Response of reef fish to partial and no-take protection at Mayor Island (Tuhua)

N.T. Shears and N.R. Usmar

DOC RESEARCH & DEVELOPMENT SERIES 243

Published by
Science & Technical Publishing
Department of Conservation
PO Box 10-420
Wellington, New Zealand

DOC Research & Development Series is a published record of scientific research carried out, or advice given, by Department of Conservation staff or external contractors funded by DOC. It comprises reports and short communications that are peer-reviewed.
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ISSN 1176-8886
ISBN 0-478-14087-8

This is a client report commissioned by Bay of Plenty Conservancy and funded from the Science Advice Fund. It was prepared for publication by Science & Technical Publishing; editing and layout by Amanda Todd. Publication was approved by the Chief Scientist (Research, Development & Improvement Division), Department of Conservation, Wellington, New Zealand.

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N.T. Shears and N.R. Usmar

Leigh Marine Laboratory, PO Box 349, Warkworth, New Zealand
Email: nickshears@xtra.co.nz

ABSTRACT

Cessation of fishing typically results in a large and rapid increase in the number and size of snapper *Pagrus auratus* in northeastern New Zealand no-take marine reserves. Mayor Island (Tuhua) in the eastern Bay of Plenty is surrounded by a restricted, no commercial fishing zone, and by a no-take reserve, both of which were established in 1993. Here we report the findings of a baited underwater video (BUV) survey that was carried out at Tuhua in March 2004 to assess the effectiveness of these two different management regimes on predatory reef fish species. The number and size of dominant reef fish species was compared between 20 BUV stations inside the no-take reserve, and 17 stations in the adjacent restricted fishing zone. Very low numbers of snapper were recorded in both the reserve ($n = 13$) and the restricted fishing zone ($n = 7$). Snapper were present on 8 out of 20 BUV deployments inside the reserve, and only 1 out of 17 outside. There was a significant difference between carnivorous reef fish assemblages inside and outside the marine reserve; however, this effect was largely explained by variation in depth and substratum type between stations. Based on these findings, and comparisons with studies from other northeastern New Zealand marine reserves, there appears to have been no response of carnivorous reef fish in either management area after 10 years of protection. However, illegal fishing observed in the no-take area compromises our ability to make meaningful conclusions about the effects of no-take protection at Tuhua. Increased compliance effort and continued monitoring is necessary to address this issue.

Keywords: baited underwater video, marine protected areas, no-take marine reserve, predatory reef fish, recreational fishing, Mayor Island (Tuhua) Marine Reserve, Bay of Plenty, New Zealand

Shears, N.T.; Usmar, N.R. 2006: Response of reef fish to partial and no-take protection at Mayor Island (Tuhua). *DOC Research & Development Series 243*. Department of Conservation, Wellington. 31 p.

1. Introduction

No-take marine reserves provide a valuable management and scientific tool for marine ecosystems by removing the impact of fishing. They provide a baseline against which changes in marine systems due to human impacts other than fishing and environmental factors can be detected. In addition, they provide control areas (without fishing), which allow investigations into the impacts of fishing on marine systems. The success of a marine reserve is generally gauged by monitoring the recovery of species that were previously targeted by fishermen in the area; for example, research in northeastern New Zealand conclusively demonstrates the recovery of species such as snapper *Pagrus auratus* and rock lobster (crayfish) *Jasus edwardsii* in marine reserves following the cessation of fishing (Kelly et al. 2000; Willis et al. 2003; Denny et al. 2004). Snapper are typically the largest and most abundant predatory reef fish species in northern New Zealand marine reserves and, of all reef fish species, generally show the most obvious response to protection from fishing (Willis et al. 2003; Denny et al. 2004). In addition to supporting a major inshore commercial fishery, snapper also support the largest recreational fishery in New Zealand, with the estimated recreational catch for northeastern New Zealand (SNA1) in 2001 being 6738 tonnes, approximately 1.5 times the commercial catch (Annala et al. 2004).

Marine Protected Areas (MPAs) that allow restricted fishing (e.g. recreational or traditional) have recently been proposed in New Zealand as a more popular alternative to no-take marine reserves. Worldwide, MPAs that allow certain forms of fishing are common; for example, Francour et al. (2001) found that both amateur and commercial fishing was allowed in half the MPAs in the Mediterranean. However, an increasing number of studies are demonstrating that such MPAs have little to no benefit on populations of target species; for example, Bohnsack (1997) pointed out that 99.5% of the Florida Keys Marine Sanctuary provided no protection for any target species. In Australia's Ningaloo Marine Park, recreational fishing pressure is sufficient to deplete fish populations below that of adjacent protected areas (Westera et al. 2003). Similarly, in northeastern New Zealand, exclusion of commercial fishing alone has been shown to have little effect or benefit on reef fish populations (Denny et al. 2003, 2004). For example, densities of snapper and crayfish within the Mimiwhangata Marine Park, where recreational fishing is allowed, were similar to fully fished sites and far lower than in nearby no-take marine reserves (Denny & Babcock 2004; Shears et al. in press).

Mayor Island (Tuhua) is located in the eastern Bay of Plenty on New Zealand's northeast coast (176º 16´E, 37º 16´S). It is situated on the edge of the continental shelf and is bathed intermittently by the warm East Auckland Current (EAC), which flows southeast along the edge of the shelf, into the Bay of Plenty, and around East Cape (Stanton et al. 1997). Reef fish assemblages around offshore islands in northeastern New Zealand are characterised by a number of subtropical and warm temperate species whose larvae are transported by the EAC (Francis

1996). The reef fish assemblages at Tuhua appear to be comparable to other northern offshore islands, with a number of typically northern and subtropical species being present (Jones & Garrick 1991; Grange 1993). Jones & Garrick (1991) and Grange (1993) noted, however, that the numbers of reef-associated fish observed were lower than expected given the nature and extent of habitat available, and the latitude and location of the island; they suggested that this was attributable to the extensive commercial and recreational use of gill nets in the 1970s and 1980s.

Since 1993, the waters surrounding Tuhua, extending to 1 nautical mile offshore, have been managed with a no-take marine reserve, which includes the north-facing coast of the island, and a restricted fishing zone, which extends around the remainder of the island. This provides a unique opportunity to compare the effects of no-take marine reserve protection with partial protection on reef fish communities. Commercial fishing is prohibited in the restricted fishing zone; however, recreational fishers are allowed to fish under a limited set of fisheries regulations, where set nets (including gill nets) and long lines (lines with more than three hooks) are prohibited, but all other legal fishing methods are allowed. Consequently, this zone is a popular destination for charter boat operators and recreational fishermen, both of whom target a range of reef fish species, especially snapper.

Given that snapper are one of the most heavily targeted inshore reef fish species, by both commercial and recreational fishermen, and have been shown to respond rapidly to no-take marine reserve protection in northeastern New Zealand, we predicted that the abundance of snapper would be considerably higher inside the no-take area of Tuhua than in the adjacent restricted fishing zone. This was tested by comparing the relative density of snapper and other reef fish species between these two areas. The main objective of this survey was to evaluate the effectiveness of the different management regimes on reef fish assemblages at Tuhua. Quantitative estimates of predatory reef fish abundance and size were made between the two different management areas using baited underwater video (BUV). This method is designed specifically to target predatory reef fish species that are attracted to bait, such as snapper (Willis & Babcock 2000). Furthermore, this survey provides baseline data, which can be used to assess future changes in fish assemblages at Tuhua. The results from Tuhua are also compared with other BUV surveys recently carried out in northeastern New Zealand (Denny et al. 2003; Taylor et al. 2003a,b), to place the findings in a regional context.

2. Methods

2.1 BAITED UNDERWATER VIDEO SURVEY

To assess differences between no-take and partial protection, the marine reserve was divided into four areas, which were compared with five adjacent areas in the restricted fishing zone (two at the western end of the reserve and three at the eastern end that encompassed Tuhua Reef) (Fig. 1). This sampling design has been used in numerous other studies of fish in New Zealand marine reserves (Willis & Babcock 2000; Denny et al. 2003; Willis et al. 2003). The design has the dual advantages of ensuring that reference areas are similar to reserve areas, and enabling the detection of any edge effects that might be related to the encroachment of fishing effects into the reserve or cross-boundary movements into or out of the marine reserve. Sampling was conducted between 22 and 26 March 2004 from the Department of Conservation's (DOC's) 'Maataariki', a 6-m-long, aluminum twin-hulled vessel.

Between two and five BUV deployments were conducted in each of the nine survey areas (Fig. 1; GPS positions and site details are given in Appendix 1). The use of the BUV technique allows the sampling of carnivorous species that are not amenable to visual methods. It also enables sampling at depths greater than those at which divers are able to operate (Willis & Babcock 2000). The video system consists of a triangular stainless steel stand, with a high-resolution colour camera positioned 1.25 m above a bait container holding approximately 300 g of pilchards (*Sardinops neopilchardus*). The BUV was deployed from the vessel to depths of up to 30 m. An attempt was made to position the BUV either on or adjacent to reef areas. Each sequence was recorded for 30 minutes from the time the video assembly reached the bottom. A 100-m long coaxial cable connected the underwater camera to a Sony GV-S50E video monitor and an 8-mm video recorder on the vessel, which enabled the person recording to ensure that the stand was upright and over suitable substratum.

Videotapes were later copied to VHS tapes for analysis and archiving. Videotapes were played back with a real-time counter, and the maximum number of each species of fish observed on the screen at any one time during each 30-second period was recorded (i.e. 60 counts were made during each 30-minute sequence). Snapper lengths were obtained by digitising video images using the Sigmascan® image analysis system. Measurements were only made of those fish that were present when the count of the maximum number of fish of a given species in a sequence was made. While this meant that some fish moving in and out of the field of view may not have been measured, it avoided repeated measurements of the same individuals. It is likely that the use of the maximum number present results in a more conservative estimate of abundance in areas of high density than in areas of low density; therefore, observed relative differences between sites are also likely to be conservative.

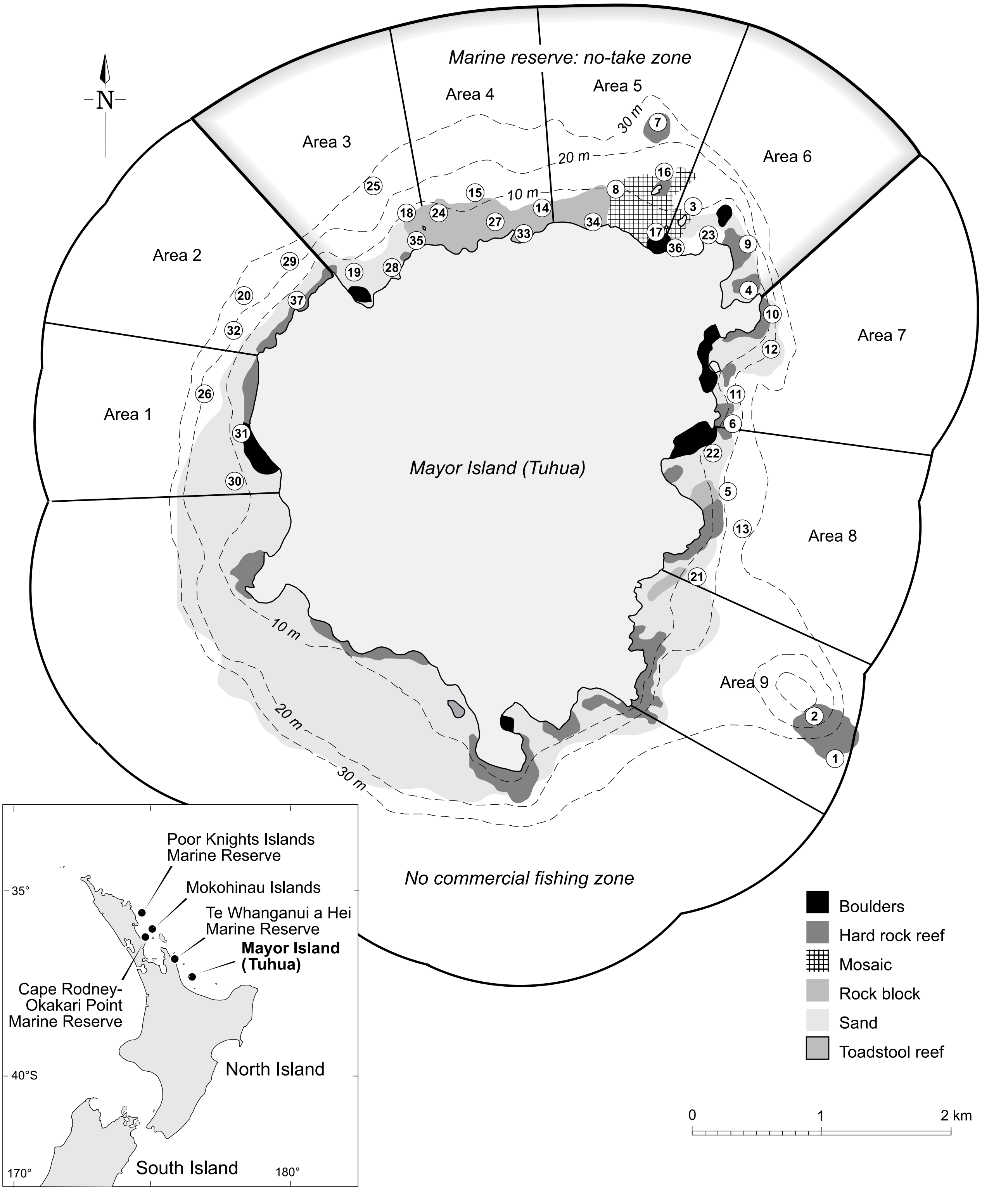


Figure 1. Map of Mayor Island (Tuhua), New Zealand, showing the nine sampling areas and the locations of the baited underwater video stations (1–37) in March 2004. Locations of other reserve and non-reserve sites included in this report are shown on the inset map: Poor Knights Islands Marine Reserve, Mokohinau Islands, Te Whanganui a Hei Marine Reserve (Hahei), and Cape Rodney–Okakari Point Marine Reserve (Leigh).

2.2 STATISTICAL ANALYSIS

Similarities in reef fish assemblages between BUV stations were investigated using principal coordinates analysis. This was based on a Bray-Curtis similarity matrix calculated on untransformed abundance data for 14 species observed during BUV surveys (these species are indicated by an asterisk in Table 1). These species only include the most commonly recorded carnivorous reef fish species, as these were considered to be reliably sampled by the BUV methodology (Willis & Babcock 2000). To determine whether overall reef fish assemblages varied with reserve status (marine reserve v. restricted fishing zone), BUV data were analysed using multiple regression, using the computer program DISTLM (Anderson 2002). This program calculates a non-parametric test for multivariate multiple regression for any linear model. Multiple regression was also used to test the importance of two environmental variables (depth and substratum type) in explaining the observed patterns in fish communities. Depth was recorded at each station using the vessel's depth sounder, and substratum type was classified using a continuous index, whereby sand = 0, sand near reef = 1, mix of reef and sand = 2 and continuous reef = 3. DISTLM was used to test the multivariate null hypothesis that there was no relationship between fish communities and the environmental variables. The effect of reserve status was then tested by including any significant environmental variables as co-variables.

The total abundance of reef fish, the number of species (S) and the abundance of dominant fish inside and outside the marine reserve were compared using a generalised linear mixed model with the GLMMIX procedure in SAS. The model was fitted to a Poisson distribution, as these data were counts and did not satisfy the assumptions of normality and homogeneity of variance required by ANOVA. A two-factor nested analysis was carried out with Status (marine reserve v. non-reserve) as the fixed factor, and Area nested within Status as a random effect.

2.3 REGIONAL COMPARISON OF REEF FISH ASSEMBLAGES

To examine reef fish densities and assemblages at Tuhua in a regional context, results were compared with data from recent BUV surveys carried out in other reserve and non-reserve areas in northeastern New Zealand (Taylor et al. 2003a,b; Denny & Babcock 2004). While BUV data are not ideal for quantitatively comparing overall reef fish assemblages between regions, they do provide useful information on the occurrence of dominant carnivorous reef fish species, from which regional comparisons can be made. BUV data from Tuhua were compared with reserve and non-reserve sites at Hahei in 2003 (Taylor et al. 2003b) and at the Poor Knights Islands in 2002 (after 4 years of complete no-take protection) (Denny et al. 2004). The entire Poor Knights Island group is included in a marine reserve, so data from the Mokohinau Islands (autumn 2002), which has no fishing restrictions, was used as a reference location for the Poor Knights (Denny et al. 2004). Data from the Poor Knights in spring 1998 (Denny et al. 2004) were also used in this comparison, as restricted recreational fishing was allowed in all of the area except two relatively small no-take areas up until that time. Reef fish assemblages were compared between these locations using principal coordinates analysis, based on abundance data for 29 reef fish species.

3. Results

3.1 REEF FISH ASSEMBLAGES AT TUHUA

A total of 33 fish species were recorded during BUV surveys at Tuhua (Table 1). The majority of these species were typical of reefs located around other offshore islands in northeastern New Zealand (Francis 1996; Denny et al. 2003). This included a number of planktivorous, schooling and pelagic fish species, but these were not included in the multivariate analyses of reef fish communities as they were generally highly variable among sites and not reliably sampled by BUV as they are not attracted into the video frame by the bait. For example, planktivorous

TABLE 1. FISH SPECIES (n = 33) AND THEIR TOTAL NUMBERS RECORDED DURING 37 BAITED UNDERWATER VIDEO (BUV) SURVEYS UNDERTAKEN AT MAYOR ISLAND (TUHUA) IN MARCH 2004.

COMMON NAME	SCIENTIFIC NAME	TOTAL NUMBER
Demoiselle	*Chromis dispilus*	46
Yellow moray*	*Gymnothorax prasinus*	31
Snapper*	*Pagrus auratus*	20
Scarlet wrasse*	*Pseudolabrus miles*	16
Pigfish*	*Bodianus unimaculatus*	12
Sandager's wrasse*	*Coris sandageri*	11
Leatherjacket*	*Parika scaber*	9
Grey moray*	*Gymnothorax nubilus*	7
Goatfish*	*Upeneichthys lineatus*	6
Hiwihiwi*	*Chironemus marmoratus*	6
Jack mackeral	*Trachurus novaezelandiae*	4
Banded wrasse*	*Notolabrus fucicola*	3
Green wrasse*	*Notolabrus inscriptus*	3
Porae*	*Nemadactylus douglasii*	3
Spotty*	*Notolabrus celidotus*	3
Sweep	*Scorpis lineolatus*	3
Half-banded perch*	*Hypoplectrodes* sp.	3
Black angelfish	*Parma alboscapularis*	2
Butterfly perch	*Caesioperca lepidoptera*	2
Trevally	*Pseudocaranx dentex*	2
Blue cod	*Parapercis colias*	1
Blue maomao	*Scorpis violaceus*	1
Combfish	*Coris picta*	1
Crimson cleanerfish	*Suezichthys aylingi*	1
Eagle ray	*Myliobatis tenuicaudatus*	1
John dory	*Zeus faber*	1
Kingfish	*Seriola lalandi*	1
Northern scorpionfish	*Scorpaena cardinalis*	1
Orange wrasse	*Pseudolabrus luculentus*	1
Short-tailed stingray	*Dasyatis brevicaudata*	1
Single-spot demoiselle	*Chromis hypsilepis*	1
Speckled moray	*Gymnothorax obesus*	1
Tarakihi	*Nemadactylus macropterus*	1

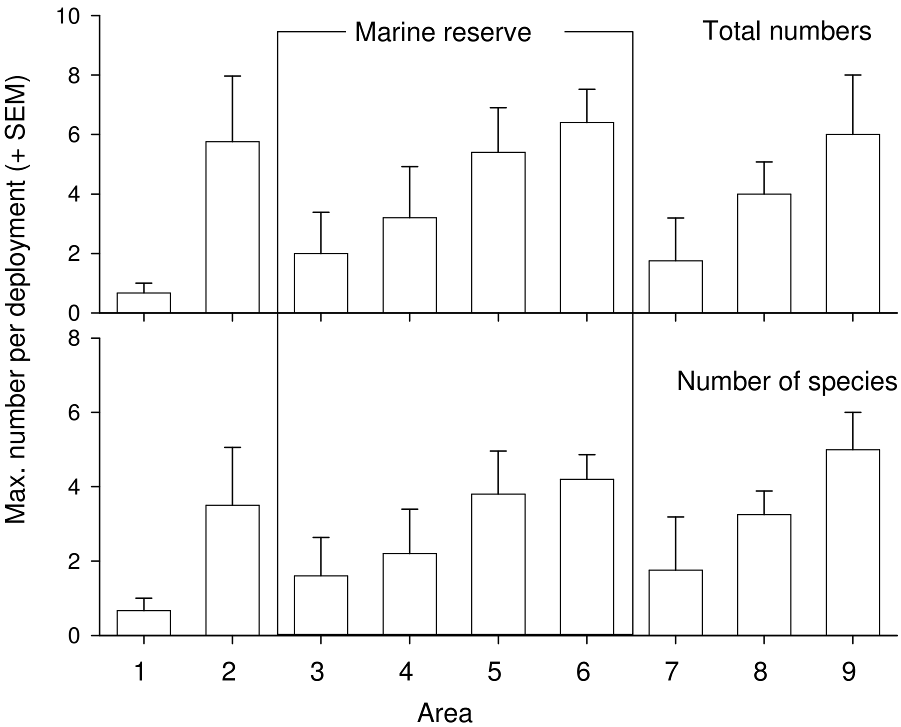
* Species included in multivariate analyses.

demoiselles (*Chromis dispilus*) were recorded in the highest numbers, with a total of 46 being recorded (Table 1), but 32 of these were recorded on one deployment. Count data for all species recorded at all BUV stations are given in Appendix 2.

Despite the large number of species detected, the overall numbers of fish recorded on BUV deployments were very low (Fig. 2). The total number of fish recorded within each sampling area generally followed the number of species. This is probably a result of the low numbers. There was no difference between areas inside and outside the reserve in the total number of fish recorded ($F = 0.82$, df = 1, 28, $P = 0.374$) or the number of species recorded ($F = 0.24$, df = 1, 28, $P = 0.632$).

In general, there was a high degree of variability in fish communities between BUV stations (Fig. 3A). This appeared to be strongly related to the physical characteristics of each site (Fig. 3B and Table 2). At nine of the BUV stations, no fish were recorded during the 30-minute deployment. These are clustered on the far right of the ordination (Fig. 3A) and were all located on areas of sand. The cluster of samples at the bottom of the ordination contained low numbers of Sandager's wrasse (*Coris sandageri*) and were also located on sand near the reef. Substratum type was strongly correlated with principal coordinates (PC) axis 1 (Fig. 3B), which tended to reflect the separation of sites on reef (left) and sand (right). Consequently, most of the reef fish species were negatively correlated with PC axis 1 (Fig. 3C). In contrast, depth was correlated with PC axis 2. A number of reef fish species were correlated with this axis, although the nature of the relationship varied between species. For example, both yellow morays (*Gymonothorax prasinus*) and scarlet wrasse (*Pseudolabrus miles*), which were mostly recorded in shallow water (< 15 m), were positively correlated with PC axis 2, while Sandager's wrasse, which were generally found in deeper water (> 15 m), were negatively correlated with this axis. Overall reef fish community

Figure 2. Mean (+ SEM) number of reef fish and number of species recorded from 37 baited underwater video samples for areas inside and outside Tuhua Marine Reserve in March 2004.



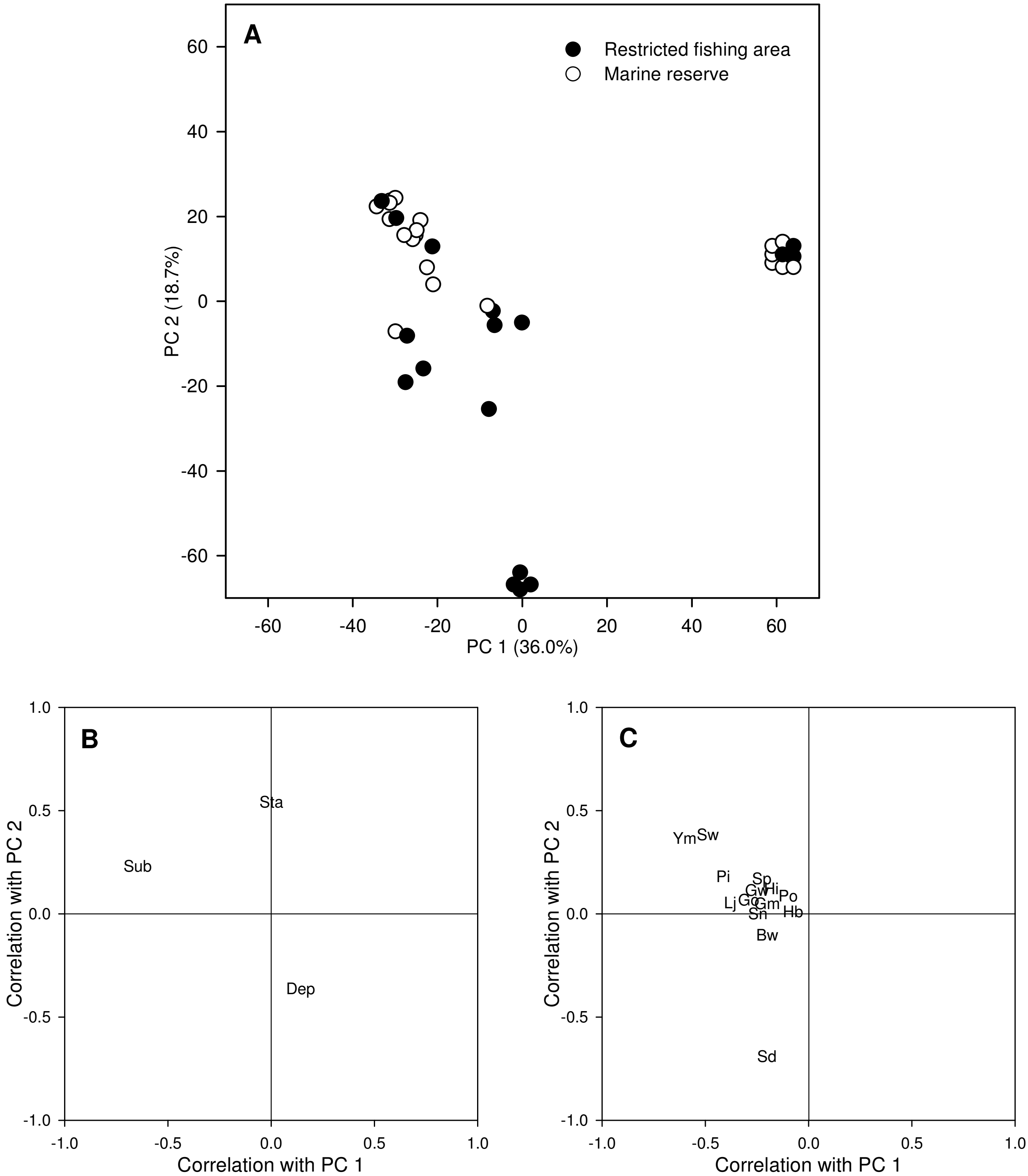


Figure 3. A. Principal coordinates analysis of reef fish assemblages (14 species) between 37 baited underwater video samples in the no-take marine reserve and the restricted fishing area at Mayor Island (Tuhua) in March 2004; and bi-plots showing the correlations between the principal coordinates axes and B. substratum type (sub), depth (dep) and status (sta; marine reserve v. restricted fishing area), and C. individual reef fish species: yellow moray (Ym), snapper (Sn), scarlet wrasse (Sw), pigfish (Pi), Sandager's wrasse (Sd), leatherjacket (Lj), grey moray (Gm), goatfish (Go), hiwihiwi (Hi), banded wrasse (Bw), green wrasse (Gw), porae (Po), spotty (Sp) and half-banded perch (Hb); see Table 1 for specific names.

TABLE 2. RESULTS OF MULTIPLE REGRESSION ANALYSIS ON REEF FISH ASSEMBLAGE DATA (COUNTS OF 14 SPECIES) FROM 37 BAITED UNDERWATER VIDEO SAMPLES COLLECTED FROM RESERVE AND NON-RESERVE SITES AT MAYOR ISLAND (TUHUA) IN MARCH 2004.

VARIABLE	COVARIABLES	df	PSEUDO *F*	*P*	% VARIATION EXPLAINED
Depth		1,35	2.44	0.025	6.5
Substratum type		1,35	6.84	0.001	16.3
Reserve status		1,35	2.71	0.021	7.2
Reserve status	Depth, Substratum	1,33	3.50	0.044	7.4

structure was significantly related to depth and substratum type, and together these variables explained 22.2% of the observed variation (Table 2).

Reef fish assemblages also differed between areas inside and outside the marine reserve (Fig. 3 & Table 2). This was reflected by the strong correlation between PC axis 2 and Status (Fig. 3B). The effect of reserve status was still apparent when the variation associated with depth and substratum type was taken into account (Table 2). Therefore, although the general patterns in carnivorous reef fish assemblages at Tuhua appear to be strongly associated with depth and the availability of reef around the island, these results suggest that there are some differences between the no-take area and the restricted fishing zone that are not accounted for by these physical variables.

3.2 DOMINANT REEF FISH SPECIES

Differences between areas in the overall abundance of the six most abundant carnivorous reef fish species are shown in Fig. 4. Snapper tended to be more common in the marine reserve (Fig. 4); however, their numbers were too low to statistically test differences in abundance between areas inside and outside the marine reserve. Only 20 snapper were recorded on all BUV deployments, seven of which were recorded on one deployment outside the marine reserve (hence the large SEM; Fig. 4). Snapper were recorded in all areas inside the reserve (on 8 out of 20 deployments), compared with only one area outside the reserve (on 1 out of 17 deployments). Snapper recorded in the reserve also tended to be larger than those recorded in the restricted fishing zone (Fig. 5), and all individuals recorded in the reserve were larger than the minimum legal size limit, with a number of fish being over 400 mm fork length.

Yellow morays and pigfish (*Bodianus unimaculatus*) were also more frequently recorded on BUV deployments inside the marine reserve (Fig. 4). In general, however, only low numbers of these species were recorded; consequently, these differences could not be statistically tested. Neither of these species was recorded in Area 1, where the majority of BUV deployments were onto sand. Therefore, the availability of reef is likely to influence the abundance of these species within each area.

Figure 4. Mean (+ SEM) relative abundance of the six most common reef fish species, from 37 baited underwater video surveys inside and outside Tuhua Marine Reserve in March 2004. Note: the no-take marine reserve includes Areas 3–6.

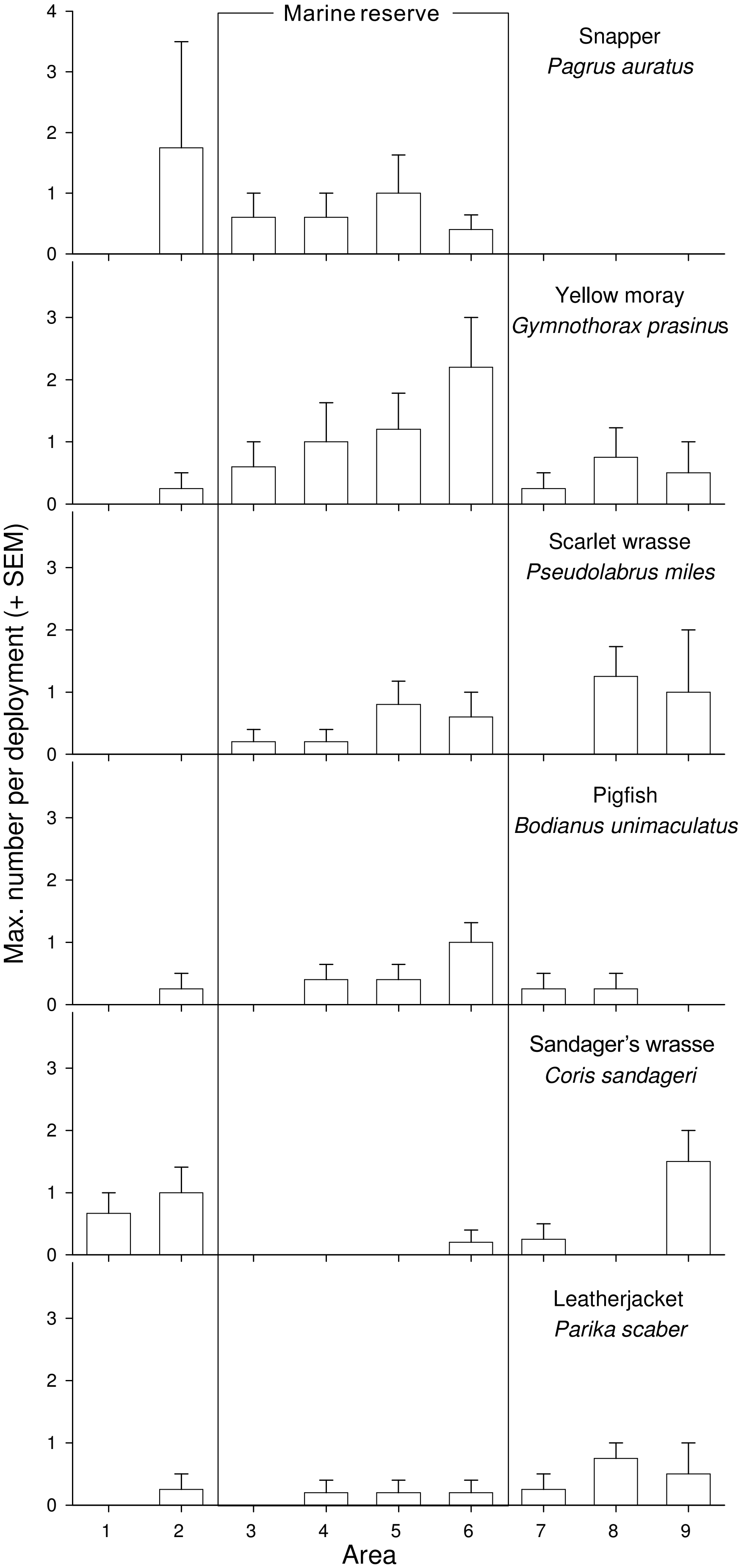
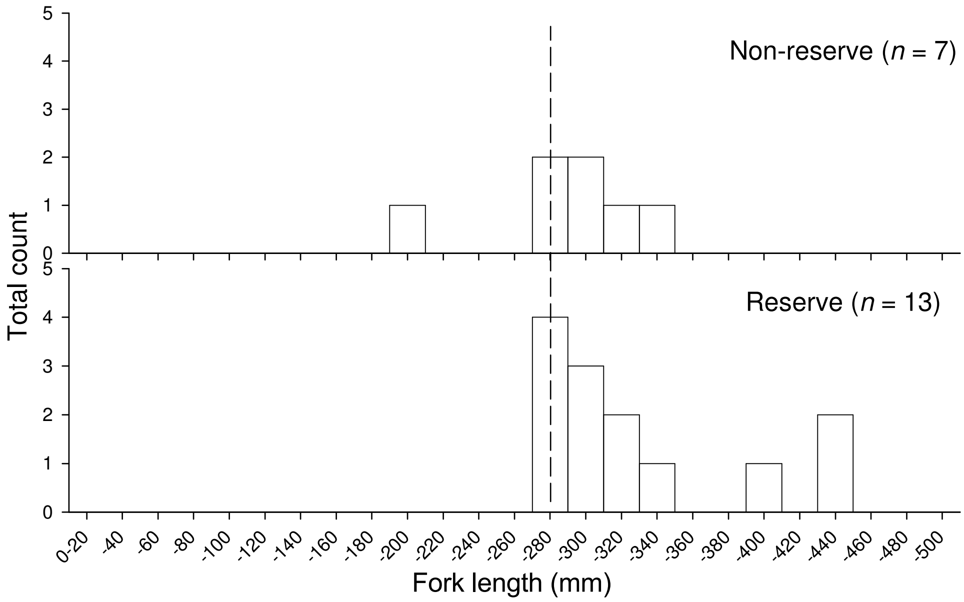


Figure 5. Size frequency distribution of snapper (*Pagrus auratus*) at Mayor Island (Tuhua) from 37 baited underwater video samples collected in March 2004. Dashed line indicates the size range that includes the minimum legal size (270 mm fork length).



3.3 REGIONAL COMPARISON OF CARNIVOROUS REEF FISH ASSEMBLAGES

Twenty-nine species were included in the regional comparison of carnivorous reef fish assemblages; these are shown with their relative abundances at each location in Appendix 3. Overall carnivorous reef fish species composition (presence/absence) was found to be very similar between Tuhua, Poor Knights and Mokohinau Islands (Fig. 6A). In contrast, the reef fish assemblage at Tuhua was considerably different from the coastal location (Hahei), where species such as spotty (*Notolabrus celidotus*), gurnard (*Chelidonichthys kumu*), conger eel (*Conger wilsoni*) and blue cod (*Parapercis colias*) were more frequently sighted on the BUV (Fig. 6B). In general, PC axis 1 reflects the gradient in species composition from coastal locations to offshore islands.

Despite the similarities in species composition between Tuhua and other offshore islands (Fig. 6), there were large differences in community structure and the overall numbers of fish recorded on BUV (Fig. 7A and Appendix 3). In general, the numbers at Tuhua were lower than at the Mokohinau and Poor Knights Islands for a range of species that were positively correlated with PC axis 1 (Fig. 7B), e.g. snapper, pigfish, scarlet wrasse, northern scorpionfish (*Scorpaena cardinalis*), yellow moray, porae (*Nemadactylus douglasii*) and half-banded perch (*Hypoplectrodes* sp.) (Appendix 3). Some species, such as hiwihiwi (*Chironemus marmoratus*) and banded wrasse (*Notolabrus fucicola*), tended to be more common at Tuhua and were negatively correlated with PC axis 1 and 2. Reef fish assemblages at Tuhua were most similar to those seen at the Mokohinau Islands (MK02), and at the Poor Knights prior to it becoming a no-take marine reserve in 1998 (PK98) (Fig. 7A). The separation of the 1998 and 2002 data from the Poor Knights (PK98 and PK02 respectively) is most likely due to the large increase in the number of snapper that occurred over this time (Denny & Babcock 2004). Although the low numbers of snapper recorded at

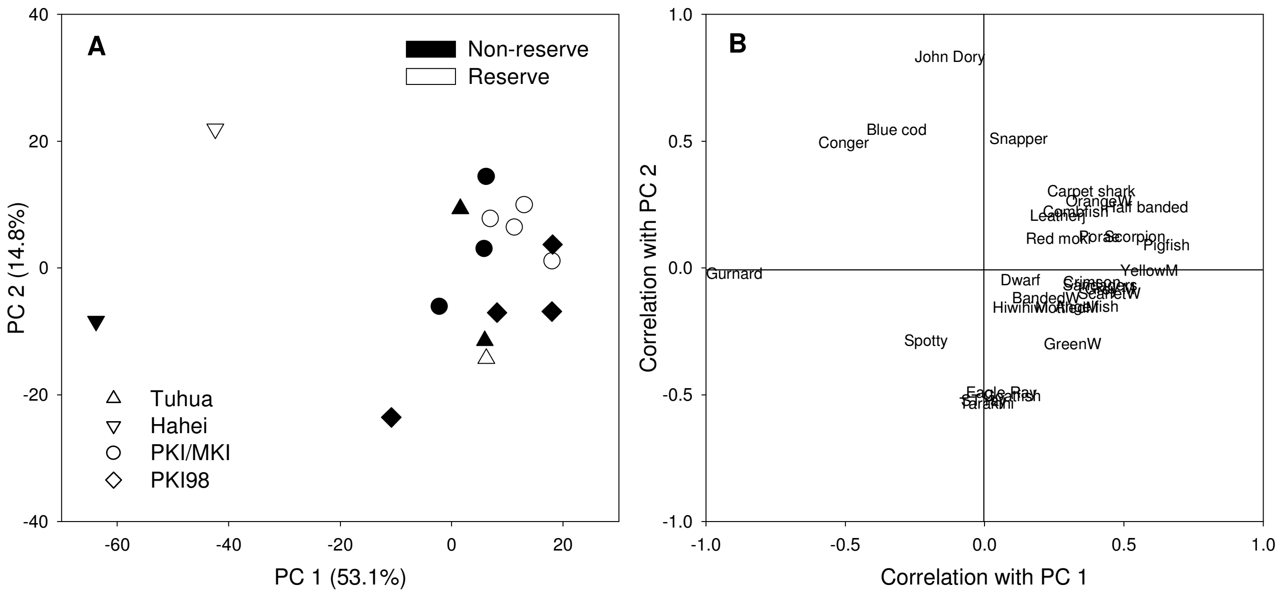


Figure 6. Regional comparison of reef fish species composition between Tuhua and other northeastern New Zealand locations, using data from previous baited underwater video (BUV) surveys at Hahei (autumn 2003; Taylor et al. 2003b) and the Poor Knights Islands (spring 1998 and autumn 2002; Denny et al. 2002). A. Principal coordinates analysis based on presence/absence data of 29 reef fish species, and B. bi-plots showing the correlations between the principal coordinates axes and individual reef fish species. BUV stations are pooled for each location into the reserve and non-reserve areas used in those surveys. Tuhua data were grouped into three general areas: West (Areas 1–2), Reserve (Areas 3–6) and East (Areas 7–9). Note that data from the Mokohinau Islands (MKI) in 2002 are also presented as a non-reserve reference location for the Poor Knights Islands (PKI). Data from the Poor Knights in 1998 (PKI98) were collected prior to the creation of the no-take reserve, so are presented as non-reserve areas.

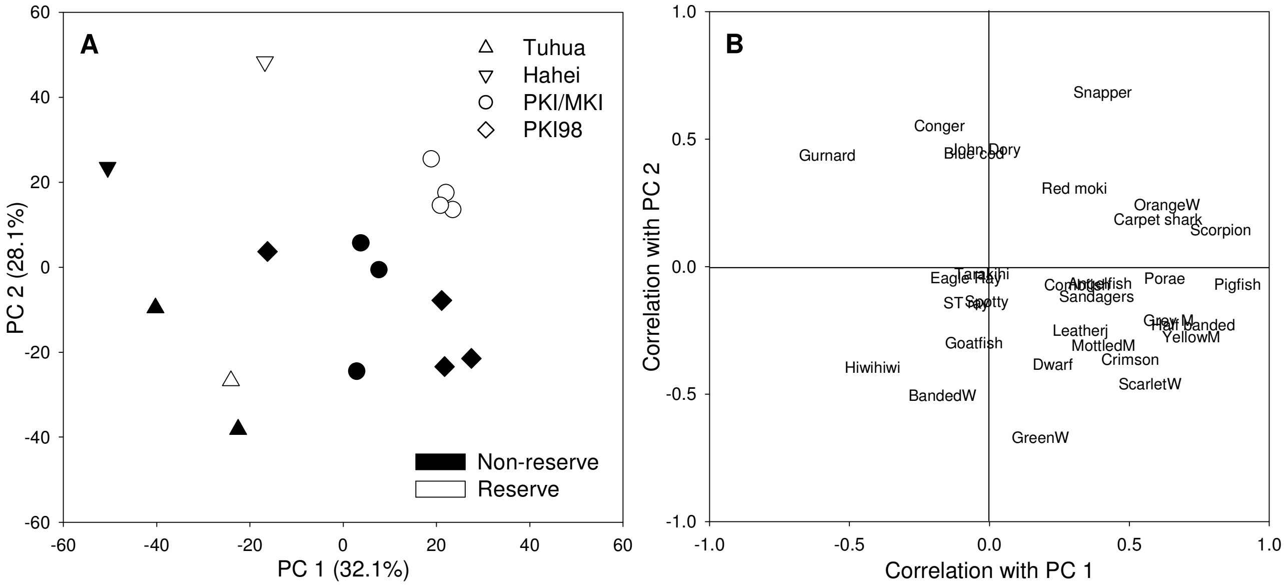


Figure 7. Regional comparison of reef fish community structure between Mayor Island (Tuhua) and other northeastern New Zealand locations, using data from previous baited underwater video (BUV) surveys at Hahei (autumn 2003; Taylor et al. 2003b) and the Poor Knights Islands (spring 1998 and autumn 2002; Denny et al. 2002). A. Principal coordinates analysis based on untransformed count data of 29 reef fish species, and B. bi-plots showing the correlations between the principal coordinates axes and individual reef fish species. BUV stations are pooled for each location into the reserve and non-reserve areas used in those surveys. Tuhua data were grouped into three general areas: West (Areas 1–2), Reserve (Areas 3–6) and East (Areas 7–9). Note that data from the Mokohinau Islands (MKI) in 2002 are also presented as a non-reserve reference location for the Poor Knights Islands (PKI). Data from the Poor Knights in 1998 (PKI98) were collected prior to the creation of the no-take reserve, so are presented as non-reserve areas.

the Poor Knights in 1998 may be in part due to the survey being carried out in spring, subsequent spring surveys at this site have also shown a large increase in the number of legal-sized snapper (Denny et al. 2003, 2004).

The numbers of legal-sized snapper found inside and outside marine reserves from recent BUV surveys in other parts of northern New Zealand (Taylor et al. 2003a,b; Denny & Babcock 2004) are shown in Fig. 8. In general, numbers were considerably higher in all marine reserves except Tuhua, where the numbers in both the no-take reserve and the partially protected area are comparable to non-reserve areas, and the small no-take areas at the Poor Knights in spring 1998 (prior to the complete no-take protection of the island group).

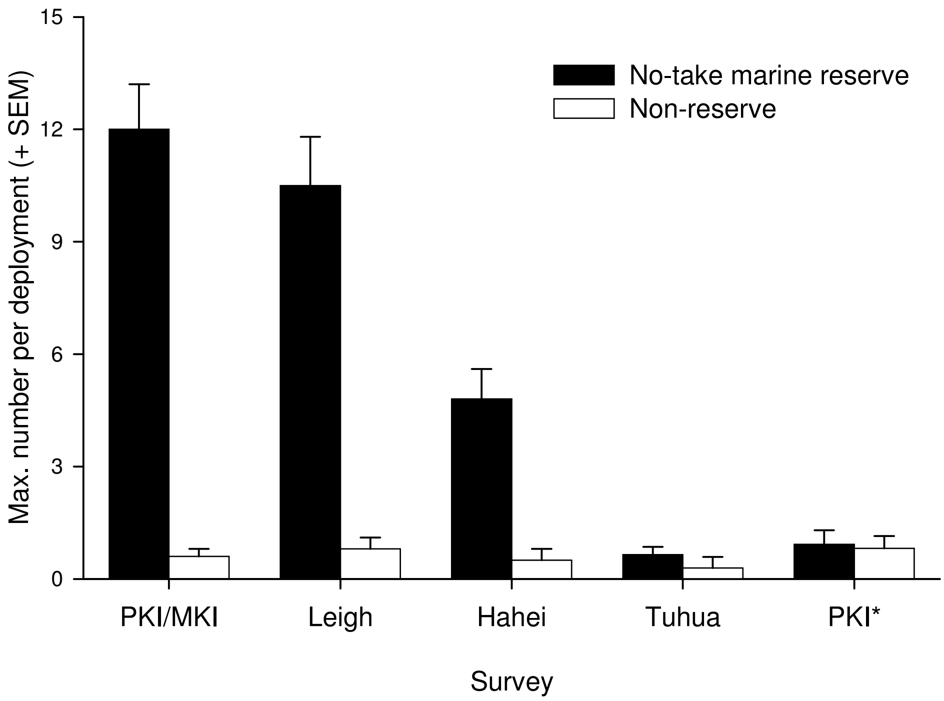


Figure 8. Regional comparison of mean (+ SEM) legal-size snapper abundance from baited underwater video surveys inside and outside marine reserves in northern New Zealand. Data are presented from the Poor Knights Islands Marine Reserve and the Mokohinau Islands (as a fished reference location) in autumn 2002 (PKI/MKI; Denny et al. 2003), Leigh reserve and non-reserve sites in autumn 2002 (Taylor et al. 2003a), Hahei reserve and non-reserve sites in autumn 2003 (Taylor et al. 2003b), Mayor Island (Tuhua) reserve and restricted fishing sites in autumn 2004 (this study) and also from the Poor Knights in spring 1998 (PKI) prior to it becoming a complete no-take reserve (Denny et al. 2002). (In 1998, comparisons were made between two small no-take areas of the Poor Knights and the remainder of the area where restricted recreational fishing was allowed.)

4. Discussion

Snapper have been shown to recover rapidly following the implementation of no-take marine reserve protection at offshore islands in northeastern New Zealand (Denny et al. 2003, 2004). However, after 10 years of no-take marine reserve protection at Tuhua we found little evidence to suggest that snapper populations have recovered in the marine reserve. Although snapper tended to be larger and more abundant in the no-take area, overall numbers were extremely low; consequently, these patterns could not be tested statistically. In addition, although the overall assemblage of carnivorous reef fish differed between the no-take reserve and the restricted fishing zone, this was largely explained by differences in substratum type and depth. However, a number of species did appear to be more abundant inside the no-take area, e.g. yellow morays and pigfish. While these species are not commercially or recreationally targeted, they are often caught as by-catch. Denny & Babcock (2004) also found higher abundances of pigfish inside Mimiwhangata Marine Park compared with outside, and suggested that this may be a result of reduced fishing pressure. While this may explain the higher abundance of pigfish and yellow morays in Tuhua Marine Reserve, the differences in abundance may also be associated with other factors, such as the availability of suitable reef habitat. The extent of subtidal reef varies considerably around Tuhua (Fig. 1). Although comparable reef habitats occur inside and outside the marine reserve (Shears & Babcock 2004), the reefs in the marine reserve are extensive and extend to depths beyond 40 m; in contrast, many of the reefs on the southern and western sides of the island are limited in extent and truncated by sand at much shallower depths (less than 10 m). Given the greater availability of reef habitat in the marine reserve, the reserve would naturally be expected to support higher abundances of reef-associated fish species. Therefore, variability in the availability of reef is likely to be important in explaining the observed patterns in reef fish assemblages around Tuhua. It is essential that this variability is taken into account when designing and analysing results from future monitoring programmes at Tuhua, to ensure that environmental variability is not misinterpreted as potential effects of the reserve.

The overall numbers of reef fish recorded on the BUV deployments were very low compared with previous surveys at both reserve and non-reserve locations in other parts of northeastern New Zealand (Fig. 7A). This finding remains consistent with studies prior to the implementation of the management regime at Tuhua (Jones & Garrick 1991; Grange 1993), and suggests that neither the no-take area nor the restricted fishing area have been effective in allowing the recovery of reef fish species. There are a number of possible reasons for this: patterns may reflect region-wide patterns, i.e. the numbers of snapper and other reef fish may be naturally lower at offshore islands in the Bay of Plenty than in areas further north; the low numbers of reef fish recorded may be an artefact of the sampling methodology; or fish populations may not have been allowed to recover due to continued fishing pressure (poaching) occurring in the reserve. Each of these possible explanations is discussed in more detail below.

4.1 REGIONAL PATTERNS IN FISH POPULATIONS

The carnivorous reef fish assemblages at Tuhua appear to be typical of those found at offshore islands in northern New Zealand (Fig. 6). However, the total numbers of reef fish at Tuhua were lower than have been observed at more northern offshore islands (e.g. Poor Knights and Mokohinau Islands) (Fig. 7). While this suggests a possible latitudinal gradient, Grange (1993) found that the total numbers of reef fish at Tuhua were lower than at the nearby White Island; he suggested that this was due to higher fishing pressure at Tuhua than at White Island. These observations combined with the findings from this study suggest that non-targeted reef fish species are less common at Tuhua than at other offshore islands. However, to fully assess these patterns, a better understanding of the distribution of reef fish species throughout the region and among habitats is needed.

It is possible that snapper, a typically northern species (Francis 1996), could show a latitudinal gradient in the level of recovery within marine reserves, i.e. the magnitude of recovery of snapper may be greater in northern reserves. However, this is not likely to explain the low numbers in the marine reserve at Tuhua, as snapper support a large commercial fishery in the Bay of Plenty (Walsh et al. 2004) and are a popular recreational target species (A. Jones, DOC Tauranga, pers. comm.). Furthermore, in Te Whanganui a Hei (Hahei) Marine Reserve, which is only 60 km to the north of Tuhua, there has been a considerable response of snapper to marine reserve protection (Taylor et al. 2003b; Willis et al. 2003).

The timing of sampling may also influence the numbers of snapper recorded in BUV surveys, as snapper have been shown to undergo large seasonal inshore and offshore movements (Willis et al. 2003). However, the Tuhua survey was carried out in March, when numbers are typically highest in northern marine reserves (Denny et al. 2003; Willis et al. 2003). Furthermore, recent surveys at the Poor Knights (marine reserve) and Mokohinau Islands (unprotected area) in April/May 2004 found very high numbers at the Poor Knights and low numbers at the Mokohinau Islands (C. Denny, University of Auckland, unpubl. data). Regardless of the inshore–offshore movement patterns of snapper, a large proportion (c. 40%) of snapper remain resident in northern reserves year round (Willis et al. 2001). The no-take area at Tuhua covers c. 4 km of coastline and includes entire reef systems; this is comparable to other reserves that have shown a response in snapper populations, e.g. Cape Rodney–Okakari Point (Leigh), Tawharanui and Hahei (Willis et al 2003). Therefore, given the size and age of the reserve at Tuhua, and the high availability of suitable reef habitat, we would expect a large resident population of snapper to be present, based on observations from other northern New Zealand marine reserves (Willis et al 2003, Denny et al 2004). However, the results from this study suggest that such a population does not exist in Tuhua Marine Reserve. It is possible that snapper at Tuhua are utilising an area larger than the no-take reserve and moving around the entire island. However, given that resident snapper have been shown to have relatively small home ranges in reserves (Parsons et al. 2003), we would still expect proportionally more snapper inside the no-take area.

4.2 METHODOLOGY

The BUV system has been extensively tested (Willis & Babcock 2000) and has been used successfully in many marine reserves around New Zealand (Willis et al. 2003; Denny et al. 2004) and overseas (Westera et al. 2003). The methodology used is thought to provide a conservative estimate of the number of fish in an area, as only the maximum number of fish in the frame at any one time is recorded. One possible factor that may have influenced the number of fish recorded on the video was the design of the DOC boat used for sampling. Although aluminium boats have been used in previous BUV surveys (Willis et al. 2003), the boat used for the Tuhua survey was an aluminum 6-m boat with turned down chines, which made it very noisy when at anchor. However, while this may have inhibited snapper from approaching the bait-pot, any effect would have been consistent across all sites. Therefore, if snapper abundance was in fact higher in the reserve, we would have expected to see proportionally higher numbers. Additional BUV stations were sampled at Tuhua in March 2005 in the no-take reserve ($n = 9$) and the restricted fishing area ($n = 7$) using a remote camera system that was not connected via a cable to the boat (NS, unpubl. data). Data from this system are comparable to those from the current study (identical frame/field of view), but any potential bias associated with the boat was removed, as once the system was deployed the boat was moved away from the immediate area. The results from the 2005 survey were highly comparable to the 2004 survey, with overall low numbers of reef fish and no difference in snapper numbers (< 1 per deployment) between both management areas (NTS, unpubl. data). This recent survey demonstrates that the boat used in the 2004 survey does not appear to have influenced the results, and that the data are comparable to those collected in other reserves (Fig. 8). Furthermore, the very low numbers of snapper found inside the reserve and in the restricted fishing zone are consistent with underwater visual census data collected at Tuhua by the Bay of Plenty Polytechnic Marine Studies course during the same sampling period (K. Young (DOC), A. Jones (DOC) and K. Gregor (Bay of Plenty Polytech), unpubl. data).

In most northeastern New Zealand reserves, snapper exhibit an aggressive behaviour around the bait-pot and are not intimidated by boats and divers (Cole 1994). In contrast, snapper at Tuhua exhibited a very timid behaviour around the bait-pot, consistent with that of fished populations rather than of snapper in a marine reserve (NRU, pers. obs.). There is little human presence at Tuhua and snapper are not exposed to fish feeding (A. Jones, DOC Tauranga, pers. comm.); however, this is not likely to explain their timid behaviour, as snapper also exhibit an aggressive behaviour towards the bait-pot in other reserves where they are not fed, e.g. Tawharanui, and in isolated parts of other reserves where feeding does not occur, e.g. parts of the Leigh marine reserve and the Poor Knights Islands (NTS, pers. obs.).

4.3 POACHING

A likely explanation for the very low numbers of snapper in Tuhua Marine Reserve is that the 'no-take' reserve is still being fished at moderate levels. While DOC carry out occasional compliance exercises at Tuhua (A. Jones, DOC Tauranga, pers. comm.), poaching is known to be a common occurrence in the reserve (NTS, pers. obs.). During the current BUV survey, numerous boats were observed fishing in the marine reserve as part of a fishing competition (NRU, pers. obs.). Furthermore, on independent research trips made to Tuhua, University of Auckland scientists observed several boats fishing in the reserve (M. Birch, University of Auckland, pers. obs). Given that reduced levels of fishing in restricted fishing areas have been shown to be ineffective in protecting reef fish species (e.g. Mimiwhangata Marine Park; Denny & Babcock 2004), illegal fishing in Tuhua Marine Reserve may explain why the abundance of commonly targeted reef fish species reflect those found in restricted fishing areas or fully fished areas, rather than those found in no-take marine reserves (Fig. 8).

Currently, there is no information available on the extent of poaching occurring in Tuhua Marine Reserve. While levels may only equate to a fraction of the fishing pressure exerted on the partial protection zone, we suggest that only low levels of fishing pressure are sufficient to prevent the establishment of a resident population of snapper. Since the overall supply of snapper to Tuhua is likely to be controlled by regional and fishery-level processes in the Bay of Plenty, if the seasonal influx of snapper to Tuhua is generally low, this will compound the effects of poaching.

5. Conclusions

The results from BUV surveys at Tuhua found no clear difference in snapper size or abundance between the no-take area and the adjacent restricted fishing zone where recreational fishing is allowed. In general, there was no apparent difference in carnivorous reef fish species between the two areas that could be attributed to differing levels of protection. Furthermore, the abundance of snapper within both of these areas was comparable to that found at fully fished sites in other northeastern New Zealand locations. It therefore appears that neither the restricted fishing zone nor the no-take area at Tuhua have been effective in allowing the recovery of reef fish at Tuhua.

The overall objective of this study was to assess the two different management regimes (no-take marine reserve and restricted fishing area) at Tuhua by comparing reef fish populations between the two management areas. From the results collected, there appears to be no clear difference between the two areas and no obvious response to no-take protection. However, throughout the course of this study we found that recreational fishing was still common practice in the no-take area at Tuhua, which seriously compromises the conclusions we can draw from this result. We believe that illegal fishing in the no-take area is the most likely explanation for the lack of response to protection in this area.

In addition, while a number of other factors may also contribute to the lack of response (e.g. regional factors affecting larval supply, movement patterns and/or habitat availability), the fact that fishing still occurs in the no-take area seriously compromises our ability to assess other potential explanations and in general jeopardises the scientific value and ecological integrity of the marine reserve. Therefore, only after a concerted compliance effort at Tuhua and continued monitoring of reef fish populations can the objective of this study be accurately assessed.

6. Management recommendations

- Due to the apparent lack of recovery of reef fish and the levels of illegal fishing observed in the no-take reserve, a concerted compliance effort is necessary at Tuhua to ensure that fishing is not taking place in the marine reserve. Collection of data on the amount, type, frequency and spatial distribution of fishing effort around Tuhua would also be beneficial in interpreting patterns in reef fish abundance. Similar information from other areas nearby (e.g. the White Island-Volkner Rocks area) would provide a valuable regional comparison on fishing effort.
- A regular BUV fish-monitoring programme should also be established at Tuhua, using a comparable design to this study. This could be incorporated into the long-term sampling programme carried out annually by the Bay of Plenty Polytechnic Marine Studies course at Tuhua. BUV monitoring will need to be carried out over a sufficient time period (> 3 years) to determine whether increased compliance effort is effective in allowing the recovery of reef fish populations. Careful positioning of BUV stations on (or as close as possible to) areas of reef is recommended, to avoid zero counts of fish on sand areas.
- Seasonal variability in the abundance of some reef fish species, in particular snapper, is very large. Therefore, it would be desirable for the BUV monitoring to be carried out biannually (autumn and spring) to assess this pattern at Tuhua. The degree of seasonal and annual variability can then be used to review the frequency of the sampling programme. It is crucial that the timing of surveys is kept consistent between years to minimise the influence of seasonal variability.
- The programme should be extended to include other islands in the Bay of Plenty, e.g. White Island and the new marine reserve at Volkner Rocks, using the same or similar methodology. This will not only provide a regional context and valuable baseline data for other areas, but will also allow a comparison to be made between Tuhua and areas with no fishing restrictions.
- Underwater visual census methods are recommended to assess how the entire reef fish assemblage at Tuhua compares with other islands, such as White Island and Volkner Rocks. This survey should be designed to assess how reef fish assemblages in the Bay of Plenty vary with a number of factors, such as depth, habitat type and wave exposure. This information is necessary to make valid comparisons of reef fish assemblages between reserve and non-reserve areas. A seasonal component could also be incorporated into this survey.

- The large number of monitoring studies likely to be needed in an expanded network of marine reserves in New Zealand will require a more long-term approach to monitoring and greater consistency in the methodologies used. At present, inconsistencies in methods and approaches used at different reserves often make comparisons among reserves difficult. In general, there is an urgent need for an MPA monitoring strategy that sets out clear guidelines on monitoring techniques, sampling design (levels of replication and stratification, e.g. depth, habitat type and wave exposure), and the frequency and timing of monitoring. For many species or groups of species, such as reef fish, monitoring techniques and sampling designs have been well developed and used extensively throughout New Zealand. Compiling this information into a national strategy will ensure a more cost-effective and scientifically robust approach to future monitoring.

7. Acknowledgements

We are very grateful to Alan Jones (DOC, Tauranga Area Office) for skippering the DOC vessel 'Maataariki' and providing operational support for the sampling. Thanks also to the Tuhua Trust Board for providing support and accommodation on shore. Chris Denny, Kim Young and Alan Jones provided valuable comments on the draft report. Thanks also to Chris Denny and Richard Taylor for providing data from BUV surveys at the Poor Knights Islands, Mokohinau Islands, Leigh and Hahei, and to Chris Edkins (DOC) for preparing Fig. 1. This study was funded by DOC Science Advice Fund, and was facilitated by Kim Young of the Bay of Plenty Conservancy, DOC.

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Appendix 1

SITE POSITIONS AND DETAILS OF BAITED UNDERWATER VIDEO STATIONS

AREA	DROP NO.	DATE (2004)	SITE LOCATION	STATUS*	LATITUDE	LONGITUDE	DEPTH (m)	HABITAT
1	26	25 Mar	Awatukoro Point	NR	37 16.722	176 13.801	21	Sand off reef
1	30	25 Mar	Moewai Bay	NR	37 17.131	176 13.745	16	Sand off reef
1	31	26 Mar	Centre NW Bay	NR	37 17.525	176 13.865	9	Sand off reef
2	20	24 Mar	Herbies hole	NR	37 16.447	176 13.982	28	Sand
2	29	25 Mar	West reserve boundary	NR	37 16.266	176 14.215	23	Reef/*Ecklonia*
2	32	26 Mar	West end of Moewai Bay	NR	37 17.025	176 13.667	21	Sand off reef
2	37	26 Mar	NW Awatukoro Point	NR	37 16.559	176 14.021	9	Reef/sand
3	18	24 Mar	SW Maori Chief	R	37 16.095	176 14.803	11.5	Sand/cobbles
3	19	24 Mar	Cathedral Bay	R	37 16.310	176 14.496	14	Sand off reef
3	25	25 Mar	SW Maori Chief	R	37 15.970	176 14.583	29	Sand
3	28	25 Mar	North Cathedral Cove	R	37 16.344	176 14.620	9	Fine sand
3	35	26 Mar	East end Opupoto Bay	R	37 16.227	176 14.729	9.5	Cobbles/*Ecklonia*
4	14	24 Mar	Te Ananui Cave	R	37 15.975	176 15.266	23	Reef/*Ecklonia*/sand
4	15	24 Mar	NW Maori Chief	R	37 16.029	176 14.945	11	Reef/sand
4	24	25 Mar	East Maori Chief	R	37 16.048	176 14.922	14	Sand off reef
4	27	25 Mar	Te Ananui Cave	R	37 16.069	176 15.183	11	Reef/sand
4	33	26 Mar	East Motunaki Rock	R	37 16.159	176 15.156	8.5	Sand off reef
5	16	24 Mar	Tabletop—2 Fathom	R	37 15.769	176 16.233	21	Reef
5	17	24 Mar	SW The Queen	R	37 15.961	176 16.092	11	Reef/mixed algae
5	34	26 Mar	Hurihurianga Bay	R	37 16.095	176 15.435	8	Reef
5	7	23 Mar	2 Fathom Reef	R	37 15.566	176 16.119	10	Reef/mixed algae
5	8	23 Mar	Hurihurianga Bay	R	37 15.970	176 15.352	22	Reef/*Ecklonia*/sand
6	23	25 Mar	East The Queen	R	37 16.045	176 16.445	16	Reef/*Ecklonia*
6	3	22 Mar	The Queen	R	37 15.958	176 16.395	29	Reef/mixed algae
6	36	26 Mar	South The Queen	R	37 16.122	176 16.484	5	Reef
6	4	22 Mar	East Turanganui Bay	R	37 16.359	176 16.755	12	Reef/mixed algae
6	9	23 Mar	Wharenui Point	R	37 16.121	176 16.765	29	Reef/*Ecklonia*
7	10	23 Mar	East reserve boundary	NR	37 16.428	176 16.931	26	Cobble/*Ecklonia*
7	11	23 Mar	Motuoneone Island	NR	37 16.775	176 16.763	26	Sand
7	12	23 Mar	North Motuoneone Island	NR	37 16.632	176 16.633	19	Reef/*Ecklonia*/sand
7	6	23 Mar	Taumo Point	NR	37 16.941	176 16.745	27	Sand
8	13	24 Mar	Te Horo	NR	37 17.867	176 16.478	18	Sand off reef
8	21	25 Mar	SE Te Horo	NR	37 17.716	176 16.459	16	Boulders/sand
8	22	25 Mar	North Te Roto Point	NR	37 17.248	176 16.542	11	Reef/mixed algae
8	5	23 Mar	North Te Roto Point	NR	37 17.321	176 16.677	20	Shell/sand
9	1	22 Mar	South Crown Tuhua Reef	NR	37 18.461	176 17.246	10.5	Reef/*Ecklonia*
9	2	22 Mar	North Crown Tuhua Reef	NR	37 18.259	176 17.118	30	Sand some algae

* Reserve (R) or no reserve (NR).

Appendix 2

COUNT DATA FROM BAITED UNDERWATER VIDEO SAMPLING AT MAYOR ISLAND (TUHUA), MARCH 2004

AREA	STATION	DATE (2004)	SITE	TOTAL SNAPPER	LEGAL SNAPPER	BLUE COD	SCARLET WRASSE	DEMOSIELLES	GREEN WRASSE	YELLOW MORAY	SANDAGER'S WRASSE	SPOTTY	LEATHERJACKET	COMBFISH	EAGLE RAY	PORAE	PIGFISH	JACK MACKERAL	GOATFISH	HIWIHIWI	BANDED WRASSE	GREY MORAY	BUTTERFLY PERCH	CRIMSON CLEANER	SINGLE SPOT DEMOISELLE	TARAKIHI	YELLOW BANDED PERCH	JOHN DORY	KINGFISH	NORTHERN SCORPIONFISH	SWEEP	BLUE MAOMAO	SHORT-TAILED RAY	TREVALLY	BLACK ANGELFISH	SPECKLED MORAY	ORANGE WRASSE
1A	26	25 Mar	Awatukoro Point	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	30	25 Mar	Moewai Bay	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	31	26 Mar	Centre NW Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	20	24 Mar	Herbies hole	7	5	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
2	29	25 Mar	Outside west reserve boundary	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0
2	32	26 Mar	West end of Moewai Bay	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2	37	26 Mar	NW Awatukoro Point	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	18	24 Mar	SW Maori Chief	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	19	24 Mar	Cathedral Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	25	25 Mar	SW Maori Chief Mid Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	28	25 Mar	North Cathedral Cove	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	35	26 Mar	East end Opupoto Bay	2	2	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
4	14	24 Mar	Te Ananui Cave	1	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	15	24 Mar	NW Maori Chief	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	24	25 Mar	East Maori Chief	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	27	25 Mar	Close in to Te Ananui Cave	2	2	0	1	1	0	3	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
4	33	26 Mar	East Motunaki Rock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	16	24 Mar	Between Tabletop and 2 Fathom	0	0	0	1	3	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
5	17	24 Mar	SW The Queen	3	3	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	34	26 Mar	In close Hurihurianga Bay	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	7	23 Mar	2 Fathom Reef	2	2	0	0	0	1	3	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued on next page

AREA	STATION	DATE (2004)	SITE	TOTAL SNAPPER	LEGAL SNAPPER	BLUE COD	SCARLET WRASSE	DEMOSIELLES	GREEN WRASSE	YELLOW MORAY	SANDAGER'S WRASSE	SPOTTY	LEATHERJACKET	COMBFISH	EAGLE RAY	PORAE	PIGFISH	JACK MACKERAL	GOATFISH	HIWIHIWI	BANDED WRASSE	GREY MORAY	BUTTERFLY PERCH	CRIMSON CLEANER	SINGLE SPOT DEMOISELLE	TARAKIHI	YELLOW BANDED PERCH	JOHN DORY	KINGFISH	NORTHERN SCORPIONFISH	SWEEP	BLUE MAOMAO	SHORT-TAILED RAY	TREVALLY	BLACK ANGELFISH	SPECKLED MORAY	ORANGE WRASSE
5	8	23 Mar	Hurihurianga Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	23	25 Mar	East The Queen	0	0	0	2	0	0	4	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	3	22 Mar	The Queen	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	36	26 Mar	South The Queen	1	1	0	0	4	0	2	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	1	0
6	4	22 Mar	East Turanganui Bay	1	1	0	0	1	0	4	1	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	9	23 Mar	Wharenui Point	0	0	0	1	0	0	1	0	0	1	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	10	23 Mar	Right of east reserve boundary	0	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	11	23 Mar	Motuoneone Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	12	23 Mar	North Motuoneone Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	6	23 Mar	Taumo Point	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	13	24 Mar	Te Horo	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	21	25 Mar	SE Te Horo	0	0	0	2	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	22	25 Mar	North Te Roto Point	0	0	0	2	3	0	2	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
8	5	23 Mar	North Te Roto Point	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	22 Mar	South Crown Tuhua Reef	0	0	0	2	1	1	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	2	22 Mar	North Crown Tuhua Reef	0	0	1	0	32	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3

REGIONAL COMPARISON OF BAITED UNDERWATER VIDEO SURVEY DATA

Data are the mean number of each fish species per baited underwater video (BUV) deployment from surveys at the Poor Knights Islands Marine Reserve in 1998 and 2002 (Denny et al. 2003), the Mokohinau Islands in 2002 (Denny et al. 2003), reserve (R) and non-reserve (NR) sites at Hahei in 2003 (Taylor et al 2003b), and reserve (R) and non-reserve (West and East) sites on Mayor Island (Tuhua) in 2004 (this study). For each location, data are averaged across general areas identified in each study, although data for Hahei are averaged across all reserve and non-reserve sites, and Tuhua sites are grouped into West (Areas 1–2), Reserve (Areas 3–6) and East (Areas 7–9).

	POOR KNIGHTS								MOKOHINAU			HAHEI		TUHUA		
	SPRING 1998				AUTUMN 2002				AUTUMN 2002			AUTUMN 2002		AUTUMN 2004		
SPECIES	CENTRE	NORTH	SOUTH	WEST	CENTRE	NORTH	SOUTH	WEST	BURGESS	FANAL	TRIG	R	NR	R	WEST	EAST
Banded wrasse	0.00	0.10	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.14	0.10
Blue cod	0.00	0.10	0.00	0.00	0.13	0.00	0.00	0.00	0.13	0.20	0.00	0.00	0.47	0.00	0.00	0.10
Carpet shark	0.00	0.60	0.00	0.00	0.38	0.56	0.60	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Combfish	0.00	0.10	0.00	0.00	0.13	0.11	0.00	0.00	0.13	0.20	0.00	0.00	0.00	0.00	0.00	0.10
Conger eel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00
Crimson cleanerfish	0.25	0.60	0.29	0.00	0.13	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Dwarf scorpionfish	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
Eagle Ray	0.00	0.00	0.00	0.20	0.13	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.10
Goatfish	0.13	0.10	0.29	0.80	0.25	0.00	0.00	0.22	0.13	0.30	0.78	0.00	0.00	0.10	0.29	0.20
Green wrasse	0.13	0.10	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.10	0.00	0.10
Grey moray	2.38	1.60	3.00	0.20	0.63	1.22	1.00	0.56	0.25	0.20	0.00	0.00	0.00	0.25	0.14	0.10
Gurnard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.07	0.00	0.00	0.00
Half-banded perch	0.63	0.90	0.43	0.00	0.38	0.56	0.60	0.11	0.38	0.20	0.33	0.00	0.00	0.05	0.29	0.00
Hiwihiwi	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.14	0.10
John dory	0.00	0.10	0.00	0.00	0.00	0.11	0.00	0.11	0.13	0.10	0.00	0.00	0.20	0.00	0.14	0.00
Leatherjacket	0.88	0.60	0.29	0.20	0.25	0.44	0.40	0.11	1.38	1.30	0.89	0.13	0.33	0.15	0.14	0.50
Mottled moray	0.25	0.20	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.05	0.00	0.00
Northern scorpionfish	0.88	0.90	0.86	0.40	1.38	1.67	1.20	0.78	0.13	0.50	0.33	0.00	0.00	0.00	0.00	0.10
Orange wrasse	0.25	0.8	0.57	0.00	1.25	1.56	1.80	0.44	0.00	0.10	0.00	0.00	0.00	0.00	0.14	0.00
Pigfish	2.50	3.70	2.71	1.60	3.75	2.33	1.80	2.44	2.38	2.70	2.33	0.00	0.07	0.45	0.14	0.20
Porae	0.25	0.30	0.43	0.00	0.50	0.44	0.80	0.56	0.25	0.40	1.11	0.00	0.00	0.15	0.00	0.00
Red moki	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sandager's wrasse	0.50	0.30	1.57	0.40	0.63	0.78	0.40	0.89	0.00	0.10	0.56	0.00	0.00	0.05	0.86	0.40
Scarlet wrasse	2.13	2.30	3.00	0.00	0.38	1.00	0.20	0.11	1.00	1.70	0.89	0.00	0.00	0.45	0.00	0.70
Short-tail ray	0.00	0.10	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Snapper	0.88	0.70	2.57	2.00	8.00	7.78	5.20	15.67	3.75	3.20	0.67	1.67	6.13	0.65	1.00	0.00
Spotty	0.00	0.00	0.29	0.20	0.00	0.33	0.00	0.00	0.00	0.10	0.56	0.13	0.13	0.10	0.00	0.10
Tarakihi	0.63	0.20	0.00	2.00	0.25	0.00	0.00	0.11	0.13	0.20	0.00	0.00	0.00	0.05	0.00	0.00
Yellow moray	2.00	2.50	2.29	0.00	1.00	1.67	2.20	0.78	0.38	0.40	0.44	0.00	0.07	1.25	0.14	0.50