E.ON Climate & Renewables

Analysis of Marine Ecology Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 3)

Technical Report

Chapter 2: Non-migratory fish

Report: 1029455
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Issued: 18/09/2013

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Chapter 4: Non-migratory fish

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Classification COMMERCIAL IN CONFIDENCE

Distribution E.ON Climate & Renewables

Revision History

Issue	Date	Changes
A	28/08/2013	First Issue to E.ON
B	18/09/2013	Draft 1 released to RRMG for comments

2. NON-MIGRATORY FISH

2.1. Introduction

Non-migratory fish surveys have been undertaken in and around the Robin Rigg Offshore Wind Farm using an epibenthic beam trawl since 2001. In the context of this report non migratory fish are defined as demersal fish which live on or near to the sea floor. The non-migratory fish survey also collects information on other epibenthic organisms such as crustacea and other invertebrates.

The presence of wind turbines in sedimentary habitats creates hard bottom habitat that can promote important changes in associated communities (Airoldi *et al.,* 2008). It has been suggested that wind turbines can play the role of artificial reefs and support communities of fish and invertebrates not previously seen in high numbers at the site (Wilhelmsson *et al.,* 2006). To date no deleterious effects on fish or the benthos have been reported as a result of wind farm construction and operation (Walker, 2010). However, the ecological impacts of offshore wind farms remain poorly understood (Garthe & Huppop, 2004, Gill & Kimber, 2005, Petersen & Malm, 2006). It is therefore it is prudent that benthic sampling programs continue and data analysis is undertaken to determine the effects to benthic invertebrates and fish assemblages given the long operational life spans of offshore wind farms (Walker, 2010).

Previous monitoring reports have included the results of the electrosensitive fish survey which collected beam trawl data along the export cable route. In line with the MEMP the electrosensitive fish survey ceased after the second year of operation, therefore this report is limited to the results of the non-migratory fish survey. Information is, however presented on the occurrence of electrosensitive species captured as part of the non-migratory fish surveys.

2.1.1. Predicted Impacts from ES

Construction

According to the Robin Rigg ES, noise and vibration associated with wind farm construction were considered insignificant as a potential source of impact on fish species in the EIA. Impacts on commercially important flat fish (plaice and sole) were considered to be negligible as they do not have a swim bladder, and demersal species (e.g. whiting) can avoid areas of high disturbance for the short duration and small area associated with construction. As a result the EIA predicted:

- No significant impacts would occur to fish populations as a results noise and vibration.

Sedimentation associated with construction activity was not considered to be potentially damaging to fish in the area of the Robin Rigg Wind Farm. The area is naturally turbid with high levels of suspended sediments in the water column and species in the area will be adapted to these conditions. As result the EIA Predicted:

- No significant impacts would occur to fish populations as a result of sedimentation.

Impacts were considered to be of a low magnitude for both migratory and non-migratory fish.

Operation

Electromagnetic fields produced by electrical cabling both between turbines and from the wind farm to the shore, may affect fish species through the emittance of small electrical fields. These fields are particularly relevant to electrosensitive species that use electric and magnetic fields for locating prey and for navigation and positioning respectively. Electromagnetic fields also have the potential to disturb the Earth's natural magnetic field, which is used for navigation by many migratory species such as salmon. Although the electric fields produced by undersea cables are traditionally considered to be negligible it has subsequently been demonstrated that relatively small emissions can be detected by UK benthic elasmobranches. Therefore, there exists the potential for electrosensitive species to detect and respond to the electromagnetic fields produced by offshore power installations. The ES predicted that:

- Impacts on electrosensitive species are expected to be of Low magnitude and so this would be an impact of, at most, moderate significance - not significant in terms of the EIA regulations. Some uncertainty remains, however, on the precise reaction of individuals when encountering electrical fields, particularly with respect to thornback rays. Ongoing monitoring is therefore recommended of populations of electrosensitive species, either through dedicated surveys or through statistical analysis of fishery catches in the area over time.

With regards to magnetic fields the ES predicted that:

- No adverse effects on migration due to magnetic fields would occur.

Considering the fish species present in the general area of the proposed Robin Rigg Wind Farm, the gadoid fish such as whiting and cod are likely to be most sensitive to the noise generated by the operating turbines as they are considered to be 'hearing-specialists'. Of the other fish species present in the general area, the flatfish and elasmobranchs are only sensitive to underwater noise within the near-field. The impact of noise and vibration from the operating wind farm is likely to induce some startle responses in fish species with good hearing capabilities such as whiting and shad. This may be accompanied by some short-term avoidance reactions followed by general habituation to the continuous noise generated by the operating turbines. Therefore the ES predicted that:

- The presence of species of commercial importance, and species that are protected under National and International legislation, gives an overall 'high' sensitivity for fish species. However, the magnitude of noise and vibration impacts is considered to be 'negligible' to 'low' so any impacts would not be significant.

There is the possibility that fish may be attracted to the proposed wind farm, although the actual size of the total fish populations may not necessarily increase. It is much more likely that the congregations of fish around the proposed wind farm would represent a small redistribution of the existing populations in the area. The wind farm is also likely to become more attractive following colonisation of turbine surfaces by colonising organisms such as sponges, anemones and the common mussel *Mytilus edulis*. Therefore the ES predicted that:

- The overall magnitude of such an impact would therefore be low to negligible, although some reef-dwelling species found in rocky substrate areas of the Solway may colonise these new structures, thereby increasing population sizes.

Changes to water quality as a result of the wind farms presence and operation may arise due to localised minor increase in suspended sediment as a result of sediment scour around the turbines, abrasion of copper slip rings located within the turbine nacelle, loss of aluminium from corrosion protection anodes, and potential accidental release of oils, lubricants etc due to maintenance activities. The ES predicted that:

- Any water quality impacts on fish would be negligible and so no significant impacts would result.

2.1.2. Solway Epibenthic Populations

The Solway is an important spawning and nursery ground for many species of commercially important fish (Ridley *et al,,* 1979), and is also important for migratory fish, particularly sea trout and salmon as they pass through the estuary into the rivers Nith, Annan, Sark, Kirtle Water, Border Esk, Eden and Wampool (Anon, 2000).

A number of studies on fish populations in the Solway Firth have occurred over the past 30 years. From this it is possible to characterise fish communities as being dominated by juvenile flatfish such as plaice (*Pleuronectes platessa*), dab (*Limanda limanda*), sole (*Solea solea*), solenette (*Buglossidium luteum*), and roundfish such as whiting (*Merlangius merlangus*). Lesser weever fish (*Echiichthys vipera*), gobies (*Pomatoschistus* sp.), gurnards (*Eutrigla gurnardus*) and dragonets (*Callionymus lyra*) are also associated with this fish community (Lancaster & Frid, 2002). During the EIA an extensive beam trawl survey was carried out in the Solway Firth over 12 months (see section Table 2.1 for details), which revealed that the most common fish and epibenthic species of commercial and ecological importance to be brown shrimp (*Crangon crangon*), plaice (*Pleuronectes platessa*), dab (*Limanda limanda*), and whiting (*Merlangius merlangus*). Two electro-sensitive species thornback ray

(*Raja clavata*) and lesser spotted dogfish (*Scyliorhinus canicula*) were also captured during these surveys. The number of species increases towards the outer estuary as conditions become less extreme and sediment types become more varied.

The Solway Firth (from Mull of Galloway to St Bees Head) supports a diverse mixed fishery targeting a wide range of fish and shellfish species. There are currently around 90 commercial fishing boats based in Cumbria with a smaller number working out of Kirkcudbright, Annan and Isle of Whithorn on the Scottish Solway coast (Solway Firth Partnership, 2011). This does not include fishing boats that come from further afield including the Isle of Man, Ireland and larger ports such as Girvan and Fleetwood. Total landings in the Solway are estimated at £4-5 million a year, employing in the region of 1,500 people around the Solway. The fisheries sector is therefore considered to be a very important part of the rural economy for the communities of Dumfries and Galloway and Cumbria (Solway Firth Partnership, 2009). Species fished include plaice (*Pleuronectes platessa*), sole (*Solea solea*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*) and whiting (*Merlangius merlangus*).

Fishing in the Inner Solway, where the offshore wind farm is located is predominantly confined to shellfish species. A relatively large fishery exists for brown shrimp (*C. Crangon)* (Lancaster & Frid, 2002), in additional cockles and mussels are occasionally targeted (Lancaster, 2002).

2.1.3. Temporal variation in fish communities

Any assessment of change relating to specific anthropogenic activity in the marine environment (such as the installation and operation of an offshore wind farm) must be identified in the context of natural fluctuations in marine populations arising from either natural cyclical events or other anthropogenic impacts. Fluctuations in fish and epibenthic populations and species assemblages are a natural feature of marine ecosystems. Henderson and Bird (2010) for example, reported large variation in the abundance of invertebrate and fish assemblages. Spatial variation in the degree of fluctuation is also seen between coastal environments in the North Sea (Tulp *et al*., 2008). Brown shrimp (*Crangon crangon*) numbers are known to fluctuate considerably between years in the Solway Firth (Lancaster & Frid, 2002), and regional long term changes in abundance have recently been reported in the Dutch Wadden Sea following a 40 year study period (Tulp *et al*., 2012).

The fluctuations in fish and epibenthic populations and species assemblages derive from multiple drivers. For example, mean grain size, tidal currents and temperature are amongst other environmental variables that have all been reported as factors driving variation in fish and epibenthic communities (Genner *et al*, 2010; Ysebaert *et al*, 2003). Seasonal variations also are reported in invertebrate and fish assemblages in estuarine habitats (Henderson & Bird, 2010), with sequential immigration of different species at different times of the year can also drive varying abundance (Henderson & Bird, 2010). Henderson & Bird (2010) reported that different species can respond differently to different environmental variables, however, they were unable to determine a single driver of variations in assemblages.

As stated above fish diversity and abundance is strongly related to environmental factors and ecosystem-level changes that have taken place in marine coastal environments over the last century (Genner *et al*, 2010). Alongside wider environmental change, anthropogenic impacts such as fishing can affect fish abundance and community structures. Commercial fisheries target large individuals, often from slow-growing, late-maturing and long-lived species that produce few offspring (Genner *et al*., 2010), and subsequently have influenced the abundance, reproductive capacity and range of target species, with many species now being economically or biologically extinct (Genner *et al*., 2010). Ocean warming is resulting in shifts in the distribution of exploited species and is affecting the productivity of fish stocks and underlying marine ecosystems, with some studies indicating a loss in productivity of fish stocks, and others indicating the opening of new fishing opportunities (reviewed by Cheung *et al*, 2009).

2.2. Survey Methods

2.2.1. Survey History

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 (Figure 2.1). 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. 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.**

Trawl surveys along the cable route at eight sampling stations have also been undertaken primarily to monitor the presence of electro-sensitive fish (see previous monitoring report (NPC, 2012)). The pre-construction, construction and operational periods were surveyed up until Operation Year 2 (Table 2.1). **In accordance with the MEMP, no further electro-sensitive surveys were required after Operational Year 2.** The Operational Year 2 Technical Report reports the analysis and results of the electrosensitive surveys. No further analysis or reporting has been undertaken within this report.

Table 2.1. 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	NM
2002		NM	NM	NM	NM	NM	NM	NM	NM			
2003												
2004												
2005												
2006												
2007								ES			ES	
2008		NM	ES/NM	NM		ES	NM		ES		NM	
2009		ES/NM				NM		NM				NM
2010		NM		ES/NM			ES/NM			ES/NM		
2011			ES/NM									
2012	ES/NM				NM							
2013	NM											

EIA baseline surveys

- Solveno Marine Environmental Consultants were commissioned to undertake monthly trawl surveys at 31 sampling stations in and around the area of the proposed wind farm using the *FV Boy Tom*.
- As the location of the cable route had not been finalised at this stage, no surveys of this area were undertaken.

MEMP monitoring

- These surveys were conducted by Amec E&I UK Ltd using the fisheries patrol vessel Solway Protector.
- In accordance with MEMP requirements, fish surveys for non-migratory species were not undertaken during pre-construction.
- During the construction phase non-migratory fish surveys were originally performed monthly for the first three months, after which survey frequency reduced to quarterly.
- For the first year of Operation three surveys were conducted, but were dropped to biannual in operational year two on agreement with the RRMG.
- Non-migratory fish surveys were performed at the same 31 sampling stations surveyed during the baseline EIA process, however during construction year one three sampling stations within the wind farm itself could not be surveyed due to the presence of the turbines, hence a maximum of 28 sampling stations were surveyed.
- Electro-sensitive fish surveys were performed biannually during pre-construction, quarterly through construction year one and quarterly though operational year one. In other years the MEMP did not require electro sensitive fish surveys to take place.

2.2.2. Sampling Methodology

The survey methodology for all construction phase surveys was carried out in accordance with the MEMP requirements to follow the baseline methodology, whereby a 2 m beam trawl with approximately 50 cm steel shoes and fitted with an iron tickler chain was towed for 15 minutes at 31 sampling stations in and around the wind farm site (Figure 2.1). The mesh size of the main body of the net was 24 mm, with a 24 mm mesh cod-end. The gear used was considered to be most appropriate for the Inner Solway as it is similar to the shrimp beam trawl gear used by the shrimp vessels which fish this area. The tow duration reflected the high tidal flows in the Solway (whereby a 15 minute tow could cover over 1 km) and the prevalence of low mobility crustacea (particularly brown shrimps) and juvenile fish in the Inner Solway.

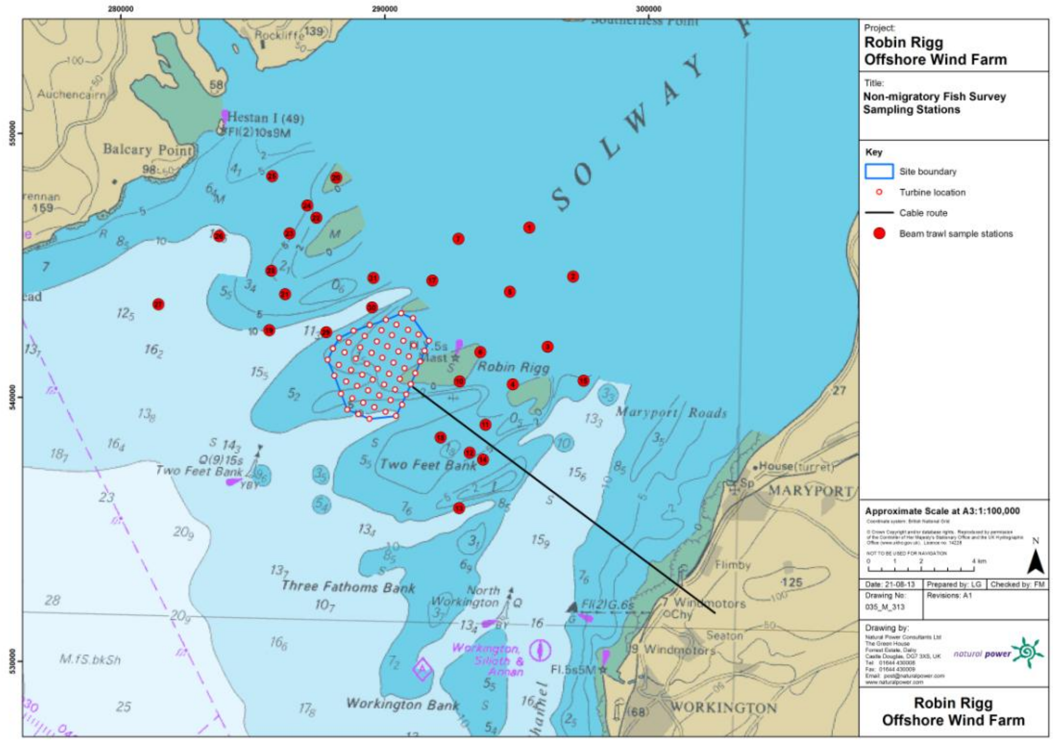

Figure 2.1. Non-migratory fish survey sampling stations.

Tow duration at each station was 15 minutes, on some occasions shorter tows were necessary due to obstructions or deteriorating weather conditions.

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. Prevailing weather conditions and sea state were also noted.

After each trawl, the number and size (total length[1]) of all large fish (including electro-sensitive elasmobranch species) were 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 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.

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

2.3. Analytical Methods

2.3.1. Treatment of dataset

Prior to statistical analysis all data was collated and standardised, species names were checked and any anomalies investigated and resolved. This raw data was used to provide total abundance by species in order to provide a preliminary description of the range of species captured during the surveys.

Prior to statistical analysis all non-benthic species not representatively sampled using the 2 m beam trawls were removed from the data set. These included jellyfish and comb jelly species. Species recorded inconsistently throughout the different survey periods were also removed, (e.g. epibionts). Lastly, some species where identification does not appear to be consistent between surveys have been combined into a single genus for analysis, for example, *Macropodia* spp., and *Pomatoschistus* spp.

Metrics describing the mean catch of fish and invertebrates and diversity indices were graphically presented with error bars representing the standard error of the mean to visually compare the means between treatment groups.

Following initial analysis of the dataset, results were affected by outliers in the dataset. These were mainly comprised of stations where no fauna was recorded in the trawl. These stations were removed for subsequent analysis and in particular for production of ordination plots to determine any patterns resulting from the remaining stations. These stations were predominately sampled during Construction Year 1.

For analysis monthly surveys were assigned to seasons based on the following criteria:

- Surveys conducted between January and March were considered to be Winter surveys;
- Surveys conducted between April and June were considered to be Spring surveys;
- Surveys conducted between July and September were considered to be Summer surveys; and,
- Surveys conducted between October and December were considered to be Autumn surveys.

2.3.2. Data analysis

Multivariate statistics

As the raw data was heavily skewed by relatively few species (for example *Crangon crangon* and *Ophiura ophiura*) fourth root transformations were applied. Statistical tests used are non-metric Multidimensional Scaling (MDS) ordinations, Analysis of Similarities (ANOSIM), Species Contributions (SIMPER), Permutational ANOVAs (PERMANOVA) and correlation of environmental variable (BIOENV). A more in-depth explanation of each test is given below. All analyses were based on a Bray-Curtis similarity index.

Construction periods have been grouped into three distinct periods for the analysis of the non-migratory fish survey data: baseline, construction and operation. The baseline and construction periods both have 10 surveys, whereas the operational phase has 5 surveys.

PERMANOVA+

PERMANOVA+ is a recent 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.

Type III PERMANOVA tests were used to determine effects of construction period in a multifactorial design that incorporates seasonal effects. Due to the unbalanced nature of the data some construction periods do not have consistent replication during all seasons. To reduce any resultant confounding effects of the unbalanced design further analysis was also undertaken using one-way ANOSIM on data collected during the winter period only. Throughout the MEMP winter survey months were sampled within every construction period therefore this permits a robust analysis of the dataset with regards to changes between construction periods.

ANOSIM

ANOSIM was used to determine whether there was a difference in fish and epifaunal invertebrate community composition between the construction periods. ANOSIM is a simple non-parametric permutation procedure applied to a similarity matrix underlying the ordination, or classification, of samples. It tests the null hypothesis (H_0) that there is no difference in fish or benthic invertebrate community composition between the construction periods. ANOSIM calculates an R value that is between -1 and +1, although normally the R value lies between 0 and 1, with R values of 1 denoting complete separation of data points between test groups and 0 denoting no difference observed between groups. R will usually fall between 0 and 1 indicating some degree of discrimination between data points. The R value itself is a useful comparative measure of the degree of separation of data points, 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 p is significant (i.e if $p \leq 0.05$.), you can conclude that there is evidence that the samples within groups are more similar than would be expected by chance. A one-way ANOSIM was used to identify any statistical difference between construction periods using winter months only as this was the season that was sampled most consistently.

In addition, to identify any spatial effect between sampling stations within and outside one tidal ellipse of the site sampling stations were assigned *a-priori* to groups based on construction period and there location with a secondary impact zone defined as one tidal ellipse at mean tide using tidal excursion ellipse data available on the Atlas of UK Marine Renewable Energy Resources (ABPmer, 2008). Of the 28 stations used in the analysis 7 were found to fall within the tidal ellipse while 21 were found to fall beyond the tidal ellipse. The difference between groups was tested using a one-way ANOSIM to assess for significant differences in fish assemblages and benthic epifaunal invertebrates using data collected during all seasons.

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. This was applied to any datasets where ANOSIM testing yielded statistically significant effects.

MDS Ordination

MDS plots were produced to examine the similarity of sites/samples in terms of their species composition. The MDS analysis plots a measure of similarity between the samples into two or more dimensional spaces so that the distance between objects corresponds closely to their input similarities. Simply stated, if sample one has a higher similarity to sample two than it does to sample three then sample one will be placed closer on the map to sample two than to sample three. The stress value indicates how faithfully the high-dimensional relationships among the samples are represented. The lower the stress value, the less distortion occurs. Generally speaking stress values exceeding 0.2 are considered to have a close to random distribution and care should be applied when interpreting these plots (Clark, 1993).

BIOENV

The BIOENV procedure identifies the best combination of environmental variables at increasing levels of complexity and correlates these with patterns in the biotic data. This is achieved by producing a Euclidean distance dissimilarity matrix for the environmental variables and maximises the rank correlation between the community Bray-Curtis dissimilarity matrix. The Spearman rank correlation coefficient is then presented for the subset of environmental variables that best explains the patterns in the multivariate community data. BIOENV was used to determine any differences in fish and epifaunal assemblages correlate with the distance from the wind farm.

Univariate statistics

The Shannon-Weiner diversity index was calculated for the fish and epibenthic invertebrates. Other univariate metrics compared between seasons and construction periods were total abundance, species richness and abundance of single species.

2.4. Non- Migratory Fish Results

2.4.1. Summary of catch

Since the baseline survey 39 species of fish and 64 species of invertebrates have been captured in the non migratory fish surveys conducted during all construction period. The most common fish species were plaice (*Pleuronectes platessa*), dab (*Limanda Limanda*) and whiting (*Merlangius merlangus)* (Table 2.2). Brown shrimp (*Crangon Crangon*), brittle stars (*Ophiura ophiura*) and hermit crabs (*Pagurus bernhardus*) were the most common invertebrates captured (see Table 2.3).

Table 2.2. Top ten most abundant species of fish caught during all non-migratory fish surveys (Baseline - Operation).

Common Name	Latin Name	Number of Individuals
Plaice	*Pleuronectes platessa*	21,399
Dab	*Limanda limanda*	20,681
Whiting	*Merlangius merlangus*	10,975
Lesser weever	*Echiichthys vipera*	4623
Solenette	*Buglossidium luteum*	3255
Pogge	*Agonus cataphractus*	2,718
Sprat	*Sprattus sprattus*	1,661
Sand goby	*Pomatoschistus minutus*	1,342
Sole	*Solea solea*	980
Scald fish	*Arnoglossus laterna*	822

Table 2.3. Top ten most abundant species of benthic invertebrates caught during all non-migratory fish surveys (Baseline - Operation).

Common Name	Latin Name	Number of Individuals
Brown shrimp	*Crangon crangon*	98,197
Brittlestar	*Ophiura ophiura*	31,908
Serpent's table brittlestar	*Ophiura albida*	9,872
Hermit crab	*Pagurus bernhardus*	2,567
Swimming crab	*Liocarcinus spp.*	2,023
Common starfish	*Asterias rubens*	837
Pink shrimp	*Pandalus montagui*	406
Masked crab	*Corystes cassivelaunus*	365
Baltic prawn	*Palaemon adspersus*	293
Plumose anemone	*Metridium senile*	281

2.4.2. Variation in catch data between Construction periods

The number of fish and invertebrate individuals caught during each standardised tow varied between construction periods. During the Baseline survey consistently higher catches were recorded than during the Construction or Operation period for fish (see Figure 2.2). The fish catch recorded during the Construction period (February 2008 – February 2010) were lower than those recorded during the Baseline surveys (November 2001 – September 2002). The catch during the Operation period (April 2010 – January 2013) was greater than those recorded during the construction period but not as great as the Baseline catch. Invertebrate catch also dropped during the Construction period but increased during Operation. For invertebrates, the mean abundance during the operation is similar to that recorded during the baseline survey.

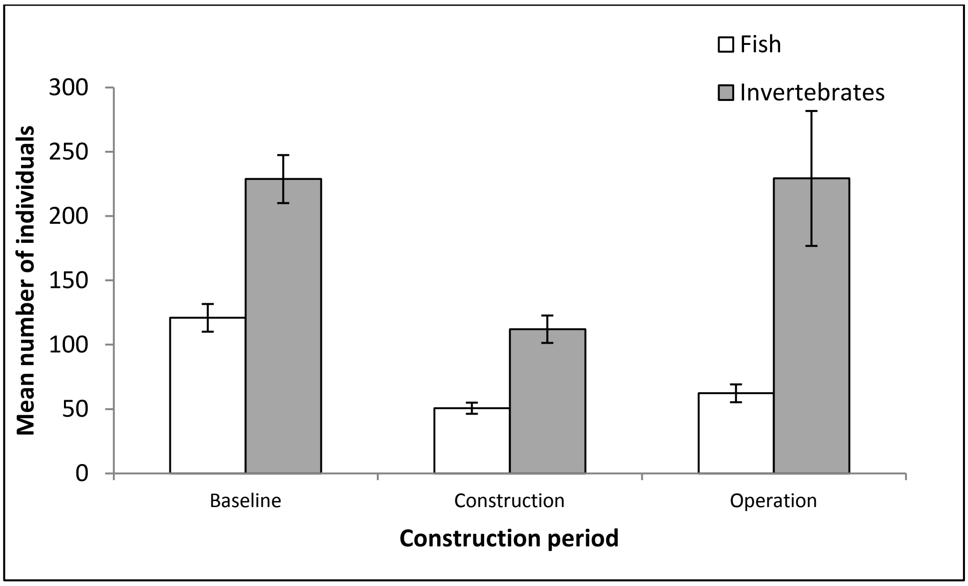

Figure 2.2. Mean catch (standardised to no. of individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

The standard error of the mean fish catch does not overlap between the construction period, baseline and operational periods indicating that there was a decline in fish numbers captured during construction (Figure 2.2). The error bars associated with the mean fish catch recorded during the Construction and Operation periods do not overlap indicating a difference in means between these periods however the difference is not as pronounced. The standard error bars of the mean invertebrate catch during each construction phase overlap between the Baseline and Operation period (Figure 2.2). There is no overlap between the Construction phase and any other period.

The mean fish catch varied with trawl location across the study area (Figure 2.3, Figure 2.4 and Figure 2.5). Catch was greatest at sites to the east and northwest of the wind farm site. The stations to the northeast of the wind farm location recorded the lowest fish catch. This pattern was visible during all construction periods although less visible during the construction phase when the lowest catches were observed.

Variations in mean catch of invertebrates were more consistent over the survey area (Figure 2.2). However, largest mean catch was recorded at trawl locations in the northwest of the survey area as a result of high brittle star densities (Figure 2.6, Figure 2.7 and Figure 2.8). Trawls conducted during the Operation period were towed through extremely dense brittle star beds resulting in a further increase in invertebrate abundance at these stations.

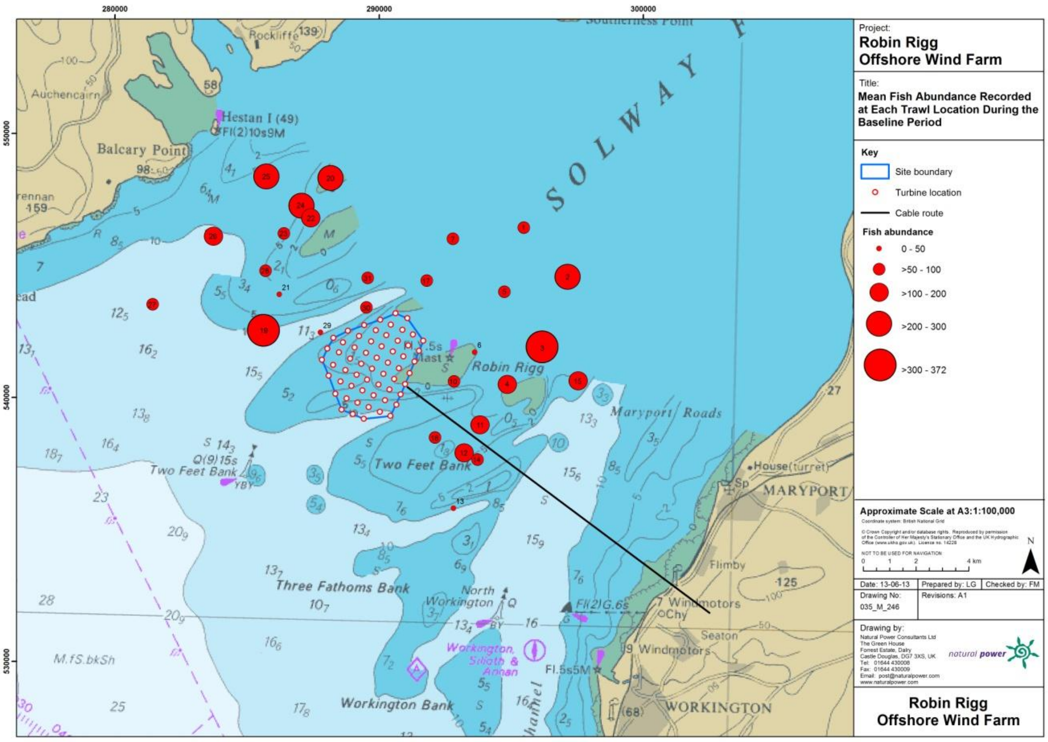

Figure 2.3. Mean fish abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Baseline period.

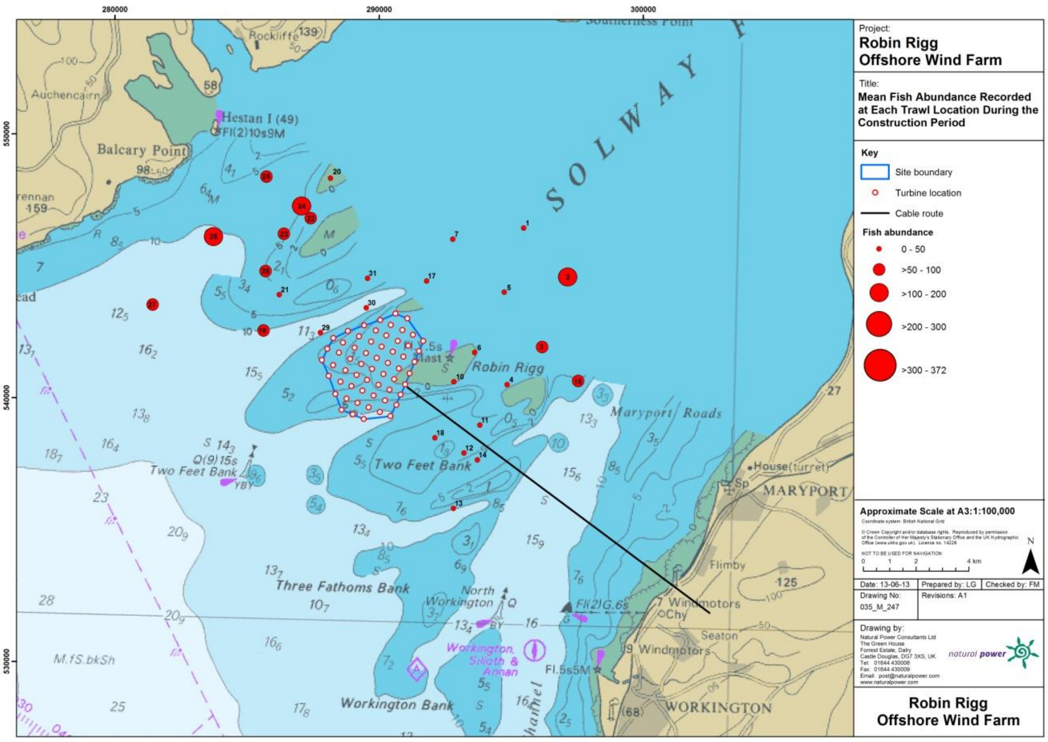

Figure 2.4. Mean fish abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Construction period.

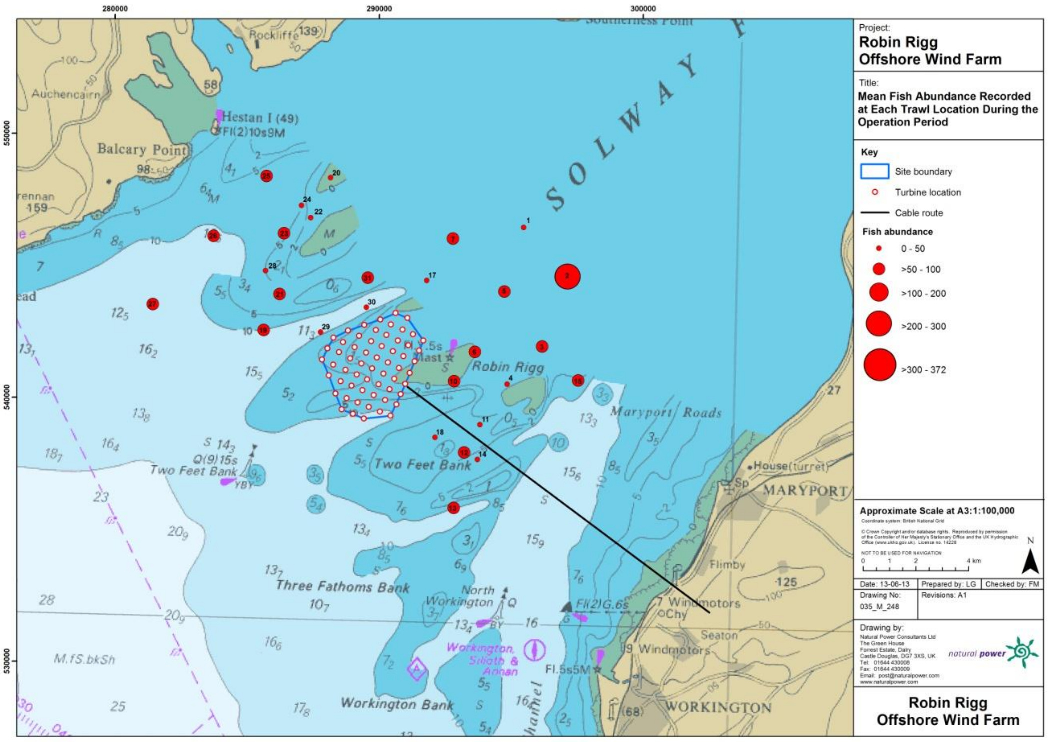

Figure 2.5. Mean fish abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Operation period.

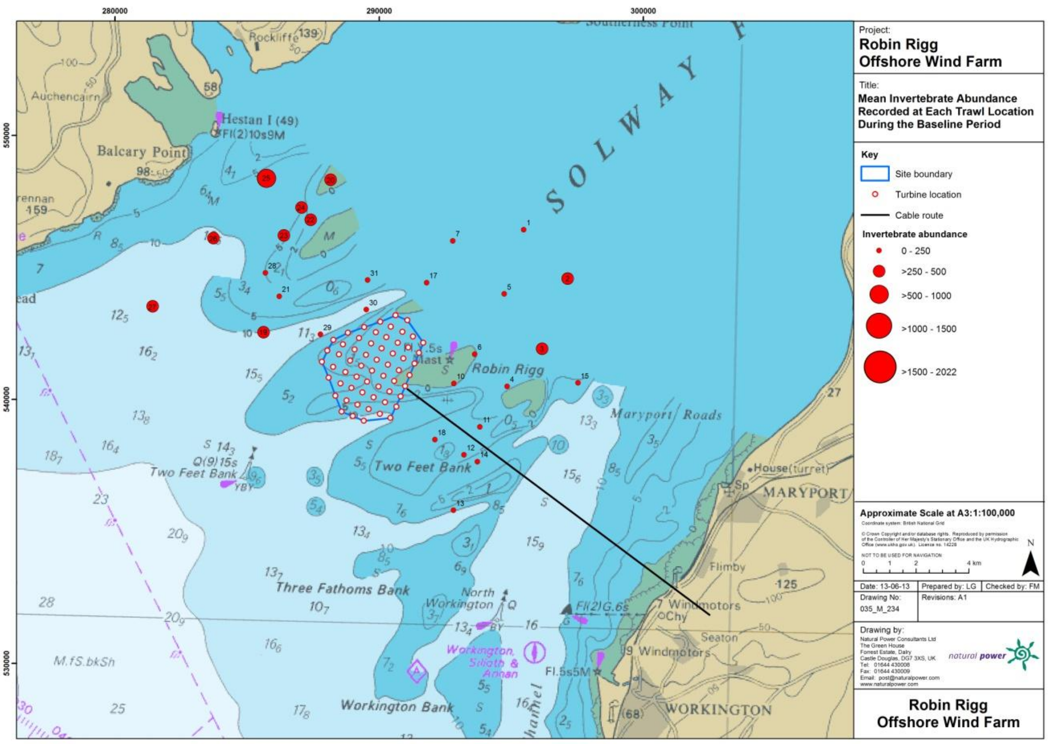

Figure 2.6. Mean invertebrate abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Operation period.

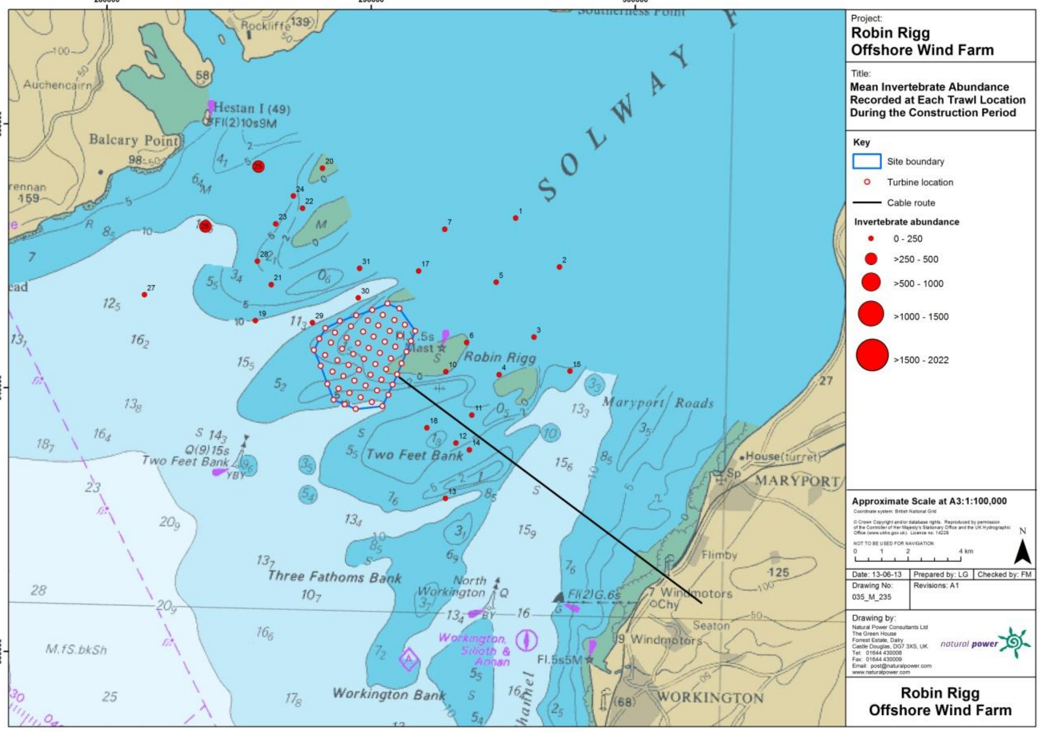

Figure 2.7. Mean invertebrate abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Operation period.

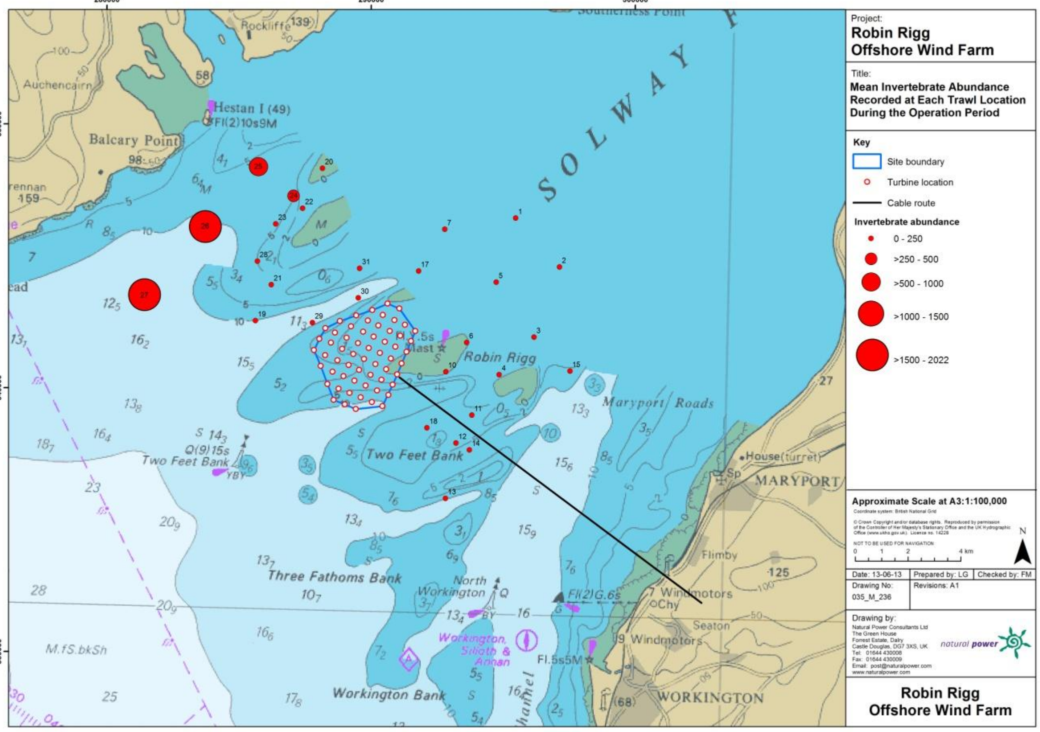

Figure 2.8. Mean invertebrate abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Operation period.

The high catch number and high variation in invertebrate catch observed during the Operation period was a result of high catches of brittle stars (*Ophiura ophiura*) (Figure 2.9) to the north west of the study area (Figure 2.10, Figure 2.11 and Figure 2.12). Despite variations in *Ophiura ophiura* abundance between construction periods the stations with increased catch rates were consistently situated to the northwest of the survey area. Peak densities were recorded at survey stations 25 – 29 during all construction periods and so the mean catch rate does represent the distribution across the entire survey area.

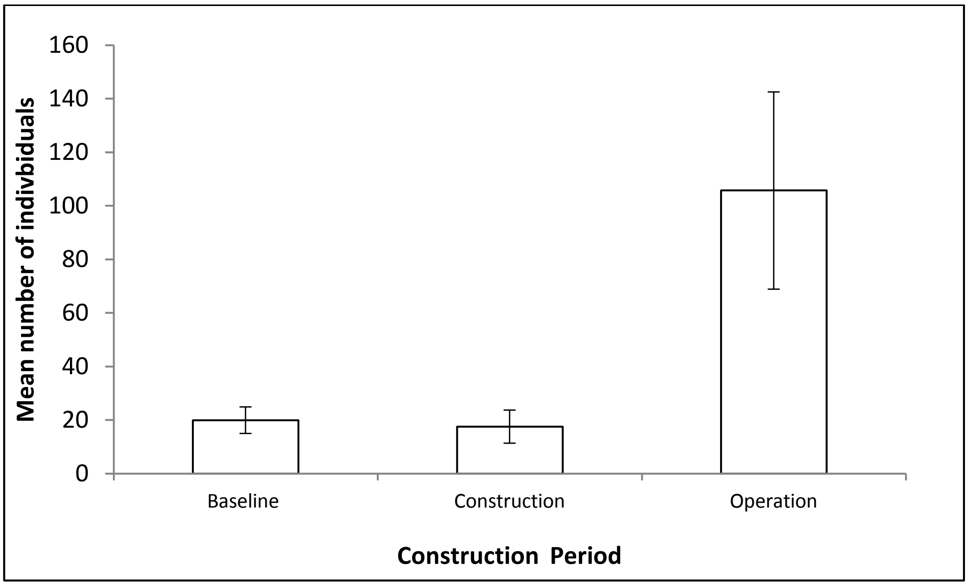

Figure 2.9. Mean catch of brittle stars (Ophiura ophiura) (individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

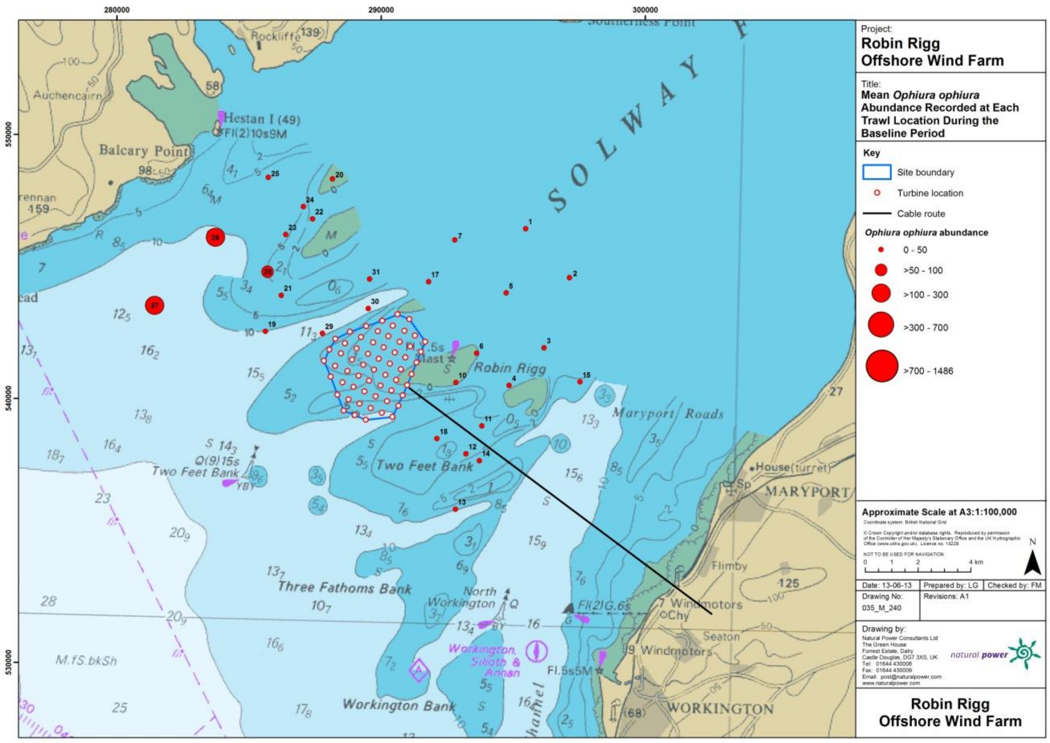

Figure 2.10. Mean brittle star (Ophiura ophiura) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Baseline period.

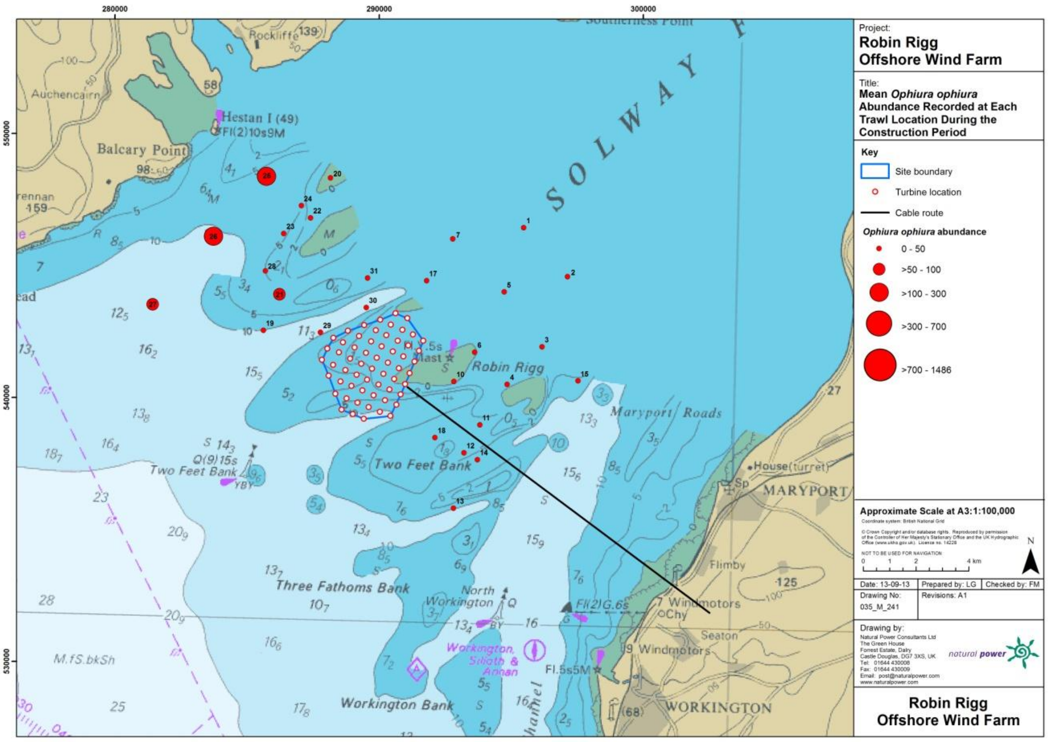

Figure 2.11. Mean brittle star (Ophiura ophiura) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Construction period.

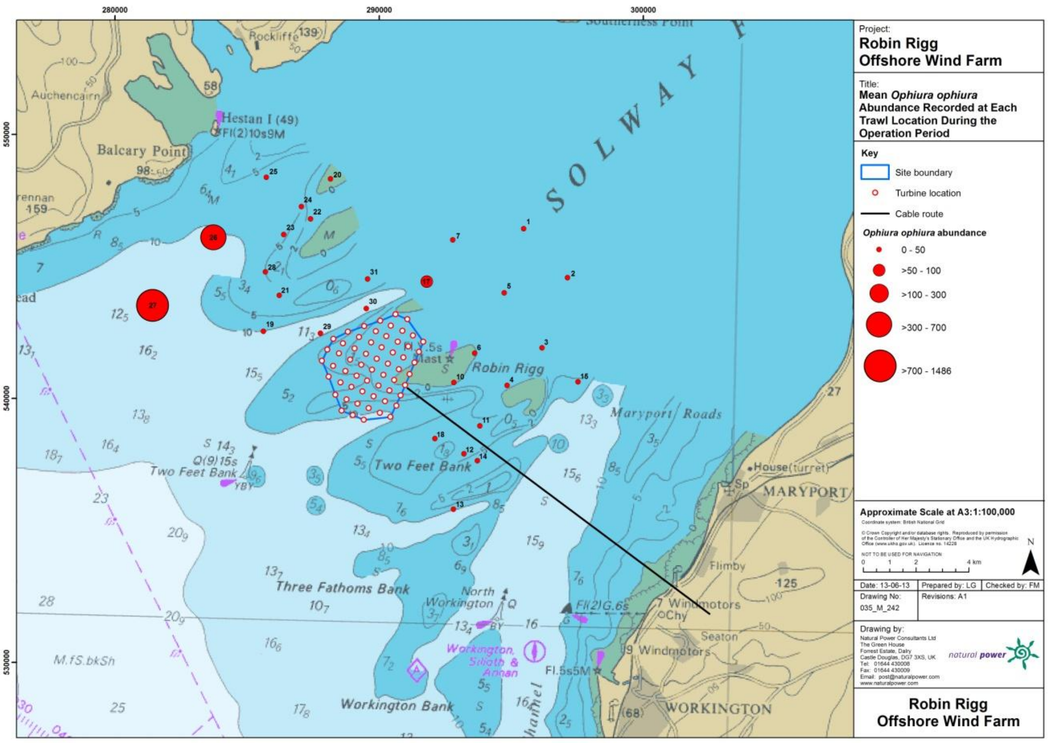

Figure 2.12. Mean brittle star (Ophiura ophiura) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Operation period.

Catches of other key species were also found to vary between construction periods. During the baseline survey catches of the commercially important brown shrimp (*Crangon crangon*) peaked with catches dropping to less than half during the Construction period (see Figure 2.13). Error bars representing the standard error of the mean did not overlap between any pairwise comparisons indicating that there are likely to be significant differences between construction periods. The lowest brown shrimp catch was recorded during the Operation period. Mean catch varied with trawl location with the largest catch to the northwest and east of the Robin Rigg Offshore Wind Farm site during the Baseline surveys (See Figure 2.14, Figure 2.15 and Figure 2.16). During the Construction period the catch was relatively low across the study area with an increase in mean catch recorded at the northwest trawl locations during the Operation period.

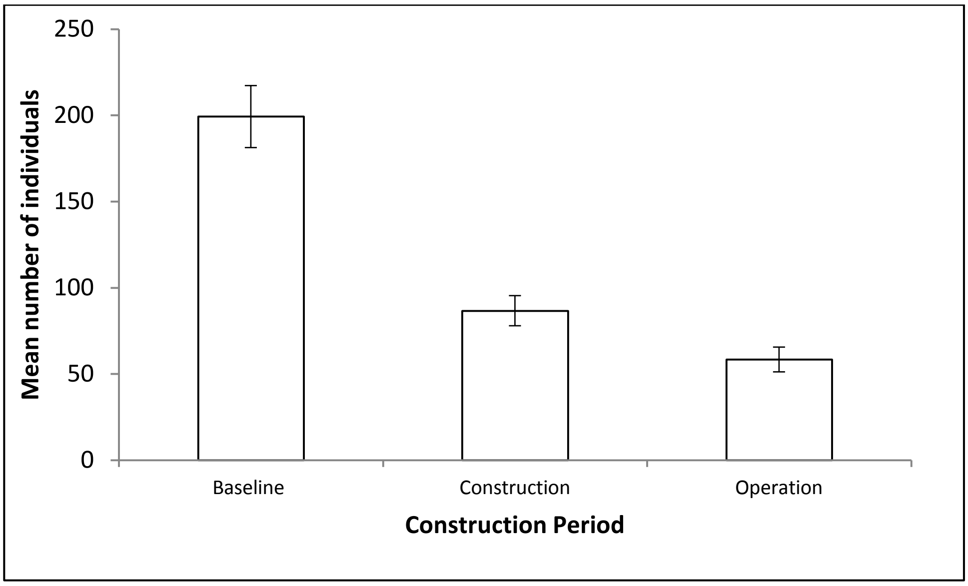

Figure 2.13. Mean catch of brown shrimp (Crangon crangon) (individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

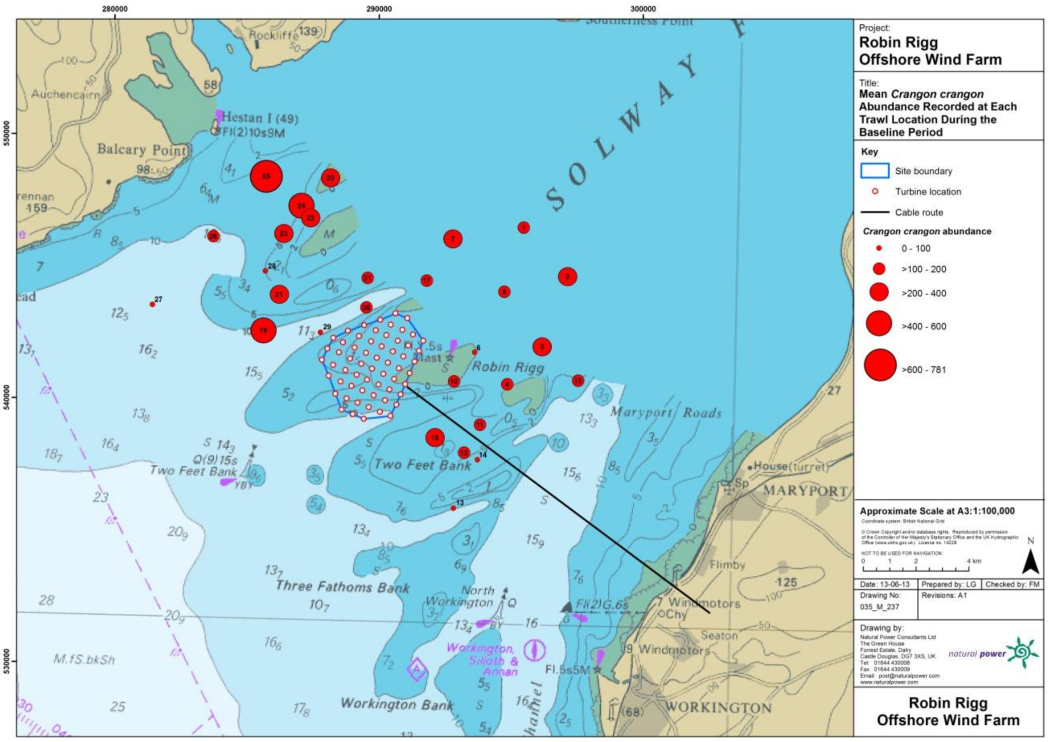

Figure 2.14. Mean brown shrimp (Crangon crangon) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Baseline period.

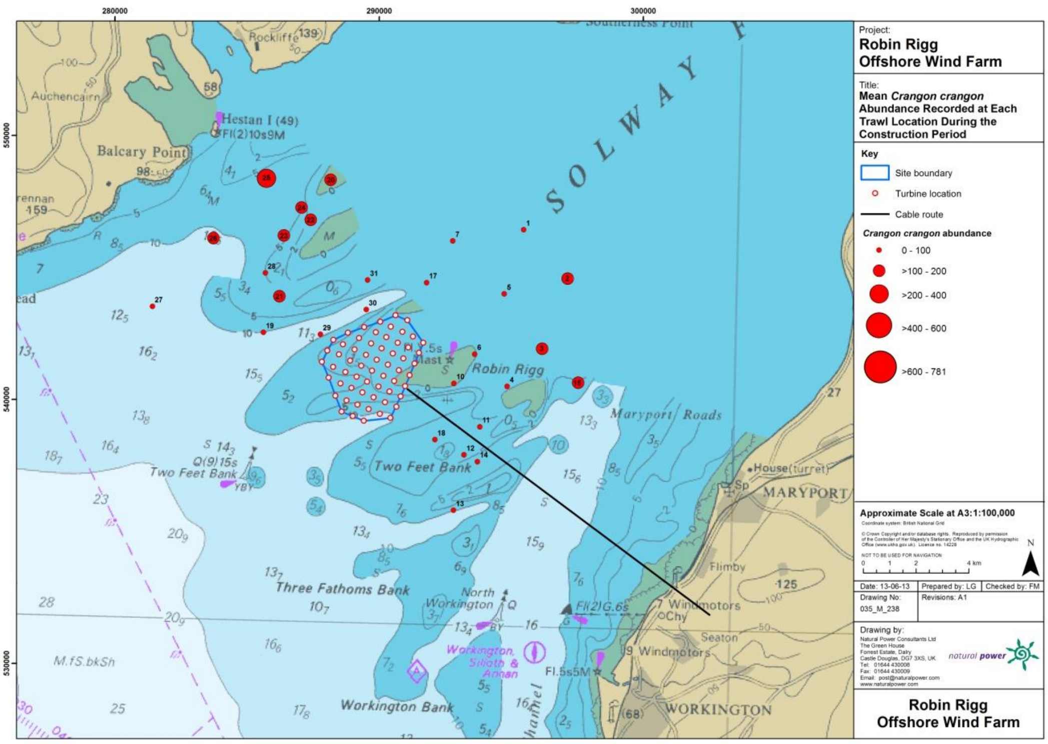

Figure 2.15. Mean brown shrimp (Crangon crangon) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Construction period.

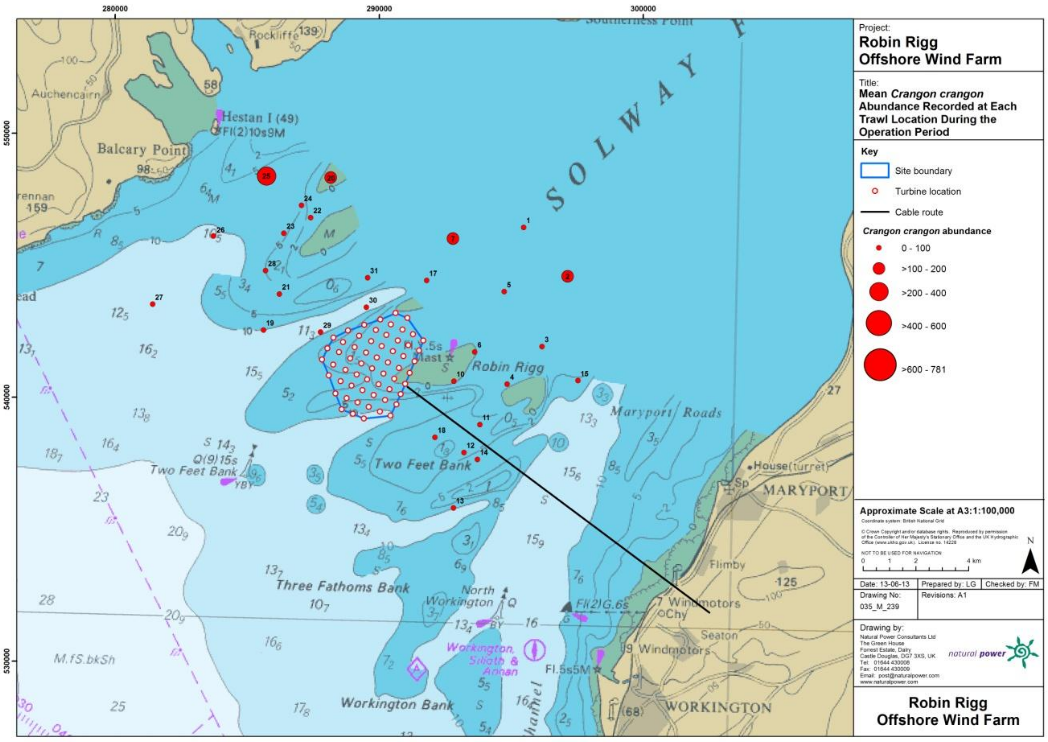

Figure 2.16. Mean brown shrimp (Crangon crangon) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Construction period.

The greatest abundance of whiting, a major prey species of marine mammals, was recorded during the Operation period with the lowest catch recorded during the Construction period (Figure 2.17). Error bars representing the standard error of the mean indicate that catches are likely to be significantly greater during the Operation period than during the Baseline or Construction periods. Spatially, the greatest mean catch of whiting was recorded at sampling stations to the east of the Robin Rigg Offshore Wind Farm site during the Baseline and Operation periods (see Figure 2.18, Figure 2.19 and Figure 2.20). During the Construction period whiting catch remained low consistently across the site.

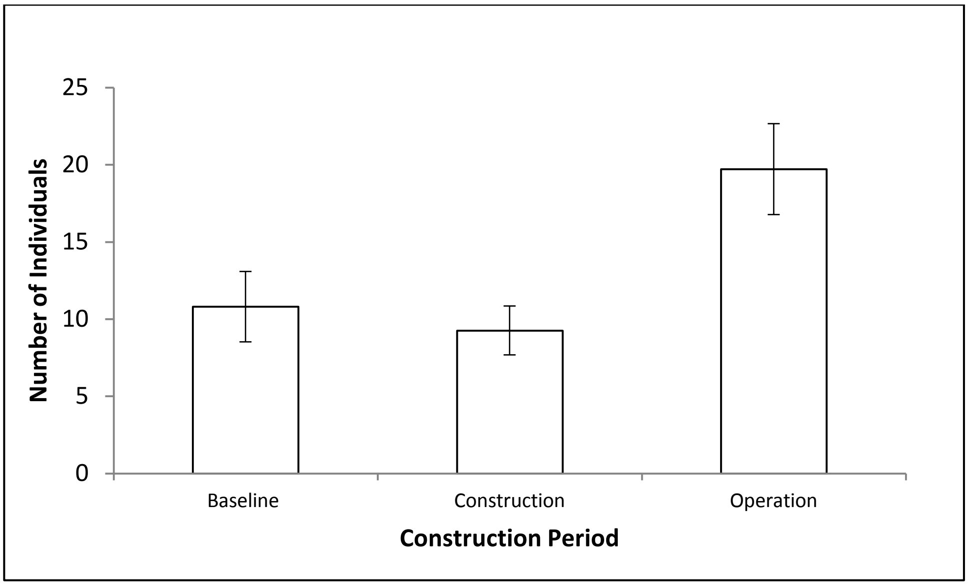

Figure 2.17. Mean catch of whiting (M. merlangus) (individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

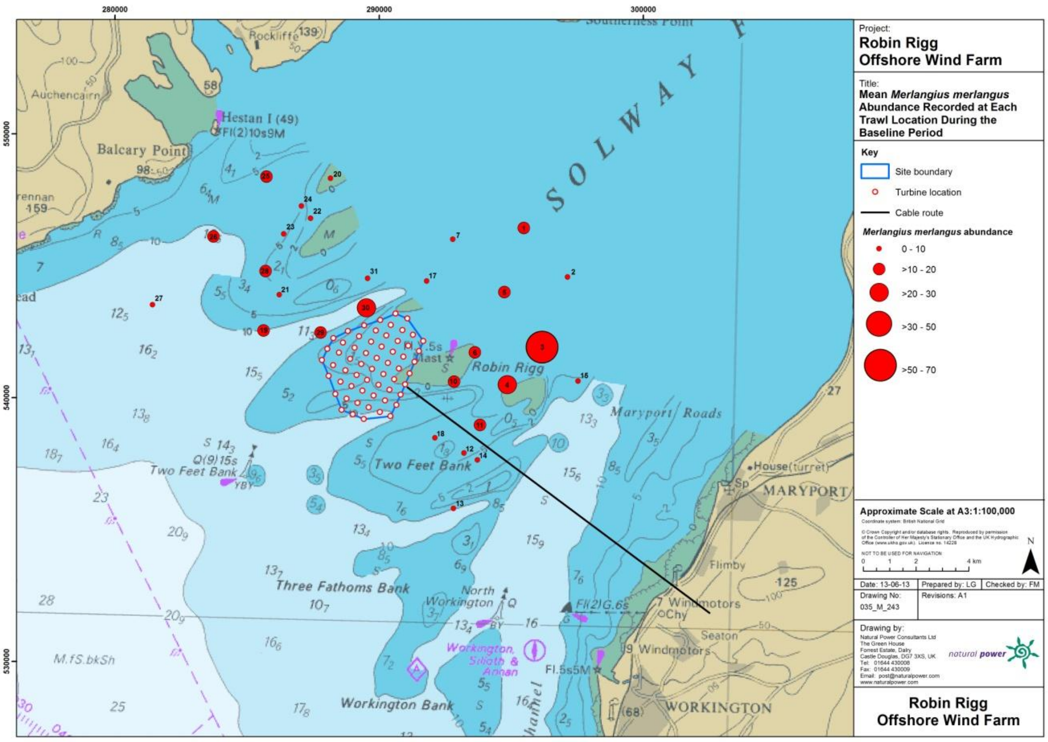

Figure 2.18. Mean whiting (Merlangius merlangus) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Baseline period.

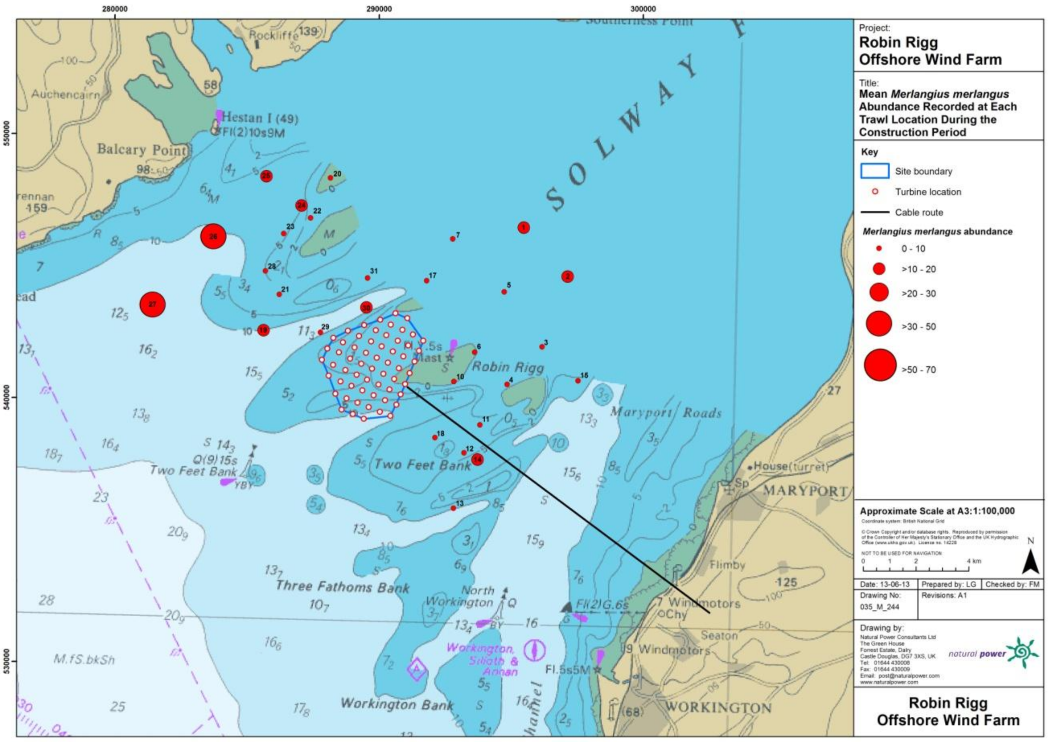

Figure 2.19. Mean whiting (Merlangius merlangus) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Construction period.

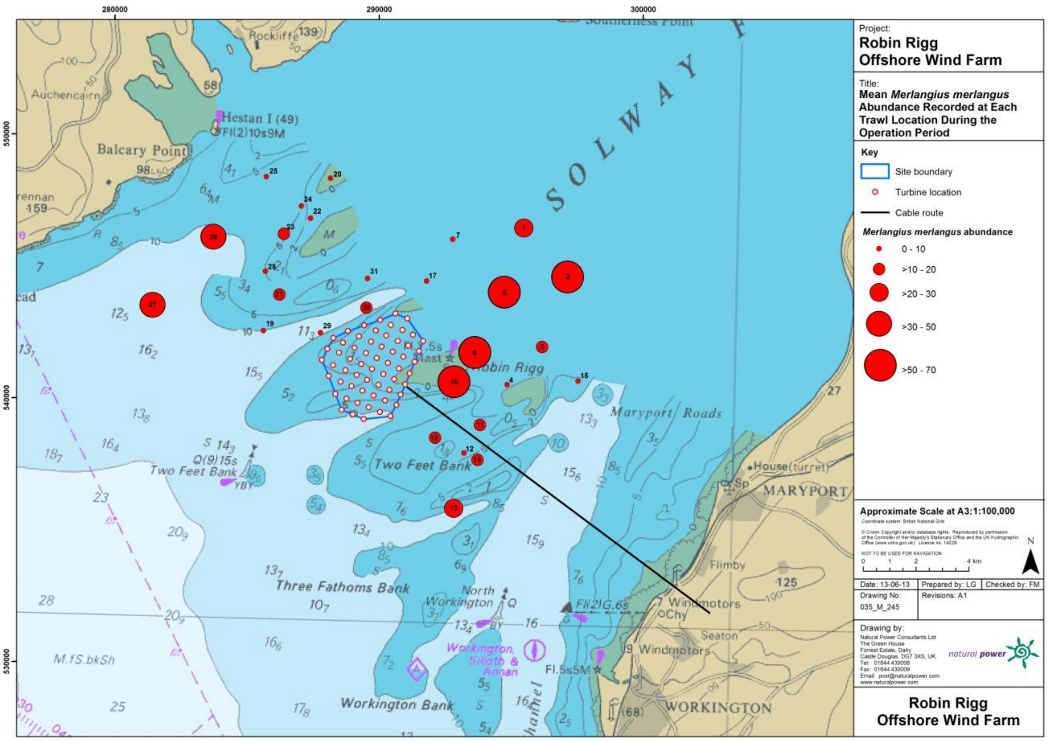

Figure 2.20. Mean whiting (Merlangius merlangus) abundance (number of individuals per 15 minute tow) recorded at each trawl location during the Operation period.

A total of 121 elasmobranches were recorded during the non-migratory fish survey at the Robin Rigg Offshore Wind Farm. Three different species were identified), blonde ray (*Raja brachyura*) (1 individual), thornback ray (*Raja clavata*) (63 individuals) and lesser spotted dogfish (*Scyliorhinus canicula*) (59 individuals). All species have been grouped into mean elasmobranch species for comparison of means between construction periods. Error bars representing standard error of the mean overlap between all construction periods which indicates there is unlikely to be a significant difference between mean elasmobranch catch (Figure 2.21).

Figure 2.21. Mean elasmobranch catch per 15 minute tow between construction periods. Error bars represent the standard error of the mean.

Further investigation looking at the two most abundant species suggests that fluctuations between construction periods of thornback ray are not likely to be significantly, this is reflected by overlapping error bars representing standard error of the mean. With respect to lesser spotted dogfish an increase was observed in mean catch between baseline and operation and construction and operation which was supported by non-overlapping error bars. There was also an increase in variation which suggests lesser spotted dogfish had a patchy distribution around the survey area.

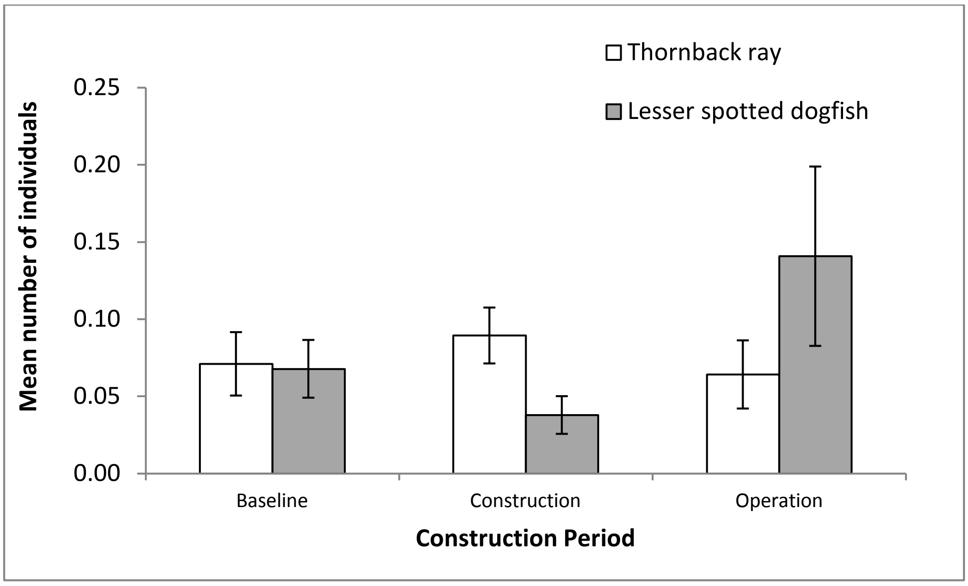

Figure 2.22. Mean thornback ray and lesser spotted dogfish catch per 15 minute tow between construction periods. Error bars represent standard error of the mean.

The abundance of other species also varied between construction periods as illustrated by the percentage change in catch (Table 2.4) where the percentage change in the most abundant fish species between construction periods was calculated using the entire dataset. Sole and solenette were excluded from these calculations due to potential misidentification during the baseline surveys. Plaice and dab have exhibited a continual decline between construction periods, while whiting declined during construction and increased to greater than baseline numbers during operation. There are no clear patterns in overall fish catch between construction periods with fluctuations appearing to be species specific.

Table 2.4. Percent change in fish catch between construction periods. (*) indicates species that were identified as one of the top five species contributing to dissimilarity between construction groups through SIMPER analysis.

Common Name	Latin Name	Baseline-Construction	Baseline-Operation	Construction-Operation
Pogge	*Agonus cataphractus**	-53	-51	6
Red gurnard	*Aspitriglia cuculus*	10	-62	-65
Dragonet	*Callionymus lyra*	38	-70	-78
Brown shrimp	*Crangon crangon*	-59	-82	-56
Lesser weever fish	*Echiichthys vipera**	-76	-83	-27
Grey gurnard	*Eutrigla gurnardus*	60	48	-8
Cod	*Gadus morhua*	-8	-100	-100
Dab	*Limanda limanda**	-64	-78	-39
Whiting	*Merlangius merlangus**	-40	-14	42
Plaice	*Pleuronectes platessa**	-81	-90	-46
Goby spp.	*Pomatoschistus spp.*	-56	-76	-45
Thornback ray	*Raja clavata*	-4	-61	-60
Lesser spotted dogfish	*Scyliorhinus canicula*	-75	-40	140
Sprat	*Sprattus sprattus*	-74	5	301

2.4.3. Variations in size frequency of commercial fish species

The three most abundant species of fish recorded during the Robin Rigg Offshore Wind Farm non-migratory fish survey program are all commercially harvested within the Irish Sea. Throughout the survey program the vast majority of fish sampled were undersized juveniles.

Of the 21,399 plaice sampled since November 2001 only 140 exceeded the minimum landing size of 27 cm for the species. Although the catch quantity has varied between construction periods the shape of the size frequency distribution has remained similar (see Figure 2.23). During the Baseline and Construction period the most abundant size classes were 50-59 mm and in the Operation period the most abundant size class was 60-69 mm. There is a second peak in the size frequency distribution most evident in the Baseline data suggesting that a number of the fish sampled are two year old fish. Due to the lower catch rate during the construction and operation year this trend is less prominent.

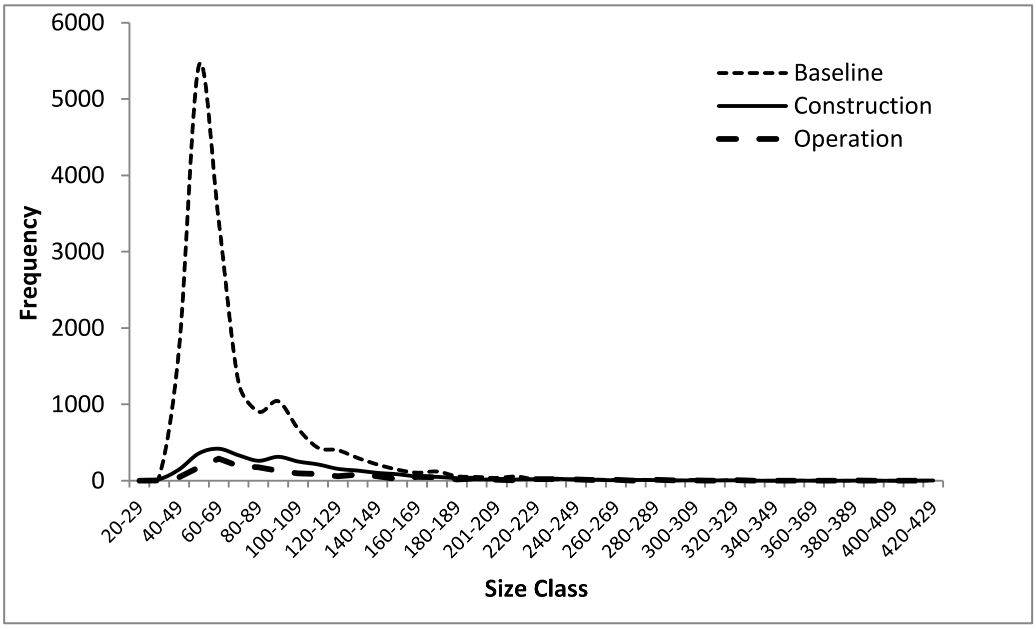

Figure 2.23. Size frequency distributions of plaice (Pleuronectes platessa) recorded during each construction period.

There is currently no minimum landing size for dab however the majority of fish caught were small juveniles and are unlikely to be of commercial interest. The most abundant size class in the size frequency distribution was 50 – 59 mm during the baseline and 60 – 69 mm during the construction and operational periods. During the Construction and Operation periods fewer dab were recorded although this is partially explained by variations in effort (see Figure 2.24). There is a second peak in the distribution at around 100 – 109mm for all three construction periods suggesting that at least two year classes use the Solway Estuary.

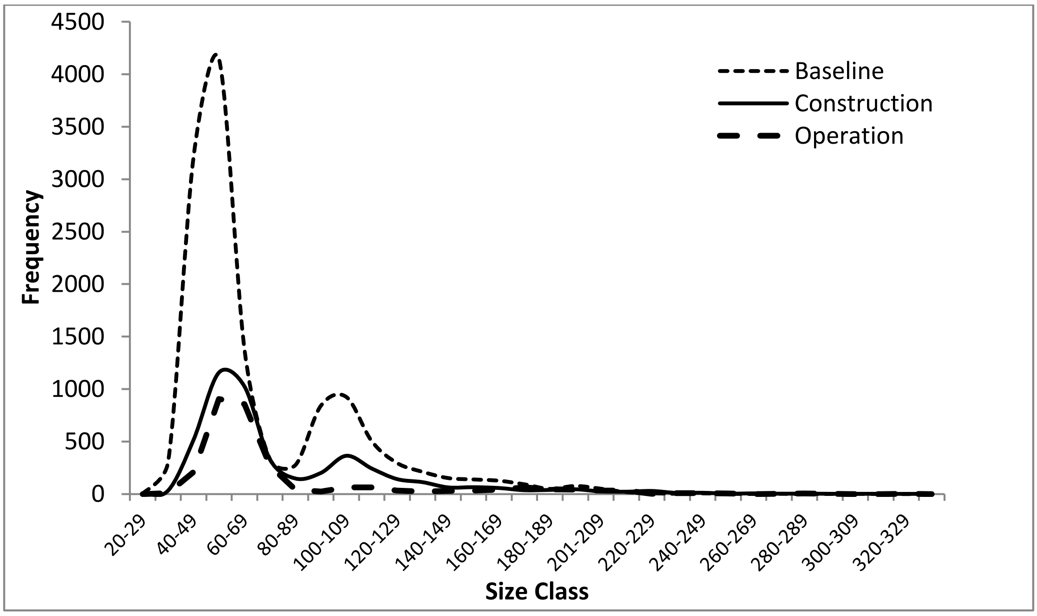

Figure 2.24. Size frequency distribution of dab (Limanda limanda) recorded during each construction period.

The total whiting catch since 2001 was 10,975, of these only two fish exceeded the minimum landing size of 27 cm for the species. Whiting size frequency distribution was similar between years although there was a greater catch rate during the Operation period (see Figure 2.25). The most frequently recorded size class varied between construction periods with the 90-99 mm class most common during the Baseline, the 80-89 mm most common during the Construction period and the 100 – 109 mm most common during the Operation period. There is no obvious second peak in the size class distributions for whiting.

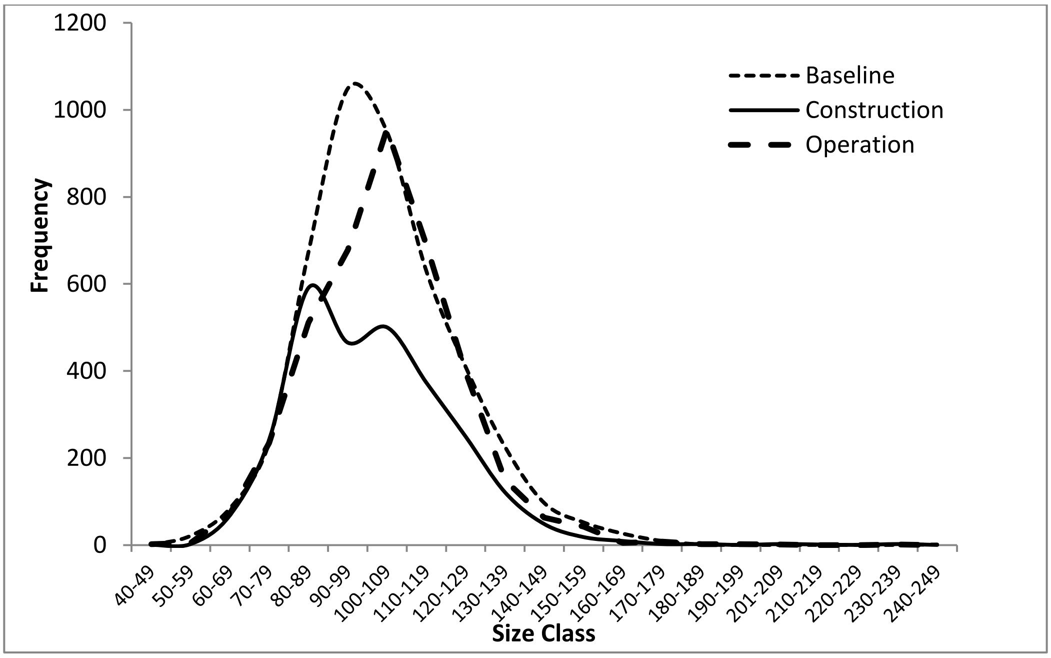

Figure 2.25. Size frequency distribution of whiting (Merlangius merlangus) recorded during each construction period.

2.4.4. Variation in catch data between Operational years

Mean fish catch was lowest during the first year of Operation (2011), there was an increase in 2012 followed by a reduction in 2013. Error bars representing the standard error of the mean indicates that there may be significant differences between 2011 and 2012 and 2011 and 2013. Overlapping error bars between 2012 and 2013 indicates that differences are unlikely to be significant (Figure 2.26). Initially this pattern was not reflected in invertebrate catch rates with the lowest catch recorded during 2011, increasing in 2012 and almost doubling again in 2013. However, sampling through dense brittlestar (*Ophiura ophiura*) beds resulted in unusually high abundances at stations to the north west of the survey area which skewed the overall mean in 2012. To account for this the outlying data, *Ophiura ophiura* catch, was removed from the data set. This indicates that invertebrate catch rates increase during the second operation year but drop to the lowest rates in the Operation period during 2013. A comparison of the standard error associated with each sample mean would suggest that in 2013 the catch rate may be significantly lower than both other operational years, whereas 2011 and 2012 are unlikely to differ significantly.

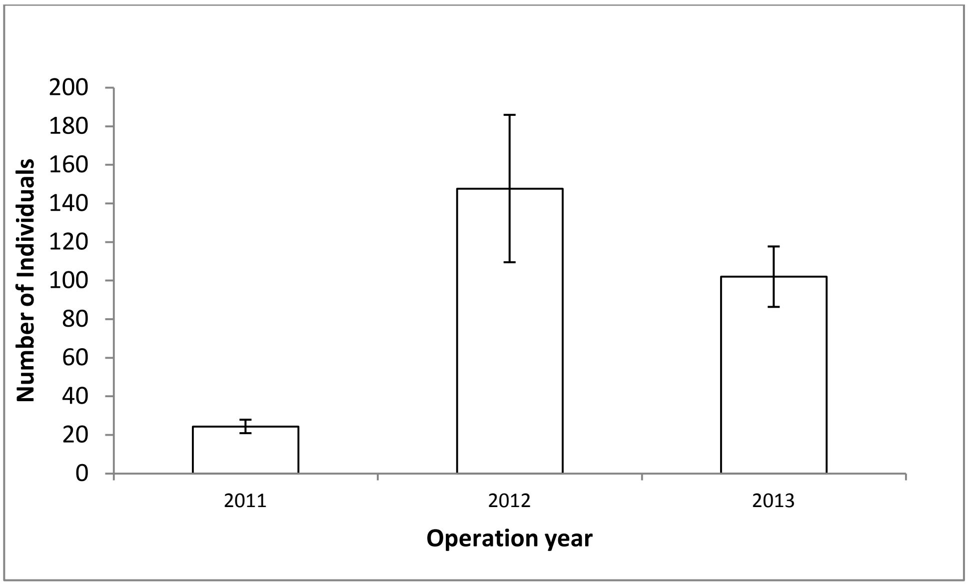

Figure 2.26. Mean fish catch abundance (standardised per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

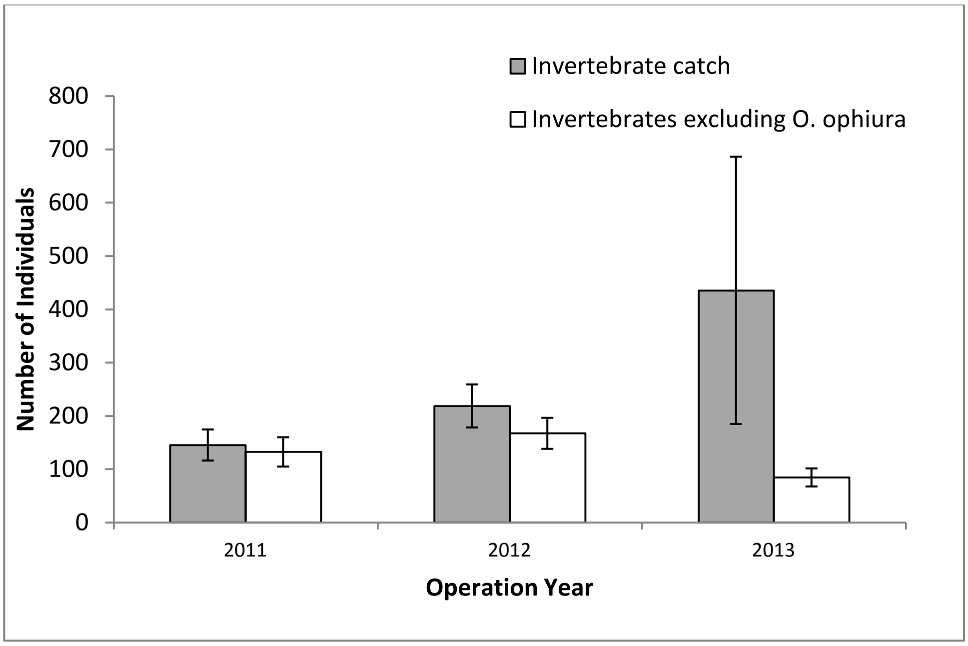

Figure 2.27. Mean invertebrate catch (standardised per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

2.4.5. Variation in catch data between seasons

Seasonal variation was observed throughout the survey with the largest mean catch per tow recorded during autumn (see Figure 2.28) for both fish and invertebrate assemblages. Invertebrate catch decreased during spring and summer and increased during winter. Error bars representing the standard error of the mean indicate that spring and summer mean catch is similar to each other but significantly different to autumn and winter mean catches. The pattern in fish communities was similar although the winter increase less pronounced. Error bars representing the standard error of the mean within each season does not overlap in any case indicating that seasonal fish catch differs significantly between seasons.

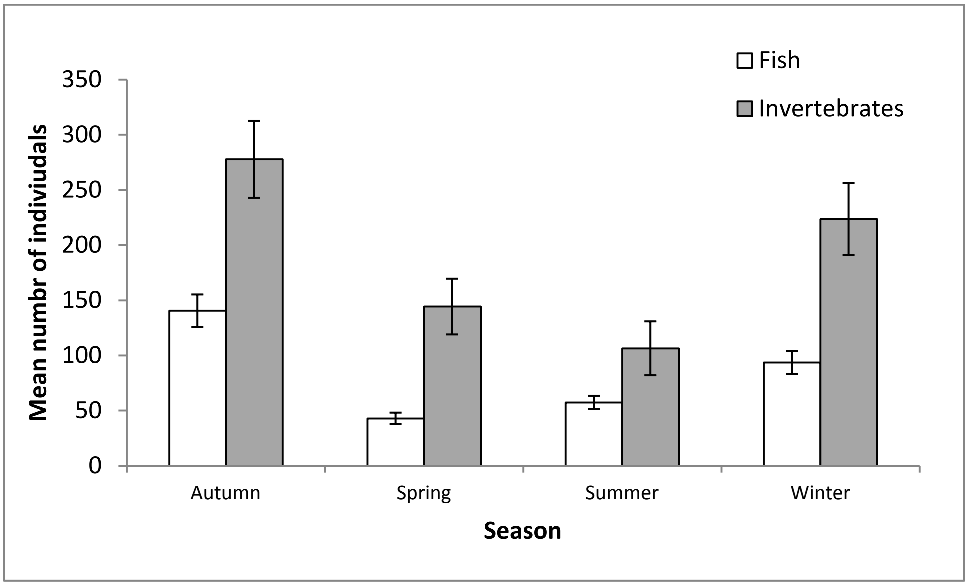

Figure 2.28. Seasonal variation in mean catch (individuals per 15 minute tow) recorded during the non-migratory fish survey (error bars = standard error of the mean).

The seasonal variation observed for invertebrates is reflected in the abundance of brown shrimp in the catch. Brown shrimp is the most abundant invertebrate species caught during each season. Error bars representing the standard error of the mean indicate that seasonal differences in brown shrimp catch is likely to be significantly different (see Figure 2.29).

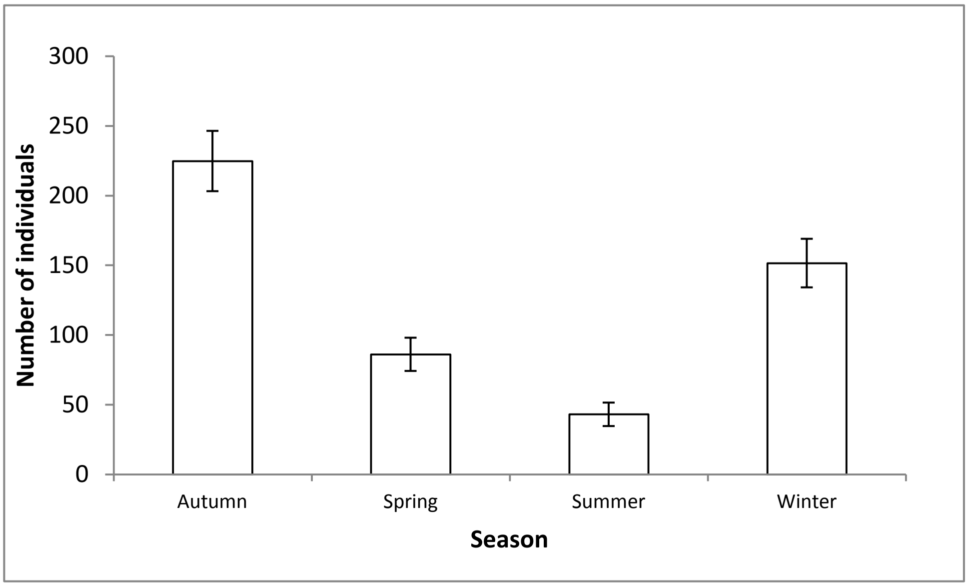

Figure 2.29. Seasonal variation in mean brown shrimp (Crangon crangon) catch (per 15 minute tow) recorded during the non-migratory fish survey (error bars = standard error of the mean).

2.4.6. Variations in diversity indices

Mean values of species richness and Shannon-Weiner diversity were calculated for each tow for comparison between construction periods. The mean number of species per tow ranged from 7.4 to 7.7 with the lowest value being recorded during the Operational period and the highest during the Baseline period (see Figure 2.30). Error bars representing the standard error of the mean overlap between all pairwise comparisons which suggests that the mean number of species between each construction period is unlikely to vary significantly. Values for Shannon-Weiner Diversity ranged from 1.06 during the Baseline period to 1.25 during the Operational period (see Figure 2.31). Variations between sampling stations within each construction period were very small, resulting in small standard errors around the mean values. Error bars representing standard errors of the mean do not overlap between seasons indicating potentially significant variations between construction periods.

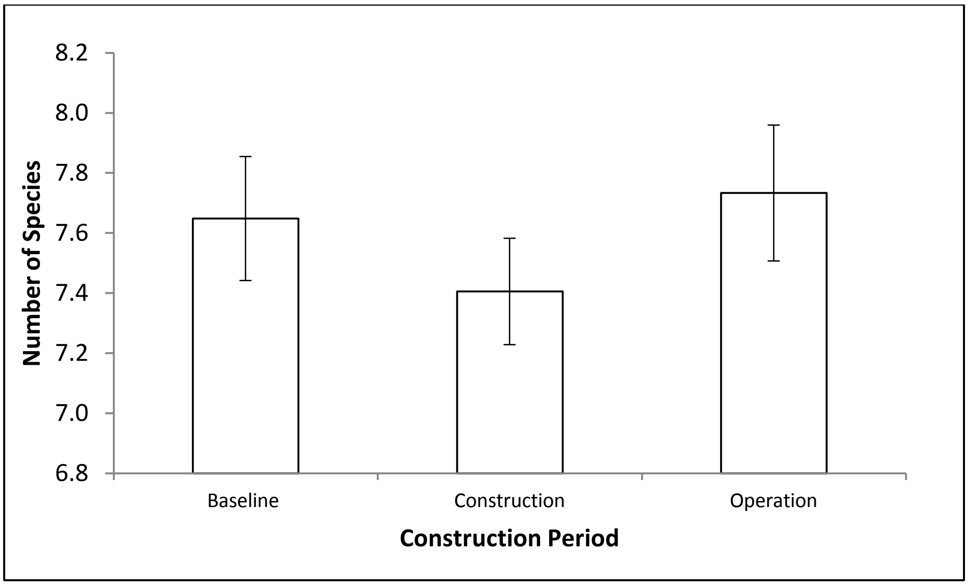

Figure 2.30. Mean species richness (no. of individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

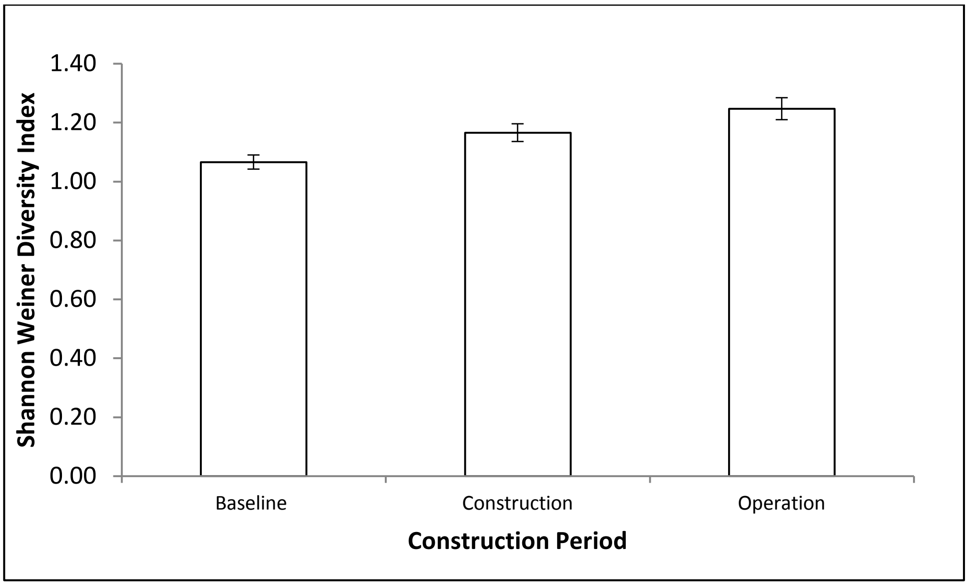

Figure 2.31. Mean Shannon-Weiner Diversity index (standardised per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

2.4.7. Variation in catch assemblages' between construction periods

PERMANOVA analysis

A two-way PERMANOVA analysis was conducted to investigate differences in fish assemblages and invertebrate assemblages between construction periods and seasons and to determine any interaction between the two factors. The outputs of the PERMANOVA analysis indicate significant differences between construction periods, season and between the interaction terms of the two factors (see Table 2.5). Type III PERMANOVA's were conducted as this is considered to provide a more conservative analysis when using unbalanced data (Anderson *et al*., 2008).

Table 2.5. Multi-factor PERMANOVA results assessing the difference between construction period and season on fish and epibenthic invertebrate assemblages (significant results in red).

Community	Factor	Pseudo-F	P
Fish	Period	15.78	0.001
	Season	18.14	0.001
	Period x Season	12.95	0.001
Invertebrates	Period	18.66	0.001
	Season	25.80	0.001
	Period x Season	6.70	0.001

For both fish and invertebrate assemblages PERMANOVA analysis identified differences between construction periods, seasons and between the interaction terms were significant (at a significant level of p = <0.05. Further pairwise investigation indicates that fish assemblages differ significantly between construction periods during every season (see Table 2.6).

Table 2.6. Two-way PERMANOVA pairwise comparison testing investigating differences in fish assemblages between construction period and season (significant results in red).

Pairwise Comparison	t-statistic	p-value
Within Autumn		
Baseline -Construction	3.96	0.001
Baseline-Operation	4.60	0.001
Construction-Operation	2.26	0.001
Within Winter		
Baseline -Construction	3.15	0.001
Baseline-Operation	3.05	0.001
Construction-Operation	3.14	0.001
Within Spring		
Baseline -Construction	2.73	0.001
Baseline-Operation	2.83	0.001
Construction-Operation	3.15	0.001
Within Summer		
Baseline -Construction	5.70	0.001
Baseline-Operation	4.90	0.001
Construction-Operation	1.90	0.003

Ordination plots depicting the distribution of sampling stations in multivariate space, representing the fish assemblage data provides no clear clustering of data points by Construction Period (Figure 2.32) and season (Figure 2.33). However it should be noted that the stress values associated with the ordination plots exceeds 0.2 and so the distribution depicted is likely to be almost randomly distributed.

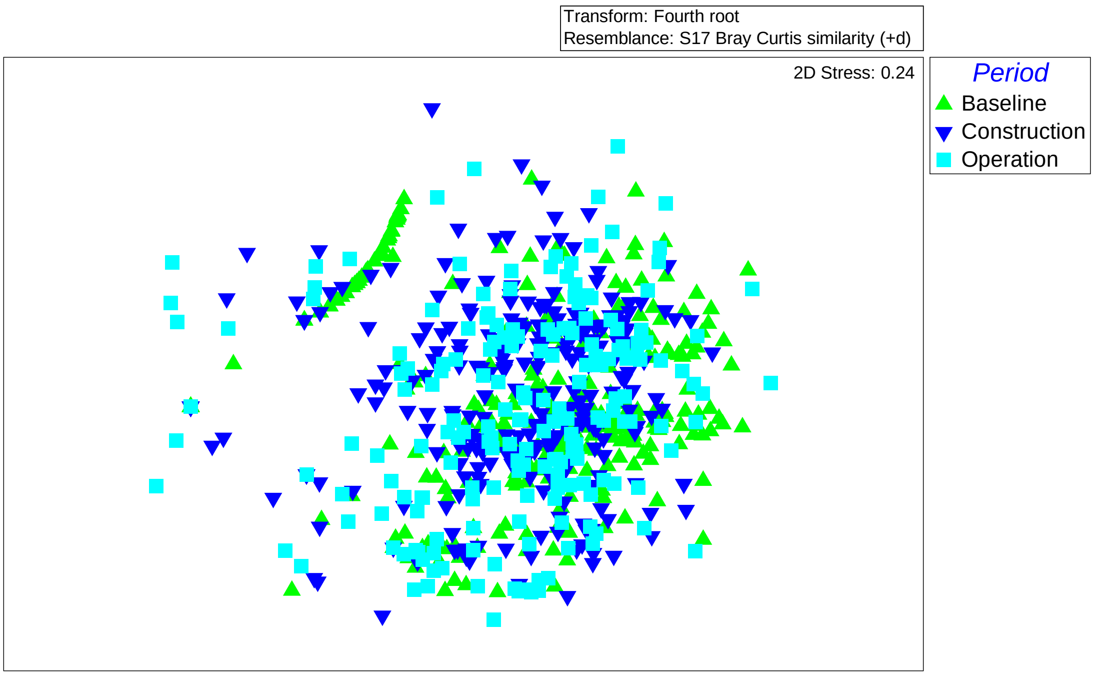

Figure 2.32. Non-metric MDS ordination plot of fish abundance (4th root transformed) surveyed during all seasons between each construction period.

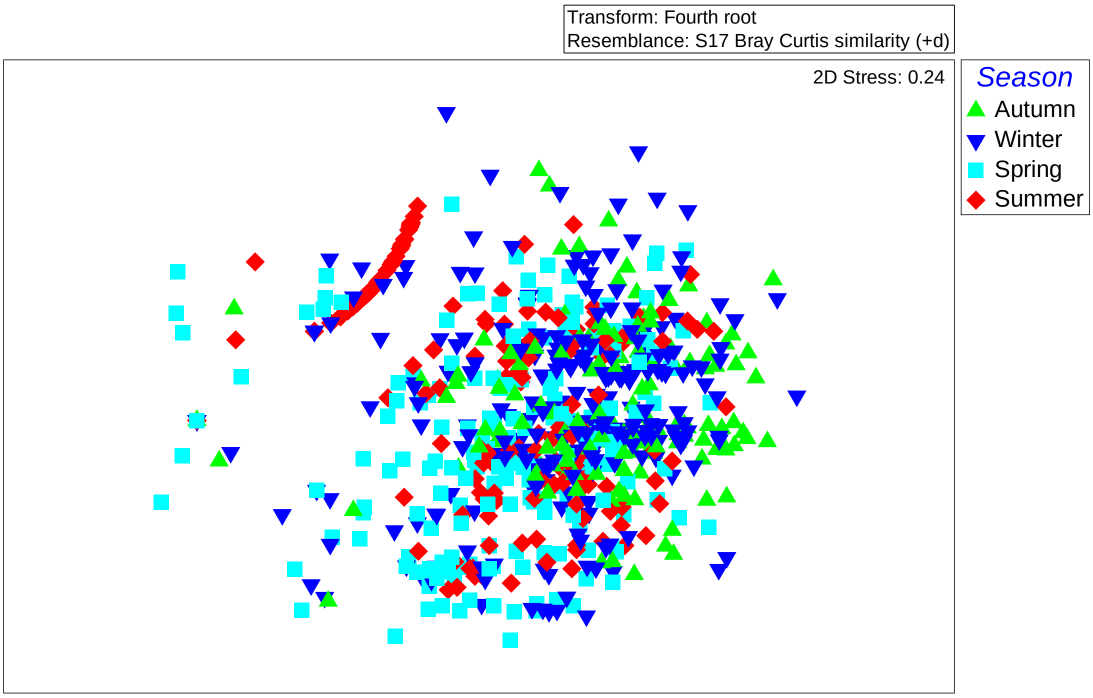

Figure 2.33. Non-metric MDS ordination plot of fish abundance (4th root transformed) between seasons.

A similar pattern of significance was detected between epibenthic invertebrate assemblages between construction periods during each season (see Table 2.7). The only non-significant pairwise comparison was observed for epifaunal invertebrate assemblages between construction and baseline periods during spring months.

Table 2.7. Two-way PERMANOVA pairwise comparison testing investigating differences in epifaunal invertebrate assemblages between construction period and season.

Pairwise Comparison	t-statistic	p-value
Within Autumn		
Baseline-Construction	3.79	0.001
Baseline-Operation	4.49	0.001
Construction-Operation	2.11	0.006
Within Winter		
Baseline-Construction	2.77	0.001
Baseline-Operation	3.37	0.001
Construction-Operation	3.94	0.001
Within Spring		
Baseline-Construction	1.06	0.337
Baseline-Operation	2.68	0.001
Construction-Operation	2.51	0.001
Within Summer		
Baseline-Construction	4.43	0.001
Baseline-Operation	3.01	0.001
Construction-Operation	1.85	0.011

Ordination plots were produced using the MDS function to identify any patterns in the distribution of epibenthic invertebrate samples in two dimensional multivariate space. No clear clustering of data points was observed with regards to Construction Period (Figure 2.34) or season (Figure 2.35).

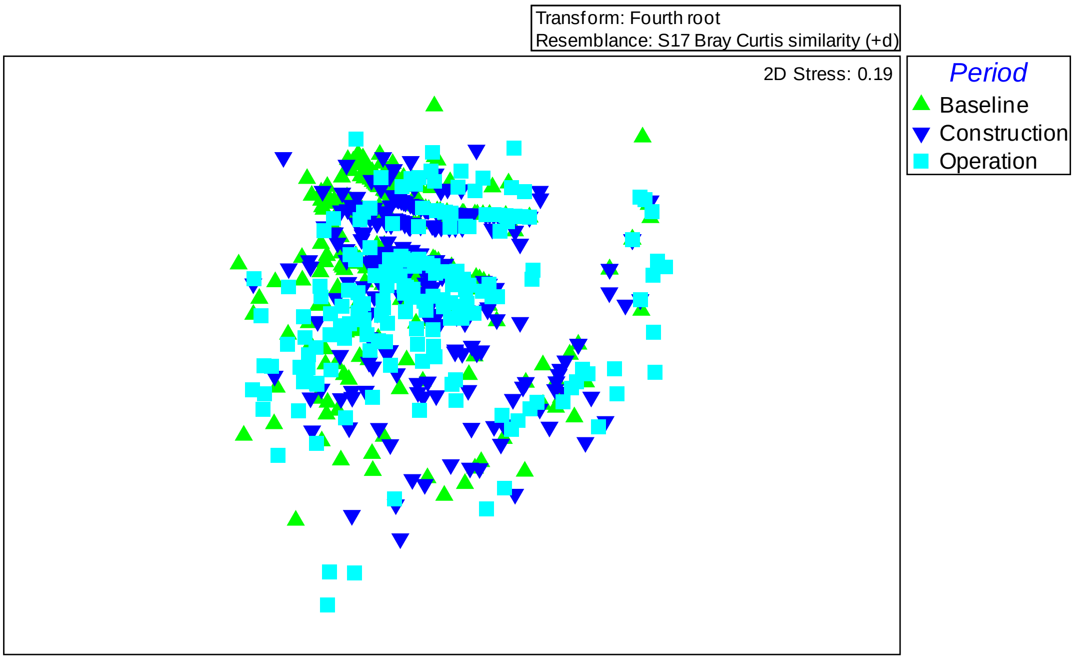

Figure 2.34. Non-metric MDS ordination plot of epibenthic invertebrate abundance (4th root transformed) surveyed during all seasons between each construction period.

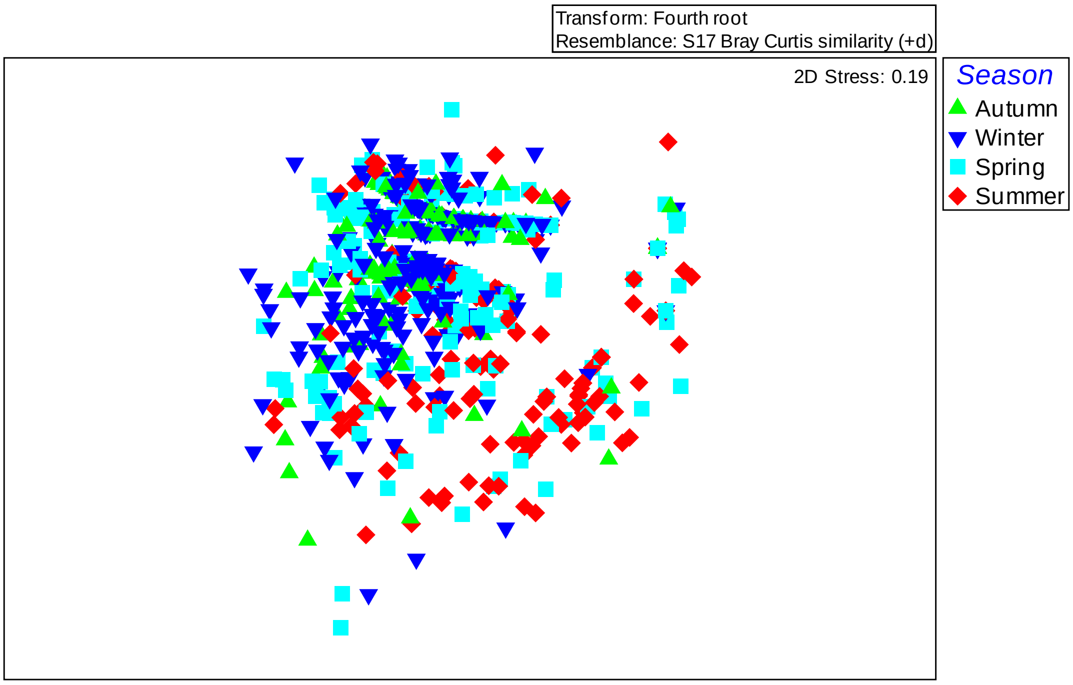

Figure 2.35. Non-metric MDS ordination plot of epibenthic invertebrate abundance (4th root transformed) between seasons.

ANOSIM analysis

The PERMANOVA tests indicates statistical differences between species assemblages within all seasons however for many of these pairwise comparisons sample size is low due to inconsistent replication during each season. Additional statistical investigation was undertaken to look at differences within the season with the greatest and most consistent sample size. Therefore one-way ANOSIM's using the single most consistently sampled season (Winter) were performed.

The ANOSIM outputs confirmed the results of the PERMANOVA testing; fish assemblages were significantly different between construction periods within winter months. Further pairwise comparisons indicate that differences occur between Baseline and Operation periods and Construction and Operation periods (Table 2.8). Global R values remained low in all cases. A low global R value denotes an overlap in the spread of the data points between construction periods so the samples are relatively similar (i.e. there is relatively little separation of data points in two dimensional multivariate space). It provides an indication of the spatial distribution of sampling stations in multivariate space which is graphically represented by the ordination plots.

Table 2.8. ANOSIM outputs investigating differences between fish and invertebrate benthic assemblages between construction periods using data collected during winter months only (significant results in red).

Data	Global R	p value	Pairwise comparisons
Fish	0.031	0.023	Baseline – Construction (R = -0.011, p = 0.616) Baseline – Operation (R = 0.087, p = 0.003) Construction – Operation (R = 0.038, p = 0.009)
Invertebrates	0.101	0.001	Baseline - Construction (R = 0.017, p = 0.278) Baseline – Operation (R = 0.137 p = 0.001) Construction – Operation (R = 0.138, p = 0.001)

The ordination plot indicates a close clustering of the majority of sampling stations, outlying stations are in every case represented by trawls where no fauna were recorded (Figure 2.36). These stations were mainly recorded during successive winter surveys in the first year of construction. The ordination plot presented depicts sampling stations in multivariate space zoomed in on the main cluster of points in the centre of the plot, this excludes the outlying sample points from the figure (Figure 2.36). No separation is visible between sampling stations collected within distinct construction periods.

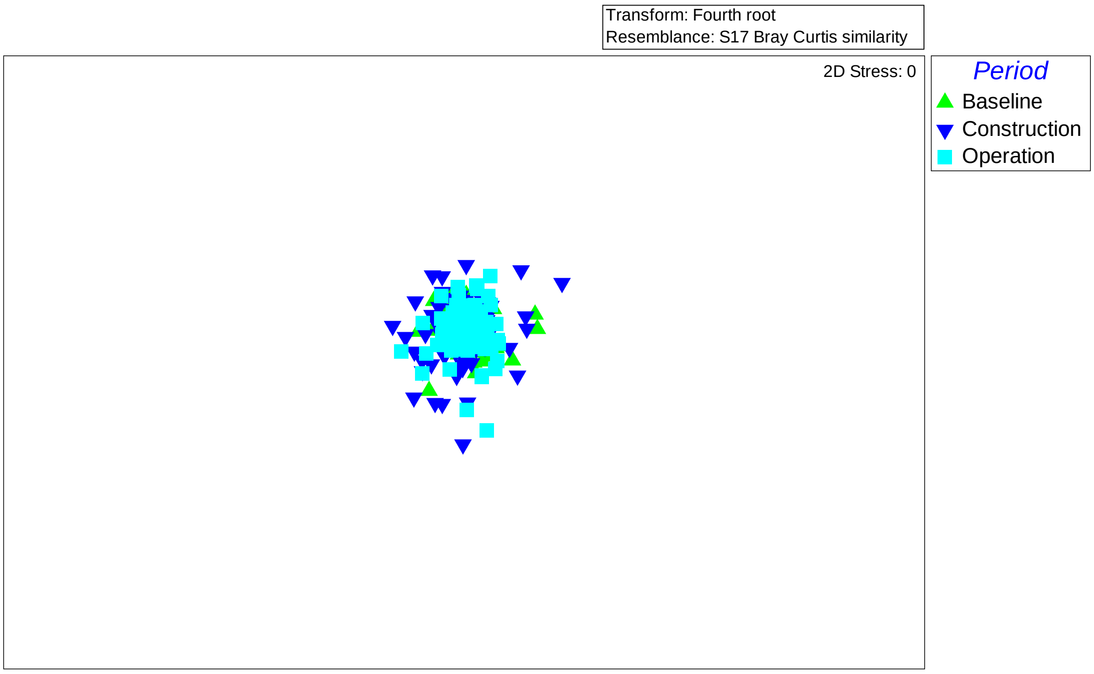

Figure 2.36. Non-metric MDS ordination plot of fish abundance (4th root transformed) surveyed during winter months between each construction period. Note: the ordination plot is zoomed in to the central cluster to provide an indication of the distribution of the majority of the data points in multivariate space. This excludes outlying data points from the ordination plot.

Using the SIMPER function in PRIMER the top five species contributing to dissimilarity between the Baseline and Operation periods and the Construction and Operation are responsible for over 60 % of the dissimilarity between assemblages in both pairwise comparisons. In both comparisons plaice, dab and whiting are the top three contributors to dissimilarity, this coincides with the most abundant species recorded throughout the environmental monitoring programme. Of the top five species there are no species contributing disproportionately to dissimilarity; contributions to dissimilarity vary between 9.8 and 15.4 %. This suggests that fluctuations in the most abundant species are responsible for differences between construction periods. Full SIMPER results are presented in Appendix 1.

ANOSIM analysis confirmed that benthic invertebrate assemblages differ significantly between construction periods (see Table 2.8) however the global R value is extremely low suggesting there is no clear separation of sample stations in multivariate space by construction period (i.e. there is a degree of overlap in the similarity of the samples). Pairwise comparisons confirmed that invertebrate assemblages differed significantly between Baseline and Operation periods and between Construction and Operation. The ordination plot of the entire winter dataset indicates a tight clustering of the majority of survey stations with the remaining seven stations distributed around the cluster. The majority of these stations are represented by those trawls where no fauna was recorded. The ordination plot presented zooms in on the central cluster and excludes the outlying stations from the plot. No clear separation of sample stations collected during each construction periods was evident for epibenthic invertebrate assemblages (see Figure 2.37).

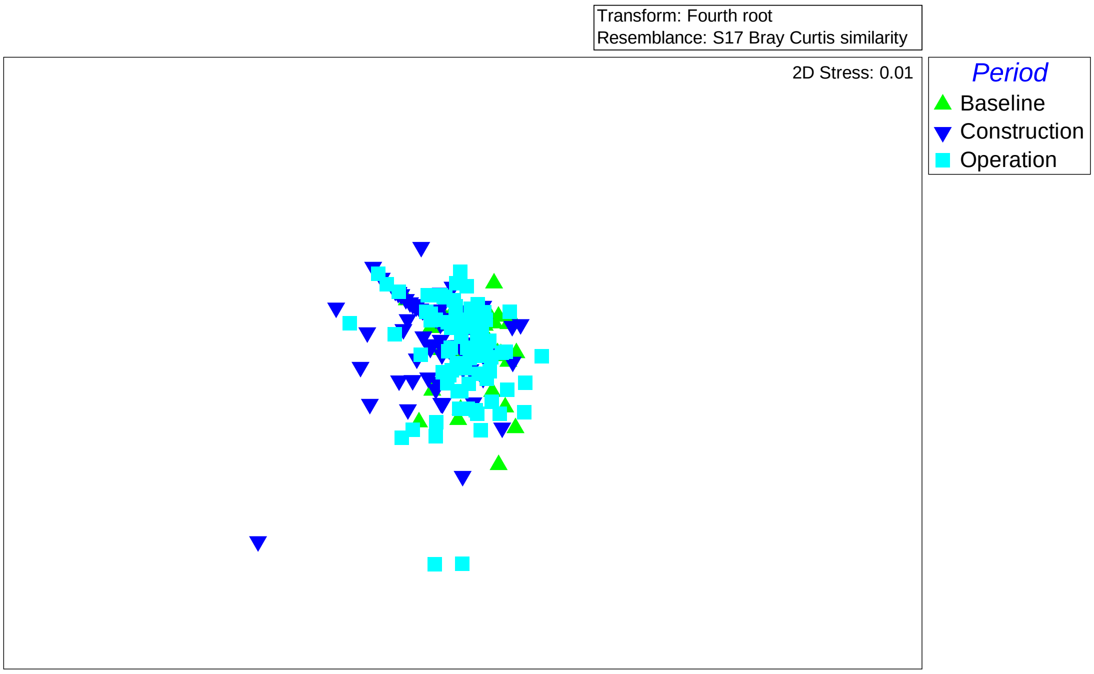

Figure 2.37. Non-metric MDS ordination plot of epibenthic invertebrate abundance (4th root transformed) surveyed during winter months between each construction period. Note: the ordination plot is zoomed in to the central cluster to provide an indication of the distribution of the majority of the data points in multivariate space. This excludes outlying data points from the ordination plot.

SIMPER analysis identified that brown shrimp contributes to 22.7 % and 23.7 % dissimilarity between the Baseline – Operation and Construction – Operation pairwise comparisons respectively. This suggests that brown shrimp is the most important species driving dissimilarity between construction periods. In both instances *Ophiura ophiura* and *Pagurus bernhardus* were second and third in the SIMPER tables. Collectively these three species contribute to 50 % of the dissimilarity between pairwise comparisons where a significant difference was detected through ANOSIM.

2.4.8. Variation in catch invertebrate communities between Operation Years

Comparisons between fish and epifaunal invertebrate assemblages between Operation years was undertaken on winter only data as this was the only month consistently sampled between years using one-way ANOSIM. Differences between both fish and invertebrate assemblages were significantly different between Operation years. Further pairwise comparisons indicated significance between all years in both cases (Table 2.9).

Table 2.9. ANOSIM outputs investigating differences between fish and invertebrate benthic assemblages between construction periods using data collected during winter months only (significant results in red).

Data	Global R	p value	Pairwise comparisons
Fish	0.231	0.001	2011 - 2012 (R = -0.247, p = 0.001) 2011 – 2013 (R = 0.350, p = 0.001) 2012 – 2013 (R = 0.099, p = 0.002)
Invertebrates	0.101	0.001	2011 - 2012 (R = 0.333, p = 0.001) 2011 – 2013 (R = 0.381, p = 0.001) 2012 – 2013 (R = 0.11, p = 0.001)

The R-values associated with the analysis of both fish and invertebrate assemblages was low indicating very little separation between sample points in two dimensional multivariate space. The ordination plot for fish assemblages had a stress value of 0.23 and so the distribution of sampling points is likely to be distributed somewhat randomly and so must be interpreted with some caution. The ordination plot for epibenthic invertebrates confirms that there is very little separation of sampling points by Operation Year.

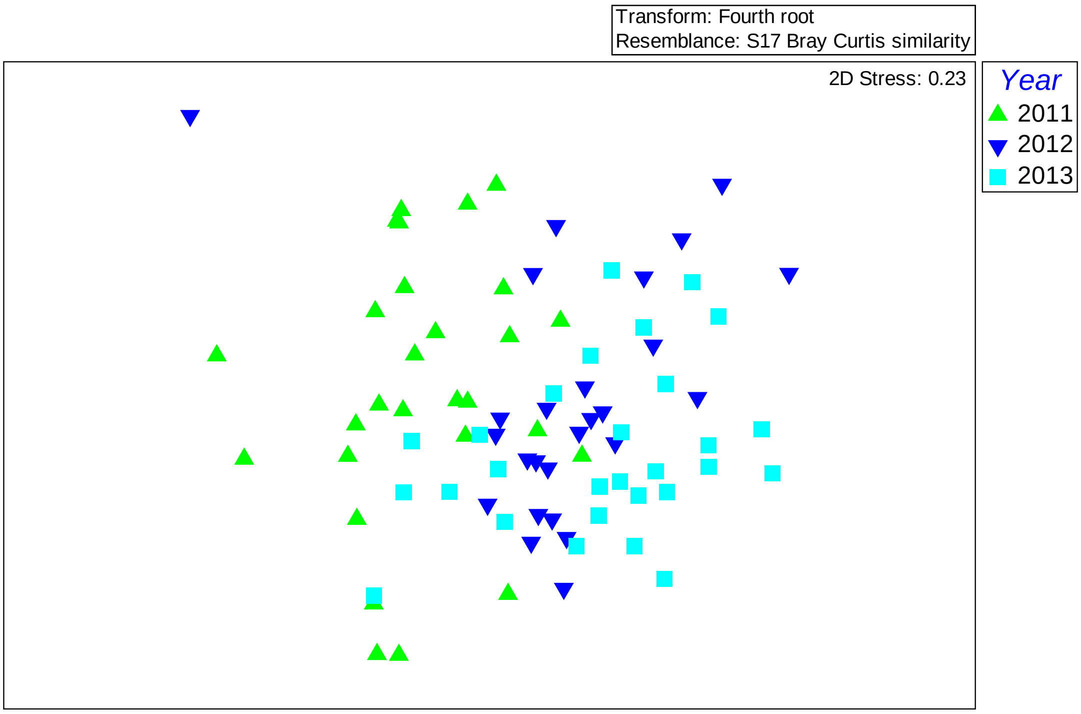

Figure 2.38. Non-metric MDS ordination plot of fish abundance (4th root transformed) surveyed during winter months in the Operation Years 2011, 2012 and 2013.

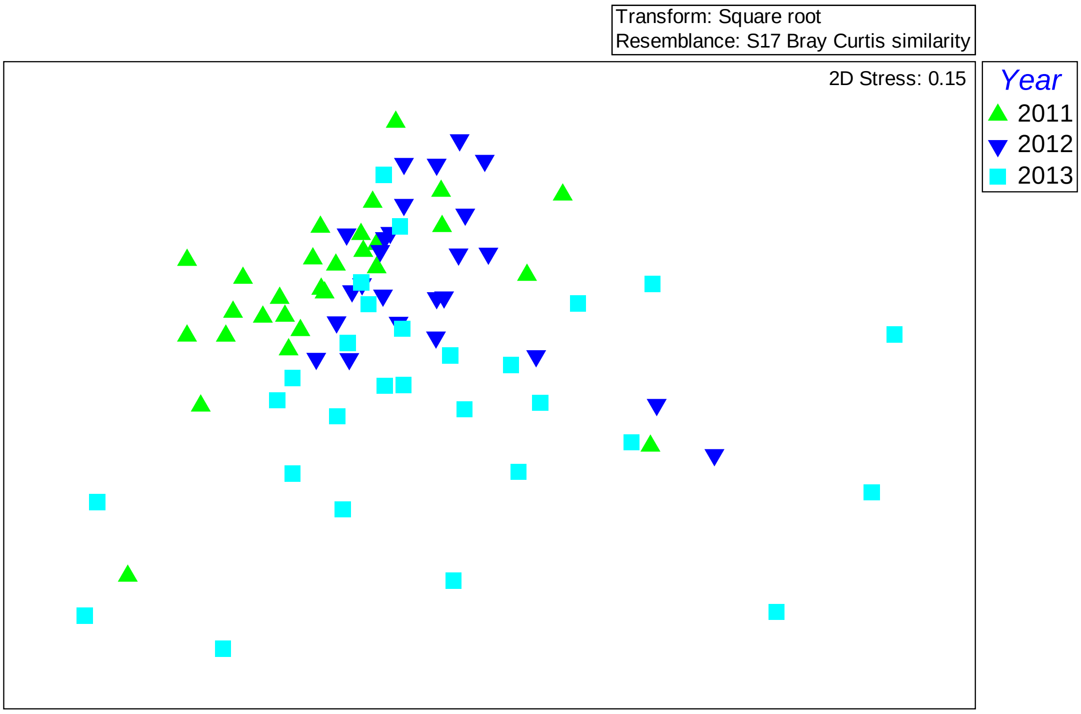

Figure 2.39. Non-metric MDS ordination plot of epibenthic invertebrate abundance (4th root transformed) surveyed during winter months in the Operation Years 2011, 2012 and 2013.

2.4.9. Variation in catch invertebrate communities inside and outside the tidal ellipse

Significant differences were detected between fish assemblages and epifaunal invertebrate assemblages between groups within and outside one tidal excursion of the site (Table 2.10). Again low R-values indicate that data points representing each trawl are cluster closely together in multivariate space.

Table 2.10. ANOSIM outputs investigating differences between fish and invertebrate benthic assemblages between construction periods using data collected during winter months only (significant results in red).

Data	Global R	p value
Fish	0.062	0.001
Invertebrates	0.043	0.001

ANOSIM analysis conducted on the entire dataset indicated that a number of pairwise comparisons between the groups defined by a specific construction period and tidal location (inside or outside one tidal excursion) were significantly different (Table 2.10). R values remained low for all comparisons indicating very low separation between groups. Significant values were identified between 10 of the possible 15 pairwise comparisons (Table 2.11). No obvious pattern was evident in the significance between stations inside and outside one tidal excursion of the site.

Table 2.11. ANOSIM pairwise comparison results for fish assemblages sampled inside and outside one tidal excursion of Robin Rigg Offshore Wind Farm during each construction period (significant results in red).

Baseline - Inside						
Baseline - Outside	R = -0.005 P = 0.57					
Construction - Inside	R = 0.039 p = 0.003	R = 0.088 p = 0.003				
Construction - Outside	R = 0.08 p = 0.019	R = 0.065 p = 0.001	R = 0.091 p = 0.008			
Operation - Inside	R = 0.062 p = 0.02	R = 0.099 p = 0.015	R = 0.027 p = 0.125	R = 0.146 p = 0.002		
Operation - Outside	R = 0.027 p = 0.178	R = 0.061 p = 0.001	R = 0.031 p = 0.135	R = 0.041 p = 0.002	R = 0.043 p = 0.157	
	Baseline - Inside	Baseline - Outside	Construction - Inside	Construction - Outside	Operation - Inside	Operation - Outside

ANOSIM analysis was also used to compare epibenthic invertebrate communities inside and outside one tidal excursion of the site during each construction period. Significant variations in invertebrate assemblages were recorded between those pairwise comparison groups outside one tidal excursion between each construction period (Table 2.12). Any pairwise comparison involving a group within one tidal excursion, was not significantly different from any other group.

Table 2.12. ANOSIM pairwise comparison results for epibenthic invertebrate assemblages sampled inside and outside one tidal excursion of Robin Rigg Offshore Wind Farm during each construction periods (significant results in red). Pairwise comparisons in grey are between test groups that are not likely to provide a direct indication of wind farm effects.

Baseline - Inside						
Baseline - Outside	R = 0.006 p = 0.411					
Construction - Inside	R = 0.009 p = 0.112	R = 0.062 p = 0.056				
Construction - Outside	R = -0.023 p = 0.725	R = 0.026 p = 0.001	R = -0.009 p = 0.564			
Operation - Inside	R = 0.036 p = 0.093	R = 0.072 p = 0.067	R = 0.006 p = 0.355	R = 0.00 p = 0.492		
Operation - Outside	R = -0.011 p = 0.625	R = 0.146 p = 0.001	R = -0.011 p = 0.61	R = 0.068 p = 0.001	R = -0.04 p = 0.815	
	Baseline - Inside	Baseline - Outside	Construction - Inside	Construction - Outside	Operation - Inside	Operation - Outside

2.4.10. Variation in catch invertebrate communities with distance from wind farm

BIOENV analysis was applied using the BEST program in PRIMER to identify any correlation between benthic assemblages and environmental variables. In this case the only environmental variable available for analysis is distance to the nearest turbine location. The resulting Spearman's rank correlation coefficient indicates extremely low correlation between both benthic fish and invertebrate communities and distance from the wind farm (see Table 2.13).

Table 2.13. The Spearman rank correlation coefficient of the correlation between benthic fish and invertebrate assemblages recorded during winter months only and distance to the closest turbine.

Benthic Community	Correlation
Fish	0.048
Epifaunal invertebrates	0.069

2.5. Discussion

The analysis undertaken on the fish and epibenthic invertebrate data was used to identify any temporal or spatial trends that could be linked to the construction and operation of the Robin Rigg Offshore Wind Farm. The data analysis also showed any trends occurring in commercially important species. The fish and epibenthic invertebrate assemblages recorded in the Solway Firth during the non-migratory fish and electro-sensitive fish survey are all common to the area. Over the 12 years of surveys conducted there were no species recorded that were of rare or high conservation value.

The present study considered broad-scale changes in fish and epibenthic invertebrate assemblages over time, between construction periods and at distance from the wind farm, taking into account seasonal differences, in the Inner Solway Firth area.

2.5.1. Impact of Construction and Operation

Temporal differences between construction years

Multivariate and univariate statistical investigations revealed that differences in fish and epifaunal assemblages have varied significant between construction period and year. Both PERMANOVA and ANOSIM revealed significant differences between construction years in fish and epifaunal species assemblages between construction periods. Within the PERMANOVA pairwise comparisons for each season, the number of samples was often very low as a result of the inconsistent sampling regime. To account for this the one-way ANOSIM assessing for differences between construction periods during winter samples is more robust. The ANOSIM revealed that there were significant differences between Baseline and Operation periods and Construction and Operation periods, but not between Baseline and Construction. This was reflected in both the fish and epifaunal invertebrate datasets. These changes in species assemblage were also accompanied by changes in catch abundance of fish, invertebrates, brown shrimp and whiting during construction.

If any impacts occurred during construction there is a possibility that recovery would be gradual throughout the Operational period, therefore variation between Operational years was investigated to identify any patterns. Low fish and invertebrate catches in 2011 followed by an increase in 2012 for fish and epifaunal invertebrates suggested that the assemblages may have been in a state of recovery. However, this is purely speculative as variation in fish and invertebrate assemblages cannot be linked to the wind farm activities within the current experimental design. Furthermore, in 2013 fish catch rates dropped. Initially, invertebrate catch rates appeared to increase but scrutiny of the data set identified large numbers of dense brittle stars (*Ophiura ophiura)* to the north west of the survey area as the cause of this increase in catch. Brittlestar beds to the north west of the site are likely to be a result of different habitat conditions, namely a finer sandy mud substrate identified during EIA investigations. This is likely to be unrelated to the wind farm presence due to the distance from the site. When *Ophiura ophiura* is removed from the dataset a similar pattern to the fish catch is observed, namely, a reduction in catch rates. Multivariate analysis confirms that there are significant differences between species assemblages during each of the Operation year.

The variations in catch and the species assemblages during the Operational years, i.e. in the absence any major modification of the marine environment as a result of the wind farm, point to the influence of natural temporal and spatial fluctuations that are typical of dynamic estuarine systems (e.g. Tulp *et al*, 2008; Ysabaert *et al*, 2003). In addition it must be noted that the largest decline in catch of fish, invertebrates, brown shrimp and whiting and changes in the species assemblages during the construction period occurred in the absence of construction activity. Very little construction took place during construction year 1 when the lowest catch rates were recorded (Entec, 2011). The majority of construction, particularly piling activity was undertaken in construction year 2. Therefore, it is unlikely that any significant changes during this period were related to construction activity.

Furthermore, although it is not possible to examine this, statistically it is possible that one of the principal reasons for a decline in catch rates since the baseline survey is due to a combination of the effects arising from shifting sand banks within the Inner Solway. During the baseline survey sampling locations were selected through consultation with local fishermen to maximise catch by following the channels adjacent to the sand banks within the study area. Subsequent surveys during the Construction and Operational periods were conducted at the same survey locations in accordance with the MEMP. However, as the Solway Firth is a mobile sand bank system influenced by tidal currents, the original sandbanks surveyed in 2001 had shifted by the commencement of the construction period surveys. As a result variation in catch abundance and species composition may be a result of shifting sand banks as catch rates of brown shrimp are known to be considerably on top of sandbanks than within the channels (Lancaster, 1998).

Multifactorial testing and an assessment of the standard error of the means recorded between seasons also indicated seasonal effects on fish and epifaunal invertebrate assemblages. It is evident from the analysis that within specific seasons variations occur throughout all construction periods with regards to multivariate data and univariate metrics. Seasonal migration of the brown shrimp population is known to occur between the inner and outer Solway Firth which in turn drives movements of predatory fish species (Lancaster and Frid, 1998) therefore it is unsurprising that seasonal differences were detected. This may validate the conclusion within the ES that the presence of magnetic fields would not result in migration effects on species in the Solway Firth. Seasonal effects were significant throughout the monitoring program suggesting that the presence of cabling did not result in significant changes in migration patterns. This is supported by Bochert and Zettler (1994) who did not observe any effect of magnetic fields on brown shrimp and pleuronectid flat fish.

Spatial differences

As a result of the dynamic nature of marine communities it is difficult to identify anthropogenic and natural changes in either species assemblages or catches by comparing temporal data between years (or in this case construction periods). Another method is used to compare data spatially.

The EIA for the Robin Rigg Offshore Wind Farm identified potential pathways such as increased suspended sediment that could occur during construction. As this is a pathway likely to be affected by tidal excursion ANOSIM analysis was used to test any differences between fish and invertebrate assemblages inside and outside one tidal excursion of the site. For fish assemblages differences were significant between a number of groups, but no clear pattern was identified. The results suggest that fish assemblages have continued to fluctuate across the site irrespective of locality within or beyond one tidal excursion of the site. For epibenthic invertebrate assemblages, significant differences were only observed between groups representing sites outside one tidal excursion for each construction period. This is expected given that sites beyond one tidal excursion incorporate more varied habitat conditions than the sites inside one tidal excursion which are located around the sand bank on which the wind farm is situated. Thus variation in invertebrate assemblages beyond one tidal excursion is likely to be greater.

The number of sampling stations within each group is also likely to affect the analysis with only 7 stations available within one tidal excursion but 21 available outside. The unbalanced nature of the dataset also results in greater replication during the Baseline period, with the lowest level of replication during the Operation period. This could explain why significance was more common between sites outside the tidal excursion and during the Baseline and Construction periods where variability was more precisely quantified. Furthermore, seasonal effects are not considered in the analysis and this is likely to further increase confounding factors within the study area, the analysis assumes that seasonal variations will affect sites inside and outside one tidal excursion uniformly although this may not be the case. As a result care must used when interpreting the results of the analysis in the context of possible effects on wind farm Construction and Operation.

This is further supported by the results of the BEST analysis which attempted to correlate varying species assemblages with distance from the wind farm. The aim of this analysis was to determine any effects that may be attributable to turbine presence. This analysis assumes that effects as a result of turbine presence decreases with distance from the site as reported by Coates *et al* (2010) albeit on a smaller scale. The low levels of correlation between species assemblages and distance from site for both fish and epibenthic invertebrate assemblages as determined from BIOENV analysis suggests wind farm presence is not driving change within the Solway Firth.

Impact of wind farm vs. natural fluctuations

Significant differences between years and sampling locations is to be expected in fish and epibenthic assemblages where environmental conditions are highly dynamic. The communities present are representative of typical estuarine environments such as those prevalent in the Inner Solway. In estuarine systems natural inter annual fluctuations have been commonly recorded in fish and benthic invertebrate assemblages around Europe (Henderson & Bird, 2010; Tulp *et al*, 2008; Ysabaert *et al*, 2003). Henderson & Bird (2010) noted rapid fluctuations in species assemblages and macro-crustacea in the Severn Estuary but was unable to correlate this to any single environmental variable. The study speculated that climate change and changes to the North Atlantic oscillation, amongst other abiotic and biotic factors, may affect species composition and abundance. This is supported by Cheung *et al* (2009) who postulate that changing ocean temperatures are large scale drivers of variation in fish distribution.

Abundances of fish and epibenthic invertebrate assemblages could also be affected by sequential immigration occurring in different magnitudes between year (Henderson and Bird, 2012). Seasons of high production where particularly strong year classes result in increased recruitment could result in varying abundances recorded between periods and during different seasons. Efforts to identify causal relationships in recruitment have been unable to identify specific environmental, anthropogenic or biological drivers; it is more likely that a number of factors are driving variation (Brunel & Boucher, 2007).

At the Robin Rigg Offshore Wind Farm solenette, grey gurnard, whiting and sprat all exhibited an increase during the operational phase. Due to the absence of any sampling stations within the wind farm boundary and a lack of a continuous data replicated equally over time it is only possible to speculate the drivers behind this change in fish species abundance. Bull and Kendall Jr (1994) suggest that fish may be attracted to artificial reefs as nursery locations. The Solway Firth is known to be a nursery area for many species; size frequency distribution suggests that at least two year classes of plaice, dab and whiting remain in the estuary before moving further into the Irish Sea. These species may be benefiting from additional shelter provided by the Solway Firth Wind Farm. However, no studies have observed effects beyond the boundary of the wind farm (Coates *et al*, 2010; Reubens *et al*, 2010, Wilhelmsson and Malm, 2008). Survey locations within the wind farm boundary would be needed to determine reef effects as a result of foundation and scour protection presence.

A question often raised is whether these changes in fish abundance are reflected in the wider Solway Firth and Irish Sea. Fisheries landings data may provide an indication of stock health, however, it is important to note that landings data is not effort corrected and so is strongly influenced by days at sea. Furthermore, it is heavily influenced by quotas which may further affect reported landings tonnage. In addition, within the study area only 0.65% and 0.02% plaice and whiting respectively are of commercially exploitable size. Juveniles recorded during the survey are likely to take between one to three years before reaching marketable size (based on year classes observed in size frequency graphs) and so there is likely to be a time lag between any effects on stock size in the Irish Sea and the Robin Rigg Offshore Wind Farm. Furthermore, any trends would be based on the assumption that whiting and plaice landed on the Cumbrian coast use nursery grounds in the Solway Firth before being recruited to the adult stock. Other nursery grounds around the Irish Sea and possibly beyond may also contribute to the adult stock. Landings data provided by the MMO indicate that for three of the most common commercially exploited fish species plaice, dab and whiting landings have declined in recent years and that this reduction occurred prior to construction of the wind farm. This contradicts the current survey findings which observed an increase in whiting abundance during the monitoring program suggesting that landings data fluctuates independently of any potential wind farm effects (Figure 2.40, Figure 2.41 and Figure 2.42).

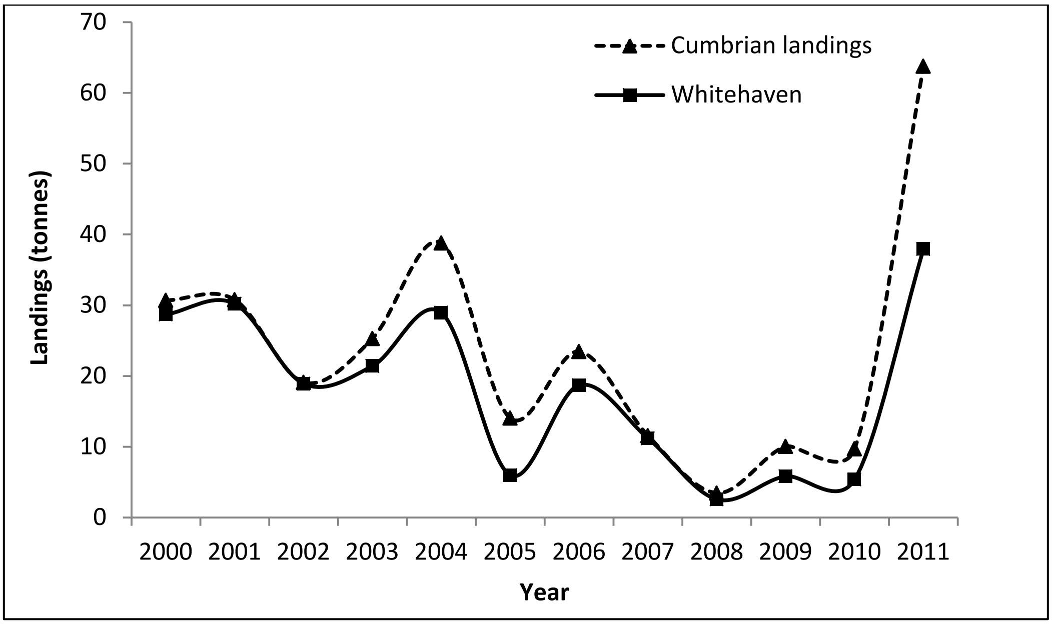

Figure 2.40: Plaice (P. platessa) landings data at Whitehaven and cumulatively at ports along the Cumbrian coast from 2000 to 2011. Data supplied by the MMO.

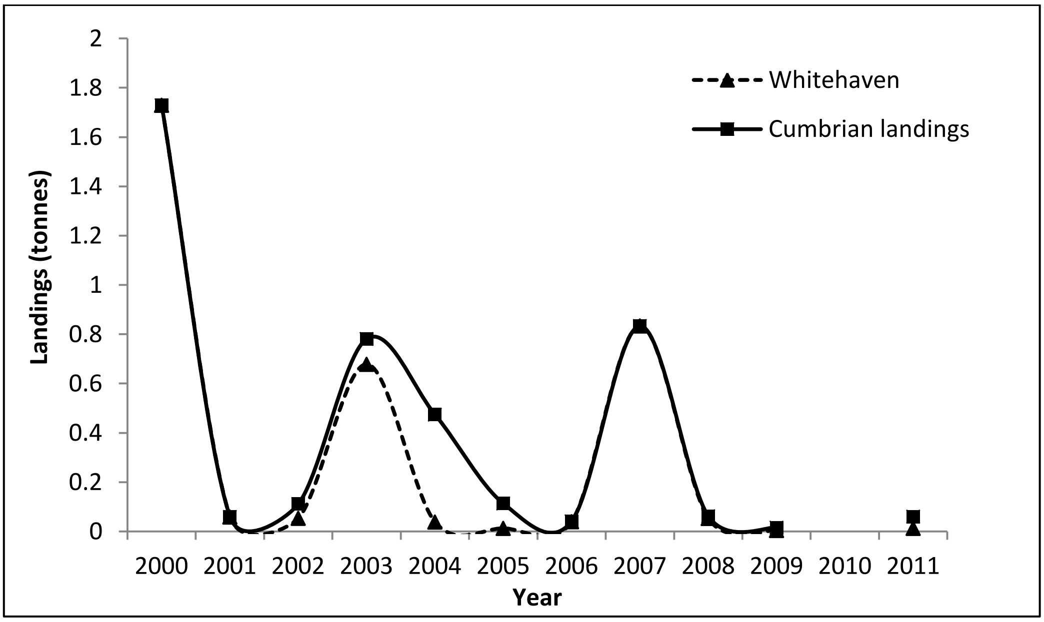

Figure 2.41: Dab (L. limanda) landings data at Whitehaven and cumulatively at ports along the Cumbrian coast from 2000 to 2011. Data supplied by the MMO.

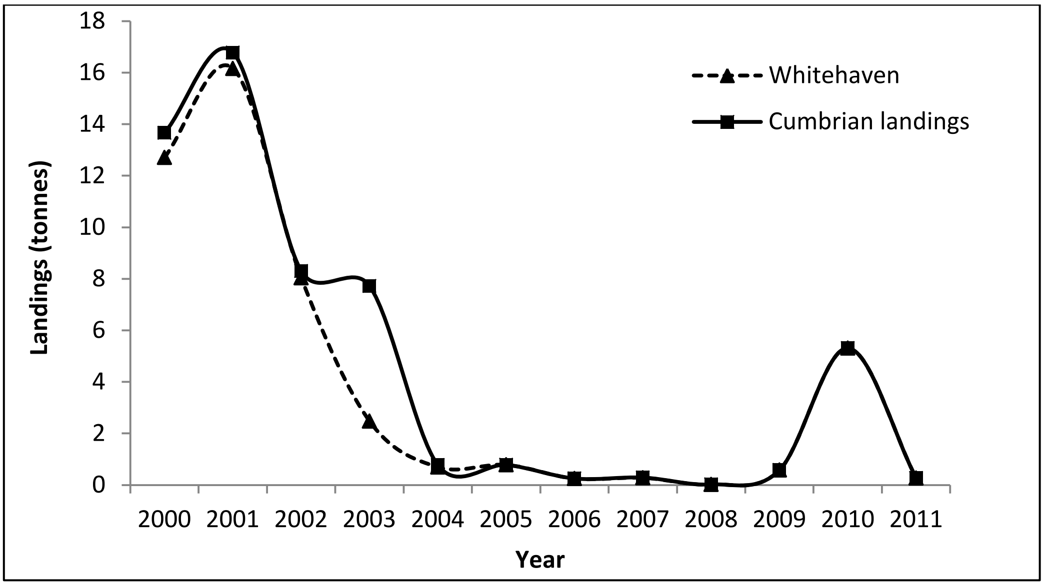

Figure 2.42: Whiting (M. merlangus) landings data at Whitehaven and cumulatively at ports along the Cumbrian coast from 2000 to 2011. Data supplied by the MMO.

Landings data for brown shrimp, in theory, can be directly compared with MEMP catch data as this fishery is based on the same sized individuals based on the assumption that the landings data reflects fishing effort. However, it is important to acknowledge that the Solway Shrimp vessels are not obliged to disclose their landings, hence the landing figures provided by the MMO are based on estimates (Figure 2.43). In addition landings often reflect market demand and are not effort related. Despite this caveat, the commercial landing figures for Cumbrian ports (none are available for Scottish ports) reveal that there has been a decline in brown shrimp landings since the year 2000 with the largest decline occurring prior to the construction of the wind farm.

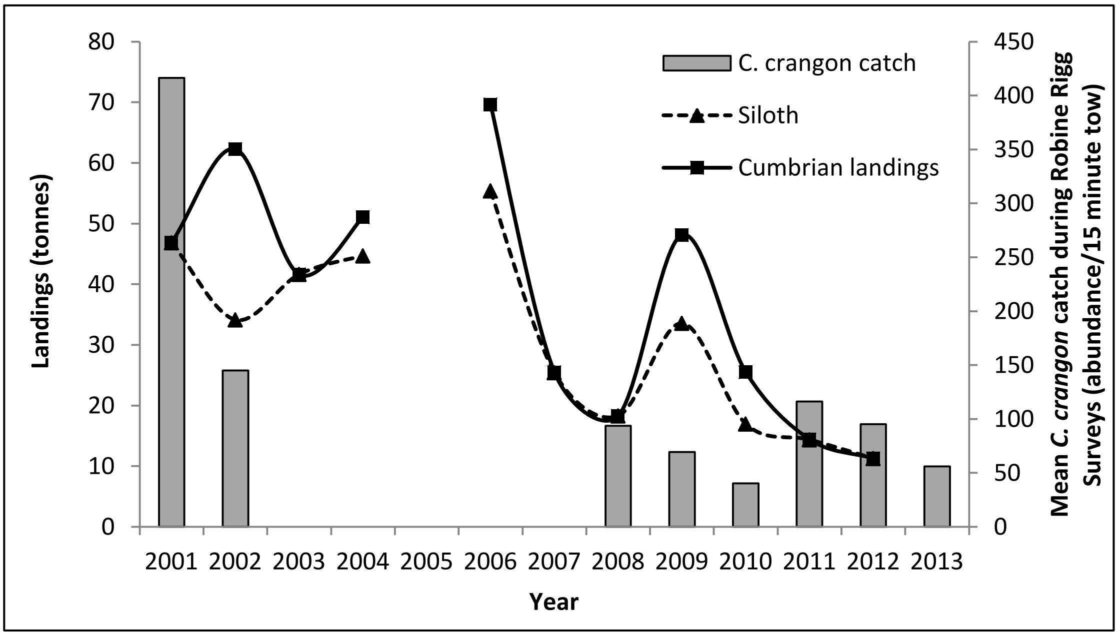

Figure 2.43: Landings data of the brown shrimp (Crangon crangon) fishery along the Cumbrian coast.

2.6. Conclusion

It is difficult to determine drivers of fish and epibenthic community shift within the Solway Firth and also differentiate between natural fluctuations and change as a result of anthropogenic pressures. Changing environmental conditions (such as the position of sandbanks and channels), natural cyclical events, the presence of Robin Rigg Offshore Wind Farm and vessels may all contribute to variation in community composition detected during the MEMP.

Empirical evidence from other wind farms in Northern Europe have recorded change in fish and invertebrate assemblages but not at the broad scale surveyed through the Robin Rigg Offshore Wind Farm MEMP. Following construction at the Belgian offshore wind farms, C-Power and Belwind, Reubens *et al*, (2009) and Coates *et al*, (2010) observed no large-scale impacts on macrobenthic populations during the first two years of operation. Coates *et al*, (2010) did however suggest that large scale changes could occur over a longer time scale and provided in excess of five years as an example.

In contrast many studies have reported effects on both fish and invertebrate assemblages around man made concrete structures in the marine environment (Coates *et al*, 2011; Leitao *et al*, 2008; Leitao *et al*, 2009; Reubens *et al*, 2011; Wilhelmsson *et al*, 2006; Wilhelmsson and Malm, 2008), however, this has been recorded on a small scale with changes only recorded in close proximity to the structures. Leitao *et al*, (2009) reports that increased attraction of fish species to an artificial reef may result in spill over into adjacent areas. Wilhelmsson *et al* (2006) also found an increase in small demersal species (gobies and blennies) abundance at a wind farm site in the Baltic Sea and speculates that reef effects on large demersal and pelagic species may be measureable but only within several hundred meters of the wind turbines. In the present study there is an increase in whiting catch during the operational phase. Reubens *et al* (2011) recorded increases in the gadoid pouting (*Trisopterus luscus*) during operation of a wind farm in the Belgian North Sea but the study did not assess change beyond the wind farm boundary. In the case of the Robin Rigg Offshore Wind Farm, the increased abundance in whiting numbers cannot be directly attributed to the presence of the wind farm as the closest trawl location in the present study was 437 metres from the nearest turbine. One can only speculate that increased whiting numbers beyond the site boundary are a result of reef effects and subsequent overspill from within the turbine array.

To date no evidence has been reported to suggest that offshore wind farms are likely to affect benthic communities beyond the boundary of the wind farm site (Coates *et al*, 2010; Reubens *et al*, 2009; Wilhelmsson and Malm, 2008). Reef effects have been known to result in spillover effects into adjacent areas however; this is generally reported for species known to have an affinity to reef habitats (Leitao *et al*, 2009). Further research is needed to determine the distance of effect that the introduction of hard substrata provided by offshore wind turbine foundations is likely to have on soft sediment benthic assemblages. In the marine environment, particularly in highly dynamic estuarine environments such as the Solway Firth, a number of abiotic and biotic factors will result in variation to a population. It is inherently difficult to disentangle natural drivers from anthropogenic drivers such as the construction and operation of an offshore wind farm.

Table 2.14: Predictions of likely effect presented in the Robin Rigg Offshore Wind Farm Environmental Statement and conclusions from the monitoring program.

ES Predictions	Conclusion
No significant impacts will occur to fish populations as a result of noise and vibration.	Lowest catch rates were recorded during the construction period however no data is available to suggest this impact is a result of construction activity. Variation in fish species composition did not correlate with distance from the wind farm.
No significant impacts would occur to fish populations as a result of sedimentation.	Sedimentation rates were not recorded. Changes in local hydrodynamics are unlikely to occur beyond the boundary of the wind farm. Conclusions cannot be determined from the current monitoring program.
No adverse effects on migration due to magnetic fields would occur.	Seasonal migrations occurred throughout the duration of the monitoring program suggesting that this was not affected by the presence of the Robin Rigg Offshore Wind Farm.
Redistribution of species of commercial importance or species of high conservation interest.	Effects on commercial species recorded during the monitoring program do not reflect changes in commercial landings data. Changes in fish abundance within the survey area cannot be used to infer effects on the Irish Sea stock.
Colonisation of foundation structures thereby increasing population sizes	Assessment of this prediction would need small scale surveys assessing colonisation of foundations and scour protection.
Redistribution of fish species in relation to change in water quality as a result of wind farm presence.	Water quality metrics were not measured during the monitoring program.

The results of the MEMP non migratory fish surveys highlights the difficulty in identifying impacts in fish and epifaunal invertebrate assemblages resulting from the Construction and Operation of offshore wind farms. Nonetheless it provides evidence that broad scale changes in fish and invertebrate communities are unlikely to occur at a magnitude beyond natural spatial and temporal variation.

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