E.ON Climate & Renewables

Analysis of Marine Ecology Monitoring Plan Data from the Robin Rigg Offshore Wind Farm, Scotland (Operational Year 2)

Technical Report

Chapter 4: Non-migratory Fish and Electrosensitive Fish

Report: 1012206
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Final Issue: 06/09/2013

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Robin Rigg Offshore Wind Farm, Scotland: Analysis of MEMP Ecological Data (Operational year 2) Technical Report

Chapter 4: Non-migratory Fish and Electrosensitive Fish

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Checked	Dr Jane Lancaster	21/09/2012
Approved	Dr Jane Lancaster	18/10/2012

Classification COMMERCIAL IN CONFIDENCE

Distribution Sally Shenton, E.ON Climate & Renewables

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Revision History

Issue	Date	Changes
A	18/10/2012	Draft Issue
B	17/01/2013	First Issue
Final	06/09/2013	Final Issue

4. NON-MIGRATORY FISH AND ELECTROSENSITIVE FISH

4.1. 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 are often poorly understood (Garthe & Huppop, 2004, Gill & Kimber, 2005, Petersen & Malm, 2006), and the recommendation that fish should be sampled closer to monopiles, to detect possible aggregations effects, and that benthic sampling should occur over longer time periods is prudent given wind farms long operational life spans (Walker, 2010).

Furthermore, fish such as (but not limited to) elasmobranchs e.g. thornback ray (*Raja clavata*) may be susceptible to the effects of electromagnetic fields such as those generated by electrical cables. Changes in electromagnetic and noise characteristics of the water column are of particular concern to these fish species, which rely on their ability to detect magnetic and acoustic stimuli for a number of behaviours including navigation and prey detection (Gill & Kimber, 2005). All elasmobranchs are able to detect magnetic fields, due to the Ampullae of Lorenzie (AoL), a group of pores on the surface of the skin that conduct electricity with a similar resistance to seawater. Some teleosts (bony fish such as plaice) are also able to detect magnetic fields (Gill *et al*., 2005), and whilst all electro and/or magneto sensitive species are acknowledged in this report, as per both COWRIE and FEPA guidance, the focal species are the elasmobranch. The reason for this being that shielding and burial are likely to attenuate much of the EMF from the cable, therefore only the most sensitive of species, i.e. the elasmobranches, are likely to be affected.

4.1.1. 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, which are detected by particularly electrosensitive species, and disturbance to 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.

4.1.2. 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*) and solenette (*Buglossidium luteum*), and whitefish such as whiting (*Merlangius merlangus*). Lesser weevers (*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 4.2.1 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 electrosensitive species such as 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*). North of the wind farm there is a brown shrimp (*C. Crangon)* fishery (Lancaster & Frid, 2002).

4.1.3. Temporal variation in fish communities

Fluctuations in fish and epibenthic populations and species assemblages are a feature of marine ecosystems, deriving from multiple drivers. For example, mean grain size, tidal currents and temperature amongst other environmental variables have all been reported as factors driving variation in fish and epibenthic communities (Genner *et al*, 2010; Ysabaert *et al*, 2003). Any assessment of change relating to specific anthropogenic activity in the marine environment (such as the installation of an offshore wind farm) must therefore be seen in relation to any long term changes in marine population, arising from either natural cyclical events or other anthropogenic impacts. 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*., 2012).

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 for example 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).

Fish diversity and abundance is strongly related to environmental factors, e.g. temperature fluctuations, and ecosystem-level changes 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).

4.2. Survey Methods

4.2.1. 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. 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 electrosensitive fish (see Section 4.5). These were undertaken during the pre-construction, construction periods, and operational periods in accordance with the requirements of the MEMP. **In accordance with the MEMP, no electrosensitive surveys were carried out in construction year 2** (Table 4.1).

Table 4.1: Summary of when fish surveys were conducted. NM = non-migratory fish; ES = electrosensitive 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	NM				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.
- Electrosensitive 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 electrosensitive fish surveys to take place.

4.2.2. Sampling methodology

The survey methodology for all non-migratory fish 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 . 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.

Tow duration at each station was 15 minutes. During some of the winter surveys, 15 minute tows were not possible (due to short daylight hours) therefore 7.5 minute tows were undertaken and the catch quantity standardised to 15 minutes. Start and finishing times and positions were noted using the vessel's Global Positioning System (GPS), depth was measured using the vessel's depth sounder and temperature was measured using the vessel's in-built thermometer. Surface water salinity was measured using a hand held refractometer and turbidity was measured using a Secchi disc. Prevailing weather conditions and sea state were also noted.

After each trawl, the number and size (total length[1]) of all large fish (including electrosensitive 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.

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

4.3. Analytical Methods

Replication rates and survey periods vary between the non-migratory fish survey and the electrosensitive fish survey. Habitat types vary between survey stations particularly along the export cable route where stations closer to shore are much rockier. As a result the two data sets have been separated for statistical investigation. This allows better determination of any effects on marine life as a result of the presence of the export cable and the presence of the wind farm.

Replication of trawl stations during each construction period has been inconsistent since the baseline. During construction periods survey effort varied between season. This prohibits the use of two-way ANOSIM analyses since construction periods where there are multiple surveys in one season and few in the other can result in detection of significance erroneously. The non-migratory fish survey was sampled most consistently during winter months and the electrosensitive fish survey sampled most consistently during summer months. Therefore, one way ANOSIM analysis was conducted on winter and summer data only for the non-migratory fish survey and electrosensitive fish survey respectively.

To investigate effects of season on fish and epibenthic invertebrate assemblages two-way PERMANOVA analysis was used.

Where outliers in the data skewed the results, for example, where trawls did not sample any fauna these were removed from the analysis.

Al statistical analysis was undertaken using the statistical package PRIMER v6. and R v. 2.14.

Multivariate statistics

All analysis was based on a Bray-Curtis similarity index. As the raw data consisted of sparse faunal abundance and species richness, with very high abundances of certain species (e.g. *Crangon crangon*) severe 4th root transformations were applied to the raw data. Winter survey data was analysed independently to remove seasonal variation as a confounding factor from the analysis using the non-migratory fish survey data. The same approach was applied to the electrosensitive fish surveys using summer months.

Due to the unbalanced nature of the survey over time construction periods have been grouped into three distinct periods for the analysis of the non-migratory fish survey data: baseline, construction and operation. Using this approach the effect of analysing unbalanced data is reduced since the baseline and construction periods both have 10 monthly surveys. Note the operational phase has 5 monthly surveys.

Statistical tests applied are non-metric Multidimensional Scaling (MDS) ordinations, Analysis of Similarities (ANOSIM), SIMPER analysis, BIOENV analysis and multifactorial PERMANOVA. Section 2.4.1 has a more in-depth explanation of each test.

Univariate statistics

The Shannon-Weiner diversity index was calculated for the fish and epibenthic invertebrates. Section 2.4.2 has a more in-depth explanation the Shannon-Weiner diversity index. Other univariate metrics compared between seasons and construction periods were total abundance, species richness and abundance of single species.

4.4. Non-Migratory Fish Results

4.4.1. Summary of catch

Since the baseline survey 39 species of fish and 64 species of invertebrates have been captured in the non-migratory fish survey over from baseline through to present (full details are presented in Appendix 4). The most common fish species were plaice (*Pleuronectes platessa*), dab (*Limanda Limanda*) and whiting (*Merlangius merlangus)* (*Table 4.2*). Brown shrimp (*Crangon Crangon*), brittle stars (*Ophiura ophiura*) and hermit crabs (*Pagurus bernhardus*) were the most common invertebrates captured (see Table 4.3).

Table 4.2: 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*	20,961
Dab	*Limanda limanda*	19,415
Whiting	*Merlangius merlangus*	10,066
Lesser Weever	*Trachinus vipera*	4,458
Solenette	*Buglossidium luteum*	2,766
Pogge	*Agonus cataphractus*	2,495
Sprat	*Sprattus sprattus*	1,485
Sand Goby	*Pomatoschistus minitus*	1,464
Sole	*Solea solea*	980
Scald Fish	*Arnoglossus laterna*	790

Table 4.3: 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*	95,235
Brittle Star	*Ophiura ophiura*	23,006
Hermit Crab	*Pagurus bernhardus*	2,177
Harbour Crab	*Liocarcinus depurator*	1,862
Common Starfish	*Asterias rubens*	623
Baltic Prawn	*Palaemon adspersus*	293
Plumose Anemone	*Metridium senile*	278
Pink shrimp	*Pandalus montagui*	138
Small shrimps	*Philocheras trispinus*	125
Small decapods	*Eualus gaimardii*	98

Mean fish catch varied with trawl location across the study area (Figure 4.1 and Figure 4.2). Catch was greatest at sites to the east and north nest of the wind farm site. The stations to the north east of the wind farm location recorded 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 4.3, Figure 4.4 and Figure 4.5). However, large mean catch was recorded at trawl locations in the north west of the survey area as a result of increased brittle star densities. 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 during operation surveys.

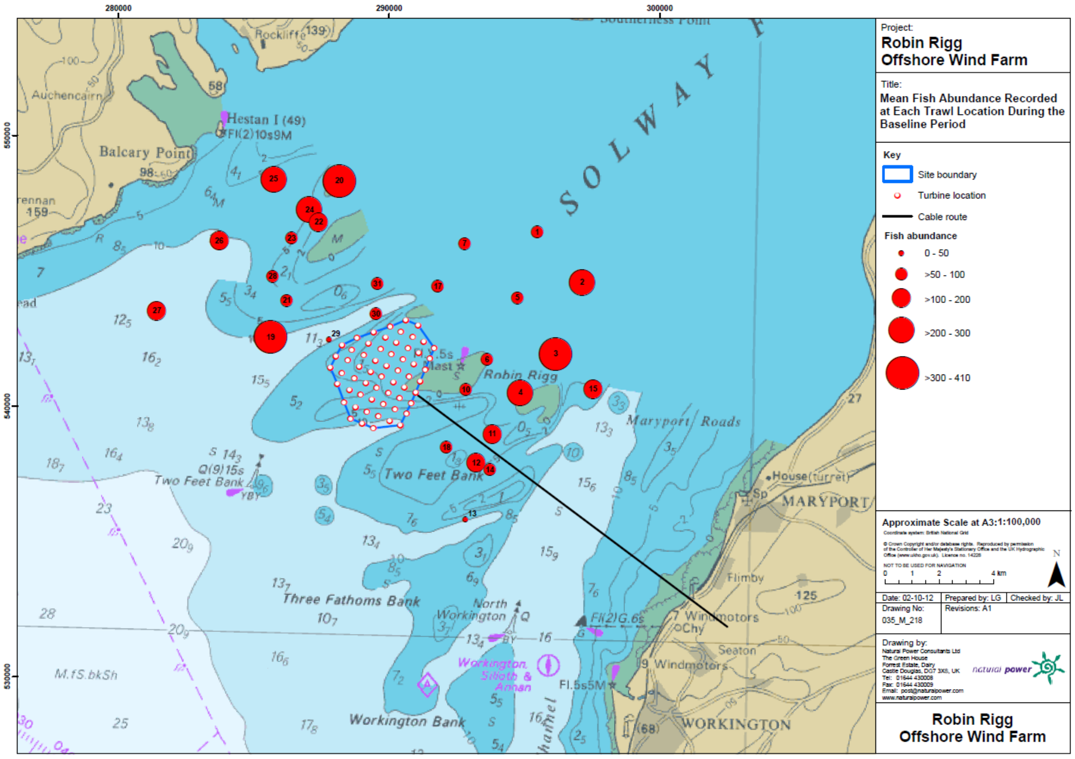

Figure 4.1: Mean fish abundance recorded at each trawl location during the baseline period.

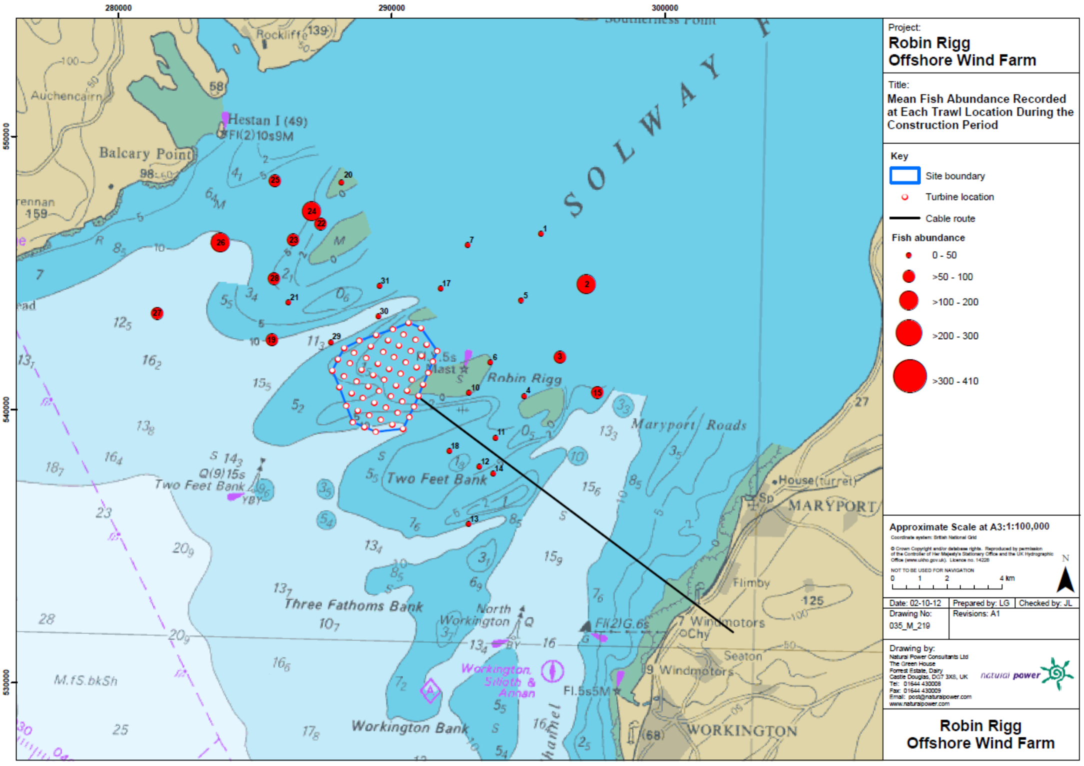

Figure 4.2: Mean fish abundance recorded at each trawl location during the construction period.

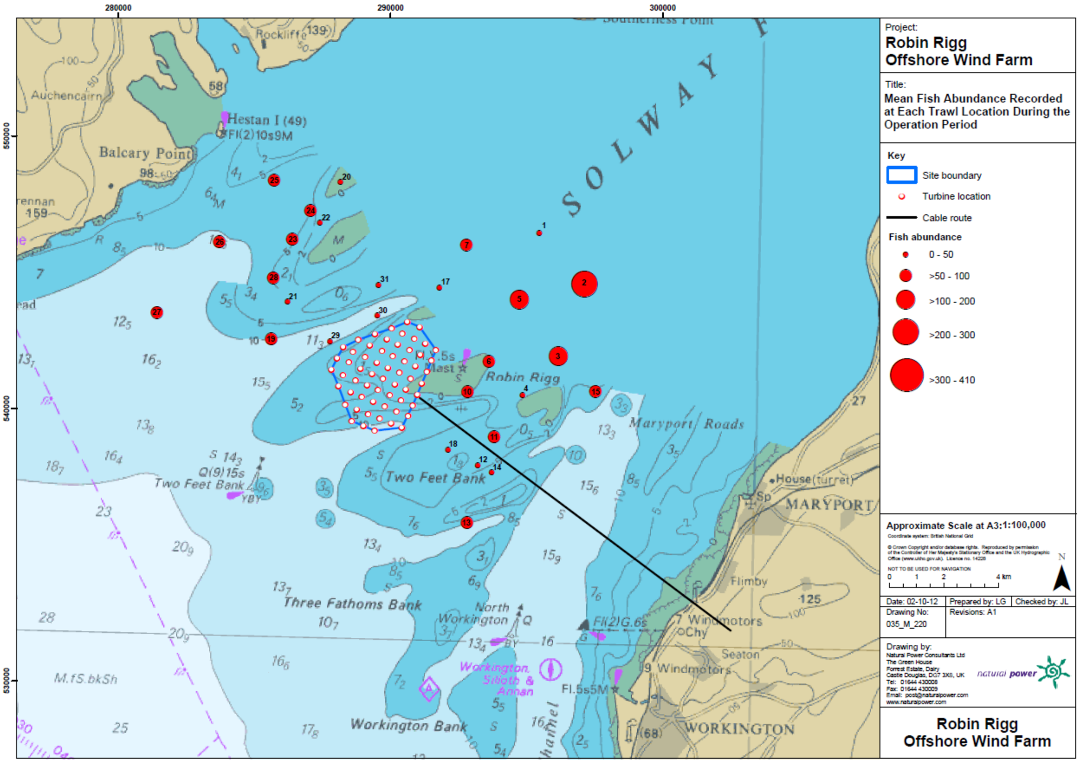

Figure 4.2: Mean fish abundance recorded at each trawl location during the operation period.

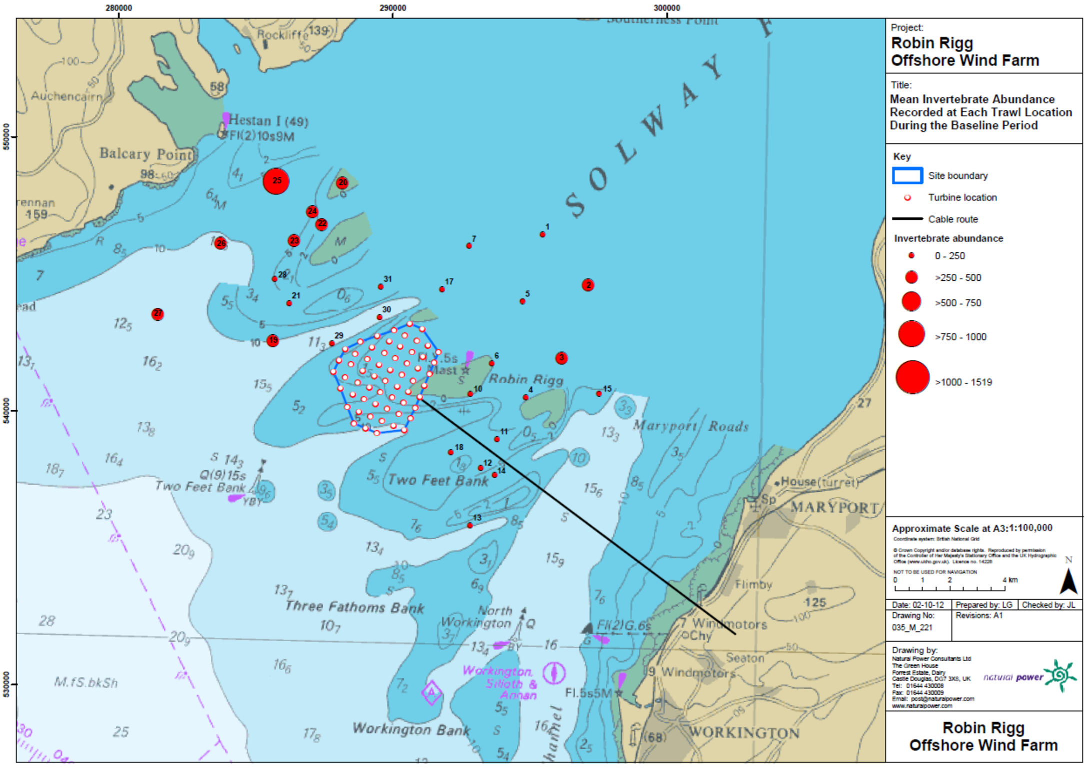

Figure 4.3: Mean invertebrate abundance recorded at each trawl location during the baseline period.

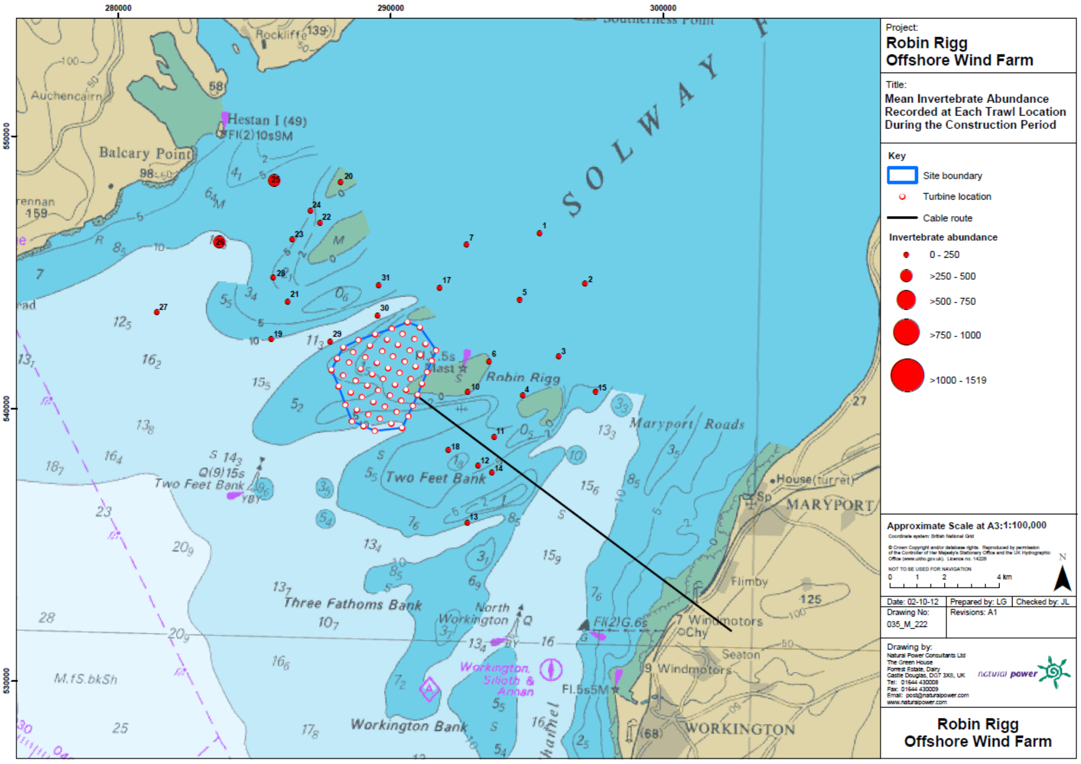

Figure 4.4: Mean invertebrate abundance recorded at each trawl location during the construction period.

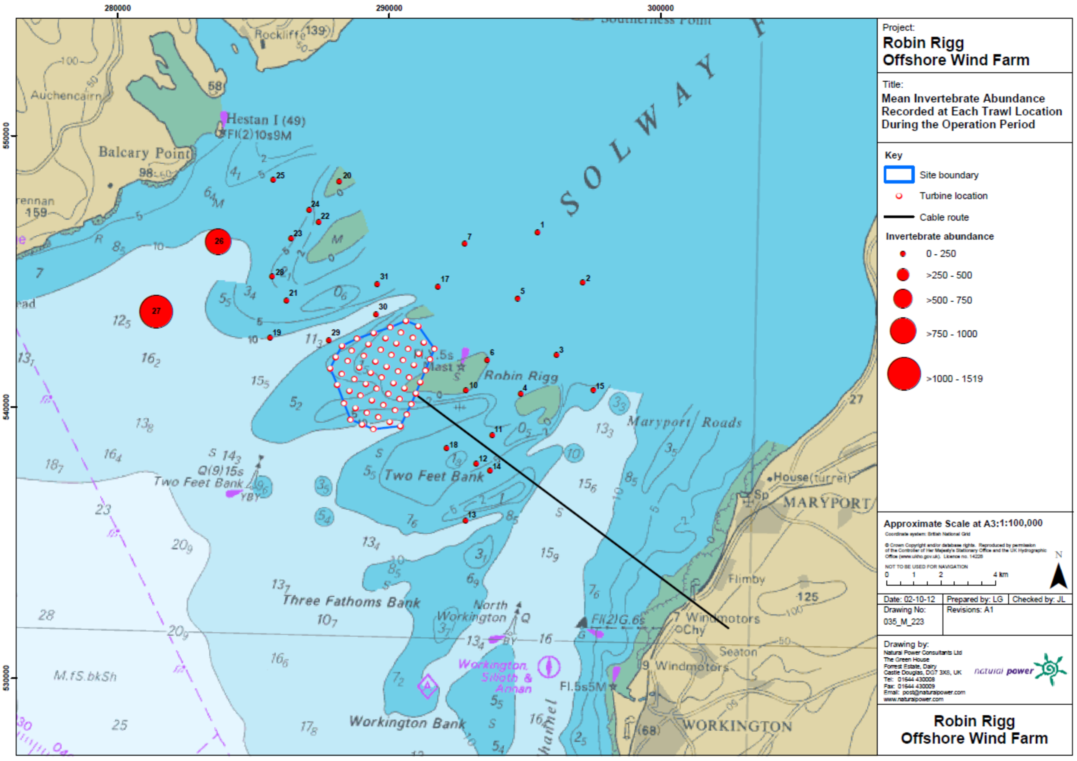

Figure 4.5: Mean invertebrate abundance recorded at each trawl location during the operation period.

4.4.2. Variations in fish and epibenthic community assemblages during each construction period

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 and invertebrates (see Figure 4.6). Fish catch dropped during the Construction period and increased slightly during the Operation period of the Robin Rigg Wind Farm. Invertebrate catch also dropped during the Construction period but increased during Operation. The increased invertebrate abundance during Operation was accompanied by a marked increase in variability between catches recorded during the same period.

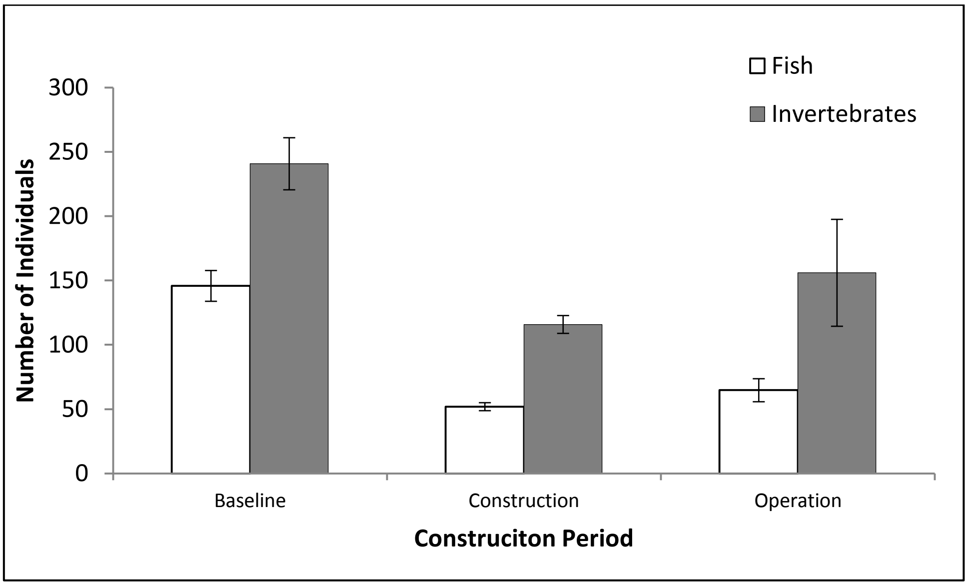

Figure 4.6: Mean catch (no. of individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

Using PRIMER v.6. a number of tests were conducted on the entire dataset investigating differences between construction periods and seasons for fish and invertebrates separately. Significance was detected between the fish and benthic invertebrate assemblages between construction periods surveyed during the winter months. However, seasonal variation also resulted in significant differences as indicated through multi factorial testing. The full analytical outputs are presented in NPC's benthic analysis report (NPC, 2012).

Table 4.4: 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	Significant pairwise comparisons
Fish	0.042	0.03	Baseline – Operation (R = 0.129, p = 0.001)
Invertebrates	0.059	0.02	Baseline – Operation (R = 0.129, p = 0.01), Constructon – Operation (R = 0.065, p = 0.022)

ANOSIM testing detected significance between fish assemblages between construction periods at a significance of P = <0.05 (see Table 4.4). The associated global R values were relatively low which suggests no separation of sampling stations based on construction period. For fish assemblages pairwise comparison confirmed that a significant difference exists between the Baseline and Operation assemblages only. The ordination plot produced for fish is not presented since the stress value associated with the plot is 0.25. A stress value approaching 0.3 indicates that the spatial distribution of data points in multivariate space are assigned almost arbitrary. Clarke (1993) recommends only interpreting ordination plots produced in MDS if the stress value is below 0.2. SIMPER analysis has been used to identify species within the assemblage that contribute most to dissimilarity between construction periods. Plaice and dab are the two biggest contributors to dissimilarity between the Baseline and Operation assemblages. Along with whiting these three species contribute to 40% of the dissimilarity between the two assemblages. The top five also include the lesser weever fish (*Echiichthys vipera*) and pogge (*Agonus cataphractus*) which cumulatively contributes to 60 % dissimilarity between the Baseline and Operation assemblages.

The top five species contributing to dissimilarlity between each significant pairwise comparison of fish assemblages have been selected to investigate change in catch between construction periods. These species drive significant differences that are detected between construction periods identified through ANOSIM therefore percent change has been calculated to quantify the difference in abundance of each species. In addition species of commercial interest and conservation concern have also been presented (see Table 4).

Since the baseline surveys solenette, grey gurnard, whiting and sprat have increased in abundance within the survey area. The remaining species have displayed a reduction in catch. The percentage change calculated for many species is based on extremely low sample sizes. This is the case for cod and the thornback ray which shows a 100 % decline in species abundance.

Table 4.5: 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.

	Baseline-Construction	**Baseline-Operaton**	**Construction-Operation**
Agonus cataphractus*	-52.77	-24.87	59.08
Aspitriglia cuculus	13.16	0.00	-11.63
Buglossidium luteum*	56.95	91.67	22.12
Callionymus lyra*	-54.77	-59.82	-11.17
Crangon crangon	-56.93	-69.88	-30.07
Echiichthys vipera*	37.60	-52.70	-65.63
Eutrigla gurnardus	60.29	171.82	69.58
Gadus morhua	-7.69	-100.00	-100.00
Limanda limanda *	-62.52	-72.47	-26.53
Merlangius merlangus *	-38.42	38.42	124.77
Pleuronectes platessa *	-80.83	-83.28	-12.79
Pomatoschistus spp.*	-74.17	-64.07	39.07
Raja clavata	-10.84	-100.00	-100.00
Scyliorhinus canicula	-73.72	-61.90	44.97
Solea solea*	-96.66	-99.07	-72.09
Sprattus sprattus*	-72.72	133.44	755.67

ANOSIM analysis confirmed that benthic invertebrate assemblages differ significantly between construction periods (see Table 4.4) however the global R value is extremely low suggesting there is no clear separation of sample stations in multivariate space by construction period. Pairwise comparisons confirmed that invertebrate assemblages differed significantly between Baseline and Operation periods and between Construction and Operation. Trawl 12 sampled in March 2003 only recovered one Baltic clam (*Macoma balthica*) resulting in this station being a clear outlier. The ordination plot depicting the spatial distribution does not include trawl 12 to better depict the spatial spread of sampling stations. No clear pattern between construction periods were evident (see Figure 4.7). SIMPER was conducted to further investigate differences between invertebrate assemblages during each construction periods. It is notable from the SIMPER analysis that the brown shrimp and the brittle star, *O. ophiura* contribute collectively to between 58% and 60% of dissimilarity between those pairwise comparisons where there is a significant difference in invertebrate assemblages. These two species are therefore largely responsible for the differences in benthic invertebrate communities identified during each construction period. *Pagurus bernhardus*, *Palaemon adspersus* and *Liocarcinus depurator* are the other three species making up the top five contributors to dissimilarity.

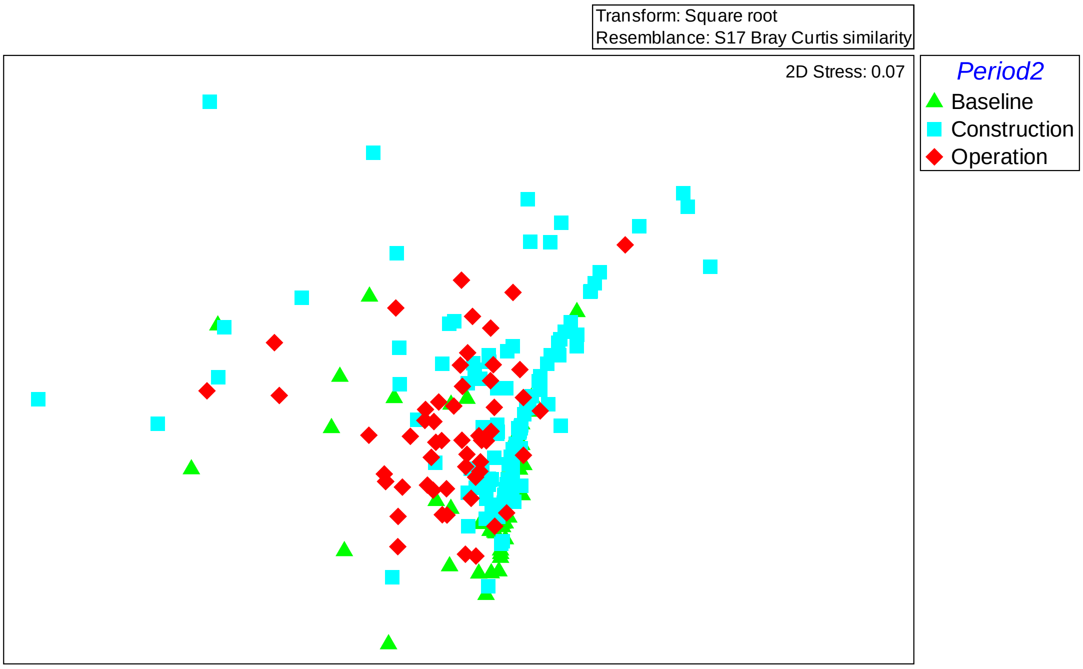

Figure 4.7: Non-metric MDS ordination plot of epibenthic invertebrate abundance (4th root transformed) surveyed during winter months between each construction period (outliers removed).

BEST analysis was used 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 rank correlation coefficient indicates extremely low correlation between both benthic fish and invertebrate communities and distance from the wind farm (see Table 4.5).

Table 4.5: 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	0.074
Epifaunal invertebrates	0.060

Two-way PERMANOVA analysis was also conducted two investigate differences in fish assemblages and invertebrate assemblages between construction periods, 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 4.6).

Table 4.6: 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	20.345	0.001
	Season	18.927	0.001
	Period x Season	7.2716	0.001
Invertebrates	Period	21.305	0.001
	Season	27.552	0.001
	Period x Season	8.1874	0.001

Further pairwise investigation indicates that fish assemblages differ significantly between construction periods during every season (see Table 4.7).

Table 4.7: Two-way PERMANOVA pairwise comparison testing investigating differences in fish assemblages between construction period and season (for data where each single trawl is considered one single replicate).

Pairwise Comparison	t-statistic	p-value
Within Autumn		
Baseline -Construction	3.963	0.001
Baseline-Operation	4.148	0.001
Construction-Operation	2.168	0.001
Within Winter		
Baseline -Construction	3.132	0.001
Baseline-Operation	2.957	0.001
Construction-Operation	2.863	0.001
Within Spring		
Baseline -Construction	2.733	0.001
Baseline-Operation	3.012	0.001
Construction-Operation	3.449	0.001
Within Summer		
Baseline -Construction	4.655	0.001
Baseline-Operation	3.012	0.001
Construction-Operation	1.924	0.005

The same pattern of significance was detected between epibenthic invertebrate assemblages between construction period during each season (see Table 4.8).

Table 4.8: Two-way PERMANOVA pairwise comparison testing investigating differences in epifaunal invertebrate assemblages between construction period and season (for data where each single trawl is considered one single replicate).

Pairwise Comparison	t-statistic	p-value
Within Autumn		
Baseline -Construction	3.7902	0.001
Baseline-Operation	4.4891	0.001
Construction-Operation	2.1186	0.002
Within Winter		
Baseline -Construction	2.7914	0.001
Baseline-Operation	3.4334	0.001
Construction-Operation	4.1011	0.001
Within Spring		
Baseline -Construction	1.5303	0.04
Baseline-Operation	3.4539	0.001
Construction-Operation	3.3609	0.001
Within Summer		
Baseline -Construction	4.7171	0.001
Baseline-Operation	3.084	0.001
Construction-Operation	1.6734	0.029

4.4.3. Seasonal variation in fish and epifaunal invertebrate assemblages

Seasonal variation was observed throughout the survey with the largest mean catch per tow recorded during autumn (see Figure 4.8) for both fish and invertebrate assemblages. Invertebrate catch decreased during spring and summer and increased during winter. The pattern in fish communities was similar although the winter increase less pronounced. This reflects the changing benthic communities detected through PERMANOVA+ analysis which indicates varying species composition as well as abundance (see Table 4.6).

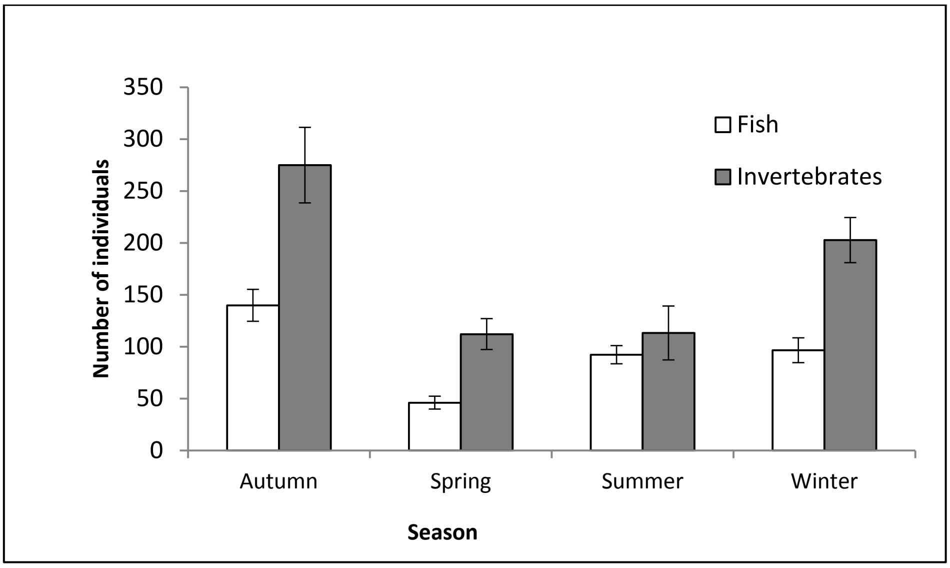

Figure 4.8: Seasonal variation in mean catch (individuals per 15 minute tow) recorded during the non-migratory fish survey (error bars = standard error of the mean).

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. Although not so pronounced the seasonal variation between the baseline only data and the construction and operation surveys exhibit a similar trend (see Figure 4.9).

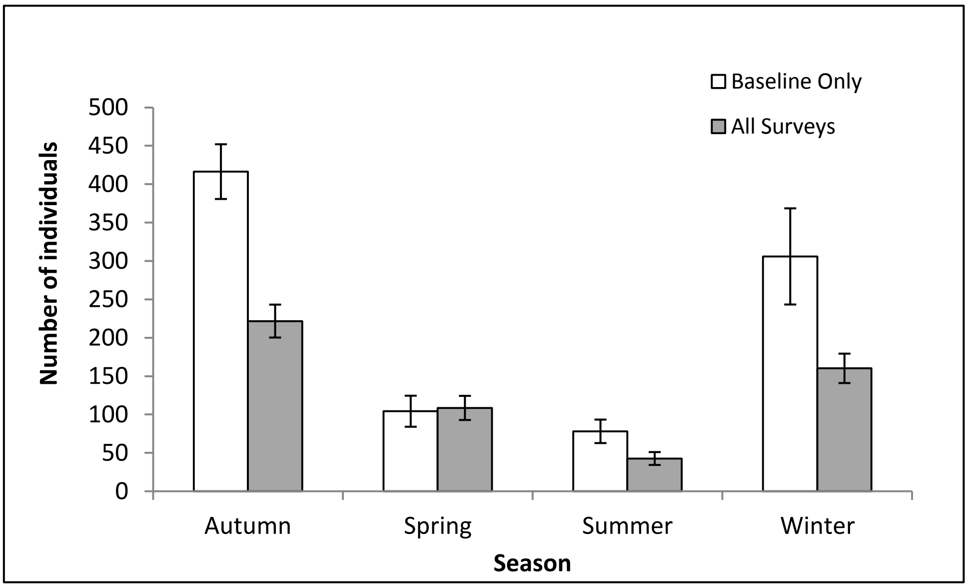

Figure 4.9: Seasonal variation in mean brown shrimp (Crangon crangon) catch (per 15 minute tow) recorded during the non-migratory fish survey (error bars = standard error of the mean).

4.4.4. 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 to 9 with the lowest value being recorded during the Construction period and the highest during the Baseline period (see Figure 4.10). Values for Shannon-Weiner Diversity ranged from 1.15 during the construction period to 1.24 during the Operational period (see Figure 4.10*: **Mean number of species (no. of individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).***

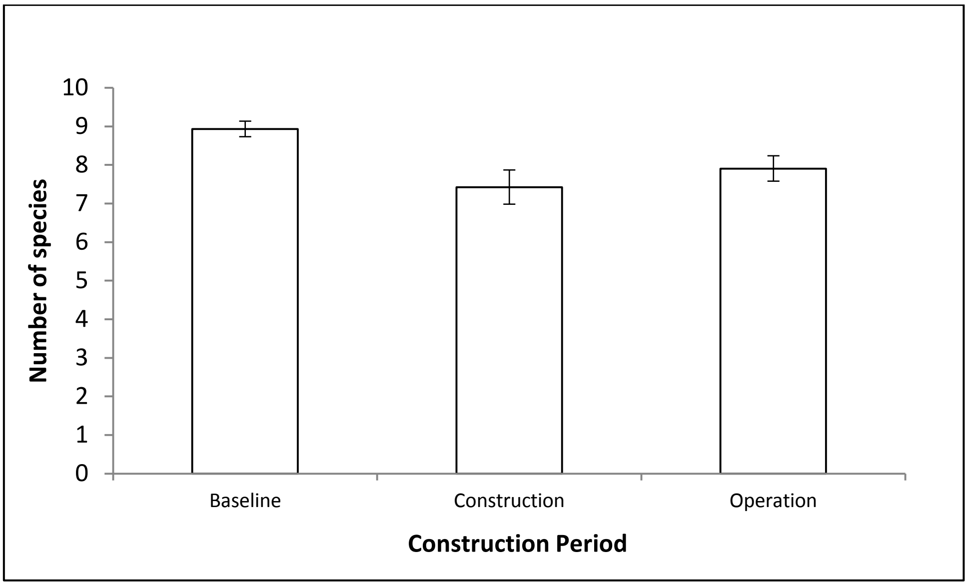

Figure 4.10: Mean number of species (no. of individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

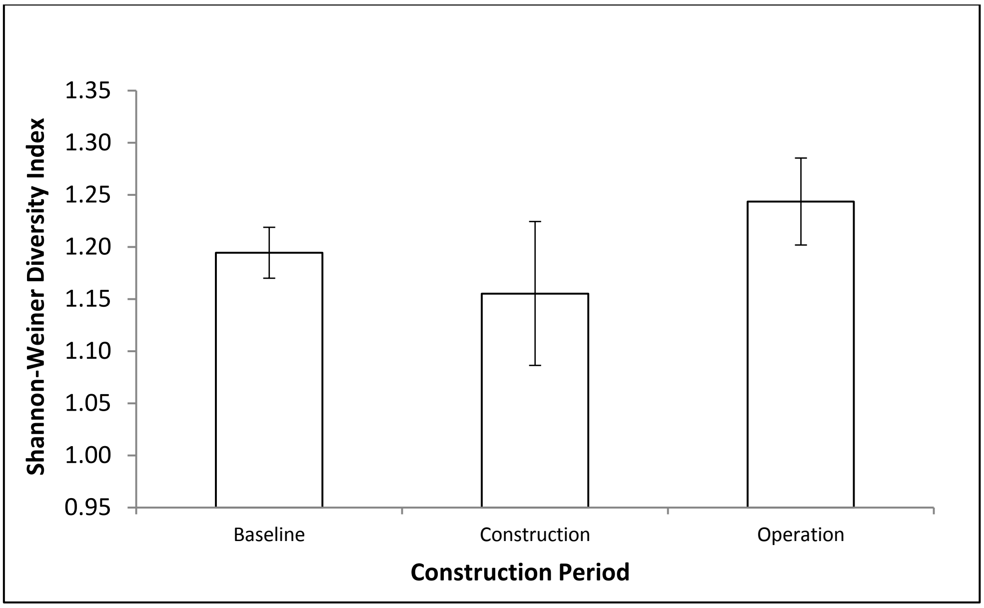

Figure 4.11: Mean Shannon-Weiner Diversity index (standardised per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

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 4,12). The lowest brown shrimp catch was recorded during the operation period. Mean catch varied with trawl location with the largest catch to the north west and east of the Robin Rigg site during the Baseline (See Figure 4.15, Figure 4,16 and Figure 4.17). During the Construction period the catch was relatively low across the study area with an increase in mean catch recorded at the north west trawl locations during the Operation period.

During Operation there was a spike in abundance of the brittle star *Ophiura ophiura* (see Figure 4.12). The mean abundance of *O. ophiura* remained relatively consistent during the Baseline and Construction periods, with just under 20 individuals recorded per tow. During the first year of operation this mean increased to 178 individuals per 15 minute tow. However, it is clear from the error bars presented that this was accompanied by a large increase in the standard error suggesting that few stations are responsible for this increase in brittle star numbers (see Figure 4.12). *O. ophiura* catch was relatively consistent across the entire site with the exception of the three north westernmost stations (see Figure 4.18, Figure 4.19 and Figure 4.19*: Mean Ophiura ophiura abundance recorded at each trawl location during the Construction period.*

During the Operation period mean abundance was greatest at these locations as a result of extremely high catches during two single trawls.

The abundance of whiting, a major prey species of marine mammals, was most abundant during the Operation period with the lowest catch recorded during the Construction period (Figure 4.14). The greatest mean catch of whiting was recorded to the east of the Robin Rigg site during the Baseline and Operation periods (see Figure 4.21, Figure 4.22 and Figure 4.23). During the Construction period whiting catch remained low consistently across the site.

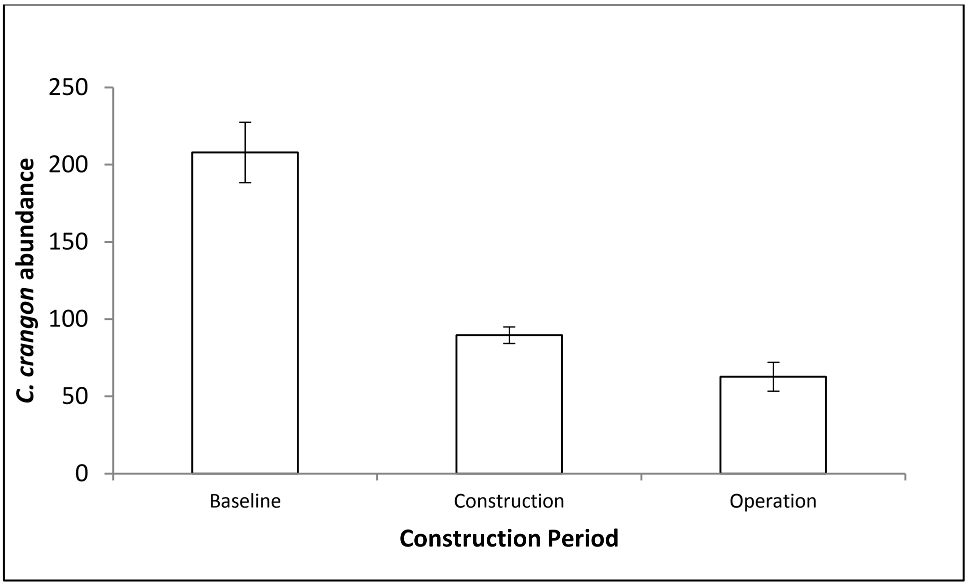

*Figure 4.12**:** Mean catch of brown shrimp (C. crangon) (individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).*

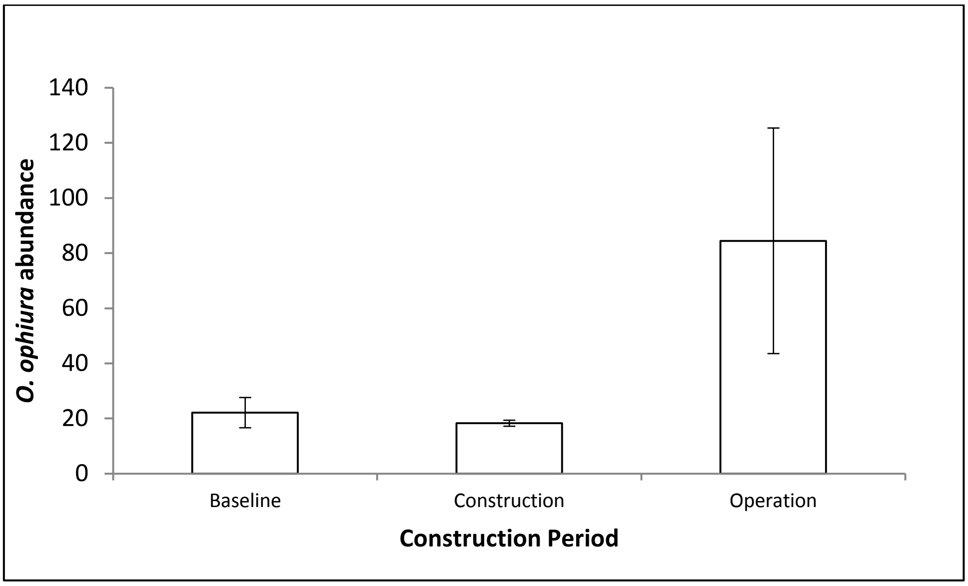

Figure 4.13: Mean catch of brittle stars (O. ophiura) (individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

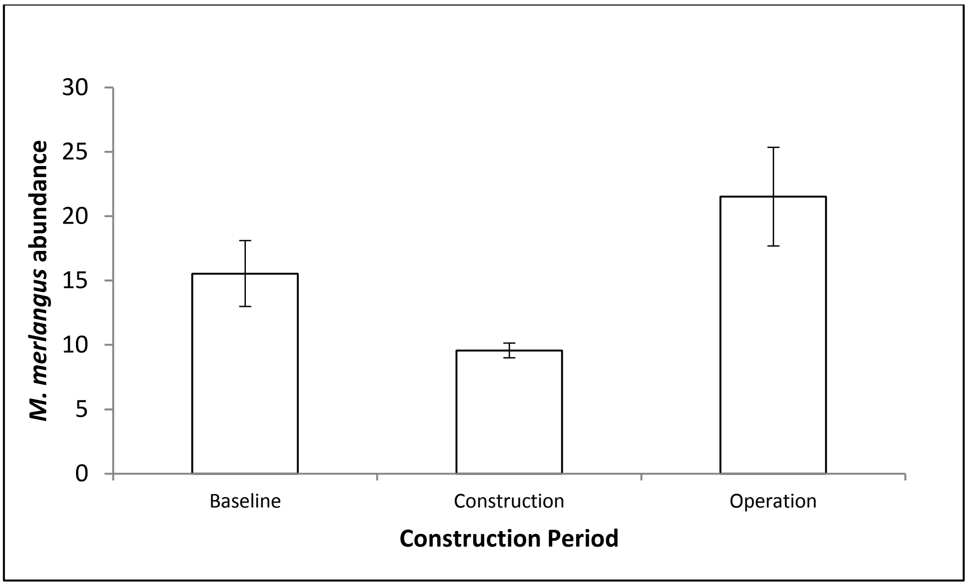

Figure 4.14: Mean catch of whiting (M. merlangus) (individuals per 15 minute tow) by construction period recorded during the non-migratory fish survey (Error bars = standard error of the mean).

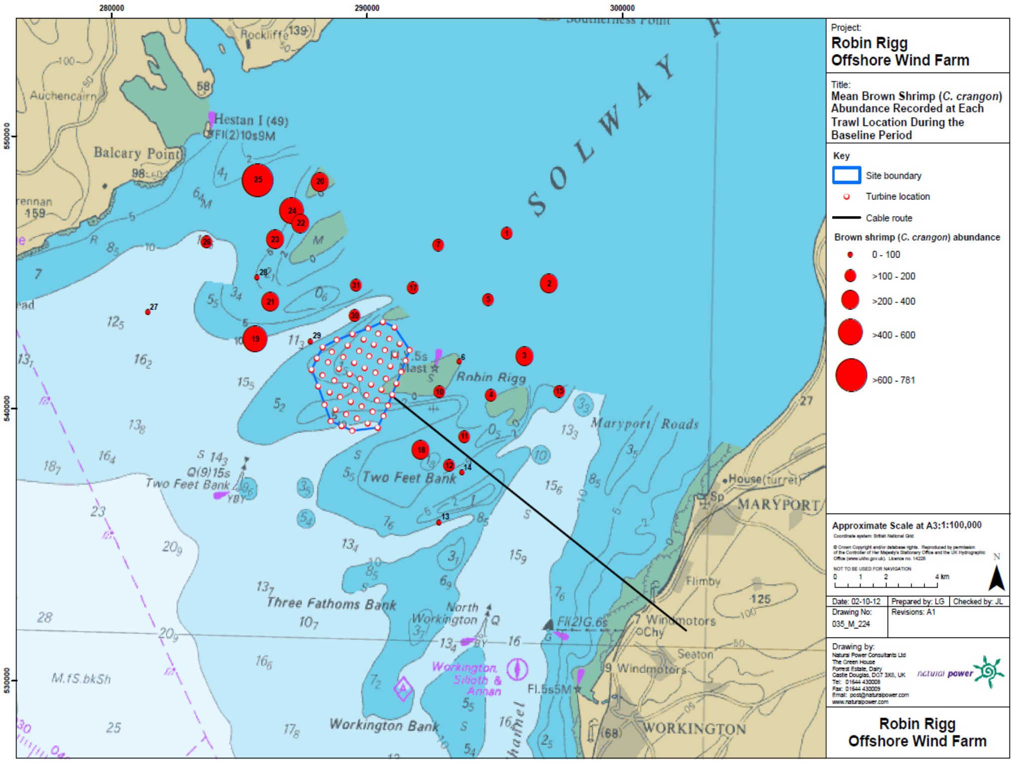

Figure 4.15: Mean Crangon crangon abundance recorded at each trawl location during the Baseline period.

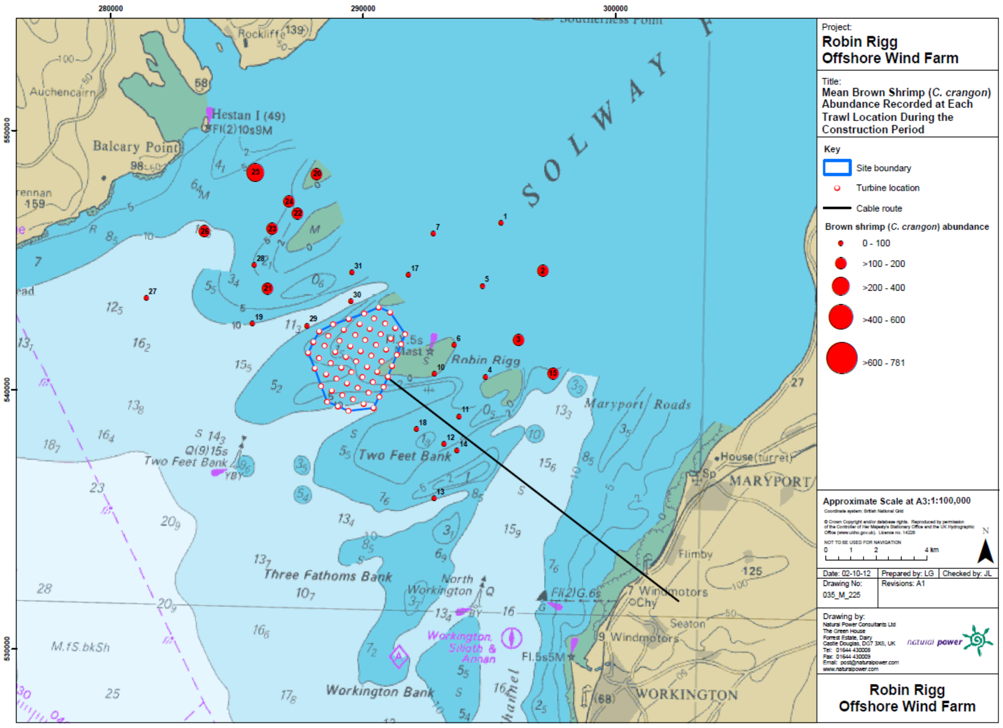

Figure 4.16. Mean Crangon crangon abundance recorded at each trawl location during the Construction period.

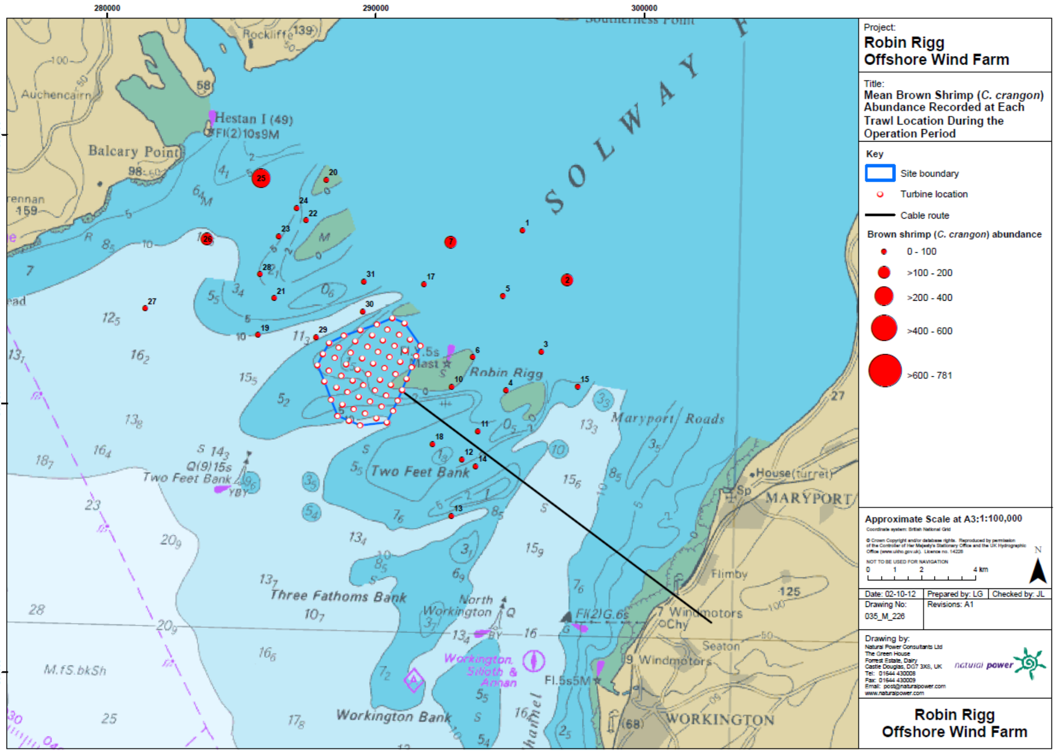

Figure 4.17. Mean Crangon crangon abundance recorded at each trawl location during the Operation period.

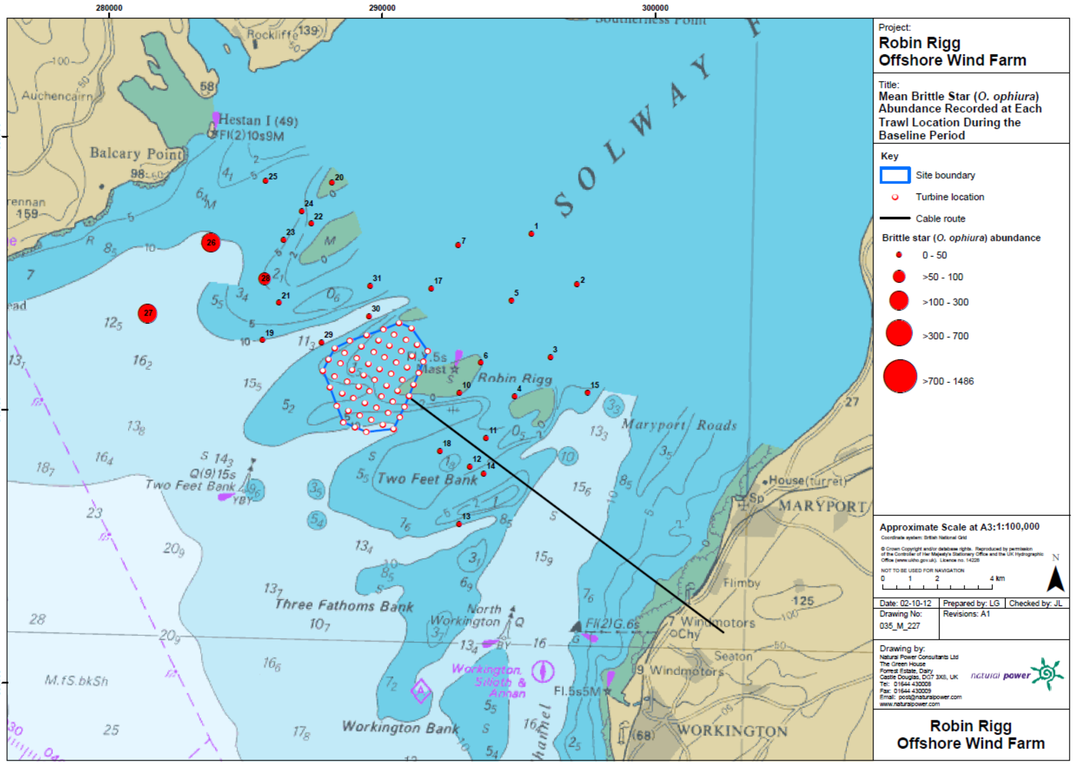

Figure 4.18: Mean Ophiura ophiura abundance recorded at each trawl location during the Baseline period.

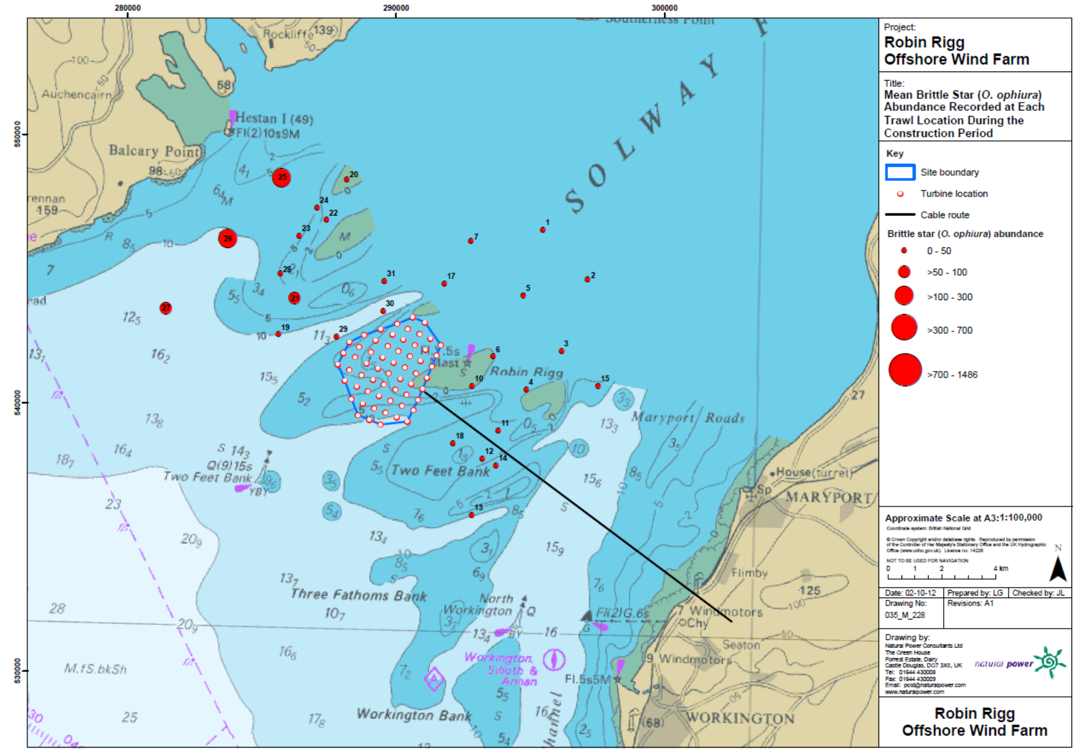

Figure 4.19: Mean Ophiura ophiura abundance recorded at each trawl location during the Construction period.

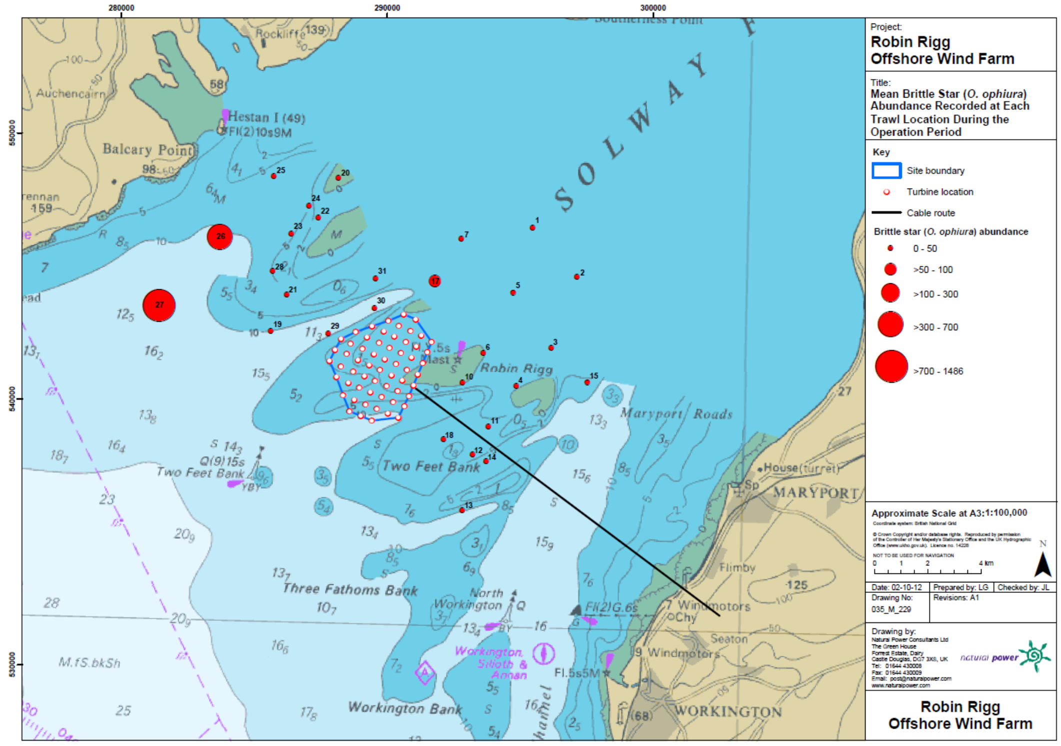

Figure 4.20: Mean Ophiura ophiura abundance recorded at each trawl location during the Operation period.

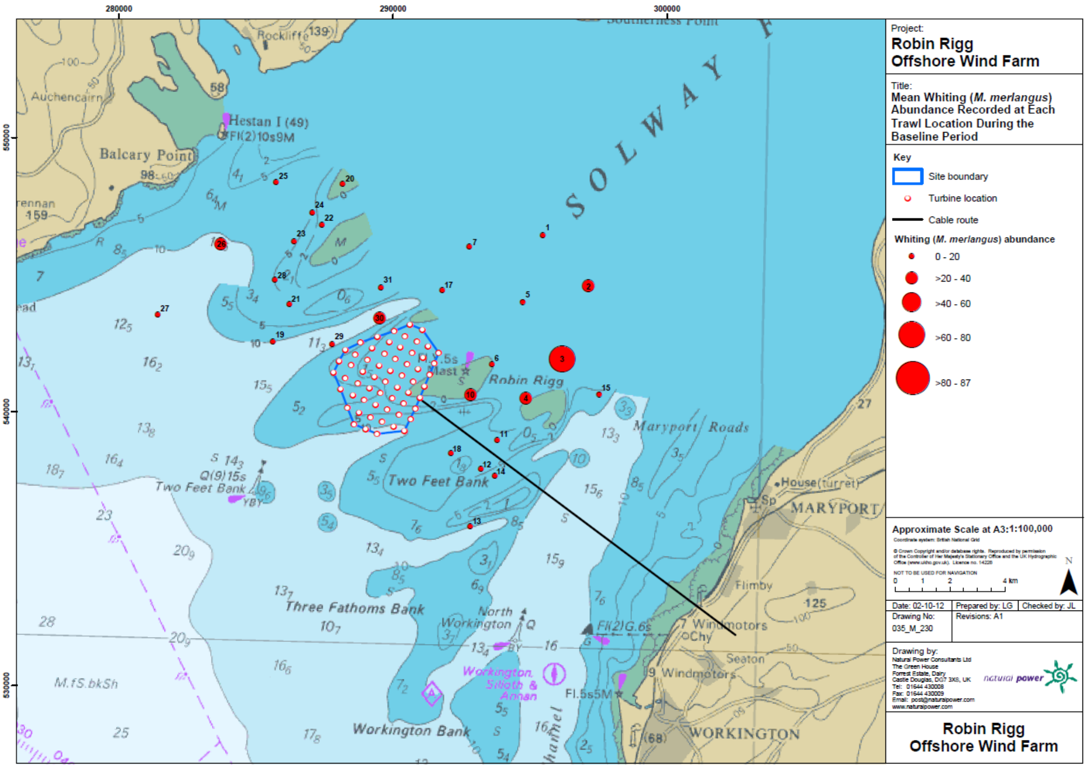

Figure 4.21: Mean Merlangius merlangus recorded at each trawl location during the baseline period.

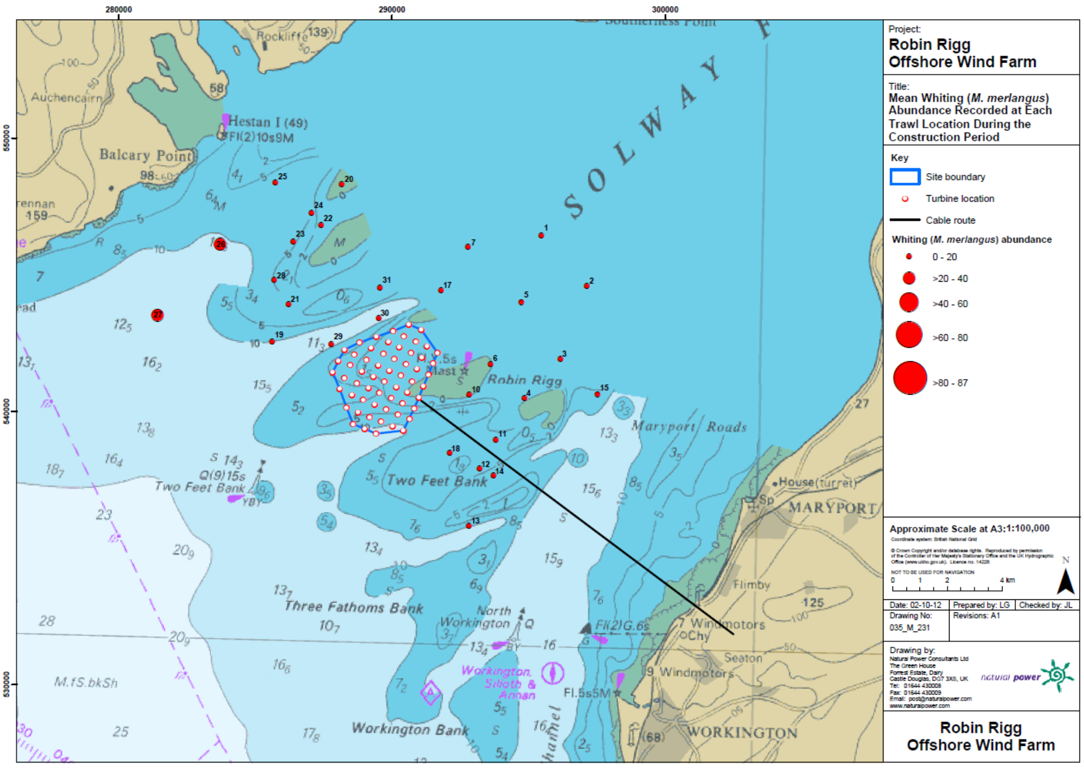

Figure 4.22: Mean Merlangius merlangus recorded at each trawl location during the baseline period.

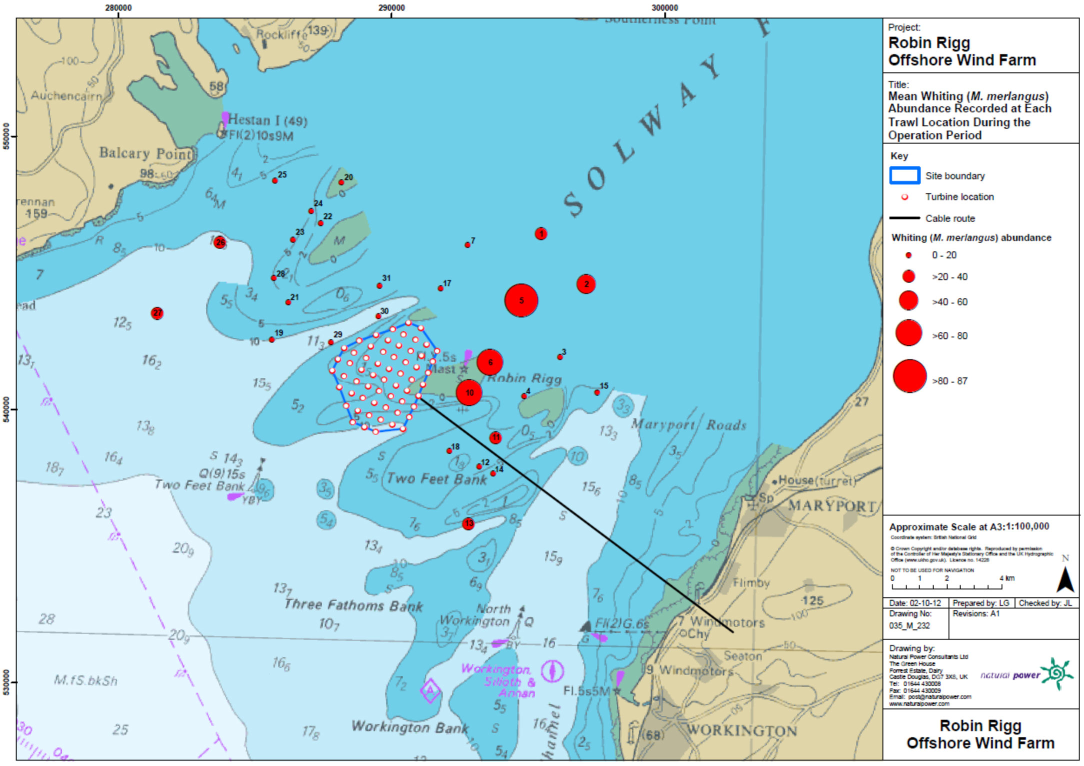

Figure 4.23: Mean Merlangius merlangus recorded at each trawl location during the baseline period.

4.4.5. Variations in size frequency

The three most abundant species of fish recorded during the Robin Rigg 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 21,008 plaice sampled since November 2001 only 132 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 4.24). 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. Due to the lower catch rate during the construction and operation year this trend is less prominent.

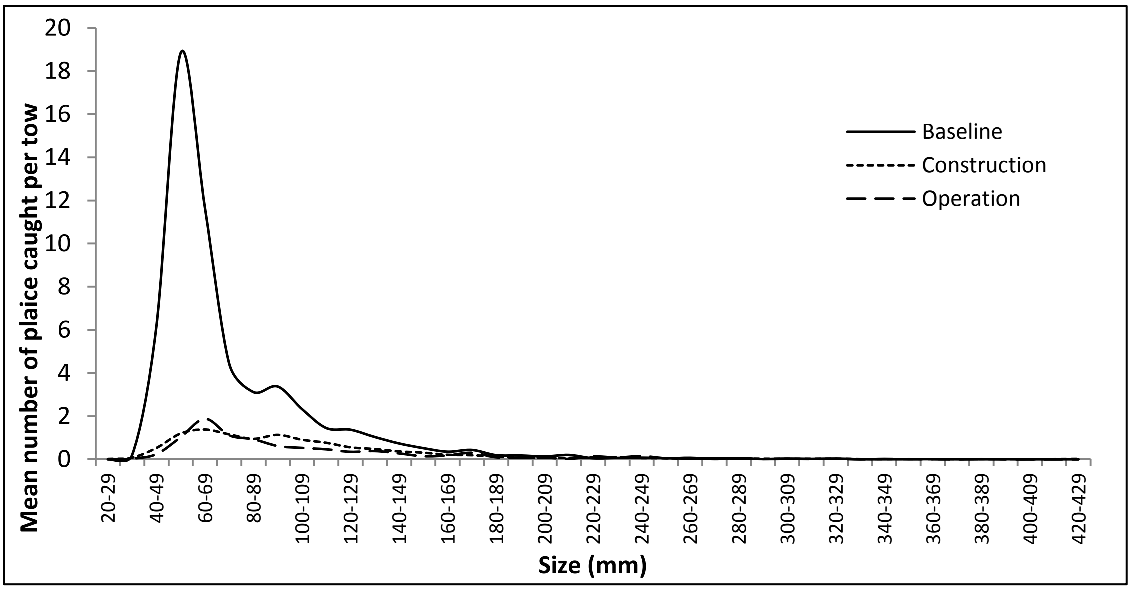

Figure 4.24: Size frequency distributions of plaice (Pleuronectes platessa) recorded during each construction period.

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 for dab although there was far fewer fish recorded in the construction and operation periods (see Figure 4.25). There is a second peak in the distribution at around 100 – 109mm for all three construction periods.

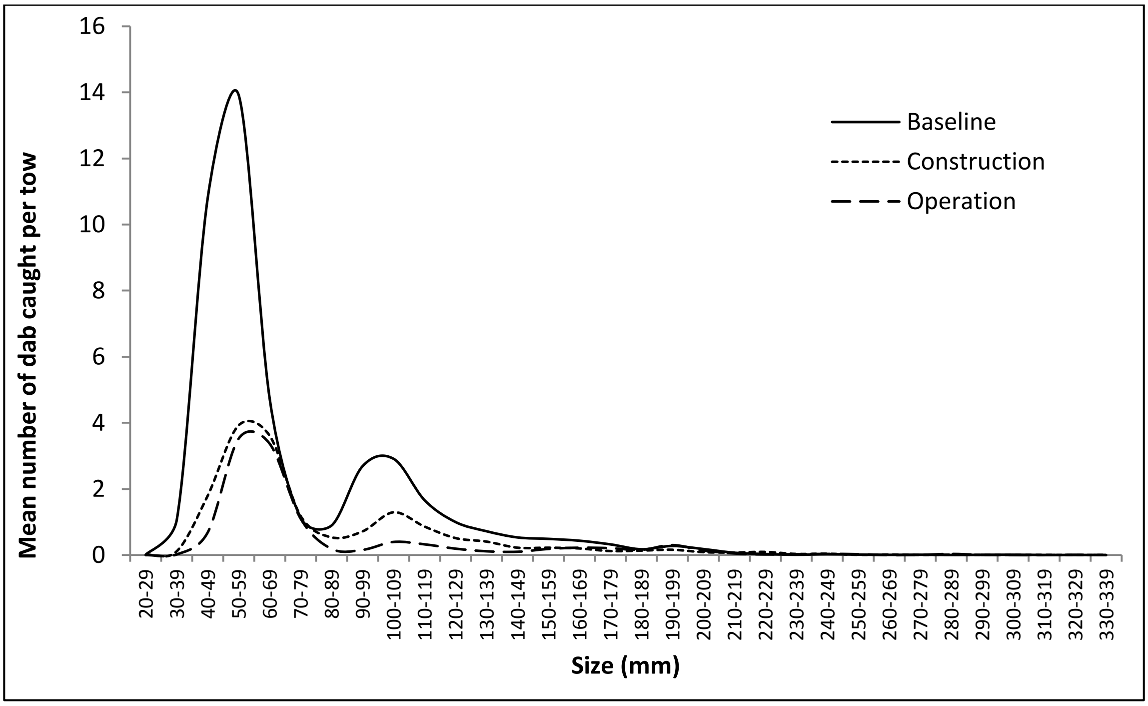

Figure 4.25: Size frequency distribution of dab (Limanda limanda) recorded during each construction period.

The total whiting catch since 2001 was 10,093, 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 4.26). The most common size class during the Baseline and Operation periods were 100 – 109 mm; however, during Construction the peak size class was only 80 – 89 mm. There is no obvious second peak in the size class distributions for whiting.

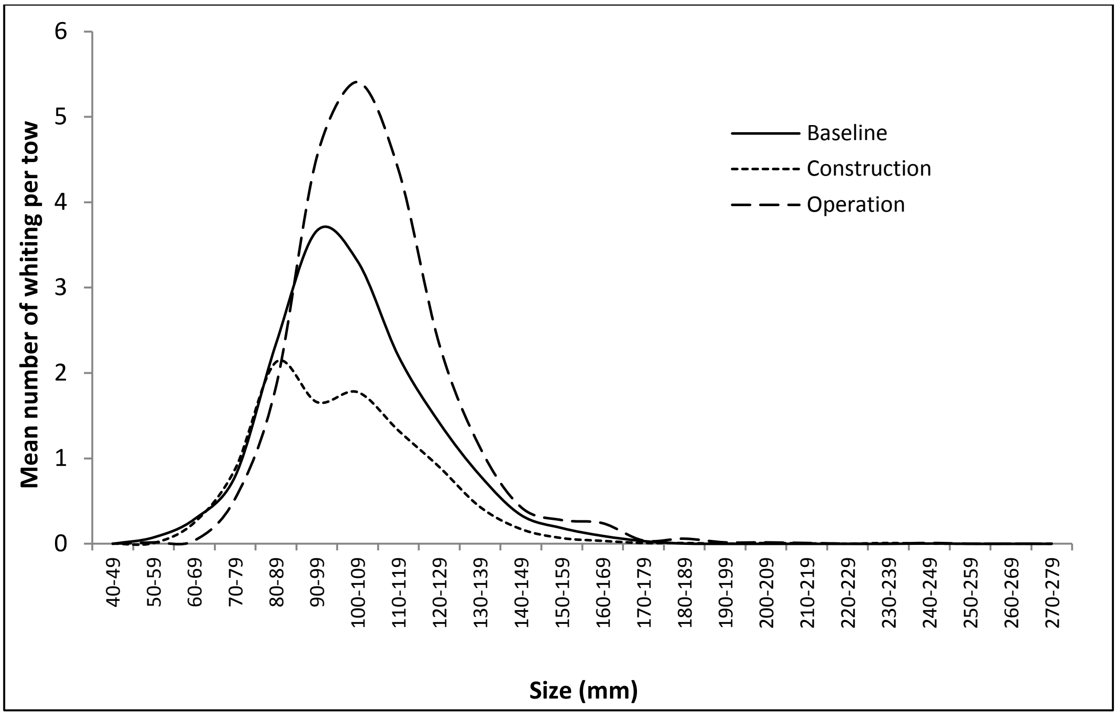

Figure 4.26: Size frequency distribution of whiting (Merlangius merlangus) recorded during each construction period.

4.5. Electrosensitive Fish Survey Results

4.5.1. Catch summary

Plaice (*Pleuronectes platessa*), whiting (*Merlangius merlangus*) and dab (*Limanda limanda*) were the three most common species recorded during the electrosensitive fish surveys (see Table 4.9). Brown shrimp (*Crangon crangon*), common starfish (*Asterias rubens*) and the hermit crab (*Pagurus bernhardus*) were the most abundant epibenthic invertebrate species (see Table 4.10).

Table 4.9: Top ten most abundant fish species recorded during all electrosensitive fish surveys (pre-construction - operation).

Common Name	Latin Name	Number of Individuals
Plaice	*Pleuronectes platessa*	558
Whiting	*Merlangius merlangus*	363
Dab	*Limanda limanda*	345
Lesser Weever	*Echiichthys vipera*	164
Solenette	*Buglossidium luteum*	99
Witch	*Pleuronectes cynoglossus*	79
Dover sole	*Solea solea*	56
Scaldfish	*Arnoglossus laterna*	54
Pogge	*Agonus cataphractus*	31
Sand Goby	*Pomatoschistus minutus*	28

Table 4.10: Top ten most abundant epibenthic invertebrate species recorded during all electrosensitive fish surveys (pre-construction - operation).

Common Name	Latin Name	Number of Individuals
Brown Shrimp	*Crangon crangon*	1,040
Starfish	*Asterias rubens*	474
Hermit crab	*Pagurus bernhardus*	215
Pink shrimp	*Pandalus montagui*	132
Swimming crab	*Liocarcinus holstatus*	43
Shore crab	*Carcinus maenas*	36
Harbour crab	*Liocarcinus depurator*	16
Whelk	*Buccinum undatum*	15
Spider crab	*Hyas araneus*	13
Brittlestar	*Ophiura ophiura*	13

4.5.2. Variation in fish and epibenthic invertebrate community assemblage

During the cable route survey the standardised catch abundance per tow showed little fluctuation between the construction periods for both fish and invertebrates (see Figure 4.27). The mean number of fish recorded ranged from 19 individuals during the construction period to 30 individuals during the operation period. The mean number of invertebrate individuals recorded during the three survey periods showed less variation along the cable route ranging from 26 individuals during the pre-construction to 24 individuals during the operation period.

Figure 4.27: Mean catch (number of individuals per 15 minute tow) by construction period recorded during the electrosensitive fish survey (Error bars = standard error of the mean).

During the entire cable route survey only summer months were surveyed in all three construction periods. Therefore, data collected in summer months was subject to multivariate investigation to determine any effects of construction period on benthic community composition for fish and invertebrates separately. The ANOSIM function detected significance between both fish and invertebrate community's with a significance threshold of p = <0.05 (see Table 4.11). For fish the global R value remained low indicating no distinct separation of replicates in multivariate space (see Table 4.11). The low global R value associated with the fish assemblage reflects the presence of outliers in the dataset; some separation of groups is evident when the outliers are removed (see Table 4.11). All pairwise comparisons were significantly different between each possible combination of construction periods.

Table 4.11: ANOSIM outputs investigating differences between fish and invertebrate benthic assemblages recorded during summer months between construction periods and seasons recorded during the electrosensitive fish surveys (significant results in red).

Data	Factor under investigation	Global R	p value	Significant pairwise comparisons
Fish	Construction Period	0.254	0.001	Pre-construction - Construction (R = 0.441, p = 0.001), Pre-construction - Operation (R = 0.167, p = 0.018), Construction - Operation(R = 0.169, p = 0.019)
Invertebrates	Construction Period	0.477	0.001	Pre-construction - Construction (R = 575, p = 0.001), Pre-construction - Operation (R = 0.179, p = 0.032), Construction - Operation (R = 0.674, p = 0.001)

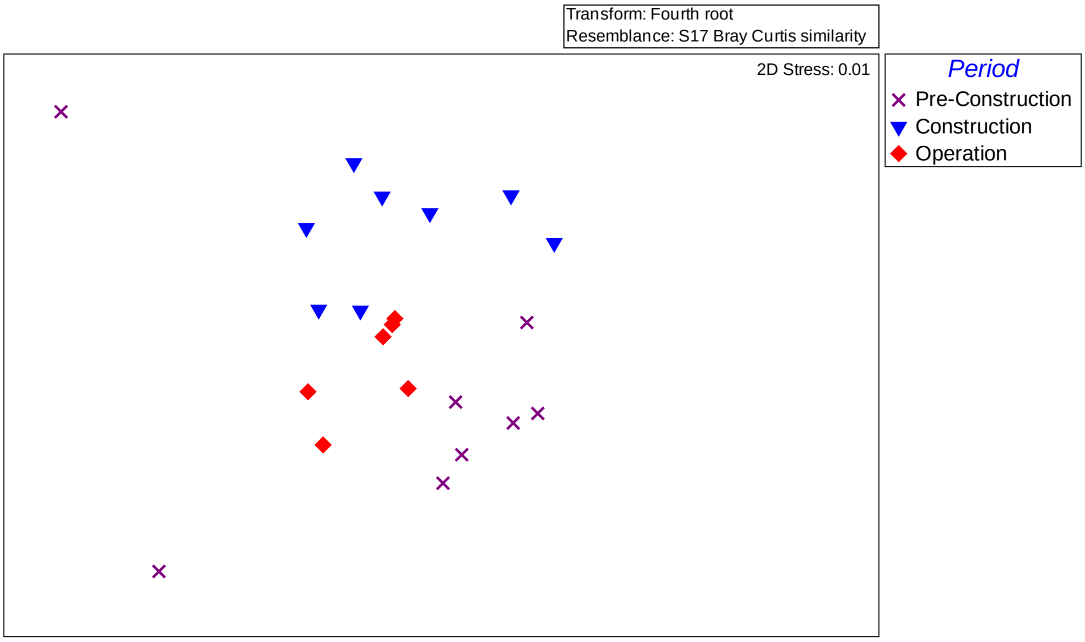

Figure 4.28: Non-metric MDS ordination plot of fish abundance recorded during summer months (4th root transformed) between construction periods. The ordination plot excludes outliers from the data.

SIMPER analysis was conducted to identify any key species driving the dissimilarity between distinct groups for those pairwise comparisons where significance was detected. There is no single species driving the difference between the fish assemblage however, whiting (*Merlangius merlangus*), plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*) are the top three species contributing to dissimilarity between the pre-construction and construction periods and the construction and operation periods. When comparing the pre-construction and operation the lesser weever fish (*Echiichthys vipera*) replaces whiting in the top three species contributing to dissimilarity.

The global R value was moderate for invertebrates indicating more obvious clustering of sampling points by the factor under scrutiny, in this case, construction period. An ordination plot was produced to indicate the spatial distribution of sampling points in multivariate space. Some sampling stations that are further removed from the main cluster of sampling points in the ordination plot are a result of no fauna being recorded during that trawl. The ordination plot depicting the spatial distribution of these species in multivariate space does not include the outliers and focuses instead on the separation between the clustered sample points (see Figure 4.29). When viewing the cluster of sampling stations in the middle of plot A at a greater scale there is some separation of sampling stations into construction periods (see Figure 4.29).

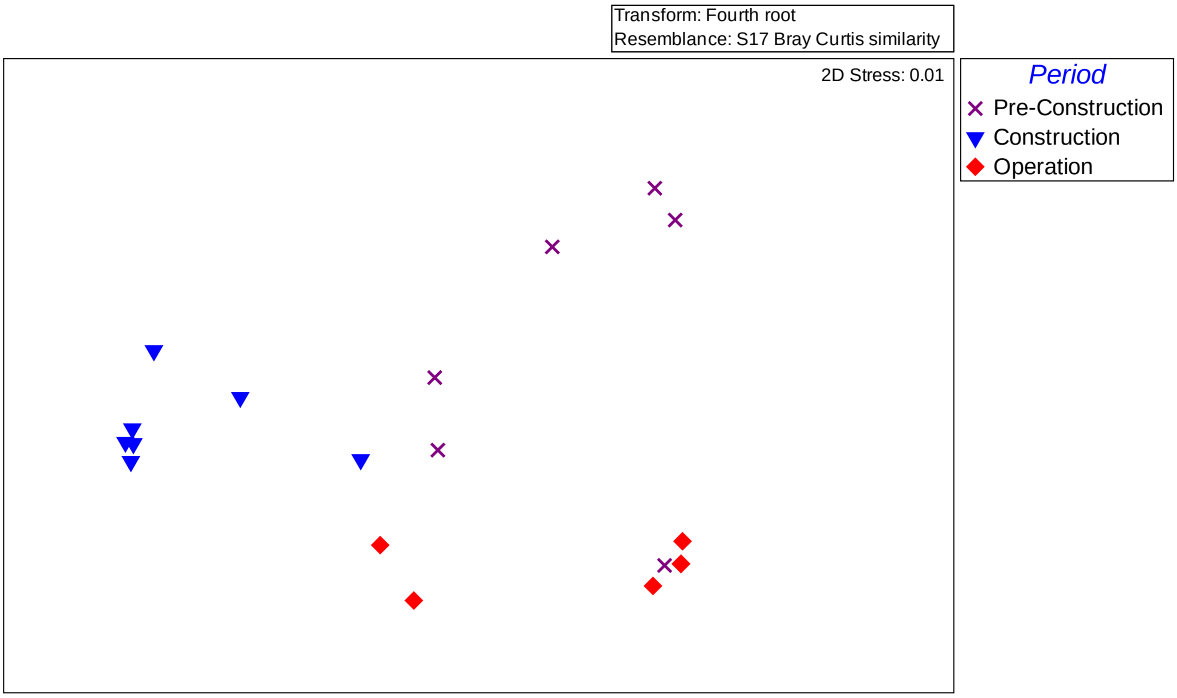

Figure 4.29: Non-metric MDS ordination plot of benthic invertebrate assemblages recorded during summer months (4th root transformed) between each construction period. The ordination plot does not include outliers.

SIMPER analysis identified key species driving dissimilarity between construction periods. Three of four species are responsible for at least 70 % of the dissimilarity in each pairwise combination. These are brown shrimp, *Crangon crangon*, the hermit crab, *Pagurus bernhardus*, the shore crab, *Carcinus maenus* and the common starfish *A. rubens*.

PERMAOVA testing was also carried out on the entire dataset with each trawl being treated as a single replicate and period and season both being tested as a factor. For both fish assemblages and invertebrate assemblages significant differences were detected between construction periods, season and between the interaction term (see Table 4.12).

Table 4.12: Multi-factorial PERMANOVA outputs assessing differences in fish and invertebrate assemblages recorded during the electrosensitive fish species (significant results in red).

		Pseudo-F	p
Fish	Period	7.899	0.001
	Season	4.205	0.001
	Period x Season	2.219	0.001
Invertebrates	Period	7.964	0.001
	Season	5.206	0.001
	Period x Season	9.327	0.001

Pairwise comparison testing was conducted to determine differences between construction periods during specific months. Pairwise comparisons were not possible between every construction period during every season due to inadequate replication. For both fish and epifaunal invertebrate assemblages all possible pairwise comparisons detected significance (see Table 4.13 and Table 4.14 respectively).

Table 4.13: Two-way PERMANOVA pairwise comparisons investigating differences in fish assemblages between construction period and season recorded during the electrosensitive fish survey (significant results in red).

Pairwise Comparison	t-statistic	p-value
Within Autumn		
Pre-construction - Construction		
Pre-construction - Operation	2.447	0.001
Construction - Operation		
Within Winter		
Pre-construction - Construction		
Pre-construction - Operation		
Construction - Operation	1.763	0.017
Within Spring		
Pre-construction - Construction		
Pre-construction - Operation		
Construction - Operation	2.778	0.005
Within Summer		
Pre-construction - Construction	2.202	0.001
Pre-construction - Operation	1.861	0.004
Construction - Operation	1.641	0.022

Table 4.14: Two-way PERMANOVA pairwise comparison testing investigating differences in epifaunal invertebrate assemblages between construction period and season recorded during the electrosensitive fish survey (for data where each monthly survey is considered one single replicate).

Pairwise Comparison	t-statistic	p-value
Within Autumn		
Pre-construction - Construction		
Pre-construction - Operation	2.114	0.002
Construction - Operation		
Within Winter		
Pre-construction - Construction		
Pre-construction - Operation	2.114	0.002
Construction - Operation		
Within Spring		
Pre-construction - Construction		
Pre-construction - Operation		
Construction - Operation	3.511	0.003
Within Summer		
Pre-construction - Construction	3.112	0.001
Pre-construction - Operation	1.731	0.028
Construction - Operation	3.914	0.001

4.5.3. Seasonal variations

There is no clear pattern in fish abundance between seasons. Fish assemblages were greatest during autumn and summer; the spring catch was moderate with the lowest catch being recorded in winter (Figure 4.30). The invertebrate catch data is lowest in spring and greatest in winter (Figure 4.30). PERMANOVA+ testing also indicated that assemblages vary significantly between seasons (Table 4.12).

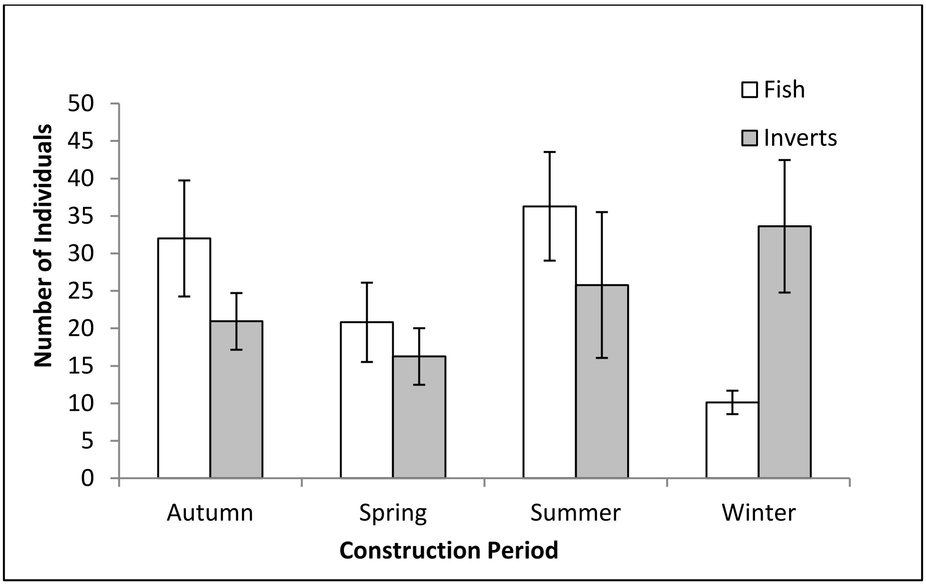

Figure 4.30: Mean catch (number of individuals per 15 minute tow) by season recorded during the electrosensitivie fish survey (Error bars = standard error of the mean).

There is little variation in the mean number of species recorded during each tow (Figure 4.31) and the mean Shannon-Weiner diversity index (Figure 4.32) values between construction periods. The mean number of species varied from 6 species during construction to 8 species during operation per 15 minute tow. The Shannon-Weiner diversity index varied from 1.23 during construction to 1.51 during operation per 15 minute tow.

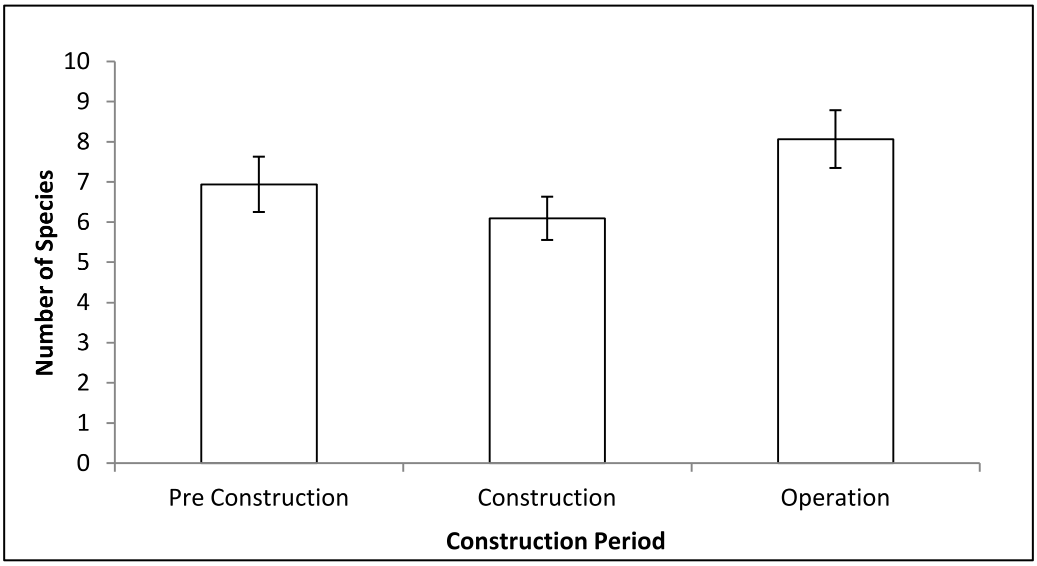

Figure 4.31. Mean number of species (per 15 minute tow) by construction period recorded during the electrosensitive fish survey (Error bars = standard error of the mean).

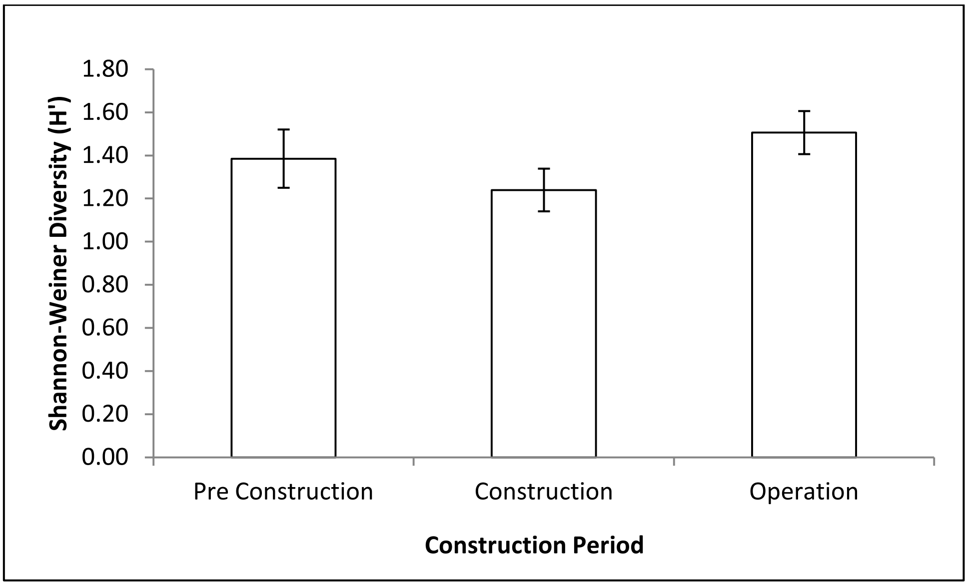

Figure 4.32: Mean Shannon-Weiner diversity index (per 15 minute tow) by construction period recorded during the electrosensitive fish survey (Error bars = standard error of the mean).

The thornback ray (*Raja clavata*) was the most commonly recorded elasmobranch species with 18 individuals being recorded overall. The only other elasmobranch species recorded was the lesser spotted dogfish (*Scyliorhinus canicula*) with 15 individuals being recorded during all surveys. The thornback ray and lesser spotted dogfish was the 16th and 19th most common species recorded respectively. The mean elasmobranch abundance remained low during all construction periods (see Figure 4.33).

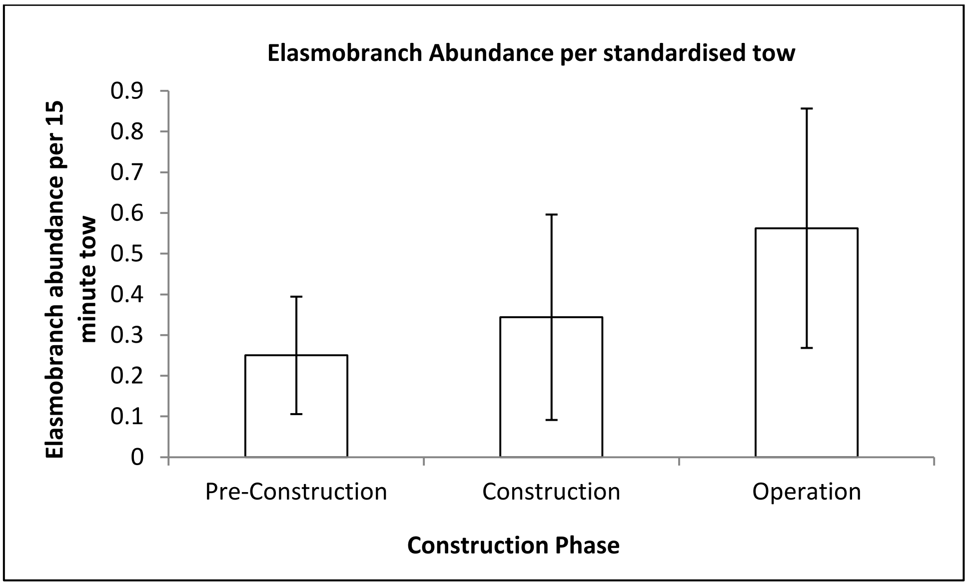

Figure 4.33: Mean elasmobranch catch (number of individuals per 15 minute tow) by construction period recorded during the electrosensitive fish survey (Error bars = standard error of the mean).

4.6. Discussion

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

4.6.1. Non-Migratory fish survey data

The present study considered broad-scale changes in fish and epibenthic invertebrate assemblages between construction periods and season in the inner Solway Firth area. The response of univariate and multivariate metrics exhibited significant change in response to construction periods and season. Catch abundance of fish, invertebrates, brown shrimp and whiting reduced following the commencement of construction, particularly in construction year one (February 2008 to February 2009). However, very little construction activity took place during this period (Table 1.1 & Figure 1.2). The only overlap between construction activities and the construction year one survey occurred in November 2008 and February 2009. Therefore, it is difficult to attribute this change to construction activity.

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 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 assemblages as determined from BIOENV analysis suggests wind farm presence is not driving change within the Solway Firth.

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 environmental variables. The study speculated that climate change and changes to the North Atlantic oscillation may affect species composition and abundance. This is supported by Cheung *et al* (2009) who postulates that changing ocean temperatures are large scale drivers of variation in fish distribution.

Historically a number of environmental variables have been correlated to fluctuations in fish and epifaunal invertebrate assemblages including temperature (Genner *et al*, 2010), local hydrodynamics (Coates *et al*, 2010; Ysabaert et al, 2003), mean grain size, organic matter content (Pearson and Rosenberg, 1978; Willhelmsson and Malm, 2008), season and state of tide (Lancaster, 1998; De Maersschalck *et al*, 2006). Although it is not possible to examine this statistically it would appear that one of the principal reasons for decline of catch rates since baseline survey is due to a combination of the effects arising from the shifting sand banks. During the baseline the survey locations were selected through consultation with local fishermen to maximise catch by following the channels adjacent to the sand banks within the inner Solway Firth. 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 was used to identify seasonal effects between years. It is evident from the analysis that seasonal variations occur throughout all construction periods surveyed. 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 validates the conclusions 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 Bocher and Zettler (1994) who did not observe any effect of magnetic fields on brown shrimp and pleuronectid flat fish.

At the Robin Rigg 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 landing can be a source of information, however cannot be directly compared, as landings data reflect fisheries effort and quota rather than Irish Sea stock sizes. In addition, within the study area only a small fraction of fish recorded in the survey for plaice and whiting are of commercially exploitable size. Juveniles recorded during the survey are likely to take two to three years before reaching marketable size and so there is likely to be a time lag between any effects on stock size in the Irish Sea and the Robin Rigg Wind Farm. Landings data provided by the MMO indicate that for three of the most common commercially exploited fish species plaice, dab and whiting have all shown declines in landings data 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 (see Figure 4.34 - Figure 4.35***: Dab (L. limanda) landings data at Whitehaven and cumulatively at ports along the Cumbrian coast from 2000 to 2010. Data supplied by the MMO***).

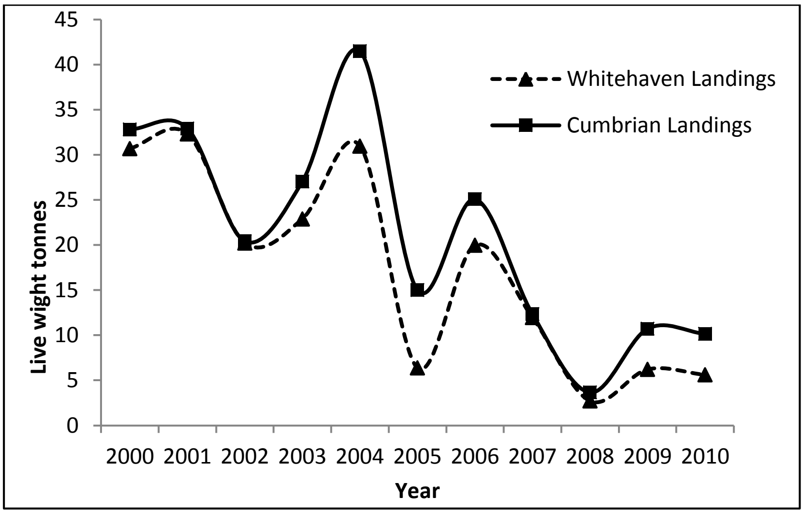

Figure 4.34: Plaice (P. platessa) landings data at Whitehaven and cumulatively at ports along the Cumbrian coast from 2000 to 2010. Data supplied by the MMO.

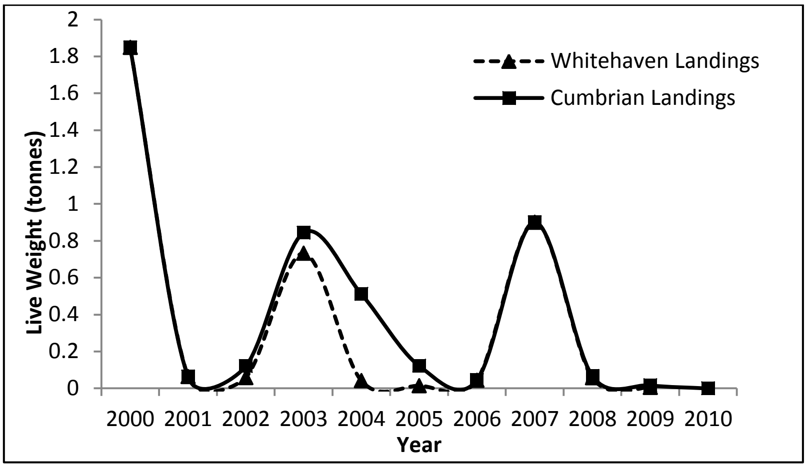

Figure 4.35: Dab (L. limanda) landings data at Whitehaven and cumulatively at ports along the Cumbrian coast from 2000 to 2010. Data supplied by the MMO.

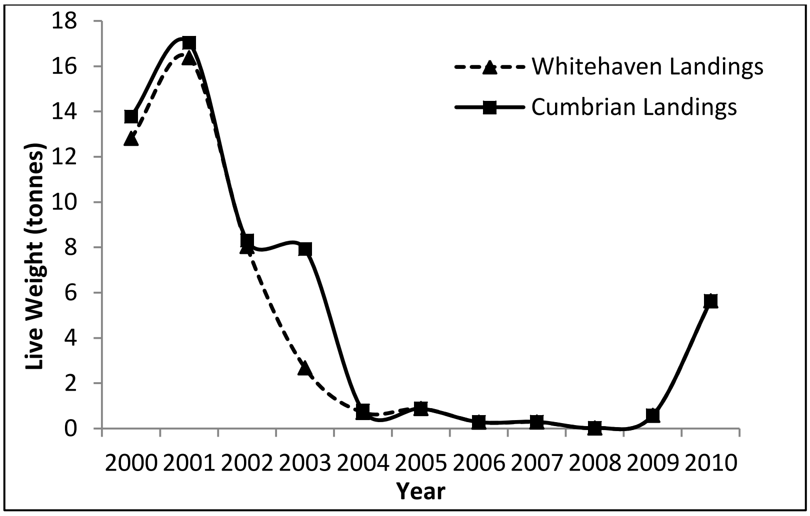

Figure 4.36: Whiting (M. merlangus) landings data at Whitehaven and cumulatively at ports along the Cumbrian coast from 2000 to 2010. Data supplied by the MMO.

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. 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 (see Figure 4.37). 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.

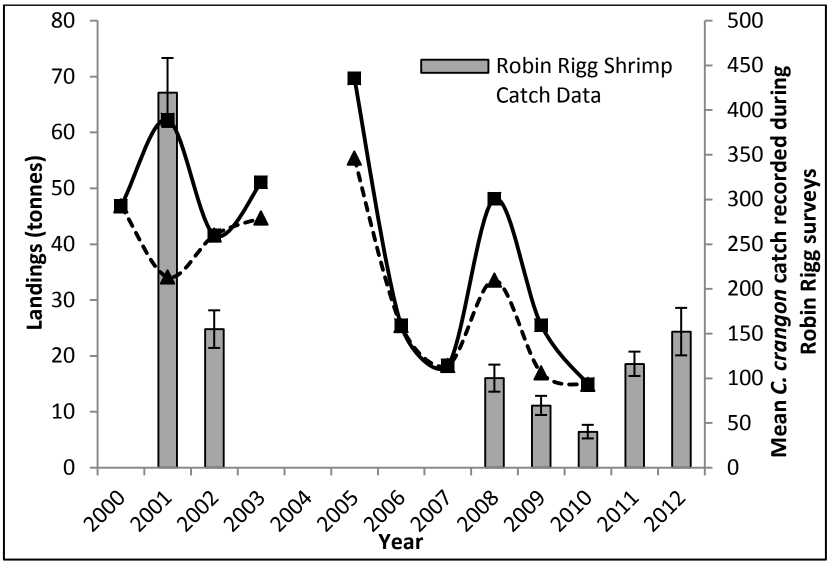

Figure 4.37: Landings data of the brown shrimp (Crangon crangon) fishery along the Cumbrian coast.

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 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 MEMP. Following construction at the Belgian offshore wind farms, C-Power and Belwind, Reubens *et al*, (2009) and Coastes *et al*, (2010) observed no large-scale impacts on macrobenthic populations during the first two years of operation.

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 demersal 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 Robin Rigg 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 within the turbine array.

4.6.2. Electrosensitive fish

Fish and epibenthic invertebrate assemblages differ significantly between construction periods and between seasons. Large variations in assemblages can be expected along the cable route as the shoreward stations exhibits a shift in substrate type to a rockier habitat (AMEC, 2011).

The replication of the electrosensitive fish surveys varies resulting in an unbalanced survey design. No baseline survey was carried out along the cable route; instead pre-construction surveys were carried out biannually, followed by quarterly surveys in the Construction and Operation periods. As with the non-migratory fish survey assemblages along the capable route are likely to be susceptible to rapid and significant natural fluctuations (Henderson & Bird, 2010; Tulp *et al*., 2008).

Elasmobranch abundance has been low throughout the duration of the survey with only 43 individuals recorded in 80 trawls. There was no significant difference detected between survey periods. During construction year one installation of the cable route did not commence until November 2008 therefore only one survey (February 2009) coincided with any construction activity (Table 1.1 and Figure 1.3). It is unlikely that construction would have caused any significant change between baseline conditions and construction year one conditions despite significance being detected when comparing each trawl as a single replicate.

The trawl locations of the electrosensitive fish survey were not carried out in the immediate vicinity of the export cable to avoid any damage to the cable during beam trawling. As a result the current survey array is not likely to detect any effects as a result of attraction to the cable route of electrosensitive species. There is limited evidence on effects and sphere of influence of electromagnetic fields on benthic species.

An experimental study by Bocher and Zettler (2004) found no effect of magnetic B fields on the brown shrimp, *Crangon crangon* and the flat fish, *Plathichthys flesus*. *Crangon crangon* is a contributor of dissimilarity in invertebrate assemblages between construction periods; it is unlikely that this is a result of magnetic fields given the distance between the trawl locations and the lack of response to magnetic fields with a similar level to that generated by electrical export cabling (Bochert and Zettler, 2004). Plaice and dab were within the top three contributors to dissimilarity between varying construction periods and seasons. The flounder, *Platichthys flesus*, along with dab and plaice are all part of the same taxonomic family, pleuronectidae. It is possible that these species would have the same response to magnetic fields generated by electrical cabling. Therefore it is unlikely that changes in dab and plaice abundance during the operational period are an effect of magnetic fields produced by the Robin Rigg export cable due to the distance between the trawl locations and the cable (Fisher and Slater, 2010).

Low numbers of elasmobranchs were recorded during the electrosensitive fish surveys and SIMPER did not identify these species as major contributors of significant change in assemblages. Kalmijn (1982) observed that species of small dogfish attack sources of electric current within 18 cm of the source during field surveys. For larger dogfish the response distance increases to 38 cm. Redistribution of the Solway Firth lesser spotted dogfish (*Scyliorhinus canicula*) population cannot be detected from survey trawls hundreds of metres from the export cable. The only other species recorded was the thornback ray, *Raja. clavata*. Kalmijin (1966) concluded that the heart rate and respiratory cycle of *Raja clavata* slowed down when exposed to electric fields typical of electrical cabling but it is not reported at what distance this effect is likely to occur. The effect of the cable route on these species cannot be determined from the design of the present study. However, the Solway Firth does not appear to be a particularly important area for elasmobranch populations based on the survey data.

4.7. Conclusions

Significant variation has occurred in epibenthic assemblage structure since the baseline survey was recorded. Previous evidence has reported similar effects in estuarine habitats and has correlated such changes with depth, salinity, tidal current velocity and sediment composition (Ysebaert *et al*, 2003). It is perhaps unsurprising that variation of benthic species and assemblages has occurred over the ten year period since the baseline survey.

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 industry wide research is needed to determine the distance of effect that the introduction of hard substrata provided by offshore wind turbine foundations are likely to have on soft sediment benthic assemblages.

Table 4.15: 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 results 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 difference from 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.
Low response of electrosensitive species along the export cable corridor	No significant effect on electrosensitive species has been detected during the monitoring program. It is possible that survey stations are too far from the export cable to determine any effect.
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 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.

For future projects a greater focus should be placed on detection of change at a finer scale, potentially assessing differences along a gradient from specific turbines. To ensure changes can be attributed to effects of turbine locations it is essential to record habitat variables during baseline, construction and operational monitoring. The presence of turbines has been reported to affect mean grain size, local hydrodynamics and organic matter at local scales around turbines which in turn results in a shift in macrobenthic community structure (Coates *et al*, 2010). A gradient approach would allow determination of the distance at which this is likely to be observed.

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