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Long-term trends in lobster populations in a partially protected vs. no-take Marine Park

Nick T. Shears[a,*], Roger V. Grace[b], Natalie R. Usmar[a], Vince Kerr[b], Russell C. Babcock[a,1]

[a]Leigh Marine Laboratory, University of Auckland, P.O. Box 349, Warkworth, Auckland, New Zealand
[b]Grace and Kerr Marine Consultants, P.O. Box 4267, Kamo, New Zealand

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ABSTRACT

Increasing the level of protection afforded to the marine environment requires assessment of the efficacy of existing marine protected areas (MPAs) in protecting exploited species. Long-term data from before and after the establishment of MPAs provide a rare but valuable opportunity to assess these effects. In this study we present long-term data (1977–2005) from before and after park establishment, on the abundance of spiny lobster *Jasus edwardsii* from fixed sites in a no-take marine park and a recreationally fished marine park, to assess the efficacy of no-take vs. partial protection. Lobster densities were comparable between both marine parks prior to park establishment, but the response of lobster populations differed markedly following protection. On average, legal-sized lobster were eleven times more abundant and biomass 25 times higher in the no-take marine park following park establishment, while in the partially protected marine park there has been no significant change in lobster numbers. Furthermore, no difference was found in densities of legal-sized lobster between the partially protected marine park and nearby fully-fished sites (<1 per 500 m^2). Long-term data from fully fished and partially protected sites suggest long-term declines in lobster populations and reflect regional patterns in catch per unit effort estimates for the fishery. The long-term patterns presented provide an unequivocal example of the recovery of lobster populations in no-take MPAs, but clearly demonstrate that allowing recreational fishing in MPAs has little benefit to populations of exploited species such as *J. edwardsii*.

1. Introduction

The need for increased protection of the marine environment from fishing is globally recognized (Pauly et al., 2002) and many coastal nations are currently working towards increasing the proportion of area covered by marine protected areas. Marine protected areas (MPAs) include areas of full protection, such as no-take "marine reserves", and areas of partial protection such as "marine conservation areas" or "marine parks" that allow various levels of fishing and have differing regulatory restrictions on fishing. However, ensuring that protection efforts achieve optimal conservation outcomes requires an assessment of the efficacy of existing marine protected areas and management regimes.

It has been well demonstrated that MPAs (of a number of forms) have a variety of benefits for conservation (Sobel, 1993; Allison et al., 1998), and also the potential to benefit fisheries through the export of production via adult spillover and

* *Corresponding author:* Tel.: +64 9422 6111; fax: +64 9422 6113.
E-mail addresses: nickshears@xtra.co.nz (N.T. Shears), GraceR@xtra.co.nz (R.V. Grace), n.usmar@auckland.ac.nz (N.R. Usmar), vincek@actrix.co.nz (V. Kerr), russ.babcock@csiro.au (R.C. Babcock).
[1] Present address: CSIRO Marine Research, Private Bag No. 5, Wembley WA 6913, Australia.
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recruitment subsidy to fished stocks (see reviews by Gell and Roberts, 2003; Hilborn et al., 2004). While there are few empirical examples of marine reserves directly benefiting local fisheries (but see Kelly et al., 2002; Russ et al., 2004), these potential fishery-related benefits are generally dependent on (or expected to develop following) the accumulation of biomass of previously exploited species inside reserve boundaries following the cessation of fishing. Conclusively demonstrating this requires empirical studies that employ data from long-term studies before and after protection at multiple sites inside and outside multiple reserves (Guidetti, 2002; Russ, 2002; Willis et al., 2003b; Edgar et al., 2004). Such studies are also important in understanding potential factors that may confound the detection and interpretation of reserve effects, e.g., increased fishing effort immediately adjacent to reserves that may result in localised declines in fished populations (Hilborn, 2002; Halpern et al., 2004).

Research conducted on no-take marine reserves in temperate systems worldwide provides strong evidence of benefits to a wide range of exploited species with differing life histories and mobilities (e.g. Edgar and Barrett, 1999; Kelly et al., 2000; Paddack and Estes, 2000; Schroeter et al., 2001; Willis et al., 2003a), however, less is known of the effects of areas under partial protection, where recreational or other forms of fishing are allowed (e.g. customary or traditional). With growing pressure worldwide to increase the level of protection afforded to marine habitats, MPA's that have partial fishing closures are often advocated by groups with direct fishing interests (Denny and Babcock, 2004) and promoted as a compromise solution. However, recreational fishing is a growing component of the total fishery harvest in many countries, and for some species may exceed the commercial harvest (e.g. Schroeder and Love, 2002). To date the impacts of this sector on aquatic resources have largely been ignored, but there is a growing awareness of the effects of recreational fishing on marine ecosystems (McPhee et al., 2002; Coleman et al., 2004; Cooke and Cowx, 2004, 2006). The recreational fishery for Caribbean spiny lobster (*Panulirus argus*) in Florida provides a clear example of the potential effects of this fishing sector. The abundance of *P. argus* in patch head and patch reef habitats is reduced by 80–90% during a 2 day "mini-season" exclusively for recreational sport divers (Eggleston and Dahlgren, 2001; Eggleston et al., 2003). In addition, it has been shown that through mishandling and injury to lobsters this recreational fishery has indirect effects on the behaviour, growth and survival of lobsters (Davis, 1981; Parsons and Eggleston, 2005).

An increasing number of studies have demonstrated that protection from commercial fishing alone has little or no conservation benefit to exploited species, and may even concentrate fishing pressure in partially protected areas (Schroeder and Love, 2002; Westera et al., 2003; Denny and Babcock, 2004). For example, in a northern New Zealand MPA (Mimiwhangata Marine Park), which is only afforded protection from commercial fishing, it has been shown that there has been no recovery of snapper (*Pagrus auratus*) populations after 10 years of recreational fishing (Denny and Babcock, 2004). At the nearby Poor Knights Islands marine reserve the number of snapper has increased rapidly over a 4 year period, following a change to total protection in 1999 (Denny et al., 2004).

Populations of the spiny lobster *Jasus edwardsii* (Hutton) have been shown to increase in no-take MPA's in Australasia (MacDiarmid and Breen, 1993; Babcock et al., 1999; Edgar and Barrett, 1999; Kelly et al., 2000; Davidson et al., 2002). *Jasus edwardsii* generally exhibit high site fidelity, spending extended periods on small areas of inshore reef, but seasonally move offshore during periods of moulting, reproduction and some feeding cycles (Annala, 1981; MacDiarmid, 1991; Kelly, 2001; Kelly and MacDiarmid, 2003). Consequently lobsters are vulnerable to fishing at reserve boundaries and contribute to local fisheries (Kelly et al., 2002). *Jasus edwardsii* is an important commercial species that supports large fisheries in Australia and New Zealand, but is also one of the invertebrate species most heavily targeted by recreational fishers in New Zealand. Very little information exists on the effect of recreational fishing on spiny lobster populations and a lack of knowledge on recreational catch is a major source of uncertainty for fisheries management in northern New Zealand (Starr et al., 2003).

In this paper we examined long-term trends in spiny lobster abundance (1977–2005) at permanent sites in two northern New Zealand marine protected areas with differing levels of protection. These included the Tawharanui Marine Park (TMP) which is completely no-take, and the partially protected Mimiwhangata Marine Park (MMP), where only restricted forms of recreational fishing are allowed. In particular, we were interested in whether partial protection at MMP has allowed the recovery of spiny lobster populations and how this compares to long-term trends at TMP, which has been afforded no-take protection since 1983. Due to the absence of long-term monitoring sites outside MMP, a separate survey of lobster populations was carried out at sites inside and outside the park to investigate potential differences associated with partial protection.

2. Materials and methods

2.1. Study areas

Both of the Marine Parks examined in this study are located on moderately exposed coasts in north-eastern New Zealand (Fig. 1). The Tawharanui Marine Park (350 ha, 36°22′S, 174°50′E) which is completely no-take, was established in July 1981, but not actively implemented until 1983. The Mimiwhangata Marine Park (Area 2000 ha, 35°25′S, 174°26′E) was formed in 1984, but commercial fishing was phased out gradually, with commercial lobster potting permitted until October 1993. Recreational fishing is allowed in the Mimiwhangata Marine Park under special fisheries regulations, which prohibit all nets and long-lines but allow the use of unweighted, single-hook lines, trolling, spearfishing and hand collecting including taking lobsters on scuba. Potting for lobsters is also permitted but restricted to one pot per person, party or boat. The physical habitats within both Marine Parks are similar and consist of large areas of shallow rocky reef, boulder fields, and soft sandy sediment (Kerr and Grace, 2005). The biological habitats on shallow reefs are typical of moderately exposed sites in northeastern New Zealand (Ballantine et al., 1973; Choat and Schiel, 1982; Shears and Babcock, 2004).

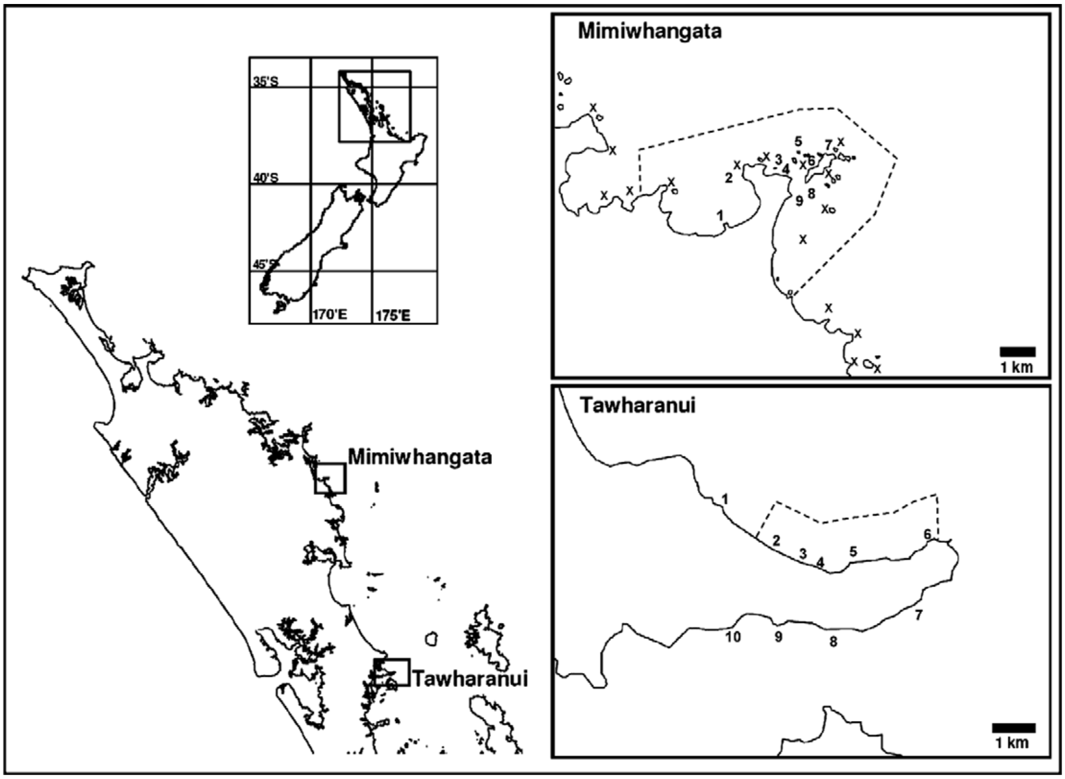

Fig. 1 – Location map of Mimiwhangata and Tawharanui showing marine park boundaries (dashed lines), position of long-term permanent transects (numbers) and sites where lobster surveys were carried out at Mimiwhangata in 2003 (X).

2.2. *Long-term monitoring*

Lobster monitoring at Mimiwhangata and Tawharanui has been carried out intermittently since 1977. Nine sites are monitored at Mimiwhangata, all of which are now located in the Mimiwhangata Marine Park (MMP), while ten sites are monitored at Tawharanui and five of these are located inside the Tawharanui Marine Park (TMP) and five outside on the adjacent fully-fished coast (Fig. 1). Initially sampling was carried out seasonally but following park establishment surveys have typically been carried out annually in late summer to autumn (February–May) when lobsters occur in shallow reef areas (MacDiarmid, 1991).

The lobster monitoring program was established prior to the development of theory behind the sampling design necessary for environmental impact assessment (Green, 1979), nevertheless some clear guidelines for the sampling were established. Sites were chosen to be spread across both study areas, but consideration was given to areas that were more sheltered from prevailing weather, appeared from the surface to be suitable for locating lobsters, and contained suitable lobster habitat below the surface. At each site one permanent transect was established by marking the start point with a stainless steel rod embedded in the rock with marine epoxy resin. Transects typically ran perpendicular to the shoreline from the low-tide mark to a maximum depth of between 5 and 10 m. At each sampling period, the exact same area of reef was sampled by locating the permanent transect marker and running a 50 m tape out in the specified direction using local landmarks as reference points. Transects were 50 m long by 10 m wide (500 m^2) with divers searching a 5 m wide area along each side of the tape. All *Jasus edwardsii* were counted and visually categorised as being of legal (⩾95 mm carapace length) or sub-legal size. Counts of the packhorse lobster *Sagmariasus verreauxi* were also made, but only very low numbers were recorded throughout the study so data are not presented. This exact methodology was repeated at each sampling time over the entire monitoring period. The weight of all lobsters greater than legal size was also visually estimated (to the nearest pound) by the same experienced diver on a number of the surveys. Weights were converted to kilograms for data analysis and presentation.

A potential problem with long term data sets is that current expectations in terms of sampling design may have evolved beyond those that existed at the time data collection was initiated. For example, one major shortcoming of the long-term sampling design in this study was the lack of replication at the site level, with only one permanent transect sampled at each site during each survey. However, long term data sets are rare and, rather than discard this invaluable information, we should look for ways to utilize their potential. In this context, while we know less about spatial variability from historical sampling at MMP and TMP than we might like, we do have a valid basis for assessing lobster density before and after implementation of particular management regimes. Spiny lobsters such as *J. edwardsii* are a highly gregarious organism (Butler et al., 1999) and this behaviour generally leads to high sampling variability and the need for high replication with random sampling techniques (MacDiarmid, 1991). Lobster distribution is also highly dependent on habitat characteristics (Zimmer-Faust and Spanier, 1987; Childress and Hernkind, 1997) and site-level variation in habitat characteristics may provide a potential source of bias for interpreting differences between fished and un-fished areas. The use of fixed permanent transects, positioned in areas of "suitable" habitat, meant that spatial variability was not confused with temporal variability. In addition, only data from surveys carried out in late summer and autumn were used in the analyses to avoid potential biases associated with the seasonal movement patterns of *J. edwardsii* (MacDiarmid, 1991). To further account for the lack of information on spatial variability and verify the patterns observed, the results are discussed in the context of other recent surveys that have employed more contemporary random sampling designs at sites inside and outside both marine parks (Tawharanui: Babcock et al. (1999), Kelly et al. (2000), Mimiwhangata: this study).

Differences in lobster abundance and biomass between the two study locations (Mimiwhangata vs. Tawharanui) prior to park establishment were tested using the GLMMIX procedure in SAS (Littell et al., 1996). The data collected are counts and were therefore modelled using a Poisson distribution with a log-link function (McCulloch and Searle, 2001). Data were compared from the five summer–autumn surveys carried out in both locations prior to park establishment (1977, 1978, 1979, 1981 and 1982), to test for differences between the two locations. Individual transects were treated as subjects upon which repeated measures were made using a first-order autocorrelation structure modified for unequal sampling intervals (modelled in SAS with the SP(POW) covariance structure, Littell et al., 1996). Differences in lobster numbers and biomass between the sites inside and outside TMP prior to park establishment were also examined.

To investigate the response of lobster populations to protection in each Marine Park, comparisons were made between pre- and post-establishment surveys using the same procedure as above. Analyses were carried out separately for each location as park establishment occurred at different times, and surveys were not carried out in the same years, for both locations (Tawharanui: 1977, 1978, 1979, 1980, 1981, 1982 and 1983 before establishment, and 1989, 1991, 1994, 1996, 2004 and 2005 after; Mimiwhangata: 1977, 1978, 1979, 1981, 1982, 1984, 1985 and 1986 before establishment, and 2002, 2003, 2004 and 2005 after). Ratios of density and biomass (plus 95% confidence limits) were calculated between significant levels to provide an estimate of the size of main effects. Note that confidence limits are asymmetrical as they are calculated on the log-scale.

2.3. Lobster abundance inside and outside Mimiwhangata Marine Park

An additional survey of lobsters was undertaken in April 2003 at sites inside and outside the Mimiwhangata Marine Park (Fig. 1). Measurements of lobster densities were made by scuba divers following the methodology established by MacDiarmid (1991) and used extensively in lobster surveys of other New Zealand MPAs since (e.g., Kelly et al., 2000). Three transects (50 m long by 10 m wide) were sampled at each site on areas of subtidal reef between 5 and 15 m deep. A 50 m tape measure was run out along a randomly determined compass bearing and a 5 m wide area was surveyed along each side of the tape. The carapace length (CL) of all lobsters was estimated visually to the nearest 5 mm. The accuracy of visual size estimation was quantified by estimating the size of specific animals and then catching them and measuring with vernier callipers. Diver visual size estimates were plotted against the actual measurements ($y = 0.926x + 6.37$, $R_2 = 0.91$). The slope was not significantly different from 1 and the y intercept did not differ significantly from 0, therefore raw values for size estimates were used.

Differences in abundance of lobsters between inside and outside MMP were tested using a generalised linear mixed model with the GLMMIX procedure in SAS. In this case, data were replicated at the site-level, so the nested factor Site (Status) was treated as a random effect, in addition to the fixed factor Status. As for the above analyses data were fitted to a Poisson distribution.

3. Results

3.1. Long-term patterns in lobster abundance

Despite large gaps in sampling intervals over the 28 year sampling period, some very clear patterns were apparent in lobster numbers between the two locations and with management status (Fig. 2). Prior to park establishment the numbers of both legal and sublegal lobster appeared to be higher at Mimiwhangata than at Tawharanui, although this was not statistically significant (Table 1(a)). There was also no significant difference in lobster numbers between sites inside and outside TMP, for surveys prior to park establishment (Table 1(b)). In general, the numbers of sublegal lobsters were highly variable among years while numbers of legal-sized lobster tend to have been more stable but considerably lower (<5 per 500 m^2) (Fig. 2). High numbers of sublegal lobsters were recorded across all sites in the late 1970's suggesting a large region-wide recruitment pulse in the mid 1970's. This was followed by a decline in numbers of sublegal lobster, presumably as these individuals moved into the exploited adult population. The numbers of sublegal lobsters have remained relatively high at TMP, but comparatively low at MMP and very rare at fished sites at Tawharanui (Fig. 2).

Overall, the long-term surveys of lobster populations have revealed differing responses to protection for the two marine parks (Fig. 2). Following park establishment at MMP (partially protected) the numbers of both legal and sublegal lobster have been consistently lower on average than before establishment. In contrast, at TMP (no-take) the number of legal-sized lobster recorded in the marine park have been consistently higher since the establishment of no-take status. The number of lobster trended steadily upwards between 1983 and 2005 and over this time the average number of legal-sized lobster in TMP was 10.9 ($CI_{95\%} = 2.7, 44.3$) times higher than prior to park establishment, while there was no difference in the number of sublegal lobsters before and after park establishment (Table 1(c)). At the fully fished sites outside TMP no legal-sized lobsters and very few sublegal-sized lobsters were recorded on surveys after the establishment of the marine park, therefore statistical testing could not be carried out. At MMP there was

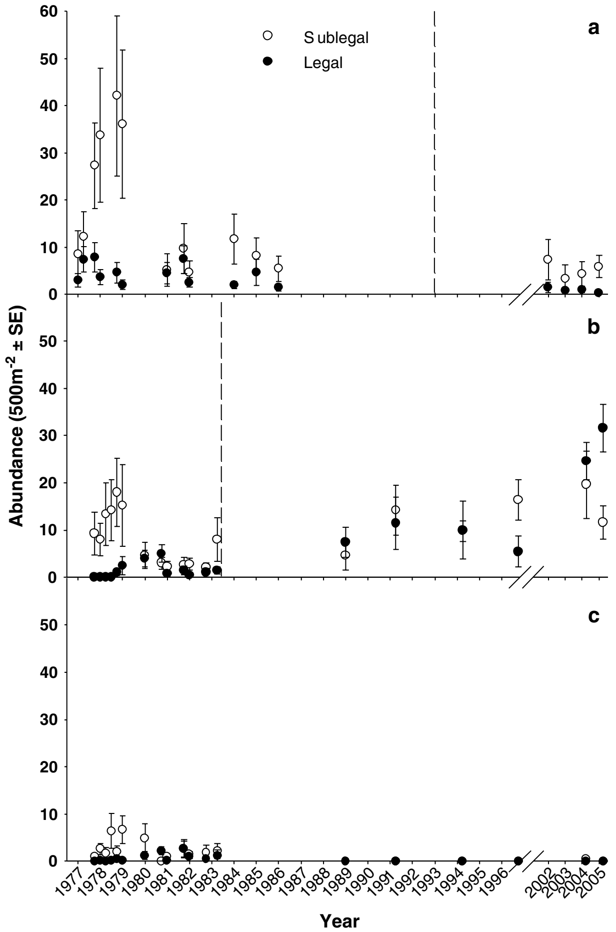

Fig. 2 – Long-term trends in spiny lobster *Jasus edwardsii* abundance on permanent transects in the Mimiwhangata Marine Park (partial protection) (a), Tawharanui Marine Park (no-take) (b) and unprotected sites at Tawharanui (c). Dashed lines indicate date of marine park implementation.

Table 1 – Results from mixed model analysis investigating differences in legal and sublegal lobster abundance between Mimiwhangata Marine Park (MMP) and Tawharanui Marine Park (TMP) before park establishment (a), between TMP and fished sites at Tawharanui (Tawh-fished) before park establishment (b) and differences before and after establishment for both TMP (c) and MMP (d)

	Fixed effect	Covariance parameter estimate
(a) MMP vs. TMP – before park establishment		
Legal	$F_{1,12} = 2.9$, $P = 0.114$	$Z = 0.50$, $P < 0.0001$
Sublegal	$F_{1,12} = 0.96$, $P = 0.347$	$Z = 0.55$, $P < 0.0001$
Biomass	$F_{1,17} = 6.51$, $P = 0.021$	$Z = 0.42$, $P=0.0003$
(b) TMP vs. Tawh. fished – before park establishment		
Legal	$F_{1,8} = 1.58$, $P = 0.225$	$Z = 0.17$, $P = 0.2238$
Sublegal	$F_{1,8} = 2.14$, $P = 0.182$	$Z = 0.55$, $P < 0.0001$
Biomass – Legal	$F_{1,8} = 1.37$, $P = 0.27$	$Z = 0.18$, $P = 0.2020$
(c) TMP – before vs. after		
Legal	$F_{1,4} = 11.6$, $P = 0.028$	$Z = 0.48$, $P = 0.0008$
Sublegal	$F_{1,4} = 2.21$, $P = 0.211$	$Z = 0.39$, $P = 0.0056$
Biomass – Legal	$F_{1,4} = 30.51$, $P = 0.005$	$Z = 0.28$, $P = 0.2012$
(d) MMP – before vs. after		
Legal	$F_{1,8} = 3.72$, $P = 0.090$	$Z = 0.48$, $P < 0.0001$
Sublegal	$F_{1,8} = 0.95$, $P = 0.357$	$Z = 0.62$, $P < 0.0001$
Biomass – Legal	$F_{1,8} = 3.20$, $P = 0.111$	$Z = 0.49$, $P < 0.0001$

The SP(POW) covariance structure was used to account for repeated measures at unequal sampling intervals.

no significant change following park establishment in the abundance of legal and sublegal lobsters (Table 1(d)). However, there was high variability among years and on average the numbers of both legal and sublegal lobsters were lower than prior to park establishment. These trends are reflected in Fig. 3, which shows the variation in lobster abundance among sites for both areas before and after park establishment. This demonstrates the high spatial variation, particularly in sublegal lobster abundance, before park establishment in both areas. The abundance of lobsters at MMP has remained highly variable among sites (Fig. 3(a)), with certain sites having consistently high abundances of sublegal lobster, while the abundance of legal lobster appears to have declined across all sites. In contrast, the recovery of legal lobsters at TMP has occurred at all sites (Fig. 3(b)), regardless of proximity to the park boundary.

3.2. *Long-term patterns in biomass of legal-sized lobster*

The biomass of legal-sized lobster was 5.1 ($CI_{95\%} = 1.5$, 18.0) times higher at Mimiwhangata than at Tawharanui prior to park establishment (Table 1(a)), while there was no difference in biomass between sites inside and outside TMP (Table 1(b)). The long-term trends in biomass (Fig. 4) generally follow the abundance data, although the effect of no-take protection at TMP was more pronounced due to the occurrence of much larger sized lobster following protection (Fig. 5). On average (between 1983 and 2005) the biomass of legal-sized lobster increased by 25 ($CI_{95\%} = 8.1$, 79.9) times at TMP following park establishment, while there has been no significant change at Mimiwhangata (Table 1(d)). As for the long-term abundance patterns (Fig. 2), lobster biomass appears to have declined at MMP. Prior to park establishment lobster populations in all areas were predominantly comprised of individuals less than one kilogram (Fig. 5). At TMP high numbers of larger lobster now occur, with many estimated to weigh over three kilograms.

3.3. *Lobster abundance inside and outside Mimiwhangata Marine Park*

Comparisons of lobster density at sites inside and outside MMP in 2003 found very low numbers at all sites (Fig. 6). Only 60 spiny lobsters, including 8 packhorse lobsters (*Sagmariasus verreauxi*), were recorded on 48 transects, 24 inside MMP and 36 outside. There was no significant difference in the density of *J. edwardsii* between sites inside and outside the Marine Park ($F_{1,14} = 0.04$, $P = 0.845$), although there was significant variation among sites ($Z = 1.52$, $P = 0.050$). All of the packhorse lobsters were recorded outside the marine park and

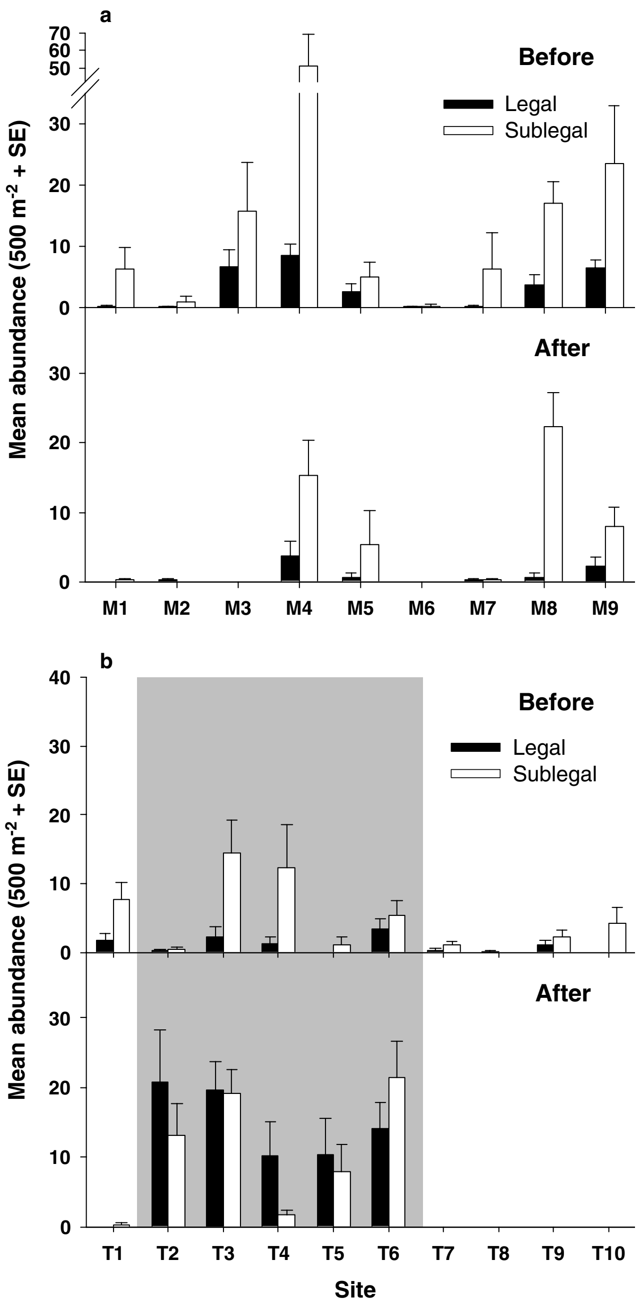

Fig. 3 – Site-level patterns of abundance of legal and sublegal sized *J. edwardsii* at Mimiwhangata (a) and Tawharanui (b) from surveys before and after park establishment. Shaded area indicates sites at Tawharanui located in the Marine Park. *Note*: all sites at Mimiwhangata are located in the Marine Park.

all were below the minimum legal size limit for this species (216 mm tail length). The majority of *J. edwardsii* were also under the legal size-limit for this species (95 mm CL), with only 8 legal-sized lobsters recorded inside the marine park and 6 outside. There was no difference in the size of lobster with respect to Marine Park status, with the mean size in the Marine Park being 82.0 ± 6.4 mm CL and 87.5 ± 4.5 mm CL outside.

4. Discussion

In this study we utilised long-term survey data from permanent sites to investigate the effect of differing levels of protection from fishing on spiny lobster (*Jasus edwardsii*) in northeastern New Zealand, by comparing data from before and after the establishment of two marine parks with differing management regimes. In the partially protected marine park (MMP), where recreational fishing is allowed, there has been no significant change in lobster abundance since protection from commercial fishing began in 1993. Furthermore, this pattern at MMP was validated by an independent survey, using a more conventional random sampling design, which revealed no difference in lobster abundance or size between the partially protected marine park and adjacent fully-fished areas. In contrast, within the no-take marine park (TMP) the abundance of legal-sized lobster during summer-autumn surveys has increased by 11 times, and biomass by 25 times, following park establishment in 1983. Lobster numbers at fully fished sites adjacent to TMP have declined since the park's establishment. This is consistent with previous studies from Tawharanui and other nearby marine reserves which report considerably higher abundances of lobsters in no-take compared to fished areas (MacDiarmid and Breen, 1993; Babcock et al., 1999; Kelly et al., 2000). Therefore, while the long-term sampling design provides little information on spatial variability within sites, the differences observed were very clear and are considered to reflect real differences before and after marine park establishment.

The greatest value of data collected both before and after MPA establishment lies in accounting for potential confounding factors that may explain differences between sites inside and outside protected areas. For example, Hilborn (2002) suggested potential biases in studies on the effects of protected areas due to (1) protected areas typically being selected in locations with high productivity and (2) that fishing effort excluded from the protected areas is redirected and may result in a decline in populations outside protected areas (displacement of fishing effort). While reserve effects may still occur in a given area, these factors may confound the interpretation of the magnitude and type of effect. The long-term data collected prior to park establishment in the present study allows us to discount the potential for differences in productivity, or other spatial variables (e.g. habitat characteristics), in explaining the effects of protection as we found no difference in lobster abundance between the two locations prior to park establishment. In fact, lobster biomass was initially highest at MMP where there has been no positive response to protection. In the absence of the pre-park establishment data the currently higher abundances of lobster in TMP, compared to MMP, may have been attributed to more "suitable" reef habitat. Similarly, prior to park establishment at Tawharanui there was some evidence that fished sites had lower numbers of lobster than sites in the marine park (Fig. 3; although not significant Table 1). While it is possible that some of the fished sites at Tawharanui (e.g., southern side of the peninsula; Fig. 1) may not be as "suitable" for lobster, sites in TMP that had comparatively low abundances prior to park establishment now support healthy populations in the absence of fishing (e.g. sites T2 and T5; Fig. 3(b)). Furthermore, the

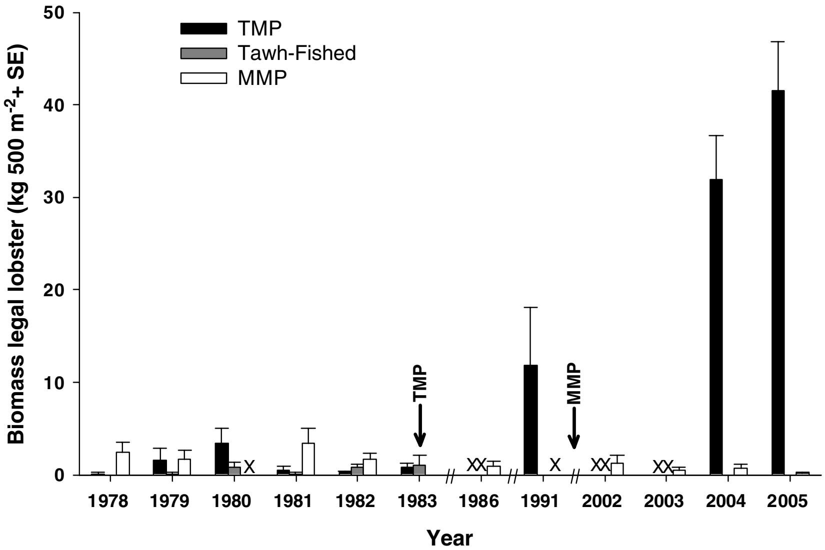

Fig. 4 – Long-term trends in biomass of legal-sized lobster on permanent transects at Tawharanui Marine Park (TMP), fully fished sites at Tawharanui (Tawh-Fished) and Mimiwhangata Marine Park (MMP). Arrows indicate timing of park implementation. X indicates not sampled.

contrasting temporal patterns observed between protected and unprotected sites at Tawharanui over a relatively small spatial scale (5–10 km) are not likely to be explained by regional variation in other environmental variables (e.g., temperature, sedimentation). Such comparisons of long-term trends in lobster populations, and the magnitude of change, provide a more accurate assessment of the effect of protection than a straight comparison between sites inside and outside the protected area.

While lobster numbers have increased dramatically in TMP, the absence of legal-sized lobster on permanent transects outside the marine park suggest a decline in lobster numbers since park establishment. This long-term decline is consistent with the potential effects of displaced fishing effort from protected areas (Hilborn, 2002; Halpern et al., 2004). However, the same declines were apparent, although not significant, at MMP where there is no commercial fishing, and similar declines in lobster populations have recently been recorded adjacent to other marine reserves in northeastern New Zealand (T. Haggitt and S. Kelly, unpubl. data). These declines appear to reflect region-wide trends in the lobster fishery rather than potential local-scale effects of displaced fishing effort. The two marine parks examined are located in different management areas of the New Zealand rock lobster fishery (MMP: CRA1 and TMP: CRA2). The future of both of these fisheries is currently uncertain (Starr et al., 2003) and the CPUE for the statistical areas in which both parks are located is very low (<0.5 kg/pot lift) (Sullivan, 2004). Furthermore, CPUE has declined considerably over the past 5 years in CRA2 and the total allowable commercial catches are not being landed (Sullivan, 2004). A major source of uncertainty for the management of the CRA1 and CRA 2 fisheries is the non-commercial catch which includes recreational, customary and illegal harvest (Starr et al., 2003).

The observed declines in legal-sized lobsters is most likely a direct effect of intensive fishing, however the reasons for potential declines in sublegal lobster at fished sites are less clear. At both MMP and the fished sites at Tawharanui there appears to have been declines in numbers of sublegal lobsters, while at the no-take TMP sites the numbers remain high. Differential recruitment among sites is not likely to explain this, due to the close proximity between fished and protected sites at Tawharanui and the fact that there were no initial differences in numbers of sublegal lobster between locations.

Furthermore, the large recruitment event in the late 1970's was apparent across all sites. One potential explanation is increased mortality rates associated with high levels of handling or damage in pots at commercially fished sites (Brown and Caputi, 1983). While this is not likely to explain the pattern at MMP, where there is no commercial fishing, recreational fishing may have similar indirect effects (Davis, 1981; Parsons and Eggleston, 2005). It is also possible that both trends can be explained by the same gregarious social phenomenon in which juvenile lobsters are attracted to adult lobsters (Butler et al., 1999), and may derive survivorship benefits from associating with adults (Zimmer-Faust and Spanier, 1987; Childress and Hernkind, 1997). The results of the current study suggest that in the absence of fishing there is a positive association between the abundance of legal and sublegal lobster over and above that of habitat quality and availability, and that this effect is manifested at scales of kilometres. A more rigorously designed monitoring program and experimental studies are necessary to further investigate this relationship.

Overall, it is clear that the management regime at MMP is not producing a measurable conservation effect in terms of protecting lobster. A similar lack of effectiveness is evident for snapper *Pagrus auratus* (Denny and Babcock, 2004). The recreational take of snapper currently exceeds the commercial take in northeastern New Zealand (Annala et al., 2004) and therefore it is highly likely that the same applies for rock lobster in inshore waters. If recreational fishing continues in

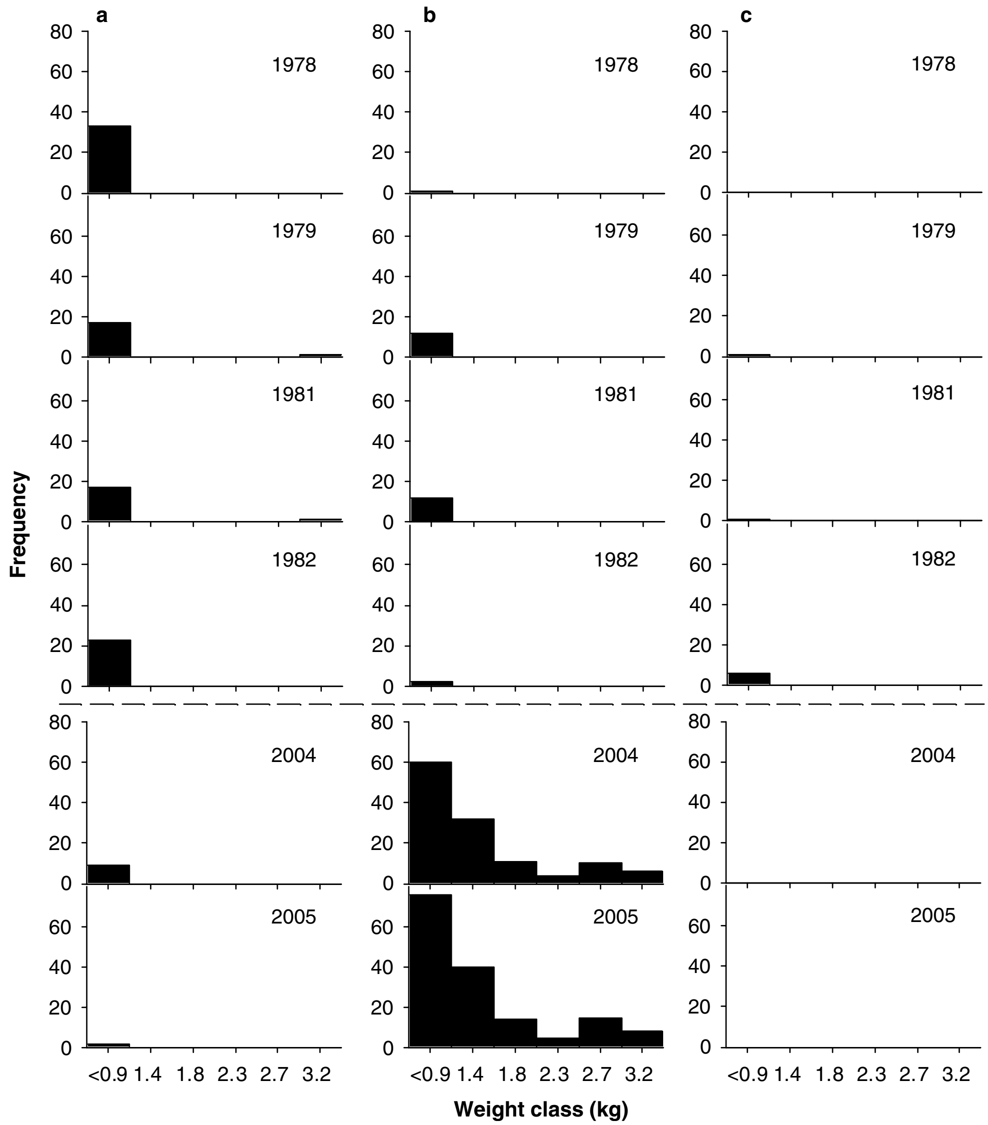

Fig. 5 – Weight distributions of legal lobster populations at MMP (a) (*n* = 9 transects), TMP (b) (*n* = 5) and Tawharanui fished sites (c) (*n* = 5). Dashed line separates surveys before and after park establishment. Data are only presented for years that surveys were carried out in all areas. Lobster weight was estimated to the nearest pound but has been converted to kilograms for presentation and analysis.

the essentially unregulated form in which it is now conducted it has the potential to have severe impacts on the target species and on the wider ecosystem. Already evidence suggests that the different management regimes of the two marine parks have had far reaching effects beyond that on populations of exploited species. At TMP where lobster and snapper (*Pagrus auratus*) numbers have increased substantially there have been long-term declines in sea urchins and a subsequent increase in kelp (Babcock et al., 1999). The existence of such a trophic cascade effect is supported by higher predation levels on sea urchins in TMP, and greater abundance of sea urchins and urchin barrens habitat, outside the marine park (Shears and Babcock, 2002). In contrast, at MMP the numbers of predators, such as lobster (this study) and snapper (Denny and Babcock, 2004), have not recovered following marine park protection. Consequently, kelp forest habitats that dominated up until the 1950's have been replaced by urchin barrens on shallow reefs (<10 m depth) that have persisted since the 1970's (Kerr and Grace, 2005).

The findings from this study clearly demonstrate the value of long-term data from before and after the establishment of protected areas in assessing the potential effects on populations of exploited species inside and outside MPA boundaries. Despite some limitations in experimental design the patterns observed are unequivocal and validate the results from other studies comparing protected and unprotected lobster populations employing more contemporary sampling designs. While future monitoring efforts should better address spatial variability at the site level they should also incorporate long-term permanent sites to allow continued assessment of long-term trends. The results clearly show that while partially protected marine parks provide exclusive areas for recreational fishermen there is little benefit to exploited species such as lobster. In contrast, substantially larger populations persist in no-take

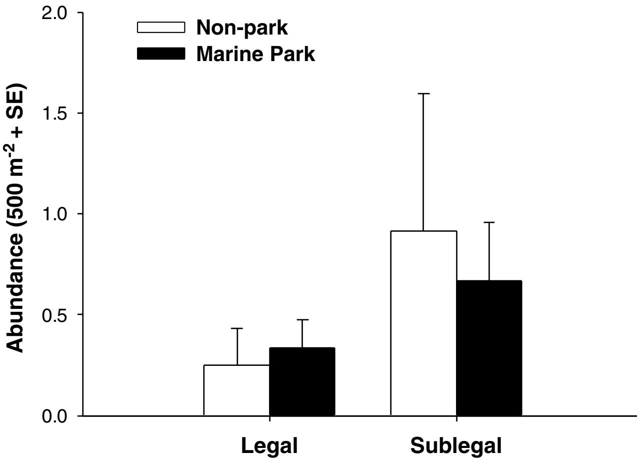

Fig. 6 – Mean abundance of legal and sublegal *J. edwardsii* inside and outside the Mimiwhangata Marine Park in 2003.

reserves despite regional trends in the fishery. Therefore we strongly recommend that legislators and natural resource managers focus on no-take protection measures when developing and implementing strategies to increase the level of protection on marine environments.

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