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

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Declaration

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

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Date: 18/09/2017

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Abstract

The effect of marine reserves upon commercially exploited marine organisms is well documented. Increases in abundance and size have been attributed to the removal of mortality imposed by fishing. Such phenomena have been seen in the Lamlash Bay no-take zone on the Isle of Arran, the Firth of Clyde. The commercially important European lobster has responded to the presence of closed area, with increased population densities and individual sizes within its boundaries whilst spill-over has been outside. Tradeoffs have been shown to exist with decreases in brown crab presence and in perceived population health.

The aim of this investigation is to assess whether this is still continuing and how the magnitude of the effects compares to previous years. A survey conducted in controlled conditions was done over two 5 day periods July and August; a total of 90 creels were placed in the NTZ and areas outside in three locations within Lamlash Bay. Passive fishing observations of 855 creels was also done.

There was an increase of 13% in body length and 115% in catch rate in the Reserve compared to the Control. Increases of 219% and 15% were seen when comparing the Reserve against the passive fishing observations. This translated into 203% and 360% increases in biomass per creel in the Reserve against the Control and Observed series. These exceeded previous years, highlighting variability within the effect marine reserves have. The conclusion that the Lamlash Bay NTZ is boosting lobster biomass within its boundaries is extremely important in echoing the invaluable contribution of NTZs in restoring and enhancing commercially exploited invertebrate communities.

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Introduction

Closed area protection through marine reserves is an important part of modern fisheries management (Roberts et al., 2003). Their increased use reflects a change from single species or method targeting to an 'ecosystem-based management approach' (Pikitch et al., 2004; Leslie and McLeod, 2009). This allows a complete ecosystem to recover in isolation from environmental pressures (Roberts et al., 2003). Diffusion of biomass away from areas of high density within the reserve has been seen to help exploited communities recover beyond their boundaries (Beukers-Stewart et al., 2005; Stobart et al., 2009; Abesamis and Russ, 2005). They are economically advantageous, offering an insurance against failures in management through the creation of secure and plentiful stocks. This is more robust than a quota based approach, which runs the risk of miscalculation, or the prohibition of practices that may be weakened through political interference (Roberts et al., 2005). Whilst their use should be complemented by other conventional policy measures (Hilborn et al., 2004), they should form the basis of regional fisheries management.

Improved marine protection is required because of the global increase in the intensity and geographical range of marine fisheries (Pauly et al., 2005; Roberts, 2010; Worm et al., 2009). Reductions in biodiversity (Agardy, 2000), abundance (Jackson, 2001) and ecological resilience (Daskalov et al., 2007) have caused complete regime shifts characterised by the simplification and desertification of marine ecosystems.

The Firth of Clyde once supported a rich and diverse marine ecosystem, associated with the range of habitats (McIntyre et al., 2012) including mud, gravel and rock seabeds supporting maerl and seagrass beds (Baxter et al., 2011; Boyd, 1986). Historic overexploitation, together with a disregard for the level of mortality imposed by fishing efforts has resulted in the area being in 'ecological meltdown'. Ineffective management, particularly the removal of the inshore trawling ban in 1984, has been responsible for this decline. The range of productive pelagic fisheries has been replaced with the domination of Nephrops (*Nephrops norvegicus*) (Roberts and Thurstan, 2010).

Total landings of higher value crustacean species including Brown crab *(Cancer pagurus)* and European lobster *(Homarus gammarus)* have increased in the region over the last few decades (Roberts and Thurstan, 2010). They are caught on a smaller scale than mobile

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fisheries (Bjordal, 2002), using static-gear (SIFT, 2012). Through greater selectivity (Zhou et al., 2010), they are not as strongly associated with detrimental impacts upon the wider ecosystem (Chícharo and Gaspar, 2007; Howarth and Stewart, 2014). However, the majority of creel fisheries are operating above the maximum sustainable yield including that of Firth of Clyde. Whist not assessed for Brown crabs in the region, adjacent areas also showed similarly high levels of mortality (Barre and Bailey, 2015).

Concerns within the local community over the state and future of the regional marine environment led to the creation of a 2.6km^2 no-take zone (NTZ) within Lamlash Bay, the Isle of Arran (COAST, 2017). Greater recruitment in juvenile scallops (Howarth, 2010) as well benefiting benthic environmental algal complexity (Howarth et al., 2011) has been attributed to its presence. Annual surveys have also been carried out since 2012 on the population of European lobsters, Brown and Velvet crabs inside and outside the NTZ, compiled by Howarth et al. (2016). Frequent, comprehensive monitoring is needed to monitor the performance of the NTZ in meeting its goals. This can be used to justify its existence, and for adaptive and responsive mechanisms to be implemented (Chape et al., 2005; Watson et al., 2014).

Aims and objectives

The aim of this investigation is to observe whether the reserve is meeting its goals in boosting lobster and crab stocks inside its boundaries and outside through spill-over. This will be achieved by contrasting the density of crustacean populations and the size of individuals within the reserve compared with areas adjacent to it. These can then be compared to previous years to assess the temporal variation in the magnitude of its effect. Population composition and health within the reserve will also be compared. Spatial variation in catch rates will be used to show any spill-over.

The exclusion of fishing has been seen to cause an increase in lobster biomass through individuals being allowed to grow larger within denser communities (Hoskin et al.,2011; Moland et al., 2013; Huserbråten et al., 2013)., This has also been seen to increase rate of injury and disease (Davies, 2015). The displacement of smaller individuals outside of the reserve has also been observed (Huserbråten et al., 2013). It can be hypothesised that:

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- The population within the reserve will have a greater density of larger individuals.
- A greater frequency of injuries will be seen within the reserve.
- Larger catch rates will be seen closer to the boundaries of the reserve.

The effects of the reserve should be pronounced, particularly on lobsters. Their low mobility causes them to spend a greater time inside the reserves boundaries (Shears et al., 2006) a factor show to increase the response to closed area protection (Roberts et al., 2005)

It is harder to predict how this has changed over time. Although marine reserves have been seen to boost stocks over time, Howarth et al. (2016) observed large fluctuations in population density. This included two years of consecutive falls in catch rates both inside and outside the NTZ. Despite being the most recent series, 2015 saw the lowest perceived population density. This investigation should answer the question as to whether this fall is continuing, has stabilised or has since recovered.

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Methods

Study Site

Lamlash Bay is located on the Isle of Arran's east coast (Figure 1). It contains a 3x1km island named Holy Isle, expanding the spatial area of the nearshore areas, which are comprised of relatively complex, rocky and shallow benthic morphology fringing upon kelp. Steep changes of depth to areas of relatively flat seabed largely composed of fine mud beyond these areas (Axelsson et al., 2010).

Figure 1: *Lamlash Bay, Firth of Clyde. Marine reserve indicated through hashed area*

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The NTZ covers both these environments, existing between the northern shore of Holy Isle and the mainland of Arran, covering an area of 2.6km^2. Here any form of fishing has been excluded since 2008. The area was divided into four study sites (Figure 2):

1 – Control area to the north of the NTZ

2 –Control area east of Holy Island

3 – Control area west of Holy Island

4 – Reserve area inside NTZ

Observations made in the Control sites were compiled to give fair representation of the crustacean communities found in different areas around the bay.

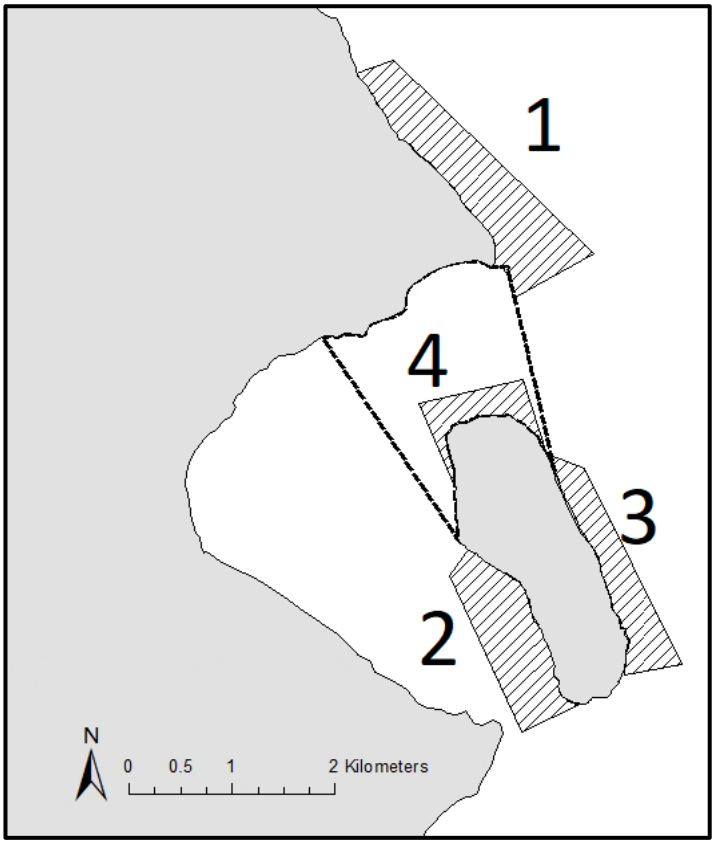

***Figure 2**: Study sites around Lamlash Bay*

Data collection

All data collection used fishing techniques aboard a local creeling vessel, the Julie Anne TT268. The investigation was divided into two sections. The first was a survey under controlled conditions. This directly contrasted the NTZ against the Control sites. Within each

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Control site, 3 strings of 5 creels were laid, 9 were placed inside the reserve. Creels used were D-shaped parlour creels, measuring 640x380x410mm with an opening of 210mmx180mm placed 10 fathoms (≈18m) with soak times ≈ 48 hours. Bait varied between salted mackerel and salmon. All individuals were returned unharmed. Due to variation in catch rates at different times of the year (Smith and Tremblay, 2003), the survey was repeated in the first week of July and August. Passive fishing observations done were also conducted aboard the Julie Anne during this time. This created three series of data: Reserve (inside the NTZ), Control (outside the NTZ) and Observed (obtained through passive fishing).

For the Observed series, factors shown to affect the success of fishing effort, including the number of creels per string, the dimensions of creels, bait and soak times (Bennet and Lovewell, 1977) differed from the controlled survey. However, it does increase the sample size and used to support any contrasts between the Reserve and Control. Tables 1 and 2 show the summary of the survey sample size.

Table 1: *Summary of crustacean sample*

Species	Number counted	Number measured
Brown crab	599	345
European lobster	806	806
Velvet crabs	784	122

Table 2 *Summary of survey effort*

Series	Strings	Creels
Reserve	18	90
Control	18	90
Observed	110	855

Explanation of measures

Size

The length of lobsters was measured with a caliper from the rear of the eye socket to the end of the base of the tail. The width at the widest part of the carapace was measured for

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crabs. Both were recorded in millimeters (mm). Weight was estimated using length-mass relationships, shown in Table 3.

Table 3: *Methodology for estimating individual crustacean mass (Leslie et al., 2004; Robinson et al., 2016).*

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

Legal landing sizes of 87mm and a width of 140mm and 65mm for Brown and Velvet crabs (ifca.gov.uk, 2017) were used. Due to the immediate discard of the majority of sublegal Brown crabs and all Velvet crabs, the Observed crab sizes cannot be used for comparison.

Population health dynamics

The condition of the crustaceans was assessed through observing any injuries or noticeable damage. The damage was quantified through a scoring system, used by Howarth et al. (2015), shown in Table 4. Scores were totaled and then presented as a percentage of the maximum score (36) for each individual.

Table 4: *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

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The sexes of the specimens were recorded as well as if the females were carrying eggs (berried). Fecundity was observed estimated through the length-egg output relationship shown in Figure 3.

$$\textit{Potential reproductive output} = (155.4 \times \textit{length}) - 10\,286$$

Figure 3: *Lobster length-egg output relationship (Lizarraga-Cubedo et al, 2003).*

Catch rate

Several different measures of catch rate were used (Table 5). The unit effort is the number of creels present on the string. Catch rate was the average for each string, rather than treating each creel independently as creels on the same string have been shown to influence one another. CPUE and WPUE present the density of individuals and biomass. VPUE was calculated through apply legal crustacean mass to market rates (Table 6).

Table 5*: Measures of catch rate*

Catch 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
Value per unit effort (VPUE) $£^{-1}$	(Total mass of legal sized target organisms x market value) ÷ number of creels

Table 6*: Market rates received (I.Cossack, Perrs Comms, 2017)*

Target species	Price
Brown crab	£4.50/kg
European Lobster	£12.0/kg

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Spatial analysis

The ArcMap 10.5 'cost distance analysis' tool was used to calculate the proximity from the first mark buoy of a string to nearest edge of the NTZ. This returned the minimum travel path in meters; exclusive underwater areas represented by a 5x5m raster grid. Catch rate and lobster size were treated per string rather than per creel.

Statistical analysis

Each qualitative variable (size, weight, potential fecundity, distance to the NTZ, damage scores and catch rates) was tested for normality through Kolmogorov-Smirnov tests to a significance of $p \geq 0.05$. This determined the selection of parametric and non-parametric analysis.

Independent samples T-tests, with Lavene's Equality of Variances adjustment, were used to compare two series of values when normally distributed. Mann-Whitney U-tests were used for non-normal series. Two-way Analysis of Variance (ANOVAs) were used to compare treatment years. To compare categorical variables, Pearson's Chi-square test was used. K-S tests were also used to compare the distribution of variables with the composition of samples.

To analyse relationships between distance variables, a combination of Spearman's Rank and Poisson General Linear Models (GLMs) was used. When creating the GLMs, variables were checked for intercorrelation, (VIF) >2. Stepwise reduction then determined the minimum adequate model. Loss of deviance from the original model was checked using ANOVAs and overdispersion of the Residual deviance <1.5 x degrees of freedom.

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Results

Crustacean population density

The mean CPUE, representing contrasts in population density of the NTZ, Control and Observed series is shown in Figure 4.

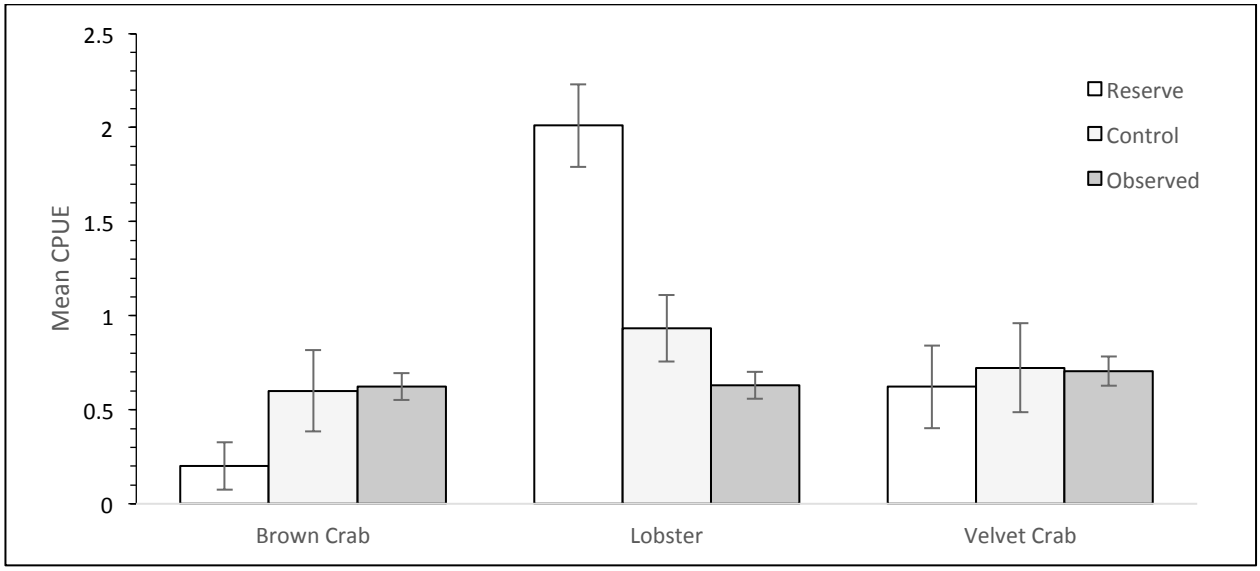

Figure 4: *Mean CPUE of crustaceans among sites and recorded during passive fishing observations (95CI).*

The CPUE of lobsters was greater inside the NTZ whilst a decrease is observed in Brown crabs and very little difference for Velvet crabs - as such no further analysis was performed. As all data was non-normally distributed, Mann-Whitney U-tests were used to compare these differences. The increase in Lobster CPUE inside the Reserve was significantly greater than in the Control (U=1824, Z=-6.62, p<.001) and the Observed (U=39.5, Z=-6.53, p<.001). With brown crabs the decrease within the Reserve was significant compared with the Control (U=77,Z=-2.76, p=.006) and Observed (U=294, Z=-4.36, p<.001).

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Individual crustacean size

The mean individual sizes of crustaceans are shown in Figure 5.

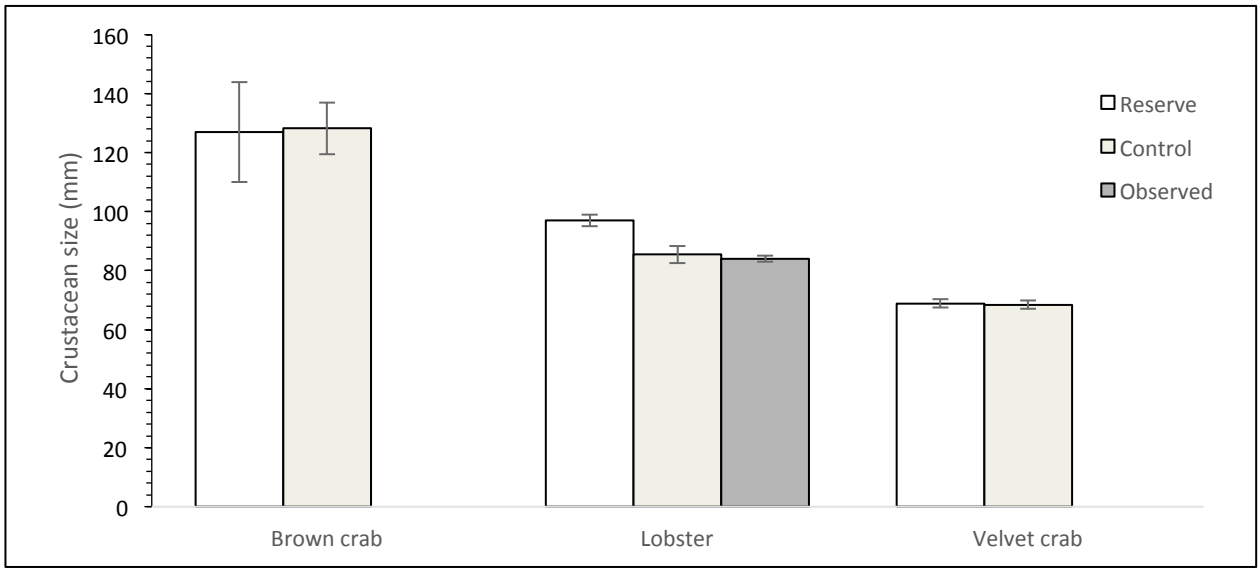

Figure 5: *Mean crustacean body sizes among sites and recorded during passive fishing observations (95CI)*

Lobsters were larger inside the Reserve compared with the Control and Observed series. The difference in crab size appears marginal and therefore will not be analysed further. Mann-Whitney U tests were used to compare mean lobster sizes as the data was non-normally distributed. The mean lobster size within the Reserve was shown to significantly greater than the Control (U=918, Z=-5.29, p<.001) and the Observed (U=1835, Z=-10.9, p<.001).

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The distribution of crustacean size in each series is shown in Figure 6. For lobsters, there was greater bias for larger individuals inside the NTZ, by 34% compared to the Control and 48.9% compared to the Observed. Two-sample K-S tests were conducted for the comparisons. Table 7 shows the difference in lobster size distribution be significant. Both species of crabs did not show significant differences in size between sites.

Table 7: *Results of K-S test on the individual size composition of crustaceans with each series*

Comparison	n	D	Z	p
Brown crabs: NTZ-Control	21:55	.118	.459	.984
Lobsters: NTZ-Control	182:82	.392	2.98	<.001
Lobsters: NTZ-Observed	182:537	.419	4.89	<.001
Velvet crabs: NTZ-Control	64:58	.135	.746	.634

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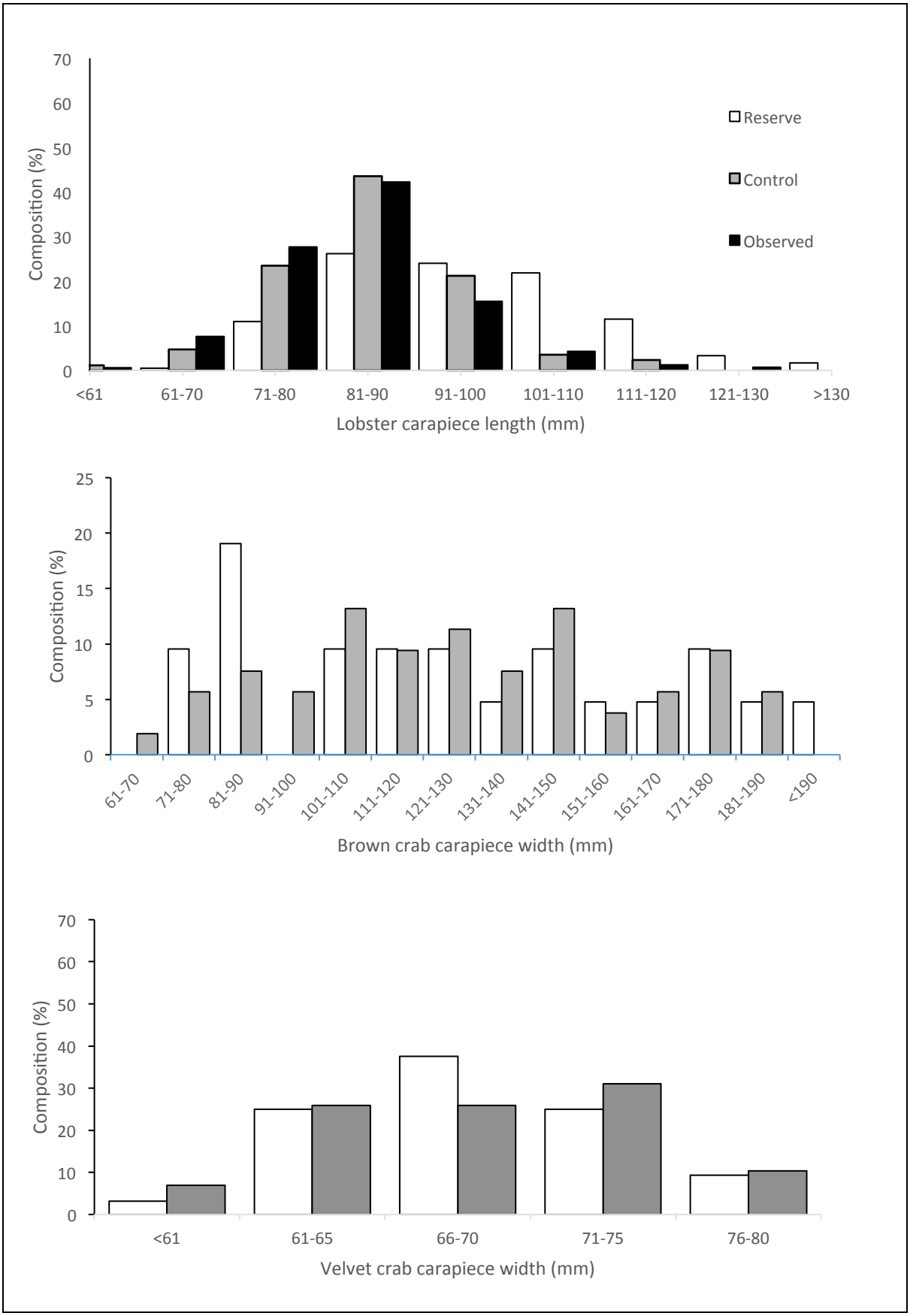

Figure 6: *Size compositions of Lobsters, Brown and Velvet Crabs among sites and recorded during passive fishing observations*

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Density of crustacean biomass

The use of WPUE aimed to assess how the combination of varying population densities and individual size affects the density of biomass present. Figures 7 show mean WPUE for all and legal crustaceans. Greater catch rates and sizes are resulting in an increase in overall lobster biomass and the quantity being recruited into the fishery.

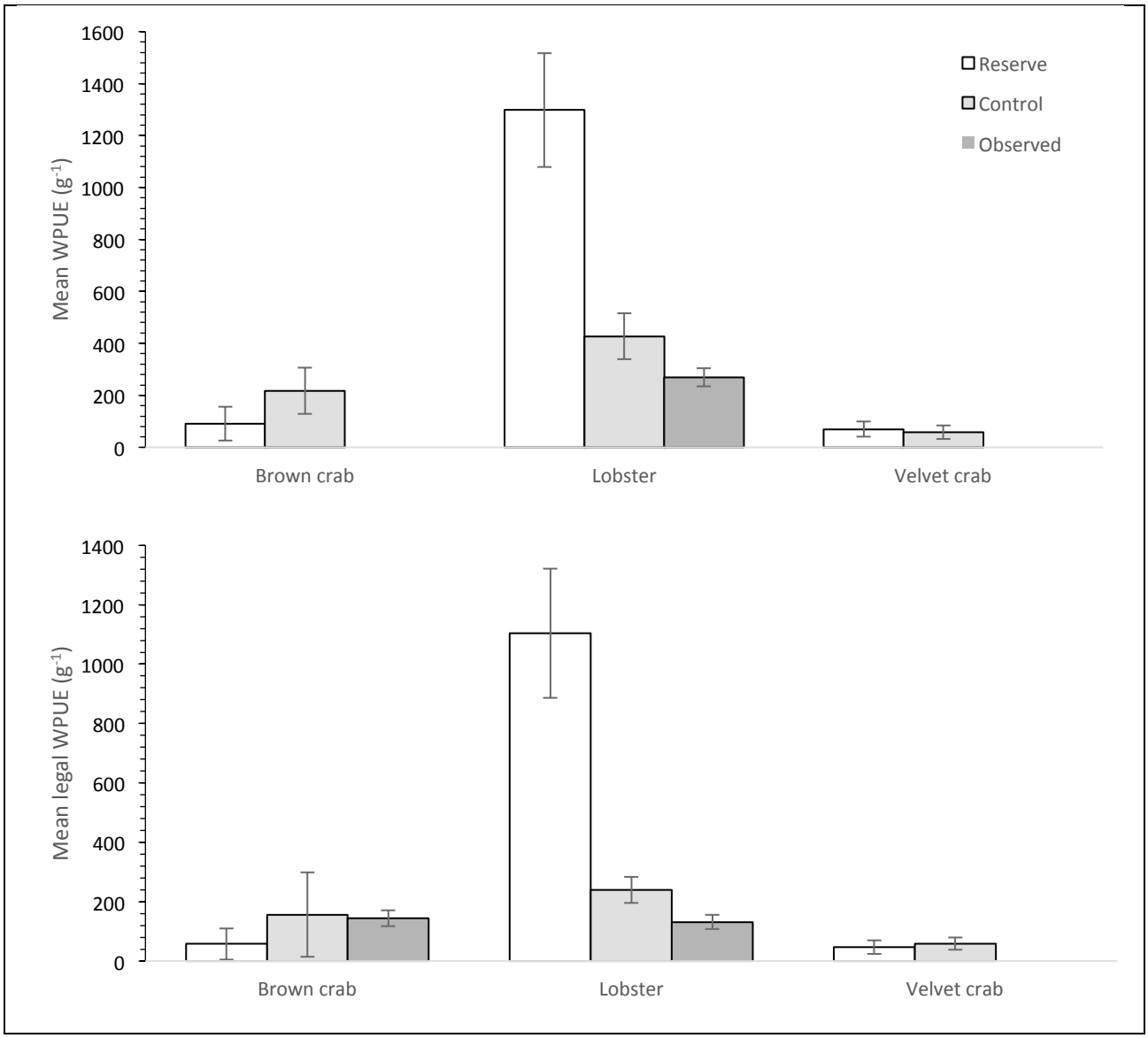

Figure 7: *Mean crustacean (top) and legal crustacean (bottom) WPUE recorded inside the NTZ, Control and recorded through passive fishing observations (95CI).*

After being found normally distributed, the increase in lobster WPUE was shown to be significant through an Independent Samples T-test (t=-7.29(22.4), p<.001). The difference within Velvet crabs was non-significant (t=.631(34), p=.532). With non-normal distributed

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series Mann- Whitney U tests were used. The difference in lobster WPUE between the Reserve and Observed series was significant (*U*=60.0, *Z*=-6.42, *p*=<.001). The decrease in Brown crabs between the Reserve and Control sites was found to be significant (*U*=99.0, *Z*= -2.02, *p*=.045). Despite the tradeoff in biomass between species, creels in the NTZ had much greater cumulative economic value, shown in Figure 8.

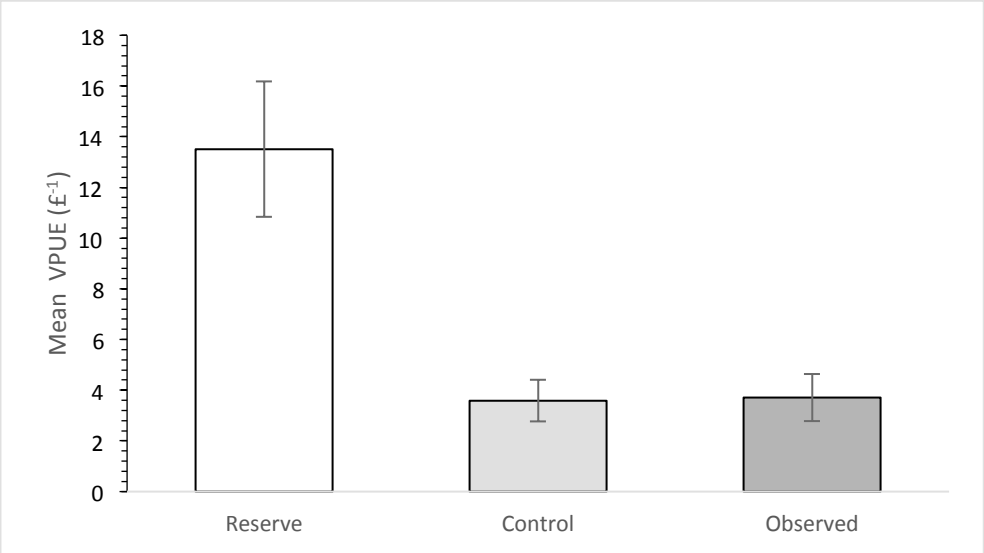

Figure 8 *Mean cumulative lobster and brown crab value within each creel placed in the Reserve and Control as well as passive fishing observations (95cl).*

Lobster population composition and health

A greater proportion of lobsters inside Reserve and Control were found to be male, 61.9% and 68.5% respectively. Chi-square analysis found site had no significant bearing upon sex composition (X^2=1.01(1), *p*=.315).

Within the female population, 23.2% inside the NTZ and 18.5% in the Control Sites were seen to be currently or had recently been berried. Chi-square analysis showed this to not be significantly influenced by being present within the NTZ compared with Control sites (X^2= .248(1), *p*=.619).

The individual potential egg output for females among sites saw a mean increase of 139% and 144% inside the NTZ (4730 (SE=206)) compared with the Control (3395 (SE=270)) and Observed (3278 SE=136)). An Independent Samples T-test found the increase between the Reserve and Control sites to be significant *(t*=3.595, *p*=.001). A Mann-Whitney U-test also

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found the increase inside the NTZ compared with the Observed to be significant (U=2508, Z=-6.04, p=<.001) after non-normal distribution was established .

A greater proportion of lobsters within the NTZ (33.0%) compared with the Control (20.2%) showed signs of injuries. Chi-square analysis showed this increase to be significant (X^2=4.969(1), p=.026). The mean damage (%) inside the NTZ was 2.47 (SE=.314) and 1.55 (SE=.375) in the Control. A Mann-Whitney U found this difference to be significant (U=6838, Z=-2.10, p=.036) after found to be non-normally distributed.

Comparison with past time series

Changes in the perceived population density, represented by CPUE, and the individual crustacean size are shown in Figure 8. There are large fluctuations in catch rates between years in all species, with a negative relationship between Brown crabs and lobsters.

Three two-way ANOVAs were conducted on the WPUE per year and site for lobsters (Table 8) to show how this variation affected suggested biomass density. Significant differences were year and site. Treatment year shown have a greater influence than location only for sub-legal lobsters.

Table 8: *Two-way ANOVAs conducted on lobster WPUE between years and sites.*
** - significant*

Size Class	Factor	F(df)	p
All	Year	6.02(4)	>.001*
All	Site	65.0(1)	>.001*
All	Year + Site	4.56 (4)	.002*
Legal	Year	3.10(4)	>.017*
Legal	Site	77.1(1)	>.001*
Legal	Year + Site	5.44(4)	>.001*
Sublegal	Year	7.36(4)	>.001*
Sublegal	Site	.690(1)	.407
Sublegal	Year + Site	1.17(4)	.327

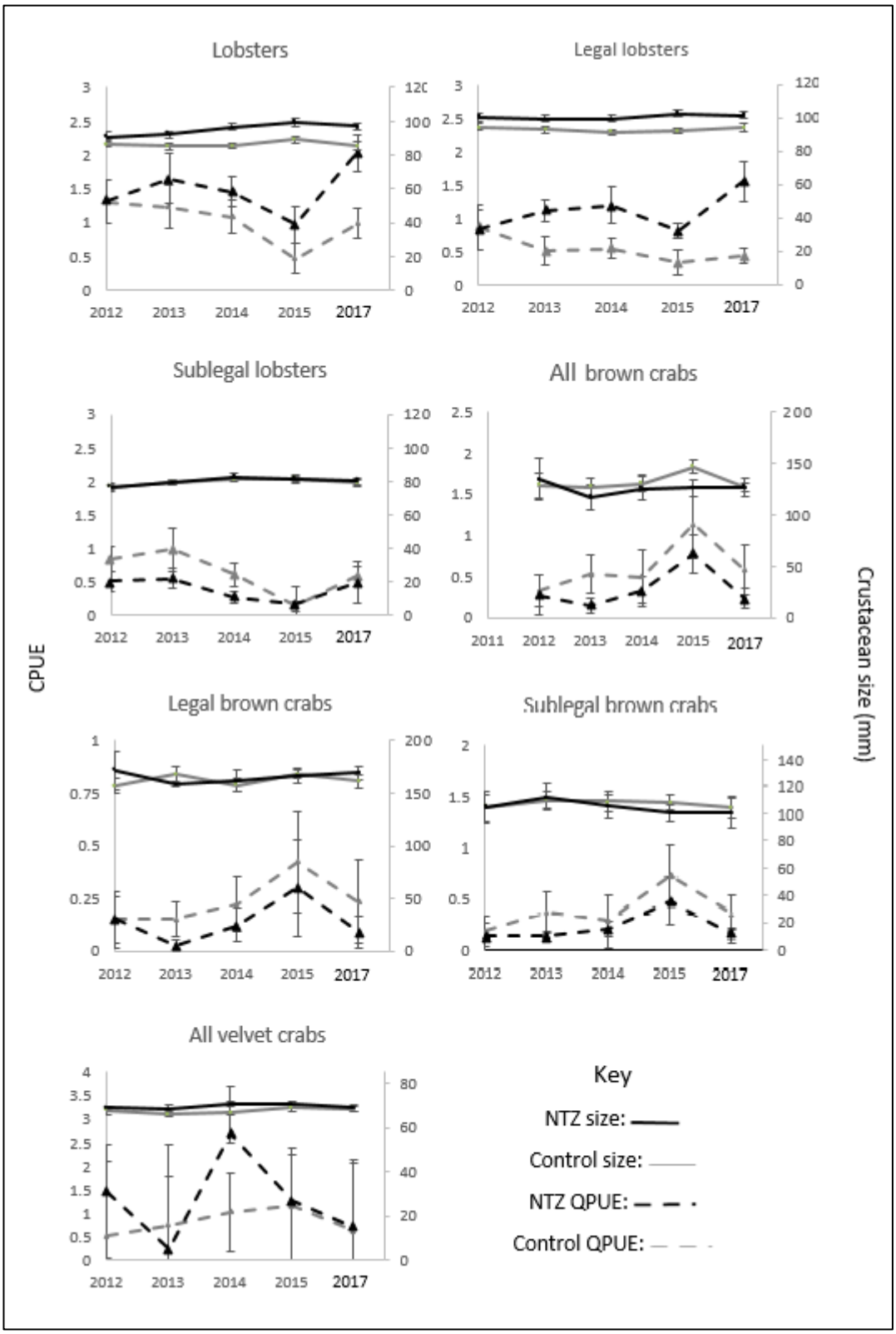

Figure 8: *Temporal variation in crustacean catch rates and individual sizes inside and outside the Lamlash Bay NTZ between the years 2012,2013,2014,2015,2017 (95cl).*

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Spill-over into surrounding areas

The influence of the proximity to the Reserve within individual lobster size is shown in Figure 9. A Spearmans Rank Test showed a significant negative (N=806, r_s=-.342, *p*>.001). When removing specimens found within the NTZ (represented by as 0 distance), the negative relationship was still signficant (N=619, r_s=-.114, *p*=.002).

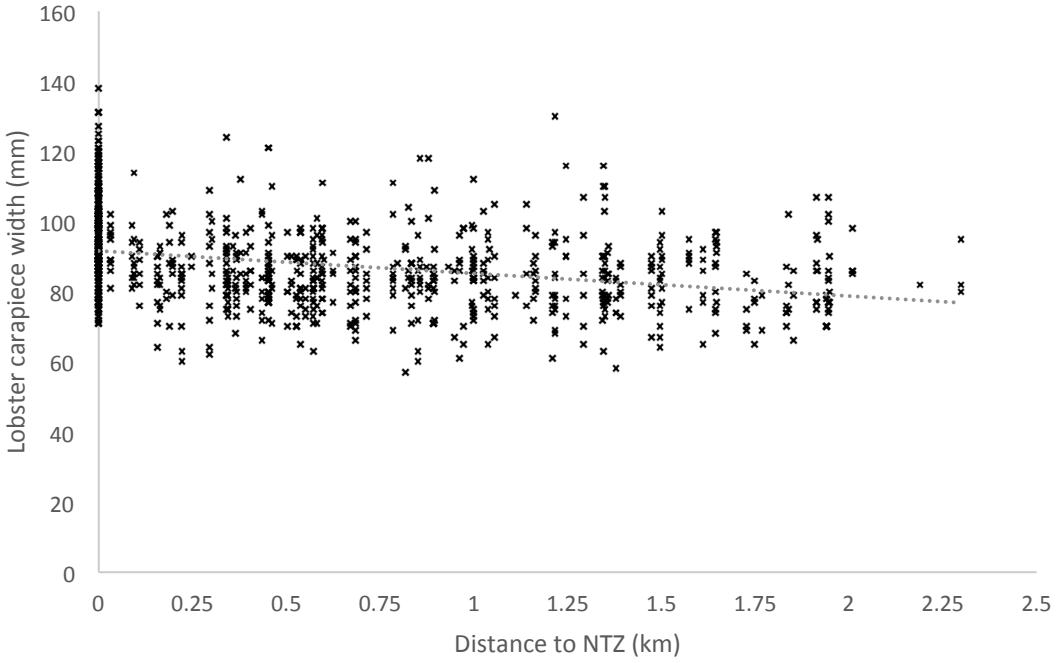

Figure 9: *Individual lobster size with varying proximity to the nearest point of the Reserve (n=806)*

Tables 9, 10 and 11 show the results of Poisson GLMs conducted on various measures of catch rate. Distance to NTZ was consistently significant and responsible for the largest deviation. The largest deviance was in Lobster WPUE, for which 12.8% was attributed to variation in the distance from the nearest point of the NTZ.

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***Table** 9: Poisson GLM on the Lobster CPUE of the compilation of control and observed sites*

CPUE model (transformation undertaken)	Proportional deviance	Minimum adequate model	%D	p(t)
Brown crab catch-rate (square root) Catshark presence Creels in line Depth Distance (log10) Velvet crab CPUE (sqrt) Catshark presence	15.1	Distance	7.58	.003
	AIC	Velvet crab CPUE	3.18	.002
	98.1			

***Table** 10: Poisson GLM on the Lobster WPUE of the compilation of control and observed sites*

WPUE model (transformation undertaken)	Proportional deviance	Minimum adequate model	%D	p(t)
Brown crab catch-rate (sqrt) Catshark presence Creels in line Depth Distance (log10) Velvet crab QPUE (sqrt) Catshark presence	21.4	Distance	12.8	<.001
	AIC	Creels in line	3.18	0.136
	1445	Velvet Crab CPUE	5.42	.006

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***Table** 11: Poisson GLM on the cumulate VPUE of each creel within a compilation of control and observed sites*

VPUE model variables (transformation undertaken)	Proportional deviance	Minimum adequate model	%D	p(t)
Brown crab catch-rate (sqrt) Catshark presence Creels in line Depth Distance (log10) Velvet crab CPUE (sqrt) Catshark presence	20.7	Distance	8.39	.002
	AIC	Creels in line	4.76	.012
	488.5	Velvet Crab CPUE	7.55	.002

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Discussion

Overview of findings

The aim of this investigation was to establish whether the Lamlash Bay NTZ was benefitting benthic crustacean populations. This study resulted in 5 main findings:

- Lobster biomass was boosted within the NTZ although there was no difference in sex composition or the probability of females carrying eggs.
- Outside of the NTZ boundaries, there was evidence of lobster biomass spill-over with a negative correlation between the distance to the NTZ and the size of lobsters
- The frequency and severity of injuries was significantly greater within the NTZ
- Crabs did not respond to the presence of the NTZ in the same manner as lobsters. Velvet crabs showed negligible differences in size and catch rate, whilst Brown crabs had a decreased catch rate equating to decrease biomass density. Although this tradeoff was shown to mask the increase enhanced potential commercial value inside the Reserve
- Lobster catch rates have recovered from decreases and exceeded those in previous years.

Implications of findings

Performance of the Lamlash Bay NTZ in boosting crustacean biomass

The large contrasts in suggested lobster biomass demonstrate the role of closed area protection in recovering commercially exploited temperate marine populations. This is consistent with other studies. Hoskin et al., (2011) saw a 427% increase in lobster catch rate Lundy, whilst Moland et al.(2013) saw an increase of 245% in several Norwegian reserves. These are larger than the 115% increase here although the increase is still significant. The 219% increase found when comparing the passive fishing observations was more similar to these other investigations. This may potentially due to the greater sample size. A similar expansion in the number of observations within the Control may have had the same effect.

It is more probable that the greater difference is due to the fall in catch rate in the Observed compared with the Control series caused by differences in methodology. Soak times

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exceeding 72 hours and greater numbers of creels on the same string have been shown to significantly reduce the fishing success of crustaceans (Tremblay et al., 2010; Miller, 1990). This highlights the importance of separating the Control and Observed data to represent the areas outside the NTZ.

The most comparable study is Howarth et al. (2015) as it was done at the same site largely using the same methodology. A 10-15mm increase was reported in individual lobster size within the NTZ. The 11.5mm increase seen here is consistent with this range. Catch rates were also greater in the NTZ, except during the first year; the average increase was shown to be 109%, comparable to the 115% increase seen in this study.

The decreases in Brown crab and small difference in Velvet crab biomass were also observed by Howarth et al. (2015), with interspecies interaction and competition believed to be main cause for this. Lobsters and crabs have specific habitat requirements, preferring small, dark enclosures in shallow and rocky benthic areas (Howard, 1980). Competition for these sheltered areas has been observed within crustaceans (Richards and Cobb, 1986). The limited spatial availability in the NTZ most likely results in the displacement of smaller crabs to areas of lower crustacean density outside the NTZ. The discrepancy in crab numbers within the NTZ may also be attributed to the survey methods. Crabs may have been deterred from entering a creel if there was already a number of lobsters present (Smith and Tremblay, 2003). The GLMs conducted found Velvet crab catch rates to be the most negatively correlated variable with all three measures of catch rate, after distance to the NTZ.

If so, it would have led to crabs being underrepresented within creels in areas returning high lobster catch rates. Moreover, the greater mobility of Brown crabs, including wide migratory ranges (Bennett and Brown, 1983; Fahy and Carroll, 2008), may limit the effect such a relatively small area of protection has compared to a less mobile species like lobsters. Changes in survey methods to include visual counts or the expansion of the NTZ to cover more of the migratory range may lead to the observation of more beneficial effects.

Influence of marine reserve on population health

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The greater frequency and severity of injuries within the lobsters surveyed point to decreased population health, seen by both Howarth et al., (2016) and Davies et al., (2015). Some have pointed to this as a negative effect of marine reserves. The greater density results in disease and injury levels to be 'unhealthy' (Davies, 2015). There is no baseline for population health, and so the importance of the observed population health is difficult to state. (Hilborn et al., 2004). Lamlash Bay may be returning to its natural unexploited state, and its natural level of interspecies inflicted injuries (Jones, 2007). The many benefits offered by marine reserve arguably outweigh the cost of decreased population health. Emphasising this effect may give marine reserves an unfair negative connotation further making their implementation more difficult (Jones, 2014)

Temporal variation in density and size

As previously stated the effects of NTZs on lobsters is known. Arguably the most significant finding of this study is the large temporal variation within this effect, particularly with catch rates between 2015 and 2017. This is important because it can be used to determine whether the NTZ still has a positive effect on lobster stocks or whether it has plateaued or even declined following two years of decreased catch rates. This stabilisation or stagnation of lobster stocks appears not to have occurred. The two most recent years (2015 and 2017) show the greatest variation, from the lowest catch rate to the highest. Although extremely promising, what has caused this is difficult to decipher.

One such factor possibly responsible is the decrease in the local fishing effort. Prior to this year, two boats fished for lobsters within Lamlash Bay; it has now been reduced to one. The remaining operator has also scaled back its activity, even though it was already smaller than the one removed. This is due to the better economic returns from fishing nephrops in deeper areas of the bay (I.Cossack, Perrs Comms, 2017). The increases in lobster size and catch rate within exclusion areas demonstrate the influence of reduced efforts on stocks in the area.

Another factor influencing catch rates is the presence of the wider MPA. Previously, dredging and trawling occurred within Lamlash Bay to the boundaries of the NTZ (H.Wood, Perrs Comms , 2017). This practice causes decreases in benthic invertebrate abundance (Jenkins, Beukers-Stewart and Brand, 2001) and habitat destruction (Auster et al., 1984).

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The legal prohibition of this activity in Lamlash Bay in 2016 (COAST, 2017) may have resulted in greater lobster abundance in the area.

Attributing decreased fishing intensity and the removal of mobile gears to a large increase in lobster presence in both sites assumes these changes outside the NTZ have significant influence. This includes spill-over from the Control into the Reserve. Lobster eggs and larvae can travel considerable distance through currents (Shanks and Eckert, 2005), meaning dispersal from the surrounding area could theoretically enter the NTZ. A greater abundance of larger reproductively active lobsters has shown to increase egg production (Leslie et al., 2006). Larvae would most likely diffuse away from the point of greater density within the reserve (Cowen, 2000). The movement of developed lobsters from areas of lower densities, the Control, to areas of higher densities is unlikely. As previously discussed there may be a shortage of space and resources within the NTZ, so an individual is more likely to move from areas of greater densities.

Another explanation may simply be that 2017 was a particularly good year for lobsters in the area. This may be associated with environmental conditions including ocean temperature, which can shape the length and subsequent success of larval development stage in marine organisms (O'Connor et al., 2007) including lobsters (Quinn et al., 2013). The influence of this could be investigated by comparing catch rates against corresponding environmental conditions. The time between surveys may be important. Prior to 2015, the survey was done on an annual basis. The two year difference may make the effect of any external factor more profound, possibly explaining the extent of the difference.

Between 2012 and 2017 there has been a 53% and 7% increase in catch rate and lobster size. With legal sized individuals this difference is 89% and 1%. Greater returns of catch rates appear to be the biggest sign of recovery. When averaged across the 5-year period, this is an 11% and 18% increases in size and catch rates per year (Howarth et al., 2016). Within the NTZ this has been large fluctuation making the true rate of recovery hard to establish. This survey shows the falls shown in the previous two treatment years not be permanent. It is more likely they are part fluctuations within a larger trend, seen in other stock assessments in the region (Thurstan and Roberts, 2010).

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Spatial influence of the NTZ through spill-over

Spill-over was observed, but the correlation between distance to the reserve and catch rates was weak. Distance was attributed to, at most, 14% of deviance between catch rate. It was consistently shown to be the most influential factor.

There are several factors that may have reduced the spill-over. Simply comparing distance from the NTZ against variables assumes there is flat plane of continuous benthic morphology suitable for lobster habitation. Although the benthos composition is continuous between the NTZ and Controls 2 and 3, around the shore of Holy Isle, it is not with Control 1, north of Holy Isle. Here there is a substantial change in depth and benthic composition before returning to kelp fringing boulders. This includes an area of seabed dominated by fine muds, reaching depths of 30m (Axelsson et al., 2010). This may influence spill-over, as the presence of lobsters may be determined by the existence of suitable habitats. This muddy depression may also present a physical boundary, limiting lobster mobility

Further research could map suitable lobster habitats; this could then be incorporated into the cost-distance analysis, which currently assumes that lobsters cannot cross land, although, Campbell, (1986) found lobsters do undertake such shallow-deep movements. When observing nephrop fishing effort, several lobsters were seen in creels placed within the muddy substrates of Lamlash Bay at depths exceeding 35m (self-observed), supporting this movement.

Another factor affecting spill-over is the action of ‘fishing the line’, or fishing close to the marine reserve boundary, as there is a greater abundance of commercial important organisms there (Kellner et al., 2007; Stobart et al., 2009). The greater mortality imposed by this increase may mask any increase in biomass from spill-over.

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Figure 10: *Spatial density of fishing observations (darker areas represent greater fishing intensity)*

Figure 10 shows a kernel density of fishing observations. If this is a representation of the spatial variation with local fishing effort, then greater effort is being focused upon areas nearer the NTZ. To observe the influence of this greater concentration of fishing, sites could be divided into predetermined subsections. The qualitative index for the relative degree of fishing effort occurring in this area could be incorporated into GLMs as a variable potentially resulting in deviances in catch rate.

Smaller, often juvenile, lobsters are more likely to be displaced through spatial competition and their smaller size (Richards and Cobb, 1986) . A greater abundance of smaller lobsters would weaken the correlation between distance and individual size, and would also affect VPUE, as only legally sized lobsters were considered. It should not affect WPUE as this was indiscriminate of the number of individuals and was only reliant upon the cumulative mass of the creel.

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Overall, the distances for which spatial variation in catch rates and size was assessed may not give a complete representation of the effect of the NTZ. The dispersal range of lobster larvae is large (Cowan, 2005) in comparison with their home range, which has been observed to be typically, >1km (Scopel et al.,2008; Huserbråten et al., 2013). The influence through recruitment of the Reserve most likely exceeds the confines of Lamlash Bay. To assess the wider role of the NTZ, analysis could be expanded further afield to other areas of suitable habitat composition. Previously this was done with the inclusion of 'Far Control', a site found along the southern coast of Arran and included as part of the passive fishing observations.

Conclusion

NTZs have been and will continue to be valuable in enhancing marine populations affected by anthropogenic exploitation. Trade-offs exist, whether that may be decreasing the population density of another species or at the expense of population health, and the degree of its effect can vary with time. However, the extent the NTZ in Lamlash Bay has been shown to benefit lobsters, other species and the wider marine environment arguably outweighs these costs. The use of similar marine reserves should play a fundamental role in restoring exploited marine environments in the future.

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