The influence of the Lamlash Bay no-take zone, Firth of Clyde, on spatial and temporal variation in the recovery of commercially exploited crustaceans.

BLUE MARINE FOUNDATION

Isle of Arran COAST Community Of Arran Seabed Trust

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Abstract

The study aims to assess whether, after nearly 10 years of protection, the fully protected No-Take Zone (NTZ) in Lamlash Bay, Firth of Clyde, Scotland, has been successful in preserving and enhancing commercially important populations of European Lobster (*Homarus gammarus*), brown crab (*cancer pagurus*), and velvet swimming crab (*Necira puber*).

A survey was conducted in controlled conditions over two 5-day periods in July and August; 90 creels were placed inside the reserve and outside the reserve in three locations, these acted as controls, in Lamlash Bay. Fishing observation of 3090 creels was also conducted to build an overview of the population outside of the reserve. Crustaceans were temporarily removed to tag them, gather data on size, sex, mortality and catch per unit effort (CPUE). The creel surveys revealed significantly higher catch per unit effort (CPUE 90% greater), weight per unit effort (WPUE 99% greater) and carapace length (10-11mm greater) in lobsters within the reserve compared with the controlled sites. Additionally, a spill-over effect was observed from tagged individuals caught 20-40km from the reserve site. Brown crabs CPUE and WPUE declined in the reserve whilst velvet crabs showed little to no effect with the presence of the reserve.

This study provides invaluable evidence that temperate marine reserves can contribute in restoring and enhancing not only invertebrate communities but the wider marine environment. It also highlights the importance of looking at multi-species interactions, as our study found the presence of the reserves resulted in higher densities of lobster but a decline of crabs.

Introduction

The marine ecosystem is a vital resource for life on our planet and is home to an array of rich and diverse life-forms, over 3 billion people depend on its resources and industries for their livelihoods; particularly fishing (UNDP, 2018). Historically, the seas around the United Kingdom once supported diverse and productive fisheries (Roberts, 2007). However, the 19th century saw demand for fish increase which encouraged the spread of more indiscriminate fishing methods such as bottom trawling (Roberts, 2007). During the mid-1900s landings for bottom fish increased, as trawling fleets expanded, and technology improved but by the turn of the 21st century the ocean and its stocks has been left in a permanent state of decline from fishing pressures (Roberts, 2007; Thurstan and Roberts, 2010). As a result of this intense fishing 31.4% of the world fish stocks are classed as overexploited (FAO, 2016).

The Firth of Clyde represents a classic example of a once very productive and diverse ecosystem that has been degraded through intensive overfishing and the use of damaging fishing methods. Today the Clyde is regarded as one of the most degraded marine environments in the UK (Thurstan and Roberts, 2010). Historically, the Clyde's fishing grounds once flourished with commercial species such as herring (*Clupea harengus*) and cod (*Gadus morhua*) (Thurstan and Roberts, 2010). However, these fisheries no longer exist and to compensate for the decline of large bodied whitefish, fishers began to target other species to fill the void in the market and keep up with demand, gradually moving to stocks at lower trophic levels towards bottom-dwelling invertebrate species, such as the Norway lobster (*Nephrops norvegicus*) and the king (*Pecten maximus*) and queen scallop (*Aequipecten opercularis*) (Pauly et al., 1998; Worm and Myers, 2003). Total landings of higher valued crustaceans such as brown crab (*Cancer pagurus*) and European lobster (*Homarus gammarus*) have also dramatically increased in the Clyde since the early 2000s (Appendix 1). They are caught using smaller, less mobile gear which is associated with having higher selectivity (Zhou et al., 2010) and less impact on the marine habitat compared with other gears (Gaspar and

Chícharo, 2007). However, it has been reported that these fisheries, particularly in the Clyde, are fishing above maximum sustainable yield and are suffering from low recruitment (Appendix 2)(Mesquita, Dobby and McLay, 2016). These species have been shown to occupy a keystone role in ecosystem via the suppression of other species (Boudreau and Worm, 2012) and their decline could affect not only the local ecosystem but the local fisheries economy.

Overall the Clyde's dramatic "ecological meltdown" is accredited to the removal of a ban on bottom trawling and scallop dredging within the three miles of the UK coast in 1984. This decline has been felt by many and in 1995 led two local divers from the Isle of Arran to act by founding the Community of Arran Seabed Trust (COAST). COAST is a community-led marine conservation foundation whose visions is to protect and restore the marine environment around Arran and the Clyde (Coast, 2012). In a bid to combat similar issues around the world, many countries have instated fully protected reserves as a management tool, which allows a complete ecosystem to recover in isolation from environmental pressures (Roberts et al., 2003). Therefore, after thirteen years of campaigning, COAST helped to set up Scotland's first No-Take Zone (NTZ) in Lamlash Bay on the Isle of Arran (Appendix 3) (Figure 1). Their aim for the reserve is to help reseed and restock not only the NTZ but the surrounding waters.

NTZs are Marine Protected Areas (MPAs) where all fisheries methods and extraction ventures are prohibited; they are the strongest level of protection where fishing gear is prohibited (Roberts and Sargant, 2002). It is becoming an ever increasing important tool in conservation and is the simplest approach to implement ecosystem based fisheries management (Roberts,Hawkins and Gell, 2005; Roberts and Hawkins, 2000). The removal of fishing pressures can results in an increase in biomass and abundance within its boundaries, facilitating greater reproductive output that can lead to "spill-over" effects through species migrating outside the reserve and larval dispersion (Hoskin et al., 2011;

Roberts et al., 2001; Ashworth and Ormond, 2005). “Spill-over” effects may help with any equity issues for local fishermen in terms of vulnerability to their livelihoods.

Various species rely on the structural complexities and benthic taxa such as maerl, hydroids and bryozoans to feed, grow and hide from predation (Howarth et al., 2011). NTZs allow habitats time to recover and promotes the density, size and age structure of commercially exploited species to a state before they were fished (Berkeley,Hixon and Larson, 2004; Howarth, 2014). Restoration of predator assemblage has also been shown to confer resistance to no-take zones against non-indigenous species invasions (Noè et al., 2018). Previous studies have already shown the Lamlash bay NTZ is benefiting local species and habitats as well as offers huge range as a management tool for fisheries (Beukers-Stewart et al., 2005; Howarth, 2014).

This study is a continuation of an annual survey, initiated in 2012, to assess the success of the Lamlash Bay No-Take Zone, Isle of Arran, Scotland, for preserving and enhancing benthic ecological communities, particularly local crustacean populations. This will be achieved by observing the abundance, movement patterns and population structure of three crustacean species in the area. Lobsters and crabs have been chosen to protect and survey due to their high value and low mobility (Moland et al., 2011, 2013b).

It can be hypothesised that reduced fishing will lead to larger and more abundant population within the reserve, resulting in higher Catch Per Unit Effort (CPUE). CPUE will be greater closer to the reserve, as the effects from spill-over become more pronounced and there will be greater frequency of injuries within the reserve. Finally, that population structure will recover and improve over time inside the reserve.

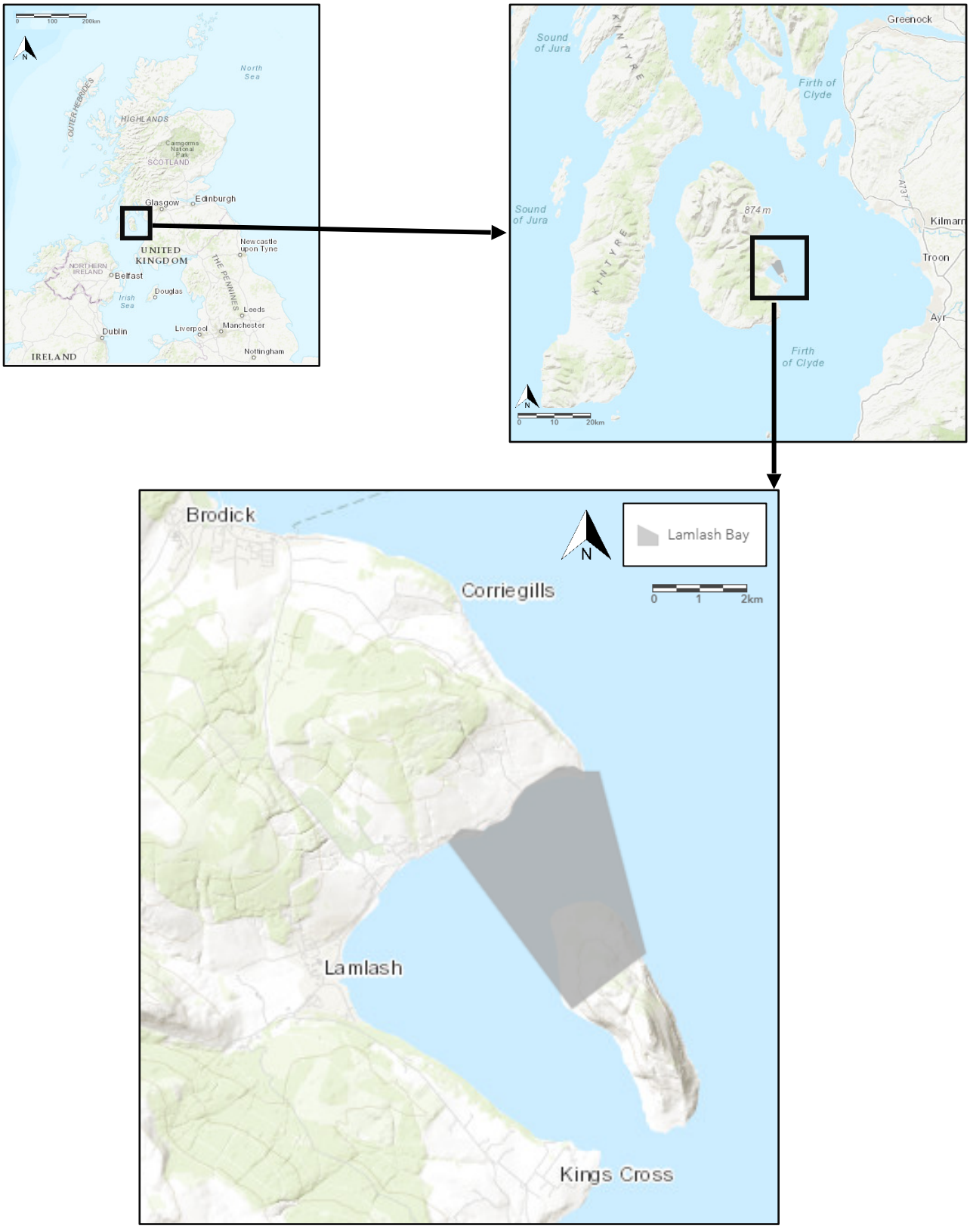


Figure 1. Maps showing Lamlash Bay reserve and putting the Firth of Clyde/Lamlash Bay into geographical context with Scotland and the Isle of Arran.

Methods

Study site

This study was conducted on the Isle of Arran, an island situated off the west coast of Scotland within the Firth of Clyde (Figure 2). Lamlash Bay, the main area of interest, is located on the east coast and contains a 3x1km island, Holy Isle. In 2008, 2.6km^2 of these waters within the bay were officially designated as a fully protected area, also known as the No-Take Zone (NTZ) (Appendix 3). Studies of the bay have reported that seabed habitats consists of complex, rocky and shallow benthic morphology with kelp (Duncan, 2003). There are areas beyond this of great depth with relatively flat seabed composed of fine mud (Axelssom et al., 2010).

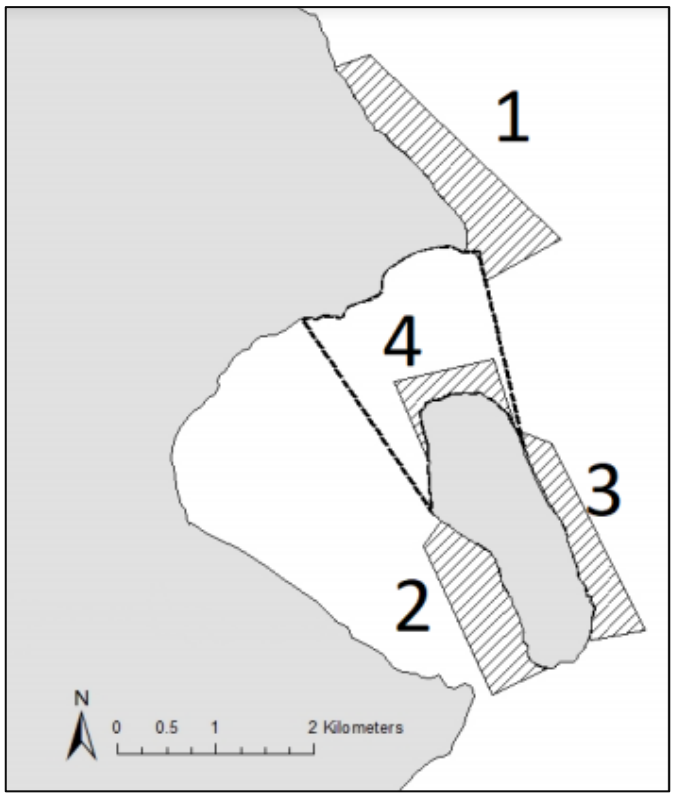


Figure 2. Study sites around Lamlash bay. 1 represents the control area to the north of the NTZ past Hamilton rock, 2 represents the control area east of Holy Island, 3 represents the control area west of Holy Island and 4 represents the reserves area inside the NTZ. Also displayed (dashed lines) are boundaries of the Lamlash Bay marine reserve.

Sampling Design

Sampling was conducted along the southern shore of the marine reserve and at control sites (Figure 2). Divergence of population trends within and outside the reserve was used as an indicator of an effect (Howarth et al., 2015). Although the marine reserve in Lamlash Bay was established in 2008, no surveys were conducted in the area prior to protection, and monitoring of crustacean populations within and outside the reserve did not begin until 2012. The survey was split into two sections, a survey under controlled conditions and passive fishing observations. These targeted surveys were conducted during one week in mid-July and 1 week in mid-August for 7 years between 2012 and 2018. As catchability varies depending on varying biological factors averaging catch rates over the 2 months was used to account for short fluctuations in catchability. Observed sites were conducted, between 2012-2018, outside the reserve, in July-August, to give a fair representation of the crustacean populations found in and around the bay. They also increased the sample size and be used to support any contrast between the Reserve and Control. All sites were on shallow boulder slopes <10m in depth close to shore and were chosen by a local and experiences creeler who previously caught lobster from those areas before the reserve. All data was collected aboard a local creeling vessel, the Julie Anne TT268. A permit was requested and authorized by Marine Scotland to allow the temporary removal of organisms from the Lamlash bay NTZ and kept onboard the vessel at all time of the survey (Appendix 4).

The control survey involved sampling crustaceans using standard specification commercial shellfish D-shaped parlour creels (pots) of two-side eye entrance design. For number of creels deployed see table 1. Mesh size was 65mm, and creels measured 640 x 380 x 410mm, with two entrances measuring 21 x 18cm. The creels have low impact on the marine environment and are very selective, thereby greatly limiting by-catch of other species. Pots were baited with offcuts of salmon and deployed in fleets of five, with 20m between each pot. Marker buoys were attached to both ends of the fleets, and pots were considered heavy enough to act as their own anchor. Three fleets were deployed within and outside the

reserve parallel to the shore. These were then left to "soak" for ca.48 hours before being hauled. In 2012, a total of 32 fleets were deployed over the two sampling periods (i.e. 16 in July and 16 in August), half of which were within the reserve and half within the near-control. Between 2014 and 2018, this number increased to 36 fleets. However, in 2013, one fleet of pots in July was deployed inside. Hence, during this year, 19 sites were sampled within the reserve and 17 outside. In 2016, no targeted crustacean survey was conducted however a few days of fishing observation were undertaken.

The additional sampling through fishing observations were conducted aboard a commercial creel vessel, the Julie Ann TT268. For the observed sites, factors such as number of creels per string (varied between 5-10 pots), the dimensions of creels, bait and soak times (48-72 h) which have shown to affect the success of fishing effort, differed from the controlled survey. However, CPUE measurements were based on average number of individuals caught, negating the fleet length and soak time has been shown to have no significant effect on catch rate (Montgomery, 2005).

Table 1. Summary of crustaceans sampled and creel effort from the crustacean survey and observation sites.

Crustaceans sampled		
Species	**Counted**	**Measured**
Lobster	811	811
Brown crab	433	165
Velvet crab	377	72
Survey effort		
Series	**Strings**	**Creels**
Reserve	18	910
Control	18	90
Observation	162	3090

Data Collection

The number of individuals of all species captured per pot was recorded. Size (to the nearest 1mm) and sex of all lobsters, brown crabs and velvet crabs were then measured. For numbers of crustaceans sampled see table 1. Lobsters were measured from the rear of the eye socket to the rear of the carapace where the connection with the abdomen is formed. In comparison, crabs were measured at the widest point of their carapace. Signs of biological condition (e.g. eggs, disease and damage) were recorded along with environmental conditions of the capture location were then recorded before individuals were returned to the sea at the capture location. The weight of crustaceans was estimated using weight-length relationship formulas (Table 2) (Leslie et al., 2006). Unlike crabs, male and female lobster's estimates were applied separately. Since 2012, the minimum landing size of lobsters on Arran was 87 mm. However, as of February, the legal landing sizes of crustaceans is as follows: 88mm for European Lobster and a width of 140 for Brown crabs and 65mm for Velvet crabs. When combining the series data, between 2012-2018, the relevant changes were made to exclude undersized lobsters under the new legislation. These regulation sizes were used to distinguish legal sized individuals from sublegal individuals, as we expect undersized individuals not be affected by fishing therefore have no effect from the presence of the reserve. Whilst we expect legal sized individuals to be affected. Future studies will need to consider changes in legal sized individuals, as of 2019 it will increase to 90mm for lobster which may affect analysis.

Table 2. Methodology for estimating individual crustacean mass (Leslie,Henderson and Riley, 2006; Robinson et al., 2010).

Crustacean	Formula to estimate mass (g)
Male lobster	$0.0022 \times \text{carapace length(mm)}^{2.7416}$
Female lobster	0.0016 c carapace $\text{length(mm)}^{2.8134}$
Brown crab	10^{x} $x=-3.945 + 3.053 \times \log_{10}$ (carapace width(mm))
Velvet crab	10^{x} ; $x=-2.767 + 2.572 \times \log_{10}$ (carapace width(mm))

Population health dynamics

The conditions of crustacean in the controlled survey were assessed through observing and noting any injuries than assigning every individual a score using the scoring system in table 3. A score of 36 was considered the most damaging a lobster could be, where limbs, claws and antennae missing and a damaged core (Howarth et al., 2016). Scores were then converted to a percentage by dividing the damaged score by 36 and multiplied by 100.

Table 3: Damage scores assigned to individual lobsters (Howarth et al., 2016).

Injury	Score assigned
Damaged or regrown limb	1
Missing limb or antenna	2
Damaged or regrown claw	2
Missing claw	4
Damage to body	8

The sex of individual specimen was recorded as well as if the female were carrying eggs (berried). Lobster fecundity was observed estimated through the length-egg output relationship shown in Figure 3 (Lizárraga-Cubedo et al., 2003).

Potential reproductive output= (155.4 x length)- 10286

Figure 3. Lobster length-egg output relationship

Tagging

All lobster caught in the targeted survey were marked with a double T-bar anchor tag (Hallprint Pty. Ltd) measuring 55mm in length. Each tag had a unique number and coloured yellow or red depending on whether individuals were caught from within or outside the no-take zone. Lobsters were tagged in their abdominal muscle immediately behind the posterior edge of the carapace, either side of the midline, to avoid puncturing the dorsal abdominal artery and gut (Smith et al., 2001), using a Monarch Marking 3030 tagging gun. In addition, tagging between the cephalothorax and abdomen can minimise tag loss during moulting (Moland et al., 2013). Information on tagged lobsters recovered outside the NTZ was reported by local fishers. The reports from fishers are voluntary without a reward system.

Data Analysis

All variables were tested for normality using histograms, boxplots and the Shapiro-Wilk test within the Package R (www.r-project.org). For each species, the mean number of individuals caught per pot was used as an indicator of their catch per unit effort (CPUE) (Table 4). Each species weight per pot was also used as an indicator of their weight per unit effort (WPUE) (Table 4).

Table 4. Formulas used to calculate of catch rates

Cate rate measure	**Calculation**
Catch per unit effort (CPUE)	Number of individuals caught/Number of creels
Weight per unit effort (WPUE) g^{-1}	Total mass of target organisms present/ Number of creels

Independent sample T-tests were used to compare two series of values when normally distributed and a Mann-Whitney U-test were used for non-normal data sets. The CPUE of velvet swimming crabs, brown crabs and lobsters were compared among sites and years (2012-2018) using a poisson generalized linear model (GLM). No survey was conducted in 2016 within the reserve, however control data was conducted and included for analysis. Model runs showed non-normality and over-dispersion, to overcome this a quasi-poisson GLM was used. To test which variable significantly influenced CPUE an analysis of deviance using Pearson's Chi-Squared test (x^2) was used. The distance of each sample location from the boundaries of the reserve was then calculated using the "Cost Distance" tool in ArcGIS 10.2. We assumed crustaceans could only travel within the marine environment and not on land.

Results

Crustacean population density

The CPUE of European lobsters was greater inside the NTZ whilst a decrease was observed in Brown and Velvet crabs. As the data's distribution was not normal a Mann-Whitney U-test was used to compare mean CPUE of the NTZ, Control and Observed series (Figure 4). The CPUE of lobsters was 90% greater inside the Reserve compare to the control and observation whilst a decrease was observed in brown (-120%) and velvet (-104%) Crabs. As all data were found to be not normally distributed, a Man-Whitney U-test was used to compare mean CPUE between crustaceans and sites. The increase in lobster CPUE inside the Reserve was significantly greater than the Control (U=293, p=<0.001) and Observation (U=1347, p=<0.001). Whilst brown crabs decrease within the Reserve was significantly greater than the Control (U=92.5, P=0.0187) and Observation (U=340.5, p=<0.001). Velvet crabs also decreased within the Reserve compare to the other two sites however the Control (U=100, p=<0.0422) was near significant whilst Observation (U=568, p=<0.0116) was non-significant.

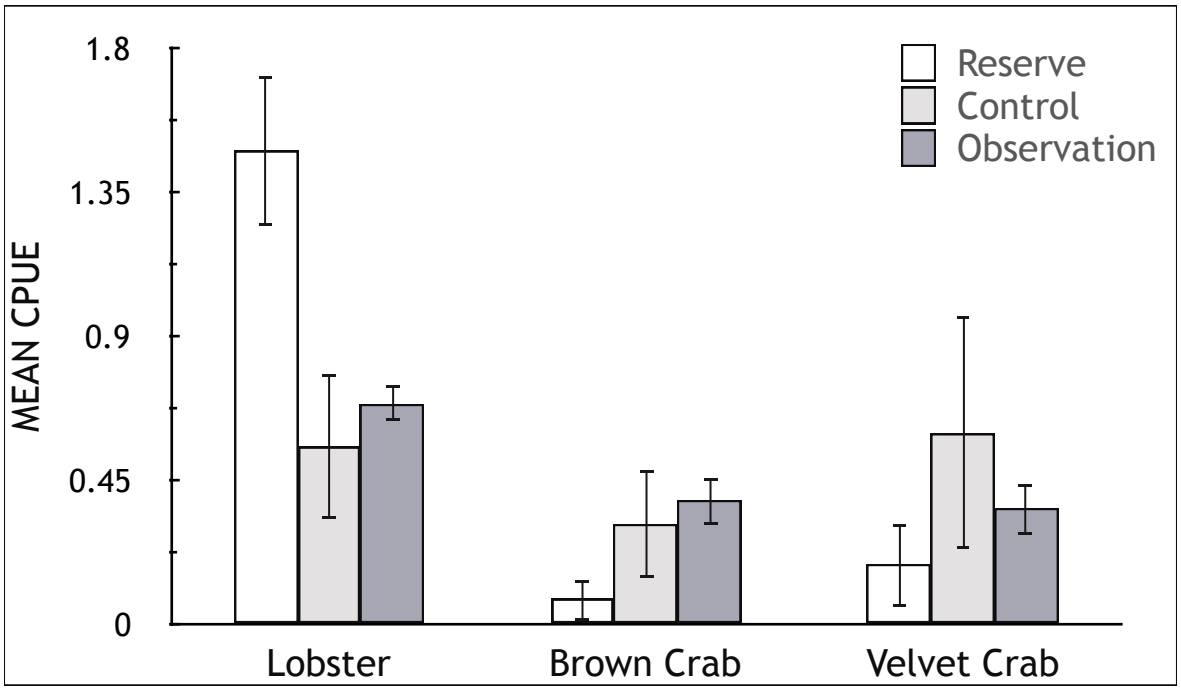


Figure 4. Mean CPUE of lobsters, brown crab and velvet swimming crab within the Reserve, control and observed sites. Error bars represent ± 1 SE.

Size and Weight distributions

The mean size of lobsters was 10 and 11 mm greater within the NTZ compared with the control and observations. Likewise, velvet swimming crabs were 2mm larger within the NTZ than the control. In contrast, brown crabs were 11 and 58mm larger within the control and observation than in the NTZ. Mann-Whitney U tests were used to compare mean sizes as the data were not normally distributed. The mean lobster size within the NTZ was shown to significantly greater than the Control and Observation data. Lobsters were larger inside the Reserve compared with the Control and Observation sites. The difference in velvet crab size appears marginal and therefore wasn't analysed further. As the data were found to be not normally distributed a Mann-Whitney U test was used to compare mean crustacean sizes (mm) between sites. Mean lobster size within the Reserve was shown to be significantly greater than the Control (U=246.5, p=<0.001) and the Observation site (U=1504, p=<0.001). Whilst mean brown crab size within the reserve significantly decreased between the Control (U=81.5, p=0.006) and the Observation (U=20.5, p=<0.001).

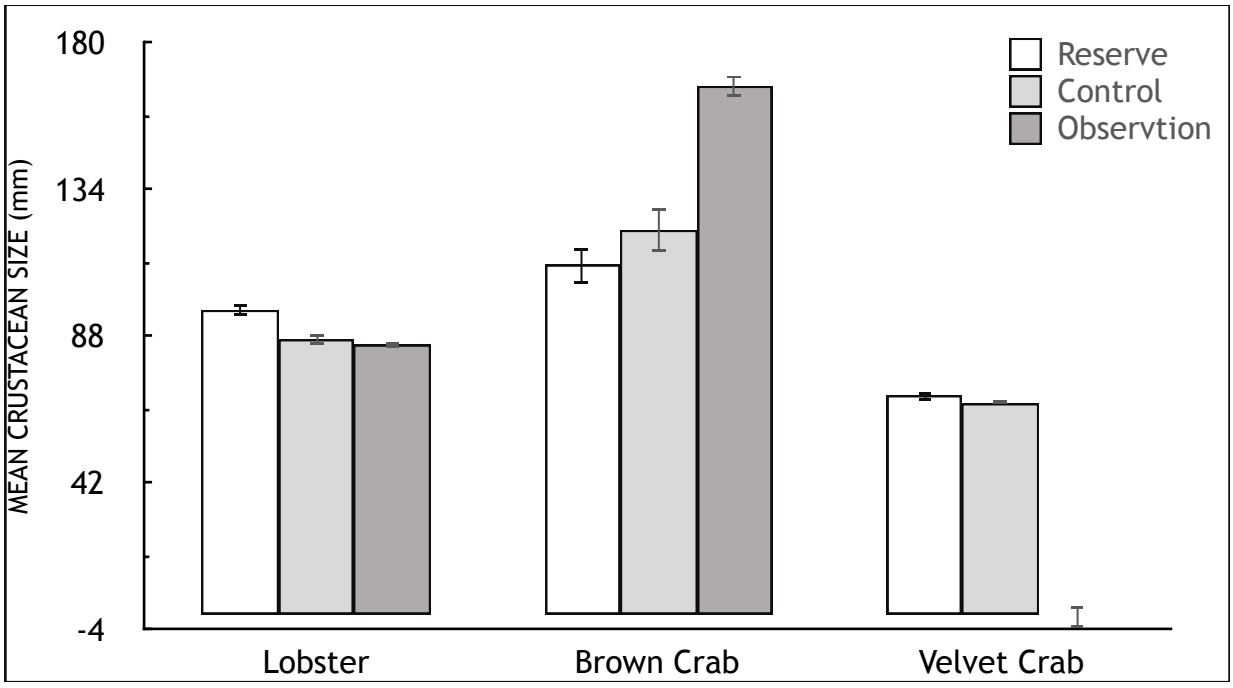
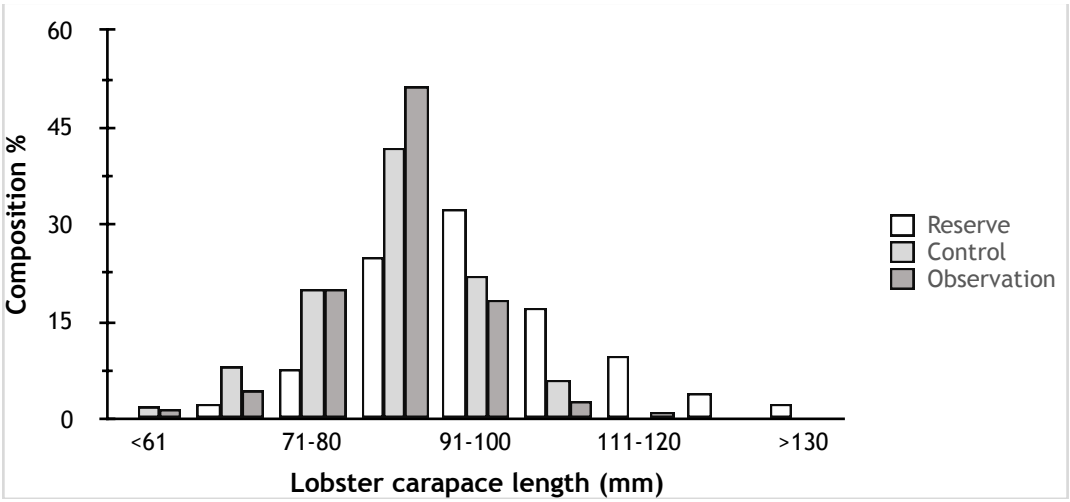
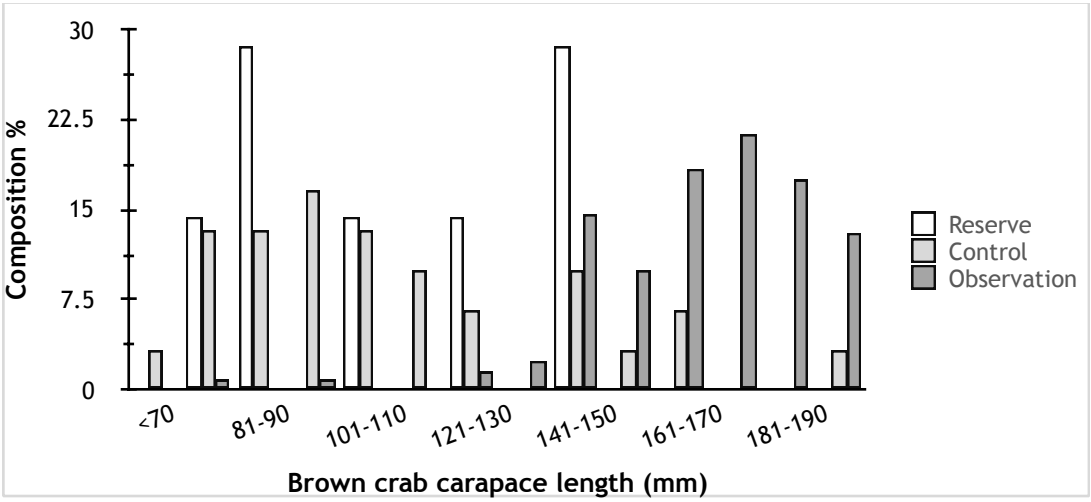


Figure 5. Mean size if lobster, brown crab and velvet crab among sites located in the reserve, control and observation. Error bars represent ± 1 SE.

The distribution of crustacean size in each series is shown in Figure 6. For lobsters, there was greater bias for larger individuals inside the reserve. Two-sample K-S tests were conducted for the comparisons. Table 5 shows the difference in lobsters size distribution to be significant. Both species of crabs did not show significant difference in their distribution between sites. However brown crabs did show difference in distribution between the Reserve and the Observation site to be significant.





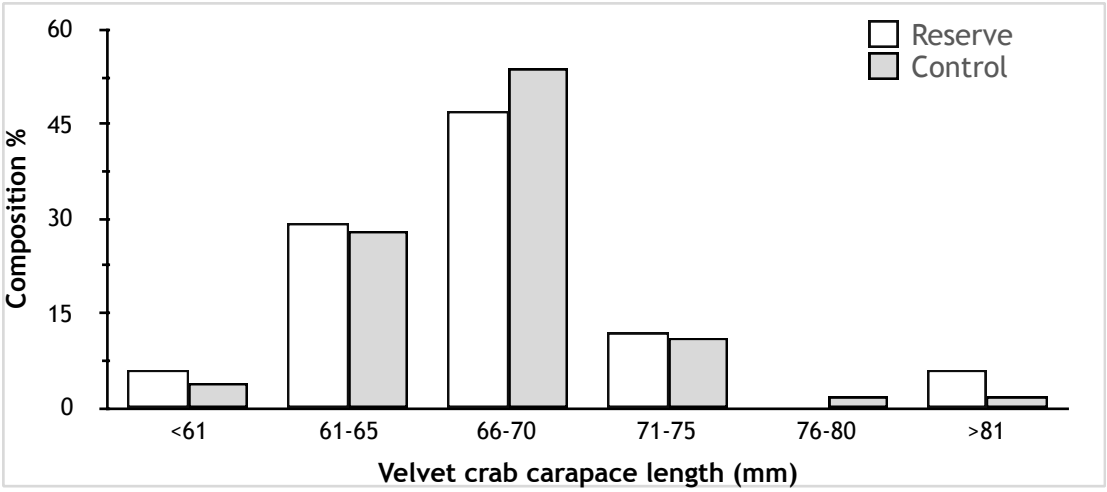


Figure 6. Size structure of lobster, brown crab and velvet crabs with the reserve, control and observation sites.

Table 5: Results of the Komogrov-Smirnov K-S two-sample tests on the individual size of distributions (% composition) of crustacean populations in the fully protected marine reserve and control and observation sites.

Species	**Test**	*N*	**D**	*P*
Lobsters	NTZ-Control	133:50	0.38902	<0.0001
Lobster	NTZ-Observation	133:616	0.43652	<0.0001
Brown Crab	NTZ-Control	7:30	0.2381	0.9045
Brown Crab	NTZ-Observation	7:131	0.84091	0.0001
Velvet Crab	NTZ-Control	17:54	0.090414	0.9999

Density of Crustacean biomass

The use of weight per unit effort (WPUE) was aimed to assess how the combination of varying population densities and individuals size affects the density of the biomass present. Figure 7 shows mean WPUE for all sizes and Figure 8 displays legal crustacean sizes. Greater catch rates and sizes are resulting in an increase in overall lobster biomass and the quantity being recruited into the fishery. Lobsters were heavier in the reserve whilst brown crabs were heavier outside the reserve. When plotting just legal sized individuals, lobsters remained heavier in the reserve whilst legal crabs in the reserve were absent.

After being found to be non-normally distributed, a Mann-Whitney U test was used to compare species mean WPUE between sites. Mean lobster WPUE within the Reserve was shown to be significantly greater than the Control (U=255, p=<0.001) and the Observation site (U=1211, p=<0.001). Difference between Mean brown crab WPUE within the Reserve and the control was to be non-significant (U=21, p=0.1744) and the Observation site was near significant (U=68, p=0.0465).

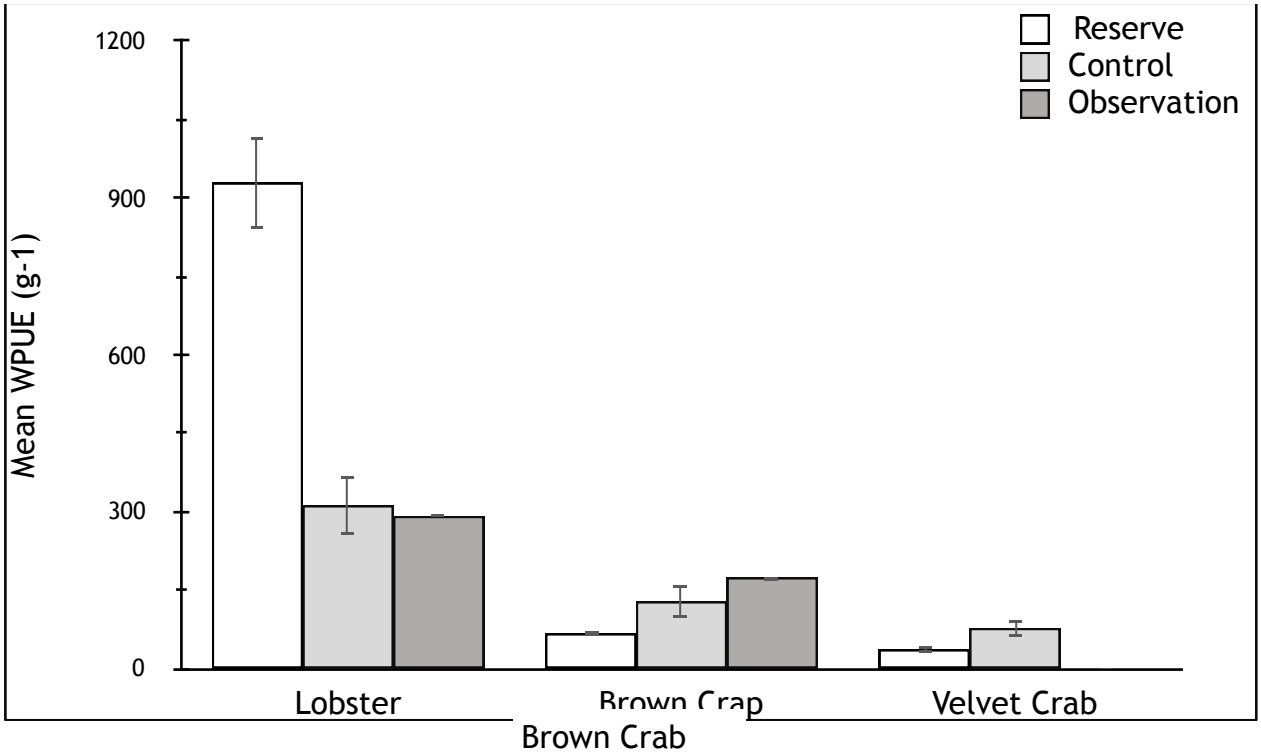


Figure 7. Mean estimated WPUE of lobster caught within the reserve, control and observation. Error bars represent ± 1 SE.

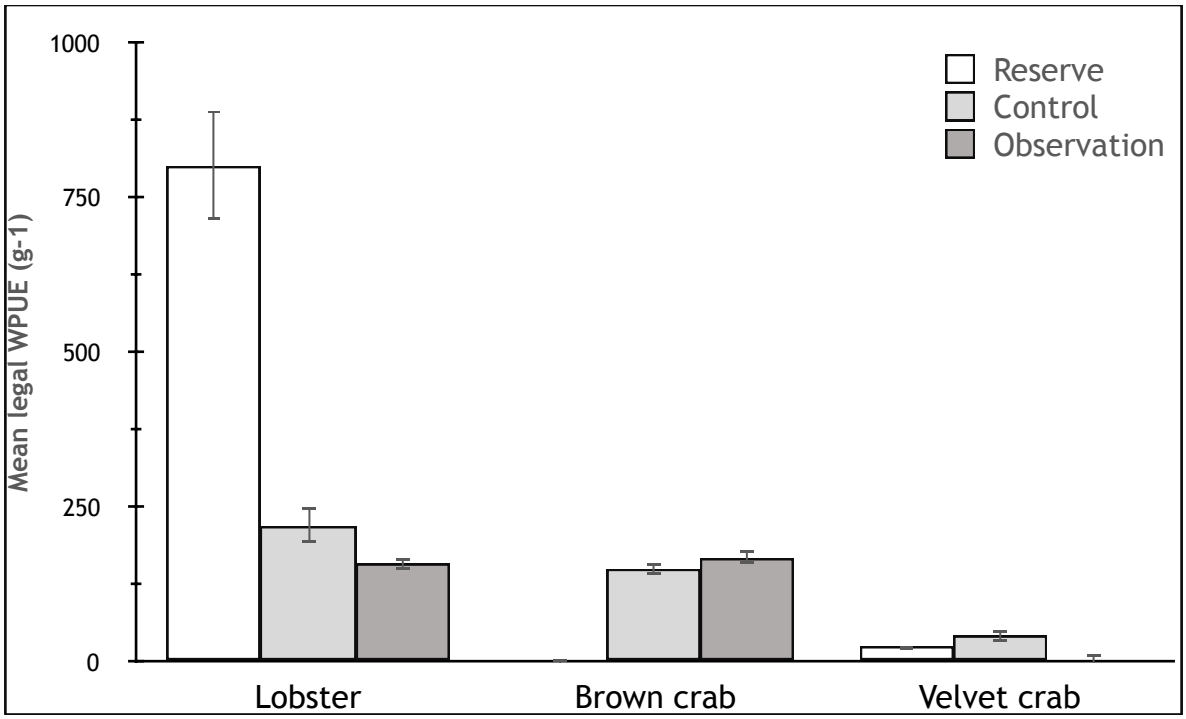


Figure 8. Mean estimated WPUE of lobster caught within the reserve, control and observation. Error bars represent ± 1 SE.

Lobster composition and health

A greater proportion of lobsters inside the Reserve and Control were found to be male, 62.9% (NTZ) and 73.6% (Control) respectively. Chi-square analysis found site had no significant bearing upon sex composition (X^2=1.65(1), p=0.199).

Within the female population between the two sites, 20.4% inside the NTZ were seen to be currently or has previously been berried, whilst 15.4% in the Control site were seen to be currently or has previously been berried. Chi-square analysis found females were significant influence by being present in the NTZ compared with the Control (X^2=17.16(1), p=<0.001).

The individual potential egg output for females among sites saw a mean increase of 26.8% and 39.1% inside the NTZ (5126(SE=214)) compared with the Control (3915(SE=302)) and the Observed(3449(SE=77)). An Independent Samples T-test found the increase between the Reserve and Control sites to be significant (t=3.281, p=0.002). A Mann-Whitney U-test found the increase inside the NTZ compared with the Observed to be significant (U=9872, p=<0.001) after non-normal distribution was established.

Damage in lobsters ranged from 0% (no damage) to 44.4% (individuals missing one claw and six legs) with a greater proportion of lobster within the NTZ (80.4%) compared with the Control (19.6%) showed signs of injuries. A Chi-square analysis showed this increase to be significant. The mean damage (%) inside the NTZ was 4.34% (SE=0.47) and in the Control was 3.55% (SE=1.28). A Mann-Whitney U found this difference to be significant insignificant (U=3686, p=0.161).

Comparison with past time series

There are large fluctuation in catch rates between years and all species, with a negative relationship between brown crabs and lobsters. For the final two years of study, lobsters CPUE declined 31% to 1.47 (SE= ±0.11) in the reserve and 52% to 0.55 (SE= ±0.11) in the control. Although since the study began the mean CPUE in the reserve increased by 11%. Similar to all lobsters, legal sized lobster CPUE declined 35% to 1.1 (SE= ±0.11) in the reserve and 49% to 0.25 (SE= ±0.05) in the control. Although since the study the mean CPUE in the reserve has increased by 29%. The CPUE of sublegal lobsters differed in that catch rates averaged lower within the reserve compared to the control with a decline of 18% in the final 2 years of the study to 0.37 (SE= ±0.07). The control showed an overall increase of 132% since its lowest point in 2015. Brown crabs CPUE have declined 166% since its peak in 2015 but show trends of being greater than the control with the final two years of the study showing declines of 106% to 0.07 (SE= ±0.03). In contrast, legal brown crabs show trends of the control averaging greater than the reserve although both have declined since the peak in 2015 by 30% in the reserve and 27% in the control. Velvet crabs have fluctuated each study year with reserve CPUE averaging lower than the control. The last two years of study, the reserve CPUE declined 135% to 0.18 (SE= ±0.06).

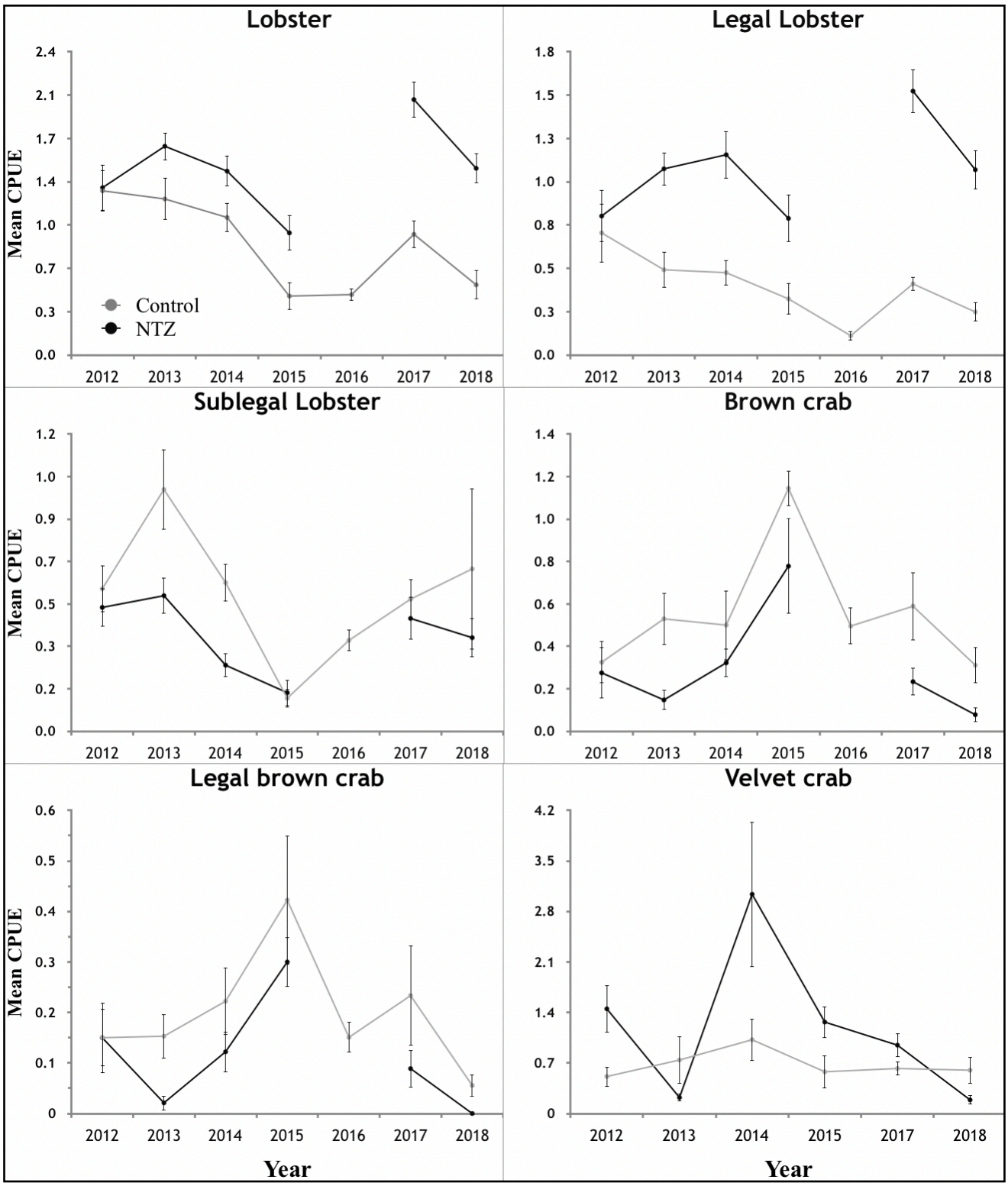


Figure 9. Mean CPUE of lobsters, legal-sized lobsters (>88), sublegal lobsters (<88), brown crab, legal-sized brown crab (>150mm) and velvet swimming crabs within the reserve and control over the 6-year study period. Error bars represent ± 1SE. Reserve CPUE for 2016 is absent due to surveying not being undertaken that year.

Table 6. Outputs from quasipoisson GLMs used to test if treatment (reserve or control) and year (2012-2018) significantly influenced the CPUE of lobsters, legal-sized lobsters (>88mm), sublegal lobsters (<88mm), brown crab, legal-sized brown crab (>150mm), sublegal brown crab (<150mm) and velvet swimming crabs.

Size Class	Deviance explained	Variable	X^2	P
All lobster	64.3%	Treatment	22.7	*<0.001
		Year	19.7	*<0.001
Legal lobster	57.5%	Treatment	44.8	*<0.001
		Year	13.3	*<0.001
Sublegal lobster	79.9%	Treatment	2.8	*0.0128
		Year	19.0	*<0.001
All brown	76.0%	Treatment	8.7	*<0.001
		Year	25.8	*<0.001
Legal brown	78.3%	Treatment	2.6	*0.003
		Year	14.6	*<0.001
Sublegal brown	81.3%	Treatment	6.08	*<0.001
		Year	14.9	*<0.001
Velvet crab	71.1%	Treatment	23.1	*<0.001
		Year	86.6	*<0.001

Significant terms are denoted with a (*)

Spill-over into surrounding area

Legal Lobster catch rates showed spatial trends as the CPUE of legal lobster declined with increasing distance from the boundaries of the reserve. A Spearmans Rank test showed a weak negative trend (N=112, r_s=-0.8285, p=0.041). A Spearmans Rank test showed the relationship between CPUE and distance from the boundaries of the reserve was insignificant (N=108, r_s=-0.2571, p=0.622).

A total of 131 lobsters were tagged during the study period. Three lobsters tagged in this study period (2018) were recaptured generating a recapture rate of 2.3%. Of the three recaptured only one had moved from within the reserve to outside. Overall, 15 tags were recaptured in this year's survey, varying from being tagged in 2012-2018, limited time allowed for the analysis of these individuals. However, two tagged lobsters, tagged in 2017, were recaptured by a local fisher far from the boundaries of the NTZ (See Appendix 4). Tag number 418 was found 20k from its original tagged location within the NTZ to the southern end of the Island. Tag number 801 was found 40km from its original tagged location near Hamilton rock, on the edge of the NTZ, to the western side of the island. While only one of the 15 recaptured lobsters had moved from outside the reserve to inside.

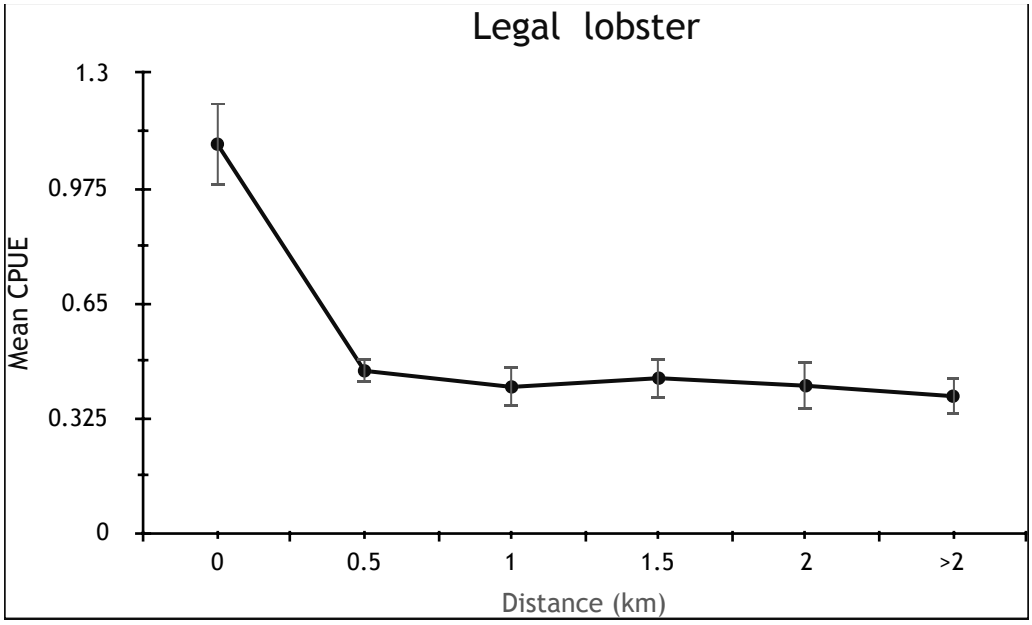


Figure 10. Mean CPUE of legal-sized lobsters (>88mm) plotted against distance from the boundaries of the fully protected reserve. A distance of 0 marks those located within the reserve. Error bars represent ± 1 SE.

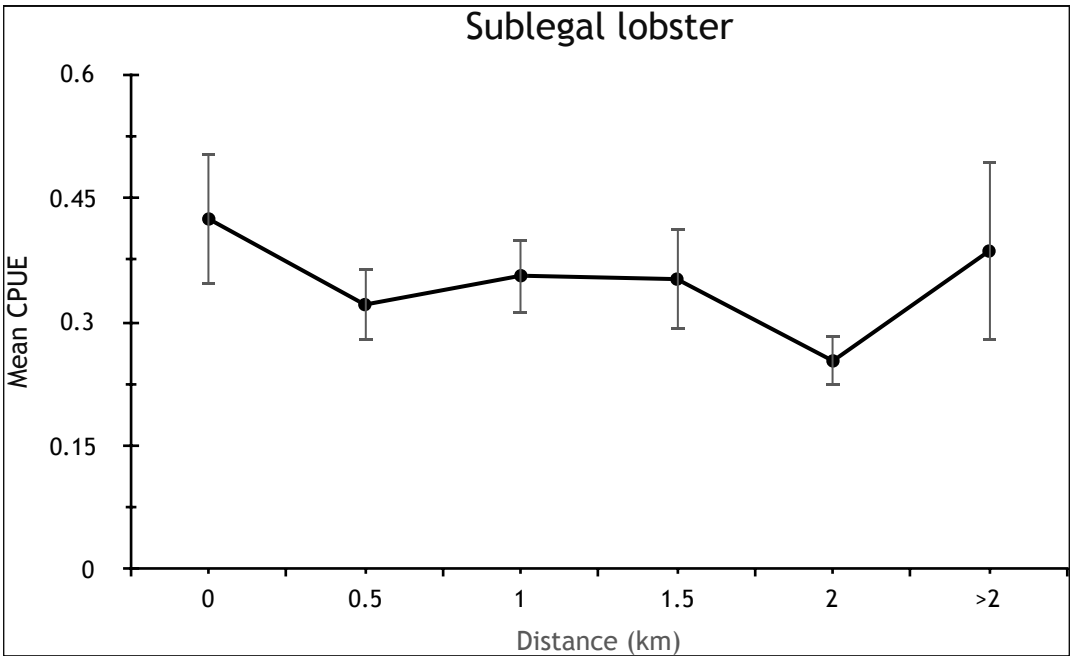


Figure 11. Mean CPUE of sublegal lobsters (<88mm) plotted against distance from the boundaries of the fully protected reserve. A distance of 0 marks those located within the reserve. Error bars represent ± 1 SE.

Discussion

Overview of Findings

The aim of this study was to assess whether the Lamlash Bay NTZ was preserving and enhancing commercially exploited crustacean population. The study resulted in the following main findings:

- Crabs and lobsters responded differently to the presence of the NTZ, brown crabs had a decrease in CPUE equating to decrease in biomass whilst lobsters CPUE increased equating to increased biomass.
- Velvet crabs had no significant response to the presence of the reserve. There was no evidence of "spill-over" from looking at the correlation between the distance to the NTZ and CPUE, however retrieved tagged individuals did show signs of "spill-over".
- Finally, the frequency and severity of injuries was greater within the NTZ.

Implications of findings

These findings provide evidence that after 10 years of protection, Lamlash Bay NTZ is benefiting European lobster populations by increasing, catch rates, body size and weight as well as potential reproductive output. This is consistent with other temperate region NTZ studies such as Lundy in the UK and in several Norwegian reserves (Hoskin et al., 2011; Moland et al., 2013a). This study, combined with previous work on this location, provides further evidence that temperate marine reserves can benefit the local fishers, community and biodiversity.

Consistent with Hoskin et al., (2011), our study saw lobster length was 10-11mm larger in the reserve than the control. The trend of increasing size and density of legal-sized lobsters with the reserve is likely due to increased survivorship of resident lobsters, owing to fishing prohibition. Also evident in the fact record lobster lengths are broken each year. The mean

potential number of eggs for individual females' lobsters was 27% higher in the reserve than outside, and the total number of eggs was 135% higher, resulting in 261,427 more eggs within the sample area. Catch rates of berried lobsters was also 133% higher within the reserve. These support the theory that individuals in the reserve experience increased survivorship resulting in increased body size and reproductive output. Unlike what has been reported by government reports, our study caught more males than females both within and outside the reserve (Mesquita,Dobby and McLay, 2016). This may explain the lower levels of berried females caught. It has been legal to catch berried females, meaning sexually mature should find refuge in the reserve, which adds to recruitment (Howarth et al., 2016).

Frequency and severity of lobster injuries was greater within the boundaries of the reserve, observed by both Howarth and Davies. The number of individuals with claw damage was higher within the reserve suggesting competition for territories due to increased lobster densities. However, there is no baseline study of population health within Lamlash bay, therefore the state of crustacean health within the reserve is hard to quantify (Hillborn et al., 2004).

Hoskin et al., (2011) saw an increase in lobster catch rate of 427%, whilst Lamlash bay only saw an increase of 91%. The increase differs greatly but the increase in Lamlash bay is still significant for the site. Series data of CPUE from 2012-2018 has shown that CPUE has not followed a clear upward trend and has fluctuate each survey year. Various factor could explain this, such as lobsters being fished above maximum sustainable yield, increased fishing along the reserve's boundaries and sublegal lobsters CPUE have declined. Here there is evidence high levels of small lobsters are being taken from the fishery and are not being replaced by recruitment (Howarth et al., 2016). Local creelers may be "fishing the line" of the reserve boundary (Kellner et al., 2007), expecting improved catch rate but putting pressure on individual near the reserve. A buffer zone around the boundary may reduce this edge effect (Harris, 1988).

Other factors influencing CPUE variation each year is the decrease and increase in local fishing effort. Prior to 2016, two boats operated within Lamlash bay; in 2017 this was reduced to one which is evident in the increase in lobster CPUE for that year. However, in August 2018 the second creeler returned to lobster fishing inside Holy Isle (I. Cossack, Perrs Comms, 2018). Both however have scaled back fishing efforts from previous years due to targeting more valuable species such as *Nephrops* deeper in the bay and wrasse as cleaner fish for the salmon farm.

The wider MPA towards the south of Arran may be influencing lobster densities in the bay. Established in 2016, the South Arran MPA prohibits the use of dredging and trawling; gears that previously fished the boundaries of the NTZ (H. Wood, Perrs Comms, 2018). Biologically and physically the gears can result in seabed habitats complexity being reduced by the removal of non-target benthic organisms, can re-suspend sediment and destroy bedforms such as maerl beds, which are important habitat for a variety of marine life (Collie,Escanero and Valentine, 1997). The protection afforded from gear prohibition may be benefiting and increasing lobster densities. A simpler explanation may be environmental conditions, such as sea temperature, is influencing lobster densities. Sea temperature can influence the success of the larval development stage in lobsters (Quinn et al., 2013). However, no analysis was conducted looking at the correlation between sea temperature and lobster densities.

Although lobster CPUE decreased further from the boundary of the reserve, the correlation overall was weak. Spill-over may be reduced due to unsuitable benthic morphology, as areas of the control sites change dramatically around Holy Isle for instance there is a sudden change in depth and benthic morphology before returning to kelp fringing boulders. This include areas within the bay being dominated by fine muds, reaching depths of 30m, which may limit lobster mobility (I.Cossack,Perrs Comms, 2018). However, fishers who voluntarily assist in recording tagged lobsters caught off Arran each year has resulted in evidence of "Spill-over" of individual lobster travelling over 20-40km to the opposite side of the island

from the inside and outside boundaries of the NTZ. As lobsters migrate from the reserve to outside, they are transferring the benefits of increased body size and reproductive output to local fishing grounds (Howarth et al., 2016). Larvae likely move away from points of higher densities to areas of lower densities outside the reserve (Leslie,Henderson and Riley, 2006) and lobsters are also likely to move away from area of lower densities to avoid competition (Richards and Cobb, 2011). Juvenile lobsters especially are solitary and aggressive and potentially cannibalistic thus require more space as they grow (Wahle and Fogarty, 2006).

Crabs were found to be smaller and less abundant in the NTZ compared to the control which was also observed by Howarth et al. (2015). Crabs may be negatively affected by the NTZ due to greater densities of large lobsters predating and/or competitively displacing them from the area. Crabs may have also been discouraged from entering the creel if there were large number of lobsters already present (Smith and Tremblay, 2003). It is also possible high seasonal migration distances is influencing densities (Tully et al., 2006). However, without baseline data it is difficult to attribute the differences to the presence of the NTZ. The small size of Lamlash bay reserve, at best, only provides protection during a limited part of these crustacean's annual range. A much larger reserve including taking into consideration spawning and aggregation sites is necessary if Lamlash bay was to benefit this species (Ungfors,Hallbäck and Nilsson, 2007).

Observation data may have varied due to the difference in fishing effort, number of creels per string, dimensions of creels as well bait and soak time compared to the controlled survey. Observation data also was recorded further from Lamlash bay for several strings, in Corrie, where little fishing has been observed for several years (I.Cossack, Perrs Comms, 2017). This may have increased sample results; however, results were still significantly higher in the reserve compared to mean observation. Further supporting the success of Lamlash bay NTZ.

Due to variability in findings each survey year, this data provides support for previous and future studies on Lamlash bay crustaceans. Our research within Lamlash bay is invaluable as studies on temperate and cold water MPAs are relatively scarce. It also highlights the importance of investigating multispecies interactions, as our research found lobster recover had a knock-on effect on crabs (Howarth et al., 2016). Overall the longer lasting the reserve the more optimal harvesting populations are (Grafton,Kompas and Van Ha, 2006) and the longer the recovery time for habitats and taxa within Arran (Hall-Spencer and Moore, 2000).

Conclusion

Our study has shown that Lamlash bay No-Take Zone is benefiting lobster population and generally the reserve is of wider importance to other species and the marine environment beyond its boundaries. Although it offers little refuge to crabs due to the reserves small size. In this regard, the Reserve alone will not be enough to combat current trends of low levels of recruitment and high fishing mortality. A combination of reduced fishing effort, MPAs and the cooperation of the local community will be the most effective way to restock and restore the marine environment around Arran. Lamlash bay is unique as it is the only statutory reserve proposed and campaigned for by the local community (Howarth and Stewart, 2014). Their efforts have resulted in seabed communities and habitats ecologically being more diverse and abundant within the NTZ (Howarth, 2012). Bottom-up management and community participation is a key to the continued success of this reserve, as it builds support and reduces cost due to compliance (Prior, 2011).

Overall, this study provides evidence that community led temperate reserves can benefit local fisheries, community and conservation.

Acknowledgements

Firstly, I would like to thank the University of York, Community of Arran Seabed Trust and Blue Marine for their collaboration and allowing the project to be conducted this year. I am extremely grateful to the team all the team at COAST for their support; specifically, Howard Wood, Jenny Stark and Paul Chandler. I would also like to thank Ieuan Jones, Matthew Norton, Natasha Walker-Milne and Debora Milenkova for their assisting during the surveys. As well as Dr. Adam Rees from Blue Marine for his assistance during passive fishing observations. I would like to thank Tim James from Creelers for allowing me to gather fishing observation data on his vessel Julie Anne. My biggest gratitude goes to Ian Cossack for assuring my safety was number one during my time on the boat, assisting with my research and generally supporting me each day. Finally, I would like to thank my supervisor, Dr Bryce Stewart for his guidance and for always keeping things awesome.

Declaration

I declare that this dissertation is my own original work and has not been submitted before to any institution for assessment purposes. Furthermore, I acknowledge all sources used and have cited these in the reference sections.

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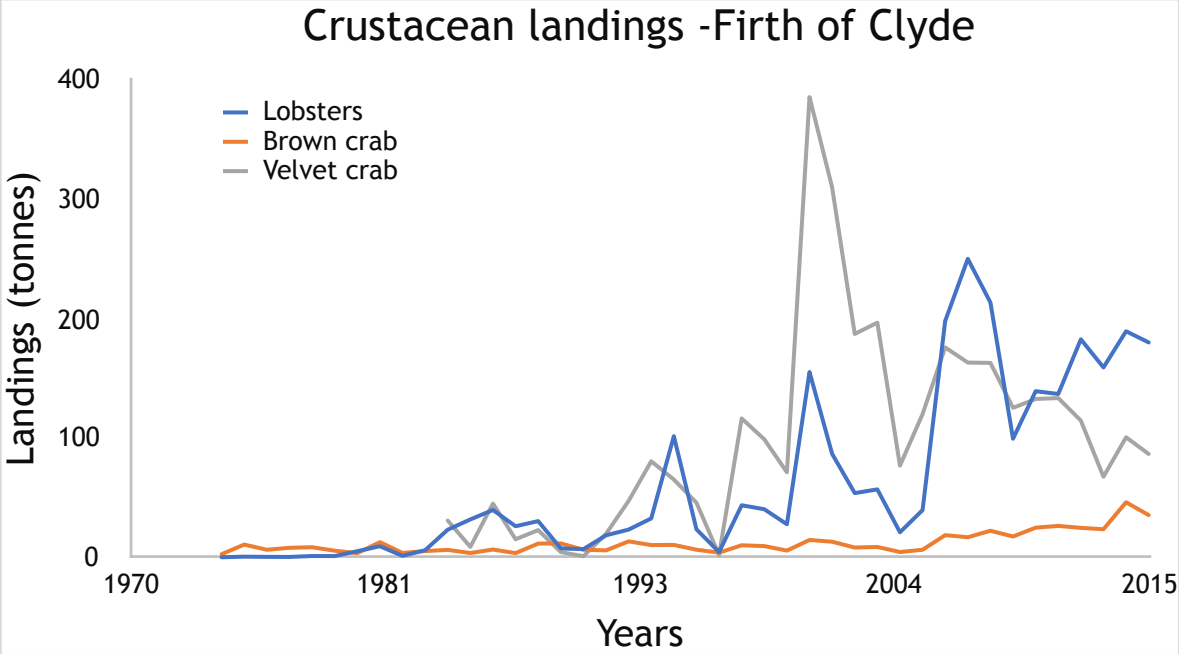
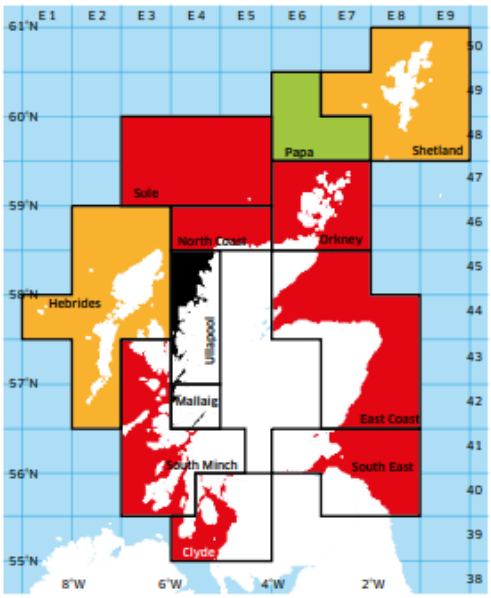
Appendix 1.



Plot showing crustacean landings (lobster, brown crab and velvet crab) over time between 1975 and 2015 in the Firth of Clyde. Data sourced from Marine Scotland 2018.

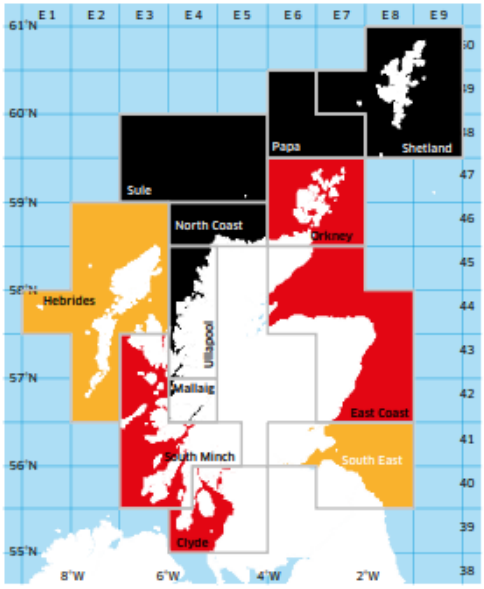
Appendix 2.

Maps showing fishing assessments for crustaceans in Scotland (Marine Scotland, 2017)



CREEL FISHERY ASSESSMENT UNITS AND ESTIMATED FISHING MORTALITY IN RELATION TO F_{MSY}, 2013-15.

- Fishing mortality around or below F_{msy}
- Fishing mortality above F_{MSY} for either males or females
- Fishing mortality above F_{MSY} for both males and females
- Not assessed for the period 2013 - 2015

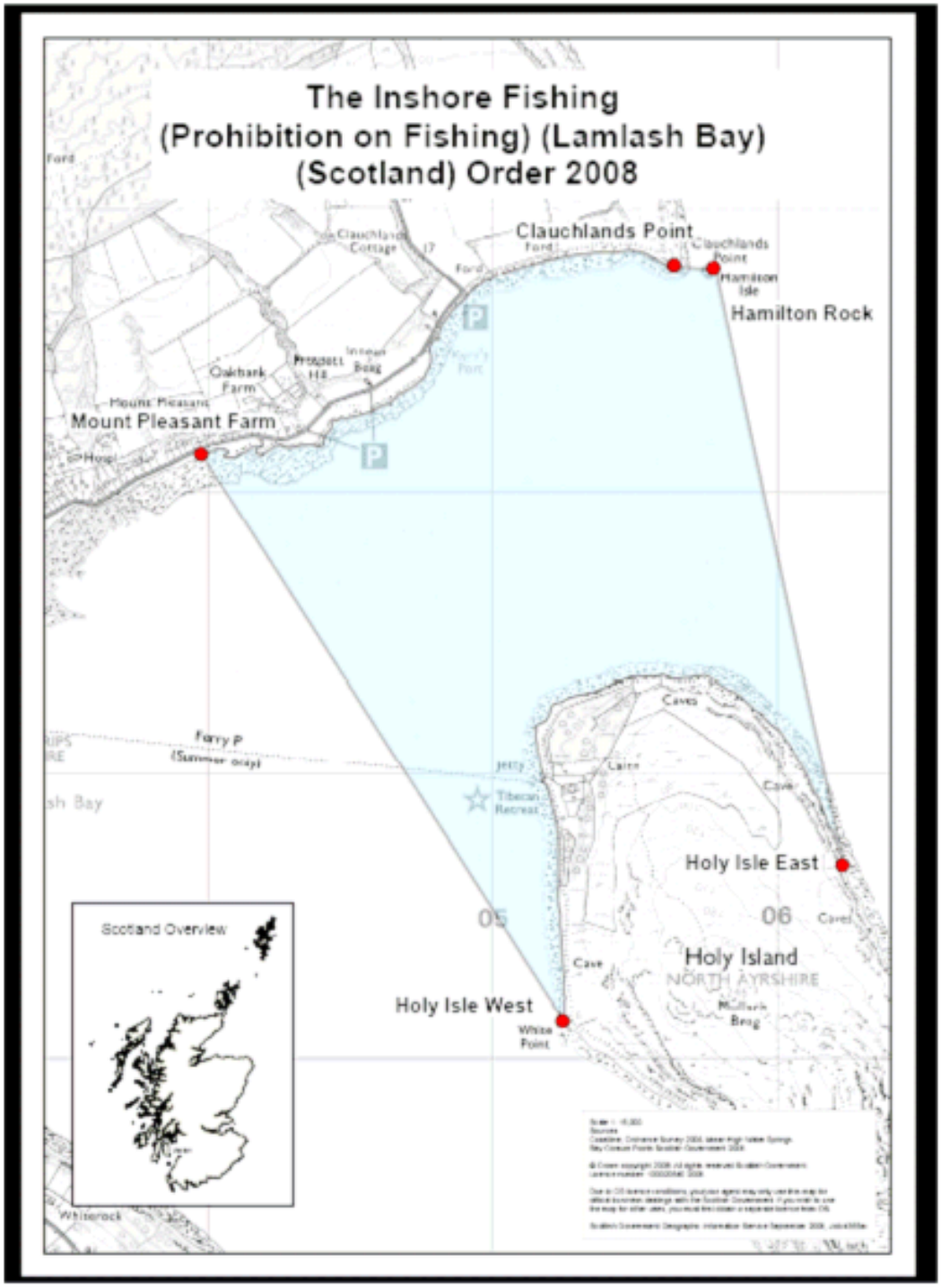


CREEL FISHERY ASSESSMENT UNITS AND ESTIMATED FISHING MORTALITY IN RELATION TO F_{MSY}, 2013-15.

- Fishing mortality around or below F_{MSY}
- Fishing mortality above F_{MSY} for either males or females
- Fishing mortality above F_{MSY} for both males and females
- Not assessed for the period 2013-2015

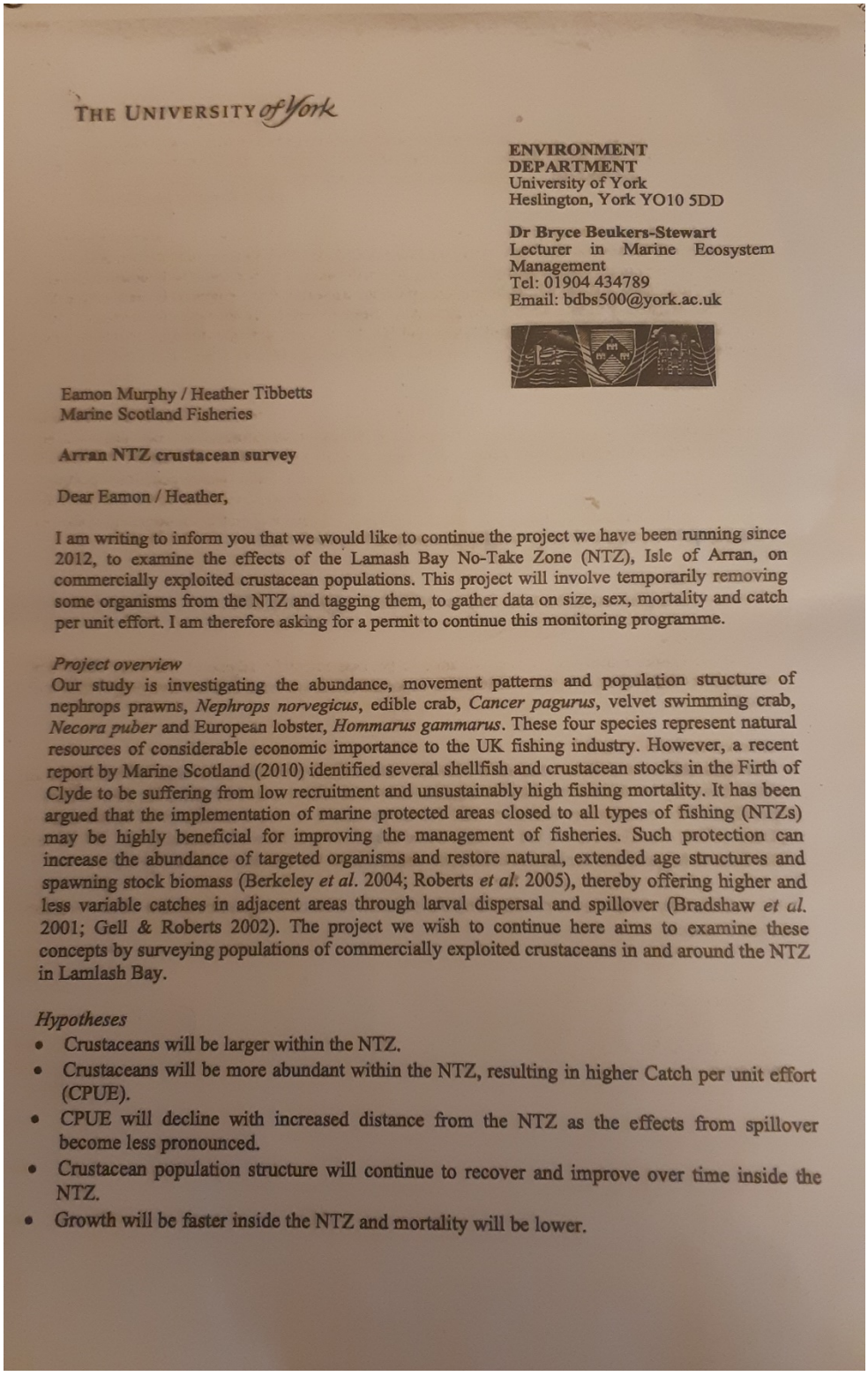
Appendix 3.

Map showing the Inshore Fishing prohibition order in Lamlash Bay from 2008.



Appendix 4.

Letter and order from Marine Scotland to allow the survey to be conducted in Lamlash Bay No-Zone where species were temporarily removed.



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Eamon Murphy / Heather Tibbetts
Marine Scotland Fisheries

Arran NTZ crustacean survey

Dear Eamon / Heather,

I am writing to inform you that we would like to continue the project we have been running since 2012, to examine the effects of the Lamash Bay No-Take Zone (NTZ), Isle of Arran, on commercially exploited crustacean populations. This project will involve temporarily removing some organisms from the NTZ and tagging them, to gather data on size, sex, mortality and catch per unit effort. I am therefore asking for a permit to continue this monitoring programme.

Project overview

Our study is investigating the abundance, movement patterns and population structure of nephrops prawns, *Nephrops norvegicus*, edible crab, *Cancer pagurus*, velvet swimming crab, *Necora puber* and European lobster, *Hommarus gammarus*. These four species represent natural resources of considerable economic importance to the UK fishing industry. However, a recent report by Marine Scotland (2010) identified several shellfish and crustacean stocks in the Firth of Clyde to be suffering from low recruitment and unsustainably high fishing mortality. It has been argued that the implementation of marine protected areas closed to all types of fishing (NTZs) may be highly beneficial for improving the management of fisheries. Such protection can increase the abundance of targeted organisms and restore natural, extended age structures and spawning stock biomass (Berkeley *et al.* 2004; Roberts *et al.* 2005), thereby offering higher and less variable catches in adjacent areas through larval dispersal and spillover (Bradshaw *et al.* 2001; Gell & Roberts 2002). The project we wish to continue here aims to examine these concepts by surveying populations of commercially exploited crustaceans in and around the NTZ in Lamlash Bay.

Hypotheses

- Crustaceans will be larger within the NTZ.
- Crustaceans will be more abundant within the NTZ, resulting in higher Catch per unit effort (CPUE).
- CPUE will decline with increased distance from the NTZ as the effects from spillover become less pronounced.
- Crustacean population structure will continue to recover and improve over time inside the NTZ.
- Growth will be faster inside the NTZ and mortality will be lower.

The first five years of survey work on this project provided support for all of these hypotheses (Howarth et al. 2016). However, results have been somewhat variable between species and between years. We therefore wish to conduct further surveys this year to determine the consistency of our findings.

Personnel
The fieldwork component of this project will be led by Dr Bryce Beukers-Stewart, a fisheries biologist and lecturer at the University of York, and Ms Eilis Crimmins, an MSc student from the same University. Pot sampling of crustaceans will take place onboard the licensed creeling vessel **Julie Ann TT268** which belongs to **Mr Tim James** and is skippered by **Ian Cossack**, who has assisted with this work in the past. All fieldwork will be conducted in accordance with the Scientific Codes of Practice and Ethics and Health and Safety Regulations of the University of York.

Methodology
Pot sampling will involve deploying three strings of five standard lobster pots (creels) inside and outside the NTZ, and leaving them to soak for periods of 48 hours at a time. This will be repeated three times within one week of July, and then carried out again in August. All species captured in the pots will be identified, counted, measured and sexed (where possible). Lobsters will also be tagged with external markers (T-bar anchor tags, Hallprint Ltd). All animals captured will then be returned to sea. Therefore, as Ian / Tim will not be benefitting from this fishing activity, they will be financially compensated for their time.

Time Frame
The project is planned to run from July 1st 2018 until August 31st 2018.

Quality Control
Dr Bryce Beukers-Stewart will be available to provide scientific advice to Ms Eilis Crimmins throughout the project. He has considerable expertise and experience in the surveying of fish and shellfish.

Dissemination of Results
The data collected will be combined with the results from previous years and written up as an MSc thesis by Ms Eilis Crimmins. If suitable, this work will also be submitted for peer-reviewed publication in due course. A report will also be produced for the Community of Arran Seabed Trust (COAST). This report and the associated data files will be made available to COAST and Mr Eamon Murphy at Marine Scotland upon request after the completion of the project.

If you have any further queries regarding our planned research programme please do not hesitate to get in touch,

Yours sincerely

Bryce Beukers-Stewart
15/6/2018

marinescotland

Scottish Government
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22 June 2018

Dear Dr Beukers-Stewart

LAMLASH BAY NO-TAKE ZONE CRUSTACEAN SURVEY DEROGATION: JULIE-ANNE TT268

We refer to recent correspondence regarding the issuing of a derogation to allow the temporary removal of organisms from the Lamlash Bay No-Take Zone (NTZ) as part of an Arran NTZ crustacean survey.

We can confirm that authority is granted, in accordance with Section 9 of the Sea Fish Conservation Act 1967 and Article 43 of Council Regulation No. 850/98, for the vessel Julie-Anne TT268 to be used in the sampling and tagging of crustaceans. Sampling will be conducted by means of three strings of five standard lobster pots.

This authority shall be valid between 0001 hours on 01 July 2018 and 2359 hours on 31 August 2018 and is subject to the following conditions:

- specimens will be returned to the sea unharmed
- operations shall be conducted for scientific purposes only
- a copy of this letter, together with a copy of the derogation application, should be kept on board the vessel at all times during the authorised period

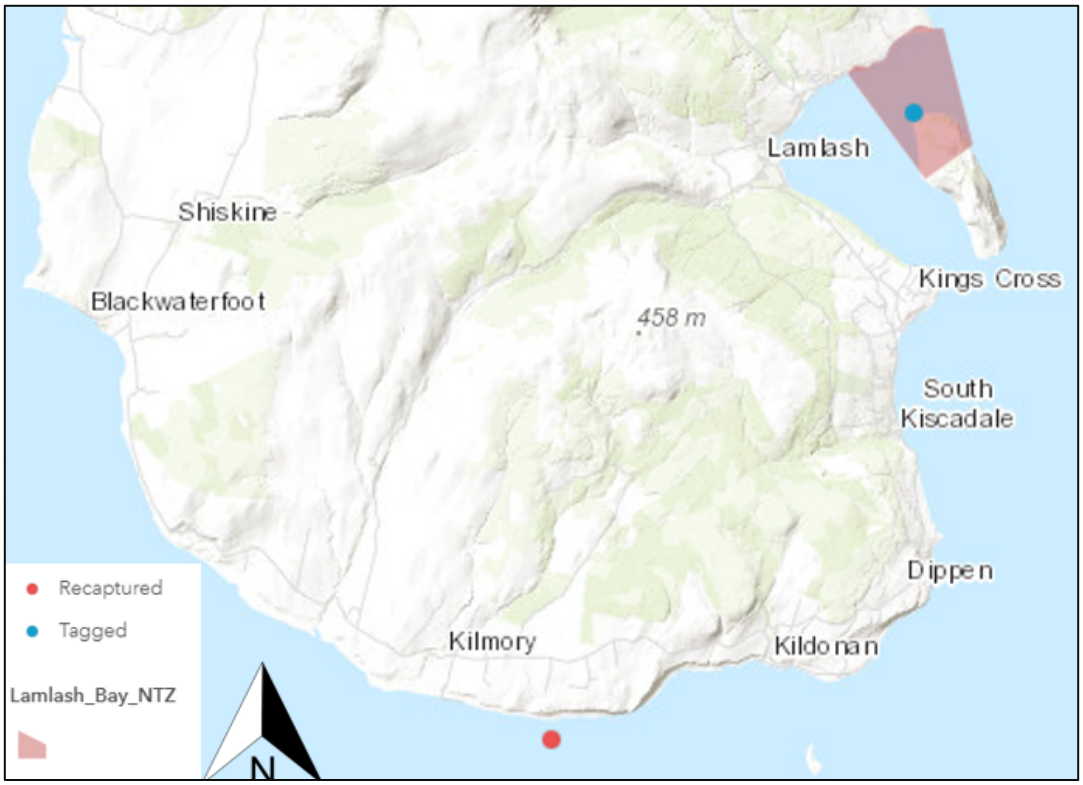
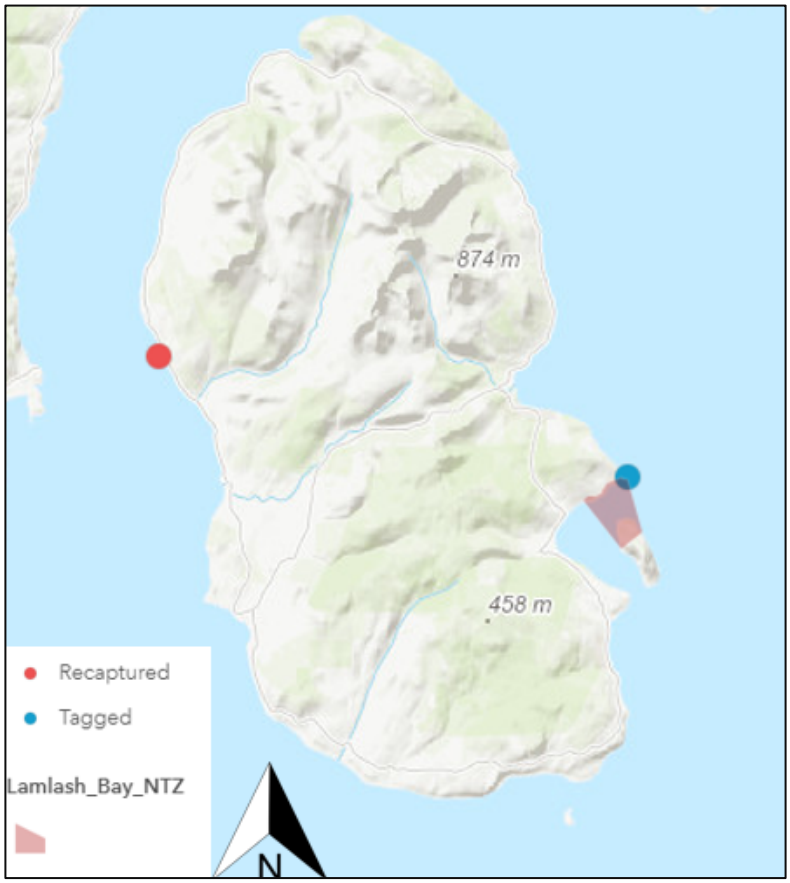
A copy of this letter will be sent to colleagues in the Fisheries Monitoring Centre for onward transmission to Marine Protection Vessels, and to all Marine Scotland Fishery Offices.

Yours sincerely

H Tibbetts

Heather Tibbetts (Miss)
Licensing Policy Officer
Access to Sea Fisheries

Victoria Quay, Edinburgh EH6 6QQ
www.gov.scot/marinescotland

Appendix 5.

Map of individuals tagged inside and around the boundaries of the NTZ in 2017 recaptured by local fishers outside the reserve.