Recovery of targeted reef fish at Tuhua Marine Reserve—monitoring and constraints

Kim Young, Sam Ferreira, Alan Jones, and Keith Gregor

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Recovery of targeted reef fish at Tuhua Marine Reserve—monitoring and constraints

Kim Young[1], Sam Ferreira[2], Alan Jones[3], and Keith Gregor[4]

[1] Bay of Plenty Conservancy, Department of Conservation, PO Box 1146, Rotorua 3040, New Zealand (corresponding author)

[2] Department of Statistics, University of Auckland, Auckland, New Zealand

[3] Tauranga Area Office, Department of Conservation, PO Box 9003, Greerton, Tauranga 3142, New Zealand

[4] Marine Studies Department, Bay of Plenty Polytechnic, Tauranga, New Zealand

ABSTRACT

In north-eastern New Zealand, reef fish species often respond differently to full protection in no-take marine reserves than to partial protection in fished reserves. Managers need good monitoring programs to help them understand the contribution of such reserves to the protection of marine resources. Tuhua Marine Reserve, at Mayor Island (Tuhua), Bay of Plenty, New Zealand, has a no-take zone and a zone that allows recreational fishing. Monitoring data, collected over a twelve-year period by underwater visual census, was used to compare changes in reef fish numbers between these two zones. No evidence of a recovery in reef fish populations in either zone was found. The retrospective grouping of data by management zones and the use of a revised sampling design suggests that the fully protected no-take zone contained more targeted reef fishes than the corresponding recreationally fished zone. This probably reflects habitat differences between the zones, since recovery (in terms of reef fish population sizes) did not occur. If a lack of a recovery is real, it is most likely caused by fishing pressure (legal and illegal) at the edges and within both zones. It is also possible that the original sampling design failed to measure changes. Our revised design of the monitoring program may yet confirm the recovery of reef fish in the Reserve.

Keywords: marine reserves, monitoring, reef fish, full protection, partial protection, edge effects, compliance, Tuhua Marine Reserve, Mayor Island (Tuhua), Bay of Plenty, New Zealand

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1. Introduction

The establishment of no-take marine reserves in New Zealand is controversial. Competing demands on marine resources result in public responses to these proposals that range from support to hostility (e.g. Taylor & Buckenham 2003). As a result, such proposals now consider a range of management options to protect the marine environment (see Taylor & Buckenham 2003 and Bentley et al. 2004a), and monitoring programmes which measure the success of reserves against their goals are under scrutiny (see Halpern et al. 2004). How well do the different options achieve the common conservation goals for marine protection in New Zealand? Can a more society-friendly method for the protection of the marine resources result in the same outcomes than those of the no-take marine reserves? How can these outcomes be confidently measured and reported? Every conservation manager has asked these questions at some stage. We focused on the first and third question.

The marine area within one nautical mile of Mayor Island (Tuhua), Bay of Plenty, New Zealand, and the fish that live there are protected by two fish management options: a no-take zone (NT zone) and a zone that allows some recreational fishing (RF zone) (Jones & Garrick 1991) (Fig. 1).

Our first question of interest is: How well do different options protect the marine environment? Both the NT and RF zones of Tuhua Marine Reserve are examples of common tools used in the protection of marine ecosystems (see McCrone 2001), however, targeted reef fish species have responded variably to the diverse levels of marine protection established elsewhere in New Zealand. For instance, targeted reef fish populations in areas that offer full protection (like the Tuhua NT zone), increased in numbers of individuals (McCormick & Choat 1987, Denny et al. 2003, Willis et al. 2003). Species that live on the reefs of partially restricted areas responded very little to such protection (Denny et al. 2003; Denny & Babcock 2004). We therefore expected that the populations of targeted reef fish species at Tuhua Marine Reserve, would exhibit signs of recovery from fishing in the NT zone, whereas those in the RF zone might not.

Indirect ecosystem recovery after a disturbance may be influenced by:

- The species pool available for colonization (Belyea & Lancaster 1999)
- The available resources at a particular time may not match the colonizing species' traits (McCook 1994)
- The existing species may inhibit colonization by new species (Lockwood & Pimm 1999)

Such mechanisms could affect the timing and sequence of recovery because an increase in the abundance of some species may trigger the decline in the abundance of others and vice versa (Rees et al. 2001). Algal species responded to changes in urchin abundance at the Leigh Marine Reserve (Babcock et al. 1999; Shears & Babcock 2002), while reef fish species reacted to changes in levels of predation (Cole 2003b). Even so, we should expect that most targeted fish species should increase in numbers and do so faster in the NT zone than in the RF zone.

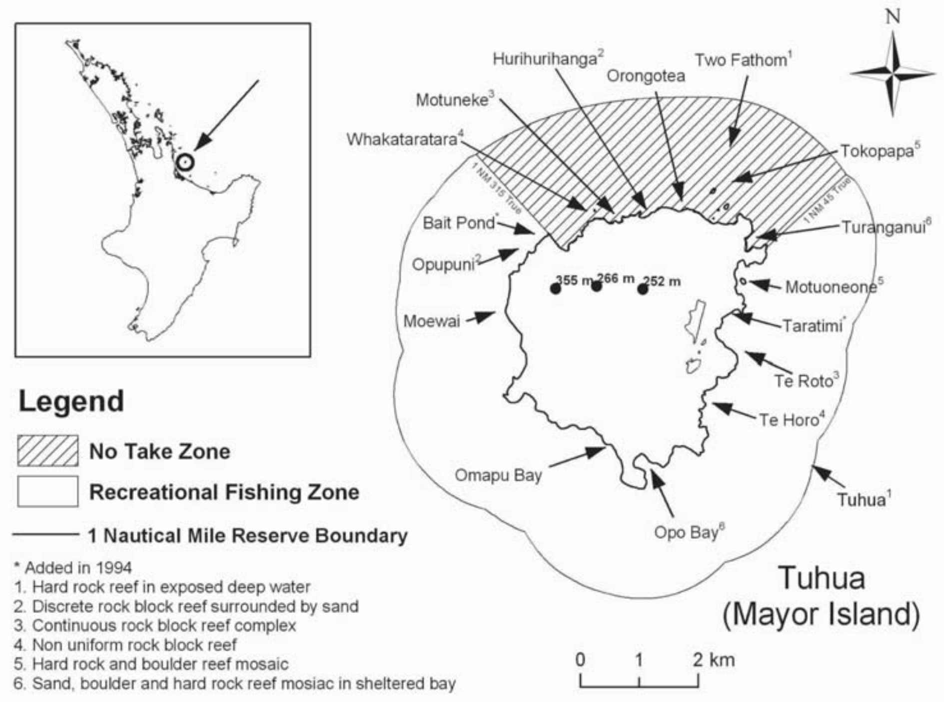


Figure 1. Tuhua Marine Reserve showing no-take (NT) and recreational fishing (RF) management zones and underwater visual census sampling locations from 1993–2002, and for 2004 and 2005.

Our second question of interest is: How do we measure the changes in fish communities effectively? Two common issues plague the monitoring of marine reserves. Firstly, most marine reserves are small. Cole (1994) and Willis et al. (2000) showed that snapper (*Pagrus auratus*) abundance declined as the distance from the centre of the Leigh Marine Reserve increased. In short, if a reserve is too small, then fishing at its edges depletes numbers within the reserve (Cole 2003a) with limited benefits accrued and measured. We therefore expected higher abundances of the popular targeted fish species near the centre of the NT zone.

The sampling designs of monitoring programmes will often change, for a variety of reasons (see Cole 2003a). The monitoring program at the Tuhua Marine Reserve is no exception. The habitat-specific, non-random, paired-sampling design used from 1993 to 2002 made it hard to make direct comparisons between the NT and the RF zones. Therefore, during 2004 and 2005 we changed the programme to a random sampling design which enabled easier comparisons between these zones.

Given these constraints, our study is necessarily complex. We ask a number of questions about fish numbers: Did abundance of targeted reef fish increase as a result of reduced fishing pressure? Is there a relationship between abundance of targeted reef fish species and distance from the core of the NT zone? Does the change in the sampling design yield different results between the two management zones? And if so, what are the ramifications for the future monitoring of the reserve?

2. Tuhua Marine Reserve

Tuhua Marine Reserve was established at Mayor Island (Tuhua) in the Bay of Plenty in 1993 to protect sub-tropical reef fish assemblages representative of the southern most tip of the East Auckland Current (Jones & Garrick 1991; Stanton et al. 1997). Before 1993, reef fish species in the area were intensively fished both recreationally and commercially. Fishers specifically targeted several species including snapper (*Pagrus auratus*), blue maomao (*Scorpis violaceus*), blue moki (*Latridopsis ciliaris*), jack mackerel (*Trachurus novaezelandiae*), koheru (*Decapterus koheru*), leatherjacket (*Parika scaber*), pink maomao (*Caprodon longimanus*), porae (*Nemadactylus douglasii*), and red moki (*Cheilodactylus spectabilis*). A dramatic decline was observed in reef fish numbers. Consequently, a no-take (NT) zone within one nautical mile of the shore (totalling 1057 ha) was proposed and gazetted (Jones & Garrick 1991). The reserve also includes a non-commercial fishing or recreational fishing zone (RF zone) along the remaining periphery of the island, within one nautical mile of the shoreline (Jones & Garrick 1991). Within this RF zone line fishing is permitted.

3. Monitoring

3.1 SAMPLING DESIGN

Since the establishment of the reserve our monitoring programme used two sampling designs (Table 1). The original design (1993–2003) comprised six sites within the NT zone and six corresponding sites in the RF zone. These sites represented broad habitat types in a non-random way. Reef structure and substrate type determined how we selected habitats to sample (Table 2, Fig. 1). We surveyed from three (1993–1995) to 50 (1996–2002) underwater visual transects at each of the sites. A transect was 50 m × 10 m, giving a total area of 500 m^2. No monitoring was undertaken in 2001 because of other management priorities on Mayor Island (Tuhua). In 2003 we investigated observer bias and sampled 15 additional transects at five existing locations. Because only five locations were surveyed, we did not include the 2003 data in our overall analysis. Thus from 1993 to 2002 our dataset comprised nine years of monitoring data.

In 2004 the sampling design changed. Sampling specific habitats was abandoned within localities, and instead the study area was stratified by management zone. We surveyed 93 randomly selected transects throughout both zones (Fig. 1). This change allowed direct comparison of reef fish populations between management zones. Annual surveys took from two weeks to one month during either late March or early April.

TABLE 1. SUMMARY OF UNDERWATER VISUAL CENSUS MONITORING DATA COLLECTION AND USE FROM 1993 TO 2005.

YEAR	NO. OF TRANSECTS IN NO-TAKE ZONE	NO. OF TRANSECTS IN RECREATIONALLY FISHED ZONE	SAMPLING DESIGN	INCLUDED IN POPULATION GROWTH RATE ANALYSIS	INCLUDED IN COMPARISON OF RELATIVE ABUNDANCE BETWEEN ZONES
1993	66	74	Non-random paired	Yes	Yes
1994	123	110	Non-random paired	Yes	Yes
1995	98	157	Non-random paired	Yes	Yes
1996	229	315	Non-random paired	Yes	Yes
1997	227	312	Non-random paired	Yes	Yes
1998	235	322	Non-random paired	Yes	Yes
1999	238	292	Non-random paired	Yes	Yes
2000	236	319	Non-random paired	Yes	Yes
2001	No monitoring undertaken because of other Mayor Island (Tuhua) management priorities				
2002	192	284	Non-random paired	Yes	Yes
2003	45	30	Selected sites for diver bias trials	No	No
2004	41	52	Randomly selected	No	Yes
2005	40	53	Randomly selected	No	Yes

TABLE 2. PAIRED SITES SELECTED* FOR NO-TAKE (NT) AND RECREATIONAL FISHING (RF) ZONES WITHIN THE TUHUA MARINE RESERVE.

NO-TAKE ZONE (NT)	RECREATIONAL FISHING ZONE (RF)	HABITAT NO.†	BROAD HABITAT TYPE
Two Fathom	Tuhua	1	Hard rock reef in deep water
Hurihurihangi	Opupuni	2	Small, discrete rock block reef surrounded by sand
Motuneke	Te Roto	3	Continuous rock block reef complex
Whakataratara	Te Horo	4	Non uniform rock block reef
Tokopapa	Motuoneone	5	Hard rock and boulder reef mosaic
Turanganui	Opo Bay	6	Sand, boulder and hard rock reef mosaic situated in sheltered bay

* Site selection based on broad habitat types defined by reef structure and substrate type.

† As used in Table 6.

3.2 UNDERWATER VISUAL CENSUS

Underwater visual censusing (UVC) was used to record the relative abundance (number of fish per transect) and size class of reef fish species living in the reserve. This is an efficient non-destructive survey method with well-understood limitations and biases (Denny et al. 2003).

The method uses transects to survey fish. Each transect began from a support boat and radiated away from it. We used a randomly assigned compass bearing for each diver pair to follow. From 1993–2002, each transect was a replicate for a site. In 2004 and 2005, each transect was a replicate for a management zone. For the latter, divers recorded all fish seen and also noted substrate and habitat features.

TABLE 3. SOURCES OF VARIATION IN COUNTS OF SELECTED REEF FISH SPECIES AT 15 SITES SAMPLED IN TUHUA MARINE RESERVE DURING 2002 AND 2003.

Data used was from underwater visual transects and a restricted maximum likelihood analyses to identify the major source of variance in our datasets. The values represent the variance associated with location, students and replicates. In nearly all the cases replicates were the key source of variance.

SPECIES	2002 VARIANCE COMPONENT			2003 VARIANCE COMPONENT		
	LOCATION	STUDENTS	REPLICATES	LOCATION	STUDENTS	REPLICATES
Banded wrasse	0.54	0.05	0.02	0.00	0.16	2.06
Black angelfish	0.00	1.51	64.26	0.04	0.00	1.78
Blue moki	66.85	208.19	1409.46	0.00	0.01	0.21
Butterfish	0.00	0.00	0.27	0.01	0.01	0.42
Butterfly perch	0.03	0.12	16.13	0.00	0.00	0.01
Goatfish	0.48	0.10	1.28	0.00	0.00	0.02
Hiwihiwi	0.00	0.00	0.08	0.00	0.00	0.01
Leatherjacket	0.00	1.75	280.47	3771.60	0.00	10136.00
Marblefish	0.27	1.63	24.90	0.83	0.11	4.10
Red moki	0.04	0.28	0.39	0.00	0.00	0.52
Sandager's wrasse	0.06	0.67	0.74	3.20	0.00	13.09
Scarlet wrasse	0.10	0.36	11.01	0.00	0.00	0.14
Snapper	0.00	0.08	17.59	0.01	0.00	0.12
Spotty	0.22	0.71	0.48	0.00	0.09	0.90
Tarakihi	–	–	–	0.00	0.00	0.07
Two-spot demoiselle	52.94	297.12	3371.12	3771.60	0.00	10136.00

TABLE 4. FISH SPECIES USUALLY TARGETED BY FISHERS AT THE TUHUA MARINE RESERVE.

COMMON NAME	SCIENTIFIC NAME
Blue maomao	*Scorpis violaceus*
Blue moki	*Latridopsis ciliaris*
Jack mackerel	*Trachurus novaezelandiae*
Koheru	*Decapterus koheru*
Leatherjacket	*Parika scaber*
Pink maomao	*Caprodon longimanus*
Porae	*Nemadactylus douglasii*
Red moki	*Cheilodactylus spectabilis*
Snapper	*Pagrus auratus*

Marine studies students from the Bay of Plenty Polytechnic did the surveys. To test for observer bias in gathering data, we used a restricted maximum likelihood analyses (Russell Cole, NIWA[1] pers. comm.). We examined data from 2002 and 2003 to determine if the variation in counts of each species among students was larger than that among sites or replicates. The variance among replicates was always much larger than that between locations or diver pairs for both of the years we tested (Table 3). We concluded that observer bias is negligibly small, and did not correct for it in our remaining analyses.

[1] National Institute of Water and Atmospheric Research, PO Box 893, Nelson, New Zealand.

4. Analyses

4.1 RELATIVE ABUNDANCE

An independent samples t-test (Sokal & Rohlf 1995) was used to determine whether the NT zone held higher numbers of reef fish. We compared the relative abundance of snapper (*Pagrus auratus*), red moki (*Cheilodactylus spectabilis*), the total number of targeted fish (Table 4), and the total number of all fish between the zones. Our analyses focused on each pair of sites in a habitat for the years from 1993 to 2002, and between the NT and RF zones for 2004 and 2005. We chose snapper and red moki as focal species because they may also represent the response of previously targeted reef fish.

Because our new monitoring design was only in place for two years, we checked these results against the variability of results from the previous years. To do this we needed to compare directly between the two management zones as opposed to habitat by habitat. We therefore discarded the habitat information and pooled the data collected from 1993–2002 into management zones. The percentage of times that the numbers of snapper, red moki, total number of targeted fish, and total number of fish were higher in the NT zone was then calculated.

4.2 POPULATION GROWTH

For the period from 1993 to 2002 we calculated the habitat-specific population growth rates for each species within the reserve (see Table 2 for habitat descriptions). We also calculated population growth rates for each of the management zones in the reserve as if we had a completely random design. Here we once again pooled the data according to management zone and regressed $\ln(N_{t+1})$ against time t. N_t was the number of individuals recorded for species i at time t. We concluded that numbers were on the increase if the slope was greater than zero. This slope represents an estimate of exponential growth (Caughley 1977).

4.3 EDGE EFFECTS

For each survey site we calculated the distance (km) from the mid point of the NT zone and regressed the total number of targeted fish against distance for each year. We concluded that distance influences fish communities if the slope was different from zero.

5. Results

5.1 RELATIVE ABUNDANCE

For most of the time from 1993 to 2002 we noted more snapper, red moki, and total number of fish in the NT zone habitats (Table 5). Snapper showed this trend most prominently and were more abundant in the NT zone for 78.26% of the comparisons. In spite of this, the total number of fish was higher in only 42.31% of the cases. Note that these differences were statistically significant for a smaller proportion of the time. For instance, snapper were only statistically more abundant in the NT zone 41.30% of the time (Table 5).

When we pooled data for each management zone, we found that the differences were statistically significant for a much higher proportion of the time. Snapper were statistically more abundant in the NT zone 87.50% of the time (Table 5) and red moki 77.78% of the time. Total number of targeted fish and all fish were higher in the NT zone than the RF zone only 20% of the time. When management zones were directly compared using the 2004 and 2005 data, we found that all four variables were consistently higher in the NT zone than the RF zone for both years (Fig. 2). In 2004 snapper were 12 times more abundant in the NT zone than the RF zone (t_{43} = 2.749, p = 0.009) and 6.25 times more abundant in 2005 (t_{53} = 2.815, p = 0.007). Red moki were 4.6 times more abundant in the NT zone than the RF zone in 2004 (t_{50} = 2.350, p = 0.023) and 8.63 times more abundant in 2005 (t_{43} = 2.899, p = 0.006). Targeted and total numbers of fish were between 2–3 times more abundant in the NT zone than the RF zone in both 2004 and 2005. These differences were only statistically significant in 2004 (targeted: t_{60}= 2.008, p = 0.049, total number of fish: t_{59} = 2.445, p = 0.018).

TABLE 5. THE PERCENTAGE OF TIME THAT WE NOTED MORE SNAPPER, RED MOKI, AS WELL AS HIGHER TOTAL NUMBERS OF FISH AND TARGETED FISH IN THE NO-TAKE ZONE (NT) ZONE THAN OTHER ZONES.*

	SNAPPER	RED MOKI	TARGETED FISH	TOTAL NO. OF FISH
Between corresponding habitats†				
Percentage of times that the mean relative abundance of the NT zone > mean relative abundance of the RF zone	78.26	62.26	66.04	42.31
Percentage of times when the differences above are significant ($p < 0.05$)	41.30	33.96	11.32	21.15
By management zone‡				
Percentage of times that the mean relative abundance of the NT zone > mean relative abundance of the RF zone	88.89	100.00	77.78	55.56
Percentage of times when the differences above are significant ($p < 0.05$)	87.50	77.78	14.29	20.00

* Data are from underwater visual census undertaken annually from six sites within the NT zone and six sites in the recreational fishing zone from 1993 to 2002.

† Between NT zone and a corresponding habitat of the recreationally fishing zone (RF) zone.

‡ Between the NT and RF zones when data where combined according to management zone.

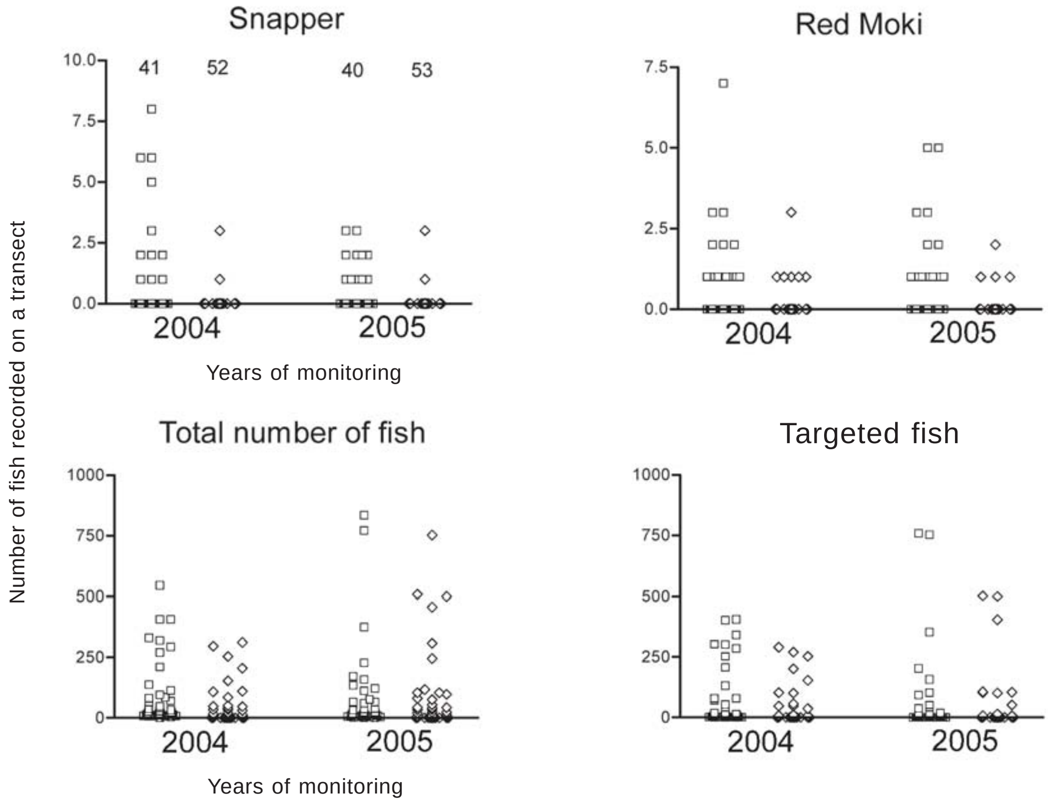
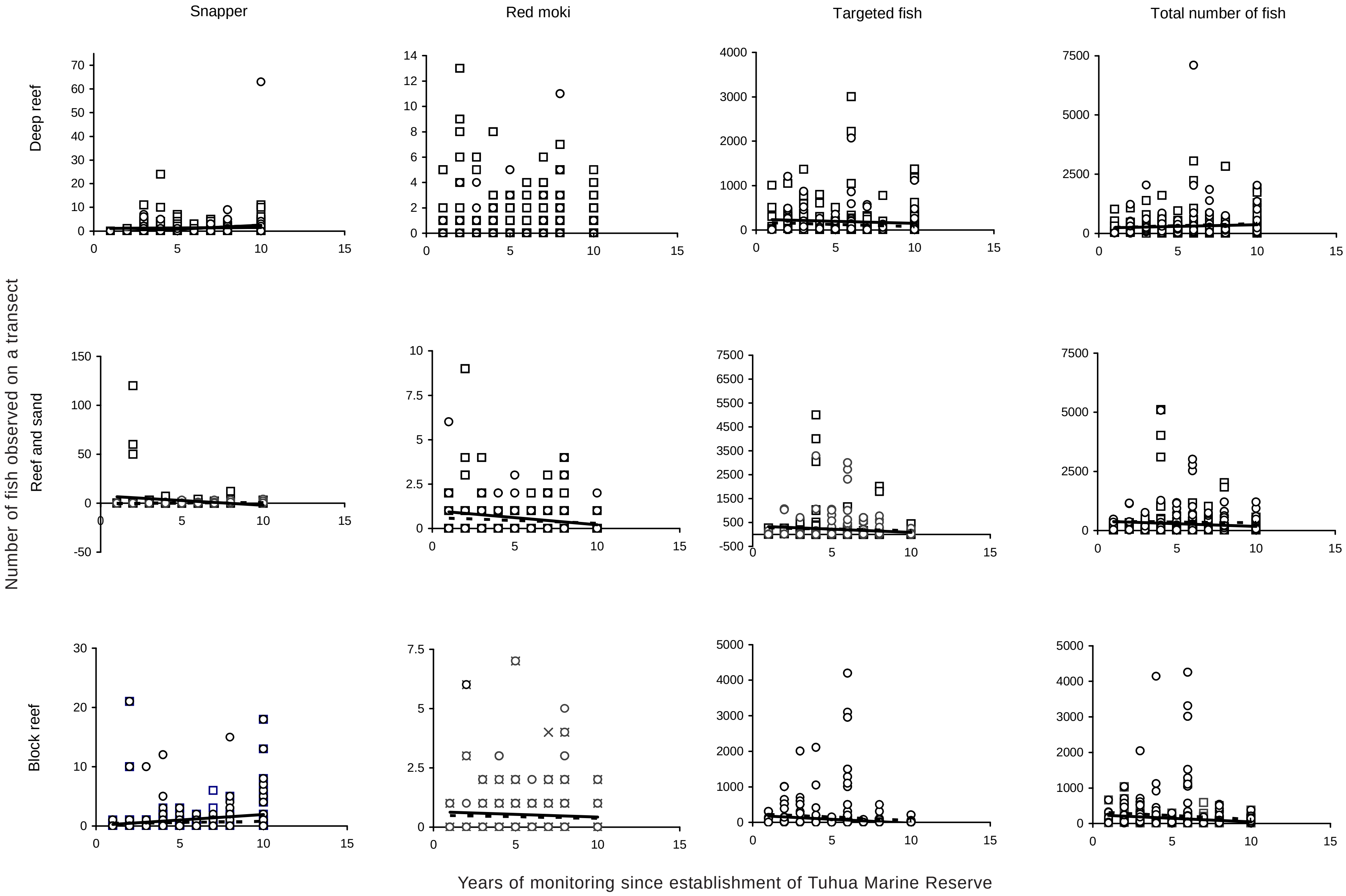


Figure 2. Comparison of four variables noted between the no-take zone (NT) (open squares) and recreationally fishing zone (RF) (open diamonds) in Tuhua Marine Reserve. Data are from underwater visual censuses undertaken at 41 sites in the NT zone and 54 sites in the RF zone in 2004 and 2005. For 2004, 41 and 52 sites were sampled in the NT and RF zones respectively; for 2005, 40 and 53 sites were sampled.

5.2 CHANGE IN POPULATION SIZES 1993–2002

Snapper numbers increased in five of the habitats in the NT zone and three in the RF zone. However, only two of these in the NT zone and RF-zone had growth rates statistically different from zero. Moreover, the relationships between relative abundance and time were weak (Fig. 3, Table 6). Red moki populations declined in all but one habitat in the NT zone, but grew in five habitats in the RF zone. While two of the declines were significant, as for snapper, time explained little of the variance in relative abundance (Fig. 3, Table 6). Total number of targeted fish increased in three habitats in the NT zone and five habitats in the RF zone. Some changes were significant, but again our models explained little of the variance. Similarly, total number of fish both increased and decreased across habitats and did so in a statistically significant way for some habitats in both zones (Fig. 3, Table 6). Our results suggest that these population growth rates that were significant may be spurious, as the models supporting them generally have little explanatory power (Table 6).

The non-random habitat design might constrain our ability to measure trends, however, when we retrospectively combined data according to management zones we found limited evidence for population growth in either management zone (Fig. 4). The results were similar to that of the habitat-specific analyses. Snapper increased in a statistically significant manner in both zones, although


Snapper
Red moki
Targeted fish
Total number of fish
Deep reef
Reef and sand
Block reef
Number of fish observed on a transect
Years of monitoring since establishment of Tuhua Marine Reserve

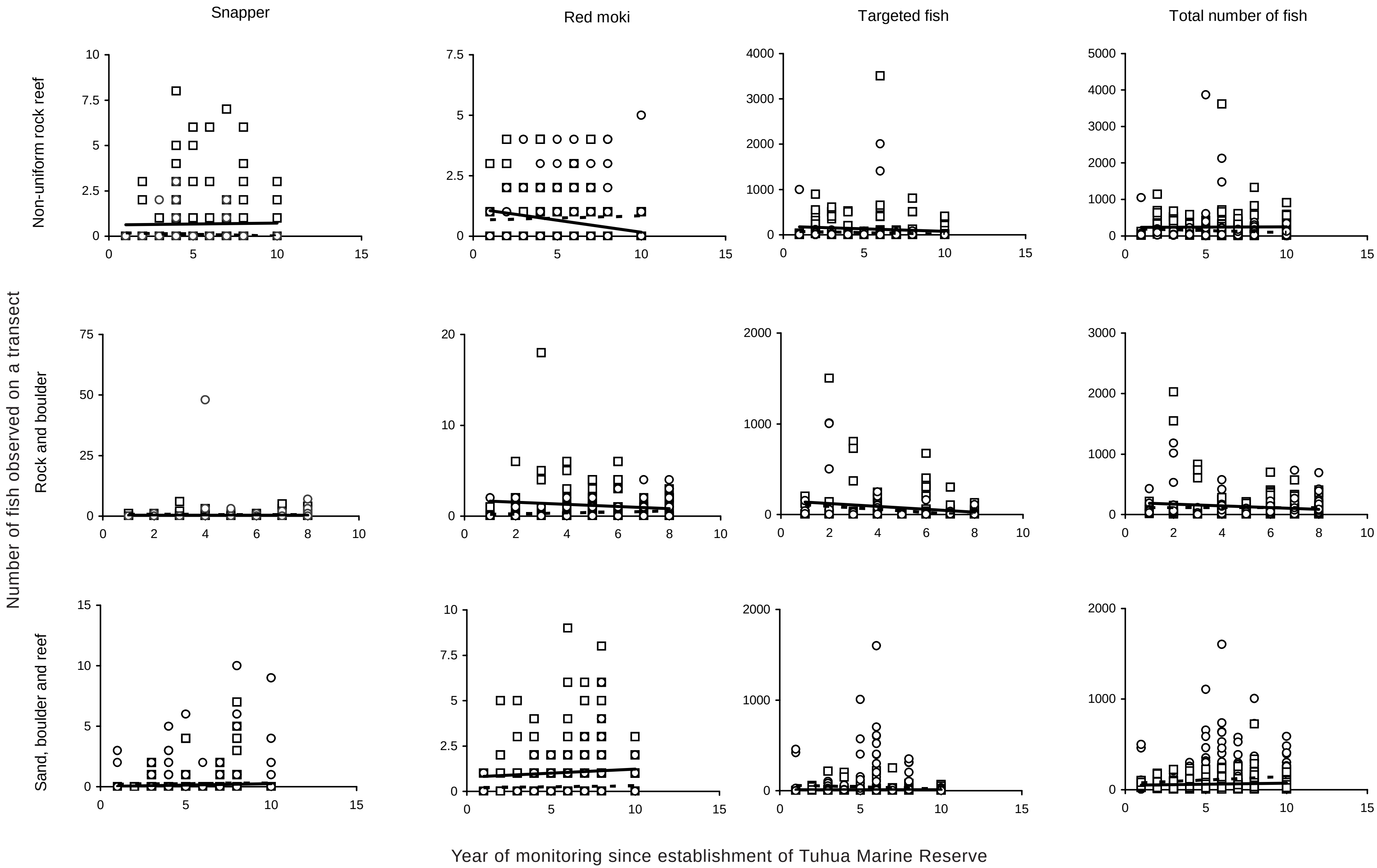


Figure 3. The abundance of snapper and red moki, as well as the number of targeted and all fish recorded in six habitat types during the initial 10 years since the Tuhua Marine Reserve was established. The no-take (NT = open squares) and recreational fishing (RF = open circles) zones are illustrated separately. The trends defined by an exponential model for the NT and RF zones are shown by the solid and broken lines.

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