Cape Rodney to Okakari Point Marine Reserve and Tawharanui Marine Reserve Lobster (*Jasus edwardsii*) Monitoring Programme: 2014 Survey

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Summary

- In 2014, spiny lobster (*Jasus edwardsii*) population abundance and size was evaluated at sites within Cape Rodney to Okakari Point Marine Reserve (CROP), Tawharanui Marine Reserve (TMR), and unprotected control sites (NR). This survey was the eighth for CROP and NR and the second for TMR under a formal monitoring programme established in 2000. Sampling was last undertaken within CROP, TMR, and NR in 2009.

- Mean lobster abundance in 2014 was highest within TMR (10.6 lobsters per 500 m^2 (± 1.9 SE)), followed by CROP (7.6 lobsters per 500 m^2 (± 1.5 SE)), and these abundances were considerably higher than for the NR sample population (1.1 lobsters per 500m^2 (± 0.24 SE)). Statistical analysis indicated that *Jasus edwardsii* abundance within TMR and CROP were 7.9 ($CL_{95\%}$ = 2.9, 20.9) and 5.3 ($CL_{95\%}$ = 2.0, 17.9) times higher the NR sample population. Abundance levels within CROP and TMR in 2014 were lower than those recorded in 2009, predominantly due to a reduction in sub-legal individuals. *Jasus edwardsii* abundance within CROP and NR remained substantially lower than abundance levels recorded in 1995.

- Mean lobster size in 2014 derived from carapace length estimates was highest within TMR at 126 mm (± 3.8, $CI_{95\%}$), followed by CROP at 118 mm (± 4.5, $CI_{95\%}$), and 86 mm (± 6.1, $CL_{95\%}$) for the NR sample population.

- Both CROP and TMR supported higher mean abundances of legal-sized (carapace length $\geq$ 95mm) lobster compared to the NR sample population in 2014 and these differences were statistically significant. For CROP, the mean legal-sized abundance of 5.5 (± 0.9 SE) per 500m^2 was 18.3 ($CL_{95\%}$ = 29.4, 35.7) times higher than NR; whereas for TMR, the legal-sized abundance of 10.6 (± 0.86 SE) per 500m^2 was 35.3 ($CL_{95\%}$ = 18.2, 68.5) times higher than NR.

- Mean lobster biomass in 2014 derived from carapace length estimates was highest within TMR at 7.8 kg (± 1.5, SE) followed by CROP at 5.2 kg (± 1.0, SE), whereas biomass for the NR sample population was at 0.21 kg ((± 0.1, SE).

- The consistently low abundance and smaller size of lobsters at unprotected (NR) sites reflects sustained fishing pressure in the Leigh area. This has been particularly evident in a progressive decline in abundance of legal-sized lobsters since 2000 at the majority of non-reserve sites sampled. It is unlikely that lobster abundance will increase markedly in fished areas in the near future unless fishing effort is reduced, or recruitment increases markedly.

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1.0 Introduction

The spiny rock lobster *Jasus edwardsii* is an ideal species to use in establishing the effectiveness of marine reserves and evaluating the effects of fishing, as *Jasus edwardsii* has responded positively to protection in a number of New Zealand marine reserves (Cole *et al.* 1990, MacDiarmid and Breen 1993, Kelly *et al.* 2000, Shears *et al.* 2006, Freeman *et al.* 2012). *Jasus edwardsii* have significant cultural and economic value, giving them wide public appeal and are conspicuous and important components of subtidal rocky reefs. *Jasus edwardsii* are considered to be high-level predators that consume a wide variety of prey including echinoids, molluscs, and bivalves and in turn are prey for a suite of species including octopus and a variety of fish (Andrew and MacDiarmid 1999). Evidence suggests that predation by *Jasus Edwardsii*, particularly on the urchin *Evechinus chloroticus,* may play a major role in structuring subtidal reef communities (Babcock *et al.* 1999, Shears and Babcock 2002, Shears and Babcock 2003).

The Cape Rodney to Okakari Point (CROP) Marine Reserve (commonly known as the Leigh Marine Reserve, established in 1975) is New Zealand's oldest and eminent marine reserve. Prior to 2000, the only information on the state of the CROP Marine Reserve lobster population was obtained from *ad hoc* surveys conducted to examine specific research questions (Cole *et al.* 1990, MacDiarmid 1991, 1994, MacDiarmid and Breen 1993, Kelly *et al.* 2000, Shane Kelly unpublished data). These surveys occurred infrequently and could not be used as a reliable means of monitoring the reserve lobster population. The Department of Conservation therefore established a formal monitoring programme for *Jasus edwardsii* in May 2000. The Cape Rodney to Okakari Point Marine Reserve Lobster Monitoring Programme provides the Department with information on the current status of the protected lobster population, monitors trends in population parameters through time, and is capable of alerting reserve managers to issues that may require a management response, such as compliance. The methods used in the survey were standardised with those developed during previous surveys of the CROP Marine Reserve and at least 4 other protected areas, to allow broader scale (100s km) generalisations about the effects of protection on lobster populations.

Between 1995 and the inception of the formal monitoring programme in 2000, *Jasus edwardsii* abundance within CROP declined from approximately 40 lobsters per 500 m^2 to around 10 lobsters per 500 m^2 and by 2001, abundance levels were approximately 5 lobsters per 500 m^2. A similar rate of decline was observed outside of the reserve reducing from 10 lobsters per 500 m^2 in 1995 to around 2 lobsters per 500m^2 in 2000. Subsequent surveys between 2001 and 2009 have quantified a modest recovery of *Jasus edwardsii* (Haggitt and Mead 2006, 2009). This report details the results of the eighth lobster survey of the CROP Marine Reserve and unprotected control sites under this programme. It also marks the second survey of Tawharanui Marine Reserve, which was added into the programme in 2009. Tawharanui Marine Reserve (TMR) is located approximately 12 km south of CROP at the southern end of Big Omaha Bay. Tawharanui Marine Reserve was initially established as a marine park in 1981 before becoming a marine reserve in 2011, concomitant with a slight modification of the offshore and western boundaries.

The principle objectives of the Lobster Monitoring Programme are to:

- Determine the current population status of *Jasus edwardsii* within CROP and TMR;
- Compare lobster size and abundance within CROP and TMR with equivalent unprotected control sites (NR);
- Compare trends in lobster populations through time within CROP Marine Reserve, relative to unprotected control sites (NR).

2.0 Methodology

2.1 Sampling design

The 2014 survey of *Jasus edwardsii* size and abundance within Cape Rodney to Okakari Point Marine Reserve (CROP), Tawharanui Marine Reserve (TMR) and the non-reserve (NR) sample area was undertaken between 28 May and 30 June 2014. As part of the lobster monitoring programme, lobster surveys of the CROP Marine Reserve have been carried out in 1995 and intermittently from 2000 to 2009. The 1995 survey included, 2 shallow (0 - 10 m) and 2 deep (>10 - 20 m) sites within the marine reserve, and 2 shallow and 2 deep unprotected control sites. Since 2000, an additional deep and shallow site has been surveyed inside and outside the marine reserve (Fig. 2.1). A total of 3 shallow and 3 deep sites in the reserve and non-reserve control area were considered the minimum required to meet the objectives of the program. It was chosen because previous surveys indicated that:

- The design had sufficient power to detect differences between reserve and non-reserve areas and would provide reliable estimates of lobster population parameters.
- The design was consistent with previous surveys and therefore allowed direct comparisons to be made with a historic data set.
- An ongoing monitoring program is more-likely to be maintained if costs are minimised.

A pre-2009 recommendation was to increase monitoring to incorporate Tawharanui Marine Reserve (TMR) into the sampling programme given its similar size and proximity to CROP. While lobster abundance within TMR has been surveyed previously (Shears *et al*. 2006), a survey undertaken in 2009 was the first to use a comparable sampling design to that used within and outside CROP, i.e., a total of 3 shallow and 3 deep sites (Fig. 2.1).

In order to eliminate seasonal effects and allow direct comparisons to surveys done elsewhere (e.g., Te Whanganui-a-Hei Marine Reserve), monitoring is conducted between May and June, which coincides with *Jasus edwardsii's* mating season. Several criteria were used in initial site selection for CROP, TMR, and NR (refer to Appendix 1.0 for site-specific details):

- Sites within each reserve were randomly selected from five potential shallow and deep sites;
- The sites contained reefs with suitable shelters for lobsters;
- The non-reserve sites were randomly selected from a number of possible sites in the area. Selection occurred prior to the survey with no knowledge of lobster abundance or population structure in the areas concerned;
- A maximum depth limit of 20 m was set to ensure repetitive, multi-day diving could be conducted safely.

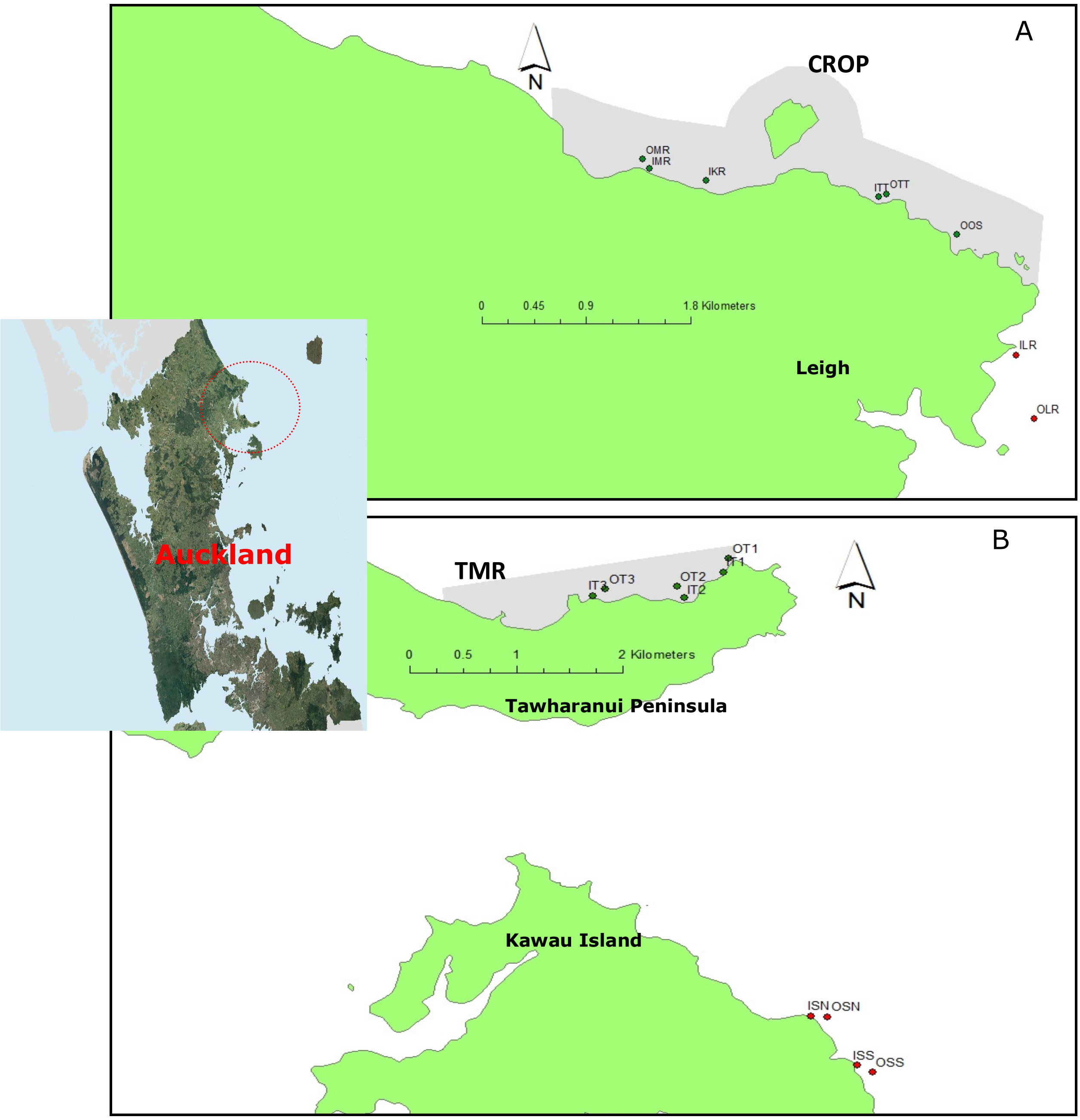

Figure 2.1. Map of the protected (green) and unprotected (red) sites included in the survey. Grey shading denotes approximate reserve boundaries for Cape Rodney to Okakari Point Marine Reserve (CROP - Map A) and Tawharanui Marine Reserve (TMR - Map B). Site abbreviations are as follows: OMR – Outer Martins Reef, IMR – Inner Martins Reef, IKR – Inner Knot Rock, ITT – Inner Table Top, OTT – Outer Table Top, OOS – Deep One Spot, ILR – Shallow Leigh Reef, OLR – Outer Leigh Reef, OT1 – Outer Tawharanui Site 1, IT1 – Inner Tawharanui Site 1, OT2 – Outer Tawharanui Site 2, IT2 – Inner Tawharanui Site 2, OT3 – Outer Tawharanui Site 3, IT3 – Inner Tawharanui Site 3 , ISN – Inner Slater North, OSN – Outer Slater North, ISS – Inner Slater South, OSS – Outer Slater South.

2.2 *Jasus edwardsii* abundance and size

Within all sites, five 50 m x 10 m (500 m^2) haphazardly placed transects were sampled. Haphazard sampling was used to ensure inter-annual samples were independent and allow data to be analysed with ANOVA-type techniques (which require independent samples), and provide an unbiased representation of lobster abundance at each site (see Creese and Kingsford 1998).

The size and, where possible, sex of lobsters within each transect were determined by visual estimation. The choice of the 50 m x 10 m transect and replication level were based on a pilot study conducted by MacDiarmid (1991) who compared the precision of 3 different transect sizes, 10 m x 10 m (n = 20), 25 m x 10 m (n = 8) and 50 m x 10 m (n = 4), each covering a total area of 2000 m^2. All transects provided a similar level of precision. Resultantly 50 m x 10 m transects (500 m^2) were chosen for this programme because they permitted at least one transect to be completed per dive in areas of high lobster abundance, and they limited the number of zero counts in areas of low lobster abundance. However, the replication level was increased from four (as per MacDiarmid 1991) to five transects per site, covering a total area of 2500 m^2.

Sex was determined using the dimorphic characteristics of male and female lobsters. Torches were used to aid in the sexing of lobsters and to ensure that lobsters in deep holes were not missed. All divers were required to estimate carapace length to within an average of 10 mm. This level of accuracy was achieved through a series of calibration dives where the size of individual lobsters was estimated, after which each lobster was caught by hand and measured with vernier callipers to obtain a true length measurement (Fig. 2.2). An analysis of covariance (ANCOVA) could not detect any significant difference between the size estimation ability of the three censors used in the survey, i.e., the slope was not significantly different from 1 ($P = 0.635$) and the y intercept did not differ significantly from 0. In northern New Zealand, the minimum legal size limit relating to the commercial and recreational *J. edwardsii* fishery occurs between 95 mm and 100 mm carapace length. For the purpose of this report, lobsters ≥ 95 mm carapace length were therefore considered to be legal and thus susceptible to fishing. *Note:* for customary fishing, a minimum size may or may not be specified by the Kaitiaki.

2.3 *Jasus edwardsii* biomass

To evaluate *Jasus edwardsii* biomass, size data for 1995-2014 surveys were converted to weight based on the equations of Saila *et al.* (1979) as follows:

Males = $\log_e W = -7.3611 + 2.92804 \log_e C$

Females = $\log_e W = -7.32429 + 2.93201 \log_e C$

2.4 Cohabitation and rocky reef habitat preference

In order to assess the degree of lobster cohabitation with CROP, TMR, and NR the number of lobsters within individual dens/shelters along each transect was recorded. In addition, the type of rocky reef habitat corresponding to *Jasus edwardsii* occurrence was recorded together with the extent of rocky reef habitat at 5m intervals along each transect. Rocky reef habitat was classified into six categories – these were: large boulder complexes (LBC); small boulder complexes (SBC), platform reef with vertical crevices (fissures) (PRC); platform reef with horizontal ledges (PRL); low lying platform reef with low complexity (PR); and cobble habitat (refer to Table 2.1 and Fig. 2.2).

Table 2.1. Rocky reef classification used to assign dominant rocky reef types when *Jasus edwardsii* were encountered along individual transects and to categorise dominant rocky reef habitat types at 5m intervals along individual transects.

Rocky reef type	**Description**
Large Boulder complex (LBC)	Boulders > 750 mm diameter. High to moderate complexity.
Small Boulder complex (SBC)	Boulders 250 mm – 750 mm diameter. High to moderate complexity.
Cobbles (C)	< 250 mm diameter. Moderate to low complexity
Platform reef with horizontal crevices (PRC)	Rock substrata with vertical crevices. Complexity ranging from high to moderate depending on crevice number, crevice depth, and crevice spatial extent.
Platform reef with horizontal ledges (PRL)	Rock substrata with horizontal ledges and undercuts, commonly at the base of vertical reef walls. Complexity ranging from high to moderate depending on ledge depth and ledge spatial extent.
Platform reef (PR)	Low lying platform reef with minimal topographic features and low complexity.

2.4 Data analysis

Abundance, size and biomass

Abundance and size data are generally presented graphically and unless otherwise stated, means are given ± their associated standard error (SE) or 95 % confidence intervals (CI). Two central univariate null-hypotheses underpin the basis of the monitoring programme. These are:

Ho_1: there is no statistically significant difference in the abundance and biomass of *Jasus edwardsii* among locations (CROP reserve, TMR, and non-reserve), depth strata (shallow versus deep) and Surveys (2000-2014-CROP; 2009-2014-TMR).

H*o*$_2$: there is no statistically significant difference in *Jasus edwardsii* size between locations (CROP reserve, TMR and non-reserve).

To investigate statistical trends in lobster abundance and biomass in 2014 between the three locations surveyed – CROP, TMR, and NR – count data were analysed with generalised linear mixed models (McCullagh and Nelder 1989) using R statistical software (R Development Core Team 2008). The model was back-fitted to a quasi-Poisson distribution (to account for over-dispersion) with a log-link function. Fixed factors in the analysis were Location (CROP, TMR and NR) and Depth (shallow versus deep), whereas the factor Site(Location×Depth) was treated as a random effect. Ratios of density (plus 95% confidence limits) based on relative odds ratios were calculated for the factor Location to provide an estimate of the size of the protection effect (if deemed statistically significant $\alpha = 0.05$). Differences in the abundance of legal and sub-legal lobsters among locations were also analysed with a generalised linear model, although depth was not included in the model. Previous survey data 1995-2009 were also analysed in this manner. All statistical significance levels corresponded to $\alpha = 0.05$. *Note*: for model outputs confidence limits associated with effects estimations are typically asymmetrical as they are calculated on the log-scale.

Differences in lobster size between CROP and TMR in 2014 were analysed with a paired-sample *t*-test (R Development Core Team 2008). Statistical comparisons with the NR size estimates were not made due to the low number of lobsters that were sized in 2014.

To investigate temporal abundance patterns between CROP and NR (2000-2014) and TMR and NR (2009-2014), univariate PERMANOVA analysis was undertaken on Log (x+1) transformed count data using a Euclidean distance measure (which is equivalent to traditional ANOVA (see Anderson *et al*. 2008)). Specifically we were interested in three main factors: 1) Survey (2000-2014 for CROP and NR; and 2009-2014 for TMR and NR); 2); Status (reserve versus non-reserve); and, 3) Depth (shallow versus deep) including associated second-order interactions. Individual analyses were run on full models (all effects) based on 4999 permutations.

To test for possible differences in habitat proportions among locations and between depths, multivariate PERMANOVA analysis was undertaken on arcsine transformed percent-cover data, again using a Euclidean distance measure and based on 4999 permutations.

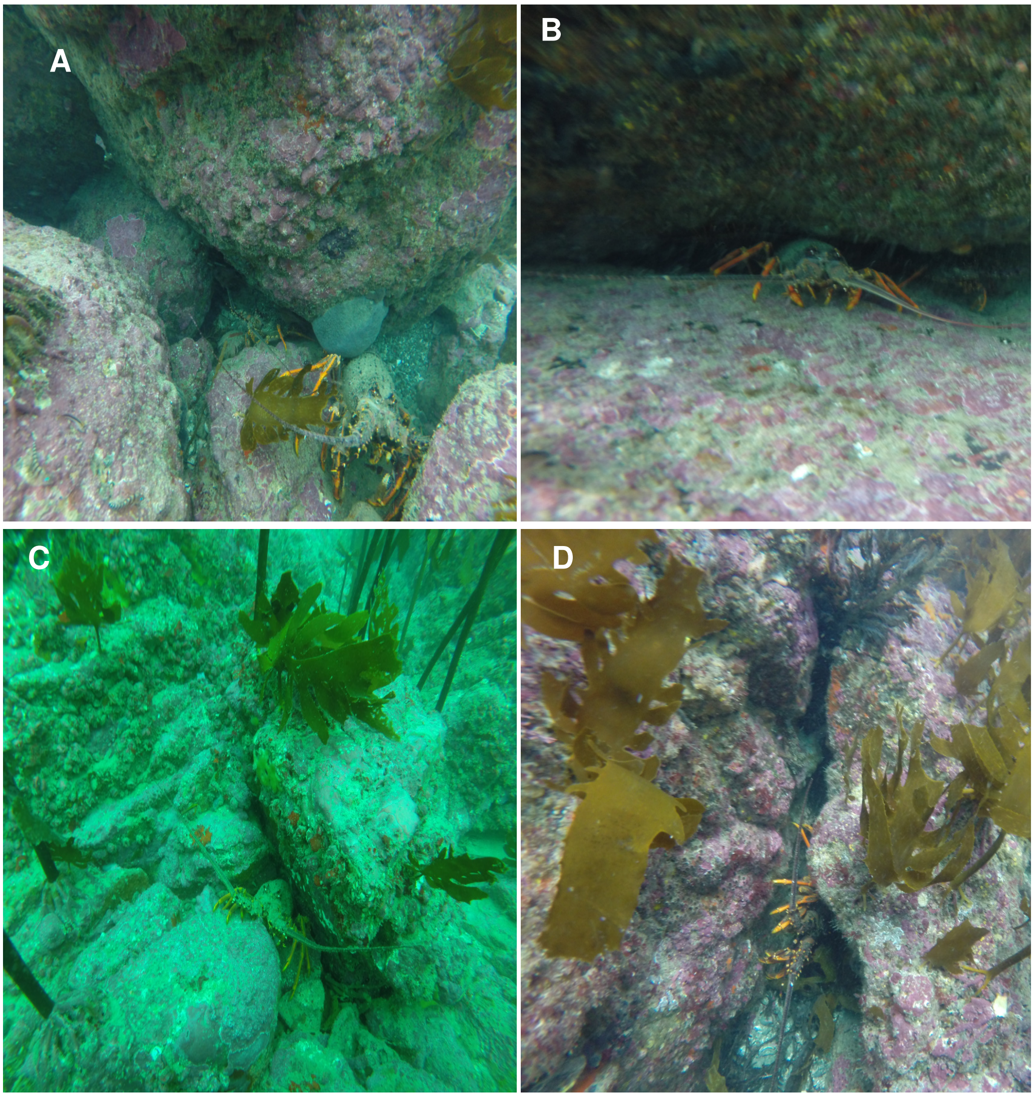

Figure 2.2. Examples of rocky reef habitat types where *Jasus edwardsii* were encountered. A = large boulder complexes (LBC); B = platform reef with horizontal ledges (PRL); C = small boulder complexes (SBC); D = platform reef with vertical crevices (fissures) (PRC).

Rocky reef habitat preference

To evaluate *Jasus edwardsii* habitat electivity (preference) Manly's alpha was calculated for each location (Manly 1974). Manly's alpha measures the proportion of resource usage, in this case rocky reef habitat type (Table 2.1), relative to the availability of that resource using the following formula:

$$\alpha_i = \frac{\frac{F_i}{H_i}}{\sum_{j=1}^{n} \frac{F_j}{H_j}} \qquad i = 1, \ldots, n \tag{1}$$

Where H is the proportional availability of a resource (i) in the environment, and F is the proportional usage of that resource. Resource use (α) ranges between 0 and 1. A value of 0 indicates resource i is never used, 1 indicates resource i is exclusively used, and 1/n indicates random use of resource i. Weighting was applied to account for variable habitat extents that may have biased results to a particular habitat type.

Cohabitation and rocky reef habitat preference

To evaluate aspects of *Jasus edwardsii* cohabitation the relationships between rocky reef habitat types and lobster size were examined graphically.

3.0 Results

3.1 *Jasus edwardsii* abundance, size and biomass

In 2014, mean *Jasus edwardsii* abundance (pooled across depths and sites) within CROP, TMR, and the non-reserve location (NR) was 7.6 lobsters per 500m^2 (± 1.5 SE), 10.6 lobsters per 500m^2 (± 1.9 SE), and 1.1 lobsters per 500m^2 (± 0.3 SE) respectively (Fig. 3.1). Within CROP and TMR, abundance levels were markedly lower than for the previous formal survey undertaken in 2009 (Fig. 3.1). For CROP, the period between 2001 and 2004 signaled a steady increase in *Jasus edwardsii* abundance, which subsequently plateaued (2006-2009) and thereafter declined (2009-2014). For the non-reserve location, lobster abundance has continued to remain at very low levels, i.e., < 2 lobsters per 500m^2. Both CROP and NR lobster populations remain substantially lower than abundances recorded in 1995 (Fig. 3.1).

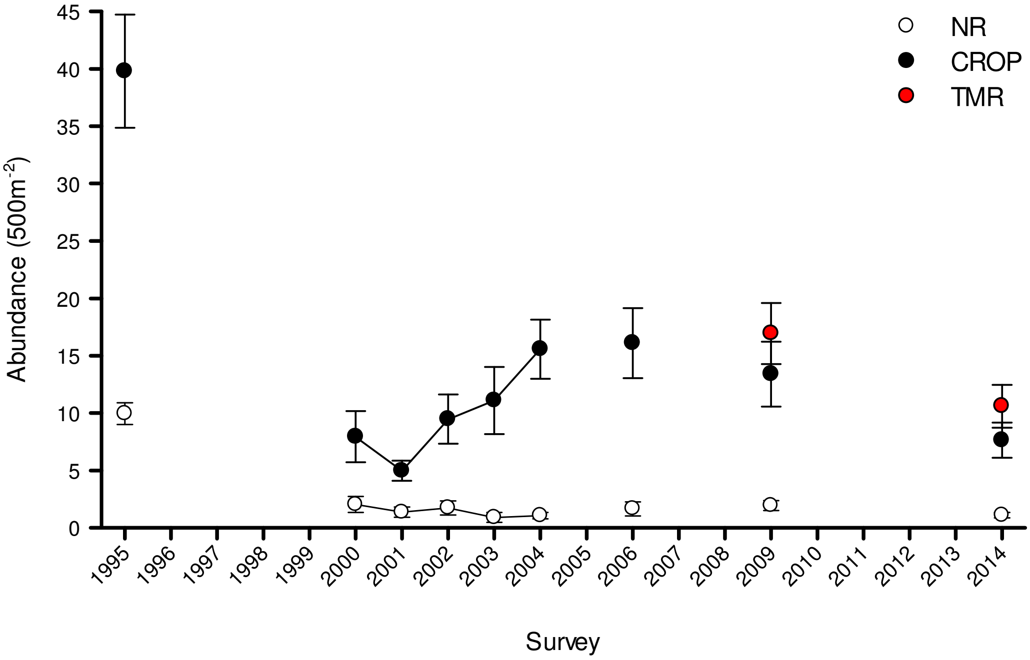

Figure 3.1. Abundance of *Jasus edwardsii* (± SE) pooled from survey sites within Cape Rodney to Okakari Point (CROP) Marine Reserve and non-reserve (NR) control sites between 1995 and 2014; and, for Tawharanui Marine Reserve (TMR) between 2009 and 2014. Data are mean values ± SE. *Note*: 1995 data are pooled from 4 sites within CROP and 4 sites outside the reserve, whereas subsequent data are pooled from 6 sites within each reserve and 6 sites outside.

Analysis of 2014 abundance data indicated a statistically significant difference among locations (CROP, TMR, and NR; $P<0.001$), although the main factor Depth and the Depth×Location interaction were not statistically significant. The random effect in the model Site(Depth×Location) was also statistically significant ($P<0.0001$) reflecting the high variability in lobster abundance among sites, between depths, and across locations. Estimates of effect sizes for reserve locations, based on relative odds ratios, indicated that 2014 lobster abundance within CROP was 6.9 ($CL_{95\%}$ = 2.7, 18.1) times higher than non-reserve levels; whereas lobster abundance within TMR was 9.6 ($CL_{95\%}$ = 3.7, 24.7) times higher than non-reserve levels. Refer to Table 3.1 for Reserve:Non-reserve (R:NR) effect sizes for previous surveys.

As evident from previous surveys, *Jasus edwardsii* abundance within CROP remained highly variable among sites and between depths surveyed in 2014, with shallow-water sites generally having higher lobster abundance than deep-water sites (Fig. 3.2a). At a site specific level, *Jasus edwardsii* has consistently attained highest abundances at Inner Table Top followed by Inner Martins Reef and Inner Knott Rock, sites all < 10m depth. While this trend was still apparent, abundance levels in 2014 were lower those recorded for the 2004-2009 period, being similar to those recorded for both 2000 and 2002 surveys. This pattern was also true for deep-water sites within CROP (Fig. 3.2a).

Mirroring site-specific trends for CROP, *Jasus edwardsii* within TMR exhibited reduced abundances relative to the initial 2009 survey at all shallow-water sites (Fig. 3.2b). In contrast, between-survey trends were variable across deep-water sites with *Jasus edwardsii* decreasing at OT1, increasing slightly at OT2, and remaining stable at OT3 (Fig. 3.2b). Shallow-water sites within TMR were characterised by greater lobster abundance than deep-water sites surveyed, with highest levels occurring at IT2 (25.4 lobsters 500 m^{-2} ± 7.3 (SE)) being consistent trend-wise with the 2009 survey.

Based on the limited data available, *Jasus edwardsii* exhibited reduced abundance at all non-reserve sites surveyed in 2014 (compared to 2009) (Fig. 3.2c), with no lobster recorded from Inner Slater South (ISS), again consistent with previous surveys. Typically *Jasus edwardsii* when present has generally attained higher abundance levels at deep-water sites e.g., Outer Leigh (OLR) Reef and Outer Slater South (OSS) (Fig. 3.2c) contrasting depth-related patterns within CROP and TMR.

Temporal analysis of *Jasus edwardsii* abundance for CROP and NR (2000-2014) based on PERMANOVA indicated that main factors in the model Survey and Depth were not statistically significant, although Status was highly statistically significant reflecting the consistently higher levels of *Jasus edwardsii* within CROP relative to NR across surveys (Table 3.2a). There was a marginally statistically significant Depth×Status interaction, which we interpret as being the result of lobster numbers changing at different rates among depths between reserve and non-reserve sample populations, i.e., deep-water sites within the NR sample population have tended to have higher abundance levels, whereas the opposite is true within CROP. The random effect in the model Site(Status×Survey×Depth) was also highly statistically significant, again reflecting the high variability in lobster abundance among sites and between depths across reserve and non-reserve locations through time (refer to Fig. 3.2a).

Similarly, temporal analysis (PERMANOVA) of *Jasus edwardsii* abundance between TMR and NR (2009 and 2014 surveys) based on PERMANOVA indicated that Survey was not statistically significant, whereas Status and Depth were statistically significant (Table 3.2b). As for CROP, there was a statistically significant Depth×Status interaction and the random effect Site(Status×Survey×Depth) was also highly statistically significant (Table 3.2b).

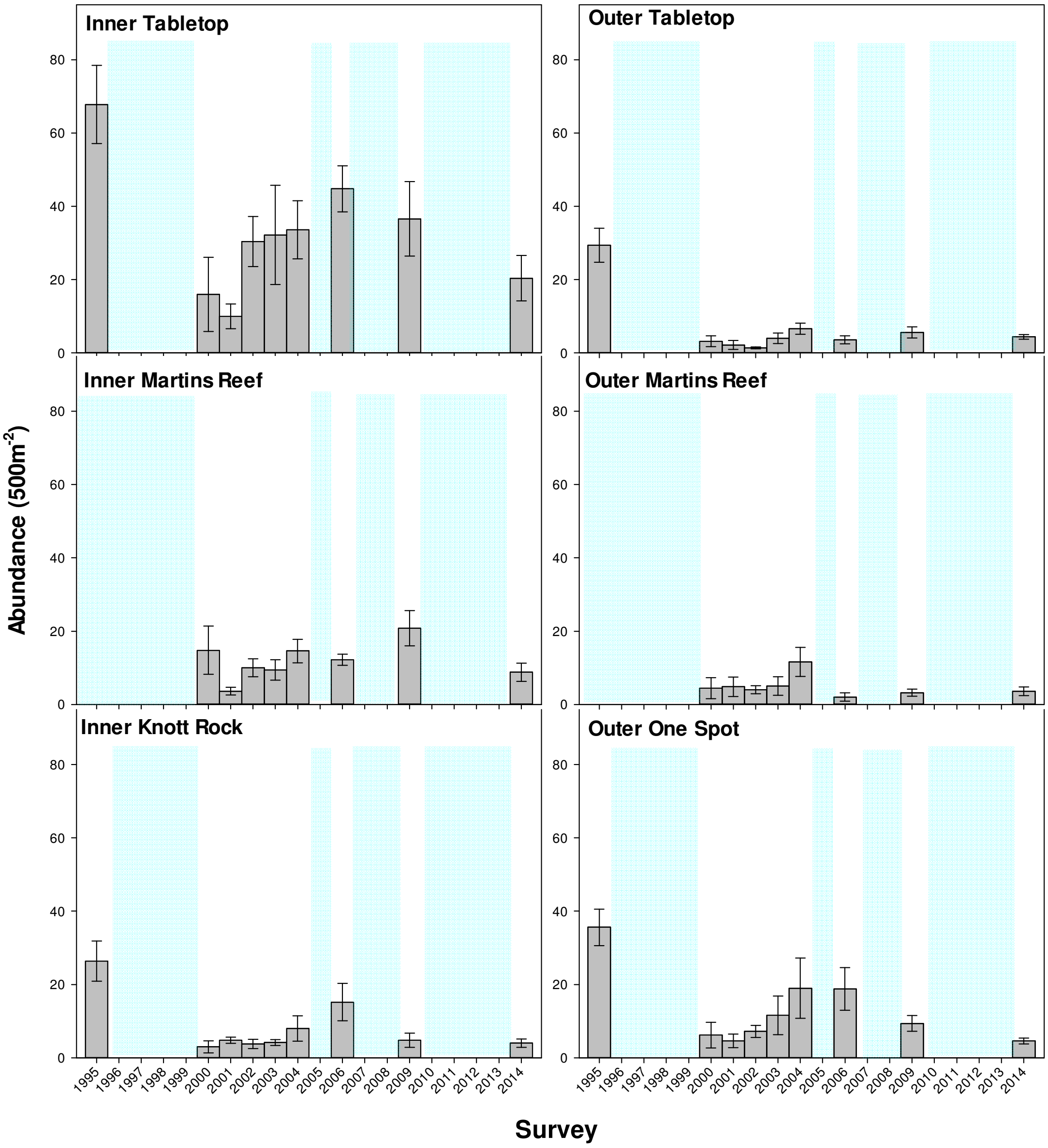

Figure 3.2a. Abundance of *Jasus edwardsii* recorded during lobster surveys of the Cape Rodney to Okakari Point (CROP) Marine Reserve between 1995 and 2014. Refer to Figure 2.1 for the location of each sampling site. Inner refers to < 8m depth and outer to > 10m depth. Data are mean values ± SE. Blue shading denotes periods when sampling was not undertaken; Y axis differs among plots and to Figs 3.2b and 3.2c.

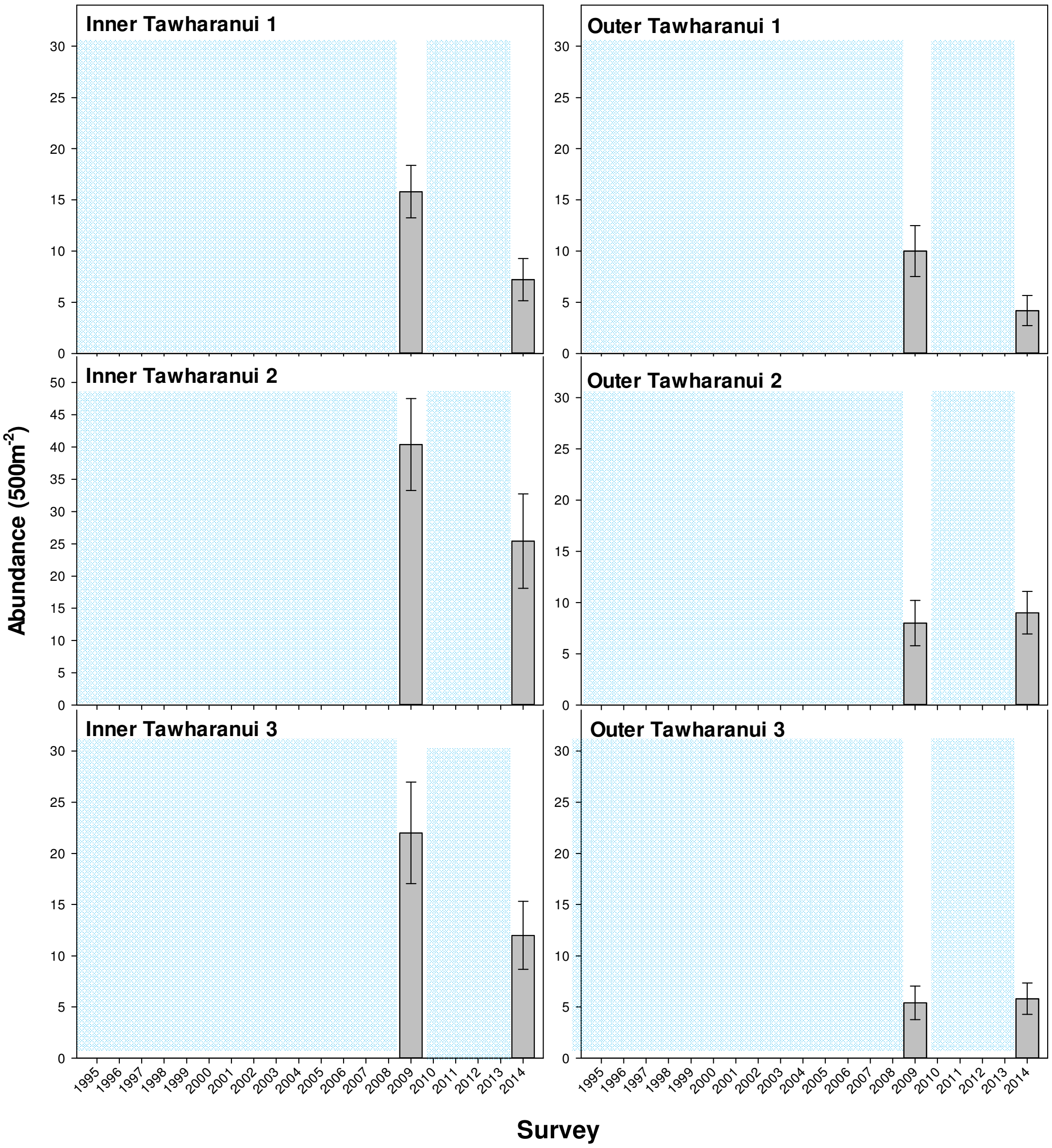

Figure 3.2b. Abundance of *Jasus edwardsii* (± SE) recorded during 2009 and 2014 surveys of Tawharanui Marine Reserve (TMR). Refer to Figure 2.1 for the location of each sampling site. Inner refers to < 8m depth and outer to > 10m depth. Data are mean values ± SE. *Note*: Blue shading denotes periods when sampling was not undertaken; Y axis differs among plots and to Figs 3.2a and 3.2c.

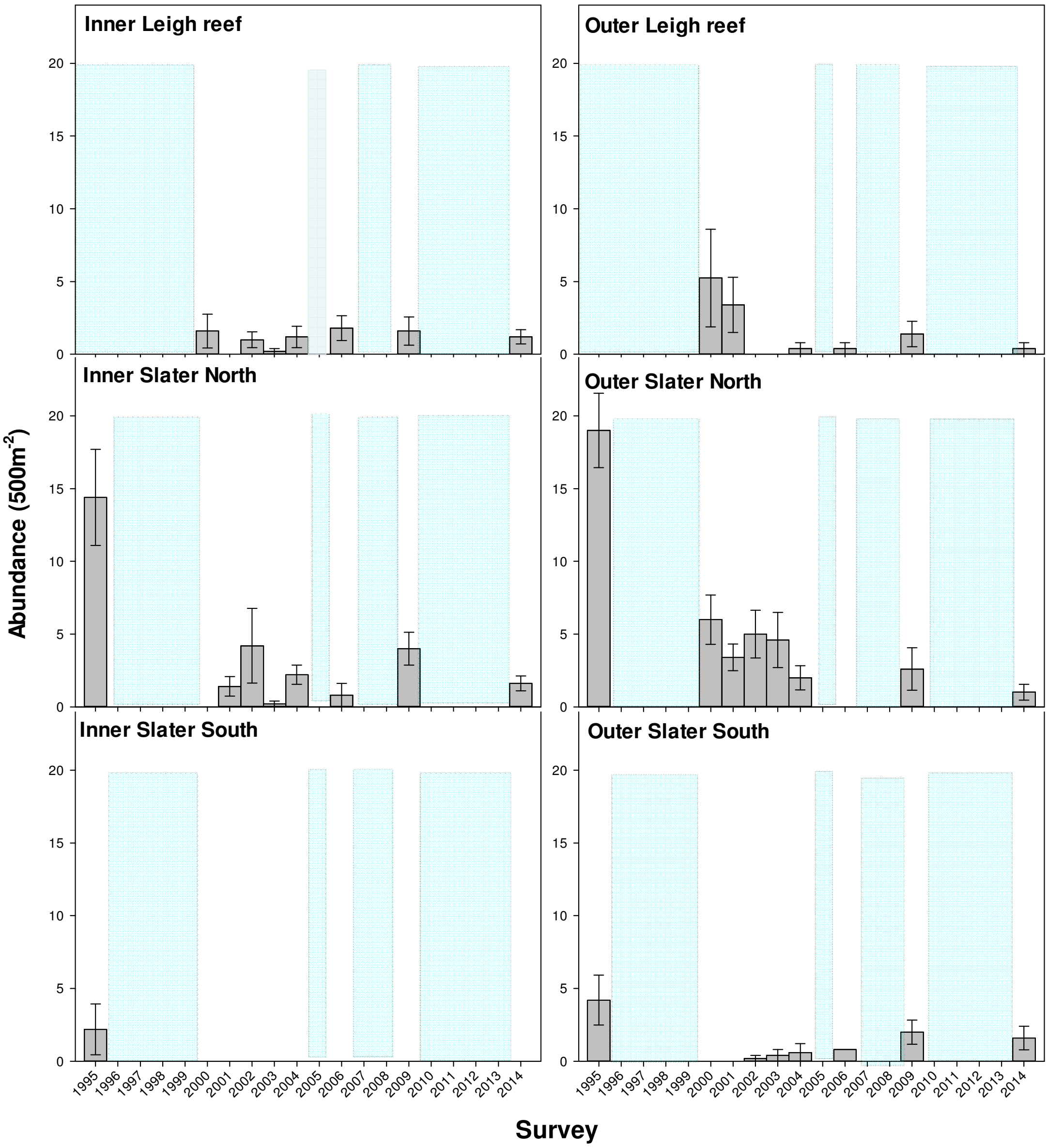

Figure 3.2c. Abundance of *Jasus edwardsii* recorded during lobster surveys of non-reserve sites between 1995 and 2014. Refer to Figure 2.1 for the location of each site. Inner refers to < 8m depth and outer to > 10m depth. Data are mean values ± SE. Blue shading denotes periods when sampling was not undertaken; Y axis differs to Figs 3a and 3b.

Table 3.1a. Mean abundance of *Jasus edwardsii* within CROP, NR (2000-2014) and TMR (2009-2014). Statistically significant ratios of reserve (R) to non-reserve (NR) abundances are denoted by: **P* < 0.05, ***P* < 0.01, ***P < 0.001.Overall = all lobster, Legal = lobster ≥ 95 mm carapace length, and Sub-legal = lobster < 95 mm carapace length. Confidence limits are asymmetric as they are calculated on the log scale.

Survey	Abundance measure	Reserve mean	Non-reserve mean	R:NR ratio	Lower 95% CL for ratio	Upper 95% CL for ratio
CROP Autumn 1995	Overall	39.81	9.90	*3.82***	*1.62*	*9.01*
	Legal	30.70	4.95	*5.57****	*2.18*	*14.24*
	Sub-legal	8.81	5.00	*1.89***	*0.80*	*4.46*
CROP Autumn 2000	Overall	7.93	2.03	*4.01***	*1.44*	*11.19*
	Legal	6.73	1.10	*4.03***	*1.45*	*11.20*
	Sub-legal	0.73	0.67	*1.10 n.s.*	*0.43*	*2.81*
CROP Autumn 2001	Overall	4.96	1.36	*3.66****	*1.77*	*7.57*
	Legal	4.27	1.13	*3.77****	*1.81*	*7.86*
	Sub-legal	0.40	0.20	*2.00 n.s.*	*0.78*	*5.11*
CROP Autumn 2002	Overall	9.46	1.76	*5.46****	*2.09*	*14.26*
	Legal	7.70	0.93	*6.49****	*2.65*	*15.85*
	Sub-legal	1.67	0.50	*3.12**	*0.79*	*12.30*
CROP Autumn 2003	Overall	11.1	0.90	*12.30****	*2.74*	*55.28*
	Legal	9.03	0.50	*18.00****	*3.20*	*101.25*
	Sub-legal	2.30	0.47	*2.00 n.s.*	*0.44*	*9.03*
CROP Autumn 2004	Overall	15.57	1.07	*15.37****	*2.86*	*37.66*
	Legal	9.63	0.40	*21.01****	*3.62*	*121.84*
	Sub-legal	4.03	0.47	*4.86***	*1.49*	*15.83*
CROP Autumn 2006	Overall	16.10	1.65	*9.54****	*2.52*	*62.43*
	Legal	11.67	0.25	37.48**	6.33	119.35
	Sub-legal	2.80	1.15	2.42*	0.67	3.04
CROP Autumn 2009	Overall	13.40	1.93	*6.93****	*2.77*	*17.34*
	Legal	6.30	0.59	*10.50****	*3.36*	*32.77*
	Sub-legal	6.20	1.13	*4.74****	*0.82*	*27.47*
TMR Autumn 2009	Overall	16.93	1.93	*8.76****	*3.49*	*22.00*
	Legal	1.67	0.59	*16.11****	*5.25*	*49.41*
	Sub-legal	3.67	1.13	*4.87***	*2.14*	*11.07*
CROP Autumn 2014	Overall	7.63	1.1	6.94***	2.67	18.06
	Legal	5.50	0.30	*18.33***	*3.91*	*85.88*
	Sub-legal	2.13	0.46	*2.93**	*1.13*	*7.62*
TMR Autumn 2014	Overall	10.60	1.10	*9.64****	*3.76*	*24.69*
	Legal	7.90	0.30	*25.33****	*13.58*	*91.95*
	Sub-legal	1.10	0.47	*2.36 n.s.*	*0.91*	*6.13*

Table 3.1b. Mean biomass of *Jasus edwardsii* within CROP, NR (2000-2014) and TMR (2009-2014). Statistically significant ratios of reserve (R) to non-reserve (NR) biomass levels are denoted by: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. Overall = all sized lobster. Confidence limits are asymmetric as they are calculated on the log scale.

Survey	Abundance measure	Reserve mean	Non-reserve mean	R:NR ratio	Lower 95% CL for ratio	Upper 95% CL for ratio
CROP Autumn 1995	Overall	25.94	3.68	_7.06***_	_4.61_	_10.80_
CROP Autumn 2000	Overall	4.18	0.77	_6.01***_	_2.37_	_15.25_
CROP Autumn 2001	Overall	3.48	0.67	_5.18***_	_2.52_	_10.65_
CROP Autumn 2002	Overall	5.48	0.60	_9.11***_	_4.08_	_20.32_
CROP Autumn 2003	Overall	6.01	0.26	_22.06***_	_5.48_	_94.62_
CROP Autumn 2004	Overall	6.78	0.20	_34.50***_	_9.74_	_122.65_
CROP Autumn 2006	Overall	10.34	0.11	_91.21***_	_10.18_	_818.31_
CROP Autumn 2009	Overall	6.49	0.48	_13.52***_	_3.89_	_46.95_
TMR Autumn 2009	Overall	9.33	0.48	_19.76***_	_7.80_	_49.22_
CROP Autumn 2014	Overall	5.15	0.21	24.52***	6.67	_224.15_
TMR Autumn 2014	Overall	7.77	0.21	_37.02***_	_4.09_	_141.16_

Table 3.2a: Results from PERMANOVA analysis of *Jasus edwardsii* abundance for CROP and NR for surveys undertaken between 2000 and 2014. Analysis was run on Log(x+1) transformed data using a Euclidean distance measure. Statistically significant *P*-values at the 5% level are shown italicised and in bold.

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Survey	7	13.55	1.94	1.09	0.3844
Status	1	254.56	254.56	142.57	***0.0002***
Depth	1	6.518	6.59	3.65	0.0642
SuxSt	7	17.77	2.54	1.42	0.2108
SuxDe	7	7.35	1.05	0.59	0.7652
StxDe	1	23.44	23.44	13.13	***0.001***
SuxStxDe	7	3.73	0.53	0.30	0.9564
Site(StxDexSu)	64	114.57	1.79	3.62	***0.0002***
Res	384	189.47	0.49		
Total	479	629.18	1.94		

Table 3.2b: Results from PERMANOVA analysis of *Jasus edwardsii* abundance for TMR and NR for surveys undertaken in 2009 and 2014. Analysis was run on Log(x+1) transformed data using a Euclidean distance measure. Statistically significant *P*-values at the 5% level are shown italicised and in bold.

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Survey	1	3.16	3.16	3.27	***0.0914***
Status	1	89.43	89.43	92.46	***0.0002***
Depth	1	5.61	5.61	5.80	***0.028***
SuxSt	1	0.24	0.24	0.25	0.6186
SuxDe	1	0.29	0.29	0.30	0.6074
StxDe	1	7.05	7.05	7.29	***0.016***
SuxStxDe	1	0.79	0.79	0.82	0.3756
Site(StxDexSu)	16	15.48	0.97	2.27	***0.0072***
Res	96	40.86	0.43		
Total	119	162.91	3.16		

Table 3.2c: Results from PERMANOVA analysis of *Jasus edwardsii* biomass for CROP and NR for surveys undertaken between 2000 and 2014. Analysis was run on Log(x+1) transformed data using a Euclidean distance measure. Statistically significant *P*-values at the 5% level are shown italicised and in bold.

Source	df	SS	MS	Pseudo-F	P(perm)
Survey	7	378.16	54.023	0.79217	0.6258
Status	1	3872.5	3872.5	56.785	***0.0002***
SuxSt	7	531.52	75.931	1.1134	0.3752
Site(StxSu)	80	5455.7	68.196	4.7852	***0.0002***
Res	384	5472.5	14.251		
Total	479	15710	54.023		

Table 3.2d: Results from PERMANOVA analysis of *Jasus edwardsii* biomass for TMR and NR for surveys undertaken in 2009 and 2014. Analysis was run on Log(x+1) transformed data using a Euclidean distance measure. Statistically significant *P*-values at the 5% level are shown italicised and in bold.

Source	df	SS	MS	Pseudo-F	P(perm)
Survey	1	30.61	30.61	0.30206	0.597
Status	1	2065.5	2065.5	20.385	***0.0002***
SuxSt	1	16.342	16.34	0.16128	0.6886
Site(StxSu)	20	2026.5	101.33	5.5464	***0.0002***
Res	96	1753.8	18.269		
Total	119	5892.8	30.607		

The abundance of legal (≥ 95mm CL) and sub-legal (< 95 mm CL) *Jasus edwardsii* within CROP, NR, and TMR has also fluctuated across surveys (Fig. 3.3); evaluation of these sub-populations essential to interpreting changes in overall abundance within and across locations through time. Following the substantial decline in *Jasus edwardsii* between 1995 and 2000 (reflected in both the protected and non-protected sample populations and within legal and sub-legal sub-populations), increases in the CROP population has been the product of recruitment (particularly evident in 2004, 2009), on-growth of recruits, and retention of adults (≥ 95mm). While sporadic recruitment has also been evident for the non-reserve sample population (again in 2004 and 2009 surveys), the limited data available infer that subsequent on-growth into the adult population has been minimal, being consistent with sustained fishing-related effects. Declines in total *Jasus edwardsii* abundance within CROP in previous surveys has often resulted from reductions in sub-legal individuals reflected in both density plots (Fig. 3.3) and size frequency distribution plots (Fig. 3.4). This was also evident in 2014 for both CROP and TMR, but to a lesser degree within the NR sample population, due to low numbers of *Jasus edwardsii* surveyed. Reserve:Non-reserve sub-legal abundance comparisons were only statistically significant for CROP (Table 3.1a).

Both CROP and TMR support substantially higher levels of legal-sized lobster compared to the NR sample population (Table 3.1a, Fig. 3.3). For the current survey, the CROP legal-sized abundance of 5.5 (± 0.86) per 500m^2 was 18.33 ($CL_{95\%}$ = 9.41, 35.7) times higher than NR levels; and, for TMR legal-sized abundance levels of 10.6 (± 0.86) per

500m^{-2} was 35.30 (CL$_{95\%}$ = 18.22, 68.5) times higher than NR levels in 2014 - refer to Table 3.1a for legal-sized Reserve:Non-Reserve comparisons for each survey. Legal-sized abundances have remained reasonably stable between 2009 and 2014 surveys, which for CROP shadows a decline between 2006 and 2009 surveys (Fig. 3.3).

Jasus edwardsii biomass within CROP in 1995 was approximately 26 kg per 500m^2 and around 6 times higher than recorded outside (Fig. 3.5; refer to Table 3.1b). Subsequent to the large decline in legal and sub-legal abundance and resultant reduction in biomass between 1995 and 2001 (Fig. 3.4), *Jasus edwardsii* biomass has remained consistently around 4-6 kg per 500m^2 within CROP and < 1 kg per 500m^2 outside (Fig. 3.5). Mean *Jasus edwardsii* biomass for CROP, TMR, and NR in autumn 2014 was 5.2 kg (± 1.0, SE); 7.8 kg (± 1.5, SE); and, 0.21 kg ((± 0.06, SE), equating to biomass being 24.5 and 37.0 times higher than outside within CROP and TMR respectively (Fig. 3.5, refer to Table 3.1b). Analysis of 2000-2014 CROP and NR biomass data indicated that reserve:non-reserve differences were statistically significant, whereas Survey was not (Table 3.2c) reflecting the reasonably stable biomass levels within the reserve since 2002 and the uniformly low biomass outside the reserve across the majority of surveys. *Jasus edwardsii* biomass within TMR was higher than CROP for both 2009 and 2014 surveys. As for CROP, biomass within TMR was statistically different to non-reserve levels and stable across consecutive surveys (Fig. 3.5; Table 3.2d).

In 2014, the average size of *Jasus edwardsii* inside TMR was 126.3 mm carapace length (± 3.8, CI$_{95\%}$) being 40 mm greater than the NR average at 86.3 mm carapace length (± 6.1, CI$_{95\%}$) (Fig. 3.6). For CROP, average *Jasus edwardsii* size was 117.6 mm carapace length (± 4.5, CI$_{95\%}$) and approximately 30 mm greater than NR (Fig. 3.6). Reserve:Non-Reserve statistical comparisons were not undertaken due to the low number of NR lobsters that were sized (n=23 in total). However, size differences were statistically different between CROP and TMR sample populations (Two sample t-test; t= -2.908; P< 0.001). Temporal patterns in mean lobster size within CROP and TMR have been routinely larger than the NR sample population. Declines in mean size through time within CROP for the most-part reflect periods when sub-legal individuals are present in higher abundances, e.g., 2004 and 2009. Changes in mean size within the NR tend to follow this pattern, but should be interpreted with caution due to the routinely low numbers of lobsters sized across surveys.

The sex ratio of lobsters in 2014 was similar across locations with both female and male lobsters occurring in similar proportions, albeit with a slight bias towards males in the NR sample population (Fig. 3. 7a). Previous surveys undertaken in CROP have demonstrated a low to moderate bias towards females, whereas the non-reserve population has been biased towards males since 2004. Prior to 2004, the non-reserve sample population was strongly biased towards females (Fig 3.7a).

Within CROP, the sex ratio of legal-sized lobsters in 1995 was strongly biased towards females (Fig 3.7b) which changed to a reasonably even sex distribution between 2000 and 2006 surveys. Legal-sized males were more abundant in the sample population in 2009, and to a lesser degree in 2014. Outside the reserve the sex ratio of legal-sized lobsters has been predominantly dominated by females with a more even sex distribution for 2009 and 2014 surveys; although again NR sex ratio patterns through time should be interpreted with some degree of caution due to the low sample size for some surveys. Within TMR, male and female legal-sized lobsters occurred at similar levels for both 2009 and 2014 surveys (Fig 3.7b).

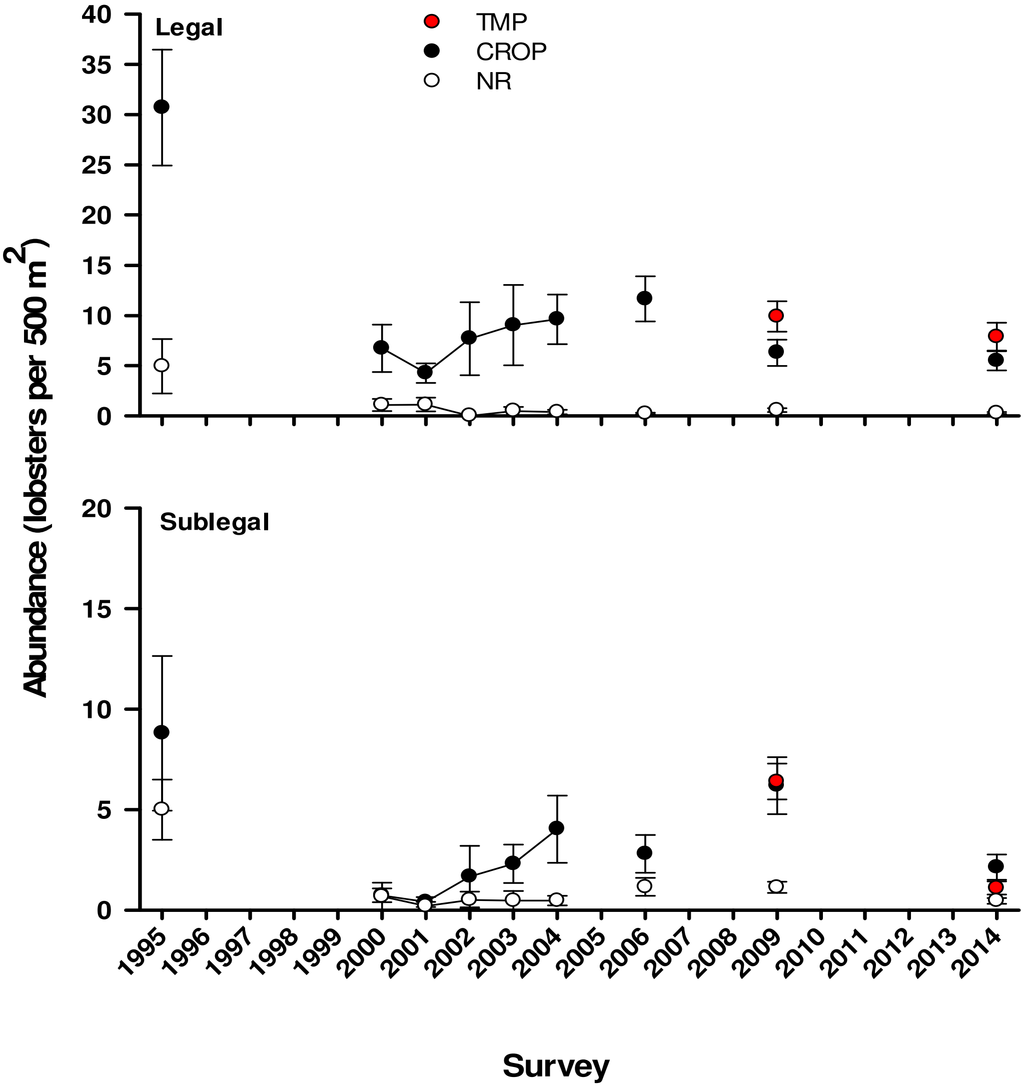

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Figure 3.3. Abundance of legal and sub-legal *Jasus edwardsii* (± SE) pooled from survey sites inside Cape Rodney to Okakari Point (CROP) Marine Reserve and non-reserve (NR) control sites between 1995 and 2014 and for Tawharanui Marine Reserve (TMR) between 2009 and 2014. Data are mean values ± SE. *Note*: 1995 data are pooled from 4 sites within CROP and 4 sites outside, whereas subsequent data are derived from 6 sites within each reserve and 6 sites outside.

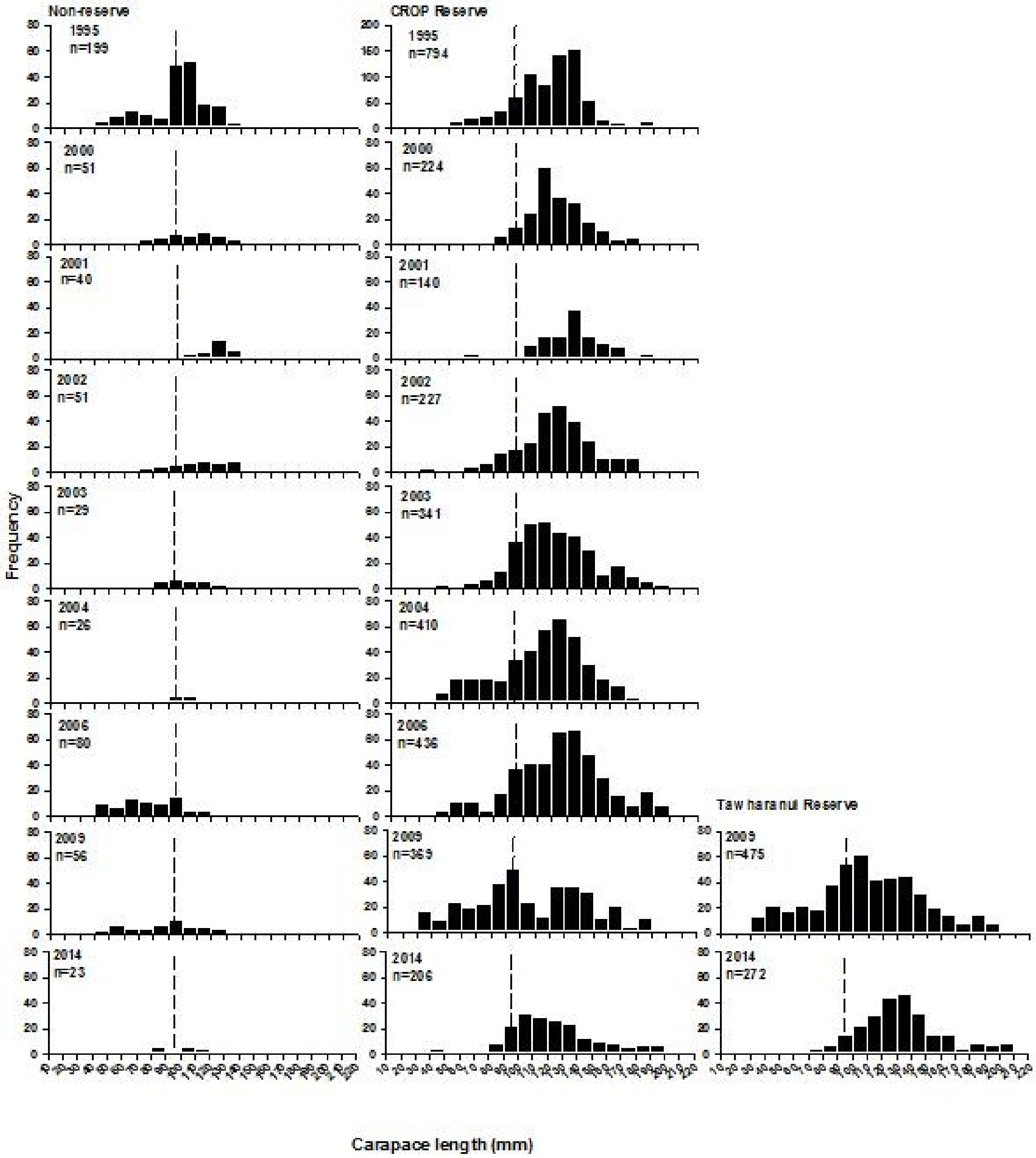

Figure 3.4. Size frequency distribution of *Jasus edwardsii* for NR and CROP (1995-2014) and TMR (2009-2014). Hashed vertical line denotes division between sub-legal and legal lobster.

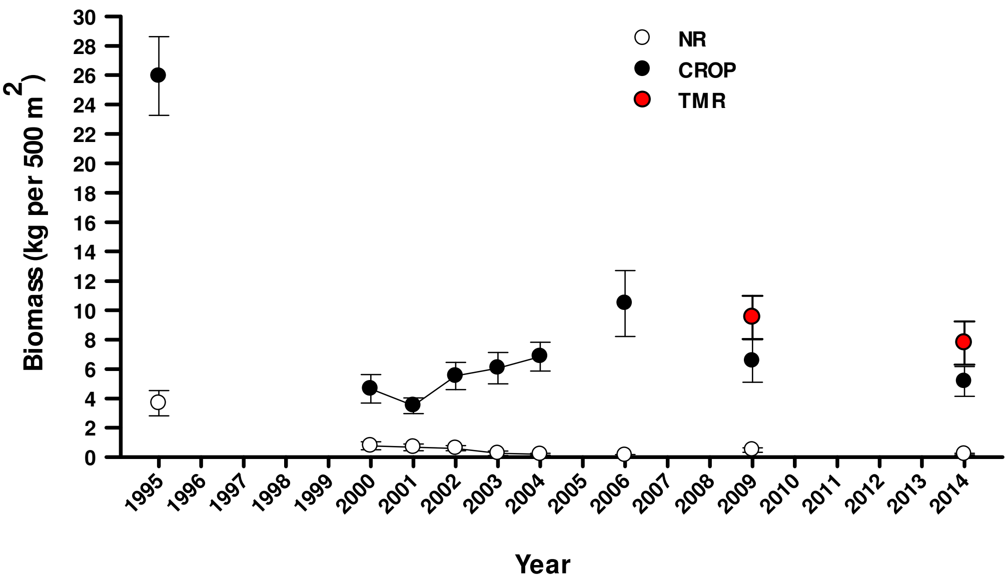

Figure 3.5. Biomass of *Jasus edwardsii* (± SE) pooled from survey sites inside Cape Rodney to Okakari Point (CROP) Marine Reserve and non-reserve (NR) control sites between 1995 and 2014 and for Tawharanui Marine Reserve (TMR) between 2009 and 2014. Data are mean values ± SE. *Note*: 1995 data are pooled from 4 sites within CROP and 4 sites outside, whereas subsequent data are derived from 6 sites within each reserve and 6 sites outside.

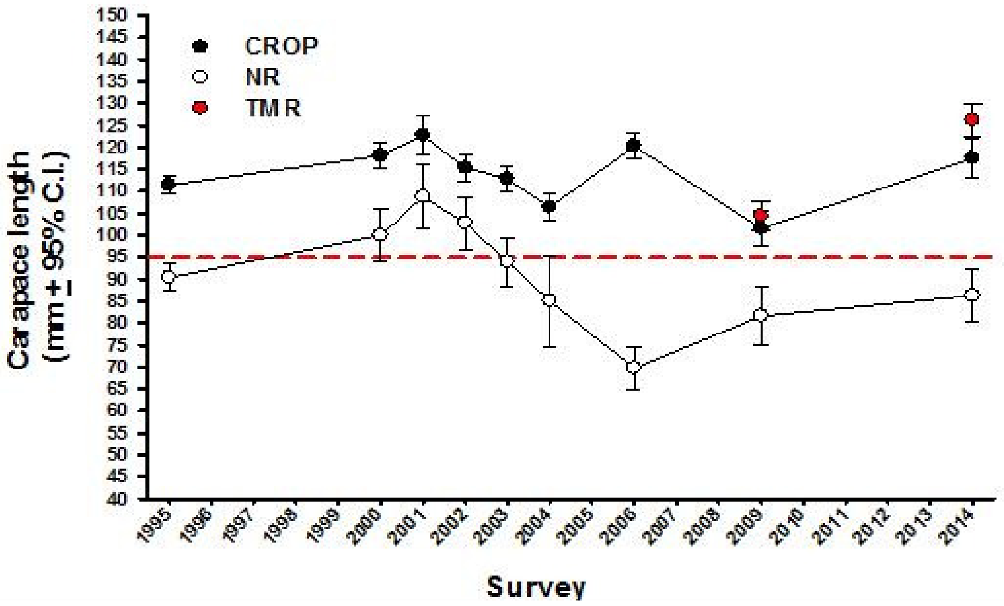

Figure 3.6. Changes in the mean size of *Jasus edwardsii* (± 95 % C.I.) within CROP and NR, between 1995 and 2014 and for TMR between 2009 and 2014. Data are mean values and associated 95 % confidence intervals.

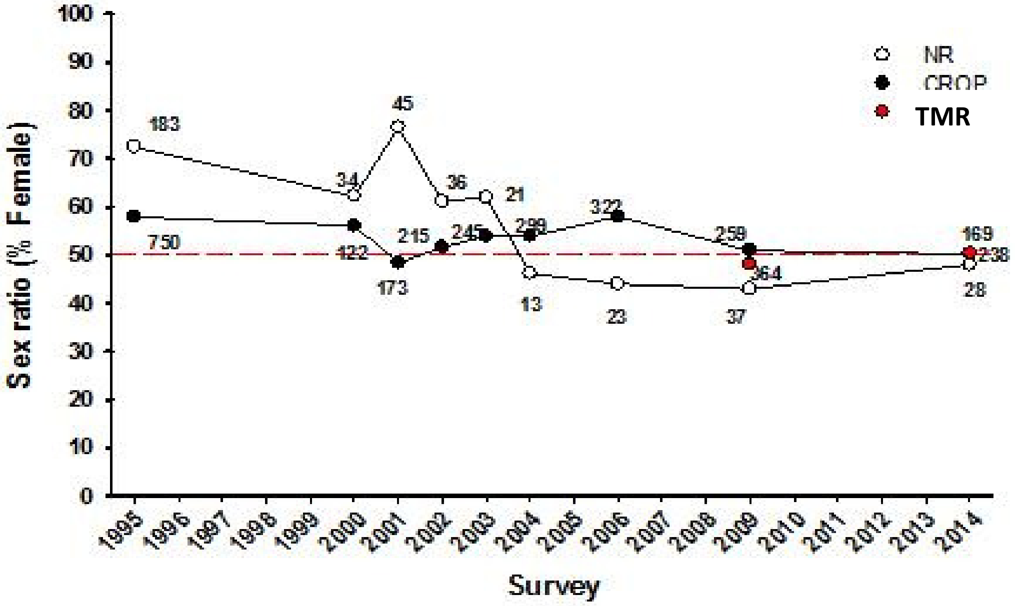

Figure 3.7a. Sex ratios (% female) of lobsters within CROP and NR between 1995 and 2014 and TMR between 2009 and 2014. Sample sizes for the estimates are given.

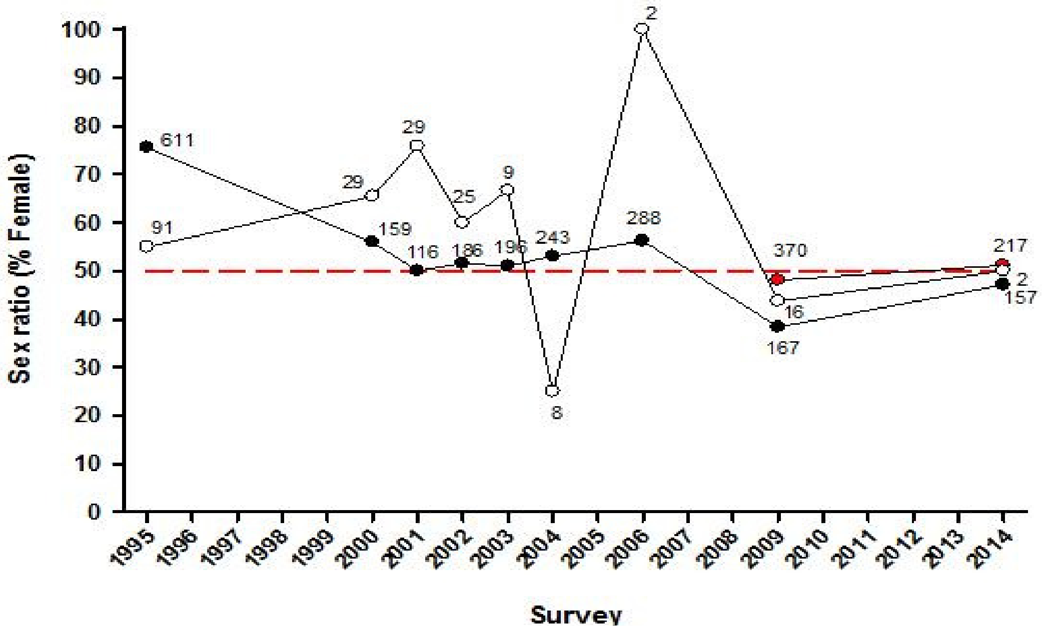

Figure 3.7b. Sex ratios (% female) of legal-sized lobsters within CROP and NR between 1995 and 2014 and TMR between 2009 and 2014. Sample sizes for the estimates are given.

3.2 Rocky reef habitat types

All six rocky reef habitat types were encountered within CROP, TMR and NR in 2014 (Fig. 3.8). Of these, large boulder complexes (LBC) and platform reef with crevices (PRC) were dominant habitat types across all locations with small boulder complexes (SBC) prevalent within TMR, and platform reef with ledges (PRL) and low lying platform reef (PR) reasonably dominant across the NR sample area (Fig. 3.8). Despite moderate variation in the proportion of rocky reef habitats across locations, none of the main factors analysed (Location and Depth) were statistically significant (Table 3.3).

3.3 Abundance and size patterns in relation to rocky reef type

In 2014, 85 % of *Jasus edwardsii* sampled within CROP occurred within large boulder habitat (LBC), 71 % of *Jasus edwardsii* sampled within TMR were associated with large boulder habitat, and 83 % of *Jasus edwardsii* sampled across the non-reserve sample area were associated with large boulder habitat (Fig. 3.9). Other rocky reef habitats where *Jasus edwardsii* were encountered included small boulder complexes, platform reef with vertical crevices, and platform reef with horizontal ledges. *Jasus edwardsii* were not associated with low-lying platform reef or cobble habitat.

Preference analysis employing Manly's Alpha indicated that *Jasus edwardsii* preferred LBC habitat within CROP, TMR, and NR, being utilised proportionately more than it was available (Table 3.4). As the level of random usage equated to 0.167 across habitats for this study, remaining rocky reef habitats with CROP were used proportionally less than they were available. For TMR, PRL was the next preferred habitat followed by SBC and PRC, and all were used proportionally more than available (Table 3.4). For NR, PRL was the only additional rocky reef habitat utilised (Table 3.4).

Table 3.3. Results from multivariate PERMANOVA of 6 rocky reef habitat (LBC; SBC; PRC; PRL: PR; and, C) proportions for CROP, TMR NR for 2014. Analysis was run on arcsine transformed data using a Euclidean distance measure. Statistically significant *P*-values at the 5% level are shown italicised and in bold.

Source	**df**	**SS**	**MS**	**Pseudo-F**	**P(perm)**
Location	2	1.4771	0.73856	2.0624	0.0571
Depth	1	9.02E-02	9.02E-02	0.252	0.8934
LoxDe	2	1.3558	0.67789	1.893	0.0916
Site(LoxDe)	12	4.2973	0.35811	2.536	***0.0002***
Res	72	10.168	0.14122	2.062	
Total	89	17.388			

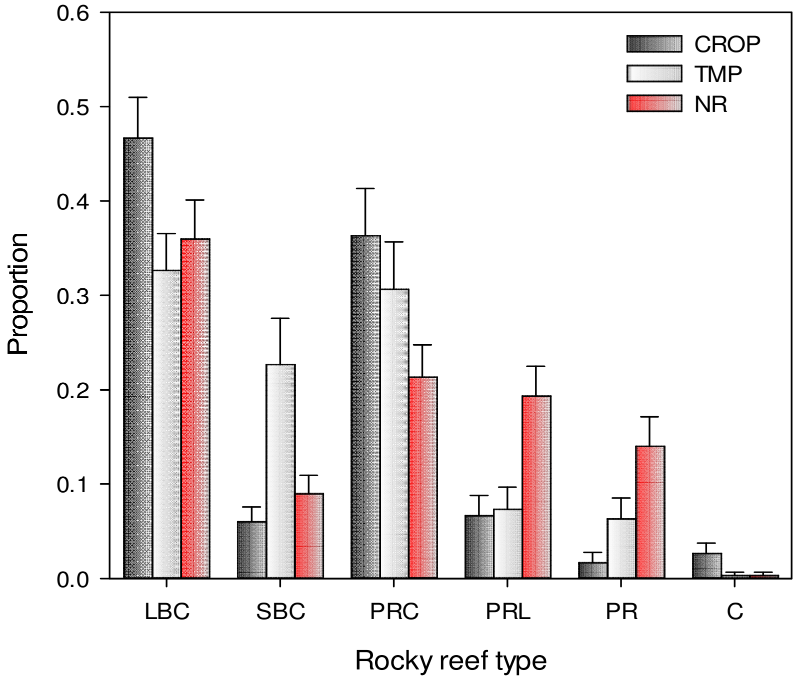

Figure 3.8. Proportion of rocky reef habitat types averaged across sample transects within CROP, TMR and NR. Data are mean values + SE. LBC = Large boulder complexes; SBC= Small boulder complexes; PRC = Platform reef with vertical crevices; PRL = Platform reef with horizontal ledges; PR = low-lying platform reef; C= cobbles.

Table 3.4. Results from Manly's alpha (α) analysis, depicting *Jasus edwardsii* habitat preferences for 6 rocky reef habitat types encountered during sampling for CROP, TMR and NR. Values are weighted by habitat extent for each location surveyed. *Note*: random usage equates to a value of 0.167. LBC = Large boulder complexes; SBC= Small boulder complexes; PRC = Platform reef with vertical crevices; PRL = Platform reef with horizontal ledges; PR = low-lying platform reef; C= cobble habitat.

Location	**LBC**	**SBC**	**PRC**	**PRL**	**PR**	**C**
CROP	0.761	0.152	0.169	0.140	0	0
TMR	0.556	0.250	0.227	0.319	0	0
NR	0.767	0	0	0.35	0	0
GLOBAL	**0.657**	**0.181**	**0.171**	**0.318**	**0**	**0**

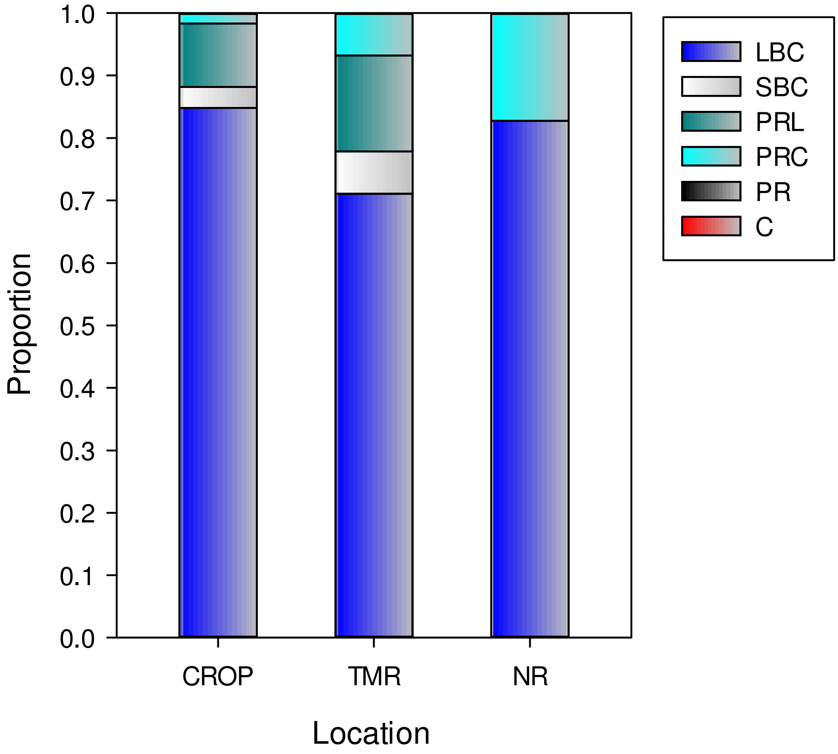

Figure 3.9. Proportion of *Jasus edwardsii* occurring within each rocky reef habitat type for CROP, TMR and NR in 2014. LBC = Large boulder complexes; SBC= Small boulder complexes; PRC = Platform reef with vertical crevices; PRL = Platform reef with horizontal ledges; PR = low-lying platform reef; C= cobble habitat.

3.4 *Jasus edwardsii* cohabitation

Jasus edwardsii were encountered in varying cohabitation densities along individual transects within CROP, TMR, and NR. Irrespective of the locations surveyed, solitary *Jasus edwardsii* had the highest frequency of occurrence followed by small aggregations, i.e., 2-4 *Jasus edwardsii*. Larger aggregations (i.e., > 5 lobsters) were only encountered within the two marine reserves, but occurred at low frequencies (Fig. 3.10). Percentage-wise, 33% of lobsters encountered within CROP, 38% of lobsters encountered with TMR, and 32% of lobsters encountered within NR were cohabitating. When evaluated by rocky reef type, large boulder habitat within CROP supported greater frequencies and densities of cohabitating *Jasus edwardsii* (Fig. 3.11). This pattern that was also evident within TMR, although PRC habitat also supported moderate frequencies and densities of cohabitating lobster (Fig. 3.11). There was no correlation between the size of individual cohabitation aggregations and size of the largest lobster within the aggregation (Fig. 3.12).

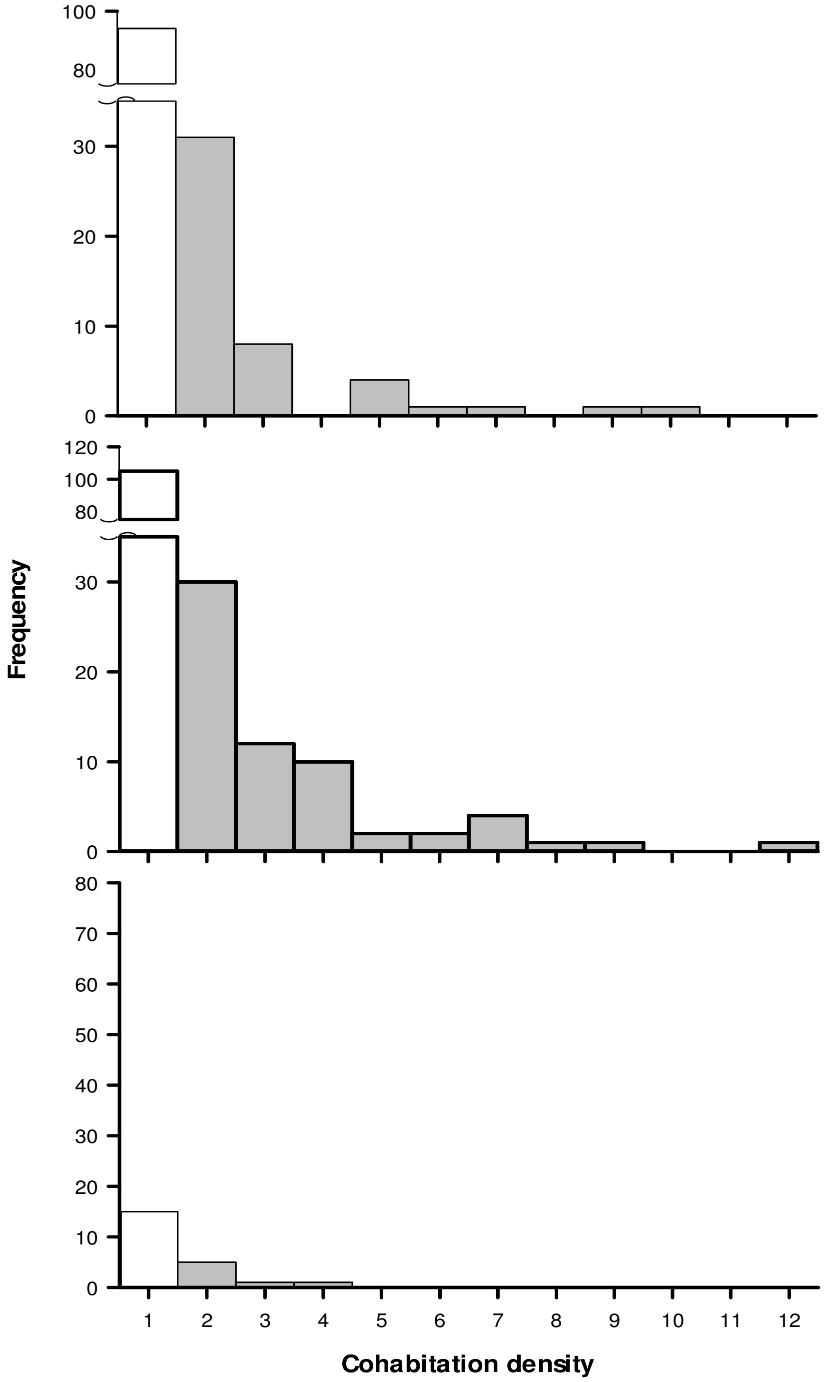

Figure 3.10 Frequency of *Jasus edwardsii* cohabitation within CROP, TMR and NR in 2014. Data are pooled for individual transects (n=30 per location). White bars denote frequency of solitary lobster whereas grey bars denote frequency of cohabitating (aggregating) lobster.

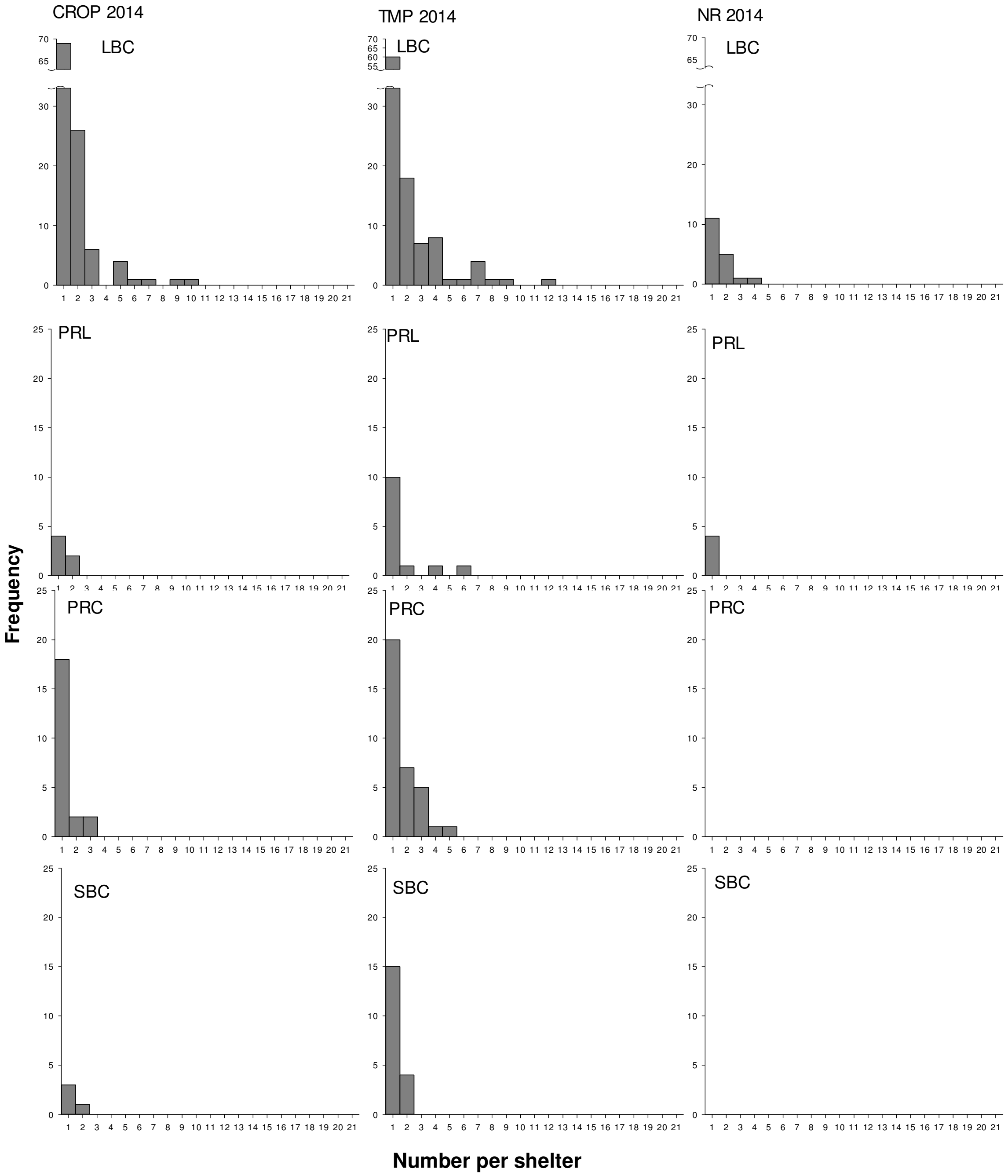

Figure 3.11. Frequency of *Jasus edwardsii* cohabitation within CROP, TMR, and NR in 2014 based on the four rocky reef habitat types where *Jasus edwardsii* were encountered. Data are pooled for individual transects (n=30 per location).

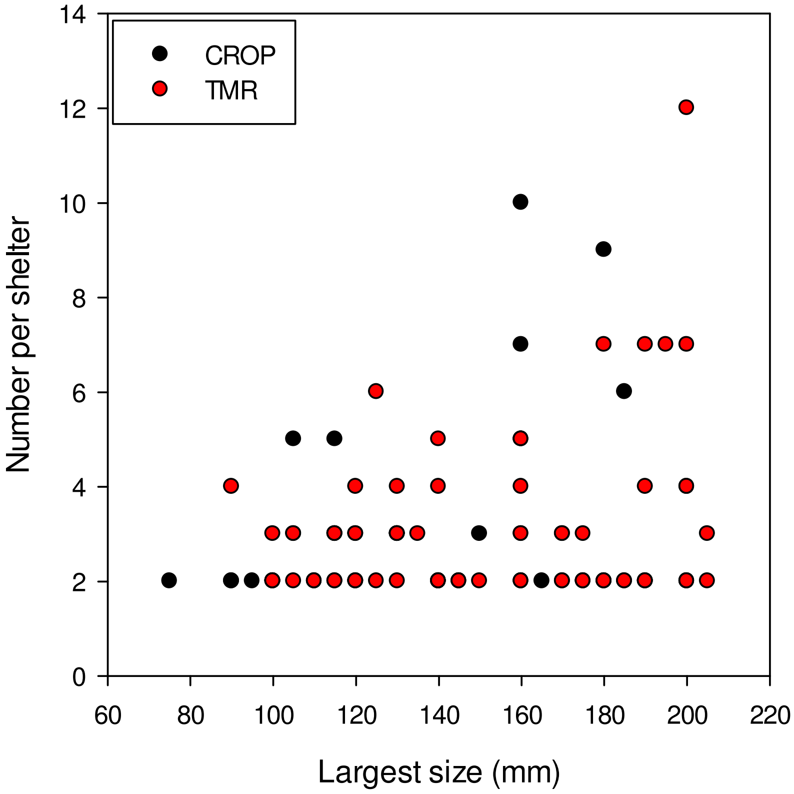

Figure 3.12. Relationship between the total number of cohabitating (aggregating) lobsters within individual shelters and the largest size of the lobster within the aggregation.

4.0 Discussion

The 2014 lobster survey marked the eighth survey of the Cape Rodney to Okakari Point (CROP) Marine Reserve and associated non-reserve sample area (NR) since the formal inception of the programme in 2000; and, the second survey of Tawharanui Marine Reserve (TMR) since its addition to the programme in 2009. Between 2001 and 2006 there was a relatively steady increase in the abundance of *Jasus edwardsii* within CROP following on from a large decline that occurred at some point between 1995 and 2000. Based on population structures through time, the increase was largely driven by recruitment, subsequent on-growth of recruits, and the retention of legal-sized lobster. The current survey suggests that overall population abundance within CROP has declined relative to 2009 levels. This is primarily due to reduced sub-legal (≤ 95 mm C.L.) abundance, as legal-sized abundance (> 95mm C.L.) has remained reasonably stable. A similar pattern was apparent for TMR between 2009-2014, whereas the NR sample population remains suppressed, fluctuating between 1-2 lobster per 500 m^2.

Based on studies done elsewhere in New Zealand, it has been demonstrated that *Jasus edwardsii* recruitment can vary considerably from year to year with large-scale pulse events strongly shaping the demographic makeup of a given lobster population (Forman *et al*. 2011). Evidence of this nature supports the irregular pattern of sub-legal abundance observed over consecutive surveys in the current monitoring programme. For example, changes to both sub-legal and legal portions of the lobster populations within CROP and TMR over the last two surveys appear reasonably synchronous, suggesting factors that influence lobster demography and abundance within these two reserves (e.g., recruitment pulses and fishing pressure) are likely to be analogous.

Natural variability aside, the general pattern of higher sub-legal *Jasus edwardsii* abundance within CROP (e.g., 2004 and 2009), and TMR (2009) relative to NR, which extends to other marine reserves such as Te Whanganui-a-Hei Marine Reserve in the Coromandel (Haggitt *et al*. 2013), infers that protection afforded by these reserves is equally important for sub-legal *Jasus edwardsii* as well as larger individuals. There are a range of plausible explanations for routinely higher densities of sub-legal lobsters within no-take marine reserves including reduced handling mortality; i.e., sub-legal *Jasus edwardsii* in the fishery may be handled more frequently and be more susceptible to handling-related effects, including mortality (Freeman and MacDiarmid 2009); higher recruitment of pueruli; and/or, attraction and migration of sub-legal individuals to higher abundances of lobsters and/or to larger individuals (Childress and Hermkind 1997; Butler *et al*. 1999; Freeman *et al*. 2012). Conversely, the consistently low abundance and smaller size of lobsters at unprotected (NR) sites reflects sustained fishing pressure in the outer Hauraki Gulf and highlights potential negative flow-on effects for both recruitment and survival of sub-legal individuals through space and time (Butler *et al*. 1999). This is particularly evident in the progressive decline and sustained suppression of legal-sized and sub-legal lobsters since 2000 at the majority of non-reserve sites sampled. It is unlikely that lobster abundance will increase markedly in fished areas in the near future unless fishing effort is reduced, or recruitment increases markedly.

Presently it is unclear as to the key factor or combination of factors that contributed to the large and pervasive reductions in *Jasus edwardsii* between 1995 and 2000. Regardless of direct and indirect causalities, an important perspective since the large decline is that the CROP reserve has consistently contained both larger and greater numbers of legal and sub-legal individuals than outside. It is worth noting that due to seasonal inshore and offshore movements of *Jasus edwardsii* associated with moulting, reproduction, and feeding, coupled with the relatively small size of the CROP reserve, the CROP lobster population is vulnerable to fishing at various times of the year (Kelly 2001). This in turn may be impeding the recovery of the *Jasus edwardsii* reserve population to pre-2000 levels. For past surveys we have suggested that reduced abundances of large lobsters (> 170mm carapace length) within the reserve population may be related to fishing activity concentrated at the reserve boundary and/or in areas where *J. edwardsii* aggregate (see Kelly and MacDiarmid 2003). Similarly, lobster fishing occurs on the eastern and western boundaries of TMR (personal observation), although it is unknown if lobsters within TMR move beyond the reserve boundary as has been identified for CROP (Kelly and MacDiarmid 2003).

For *Jasus edwardsii,* Freeman *et al*. (2009) found that in instances where reserve boundaries intersect continuous rocky reef habitat, emigration beyond the reserve boundary is likely to occur. Applying this inference to TMR, emigration beyond the reserve boundary is most-likely to occur in the eastern region, where rocky reef habitat extends well beyond the reserve (Grace 2009). Determining if changes in *Jasus edwardsii* abundance within marine reserves through space and time are due to fishing activity is, however, burdened with uncertainty as it requires up to date information on movement rates relative to reserve boundaries, fine-scale spatial data on size and abundance and measurements of fishing pressure (Davidson *et al.* 2002).

For both 2009 and 2014 surveys, Tawharanui Marine Reserve was characterised by higher mean abundance of legal-sized *Jasus edwardsii* than CROP, although sub-legal lobsters occurred at lower levels in 2014. While it is not possible to comment on temporal trends within TMR in detail, incorporating this marine reserve into the lobster programme is an excellent directive as it improves the design by replicating the protection effect and increases our spatial understanding of protection over relatively small spatial scales (10s km). It is worth noting that present-day abundances of legal and sub-legal *Jasus edwardsii* within TMR are substantially lower than those presented for this area in 2005 by Shears *et al*. (2006). In that study, the abundance of legal and sub-legal lobsters was approximately 30 per $500m^2$ and 10 per $500m^2$, respectively. Differences in abundance levels between Shears *et al*. (2006) and those reported in this report are due to different sampling methodologies, i.e., Shears *et al*. (2006) sampled 5 individual transects in total, whereas 30 transects are surveyed under the current programme to ensure within-site replication. Due to this methodological disparity, results among the two studies are incomparable.

Irrespective of the locations surveyed, the majority of *Jasus edwardsii* enumerated in 2014 were associated with large boulder complexes and based on the analysis undertaken across all habitat types there was strong evidence for preference for this particular rocky reef habitat. For TMR, platform reef with vertical crevices (PRC), platform reef with horizontal ledges (PRL), and small boulder reef complexes (SBC) were also utilised by *Jasus edwardsii.* Similar specificity for large boulder reef complexes has been demonstrated at Hahei (Haggitt *et al*. 2013) and for other lobster species (Lucieer and Pedersona 2008) and while these associations are only observational, in that specifically designed habitat preference experiments have not been undertaken, understanding how lobsters respond to physical attributes of their environment is important for marine reserve design (Freeman *et al*. 2009), developing robust sampling methodologies, and aiding in the interpretation of monitoring data.

Largest cohabitation densities were also associated with large boulder reef habitat within CROP and TMR, with larger aggregations being comprised of a broad range of sizes, supporting our current working hypothesis that large boulder habitat is likely important to *Jasus edwardsii* on multiple levels including reduced mortality (Butler *et al.* 1999) and, by default, greater reproductive selection and output (Melville-Smith *et al.* 2009). Foraging and predation rates on invertebrates such as the urchin *Evechinus chloroticus* and the gastropod *Cookia sulcata* are also likely to be greater within this rocky reef habitat type.

In this study solitary lobsters were encountered more-frequently than cohabitating (aggregating) lobsters; a pattern consistent across all locations and in accordance with the 2009 survey (Haggitt and Mead 2009), and with MacDiarmid (1994). MacDiarmid (1994) demonstrated that the proportion of cohabitation in *Jasus edwardsii* for certain lobster sizes is lower in autumn and winter, coinciding with the peak of mating. For 2014 survey data there was no obvious correlation between the size of the largest lobster within individual aggregations and the total size of the aggregation, which has been demonstrated for *Jasus edwardsii* within Te Tapuwae o Rongokako Marine Reserve (Gisborne) (Freeman 2008). MacDiarmid (1994) acknowledges that variable/patchy rates of cohabitation and dispersion within sites may directly relate to variable rates of predation in accordance with the level of dispersion. Interestingly, MacDiarmid (1994) recorded cohabitation densities of up to 100 individuals within CROP, clearly much larger than cohabitation levels recorded in this study.

Conclusions and recommendations

Despite what can only be considered as limited recovery of the CROP lobster population over the last 14 years relative to abundance levels recorded in 1995, *Jasus edwardsii* abundance within CROP and TMR in autumn 2014 was 5.5 and 7.7 times higher than in the adjacent non-reserve sample area. For legal-sized *Jasus edwardsii,* abundance within CROP and TMR in 2014 was approximately 18 and 25 times higher than levels enumerated outside. In terms of total biomass, 2014 levels within CROP and TMR were approximately 24.5 and 37 times higher than outside.

Monitoring of the Cape Rodney to Okakari Point Marine Reserve, and Tawharanui Marine Reserve should continue over consecutive years to:

- Provide data on the effectiveness of the marine reserve to inform reserve management;
- Determine the natural variability in the resident lobster population;
- Detect shifts in the size and abundance that cannot be attributed to natural variability;
- Determine recovery dynamics and the frequency of recruitment pulses within sample populations.
- Enable comparisons between two nearby MPAs with similar habitat structure.

The methodologies used in the CROP and TMR Lobster Monitoring Programme are allowing the objectives of the programme to be met and should be retained in future surveys to ensure consistency and permit direct comparisons with other studies.

5.0 References

Anderson, M.J.; Gorley, R.N.; Clarke, K.R. 2008: PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. PRIMER-E: Plymouth, UK 217 pp

Andrew, N.L.; MacDiarmid, A.B. 1999: Sea urchin fisheries and potential ecological interactions with a kina fishery in Fiordland. *Department of Conservation report* 13p.

Babcock, R.C.; Kelly, S.; Shears, N.T.; Walker, J.W.; Willis, T.J. 1999: Changes in community structure in temperate marine reserves. *Marine Ecology Progress Series 189:125*-134.

Butler, I.V.M.J.; MacDiarmid, A.B.; Booth, J.D. 1999: The cause and consequence of ontogenetic changes in social aggregation in New Zealand spiny lobsters. *Marine Ecology Progress Series 188*: 179-191.

Childress, M.J.; Hernkind, W.F. 1997: Den sharing by juvenile Caribbean spiny lobsters (*Panulirus argus*) in nursery habitat: cooperation or coincidence? *Marine & Freshwater Research 48*:751-758.

Cole, R.G.; Ayling, M.A.; Creese, R.G. 1990: Effects of marine reserve protection at Goat Island northern New Zealand. *New Zealand Journal of Marine and Freshwater Research* 24: 297-210.

Creese, R.G.; Kingsford, M. J. 1989: Organisms of reef and soft substrata intertidal environments. In: Studying Temperate Marine Environments, Canterbury University Press pp 167-193.

Davidson, R.J.; Villouta, E.; Cole, R.G.; Barrier, R.G.F 2002: Effects of marine reserve protection on spiny lobster (*Jasus edwardsii*) abundance and size at Tonga Island Marine Reserve, New Zealand. *Aquatic Conservation: Marine & Freshwater Ecosystems 12*: 213-227.

Forman, J.S.; McKenzie, A.; Stotter, D. S. 2011: Settlement indices for 2009 for the red rock lobster (*Jasus edwardsii*). *New Zealand Fisheries Assessment Report* 2011. 21p.

Freeman, D.J. 2008: The ecology of spiny lobsters (*Jasus edwardsii*) on fished and unfished reefs. Unpublished PhD thesis, University of Auckland, New Zealand.

Freeman, D. J.; MacDiarmid, A.B. 2009: Healthier lobsters in a marine reserve: effects of fishing on disease incidence in the spiny lobster, *Jasus edwardsii*. *Marine & Freshwater Research 60*:140-145.

Freeman, D.J.; MacDiarmid, A.B.; Taylor, R.B. 2009: Habitat patches that cross marine reserve boundaries: consequences for the lobster *Jasus edwardsii*. *Marine Ecology Progress Series 388*: 159-167.

Freeman, D.J; MacDiarmid, A.B.; Taylor, R.B.; Davidson, R.J.; Grace, R.G.; Haggitt, T.R.; Kelly, S.; Shears N.T. 2012: Trajectories of spiny lobster *Jasus edwardsii* recovery in New Zealand marine reserves: is settlement a driver? *Environmental Conservation* 37: 295-304.

Grace, R.G. 2009: Tawharanui Marine Reserve Habitat Map www.doc.govt.nz /Documents/.../marine.../tawharanui-habitat-map.pdf.

Haggitt, T.R.; Mead, S.T 2006: Cape Rodney to Okakari Point lobster monitoring programme. *Report to the Department of Conservation* 35p.

Haggitt, T.R.; Mead, S.T 2009: Cape Rodney to Okakari Point and Tawharanui Marine Park lobster monitoring programme. *Report to the Department of Conservation* 39p.

Haggitt, T.R.; Mead, S.T.; Smith, H.; Hillock, K. 2013: Te Whanganui-a-Hei Marine Reserve Benthic and Lobster Monitoring Programme 2013 Survey. *Report to the Department of Conservation* 91p.

Kelly, S.; Scott, D.; MacDiarmid, A.B.; Babcock, R.C. 2000: Spiny lobster, *Jasus edwardsii*, recovery in marine reserves. *Biological Conservation 92*:359-369.

Kelly, S. 2001: Temporal variation in the movement of the spiny lobster *Jasus edwardsii*. *Marine and Freshwater Research 53*: 213-211.

Kelly, S.; MacDiarmid, A.B. 2003: Movement patterns of mature spiny lobsters, *Jasus edwardsii*, from a marine reserve. *New Zealand Journal of Marine and Freshwater Research. 37*: 149-158.

Lucieer, V.; Pedersona, H. 2008: Linking morphometric characterisation of rocky reef with fine scale lobster movement. *Journal of Photogrammetry and Remote Sensing*. 63:496-509.

MacDiarmid, A.B. 1991: Seasonal changes in depth distribution, sex ratio and size frequency of spiny lobster *Jasus edwardsii* on a coastal reef in northern New Zealand. *Marine Ecology Progressive Series 70*: 129-141.

MacDiarmid, A.B. 1994: Cohabitation in the spiny lobster *Jasus edwardsii* (Hutton 1875). Proceedings of the fourth international workshop on lobster biology and management 1993. *Crustaceana* 66: 341-354.

MacDiarmid, A.B.; Breen, P.A. 1993: Spiny lobster population changes in a marine reserve. In: Battershill, C.N; Schiel, D.R; Jones, G.P; Creese, R.G; MacDiarmid, A.B. (Eds.), Proceedings of the Second International Temperate Reef Symposium. NIWA Marine, Wellington. p. 47-56.

Manly, B.F. 1974: A model for certain types of selection experiments. *Biometrics* 30: 281–294.

McCullagh P.; Nelder J.A. 1989: Generalized linear models. Chapman and Hall, London. 511 p.

Saila, S.B.; Annala, J.H.; McKoy, J.L.; Booth, J.D. 1979: Application of yield models to the New Zealand rock lobster fishery. *New Zealand Journal of Marine and Freshwater Research* 13:1, 1-11

Shears, N. T.; Babcock, R. C. 2002: Marine reserves demonstrate top-down control of community structure on temperate reefs. *Oecologia 132*: 131-142.

Shears, N. T.; Babcock, R. C. 2003: Continuing trophic cascade effects after 25 years of no-take marine reserve protection. *Marine Ecology Progressive Series*. *246*: 1-16.

Shears, N. T.; Babcock, R. C; Duffy, C.A.J.; Walker, J.W. 2004: Validation of qualitative habitat descriptors commonly used to classify subtidal reef assemblages in north-eastern New Zealand. *New Zealand Journal of Marine and Freshwater Research 38*: 743-752.

Shears, N. T.; Grace, R. V.; Usmar, N.R.; Kerr, V.; Babcock, R. C. 2006: Long-term trends in lobster populations in a partially protected vs. no-take marine park. *Biological Conservation* 132: 222-231.

Appendix 1

Table A1. Site coordinates and habitat descriptions based within CROP reserve, TMR and non-reserve sites sampled.

Cape Rodney to Okakari Point Marine Reserve site characteristics

Site	**Depth range**	**Habitat**
Inner Table Top Reef (ITT) Shallow *Carpophyllum* / *Ecklonia* forest habitat E 2672533.1 N 6546363.6	2-5m	Large and small boulder complexes intermixed with patches of loose gravel. Mixed algal habitat comprised of *Carpophyllum maschalocarpum*, *Ecklonia radiata* and turfing reds including *Pterocladia* spp and *Osmundaria colensoi* < 3 m depth. *Ecklonia radiata* abundant > 5 m depth. Urchins generally restricted to crevices and are cryptic. Lobsters occur under boulders, in large dens and in the open, often in very shallow water.
Outer Table Top Reef (OTT) *Ecklonia* forest habitat / Sponge flats E 2673003.41 N 6546653.6	15-20m	Predominantly low-lying platform reef characterised by deep undercut ledges. Large and small boulder complexes common. Low density *Ecklonia radiata*, with sponges very common. Lobsters occur in predominantly under large boulders and to a lesser degree in small crevices, reef overhangs and in the open.
Inner Martins Reef (IMR) Mixed algae / *Ecklonia* forest habitat E 2670828.3 N 6546514.7	3-8m	Boulder habitat and platform reef intermixed with loose gravel patches. Generally mixed algal habitat comprised of *Carpophyllum maschalocarpum*, with *Ecklonia radiata* dominant > 5m depth. Lobsters occur predominantly under large boulders and in reef crevices.
Outer Martins Reef (OMR) *Ecklonia* forest habitat E 2670954.3 N 6546678.5	13-15 m	Platform reef typified by deep cuts and ledges. Reef terminates in sand at about 15 m. Deep undercuts common on the reef sand interface. *Ecklonia radiata* and sponges abundant. Lobsters generally found under ledges, particularly around the reef-sand interface.
Inner Knot Rock (IKR) Shallow *Carpophyllum* / *Ecklonia* forest habitat E 2671315.1 N 6546401.6	3-5 m	Platform reef typified by deep cuts and ledges and occasional large boulders. *Ecklonia radiata* forest common between 5–8 m, whereas mixed algae predominate on reef < 3 m depth. Sand flats common between reef platforms. Lobsters generally found under boulders and reef crevices
Outer One-Spot Reef (OOS) *Ecklonia* forest habitat E 2673556.4 N 6546020.4	12-16 m	Large boulder habitat and platform reef intermixed with loose gravel patches. *Ecklonia radiata* and sponges dominant. Lobsters occur under boulders and in reef crevices.

Tawharanui Marine Reserve site characteristics

Site	**Depth range**	**Habitat**
IT1 Shallow *Carpophyllum* / *Ecklonia* forest habitat and urchin barrens E 2677443.7 N 6535898.2	2-6 m	Platform reef and large and small boulder complexes. Mixed algal habitat comprised of *Carpophyllum maschalocarpum*, *Ecklonia radiata* and turfing reds including *Pterocladia* spp and *Osmundaria colensoi* < 3 m depth. Barrens habitat patchy and *Ecklonia radiata* abundant > 5 m depth. Lobsters predominantly occur under boulders, often in very shallow water.
OT1 *Ecklonia* forest habitat / Sponge flats E 2677304.7 N 6536073.7	12-15 m	Low-lying platform reef characterised by crevices. Small boulder habitat very common with occasional large boulders also present. High density *Ecklonia radiata*, with sponges common. Lobsters predominantly occur under boulders and in reef crevices.
IT2 Shallow *Carpophyllum* / *Ecklonia* forest habitat and urchin barrens E 2676896.8 N 6535560.0	2-8 m	Platform reef and boulder complexes. Mixed algal habitat comprised of *Carpophyllum maschalocarpum*, *Ecklonia radiata* and turfing reds including *Pterocladia* spp and *Osmundaria colensoi* < 3 m depth. Barrens habitat patchy and *Ecklonia radiata* abundant > 5 m depth. Lobsters occur predominately under boulders, but also found under ledges and in deep crevices often in very shallow water.
OT2 *Ecklonia* forest habitat E 2676769.3 N 6535925.5	12-15 m	Platform reef characterised by deep undercut ledges and crevices with occasional large and small boulder patches. High density *Ecklonia radiata*, with sponges common. Lobsters occur in small crevices and under boulder habitats.
IT3 Shallow *Carpophyllum* / *Ecklonia* forest habitat and urchin barrens E 2676299.6 N 6535574.8	3-6 m	Platform reef with crevices and ledges and boulder complexes. Mixed algal habitat comprised of *Carpophyllum maschalocarpum*, *Ecklonia radiata* and turfing reds including *Pterocladia* spp and *Osmundaria colensoi* < 3 m depth. Barrens habitat patchy and *Ecklonia radiata* abundant > 5 m depth. Lobsters predominantly occur under boulders and in reef crevices.
OT3 *Ecklonia* forest habitat E 2676291.1 N 6535802.2	12-16 m	Platform reef characterised by deep undercut ledges and crevices with occasional large and small boulder patches. High density *Ecklonia radiata*, with sponges common. Lobsters occur in small crevices and under boulder habitats.

Non-reserve site characteristics

Site	**Depth**	**Habitat**
Inner Leigh Reef (ILR) Urchin barrens / *Ecklonia* forest habitat E 2674112.9 N 6544885.5	5-8 m	Mix of boulders and greywacke platform reef with deep ledges. Extensive urchin barrens between 3–5 m give way to *mixed* algal habitat and *Carpophyllum flexuosum and Ecklonia radiata* habitat at depths > 5 m. Lobsters occur in reef crevices, ledges and under boulders.
Outer Leigh Reef (OLR) *Ecklonia* forest habitat E 2674902.6 N 6544197.3	15-18 m	Extensive platform reef and large boulder complexes terminate in sand at ~ 25 m depth. *Ecklonia radiata* extensive on reef surfaces. Lobsters occur predominantly in large boulder habitat
Inner Slater North (ISN) *Ecklonia* forest habitat E 2678314.6 N 6530967.6	5-8 m	Large boulder complexes intermixed with patches of loose gravel. Algal habitat predominantly comprised of *Carpophyllum maschalocarpum* and *Ecklonia radiata*. Lobsters occur under boulders.
Outer Slater North (OSN) *Ecklonia* forest habitat E 2678597.8 N 6531046.2	15-20 m	Large boulder reef terminating in sand at ~ 18 m depth. *Ecklonia radiata* abundant throughout.
Inner Slater South (ISS) Urchin barrens E 2678697.3 N 6530441.3	3-8 m	Mix of small boulders and greywacke platform reef. Patchy urchin barrens between 3–5 m, with mixed algal habitat dominant on boulder tops.
Outer Slater South (OSS) *Ecklonia* forest habitat E 2678854.5 N 6530519.9	15-20 m	Large and small boulder reef terminating in sand at ~ 20 m depth. *Ecklonia radiata* abundant throughout. Lobsters occur under boulders.