ATIU & TAKUTEA NEARSHORE INVERTEBRATE & FINFISH ASSESSMENT

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1. PROJECT BACKGROUND

Biodiversity of coastal and marine ecosystems in the Cook Islands is critical to the health and well-being of local communities, often for the provision of natural resources, food, shelter, medicine and cultural traditions. Island geography ranges from the high island of Rarotonga and raised coral atolls of Atiu, Mauke, Mangaia and Mitiaro with shallow lagoons and fringing reefs; to atolls such as Aitutaki and Manuae which are characterized by large, deep lagoons and minimal terrestrial areas encircled by coral reefs.

The use of marine resources in the Cook Islands is concentrated within the coastal zone. Over harvesting can occur and is typically limited to a few select species. This represents a critical need to first understand the biology and ecology behind these valuable resources.

Some inshore reef fisheries are in a degraded state of health due to over-fishing, poor management practices and a lack of knowledge or awareness of such issues. Compounding the need to secure biodiversity and food resources against poorly managed fisheries is the lack of opportunities to generate household income, which leads to increased dependence on subsistence fisheries that cannot be easily accommodated using either traditional or formal systems.

The South Pacific is highly vulnerable to climatic influences such as the El Niño and La Niña cycles due to the underlying geography of most Pacific Island nations. The worsening of extreme climatic events in recent years reinforces the need for a targeted approach to water, land, forest and coastal management. Available scenario modelling indicates that greenhouse gas emissions will cause a temperature rise that will adversely affect coral reefs and other coastal marine ecosystems and have significant impacts on the biodiversity. Increased seawater temperatures are likely to cause increased coral bleaching, while more extreme and frequent storm events will lead to storm surges, inundation and flooding. Bodies of freshwater in the Cook Islands are extremely limited, with no large lakes or rivers. Changes in sea temperatures and currents will likely shift the patterns of occurrence of tuna species, whales and possibly the migration patterns of sea turtles on a large scale. Climate change and disaster risks also threaten livelihoods, whether based on agriculture, fisheries, forestry, tourism or trade, and in some cases local populations living on atolls will be required to relocate due to the impacts of climate change and expected sea-level rise. It is likely that climate change and the expected increase in the frequency and intensity of weather-related events (combined with changing rainfall patterns, increased temperatures and coastal erosion) will challenge food security in the Cook Islands over the next few decades.

Effective management of coastal and marine resources is necessary to minimize natural and human-induced impacts on the environment. Management can be directed to meet specific objectives, at both national and community levels and is of the utmost importance for the conservation of protected, endangered or highly impacted species. However, the most important factor to consider is what level of management is appropriate for both the marine resources and the communities whom depend on them. In the Cook Islands, most inshore marine resources are managed through a traditional/cultural system: *Rā'ui*. *Rā'ui* is a small-scale area designated by traditional leaders in conjunction with local communities and managed with the assistance of government. Typically *rā'ui* sites are identified for the temporary protection of a particular resource (for example, trochus). Traditional leaders may request managers monitor and assess the status of the resource and inform when areas have harvestable stock.

1.1 Rationale

Overall, research and monitoring of important marine resources in the Cook Islands is limited and patchy. Efforts to monitor and manage biodiversity in the Cook Islands have made only limited progress to date. The following marine survey forms a comprehensive baseline assessment for Atiu and Takutea. The primary objective for this assessment was to:

- Identify areas of high abundance and diversity
- Assess the distribution and abundance of species of interest
- Note differences, if any, between regulated, non-regulated and *rā'ui* areas
- Compare current populations to historical records

This assessment will form a consistent, updated point for reference for future surveys and monitoring programs, as well as inform management regarding the ecological status and stocks of important marine resources. Our work focuses on coastal and inshore zones.

1.2 Atiu Enua

Atiu or *Enua manu* as it's locally known, is situated at 19° 59.659'S 158° 7.090'W. Together with Mitiaro to the northeast and Mauke to the southeast, these islands are commonly referred to as *Ngaputoru*. The *Ngaputoru* group has been dated to be around 12.3 million years old and undertook a period of tectonic uplift during the eruption of the capital island Rarotonga, approximately 185 km away (National Environment Service, 2011). The formations of these raised coral atolls or *makatea*, elevated late Pleistocene reef limestone on Atiu to its highest point of 72 m.

Atiu consists of a fringing coral reef with a total reef circumference of 22 km (National Environment Service, 2011) that encompasses the entire island with the widest reef flat area located on the southern side and *makatea* cliffs on the north-eastern side. The southern side has a limited lagoon area, with many intertidal pools that connect to narrow passages running through the reef.

There are two designated *rā'ui* on Atiu: Vai Piake and Te Vai; these are located on the western and southern sides of the island, respectively (Figure 1). As part of promoting the tourism industry, a coral garden was advertised at Te Vai *rā'ui* for visiting tourists.

The introduction of trochus (*Trochus niloticus*) to the Cook Islands began in the late 1950's, and was hailed a success because of Aitutaki's thriving populations (Passfield, 1997). As a result of this, there was an initiative to further introduce the species to the *Ngaputoru* group and also the northern group islands, Manihiki, Rakahanga and Penhryn. In May 1998 a total of 180 Trochus were airfreighted from Rarotonga to Atiu and resettled at Te Vai Rā'ui (Ponia, 2000). This introduction was to alleviate pressure from other target species such as *paua* (*Tridacna maxima*) and *ariri* (*Turbo setosus*), however, today *paua* still remains as the most favoured target species for locals and is harvested during reef gleaning excursions.

1.3 Takutea Enua

Takutea is situated at 19° 48.748'S 158° 17.287'W and lies approximately 23 km northwest of its neighbouring island Atiu. Takutea isgeologically classified as a sand cay and is surrounded with a fringing coral reef with a total reef circumference of 6 km (National Environment Service, 2011). Shallow reef flats comprise the northern, western and southern sides of the island while a steep fore reef drop-off is found on the eastern side. Due to these shallow reef flats, no natural passages and strong wave action, access onto Takutea can be difficult.

Takutea is home to significant populations of sea birds; masked boobies (*Sula dactylatra*), red-tailed tropicbirds (*Phaethon rubricauda*), frigate birds (*Frigata minor*) as well as the migratory bristle-thighed curlew (*Numenius tahitiensis*) are commonly observed (UNDP, 2016). Due to its sandy beaches, Takutea is also an important breeding site for sea turtles. Other sensitive species found on Takutea include the *paua* (*Tridacna* spp.) and the coconut crab (*Birgus latro*).

While there are no specific marine regulations surrounding Takutea, the people of Atiu regard it as a form of *rā'ui*. Under the Environment Regulations 2008, Atiu and Takutea are considered Community Conservation Areas (United Nations Development Programme, 2013). Takutea is managed under the control of landowners through the Takutea Trust. The people of Atiu ferry across and gather from the island for important functions and social events but only with the permission of the Takutea trustees. The frequencies of these visits vary from year to year.

Ponia (1998) survey of Takutea coincided with an introduction of 200 Trochus (*Trochus niloticus*) to the island (Ponia, 2000). It was part of an initiative to introduce a viable food source that could alleviate fishing pressure and overharvest of other species due to *Trochus* fast growth and reproductive rate. Some Atiuans speculate that their resources on Takutea are being harvested without permission by people from islands other than Atiu.

2. METHODOLOGY

Our Atiu epedition took place from the 21st to the 30th May 2018 with a total of ten sites surveyed. For historical comparisons, inner reef sites of Avaavaroa (Tarapaku) and Te Vai, were two that were previously surveyed by Ponia (1998). The other eight sites were added to capture a representative sample of the island (Fig. 1a).

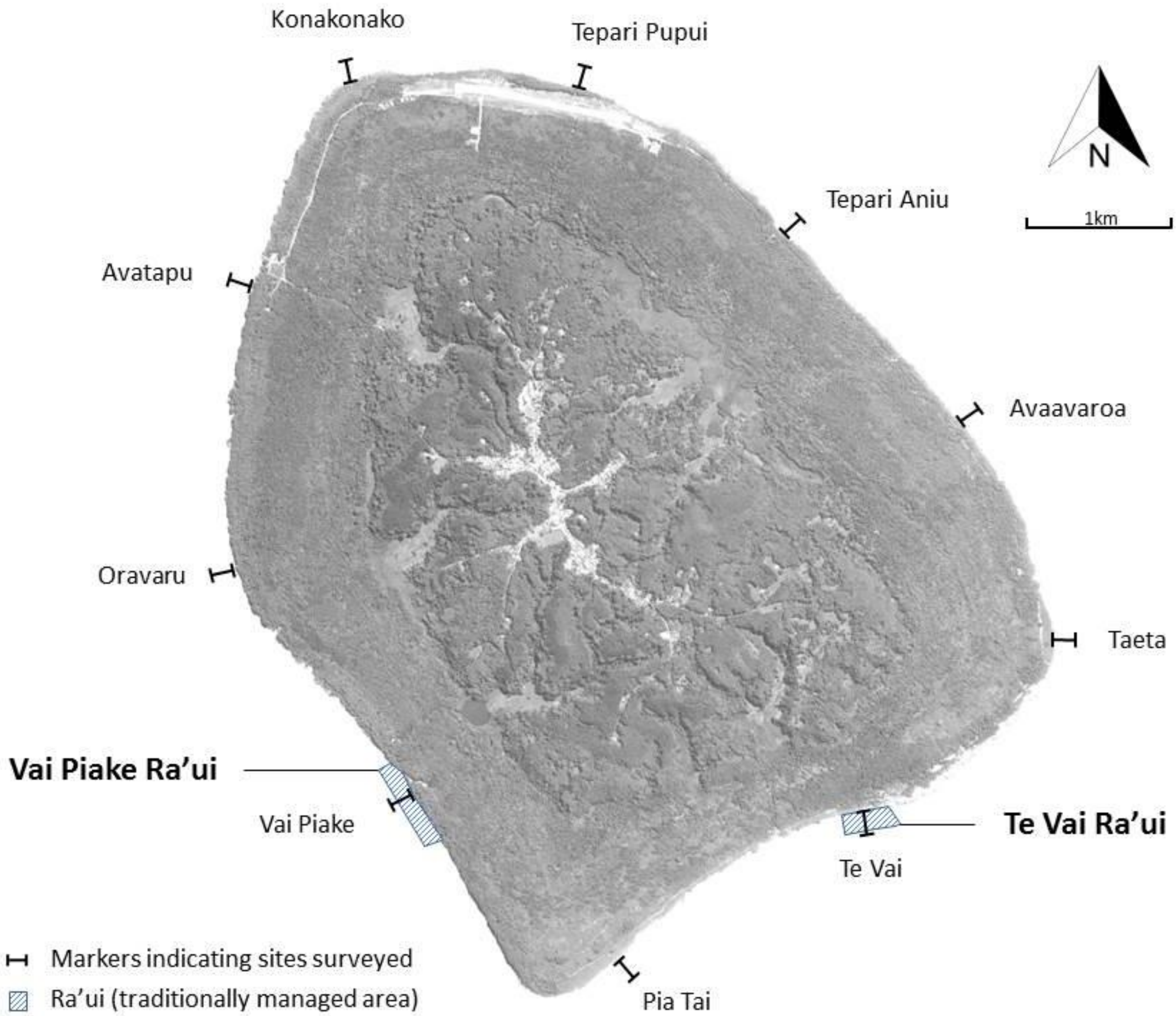


Figure 1a. Atiu survey sites and two designated *rā'ui* areas. Map source: Google DigitalGlobe.

The Takutea expedition took place on the 24th and 25th of May, 2018 with a total of four sites surveyed. For historical comparisons, Tautara, Taupoto and Aumatangi are three sites of the inner reef Ponia et al. established in 1998. Our sites were placed in the same locations with one site added at Te-Mangauri to capture a representative sample of the island (Fig 1b).

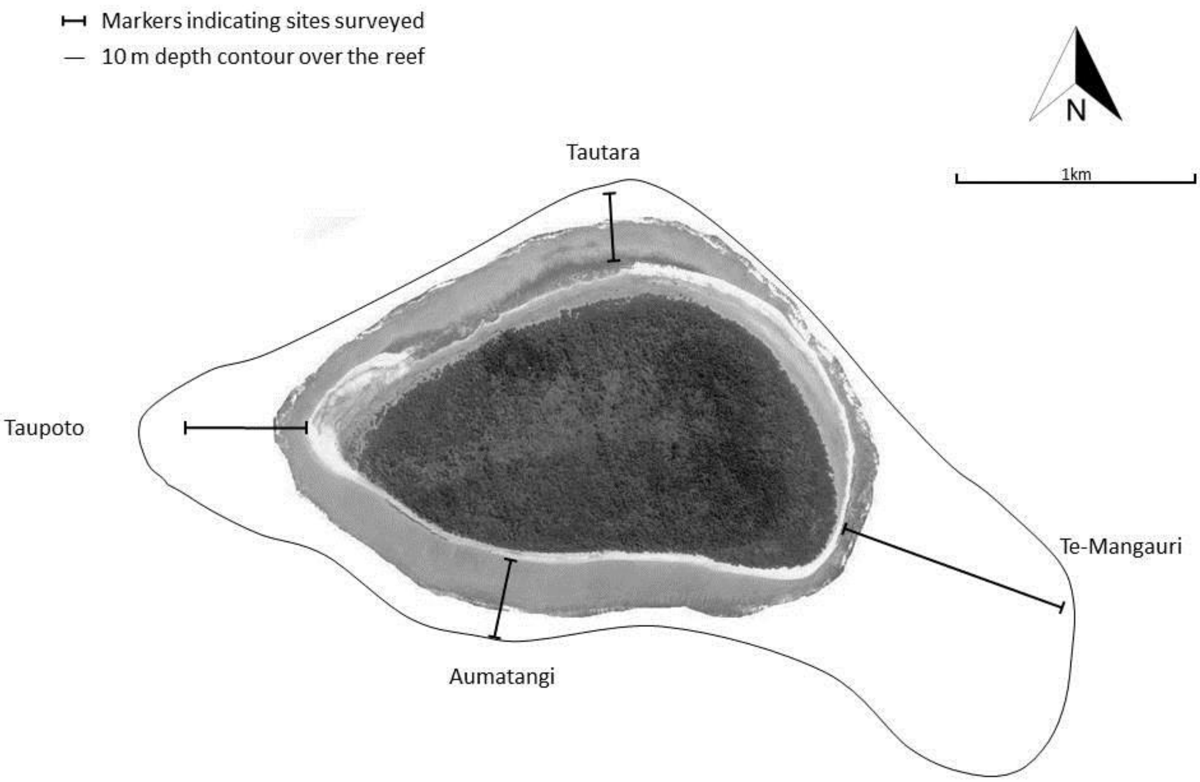


Figure 1b. Takutea survey sites. Map source: Google DigitalGlobe.

2.1 Habitat zones

Within each site, habitats were identified as inner reef benthos (RBT), reef front (RFT) and over reef (ORT). Habitats were surveyed on the inner reef by walk sampling and if required, snorkelling, whilst the over reef habitat was conducted using SCUBA.

2.1.1. Inner reef habitat

For habitats RBT and RFT located on the inner reef, invertebrates were surveyed using the belt transect method. Four 40 m transects (replicates) were surveyed in each habitat zone. Finfish, coral and substrate data was not collected on the inner reef due to an insufficient depth of water for snorkel surveying and photoquadrat image collection.

2.1.2. Fore reef habitat

For the ORT habitat, SCUBA surveys for finfish and invertebrates were conducted in 10 m depth of water. Finfish data was collected along one transect (replicate) with 4 m width (2 m on each side of transect) and 50 m length. Invertebrates were surveyed using the same transect, with a 1 m width and 40 m length. Substrate data was collected along the same path, with a total of 10 x 1 m^2 photo quadrats gathered for substrate analysis.

2.2 Data Analysis

Data collection of all species included identification to the lowest possible taxonomic classification, counts, and measurements. Identification of all species of fish, invertebrates and corals were obtained from a number of resources including the Cook Islands Biodiversity website, Veron (2000), Randall (2005) and Allen et al. (2012).

2.2.1. Invertebrates and finfish

Microsoft Excel was used for data entries and for basic computations such as Pivot tables and Pivot charts for both invertebrates and fish. To compare invertebrate species densities and species richness between sites, the statistical package R was used to perform analysis of variance (ANOVA). Statistical analyses were not performed for finfish data, due to a lack of replication within each site. The standard error (SE) for the mean was also calculated and is used as the measure of variance.

2.2.2. Coral and substrate

DxO Viewpoint 3 software was used to straighten photoquadrats image perspective and CPCe 4.1 software was used to select random points of assessment (n = 16) and record substrate or coral species at each point.

3. RESULTS

3.1 Atiu Invertebrates

A total of 2,645 individuals were observed across 86 transects, representing a total of 31 taxa. There were 28 species of marine invertebrates recorded on the inner reef and 11 species recorded over the reef. The most frequently observed species was the tube snail *ungakoa* (*Dendropoma* spp.) with a total of 902 individuals recorded across all transects. The *rori toto* (*Holothuria atra*) and the red urchin (*Parasalenia gratiosa*) were also frequently observed with 739 and 250 individuals recorded across all transects, respectively.

3.1.1 Invertebrate densities

Average invertebrate density on the inner reef was greatest at Pia Tai (223 ± 58 ind./100 m^2). No invertebrates were recorded at Tepari Pupui (Figure 2). Densities at Pia Tai were significantly greater than Konakonako, Oravaru, Tepari Aniu, Tepari Pupui and Vai Piake ($p < 0.001$).

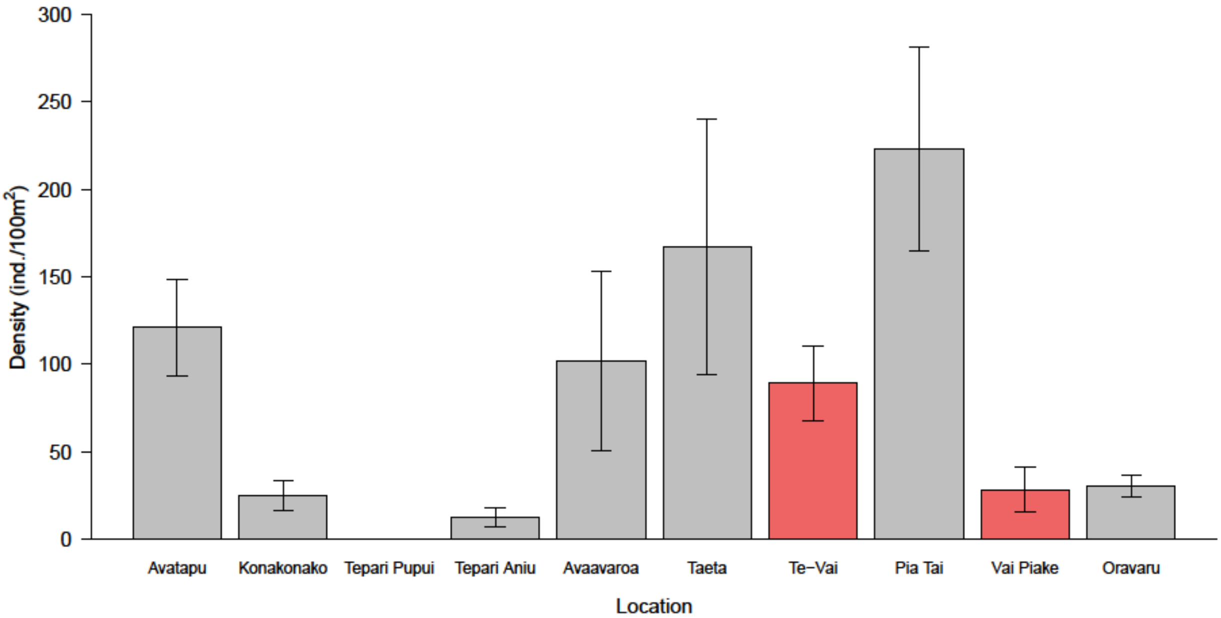


Figure 2. Invertebrate densities on the inner reef in control (grey) and *rā'ui* (red) sites.

Invertebrate densities over the reef were greatest at Avaavaroa (63 ind./100 m^2). No invertebrates were recorded at Taeta, Te-Vai Rā'ui, Pia Tai and Vai Piake (Figure 3).

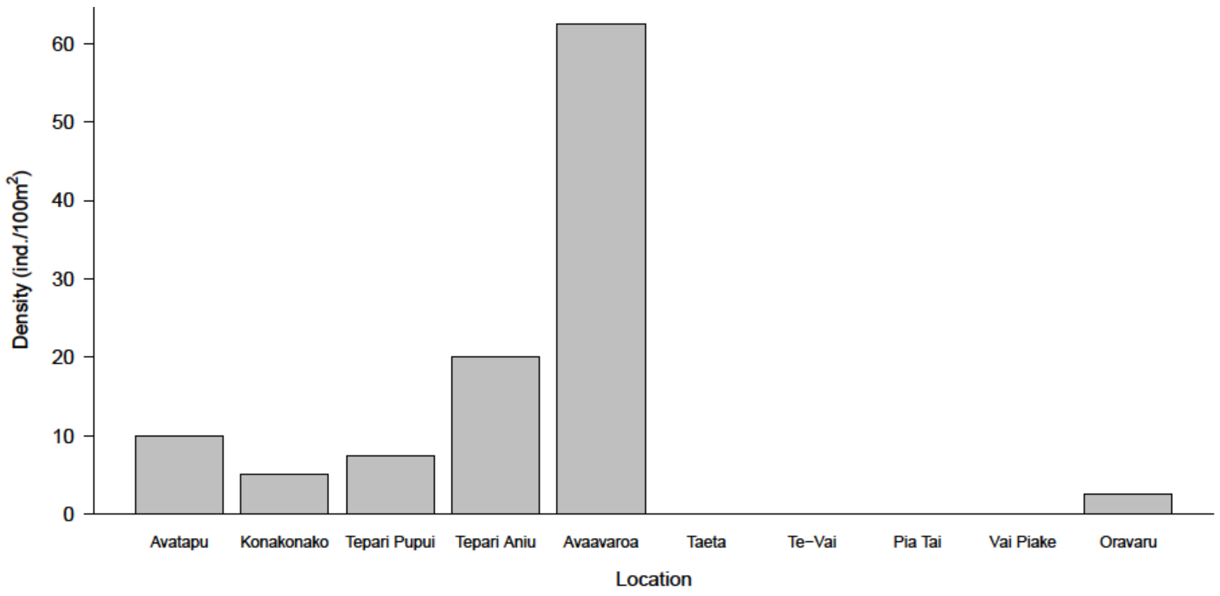


Figure 3. Invertebrate densities over the reef in control (grey) and *rā'ui* (red) sites.

Average *ungakoa* density on the inner reef was greatest at Pia Tai and Taeta (132 ± 54 ind./100 m^2 and 120 ± 69 ind./100 m^2 respectively). *Ungakoa* were not recorded at Avatapu, Konakonako, Tepari Pupui, Vai Piake and Oravaru (Figure 4). Densities at Pia Tai were significantly greater than Avatapu, Konakonako, Oravaru, Tepari Pupui and Vai Piake ($p = 0.001$).

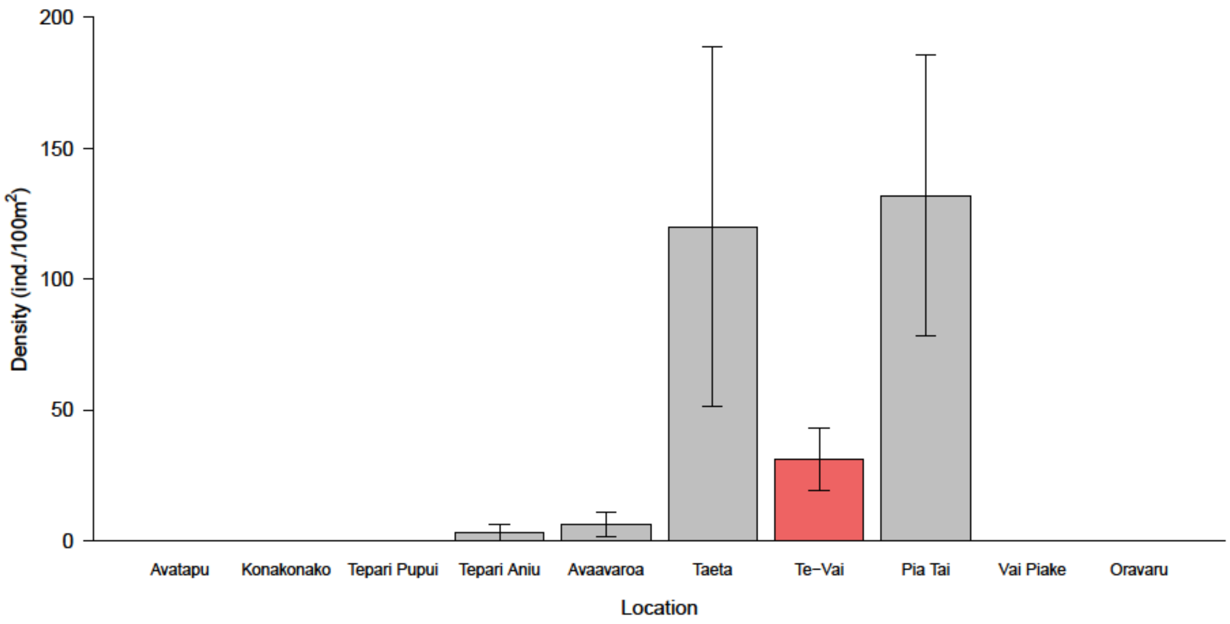


Figure 4. *Ungakoa* densities on the inner reef in control sites (grey) and *rā'ui* sites (red).

Average *rori toto* density on the inner reef was greatest at Avatapu (83 ± 32 ind./100 m^2). *Rori toto* were not recorded at Tepari Pupui and Avaavaroa (Figure 5). Densities at

Avatapu were significantly greater than Avaavaroa, Konakonako, Oravaru, Taeta, Tepari Aniu, Tepari Pupui and Vai Piake ($p < 0.001$). The greatest mean length of *rori toto* was at Avaavaroa (180 ± 12 mm) (Figure 6). Mean lengths at Tepari Aniu were significantly greater than Avatapu and Oravaru ($p < 0.001$).

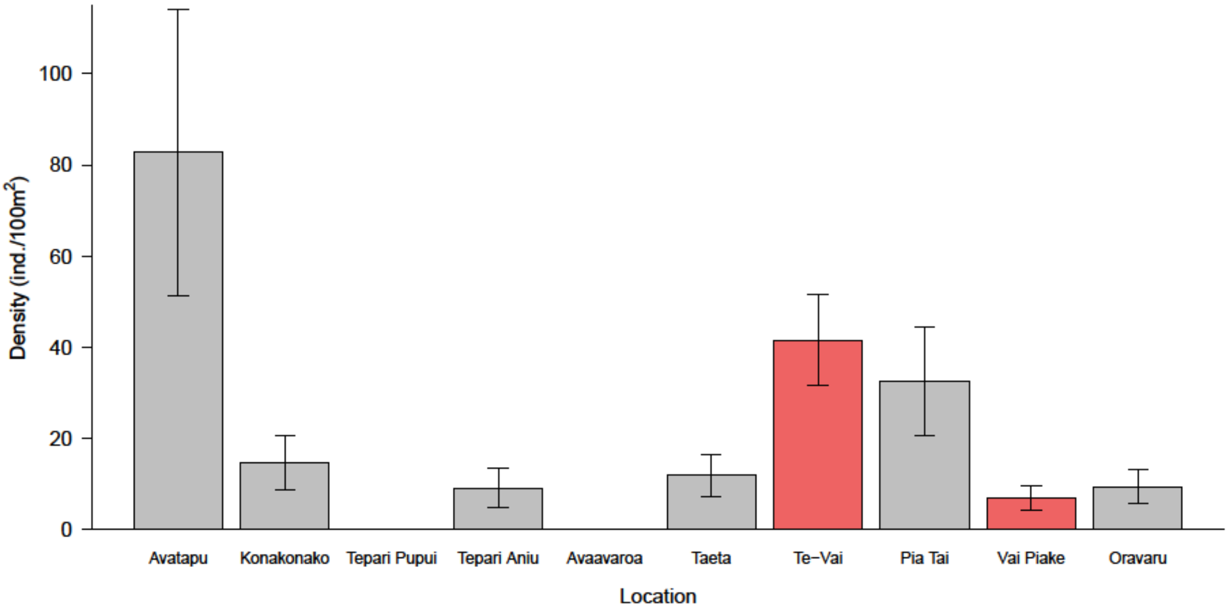


Figure 5. *Rori toto* densities on the inner reef in control sites (grey) and *rā'ui* sites (red).

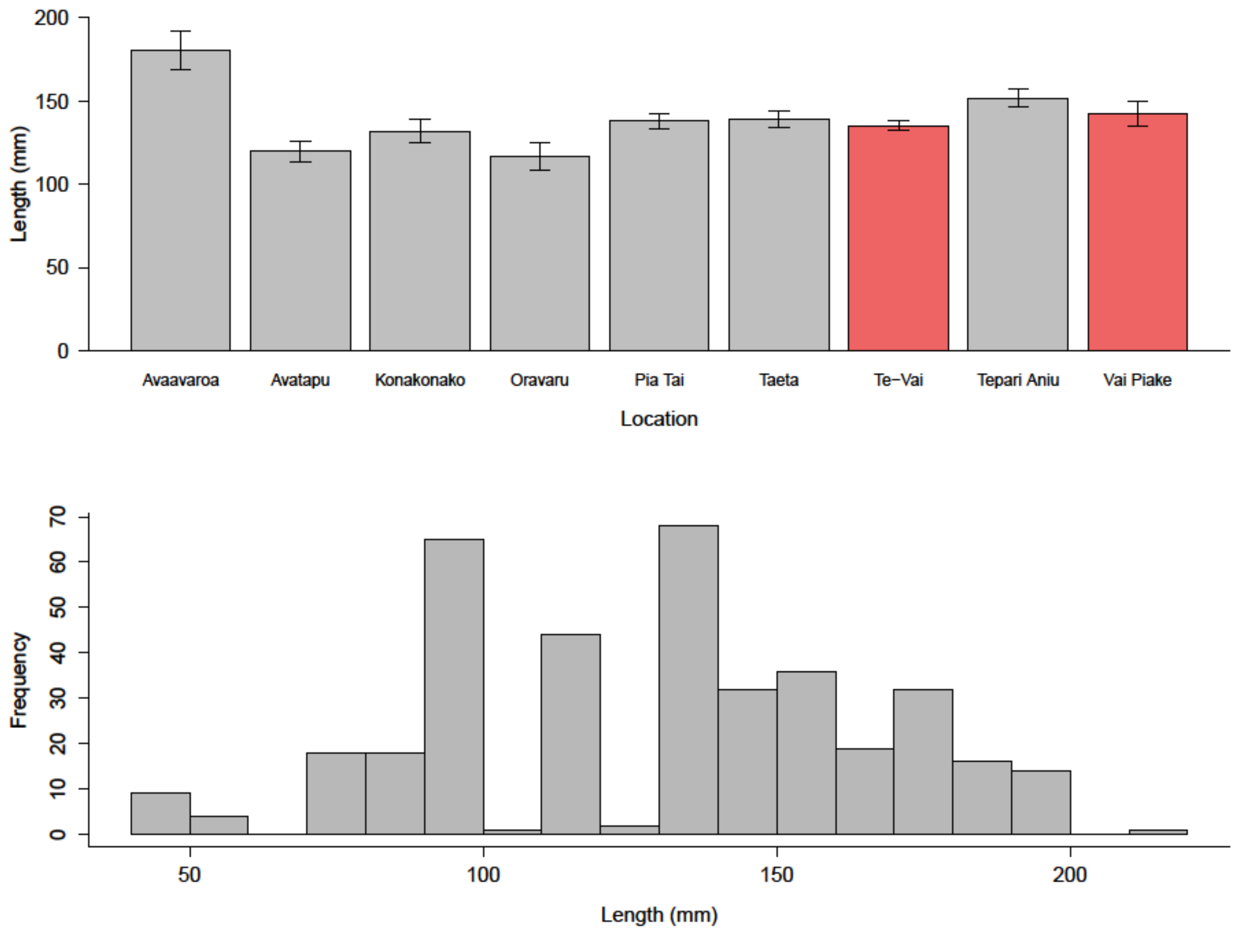


Figure 6. Top: Mean lengths of *rori toto* on the inner reef in control sites (grey) and *rā'ui* sites (red). Bottom: The length-frequency of *rori toto* on the inner reef.

Average *rori puakatoro* (*Actinopyga mauritiana*) density on the inner reef was greatest at Avatapu (7 ± 2 ind./100 m^2). *Rori puakatoro* were not recorded at Tepari Pupui and Vai Piake (Figure 7). Densities at Avatapu were significantly greater than Tepari Pupui and Vai Piake ($p = 0.023$). The greatest mean length of *rori puakatoro* was at Tepari Aniu (188 ± 8 mm) (Figure 8). Mean lengths at Tepari Aniu were significantly greater than Avatapu and Oravaru, as well as mean lengths at Taeta also significantly greater than Avatapu ($p < 0.001$).

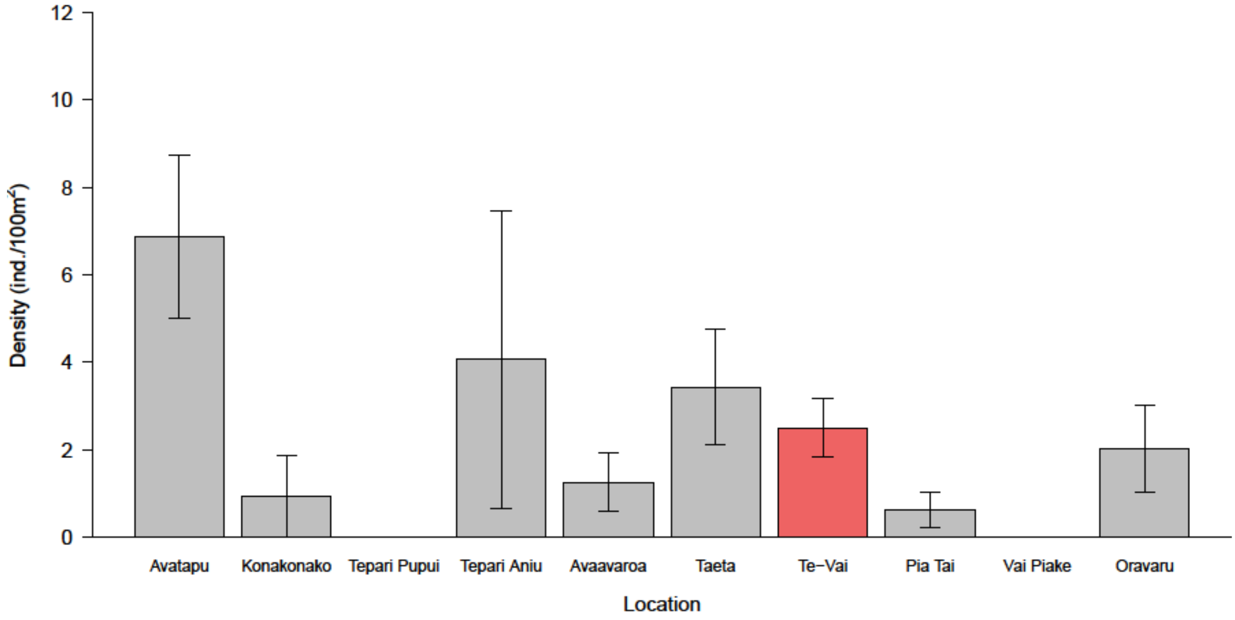
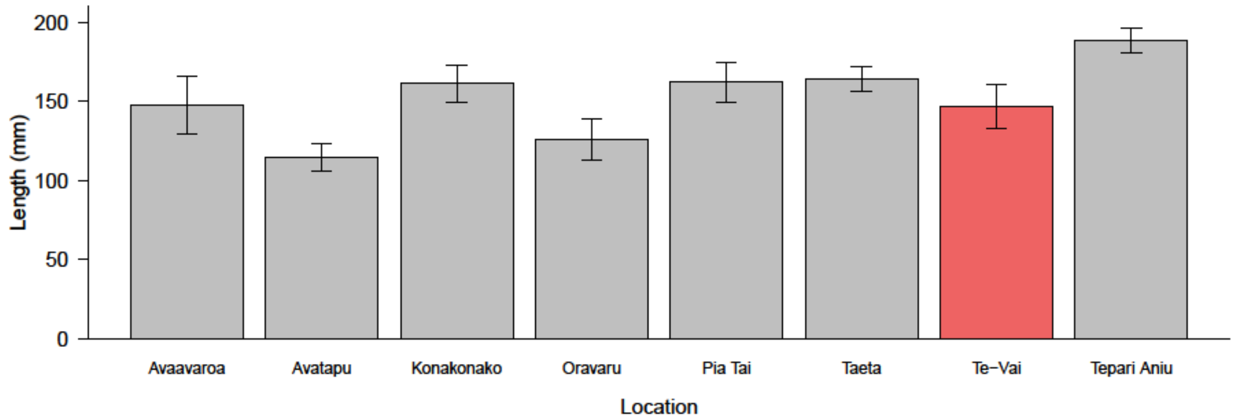


Figure 7. *Rori puakatoro* densities on the inner reef in control sites (grey) and *rā'ui* sites (red).



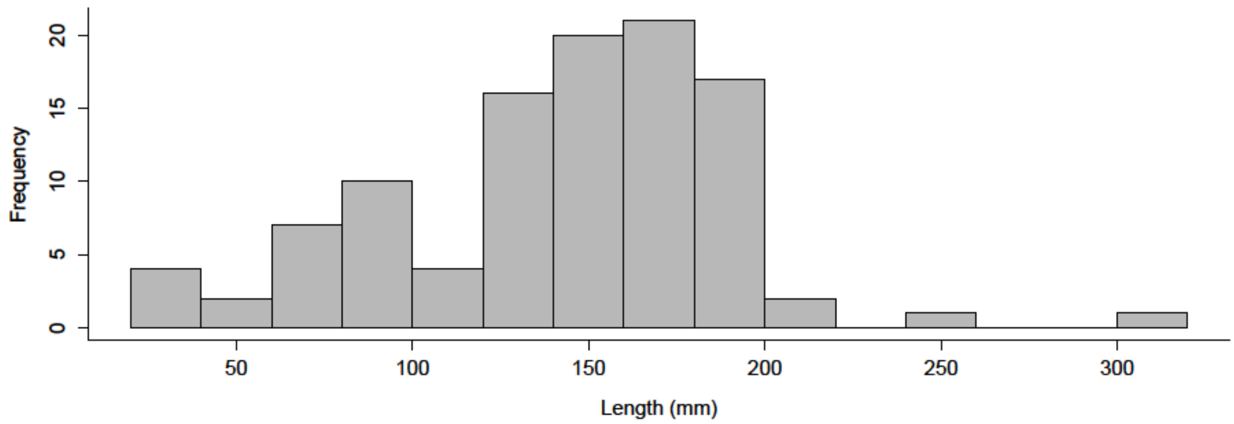


Figure 8. Top: Mean lengths of *rori puakatoro* on the inner reef in control sites (grey) and *rā'ui* sites (red). Bottom: The length-frequency of *rori puakatoro* on the inner reef.

Average *paua* density on the inner reef was greatest at Oravaru (3 ± 1 ind./100 m^2). *Paua* were not recorded at Avaavaroa, Avatapu, Konakonako, Tepari Aniu, Tepari Pupui and Vai Piake (Figure 9). Densities at Oravaru were significantly greater than Avaavaroa, Avatapu, Konakonako, Tepari Aniu, Tepari Pupui and Vai Piake ($p < 0.001$). The greatest mean length of *paua* was at Pia Tai (120 ± 10 mm) (Figure 10). No significant differences were found in mean lengths between sites.

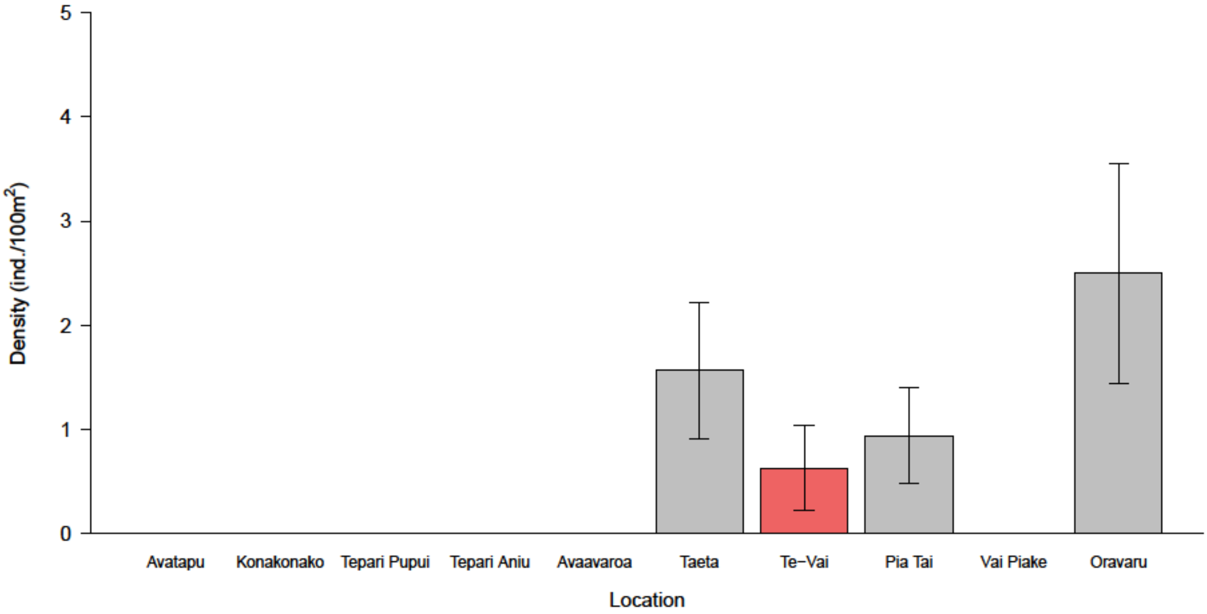
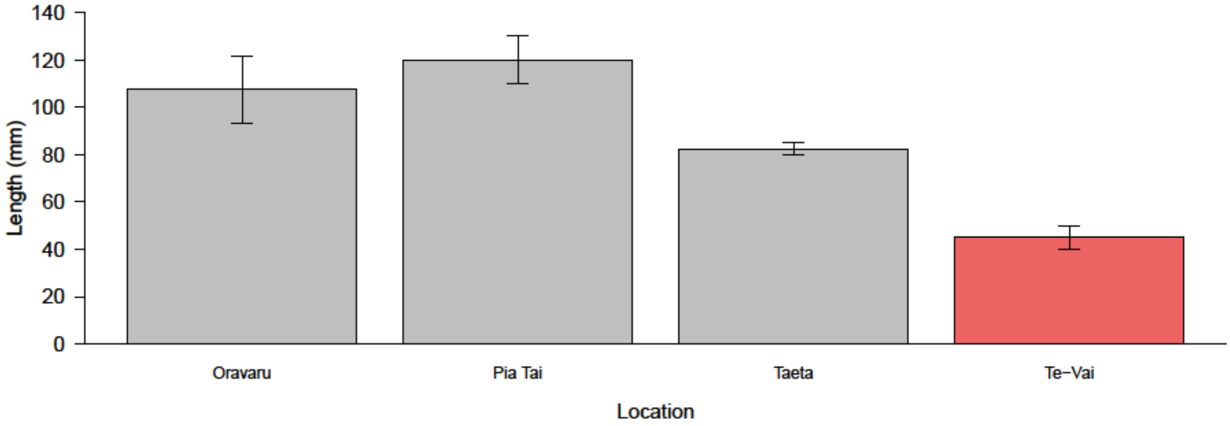


Figure 9. *Paua* densities on the inner reef in control sites (grey) and *rā'ui* sites (red).



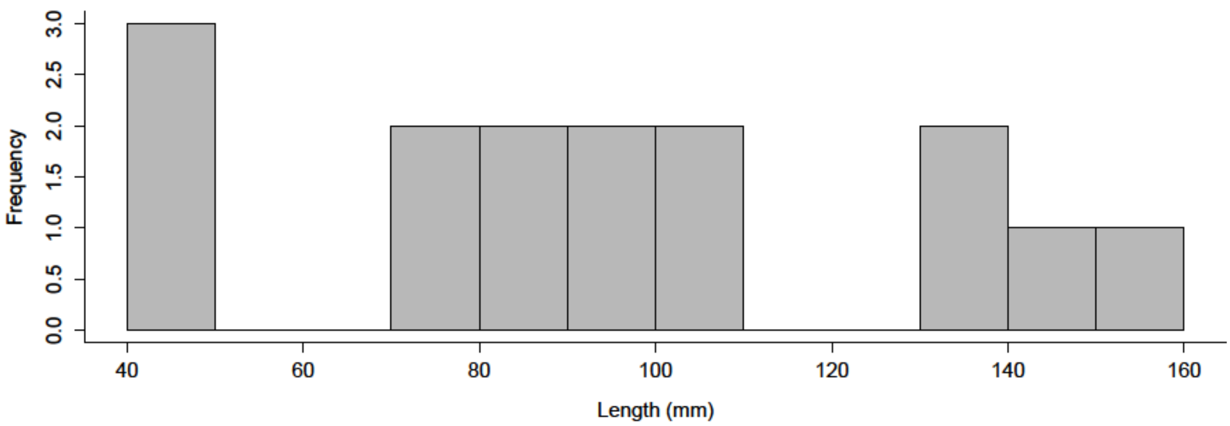


Figure. 10. Top: Mean lengths of *paua* on the inner reef in control sites (grey) and *rā'ui* sites (red). Bottom: The length-frequency of *paua* on the inner reef.

3.1.2. Species richness

Average species richness on the inner reef was greatest at Pia Tai (6 $\pm$ 1 no. taxa/40 m^2). No species were recorded at Tepari Pupui (Figure 11). Species richness at Pia Tai was significantly greater than all other sites except for Te-Vai Rā'ui and Taeta ($p < 0.001$). Species richness at Te-Vai Rā'ui was also found significantly greater than Avatapu, Konakonako, Tepari Aniu, Tepari Pupui and Vai Piake ($p < 0.001$). Species richness at Taeta was also significantly greater than Tepari Pupui and Vai Piake ($p < 0.001$).

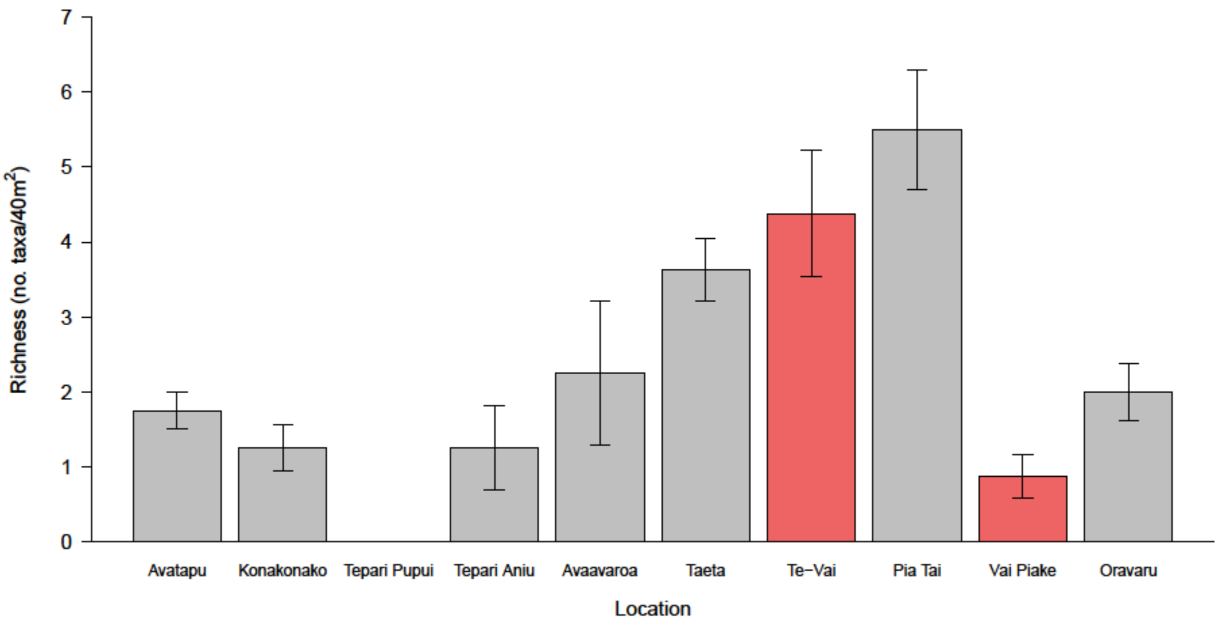


Figure 11. Invertebrate species richness on the inner reef in control (grey) and *rā'ui* (red) sites.

3.2 Takutea Invertebrates

A total of 1049 individuals were observed across 36 transects, representing a total of 17 taxa. There were 13 species of marine invertebrates recorded on the inner reef and 9 species recorded over the reef. The most frequently observed species was the *paua kura* (*Chama pacifica*) where a total of 352 individuals were recorded across all transects. The *paua* and *ungakoa* were also frequently observed with total individuals of 298 and 169, respectively.

3.2.1 Invertebrate densities

Average invertebrate density on the inner reef was greatest at Aumatangi (122 ± 40 ind./100 m^2) (Figure 12). Densities at Aumatangi were significantly greater than Taupoto and Te-Mangauri ($p = 0.011$).

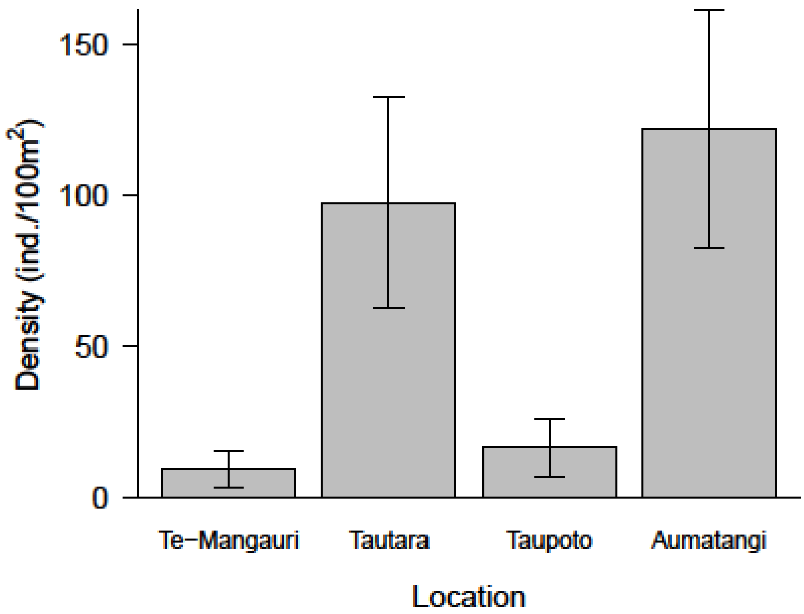


Figure 12. Invertebrate densities on the inner reef.

Invertebrate densities over the reef were greatest at Tautara (243 ind./100 m^2) least at Aumatangi (5 ind./100 m^2) (Figure 13).

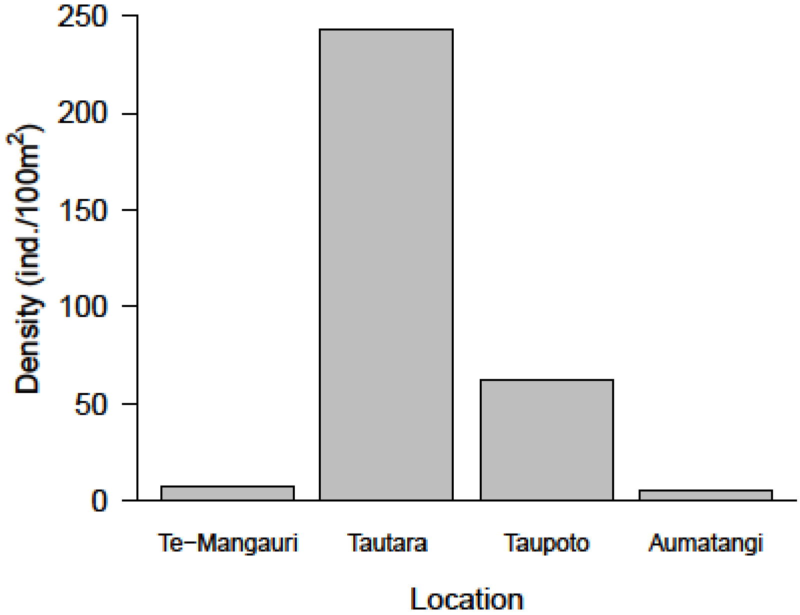


Figure 13. Invertebrate densities over the reef.

Average *paua kura* density on the inner reef was greatest at Tautara (63 ± 31 ind./100 m^2). No *paua kura* were recorded at Aumatangi (Figure 14). No significant differences were found in average density between sites.

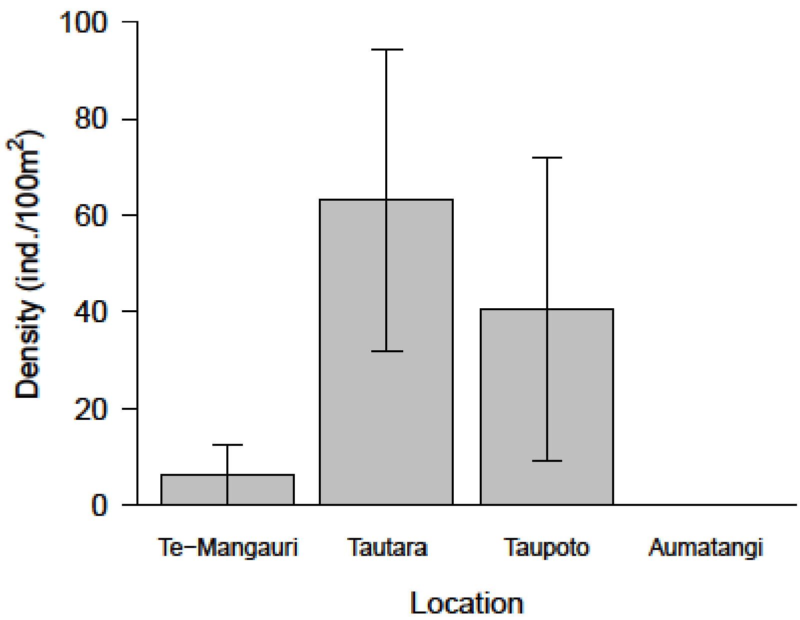


Figure 14. *Paua kura* densities on the inner reef.

Average *paua* density on the inner reef was greatest at Aumatangi (87 ± 33 ind./100 m^2). No *paua* were recorded at Te-Mangauri (Figure 15). Densities at Aumatangi were significantly greater than all other sites (p = 0.002). The greatest mean length of *paua* was at Aumatangi (159 ± 4 mm) (Figure 16). Mean lengths at Aumatangi were significantly greater than Tautara (p = 0.009).

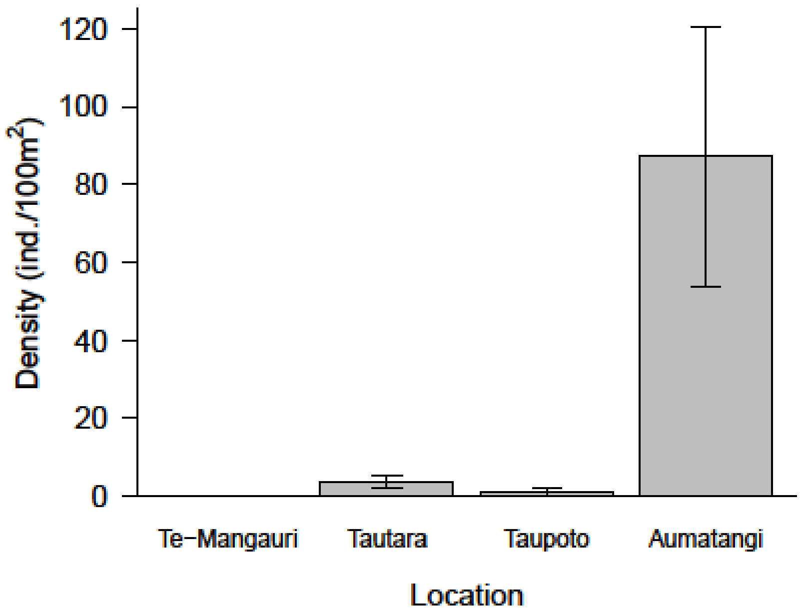
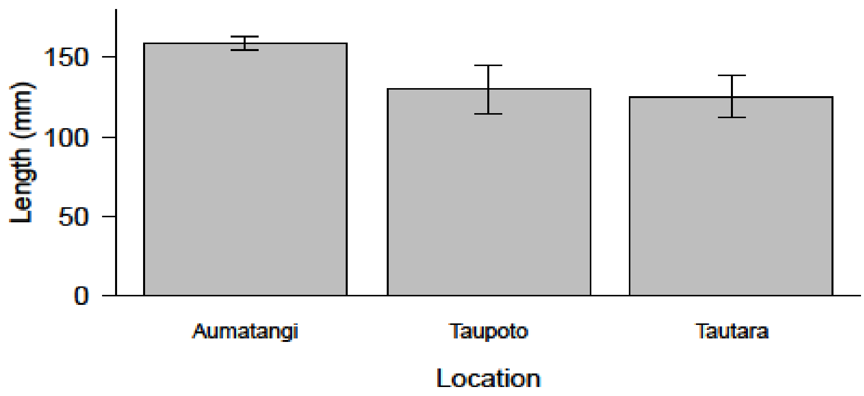


Figure 15. *Paua* densities on the inner reef.



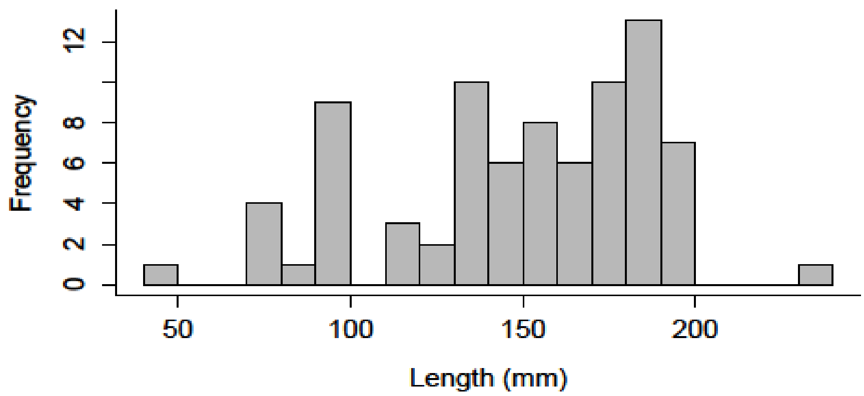


Figure 16. Top: Mean lengths of *paua* on the inner reef. Bottom: The length-frequency of paua on the inner reef.

Average *ungakoa* density on the inner reef was greatest at Tautara (21 ± 13 ind./100 m^2). No *ungakoa* were recorded at Taupoto (Figure 17). No significant differences were found in average density between sites.

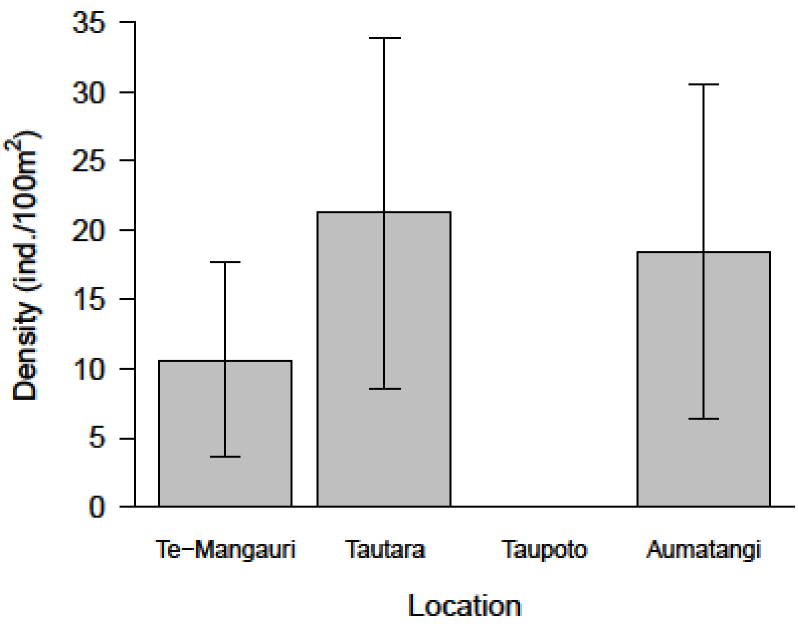


Figure 17. *Ungakoa* densities on the inner reef.

Average *rori toto* density on the inner reef was greatest at Tautara (7 ± 3 ind./100 m^2). No *rori toto* were recorded at Te-Mangauri (Figure 18). No significant differences were found in average density between sites. The greatest mean length of *rori toto* was at Tautara (167 ± 7 mm) (Figure 19). Mean lengths at Tautara were significantly greater than Aumatangi and Taupoto (p = 0.003).

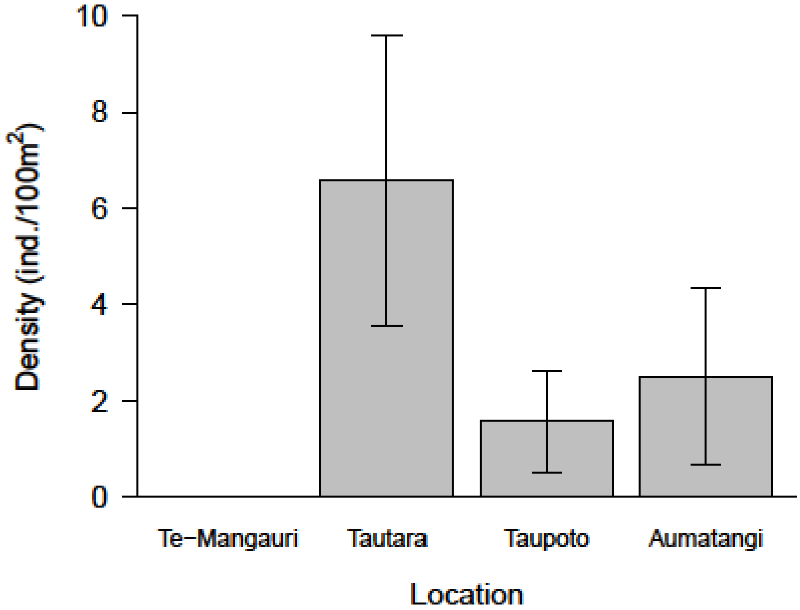


Figure 18. *Rori toto* densities on the inner reef.

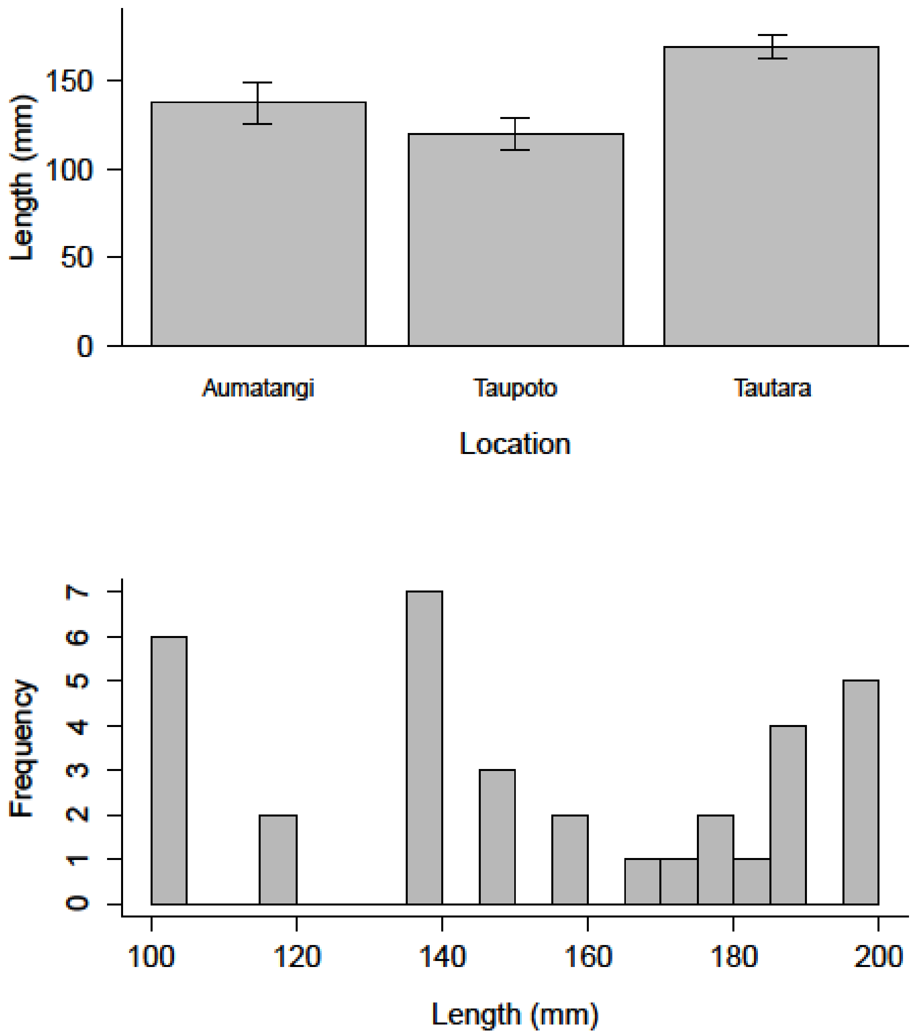


Figure 19. Top: Mean lengths of *rori toto* on the inner reef. Bottom: Length-frequency of *rori toto* on the inner reef.

Average *rori puakatoro* density on the inner reef was greatest at Te-Mangauri (4 ± 1 ind./100 m^2) (Figure 11). Densities at Te – Mangauri were significantly greater than Taupoto ($p = 0.027$). No significant differences were found in mean lengths of *rori puakatoro* between sites.

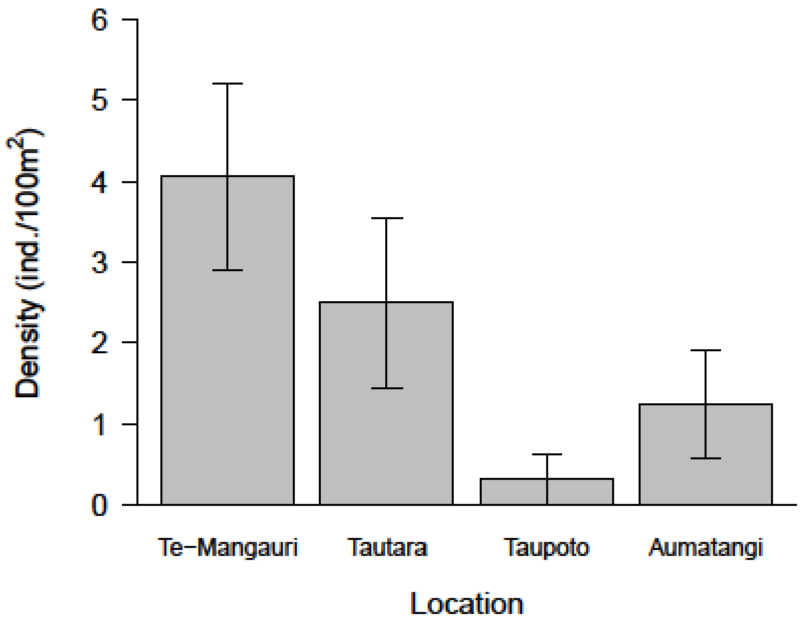


Figure 20. *Rori puakatoro* densities on the inner reef.

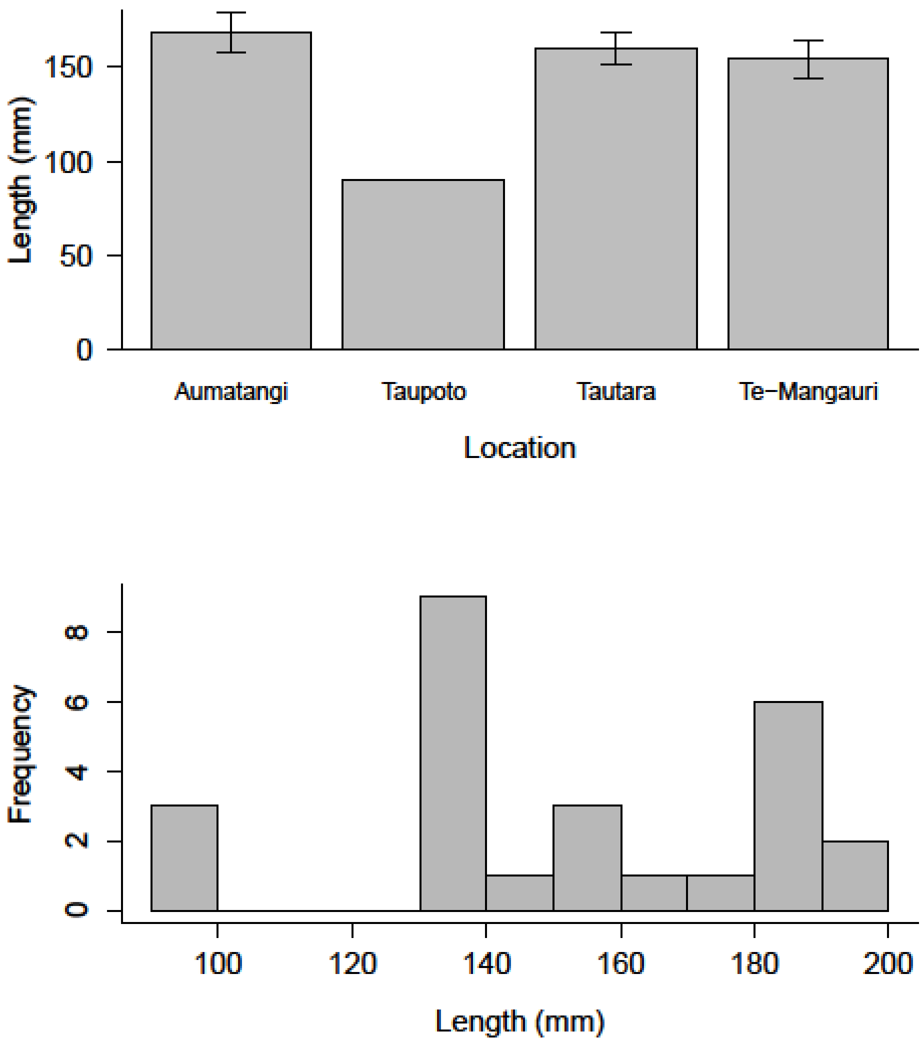


Figure 21. Top: Mean lengths of *rori puakatoro* on the inner reef. Bottom: Length-frequency of *rori puakatoro* on the inner reef.

3.2.2. Species richness

Average species richness on the inner reef was greatest at Aumatangi and Tautara (3 ± 0 no. taxa/40 m^2 and 3 ± 1 no. taxa/40 m^2), respectively. Average species richness was least at Te-Mangauri (1 ± 0 no. taxa/40 m^2) (Figure 22). No significant differences were found in species richness between sites.

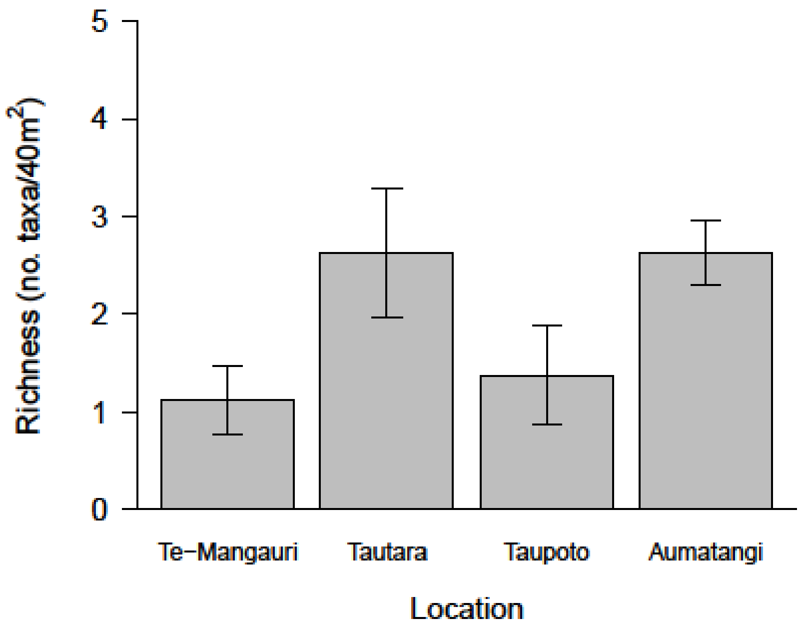


Figure 22. Invertebrate species richness on the inner reef.

3.3 Atiu Finfish

A total of 3,768 finfish were observed across ten transects representing a total of 83 taxa. The most frequently observed species was *Chromis acares* where a total of 1,097 individuals were recorded across all transects. *Maito* (*Ctenochaetus striatus*) and olive anthias (*Pseudanthias olivaceus*) were also frequently observed with total individuals of 728 and 445, respectively.

3.3.1. Finfish density

Finfish density over the reef was greatest at Tepari Aniu (304 ind./100 m^2) and least at Avatapu (109 ind./100 m^2) (Figure 23).

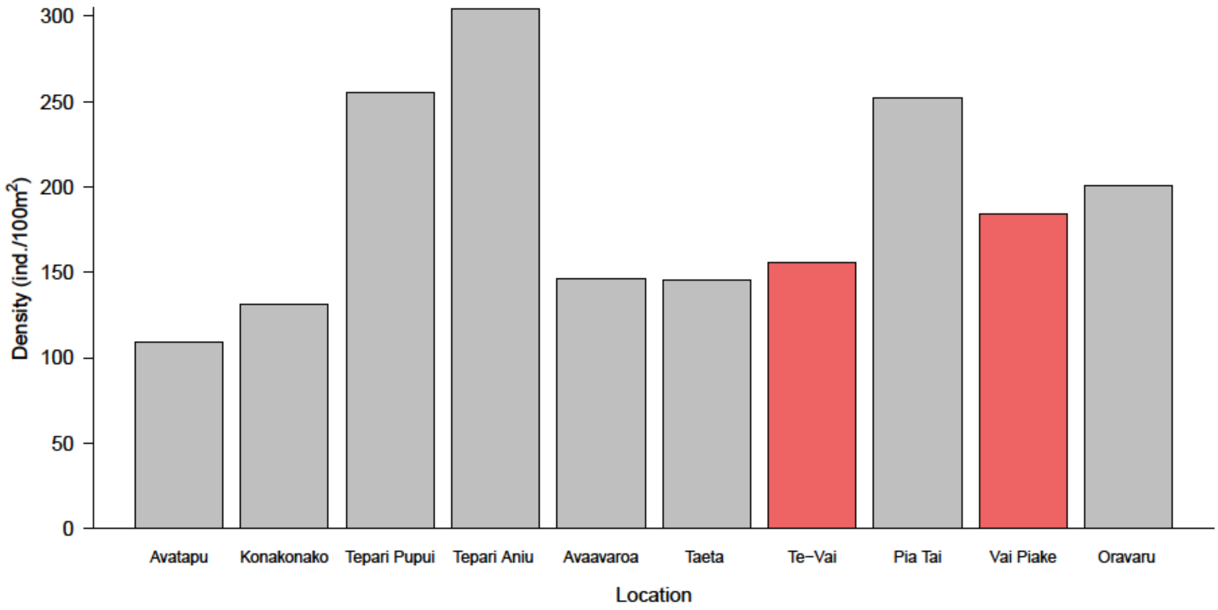


Figure 23. Finfish density over the reef in control (grey) and *rā'ui* (red) sites.

3.3.2. Species richness

Average species richness over the reef was greatest at Avatapu (41 taxa/50 m^2) and least at Te-Vai Rā'ui (28 taxa/50 m^2) (Figure 24).

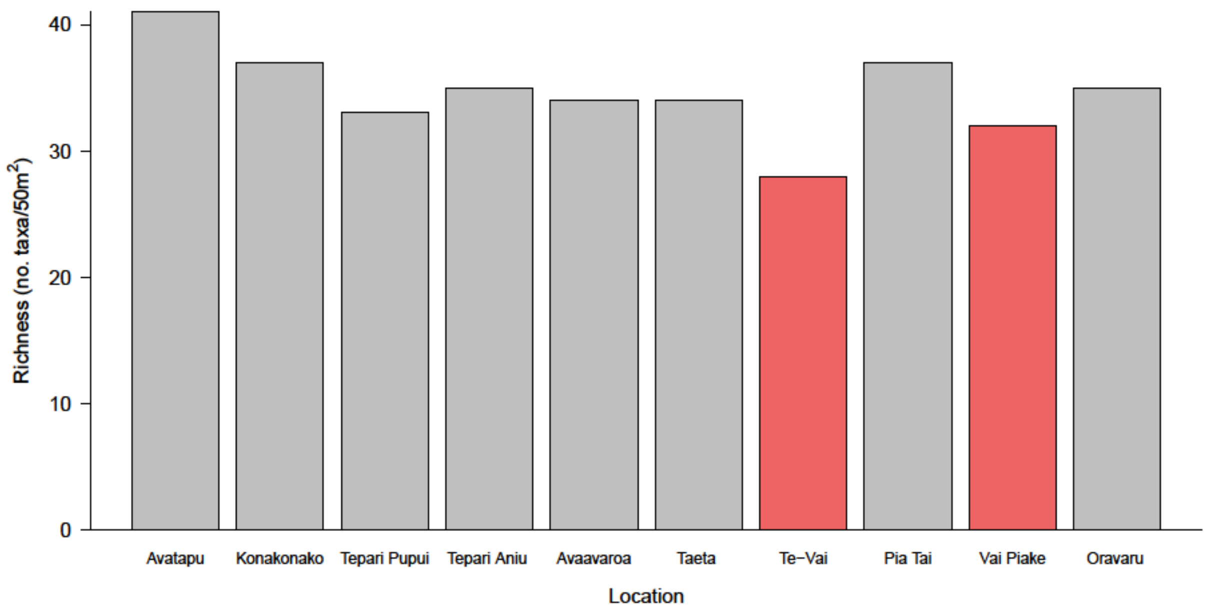


Figure 24. Finfish species richness over the reef in control (grey) and *rā'ui* (red) sites.

3.4 Takutea Finfish

A total of 1025 fish were observed across 4 transects representing a total of 54 taxa. The most frequently observed species was *Pomachromis fuscidorsalis* where a total of 160 individuals were recorded across all transects. *Chromis acares* and *Pseudanthias olivaceus* and were also frequently observed with a total of a 150 individuals of each species recorded.

3.4.1. Finfish density

Finfish density over the reef was greatest at Aumatangi with (175 ind./100m^2) and least at Taupoto with (83 ind./100 m^2) (Figure 25).

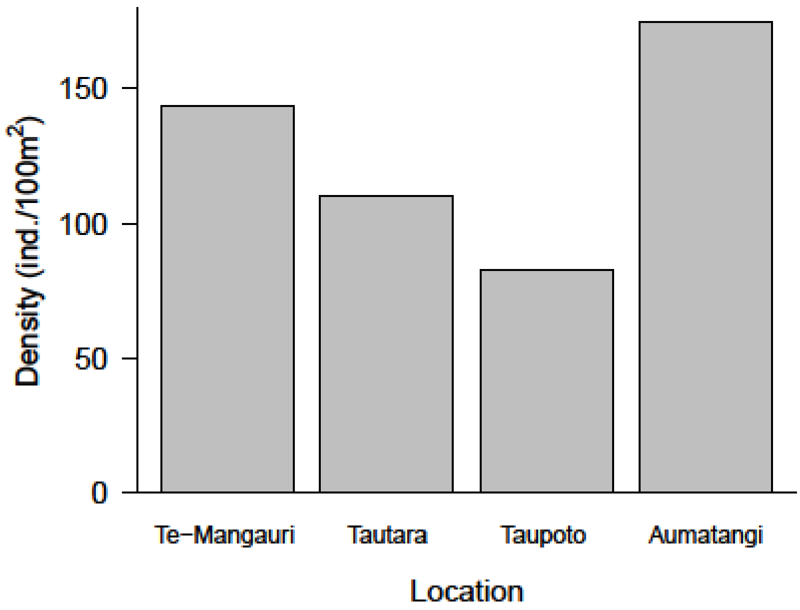


Figure 25. Finfish density over the reef.

3.4.2. Species richness

Average species richness over the reef was greatest at both Te-Mangauri and Tautara (32 taxa/50 m^2) and least at Taupoto (20 taxa/50 m^2) (Figure 26).

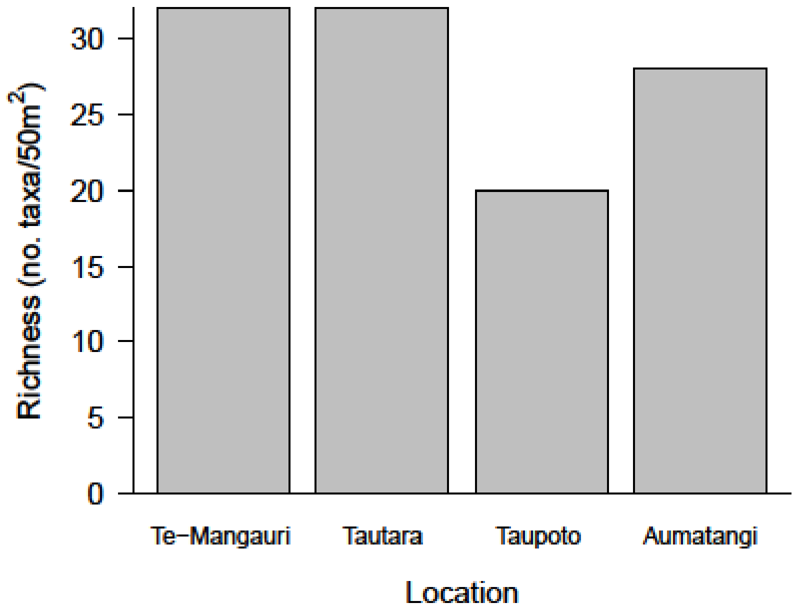


Figure 26. Finfish species richness over the reef.

3.5 Coral and substrate

3.5.1 Atiu substrate

Over the reef, the total live coral cover was 19% (Figure 14). The average hard coral cover was greatest at Avatapu (21 ± 5 %) and least at Tepari Pupui (15 ± 2 %). Hard substrate accounted for the highest percentage cover over the reef with an overall average of (39 ± 5 %).

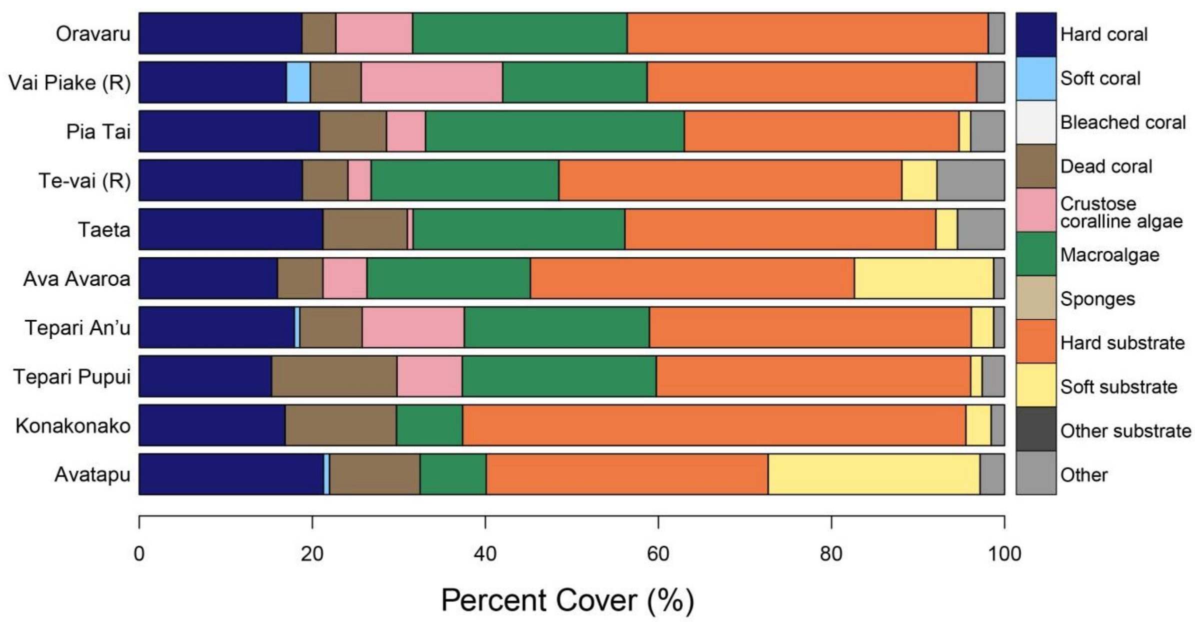


Figure 27. Substrate type and percentage cover from over the reef in control and *rā'ui* (R) sites.

3.5.2 Takutea substrate

Over the reef, the total live coral cover was 7% (Figure 25). Average hard coral cover was greatest at Tautara (10 ± 2 %) and lowest at Taupoto (1 ± 1 %). Hard substrate accounted for the most percentage cover over the reef with an overall average of (47 ± 5 %).

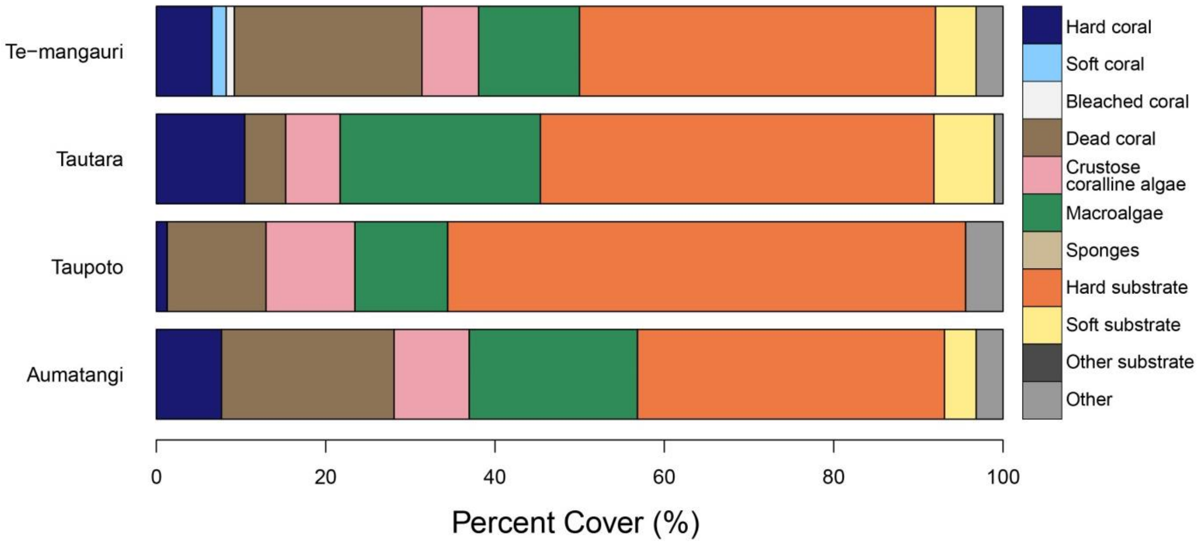


Figure 28. Substrate type and percentage cover from over the reef.

4. DISCUSSION AND BIOLOGICAL INFORMATION

4.1 Atiu Enua

The greatest invertebrate density was found in Pia Tai on the southern point of Atiu and was significantly greater than all other sites except for Avatapu, Vai Piake Rā'ui, Avaavaroa, Taeta and Te-Vai Rā'ui. This shows that with the exception of Avaavaroa, sites on the inner reef, located on the windward side are more abundant in invertebrate density than sites on the leeward side (Figure 15). Pia Tai was also found to have the greatest densities of *ungakoa* and was significantly greater than all other sites except Tepari Aniu, Avaavaroa, Taeta and Te-Vai Rā'ui. The geological landscape of Atiu may be a contributing factor that limits the density of invertebrates on the inner reef. For example, on the north eastern side, Tepari Aniu had no RFT habitat as the site had a narrow reef and didn't extend further than the *makatea* cliffs. The same narrow reef occurs on the northern side near the airport where the team observed Tepari Pupui being depauperate of any invertebrates in both RBT and RFT habitats. In contrast with these narrow reef flats, the southern side sites of Pia Tai and Te-Vai Rā'ui have 120 m wide reef flats that extend out to the surf zone (Rongo et al. 2014). In sites such as these north sides, large swells can impact the success of invertebrates by reducing the food resources and available habitats. Furthermore, the wide reef flat on the south side likely buffers the impacts of large swells, providing a suitable habitat for invertebrate species to reproduce in abundance.

Ponia (1998) found the highest biodiversity within Te-Vai Rā'ui in their survey almost 20 years ago. It must be noted, however, that Pia Tai was not surveyed in 1998. We found the highest biodiversity in Pia Tai, located only 2 km away. Vai Piake Rā'ui, also located 2 km in the opposite direction of Pia Tai was found to be significantly different in density of invertertebrates (Figure 2). This shows that high biodiversity in Pia Tai and Te-Vai Rā'ui in 1998, may be another result of the geological feature mentioned above. The wide narrow reef flat that buffers oceanic swells; may not only provide suitable habitats for species to reproduce in abundance, but also different species to reproduce in the area. With the high densities and biodiversity recorded at Pia Tai along with high biodiversity recorded at Te-Vai Rā'ui (Ponia 1998) there is evidence to suggest that the southern stretch of Atiu is a biodiversity hotspot.

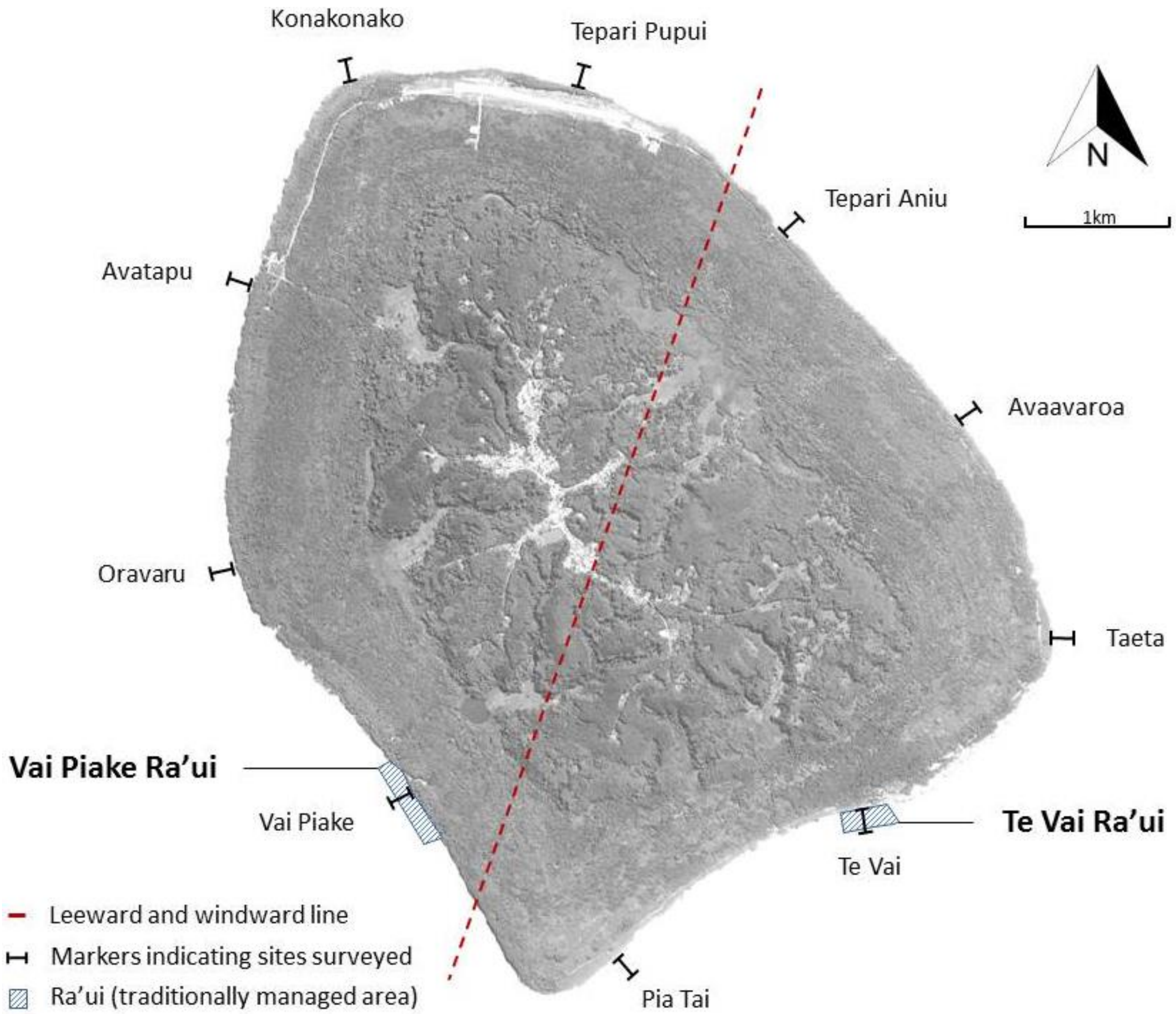


Figure 15. Atiu survey sites with a line distinguishing between the windward and leeward sides.

Paua is a species of interest to the island council as it is a favourable food source for the Atiu community. The highest density of *paua* was found at Oravaru, which is located on the western side of the island near the Mokoero Nui reserve. The only other sites where *paua* were recorded were the windward sites of Taeta, Te-Vai Rā'ui and Pia Tai. It is possible that the terrestrial reserve of Mokoero Nui may restrict or discourage harvest of adjacent marine life. Mokoero Nui's success comes because of the community buy-in on conserving biodiversity, if this reserve is continued on the reef, up to the surf zone there is no reason this marine reserve will serve as a problem to the public. Traditional *rā'ui* can still be observed at the designated sites Vai Piake and Te-Vai and continue to provide resources for the community; the proposed reserve will protect the highest density of *paua* in Atiu and serve as a source population for the island. We suggest initiation of discussions regarding expansion of the Mokoero Nui reserve to the reef drop-off.

The coral garden advertised at Te-Vai Rā'ui for visiting tourists seems as though may be encouraging as an area for snorkelling at the *rā'ui* site. As it is great promotion for the tourism industry, these activities may affect the biodiversity and should be monitored.

Hard coral cover percentage for Atiu over the reef was greatest at Avatapu (21 ± 5) and lowest at Tepari Pupui (15 ± 2). Te-Vai Rā'ui was fifth for hard coral cover (19 ± 2), with an overall average hard coral cover of 18 ± 4. This average is below the indo-pacific average of 22.1 % (Bruno & Selig, 2007); sites such as Avatapu and Taeta are able to meet this percentage of coral cover. Although this is over the reef cover, the Te-Vai Rā'ui coral garden area covers the inner reef passages of depths between 1.5 m and beyond that lead out over the reef. As the habitats are comparable perhaps it may be worth looking at an alternative area for coral garden promotion. Avatapu, for example, provides the highest coral cover, is near the harbour for easy access, not located in a *rā'ui* and on the leeward side of the island for safer weather conditions.

4.2 Takutea Enua

The greatest density of *paua* was found at Aumatangi on the south side of Takutea where the reef flat width was approximately 180 m. No *paua* were recorded in Te-Mangauri likely due to the short reef flat of about 25 m, which may make the inner reef along the eastern side unsuitable for larval settlement. Reef flat widths at Tautara in the north and Taupoto to the west are approximately 170 m and 80 m, respectively, and both had significantly lower *paua* densities than Aumatangi. To access Takutea, boats from Atiu land about halfway between these two sites. *Paua* densities around Takutea indicate that fishers may be harvesting *paua* closer to where they land the boat rather than walking around to the farthest southern side of the island. Furthermore, mean *paua* lengths at Aumatangi were significantly greater than at Tautara. *Paua* at Aumatangi have had had more time grow to larger sizes compared to *paua* at Tautara, further supporting the notion that harvests typically occur where the boats land.

A survey conducted by Ponia et al. (1998) coincided with an introduction of 200 trochus to the island. During our survey, no trochus were observed on or off transects in Takutea. Factors such as susceptibility to predators, strong wave action and/or currents hindering settlement, or overharvest may have contributed to the decline. The trochus introduction to Takutea was apparently unsuccessful.

Finfish species richness was greatest in Te-Mangauri and Tautara. Although Te-Mangauri has a short inner reef, it has the widest area over the reef extending approximately 1 km from the reef crest (Figure 1). This area that is not regularly fished because of rough seas and swirling currents caused by the reef extension and its eastward facing position (V. Paretoa, personal communication, 24-May, 2018). The high biodiversity found along east and north-east sides of Takutea is consistent with the area being less fished.

5. RECOMMENDATIONS

Outlined below are suggested recommendations that should have little immediate impact in the quantity of species harvested, but should have long term positive benefits for subsistence fishers, ecosystem resilience and biodiversity conservation in Atiu and Takutea. These recommendations may be accepted or modified to suit the need of fishermen, communities and managers.

Atiu

- All invertebrate species shall not be subject to any form of sale, whether local or commercial, and only be subject to subsistence fishing by the Atiu community.
- Establishing a marine reserve for *paua* around the already established terrestrial Mokoero Nui reserve. *Paua* may be the most easily species to be overharvested and careful management of this species is imperative to its survival. To regulate harvesting we recommend:
    - Minimum Size Limit (150 mm)
    - Daily bag limit (30 *paua* / person / day)
    - Never harvest *paua* from over the reef
- We recommend not advertising adjacent areas for tourism purposes at Te-Vai. Avatapu should be considered for coral garden as over the reef has the highest coral cover.

Takutea

- All invertebrate species shall not be subject to any form of sale, whether local or commercial, and only be subject to subsistence fishing by the Atiu community.
- Establishing a permanent marine reserve for *paua* at Aumatangi to serve as a source population for Takutea and Atiu. To regulate *paua* harvests we recommend:
    - Minimum Size Limit (e.g. 150 mm)
    - Daily bag limit (e.g. 30 *paua* / person / day)
    - Never harvest *paua* from over the reef
- FADs, floats, plastic debris that may be impact seabirds and biodiversity, we recommend that during each visit to Takutea, boats remove as much rubbish as reasonably possible.

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