Davidson Environmental Limited

Tonga Island Marine Reserve, Abel Tasman National Park: update of biological monitoring, 1993 – 2013

Research, survey and monitoring report number 771

A report prepared for:
Department of Conservation
Private Bag 5
Nelson

August 2013

In memory of Russell G Cole (1963-2013)

A true marine reserve believer and our friend

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SUMMARY

1. This report presents data regularly collected from Tonga Island Marine Reserve and adjacent control sites over a period of 20 years (1993 to 2013).
2. Updated data includes: (i) reef fish size and density; (ii) lobster size sex and density; (iii) key rocky invertebrate species density; (iv) scallop size and density; and (v) horse mussel density..
3. In March 2013, black foot paua size and density data were collected for the first time.
4. At the end of the study, legal sized blue cod were 40 times more abundant in the reserve than at control sites. In 2013, only 5% of the cod population at sites was > 30 cm length, compared to 48% within the reserve. In the reserve, blue cod up to 48 cm length were recorded, whereas cod in control areas seldom reached 40 cm length.
5. For other edible reef fish species, increases in the size of blue moki were the only documented change attributable to reservation.
6. The density of lobsters inside the reserve increased dramatically from 1.01 individuals per 100 m^2 (deep strata) in 1994 to 7.1 individuals per 100 m^2 in 2013.
7. At the end of the study, shallow lobsters were 8 times more abundant, and deep lobsters 6.8 times more abundant in the reserve than in control sites.
8. Large reproductive males and females dominated the reserve lobster population. This suggests that relative to a similar area of unprotected coastline, where large males and females were relatively uncommon, the reserve will produce significantly more offspring.
9. Kina was the only rocky invertebrate species that changed in density due to reservation. Between 1993 and 2008, kina density declined within the reserve, while at adjacent control sites kina density increased.
10. Horse mussels were abundant at two sites in the reserve. Large numbers of live and dead horse mussels were frequented by snapper and eagle rays.
11. Scallop numbers in the reserve crashed after 2008, but remained stable at control sites. The reason(s) for this phenomenon remains unknown.
12. Black foot paua were recorded occasionally within the reserve and at control sites. The largest paua in the study was 125 mm in length, and was recorded from a reserve site. All other paua were below the legal size limits specified in recreational fisheries regulations for this region. The highest density of paua recorded was from a control site adjacent to the reserve.

1.0 INTRODUCTION

This report presents data collected during a monitoring programme based at Tonga Island Marine Reserve, Abel Tasman coast, Tasman Bay. To date, data has been collected over a period of 20 years from the reserve and adjacent control sites (Davidson, 1999, 2001, Davidson *et al.* 2002, Davidson and Richards 2007, present study).

Since 1993, a variety of biological data has been collected. Data collected since the last report (Davidson and Richards 2007) has been highlighted in the following list.

- Shore profiles.
- Key benthic invertebrate density from rocky substrata.
- Key benthic invertebrate species size from rocky substrata.
- Reef fish densities and edible species size.
- Rock lobster density, size and sex.
- Horse mussel density.
- Scallop size and density.
- Black foot paua size and density.
- Baited underwater video.

The sample frequency for each aspect of the study has been variable. Reef fish and lobster data for example, have been collected more regularly than other data. Since 1999, lobster and fish data have been collected annually, whereas some data has been collected less frequently, or in the case of black foot paua, on one occasion (see Table 6).

2.0 STUDY AREA

The Abel Tasman coastline, including the Tonga Island Marine Reserve, is located centrally within Tasman and Golden Bays, Nelson. Tonga Island Marine Reserve was established in November 1993. The reserve is 1835 hectares in size and extends one nautical mile (1.852 km) offshore from mean high water (Figure 1). The marine reserve boundaries extend from the headland immediately north of Bark Bay to Awaroa Head, and include the shoreline of all islands and stacks within its boundaries.

The coastline within the marine reserve and at control sites is located adjacent to the Abel Tasman National Park (see Dennis, 1985, for review). Although this coastline is sheltered from large ocean swells, it is influenced by wind-generated waves that quickly subside with a drop or change in wind direction. High sediment input from the hill catchments both within and adjacent to this coast (i.e. Motueka River), combined with regular sea-breezes and large tides (4.7 m extreme high tide), result in water clarity of approximately 2-8 m horizontal distance. In 2013, after a prolonged dry period and no river floods, water visibility along some of the coast increased to approximately 12 m horizontal distance. Water temperatures range from 10-22^{o} C (Dix, 1970).

Rocky reefs extending to a depth of approximately 4-14 m are bordered by gently sloping soft sediment shores. Shallow soft shores are primarily characterised by broken shell and sand that grades with increasing depth to finer substrata and eventually silt and clays. Granite boulder and bedrock substrata dominate the Abel Tasman coast. Less than 1% of rocky shores along the National Park coast are composed of limestone, with all of it being located north of Separation Point and outside the marine reserve (Davidson 1992, Davidson and Chadderton, 1994).

The distribution of habitats and associated communities on the granite shores of the Abel Tasman are relatively homogeneous (Davidson, 1992). The exception is the community associated with limestone substrata. Davidson and Chadderton (1994) reported that subtidal communities on limestone were dramatically different to communities on granite. All rocky sample sites in the present study were granite.

3.0 SAMPLING SUMMARY SINCE 2007 REPORT

Data collected in relation to the Tonga Island Marine Reserve have previously been presented in three monitoring reports (Davidson, 1999, 2001; Davidson and Richards 2007). The current report, which incorporates data collected since Davidson and Richards (2007) (Table 6), compares changes in the density, size and/or sex of monitored species between marine reserve sites and adjacent control sites over the entire sampling period from 1993 to 2013 (Figures 1 to 5, Tables 1 to 5).

Table 1. Reef fish sites sampled annually since 2007.

Type	Coordinates	Location	Code	Treatment	Substratum
Reef fish	40 47.05806,172 59.90864	Separation Point	CF1	Control	Boulder, cobble
Reef fish	40 48.170,173 00.530	Totaranui north	CF2	Control	Bedrock
Reef fish	40 48.858,173 01.115	Totaranui Reef	CF3	Control	Bedrock
Reef fish	40 51.12408,173 02.62163	Awaroa	CF4	Control	Bedrock, boulder
Reef fish	40 51.15995,173 02.77066	Canoe Bay	RF1	Reserve	Boulder, cobble
Reef fish	40 51.39304,173 03.44764	Abel Head	RF2	Reserve	Boulder, cobble, bedrock
Reef fish	40 51.72980,173 03.67184	Cottage Loaf	RF3	Reserve	Boulder, cobble, bedrock
Reef fish	40 53.10127,173 03.51041	Reef Pt.	RF4	Reserve	Bedrock, boulder
Reef fish	40 53.45573,173 04.13343	Tonga Is.	RF5	Reserve	Bedrock, boulder
Reef fish	40 54.23512,173 03.74018	Foul Pt.	RF6	Reserve	Bedrock, boulder
Reef fish	40 54.58073,173 04.14347	Whale Rock	RF7	Reserve	Bedrock, boulder
Reef fish	40 55.10164,173 04.30913	Bark Bay Reef	CL5	Control	Boulder, cobble, bedrock
Reef fish	40 56.35684,173 03.70098	Totara Rocks	CL6	Control	Bedrock, boulder

Table 2. Lobster sample sites sampled annually since 2007.

Type	Coordinates	Location	Code	Treatment	Substratum
Lobster	40 47.05806,172 59.90864	Separation Point, 1	CL1	Control	Boulder, cobble
Lobster	40 51.12408,173 02.62163	Awaroa, 2	CL2	Control	Bedrock, boulder
Lobster	40 51.70603,173 03.66512	Cottage Loaf, 3	RL1	Reserve	Boulder, cobble, bedrock
Lobster	40 53.43768,173 04.13356	Tonga Is. 4	RL2	Reserve	Bedrock, boulder
Lobster	40 54.23333,173 03.75072	Foul Pt. 5	RL3	Reserve	Bedrock, boulder
Lobster	40 54.58073,173 04.14347	Whale Rock, 6	RL4	Reserve	Bedrock, boulder
Lobster	40 54.69568,173 03.85761	Mosquito Reef, 7	RL5	Reserve	Bedrock, boulder
Lobster	40 55.10164,173 04.30913	Bark Bay Reef, 8	CL3	Control	Boulder, cobble, bedrock
Lobster	40 56.28063,173 03.74358	Totara Rocks, 9	CL4	Control	Bedrock, boulder
Lobster	40 56.90667,173 04.06431	Pitt Head, 10	CL5	Reserve	Bedrock, boulder

Table 3. Scallop and horse mussel sites sampled in 2008, 2010, and 2013.

Type	Coordinates	Location	Code	Treatment	Substratum
Scallop, horse mussel	40 53.059,173 03.212	Tonga north inshore	RSH1	Reserve	Sand, shell
Scallop, horse mussel	40 53.08315,173 03.35917	Tonga north (offshore)	RSH2	Reserve	Sand, shell
Scallop, horse mussel	40 53.44986,173 03.11798	Tonga south	RSH3	Reserve	Sand, shell
Scallop, horse mussel	40 54.96729,173 03.52886	Bark Bay (north), 4	CSH1 (north)	Control	Sand, shell
Scallop, horse mussel	40 55.08517,173 03.44385	Bark Bay (centre), 5	CSH2 (middle)	Control	Silt, shell

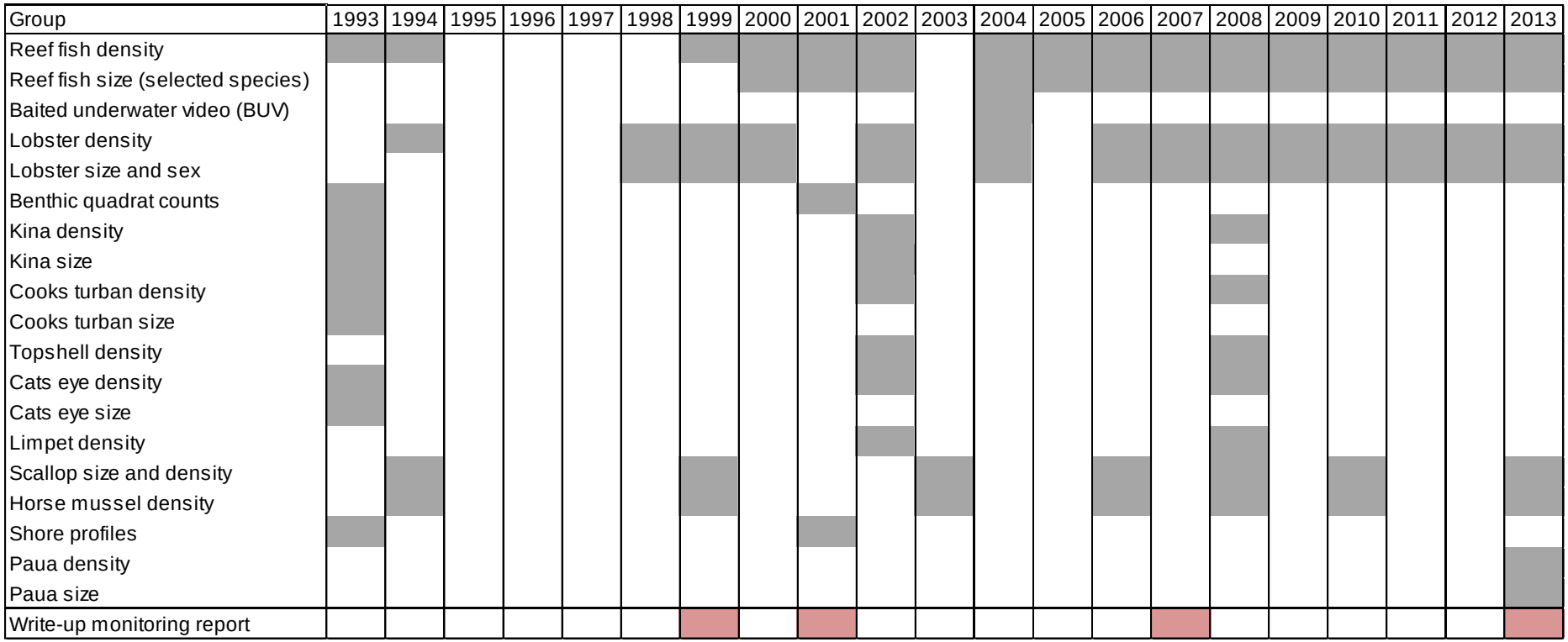
Table 4. Black foot paua sites sampled in 2013.

Type	Coordinates	Location	Code	Treatment	Substratum
Black foot paua	40 48.22345,173 00.55782	Anapai	CB1	Control	Bedrock
Black foot paua	40 50.38838,173 00.89888	RataKura Point	CB2	Control	Bedrock
Black foot paua	40 51.32175,173 02.83716	Canoe Bay	RB1	Reserve	Bedrock
Black foot paua	40 53.49448,173 04.11720	Tonga Island	RB2	Reserve	Bedrock, large boulders
Black foot paua	40 53.94527,173 03.29827	Tonga Quarry Arches	RB3	Reserve	Bedrock
Black foot paua	40 54.25572,173 03.74434	Foul Point	RB4	Reserve	Bedrock
Black foot paua	40 54.75786,173 03.71389	Mosquito reef South	RB5	Reserve	Bedrock, large boulders
Black foot paua	40 55.11512,173 04.30229	Bark Bay Reef	CB3	Control	Bedrock, large boulders
Black foot paua	40 56.08962,173 03.59312	Frenchman Bay	CB4	Control	Bedrock

Table 5. Key invertebrate sites sampled in 2008.

Type	Coordinates	Location	Code	Treatment	Substratum
Key species	40 47.04179,172 59.90323	Separation Pt. 1	CI1	Control	Bedrock, boulder
Key species	40 51.09813,173 02.66039	Awaroa Head, 2	CI2	Control	Bedrock, boulder
Key species	40 51.14185,173 02.80856	Canoe Bay, 3	RI1	Reserve	Bedrock, boulder
Key species	40 54.02087,173 03.41261	Arch Pt. 4	RI2	Reserve	Bedrock, boulder
Key species	40 54.21737,173 03.73238	Foul Pt. 5	RI3	Reserve	Bedrock, boulder
Key species	40 54.57986,173 04.15273	Whale Rock, 6	RI4	Reserve	Bedrock, boulder
Key species	40 56.34183,173 03.66733	Totara Rock, 7	CI3	Control	Bedrock, boulder

Table 6. Sampling events for Tonga Island Marine Reserve and controls, 1993 to 2013.



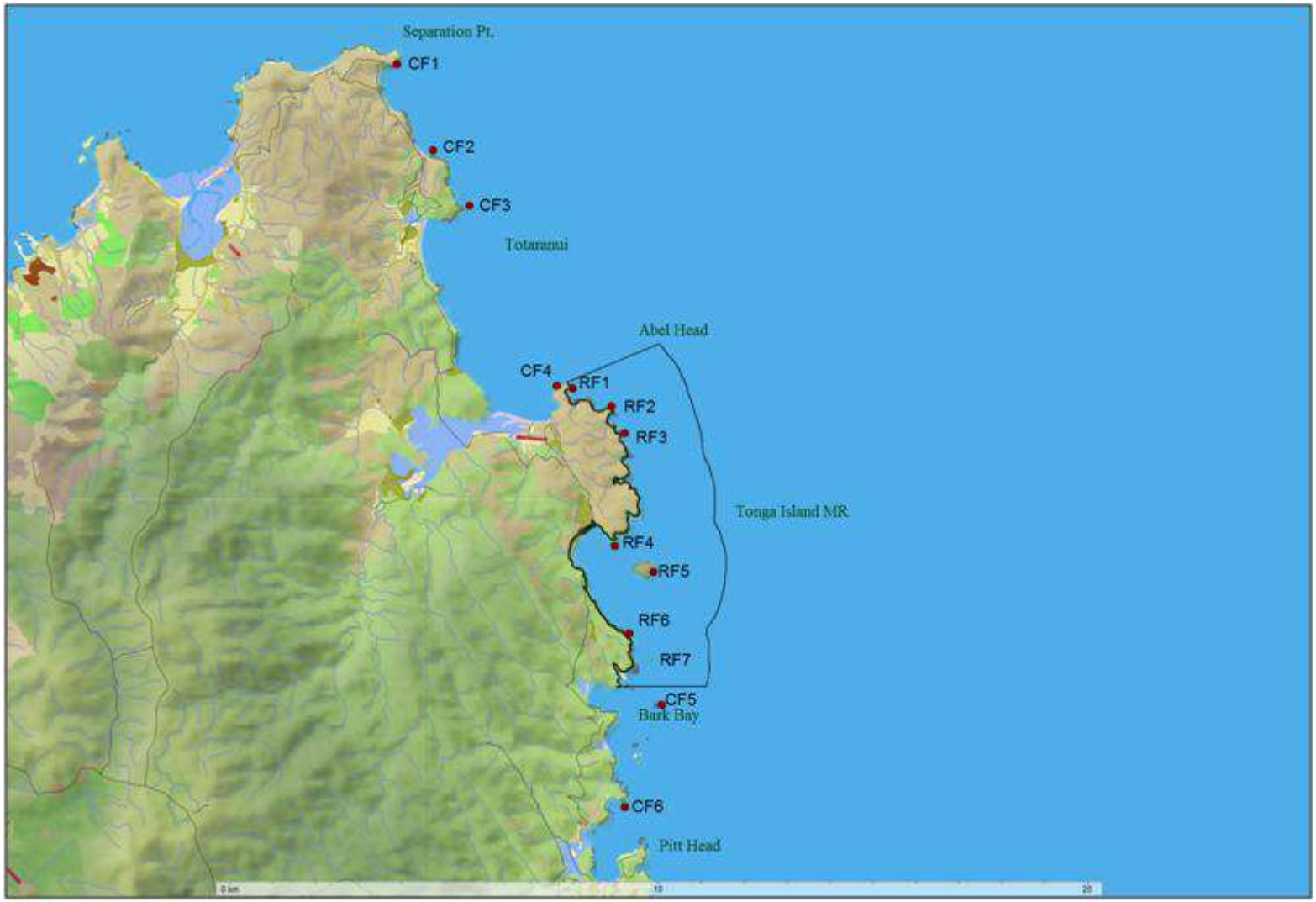


Figure 1. Location of reserve (RF) and control (CF) sites along the Abel Tasman National Park coastline for reef fish sampled since 2007.

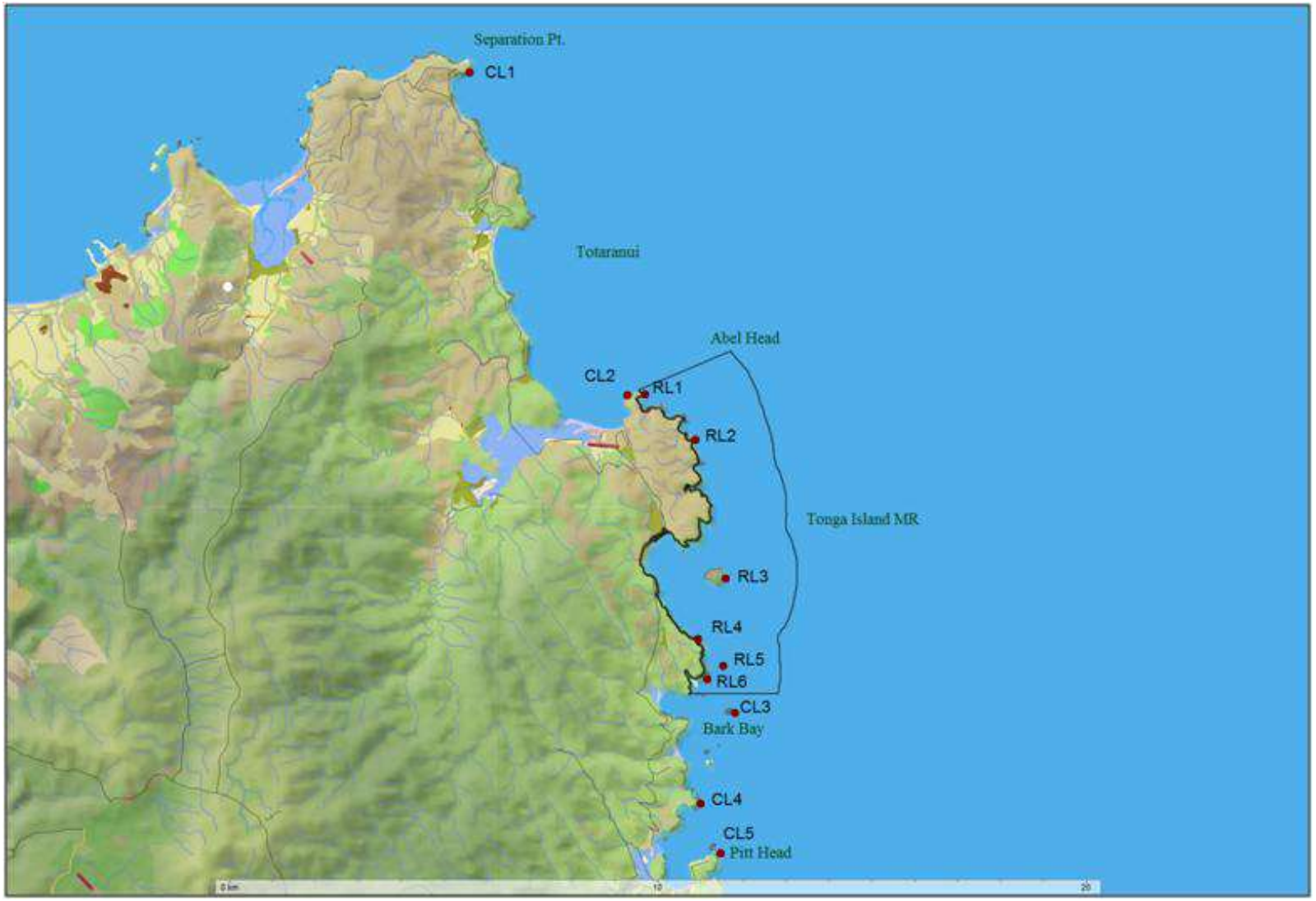


Figure 2. Location of reserve (RF) and control (CF) sites along the Abel Tasman National Park coastline for lobsters sampled since 2007.

Figure 3. Location of reserve (RF) and control (CF) sites along the Abel Tasman National Park coastline for scallops and horse mussels sampled since 2007.

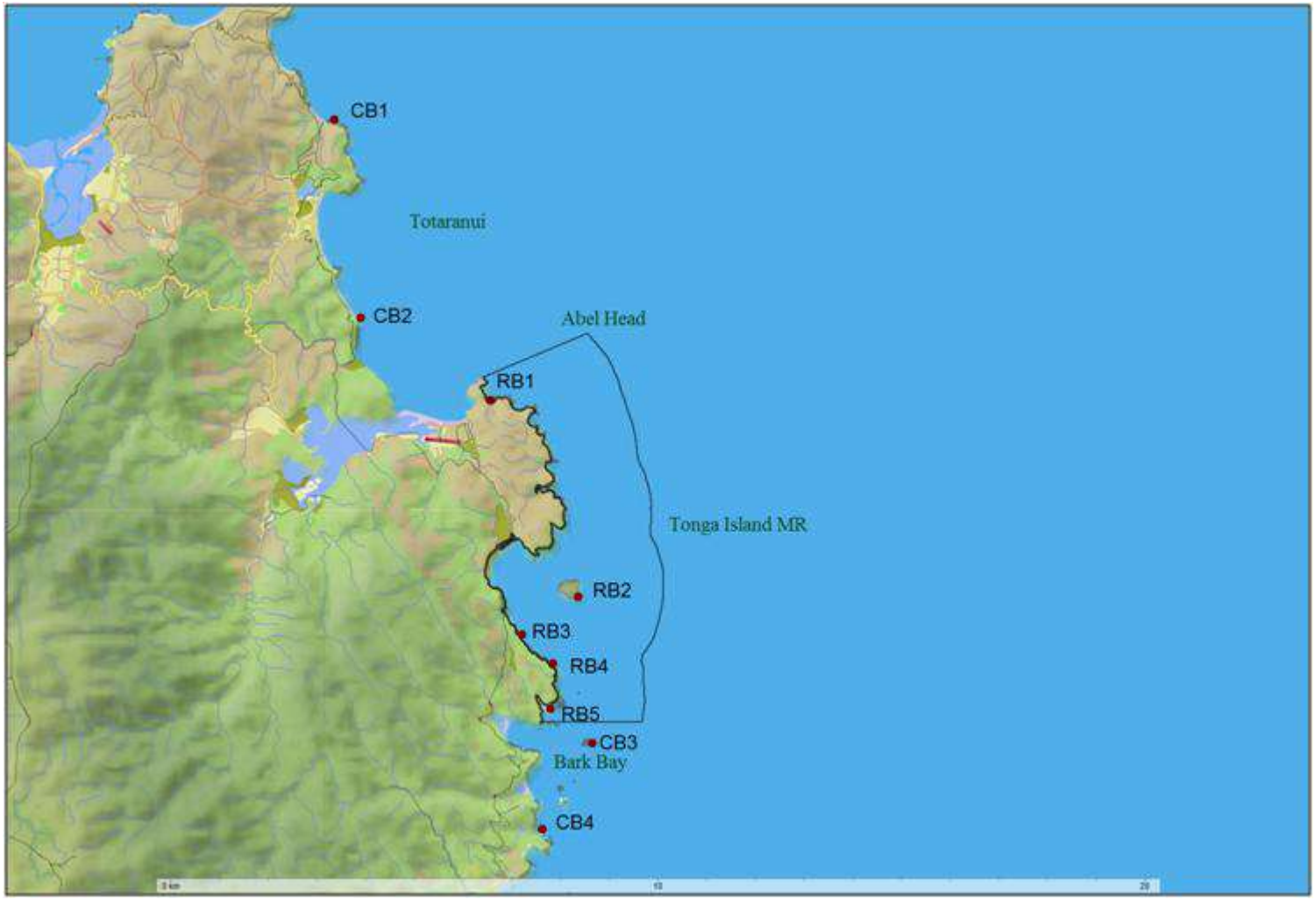


Figure 4. Location of reserve (RF) and control (CF) sites along the Abel Tasman National Park coastline for black foot paua sampled in February 2013.

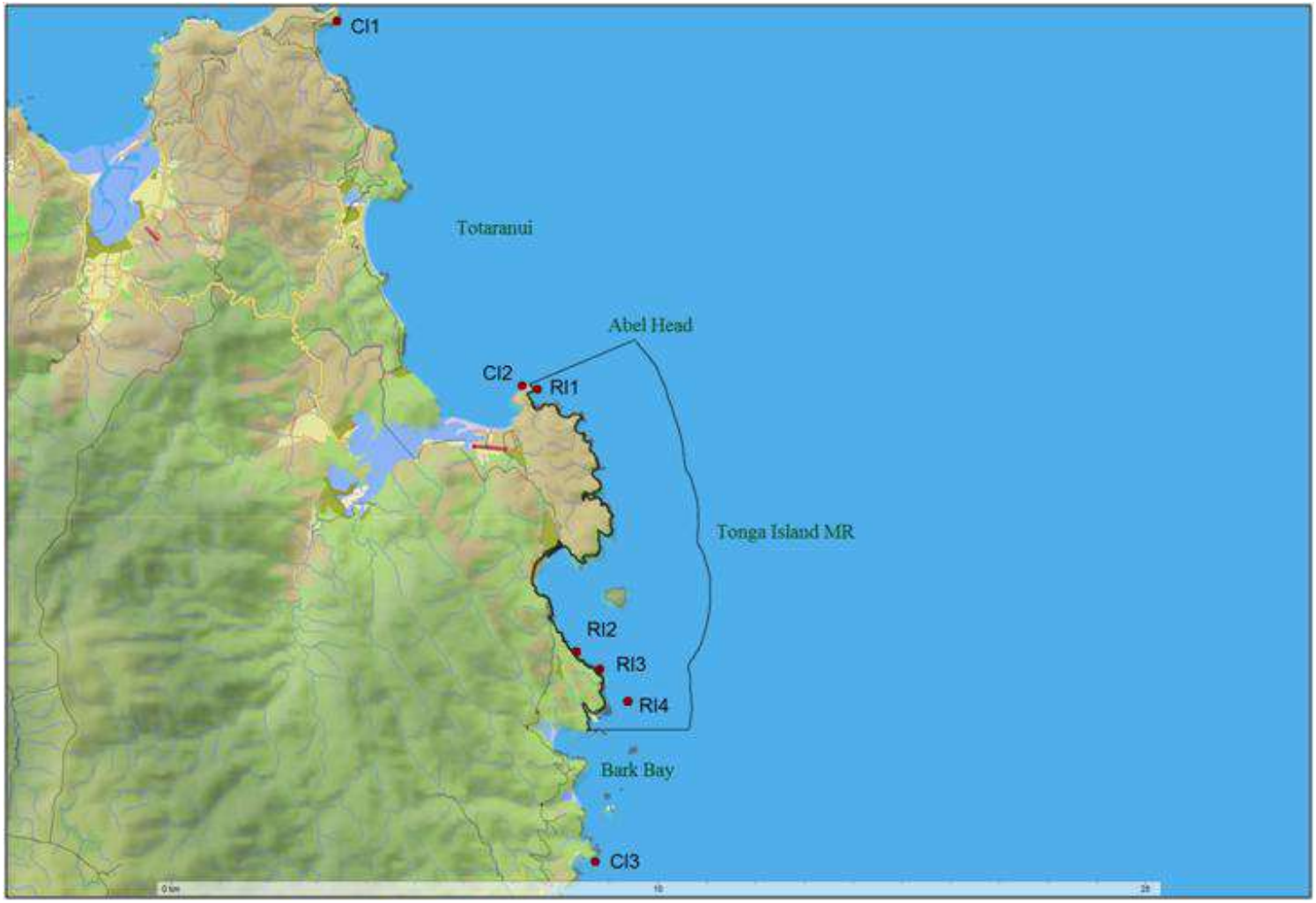


Figure 5. Location of reserve (RF) and control (CF) sites along the Abel Tasman National Park for key rocky invertebrate species collected in 2008.

4.0 MATERIALS AND METHODS

4.1 Fish density derived from underwater visual transects

In all years since 2007, the density of blue cod (*Parapercis colias*) and other reef fish was monitored using established underwater visual transect methods (Bell, 1983; McCormick and Choat, 1987; Choat *et al*., 1988; Buxton and Smale, 1989; Cole *et al.*, 1990; Cole, 1994; Willis *et al*., 2000).

All transects were established parallel to shore in boulder and reef habitat at depths from 5 - 12 m (Tables 1 and 6, Figure 1). Since 2000, the size of blue cod, blue moki (*Latridopsis ciliaris*), red moki (*Cheilodactylus spectabilis*), tarakihi (*Nemadactylus macropterus*), butterfish (*Odax pullus*) and snapper (*Pagrus auratus*) was visually estimated by trained and ground-truthed divers to the nearest centimeter of fish body length. Divers ignored triplefins (Tripterygiidae) and cave- and crevice-dwelling species. Since 2007, the same two divers have collected all fish data in the reserve and control sites.

At each site, a lead weight at the start of the transect line was dropped onto the substrate within the designated depth range. The line was automatically reeled off a spool as the diver holding the spool swam away from the lead weight. At a distance of 5 m from the weight (indicated by a marker on the line), the diver started counting fish present within an estimated 2 m wide x 2 m high x 30 m long "tunnel". Transects were swum at a constant slow speed, but fast enough to ensure that swimming fish did not overtake the divers. Twelve replicate transects were sampled at each site. Underwater visibility was at least 4.5 m horizontal distance for the collections of fish transect data.

4.2 Spiny lobster density, sex and size

The density of spiny lobsters (*Jasus edwardsii*) was monitored in marine reserve and adjacent control sites annually since 2007 (Figure 2, Tables 2 and 6). Pre 2007, lobster data was collected less frequently, particularly during the early years of monitoring (Table 6).

In 1994, the density of spiny lobsters was sampled in three to thirty 30 x 4 m (120 m^2) quadrats per site. From 1998 onwards, lobster density, size and sex were sampled in ten 25 x 4 m quadrats (100 m^2) per site. Since 1998, quadrats were also depth-stratified at each site, with five quadrats sampled at a depth of 6 - 7 m, and five sampled at 10 - 11 m depth. A further change to methodology was made in 2013. Due to the large numbers of lobsters at reserve sites, the number of quadrats sampled in each depth strata was reduced from five to four. This enabled divers to complete the work safely in a single dive.

The methodology for estimating lobster size also changed during the monitoring programme. In the 1994 survey, total body length was visually estimated and individuals were grouped into four size classes: juvenile (< 150 mm), small (150 – 250 mm), medium (250 – 350 mm), and large (> 350 mm). From 1998 onwards, carapace length (CL), estimated to the nearest 5 mm, replaced estimations of total body length. Lobsters were separated into three size groups based on carapace length: (i) reproductive male (≥140 mm CL (ii) non-reproductive male (85-139 mm), (iii) mature female (≥85 CL), (iii) juvenile ≤ 80mm CL. A ruler attached to an extendable lanyard was used to measure lobsters. Many lobsters could not be measured; in this instance the ruler was use as an aid to size estimation.

Lobster quadrats were haphazardly placed and oriented within the depth stratum. Two divers independently searched all crevices, caves and cracks within each quadrat using an LED dive torch. The size and sex of lobsters encountered was recorded. A core group of five divers were involved in most of the surveys. Since 2007, the same three divers collected lobster data.

Occasionally, the size and sex of some lobsters could not be measured because they were deeply concealed beneath boulders or within caves. As a result, the number of lobsters in density and size data does not correspond. Underwater visibility was at least 2 m during all lobster counts.

4.3 Scallop density and size and horse mussel density

Since 2007, the density of scallops (*Pecten novazelandiae*) and horse mussels (*Atrina zelandica*), and the size frequency of scallops was sampled on three occasions in ten haphazardly placed sets of 50

continuous 1 m^2 quadrats (Tables 3 and 6, Figure 3). Each set of 50 quadrats was deployed haphazardly by divers instructed to swim a different compass bearing at least 10 m distance from the previous set of quadrats. Within each quadrat, divers counted all scallops and horse mussels and measured the maximum width of all scallops.

These data had been previously sampled on four occasions (Table 6). In 2008, 2010 and 2013, quadrats were sampled from two control sites in Bark Bay (Bark Bay middle and Bark Bay north), and three reserve sites in Tonga Roadstead (Tonga north inshore and offshore and Tonga south) (Figure 3, Table 3).

4.4 Black foot paua density and size

The density and size (maximum length) of black foot paua (*Haiotis iris*) was sampled at five reserve and four control sites in February 2013 (0-2 m depth below mean low water) (Figure 4, Table 4). Divers methodically searched each site in an attempt to find a minimum of 50 paua. Paua were measured with callipers to the nearest mm *in situ.*

At each site, paua density was sampled in a minimum of twenty-nine 1 m^2 quadrats haphazardly deployed in 0-2 m depth below mean low water.

4.5 Kina, Cooks turban, cats eye, top-shell and limpet density

The density of kina (*Evechinus chloroticus*), cooks turban (*Cookia sulcata*), cats eyes (*Turbo smaragdus*), top-shells (*Trochus* sp.) and limpets (*Cellana sp.*) was sampled on one occasion (2008) since 2007 (Figure 5, Tables 5 & 6). Not all sites previously investigated were sampled; rather, a subset of sites sampled in 1993 was used. At each site density data were collected from 60 haphazardly deployed 1 m^2 quadrats sampled from a 5-10 m depth range.

4.6 Statistical analysis

All size and density raw data were entered into a Mircrosoft Excel 2010 spreadsheet. Mean, standard deviation, standard error and sample sizes were calculated using inbuild function commands. On

occasion raw data from individual sites were pooled into reserve and control groups where means, standard deviation and standard errors were calculated in Excel 2010. Statistical analyses of raw data were conducted using Sigmaplot 12.5 unpaired t-Test where data were first tested using the Shapiro-Wilk Normality Test. An equal variance test was also conducted on raw data to check variablility about the means. The P value determining the probability of being incorrect in concluding that the data is not normally distributed was set at 0.05. All raw data in the present study failed this test and a Mann-Whitney Rank Sum Test was then applied. The Mann-Whitney Rank Sum Test tests for a difference between two groups that is greater than what can be attributed to random sampling variation. The null hypothesis was that the two samples were not drawn from populations with different medians. The Rank Sum Test is a nonparametric procedure, which does not require assuming normality or equal variance. It ranks all the observations from smallest to largest without regard to which group each observation comes from. The ranks for each group are summed and the rank sums compared. If there is no difference between the two groups, the mean ranks should be approximately the same. If they differ by a large amount, we assumed that the low ranks tend to be in one group and the high ranks are in the other, and conclude that the samples were drawn from different populations (for example, that there is a statistically significant difference).

In all significance tests Alpha was set at 0.05 where α is the acceptable probability of incorrectly concluding that there is a difference.

5.0 RESULTS AND DISCUSSION

5.1 Underwater visual fish surveys

Divers recorded a variety of reef fish from cobble, boulder and bedrock habitats in the Tonga Island Marine Reserve and associated control sites (Figures 6 and 7). Spotty (*Notolabrus celidotus*) were the most abundant reef fish from both reserve and control sites. Spotty abundance increased over the duration of the study both within and outside the reserve. The abundance of tarakihi (*Nemadactylus macropterus*) varied dramatically between years, but was most often the next most abundant species. Goatfish (*Upeneichthys lineatus*), blue cod (*Parapercis colias*), butterfly perch (*Caesioperca lepidoptera*) and scarlet wrasse (*Pseudolabrus miles*) were relatively common in counts, but were usually below densities recorded for spotties and tarakihi. Banded wrasse (*Notolabrus fucicola*), blue moki (*Latridopsis ciliaris*), marblefish (*Aplodactylus arctidens*), leatherjackets (*Parika scaber*), , sweep (*Scorpis lineolatus*) and red moki (*Cheilodactylus spectabilis*) were also present (although uncommon) at sites. Butterfish (*Odax pullus*), sea perch (*Helicolenus percoides*) and magpie perch (*Cheilodactylus nigripes*) were rarely seen at some sites (Figures 6 and 7).

5.1.1 Fish density

Blue cod (*Parapercis colias*) were recorded from pooled reserve and control groups on all sample occasions (Figure 8). Blue cod were classified as being small (< 30 cm total length) or large (≥ 30 cm total length) based on legal size limits specified in the recreational fisheries regulations for this region. A significant difference in the mean density of small blue cod occurred between control and reserve sites in 2004, 2006 and 2007 (Figure 8, Table 7). The mean density of small blue cod at control sites generally mirrored the density in the reserve over the 20-year sample period, with major peaks in February 2005, March 2011 and March 2013. The mean density of small blue cod from the reserve sites peaked in the same years as in control sites. Despite relatively large year-to-year variation, the mean density of blue cod in reserve and control sites generally increased over the duration of the study.

Large blue cod were often absent from control sites (Figure 8). Apart from the first six years of the study, the number of large blue cod at control sites remained low relative to reserve sites (Figure 8). No large blue cod were recorded from the reserve in the first two sample years (Figure 8). Relative to control sites, the density of large blue cod was significantly higher at reserve sites in all years from April 2002 onwards (Table 7). At the end of the study, large blue cod were 40 times more abundant in the reserve compared to control sites.

Table 7. Mann-Whitney U test statistics comparing the density of small and large blue cod between Tonga Marine Reserve and adjacent control sites for each of 16 sampling years between 1993 and 2013.

Reserve versus control	Small blue cod (< 300 mm TL)				Large blue cod (≥ 300 mm TL)			
	U statistic	P value	N	Sig.	U statistic	P value	N	Sig.
December 1993	4069	0.528	48,123	NS.	4128	1.0	48,123	NS.
December 1994	345	0.513	18,21	NS.	360	1.0	18,21	NS.
September 1999	5776	0.545	72,85	NS.	5580	0.110	72,85	NS.
December 2000	5454	0.254	72,84	NS.	5441	0.05	72,84	NS.
March 2001	4677	0.890	72,84	NS.	5442	0.051	72,84	NS.
April 2002	5369	0.090	72,84	NS.	2556	<0.001	72,84	Sig.
February 2004	5286	0.028	72,84	Sig.	4896	<0.001	72,84	Sig.
February 2005	2898	0.552	72,84	NS.	5040	0.001	72,84	Sig.
April-May 2006	5340	0.030	72,84	Sig.	5296	0.006	72,84	Sig.
February 2007	5356	0.040	72,84	Sig.	4896	<0.001	72,84	Sig.
March 2008	5391	0.166	72,84	NS.	5259	0.004	72,84	Sig.
March 2009	5475	0.333	72,84	NS.	5042	<0.001	72,84	Sig.
March 2010	5384	0.166	72,84	NS.	4713	<0.001	72,84	Sig.
March 2011	5527	0.589	72,84	NS.	4825	<0.001	72,84	Sig.
April 2012	5448	0.272	72,84	NS.	5040	<0.001	72,84	Sig.
March 2013	5840	0.429	72,84	NS.	2051	<0.001	72,84	Sig.

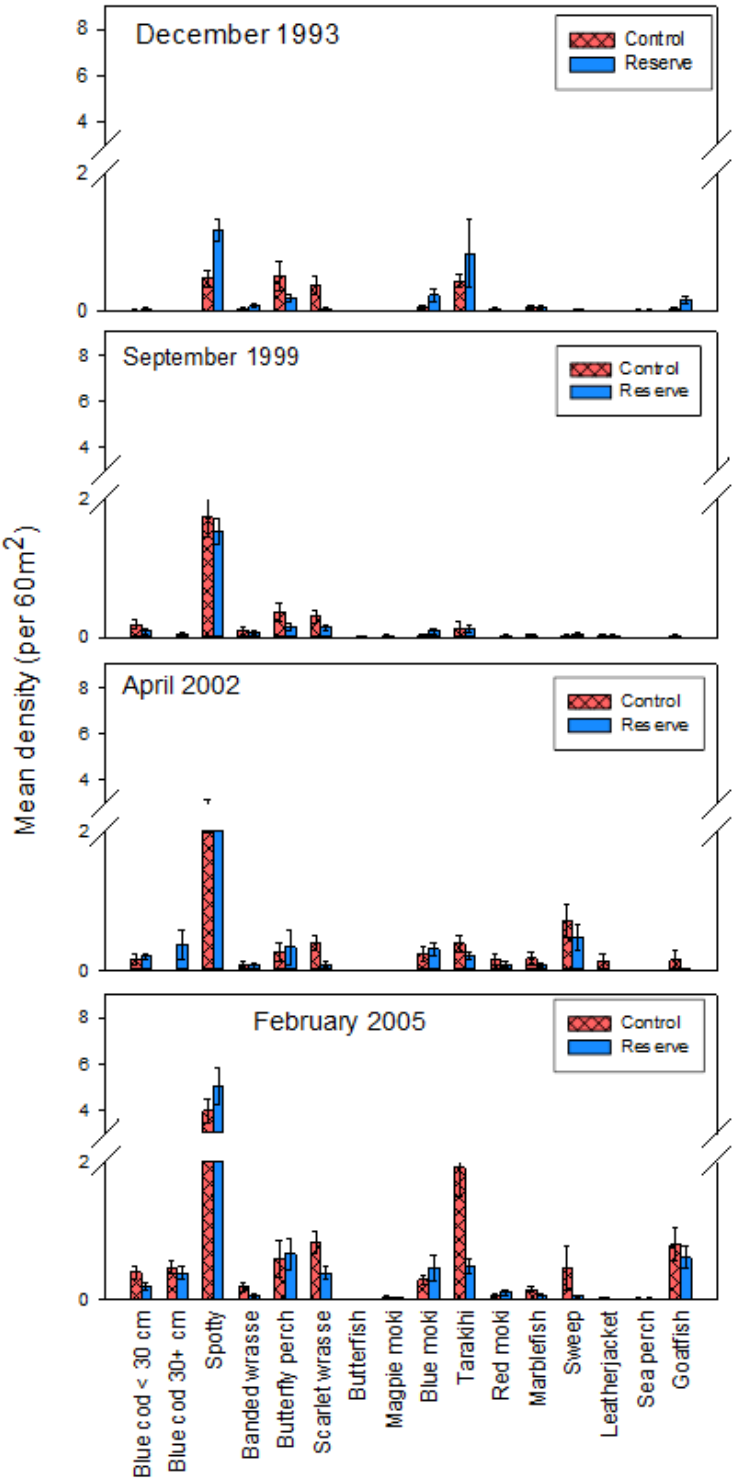


Figure 6. Mean densities of reef fish sampled in selected years from Tonga Marine Reserve sites (blue) and adjacent control sites (red). Error bars are +/- 1 s.e.

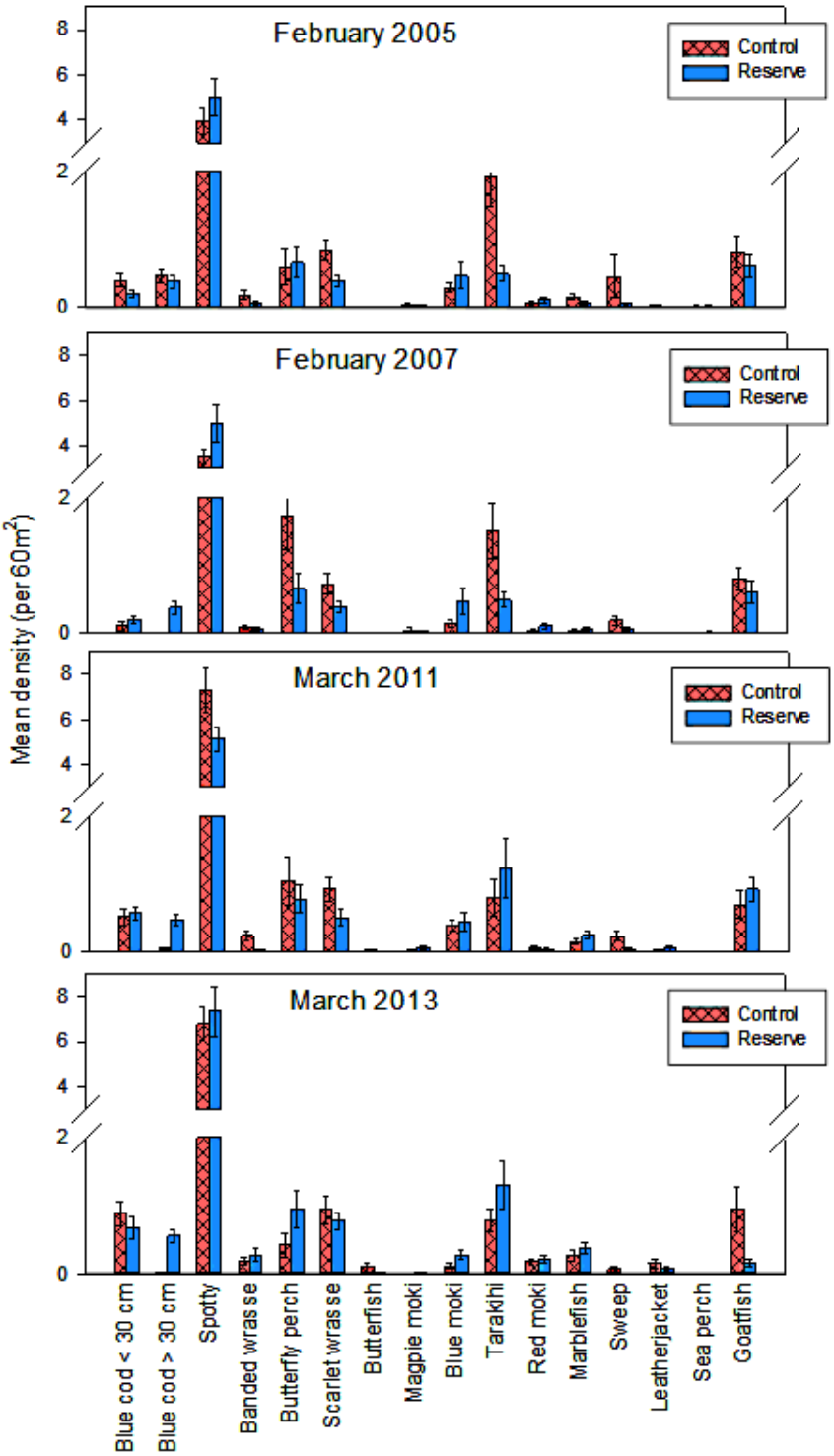


Figure 7. Mean densities of reef fish sampled in selected years from Tonga Marine Reserve sites (blue) and adjacent control sites (red). Error bars are +/- 1 s.e.

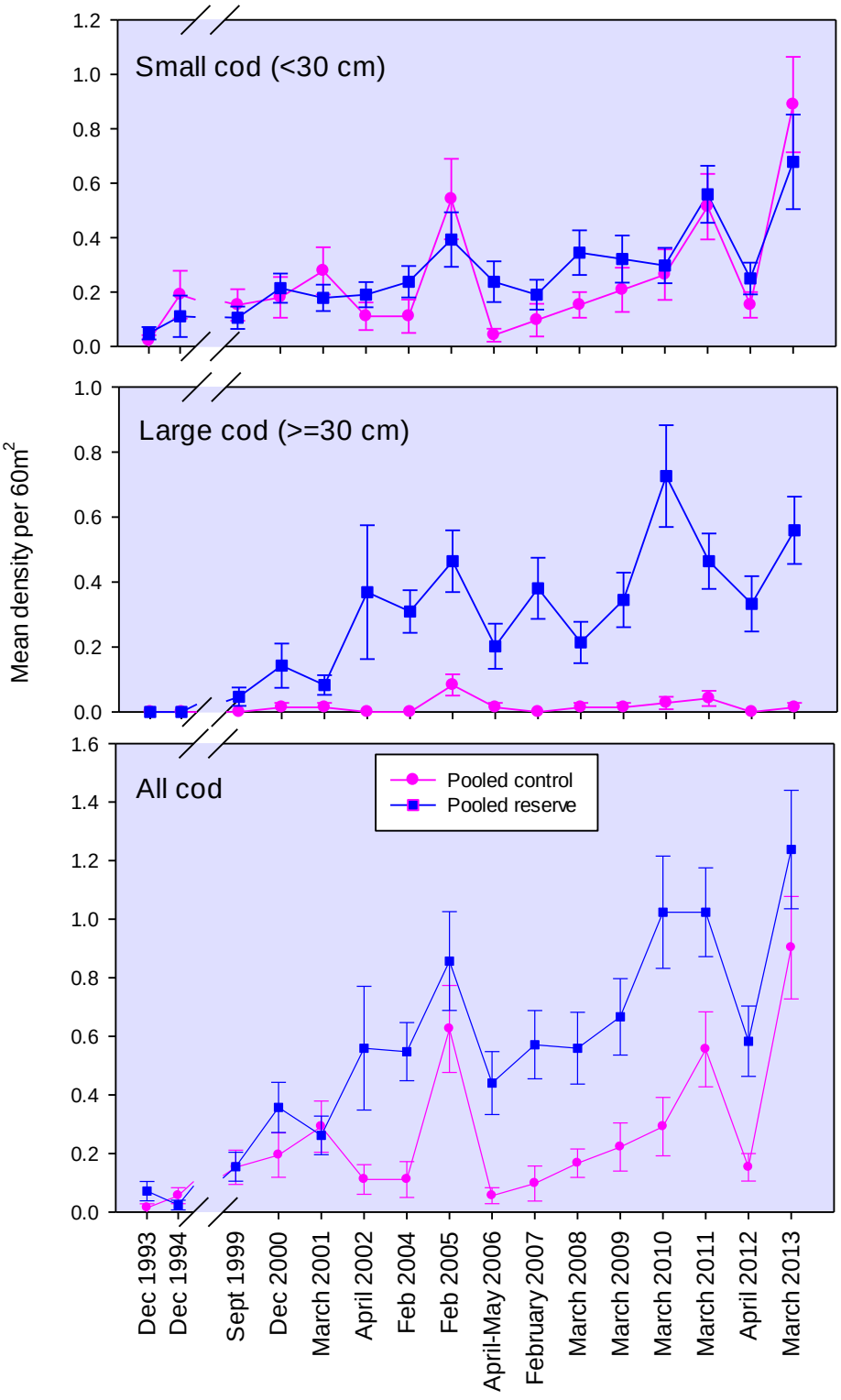


Figure 8. Mean density of small (top), large (middle) and all (bottom) blue cod from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled from 1993 to 2013. Error bars are +/- 1s.e.

Spotty (*Notolabrus celidotus*) were recorded from reserve and control sites in all years (Figure 9). Little difference in the densities of spotties between the reserve and control sites existed in each sampling year; however, the density of spotties displayed considerable inter-annual variation with at least four density peaks (Figure 9). The density of spotties in reserves and at control sites peaked in April-May 2006, March 2011 and March 2013. Overall, spotties were considerably more abundant in the second half of the study (Figure 9). At the end of the study, spotties in both reserve and control sites were 14 times more abundant than at the start of the study. No obvious pattern of density in relation to reservation was apparent.

Tarakihi (*Nemadactylus macropterus*) were recorded from reserve and control sites in all years (Figure 9). The density of tarakihi at reserve and control sites varied considerably between years, with peaks recorded in December 1994, December 2000, February 2005, March 2008 and March 2010 (Figure 9). Very low densities were recorded at control and reserve sites in September 1999, April 2002, April-May 2006, March 2009 and April 2012. In some years, tarakihi were rare to absent in some reserve and control sites.

The density of tarakihi at reserve and control sites followed similar trends over the duration of the study. Although only small differences in tarakihi density existed between reserve and control sites, during the peaks in density tarakihi were usually more abundant at control sites than reserve sites. Tarakihi density showed no overall increase or decrease over the duration of the study; however, the peaks were lower in the second half of the study. No obvious pattern of mean density in relation to reservation was apparent.

With the exception of December 1994, the density of blue moki (*Latridopsis ciliaris*) was generally higher at reserve sites than control sites. In December 2000, March 2001, February 2004, February 2007, March 2008, and April 2012 the density of blue moki was significantly higher at reserve sites than control sites ($P<0.047$) (Figure 10). The density of blue moki in reserve and control sites fluctuated substantially throughout the duration of the monitoring programme; however, there was no consistent pattern of increase or decrease either within the reserve or at control sites (Figure 10).

The density of red moki (*Cheilodactylus spectabilis*) also fluctuated throughout the monitoring programme (Figure 10). In most years, density of red moki was comparable between reserve and

control sites. An exception occurred from March 2008 to 2010, when densities were lower at control sites than reserve sites (Figure 10). At the end of the study, the density of red moki at reserve and control sites was the highest recorded throughout the monitoring programme.

The density of other reef fish species was low relative to the aforementioned species, and did not differ between control and reserve sites. Of biological interest, however, was the regular occurrence of the Australian migrant magpie perch (*Cheilodactylus nigripes*) in transects from February 2005 onwards. Although only ever seen as individual adults, this species seems to be widespread and their increased incidence in transects suggests their abundance has increased since they were first reported along this coast (Davidson 1992).

5.1.2 Fish size

The mean size of blue cod at reserve sites remained relatively constant over the 13-year period, with mean size ranging from 26.9 cm to 31.4 cm. The mean size of blue cod at control sites was consistently lower than at reserve sites. Lowest mean length of blue cod at control sites was recorded in February 2004 (17.2 cm) and March 2013 (20.3 cm) (Figure 11).

From 2002 onwards, size-frequency histograms of blue cod at reserve sites differed from those at control sites (Figures 12a and 12b). The blue cod population at reserve sites consisted of a wider range of sizes, with much of the blue cod population comprised of individuals larger than the legal size limits specified in the recreational fisheries regulations for this region (i.e., ≥ 30 cm total length). Conversely, large individuals were seldom present at control sites. For example, at the end of the study, only 5% of the cod population at control sites were 30 cm length and over, compared to 48% at reserve sites.

The average length of blue moki at reserve sites fluctuated between 29.9 and 41 cm over the sample period (Figure 11). In contrast, the average size of blue moki at control sites was always lower and fluctuated between 22.7 cm and 36 cm. Fluctuations in the mean size of blue moki over the duration of the study appeared to follow similar trends at control and reserve sites (Figures 13a and 13b).

In most years, blue moki that were larger than the legal size limits specified in the recreational fisheries regulations for this region (i.e., > 40 cm) were more frequently observed at reserve sites than

control sites (Figures 13a and 13b). Large individuals were only occasionally encountered at control sites, with the largest individual being 53 cm TL (2013). On occasion individuals up to 70 cm were observed in the reserve. In some years, small blue moki (< 20 cm) were uncommon or absent from both control and reserve sites (December 2000, April 2002, April-May 2006, March 2013). It was in these years that peaks in the mean size of blue moki occurred (Figure 11).

The mean size of red moki at control and reserve sites increased between 1993 and March 2008 (Figure 14). For the following four years, mean size declined. In 2013, the mean size of red moki at control and reserve sites was similar to what it had been in 2000. The mean size of red moki was usually higher at reserve sites relative to control sites; however, these differences were often not statistically significant (Figure 14). Overall, mean size of red moki displayed comparable patterns at control and reserve sites.

Following the first five years of monitoring, the mean size of tarakihi stabilized, with similar patterns occurring at control and reserve sites (Figure 14). Although most tarakihi were 8 - 15 cm TL, mean size was usually higher at reserve sites. Tarakihi were often observed in schools comprising 4 to 50 individuals, and at depths of 3-10 m. In some years, a larger size class (19-26 mm TL) was common.

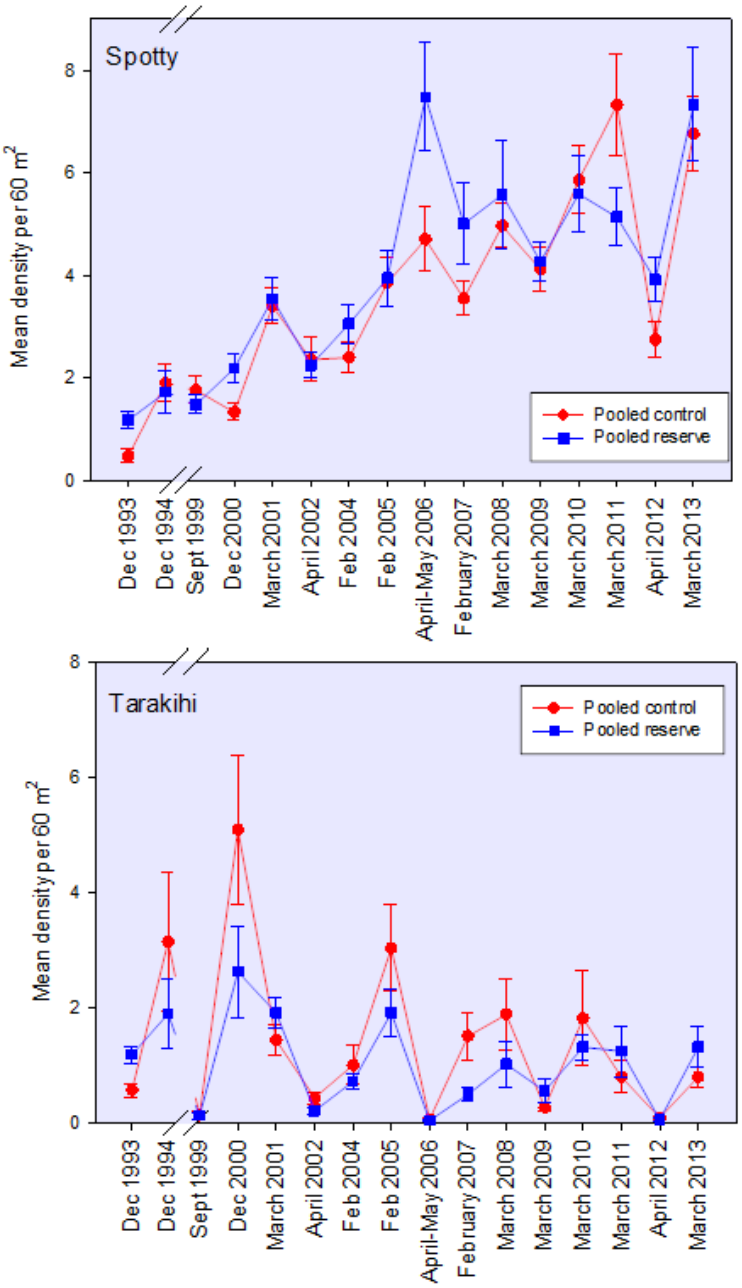


Figure 9. Mean density of spotties and tarakihi from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled from 1993 to 2013. Error bars are +/- 1 s.e.

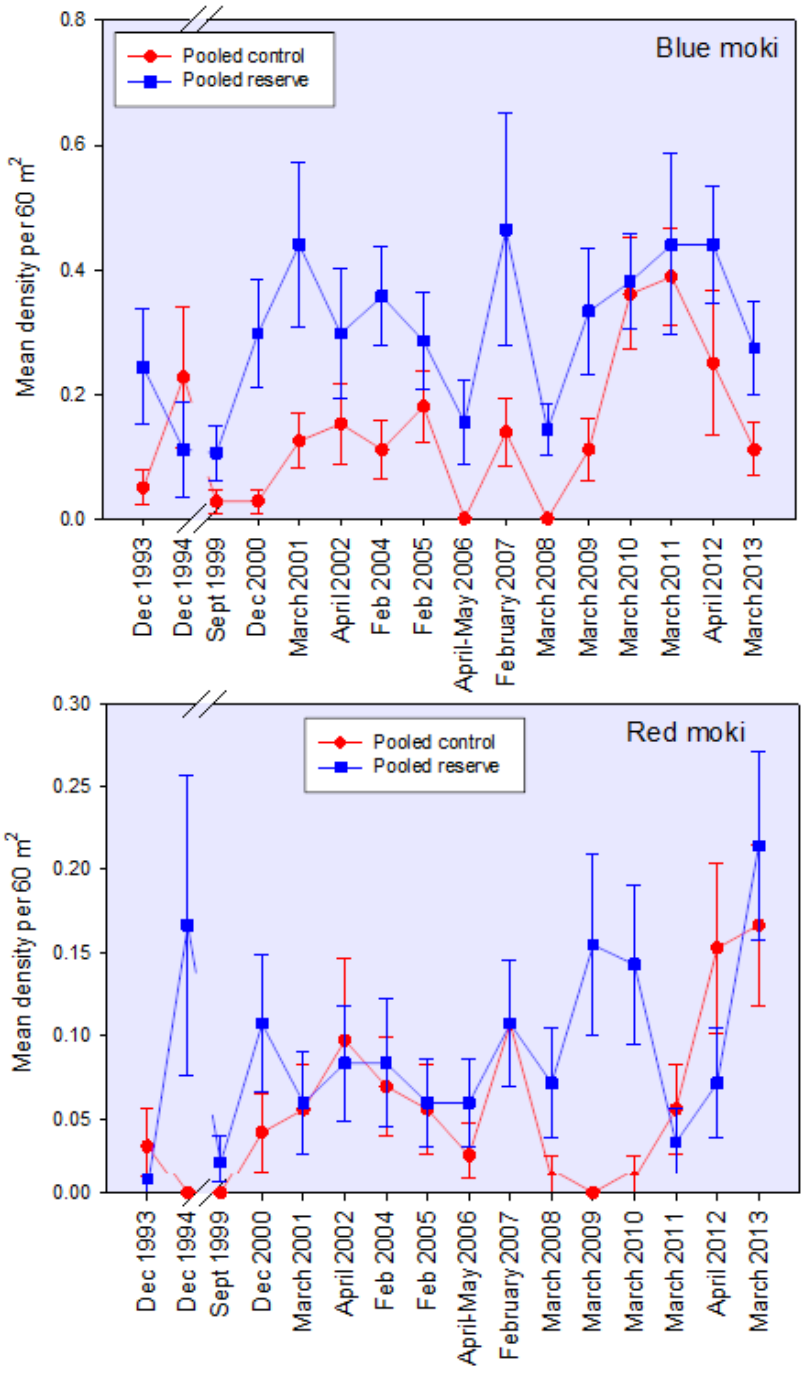


Figure 10. Mean density of blue moki and red moki from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled from 1993 to 2013. Error bars are +/- 1 s.e.

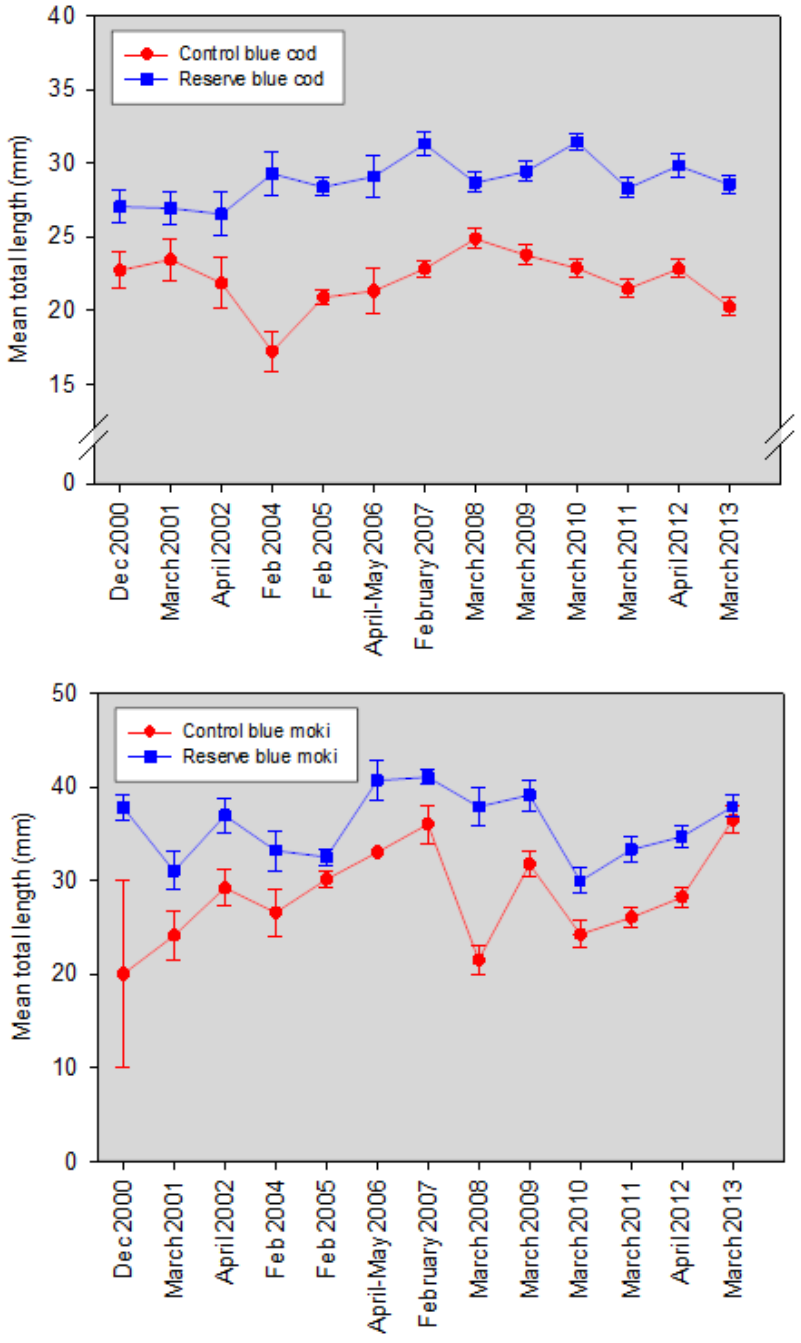


Figure 11. Mean size of blue cod and blue moki from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled from 1993 to 2013. Error bars are +/- 1 s.e.

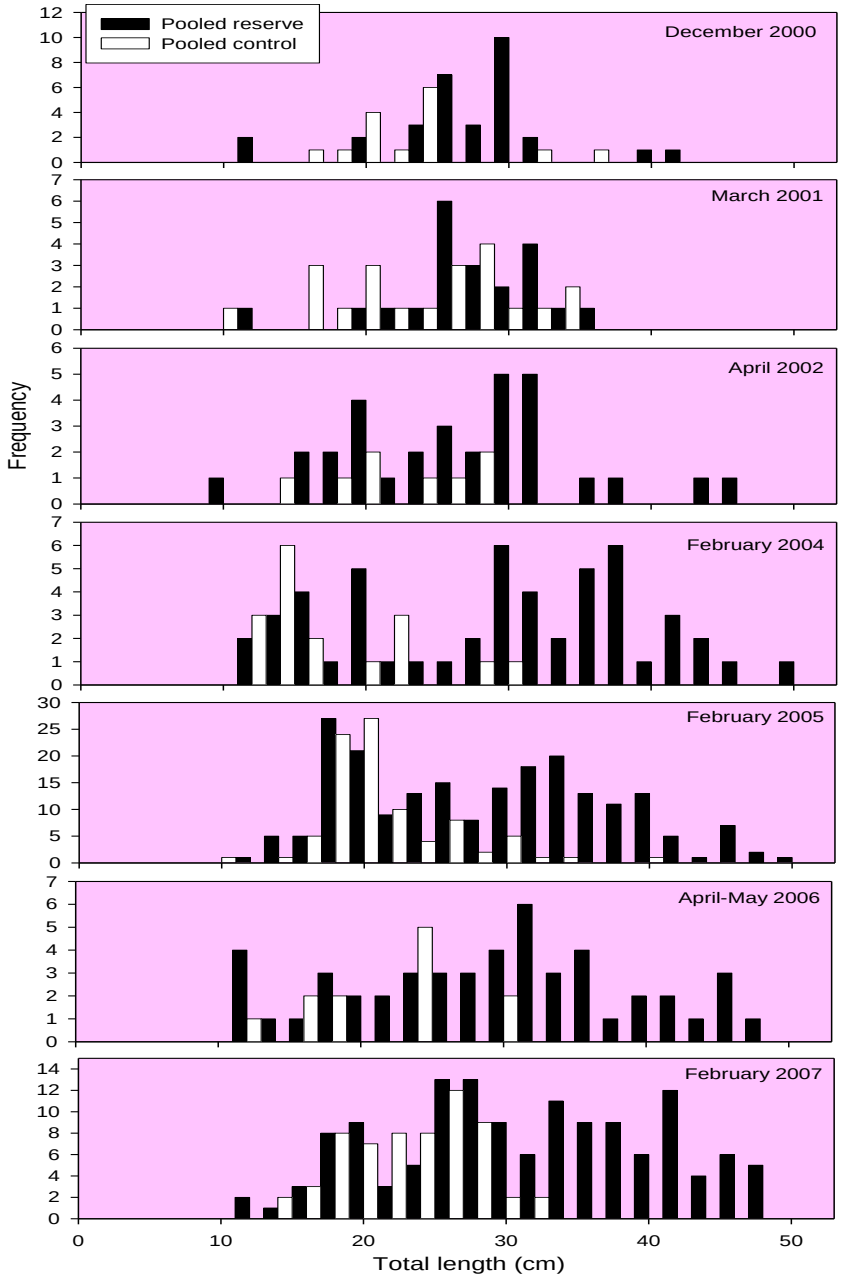


Figure 12a. Size frequency of blue cod from Tonga Marine Reserve sites and adjacent control sites sampled from 2000 to 2007.

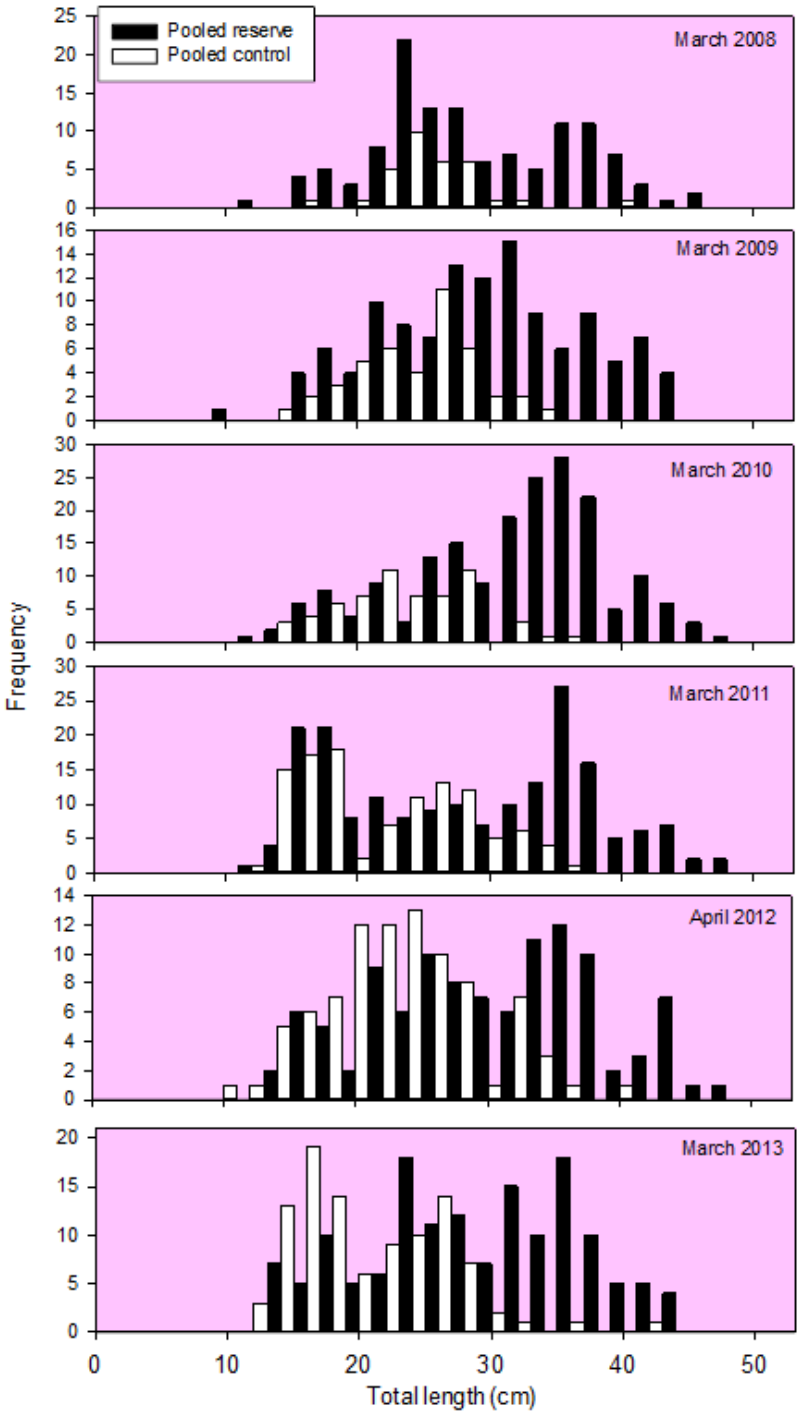


Figure 12b. Size frequency of blue cod from Tonga Marine Reserve sites and adjacent control sites sampled from 2008 to 2013.

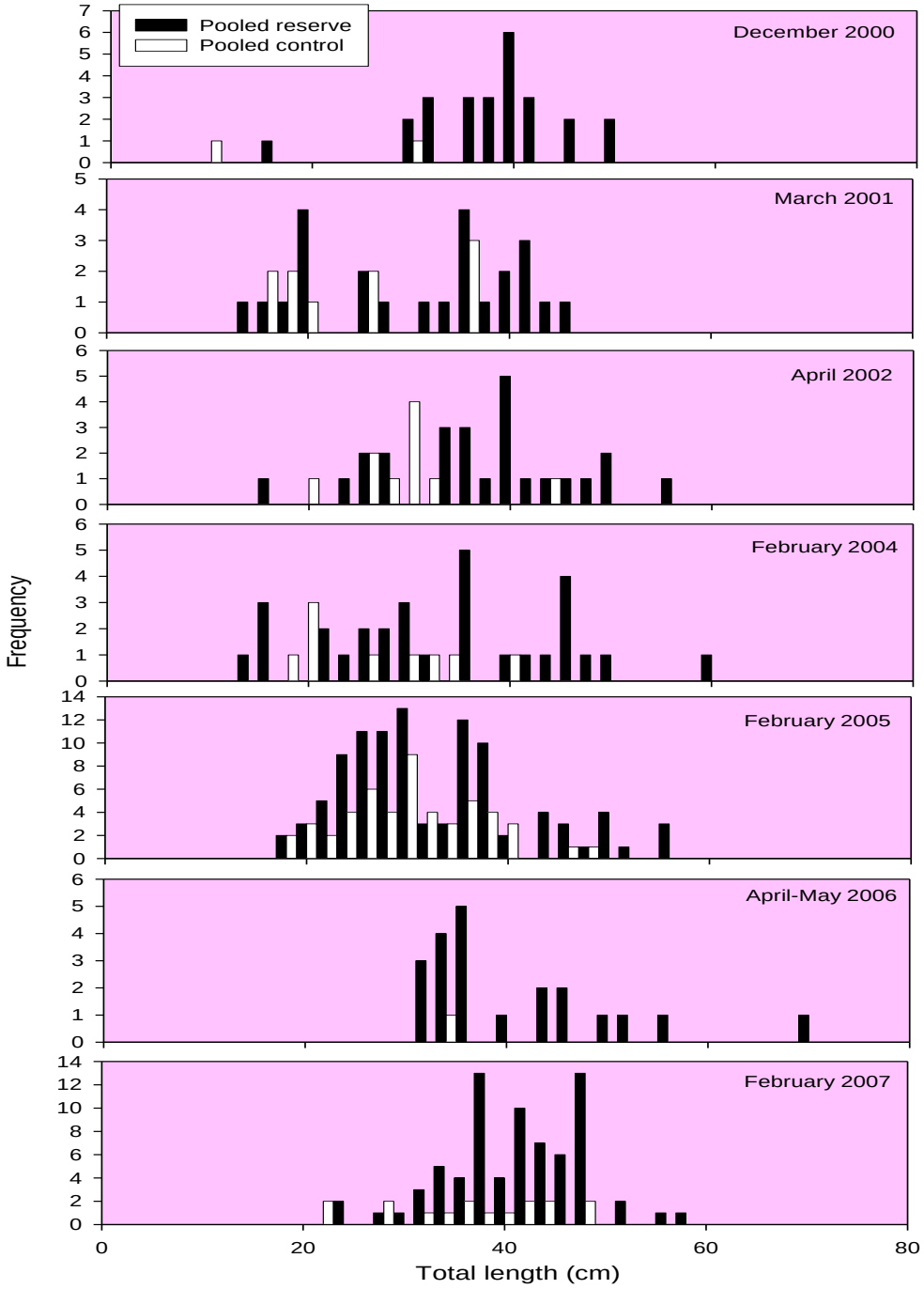


Figure 13a. Size frequency of blue moki from Tonga Marine Reserve sites and adjacent control sites sampled from 2000 to 2007.

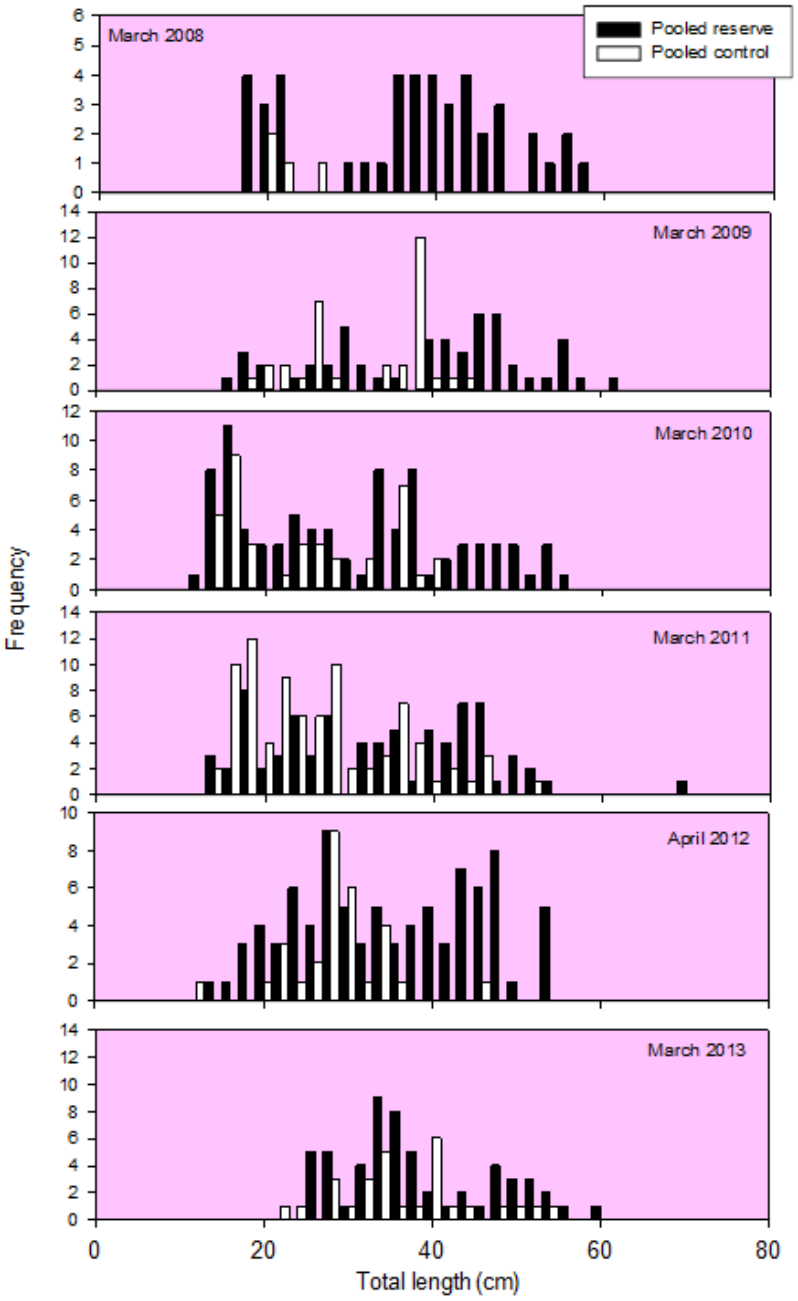


Figure 13b. Size frequency of blue moki from Tonga Marine Reserve sites and adjacent control sites sampled from 2008 to 2013.

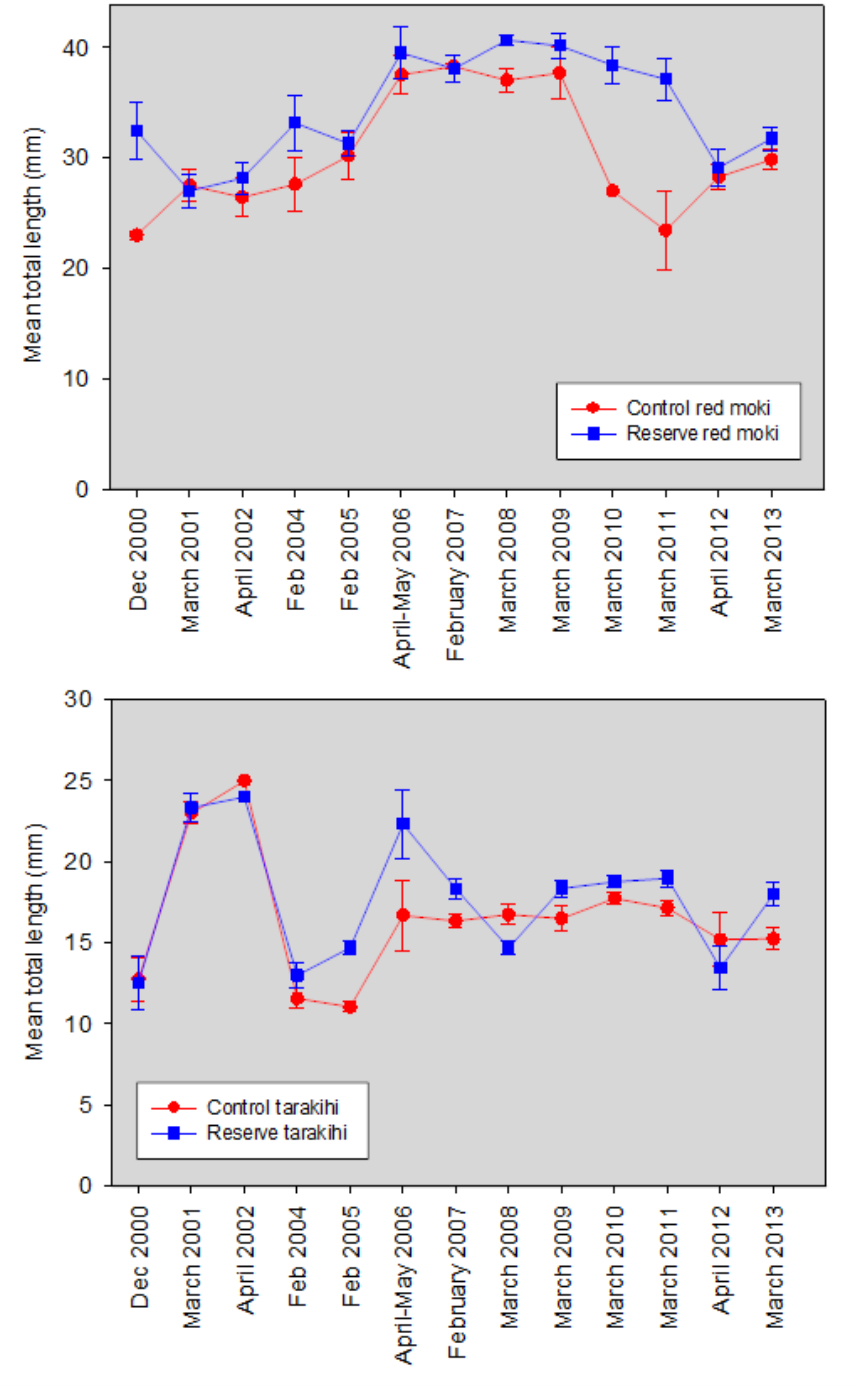


Figure 14. Mean size of red moki and tarakihi from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled from 2000 to 2013. Error bars are +/- 1 s.e.

5.2 Spiny lobster density, sex and size

Lobster density

In all years at reserve and control sites, lobsters were recorded from boulder and bedrock habitats. Rocky habitat was most often located in relatively shallow water (< 12-14 m depth) on rocky shores along the length of the Abel Tasman. In some areas of the Abel Tasman, rocky habitat ended at a depth of < 3 m. Lobsters were occasionally observed in these shallow rocky areas; however, this usually occurred within in the reserve.

Although the density of lobsters within both shallow and deep strata in the reserve fluctuated throughout the study, density generally increased over the 20-year duration of monitoring (Figure 15). Conversely, although the density of lobsters in the shallow and deep strata at control sites initially increased, density declined during later years of monitoring. At control sites, the peak in lobster density in the deep strata (December 2002) was larger and five years earlier than the peak (December 2002) in the shallow strata (Figure 15).

In the latter half of the study, the density of lobsters was significantly greater inside the reserve than at control sites. In 2013, the mean density of lobsters in the shallow strata was 8 times greater at reserve sites than control sites, while the mean density of lobsters in the deep strata was 6.8 times greater at reserve sites than control sites. In 2013, lobster density within the reserve was significantly greater than at the beginning of the study (Figure 15).

Within the reserve, mean lobster density was usually greater in the deep strata than the shallow strata; however, by the end of the study, density in the shallow strata was comparable to that in the deep strata (Figure 15).

Lobster sex and size classes

Temporal patterns in the abundance of mature females, non-reproductive males, and reproductive males cannot be compared between the pre- and post-1998 data as the length measurement methodology changed from total length to carapace length. However, for juveniles, the upper size limit of the juvenile size category in pre- 1998 data corresponds to approximately 80-85 cm CL.

The densities of juvenile lobsters (≤ 80 cm CL) in the reserve and at control sites followed similar trends over the duration of the study (Figure 16). Although 10 - 30 juveniles were usually recorded at reserve and control sites per year (approximately 500 m^2 searched inside and outside the reserve), significantly higher numbers were recorded at reserve sites in December 2000 and 2002 (and to a lesser extent February 2007), and at control sites in December 2002. Juvenile lobsters from the 2000-2002 peaks grew through to the larger size class, and were recorded as mature females from 2006 onwards, or as non-reproductive males in 2006 and reproductive males from 2007 onwards (Figures 16-22). A small increase in the number of non-reproductive males and reproductive females at control sites was also recorded following this juvenile peak; however, this small increase was short lived, with few males growing through to reproductive size at control sites.

The abundance of mature females and reproductive males in reserve sites increased from 2006, and was greater than at control sites (Figures 16-22). In contrast, the abundance of mature females and reproductive males at control sites remained low (Figure 16).

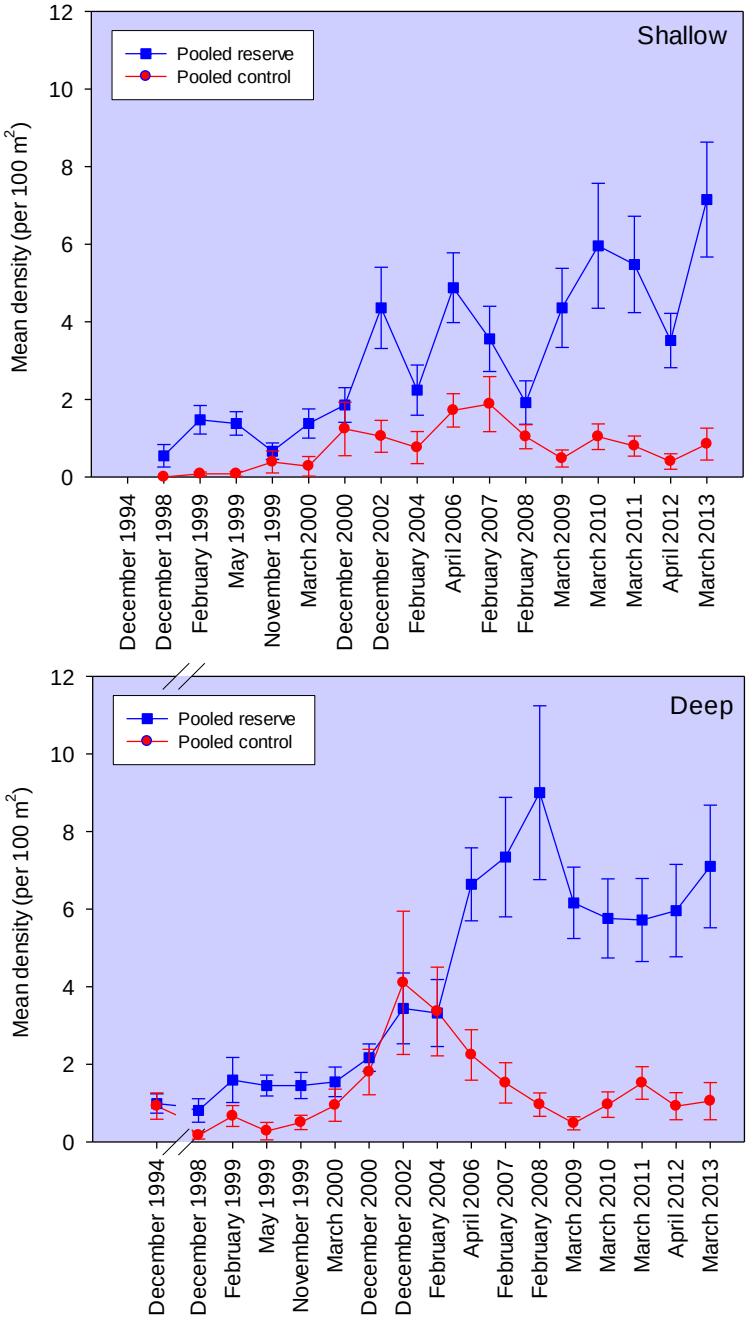


Figure 15. Mean density of lobsters from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled from 1994 to 2013 from deep and shallow strata. Error bars are +/- 1 s.e.

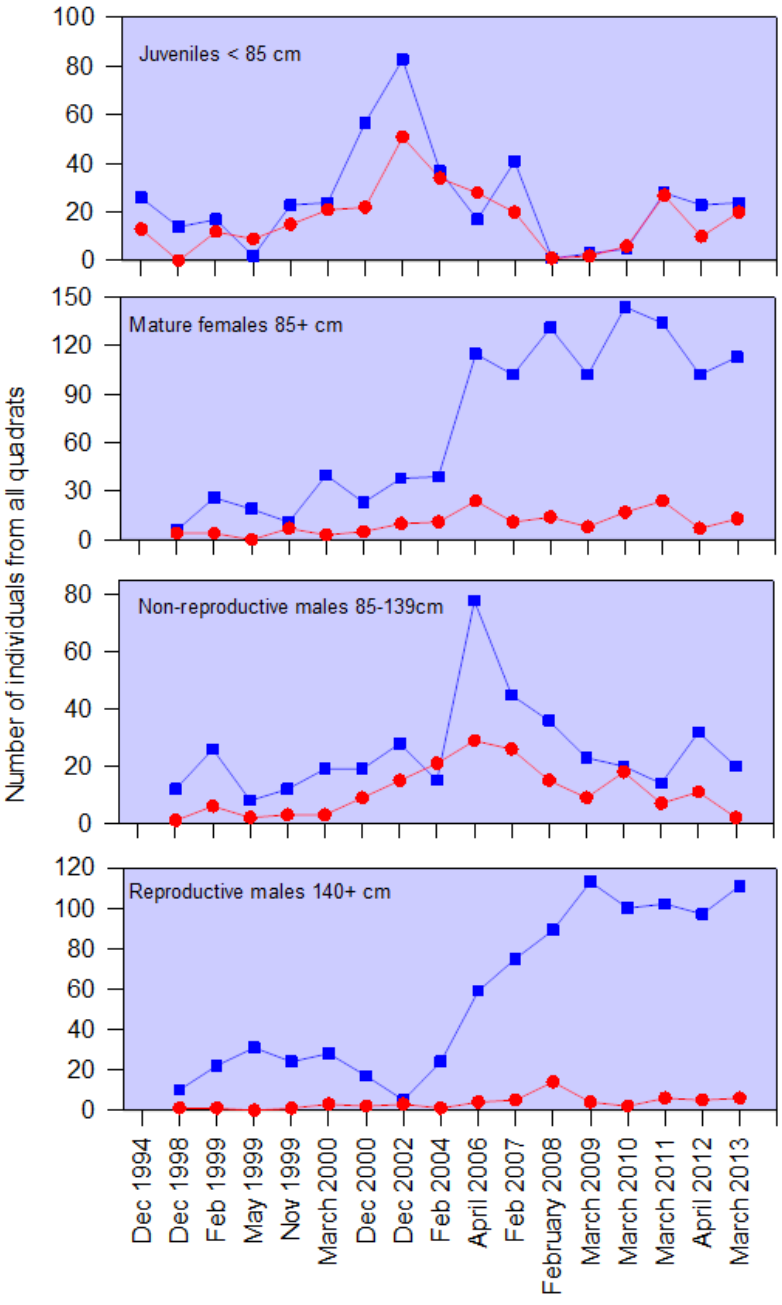


Figure 16. Number of lobsters that could be sexed from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled from 1994 to 2013. Lobsters have been divided into reproductive classes according to MacDiarmid (1989). Sizes are estimated carapace length (to nearest 5 mm). Counts of extra lobsters from outside quadrats have been excluded.

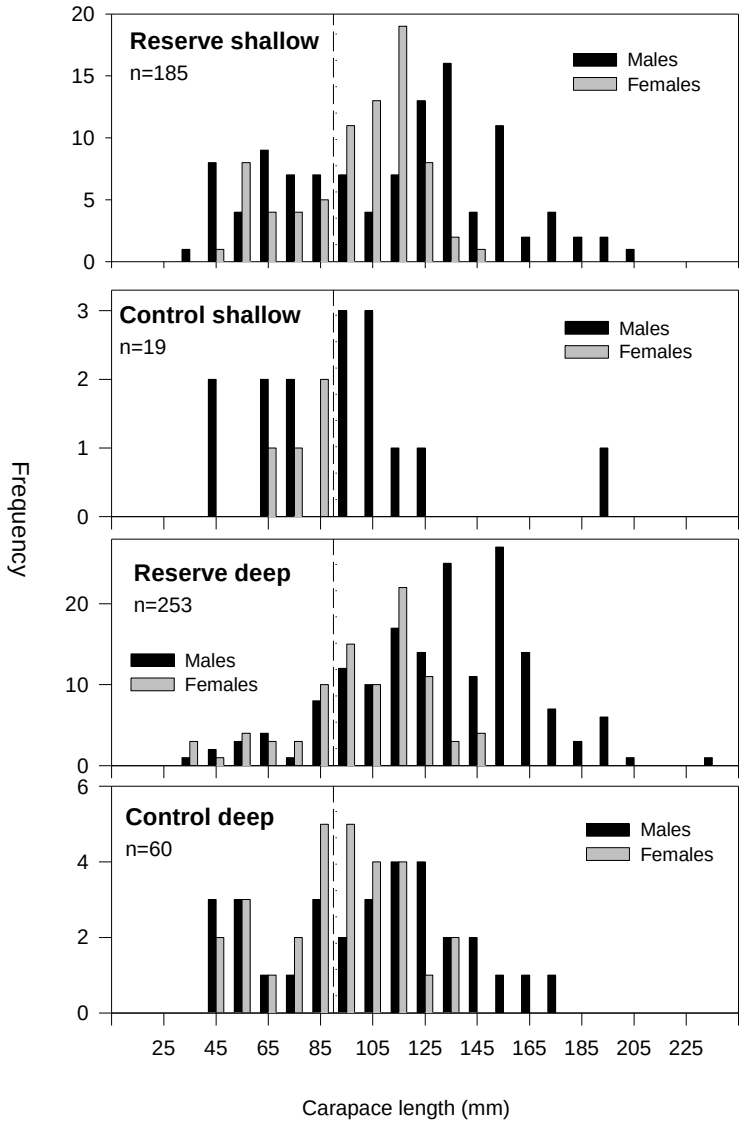


Figure 17. (from Davidson *et al.* 2002) Size-frequency distributions of lobsters from shallow and deep strata in Tonga Marine Reserve sites and adjacent control sites sampled from 1998 to 2000. Sizes are estimated carapace length (to nearest 5 mm).

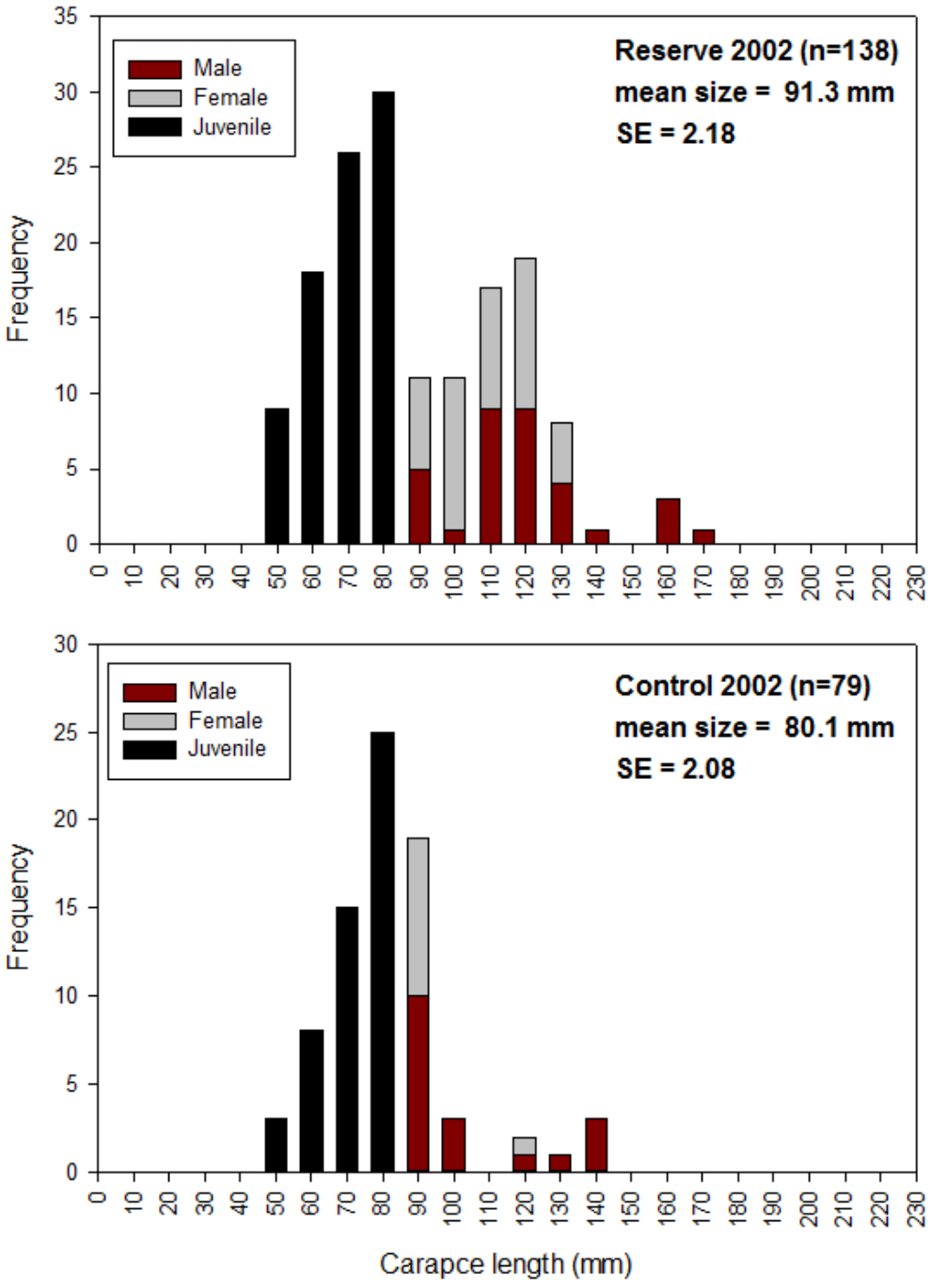


Figure 18. Size-frequency distributions of lobsters from Tonga Marine Reserve sites (top) and adjacent control sites (bottom) sampled in 2002. Sizes are estimated carapace length (to nearest 5 mm).

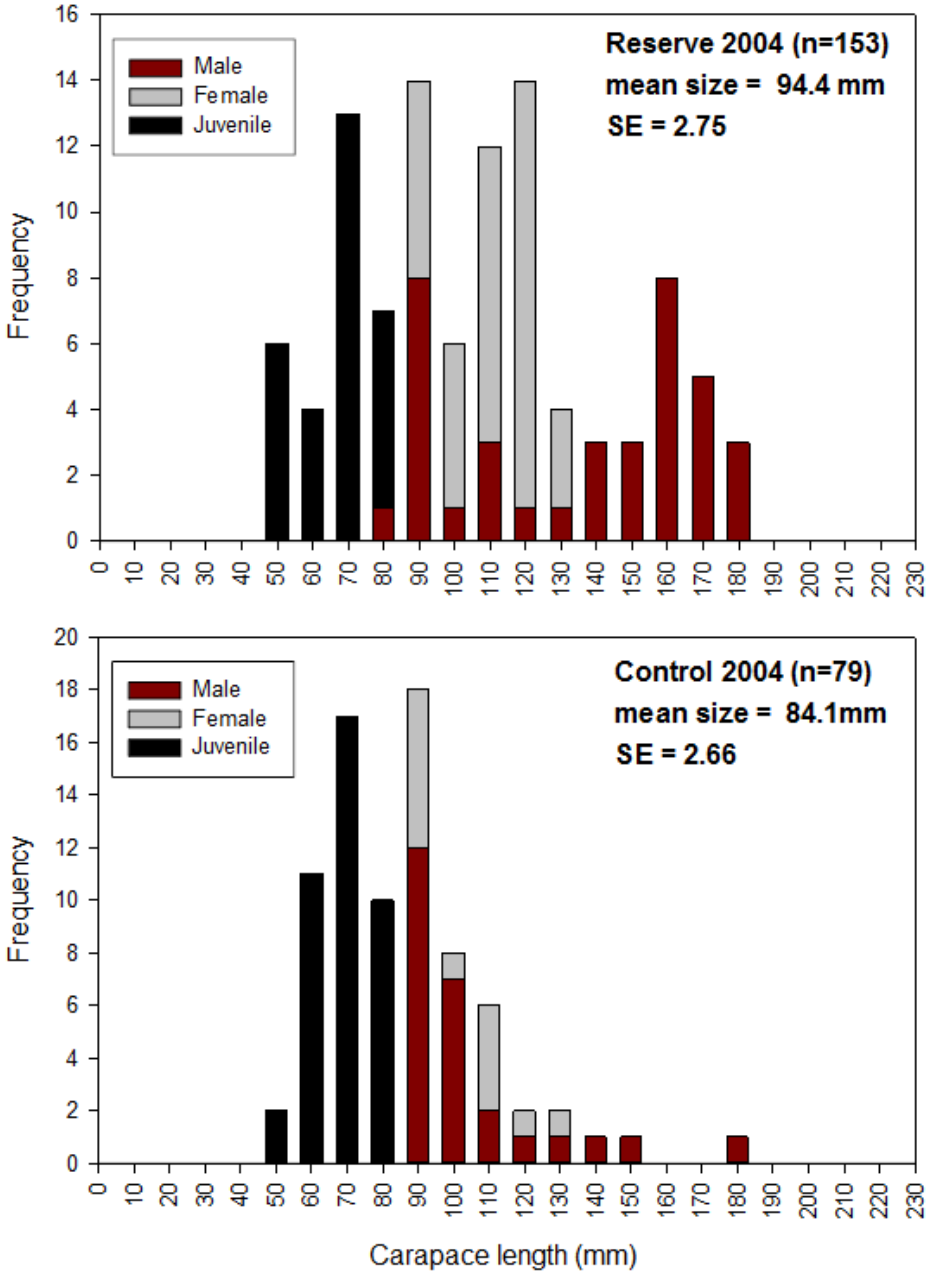


Figure 19. Size-frequency distributions of lobsters from Tonga Marine Reserve sites (top) and adjacent control sites (bottom) sampled in 2004. Sizes are estimated carapace length (to nearest 5 mm).

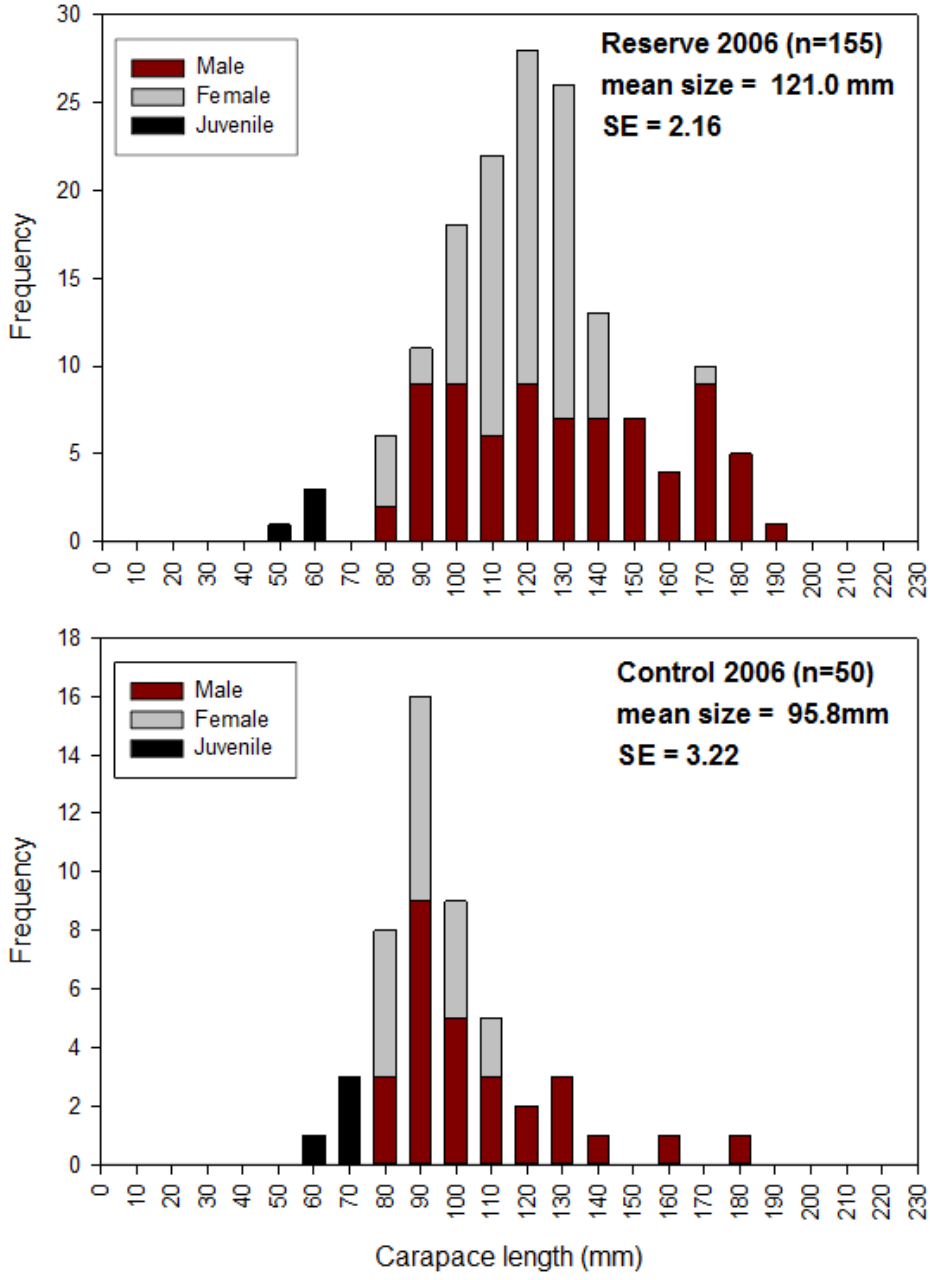


Figure 20. Size-frequency distributions of lobsters from Tonga Marine Reserve sites (top) and adjacent control sites (bottom) sampled in 2006. Sizes are estimated carapace length (to nearest 5 mm).

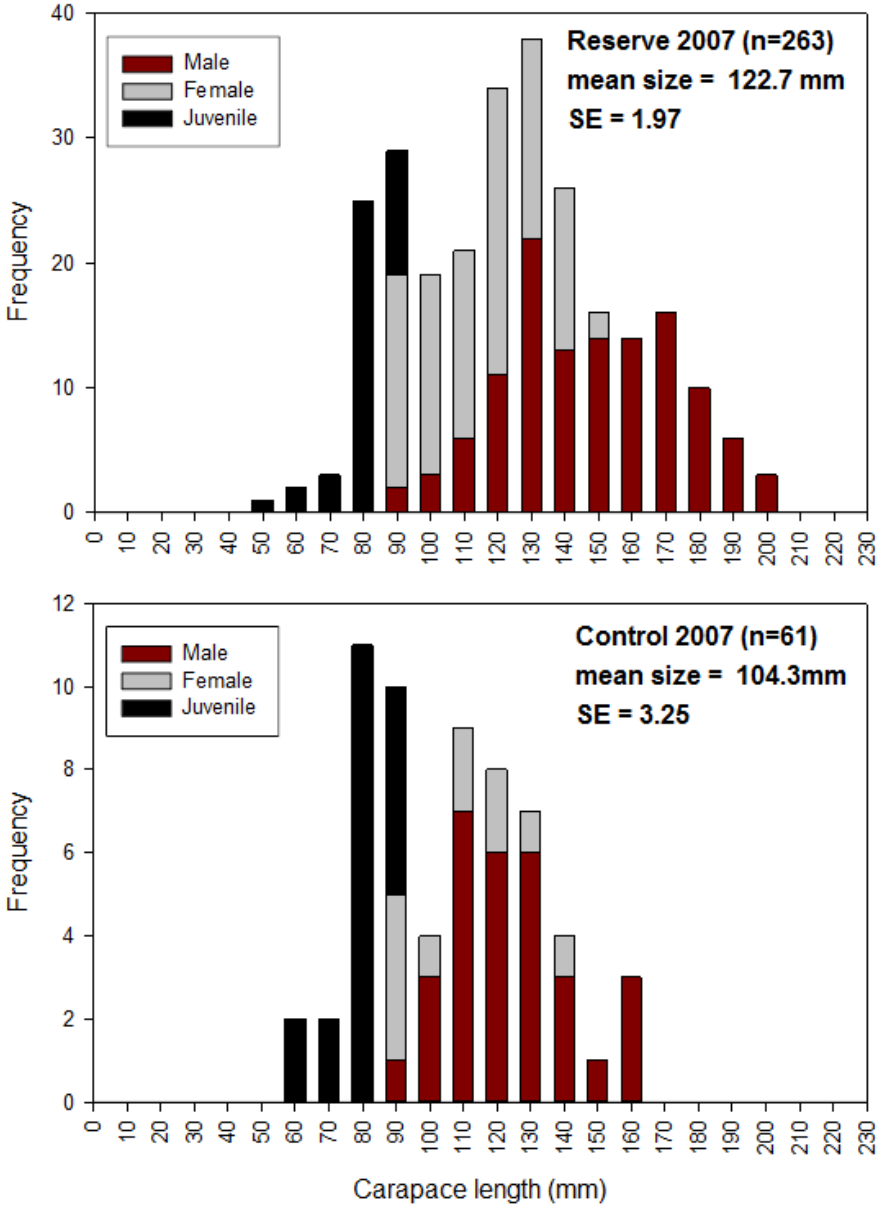


Figure 21. Size-frequency distributions of lobsters from Tonga Marine Reserve sites (top) and adjacent control sites (bottom) sampled in 2007. Sizes are estimated carapace length (to nearest 5 mm).

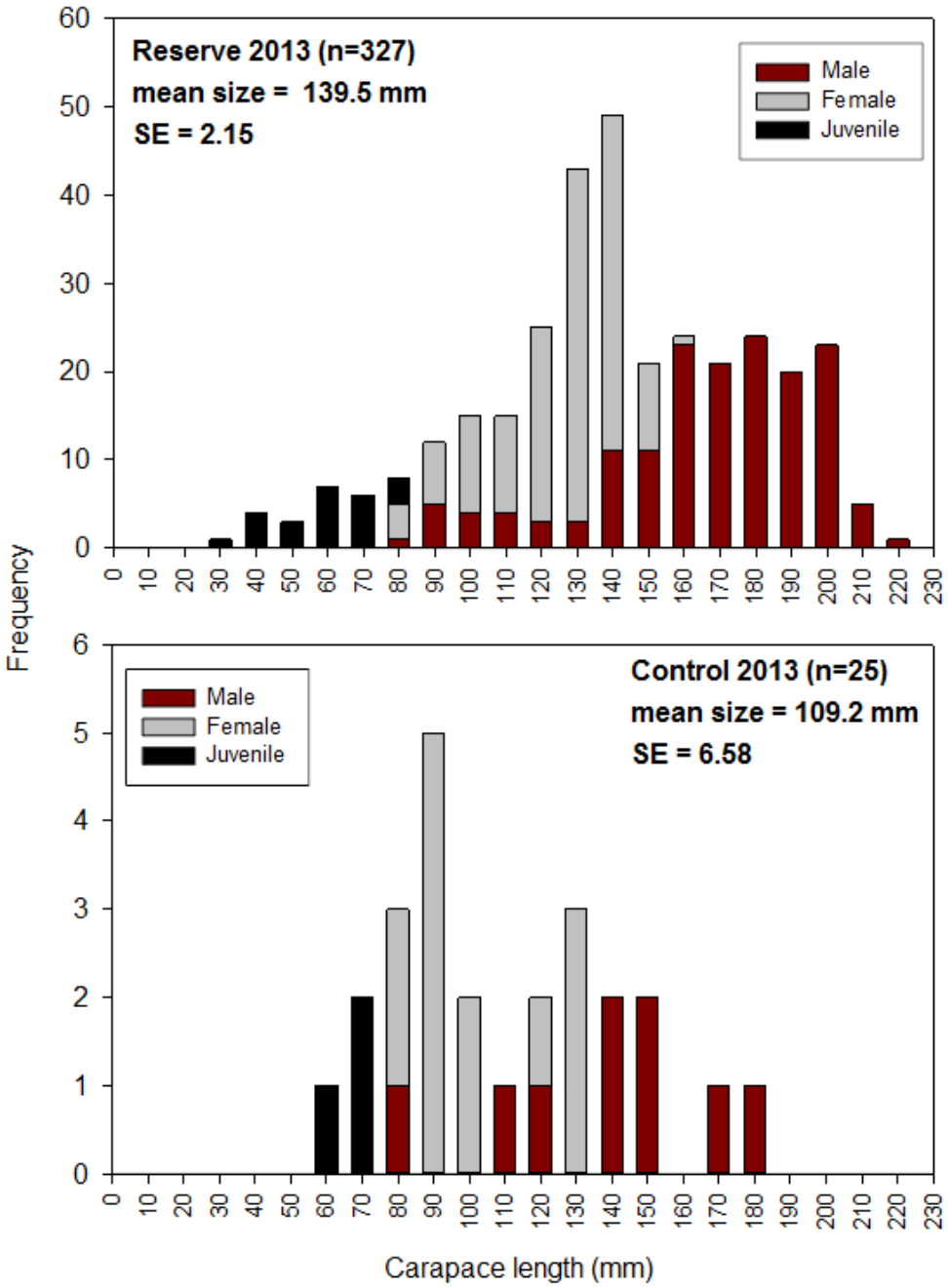


Figure 22. Size-frequency distributions of lobsters from Tonga Marine Reserve sites (top) and adjacent control sites (bottom) sampled in 2013. Sizes are estimated carapace length (to nearest 5 mm).

5.3 Kina density

Kina density declined at reserve sites over the monitoring period (Figure 23). The decline in kina density at reserve sites was not large (i.e. 1.57 to 1.18 individuals per m^2); however, it contrasted an increase in kina densities at control sites (0.75 to 1.4 individuals per m^2) (Figure 23).

5.4 Cook's turban density

In 1993, the density of Cook's turban was comparable between reserve and control sites (Figure 23). At both control and reserve sites the density of Cook's turban increased in 2002 and again in 2008, with a non-significant trend of higher density at reserves sites than in control sites in 2008 ($P = 0.098$).

5.5 Cats-eye snail density

The density of cats-eye snails exhibited similar patterns at control and reserve sites (Figure 23). Initially, density increased between 1993 and 2002, followed by a large decrease in 2008, with the magnitude of increase and then decline greater at reserve sites than control sites (Figure 23).

5.6 Top-shell density

Changes in the density of top-shells (*Trochus* sp.) followed similar trends at reserve and control sites (Figure 24). Initially, density declined between 1993 and 2002, followed by an increase in 2008, with the magnitude of decline and then increase greater at control sites than reserve sites (Figure 24).

5.7 Limpet density

The density of limpets (*Cellana* sp.) displayed similar trends at reserve and control sites (Figure 24). Initially, density declined between 1993 and 2002, followed by an increase in 2008, with the magnitude of decline and then increase greater at control sites than reserve sites (Figure 24).

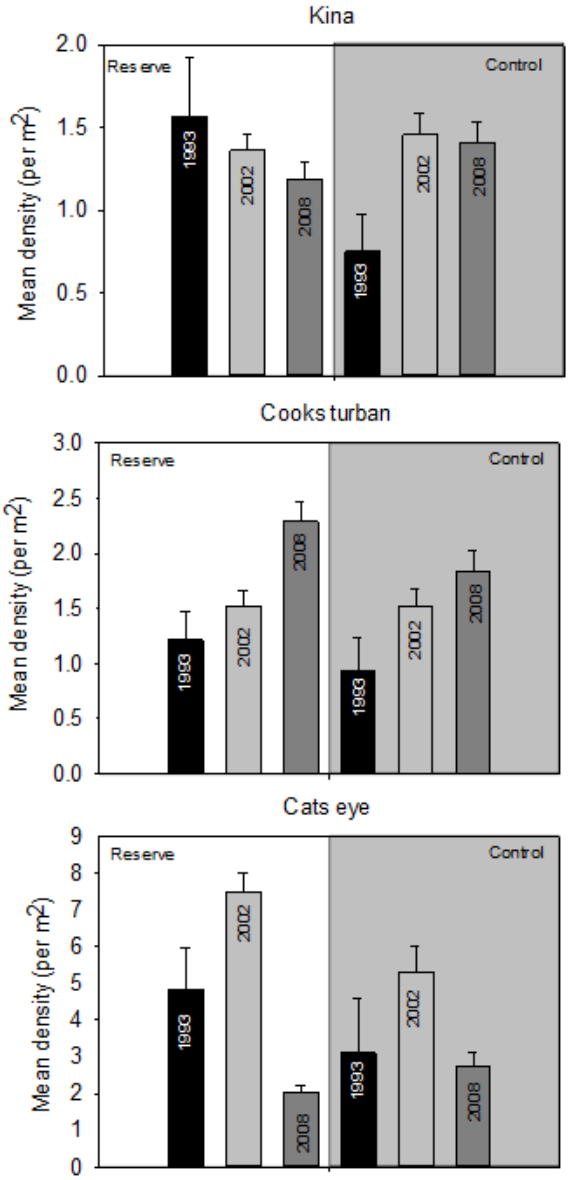


Figure 23. Mean density of kina, Cook's turban and cats-eyes from Tonga Marine Reserve sites and adjacent control sites sampled on three occasions between 1993 and 2013. Error bars are +/- 1 s.e.

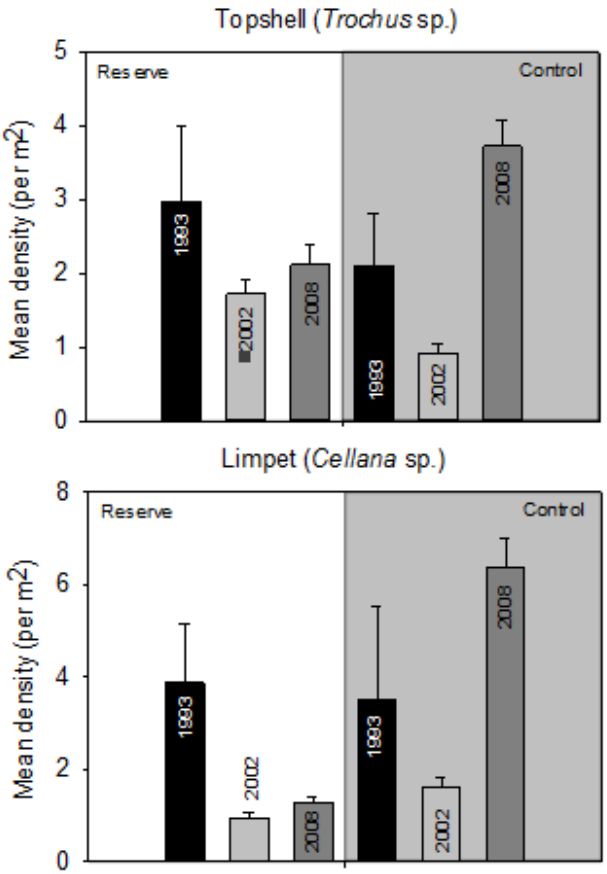


Figure 24. Mean density of topshells and limpets from Tonga Marine Reserve sites and adjacent control sites sampled on three occasions between 1993 and 2013. Error bars are +/- 1 s.e.

5.8 Scallop size and density

Mean density of scallops was comparable between reserve and control sites in the first two sampling periods (1994, 1999) (Figure 25). In 2003 and 2006, the density of scallops at reserve sites was significantly greater than at control sites. In 2008, the density of scallops at reserve sites declined to levels at control sites. In 2010 and 2013, the density of scallops in reserve sites was significantly lower than density in control sites. The density of scallops at the two control sites remained relatively stable over the same period.

Scallop size showed comparable patterns at both reserve and control sites over the duration of the study (Figures 26, 27a and 27b). In some years, recruitment size classes were recorded. For example, in 2010 a recruitment pulse comprising 30-60 mm scallops was recorded at both control and reserve sites (Figure 27b). Three years later, adults from this event were present at the control sites, but almost no adults were recorded from the reserve sites.

5.9 Horse mussel density

The mean density of horse mussels at reserve and control sites was low at the start of the study (Figure 25). At control sites, the density of horse mussels increased from the beginning of the study to peak in 1999 and 2003, followed by a decline to relatively stable levels from 2006 to 2013 (Figure 27). Although densities of horse mussels tended to fluctuate more at reserve sites, from 2006 onwards density was greater at reserve sites than at control sites.

5.10 Black foot paua

Black foot paua were sampled from reserve and control sites for the first time in 2013. Only two of the four control sites and two of the five reserve sites supported paua. Of the four sites with paua, density was significantly higher at the control site located at Ratakura Point north of the marine reserve than at the other three sites, which all had comparable paua densities (Figure 28).

The mean size of paua was greater at reserve sites than control sites and the largest paua recorded was from a reserve site (Figure 29). At Tonga Quarry arches one paua which met the legal size limits specified in the recreational fisheries regulations for this region was recorded (i.e. ≥ 125 mm length). This individual was considerably larger than any other paua recorded in this study, or in the study at Horoirangi Marine Reserve, North Nelson (Davidson *et al*., 2013). At Tonga Quarry arches, 19 paua were larger than the largest paua recorded at all other sites sampled in the present study (i.e. > 112 mm length).

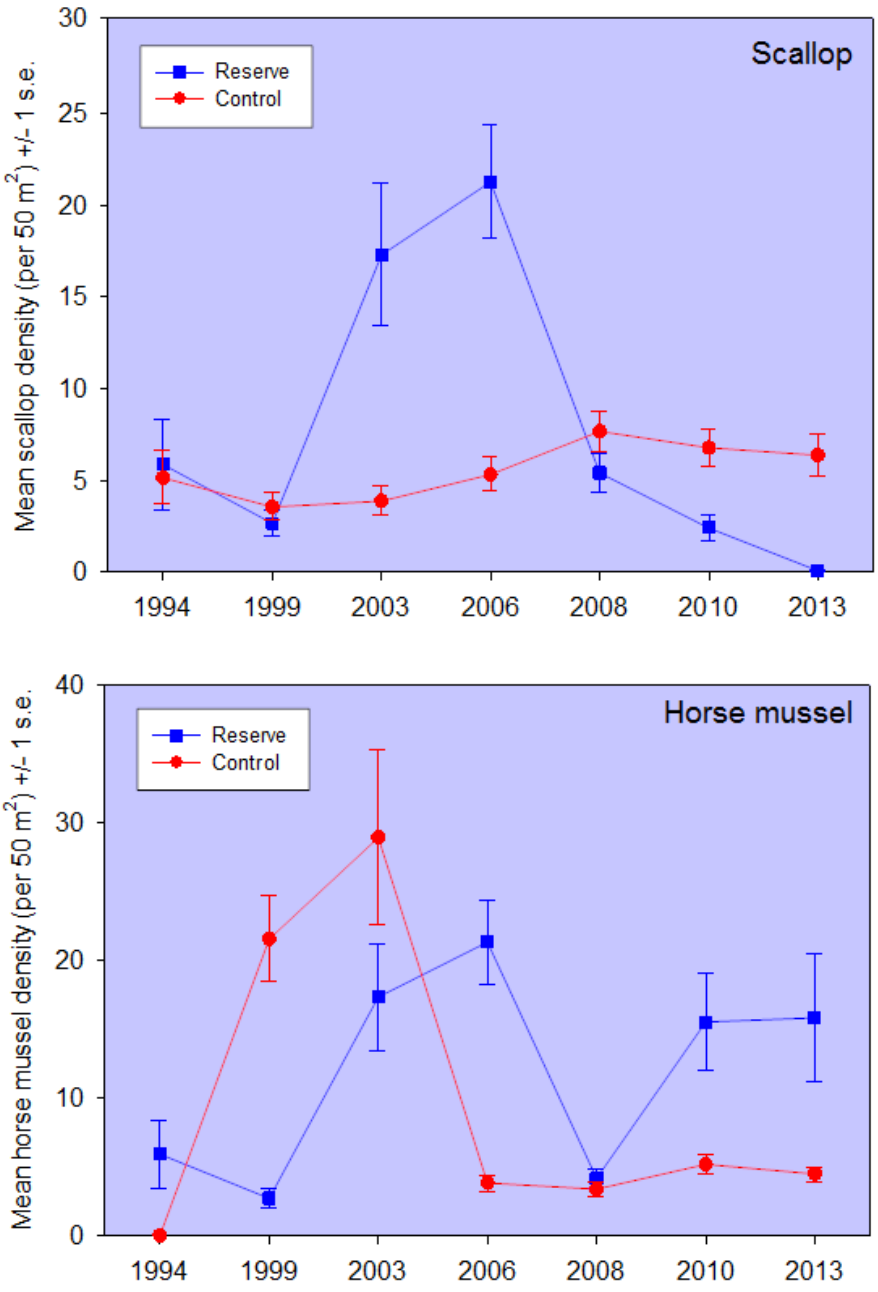


Figure 25. Mean density of scallops and horse mussels from Tonga Marine Reserve sites (blue) and adjacent control sites (red) sampled intermittently between 1994 and 2013. Error bars are +/- 1 s.e.

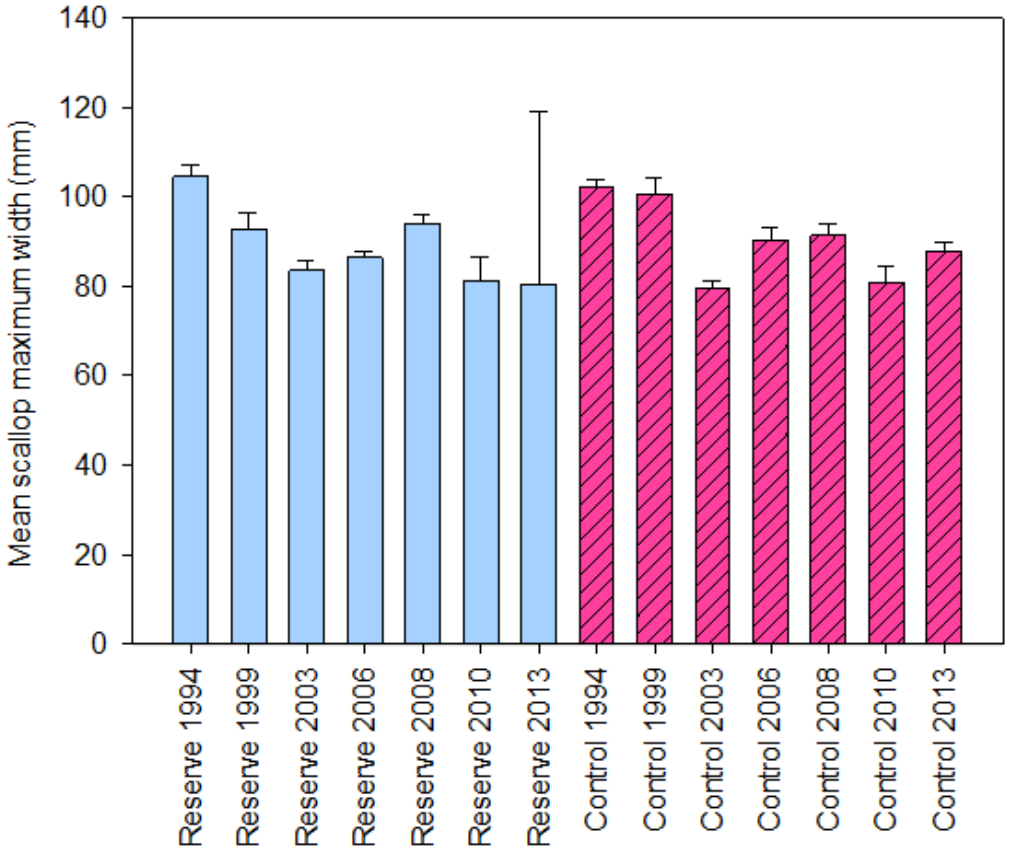


Figure 26. Mean size of scallops from reserve (blue) and adjacent control (red) sites sampled from 1994 to 2013. Error bars are 95% confidence.

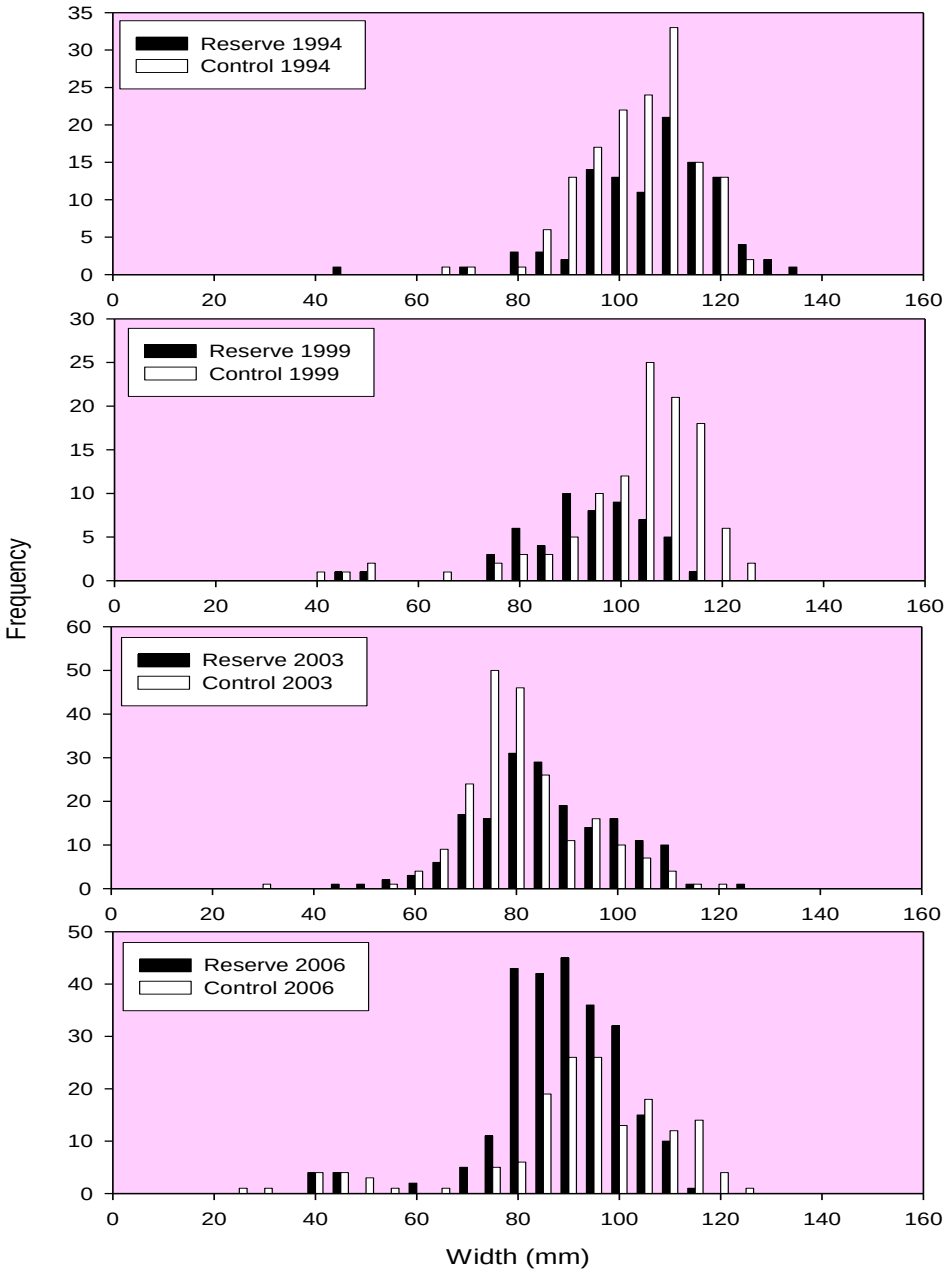


Figure 27a. Size-frequency of scallops from Tonga Marine Reserve sites and adjacent control sites for each sample occasion (1994, 1999, 2003 and 2006).

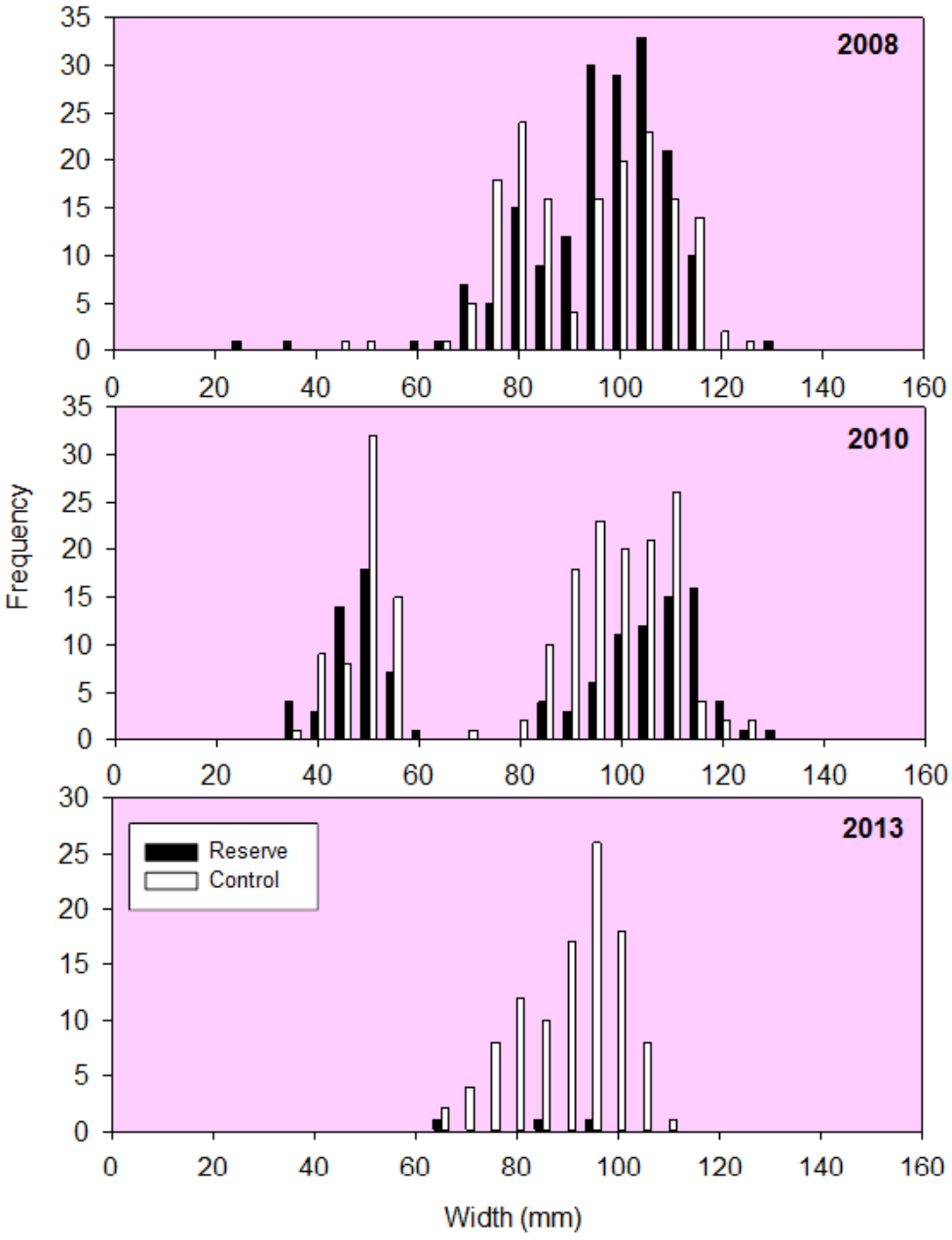


Figure 27b. Size-frequency of scallops from Tonga Marine Reserve sites and adjacent control sites for each sample occasion (2008, 2010 and 2013).

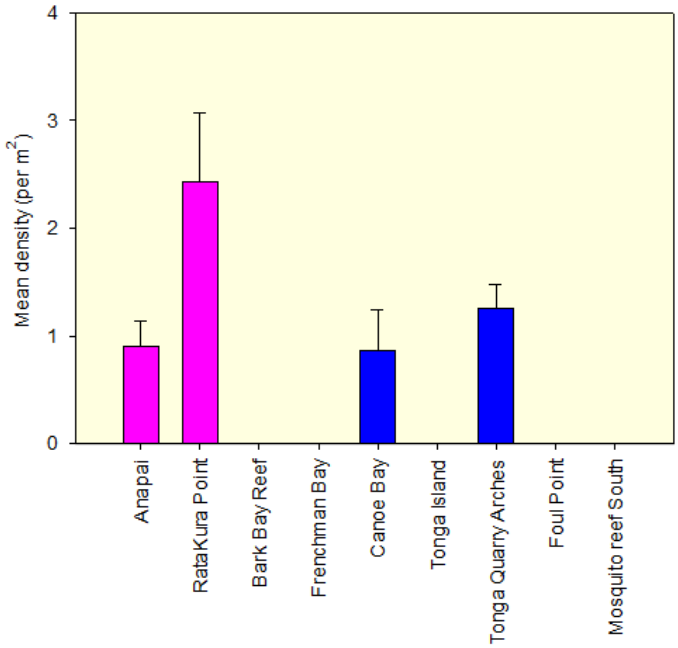


Figure 28. Mean density of black foot paua from reserve (blue) and adjacent control (red) sites sampled in 2013. Error bars are +/- 1s.e.

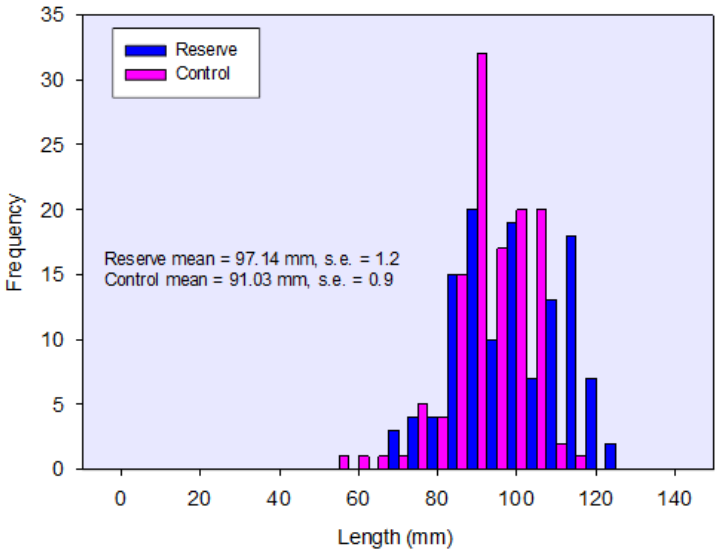


Figure 29. Size-frequency of black foot paua from Tonga Marine Reserve sites and adjacent control sites in 2013.

60 DISCUSSION AND CONCLUSIONS

This report presents data collected from the Tonga Island Marine Reserve and associated control sites over a period of 20 years from 1993 to 2013 (note: no data were collected from 1995 to 1998). This study adds to a growing body of literature demonstrating changes in the marine environment following the implementation of marine reserves, both in New Zealand and internationally (Mace and Johnson 1983, Buxton and Smale 1989; Cole and Creese 1990; Cole *et al.*, 1992; MacDiarmid and Breen 1993; Cole 1994; Blackwell 1997, 1998; Bennett and Attwood 1991, 1993; MacDiarmid 1993; Carbines 1998, 1999; Edgar and Barrett 1999; Cole *et al.*, 2000; Kelly 1999, 2000, 2001; Willis 2000; Willis *et al.*, 2000; Davidson 2001; Davidson *et al.*, 2002, 2005; Cole *et al.* 2002; Denny *et al.*, 2004; Freeman 2005; Shears *et al*., 2006; Pande *et al.*, 2008; Freeman and MacDiarmid 2009, Guisado *et al.*, 2012; Freeman *et al.*, 2012). Changes observed in marine reserves in this country have generally been directly attributed to the cessation of fishing, as all of New Zealand's marine reserves are no-take.

Biological changes following the implementation of marine reserves are variable, and often species-specific. For example, at the 20 year old Long Island-Kokomohua MR located in the Marlborough Sounds, blue cod, lobster and paua abundance and size have increased, but few other changes have been conclusively attributed to reservation (Davidson and Richards 2005; Davidson *et al*., 2009). For many marine reserves in New Zealand, changes in the density, size and sex classes of blue cod, lobster and paua have often been dramatic. For example, in 2009 at Long Island-Kokomohua Island MR, nearly 30% of blue cod were > 330 mm length compared to only 13.6 % at control sites. Further, the density of cod meeting legal size limits specified in recreational fisheries regulations for this region (i.e. > 300 mm) was 3.6 times greater in the reserve compared to adjacent control sites, while the density of lobsters meeting legal size limits was 5.6 times greater inside the reserve.

At Tonga Island MR, previous monitoring has documented an increase in the size and density of lobsters and blue cod, and an increase in the density of scallops in particular years (Davidson and Richards 2007). With the exception of blue cod (and to a lesser degree blue moki), no other reef fish had responded to reservation by 2007. Davidson and Richards (2007) stated that the magnitude of change was smaller at Tonga Island MR than at Long Island-Kokomohua MR.

and many other marine reserves in New Zealand. Davidson and Richards (2007) hypothesized that the lack of response by some species, and the small scale of change at Tonga Island MR may have been due to factors such as:

- The biology of particular reef fish species (e.g. tarakihi).
- Heavy fishing pressure and low stocks prior to reservation.
- High levels of continued fishing pressure on the adjacent coast.
- The isolation of reef habitats within Tasman and Golden Bays.
- The low energy coastline.
- The relatively low productivity and fertility of adjacent the catchments.

The authors concluded that recovery in the reserve for many species may take a relatively long time compared to many marine reserves around New Zealand, and that the scale of the change may be at a lower level compared to reserves located in higher energy, productive coastal locations. The present study adds six years more data and describes changes in the Tonga Island MR after 20 years of reservation.

6.1 Reef fish

The abundance and size of blue cod increased in the Tonga Island Marine Reserve over the study period. Relative to adjacent control sites, the population structure, abundance and behaviour of blue cod all changed in the reserve. For example, at the end of the study large legal sized blue cod were 40 times more abundant in the reserve compared to control sites. Further, in 2013 only 5% of the cod population at control sites was > 30 cm length, compared to 48% at reserve sites. In the reserve, blue cod up to 48 cm length were recorded, whereas blue cod at adjacent control sites seldom reached 40 cm. Cole *et al.* (2000) suggested that even relatively small marine reserves would protect blue cod as a proportion of the population would remain in the same physical area for long periods (i.e. years); therefore, the blue cod response to reservation was not unexpected.

Although the density of blue cod has increased at both Tonga Island MR and Long Island-Kokomohua MR, cod densities increased more rapidly and reached higher levels at the Long

Island-Kokomohua MR. For example, the mean density of all blue cod at Long Island has consistently been over 6 individuals per 60 m^2 since April 1999. In comparison, blue cod density at Tonga Island MR has not risen above 1.4 individuals per 60 m^2 over the duration of the study. The reasons for this dramatic difference are probably related to Long Island's proximity to vast areas of blue cod habitat in the Marlborough Sounds, compared to Tonga Island MR, which is isolated in the centre of Tasman and Golden Bays. It is probable that recruitment into the reserve population is considerably higher at Long Island compared to the Abel Tasman coast. It is unknown what density blue cod will reach in the Tonga Island Marine Reserve; however, it is certain that the abundance of this species continues to rise due to the exclusion of fishing.

Other reef fish species have showed little or no change that can be attributed to reservation. Spotty, red moki and tarakihi densities were highly variable over the 20-year study period, with temporal fluctuations in density and population size structure comparable between reserve and adjacent control sites. This suggests reservation had little effect on these species of reef fish.

With the exception of 1994, the density of blue moki was consistently higher inside the reserve than at adjacent control sites. Peaks in density both within and outside the reserve often occurred in the same years, suggesting factors other than reservation, such as migration, may also be important. Since 2000, the average size of blue moki was always greater in the reserve than at control sites. This is likely due to reservation, as spear fishing and netting probably remove large fish from outside the reserve.

Snapper were occasionally recorded by divers in fish counts. Because snapper either actively avoid divers or remain at the visual limits of divers, it is likely snapper are more abundant along this coast than diver counts suggest. For example, in 2013 a school of 300-400 snapper approximately 300-440 mm in length was observed within the reserve. These were outside the transect area, and were therefore not recorded in density measurements.

6.2 Spiny lobsters

Increases in both the density and size of lobsters were greater inside the reserve than at control sites. This happened after a period of 7-8 years of reservation. Relative to control sites, the densities of shallow lobsters at the end of the study was 8 times greater inside the reserve. Similarly, the density of deep lobsters was 6.8 times more abundant inside the reserve than at control sites. Haggitt *et al.* (2011) reported that after 18 years of reservation, the density of lobsters in Te Whanganui-a-Hei MR, in northern New Zealand was 9 times higher than at control sites. An increase in lobster density has also been reported for other northern South Island MR's. Davidson and Richards (2009) reported that the density of lobsters inside the Long Island-Kokomohua MR in 2009was 3.3 times greater than at control sites, and 12 times greater in 2013 (20 years after reservation). For the youngest reserve in the northern South Island (Horoirangi MR), lobster density was 3.5 times greater inside than outside reserves after seven years of reservation (Davidson *et al*., 2013).

Spiny lobsters are intensively fished in many areas of New Zealand (Lipcius and Cobb, 1994). Several studies have shown abundance and size of spiny lobsters to be greater in protected areas than in nearby fished areas (e.g. MacDiarmid and Breen, 1993; Edgar and Barrett, 1999**;** Kelly *et al.*, 1999, 2000; Davidson *et al*., 2002, Davidson 2004, Pande *et al*., 2008; Freeman *et al*., 2012; Guisado *et al*., 2012). These studies suggest that some lobsters remain within un-fished areas, but there is also evidence that migrations may cross reserve borders (e.g. Kelly *et al.*, 2000; Kelly, 2001, Freeman *et al*., 2012.). There is also evidence that egg production may be limited in intensively-fished populations due to a lack of large males (MacDiarmid and Butler, 1999). Fishing may also influence the growth and health of lobsters (Freeman *et al*., 2009; Freeman *et al*., 2012a).

During the present study, lobster abundance increased dramatically in reserves from 1.01 individuals per 100 m^2 at the deep strata in 1994 to 7.1 individuals per 100 m^2 in 2013. The increase in lobster abundance in Tonga Island Marine Reserve was initially slow (Davidson *et al.* 2000), increasing more rapidly from 2000 onwards (7-8 years after reservation). A comparable delay in the increase in lobster density has also been recorded at Long Island-Kokomohua MR and Horoirangi MR as well as other reserves in New Zealand (see Freeman *et*

al., 2012 for review). Freeman et al., (2012) suggested that the rate of lobster recovery and its scale was likely influenced by proximity to juvenile settlement areas. In the present study, a large pulse in small non-reproductive lobsters was recorded in 2007. These recruits grew through to the larger reproductive sizes in the reserve, but did not appear at the control sites, presumably due to removal via fishing or because they moved into the reserve, where other lobsters were common.

Davidson *et al.* (2002) estimated that approximately nine times as many eggs would be produced from the Tonga Island Marine Reserve compared to an equivalent length of fished coast in Tasman Bay. This was based on the mean size of female lobsters, their density, and known egg production. Since the calculation of this estimate, the abundance of reproductive females within the reserve has increased, further increasing egg production within the reserve relative to the adjacent coast. This is further enhanced by an increase in the number of large reproductive males within the reserve, which ensures high fertilisation rates compared to control areas where large males are considerably less abundant.

6.3 Key rocky invertebrates

Key rocky reef invertebrates were sampled on three occasions over the 20-year period. Kina (*E. chloroticus*) were the only invertebrate species to show changes in density that could be attributed to reservation. Between 1993 and 2008, the density of kina declined within the reserve, while it increased at control sites. Declines in kina density have been reported at other marine reserves in New Zealand (e.g. Shears and Babcock 2003). For example, Haggitt *et al*. (2011) reported a decline in the abundance of kina at Te Whanganui-a-Hei MR, which coincided with a corresponding increase in the percentage cover of macroalgae.

There is some indication that the reserve may have impacted on the abundance of cats-eyes, top shells and limpets (Shears and Babcock 2003). Although observed changes also occurred at control sites, the magnitude of decline was larger in the reserve. Future monitoring of key rocky invertebrates will help interpret these potential reserve effects.

6.4 Scallops and horse mussels

At the start of the horse mussel study (1994) individuals were relatively uncommon reserve and control sites. The density of horse mussels at control sites increased in 1999 and 2003, before declining again by 2006 at which time their density stabilize for the remainder of the monitoring programme. Over the same period, horse mussels also recruited into the reserve, dipped in 2008 and then recovered from 2010 onwards. These patterns of abundance suggest that horse mussel density can be highly variable and may be related to recruitment and mortality events and/or natural patchiness. Decreases in the density of horse mussels at control sites may result from regular dredging for scallops, which can result in horse mussel mortality. In the reserve, large numbers of dead horse mussels were often observed amongst living horse mussels. Although these were not counted as live mussels, they continue to function as a biogenic habitat. In 2013, snapper and eagle rays were regularly encountered within reserve horse mussel beds. No areas of standing dead horse mussels were observed from control sites further suggesting dredging occurs at the control sites.

Scallop density remained relatively low at the control sites throughout the study, but increased in the reserve by 2003 and 2006. From 2008, they declined in abundance, and at the end of the study only three individual scallops were recorded from reserve quadrats. Scallop numbers in Tasman and Golden Bays also declined over this period. The reason for their decline is unknown; however, it is unlikely to be due to fishing in the reserve.

Scallop size-frequency data showed variable recruitment events and variable numbers of recruits. In 2010, a large recruitment event was recorded; however, this did not lead to an increase in adults at reserve or control sites in 2013. Rather the density of scallops at reserve sites in 2013 was the lowest for the entire study despite the strong recruitment event in 2010. The reason for the death of these recruits in the reserve remains a mystery.

6.5 Black foot paua

Black foot paua were sampled at a small number of sites in the Abel Tasman MR and in adjacent control areas for the first time in 2013. Diver observations suggest black foot paua are

absent from much of the Abel Tasman coast. Where present, they were usually found at or immediately below low water, and their size was usually below the legal size limits specified in recreational fisheries regulations for this species in this region. Paua were most abundant from one of the two control sites. Diver observations suggest paua inhabited areas of bedrock orientated to the north to north-east, which is the predominant direction of most wave action along this coast. South facing sites or sheltered sites that were searched by divers generally lacked paua. Rocky substrata that supported paua were usually located in shallow water < 5 m depth, and surrounded by medium and coarse sands.

The largest paua in the study was 125 mm length, and was recorded from a reserve site. Despite thorough searches, only one paua under 60 mm length was observed during the present study. The location of juveniles along this coast remains unknown, but they may occur under boulders located close to bedrock adult habitat. No adults were observed on boulders. No paua were recorded from any sites searched south of the reserve, although divers did not turn boulders.

Paua, although mostly of sublegal size, were generally larger than individuals recorded from Horoirangi MR, but were less abundant. Unlike the North Nelson coast, paua were absent from most sites visited by searching divers on the Abel Tasman coast (Davidson *et al*. 2013).

7.0 BIOLOGICAL MONITORING

With assistance from Department staff of the Motueka area, Davidson Environmental Ltd. carries out the current monitoring programme funded by the Department of Conservation, Nelson. This study has spanned a period of 20 years and has detected impacts that can be attributed to the establishment of the marine reserve. The study has also established a long-term data set that can be used to detect potential future changes due to reservation that may be slower to manifest themselves. Based on findings to date, the following monitoring is recommended over the next six years.

Spiny lobsters

Collect number, sex and size annually from existing reserve and control sites.

Fish

Collect number annually using traditional visual underwater count methodology from existing reserve and control sites. Collect estimates of edible reef fish length from all sites.

Key macro-invertebrates

Sample key invertebrate density every fifth year as outlined by Davidson (2001). This is due next in 2014. This is strongly suggested to further investigate changes in the kina population and potentially other invertebrate grazers.

Scallops and horse mussels

Horse mussel density is highly variable between sample events. Further, scallop densities have plummeted in the reserve. It is suggested that scallops density and size and horse mussel density be sampled more often (i.e. once every second year) according to methods outlined in Davidson (2001). The next sample is due in the summer of 2015.

Paua

No paua sampling is suggested in the near future.

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