Westermost Rough Offshore Wind Farm Shellfish Survey 2017

A Study Commissioned by the Holderness Fishing Industry Group

Mike Roach and Mike Cohen

m.roach@hfig.org.uk

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Introduction

Background to the study

The Holderness Fishing Industry Group (HFIG) conducted a survey in 2017 investigating the short-term effects of the construction of the Westermost Rough offshore windfarm on the commercially important crustacean stocks in the area. This survey supports the research undertaken by HFIG in 2013 (baseline survey (Roach & Cohen, 2013)) and 2015 (first year post build of the wind farm (Roach & Cohen, 2015)), forming part of the continuing study of the effects of wind farm construction on commercial shellfish stocks. The survey in 2017 was supported via a donation from West of Morecambe Fisheries Limited (www.westofmorecambe.com) to support the ongoing scientific programme of HFIG.

HFIG researchers were concerned that the results reported in Roach & Cohen (2015) did not reflect the true impacts of the wind farm construction. This was primarily because of the Westermost Rough site being closed to fishing during the construction phase and subsequently being reopened during the 2015 survey period. The quasi-no take zone skewed the results reported during this survey, causing analysis to be separated into before and after the site being reopened to fishing (Roach & Cohen, 2015). This closure followed by a reopening of the site meant that the true reflection of the effects of the construction were difficult to ascertain. It did however raise the question of what are the effects of reopening a site to fishing exploitation that has been previously closed (Roach *et al.*, *under review*). There was also an increase in abundance of Atlantic Cod (*Gadus morhua*) caught in the shellfish pots reported between the baseline in 2013 and 2015 (increase of 642%). This was of concern as Atlantic Cod have been associated with predation on juvenile lobsters and their food sources. It was a point of concern that the WMR wind farm was acting as a fish aggregating device. This could potentially affect the food web around the wind farm.

Due to these concerns, the survey (third year post build) of the WMR wind farm was commissioned by HFIG to further investigate its effects on commercial shellfish stocks. The survey was timed for any no take zone effects to be negated by the fact that the site has been subjected to fishing pressure since 13th August 2015. This allowed the survey to study the effects of the wind farm whilst fishing pressure was stable, without the intense pressure reported in the 2015 report immediately following the opening of the site.

Review of recent literature

A comprehensive literature review was conducted for the 2013 and 2015 reports (Roach & Cohen, 2013, 2015) looking at potential effects and impacts of offshore wind farms on the marine environment. Below is a short review of the literature published in the interim period.

As offshore renewable energy expands there is a driver to understand the short and long-term effects of offshore wind energy installations on ecosystem services. Modelling of offshore wind ecosystems has been demonstrated to show a positive response of upper trophic level species to the installation of offshore wind farms. (Raoux et al., 2017). Lower trophic level species such as infauna can also benefit from the absence disturbance due to mobile fishing gear. Exclusion of mobile fishing gear such as trawling due to the physical impracticalities of trawling thorough an offshore wind farm has demonstrated to improve macrofaunal diversity (Coates *et al.*, 2016). However, there is focus on the co-location of fisheries (Hooper & Austen, 2014) and aquaculture (Griffin *et al.*, 2015) with offshore energy installations. This is predominantly static fisheries such as netting and potting fisheries. However, Stelzenmüller *et al*., (2016) theorised that there would be an 50% loss to a fishers' earnings from netting due to offshore wind farms if the areas are excluded to fishing. This was not observed when the potting fishery was assessed in the same survey.

Potential habitat enhancement is thought to be one of the positive effects of offshore installations and is the focus of recent literature. Both by introducing new hard substrate in areas not previously characterised by such. *Cancer pagurus* abundance has been demonstrated to be positively influenced by offshore wind installations and the installations providing habitat for a projected 27% of the population production (Krone et al., 2017). New settling surfaces for sessile species can increase diversity by providing surfaces for lower trophic level species to colonise (De Mesel *et a*l., 2015). The individual turbines and installations can to act as aggregating devices for fish species. Individual turbines have been demonstrated to provide new and additional habitat for fish species. van Hal *et al*., (2017) observed increase abundance of fish species around individual turbine structures, using them for shelter and feeding.

There are current studies being undertaken in the United States investigating the impact of EMF generated by sub-sea power cables on marine organisms (full reports not yet published). These are currently investigating HVDC cables as opposed to HVAC cables that exist for the WMR wind farm (Love *et al.*, 2016). There are also in-situ studies investigating the effects of EMF from sub-sea cables acting as a barrier to migration for commercially important crab species. Early indications are that crab species will cross a live unburied HVDC cable in order to access bait therefore the cables should not act as a barrier to migration (Bureau of Ocean Energy Mangaement, 2016).

Methodology

Site Description

This study mirrored that of the 2013 and 2015 Westermost Rough surveys. The study site was the Westermost Rough (WMR) offshore wind farm. The WMR wind farm is located east of Tunstall on the north-east coast of the UK. The central point of the wind farm is located at 53º 48.37'N, 000º 09.02'E. The closest point to shore is 7.7 km and the furthest point is 13.3 km offshore. The WMR wind farm covers an area of approximately 35 km^2. It consists of 35, 6 MW turbines and associated substation. The substrate is predominantly rock and cobble and the depth ranges from 15 -23 metres.

Sampling regime

The sampling equipment deployed was intended to closely reflect the fishing gear used in in the local fishery. Four fleets (strings of pots) were deployed at the four sample sites selected for the baseline survey in 2013 (See Roach & Cohen, 2013). There was a treatment fleet placed within the turbine array and another over the export cable, there were a further two fleets located approximately 1 km to the north of these sites to act as controls (Figure 1). The control sites were selected due to being north of the wind farm (prevailing current drifts north/south) and being on similar substrate and depth as the treatment fleets.

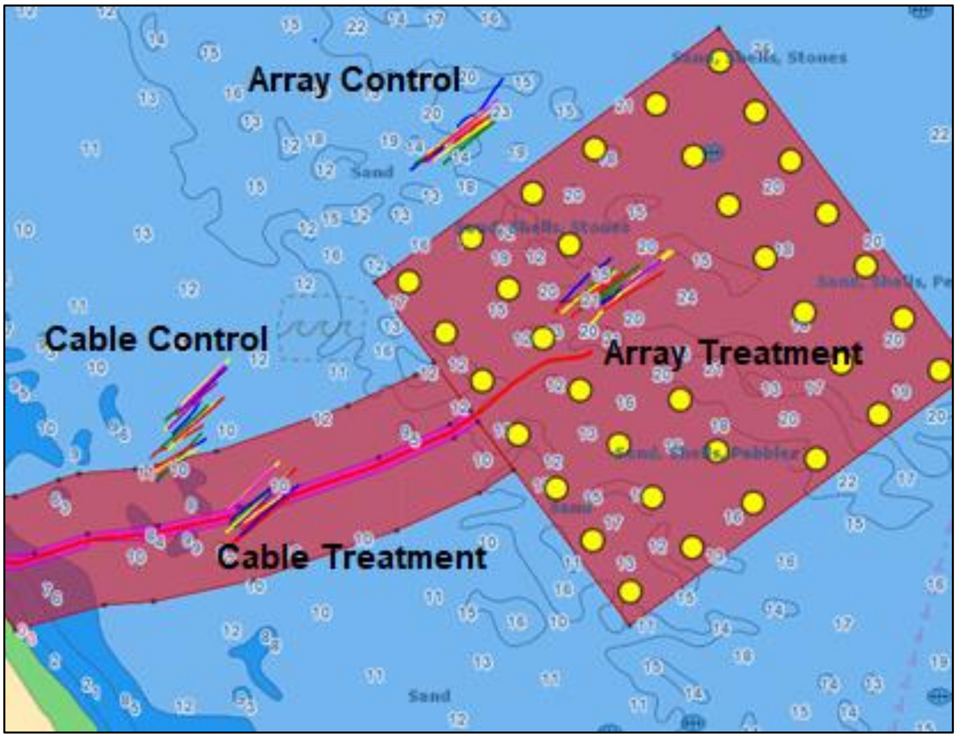

Figure 1: Location of the fleets deployed during the 2017 WMR shellfish survey. The outer red boundary represents the fishing exclusion zone that was in place during the construction phase. Each time a fleet was deployed a new track was created and given a different colour. Image taken from Maxsea Time Zero chart plotter used on the R.V. Huntress.

The fleets (strings of pots) consisted of 30 shellfish pots/creels (subsequently referred to as pots). Each fleet consisted of 25 pots with a 70 mm mesh size and a 96.5 cm base: and 5 pots with a 30 mm mesh size and 76.2 cm base. The smaller mesh sized pots were used to capture the smaller animals that could escape the large mesh pots. The smaller mesh pots were placed every 6th pot in the fleets. Pots were spaced 40m apart, with a 2m 'leg' of rope attaching the pot to the main ground rope. Each end of the fleet was secured with a 20 kg anchor which was also attached to a surface marker buoy. The bait used for the entire survey was mackerel (*Scomber scombrus*); except for a single survey day where horse mackerel (*Trachurus trachurus*) was used due to a lack of mackerel availability. Each pot was baited with 2 'frames' each time they were deployed.

Catch data was recorded of all commercial species and bycatch as each pot was hauled onto the vessel. The commercial catch was separated into their respective species and sexes and what type of pot they were caught in. Size (carapace length (CL) of lobsters and carapace width (CW) of crab species), condition (Table 1) and ovigerous status of females were recorded for every individual. Lobster egg stage (if ovigerous) and whether the tail fan had been V notched was also recorded. Fish bycatch size was recorded as total length and invertebrate species bycatch abundance was recorded (Annex 1).

Table 1: Condition index used to determine the quality of the animals captured

Grade	Description
1	Healthy specimen, no physical impairments or signs of disease or biofouling
2	Soft shelled (pre or newly moulted)
3	Missing pereopods but not chelipeds, no visible signs of disease or biofouling
4	Missing chelipeds and possibly pereopods, no visible signs of disease or biofouling
5	Visible signs of disease e.g. black spot or large amounts of biofouling (> 10%), but no physical impairments
6	Visible signs of disease e.g. black spot or large amounts of biofouling (> 10%), but physical impairments and missing chelipeds and pereopods or possibly both.

It was intended that the pots were hauled twice per week during the survey period. However, this was not possible due to inclement weather and mechanical problems on the R.V. Huntress. A mean soak time of 4.1 days (s.d. +/- 1.5 days) was achieved for the survey period. Occasions when the soak period was too great, were discounted from the data and the pots reset and rebaited to ensure standardisation throughout the survey. The R.V. deployed 19 days for the survey with data being collected on 16 occasions. The mean sea surface temperature for the study period was 14.9^{o} C.

All catch was returned to the sea post recording and all lobsters over the minimum landing size (87 mm CL) were V notched (n = 871), in keeping with the established stock conservation programme of the fishery.

On all survey days, to ensure scientific robustness and safe working practices, an independent observer was present on board the R.V. Huntress. This observer was provided by West of Morecambe Fisheries Limited.

Data analysis

Changes were made to the data analysis of this report in comparison to the previous reports (Roach & Cohen 2013 & 2015). Catch per unit of effort (CPUE) has been reclassified as the mean number of individual caught per sample fleet as opposed to the mean number of individuals sampled per sample pot. This change was adopted to reflect the common practice of calculating CPUE that is reported widely in the literature. Therefore, the separate analysis of the median abundance of individuals per site was not required. The condition index (Table 1) was used to assess whether an individual was of a quality that could be landed to market. These criteria (alongside size data) was used to calculate landings per unit of effort (LPUE), i.e. the mean number of individuals per fleet that were above the minimum landing size (MLS) and of a quality to land to market. Separate analysis of the condition of individuals between sites was not required as this was considered when calculating LPUE.

Catch data

2017

The CPUE of lobsters conformed to a normal distribution (Shapiro Wilkes, $p > 0.05$) and was equally variable (Levene's Test, $p > 0.05$). The CPUE and LPUE of edible crabs and velvet crabs (and LPUE of lobsters) did not conform to a normal distribution (Shapiro Wilkes, $p < 0.05$), however were equally variable (Levene's Test, $p > 0.05$). Due to the violation of ANOVA assumptions both a one-way ANOVA and a Kruskall Wallis test was applied to test whether the mean CPUE and mean LPUE differed significantly between the turbine array and export cable treatment and control sites. Standardised residuals of ANOVA analysis were checked for normality to ascertain if ANOVA was the correct analysis applied. Therefore, one-way ANOVA analysis was applied to the CPUE/LPUE data of lobsters and edible crabs. Velvet crab CPUE/LPUE were analysed using Kruskall Wallis analysis.

2013/2017

Analysis of the catch data between years involved between site analysis and between year analysis (2013, 2015 & 2017). Due to there being three survey years a repeated measures test was applied. A two-way repeated measures ANOVA was applied to the CPUE/LPUE data to test the null hypotheses the mean CPUE/LPUE did not differ significantly between sites or years and there was no significant interaction between site and year. Due to violation of the assumption of normality for ANOVA previously discussed, the standardised residuals of all ANOVA analysis were checked for conformity to normality. In all cases the standardised residuals conformed to a normal distribution (Shapiro Wilkes, $p > 0.05$), therefore the two-way repeated measures ANOVA analysis was applied.

Size distribution

To analyse the size distribution of the commercial catch sampled, a none-parametric, two-sample Kolmogorov Smirnov test was applied. Testing the hypotheses that there was no significant difference in the size distribution of commercial catch sampled at the treatment and control sites for both the turbine array and export cable. This test was also applied to analyse the within site variation of the size distribution, of commercial catch between the 2017 and the baseline year (2013). Empirical cumulative distribution function (ECDF) plots were generated from the size data. This demonstrated the proportion of commercial catch between the control and treatment sites for the turbine array and export cable that were less than each observed length (Thomas *et al*., 2015). This was also applied to the within site size distribution between the 2017 and baseline (2013) surveys. The size data for each of the species/sites did not conform to a normal distribution and there was large variation in the number of individual sampled on a daily/site basis. To support the Kolmogorov Smirnov analysis, a Generalised Linear Mixed Models (GLMM) can be used when the data are not normally distributed and when there is the potential for pseudo-replication (repeated sampling go the same site) (Zuur & Ieno, 2016). This was applied to the size data of each of the commercial species sampled, generating a model to assess the difference in the proportion of individuals at each size between the control and treatment sites of the turbine array and export cable. A binomial GLMM was applied where Site (control/treatment) was the response variable, Size of individual (CL/CW) was the fixed effect and Haul (survey day) was the crossed random intercept. Sex, Berried status and Grade were initially included in the model, however berried was removed due to the factor only applying to female lobsters. Sex and grade were deemed as not significant ($p > 0.05$) factors within the model. Therefore, the simplest model was the best description of the size distribution between the two sites;

Ln (Site ~ Size + Haul)

GLMM was applied using the lme4 package in R statistical software (Bates *et al.,* 2015). This follows a similar method described by (Holst & Revill, 2009), analysing differences in catch composition of different trawl types. Each model was validated by checking the standardised residuals conformed to normality (Shapiro Wilkes, $p > 0.05$) and comparison to the two-sample Kolmogorov Smirnov tests and ECDF plots. Plots were also generated from the models to allow inference as to where in the distribution the differences in proportion at size lay.

The GLMM analysis was only applied to the 2017 size data. It was not applied to the between years size data due to the model requiring the same number of Hauls (survey days). The survey days in 2017 (n = 16) and 2013 (n = 24) made GLMM analysis of size distribution between years unsuitable.

Results

2017 Comparison between treatments

Sampling was conducted between the 22nd June and 26th September 2017 (sample days at sea, n = 16). A total of 16142 animals were sampled (lobsters (n = 4959); edible crabs (n = 5235) and velvet swimming crabs (n = 5948)). The presence of non-commercial target species was also recorded (Annex 1).

Catch per Unit of Effort and Landings per Unit of Effort

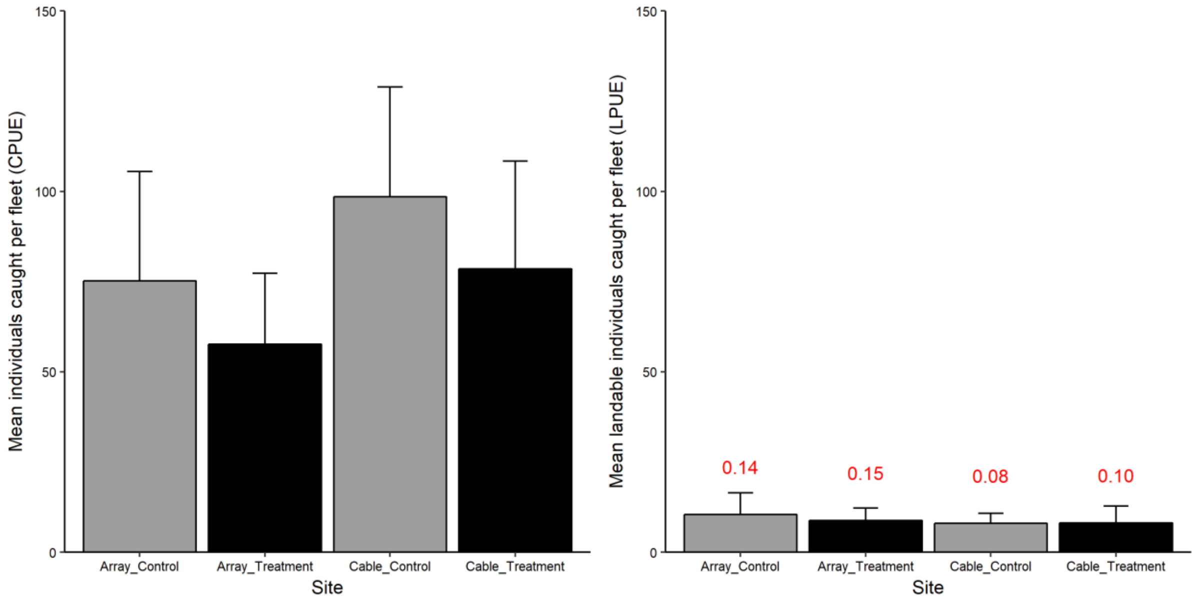

Figure 2: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of lobsters sampled at the four sites of the WMR wind farm. The top of the bars represents the mean value and the error bars represent the standard deviation. The values in red above the bars of the LPUE plot represent the ratio between the LPUE/CPUE for that specific site. This applies to all subsequent bar plots reported.

Mean lobster CPUE (Annex 2, Table 1) did not differ significantly between either the turbine array or the export cable control and treatment (ANOVA, $p > 0.05$ (Table)). Mean lobster CPUE did differ significantly between the wind farm treatment and the control for the export cable (ANOVA, $p < 0.05$ (Figure 2, Table 2)). There was no significant difference in mean lobster LPUE between any of the sites sampled

(ANOVA, p > 0.05 (Table 2)). The highest ratio of LPUE to CPUE was at the wind farm control and treatment sites, indicating a greater return of catch per effort at the offshore sites.

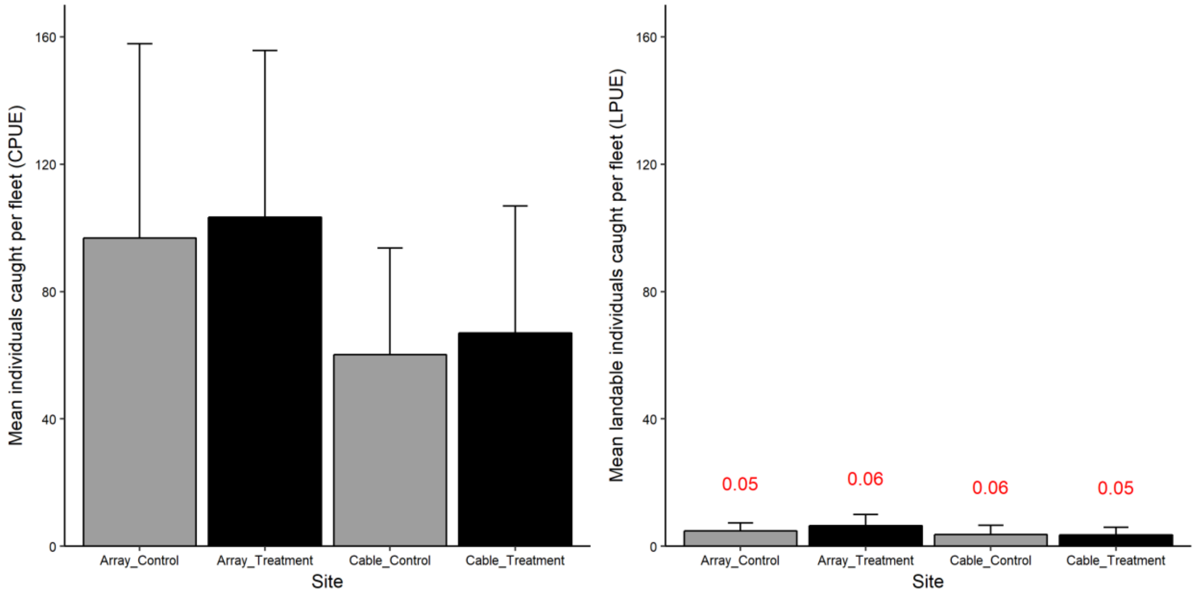

Figure 3: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of edible crabs sampled at the four sites of the WMR wind farm.

There was no significant difference in mean edible crab CPUE or LPUE (Annex 2, Table 1) between any of the treatment and control sites sampled, also between the wind farm and export cable (ANOVA, p > 0.05 (Table 2)). The ratios between the LPUE and CPUE also showed little variation (0.01) between the four sites sampled (Figure 3).

There was no significant difference in mean velvet swimming crab CPUE or LPUE (Annex 2, Table 1) between either of the control and treatment sites for both the wind farm and export cable. However, there was a significant difference in both mean CPUE and LPUE of velvet swimming crabs between the both the export cable and wind farm sites (Figure 4) (Kruskal Wallis, p < 0.05 (Table 2))

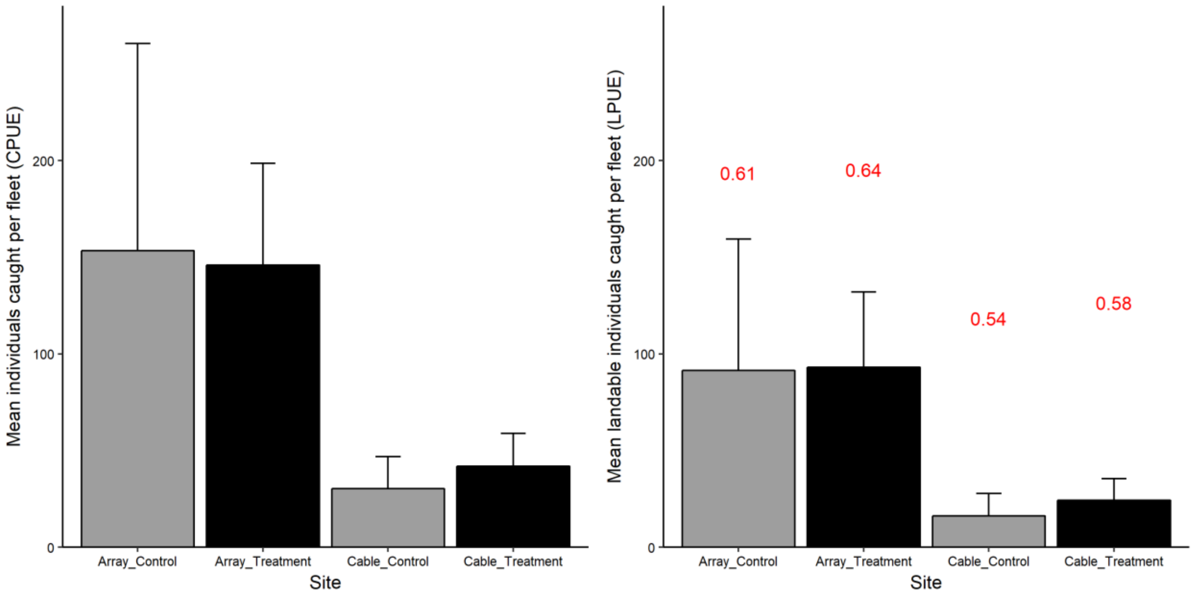

Figure 4: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of velvet swimming crabs sampled at the four sites of the WMR wind farm.

Table 2: Results of ANOVA analysis of CPUE and LPUE for lobster and edible crab and results of Kruskal Wallis analysis for CPUE and LPUE for velvet swimming crab.

Species	Unit of effort	Statistical Test	Test Statistic	df	p
Lobster	CPUE	ANOVA	5.79	3	< 0.01
Edible crab	CPUE	ANOVA	3.21	3	< 0.05
Velvet crab	CPUE	Kruskal Wallis	41.64	3	< 0.001
Lobster	LPUE	ANOVA	1.01	3	n.s.
Edible crab	LPUE	ANOVA	3.20	3	< 0.05
Velvet crab	LPUE	Kruskal Wallis	43.39	3	<0.001

Size distribution

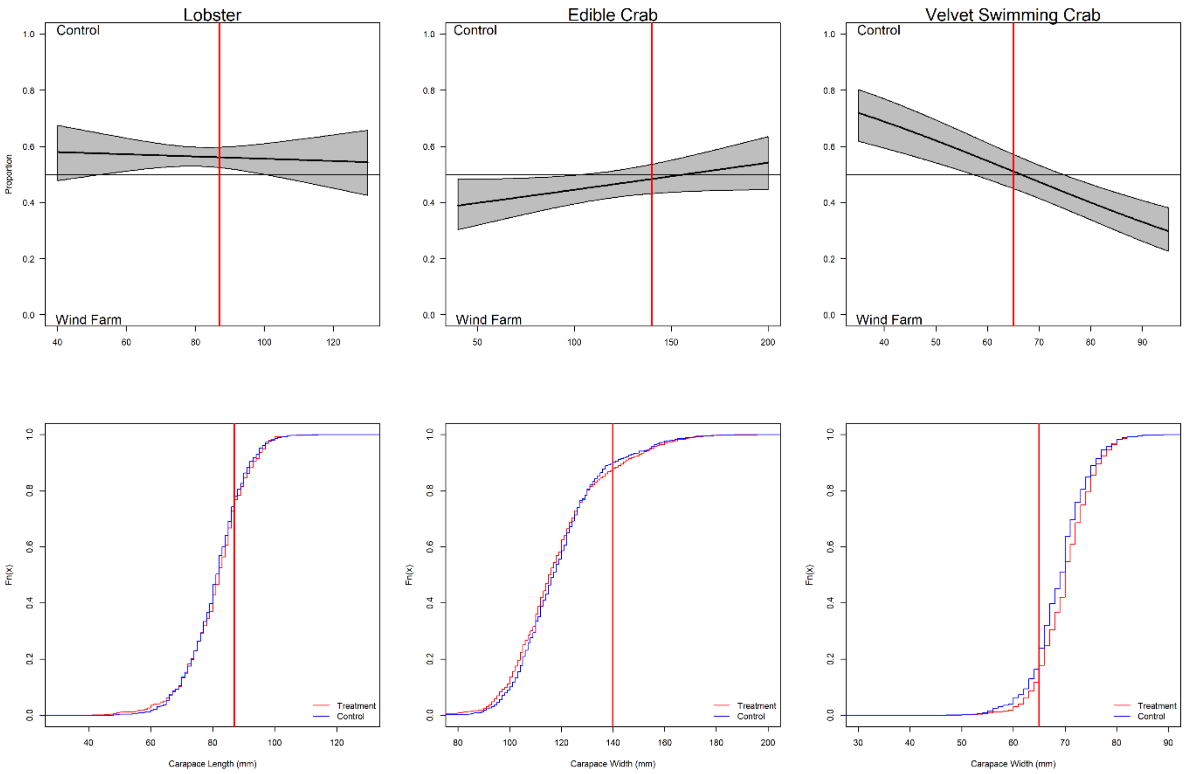

Figure 5: Size distributions of the commercial catch sampled at the **turbine array** during the WMR survey in 2017. The top plots are derived from GLMM modelling of the proportion of animals sampled between the turbine array (wind farm (bottom box)) and the control site (top box). The grey shaded areas represent the 95% confidence intervals and the bold black line the mean value. The central horizontal line represents the 0.5 (50%) value, points overlapping this line indicate that there was no significant difference in the proportion of that sized animal between the two years. A value of 0.75 indicates that 75% of the lobsters sampled at that size were sampled in the control and the other 25% were sampled in the wind farm. This applies to all subsequent plots derived from GLMM analysis.
The bottom plots are the Empirical cumulative distribution function (ECDF) of the commercial species sampled at the turbine array treatment (red) and control (blue).

The size frequency distributions of lobsters did not differ significantly between turbine array treatment and control (Kolmogorov Smirnov, D = 0.04, $p > 0.05$). This was supported by the ECDF plot showing no variation is size distribution. The GLMM analysis (Table 3) plot shows that whilst there was no difference in distributions, there was a slightly greater proportion of lobsters between 60 – 90 mm CL in the control site (Figure 5).

There was no significant difference in the size distribution of edible crabs sampled between the turbine array treatment and control sites (Kolmogorov Smirnov, D = 0.05, p > 0.05). The GLMM analysis (Table 3) and ECDF plots support the result of the analysis demonstrating little variation in proportion or empirical distribution between the two sites (Figure 5).

Velvet crab size distribution differed significantly between the turbine array treatment and control sites (Kolmogorov Smirnov, D = 0.09, p < 0.001). The plot derived from GLMM analysis (Table 3) shows that below the MLS of 60 mm CW there was a greater proportion of velvet crabs in the control site. Whereas greater than 75 mm CW there was a greater proportion of velvet crabs in the treatment site. The ECDF plot, shows that the empirical distribution of the velvet crabs had a greater distribution in the treatment site ranging from 55 – 80 mm CW (Figure 5).

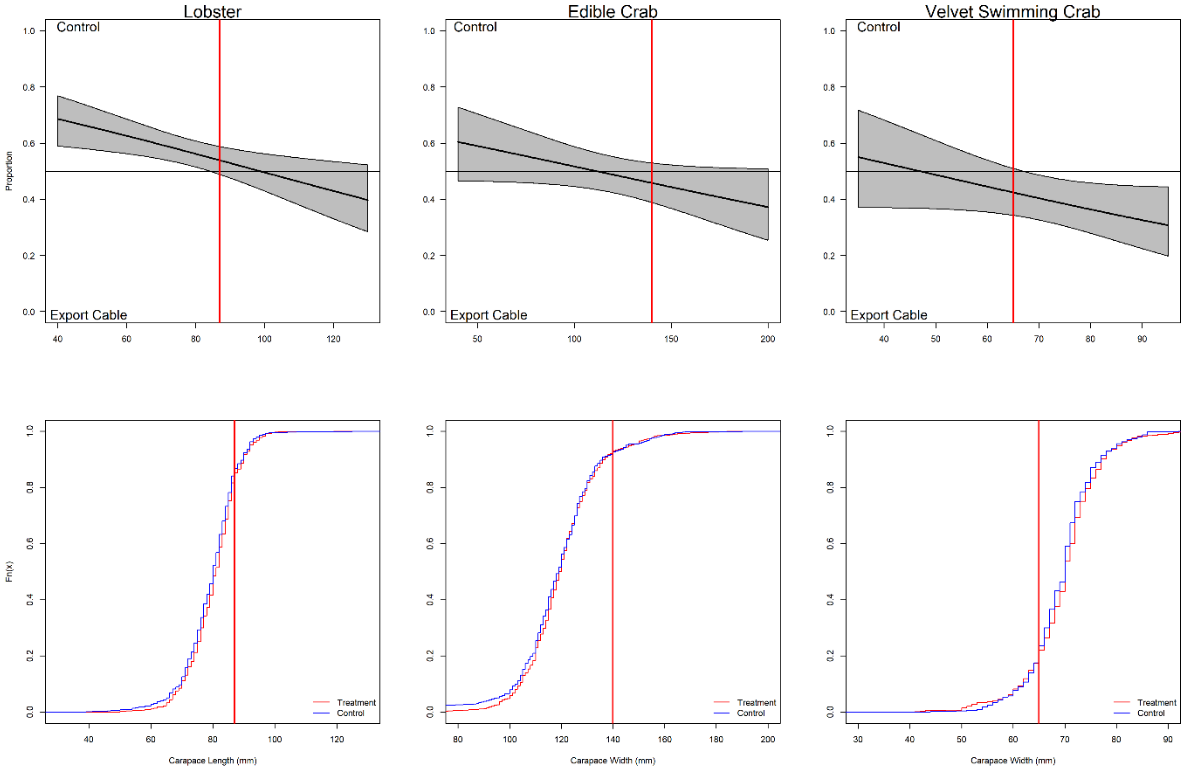

Figure 6: Size distributions of the commercial catch sampled at the **export cable** during the WMR survey in 2017. The top plots are derived from GLMM modelling of the proportion of animals sampled between the export cable (bottom box) and the control site (top box).
The bottom plots are the Empirical cumulative distribution function (ECDF) of the commercial species sampled at the export cable treatment (red) and control (blue).

There was a significant difference in the size distribution of lobsters sampled between the export cable treatment and control sites (Kolmogorov Smirnov, $D = 0.05$, $p < 0.05$). The GLMM analysis (Table 3) demonstrated that there was a greater proportion of lobsters < 80 mm CL at the control site and no difference in lobsters > 80 mm CL between the two sites. However, the ECDF plot (Figure 6) shows that the empirical distribution is slightly greater in the treatment site from 60 – 87 mm CL than the control site.

The size distribution of edible crabs did not differ significantly between the export cable treatment and control sites (Kolmogorov Smirnov, $D = 0.05$, $p > 0.05$). The GLMM (Table 3) and ECDF plots support the result of the analysis demonstrating little variation in proportion or empirical distribution between the two sites (Figure 6).

There was no significant difference in the size distribution of velvet crabs between the export cable treatment and control sites (Kolmogorov Smirnov, $D = 0.07$, $p > 0.05$). The results of GLMM analysis (Table 3, Figure 6) demonstrate that greater than the MLS of 65 mm CW there was a greater proportion of velvet crabs recorded in the export cable treatment site than the control site. This is supported by the ECDF plot (Figure 6), demonstrating a greater empirical distribution in the export cable treatment site than the control site.

Table 3: GLMM parameters for the comparison between the control and treatment sites of both the turbine array and the export cable.

Species	Treatment	Response	Intercept Variance	Parameter	Estimate	Standard Error
Lobster	Turbine Array	Control and Treatment	0.04	β_0 β_1	0.38 - 0.001	0.39 0.005
Lobster	Export Cable	Control and Treatment	0.12	β_0 β_1	1.31 -0.013	0.39 0.005
Edible Crab	Turbine Array	Control and Treatment	0.12	β_0 β_1	-0.61 0.004	0.27 0.002
Edible Crab	Export Cable	Control and Treatment	0.22	β_0 β_1	0.66 -0.006	0.39 0.003
Velvet Crab	Turbine Array	Control and Treatment	0.21	β_0 β_1	1.99 -0.030	0.41 0.006
Velvet Crab	Export Cable	Control and Treatment	0.38	β_0 β_1	0.79 -0.017	0.68 0.009

Sex Ratio and Ovigerous Status

Table 4: Sex Ratio of all commercial species sampled across all sites.

Site	Lobster			Edible Crab			Velvet Crab		
	Male (n)	Female (n)	Ratio	Male (n)	Female (n)	Ratio	Male (n)	Female (n)	Ratio
Array Treatment	461	461	1 : 1	1042	612	1.7 : 1	1154	1183	1 : 1
Array Control	592	612	1 : 1	1005	543	1.8 : 1	1066	1390	1 : 1.3
Cable Treatment	649	607	1.1 : 1	845	226	3.7 : 1	411	260	1.5 : 1
Cable Control	796	781	1 : 1	713	249	2.8 : 1	347	137	2.5 : 1

Sex ratio of lobsters remained similar across all four sites (1:1), except for slightly more male lobsters than female in the Cable Treatment site (1.1:1.3). Edible crab sex ratio showed a greater number of male crabs across all sites, Cable Treatment being the greatest ratio of male to female edible crabs 3.7:1). There was a greater amount of female velvet crabs in the Array Control site (1:1.3), this was the only site where there were more females than males across the three commercial species (Table 4).

A total of 222 ovigerous lobsters were sampled during the 2017 survey period. Of which 133 (59.9%) were below the MLS of 87 mm CL. The Array Control site had the greatest abundance of ovigerous lobsters and the Cable Treatment site showed the lowest abundance. GLMM analysis of ovigerous lobsters did not generate a significant model of the difference in ovigerous lobster abundance and size between either the turbine array export cable control and treatment sites. The size distribution of ovigerous lobsters did not differ significantly between the treatment sites of either the turbine array or export cable (Kolmogorov Smirnov, $p > 0.05$).

There were only 4 ovigerous edible crabs sampled and 19 velvet crabs sampled across all sites in 2017. Statistical analysis of ovigerous status of crab species was therefore not possible, due to the low n value.

Fish Analysis

All bycatch of fish species presence and absence is reported in Annex 1. Due to the high abundance of juvenile cod (*Gadus morhua*) in 2015 (reported in Roach & Cohen 2015), this section is also reported in this report. There was a reduction of cod bycatch across all sites observed in 2017 in comparison to 2015. However, the overall cod abundance is similar to that observed in the baseline year in 2013. Cod abundance in the Array Treatment site was greatest in 2013 (n = 7) and 2015 (n = 41), however in 2017 this was the site of the lowest cod abundance (n = 2). Due to the low numbers of cod observed (daily counts per fleet were less than 5 for 20% of the expected counts), analysis was not possible for either of the years or sites (Figure 7).

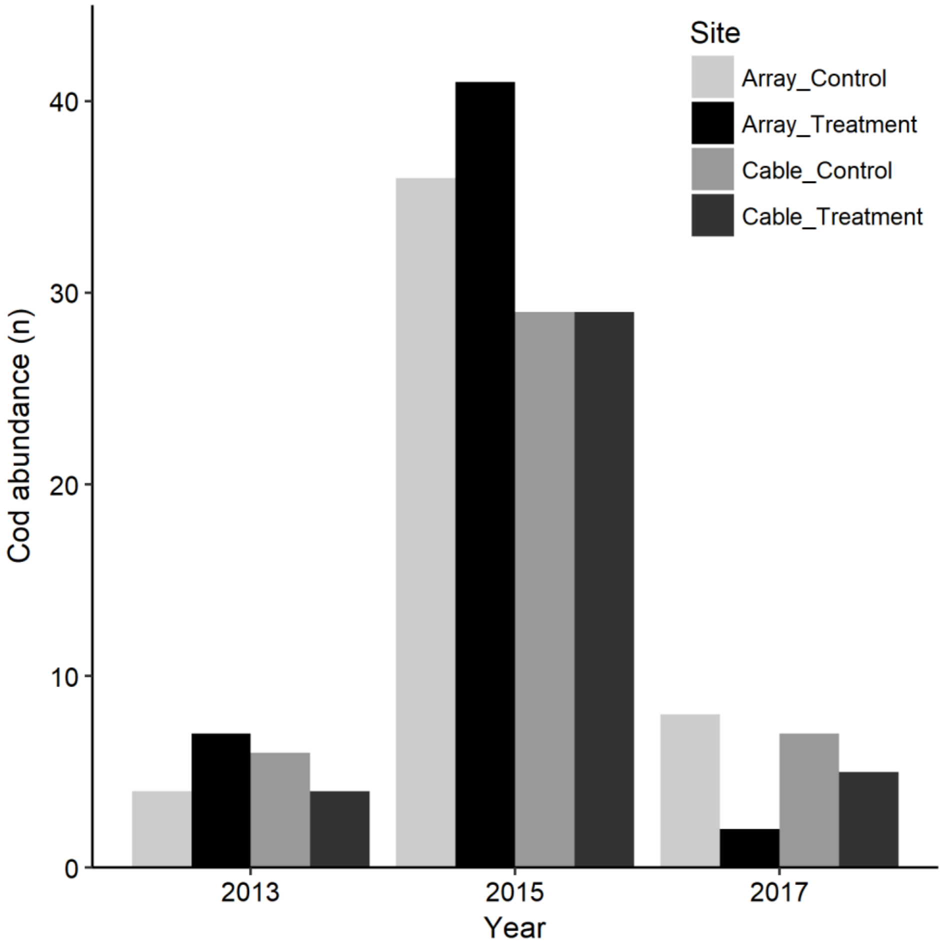

Figure 7: Barplots of total abundance of cod (*Gadus morhua*) sampled at each site of the WMR wind farm for each of the survey years. Error bars are not reported as the plot presents total abundance sampled rather than mean abundance.

Comparison between years

Catch per Unit of Effort and Landings per Unit of Effort

Lobster

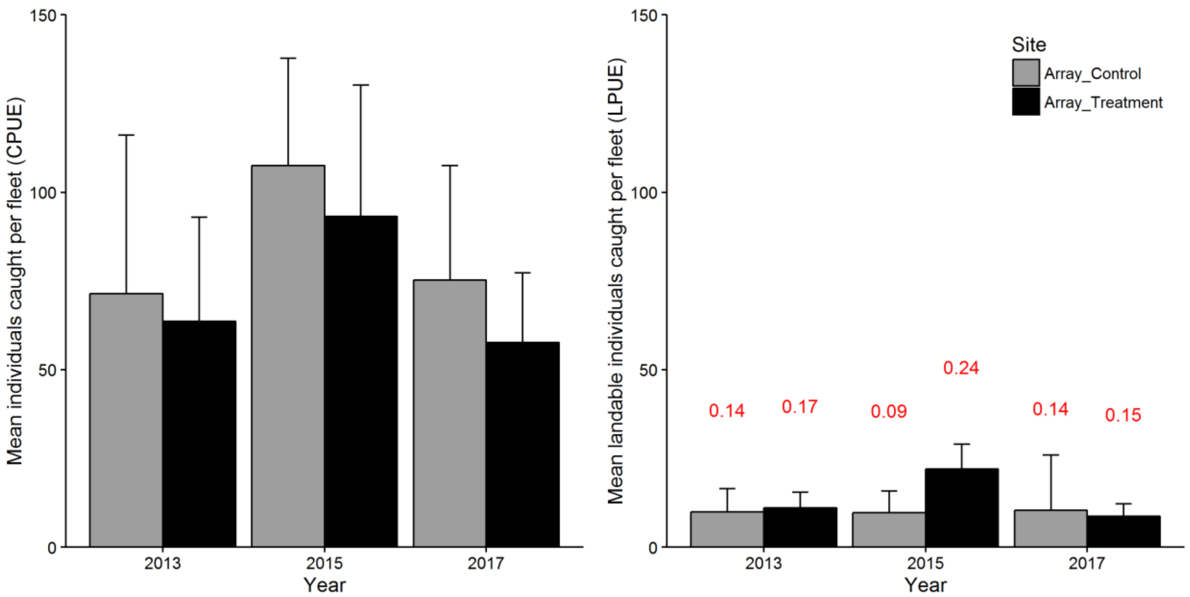

Figure 8: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of lobsters sampled at the **turbine array** of the WMR wind farm for the three sampling years.

There was no significant difference in mean CPUE of lobsters (Annex 2, Table 2) between the turbine array treatment and control sites and no significant interaction between Site and Year (ANOVA, $p > 0.05$ (Table 5)). However, there was a significant difference in mean CPUE of lobsters between years (ANOVA, $p < 0.001$ (Table 5)). There was a significantly greater CPUE in 2015 than in either the baseline in 2013 or the second-year post build in 2017 (Figure 8). Mean LPUE of lobsters also differed significantly between years and between sites, there was also a significant interaction between site and year (ANOVA, $p < 0.001$ (Table 5)). This was predominantly due to a greater mean LPUE in the Array Treatment site in 2015 (Annex 2, Table 2 (Figure 8)). This was highlighted by a greater ratio of LPUE/CPUE in the Array Treatment site in 2015 (Figure 8).

There was no significant difference in mean CPUE of lobsters between the export cable treatment and control sites, also no significant interaction between site and year (ANOVA, $p > 0.05$ (Table 5)). Mean CPUE lobsters did differ significantly between years (ANOVA, $p < 0.001$ (Table 5)). There was a significantly greater CPUE in the export cable control site in 2017 than in either the export cable treatment or control sites in 2013 (Figure 9). Mean LPUE of lobsters did not differ significantly between sites, years and there was no significant interaction between site and year (ANOVA, $p < 0.05$ (Table 5, Figure 9)). The greatest ratio of LPUE/CPUE was between the export cable treatment site in 2013 with the lowest ratio observed in 2015 for both treatment and control sites (Figure 9).

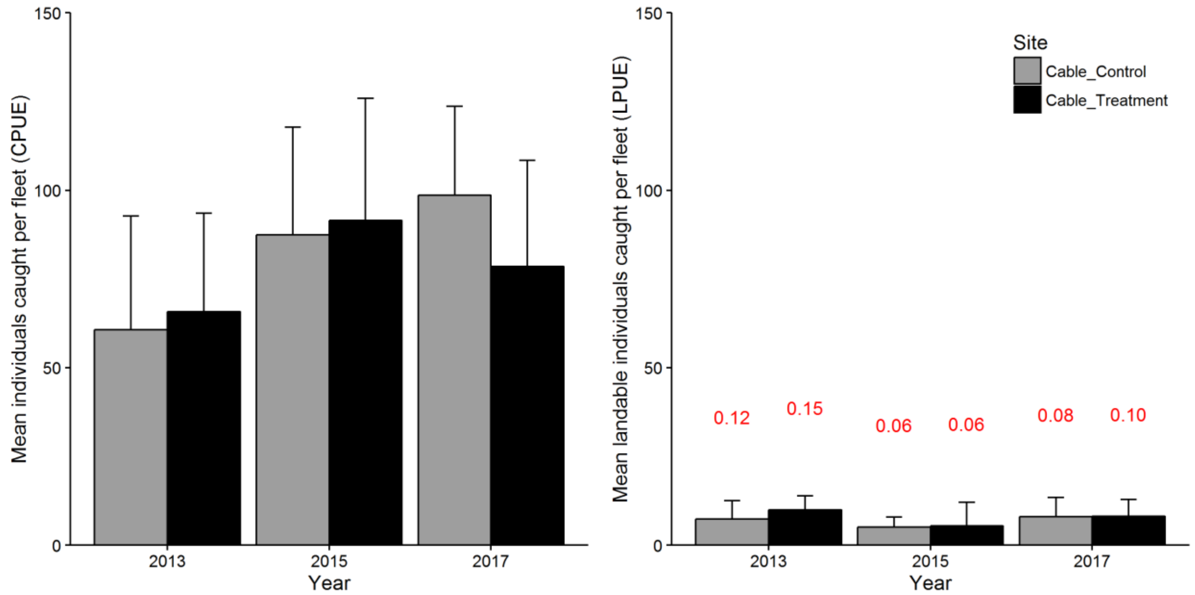

Figure 9: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of lobsters sampled at the **export cable** of the WMR wind farm for the three sampling years.

Edible Crab

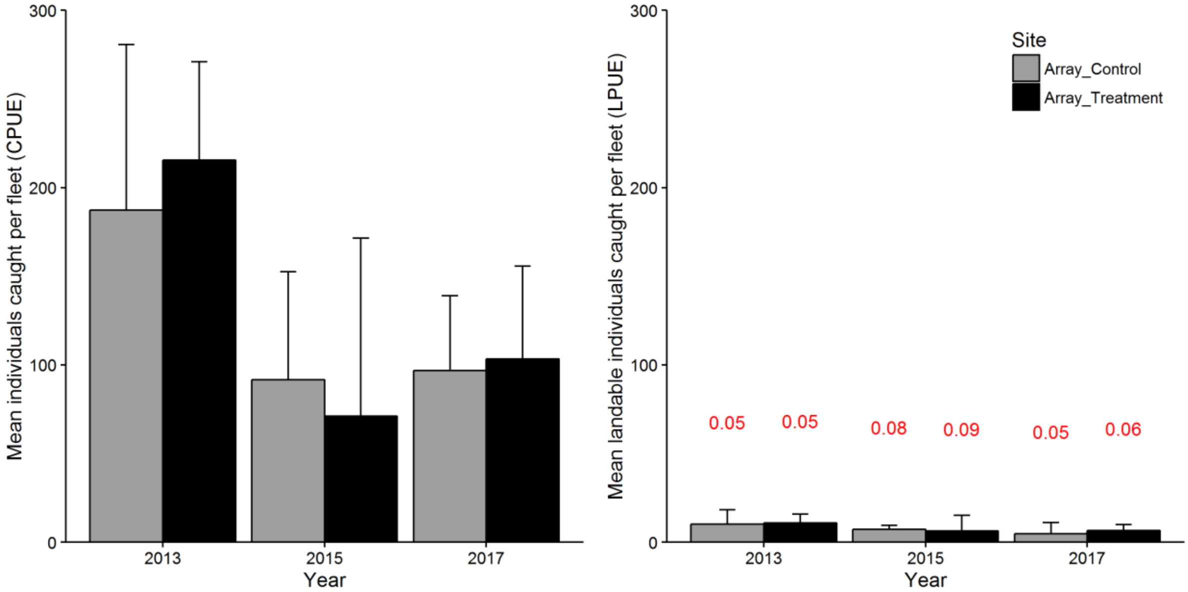

Figure 10: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of edible crabs sampled at the **turbine array** of the WMR wind farm for the three sampling years.

There was no significant difference in mean CPUE of edible crabs between either of the turbine array control and treatment sites and no significant interaction between site and year (ANOVA, $p > 0.05$ (Table 5)). Mean CPUE of edible crabs differed significantly between years (ANOVA, $p < 0.001$ (Table 5)), there was a significantly greater CPUE of crabs in both the turbine array treatment and control sites in 2013 than in 2015 or 2017 (Figure 10). This was not evident in the mean LPUE of edible crabs. There was no significant difference in mean LPUE of edible crabs between sites or year. There was also no significant interaction between site and year.

The mean CPUE and LPUE of crabs sampled in the export cable treatment and control followed the same trend. There was no significant difference between mean CPUE of edible crabs between sites and no significant interaction between site and year (ANOVA, $p > 0.05$ (Table 5)) but a significant difference between years (ANOVA, $p < 0.001$ (Table 5)). Mean CPUE of edible crabs was significantly greater in the export cable treatment and control in 2013 than in 2015 and 2017 (Annex 2, Table 2). Mean LPUE of edible crabs did not differ significantly between sites or years and there was no significant interaction between site and year (ANOVA, $p > 0.05$, (Table 5, Figure 11)). There was little variation (0.02) in the ratio between LPUE/CPUE across the three survey years with LPUE representing a very low ratio of the CPUE.

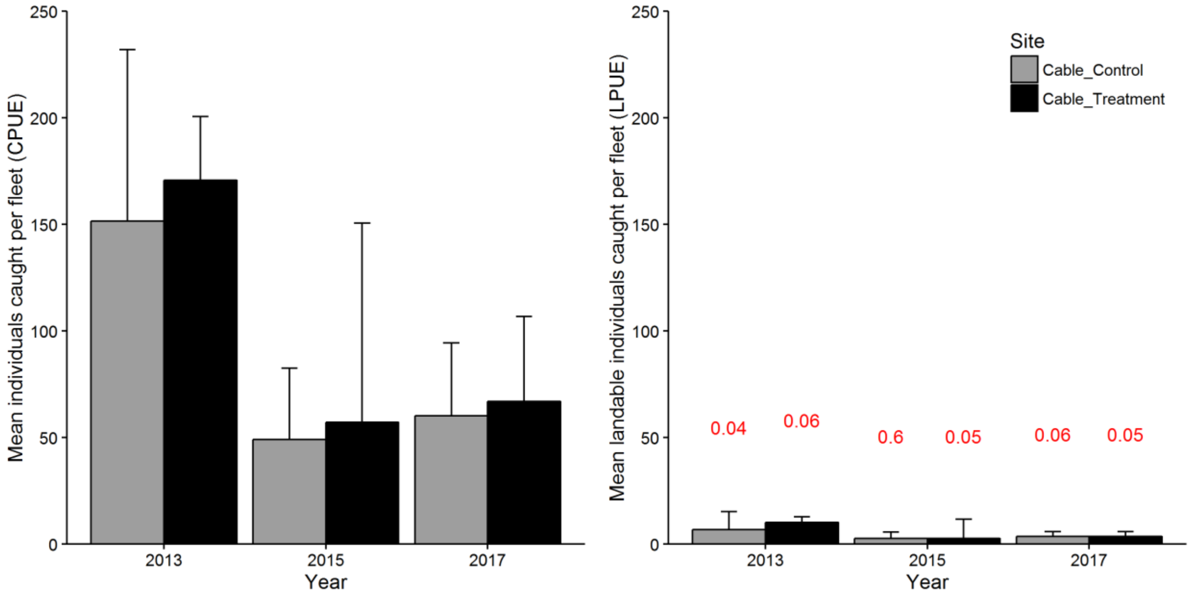

Figure 11: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of edible crabs sampled at the **export cable** of the WMR wind farm for the three sampling years.

Velvet Crab

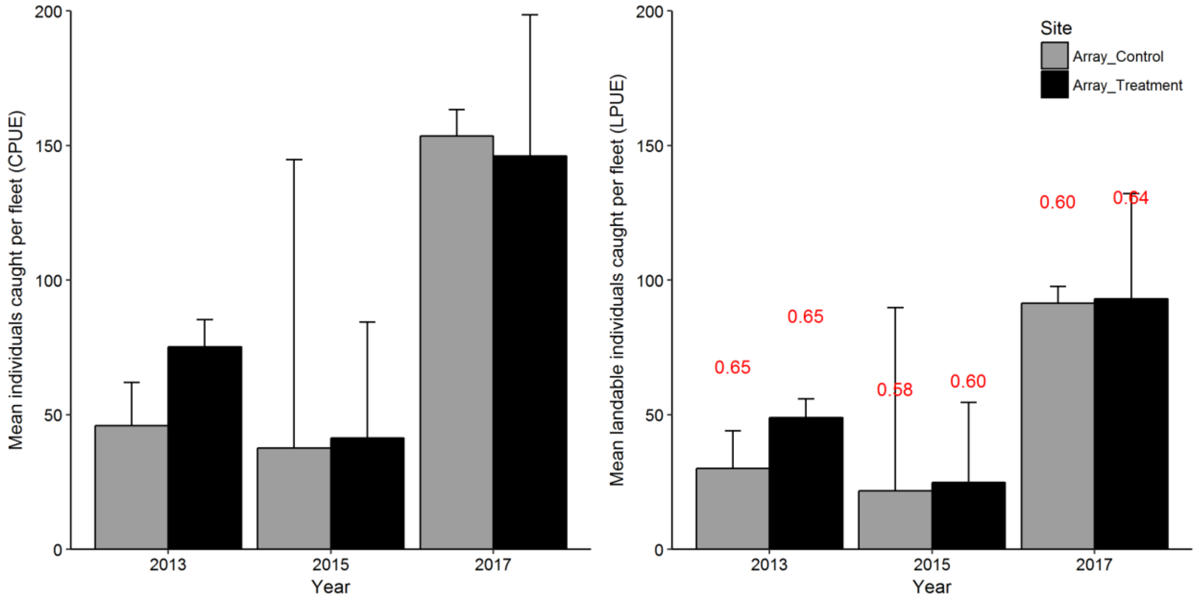

Figure 12: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of velvet crabs sampled at the **turbine array** of the WMR wind farm for the three sampling years.

There was no significant difference in mean velvet crab CPUE between the turbine array treatment and control sites (ANOVA, p > 0.05 (Table)). There was a significant interaction between site and year and a significant difference in mean CPUE of velvet crabs between years (ANOVA, p < 0.01 (Table 5)). Mean CPUE at both the turbine array treatment and control site was significantly greater in 2017 than in 2013 and 2015 (Annex 2, Table 2, Figure 12). Mean LPUE of velvet crabs did not differ significantly between years (ANOVA, p > 0.05 (Table)). There was a significant interact (p < 0.05, (Table 5)) between site and year and a significant difference of mean LPUE between years. Mean LPUE was significantly greater at both the turbine array control and treatment sites in 2017 than in 2013 and 2015 (Annex 2, Table 2). Although mean LPUE in the turbine array sites differed significantly between years, the ratio between LPUE/CPUE showed little variation (0.06) between years.

There was a significant difference in mean CPUE of velvet crabs sampled at the export cable control between sample years and between sites (ANOVA, p < 0.001, (Table 5)) but no significant interaction between site and year (ANOVA, $p > 0.05$, (Table 5)). This was attributed to the mean CPUE of velvet crabs across both sites in 2015 was significantly lower than in 2013 and 2017 (Annex 2, Table 2 (Figure 13)). Mean LPUE was also significantly different between sites and year (ANOVA, $p < 0.0001$, (Table 5)) but no significant interaction between site and year (ANOVA, $p > 0.05$, (Table 5)). This was attributed to the mean LPUE of velvet crabs in the cable treatment site in 2013 was significantly greater than that in the cable control site in 2017 (Annex 2, Table 2). This was reflected in the ratio between the LPUE/CPUE between the two factors being greatest (difference of 0.08).

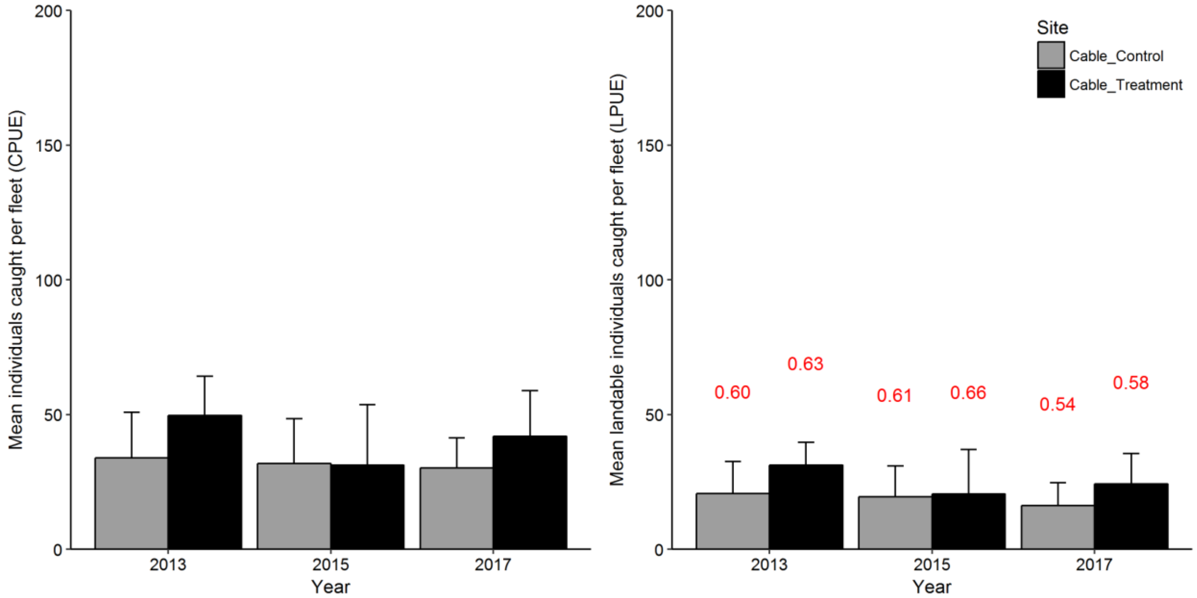

Figure 13: Bar plot of the Catch per unit of effort (CPUE) and the Landings per unit of effort (LPUE) of velvet crabs sampled at the **export cable** of the WMR wind farm for the three sampling years.

Table 5: Results of two-way repeated measures ANOVA testing CPUE and LPUE between site and year for all three commercial species sampled during the WMR surveys.

Species	Treatment	Effort	Factor	F Value	p
Lobster	Turbine Array	CPUE	Site	0.398	n.s.
			Year	29.003	< 0.001

			Site*Year	0.310	n.s.
Lobster	Turbine Array	LPUE	Site	19.90	< 0.001
			Year	40.36	< 0.001
			Site*Year	25.11	< 0.001
Lobster	Export Cable	CPUE	Site	3.269	n.s.
			Year	25.57	< 0.001
			Site*Year	1.043	n.s.
Lobster	Export Cable	LPUE	Site	1.243	n.s.
			Year	2.072	n.s.
			Site*Year	1.578	n.s.
Edible Crab	Turbine Array	CPUE	Site	2.529	n.s.
			Year	39.166	< 0.001
			Site*Year	2.180	n.s.
Edible Crab	Turbine Array	LPUE	Site	0.035	n.s.
			Year	0.492	n.s.
			Site*Year	0.001	n.s.
Edible Crab	Export Cable	CPUE	Site	2.438	n.s.
			Year	37.358	< 0.001
			Site*Year	0.000	n.s.
Edible Crab	Export Cable	LPUE	Site	0.000	n.s.
			Year	1.653	n.s.
			Site*Year	0.065	n.s.
Velvet Crab	Turbine Array	CPUE	Site	0.752	n.s.
			Year	69.858	< 0.001
			Site*Year	6.730	< 0.01
	Turbine Array	LPUE	Site	0.453	n.s.

Velvet Crab			Year	46.178	< 0.0001
			Site*Year	4.568	< 0.05
Velvet Crab	Export Cable	CPUE	Site	10.810	< 0.001
			Year	4.877	< 0.001
			Site*Year	1.588	n.s.
Velvet Crab	Export Cable	LPUE	Site	16.852	< 0.0001
			Year	12.922	< 0.0001
			Site*Year	2.075	n.s.

Size Distribution

This section of the report focuses on the difference in size distribution between the 2017 survey and the baseline survey undertaken in 2013 only. The 2015 data is plotted in the ECDF plots for reference only, the analysis between 2013/15 was reported in Roach and Cohen (2015).

Lobster

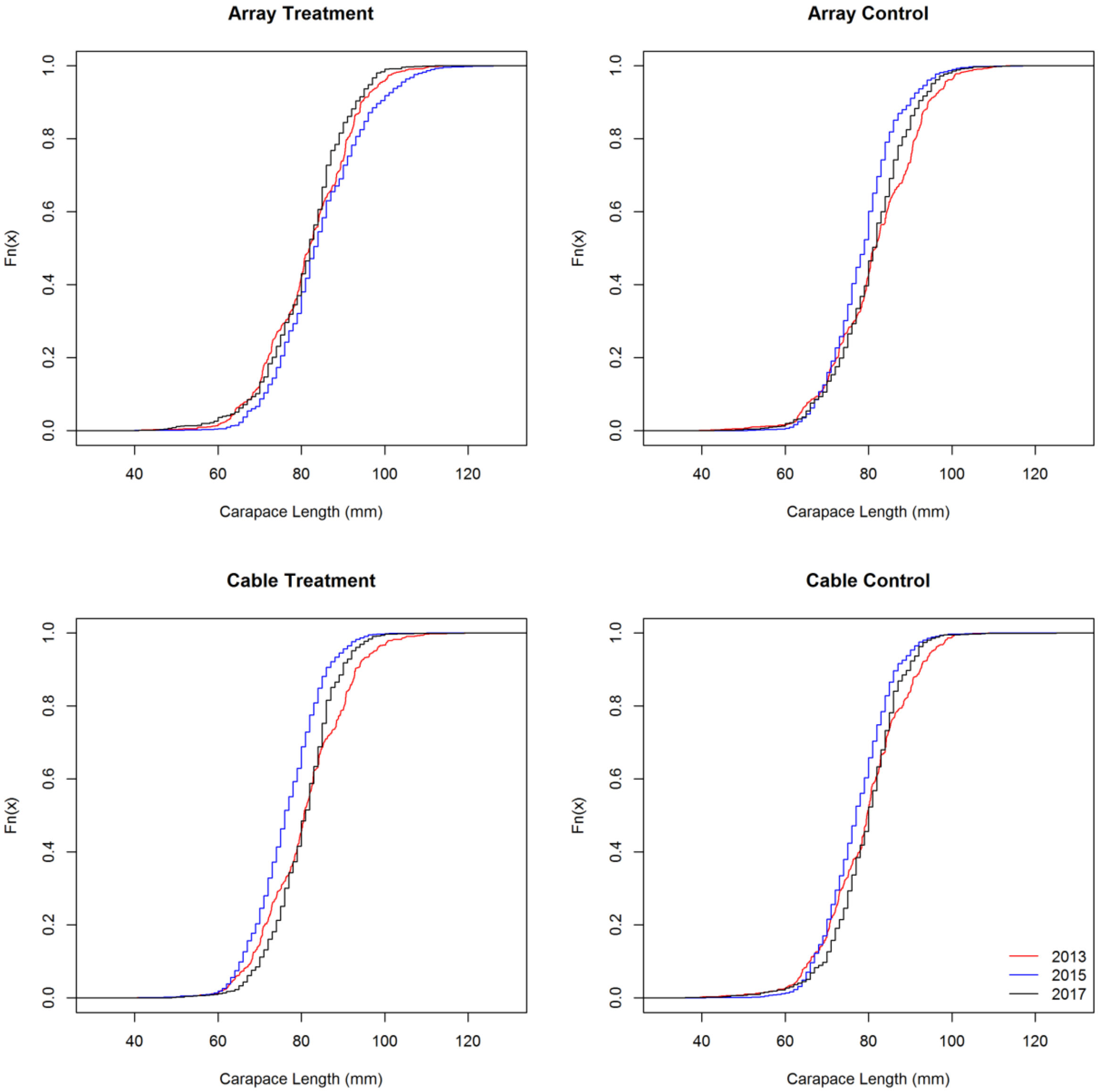

Figure 14: Empirical cumulative distribution function (ECDF) of lobsters sampled at the four survey sites during the WMR surveys for 2013 (red), 2015 (blue) and 2017 (black).

For all sites there was a significant difference in the size distribution of lobsters between the baseline survey in 2013 and the survey undertaken in 2017 (Kolmogorov Smirnov, $p < 0.001$ (Table 6)). The ECDF plots (Figure 14) show that in the Array Treatment site there was a greater empirical distribution of lobsters in 2017 up to approximately 80 mm CL, above that there was a greater distribution observed in 2013. The Array Control site showed little difference up to 80 mm CL then a greater empirical distribution in 2013. The Cable Treatment and Cable Control sites showed a similar trend, but the distribution shifted around the MLS of 87mm CL (Figure 14).

Edible Crab

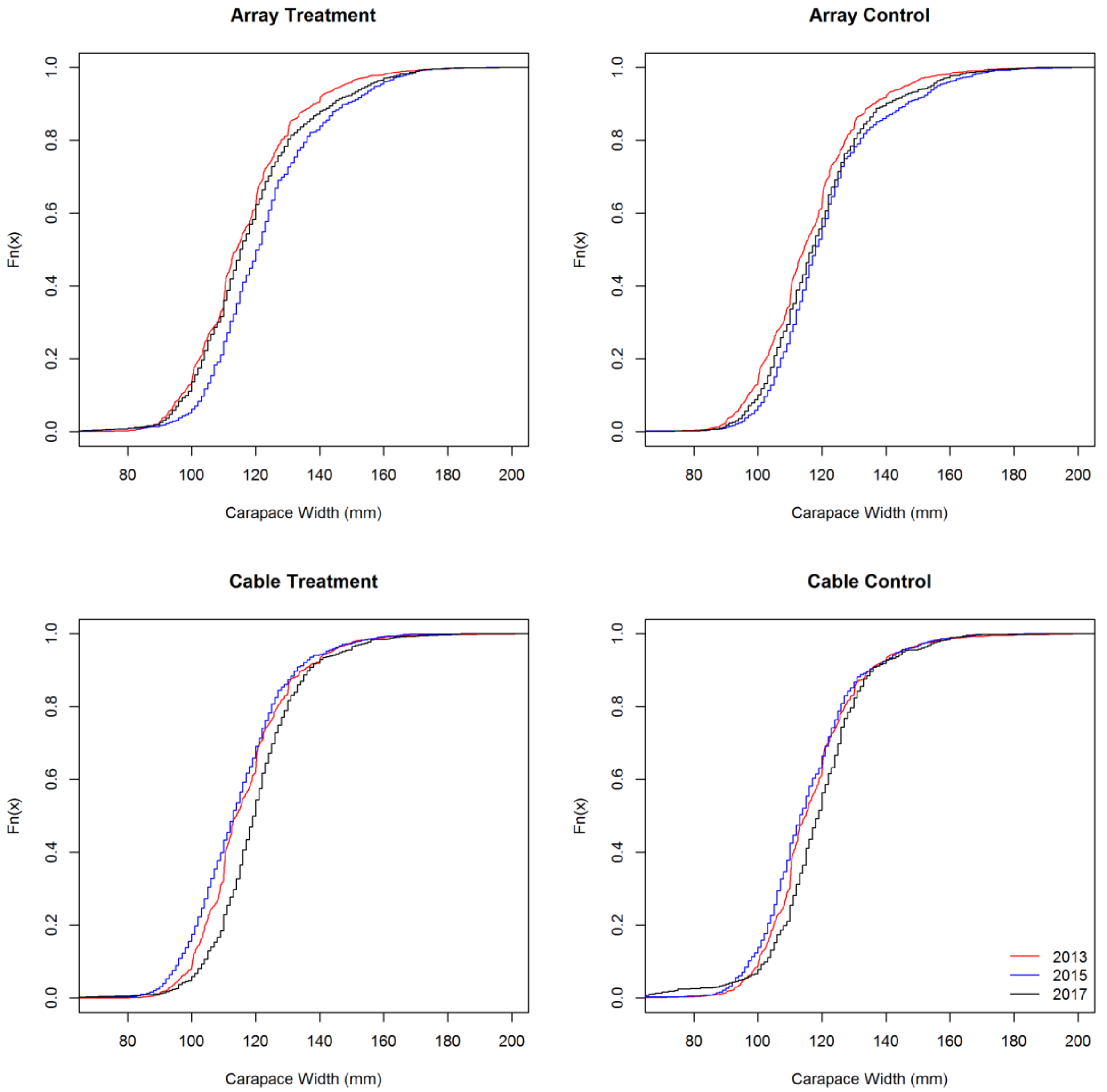

Figure 15: Empirical cumulative distribution function (ECDF) of edible crabs sampled at the four survey sites during the WMR surveys for 2013 (red), 2015 (blue) and 2017 (black).

For all sites there was a significant difference in the size distribution of edible crabs between the baseline survey in 2013 and the survey undertaken in 2017 (Kolmogorov Smirnov, $p < 0.001$ (Table 6)). The ECDF plots (Figure 15) show that in the Array Treatment and Array Control sites there was a slightly greater empirical distribution observed across the size spectrum in 2017 than in 2013. This was the mirrored in the

Cable Treatment and Control sites however there was a greater distance between the empirical distributions in 2017 than in 2013 (Figure 15).

Velvet Crab

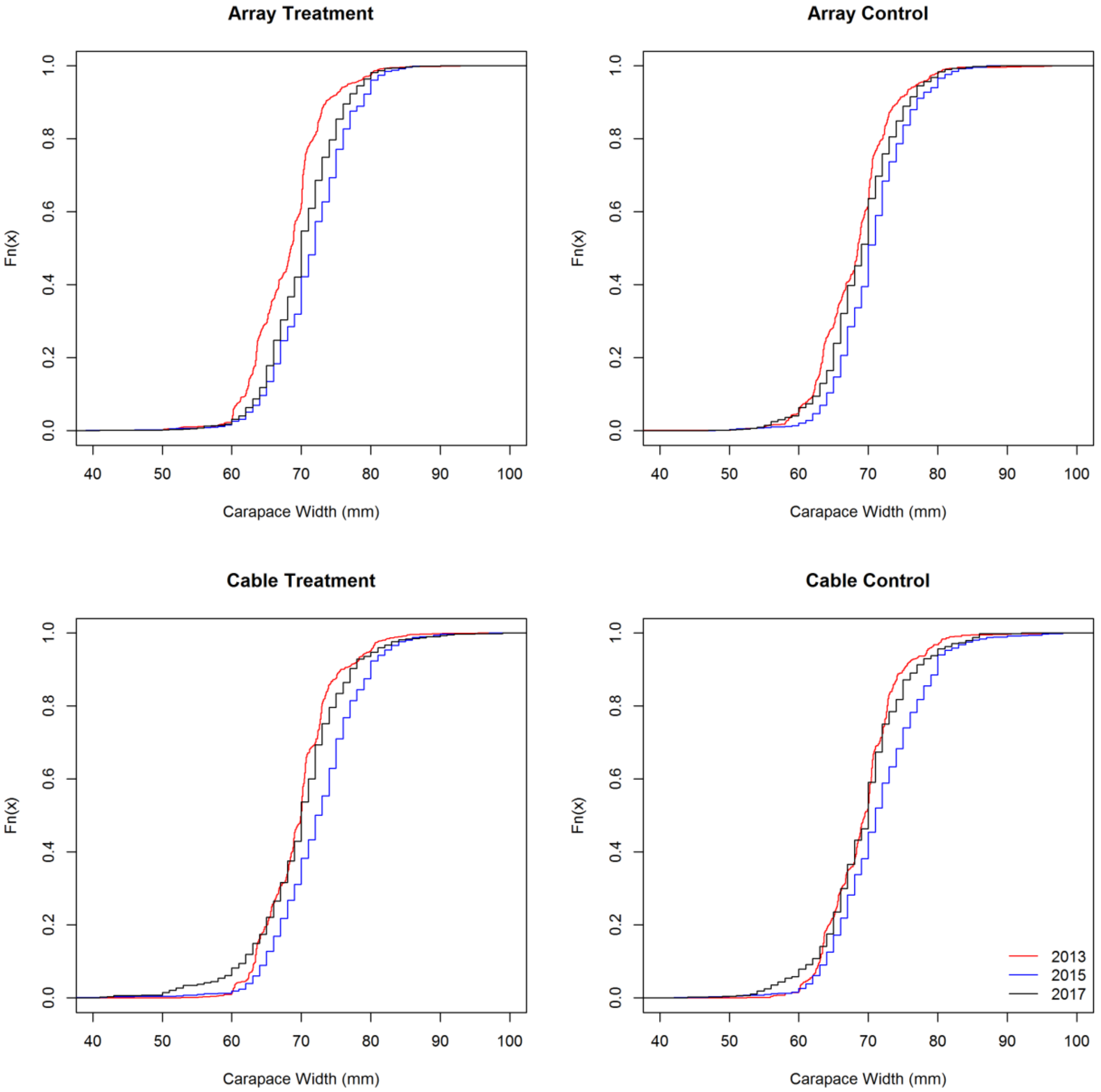

Figure 16: Empirical cumulative distribution function (ECDF) of velvet crabs sampled at the four survey sites during the WMR surveys for 2013 (red), 2015 (blue) and 2017 (black).

For all sites there was a significant difference in the size distribution of velvet crabs between the baseline survey in 2013 and the survey undertaken in 2017 (Kolmogorov Smirnov, $p < 0.001$ (Table 6)). The ECDF plots (Figure 16) show that in the Array Treatment demonstrated the greatest difference between the two distributions over the four sites. The empirical distribution of velvet crabs observed in the Array Treatment site in 2017 across the entire size spectrum was greater than that in 2013. The empirical distribution of the Array Control site was also greater in 2017 than in 2013. This was mirrored for the Cable Control and Treatment fleets, with 2017 demonstrating a greater empirical distribution than in 2013 (Figure 16).

Table 6: Results of two sample Kolmogorov Smirnov tests analysing differences in size distribution of the commercial species sampled across all sites surveyed at WMR between the baseline survey in 2013 and the 2017 survey.

Species	Site	Test Statistic	p
Lobster	Array Treatment	0.11	< 0.0001
Lobster	Array Control	0.12	< 0.0001
Lobster	Cable Treatment	0.13	< 0.0001
Lobster	Cable Control	0.09	< 0.0001
Edible Crab	Array Treatment	0.07	< 0.0001
Edible Crab	Array Control	0.09	< 0.0001
Edible Crab	Cable Treatment	0.21	< 0.0001
Edible Crab	Cable Control	0.16	< 0.0001
Velvet Crab	Array Treatment	0.23	< 0.0001
Velvet Crab	Array Control	0.13	< 0.0001
Velvet Crab	Cable Treatment	0.14	< 0.0001
Velvet Crab	Cable Control	0.09	< 0.05

Discussion

2017 Comparison between treatments

Catch per unit of effort and landings per unit of effort

Lobster CPUE did not differ between either of the treatments for both the turbine array and export cable (Figure 2). There was a significantly greater CPUE in the cable control site than in the turbine array treatment site. This was predominantly due to a greater proportion of smaller lobsters in the export cable control site (Figure 6). This is supported by the fact that the LPUE between sites did not differ significantly (Figure 2). The results indicate that the catch rate of lobsters and the number of lobsters that could have been retained for landing (LPUE) are not influenced by the operation phase of either the turbine array or export cable.

Edible crabs showed no difference in either CPUE or LPUE between the treatments for the turbine array and export cable (Figure 3). The retention rates for edible crabs were the lowest of all three species sampled (0.05/0.06) indicating that the area demonstrates low returns for edible crabs. Krone *et al*., (2017) observed that turbine foundations acted as a potential nursery ground for edible crabs. This was a study conducted in an area where the wind farm installation introduced new hard substrate unlike the WMR which was installed on a complex cobble habitat. The WMR was installed in 2014/2015, therefore the potential nursery effects are too soon to be observed. Further study of the WMR may observe the nursery effect for edible crabs. The study period was also during the period where edible crabs were undergoing ecdysis, this influenced the lower LPUE for edible crabs.

There was no significant difference in CPUE or LPUE of velvet crabs between either of the treatments for the turbine array or export cable (Figure 4). The ratio between LPUE and CPUE was the greatest for velvet crabs in comparison to the other commercial species sampled (> 0.5), indicating a much higher return of velvet crabs per unit of effort. However, there was a new management measure implemented by the NEIFCA in January 2016 implementing two mandatory escape gaps in all pots inside of six nautical miles (North Eastern Inshore Fisheries and Conservation Authority, 2015). The escape gaps were designed to allow smaller catch (predominantly lobsters) to escape the pots prior to capture. This affected the velvet crab fishery as legal sized velvet crabs were able to pass through the escape gaps. As the pots deployed for this survey were exempt from this byelaw we observed a significantly greater number of velvet crabs in the survey fleets (Figure 4) than reported anecdotally by the commercial fishermen in the area. The greater CPUE in the turbine array fleets in comparison to the export cable fleets was due to velvet crabs residing further offshore than the location of the export cable fleets were located.

Overall the catch rates and rates of catch that could have been retained for landing did not appear to be affected by the operation phase of the WMR wind farm. There was no difference in the treatments for the three commercial species, for both the turbine array and export cable.

Size distribution

The size distribution of lobsters did not differ significantly between the control and treatment sites of the turbine array (Figure 5). This distribution shift when compared to the same sites in 2015 (Roach & Cohen, 2015), indicates that there is no observable effect of the turbine array operation on the size distribution of lobsters. It also indicates that once the turbine array was subjected to fishing exploitation post construction, the size distribution reflected that of the control fleet within a relatively short period. The size distribution of lobsters within the export cable was significantly different between the control and treatment fleets. The plot derived from GLMM analysis (Figure 6) indicate that there was a greater proportion of lobsters < 70 mm CL in the control fleet than the treatment. The inverse of this trend was observed in 2015 (Roach & Cohen, 2015), demonstrating a greater proportion of lobsters > 100 mm CL in the control fleet. There is current theory that elasmobranch species can be attracted to the EMF generated by HVAC cables (Ashley, Mangi, & Rodwell, 2014; Bureau of Ocean Energy Mangaement, 2016; Rodmell & Johnson, 2002). Elasmobranch species are thought to predate on juvenile lobsters. It is possible that Elasmobranch species may be attracted to the HVAC export cable and are in turn predating upon the smaller lobsters in the area. As the difference is only slight and the literature on the attraction of EMF is currently sparse, this effect may be unlikely. Additionally, the removal of boulders during the laying of the export cable may have reduced shelter availability for smaller lobsters (Howard, 1980). As the inverse distribution was observed in 2015 this is unlikely, and the size distribution difference may be attributed to natural variation between the two sites.

Edible crabs size distribution did not differ significantly between the either the turbine array or export cable control and treatment fleets (Figure 5 & 6). This indicates that there is on observable effect of either the turbine array or export cable on the edible crab size distribution. Further study of the size distribution within the turbine array may support the theory of wind turbines acting as nursery areas for edible crabs. An increase in the proportion of edible crabs of a smaller size in future years would be expected.

There was a significant difference in the size distribution of velvet crabs between the treatment and control sites for the turbine array and export cable. GLMM analysis revealed that there was a greater proportion of velvet crabs in both treatment sites than their controls (Figure 5 & 6). The difference in the export cable sites is only slight and is likely to be attributed to natural variation. The previously discussed change in management measures affecting velvet crabs, is likely to be the reason for the difference in the distributions within the turbine array. The increased velvet crabs in the turbine array sites (Figure 4) may be taking advantage of the potentially increased diversity associated with offshore wind turbines (De Mesel *et al*., 2015). There may be a greater amount of resources available within the turbine array (De Backer et al., 2014; Kröncke et al., 2011; Vandendriessche et al., 2015), both attracting larger velvet crabs and increasing growth rates due to increased nutrient availability. Although the GLMM analysis of velvet crab size distribution between the export cable sites show a slight increase in the proportion of velvet crabs in the treatment site; there was no significant difference observed.

Sex ratio and ovigerous status

Sex ratio of lobsters was similar to that reported in the previous two surveys (Roach & Cohen, 2013, 2015). Ovigerous lobsters accounted for 9% of the females sampled during the survey, with ~60% of these being below the MLS. This indicates that the majority of females can breed at least once prior to being caught. However recent national legislation enforced on the 1st October 2017 makes it illegal to land any ovigerous females. Further studies should see this proportion of ovigerous females increase and the proportion of ovigerous lobsters of a larger size increase.

The high number of edible crabs that were of a grade 2 (soft shelled), reflected by the low LPUE (Figure 3), indicates that the survey was undertaken whilst edible crabs were undergoing ecdysis. This could potentially explain the absence of ovigerous edible crabs as they adopt a more sessile lifestyle during the brood period.

Presence of fish species

The increased presence of Atlantic Cod caught in pots observed in 2015 (Roach & Cohen, 2015), were of concern due to their potential influence on the food web in the area (Raoux et al., 2017; van Hal et al., 2017). The abundance of Atlantic Cod observed in 2017 did not reflect those observed in 2015 (Figure 7). The abundance observed was similar to that observed in 2013. There were only two Atlantic Cod observed within the turbine array treatment site, the lowest of all sites (Figure 7). Due to the safety zone around each of the individual turbines of 50m, the turbine array treatment fleets were deployed away from the turbines. van Hal *et al*., (2017) observed that fish species were aggregating around the turbines for protection and feeding purposes. It may be that the presence of the turbines discourages Atlantic Cod from moving around the area as much, decreasing the chance of encountering a pot.

Comparison between 2017 and baseline

Catch per unit of effort and landings per unit of effort

Lobster CPUE and LPUE did not differ significantly between control and treatment sites, however there was a significant difference between years (Figure 8). This was accounted for by the greater CPUE in both the turbine array treatment and control sites in 2015. As the 2015 data is aggregated data, before and after the turbine array was closed to fishing exploitation, the closure of the site influenced the CPUE of the site (Roach & Cohen, 2015). The closure during the construction phase acted as de-facto no take zone. Biomass and abundance of lobsters has been demonstrated to increase in areas where fishing exploitation is absent (ref). This can account for the difference in CPUE of lobsters between years. There was no significant difference between sites or years of lobster CPUE/LPUE in the export cable, except for the cable control site having a significantly greater CPUE in 2017 than the export cable treatment and control sites in 2017. This did not translate into a significant increase in LPUE from the same sites when compared between years. As this was an increase in CPUE from the baseline and in the control site it is likely to be natural variation as opposed to effects of the export cable.

Although there was no significant interaction of mean edible crab CPUE between site and year, there was a significant difference between years. Mean CPUE of edible crab for both the turbine array and export cable treatment and control was significantly greater in 2013 than in 2015/7 (Figure 10 & 11). This is likely to be attributed to natural variation in the crab population as there was no significant difference in mean edible crab CPUE between the control and treatment sites in any of the survey years. The edible crabs that could have been retained for landing (LPUE) showed no significant difference between years and sites. This supports the theory of natural variation being the increase of CPUE in 2013. The highest ratio of LPUE/CPUE was in 2015 when the CPUE was lowest of the three years. This can be attributed to the de-fact no take zone effects of the closed turbine array observed in 2015.

The mean CPUE of velvet crabs observed within the turbine array differed significantly between years (Figure 12). There was a drop in mean CPUE in 2015 from 2013, this can be attributed to the increased CPUE of lobsters within the same pots. Lobsters are often the dominant species in inter-species interactions within a mixed species pot fishery. However, the greatly increased CPUE of velvet crabs observed in 2017 can be attributed to the escape gap management measure. The increased population of velvet crabs that are not being exploited to the same levels as previous years is being reflected by the greater CPUE in 2017. This trend was not observed for the export cable. There was no significant difference in CPUE/LPUE between years or sites. Velvet crabs had the highest ratio of LPUE/CPUE than the other species sampled, indicating an exploitable population in the area that has a high yield in relation to effort.

Size distribution

The size distribution of lobsters in 2017 differed significantly across all sites when compared to the baseline (2013). Figure 14 demonstrates that the empirical distribution of lobsters was greater in 2013 at sizes > 85 mm CL and a greater distribution of smaller lobsters in 2017. This was the general trend for all four sites. As the control sites follow the same trend as the treatment sites it is likely that this is due to natural variation rather than effects of the turbine array or export cable.

There was a significant difference of the size distribution of edible crabs across all sites between 2017 and 2013. Across all sites the empirical distribution was greater in 2017 than in 2013 (Figure 15), indicating a population of larger animals sampled. In 2013 the majority of the catch sampled were of a smaller size (indicated by a high CPUE and a relatively low LPUE in 2013 (Figure 10 & 11)). There was also an additional management measure implemented in January 2016 (North Eastern

Inshore Fisheries and Conservation Authority, 2015) for edible crab, increasing the MLS from 130 mm CW to 140 mm CW. This increase in MLS means that there were a greater number of edible crabs sized 130-140 mm CW observed in 2017 than in 2013.

Velvet crab size distribution differed significantly between years across all sites (Figure 16). The difference in empirical distribution was greatest in the turbine array treatment site than in the control site. This was influenced by the change in management measures and the possible increase in velvet crab size and population previously discussed. Although there was a significant difference in size distribution between years for the export cable sites, the empirical distribution shows that the difference was slight between years (Figure 16).

Conclusion

The overall results for the three species show little variation in population structure between the control and treatment sites for the turbine array and export cable. However, the introduced management measures affecting edible and velvet crabs may be masking small effects of the WMR operational phase. As reported in 2015, there have been external influences on the survey in 2017 that may be inadvertently influencing the results of the survey, however these are likely to be slight. Further study can assess whether the WMR wind farm can act as a nursery ground for juvenile crustaceans and whether the individual turbines fish aggregating effect influence the local crustacean populations.

References

Ashley, M. C., Mangi, S. C., & Rodwell, L. D. (2014). The potential of offshore windfarms to act as marine protected areas – A systematic review of current evidence. *Marine Policy*, *45*, 301–309.

Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48.

Bureau of Ocean Energy Mangaement. (2016). *Environmental Studies – Electromagnetic Fields (EMF) Applied Science for Informed Decisions on Ocean Energy*.

Coates, D. A., Kapasakali, D. A., Vincx, M., & Vanaverbeke, J. (2016). Short-term effects of fishery exclusion in offshore wind farms on macrofaunal communities in the Belgian part of the North Sea. *Fisheries Research*, *179*, 131–138.

De Backer, A., Van Hoey, G., Coates, D., Vanaverbeke, J., & Hostens, K. (2014). Similar diversity-disturbance responses to different physical impacts: Three cases of small-scale biodiversity increase in the Belgian part of the North Sea. *Marine Pollution Bulletin*, *84*(1–2), 251–262.

De Mesel, I., Kerckhof, F., Norro, A., Rumes, B., & Degraer, S. (2015). Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. *Hydrobiologia*, *756*(1), 37–50.

Griffin, R., Buck, B., & Krause, G. (2015). Private incentives for the emergence of co-production of offshore wind energy and mussel aquaculture. *Aquaculture*, *436*, 80–89.

Holst, R., & Revill, A. (2009). A simple statistical method for catch comparison studies. *Fisheries Research*, *95*(2–3), 254–259.

Hooper, T., & Austen, M. (2014). The co-location of offshore windfarms and decapod fisheries in the UK: Constraints and opportunities. *Marine Policy*, *43*, 295.

Howard, a. E. (1980). Substrate controls on the size composition of lobster (*Homarus gammarus*) populations. *ICES Journal of Marine Science*, *39*(2), 130–133.

Kröncke, I., Reiss, H., Eggleton, J. D., Aldridge, J., Bergman, M. J. N., Cochrane, S., … Rees, H. L. (2011). Changes in North Sea macrofauna communities and species distribution between 1986 and 2000. *Estuarine, Coastal and Shelf Science*, *94*(1), 1–15.

Krone, R., Dederer, G., Kanstinger, P., Krämer, P., Schneider, C., & Schmalenbach, I. (2017). Mobile demersal megafauna at common offshore wind turbine foundations in the German Bight (North Sea) two years after deployment - increased production rate of *Cancer pagurus*. *Marine Environmental Research*, *123*, 53–61.

Love, M. S., Nishimoto, M. M., Clark, S., & Bull, A. S. (2016). *Renewable Energy in Situ Power Cable Observation*. U.S. Department of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. OCS Study 2016-008. 86 pp.

North Eastern Inshore Fisheries and Conservation Authority. Crustacea Conservation Byelaw (2015).

Raoux, A., Tecchio, S., Pezy, J. P., Lassalle, G., Degraer, S., Wilhelmsson, D., Niquil, N. (2017). Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning? *Ecological Indicators*, *72*, 33–46.

Roach, M., & Cohen, M. (2013). Shellfish Monitoring Report 2013 A study conducted for DONG Energy.

Roach, M., & Cohen, M. (2015). *Westermost Rough Fish & Shellfish Monitoring Report 2015 ; Including Comparison to Baseline Data 2013 A study conducted for DONG Energy*.

Rodmell, D., & Johnson, M. (2002). The development of marine based wind energy generation and inshore fisheries in UK waters: Are they compatible? In *Who owns the sea?* (pp. 76–103).

Stelzenmüller, V., Diekmann, R., Bastardie, F., Schulze, T., Berkenhagen, J., Kloppmann, M., … Kraus, G. (2016). Co-location of passive gear fisheries in offshore wind farms in the German EEZ of the North Sea: A first socio-economic scoping. *Journal of Environmental Management*, *183*, 794–805.

Thomas, R., Lello, J., Medeiros, R., Pollard, A., Seward, A., Smith, J., Vaughan, I. (2015). *Data Analysis with R Statistical Software A guidebook for Scientists*.

van Hal, R., Griffioen, A. B., & van Keeken, O. A. (2017). Changes in fish communities on a small spatial scale, an effect of increased habitat complexity by an offshore wind farm. *Marine Environmental Research*, *126*, 26–36.

Vandendriessche, S., Derweduwen, J., & Hostens, K. (2015). Equivocal effects of offshore wind farms in Belgium on soft substrate epibenthos and fish assemblages. *Hydrobiologia*, *756*(1), 19–35.

Zuur, A. F., & Ieno, E. N. (2016). A protocol for conducting and presenting results of regression-type analyses. *Methods in Ecology and Evolution*, *7*(6), 636–645.

Annex 1 - Bycatch

Presence and absence table of all by-catch caught during the baseline survey (2013), the first-year post build survey (2015) and third year post build survey (2017) for the WMR monitoring project (P= Present, A = Absent)

Common Name	Scientific Name	2013	2015	2017
Shore crab	*Carcinus maenas*	P	A	P
Spiny Squat lobster	*Galathea strigosa*	P	P	P
Long Clawed Squat Lobster	*Munida rugosa*	P	P	P
Marbled swimming crab	*Liocarcinus marmoreus*	P	P	P
Harbour Crab	*Liocarcinus depurator*	P	P	P
Hermit crab	*Eupagarus bernhadus*	P	P	P
Long legged spider crab	*Macropodia rostrata*	P	P	P
Wrinkled Swimming Crab	*Liocarcinus corrugatus*	A	P	P
Common urchin	*Echinus esculentus*	P	P	P
Common starfish	*Asteria rubens*	P	P	P
Dab	*Limanda limanda*	P	P	P
Sea scorpion/ Bullhead	*Myoxocephalus scorpius*	P	P	P
Pouting	*Trisopterus luscus*	P	P	P
Poor cod	*Trisopterus minutus*	P	P	P
Cod	*Gadus morhua*	P	P	P
Butter fish	*Pholis gunnelis*	P	A	A
Ling	*Molva molva*	P	P	A
Whiting	*Merlangius merlangus*	P	P	P
Ballan wrasse	*Labrus bergylta*	P	P	P
Three bearded rockling	*Gaidropsarus vulgaris*	P	P	P
Tompot blenny	*Parablennius gattorugine*	P	P	P

Coley/Saithe	*Pollachius virens*	A	P	P
Pollack	*Pollachius pollachius*	P	A	A
Pogge/ Armoured bullhead	*Agonas cataphractus*	A	P	A
Red Mullet	*Mullus surmuletus*	A	P	P
Top Knot	*Zeugopterus punctatus*	A	P	A
Lumpsucker	Cyclopterus lumpus	A	A	P

Annex 2 – Supporting Statistics

Table 1: Descriptive statistics of CPUE and LPUE for each species sampled at each site during the 2017 WMR survey.

Species	Site	Unit of Effort	Mean	s.d.
Lobster	Array Control	CPUE	75.25	30.23
Lobster	Array Treatment	CPUE	57.63	19.66
Lobster	Cable Control	CPUE	98.56	30.36
Lobster	Cable Treatment	CPUE	78.50	29.87
Lobster	Array Control	LPUE	10.44	6.01
Lobster	Array Treatment	LPUE	8.75	3.51
Lobster	Cable Control	LPUE	8.00	2.85
Lobster	Cable Treatment	LPUE	8.13	4.70
Edible Crab	Array Control	CPUE	96.75	61.03
Edible Crab	Array Treatment	CPUE	103.38	52.31
Edible Crab	Cable Control	CPUE	60.13	33.57
Edible Crab	Cable Treatment	CPUE	66.94	39.87
Edible Crab	Array Control	LPUE	4.87	2.42
Edible Crab	Array Treatment	LPUE	6.50	3.54
Edible Crab	Cable Control	LPUE	3.64	2.94
Edible Crab	Cable Treatment	LPUE	3.62	2.33
Velvet Crab	Array Control	CPUE	153.50	107.14
Velvet Crab	Array Treatment	CPUE	146.06	52.49
Velvet Crab	Cable Control	CPUE	30.25	16.65
Velvet Crab	Cable Treatment	CPUE	41.94	17.00
Velvet Crab	Array Control	LPUE	91.44	68.01
Velvet Crab	Array Treatment	LPUE	93.13	39.04
Velvet Crab	Cable Control	LPUE	16.31	11.46
Velvet Crab	Cable Treatment	LPUE	24.31	11.23

Table 2: Descriptive statistics of CPUE and LPUE for each species sampled at each site and during each year of the WMR survey.

Species	Year	Site	Unit of Effort	Mean	s.d.
Lobster	2013	Array Control	CPUE	71.39	44.67
Lobster	2013	Array Treatment	CPUE	63.70	36.97
Lobster	2013	Cable Control	CPUE	60.70	32.05
Lobster	2013	Cable Treatment	CPUE	65.78	34.39
Lobster	2013	Array Control	LPUE	10.00	6.53
Lobster	2013	Array Treatment	LPUE	11.13	6.98
Lobster	2013	Cable Control	LPUE	7.33	5.19
Lobster	2013	Cable Treatment	LPUE	9.10	6.59
Lobster	2015	Array Control	CPUE	107.57	29.31
Lobster	2015	Array Treatment	CPUE	93.22	32.24
Lobster	2015	Cable Control	CPUE	87.43	27.71
Lobster	2015	Cable Treatment	CPUE	91.52	25.12
Lobster	2015	Array Control	LPUE	9.78	4.40
Lobster	2015	Array Treatment	LPUE	22.00	15.52
Lobster	2015	Cable Control	LPUE	5.10	3.91
Lobster	2015	Cable Treatment	LPUE	5.50	5.49
Lobster	2017	Array Control	CPUE	75.20	30.23
Lobster	2017	Array Treatment	CPUE	57.63	19.66
Lobster	2017	Cable Control	CPUE	98.56	30.36
Lobster	2017	Cable Treatment	CPUE	78.50	29.87
Lobster	2017	Array Control	LPUE	10.44	6.01
Lobster	2017	Array Treatment	LPUE	8.75	3.51
Lobster	2017	Cable Control	LPUE	8.00	2.85
Lobster	2017	Cable Treatment	LPUE	8.13	4.70
Edible Crab	2013	Array Control	CPUE	187.35	93.42
Edible Crab	2013	Array Treatment	CPUE	215.57	100.34

Edible Crab	2013	Cable Control	CPUE	151.61	80.36
Edible Crab	2013	Cable Treatment	CPUE	170.74	93.41
Edible Crab	2013	Array Control	LPUE	10.11	8.15
Edible Crab	2013	Array Treatment	LPUE	10.89	8.81
Edible Crab	2013	Cable Control	LPUE	6.81	8.43
Edible Crab	2013	Cable Treatment	LPUE	10.22	9.09
Edible Crab	2015	Array Control	CPUE	91.61	55.43
Edible Crab	2015	Array Treatment	CPUE	71.13	42.23
Edible Crab	2015	Cable Control	CPUE	49.04	29.93
Edible Crab	2015	Cable Treatment	CPUE	57.26	34.29
Edible Crab	2015	Array Control	LPUE	7.22	5.08
Edible Crab	2015	Array Treatment	LPUE	6.30	6.28
Edible Crab	2015	Cable Control	LPUE	2.76	2.70
Edible Crab	2015	Cable Treatment	LPUE	2.68	2.16
Edible Crab	2017	Array Control	CPUE	96.75	61.03
Edible Crab	2017	Array Treatment	CPUE	103.38	52.31
Edible Crab	2017	Cable Control	CPUE	60.13	33.57
Edible Crab	2017	Cable Treatment	CPUE	66.94	39.87
Edible Crab	2017	Array Control	LPUE	4.87	2.42
Edible Crab	2017	Array Treatment	LPUE	6.50	3.54
Edible Crab	2017	Cable Control	LPUE	3.63	2.94
Edible Crab	2017	Cable Treatment	LPUE	3.61	2.33
Velvet Crab	2013	Array Control	CPUE	45.96	16.04
Velvet Crab	2013	Array Treatment	CPUE	75.18	43.05
Velvet Crab	2013	Cable Control	CPUE	33.96	16.97
Velvet Crab	2013	Cable Treatment	CPUE	49.70	22.55
Velvet Crab	2013	Array Control	LPUE	30.05	13.92
Velvet Crab	2013	Array Treatment	LPUE	48.92	29.72

Velvet Crab	2013	Cable Control	LPUE	20.67	11.93
Velvet Crab	2013	Cable Treatment	LPUE	31.19	16.57
Velvet Crab	2015	Array Control	CPUE	37.65	10.12
Velvet Crab	2015	Array Treatment	CPUE	41.39	9.90
Velvet Crab	2015	Cable Control	CPUE	31.78	14.60
Velvet Crab	2015	Cable Treatment	CPUE	31.17	11.11
Velvet Crab	2015	Array Control	LPUE	21.78	6.98
Velvet Crab	2015	Array Treatment	LPUE	24.91	6.16
Velvet Crab	2015	Cable Control	LPUE	19.52	8.53
Velvet Crab	2015	Cable Treatment	LPUE	20.52	8.36
Velvet Crab	2017	Array Control	CPUE	153.50	107.14
Velvet Crab	2017	Array Treatment	CPUE	146.06	52.49
Velvet Crab	2017	Cable Control	CPUE	30.25	16.65
Velvet Crab	2017	Cable Treatment	CPUE	41.94	17.00
Velvet Crab	2017	Array Control	LPUE	91.44	68.01
Velvet Crab	2017	Array Treatment	LPUE	93.12	39.04
Velvet Crab	2017	Cable Control	LPUE	16.31	11.46
Velvet Crab	2017	Cable Treatment	LPUE	24.31	11.23