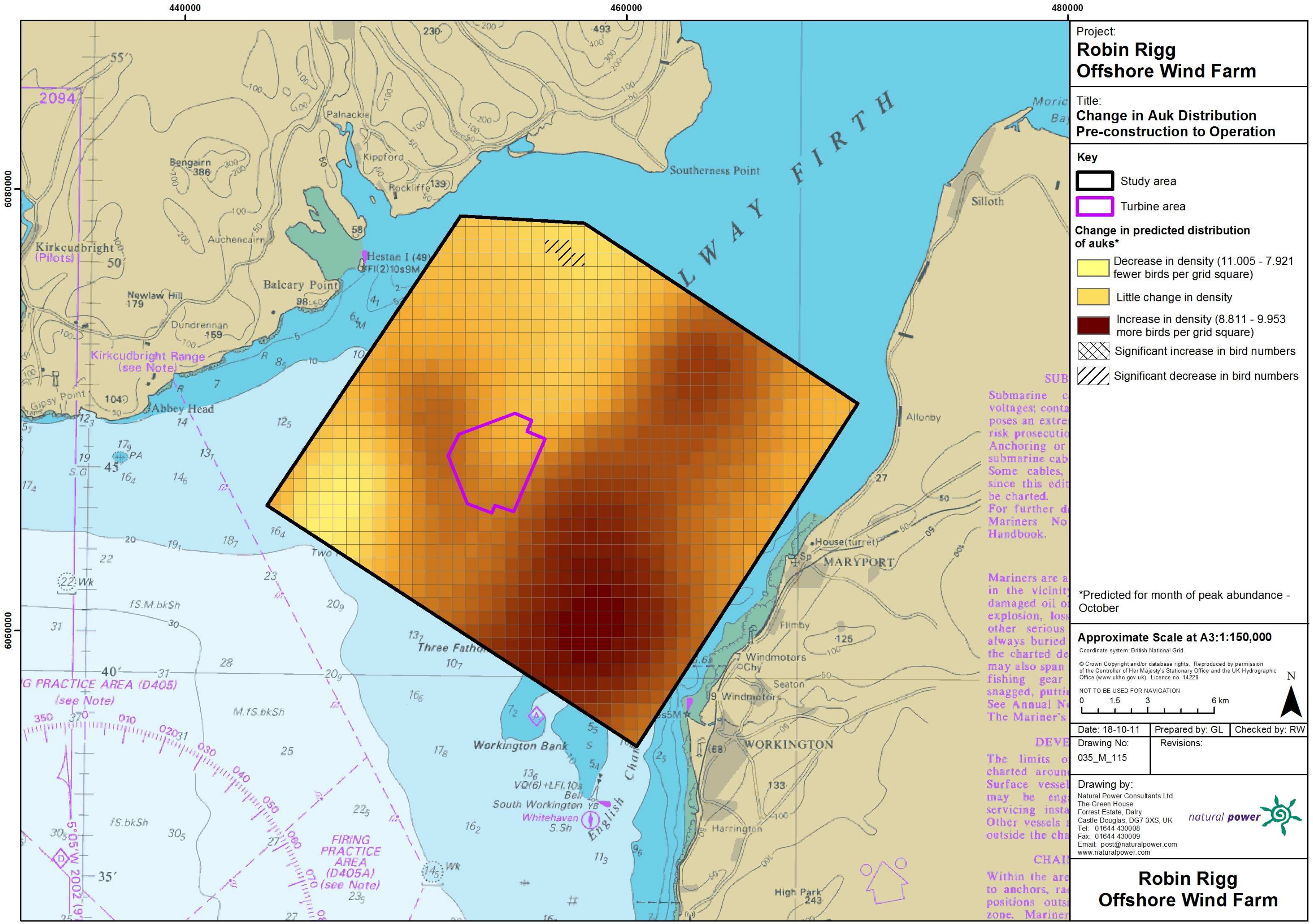


Figure 6.70c: Difference plot of the change in predicted density of auks between the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines

- Birds in flight

The percentage of auks recorded in different height bands relative to rotor height can be found in Table 6.22 and Figure 6.71. The band 35-125 represents rotor height. No Chi-square test was carried out for this species as less than 1% of flights were at turbine rotor height.

Table 6.22: Proportion of auks recorded in different height bands through the three stages of development.

	Flight band (m)					
	0 - 5	6 - 25	26 - 34	35 - 125	126 - 200	200+
Pre-construction	99	1	0	0	0	0
Construction	92.1	6.9	0.5	0.4	0	0
Operation Yr. 1	94.8	4.8	0.3	0	0	0

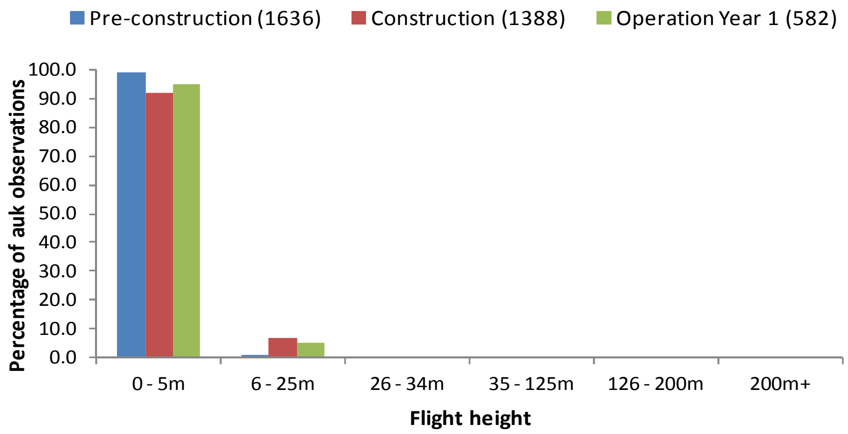


Figure 6.71: Percentage of auks recorded in different flight bands during the different stages of the development. Figures in brackets represent total number.

6.2.13. Summary of abundance estimates

Table 6.23 below summarises the abundance estimates calculated for each species (based on numbers observed on the water) discussed in the sections above.

Table 6.23: Summary of abundance estimates calculated for each species (based on numbers observed on the water) discussed in the sections above. Numbers in brackets represent the observations used in the analysis. Red squares indicate a decrease within the wind farm site compared to pre-construction and green squares an increase.

Species	Study area			Wind farm site			% Of total within site		
	Pre-construction	Construction	Operation year. 1	Pre-construction	Construction	Operation year. 1	Pre-construction	Construction	Operation year. 1
Common scoter	20784 (269)	13298 (747)	61123 (205)	3	6	1	0.01	0.04	0
Red-throated diver	123 (153)	89 (173)	164 (205)	1	1	1	0.94	1.17	0.02
Manx shearwater	** (16)	** (86)	** (27)	**	**	**	**	**	**
Gannet	72 (60)	48 (97)	** (11)	1	2	**	1.81	0.92	**
Cormorant	97 (110)	68 (222)	189 (102)	5	16	9	5.07	23.1	4.69
Kittiwake	350 (145)	111 (323)	166 (56)	15	8	9	4.32	6.85	5.21
Large gulls	240 (128)	378 (86)	114 (78)	11	5	4	4.58	1.32	3.51
Guillemot	1221 (1942)	1109 (3461)	1455 (954)	69	47	58	5.68	4.23	3.96
Razorbill	1894 (484)	484 (1059)	2108 (218)	182	16	148	9.63	3.23	7.01
Auk species	2962 (2506)	1482 (4689)	5881 (1241)	199	54	277	6.72	3.64	4.71

7. MARINE MAMMALS

7.1. Analysis methodology

The stages of ecological analysis for marine mammals are identified below. Two mammal species (harbour porpoise and grey seal) were recorded and were the focus for analysis (for previous analysis, see Report No 035_R_NPC_EON_1).

To ensure a robust approach was undertaken, the following steps were followed:

i) All data available from the sub-consultants since 2004 has been collated by NPC, to ensure a complete dataset is available to E.ON and the RRMG. Data spreadsheets were converted to a standardised format and combined. Survey routes and observations were then visualised using ArcGIS. Throughout these two procedures, data were checked visually and any concerns were referred back to the 3rd party surveyors (Peter Ullrich) and errors were either corrected or data removed from the analysis if no information was available as to where mistakes had been made or errors existed.

ii) Raw data were plotted in ArcGIS with circles of differing sizes representing the number of individuals constituting each observation. Colour was used to distinguish between animals observed during the different construction periods.

iii) Boat survey transects were segmented by distance (1000 m) to produce replicate sampling blocks of equal effort. The number of observations was calculated for each block. The depth and sediment type[9] for each sample block was also extracted using ArcGIS. Depth was adjusted for tidal state using tidal measurements recorded at Workington[10].

All data was divided into three phases: pre-construction (2004-2007); construction (January 2008-February 2010) and operational year one (March 2010-March 2011).

All statistical analysis was performed in R 2.13.1.

iv) The data from all three phases were combined into a single model to look for a difference between the different phases of development. General Additive Models (GAMs) were fitted to both the harbour porpoise and grey seal data, incorporating a variety of covariate combinations (sea state, depth, sediment type, month, distance to coast, xy position). The final model included month, sea state, depth and xy position.

v) General Additive Models (GAMs) were also fitted to data from each development phase separately, again incorporating a variety of covariate combinations (sea state, depth, sediment type, month, distance to coast, xy position). The final models were chosen based on GCV score and for all three phases included month, sea state and xy position. Distance from coast was removed from the analysis due to its correlation with depth, as was sediment type correlated with xy position. These GAMs were then used to predict distribution across the whole survey area producing density surfaces and abundance estimates for the entire survey and turbine area.

This analysis could only be performed on the harbour porpoise data as there were insufficient seal sightings. The nature of the marine mammal date also meant that it was not possible to incorporate a detection function into the model.

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[9] SeaZone Solutions Limited

[10] Data supplied by the British Oceanographic Data Centre as part of the function of the National Tidal & Sea Level Facility, hosted by the Proudman Oceanographic Laboratory and funded by the Environment Agency and the Natural Environment Research Council

For each prediction grid cell, the difference in value between the three phases of the development was calculated (difference plots). Parametric bootstrap methodology was used to calculate standard errors around overall predictions for turbine and survey areas and for each individual grid cell in order to assess statistical significance of any change observed. The standard errors were converted to standard Z scores in order to assess significance to individual prediction squares.

7.2. Results

7.2.1. Harbour porpoise

The data available for harbour porpoise is shown in Figure 7.1a (overleaf), Figure 7.1b (below) and Table 7.1. The raw data suggests there was no change in the numbers recorded through the three different development phases. The overall SPUE for all three phases combined was 0.05.

Table 7.1: The number of harbour porpoise and SPUE recorded in each development phase. SPUE = number of sightings per survey segment.

	Pre-construction	Construction	Operation year 1
No. individuals	99	249	68
SPUE	0.06	0.05	0.05

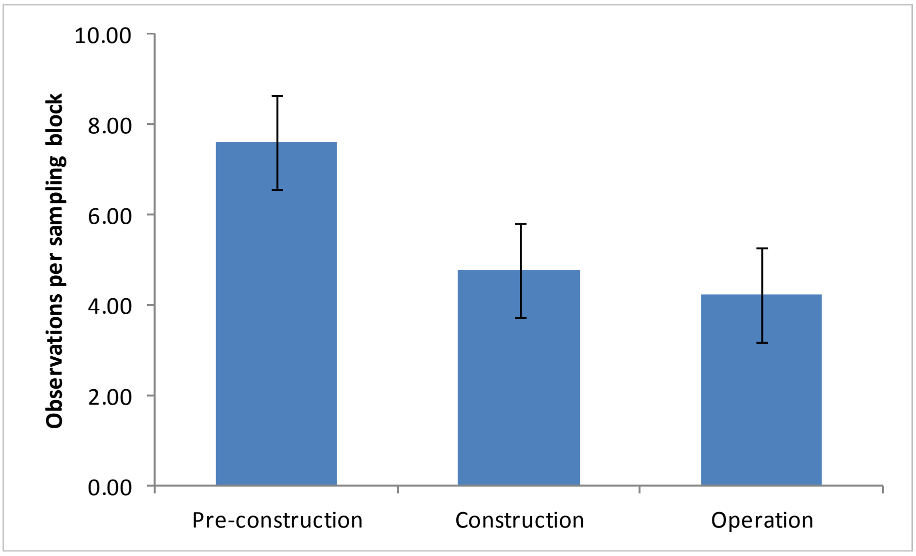

Figure 7.1b: Mean number of harbour porpoise per sampling block (+/- standard errors) for each development phase.

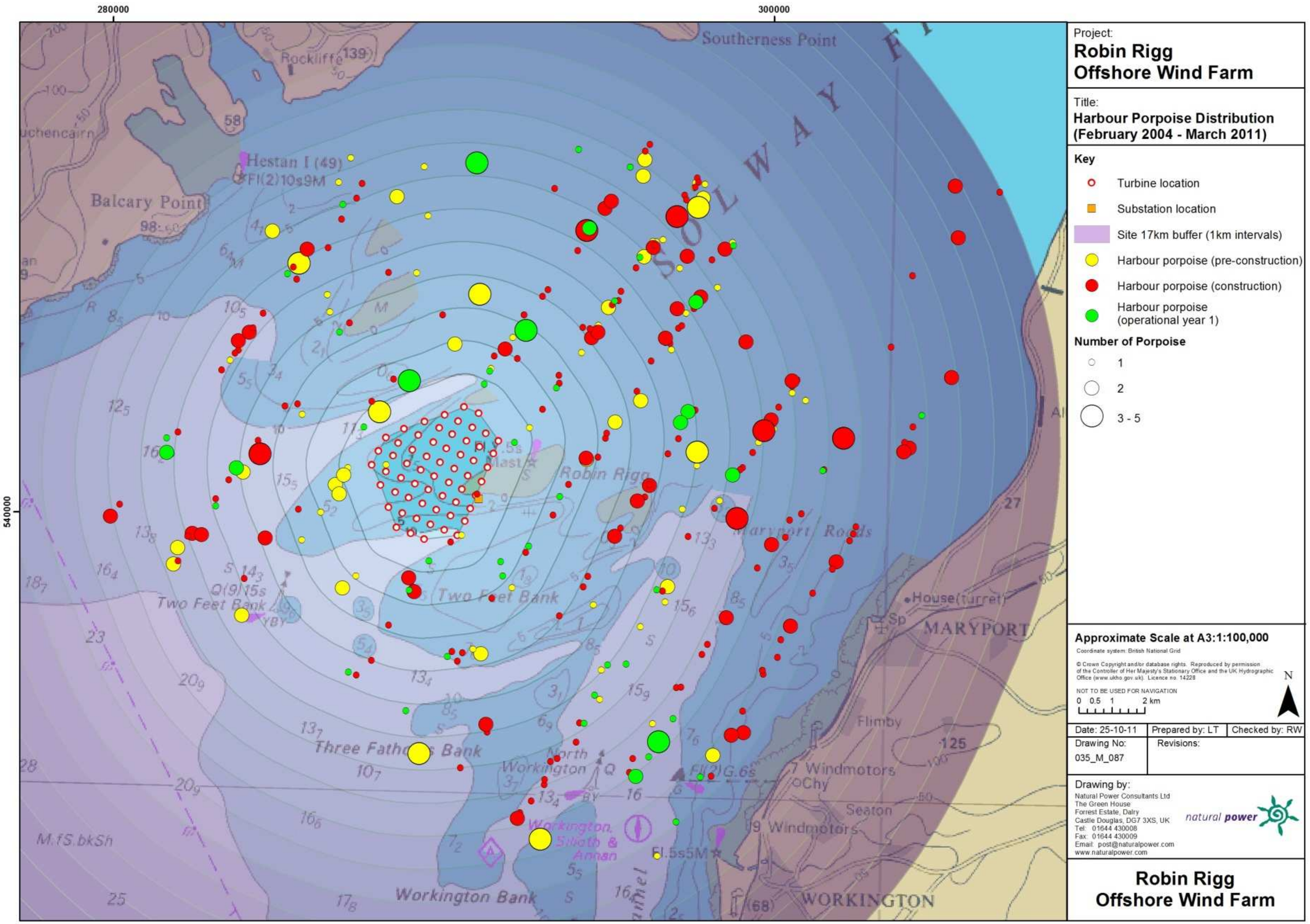

Figure 7.1a Locations of raw observations of harbour porpoise during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group observed.

Harbour porpoise were recorded in every month a survey was performed. The raw data show no obvious seasonal trends although a large peak in sightings was recorded in August of operational year one (see Figure 7.2).

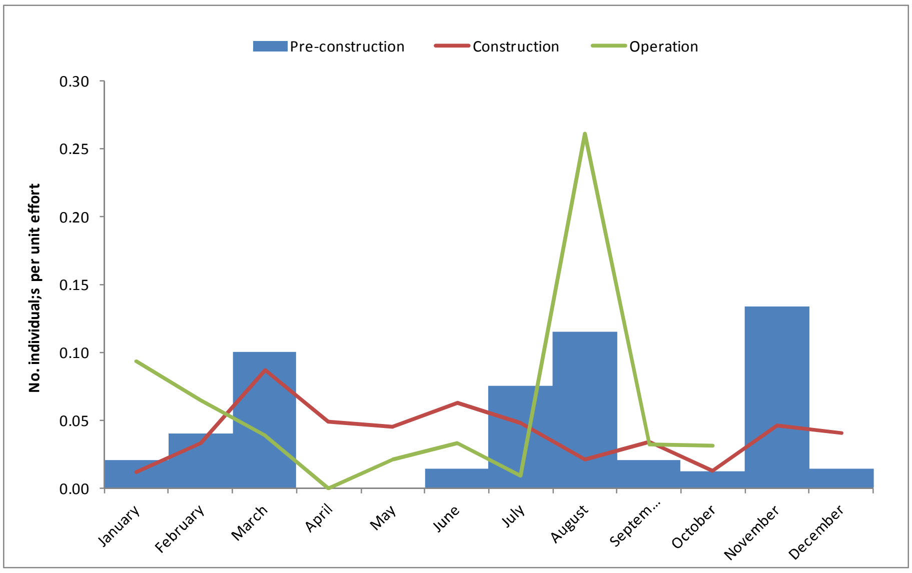

Figure 7.2: Mean number of harbour porpoise observed per month during the pre-construction, construction and operational phases.

The final GAM comparing all three development phases included construction period, xy position, month, depth and sea state. No significance difference in harbour porpoise presence was found between different construction periods (p = 1). All other variables in the model were significant. The final model explained 18.9% of the deviance.

Density estimates calculated for each development phase are shown in Table 7.2. These numbers will drastically underestimate the overall number of porpoises within the survey area because no detection function was included in the analysis. However, the proportion of animals within the turbine area compared to the entire survey will remain the same. They suggest a drop in numbers within the wind farm site during the construction phase, with numbers increasing again during operational year one.

While it is difficult to know the true distribution of harbour porpoise within the Solway Firth prior to construction (due to the lack of available data), the density maps suggest a decrease in abundance in the vicinity of the wind farm site during the construction period (Figure 7.3b) which appears to be significant (Figure 7.4a).

The data may suggest an increase in porpoise abundance post construction but it is advised to wait until the operation year two data is available before drawing any conclusions.

Table 7.2: Predicted harbour porpoise estimates for the survey area and wind farm site during each development phase.

	Pre-construction		Construction		Operation yr 1	
	Survey area	Site	Survey area	Site	Survey area	Site
Density estimate	14	0.5	11	<0	12	0.5
% within site	3.8		0.5		2.8	

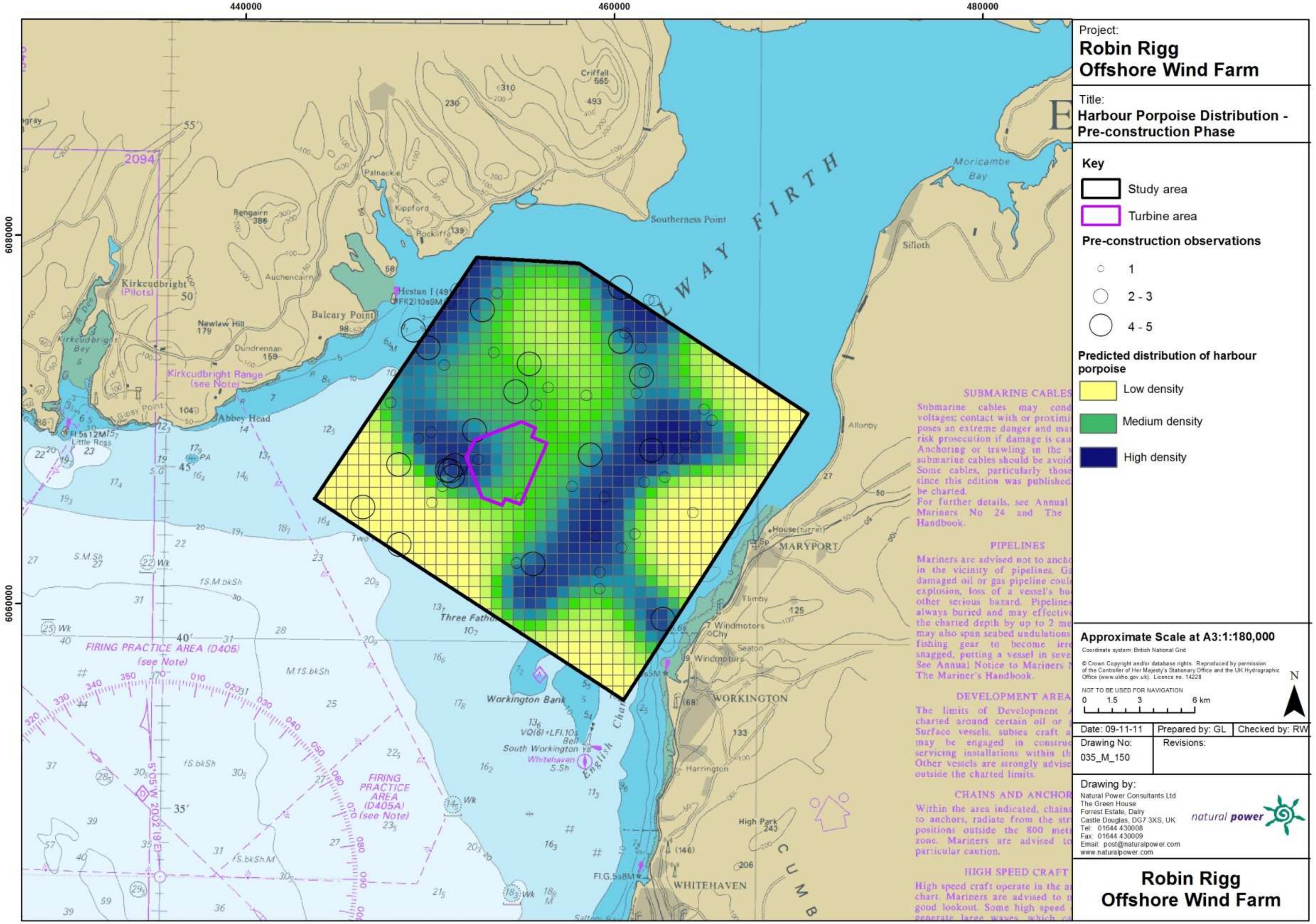

Figure 7.3a: Density surface map of the predicted density of harbour porpoise across the survey area during the pre-construction phase. Open circles show the locations of the raw observations.

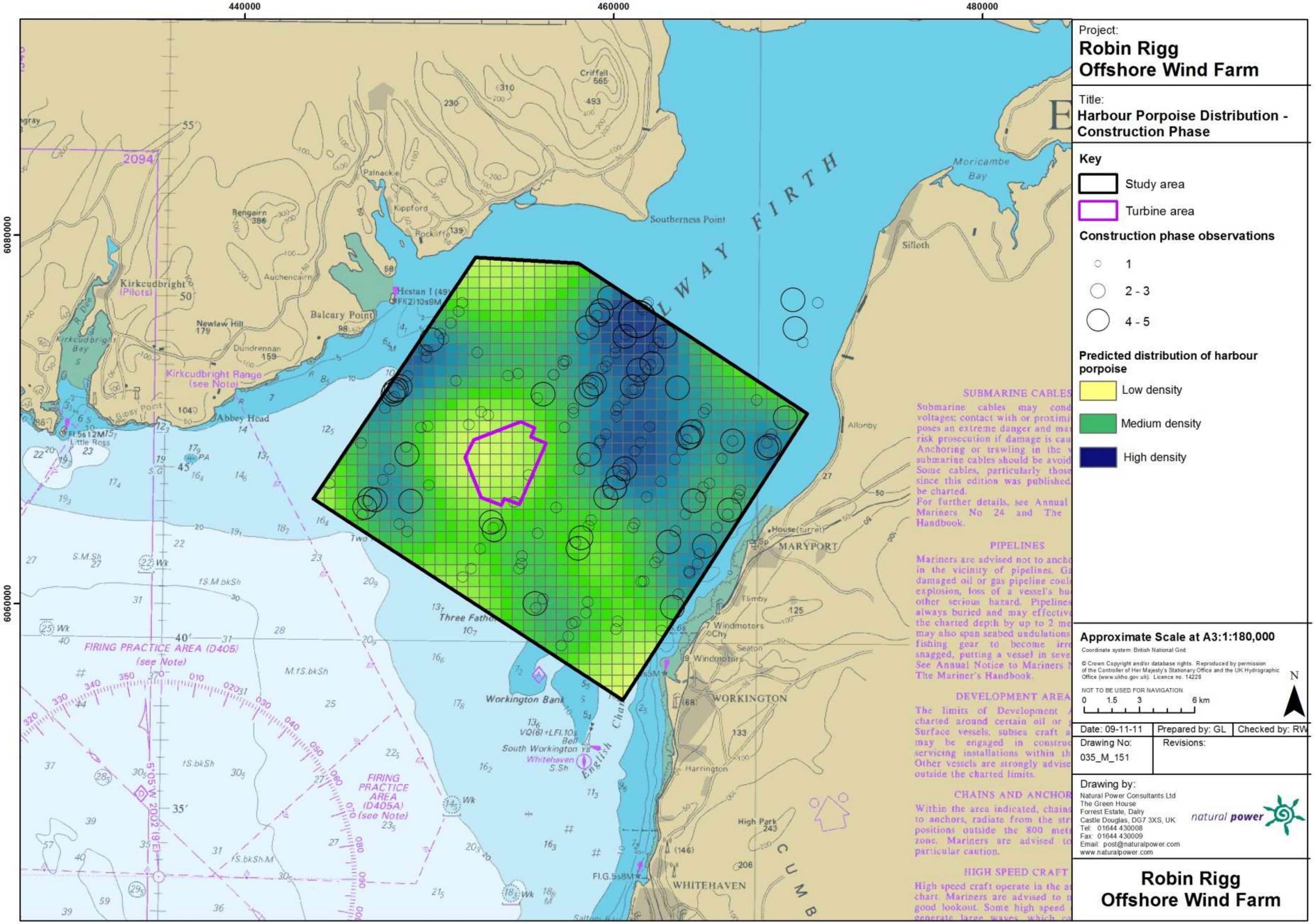

Figure 7.3b: Density surface map of the predicted density of harbour porpoise across the survey area during the construction phase. Open circles show the locations of the raw observations.

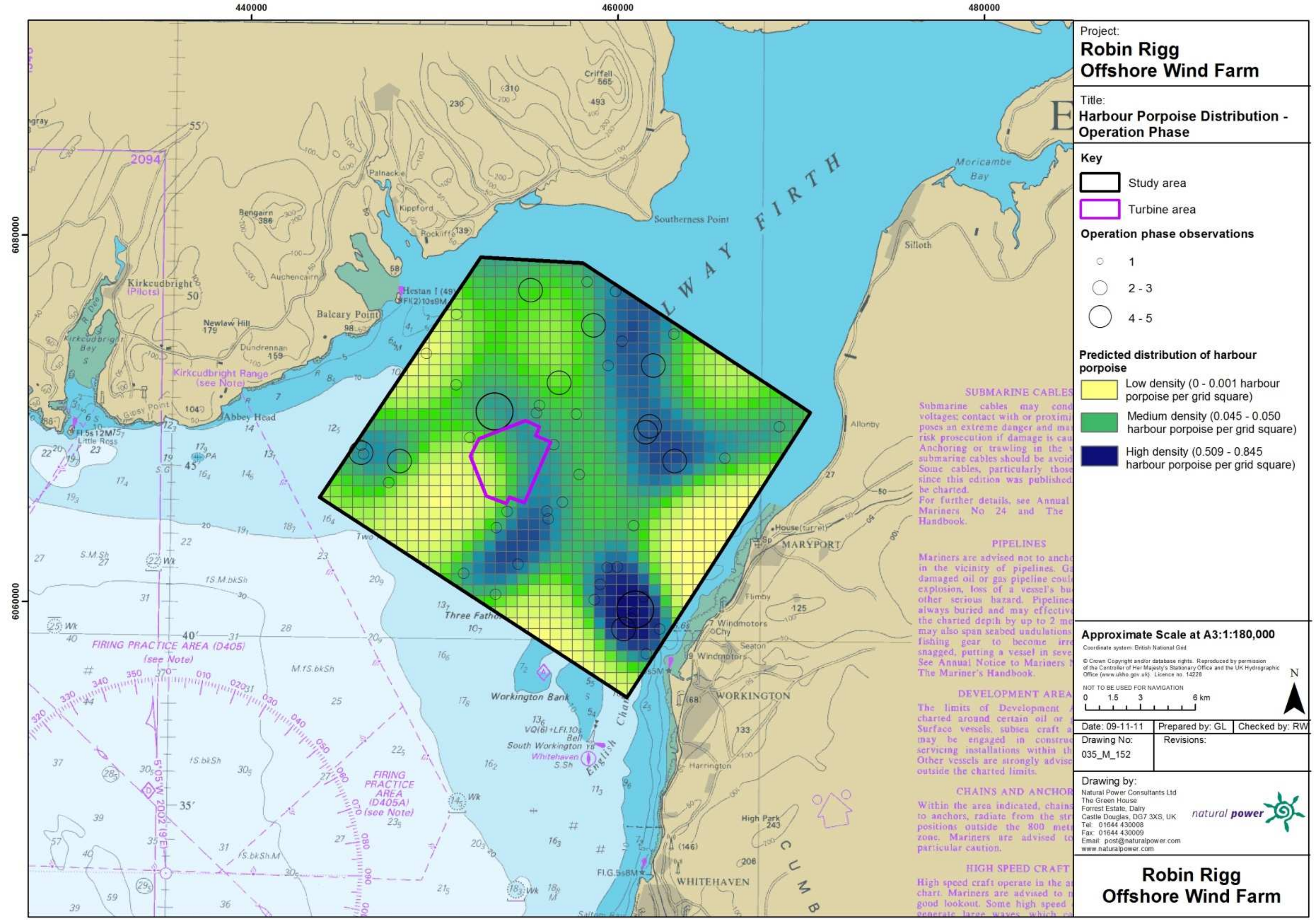

Figure 7.3c: Density surface map of the predicted density of harbour porpoise across the survey area during the operational phase. Open circles show the locations of the raw observations.

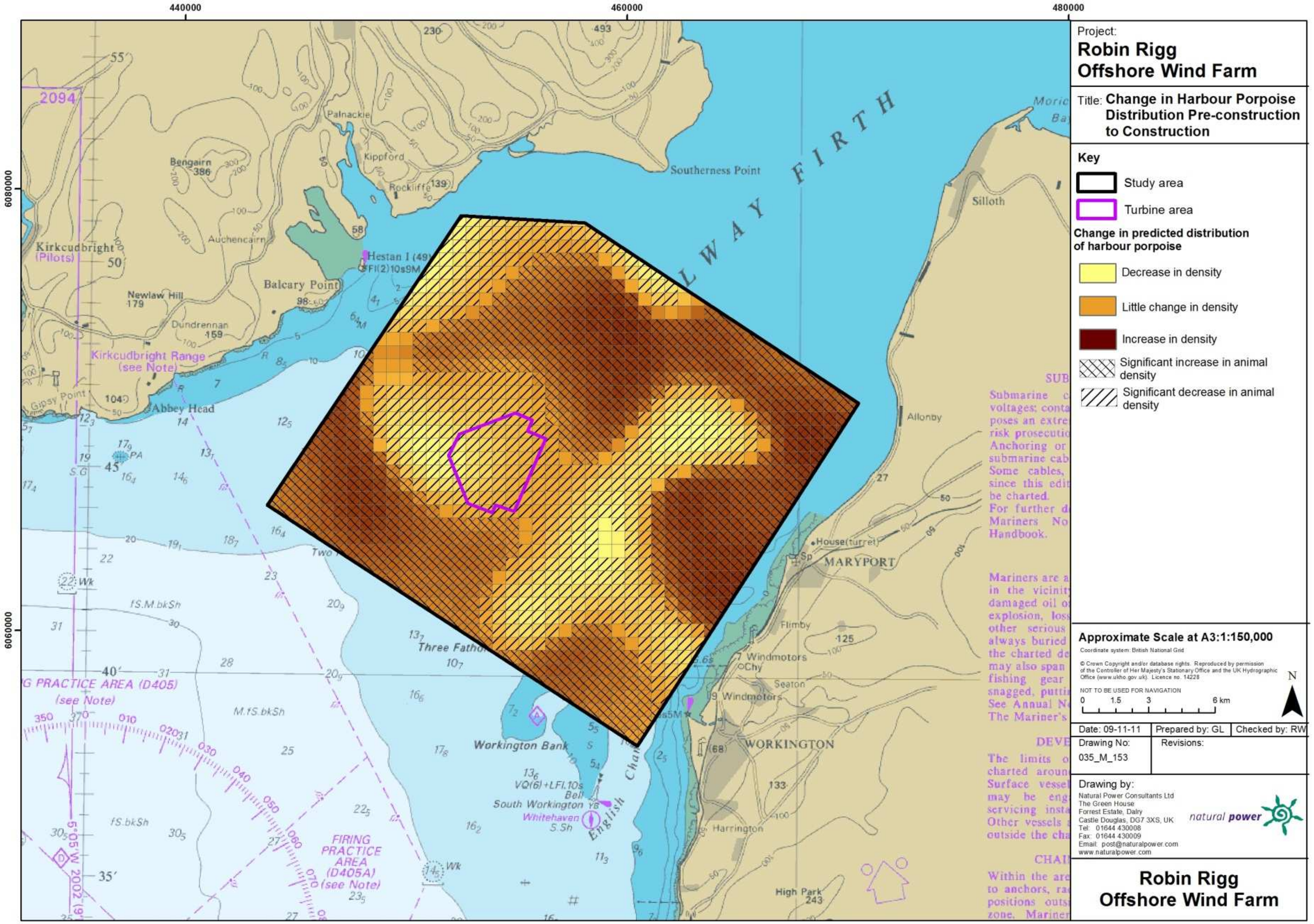

Figure 7.4a: Difference plot of the change in predicted density of harbour porpoise between the pre-construction and construction phase. Significant differences are marked with diagonal or hashed lines.

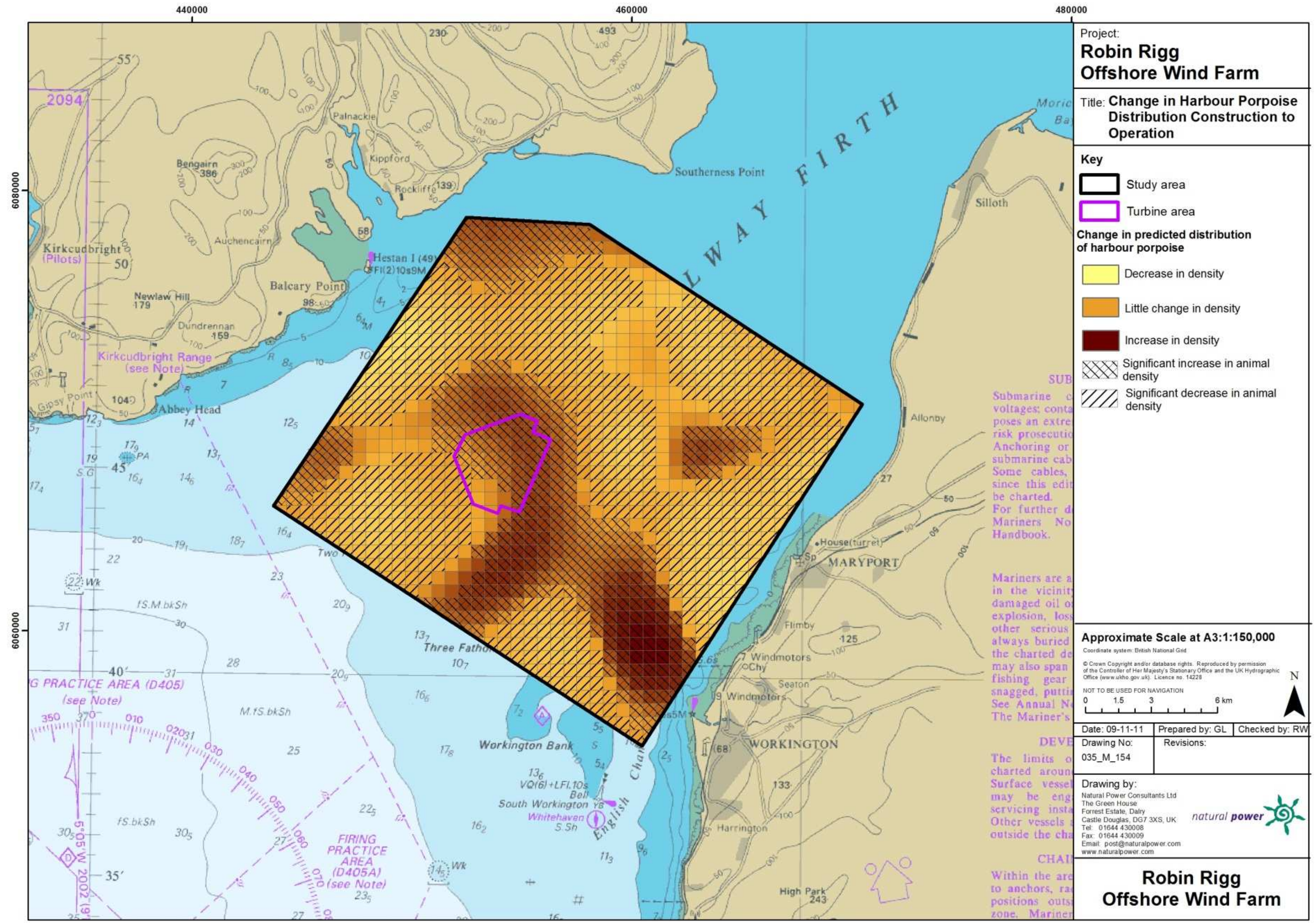

Figure 7.4b: Difference plot of the change in predicted density of harbour porpoise between the construction and operational phases. Significant differences are marked with diagonal or hashed lines.

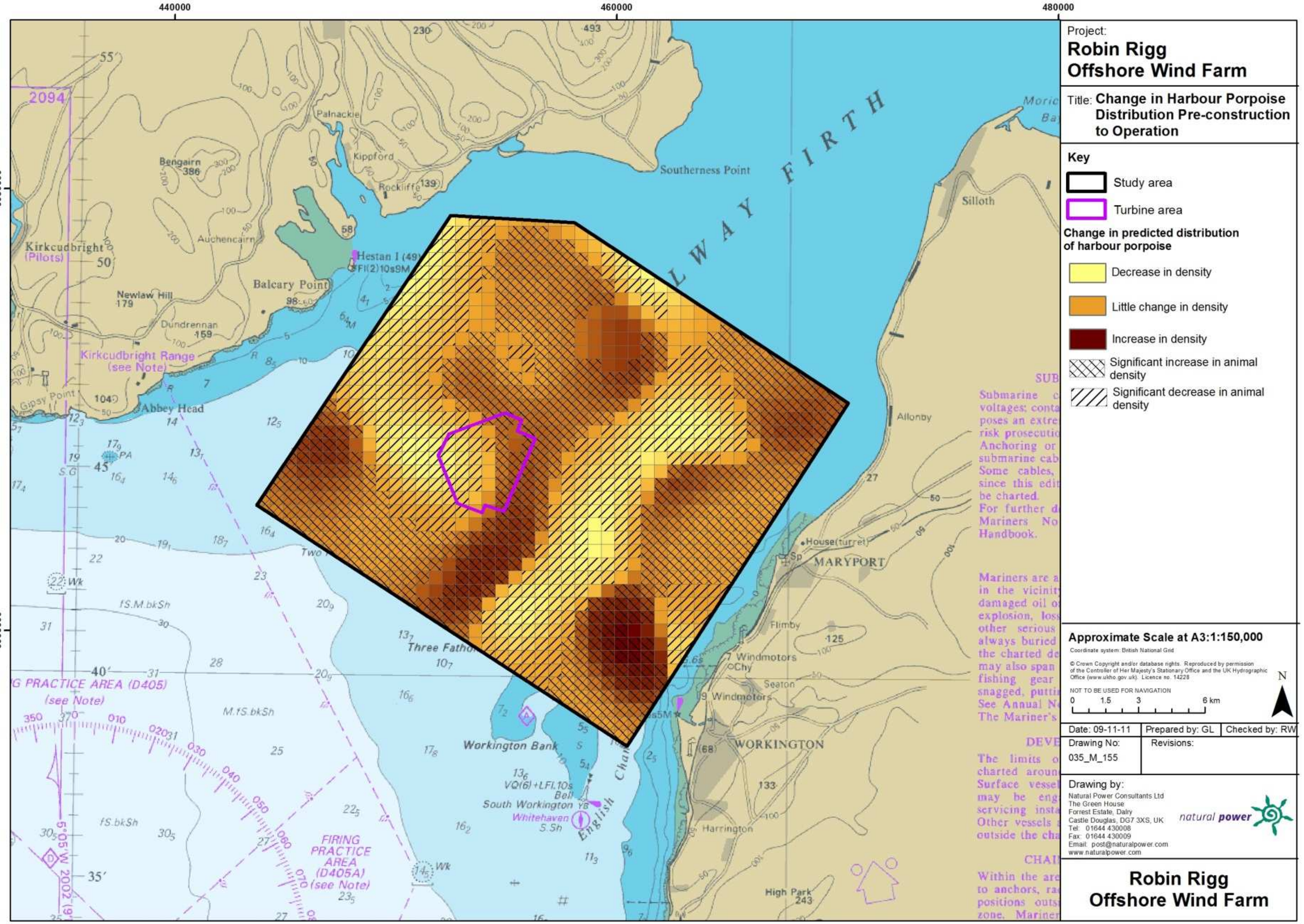

Figure 7.4c: Difference plot of the change in predicted density of harbour porpoise the pre-construction and operational phases. Significant differences are marked with diagonal or hashed lines

7.2.2. Grey seal

The data available for grey seal is shown in Figure 7.5a (over page), Figure 7.5b (below) and Table 7.3. The raw data suggests there was no change in the numbers recorded through the three different development phases. The overall SPUE for all three phases combined was 0.01.

Table 7.3: The number of grey seal and SPUE recorded in each development phase. SPUE = number of sightings per survey segment.

	Pre-construction	Construction	Operation year 1
No. individuals	20	41	19
SPUE	0.01	0.01	0.01

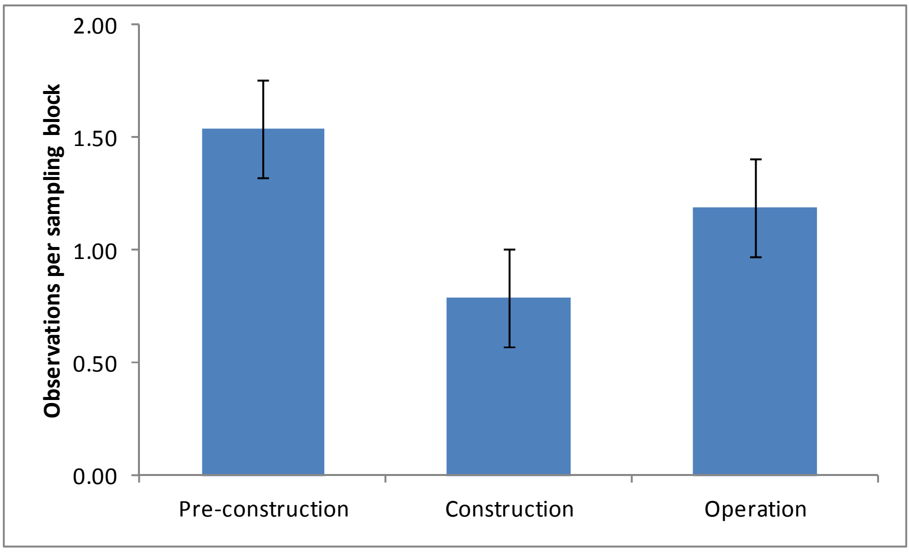

Figure 7.5b: Mean number of grey seal per sampling block (+/- standard errors) for each development phase.

Grey seal abundance varied through the year. The raw data show no obvious seasonal trends although a large peak in sightings was recorded in August of operational year one (see Figure 7.6). This particular survey had exceptionally good weather and is reflected the large numbers observed for both grey seal and harbour porpoise in this month. This peak may not be so apparent once the operational year two data is analysed.

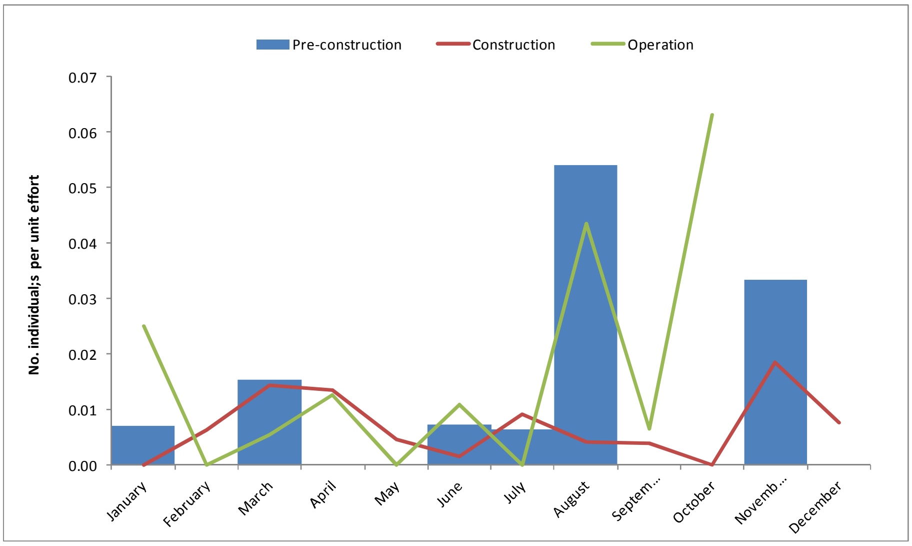

Figure 7.6: Mean number of harbour porpoise observed per month during the pre-construction, construction and operational phases.

The final GAM comparing all three development phases included construction period, xy position, month, depth and sea state. No significant difference was found in grey seal sightings between the different development periods (p = 1). All other variables in the model were significant. The final model explained 24.4% of the deviance.

Unfortunately there were too few data to produce density maps as for the grey seal.

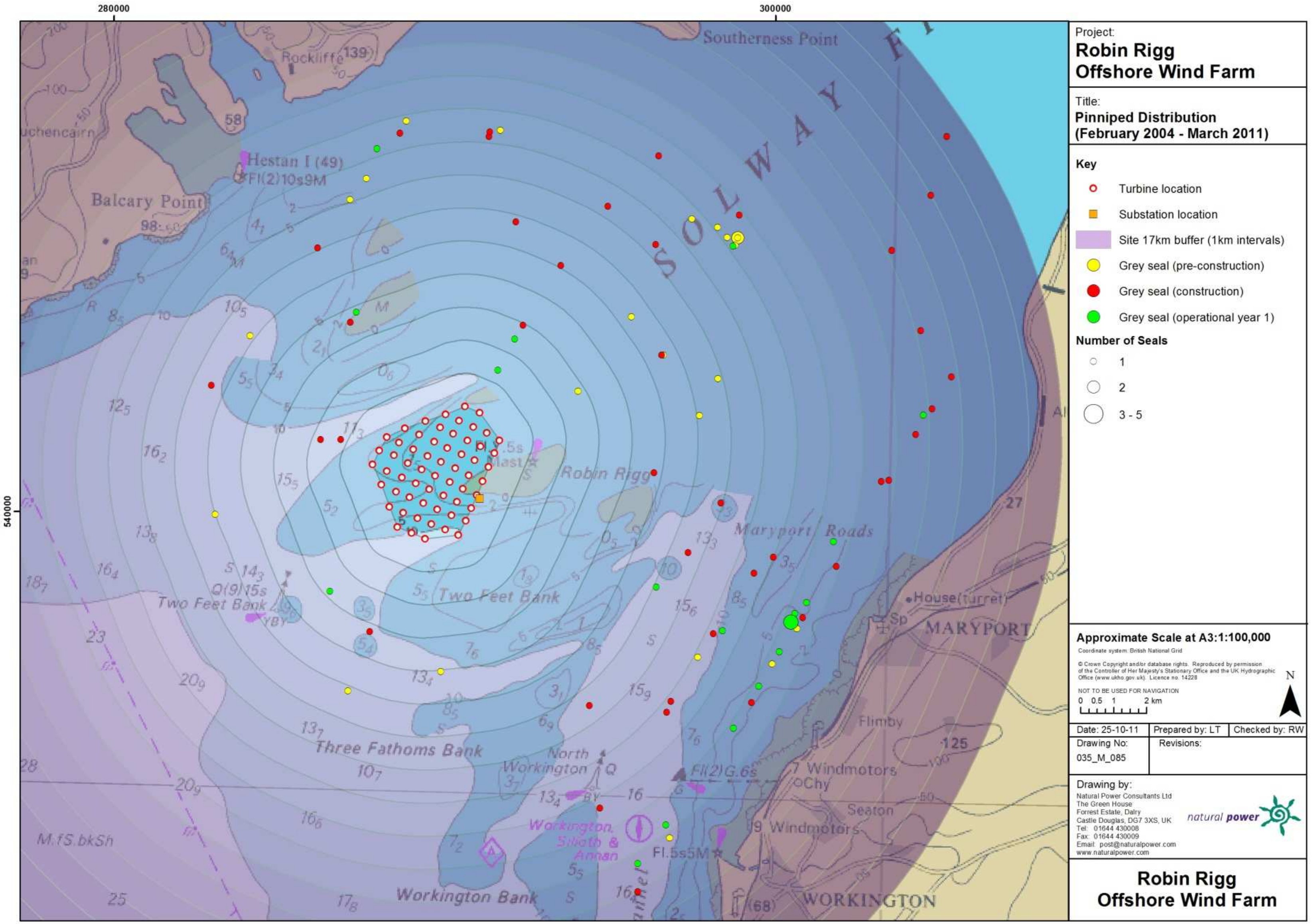

Figure 7.5a Locations of raw observations of grey seal during the pre-construction (yellow), construction (red) and operational (green) phases. The size of the symbols represents the size of the group observed

7.2.3. Stranding data

In the previous report (035_R_NPC_EON_1), harbour porpoise stranding data for the Solway Firth were presented between the years 2000 and 2009. For the purpose of this report, the data period has been extended to include 2010 (operational year one: Figure 7.7a). The monthly distribution of reports can be found in Figure 7.7b. As with the previous report, there is no significant difference in the number of stranded porpoise reported each year (Friedman's Test: S = 6.49, p = 0.77, 10 df).

There was discussion within the ES that the Solway Firth may be a calving ground for harbour porpoise, based on personal accounts and stranded reports. As a result, the stranding data were examined for reports of harbour porpoise calves. A calf was defined as an animal of less than 120 cm in length[11]. In total, 28 calves have been reported stranded between 2000 and 2010. The annual and monthly distribution of these reports is represented by the brown line on Figure 7.7a and b. Although stranded calves are being found, there is insufficient data to conclude definitively this is a preferred calving area. A point of note is that prior to operational year one, only one porpoise calf was observed during the boat-based surveys (November 2004). Two calves were reported in operation year one and to date, three have been reported in operational year two.

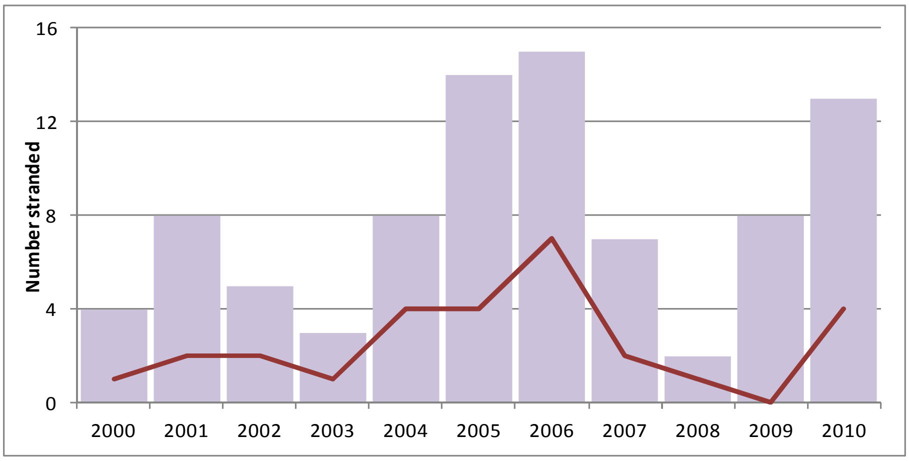

Figure 7.7a: The annual distribution of stranded harbour porpoise reported between the years 2000 and 2010 in the Solway Firth. Purple bar = total number; brown line = animals less than 120 cm in length (calf).

[11] Based on Learmonth, 2006. Used a length of 120 cm to indicate calf based on research on harbour porpoise stranding data from around the Scottish coast which found males aged less than one year ranged between 84 and 120 cm in length and females between 66 and 130 cm.

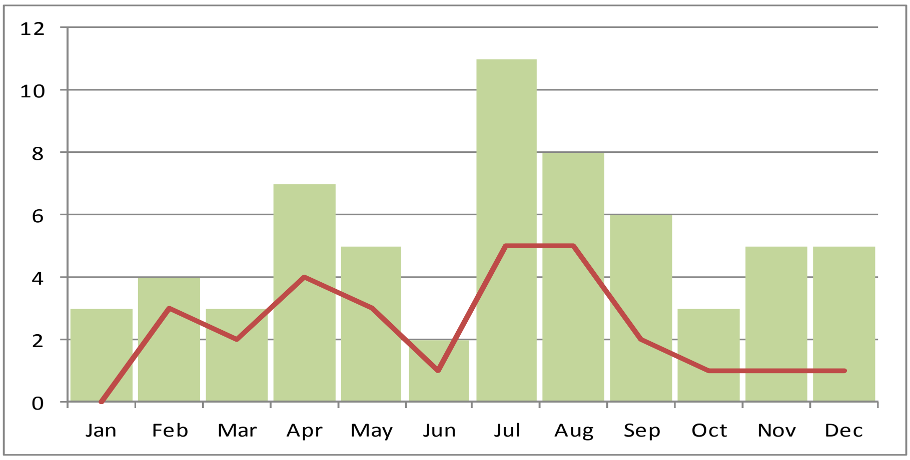

Figure 7.7b: The monthly distribution of stranded harbour porpoise reported between the years 2000 and 2010 in the Solway Firth. Purple bar = total number; brown line = animals less than 120 cm in length (calf).

Based on these data, there is no discernible effect from Robin Rigg on numbers of harbour porpoise stranded in the Solway Firth.

8. SUBSEA NOISE

Condition 21 of the FEPA licence required the licensee to "make provision during the construction phase of the wind farm to monitor subsea noise and vibration during construction work and for the first year of operation". Background noise levels were measured by Subacoustech Environmental, along with noise levels produced during piling. Measurements were repeated during the first year of operation and the data interpreted in respect of potential impact of operational noise on marine species. A summary of each of these operations can be found below.

8.1. Construction phase monitoring

Recordings of background underwater noise in the Solway Firth region during periods when no piling was being carried out indicated fairly typical levels of ambient noise for coastal regions around the UK. Varying levels of vessel activity caused the greatest variation in levels of background noise over the measurement period (dominant factor in determining background level).

A series of underwater noise measurements were undertaken along four transects radiating out from the wind farm (see Figure 8.1), during impact piling operations to secure 4.5 m diameter steel monopoles into the seabed between 16th January 2008 and the 4th February 2009. The data were used to predict estimated ranges within which marine animals are likely to suffer lethality and physical injury as a result of high levels of underwater noise. Data were also analysed in terms of the hearing ability of various species of fish and marine animal in order to estimate the ranges out to which these species are likely to avoid the sound.

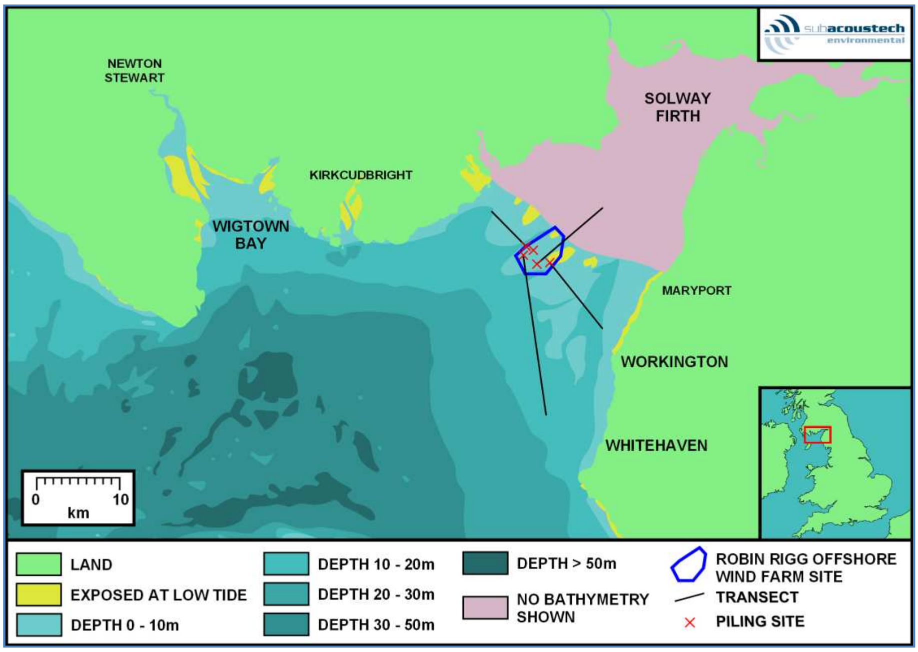

Figure 8.1: Approximate location of the Robin Rigg Offshore Wind Farm and the transects along hich noise measurements were taken during impact piling operations.

The measured levels of underwater noise, and the fit to the measured data indicate species of marine animal may suffer lethality out to a maximum range of 3 m and physical injury out to a maximum range of 40 m. Behavioural avoidance to the underwater noise has been estimated based on the 90 dB_{ht} perceived level for species of fish and marine mammal.

Levels of underwater noise measured at the beginning of the soft start procedure are likely to be below the levels that would cause lethal effects but will be above 90 dB_{ht} and therefore likely illicit a behavioural response i.e. flee the area.

The data indicate that the greatest range from piling operation at which sound will be perceived at 90 dB_{ht} or above, were in the deeper waters to the south and west of the site, with herring and cod likely to perceive aversive levels of noise out to a maximum of 18 km. Dab are likely to avoid a region of up to 5.5 km from the noise source (see Table 8.1 for more details). Behavioural avoidance ranges are estimated to be considerably lower in the shallower water regions to the north, south and east of the site with maximum avoidance ranges of 10 km for the herring.

Table 8.1: Summary of behavioural response predicted for fish species along different transects relative to the Robin Rigg Offshore Wind Farm.

Species	Range at which 90 dB_{ht} perceived (km)			
	South transect	Southeast transect	Northeast transect	Northwest transect
Dab	5.5	2.5	1.8	1.5
Cod	18	8	5	6
Herring	18	10	6	7

As for fish, the maximum behavioural range for marine mammals was along the southern transect with those predicted for the other transects being similar (see Table 8.2).

Table 8.2: Summary of behavioural response predicted for marine mammal species along different transects relative to the Robin Rigg Offshore Wind Farm.

Species	Range at which 90 dB_{ht} perceived (km)			
	South transect	Southeast transect	Northeast transect	Northwest transect
Harbour seal	9	6	6.5	7
Harbour porpoise	12.5	8	8	7.5
Bottlenose dolphin	9	6.5	7.5	5.5

A comparison of behavioural impact ranges based on the measured underwater noise data with predictions made in a 2005 study using an seismic airgun and a representative sound source have indicated the accuracy of predictions using this method. The predicted data agree well with the measured data obtained along transects in shallower water. However, the 2005 predictions underestimate the impact ranges estimated along deeper water transects

8.2. Operation phase monitoring

Measurements were taken along six different transects extending from turbines on the periphery of the site (see Figure 8.2). Measurements were also taken at various locations within the site. Background measurements taken during the construction phase were used as baseline levels of ambient noise. A number of measurements were taken at 5 and 10 km from the site to evaluate current background levels for comparison with those associated with the wind farm.

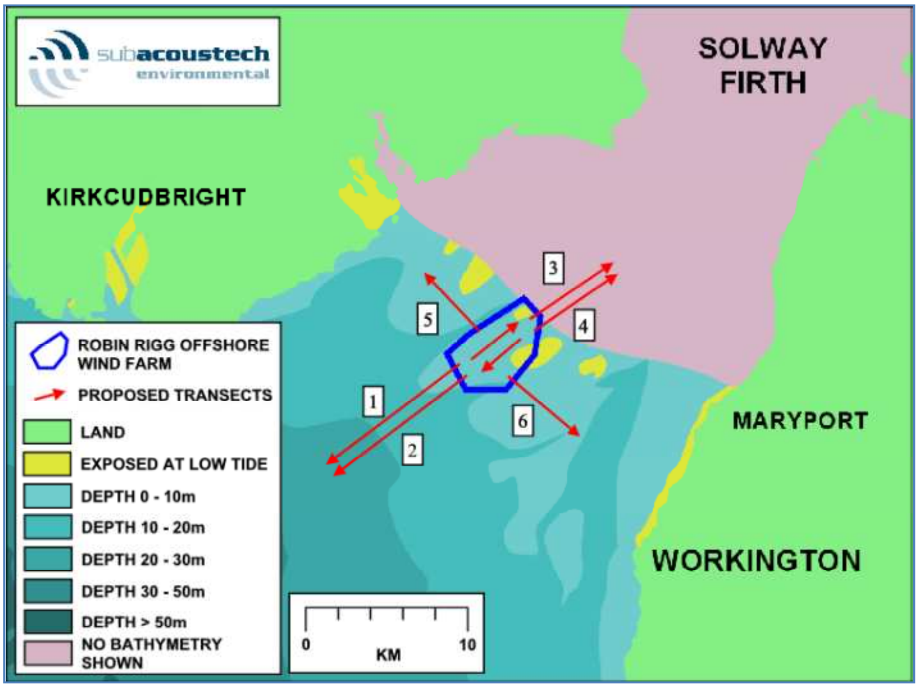

Figure 8.2: Approximate location of the Robin Rigg Offshore Wind Farm and the transects along which noise measurements were taken during operational year one.

Data recorded at ranges of approximately 20 m up to 5 km on each transect indicate that the underwater noise from the operational turbines is generally of a low frequency nature, with components of underwater noise mainly evident below approximately 500 Hz. Unweighted broadband recordings of underwater noise indicate that in most cases, the operational turbine noise was not detectable above background sea noise.

The levels of underwater noise measured throughout the survey were sufficiently low that lethal, physical injury and auditory damage to marine species (fish and marine mammal) will not occur.

The data were analysed in terms of the dB_{ht} metric for various species of fish and marine mammals. These data have provided an indication of the actual levels of underwater noise that could be heard by marine species during the measurements and an assessment of potential impacts. For all of the recorded data the perceived levels of underwater noise were considerably below those considered likely to cause a behavioural avoidance response. For the mammals (harbour porpoise, harbour seal and bottlenose dolphin), the dB_{ht} levels varied very little with range from a turbine and probably represented background noise. For the fish species (cod, herring and dab), although for some of the measurements a trend line could be fitted to the transect data, the data indicate that perceived levels are insufficient to cause any behavioural responses in these species.

Measurements inside the wind farm array indicate that the levels of underwater noise here are largely the same as those at the nearest distances from a turbine along a transect.

Overall, the data analysed in terms of the dB_{ht} metric indicate that the underwater noise within the wind farm array is insufficient to cause death, physical injury or auditory injury, and is unlikely to cause any behavioural avoidance response in fish or marine mammal species.

9. DISCUSSION

9.1. Benthic Infauna

The analysis undertaken on the benthic infauna data was used to identify any temporal or spatial trends and to determine whether the construction and operation of the wind farm may be linked to these trends.

The species and habitats found in the Solway Firth during the surveys are all common to the area. There were no species recovered that were of rare or high conservation value.

9.1.1. Temporal Variations in Benthic Communities

The Solway Firth estuary forms the third largest continuous area of sedimentary habitat in the country. Tidal currents in the estuary are moderately strong and levels of wave energy are high. The area where the wind farm is located is characteristic of this high wave exposure, comprising a highly dynamic environment with shifting subtidal sand banks (Scottish Natural Heritage & English Nature, 2000). The subtidal area within the Solway Firth has been described as being dominated by mobile sediments brought into the area from the Irish Sea. Abundance and species diversity have both been reported to be low within the Solway Firth (Cutts & Hemingway, 1996). A later study undertaken by Axelsson *et al.,* (2006) also found overall species diversity and abundance to be low throughout the Solway Firth.

The scenario of low species diversity and abundance has been observed since the start of the Robin Rigg Offshore Wind Farm surveys, with very little change in the biotope composition since the baseline surveys were conducted. The predominant biotope throughout all construction periods was *Nephtys cirrosa* and *Bathyporeia spp.* in infralittoral sand (SS.SSa.IFiSa.NcirBat). Other common biotopes were *Abra prismatica, Bathyporeia elegans* and polychaetes in circalittoral fine sand (SS.SSa.CFiSa.ApriBatPo) and Infralittoral mobile clean sand with sparse fauna (SS.SSa.IFiSa.IMoSa). The biotope identified only in the baseline survey and not in the rest of the subsequent surveys was Infralittoral muddy sand (SS.SSa.IMuSa). According to the ES, this biotope occurred in the inshore part of the original cable route, and as the subsequent surveys did not survey this particular area no comparison can be made.

Surveys undertaken by Cutts & Hemingway (1996) identified the same biotopes as those reported here. For comparison, the results from Cutts & Hemingway can be found in Table 9.1.

The biotopes identified during the construction periods certainly seem to be in keeping with previous characterisations of the Solway Firth, suggesting the wind farm has had very little impact upon the benthic invertebrates driving the biotopes. However, the locations of the biotopes appear to have shifted spatially throughout the construction periods (see Figures 4.1 - 4.4).

Table 9.1: Sub-tidal biotope codes and descriptions identified by Cutts & Hemingway (1996) during their 1994 survey.

Biotope*	Description
SSND.P.IMP	**Impoverished with occasional polychaetes.** Area comprising fine to medium sand. Very low species abundance and diversity with only a few polychaetes such as *Nephtys* spp. present. This biotope is very impoverished.
SSND.NEP.A	***Nephtys* sp. and amphipods**. Sediment composed of fine to medium sand. Very low species diversity and abundance with only a few polychaetes and amphipods present such as *Nephtys cirrosa* and *Bathyporeia elegans*.
SSND.NEP.MG.A	***Nephtys* spp., *Magelona mirabilis* and amphipods**. This biotope comprises fine sand with a variety of polychaetes and amphipods. *Magelona mirabilis* and the amphipod *Bathyporeia elegans* are the dominant species.
SSND.BAT.P	***Bathyporeia elegans* and polychaetes**. Area of fine sand dominated *by Bathyporeia elegans* and polychaetes such as *Nephtys cirrosa*.
SSND.MG.B	***Magelona mirabilis* and bivalves**. Fine sand dominated by abundant *Magelona mirabilis*. *Nephtys* are also present, together with a number of bivalves, of which *Tellina tenuis* is dominant.
SMXD.NEP.A	***Nephtys* spp. and amphipods**. Mixed sediment including medium sand and gravel. Very low species diversity and abundance with only a few polychaetes and amphipods present, i.e. *Nephtys cirrosa* and *Gastrosaccus spinifer*.
SMXD.P.IMP	**Impoverished with occasional polychaetes**. Mixed sediment including coarse sand, rocks and pebbles. Very low species abundance and diversity with only a few polychaetes such as *Nephtys* sp. present. This biotope is very impoverished.
*Biotope codes were classified using the 04.94 version of the MNCR classification.	

There was a shift in communities between baseline and the second year of construction from one dominated by amphipods & polycheates (SS.SSa.IFiSa. NcirBat) to one dominated by bivalves and polychaetes (SS.SSa.CFiSa.ApriBatPo). A further shift was seen in operational year one when the community appears to have shifted back towards the baseline conditions, i.e. SS.SSa.IFiSa.NcirBat.

By statistically examining the variation between years, the predominant species in each year and the biotopes present, a clear pattern of infaunal communities can be seen. The statistical analysis indicates the area within and around the wind farm site has not greatly changed since the baseline survey. Initial analysis of the benthic infauna data suggests very little difference between the construction periods, with the MDS plots showing very little separation between each construction period. This is backed up by the ANOSIM results which also show very little difference between the construction periods.

However, further analysis using PERMANOVA+ did identify some changes occurring throughout the construction periods. The baseline and pre-construction periods were compared against each other to see if there were any natural changes occurring as the two surveys were undertaken six years apart. There seems to be some change occurring in the benthic infaunal community, although whether this change is natural or not is difficult to determine. Certainly, this change has occurred prior to the wind farm construction. This change is also observed between the operational period and the baseline and between the operational and pre-construction periods.

Analysis using PERMANOVA+ identified the benthic infaunal variations discussed above, but this was not identified by the initial analysis. This suggests that any changes are subtle, and could be explained by the naturally dynamic environment of the Solway Firth. This theory is also supported by looking at the species driving the community assemblage of each construction period, with little variation and *Nephtys cirrosa* and *Bathyporeia elegans* being the dominant species throughout.

9.1.2. Spatial Patterns of Benthic Communities

The benthic infauna data was analysed for any spatial variation, i.e. any variation between the wind farm and cable route grabs and the control sites. The MDS plots (Figure 4.4) showed that there was no discernible difference between the three areas, and that the wind farm and cable route grabs did not differ from the control sites, although these are located fairly close to the development sites (within one tidal ellipse).

9.1.3. Evaluation of ES Predictions

The ES predicted any impacts on the benthos as a result of construction activity in this area would not be significant and where any may occur, they would be of a short duration. In addition, the ES predicted that any sedimentation or disturbance suffered by fauna would be short in duration due to the highly dynamic nature of the area and therefore would not cause significant impacts on the benthos. During the operational years the ES predicted that there would be no changes to the hydrodynamic regime of the area, and that given the spacing of the turbines and the high currents and tidal range of the area any impacts on the site are insignificant and no impacts are predicted on the benthic communities.

Analysis of the infaunal data showed no significant differences between the pre-construction and construction years, but a subtle temporal shifting of communities around the whole site which may be considered to be characteristic of the dynamic equilibrium present at the Solway Firth. In addition, no significant differences were found between the benthic communities at the wind farm, cable route or control sites in any construction period.

On this basis, the ES predictions appear to be correct.

9.2. Fish and Epibenthos

The analysis undertaken on the fish and epibenthic data was used to identify any temporal or spatial trends and to determine whether the construction and operation of the wind farm may be linked to these trends. The data analysis also showed any trends occurring with commercially important species. The fish and epibenthos found in the Solway Firth during the surveys are all common to the area. **There were no species recovered that were of rare or high conservation value**.

Since the baseline survey in 2001, 38 species of fish and 53 species of invertebrates have been captured during the non-migratory and electro-sensitive (cable route) trawls. These species comprised of both commercial and non-commercial species, all of which are common to the wind farm area. The most common fish found were the commercially important species plaice, dab, and whiting, followed by the less commercially important species of lesser weever, sprat, and solenette. The epibenthos is dominated by the commercially important brown shrimp followed by brittlestars, hermit crabs, and harbour crabs.

Species caught reflect local fishery activities in the area, such as the brown shrimp fishery, and commercially exploited species in the surrounding area of the Irish Sea, such as plaice and whiting. The results also support the status of the Solway Firth as a nursery area, as the majority of commercially important fish were juveniles (0 or I group).

9.2.1. Variations in Fish and Epibenthic Communities

Variations in Catch Quantity

Numbers of fish caught between construction periods was found to differ significantly, with the greatest catches recorded during the baseline surveys. Catches were at their lowest during the pre-construction phase, after which numbers showed a steady increase up to and including operational year one, however, only further monitoring will determine if this pattern continues.

Numbers of epibenthic species caught between construction periods did not differ significantly, and although overall abundance did decline considerably from the baseline surveys, they have remained fairly constant since.

This pattern should be interpreted with caution as the survey design has varied considerably throughout the monitoring regime as a result of the requirements of the MEMP, making comparisons between years difficult (see section 5.5.1). It would appear logical to assume that the low catch of fish during the pre-construction year is due to the fact that only the cable route was surveyed. In subsequent years, when both the cable route and the rest of the non-migratory fish survey stations were surveyed, fewer fish in general were captured on the cable route (Figure 5.2). As such, it is better to consider the changes between the baseline and construction year one surveys, as these represent a more robust comparison of the fish and epibenthic communities across the site, although the time difference between the two periods will have to be taken into account.

A decline in fish and epibenthic species was recorded between the baseline and construction year one surveys. Although these surveys are easier to compare as non-migratory fish surveys took place in both years, there are a number of other factors which could affect the catch apart from the limited construction activity that took place that year:

- The first, potentially most influential reason is down to the dynamic sedimentary environment of the Solway Firth and the positioning of the trawls. When the baseline survey was designed, trawl locations were placed, on advice from local fishermen, within the channels between sand banks where the catches would be greatest. During the six years between the baseline and construction year one surveys, changes occurred in the positioning of these channels, a natural process in the Solway Firth, which resulted in some sampling stations no longer being positioned within the channels, but instead on the banks where catches in the Solway are known to be considerably less (Lancaster & Frid, 1998).

- Differences in the construction activity and survey programme between years could also have had an effect on catch. During the first year of construction, there was very little activity at the site with trenching was undertaken, mainly along the cable route. This first year of construction also incorporated the cable route surveys, where the catch was found to be consistently less per tow, therefore bringing the overall mean catch per tow per survey down. Declines in catch during the first year of construction are therefore unlikely to be due to construction activity apart from along the cable route where the majority of activity took place. The greatest construction impact to the wind farm site would have occurred during the second year of construction, when the majority of the turbine bases were being installed.

When examined at the sampling station level, it is evident that the declines in fish abundance were fairly uniform across all stations between baseline and construction year one, before increasing, again uniformly, through construction year two. Operational year one on the other hand, saw a greater increase in numbers at the sampling stations nearest to the Scottish coast. This uniform decline across the site followed by the increase in catch at those sampling stations nearest to the Scottish coastline is very similar to the pattern seen in both the overall invertebrate catch and more specifically, in the catch of the brown shrimp. Brown shrimp are an important food source for many species in the Solway and, with the invertebrate catch in operational year one skewed heavily by the presence of high brittle star catches, provide an important indicator of the distribution of prey items (other than brittle stars) for many of the fish species encountered during the surveys.

Changes in brown shrimp numbers are also important commercially, as they represent an important fishery in the Solway Firth. Brown shrimp catches were found to be significantly different between construction periods, with the greatest abundance recorded during the baseline surveys and, after a minimum catch recorded during the pre-construction period, have remained fairly consistent between construction and operational years.

Brown shrimp numbers are known to fluctuate considerably between years (Lancaster & Frid, 1998). Given this fact, combined with the shift in the sand banks in relation to tow positions, it is extremely difficult to attribute the declines in shrimp numbers to wind farm construction activity. Due to the fact that the greatest decline in abundance came prior to the majority of construction activity beginning, it is unlikely that the observed differences are a result of the wind farm development. Landings of brown shrimp from Silloth, a port in the Inner Solway, and from the entire Irish Sea provide a baseline of sorts to the catch recorded during the sampling trawls and although not comparable in terms of numbers, give an indication of wider population changes in the species. It can be seen that the Silloth landings, which mirror those of the Irish Sea as a whole, are showing a reduced catch when compared to previous cycles of abundance, indicating that there may be a wider reduction in shrimp numbers across the Solway as a whole, and that declines in the sampling trawls are not solely a product of shifting sand banks.

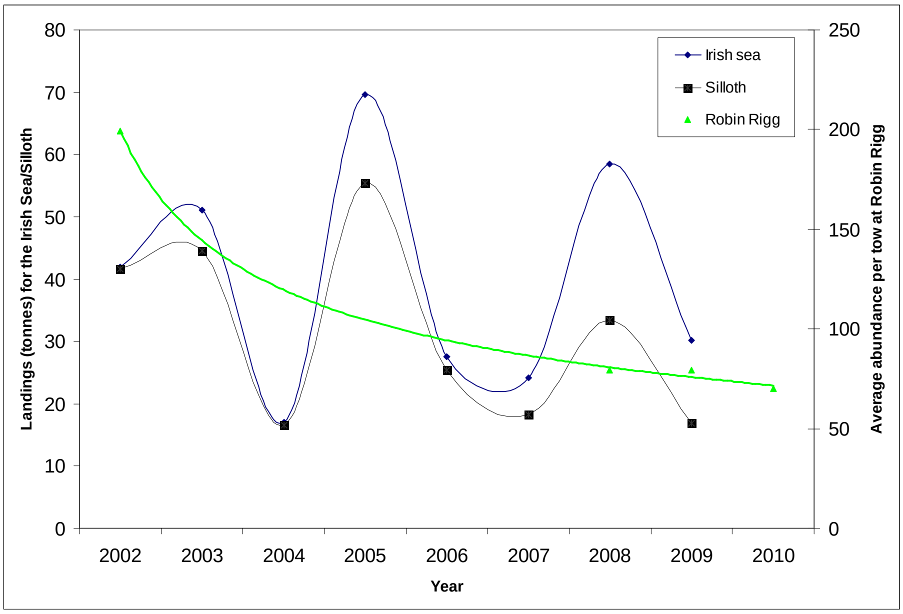

Figure 9.1: Landings data for brown shrimp for the Irish Sea and Silloth, showing a similar trend as found in the Robin Rigg sampling trawls (normalised per tow per survey).

No significant seasonal differences were recorded for fish or invertebrates during the surveys, although a general pattern of abundance was observed with the fewest individuals captured during the spring sampling occasions and the greatest numbers caught during autumn. This seasonal variation in fish catch reflects recognised patterns of migration within the Solway Firth. Fish species tend to mirror the migration of brown shrimps, as they are an important prey source to many fish species and although not significantly different between surveys, seasonal variations were evident with brown shrimps migrating to the outer Solway (around the wind farm site) in the autumn and winter and into the Inner Solway during the late spring and summer (Lancaster & Frid, 1998).

Community Assemblages and Variations in Species Abundance

The fish and epibenthic community assemblage were analysed using MDS plots and ANOSIM, however, no particular clustering or separation of construction periods was observed. Neither did the ANOSIM results indicate that there was any variation in the community assemblages throughout the construction periods. This indicates that the fish and epibenthic community assemblages in the survey area as a whole maintained a dynamic equilibrium throughout all construction periods. MDS plots and ANOSIM testing for any seasonal variation also indicated no particular variation across the seasons.

Despite the lack of change evident in the community assemblages, analysis of the diversity indices revealed significant differences between the communities present during each construction period. This was further examined using SIMPER analysis, which highlights the most dominant species driving any differences between the construction periods.

From the SIMPER analysis, certain species were shown to always have a strong presence in the community, whilst others were more variable in their abundance. Throughout all construction periods, plaice accounted for the largest contribution towards the fish community, closely followed by dab, except during the second year of construction when whiting, present in all years except pre-construction, showed a larger percentage contribution. The lesser weever showed a large amount of variability between periods, accounting for the third highest contribution to the fish assemblage of the baseline and construction year one periods (despite declining), before losing its significance to the community in construction year two. During operational year one however, the lesser weever was again a strong contributor to the community, making up over 16% of the fish catch during that year.

As described before, differences in the construction activity between the two construction years existed, with very little activity at the site during construction year one, primarily trenching along the cable route. This was followed by construction year two when the majority of the turbines were installed, thus creating the largest amount of disturbance at the wind farm site. As the lesser weever lives buried in the sand with only its head and back uncovered, any disturbance within its habitat is likely to drive it away. As the area of disturbance during construction would not have been limited to within the wind farm site boundary, but would have extended further out along the tidal ellipse, it is possible that the changes in catch reported here are due to the relocation of individuals outside of the survey area during construction year two and which are now returning to within the sampling area. However, cause and effect relationships in the marine environment are rarely that simple and any changes observed are often the result of a number of interacting factors, e.g. climatic changes, increase in competing species, predator prey relationships, disturbance, cyclical changes in abundance etc.

For the most abundant fish species (plaice, dab and whiting), catches were always greatest during the baseline period, however after this, the patterns of abundance changed:

- Whiting showed greatly reduced catches only during construction year one;
- Plaice catch was low but comparable in all years except the baseline; and
- Dab showed a consistent decrease through time from baseline to operational year one.

Seasonal changes in abundance were also apparent, with both whiting and dab abundant in autumn, and plaice most abundant during the winter surveys. This seasonal variation is likely a response to the migration of brown shrimp into the outer Solway during the autumn and winter months.

In the epibenthos, the brown shrimp was the greatest contributor to the community assemblage in all years, often closely followed by the hermit crab. Other species which contributed to the epibenthic community include the shore crab, the harbour crab, the pink shrimp, and the brittle star.

In addition to the changes in community described using the SIMPER analysis, changes in other species across the surveys were also evident. Of these, the declines of the common goby and sole from the baseline period are likely the result of misidentification, and were correctly identified as sand goby and solenette in subsequent construction periods. As such, changes in the abundances of these species since the baseline period should be treated with caution and have not been included in any of the statistical analysis discussed below.

Of the top ten species caught throughout all construction periods; pogge and plaice showed the largest overall percentage decline, although this was only statistically significant for plaice. The greatest decline in plaice abundance occurred between the baseline survey and the second year of construction, although at the same time the scald fish, another demersal species, showed statistically significant increases in abundance.

In addition to the most abundant species, changes in the commercially important fish species also needs to be determined and, aside from plaice, cod showed the largest decline between the baseline surveys and operational year one, although this was not statistically significant. Other species to see declines in abundance across the survey period were the flounder and the seasnail, although the only statistically significant declines were seen in flounder between the baseline and operational period one. The shore rockling, sea stickleback), turbot and lumpsucker also showed declines in abundance, although these species were only recorded once or twice during the baseline surveys and can be regarded as rare or unusual species. As such no conclusions can be drawn at this stage regarding population changes in these species as catch frequency was too low to allow any statistical analysis.

Variations in Size Frequency

The vast majority of commercially important species captured were undersized juvenile dab, plaice and whiting. In order to describe patterns in the population structure of individual species, size frequency data was examined for the three most abundant species.

In general, the dominant size classes did not differ between construction periods or season for the three species, although abundances did vary considerably. Significant differences were only found between seasons for whiting, and between construction periods for plaice. In terms of size, the flat fish species both showed peaks in size frequency at 41-90 mm, with whiting considerably larger at 80-120 mm.

Commercial Fish Landings Data

A question often asked of the Robin Rigg fish survey data is: Can commercial fishing data be used in order to give context to the survey data, such as that used for brown shrimp?

Catch, or landings data, is a potential source of information against which we can compare survey data in order to provide more regional context

For fish catches there are several factors which restrict the use of this data. Fish landings data is heavily influenced by external drivers such as quotas and market forces which can bias the results and make the data unsuitable for comparison. Landings data may in fact bear no relation to the numbers caught by the fishermen as the lack of a market for a given species in the area may mean that there is a high amount of discard and subsequent low level of landings. Landings of species controlled with quota (such as cod, whiting, plaice etc) are affected by further controls, and so as well as market forces dictating what is targeted by the fishermen, the quotas can dictate what proportion of the catch is actually landed. Comparison between landings data from Whitehaven and over the entire Irish Sea in relation to Robin Rigg survey data are displayed in Figure 9.2 and Figure 9.3. Inconsistencies between this data and our survey catch data are evident, for example, gurnard catches increased over time during our surveys, however at the Irish Sea level, landings are declining (see Figure 9.2).

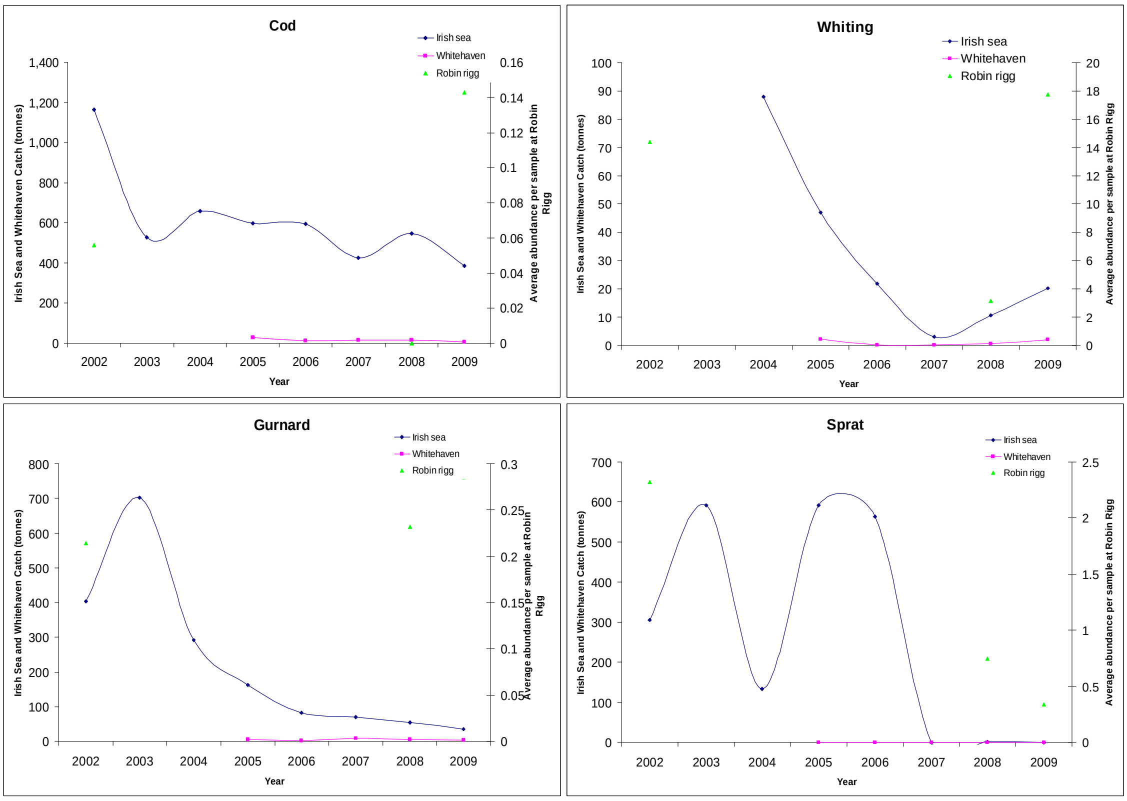

Figure 9.2: Landings data for Whitehaven and the Irish Sea compared to Robin Rigg Catch Data for cod, whiting, gurnard, and sprat

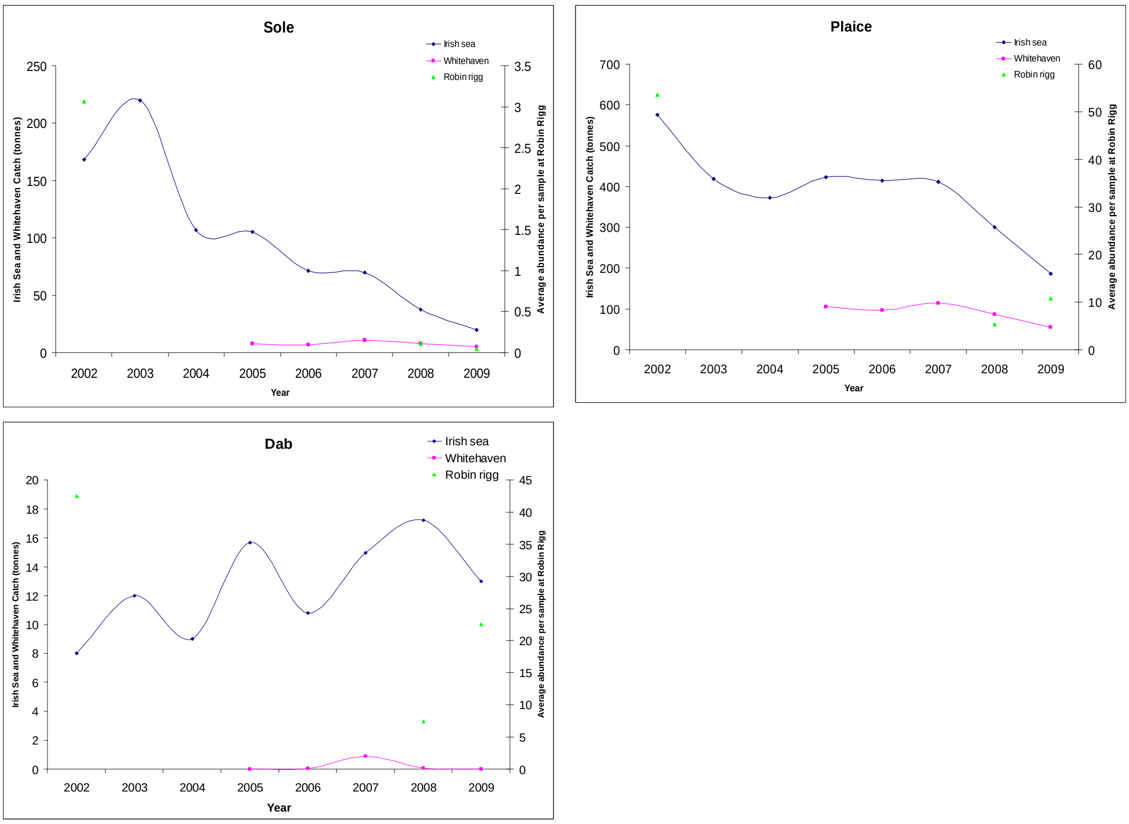

Figure 9.3: Landings data for Whitehaven and the Irish Sea compared to Robin Rigg Catch Data for sole, plaice and dab.

Another factor to consider when comparing against fish landings data, is the fact that the majority of fish species of commercial importance captured in the Robin rig surveys are juveniles, where as commercial landing figures are based on catches of adults. The area of the Solway Firth where Robin Rigg is located is a nursery area for many species of fish. Any juveniles caught within the surveys are likely to take at least 2-3 years to reach a size where they would be targeted by commercial fishermen. As such, we would expect to see a time lag of 2-3 years between any change in a species' abundance in the Robin Rigg survey trawls, and that change manifesting itself in the landing statistics for the area. However, it is not simply a case of looking for a time lag in catches, as the high levels of mortality exhibited in the juvenile stages means that external pressures (predation, food availability, etc) also play a huge role in the recruitment of adult individuals into a commercial fish stock.

As a result of all this uncertainty, commercial fish landings data cannot be used to support the catches data recorded during the Robin Rigg survey trawls. This differs to the situation with brown shrimp which are caught as adults during our surveys and, as a targeted non quota species, have commercial landings which are not subject to as many external controls.

CSEMP Station

As part of the Clean Sea's Environment Monitoring Programme (CSEMP), formerly the National Marine Monitoring Programme (NMMP) SEPA undertake regular monitoring of a sampling station of Kirkcudbright relatively close to the Robin Rigg site. Although sampling trawls are undertaken at this site no quantitative fish catch data is collected (i.e. total catches of each species are not recorded), with data being limited to the level of contaminants in the liver of plaice. Therefore there is no data from this sampling station which can used to compare with the trawl data collected at Robin Rigg.

9.2.2. Electro-sensitive Fish

Although many species of fish and invertebrate have showed evidence of sensitivity to electromagnetic fields, based upon current guidance only the most sensitive species, i.e. elasmobranchs, have been considered in terms of community changes as a result of the wind farm installation.

In total, only three types of elasmobranch were caught during the surveys: thornback ray, blond ray, and lesser-spotted dogfish, caught during both the non-migratory fish and electro-sensitive fish (cable route only) trawls. There were no significant differences found between total elasmobranch catches across the construction periods. However this result needs to be treated with caution as overall numbers of elasmobranch caught in total were low.

From the data it appears that the elasmobranchs caught during the non-migratory surveys do not differ by much between periods and seem to generally follow the trend observed by the other fish. During operational year one, however, there appears to be a larger number of elasmobranch caught along the cable route and over the site as a whole. However, after a single operational year it is difficult to establish any causal relationship between EMF production of the cable and the distribution of elasmobranch species.

9.2.3. Evaluation of ES Predictions

The ES predicted that there would be no significant impacts on fish populations as a result of noise and vibration or sedimentation during the construction of the wind farm. During the operational stage of the wind farm, the ES predicted that noise and vibrations impacts would be low to negligible with no significant impacts and no additional significant impacts would occur from any change in water quality. The ES also predicted a potential increase in fish population size due to the turbines becoming a 'Fish Attraction Device (FAD)'.

The general trend observed throughout the surveys is a decrease in fish and epibenthic populations from the baseline to the pre-construction, but then a general increase in fish and epibenthic abundance from the pre-construction period through to operational year one.

This pattern should be treated with some caution as a result of inconsistencies in sampling regime between baseline and MEMP surveys. In general, there was a decline in certain demersal dwelling fish species during the second year of construction but this appears to be a temporary impact and was not observed across all species. For example, catches of the scald fish (another demersal species), showed great increases in abundance during construction year two, indicating that any changes seen during this period are not likely to be the sole result of any disturbance caused by construction. Indeed, it was predicted during the EIA that the impacts of noise and vibration would be negligible towards flatfish due to the lack of swim bladder, and when abundances across construction periods are examined, it appears that aside from the large declines between the baseline and pre-construction surveys in plaice and dab, there have been little if any reductions in flatfish numbers, with no overall correlation between flatfish abundance and construction activity (see Figure 9.4).

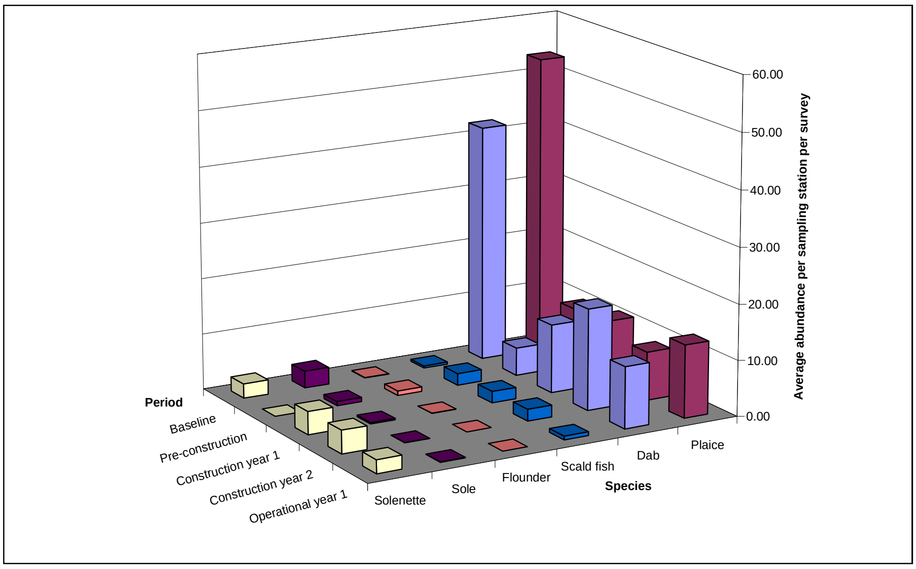

Figure 9.4: Average abundance of flatfish species per sampling station per survey during the different phases of the development.

In summary, the data collected since the baseline appears to support the ES predictions, however it is too early in the operational phase to tell whether any short-term impacts caused by the construction of the wind farm have been fully remediated. Also, it is too early to tell whether the operation of the wind farm is causing any impacts upon the fish and epibenthic communities.

9.3. Birds

Due to the foresight of those involved in the development of the MEMP for the Robin Rigg Offshore Wind Farm, baseline ornithological data collected during the course of this development allow sophisticated analysis and detailed investigation of the potential impacts of this site on the marine environment. Analysis of this type of data is at the cutting edge of current statistical practise (i.e. Lapena *et al*., 2010; 2011; Petersen *et al*., 2011) and as such NPC and E.ON have aimed to build on and refine our analytical technique throughout the course of the MEMP analysis, seeking external support from CREEM. NPC has listed caveats and accepted uncertainty wherever present, and have considered these with due caution when interpreting results and drawing conclusions from the data in order to ensure the reliability of the findings that we present.

The first-stage construction analysis used Generalised Linear Models (GLMs) as they allow the construction of complex models using data with a Poisson error distribution, as would expect to find with count data. Although these models allow the inclusion of environmental variables, they do not allow the modelling of relationships that are not linear, as is often the case in ecological systems. As a result, analysis methods were improved and developed by NPC before incorporating the operational year one data.

Distance sampling methods were employed during the collection of data for birds on the sea. This involves grouping observations into distance bands relative to the survey vessel, making it possible to incorporate a detection function into the analysis. An estimation of the total number of birds seen within the covered region of the survey (i.e. 300 m either side of the transect line) area is produced which can then be extrapolated to the entire survey area.

The detection function was then incorporated into Generalised Additive Models (GAMs). These were used in preference to the GLMs used for the previous report as they allow for more complex relationships between response variables and covariates. A quasi-poisson error structure was used instead of the poisson distribution used previously, as a quasi-poisson error structure can correct for deviations from the assumption that the variance is equal to the mean. Outputs from these models were then used to produce density plots for each development phase, allowing usage of the site by each species to be visualised.

A number of caveats need to be taken into account when interpreting the results presented here:

- Distance sampling assumes all animals on the line taken by the survey vessel are observed (referred to as g (0) = 1). However, no data are available to demonstrate whether this was the case. In some situations, the greater number of observations in band two suggests that this assumption was violated. In these cases, observations from bands one and two were combined for detection function fitting.
- X and Y positions were used as covariates as a proxy for unmeasured determinants of distribution. This has low predictive power for un-surveyed areas and the fit of the surface is likely to be less refined than if more predictive covariates were used.
- Calculation of significance by converting to a z-score assumes a normal distribution of the predictions for each grid square.
- Spatial and temporal autocorrelation are not accounted for within the present modelling framework and is likely to result in overly precautionary results. One option would be to use Generalised Estimating Equations (GEE) but at the time of this analysis, there was not an "off the shelf" method of conducting this analysis within R. It may be possible to develop this approach for later phases of the operational analysis.
- Zero inflation of the data is not accounted for within this modelling framework. This will be tested for in the next stage of the analysis, with changing the distribution family to negative binomial being one possible option, should it be an issue.

There are two potential types of impact arising from offshore wind farm, displacement and collision risk. Detailed analysis of collision risk was not possible within this report due to “snap shots” not being incorporated into the data collection methods. It may be possible to perform collision risk analysis using only those birds recorded with 100 m of the vessel but more data will be required (i.e. operation year two) before this will be possible and even then, it may not be possible for all species.

In addition, the next detailed step is to improve the analysis of the data; it may be appropriate to create/separate out the turbine area from the remaining survey area to allow responses to the turbines to be identified. The density plots have allowed analysis of potential displacement effects.

A summary of the main conclusions for each species can be found in Table 9.2 below.

Table 9.2: Summary of predictions made in the ES and main conclusions from present analysis.

Ecological Group: Birds	Predictions from ES	Main conclusions from construction analysis	Main conclusions from operational year 1 analysis
Common scoter	• 70660 individuals recorded, 11.69 per unit sample effort. • Some displacement expected (up to 800 m from wind farm area). • For impacts to influence the national population common scoter would need to be displaced from an area greater than 3 km. • Collision impacts were predicted to be low (3.4 birds per annum).	• 87910 individuals recorded, 7.05 per unit sample effort. • Some evidence for a decrease in birds across the whole survey area but potentially due to other environmental factors e.g. benthic prey. • Density maps support a shift in focus of core areas for common scoter along the northern coastline in inshore areas. • Evidence suggests that Robin Rigg has not affected common scoter distribution in the Solway from this baseline information to construction.	• 19547 individuals recorded, 6.39 per unit sample effort. • No indication of an impact from the development on numbers observed on the sea within study area (pre vs. post). • Some evidence for a decrease in number of flying birds (pre vs. post) but more data required to confirm.
Red-throated diver	• 550 individual red-throated divers recorded, 0.09 per unit sample effort. All divers: 1046/0.17. • Some displacement expected (up to 800 m from wind farm area). • For impacts to influence the national population red-throated diver would need to be displaced from an area greater than 5km. • Collision impacts for	• 562 individual red-throated divers recorded, 0.05 per unit sample effort. All divers: 2182/0.17. • Across the survey area, more divers (all species) were observed in flight during the construction phase than pre-construction. • Evidence for a shift away from the wind farm area during construction.	• 506 individual red-throated divers recorded, 0.17 per unit sample effort. All divers: 794/0.26. • No overall decrease in numbers (pre vs. post) but some evidence of a decrease in numbers within the wind farm site. • Distribution maps highlight the importance of shallow coastal waters for this species. • Wind farm area was not

Ecological Group: Birds	Predictions from ES	Main conclusions from construction analysis	Main conclusions from operational year 1 analysis
	red-throated diver were predicted to be low (3.3 birds per annum). •		used much prior to construction resulting in any impacts being small or potentially ecologically insignificant.
Manx shearwater	• 1566 individuals recorded, 0.26 per unit sample effort. • ES survey work only recorded Manx shearwater in the Spring-Summer months (breeding season) with peak counts between April and August.	• 1672 individuals recorded, 0.13 per unit sample effort. • Distribution in the Solway is similar between baseline/pre-construction and during construction periods. • Observed patterns of Manx shearwater are skewed by the detection of significant aggregations in the baseline/ pre-construction and construction period. Count anomalies of 100, 1000, birds recorded against a background of lower counts (1-5 birds) across the survey area. • Therefore some limited evidence for displacement during the construction period but difficult to be definitive due to inconsistent records.	• 160 individuals recorded, 0.05 per unit sample effort. • Simple GLM found no difference in numbers on the water (pre vs. post) but a reduction in numbers in flight. • Insufficient data to conduct full pre/post analysis.
Gannet	• 476 individuals recorded, 0.08 per unit sample effort. • Predominantly recorded during the Spring-Summer (breeding season) with peak counts between April and October. • Observations evenly distributed across the survey area.	• 845 individuals recorded, 0.07 per unit sample effort. • Evidence for a decrease of gannet in flight during the construction phase (19% decrease in raw observations). • Evidence for a decrease of gannet on sea during the construction phase (24% decrease in raw observations). • Clear spatial evidence from the small scale and large scale for displacement effects of gannet is hard to determine statistically	• 132 individuals recorded, 0.04 per unit sample effort. • Simple GLM found decrease in numbers on the sea (pre vs. post) but not for birds in flight. • Improved analytical techniques suggest decline with wind farm site during construction. • Raw data for operation year 1 suggest a displacement rate of 50% but more data required to complete the analysis. •

Ecological Group: Birds	Predictions from ES	Main conclusions from construction analysis	Main conclusions from operational year 1 analysis
		from these data.	
Cormorant	• 454 individuals recorded, 0.08 per unit sample effort. • Highest numbers of cormorants recorded during the Spring-Summer with a focus in distribution in the north-west of the Solway close to the Scottish coast off Balcary Point. • The Solway cormorant population was identified as medium sensitivity in the ES but with no significant impacts predicted.	• 3266 individuals recorded, 0.26 per unit sample effort. • Raw count data for cormorant clearly indicates a shift in peak numbers associated with the presence of Robin Rigg OWF, in the centre of the Solway. • Cormorant observations increased approximately three-fold both in flight and on the sea in proximity to Robin Rigg. • Density maps clearly show a shift in peak cormorant observations in and around Robin Rigg; this is supported by E.ON construction and operation staff.	• 1225 individuals recorded, 0.40 per unit sample effort. • Simple GLM found increase in numbers in flight pre vs. construction. • Also found increase in pre vs. post for both birds on the water and in flight. • Possible shift in distribution from northern to southern side of the Solway Firth but more data required to confirm. No evidence that this shift is related to development. • Increased number of cormorants within wind farm area during operation year 1 although not as pronounced as for construction phase.
Kittiwake	• 922 individuals recorded, 0.15 per unit sample effort. • Highest numbers recorded in spring and summer (breeding season).	• 1794 individuals recorded, 0.14 per unit sample effort. • Basic analysis of numbers observed both in flight and on the sea would indicate a decrease in kittiwake numbers during the construction phase across the whole study area. • However this is difficult to link to the Robin Rigg OWF from the more complex analysis (including environmental variables), specific and clear evidence for displacement both in flight and on the sea is hard to identify.	• 286 individuals recorded, 0.09 per unit sample effort. • Evidence of a decrease in numbers during construction and some evidence of an increase during operation, more data required to confirm. • No clear evidence for changes in distribution relative to the wind farm area but again, more data required to confirm.
All gulls combined	• 5076 individual large gulls recorded, 0.84	• 17503 individual large gulls recorded, 1.40 per	• 3949 individual large gulls recorded, 1.29 per

Ecological Group: Birds	Predictions from ES	Main conclusions from construction analysis	Main conclusions from operational year 1 analysis
	per unit sample effort. Herring gull: 1294/0.21; Great black-backed gull: 207/0.03.	unit sample effort. Herring gull: 1837/0.15; Great black-backed gull: 587/0.05.	unit sample effort. Herring gull: 255/0.08; Great black-backed gull: 224/0.07. • Simple GLM found increase in numbers pre vs. post both on the sea and in flight. • Analysis of single species suggested this was primarily due to increase in greater black-backed gulls. • Density surface model suggests no difference in gull presence pre vs. post of the entire study area.
Guillemot	• 4157 individuals recorded, 0.69 per unit sample effort. • The focus of guillemot numbers was observed in the relatively deeper waters of the outer Solway, in the south-west of the study area. • Numbers were highest in spring-summer but with an increase in numbers also observed in the autumn, with low numbers in August.	• 5840 individuals recorded, 0.47 per unit sample effort. • Evidence for a decrease in guillemot numbers in flight (5% decreases in raw observations). • Evidence for a decrease on the sea during construction (32% decreases in raw observations) supported further when other environmental variables are taken into account. • The data support partial displacement of guillemot away from the wind farm area during construction.	• 1736 individuals recorded, 0.57 per unit sample effort. • Decrease in numbers pre vs. construction. • Increase in numbers construction vs. operation. • Some evidence guillemots may be avoiding wind farm area but more data required to confirm.
Razorbill	• 2199 individuals recorded, 0.36 per unit sample effort. • Less abundant than guillemot. • Distribution more even than that for guillemot.	• 2956 individuals recorded, 0.24 per unit sample effort.	• 608 individuals recorded, 0.20 per unit sample effort. • Decrease in numbers pre vs. construction. • Increase in numbers construction vs. operation. • No evidence of avoiding wind farm site post-construction.
Auk species	• 6095 individuals recorded, 1.01 per unit sample effort.	• 10721 individuals recorded, 0.86 per unit sample effort.	• 3106 individuals recorded, 1.02 per unit sample effort.

Ecological Group: Birds	Predictions from ES	Main conclusions from construction analysis	Main conclusions from operational year 1 analysis
		•	• Density estimates suggest displacement rate of 30%. • Decrease in numbers pre vs. construction. • Increase in numbers construction vs. operation.

The only species analysed for which an increase in abundance was found post construction was the cormorant and large gull. As discussed in the previous report, the evidence suggests a shift in cormorant distribution toward the turbine area during the construction period although the increase within the turbine area was not significant. New analysis suggests this increase has continued into the operational phase of the development although the greatest shift appears to have occurred between the northern and southern shores of the Firth, completely unrelated to the presence of turbines.

These results are not unexpected. A high increase in common and herring gull has been reported for the Bligh wind farm in Belgium (Vanermen *et al*., 2010), suggesting such species are attracted to offshore wind farms. Radar work conducted at Nysted and Horns Rev (Denmark) concluded that cormorants and gulls did not show avoidance of wind farms.

Avoidance of wind farms by divers has been reported for Nysted and Horns Rev (Petersen *et al*., 2006), but the data discussed here suggests that the turbine area was not important for these species prior to the construction of Robin Rigg, therefore any declines found post construction are not ecologically significant.

Avoidance by gannets has been reported for the Bligh wind farm, Belgium (Vanermen *et al*., 2010). The raw data presented here suggests a reduction in abundance within the study area during operational year one but so few gannets were recorded during operation year one that a complete analysis was not possible at this stage. There is presently no evidence to indicate whether this apparent decline is due to the presence of the wind farm or an indication of a general reduction in abundance in the area. Quantitative data covering the period under discussion is difficult to find. Nationally, gannets have shown an upward trend in population size, increasing by 18% between 2000 and 2008 (JNCC, 2008). Colony counts from the colony closest to the development, Scar Rocks, Wigtown (SMP, 2012), suggest the colony was at stable prior to construction (see Figure 9.5). Further data collection may help clarify whether this apparent reduction is long-term or temporary.

A decrease in auks during construction was reported in the previous report. This was confirmed by the new analysis but there is also evidence of numbers returning during operation year one. There is also some evidence that they are avoiding the turbine area, as has been reported for other wind farm sites (Blew *et al*., 2008; Pettersson, 2005), but more data is required to confirm this.

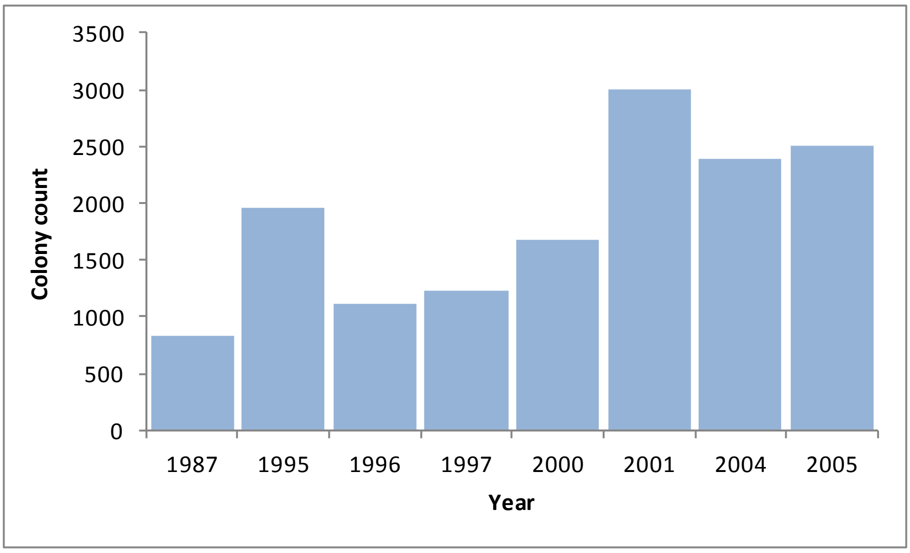

Figure 9.5: Colony counts based on number of occupied nests, from the Big Scar gannet colony, Wigtown. Reproduced from the Seabird Monitoring Programme database (http://jncc.defra.gov.uk/smp).

9.4. Marine Mammals

The number of grey seals recorded as part of the boat-based surveys is low, preventing the level/sophistication of analysis used for other species being carried out. Generalised additive models do, however, suggest there has been no variation in abundance through the three development phases.

It may be more informative to try to identify other sources of information for this species, in particular counts from local haul-out sites. The Special Committee On Seals (SCOS) conduct regular counts of major haul-out sites through the country to inform and comply with the Conservation of Seals Act 1970 and the Marine (Scotland) Act 2010. Smaller sites are also surveys but less frequently. There is presently a consultation underway by the Scottish Government to identify new haul-out sites for protection under the Marine (Scotland) Act. Two sites have been proposed within the Solway Firth:

- Little Scares in Luce Bay, between the Mull of Galloway and Burrow Head;
- Solway Firth outer sandbanks between Southerness Point and Dubmill Point;

Suggesting there may be additional data available for analysis.

The data for harbour porpoise is also limiting although further analysis was possible. Generalised Additive Models again suggest there is no difference in presence between the three development phases.

The density plots suggest avoidance of the turbine area during the construction period although the limited pre-construction data reduces confidence in the baseline.

As with the grey seals, it may be informative to try and source additional data collected prior to the construction of the wind farm. For example, it is reported in the ES that the Solway Shark Watch and Sea Mammal group recorded 81 harbour porpoise between August 2000 and 2001. Another possible source of data could include the Sea Watch Foundation.

Data from operational year one suggest that harbour porpoise are again using the area where the wind farm is located but it is recommended that operational year two data is analysed before drawing any definitive conclusions.

10. CONCLUSIONS

10.1. Fish and benthos

- Predictions made in the environmental statement relating to the potential impacts of the construction and operations of the Robin Rigg Offshore Wind Farm were supported by the data collected. There is no evidence, to date, that the construction and operation of the Robin Rigg Offshore Wind Farm has had any significant or permanent impact upon the fish and benthic fauna in the immediate or surrounding area.
- The predominant biotope in the area, *Nephtys cirrosa and Bathyporeia spp. in infralittoral sand* (SS.SSa.IFiSa.NcirBat), is characteristic of naturally high energy environments, and has been the predominant biotope since the baseline survey. Over the construction years there appears to have been spatial shift in biotopes, with *Abra prismatica, Bathyporeia elegans and polychaetes in circalittoral fine sand* (SS.SSa.CFiSa.ApriBatPo) biotope emerging, with a return to SS.SSa.IFiSa.NcirBat during the operational year.
- Fish and, to an extent, epibenthic abundances, did vary across the construction periods, with the largest abundance caught during the baseline survey. This, however, is thought to be due to the shifting of channels so that the trawls are no longer in the channel but on top of the sand bank where there is naturally less fish and epibenthos. The fish and epibenthic community assemblage, however, did not show any considerable change throughout the construction periods compared to the baseline.
- Temporal changes in community structure and biodiversity point to the need for continued monitoring with regards to the electro-sensitive fish. It is also recommended that additional grab sites are added to the north-west and south-west of the wind farm.

10.2. Birds and marine mammals

- Little indication of a significant effect on common scoter and red-throated diver, as predicted by ES.
- Increase in cormorant and large gull species during construction phase and into operation year one.
- Indication from operational year one of partial avoidance of wind farm site by auks (displacement rates of circa 30% for auk species [guillemot and razorbill]).
- Unable to model birds in flight due to no snapshot data available.
- No evidence in a decline in harbour porpoise abundance between the three development phases, but some evidence for avoidance of wind farm during construction period.
- Too little data available to analyse a number of species, currently including fulmar, Manx shearwater, scaup, tern species and grey seal.

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12. APPENDIX

12.1. Total abundance of benthic infauna 2001 – 2011.

Species	Total numbers caught
Bathyporeia elegans	1048
Nephtys cirrosa	507
Scalibregma inflatum	258
Tellina fabula	166
Mysella bidentata	159
Magelona johnstoni	144
Pseudocuma longicornis	144
Scolelepis mesnili	110
Pomatoceros lamarcki	76
Bathyporeia nana	72
Nucula nitidosa	69
Abra alba	63
Gastrosaccus spinifer	61
Echinocardium cordatum	49
Donax vittatus	34
Nemertea	29
Bathyporeia sarsi	28
Ophelia borealis	28
Glycera tridactyla	24
Nephtys hombergii	24
Pomatoceros sp.	23
Mactra stultorum	22
Pontocrates altamarinus	21
Tellimya ferruginosa	21
Eteone flava/longa	20
Spio decorata	20
Spio martinensis	16
Sigalion mathildae	14
Perioculodes longimanus	13
Lagis koreni	12
Nephtys (juv.)	11
Pariambus typicus	10
Pontocrates arenarius	10
Nephtys assimilis	9
Pholoe inornata	9
Pholoe minuta	9
Spiophanes bombyx	9
Schistomysis spiritus	8
Scoloplos armiger	8
Urothoe brevicornis	8
Mytilus edulis	7
Polycirrus	7
Tanaopsis graciloides	7
Microphthalmus similis	6
Pharus legumen	6
Bathyporeia indet.	5
Paraonis fulgens	5
Photis longicaudata	5
Sthenelais boa	5
Urothoe poseidonis	5
Chrysallida decussata	4

Species	Total numbers caught
Phoronis sp.	4
Podarkeopsis capensis	4
Sthenelais limicola	4
Cephalothricidae indet.	3
Cerianthus lloydii	3
Eumida sanguinea	3
Haustorius arenarius	3
Hydrobia ulvae	3
Liocarcinus marmoreus	3
Mediomastus fragilis	3
Ophiura albida	3
Owenia fusiformis	3
Polydora caeca (agg.)	3
Spio armata	3
Actiniaria sp.	2
Ammodytes tobianus	2
Ampelisca spinipes	2
Conopeum reticulatum	2
Decapoda larva	2
Dyopedos monacanthus	2
Eusyllis blomstrandi	2
Magelona mirabilis	2
Mya truncata	2
Nephtys kersivalensis	2
Abra nitida	1
Alcyonium digitatum	1
Ampharete lindstroemi	1
Angulus tenuis	1
Asterias rubens	1
Cliona sp.	1
Crangon crangon	1
Echinocardium flavescens	1
Escharella immersa	1
Eteone foliosa	1
Eteone picta	1
Eulalia ornata	1
Exogone hebes	1
Golfingia elongata	1
Heteroclymene robusta	1
Hirudinea	1
Hydrozoa	1
Lagotia viridis	1
Malmgrenia arenicolae (agg.)	1
Ophiothrix fragilis	1
Phialella quadrata	1
Pholoe synophthalmica	1
Pisces juv.	1
Pisidia longicornis	1
Polinices pulchellus	1
Pomatoceros triqueter	1
Pomatoschistus	1
Sabellaria spinulosa	1
Schistomysis kervillei	1
Solen marginatus	1
Spisula	1

Species	Total numbers caught
Syllidia armata	1
Tritonia (juv.)	1
Verruca stroemia	1
Total abundance	3,527
Total no. of species	109

12.2. Fish species captured in trawl surveys 2001-2011.

Common Name	Scientific Name	Total catch
Plaice	*Pleuronectus platessa*	*21,935*
Dab	*Limanda limanda*	*19,621*
Whiting	*Merlangius merlangus*	*12,392*
Lesser weever	*Echiichthys vipera*	*4,704*
Sprat	*Sprattus sprattus*	*2,534*
Solenette	*Buglossidium luteum*	*2,488*
Pogge	*Agonus cataphractus*	*2,136*
Sand goby	*Pomatoschistus minitus*	*1,465*
Sole	*Solea solea*	*1,024*
Scald fish	*Arnoglossus laterna*	*926*
Pipefish	*Syngnathus acus*	*248*
Bib	*Trisopterus luscus*	*156*
Dragonet	*Callionymus lyra*	*150*
Red gurnard	*Aspitriglia cuculus*	*137*
Grey gurnard	*Eutrigla gurnardus*	*132*
Lesser spotted dogfish	*Scyliorhinus caniculus*	*76*
Seasnail	*Liparis liparis*	*76*
Thornback ray	*Raja clavata*	*69*
Five barbed rockling	*Gaidropsarus vulgaris*	*45*
Flounder	*Platichthys flesus*	*40*
Cod	*Gadus morhua*	*34*
Tub gurnard	*Trigla lucerna*	*32*
Brill	*Scophthalmus rhombus*	*31*
Sand eel	*Hyperoplus lanceolatus*	*21*
Bull rout	*Myoxocephalus scorpius*	*20*
Transparent goby	*Aphia minuta*	*13*
Buttterfish	*Pholis gunnellus*	*9*
Long-spined sea scorpion	*Taurulus bubalis*	*8*
Turbot	*Scophthalmus maximus*	*5*
Common goby	*Pomatoschistus microps*	*4*
Three barbed rocking	*Gaidropsarus vulgaris*	*3*
Lemon sole	*Microstomous kitt*	*2*
Blonde ray	*Raja brachyura*	*2*
Tadpole fish	*Raniceps ranranis*	*2*
Shore rockling	*Gaidropsarus mediterraneus*	*1*
Sea stickleback	*Spinachiaspinachia*	*1*
Lumpsucker	*Cyclopterus lumpus*	*1*
Ling	*Molva molva*	*1*
Total		*70,545*

12.3. Bird species recorded during boat-based surveys 2001-2011.

	Flight			Flight Total	Sea			Sea Total	Grand Total
	Pre	During	Post Yr1		Pre	During	Post Yr1		
Arctic Skua	8	39	4	51	2	11		13	64
Arctic Tern		3		3		1		1	4
Auk species	143	222	147	512	116	428	151	695	1207
Bar-tailed Godwit		2		2					2
Black Guillemot		1		1	1	2		3	4
Black-headed Gull	124	328	60	512	19	81	27	127	639
Black-tailed Godwit		1		1					1
Black-throated Diver	3	1		4	3	5		5	5
Buzzard		1		1					1
Canada Goose		1		1					1
Carrion Crow		1		1					1
Collared Dove						1		1	1
Commic Tern	21	20		41	11	3		14	55
Common Gull	514	2131	451	3096	164	606	192	962	4058
Common Scoter	366	828	208	1402	373	1099	318	1790	3192
Common Tern	2	7	1	10		1		1	11
Cormorant	153	598	272	1023	142	398	133	673	1696
Cormorant/Shag	1			1	1			1	2
Curlew	2	3		5					5
Curlew/Whimbrel			1	1					1
Diver species	164	475	121	760	123	303	49	475	1235
Duck species			1	1					1
Dunlin	6	9		15		1		1	16
Eider		2		2		1		1	3
Feral Pigeon	1			1					1
Finch species	2	1		3					3
Fulmar	97	56	6	159	10	6	1	17	176
Gannet	235	431	51	717	77	152	16	245	962
Golden Plover	1		1	2					2
Goldeneye	1			1					1
Goosander			11	11		3	21	24	35
Goose species		1	3	4		1		1	5
Great Black-backed Gull	120	214	52	386	42	158	63	263	649
Great Crested Grebe	12	1	2	15	26	16	9	51	66
Great Northern Diver	6	8		14	5	14		19	33
Great Skua	3	4		7					7
Grey Goose			1	1					1
Grey Heron	1			1					1

Grey Plover		1		1					1
Grey Plover(?)	1			1					1
Greylag Goose			1	1					1
Guillemot	262	536	152	950	2196	3674	878	6748	7698
Gull species	40	315	27	382	6	81	11	98	480
Gull species(large)	23	74	28	125	5	18		23	148
Gull species(mixed)					1			1	1
Gull species(small)	1	70	7	78	3	36	15	54	132
Hen Harrier		1		1					1
Herring Gull	459	664	95	1218	65	147	25	237	1455
Herring/Lesser Black-backed Gull	5			5					5
Hirundine species		3		3					3
House Martin		1	1	2					2
Kestrel	1			1					1
Kittiwake	298	497	93	888	168	417	54	639	1527
Knot					1			1	1
Lapwing			1	1					1
Lesser Black-backed Gull	132	244	13	389	27	118	3	148	537
Little Auk		1		1					1
Little Gull	9	6	1	16	1	2		3	19
Little Tern	3			3					3
Long-tailed Duck		1		1					1
Mallard						1		1	1
Manx Shearwater	123	209	31	363	17	100	21	138	501
Meadow Pipit	16	74		90		1		1	91
Merlin	1			1					1
Mute Swan					1			1	1
Oystercatcher	9	8	1	18					18
Passerine species	7	19		26					26
Peregrine	1	1	2	4					4
Pied Wagtail	1	2		3					3
Pink-footed Goose		14	11	25		4	1	5	30
Pink-footed Goose(?)		1		1					1
Pipit species	12	3	8	23					23
Pomarine Skua	2	1		3					3
Puffin	1	6		7	2	1	1	4	11
Purple Sandpiper			1	1					1
Raptor (Buzzard?)			1	1					1
Razorbill	192	154	24	370	501	1089	224	1814	2184
Red-breasted Merganser	4	5	3	12	7	4	4	15	27
Redshank		1		1					1
Red-throated Diver	95	180	110	385	160	204	73	437	822
Ringed Plover	1	3		4					4

Sand Martin	8	6		14					14
Sanderling		1		1					1
Sandwich Tern	56	197	36	289	1	20	1	22	311
Scaup	9	1	3	13	5	4	5	14	27
Shelduck	2	4	1	7		2		2	9
Skua species		2	1	3		1		1	4
Skylark	3	1		4					4
Song Thrush/Redwing		1		1					1
Sparrow hawk	1	1		2					2
Species									1
Starling		1	1	2					2
Storm Petrel	16	13		29		2		2	31
Swallow	11	70	3	84					84
Swan species	1			1					1
Swift	2	5		7					7
Teal	1			1		1		1	2
Tern species	13	37	4	54		5		5	59
Turnstone	1	1		2					2
Velvet Scoter	1	1	1	3	5	2		7	10
Wader (large)		1		1					1
Wader (small)	5	7		12					12
Wader species	1	1		2		2		2	4
White/Pied Wagtail	2	2		4		1		1	5
Whooper Swan	1	1		2		1	3	4	6
Grand Total									30543

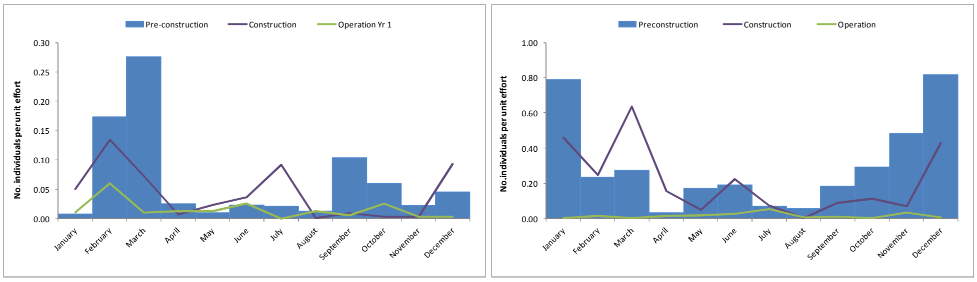
12.4. Supplementary analysis: large gulls.

Summary of available data for birds, expressed as total number recorded in each phase (Total) and the number of sightings per unit survey effort (SPUE). Effort is defined as the total number of segments surveyed for each phase.

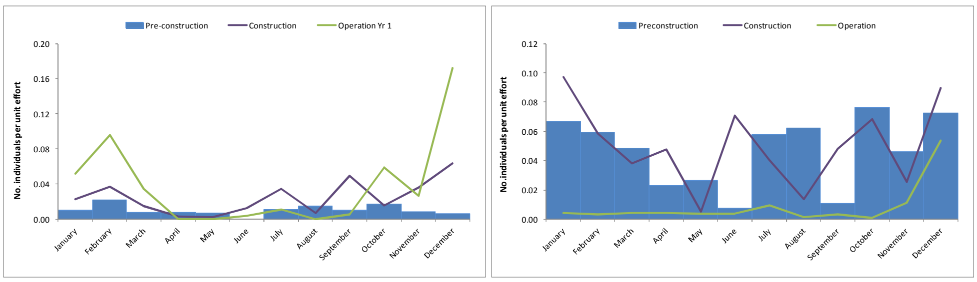
	Pre-construction		Construction		Operation year 1	
	Total	SPUE	Total	SPUE	Total	SPUE
Herring gull	1294	0.21	1837	0.15	255	0.08
Great black-backed gull	207	0.03	287	0.05	224	0.07
Large gulls	5076	0.84	17503	1.40	3949	1.29

Summary of the outputs from the simple GLMs in the form of p-values. Data is divided into birds on the water and birds in flight. A value of 0.05 or less was used to define significance.

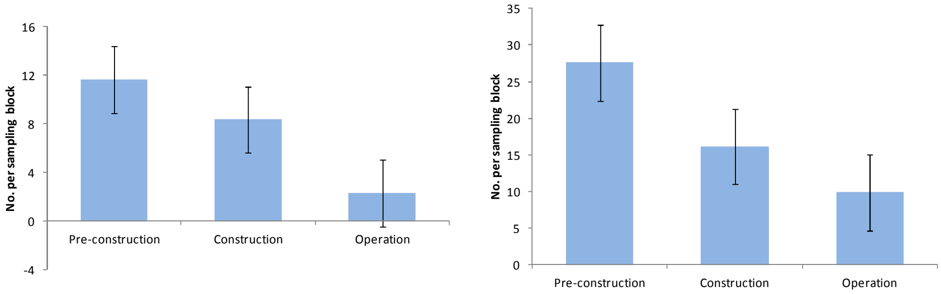
On Sea	Preconstruction to construction	Construction to operation	Preconstruction to operation
Herring gull	0.157	0.361	0.130
Greater black-backed gull	0.023	0.040	<0.001
Large gulls	0.251	0.168	0.043



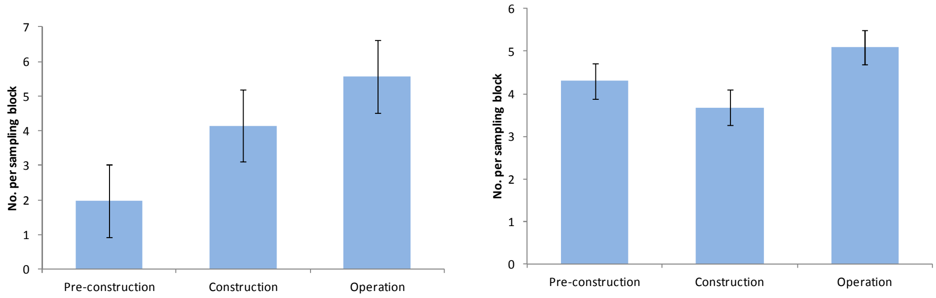
Mean number of herring gulls observed on the sea (left) and in flight (right) per month during the pre-construction, construction and operational phases



Mean number of great black-backed gulls observed on the sea (left) and in flight (right) per month during the pre-construction, construction and operational phases



Mean number of herring gull observed per sampling block on the sea (left) and in flight (right) during the pre-construction, construction and operational phases (±standard error)



Mean number of great black-backed gull observed per sampling block on the sea (left) and in flight (right) during the pre-construction, construction and operational phases (±standard error)