The Effects of a No-Take-Zone on Crustacean Population Recovery in Lamlash Bay, Scotland

MSc. Marine Environmental Management - Summer Placement

Brian Christie: Y3587129

Supervisor: Dr Bryce Stewart

Word Count: 4995

UNIVERSITY of York

Isle of Arran COAST Community Of Arran Seabed Trust

The Effects of a No-Take-Zone on Crustacean Population Recovery in Lamlash Bay, Scotland

Abstract:

Marine No-Take-Zones (NTZs) are a powerful management tool that can facilitate ecosystem recovery post-overexploitation. Resultant increases to biological productivity within a NTZ can spillover to connected areas benefiting fishing industries. This study is a continuation of annual crustacean surveys running since 2012. It investigates the response of three commercial decapod crustacean species populations: European lobster (*Homarus gammarus*), brown crab (*Cancer pagarus*) and velvet crab (*Necora puber*) to seven years of protection within the Lamlash Bay NTZ - Isle of Arran, Scotland. These species are economically important to the UK, and may fulfil a keystone role in the Firth of Clyde ecosystem. Monitoring NTZ impact on these species is therefore essential to guide ongoing and wider management strategies. Creeling, through a combination of controlled targeted surveys and passive fishing observations, was used to sample populations within the NTZ and at unprotected Near and Far Control sites. Data was collected during July and August 2015 on crustacean size, abundance, gender and the prevalence of damage and disease. Lobster growth and movement were assessable via a tag and release programme. Catch per Unit Effort (CPUE) in the NTZ was 107% higher for lobster and 137% higher for velvet crab compared to the Near Control. Conversely, brown crab CPUE was 32% lower in the NTZ. Legal-sized lobster CPUE exhibited a significant negative correlation with distance from NTZ boundary, demonstrating a possible spillover effect. The prevalence of lobster damage and disease was not significantly different between the NTZ and the Near Control, indicating no effect of abundance on health. Lobsters within the NTZ were on average 17.42mm larger than those in the Far Control, providing strong evidence for population size-structure recovery. The NTZ appears to be facilitating crustacean

population recovery, with spillover to adjacent areas. This serves both conservation and fishery management objectives.

Introduction:

Global fishing effort increased dramatically during the 20th Century (Srinivasan *et al.,* 2012) and continues to escalate (Watson *et al.,* 2012). This fishery exploitation has led to severely degraded marine ecosystems worldwide (FAO, 2014). Advances in technology have facilitated the increased removal of target biomass (Pauly *et al.,* 2002). Mobile, bottom-active gears such as trawls and dredges are devastating fragile biogenic habitats (Thrush and Dayton, 2002). Poor gear-selectivity is generating high-levels of bycatch and discards (Davies *et al.,* 2009). These impacts can all affect ecosystem health and function, likely lowering ecosystem resilience (Hughes *et al.,* 2005). Consequently, affected ecosystems may be more at risk of invasive alien species (Galil, 2007; Didham *et al.,* 2005), trophic cascades, ecosystem regime shifts (Daskalov *et al.,* 2007), and ecosystem simplification (Howarth *et al.,* 2013). Ultimately, overfishing threatens the security of marine ecosystem service provision (Worm *et al.,* 2006).

The Firth of Clyde in Scotland is regarded to be one of the most degraded marine environments in the UK (Howarth *et al.,* 2013). The Clyde once provided productive commercial fishing grounds for species such as herring (*Clupea harengus*), cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (Thurstan and Roberts, 2010). However, systematic overfishing from the 1880's onwards resulted in a series of 'boom-and-bust' fisheries, culminating in the collapse of pelagic and groundfish commercial stocks by the early 21st Century (Thurstan and Roberts, 2010). The Clyde's ecosystem is now significantly altered with whiting (*Merlangius merlangus*) representing over 70% of demersal fish biomass in 2009, and the size-structure of many fish populations deficient in larger, commercially viable individuals (Heath and Speirs, 2011). The only fish caught commercially in the Clyde since 2003 have been as bycatch from the *Nephrops* prawn (*Nephrops norvegicus*) fishery (Howarth *et al.,* 2013).

The area's dramatic ecological transition is strongly accredited to the sequential weakening of laws introduced in the 19th Century that banned trawling in the Clyde (Thurstan and Roberts, 2010). The most recent of which was the lifting of a three nautical mile ban on trawling from the shoreline in 1984, implemented in an effort to sustain demersal finfish landings (McIntyre *et al.,* 2012). Consequently, prawn trawling and commercial scallop dredging have come to dominate the Clyde's fishing industry (Thurstan and Roberts, 2010). These fishing methods epitomise concerns regarding modern fishing techniques. They are extremely efficient at removing target biomass, have a very high level of bycatch and associated discard mortality and devastate fragile habitats through physical contact (Thrush and Dayton, 2002; Løkkeborg, 2005). These factors, acting synergistically, may be preventing effective fish stock recovery in the Clyde (McIntyre *et al.,* 2012; Thurstan and Roberts, 2010). Thus these practices likely helped force the Clyde's ecosystem regime shift and concurrent reduction in complexity, and continue to suppress it into its current state (Thurstan and Roberts, 2010; Howarth *et al.,* 2013).

Marine Protected Areas (MPAs) are one management tool that may reduce or even reverse the effects of overfishing (Halpern *et al.,* 2010). MPAs can be implemented in various permutations regarding size, restrictions, enforcement and management. Ultimately, the more protection that is provided the greater the ecological benefits that will be derived (Sciberras *et al.*, 2013). No-Take-Zones (NTZs) are MPAs where all extractive ventures are prohibited (National Research Council, 2001). This absolute removal of local fishing pressures results in increases to biomass and abundance within NTZ boundaries (Williamson *et al*., 2004). Additionally, NTZs allow for population age structure to be restored thus increasing the number of older, more fecund individuals (Hoskin *et al.,* 2011). This facilitates greater reproductive output (Williams, 1975; Lizárraga-Cubedo *et al.,* 2003) that can 'spillover' via larval transport and species migration to connected areas (Ashworth and

Ormond, 2005; Hoskin *et al.,* 2011). NTZs also permit habitat recovery, promoting increased habitat heterogeneity and three-dimensional complexity that further supports recovering marine communities and ecosystem function (Beukers-Stewart *et al.,* 2005; García-Charton *et al.,* 2008).

In 2008, Scotland's first NTZ was established in Lamlash Bay on the Isle of Arran, in the Clyde. The Lamlash Bay NTZ covers an area of 2.67km^2 (Thurstan and Roberts, 2010). It encompasses a diverse array of habitats such as maerl beds, kelp forests and benthic sediment sizes ranging from boulders to fine mud. The intention of this NTZ was to benefit both local conservation and fishery management objectives (Howarth, 2012); a well-recognised potential attribute of marine NTZs (Pikitch *et al.,* 2005).

Arran, much like the rest of the Clyde, has a rich fishing heritage (Thurstan and Roberts, 2010). Lamlash Bay in particular was formerly host to numerous sea angling tournaments and productive finfish fisheries (COAST, 2006). While these are no longer present, the bay and its surrounding waters do support commercial fisheries for European lobster (*Homarus gammarus*), edible/brown crab *(Cancer pagarus*), velvet swimming crab (*Necora puber*), king scallops (*Pecten maximus*) and langoustine (*Nephrops norvegicus*). Monitoring the impact of the NTZ is important to assess its performance, particularly for these commercial species. Additionally, data gathered will help inform ongoing local and wider management strategies throughout the Clyde. This is especially pertinent given the pending South Arran MPA which, as per the 2014 proposal, will cover >250km^2 and encompass the Lamlash Bay NTZ (SNH, 2015).

This study is a continuation of annual crustacean surveys initiated in 2012 (Dubois, 2012; Gratton, 2013; Judge, 2014) designed to assess the response of decapod crustaceans (European lobster, brown crab and velvet crab) to the protection conferred by the Lamlash Bay NTZ. These three target species represent a valuable fishing resource for Scotland, with an estimated total value of £28.4 million in 2013 (brown crab £13.8 million; velvet crab £4 million; European lobster £10.6 million) (Marine Scotland, 2015). However, present creel fishery management appears to be inadequate. All

three species have exhibited continual signs of unsustainable exploitation (Figure 1) (Marine Scotland, 2012; 2013; 2014; 2015), with multiple areas fished above F_{MSY} for both males and females of the species.

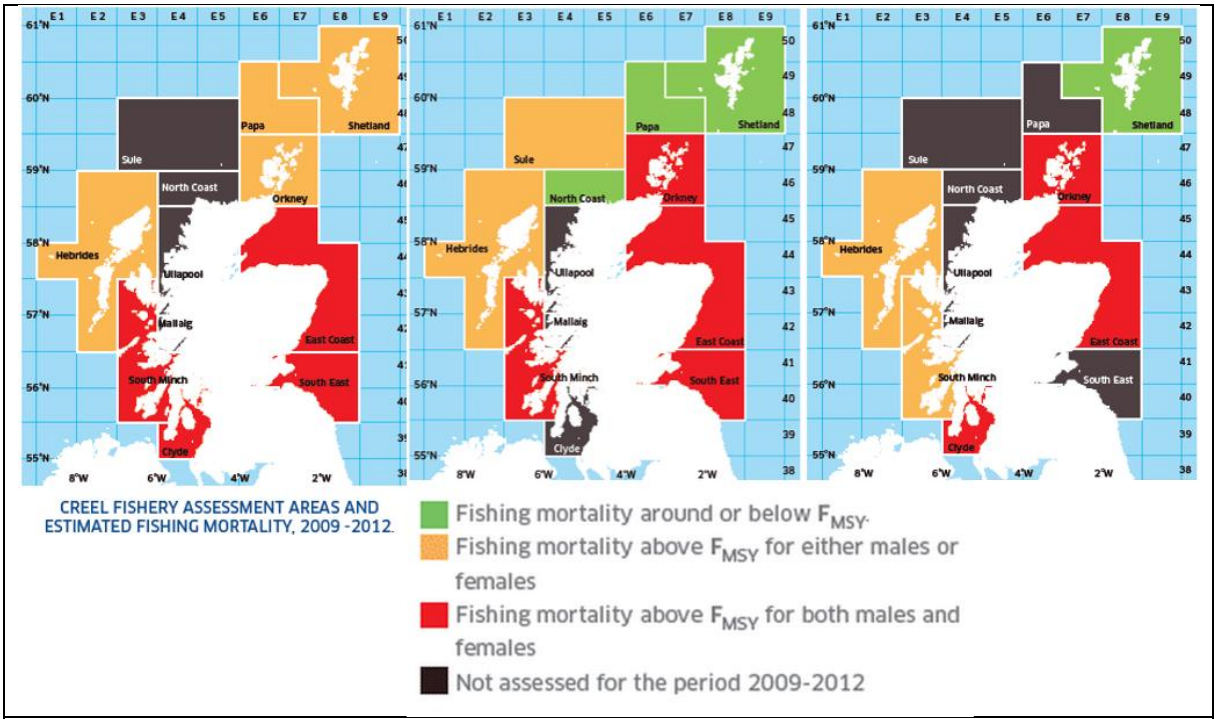

Figure 1. Stock assessments for European lobster (*Homarus gammarus*) (left), edible/brown crab (*Cancer* pagarus) (centre) and velvet swimming crab (*Necora puber*) (right), based on estimated creel fishery mortality for the period 2009-2012. Adapted from Marine Scotland (2015)

Large benthic decapods such as lobsters and crabs, have been shown to occupy a keystone role in ecosystems via the suppression of other species (Boudreau *et al.,* 2012). The ongoing overexploitation of lobster and crab populations in the Clyde may therefore jeopardise the wider ecosystem and have economic impacts beyond their just fisheries. Fortunately, the Lamlash Bay NTZ and pending South Arran MPA offer refuges to these species that may help them sustain healthy populations despite overexploitation. However, there is constant pressure from the fishing industry to validate these claims and justify the rationale behind protected areas. While it has been shown in

numerous instances that NTZs increase crustacean abundance within the protected area (Follesa *et al.*, 2007; Hoskin *et al.,* 2011; Wootton *et al.,* 2012), it has also been demonstrated that increased population densities can result in a higher prevalence of damage and disease (Wootton *et al.,* 2012).

To assess the impact of the Lamlash Bay NTZ on crustacean population recovery, this study investigates data from 2015 to compare:

1a) Abundance of all target species between the NTZ and Near/Far Controls

2a) Mean size of all target species between the NTZ and Near/Far Controls

3a) Estimated lobster biomass between the NTZ and Near/Far Controls

4a) Prevalence and severity of lobster damage and disease between the NTZ and Near Controls

5a) Estimated lobster fecundity between the NTZ and Near/Far Controls

Additionally, data from 2012 to 2015 is analysed to compare:

1b) Abundance of lobster between the NTZ and Near Controls

2b) Lobster movement and growth between the NTZ and Near Controls

Methods:

- *Study Site*

The Isle of Arran is situated in the Firth of Clyde, Scotland. Lamlash Bay is a sheltered body of water located between Arran's eastern coast and Holy Isle. The NTZ, designated in 2008 under the Inshore Fishing (Scotland) Act 1984, covers an area of water 2.67km^2 across the northern entrance to Lamlash Bay (Figure 2) (Thurstan and Roberts, 2010). Near Control locations (N1, N2 and N3) were positioned around the NTZ, <2km away from the NTZ boundary (Figure 2). Far Control locations (F1, F2, F3, F4 and F5), positioned along Arran's southern coastline and off the Isle of Pladda (Figure 2), were 7-18km away from the NTZ boundary. Fleets deployed within the NTZ, Near and Far Controls all targeted similar a lobster habitat of rocky benthic substrate bordering kelp forests.

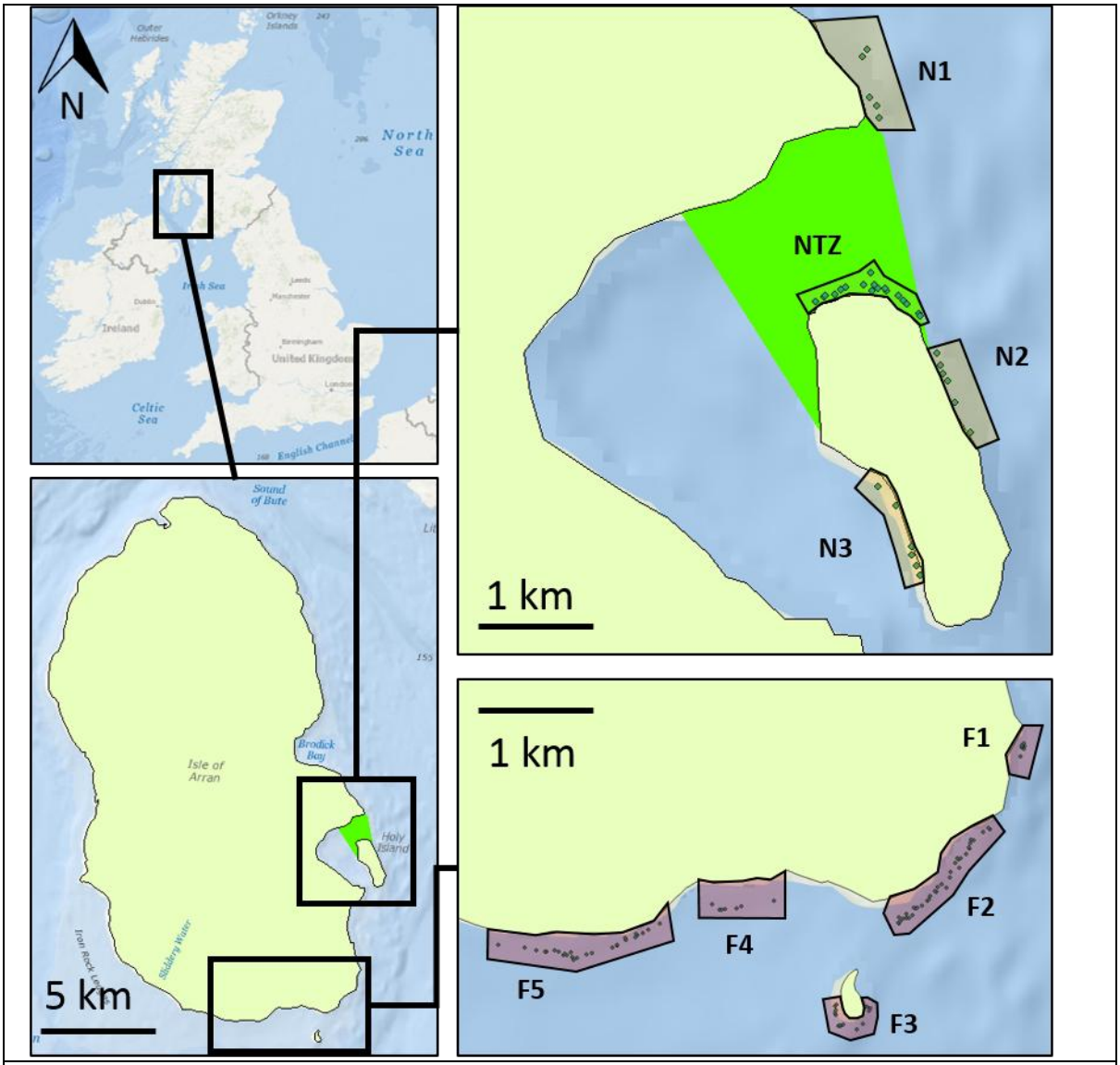

Figure 2. The location of the Isle of Arran in relation to the rest of the United Kingdom. No-Take-Zone (NTZ), Near Control (N1-3) and Far Control (F1-5) sites are indicated with fleet GPS coordinate locations shown. The NTZ area is highlighted in green

- *Data Collection*

Data were collected through controlled sampling surveys and passive fishing observations aboard a small commercial creeling vessel, the Julie Anne TT268. Controlled surveys were conducted during two one-week periods, one at the beginning of July and one at the beginning of August 2015. Sampling effort was equal between these surveys, and between locations inside and in close proximity to the NTZ (Figure 2). Passive observations were recorded throughout July and August 2015, at various locations outside of the NTZ (Figure 2). D-shaped parlour creels, baited with salted oily fish, were used in both modes of collection. These creels measured approximately 64 x 38 x 41cm and had two entrances each measuring 21 x 18cm. During the surveys, creels were deployed in fleets of five. For the observations, fleets varied from five to eleven creels. In both instances, creels were separated by a length of 10 fathoms (18.288m) from their nearest neighbouring creels. This distance has the potential for neighbouring creels to impact one another's catch-rates (Smith and Tremblay, 2003). Consequently, each fleet as opposed to each creel was treated a single control. Survey fleets were soaked for a 48 hour period prior to retrieval for measurements, whilst observation fleet soak times varied from 48-72 hours. Montgomery (2005) found soak times of 24-72 hours to not significantly alter overall catch-rates of lobster, so differences in soak time are not expected to inflate measures of abundance.

- *Variables Recorded*

During controlled sample surveys, the abundances of all target and bycatch species were recorded per creel. Lobster, brown crab and velvet crabs were then sexed, and measured to the nearest mm using calipers. Lobster length was measured from the rear of the eye socket to the posterior edge of the carapace. Velvet and brown crabs were measured at the widest point across the carapace. Observations were then recorded for these three species on the presence of notable features including: disease, damage, eggs/ berries and new/ regrown body parts. During passive fishing observations, the abundances of all target and bycatch species were recorded per creel. All lobsters were measured, sexed and where possible observations made on the presence of afore mentioned notable features. The depth and GPS co-ordinates at the first fleet marker buoy were recorded for each fleet retrieved in both survey and observation trips.

- *Tagging*

All lobsters caught during the controlled sample surveys were fitted with a T-bar anchor tag (Hallprint Pty. Ltd, South Australia), measuring 55mm in total length and 40mm in filament length. These tags could be quickly applied and exhibit a high retention rate during the moulting phase. University of York contact details were printed alongside a unique identification number on the filament of each tag. A Monarch Marking 3030 tagging gun was used to insert tags dorso-laterally into the abdominal muscle immediately behind the posterior edge of the carapace. During insertion, care was taken to avoid the midline to prevent the dorsal abdominal artery or abdomen being punctured. Tag filaments were colour coded green for lobsters caught within the NTZ and red for those caught outside. Once tagged, individuals were gently lowered and released into the sea, to reduce the risk of immediate tag rejection (González-Vicente et al., 2012), at the same approximate location to capture.

- *Analyses*

All statistical analyses were conducted in R (version 3.2.0) and all spatial analyses were conducted in ArcGIS (ArcMap 10.2.1). Data from sites N1-3 and F1-5 were pooled to provide overall Near Control and Far Control datasets respectively.

Abundance of target species was calculated as Catch per Unit Effort (CPUE):

$$CPUE = \frac{\text{Number of individuals caught in fleet}}{\text{Number of creels in fleet}}$$

Lobster weight was calculated using the following formulas (Howarth, 2014; Leslie *et al*., 2006):

Male weight = 0.0022 x (carapace length (mm) ^ 2.7416)

Female weight = 0.0016 x (carapace length (mm) ^ 2.8134)

Lobster biomass was calculated as Weight per Unit Effort (WPUE):

$$WPUE = \frac{\text{Total weight of lobsters caught (g) in fleet}}{\text{Number of creels in fleet}}$$

Lobster egg output was calculated using the following formula (Howarth, 2014; Lizárraga-Cubedo *et al*., 2003):

Egg output = (carapace length (mm) x 155.4) - 10286*

**mínimum carapace length 81mm due to smallest size of berried female recorded*

Lobster reproductive potential was calculated as Reproductive Output per Unit Effort (ROPUE):

$$ROPUE = \frac{\text{Total number of potential eggs in fleet}}{\text{Number of creels in fleet}}$$

The ‘Cost Distance’ tool in ArcGIS was used to calculate the shortest distance from each fleet’s first marker buoy’s GPS coordinates to the nearest point of the NTZ boundary, exclusively through the marine environment.

Mann-Whitney-Wilcoxon tests were used to compare CPUE (lobster, brown and velvet), WPUE (lobster) and ROPUE (lobster) between the NTZ and Near/Far Controls, as well as mean minimum lobster movement between the NTZ and Near Control. One-way ANOVAs were used to compare lobster carapace length between the NTZ and Near/Far Controls, and brown/velvet carapace lengths between the NTZ and Near Controls. Spearman’s rank correlations were used to investigate correlations between lobster CPUE, WPUE and ROPUE against distance from the NTZ boundary. Fisher’s exact tests were used to compare lobster disease and damage between the NTZ and Near Control, as well as berried lobsters between the NTZ and Near/Far Controls.

Results:

Abundance:

- *Lobster*

Total lobster CPUE in the NTZ was 107.1% higher compared to the Near Control (Mann-Whitney-Wilcoxon test, U=243.5, p<0.01; Table 1, Figure 3a) and 9.2% higher compared to the Far Control (Mann-Whitney-Wilcoxon test, U=898, p=0.682; Table 1, Figure 3a). Legal-sized lobster (CL≥87mm) CPUE in the NTZ was 143.3% higher to the Near Control (Mann-Whitney-Wilcoxon test, U=244, p<0.01; Table 1, Figure 3b) and 224.5% higher compared to the Far Control (Mann-Whitney-Wilcoxon test, U=1358.5, p<0.001; Table 1, Figure 3b).

Table 1. Summary of lobsters caught in the No-Take-Zone (NTZ), Near Control and Far Control during the 2015 Crustacean Surveys

Area	Mean CPUE	Legal Size (%)	Mean Legal CPUE	Mean Size (mm)	Mean Legal Size (mm)	Gender Ratio (M:F)	Berried Females (%)
NTZ *(n=87)*	0.967	80.5	0.811	99.52	103.03	1:0.45	29.6
Near Control *(n=42)*	0.467	71.4	0.333	89.14	92.67	1:0.69	5.6
Far Control *(n=702)*	0.855	29.1	0.250	82.09	92.68	1:0.96	5.5

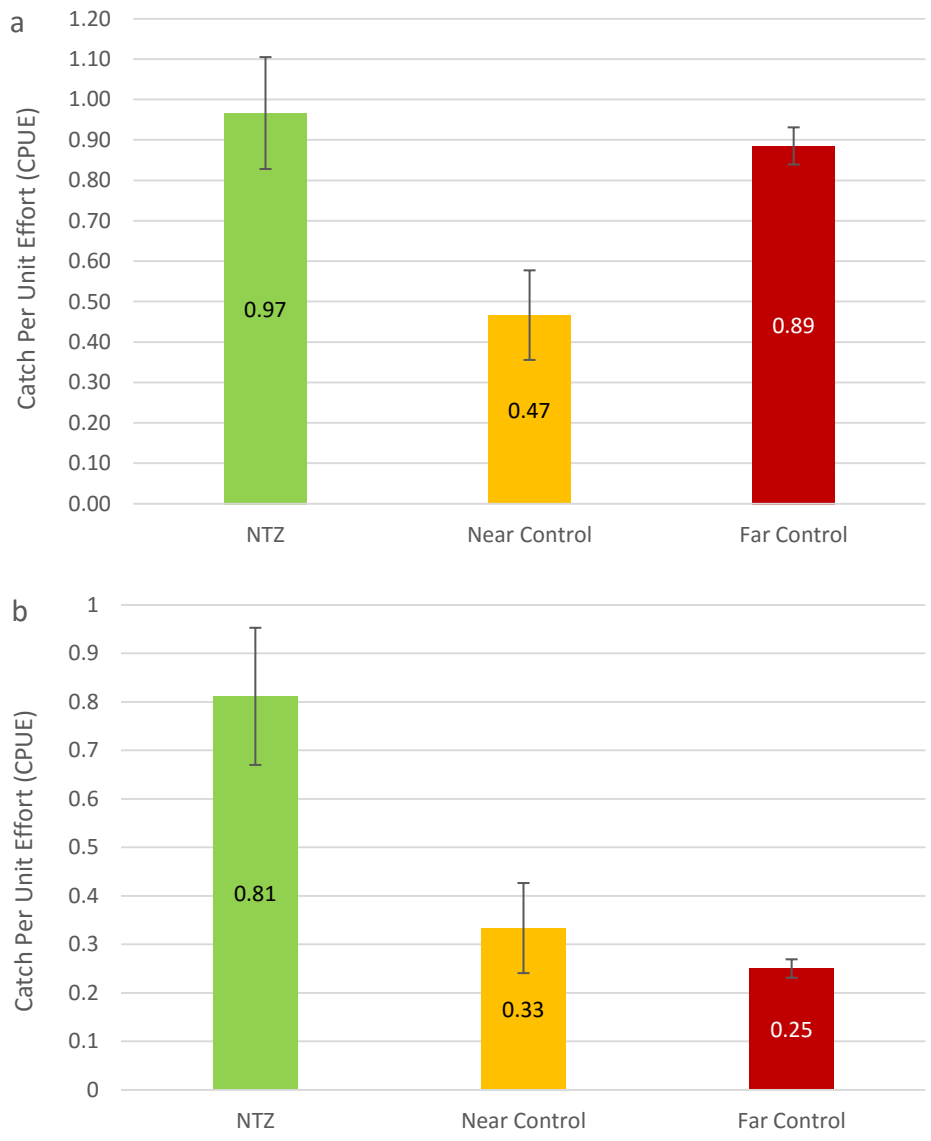

Figure 3. The mean number of **(a)** total lobsters and **(b)** legal-sized lobsters (carapace length ≥ 87mm) caught per creel in the No-Take-Zone (NTZ), Near Control and Far Control (±SE) during the 2015 Crustacean Surveys

Mean legal-sized lobster CPUE showed a significant negative correlation with distance from the NTZ boundary (Spearman's rank correlation, r =-0.266, d.f.=126, p=0.002; Figure 4).

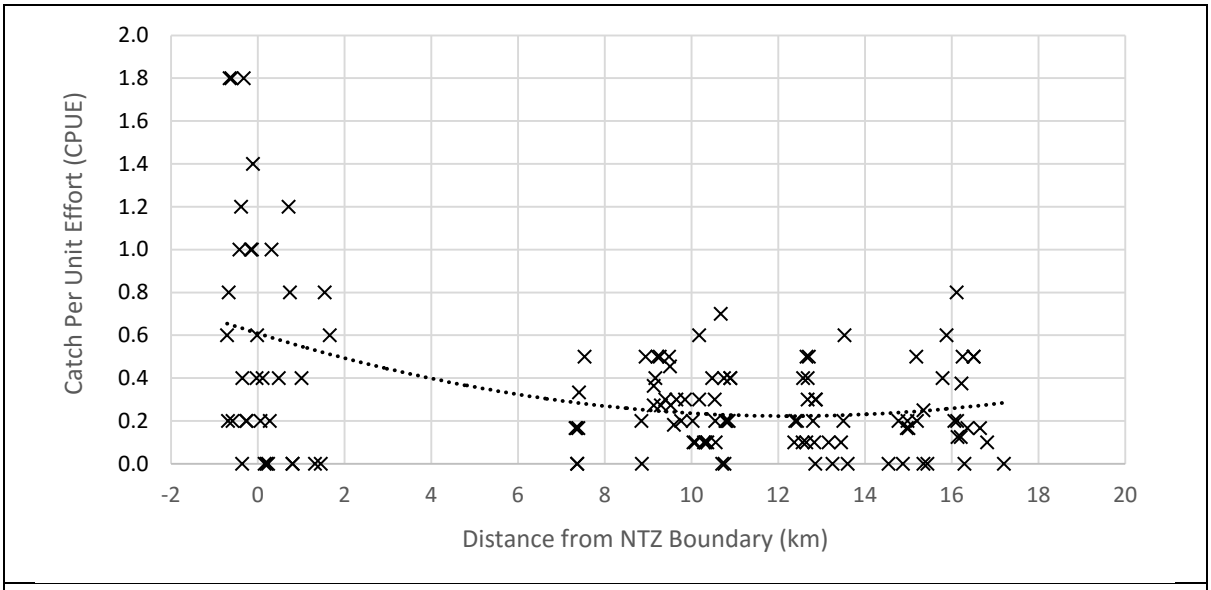

Figure 4. The mean number of legal-sized lobsters (carapace length ≥ 87mm) caught per creel in the No-Take-Zone (NTZ), Near Control and Far Control during the 2015 Crustacean Surveys, plotted against the distance (km) of fleet location from the NTZ boundary. A polynomial regression line has been fitted (R^2 = 0.2019). Negative x-axis values indicate fleets deployed within the NTZ

- *Brown Crab*

Mean total brown crab CPUE was 32% lower in the NTZ compared to the Near Control (Mann-Whitney-Wilcoxon test, U=135, p=0.398; Figure 5a) and 38.7% lower compared to the Far Control (Mann-Whitney-Wilcoxon test, U=500.5, p=0.006; Figure 5a). Mean legal-sized brown crab (CL≥140mm) CPUE was 59.1% lower in NTZ compared to the Near Control (Mann-Whitney-Wilcoxon test, U=94, p=0.029; Figure 5b).

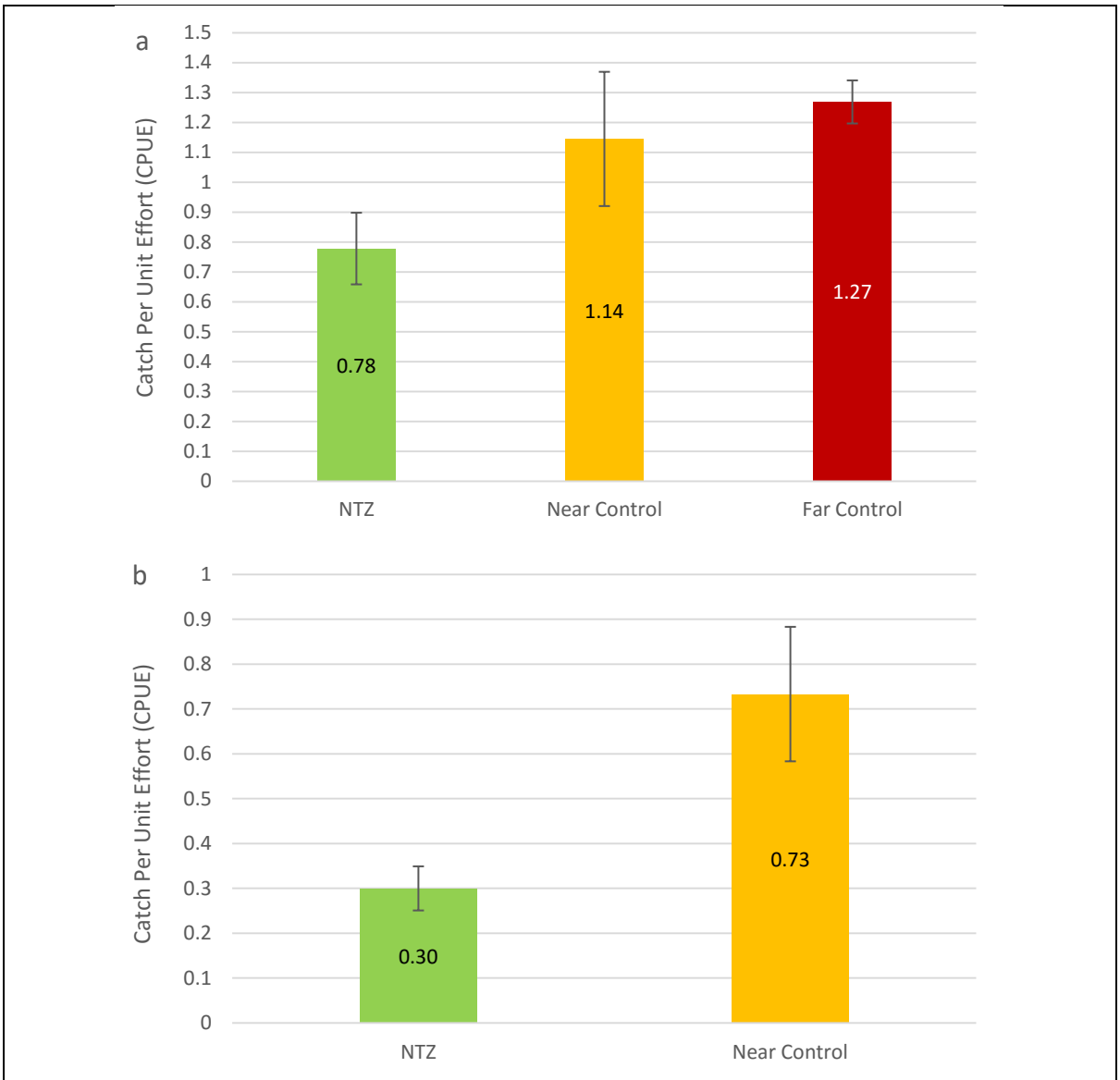

Figure 5. The mean number of **(a)** total brown crabs caught per creel in the No-Take-Zone (NTZ), Near Control and Far Control (±SE) and **(b)** legal-sized brown crabs (carapace length ≥ 140 mm)

caught per creel in the NTZ and Near Control (±SE), during the 2015 Crustacean Surveys

- *Velvet Crab*

Mean total velvet crab CPUE was 136.7% higher in the NTZ compared to the Near Control (Mann-Whitney-Wilcoxon test, *U*=258.5, *p*=0.002; Figure 6) and 79.6% higher compared to the Far Control (Mann-Whitney-Wilcoxon test, *U*=1135, *p*=0.022; Figure 6).

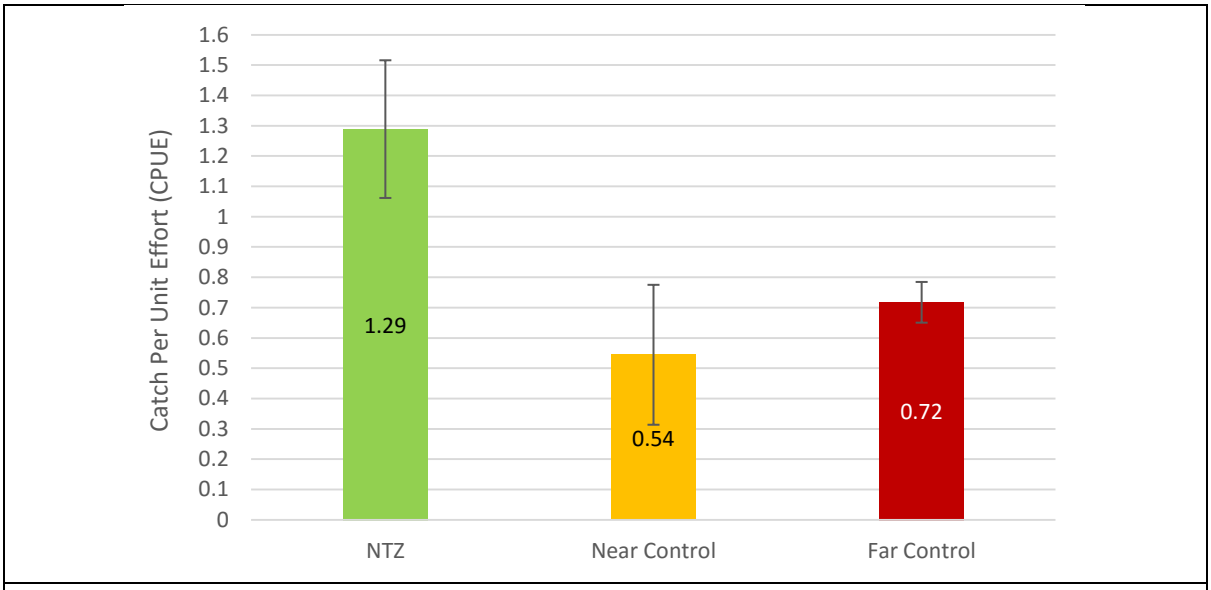

Figure 6. The mean number of total velvet crabs caught per creel in the No-Take-Zone (NTZ), Near Control and Far Control (±SE), caught during the 2015 Crustacean Surveys

Size:

- *Lobster*

The mean size of lobsters caught in the NTZ was 11.6% higher compared to Near Control (one-way ANOVA, $F_{(1,127)}$=23.8, p<0.001; Table 1) and 22% higher compared to Far Control (one-way ANOVA, $F_{(1,787)}$=242.6, p<0.001; Table 1). The mean legal-size of lobsters caught in the NTZ was 11.2% higher compared to Near Control (one-way ANOVA, $F_{(1,101)}$=26.1, p<0.001; Table 1) and 11.2% higher compared to Far Control (one-way ANOVA, $F_{(1,275)}$=120.8, p<0.001; Table 1). A visualisation of population size-structures for the NTZ, Near Control and Far Control can be seen in Figure 7.

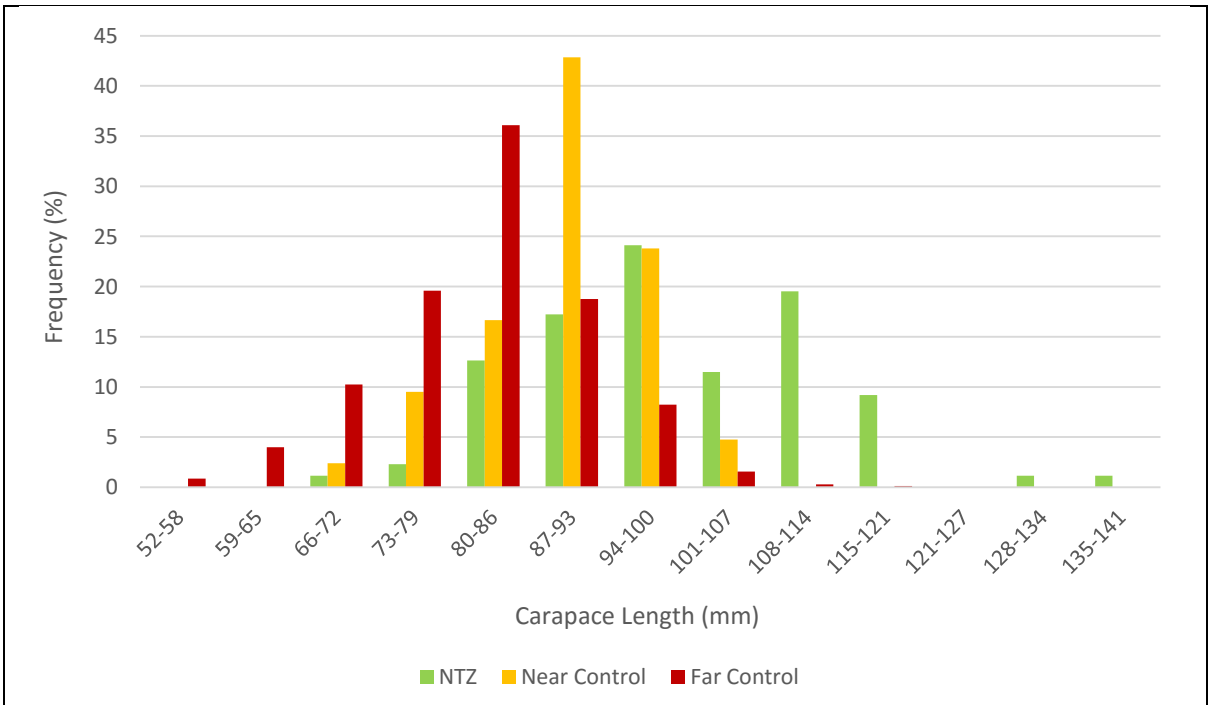

Figure 7. Size distributions of total lobster populations in the NTZ (*n = 87*), Near Control (*n = 42*) and Far Control (*n = 702*) caught during the 2015 Crustacean Surveys

Mean lobster CL showed a significant negative correlation with distance from the NTZ boundary (Spearman's rank correlation, r=-0.4526, d.f.=126, p<0.001; Figure 8).

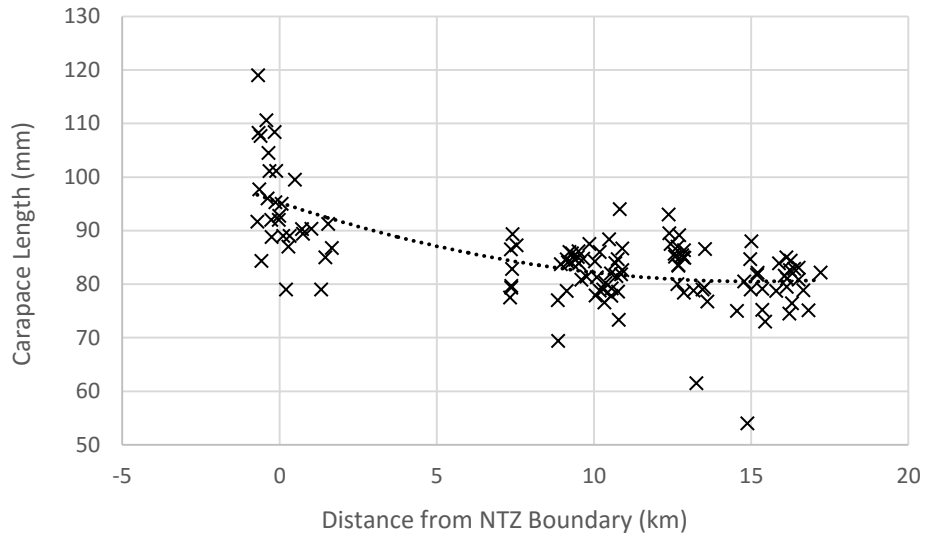

Figure 8. Mean lobster carapace length (mm) per fleet in the No-Take-Zone (NTZ), Near Control and Far Control during the 2015 Crustacean Surveys, plotted against the distance (km) of fleet location from the NTZ boundary. A polynomial regression line has been fitted (R^2 = 0.4547). Negative x-axis values indicate fleets deployed within the NTZ

- *Brown Crab*

The mean size of brown crabs caught in the NTZ was 14% lower compared to Near Control (one-way ANOVA, $F_{(1,172)}$=14.4, p<0.001). The mean legal-size of brown crab (CL≥140mm) caught in the NTZ was 0.9% lower compared to Near Control (one-way ANOVA, $F_{(1,91)}$=0.14, p=0.706).

- *Velvet Crab*

The mean size of velvet crabs caught in the NTZ was 2.6% higher compared to Near Control (one-way ANOVA, $F_{(1,160)}$=4.2, p=0.041).

Lobster Health:

- *Disease*

Shell disease was present on two lobsters (2.3% occurrence) inside the NTZ and two lobsters in the Near Control (4.8% occurrence). However, the difference between these occurrence rates was not statistically significant (Fisher's exact test, p=0.596).

- *Damage*

Damage to lobsters was coded into categories based on severity/type (Figure 9). Lobsters in the NTZ had a higher prevalence of damaged and/or regrown claws (Figure 9). Additionally, the only lobster found with both claws absent was observed within the NTZ (Figure 9). The Near Control had a higher prevalence of missing claws/ carapace damage/ tail damage and also of damage to/ absence of minor limbs and antennae (Figure 9). There was a greater incidence of undamaged lobsters in the Near Control compared to the NTZ (Figure 9). Of these variations, only the higher instance of damaged and/or regrown claws was statistically significant (Fisher's exact test, p=0.005). All other differences were non-significant (Fisher's exact tests, p>0.05). Further investigation revealed there to be no significant difference with regards to gender and frequency of healthy lobsters or those with damaged/ regrown claws (Fisher's exact tests, p>0.05).

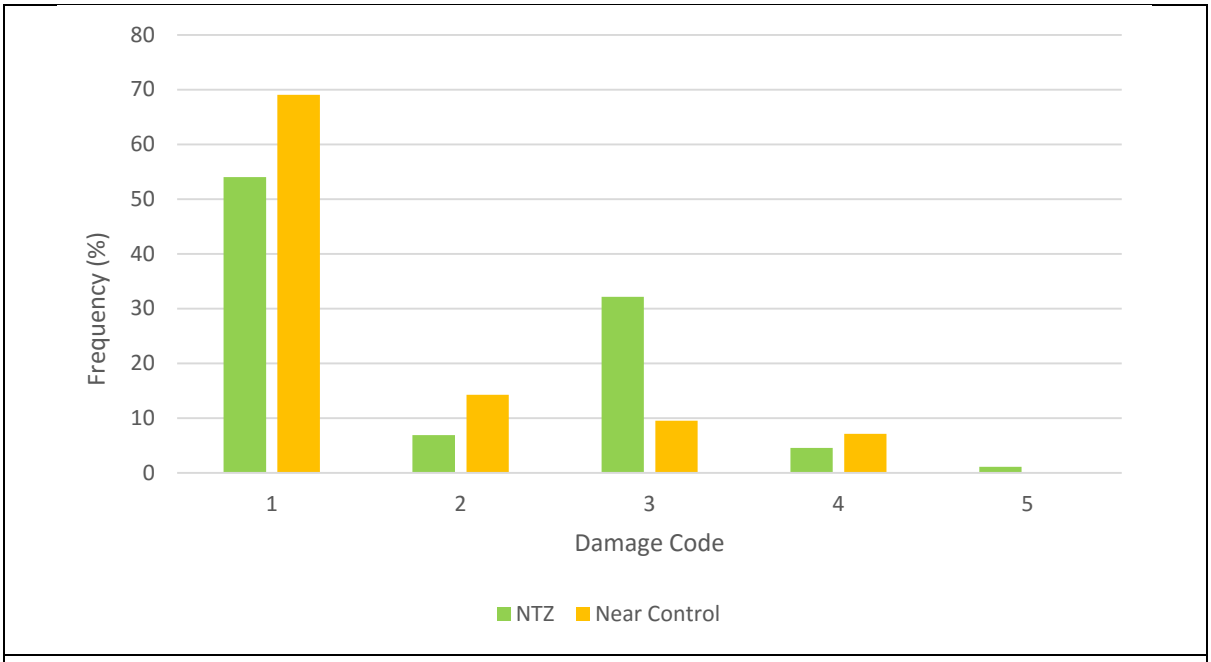

Figure 9. The frequency of damage/injury for lobsters within the No-Take-Zone (NTZ) and Near Control, as coded for using the following **Damage Codes: 1)** undamaged (NTZ, *n* = 47; Near Control, *n* = 29); **2)** missing/damaged/regrown antennae/minor limb (NTZ, *n* = 6; Near Control, *n* = 6); **3)** damaged/regrown claws(s) (NTZ, *n* = 28; Near Control, *n* = 4); **4)** missing claw and/or carapace/tail damage (NTZ, *n* = 4; Near Control, *n* = 3), and **5)** both claws missing (NTZ, *n* = 1; Near Control, *n* = 0)

Lobster Biomass:

Mean total lobster WPUE was 186.9% higher in the NTZ compared to the Near Control (Mann-Whitney-Wilcoxon test, U=260.5, p=0.002; Figure 10a, Table 1) and 87.5% higher compared to the Far Control (Mann-Whitney-Wilcoxon test, U=1189, p=0.006; Figure 10a; Table 1). Mean legal-sized lobster WPUE was 232% higher in the NTZ compared to the Near Control (Mann-Whitney-Wilcoxon test, U=259, p=0.002; Figure 10b, Table 1) and 346.9% higher compared to the Far Control (Mann-Whitney-Wilcoxon test, U=1450.5, p<0.001; Figure 10b, Table 1).

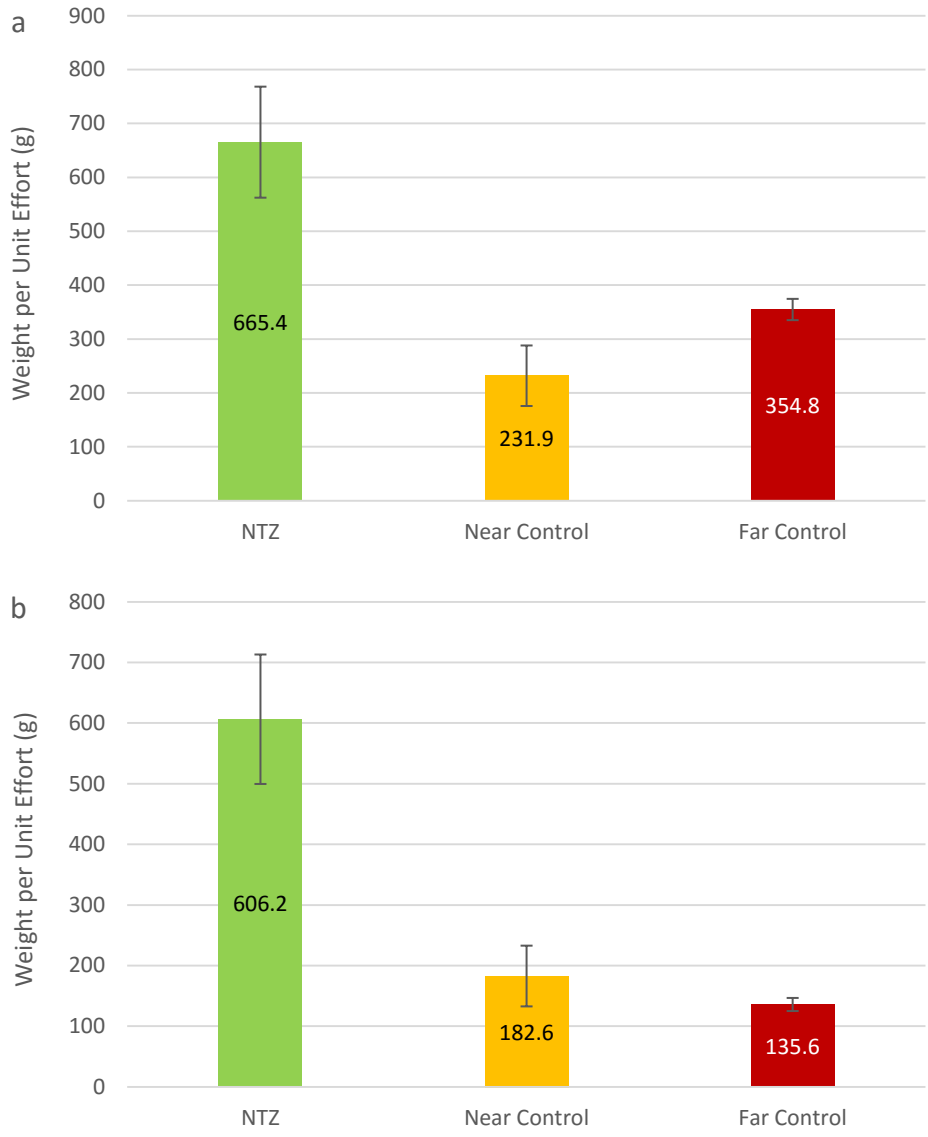

Figure 10. The mean weight (g) of **(a)** total lobsters and **(b)** legal-sized lobsters (carapace length ≥ 87mm) caught per creel in the No-Take-Zone (NTZ), Near Control and Far Control (±SE) during the 2015 Crustacean Surveys

Mean lobster WPUE had a slight negative correlation with distance from the NTZ boundary but this was not significant (Spearman's rank correlation, r=-0127, d.f.=126, p=0.154; Figure 11a). However,

there was a significant negative correlation for mean legal-sized lobster WPUE with distance from the NTZ boundary (Spearman's rank correlation, *r*=0.260, d.f.=126, *p*=0.003; Figure 11b).

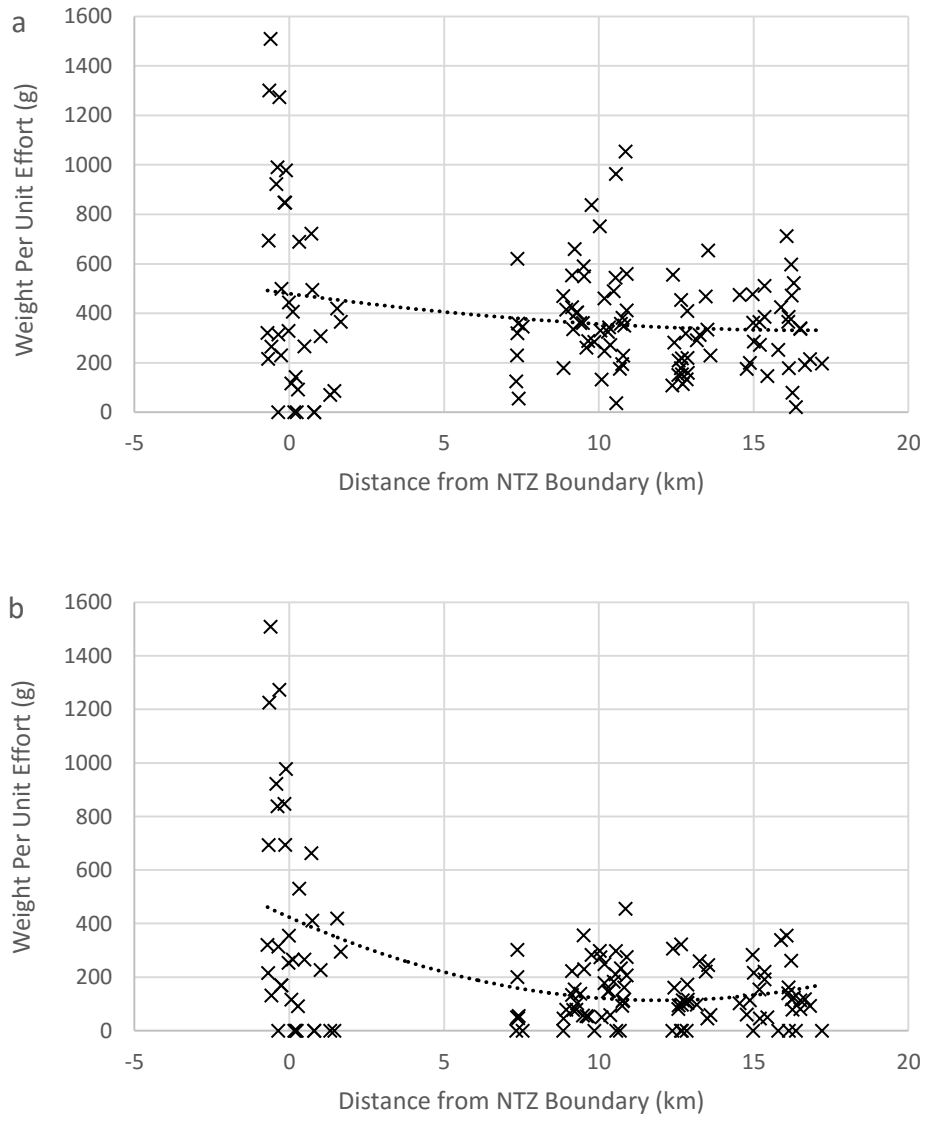

Figure 11. The mean weight of lobsters (g) **(a)** and legal-sized lobsters (carapace length ≥ 87mm) **(b)** caught per creel in the No-Take-Zone (NTZ), Near Control and Far Control during the 2015 Crustacean Surveys, plotted against the distance (km) of fleet location from the NTZ boundary. Polynomial regression lines have been fitted: **(a)** (R^2 = 0.048) and **(b)** (R^2 = 0.250). Negative x-axis values indicate fleets deployed within the NTZ

Lobster Fecundity:

- *Berried Females*

In the NTZ, berried females as a proportion of the female population were: 433% more abundant compared to the Far Control but this was not significant (Fisher's exact test, p=0.064; Table 1); and 436.5% more abundant compared to the Far Control which was significant (Fisher's exact test, p<0.001; Table 1). There was no significant difference between the Near Control and Far Control (Fisher's exact test, p>0.05; Table 1).

- *Potential Reproductive Output*

Mean potential lobster reproductive output for females (CL≥81mm) per creel was 76.9% higher in the NTZ compared to the Near Control (Mann-Whitney-Wilcoxon test, U=224, p<0.05; Figure 12) and 42.8% higher compared to the Far Control (Mann-Whitney-Wilcoxon test, U=1043, p=0.119; Figure 12).

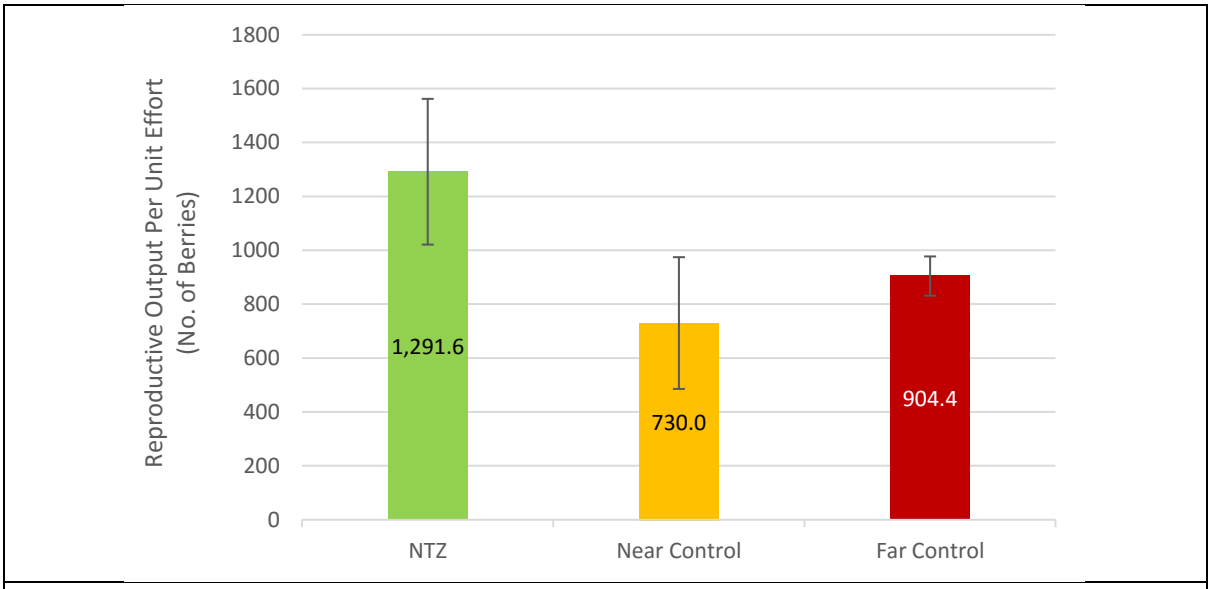

Figure 12. Mean potential Reproductive Output Per Unit Effort (ROPUE) for female lobsters (carapace length ≥ 81mm) caught in the No-Take-Zone (NTZ), Near Control and Far Control (±SE) during the 2015 Crustacean Surveys

Analyses 2012-2015:

Lobster Abundance

Total lobster CPUE was significantly different between the NTZ and Near Control ("protection") and between years ("years") (Two-way ANOVA, protection p=0.001, years p<0.001; Figure 13a). Legal-sized lobster CPUE was significantly different between the NTZ and Near Control ("protection") but was not significantly different between years ("years") (Two-way ANOVA, protection p<0.001, years p=0.140; Figure 13b).

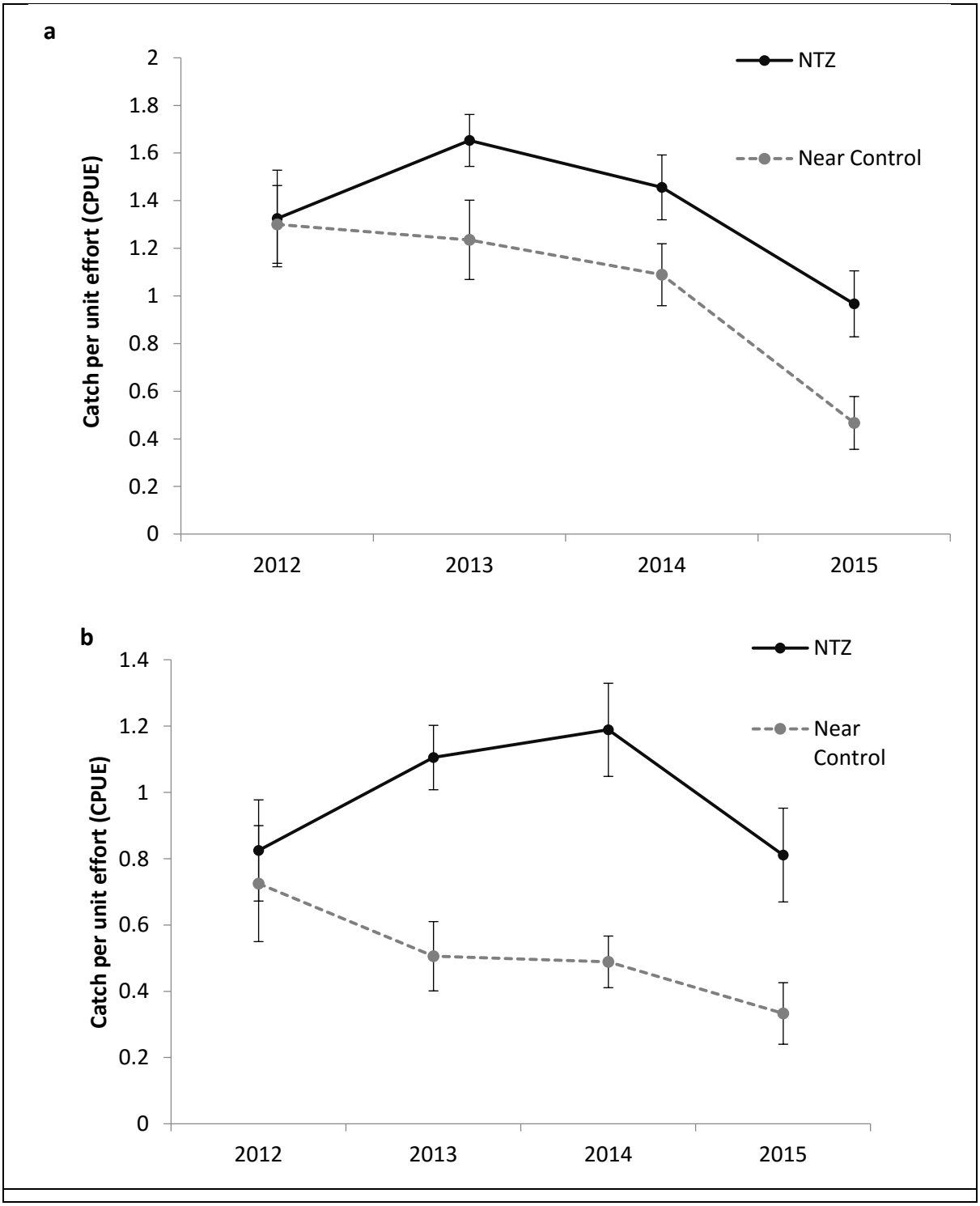
a
Catch per unit effort (CPUE)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2012
2013
2014
2015
NTZ
Near Control
b
Catch per unit effort (CPUE)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2012
2013
2014
2015
NTZ
Near Control

Figure 13. Catch per Unit Effort (CPUE) for **(a)** all lobsters and **(b)** legal-sized lobsters (carapace length ≥ 87mm) across Crustacean Surveys from 2012 to 2015 for the NTZ and Near Control (± SE)

Lobster Growth and Movement:

A total of 832 lobsters were caught and tagged during annual crustacean surveys conducted from 2012 to 2015. 67 of these were recapture events, generating a recapture rate of 8%. Additionally, 11 tagged lobsters were reported as caught during local creel fishing in 2013. Therefore total recaptures numbered 78, with 55 recaptures occurring in the NTZ and 23 in the Near Controls.

Out of the total 78 recaptures, excluding those where estimated growth could have been attributable to human error during measurement, 21 individuals had moulted since the previous capture and averaged a carapace length growth rate of 0.89mm per month (±0.07 SE). 19 of these individuals were caught within the NTZ and averaged a carapace growth length of 0.88mm per month (±0.07 SE), the remaining two caught in the Near Controls averaged a carapace growth length of 1.05mm per month (±0.27 SE). Given the skew towards frequency of moulted individuals in the NTZ, no further analysis was possible.

Excluding one individual due to absent previous data, four individuals are recorded as having moved into the NTZ and three having moved out, equating to a net movement rate of 1.3% between 2012 and 2015. The mean minimum distance moved for recapture events for the same time series was: total 0.66km (±0.12 SE), NTZ 0.48km (±0.06 SE) and Near Control 1.66km (±0.35 SE). This proved to be significantly different (Mann-Whitney-Wilcoxon test, U=873, p=0.005).

Discussion:

Velvet Crab:

This study found the mean CPUE of velvet crab to be significantly higher in the NTZ compared to both controls. This is congruent with results from Dubois (2013) and Judge (2014), with only Gratton's (2013) dataset exhibiting lower CPUE within the NTZ. Dubois speculated that increased abundance in the NTZ may be attributable to habitat types and associated assemblages of competitors on the northern shore of the NTZ. However, the 2015 surveys were located exclusively along the southern shore of the NTZ which challenges this notion. Mean velvet crab carapace length was significantly larger (1.79mm) in the NTZ compared to the Near Control, which is consistent with results from Dubois (2013) and Gratton (2013). Without a baseline dataset it is hard to attribute either of these differences solely to protection by the NTZ. As little information exists on the movement patterns of velvet crab, it is possible they may instead be linked to natural population or environmental variation.

Brown Crab:

Brown crabs were found to be significantly smaller and less abundant in the NTZ compared to the Near Control. This is consistent with Judge (2014) and Gratton (2013), but counter to Dubois (2013). Intriguingly, differences in CPUE for legal-sized brown crab were even more pronounced, being 59.1% lower in the NTZ. This indicates a significant difference in population size/age structures, with fewer larger individuals present within the NTZ. It is possible that higher abundances of larger lobsters may be suppressing crabs by outcompeting them for resources (Hoskin *et al.,* 2011).

However, it is also possible that, due to high seasonal migration distances (Tully *et al.,* 2006), the relatively small Lamlash Bay NTZ does not confer adequate protection to brown crabs. Additionally, local creelers 'fishing the line' (Kellner *et al.,* 2007; Iain Cossack, pers.comms, 2015) for lobster spillover from the NTZ may be placing a disproportionate amount of pressure on crabs in proximity to the NTZ. To investigate these possibilities, size analyses of brown crabs at Far Control sites are recommended. These would ideally be conducted prior to implementation of the Arran South MPA in order to provide a baseline.

Lobsters:

Lobsters within the NTZ are getting increasingly larger. The mean size of lobsters caught in the NTZ during annual crustacean surveys is following a steady upwards trajectory: 92.31mm in 2013 (Gratton, 2013), 96.54mm in 2014 and 99.52mm in 2015 (Table 1). Indeed, in 2015 the largest lobster recorded in four years of surveying (carapace length = 135mm) was caught in the NTZ. This study consequently further supports a key finding of all three previous surveys, that the NTZ is providing effective protection against longevity overfishing (Diekert, 2012).

Counterintuitively, total mean CPUE was not significantly different between the NTZ and Far Control in 2015. This is the first time in the survey series this has occurred, and may be connected to passive fishing observations covering more and novel/farther Far Control sites than previously included. The NTZ did however have a significantly higher CPUE compared to the Near Control. Legal-sized lobster CPUE was significantly higher in the NTZ compared to both Near and Far Controls. The Far Control harboured the lowest abundance of legal-sized lobsters with a CPUE of 0.25 (±0.01 SE) compared the NTZ's 0.81 (±0.14 SE).

Both the mean size of all lobsters and the CPUE of legal-sized lobsters showed a significant negative correlation with distance from the NTZ boundary. This provides positive evidence of spillover effects from the NTZ benefiting surrounding the areas. Viewing the population size-structures alongside legal CPUE and total CPUE data, suggests targeted lobster fishing along the NTZ boundary. Such

'fishing the line' seeks to harness improved catch-rates as a result of spillover from a protected area. If occurring, this may explain suppressed lobster abundance in the Near Control despite population size-structure being enhanced. Such behaviour however, may be unintentional as creelers operating out of Arran do fish the near Control throughout the year. Far Controls are fished only during the summer months due to weather constraints (Iain Cossack, pers.comms, 2015).

Analyses of biomass revealed that WPUE for total lobsters was significantly higher (87.5%) in the NTZ compared to the Far Control. This is despite CPUE for the same lobsters being non-significantly different. Legal-sized lobster WPUE saw an even more pronounced difference with 346.9% more WPUE in the NTZ versus the Far Control. Therefore, while potential ROPUE was not significantly different between the NTZ and Far Control in terms of egg production, lobster reproductive output in the NTZ may be higher than estimated. This is because larger individuals contribute disproportionately more fecundity to a population via larger and healthier eggs (Tully et al., 2001; Agnalt, 2008) in addition to just the absolute number. Furthermore, the arbitrary cut off of minimum carapace length 81mm may not accurately reflect mean sexual onset of maturity for female lobsters in the Firth of Clyde (Lizárraga-Cubedo et al., 2003). Determining mean sexual onset on maturity for lobster populations in the Clyde will maximise accuracy of fecundity analyses.

There was no significant difference between prevalence of disease in the NTZ and the Near Control. This has remained constant since 2012 and it is believed that shell disease inflicts minimal damage on hosts (Wootton *et al.,* 2012). The overall occurrence of damage/injury was found to not be significantly different however, there were significantly more individuals with claw damage inside the NTZ versus the Near Control. As abundance and size data suggests spillover, likely resulting from increased density, it follows there would be more territorial disputes. Therefore, heightened levels of claw damage may provide another signal for elevated lobster abundance in the NTZ. These results

show density is not adversely affecting lobster population health, counter to the findings of Wootton *et al*., (2012).

CPUE and legal CPUE initially appear to demonstrate a negative trend for both the NTZ and Near Control over the time series. However, the sampling year was not a significant influencing factor of legal-sized CPUE whilst the presence of NTZ protection was. Ultimately however, North Atlantic sea temperatures have been >2^{o}C throughout the summer this year (Met Office, 2015) which may have dramatically reduced lobster movements. Fishermen throughout the Clyde have been commenting on this year's particularly poor catch-rates (pers.comms, Bryce Stewart) and hold the dramatic climatic shift accountable (pers.comms, Iain Cossack).

Recaptures revealed that lobsters do move between the NTZ and Near Controls, and that there is the reasonable potential for moving individuals to exceed 2km (*n*=8). Based on this, future studies may wish to focus on a higher resolution of Near Control sites up to ~3km away from the NTZ boundary to better assess levels of NTZ overspill. Whilst lobsters caught in the Near Control did move significantly further than those caught in the NTZ, this is likely non-comparable given the small NTZ sampling area and relatively large distances between Near Control sites.

Conclusions:

The Lamlash Bay NTZ is facilitating lobster population recovery. Lobsters inside the NTZ are exhibiting classic signs of recovery, most notably an increasing size and abundance of larger individuals. This appears to be spilling over into adjacent areas, restoring population size-structures. However, there may be evidence of "fishing the line" reducing abundance of lobsters immediately outside the NTZ. Velvet crabs may be receiving the benefits of protection but this is hard to discern. Brown crabs may be adversely affected at a local scale due to a combination of increased lobster competition and targeted "fishing the line" along the NTZ boundary. The implications for management are to consider the creation of a buffer zone to help reduce edge effects (Harris, 1988). Alternatively, key influential stakeholders such as the Community of Arran Seabed Trust (COAST) could make local fishermen aware of the possible consequences of "fishing the line". This could generate good self-management without the need for a lengthy legislative process. At a wider scale, given the early success of this NTZ, the Scottish Government should consider establishing a coherent network of MPAs. Results from Lamlash Bay NTZ indicate this could be for the mutual benefit of both conservation and fishery management.

Word Count: 4995

Acknowledgements

Firstly, I would like to thank Tim James and Iain Cossack from Creelers. Without their expertise and the use of their creeling boat, the Julie Anne TT268, this year's crustacean surveys would not have been possible. In particular, I wish to thank Iain for his tireless enthusiasm, insightful comments and the many cups of tea brewed! I am also very grateful to Andrew Binnie and Andrew Telford from COAST. They acted as a superb source of information on local marine policy, made the office a welcoming environment, and filled my calendar social events. Many thanks to the Kilfinan Trust who helped fund COAST NTZ research. I would also like to acknowledge all of my MSc. MEM predecessors (Matthew Judge (2014), Paul Gratton (2013), Pascal Dubois (2013) and Ross Greig (2011)) for their work and contribution to the survey datasets. Thanks too to Jennifer Stark and Jessica Roberts for their assistance in gathering survey data. A special thanks is owed to Jim Henderson for giving me a place to stay on Arran that felt like home. Finally, I would like to give the biggest thanks to my supervisor, Dr Bryce Stewart. Bryce brought me up to speed on all things decapod, prepared BBQ scallops and taught me how to wrangle lobsters without losing any fingers.

Examination No. Y3587129

Disclaimer

I hereby declare that this MSc. Marine Environmental Management Summer Placement 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.

……. …….

Brian James Christie 20/09/2015

Extra-Curricular Activities: During my time on placement I assisted COAST with a number of community outreach events to raise awareness of and promote education about marine conservation:

- Joined the COAST team for a shore scramble at Kildonan (13th July). I helped identify the species we discovered and provided ecological/ biological background information.
- Manned the COAST stall and sea life touch tank at the Lamlash Heather Queen festival (18th July), Arran Farmer's Show (5th August) and Arran Highland Games (8th August). I helped gather animals for the touch tank, set up and pack up the stall. Time at these events was split between: educating children and parents about touch tank inhabitants, speaking to the public about marine conservation around Arran and operating the small shop.
- Helped local and holiday children make arts and crafts sea animals to use in a short puppet show on marine conservation. I then donned my costume to become Ollie the Oystercatcher, and narrated COAST's first ever craft day puppet show (31st July).
- Interviewed by Don Currie from Scotland Outdoors magazine on my work with COAST and marine conservation in general. Liaised with reporters from the New York Times and the French magazine GEO about the crustacean research surveys.

Extra-curricular photos) Lamlash Heather Queen (top left), Arran Highland Games (top right) and COAST's Craft Day (bottom left and bottom right)

MEM Summer Placement 2015 – Counting Lobsters on the Isle of Arran

I have worked in marine conservation overseas many times before, but never had the opportunity work in the UK. That all changed with my MEM Summer placement when I travelled north to work with the Community of Arran Seabed Trust (COAST), in Scotland.

Just another day *on* the office

COAST is a fantastic, community led organisation with an impressive track record for getting marine conservation done – so I was very excited to work with them! My project was a continuation of ongoing

research investigating how Scotland's first No-Take-Zone (NTZ) is benefitting decapod crustaceans like the European lobster.

My time was split between conducting field research aboard a local creeling vessel, analysing data in the office and volunteering with COAST at their numerous community outreach events… if I am unlucky, a video of me as Ollie the Oyster Catcher (narrating a children's puppet show) will surface on YouTube!

I feel this varied and challenging experience has bolstered my C.V. and given me plenty of valuable research skills to take with me on my career.

Inspiring the next generation of 'MEMers'

With my masters drawing to a close, the next step will be working with York lecturer Bryce Stewart, to help publish the crustacean surveys and hopefully get my name into some reference lists.

However, it wasn't all hard work – there was plenty of time to explore the island and pretend to be a Viking!

Largest lobster caught in Lamlash Bay NTZ!

~ Brian Christie

References:

Agnalt, A.L. (2008). Fecundity of the European lobster (Homarus gammarus) off southwestern Norway after stock enhancement: do cultured females produce as many eggs as wild females? *Ices Journal of Marine Science,* Vol. 65, Issue 2, pp. 164-170

Ashworth, J. S. and Ormond, R. F. G. (2005). Effects of fishing pressure and trophic group on abundance and spillover across boundaries of a no-take zone. *Biological Conservation*, Vol. 121, Issue 3, pp. 333-344

Beukers-Stewart, B. D., Vause, B. J., Mosley, M. W., Rossetti, H. L. and Brand, A. R. (2005). Benefits of closed area protection for a population of scallops. *Marine Ecology Progress Series*, Vol. 298, Issue 15, pp. 189-204

Boudreau, S. A. and Worm, B. (2012). Ecological role of large benthic decapods in marine ecosystems: a review. *Marine Ecology Progress Series,* Vol. 469, pp. 195-213

COAST, Community of Arran Seabed Trust. (2006). Caught in time (Video Documentary). [Online] Available from: https://www.youtube.com/playlist?list=PLR3_riD2VR2hrc8BsuZmF7RbY2daHHdcp [Accessed: 14th September 2015]

Daskalov, G. M., Grishin, A. N., Rodionov, S. and Mihneva, V. (2007). Trophic cascades triggered by overfishing reveal possible mechanisms of ecosystem regime shifts. *Proceedings of the National Academy of Sciences*, Vol. 104, No. 25, pp. 10518-10523

Davies, R. W. D., Cripps, S. J., Nickson, A., & Porter, G. (2009). Defining and estimating global marine fisheries bycatch. *Marine Policy*, Vol. 33, No. 4, pp. 661-672

Didham, R. K., Tylianakis, J. M., Hutchinson, M. A., Ewers, R. M. and Gemmell, N.J. (2005). Are invasive species the drivers of ecological change. *Trends in Ecology and Evolution*, Vol. 20, pp. 470–474

Diekert, F. K. (2012). Growth Overfishing: The Race to Fish Extends to the Dimension of Size. *Environmental & Resource Economics,* Vol. 52, Issue 4, pp. 549-572

Dubois, P. (2013). *The Response of Commercially Exploited Crustaceans to Protection in Scotland's First No Take Zone – Lamlash Bay, Isle of Arran*, University of York

Follesa, M. C., Cuccu, D., Cannas, R., Sabatini, A. and Cau, A. (2007). Emigration and retention of Palinurus elephas (Fabricius, 1787) in a central western Mediterranean marine protected area. *Scientia Marina*, Vol. 71, Issue 2, pp. 279-285

FAO, Food and Agriculture Organisation of the United Nations, Fisheries Department. (2014).*The state of world fisheries and aquaculture*. Rome

Galil, B. S. (2007). Loss or gain? Invasive aliens and biodiversity in the Mediterranean Sea. *Marine Pollution Bulletin*, Vol. 55, Issue 7, pp. 314-322

García-Charton, J. A., Pérez-Ruzafa, A., Marcos, C., Claudet, J., Badalamenti, F., Benedetti-Cecchi, L., Falcón, J. M., Milazzo, M., Schembri, P. J., Stobart, B., Vandeperre, F., Brito, A., Chemello, R., Dimech, M., Domenici, P., Guala, I., Le Diréach, L., Maggi, E. and Planes, S. (2008). Effectiveness of European Atlanto-Mediterranean MPAs: Do they accomplish the expected effects on populations, communities and ecosystems? *Journal for Nature Conservation*, Vol. 16, Issue 4, pp. 193-221

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

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

Halpern, B. S., Lester, S. E. and McLeod, K. L. (2010). Placing marine protected areas onto the ecosystem-based management seascape. *Proceedings of the National Academy of Sciences*, Vol. 107, Issue 43, pp. 18312-18317

Harris, L. D. (1988). Edge effects and conservation of biotic diversity. *Conservation Biology*, Vol. 2, Issue 4, pp. 330-332

Heath, M. R. and Speirs, D. C. (2011). Changes in species diversity and size composition in the Firth of Clyde demersal fish community (1927–2009). *Proceedings of the Royal Society of London B: Biological Sciences*, doi:10.1098/rspb.2011.1015

Hoskin, M. G., Coleman, R. A., Von Carlshausen, E. and 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*, Vol. 68, Issue 2, pp. 185-200

Howarth, L. (2014). *Measuring the effects of Scotland's first fully protected marine reserve* (Doctoral dissertation, University of York)

Howarth, L. M. (2012). Exploring the fishery and ecological effects of Lamlash Bay no-take zone. *Science report for Community of Arran Seabed Trust*.

Howarth, L. M., Roberts, C. M., Thurstan, R. H. and Stewart, B. D. (2013). The unintended consequences of simplifying the sea: making the case for complexity. *Fish and Fisheries*, Vol. 15, Issue 4, pp. 690-711

Hughes, T. P., Bellwood, D. R., Folke, C., Steneck, R. S. and Wilson, J. (2005). New paradigms for supporting the resilience of marine ecosystems. *Trends in ecology & evolution*, Vol. 20, Issue 7, pp. 380-386

Judge, M. (2014). *Response of decapod Crustaceans to protection within the Lamlash Bay No-take Zone, Scotland,* University of York

Kellner, J. B., Tetreault, I., Gaines, S. D. and Nisbet, R. M. (2007). Fishing the line near marine reserves in single and multispecies fisheries. *Ecological Applications*, Vol. 17, Issue 4, pp. 1039-1054

Leslie, B., S. Henderson, and D. Riley. (2006). Lobster stock conservation: V-Notching. *Fisheries Development Note*, No. 22, Scalloway, Shetland

Lizárraga-Cubedo, H. A., Tuck, I., Bailey, N., Pierce, G. J. and Kinnear, J. A. M. (2003). Comparisons of size at maturity and fecundity of two Scottish populations of the European lobster, Homarus gammarus. *Fisheries Research*, Vol. 65, Issue 1, pp. 137-152

Løkkeborg, S. (2005). *Impacts of trawling and scallop dredging on benthic habitats and communities* (No. 472). Food & Agriculture Organisation

Marine Scotland. (2012). *Fish and Shellfish Stocks (2012 Edition)*, Marine Scotland Science, Scottish Government. [Online] Available from: http://www.gov.scot/Publications/2012/05/9899 [Accessed: 1st September 2015]

Marine Scotland. (2013). *Fish and Shellfish Stocks (2013 Edition)*, Marine Scotland Science, Scottish Government. [Online] Available from: http://www.gov.scot/Publications/2013/09/6505 [Accessed: 1st September 2015]

Marine Scotland. (2014). *Fish and Shellfish Stocks (2014 Edition)*, Marine Scotland Science, Scottish Government. [Online] Available from: http://www.gov.scot/Publications/2014/09/5642 [Accessed: 1st September 2015]

Marine Scotland. (2015). *Fish and Shellfish Stocks (2015 Edition)*, Marine Scotland Science, Scottish Government. [Online] Available from: http://www.gov.scot/Publications/2015/05/4861/0 [Accessed: 1st September 2015]

McIntyre, F., Fernandes, P. G. and Turrell, W. R. (2012). Clyde ecosystem review. *Scottish Marine and Freshwater Science Report, Marine Scotland Science, Edinburgh*

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,* Vol. 39, Issue 2, pp. 353-363

National Research Council. (2001). Marine protected areas: tools for sustaining ocean ecosystems. Washington, DC: National Academy Press

Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., Watson, R. and Zeller, D. (2002). Towards sustainability in world fisheries. *Nature*, Vol. 418, Issue 6898, pp. 689-695

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., Doukakis, P., Fluharty, B., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel, M., McAllister, M. K., Pope, J. and Sainsbury, K. J. (2004). Ecosystem-based fishery management. *Science,* Vol. 305, No. 5682, pp. 346-347

Sciberras, M., Jenkins, S. R., Kaiser, M. J., Hawkins, S. J. and Pullin, A. S. (2013). Evaluating the biological effectiveness of fully and partially protected marine areas. *Environmental Evidence*, Vol. 2, Issue 4, pp. 1-31

Smith, S. J. and Tremblay M. J. (2003). Fishery-independent trap surveys of lobsters (Homarus americanus): design considerations. *Fisheries Research,* Vol. 62, Issue 1, pp. 65-75

SNH, Scottish Natural Heritage. (2015). South Arran Marine Protected Area. [Online] Available from: http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/national-designations/mpas/mpa-arr/ [Accessed 2nd September 2015]

Srinivasan, U. T., Watson, R. and Sumaila, U. R (2012). Global fisheries losses at the exclusive economic zone level, 1950 to present. *Marine Policy,* Vol. 36, Issue 2, pp. 544-549

Met Office. (2015). So what happened to our summer? [Online] Available from: http://blog.metoffice.gov.uk/2015/08/28/so-what-happened-to-our-summer/ [Accessed: 12th September 2015]

Thrush, S. F., and Dayton, P. K. (2002). Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. *Annual Review of Ecology and Systematics*, Vol. 33, pp. 449-473

Thurstan, R.H and Roberts, C.M. (2010). Ecological Meltdown in the Firth of Clyde, Scotland: Two Centuries of Change in a Coastal Marine Ecosystem. *PLoS ONE*, Vol. 5, Issue 7, e11767

Tully, O., Roantree, V. and Robinson, M. (2001). Maturity, fecundity and reproductive potential of the European lobster (Homarus gammarus) in Ireland. *Journal of the Marine Biological Association of the United Kingdom,* Vol. 81 Issue 1, pp. 61-68

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)

Watson, R., Cheung, W. W.L., Anticamara, J. A., Sumaila, R. U., Zeller, D. and Pauly, D. (2012). Global marine yield halved as fishing intensity redoubles. *Fish and Fisheries*, Vol. 14, pp. 493–503

Williams, G. C. (1975). Sex and Evolution. Princeton University Press

Williamson, D. H., Russ, G. R. and Ayling, A. M. (2004). No-take marine reserves increase abundance and biomass of reef fish on inshore fringing reefs of the Great Barrier Reef. *Environmental Conservation*, Vol. 31, Issue 2, pp. 149-159

Wootton, E. C., et al. (2012). Increased Disease Calls for a Cost-Benefits Review of Marine Reserves. *PLoS ONE,* Vol. 7, Issue 12, e51615

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., Jackson, J. B. C., Lotze, H. K., Micheli, F., Palumbi, S. R., Sala, E., Selkoe, K. A., Stachowicz, J. J. and Watson, R. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science,* Vol. 314, No. 5800, pp. 787-790