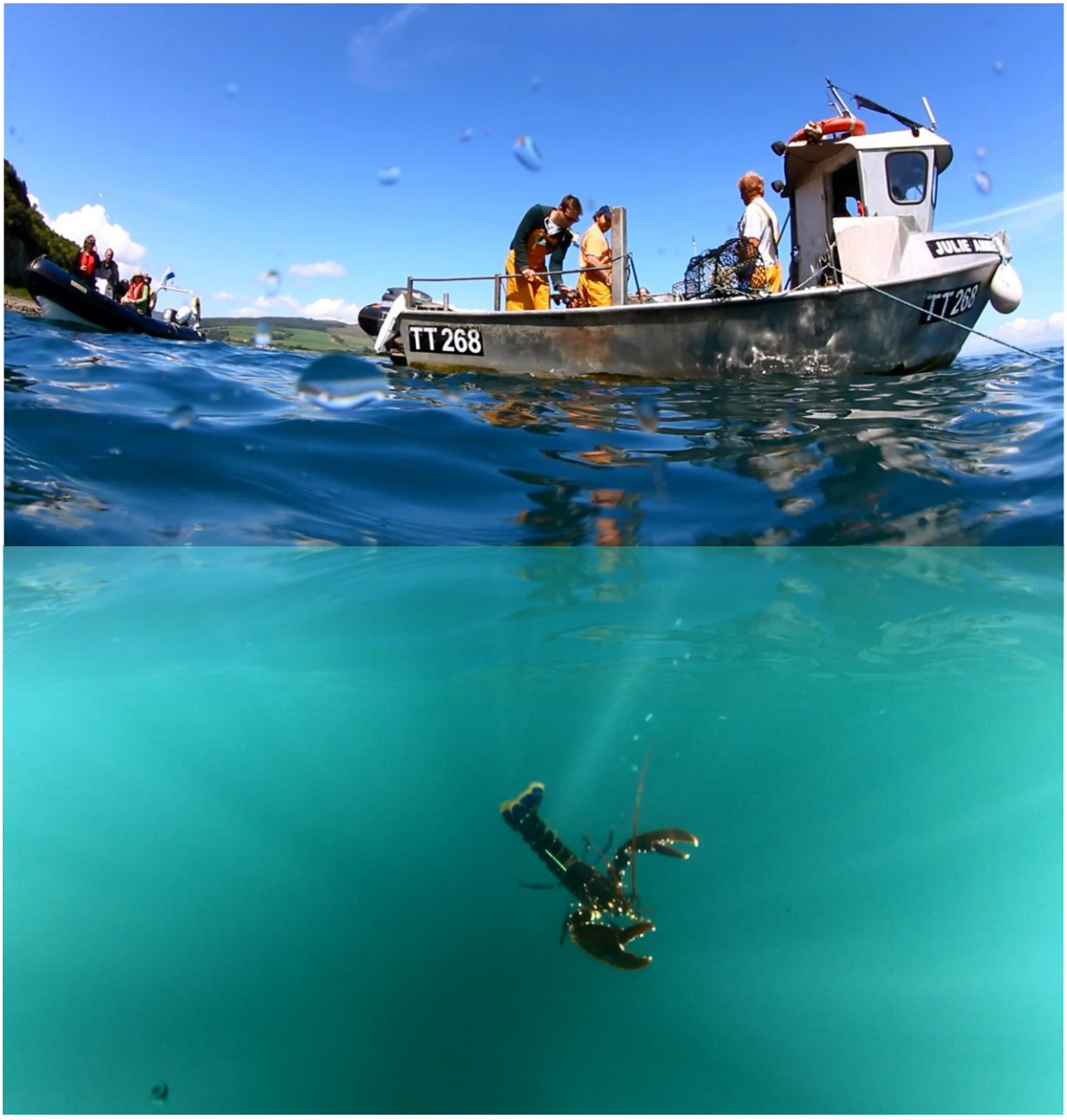
Response of decapod Crustaceans to protection within the Lamlash Bay No-take Zone, Scotland

Matthew Judge
MSc. Marine Environmental Management
Summer Placement Report
University of York
Community of Arran Seabed Trust

Word Count: 4982



Isle of Arran COAST
Community Of Arran Seabed Trust

Abstract

No-take zones are increasingly being used as a tool to address declining marine biodiversity and provide benefits to the fishing industry. This study investigates the response of three economically important decapod crustaceans: the European lobster, the brown crab and the velvet crab to protection within a small NTZ located in Lamlash Bay, on the Isle of Arran. Fishing observation surveys and targeting creeling took place over two months in the summer of 2014 - recording the abundance and characteristics of the target species as well recording the prevalence of damage and disease. Additionally a tag and release programme on the lobster took place during the targeted surveys to allow for continued analysis of population recovery, migration and growth rates. Following 6 years of protection, lobster appear to be showing classic signs of recovery. CPUE is around 44% greater within the NTZ than in fished areas nearby and a greater proportion of the protected individuals are of minimum landing size. Although there are significantly higher rate of damage on lobster within the NTZ, this indirectly provides evidence of population recovery.

There is some evidence of the NTZ providing benefits to the surrounding fishery, as CPUE decreases with distance from the NTZ; although the data is ambiguous under current statistical analysis .

The response of decapod Crustaceans to protection within the Lamlash Bay No-take Zone, Scotland

Introduction:

Biodiversity loss in the marine environment is being driven largely by anthropogenic-caused habitat degradation and direct species loss, of which overfishing is the greatest proximate cause (Jackson, 2008; Hoskin et al., 2011). Increasing demand for seafood products over the last 200 years has driven the significant intensification and diversification of fishing effort resulting in profound changes in marine ecosystems worldwide; including biodiversity loss, trophic cascades, habitat degradation and stock collapses (Jacquet & Pauly, 2007).

In the *Firth of Clyde* for example, ecological changes have occurred over the last two centuries that have led to major ecological meltdown and place the marine ecosystems in the *Clyde* near the endpoint of overfishing; the complete commercial extinction of marine species (Thurstan & Roberts, 2010)

Consequently, the use of Marine Protected Areas (MPAs) as a management tool has increased in recent years in a concerted and targeted attempt to reverse marine biodiversity loss, driven both by scientific consensus of the efficacy of MPAs and a legal framework for their designation under the Convention on Biological Diversity (Stewart et al., 2007; CBD, 2010) The governance of marine resources through the use of MPAs can be infinitely configured, but ranges from complete and open access to total prohibition of activity within an area (Mascia, 2004) . The various levels of protection from extractive activities afforded

by different configurations will have differing ecological benefits; with greater protection resulting in greater ecological benefits (Sciberras & Jenkins, 2013). The term 'No-Take Zone' (NTZ), therefore, refers to an MPA in which extractive activities are completely restricted within a defined area (Pomeroy et al., 2006). NTZs are known for their dual potential as conservation and fisheries management tools (NCEAS, 2001; Roberts et al. 2001; Sanchirico et al. 2005) and the strong body of empirical evidence that exists concludes that NTZs can deliver rapid and long-lasting benefits, including the enhancement of biomass and species density with zone boundaries (Guidetti et al., 2005), increased reproductive output (Goni et al., 2003), and the migration of species and larvae dispersal from within a reserve to adjacent areas (spillover) which may increase fisheries benefits in nearby areas (Gaines et al., 2010; Hoskin et al., 2011). However the ecological effects following NTZ designation may not be universally positive. The increasing density of species within NTZ may not always be advantageous, and may actually hinder certain conservation objectives, as classic epidemiological theory and empirical studies suggest that higher population densities will increase the prevalence and intensity of disease and damage (Kermack & McKendrick, 1927; Wootton et al., 2012). In the Lundy Marine Conservation Zone in southern England, increased population densities of the European lobster resulted in the increased prevalence of injury and shell disease (Wootton et al., 2012). Thus, it is important for rigorous evaluation of the ecological implications of no-take zones which would allow for cost-benefit reviews of marine reserves to occur (Wootton et al., 2012). However, no-take zones are often applied without sufficient and rigorous evaluation of their ecological implications (Edgar et al., 2004)**,** and testing the general hypothesis that exploited populations within a NTZ will experience positive changes compared to areas that are still fished is difficult without a testable priori hypothesis (Hoskin et al., 2011). The best surveys

compare a single marine protected area with multiple control sites, accounting for variation among places, and then comparing those sites multiple times before and after the anthropogenic impact, accounting for temporal variation (Underwood, 1994; Hoskin et al., 2011). However, the reason that many NTZ studies do not use this approach is because it is often not possible to assess the ecological conditions in a proposed NTZ prior to designation, as designation often outpaces the scientific and funding process (Hoskin et al., 2011). In the case where no 'before' data is available an asymmetrical post-impact field evaluation is a suitable alternative utilising multiple control sites to estimate 'before data' and account for temporal variation (Underwood, 1994; Queiroz et al., 2006; Hoskin et al., 2011).

This study therefore presents results from an asymmetrical post-impact field evaluation focussing on the response of three decapod crustacean species targeted by the commercial potting fishery in the *Firth of Clyde:* the Common lobster (*Homarus gammarus),* the brown crab (*Cancer pangarus),* and the velvet crab (*Necora puber),* to protection from fishing within, and in areas near, a NTZ established in Lamlash Bay on the Isle of Arran in 2008. This studies hypotheses comes from the general model that NTZs remove or reduce fishing mortality and fishing-related disturbances resulting in populations within NTZs thriving relative to those in places where fishing is on-going (NCEAS, 2001; Hoskin et al., 2011). Specifically this study hypothesises that the mean abundance of crustaceans will increase within the NTZ relative to fished areas and the mean size of crustaceans within the NTZ will increase relative to fished areas. A third hypothesis expects to demonstrate a spillover has occurred from the NTZ to nearby fished areas demonstrated by a decreasing catch per unit effort with distance from the NTZ**.** Additionally the study hypothesises that occurrence of

infectious disease and injury will be greater within the NTZ than in areas that are still being fished.

The fisheries for the common lobster, brown and velvet crab represents over a quarter of all UK shellfish despite the industry primarily existing on a part-time basis (McIntyre et al., 2012). Landings from the three species generated over £33 million in 2011 - £13 million from the common lobster, £14.2 million from the brown crab and £5.8 million from the velvet crab (Marine Scotland, 2013). All three species are currently experiencing overfishing to some degree within *the Clyde* (Figure 1). Lobster and brown crab, particularly males, are experiencing growth overfishing in most areas and the three species are currently being fished at levels significantly above $\mathbf{F}_{max}$ (Marine Scotland 2013; Figure 1)

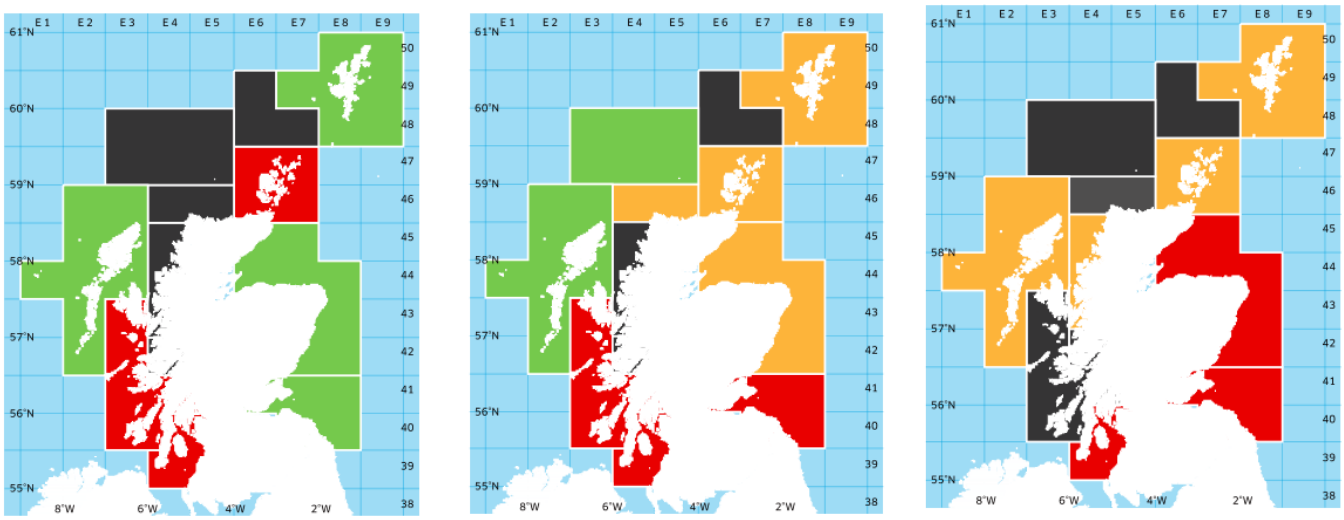


Figure 1 - Stock Assessments for velvet crab (left), lobster (centre) and brown crab (right) based on creel fishery mortality from 2006-2008. All three species are experiencing mortality above F_{max}, represented by red shading around the Firth of Clyde (southern most segment) (Marine Scotland, 2013)

While there is no great risk of stock collapse as stocks are currently stable (Royal Society of Edinburgh, 2004), continued high fishing effort combined with single or multiple stochastic events could feasible cause the loss of species, especially ones that are already being exploited beyond MSY (Jonzén et al., 2002; Poudel et al., 2012) . Considering the change in

trophic level in the *Firth of Clyde* over the last two centuries (Thurstan & Roberts, 2010), protecting crustacean species is especially important, both ecologically and economically**.** There is therefore a need for effective conservation measures to aid stock recovery and achieve sustainable exploitation of these species. The Lamlash Bay NTZ may therefore be a useful tool to help to preserve crustacean species if the NTZ is representative of habitats in an area and is large enough to cover the migration and home-range movement of the species (Ormond & Gore, 2005; OSPAR, 2010)

Methodology:

Site Location –

Lamlash Bay is an inlet located on the south-eastern shore of the Isle of Arran (Figure 2). A significant proportion of Lamlash Bay is protected from all extractive fishing activities, after designation of a NTZ within the bay, under the Inshore Fishing (Scotland) Act, 1984 in 2008 (Poulcott et al., 2012b). The NTZ covers 2.65 km^2 and was designed to protect a range of habitats and features, including maerl beds, rocky, muddy and sandy seabeds. Lobster habitat exists towards the south and north east ends of the NTZ (Poulcott et al., 2012a)

Surveys were carried out within the NTZ and in two additional control locations to represent near and far controls. The reference locations included three sites each (N1, N2, N3, and F1, F2, F3). The near control sites were located relatively close to the NTZ (<2.5 km) around the east and western coasts of Holy Isle, and north of Hamilton rock. The far control sites were

located between 5 and 12 km from the NTZ, primarily of the coast of Kildonan and around the island of Pladda. Compared to previous years there has been a reduction in the maximum distance of the far controls from the NTZ, due to a maintenance issue with the longer range fishing vessel (Kimberly OB345) which was commissioned in previous surveys. The reference locations represent similar lobster ground to those found within the NTZ and were actively and regularly fished by commercial creelers.

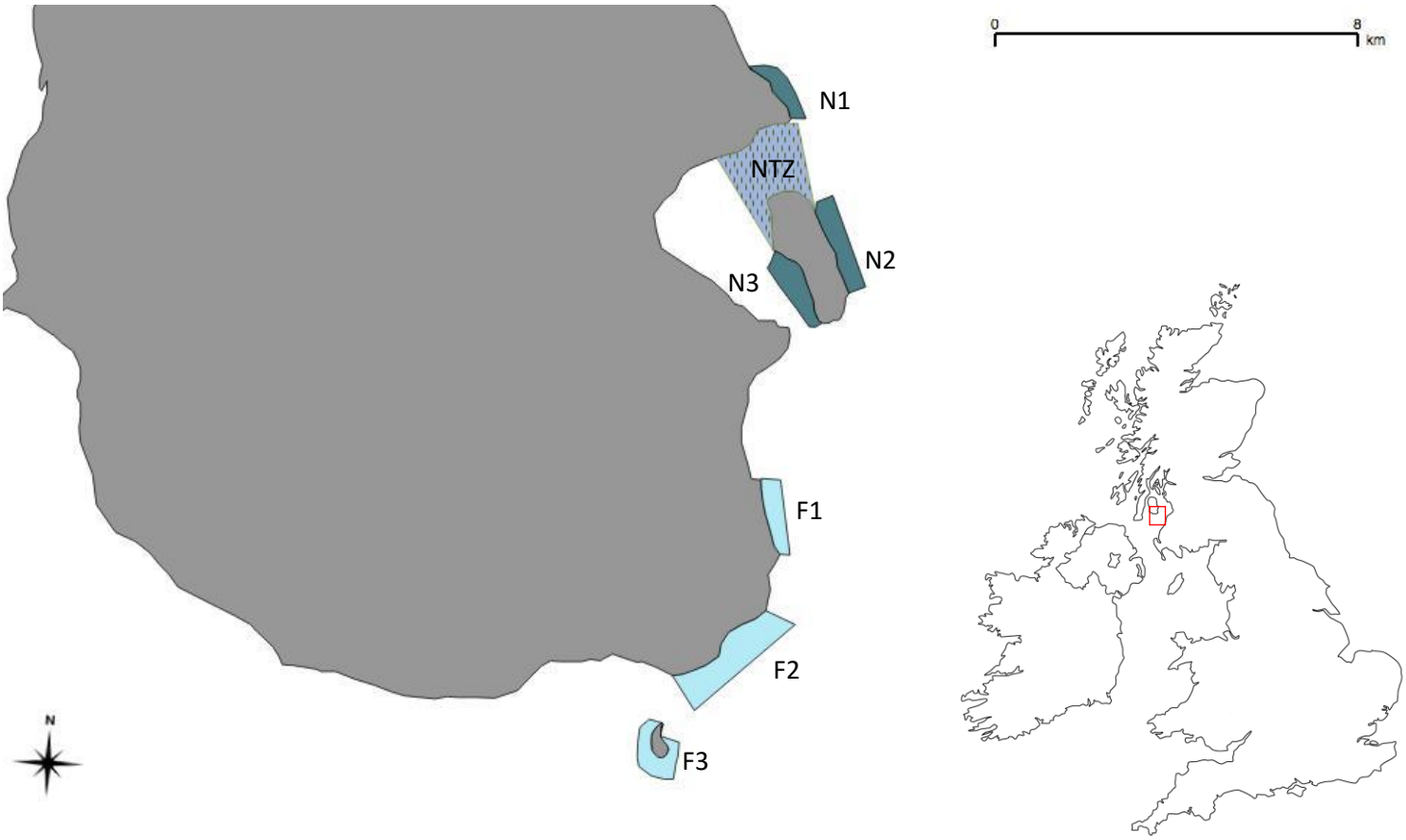


Figure 2 - The location of the near controls (N1-N3) and far controls (F1-F3) in relation to the Lamlash Bay no-take Zone (dotted area)

Data Collection:

Data was collected through passive observation and targeted pot sampling on board a commercial creeling vessel – the Julie-Anne TT268 inside and outside the NTZ throughout July and August 2014. The targeted fishing involved baiting, releasing and retrieving even

numbers of D-shaped creels within the NTZ and in adjacent waters (N1,N2,N3) for two one-week periods in July and August, while the observation sampling involves passively noting the catch landed by the commercial fishers throughout July and August, also from D-shaped creels. In the majority of targeted sample each string of creels was soaked for 48 hours except where bad weather limited creel retrieval, which happened once. For the observation surveys, creels were soaked for periods of 48-72 hours. For both targeted and observation surveys a mixture of bait was used at the discretion of the creelers, although the same bait was used between sites during the targeted surveys. Both varying bait and soak times are unlikely to significantly affect lobster catch rates (Montgomery, 2005).

During the targeted sampling 5 creels were used per string, but during the observation surveys the number of creels per string varied between 6 and 11. Consequently catch per unit effort (CPUE) measurements are based upon the average number of each crustacean species caught per creel, to overcome this discrepancy.

Recorded Variables:

Crustaceans

The abundance of individual species per creel, both the focus species in this survey and those caught as bycatch, were recorded during the targeted and observation surveys. During the target surveys each target species was sexed and measured to the nearest millimetre using a set of calipers. Lobsters were measured from behind the eye socket to the end of the carapace where the posterior edge meets the abdomen determining carapace length (CL), and the brown and velvet crab were measured at the widest point of the carapace. During observation surveys all lobsters caught were sexed and measured, but just legal sized (>140 mm) brown crabs were sexed and measured. Velvet crabs (not landed

by the Julie-Anne TT268) and juvenile brown crab abundance were recorded before they were returned to the sea.

For both surveys lobsters were checked for physical damage, presence of eggs (berries), and indications of disease. Where unique damage was identified a photograph was taken to aid later identification.

Environment

For each string of creels hauled aboard the vessel, both for targeted and observation surveys, environmental parameters were noted. The exact location of the string was recorded using the ship's on board GPS system, the depth where the first pot in each string was hauled, and the sea-surface temperature were also recorded using the *fishfinder* device on board the Julie-Anne.

Lobster Tagging:

During the targeted surveys all lobsters caught were fitted with a T-bar anchor tag in a continuation of the capture-mark-recapture study performed during these surveys since 2011. In Lobsters, the loss of tags is low compared to other species, and so tagging can be a reliable tool to aid with population assessment and estimation of movement and biomass recovery inside and outside a marine reserve (González-Vicente et al., 2012). Tags, which were coloured green for lobsters caught within the NTZ, and red for those caught outside included a unique identifying number and University of York contact information. They were inserted dorso-laterally in the abdominal muscle immediately behind the posterior edge of the carapace, with care taken to avoid puncturing the lobsters arteries and guts. After tagging, the lobsters were returned to the sea, with care taken to reduce the risk of immediate tag rejection (González-Vicente et al., 2012).

Statistical and Spatial Analysis:

Spatial analysis was performed on QGiS while all statistical tests were performed using R. Data was tested for normality using the Shapiro test and Levene's test was used to assess homogeneity of variance. The majority of the data breaks the assumptions for ANOVA testing (unequal sample size, normality and homogeneity of variance) and so non-parametric testing was primarily used. When distribution between assessed groups was visually similar Kruskal-Wallis testing was used. Post-hoc testing to identify where significant differences occurred was Pairwise Wilcoxon Rank Sum testing, with the "holm" corrector applied to take into account multiple comparisons (Planetary and Marine Computing, n.d.).

Results

Lobster:

CPUE within the NTZ was 43% higher than all areas outside (near and far control pooled) (unpaired t.test, p = 0.006) and CPUE variation between the near and far controls to the NTZ was small compared to the pooled dataset. CPUE within the NTZ was 43% and 42% higher than the near and far controls, respectively (Figure 3, ANOVA, p = 0.001). Post-hoc testing suggest a significant difference between the near and far controls compared to the NTZ but no statistical difference between the control sites (Tukey HSD, near/NTZ p = 0.003, far/NTS p = 0.001, far/near p =0.99)

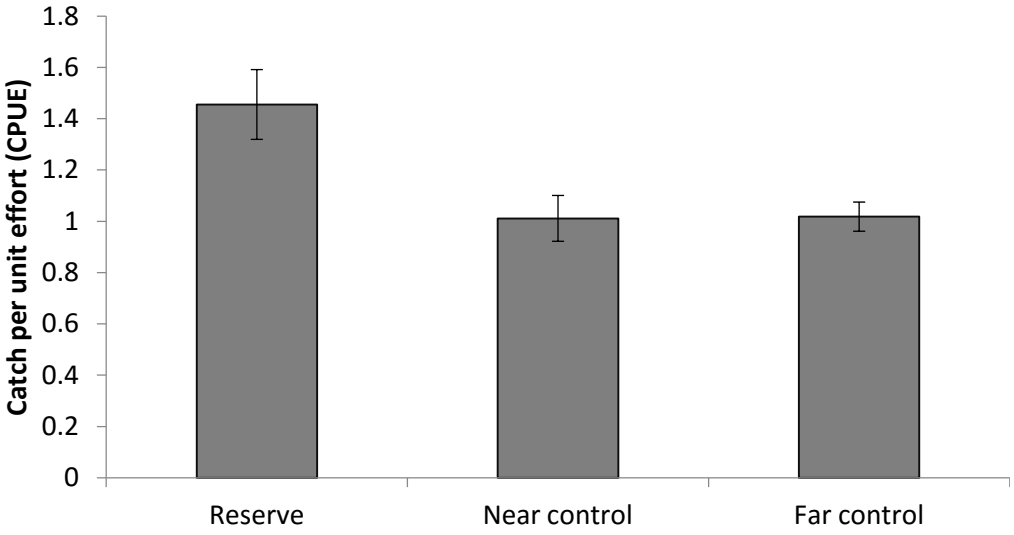


Figure 3 - Mean CPUE for all lobster in the NTZ, Near and Far Controls (± se)

CPUE for legal lobster (carapace length >87 mm) was 183% higher than all outside areas (Mann–Whitney U test, $p<0.0001$) but greater variation exists between the near and far controls sites and the NTZ when compared individually. Legal lobster CPUE within the NTZ compared to the near and far controls was 159%, and 189%, respectively (Kruskal-Wallis test, $p<0.00001$; figure 4). Post-hoc testing mirrored the result for all lobster; that statistical differences occur between the near and far sites and the NTZ, but not between the control sites (Pairwise Wilcoxon rank sum test, near/NTZ $p=0.0001$, far/NTZ $p< 0.00001$, far/near $p = 0.82$)

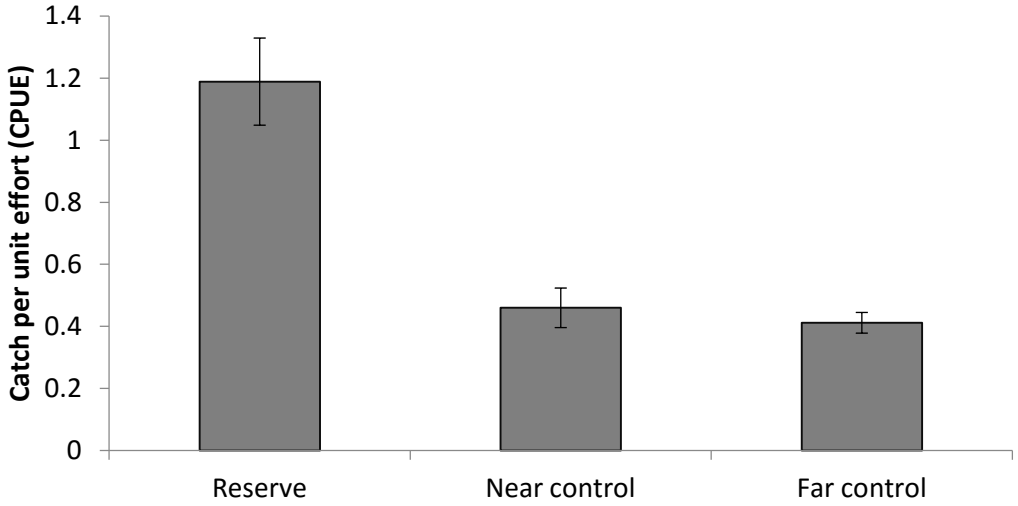


Figure 4 - Mean CPUE for legal lobster (carapace length >87 mm) for the NTZ, near and far controls (± se)

The mean carapace length of lobster within the NTZ was 96.55 mm, compared to 86.16 mm for the near control and 85.12 mm for the far control site. This represents an 8.8% difference between lobsters outside and inside the NTZ. The difference is significant (Kruskal-Wallis test, p =<0.0001) and once again the statistical difference occurs between both controls sites and the NTZ, but not between controls (Pairwise Wilcoxon rank sum test, near/NTZ p=<0.00001, far/NTZ p< 0.00001, far/near p = 0.11). In the NTZ a higher proportion of the lobsters caught were above minimum landing size (figure 4).

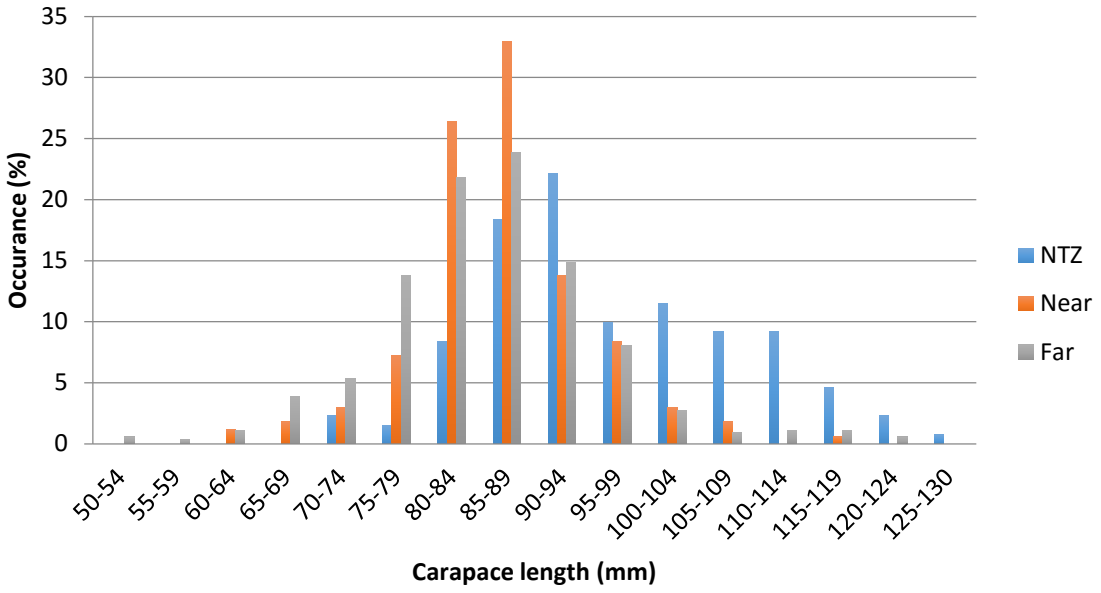
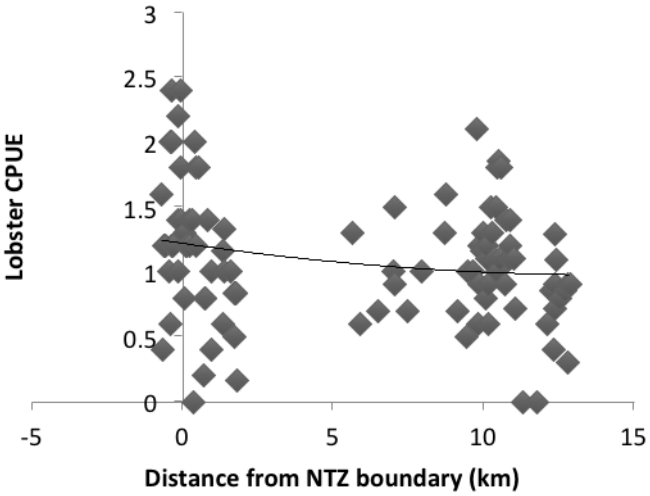


Figure 5 - The size distribution of lobster as a proportion of total catch in the NTZ (n=131), near control (n=167) and the far control (n =545), caught during targeted and observation surveys in July/August 2014.

82% of lobster caught within the NTZ were at a minimum landing size or greater whereas at the near control site 44% of lobsters caught were of legal size, and at the far control site 41% of the lobsters were of legal size. (see table A1)

Lobster CPUE including legal and sublegal lobsters demonstrates a significant yet moderate negative correlation with distance (Spearman's rank correlation, r = -0.272, p = 0.006; figure 5a). Within the NTZ, CPUE decreases with distance from the NTZ boundary, suggesting the highest CPUE effort within the NTZ is located nearer the boundaries of the zone, which is at odds with previous surveys in Lamlash Bay (Gratton, 2013). However the difference in CPUE with distance within the NTZ is not statistically significant (Spearman's rank correlation, r = 0.48, p =0.05, figure 5b)



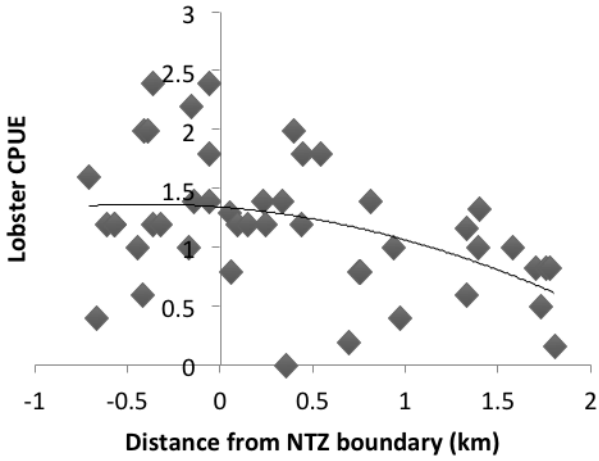


Figure 6a - CPUE for all sized lobster in the NTZ, near and far control sites, plotted against distance (km) from the NTZ boundary. Fitted with a polynomial regression curve (r^2 =0.046)
Figure 5b) CPUE for all sized lobster in the NTZ and near control sites, plotted against distance (km) from the NTZ boundary. Fitted with a polynomial regression curve (r^2 = 0.19)

For legal sized lobster CPUE there is a greater negative corrleation with distance than with all lobster sizes (Spearman's rank correlation, r = -0.359, p =0.0002; figure 6a). Within the NTZ CPUE of legal size lobster decreases with distance from the NTZ boundary, again

suggesting that the highest CPUE occurs near the boundary. However, as with all lobster CPUE, the difference was not statisfically significant (Spearman's rank correlation, r = 0.34, p = 0.15; figure 6b)

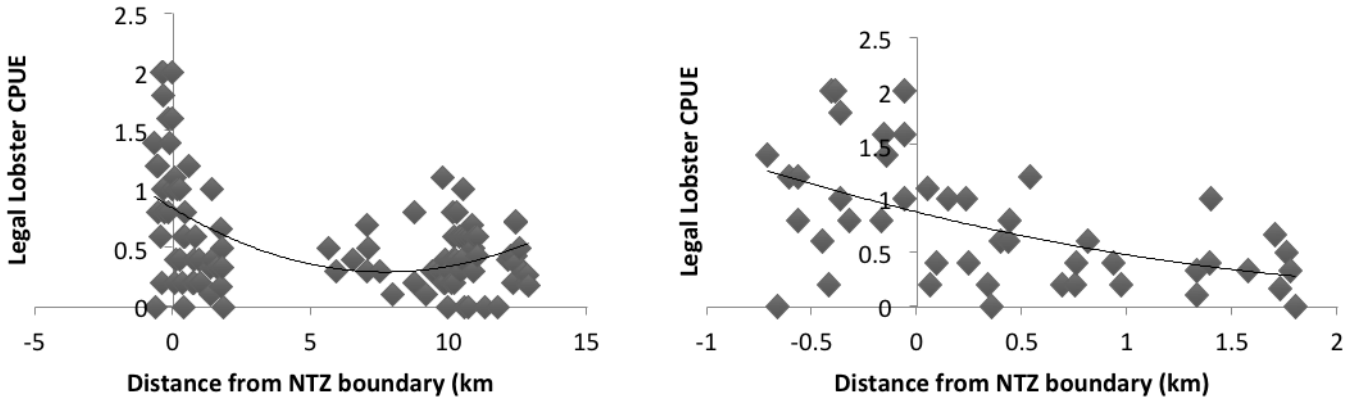


Figure 7a - CPUE for legal sized (carapace length >87 mm) lobster in the NTZ, near and far control sites, plotted against distance (km) from the NTZ boundary. Fitted with a polynomial regression curve (r^2 = 0.17)
Figure 6b – CPUE for legal sized (carapace length >87 mm) lobster in the NTZ and near control sites, plotted against (km) from the NTZ boundary. Fitted with a polynomial regression curve (r^2 = 0.28)

The mean size of lobster also shows a significant negative correlation with distance from the NTZ boundary (Spearman's rank correlation, r = -0.304, p= 0.0018; figure 7). Within the NTZ there is a negative, but insignificant correlation with distance from the NTZ boundary (Spearman's rank correlation, r = 0.199, p = 0.426). For additional results see Table A1.

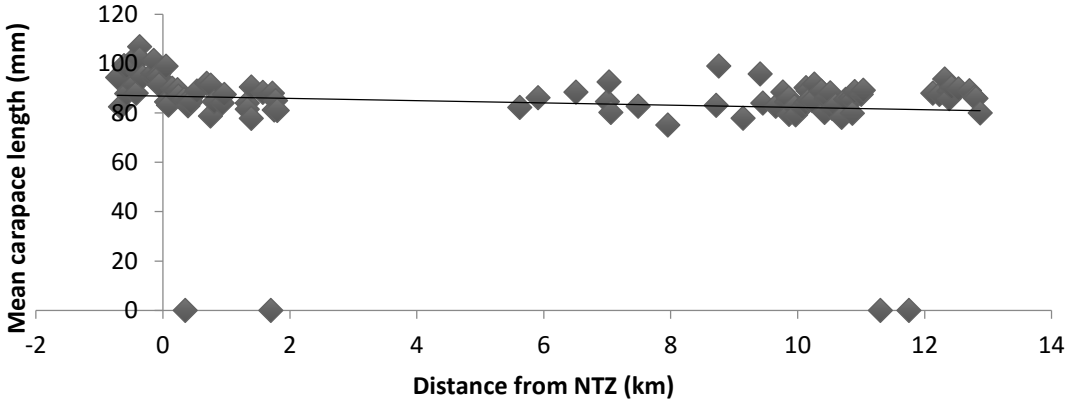


Figure 7 – Mean carapace length for all sized lobster, plotted against distance from the NTZ boundary (km). Fitted with a polynomial regression curve (r^2 = 0.01)

Brown crab:

The highest abundance of brown crab occurred in the far control site where mean CPUE was 114% higher than the NTZ, and 46% higher than the near control site (Kruskal-Wallis test, p = 0.01). Post hoc testing showed the difference between sites occurs significantly between the far control and NTZ only (Pairwise Wilcoxon rank sum test, near/NTZ p = 0.542, far/NTZ p = 0.037, near/far p = 0.08; figure 8)

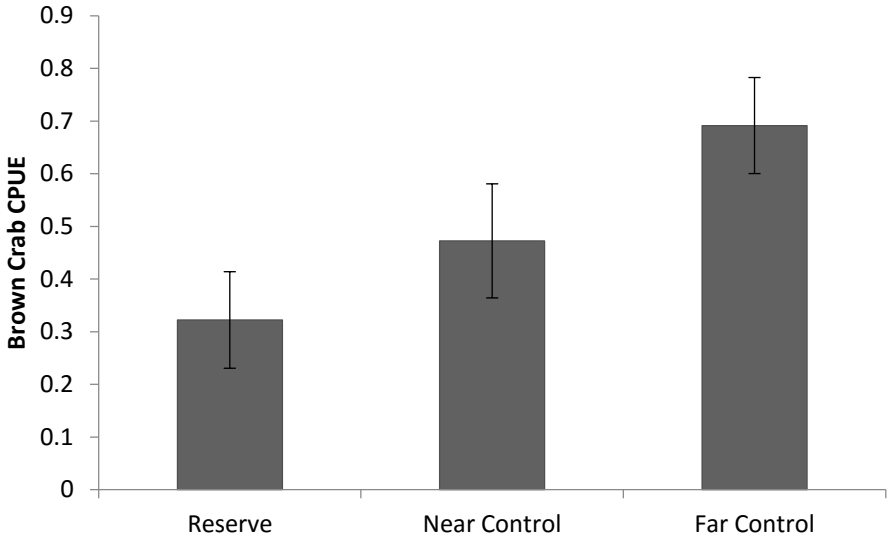


Figure 8 - Mean CPUE for brown crab in the NTZ, near and far control sites (± se)

Legal brown crab CPUE was also highest in the far control site, where mean CPUE was 202% higher than the NTZ and 71% higher than the near control sites (Kruskal-Wallis test, p = 0.01). Post hoc testing reveals statistical differences mirror those for all brown crab; that the difference is significant between the far control sites and the NTZ (Pairwise Wilcoxon rank sum test, near/NTZ p = 0.352, far/NTZ p = 0.017, far/near p = 0.119; figure 9).

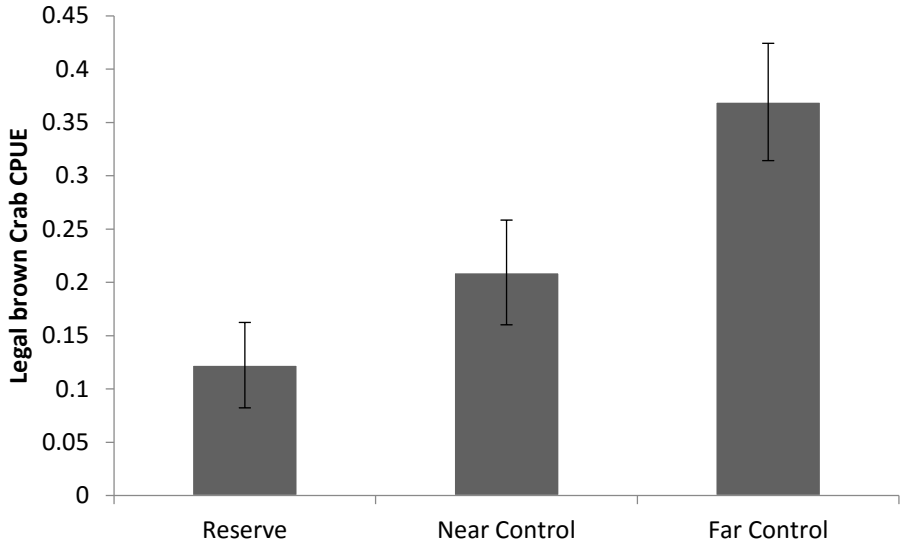


Figure 9 - Mean CPUE for legal sized (carapace length >140 mm) brown crab in the NTZ, near and far control sites (± se)

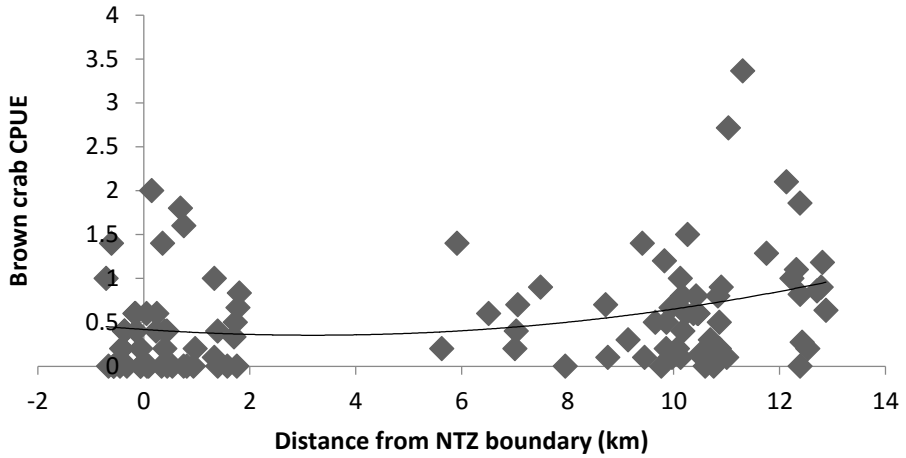


Figure 10 - CPUE for brown crab in the NTZ, near and far control sites, plotted against distance (km) from the NTZ boundary. Fitted with a polynomial regression curve (r^2 = 0.08)

Brown crab CPUE increases as distance from the NTZ increases (Spearman's rank correlation, r = -0.32, p = 0.001, figure 10

The mean size of brown crab was highest in the far control site, where the average carapace length of brown crab was 157.7 mm, compared to 137.5 mm in the near control site and 128 mm in the NTZ (Kruskal-Wallis test, p < 0.00001). Statistical differences occurred

between the NTZ and the far control site, and between the controls sites, but not between the near control and the NTZ (Pairwise Wilcoxon rank sum test, near/NTZ p =0.18, far/NTZ p< 0.00001, far/near p< 0.00001). For additional results see Table A2.

Velvet crab:

Velvet crab CPUE was 115% higher in the NTZ than in the near control site and 214% higher in the NTZ than in the far control site. However the difference in mean CPUE is not strongly statistically significant (Kruskal-Wallis test, p = 0.03). Post hoc testing reveals a mild statistical difference between the far control site and the NTZ only (Pairwise Wilcoxon rank sum test, near/NTZ p =0.178, far/NTZ p< 0.044, far/near p< 0.342; figure 11). With distance, velvet crab CPUE demonstrates a significant negative correlation (Spearman's rank correlation, r -0.28, p = 0.004, figure 12)

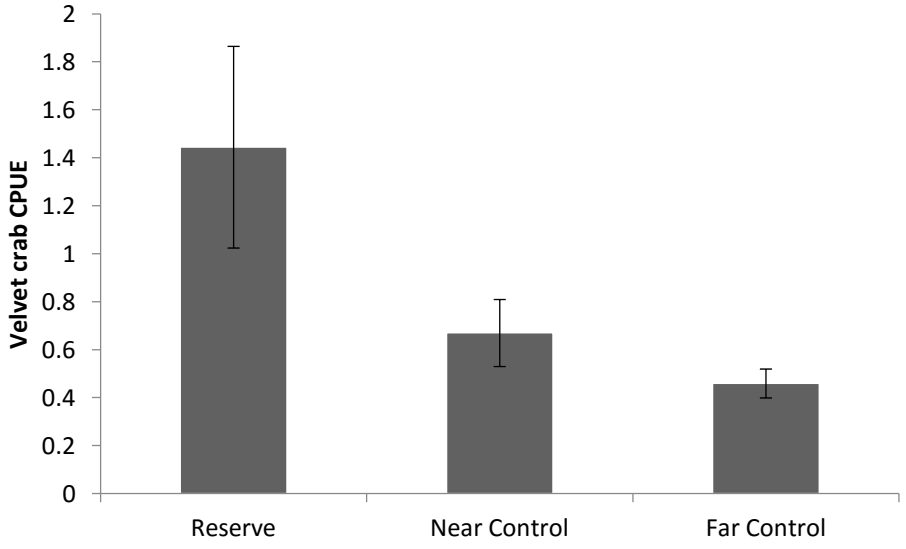


Figure 11 - Mean CPUE for velvet crab in the NTZ, near and far control sites (± se)

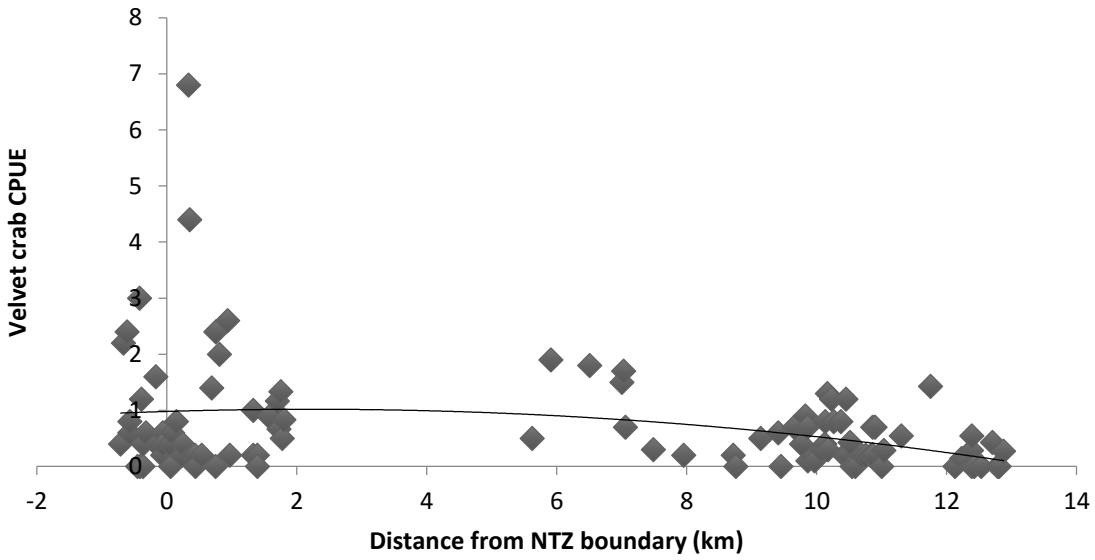


Figure 12 - CPUE for velvet crab in the NTZ, near and far control sites, plotted against distance (km) from the NTZ boundary. Fitted with a polynomial regression curve (r^2 = 0.09)

Comparison of the mean size of velvet crab are made using data from the targeted surveys only, as velvet crab were not measured during observation survey. Mean carapace length of velvet crab in the NTZ was 70.60 mm, compared to 66.68 mm for the near control site (Mann-Whitney-Wilcoxon Test, p>0.00001). For additional results see table A3.

Lobster health:

Berried females:

Berried females were 110% more prominent in the NTZ than in the near control site, and 188% higher than in the far control site, although the difference was not statistically significant (Fisher's exact test, p = 0.07)

Damage:

Grouping all incidences of physical damage on the body of the lobster, damage was 241% more prominent in the NTZ than in the near control zone and 336% more prominent than in the far control site (Fisher' exact test, $p>0.00001$)

Claw damage (including indents, cracks, missing parts etc.) was 350% more prominent in the NTZ than in the near control site, and 728% more prominent in the NTZ than in the far control zone (Fisher's exact test, $p<0.00001$)

Incidences of damage to the lobster's antennae (which includes both a missing or broken antennae) were 401% more prominent in the NTZ than in the near control site and 307% more prominent in the NTZ than in the far control site (Fisher's exact test, $p = 0.004$)

The presence of a regrown claw was 4.82% more prominent in the near control than the NTZ, and 443% more prominent in the near control than in the far control site (Fisher's exact test $p = 0.04$)

Only two incidences of carapace damage were recorded, one in the far control site, and one in the near control site

Disease:

One instance of disease was recorded during the survey, which was presence of low severity black lesions.

Tagging and recapture:

During the targeted surveys a total of 229 lobsters were tagged: 131 from the NTZ and 98 from the near control sites. During the two one-week targeted surveys 26 lobsters were recaptured: 17 from the 2013 surveys, 9 from this year's survey, and 1 from 2012. One lobster was recaptured twice, which results in a total recapture rate of 10.91%. Excluding lobsters that grew by ≤1 mm (possible human measurement error) 10 out of 26 lobsters experienced growth via moulting. The average growth of carapace was 11.8 mm or an average increase of 11.98%.

Two recaptured lobster moved from one 'zone' to the other; one moving a minimum of 527 m from outside the NTZ to inside the NTZ and the other moving outside the NTZ from inside (distance unknown). The minimum distance travelled by lobsters that were tagged and recaptured during the 2014 targeted surveys ranged from 55 m to 1.026 km. The average distance travelled for these recaptured lobster was 295 m. There was no significant difference between the average distance travelled by lobsters that were tagged in the NTZ (325.85 m) and in the near controls (233.33 m) (^1/4 transformed unpaired t.test p =0.62)

Response over time:

Lobster:

Analysis of both targeted and observation data taken over the last 4 years is not possible because of differences in methodology and the variation in location of the far control sites, so the following analysis is based on the targeted surveys only:

Total lobster CPUE in 2012 within the NTZ was not significantly higher than the CPUE in the near control site (unpaired t test, p = 0.92). In 2013 the CPUE in the NTZ increased by 25% over the 2012 average and was now significantly different from the CPUE in the near control site (unpaired t test, p =0.04). In 2014 the CPUE in the NTZ fell by 13% over the 2013 average and again the difference in CPUE inside and outside the NTZ was not significant (unpaired t.test, p = 0.056). Figure 13 shows CPUE in and outside the NTZ for all lobster, over the last 3 years where targeted surveys have taken place in Lamlash Bay.

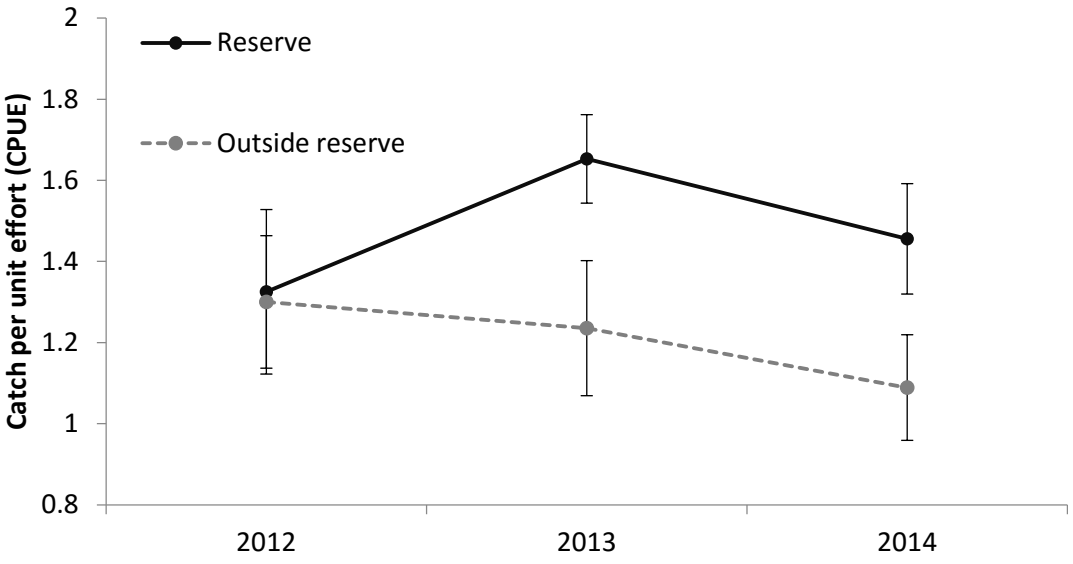


Figure 13 - CPUE for all sized lobster inside and outside the NTZ over time, based on targeted surveys only (± se)

A nested ANOVA test using the targeted survey data pooled for the last three years, in which protection was nested within the year, showed a significant difference between CPUE inside and outside the NTZ ("protection") but no significance difference between year or protection nested within year (Nested ANOVA, protection p = 0.026, year p =0.4228, year:protection p = 0.370)

For legal sized lobster in 2012 the CPUE within the NTZ was not significantly different to those outside (unpaired t.test p =0.668). In 2013 legal sized CPUE inside the NTZ increased by 33.9% over 2012. In 2013 the difference between CPUE inside and outside the NTZ was significant (Mann-Whitney-Wilcoxon test, p= 0.0008). In 2014 the legal sized CPUE within the NTZ increased by 7.6% over 2013. The difference between CPUE inside and outside the NTZ was statistically significant (Mann-Whitney-Wilcoxon test, p = 0.0005). Figure 14 shows CPUE inside and outside the NTZ for legal sized lobster, over the last three years when targeted surveys have taken place.

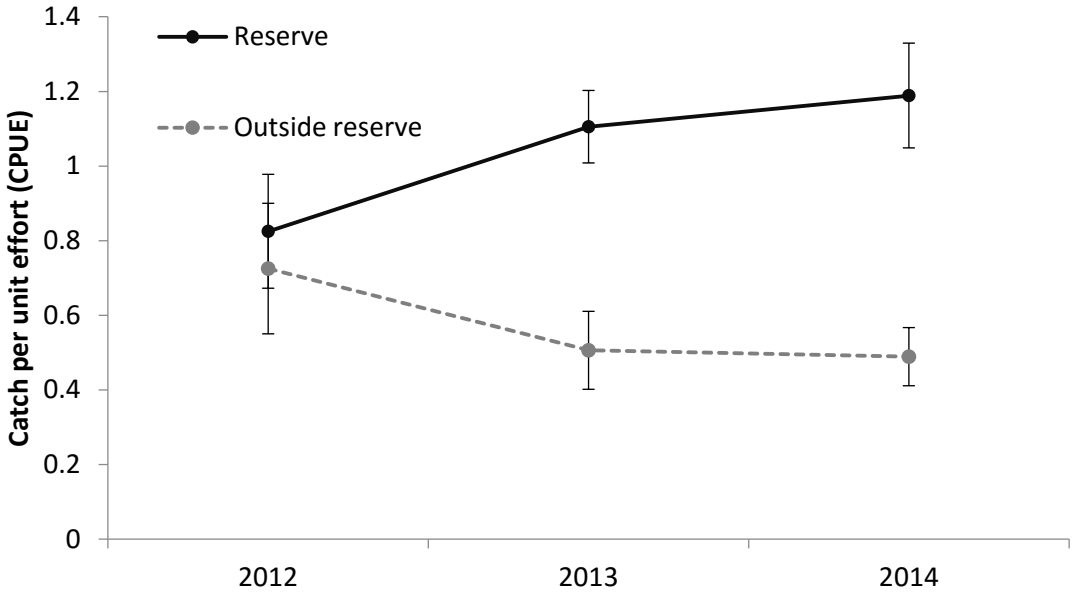


Figure 14 - CPUE for legal sized (carapace length > 87 mm) lobster inside and outside the NTZ over time, based on targeted surveys only (± se)

A nested ANOVA for legal sized lobster where protection was nested in year showed both a significant difference between CPUE for location and for protection nested within year (Nested ANOVA protection p< 0.00001, year p =0.875, year:protection p = 0.04) Post hoc testing showing the significance is shown in table 1.

Table 1 - Tukey HSD post-hoc significance results for legal sized lobster (carapace length >87 mm) for the NTZ and near control site. *(Significant results only)*

Year: protection	P value =
2014: NTZ – 2013:Outside	0.0028
2013:NTZ – 2014:Outside	0.0071
2014:NTZ – 2014:Outside	0.0017
2013:NTZ -2013:Outside	0.01

Discussion and conclusions:

Lobster:

Following the designation of Lamlash Bay as a no-take zone in 2008, lobster populations appear to be demonstrating a classic recovery response. Increased abundance of lobster, higher mean size, and a significant proportion of the population above legal landing size compared to fished areas lends further evidence to the scientific consensus regarding the efficacy of fully protected marine reserves to provide population benefits (Sciberras & Jenkins, 2013; Kelaher et al., 2014). This years survey results for lobster reaffirm previous work undertaken in Lamlash Bay NTZ (Howarth, 2010; Howarth, 2013; Gratton, 2013) and work undertaken in the Lundy Bay marine reserve (Hoskin et al., 2011; Wootton et al., 2012) showing that even small NTZ's can have benefits for European lobster. Hoskin et al., (2011) and Wootton et al., (2012) found a greater difference in lobster abundance between Lundy Bay NTZ and their control locations (500% and 771%, respectively) whereas in Lamlash Bay abundance within the NTZ has not been found to exceed 43% over control sites during

surveying undertaken since 2012. Control sites during this study had a significantly greater CPUE than the control sites used in the Lundy Bay study (1.11 compared to 0.017) which may suggest a more productive environment near Lamlash (Wootton et al., 2012)(Gratton, 2013). Mean size of lobster has been found to be increasing year on year in Lamlash Bay, and the change between 2014 and 2013 (96.54 mm from 92.31 mm) is significant. The high average size of lobster in the NTZ this year compared to the mean size in areas close by suggests that the lobsters in the NTZ are contributing most to the growth increase. The relatively short movement patterns found through the tagging and recapture of lobster and their known and observed growth rate means it is unlikely that individuals arriving from outside the NTZ are contributing to changes in size structure within NTZ (Bannister et al., 1994; Wootton et al., 2012).

Exploring the trend of lobster abundance over time, the picture of recovery is less clear. No significant difference is noted between CPUE in the NTZ over time, despite Gratton (2013) suggesting that the (non-significant) CPUE increase between 2013 and 2012 was due to continued occupation of vacant lobster territory. A major limitation of using targeted surveys with relatively low sample size for this type of comparison is that external factors, which may effect the outcome of sampling but not represent true population dynamics, can significantly alter results. This year during the second week of surveying in the NTZ several creels came back empty, which aroused the suspicion of creeler Iain Cossack who recognised the pattern of empty creels as evidence of illegal fishing/survey interference occurring within the NTZ. Unfortunately it is impossible to confirm or deny this theory. The presence of empty creels in the NTZ caused the decrease in CPUE noted in the NTZ this year but it is non significant . The non significance of changes or year means it cannot be said that at present there is *significant* evidence of increasing CPUE of over time. The

dataset including the observation studies produces significant results, but cannot be used to compare temporal patterns due to variation in study methodology year on year. The robust use of statistical analysis method asymmetrical ANOVA, for which the nested ANOVA used in this study is an early stage, is the next step for analysing multiple-year data of this type (R. Coleman; K.McGuinness, pers.comms., 2014).

CPUE decreases with distance for both lobster size classes (figure 5a;6a), which may suggest that spillover is occurring. Harmelin-Vivien et al., (2008) suggest spillover benefits occur at very small spatial ranges (100s of metres) and fished sites in Lamlash Bay < 500 m from the NTZ display higher CPUE than those > 500 km away (figure 5b;6b). Tagging and recapture surveys found low movement of tagged lobster from one zone to another, but the very small sample size means the tagging results are circumstantial at best. Based on our understanding of marine reserves spillover is likely to be occurring (Goñi et al., 2010), but more data needs to be gathered before reliable conclusions can be drawn.

Brown crab:

Following protection since 2008 brown crab within Lamlash Bay are less abundant and smaller than crabs found in the far control site. In post-impact assessments a far control site may be considered representative of your impact site prior to its impact, and so the far control site on Arran may indicate baseline conditions within the NTZ (Underwood, 1994; Hoskin et al., 2011) Based on this assumption it appears that Lamlash Bay NTZ provides no benefits for the brown crab. Possible explanations for this include the suppression of the

brown crab as a result of increased competition for habitat and resources (Hoskin et al., 2011) or more likely, that the high migration rate among brown crab renders the small size of Lamlash Bay NTZ ineffective at providing sufficient protection from fishing. Extensive tag and recapture data from a survey undertaken in Irish waters showed an average crab movement of between 1 -1.5 km per day (Tully et al., 2006) which supports this theory. However the disparity between the mean CPUE in the NTZ and the far control site is very high, and if we assume the NTZ has no effect on brown crab populations then the reason for this disparity is unclear.

Velvet crab:

Gratton (2013) found that the average CPUE of velvet crab in the NTZ was lower than in fished areas but this year's survey found a significant and dramatic increase in velvet crab CPUE within NTZ compared to adjacent areas. This raises question about the robustness of the survey design used in Lamlash. Asymmetrical assessment is a robust survey technique and when properly undertaken can provide unambiguous results, but relies on a careful design and consistency between years (Hoskin et al., 2011). The high standard error for velvet crab CPUE within the NTZ (figure 11) and the fact than CPUE varied between strings as much as 3300% demonstrates the importance of using the same control sites year on year. The variation between seabed habitats and depth difference for the location of pots placed in the NTZ are likely factors that explains the huge range in velvet crab CPUE (Norman & Jones, 1992; Freire & Gonzalez-Gurriaran, 1995).

Damage and disease:

In direct contrast to previous findings in Lamlash Bay (Gratton, 2013), there was an increased prevalence of bodily damage to lobsters within the NTZ. This confirms the

findings of Wootton et al., (2012), as well as epidemiological theory (Kermack & McKendrick, 1927) which would suggest that a greater lobster density would fuel increasing body-to-body conflict. Indirectly, this finding supports the growing body of evidence that lobster populations within Lamlash Bay NTZ are recovering.

Very low incidences of low-severity disease were recorded in the NTZ, and though prevalence is likely higher than identified in this study it is likely that the disease is currently conflicting minimal damage upon hosts (Wootton et al., 2012)

Acknowledgements:

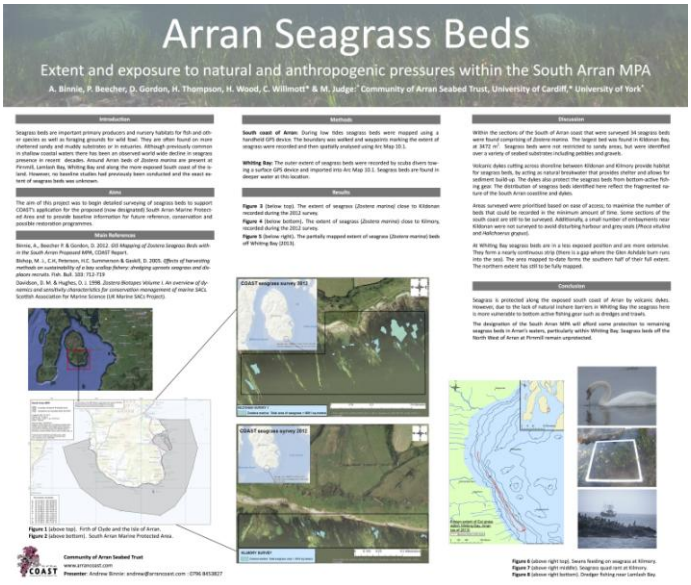
I would like to extend my deepest gratitude to Iain Cossack, and Tim James (Creelers) for their assistance and enthusiasm with these surveys, their friendly and welcoming attitude and their continued support over the years. Thank you also the Community of Arran Seabed Trust for providing local logistical support, providing me with accommodation and a joyful summer of hard work and hard play. Thank you to the Kilfinan Trust who helped via COAST to fund my research. Thanks for Bryce Stewart for his invaluable assistance and helping me 'learn the ropes', his friendship and his wisdom (and that one pint too!)

Additional work undertaken outside of placement:

While I was with COAST I spend the majority of my free time working full office hours. This involved a variety of work-based tasks, including general administration (emails, printing etc.) as well as more specific 'mini-projects'. Particularly memorable occasions include:

- Assisting with three shore and scramble days with COAST and the Scottish Natural Trust. This involved taking groups of adults and children around the local marine environment, explaining the new Marine Protected Area and NTZ to them, as well as guiding them on local marine biology as we explored the environment. My experience in this regard culminated with me solely representing COAST at one event toward the end of my stay.
- I also helped COAST/Revive the Clyde on several occasions at their publicity events. Primarily this involved me showing a lobster for children to hold and learn about, and engaging with the public.

- I also assisted with preparation for the Marine Protected Area celebration that took place on the 23rd August
- I produced and designed a poster for COAST, which was displayed at the International Marine Conservation Congress, based on a sea grass survey that COAST had been undertaking other the past year.



I produced a series of short web-based videos for COAST continued public outreach programme. They can be seen at youtube.com/arrancoast

Appendix:

Table A1 - Statistical analysis of lobster metrics in the NTZ, near control and far control sites.

Variable	NTZ (n = 131)	Near control (n=	Far control (n = 545)	Statistical Test	P
Mean CPUE	1.455	1.011	1.018	ANOVA	**0.001**
Mean legal CPUE	1.188	0.459	0.411	Kruskal-Wallis	**<0.00001**
Large lobster %	82%	44%	41%	Fisher's Exact Test	**<0.00001**
Mean Size (mm)	96.55	86.12	85.12	Kruskal - Wallis	**0.0001**
Male: Female	1:0.506	1:0.518	1:0.764	Fisher's Exact test	**0.02**
Berried population (%)	6.5%	3.08%	2.25%	Fisher's exact test	0.07

Table A2 - Statistical analysis of brown crab metrics in the NTZ, near control and far control sites.

Variable	NTZ (n = 33)	Near control (n= 59	Far control (n = 129)	Statistical Test	P
Mean CPUE	0.322	0.472	0.691	Kruskal-Wallis	**0.01**
Mean legal CPUE	0.122	0.209	0.369	Kruskal-Wallis	**0.01**
Large brown crab %	39.39%	52.54%	N/A	Fisher's Exact Test	0.563
Mean Size (mm)	128	137.5	157.7	Kruskal - Wallis	**< 0.0001**
Male: Female	1:0.737	1:0.844	1:0.613	Fisher's Exact test	0.89

Table A3 - Statistical analysis of velvet crab metrics in the NTZ, near control and far control sites.

Variable	NTZ (n = 98)	Near control (n= 94	Far control (n = 262)	Statistical Test	P
Mean CPUE	1.444	0.699	0.459	Kruskal-Wallis	**0.03**
Mean legal CPUE	0.122	0.209	N/A	Kruskal-Wallis	**0.01**
Large velvet crab %	91.8%	71.27%	N/A	Fisher's Exact Test	0.2805
Mean Size (mm)	70.60	66.68	N/A	Man-Whitney-Wilcoxon Test	**< 0.0001**
Male: Female	1:0.463	1:0.88	N/A	Fisher's Exact test	0.201

Table A4 - Statistical analysis of lobster health metrics in the NTZ, near control and far control sites

Location	Berried % (p=0.07)	Total damage % **(p<0.00001)**	Claw damage % **(p<0.00001)**	Antennae damage % **(p= 0.004)**	Regrown claw % **(p=0.04)**	Carapace damage % (p= 0.4)	Disease % N/A
NTZ (n = 131)	6.5	33.98	13.91	9.16	4.8	N/A	0.76
Near control (n =167)	3.08	9.86	3.08	1.82	5.03	0.59	N/A
Far control (n = 545)	2.25	7.70	1.69	2.25	0.92	0.18	N/A

References:

Bannister, R.C., Addison, J.. & Lovewell, S.R.J., 1994. Growth, movement, recapture-rate and survival of hatchery- reared lobsters (Homarus gammarus Linnaeus, 1758) released into the wild on the English east coast. *Crustaceana*, 67(2).

CBD, 2010. *Strategic Plan for Biodiversity 2011 – 2020 and the Aichi Targets*, Convention on Biological Diversity.

Edgar, G.J., Bustamante, R.H., Fariña, J.-M., Calvopiña, M., Martínez, C. & Toral-Granda, M.V., 2004. Bias in evaluating the effects of marine protected areas: the importance of baseline data for the Galapagos Marine Reserve. *Environmental Conservation*, 31(3), pp.212–218.

Freire, J. & Gonzalez-Gurriaran, E., 1995. Feeding ecology of the velvet swimming crab Necora puber in mussel raft areas of the Ria de Arousa (Galicia,NW Spain). *Oceanographic Literature Review*, 119, pp.139–154.

Gaines, S.D., Lester, S.E., Grorud-Colvert, K., Costello, C. & Pollnac, R., 2010. Evolving science of marine reserves: new developments and emerging research frontiers. *Proceedings of the National Academy of Sciences of the United States of America*, 107(43), pp.18251–5.

Goñi, R., Hilborn, R., Díaz, D., Mallol, S. & Adlerstein, S., 2010. Net contribution of spillover from a marine reserve to fishery catches. *Marine Ecology Progress Series*, 400, pp.233–243.

Goni, R., Quetglas, A. & Renones, O., 2003. Size at maturity, fecundity and reproductive potential of a protected population of the spiny lobster Palinurus elephas (Fabricius, 1787) from the western Mediterranean. *Marine Biology*, 143(3), pp.583–592.

González-Vicente, L., Díaz, D., Mallol, S. & Goñi, R., 2012. Tag loss in the lobster Palinurus elephas (Fabricius, 1787) and implications for population assessment with capture-mark-recapture methods. *Fisheries Research*, 129-130, pp.1–7.

Gratton, P., 2013. *The Recovery of Crustacean Populations in Lamlash Bay No-Take Zone , Scotland*, University of York.

Guidetti, P., Bussotti, S. & Boero, F., 2005. Evaluating the effects of protection on fish predators and sea urchins in shallow artificial rocky habitats: a case study in the northern Adriatic Sea. *Marine environmental research*, 59(4), pp.333–48.

Harmelin-Vivien, M., Ledireach, L., Bayle-sempere, J., Charbonnel, E., Garcia-charton, J., Ody, D., Perezruzafa, A., Renones, O., Sanchezjerez, P. & Valle, C., 2008. Gradients of abundance and biomass across reserve boundaries in six Mediterranean marine protected areas: Evidence of fish spillover? *Biological Conservation*, 141(7), pp.1829–1839.

Hoskin, M.G., Coleman, R. a., von Carlshausen, E. & Davis, C.M., 2011. Variable population responses by large decapod crustaceans to the establishment of a temperate marine no-take zone. *Canadian Journal of Fisheries and Aquatic Sciences*, 68(2), pp.185–200.

Howarth, L.., 2010. *Is there early evidence of the Lamlash Bay No Take Zone providing scallop fishery benefits ? Is there early evidence of the Lamlash Bay No Take Zone providing scallop fishery benefits?*, University of York.

Howarth, L.., 2013. *Summary of Research within Lamlash Bay No-take Zone*, Lamlash, Isle of Arran, University of York.

Jackson, J., 2008. Ecological extinction and evolution in the brave new ocean. *Proceedings of the National Academy of …*, 105, pp.11458–11465.

Jacquet, J.L. & Pauly, D., 2007. The rise of seafood awareness campaigns in an era of collapsing fisheries. *Marine Policy*, 31(3), pp.308–313.

Jonzén, N., Cardinale, M., Gårdmark, a, Arrhenius, F. & Lundberg, P., 2002. Risk of collapse in the eastern Baltic cod fishery. *Marine Ecology Progress Series*, 240, pp.225–233.

Kelaher, B.P., Coleman, M.A., Broad, A., Rees, M.J., Jordan, A. & Davis, A.R., 2014. Changes in fish assemblages following the establishment of a network of no-take marine reserves and partially-protected areas. *PLoS ONE*, 9.

Kermack, W.O. & McKendrick, a. G., 1927. A Contribution to the Mathematical Theory of Epidemics. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 115(772), pp.700–721.

Marine Scotland, 2013. *Fish and Shellfish Stocks (2013 Edition)*, Marine Scotland Science, Scottish Government

Mascia, M.B., 2004. Social Dimensions of Marine Reserves. In *Marine Reserves: A Guide to Science, Design and Use*. Island Press, pp. 164–186.

McIntyre, F., Ferdandes, P. & Turrell, W., 2012. Clyde Ecosystem Review. *Scottish Marine and Freshwater Science*, 3(3).

Montgomery, S.S., 2005. Effects of trap-shape, bait, and soak-time on sampling the eastern rock lobster, Jasus verreauxi. *New Zealand Journal of Marine and Freshwater Research*, 39(2), pp.353–363.

NCEAS, 2001. Scientific Consensus Statement on Marine Reserves and Protected Areas. *Annual Meeting of the American Association For the Advancement of the Sciences*. Available at: http://www.nceas.ucsb.edu/Consensus/consensus.pdf [Accessed August 11, 2014].

Norman, C. & Jones, M., 1992. Influence of Depth , Season and Moult Stage on the Diet of the Velvet Swimming Crab Necora puber (Brachyura , Portunidae). *Estuarine, Coastal and Shelf Science*, pp.4–5.

Ormond, R.F.. & Gore, M.., 2005. No-take zones: does behaviour matter? In *Aquatic telemetry: advances and applications. Proceedings of the Fifth Conference on Fish Telemetry held in Europe. Ustica, Italy, 9-13 June 2003.* Rome: FAO, pp. 9–13.

OSPAR, 2010. *Guidance on developing an ecologically coherent network of OSPAR Marine Protected Areas*,

Planetary and Marine Computing, Univariate, Non-parametric Statistics. Available at: http://www.pmc.ucsc.edu/~mclapham/Rtips/nonparametric.htm [Accessed August 5, 2014].

Pomeroy, R.S., Mascia, M. & Pollnac, R., 2006. Report and Documentation of the Expert Workshop on Marine Protected Areas and Fisheries Management: Review of Issues and Considerations. *FAO Fisheries Report*, 825, p.332.

Poudel, D., Sandal, L. & Kvamsdal, S., 2012. Analyzing Risk of Stock Collapse in a Fishery under Stochastic Profit Maximization. *NHH Dept. of Finance & …*, (April).

Poulcott, P., McLay, H., Allan, L. & Clarke, S., 2012a. Mapping of the marine habitats and species of Lamlash Bay , Arran. *Scottish Marine and Freshwater Science*, (400).

Poulcott, P., McLay, H., Allan, L. & Clarke, S., 2012b. Scallop Abundance in the Lamlash Bay No Take Zone: A Baseline Study. *Scottish Marine and Freshwater Science*, 3(7).

Queiroz, N.C., Lima, F.P., Ribeiro, P. a., Pereira, S.G. & Santos, A.M., 2006. Using Asymmetrical Designs for Environmental Impact Assessment of Unplanned Disturbances. *Hydrobiologia*, 555(1), pp.223–227.

Roberts, C.M., Bohnsack, J. a, Gell, F., Hawkins, J.P. & Goodridge, R., 2001. Effects of marine reserves on adjacent fisheries. *Science (New York, N.Y.)*, 294(5548), pp.1920–3.

Sanchirico, J.N., Hastings, A. & Wilen, J.E., 2005. *No-take Zones as Optimal Fishery Management*, Reykjavik, Iceland.

Sciberras, M. & Jenkins, S., 2013. Evaluating the biological effectiveness of fully and partially protected marine areas. *Environmental …*, 2(4), pp.1–31.

Stewart, R.R., Ball, I.R. & Possingham, H.P., 2007. The effect of incremental reserve design and changing reservation goals on the long-term efficiency of reserve systems. *Conservation biology : the journal of the Society for Conservation Biology*, 21(2), pp.346–54.

The Royal Society of Edinburgh, 2004. *Inquiry into the future of the Scottish Fishing Industry*, Edinburgh.

Thurstan, R.H. & Roberts, C.M., 2010. Ecological meltdown in the Firth of Clyde, Scotland: two centuries of change in a coastal marine ecosystem. *PloS one*, 5(7), p.e11767.

Tully, O., Robinson, M., Cosgrove, R., Keeffe, E.O., Doyle, O. & Lehane, B., 2006. The Brown Crab (Cancer pagurus L.) Fishery: Analysis of the resource in 2004-2005. *Fisheries Resource Series, Bord Iascaigh Mhara (Irish Sea Fisheries Board)*, 4(4).

Underwood, A.., 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. *Ecological applications*, 4(1).

Wootton, E.C., Woolmer, A.P., Vogan, C.L., Pope, E.C., Hamilton, K.M. & Rowley, A.F., 2012. Increased disease calls for a cost-benefits review of marine reserves. *PloS one*, 7(12), p.e51615.