AITUTAKI & MANUAE 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 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* are small-scale areas 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 assessment for Aitutaki and Manuae. The primary objectives 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
- Compare population densities and species compositions between islands

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 focusses on coastal and inshore zones.

1.2 Aitutaki Enua

Aitutaki is an island located 250 km north of Rarotonga. The island is geologically classified as an 'almost atoll' due to exposed volcanic remnants within a fringing coral reef (Wood and Hay, 1970). Aitutaki has a total land area of 1,800 ha and lagoon area of 8,000 ha. As the second most populated island both for locals and tourists, the population on Aitutaki was estimated at 2,038 in 2011.

Aitutaki has legal regulations for its inshore marine species. Implemented in November of 1990, The Aitutaki Fisheries Protection By-Laws in part, regulate harvest of *Tridacna* spp., *Arca* spp. and *Turbo* spp. in lagoon waters and to a distance of 200 meters beyond the outer reef edge on the islands of Aitutaki and Manuae (Aitutaki By-Laws, 1990). The By-Laws include harvest limits where no more than 20 animals per genus may be harvested per day. Minimum size limits are also in place and prohibit harvest of *Tridacna* spp. less than 75 mm, *Arca* spp. less than 50 mm and *Turbo* spp. less than 38 mm. The By-Laws prohibit sale and/or removal of these species from their respective islands, however, permits issued by the Aitutaki Island Council may be obtained which allow harvests greater than the daily bag limit and/or less than the minimum size limit.

In 2010, the Ministry of Marine Resources and Cook Islands Government implemented the Aitutaki and Manuae Bonefish Management Plan. The purpose was to establish an ecologically sustainable bonefish fishery on both islands. Spawning and nursery sites of bonefish (*Albula glossodonta*) were identified and bonefish fishing restricted to designated areas. Fishing licencing and fishing guide requirements were imposed as well as fishing gear restrictions and a ban on bonefish export.

1.3 Manuae Enua

Manuae is an uninhabited island, approximately 100 km south-east of Aitutaki. Workers on a small copra plantation were the last humans to inhabit Manuae, but by the early 1970s, the island was deserted. The island is a true atoll composed of two islets (Manuae and Te Au O Tu) situated within a 1,375 ha lagoon. On the western side sits the islet of Manuae with a land mass of 235 ha. To the east sits the islet of Te Au O Tu with a land mass of 430 ha.

Entrance into the lagoon is made through a man-modified reef passage on the northern end of the Manuae islet. The passage is narrow and shallow, restricting the size of boats that can enter the lagoon and constraining entrances to be made on higher tides. The passage entrance is also at an angle to the reef crest and may be overlooked or confused with the larger, incomplete passage 200 m to the southwest.

There are no habitable structures remaining on Manuae and remnants of old buildings scatter the northern end of the Manuae islet. On the north east of Manuae islet, an old airstrip is visible but is overgrown. Today, visitors to Manuae are most often Aitutakian fishermen and fishing charter guides.

Aitutakian fishermen generally visit Manuae on artisanal fishing trips. They target pelagic fish outside the reef, spiny lobsters on the reef crest and coconut crabs in the forests with the goal of transporting these species back to Aitutaki for later consumption. Giant clams (*Tridacna* spp.) are also targeted by Aitutakian fishermen but as per the Aitutaki Fisheries Protection By-Laws, giant clam export from Manuae is prohibited which presumably motivates fishermen to consume their clam harvest before departing.

Catch and release fishing for bonefish within the lagoon and for giant trevally from a boat outside the reef are the main attractions for tourists. When camping, tourists may harvest and consume giant clams (*Tridacna* spp.) and coconut crabs (*Birgus latro*) but infrequently transport these species back to Aitutaki (Quinton Schofield, Wet & Wild Aitutaki personal communication, 7th November 2017).

2. METHODOLOGY

Surveys in Aitutaki and Manuae took place from September to November 2017.

Surveying of finfish, invertebrates and substrate was conducted within areas of interest on the islands of Aitutaki (Fig. 1) and Manuae (Fig. 2). Areas of interest included all *rā'ui*, legally regulated areas (marine reserves) and control areas (unregulated areas open to harvest). Within each area of interest, two sampling sites were selected. In Manuae, to make comparisons with historic data, sites were placed in the same locations as Ponia (1998b) and additional sites were added with their locations selected to capture a representative sample of the island. Surveys were conducted with SCUBA, snorkel and walk sampling.

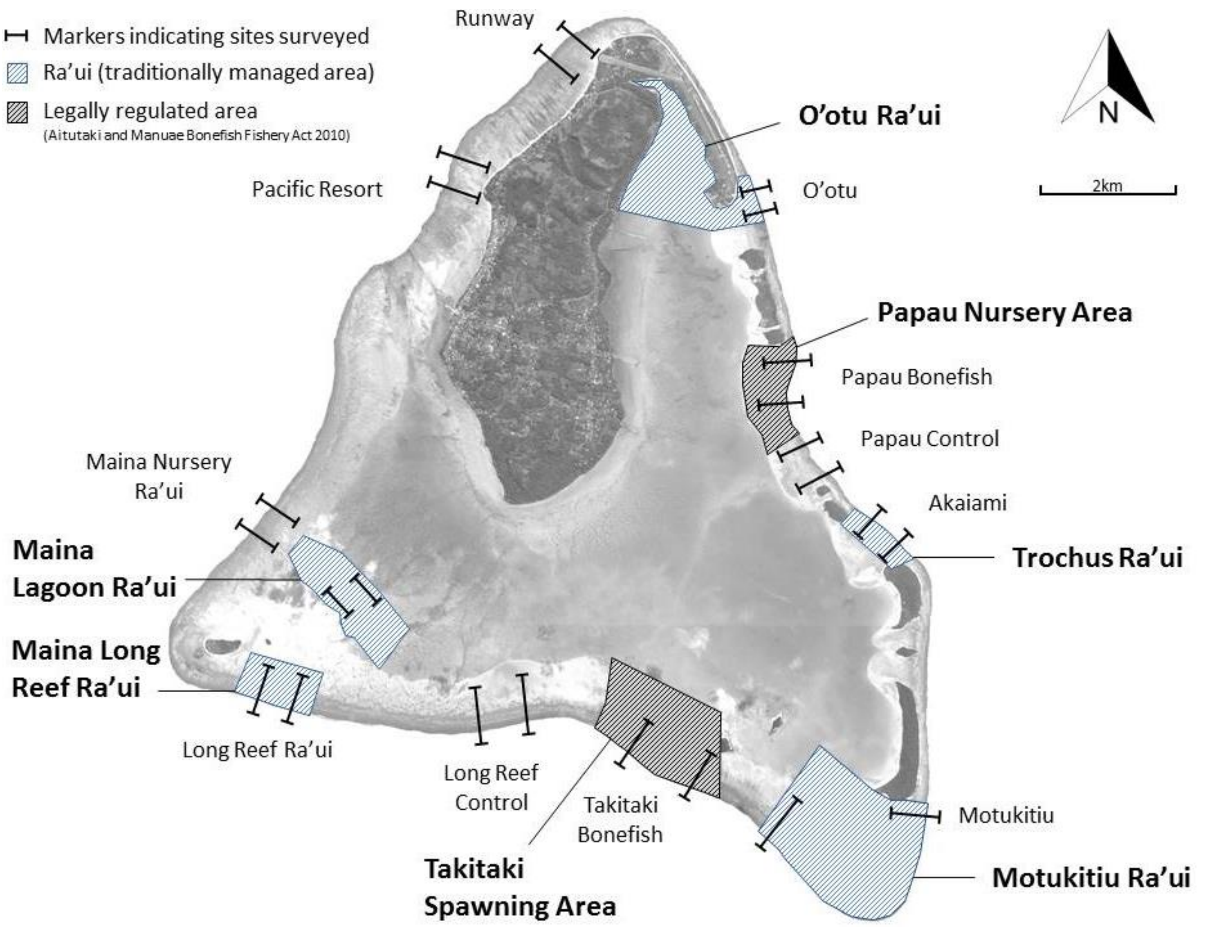

Fig. 1. Aitutaki survey sites and areas with traditional and legal management. Map source: Google DigitalGlobe.

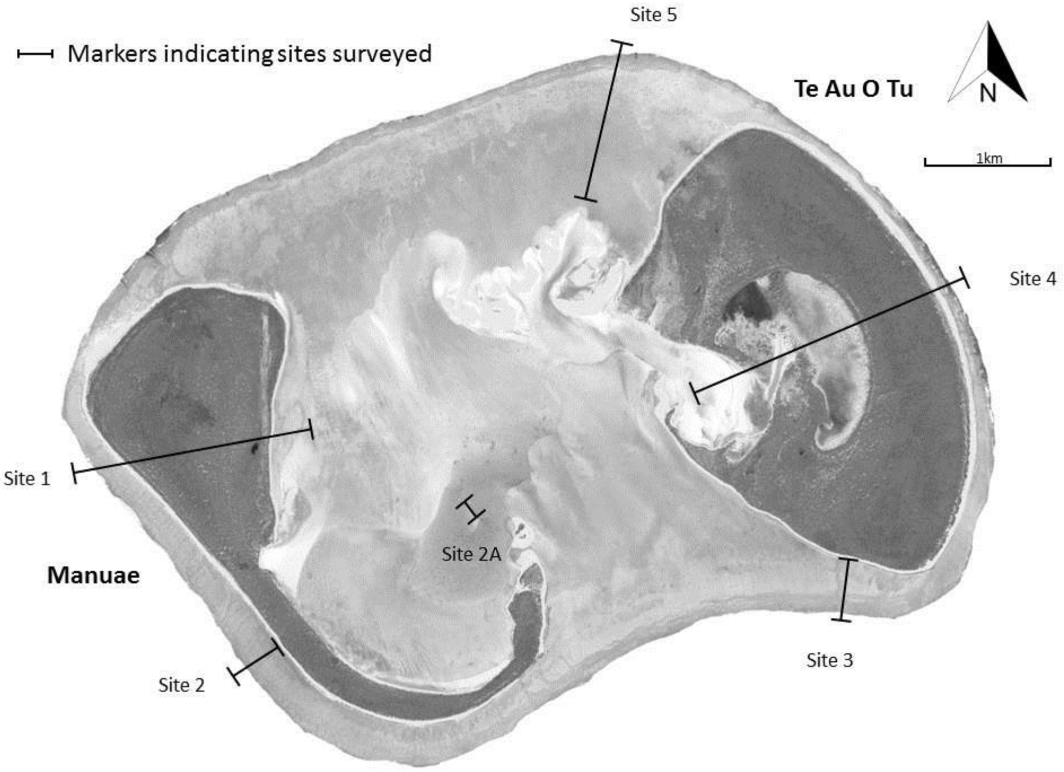

Fig. 2. Manuae survey sites. Map source: Google DigitalGlobe.

Within each site, habitats were identified as shallow sandy bottom (SBT), deeper mid-lagoon (MLT), inner reef crest (RBT) and outer reef crest (RFT) within the lagoon, and fore reef (ORT), outside the reef (Fig. 3). For each habitat within the lagoon, invertebrates were surveyed along four 1 x 40 meter transects. If lagoon water depth was sufficient for snorkel or SCUBA surveys, finfish data were collected along a single 4 x 4 x 50 meter fish transect (FT), generally near the MLT transect. Along the same transect, 50 x 0.25 m^2 photoquadrats were collected to analyse substrate composition. Photo quadrats and the FT transect of

For ORT habitats, SCUBA surveys for finfish were conducted in 10 meters depth of water, along a single 4 x 4 x 50 meter transect. Invertebrate data was collected along the same path, sampling within 1 x 40 meter transect. Substrate data was also collected along the same path, gathering ten 1 m^2 photoquadrats for substrate analysis.

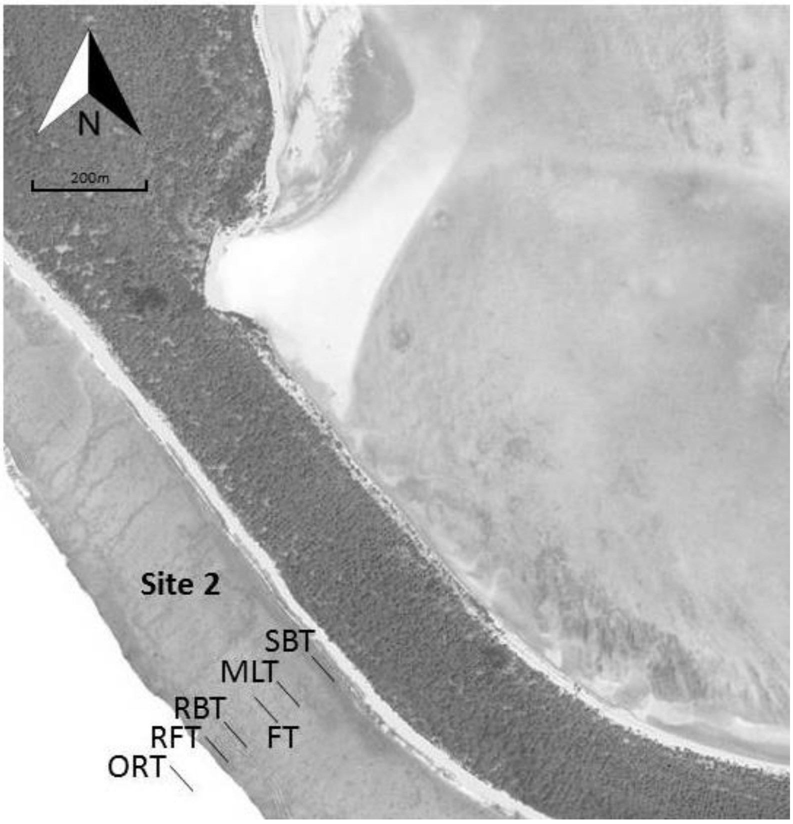

Fig. 3. Habitat types and relative locations within Site 2 on Manuae. Map source: Google DigitalGlobe.

For species of interest (sea turtles, *Cheilinus undulatus, Caranx ignobilis, Ablula glossodonta* and Carcharhinidae, for example) observed off transect, species data was collected but not included in the analyses.

Data collection of all species included identification to the lowest possible taxonomic classification, counts, and measurements when applicable. For finfish, fork length measurements were visually estimated. For invertebrate data collection, corals were excluded as they were captured and analysed within the substrate photoquadrats. For invertebrates, length measurements were gathered (mm) for the first ten individuals of commercially valuable species. Photoquadrats were analysed using several software packages that: straighten image perspective, select random points of assessment (n = 16) and record substrate or coral species at each point. Photoquadrat images were lens corrected with DxO Viewpoint 3 software and analysed with CPCe 4.1 software.

Turtle walk surveys were used to locate preferential nesting beaches. In Manuae, a Garmin etrex 20x was used to record GPS waypoints for each set of turtle tracks (up and down the beach slope) leading to an active nest. Confirmation of active nesting was made by careful excavation of randomly selected nests.

Analysis of variance (ANOVA) was used to compare means across designations (fixed factor; 3 levels: regulated, *rā'ui* and control), habitats (fixed factor; 5 levels for invertebrates: SBT, MLT, RBT, RFT and ORT; 2 levels for finfish: FT and ORT) and survey sites (nested factor within designation; island specific). For Manuae, since there was only one designation (regulated), this factor was excluded from the analyses. Raw measurements were standardised to represent all variables at densities per 100 m^2, except for length data. For replicates where certain species were not observed, zeros were incorporated into the data and used in the calculation of means and variation measures.

For invertebrates, three types of analyses were conducted. First, an overall analysis was performed to test differences among survey sites and designations at the scale of survey site (i.e.: habitats were grouped together and not considered) within the lagoon only. Secondly, an analysis was performed to test for differences across all five habitat types. Here, the factor "habitat" is crossed with the nested group of "designation/survey". Thirdly, for selected species variables, raw length data ("zero data" not included) was analysed at the scale of survey site within the lagoon and tested for differences between survey sites. The size distribution was also assessed and statistically compared to a normal distribution using a Shapiro-Wilk normality test. Due to low levels of replication or species records, some analyses could not be conducted.

For finfish, analysis was performed at the scale of habitats where differences were compared among survey sites and designations between FT and ORT habitats. Due to low levels of replication (Aitutaki, n=2 per survey site; Manuae, n=1 per survey site) or species records, some analyses could not be conducted.

All analyses were conducted using the statistical package R.

3. RESULTS

3.1 Aitutaki: Invertebrates

A total of 31,959 individuals were observed across 272 transects, representing 41 different genera/species during our invertebrate surveys in Aitutaki. The most frequently observed species of invertebrate was the sea cucumber, *Holothuria atra,* where a total of 15,953 individuals were recorded across all transects. The sea urchin, *Echinometra mathei,* was also dominant across all transects (n = 6,490).

3.1.1 Total Abundance

On average, total abundance ranged from 73.33 ± 7.48 ind./100 m^2 at Takitaki Bonefish Reserve to 772.97 ± 7.48 ind./100 m^2 at O'otu Rā'ui, a 10-fold difference between survey sites. The greatest densities were recorded at O'otu Rā'ui and Runway Control and were both significantly greater than densities of the regulated survey sites, Papau Bonefish Reserve and Takitaki Bonefish Reserve. This trend drove significant differences between regulated sites and both *rā'ui* and control sites (*Designation/Survey:* $F_{(8,261)} = 6.663$, $p < 0.0001$). Densities at O'otu Rā'ui were also noted to be significantly greater than 9 of the 10 other survey sites in Aitutaki (Fig. 4).

While the greatest densities of invertebrates were recorded in the RFT habitat of the O'otu Rā'ui, (mean ± 1 S.E. = 972.50 ± 273.01 ind./100 m^2), across all sites, the MLT and RBT habitats had the greatest numbers of invertebrates. Furthermore, densities within all lagoon habitats were significantly greater than the ORT habitat for all sites outside the lagoon (*Habitat:* $F_{(4,271)} = 10.629$, $p < 0.0001$).

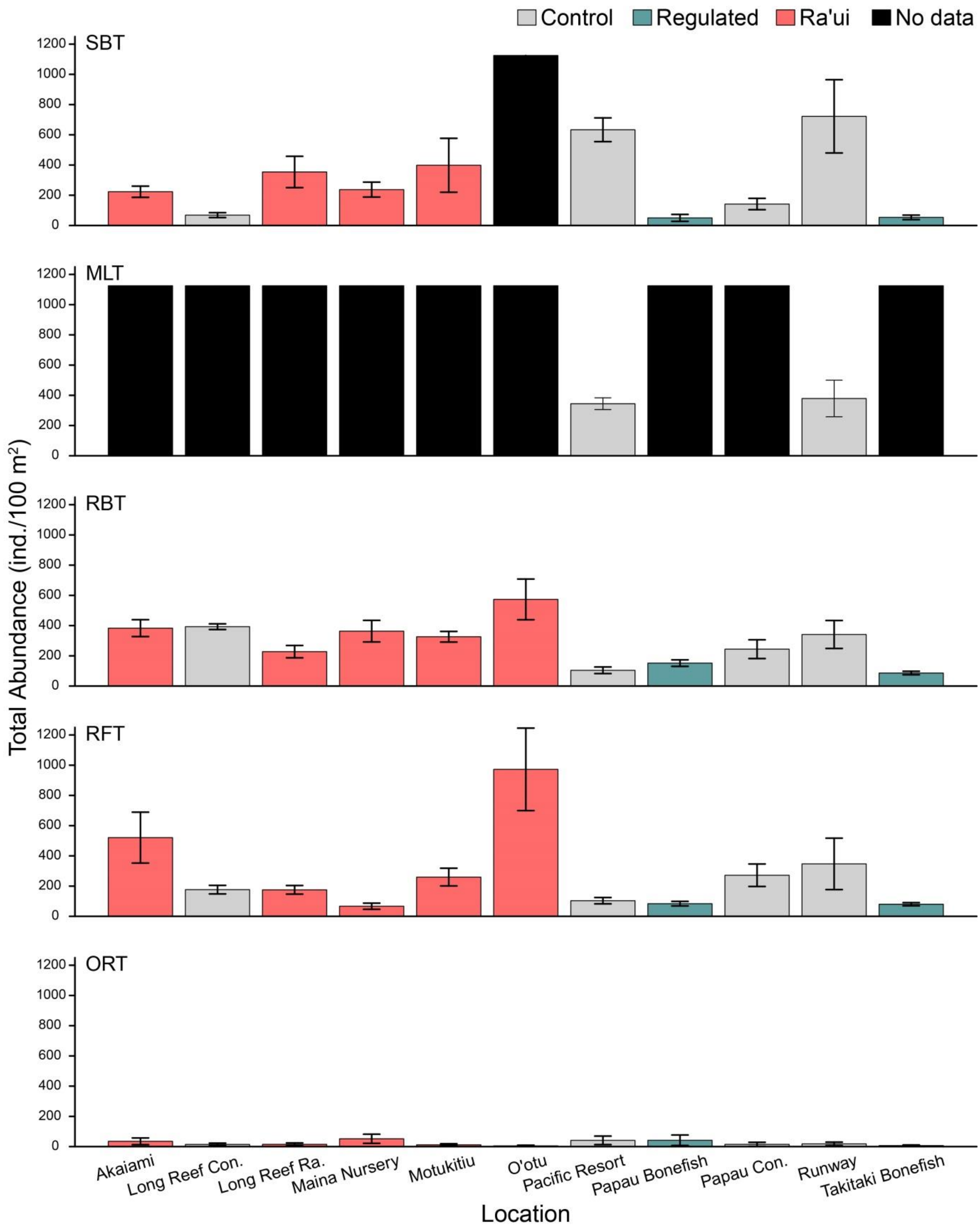

Fig. 4. Mean total abundance (± 1 S.E.) of invertebrates in 11 survey sites and 5 habitats of Aitutaki.

3.1.2 Total richness

Of the 41 different genera/species observed across all transects, overall, O'otu Rā'ui had the greatest diversity (mean ± 1 S.E. = 21.6 ± 1.29 ind./100 m^2) and was significantly greater than 9 of the 10 other survey sites. This trend drove significant variation between *rā'ui* and both regulated and control sites (*Designation:* $F_{(2,261)} = 17.552$, $p < 0.0001$). Furthermore, Maina Nursery, Akaiami Rā'ui, Papau Control, Long Reef Rā'ui and Long Reef Control also had significantly greater diversity compared to Pacific Resort Control, where the lowest diversity was recorded (Fig. 5). Within habitats, species diversity was concentrated in the RBT habitat of the Maina Nursery Rā'ui (mean ± 1 S.E. = 26.25 ± 1.77 ind./100 m^2) followed by the RBT and RFT habitats of the O'otu Rā'ui (means ± 1 S.E. = 22.81 ± 2.24 ind./100 m^2 and 20.31 ± 1.29 ind./100 m^2 respectively).

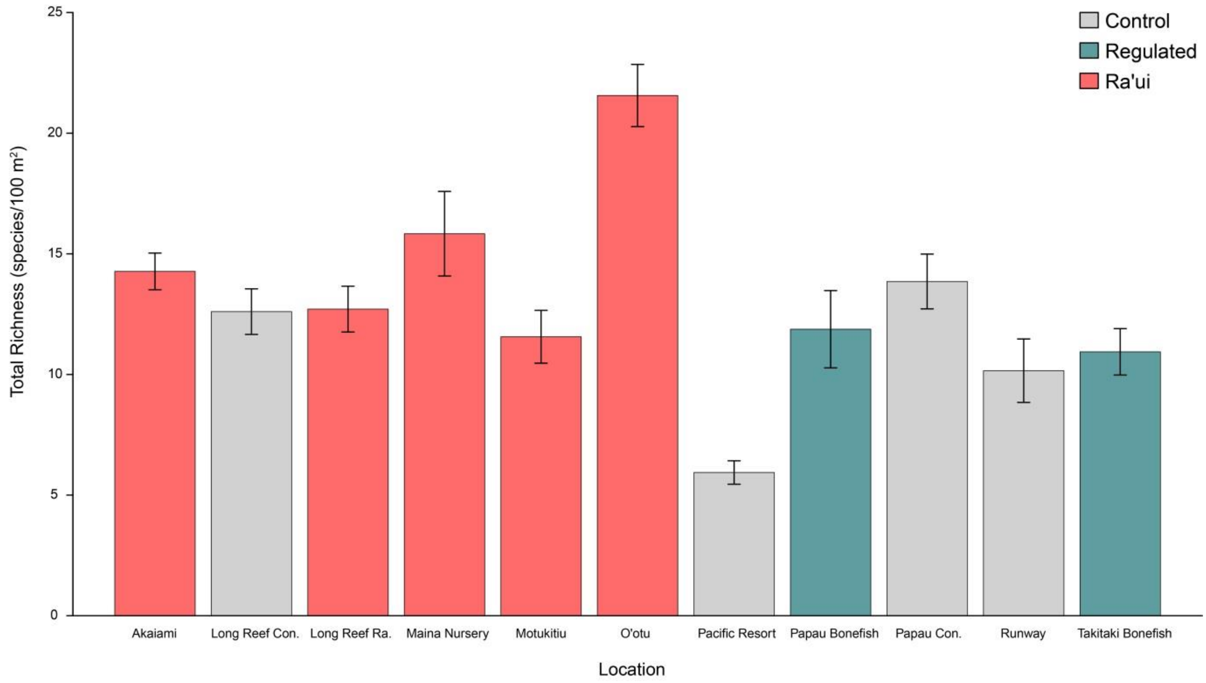

Fig. 5. Mean species richness (± 1 S.E.) of invertebrates in 11 survey sites within Aitutaki

3.1.3 Paua (Tridacna spp.*)*

Overall, *Paua* densities were greatest in Long Reef Rā'ui (mean ± 1 S.E. = 16.04 ± 4.57 ind./100 m^2) and Long Reef Control (mean ± 1 S.E. = 13.96 ± 7.36 ind./100 m^2), where densities were approximately 8.5 times greater compared to other sites (Fig. 6). Differences among survey sites were detected (*Designation/Survey:* $F_{(8,261)} = 4.982$, $p < 0.0001$) where within the control designation, Long Reef Control had significantly greater densities of *paua* than Pacific Resort, Papau Control and Runway Control; and within the *rā'ui* designation, Long Reef Rā'ui had significantly greater densities of *paua* than Akaiami Rā'ui, Maina Nursery Rā'ui, Motukitiu Rā'ui and O'otu Rā'ui.

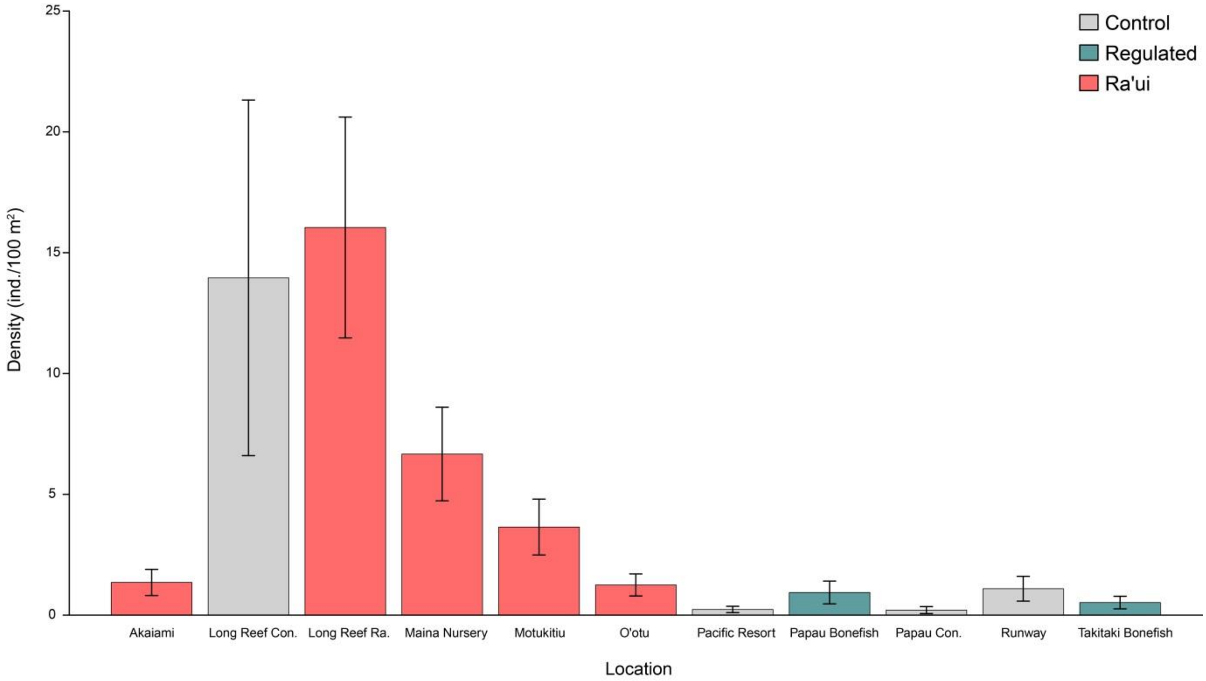

Fig. 6. Mean density (± 1 S.E.) of *Tridacna* spp. in 11 survey sites within Aitutaki

Considering different habitats, the highest densities of *paua* were recorded in the RBT and SBT habitats, particularly the RBT habitat of Long Reef Rā’ui (mean ± 1 S.E. = 35.94 ± 10.05 ind./100 m^2), Long Reef Control (mean ± 1 S.E. = 27.81 ± 21.43 ind./100 m^2) and Maina Nursery Rā’ui (mean ± 1 S.E. = 15.94 ± 4.01 ind./100 m^2); and the SBT habitat of Long Reef Control (mean ± 1 S.E. = 13.13 ± 4.72 ind./100 m^2) and Long Reef Rā’ui (mean ± 1 S.E. = 10.94 ± 3.57 ind./100 m^2).

Paua were largest in the Papau Bonefish Reserve (mean ± 1 S.E. = 96.11 ± 15.41 mm) and smallest in Runway Control (mean ± 1 S.E. = 71.43 ± 6.01 mm), but no significant difference were detected amongst survey sites and designations. However, across all survey sites, the length-frequency distribution was significantly different from a normal distribution and skewed left, with the majority of lengths smaller than the 75 mm minimum size allowable for harvest (Fig. 7).

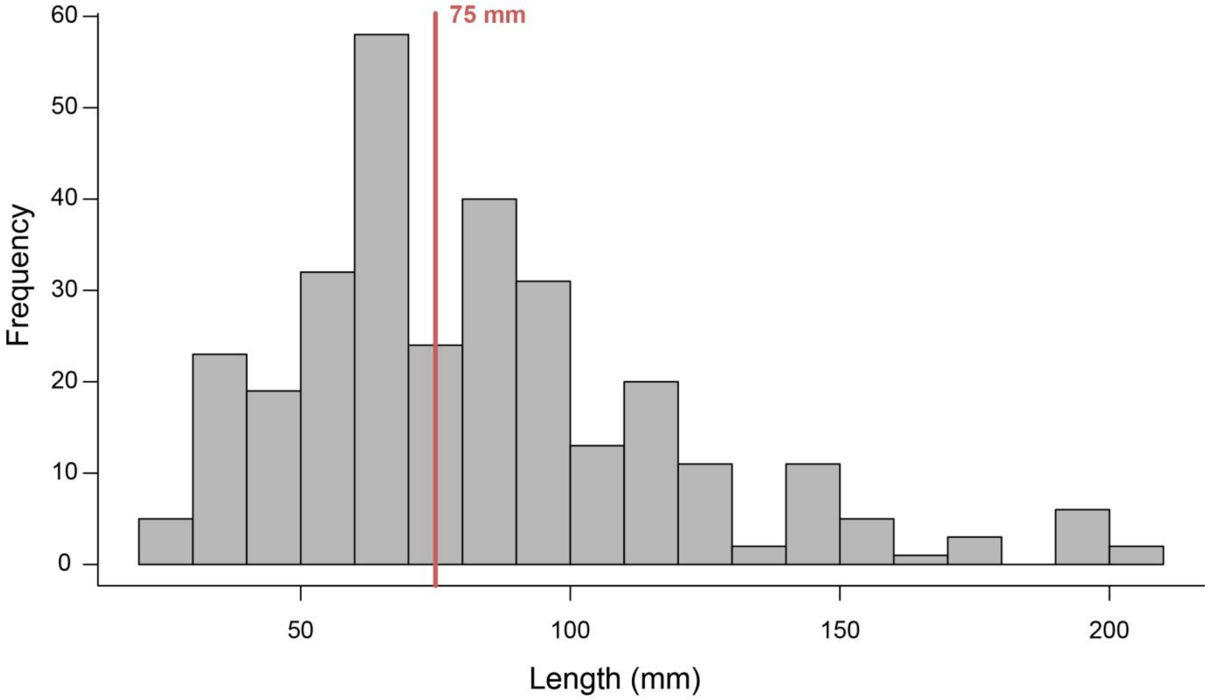

Fig. 7. Length-frequency histogram of *Tridacna* spp. within Aitutaki with 75 mm minimum allowable harvest size indicated.

3.1.4 Pipi (Pinctada maculata)

Pipi were observed on 17 of 272 transects. *Pipi* densities were low across all sites and habitats. The highest density was recorded within the RBT habitat of Runway Control (mean ± 1 S.E. = 16.88 ± 11.84 ind./100 m^2) and was approximately three times greater than the second highest density. Despite this, no significant differences in densities were detected between sites or habitats. On average, *pipi* size was 20.5 ± 4.21 mm and did not differ significantly between survey sites.

3.1.5 Pārau (Pinctada margaritifera)

A total of two *pārau* were observed on a single transect within the RBT habitat of Papau Bonefish Reserve. There were no significant differences in *pārau* densities between sites or habitats.

3.1.6 Trochus (Tectus niloticus)

The greatest densities of trochus were observed at the Akaiami Rā'ui, concentrated within the RBT (mean ± 1 S.E. = 114.06 ± 35.76 ind./100 m^2) and RFT (mean ± 1 S.E. = 110.00 ± 50.80 ind./100 m^2) habitats. The density of trochus within Akaiami Rā'ui was significantly greater than all other sites in Aitutaki (*Designation/Survey:* $F_{(8,261)} = 7.839$, $p < 0.0001$), driving further significant differences between *rā'ui* sites and other designations (Fig. 8).

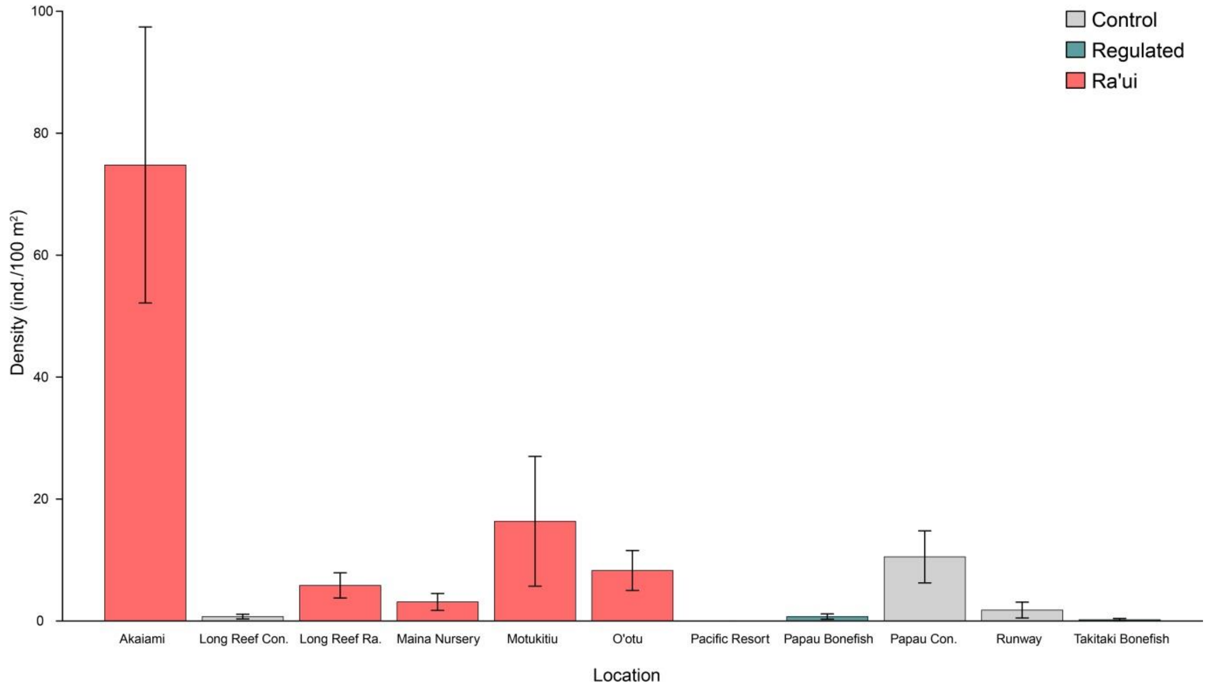

Fig. 8. Mean density (± 1 S.E.) of *Tectus niloticus* in 11 survey sites within Aitutaki.

Trochus lengths were significantly different between sites (*Designation/Survey:* $F_{(7,309)} = 10.716$, $p < 0.0001$). The largest trochus were measured in the Maina Nursery Rā'ui (mean ± 1 S.E. = 110.64 ± 2.96 mm) and were on average 1.13 times larger than trochus measured in the Akaiami Rā'ui (mean ± 1 S.E. = 97.74 ± 1.63 mm). The length-frequency distribution analysis shows that the majority of trochus fall within the harvest size limits (80-110 mm, Fig. 9).

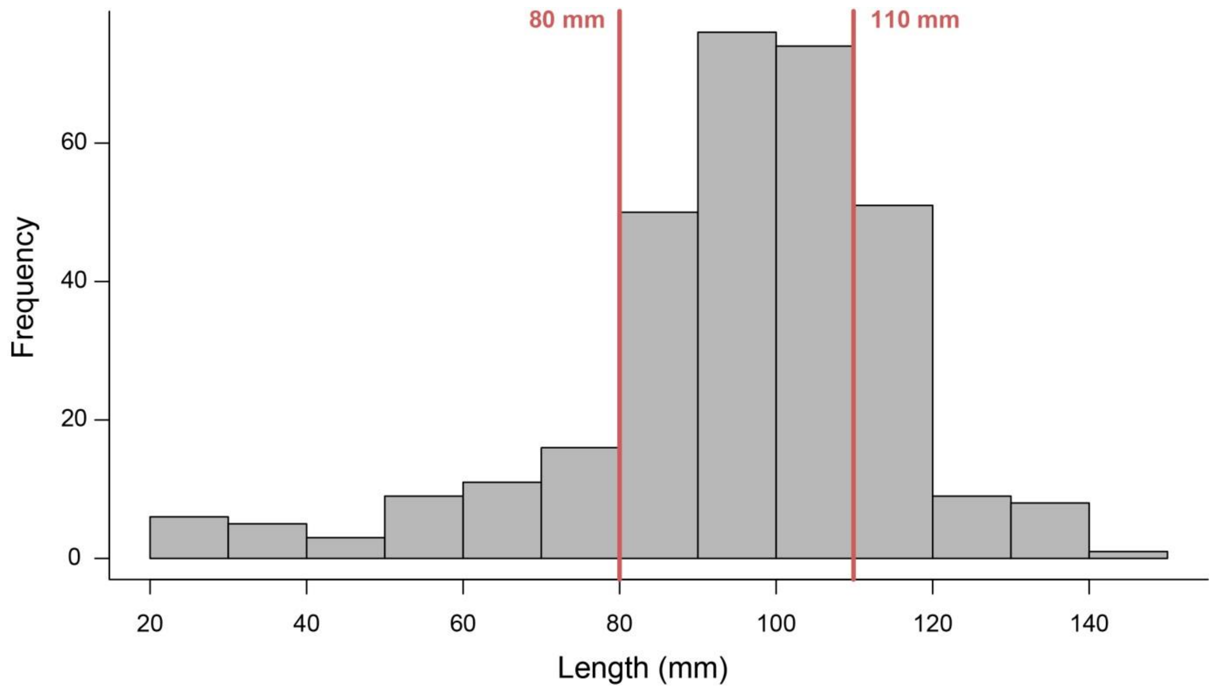

Fig. 9. Length-frequency histogram of *Tectus niloticus* within Aitutaki with 80-110 mm slot harvest size indicated.

3.1.7 Ariri (Turbo setosus)

There were no *ariri* recorded.

3.1.8 Ungakoa (Dendropoma maximum)

Ungakoa densities were greatest within Maina Nursery Rā'ui (mean ± 1 S.E. = 26.46 ± 8.04 ind./100 m^2) and Long Reef Control (mean ± 1 S.E. = 24.69 ± 6.38 ind./100 m^2). These densities were significantly greater than Papau Control (*Designation/Survey:* $F_{(8,261)} = 2.65$, $p < 0.01$).

Significant differences were detected at the habitat scale where, on average, densities were greater within the SBT habitat, followed by the RBT habitat (*Habitat:* $F_{(4,271)} = 3.05$, $p = 0.018$).

3.1.9 Rori Toto (Holothuria atra)

Overall, the greatest densities of *rori toto* were observed at Runway Control (mean ± 1 S.E. = 315.00 ± 80.87 ind./100 m^2) and Pacific Resort Control (mean ± 1 S.E. = 262.89 ± 48.42 ind./100 m^2) and these densities were significantly greater than those of Takitaki

Bonefish Reserve, Papau Control and Papau Bonefish Reserve, where the lowest densities of *rori toto* were recorded (*Designation/Survey:* $F_{(8,261)} = 4.25$, $p < 0.001$, Fig. 10)

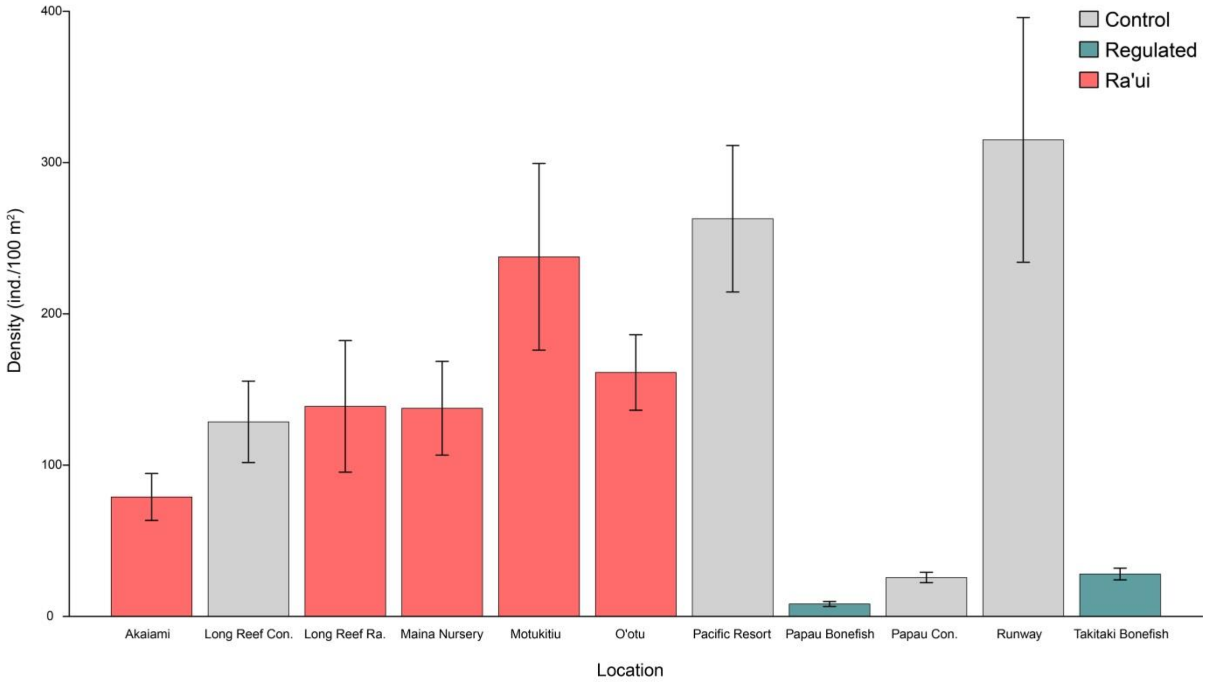

Fig. 10. Mean density (± 1 S.E.) of *rori toto* in 11 survey sites within Aitutaki.

Rori toto densities were highest near shore in SBT habitats. Densities decreased by a factor of approximately 4.9 towards the reef crest RFT habitat (*Habitat:* $F_{(4,271)} = 21.14$, $p < 0.001$). No *rori toto* were observed in the ORT habitat.

Size analysis for *rori toto* detected significant differences in lengths (*Designation/Survey:* $F_{(8,2582)} = 33.684$, $p < 0.001$). In contrast to the density results, the largest *rori toto* were recorded at Papau Control, Papau Bonefish Reserve and Takitaki Bonefish Reserve and were approximately 1.4 times larger than *rori toto* at Motukitiu Rā'ui and Runway Control (Fig. 11).

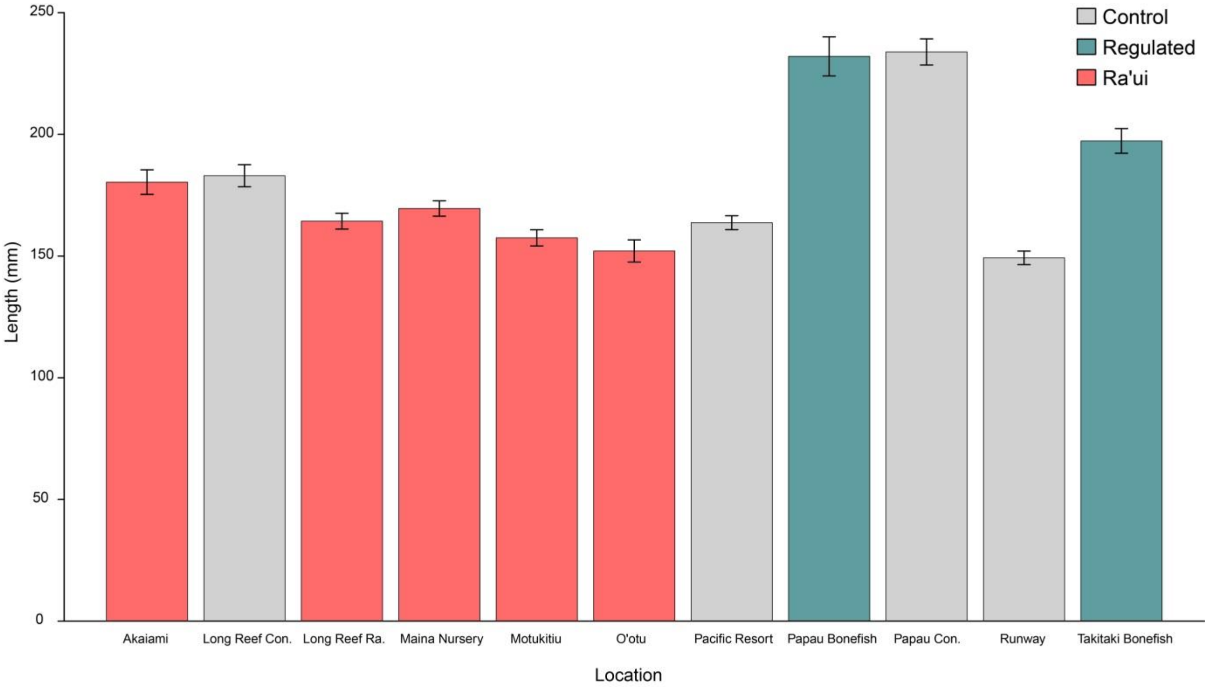

Fig. 11. Mean length (± 1 S.E.) of *rori toto* in 11 survey sites within Aitutaki.

3.1.10 Rori Piripiri (Holothuria leucospilota)

Rori piripiri were recorded at 9 of the 11 sites. The greatest densities were recorded at O'otu Rā'ui and Runway Control (mean ± 1 S.E. = 42.81 ± 12.96 ind./100 m^2 and 19.45 ± 7.03 ind./100 m^2 respectively). Furthermore, densities recorded at O'otu Rā'ui were significantly greater than those at all other survey sites (*Designation/Survey:* $F_{(8,2582)} = 33.684$, $p < 0.001$).

Approximately 70% of *rori piripiri* were observed in RBT and RFT habitats. Within these habitats, densities of *rori piripiri* were greatest within O'otu Rā'ui, driving significant differences among sites and habitats (*Habitat/Designation/Survey:* $F_{(24,271)} = 1.740$, $p = 0.019$). High densities were also noted in the SBT and MLT habitats of the Runway Control, with animals commonly observed in all habitats other than ORT.

3.1.11 Rori Rimu (Stichopus chloronotus)

Overall, Papau Control and Maina Nursery Rā'ui had the greatest densities of *rori rimu* (mean ± 1 S.E. = 13.65 ± 4.55 ind./100 m^2 and 11.15 ± 4.09 ind./100 m^2 respectively; Fig. 12). Between sites, densities at Papau Control were significantly greater than densities in Akaiami Rā'ui and Pacific Resort Control (*Designation/Survey:* $F_{(8,261)} = 4.401$, $p < 0.001$).

Densities of *rori rimu* were concentrated within the RFT habitat across several sites, including Papau Control, driving significant differences in the data (*Habitat/Designation/Survey:* $F_{(24,271)} = 3.244$, $p < 0.001$).

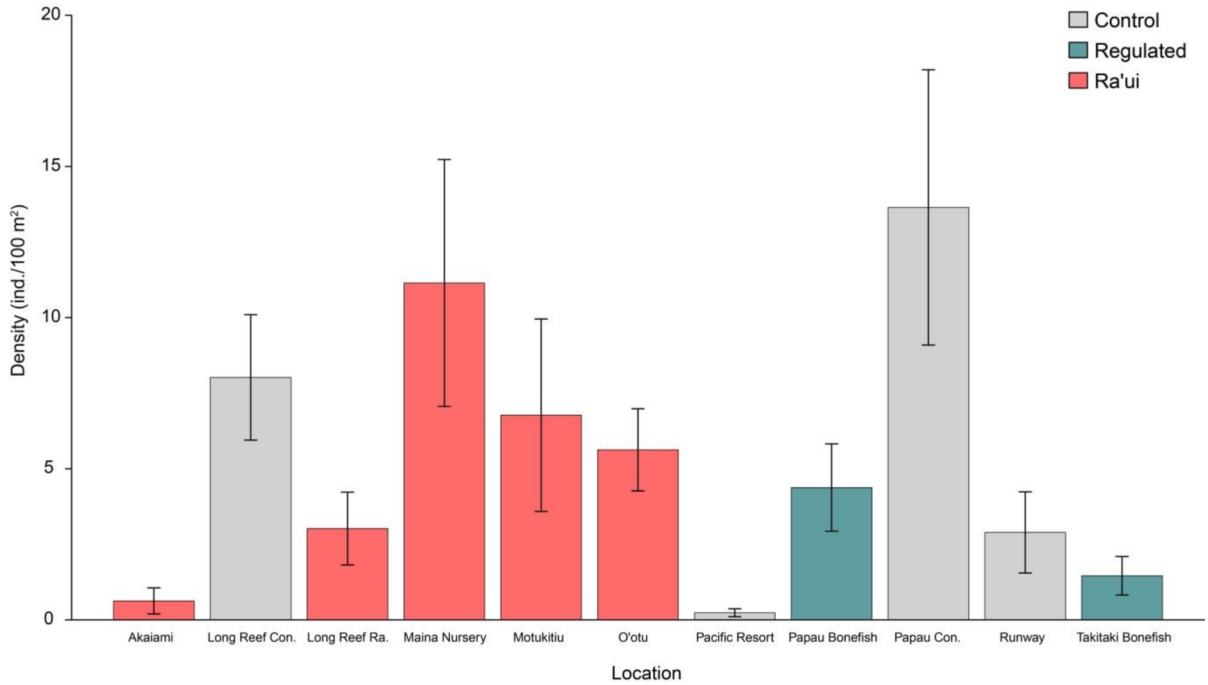

Fig. 12. Mean density (± 1 S.E.) of *rori rimu* in 11 survey sites within Aitutaki.

3.1.12 Rori Puakatoro (Actinopyga mauritiana)

Between sites, significant differences of *rori puakatoro* were detected (*Designation/Survey:* $F_{(8,261)} = 4.986$, $p < 0.001$) where densities within O'otu Rā'ui (mean ± 1 S.E. = 17.34 ± 6.06 ind./100 m^2) and Runway Control (mean ± 1 S.E. = 14.69 ± 4.47 ind./100 m^2) survey sites were approximately 77 times greater than densities of *rori puakatoro* at Papau Bonefish Reserve (mean ± 1 S.E. = 0.21 ± 0.14 ind./100 m^2).

For 8 of the 9 survey sites where *rori puakatoro* were observed, densities were greatest in the RFT habitats (*Habitat/Designation/Survey:* $F_{(24,271)} = 2.123$, $p < 0.01$). No *rori puakatoro* were record in the ORT habitat.

3.1.13 Vana (Echinothrix diadema)

There were no *vana* recorded.

3.1.14 Āvake (Tripneustes gratilla)

Overall, *āvake* were observed in only four of the 11 survey sites. Among these sites, Papau Bonefish Reserve had the greatest densities of *āvake* (mean ± 1 S.E. = 5.73 ± 3.50 ind./100 m^2.

Within Papau Bonefish Reserve, the majority of *āvake* were observed in the RBT habitat (mean ± 1 S.E. = 16.88 ± 9.69 ind./100 m^2), and similarly for O'otu Rā'ui and Runway Control. Lower densities of *āvake* were also noted for SBT habitats within Papau Bonefish Reserve and Akaiami Rā'ui. No *āvake* were observed in either the RFT or ORT habitats.

3.1.15 Vana (Echinothrix diadema)

Overall *vana* densities were greatest in *rā'ui* designated survey sites (*Designation:* $F_{(2,261)} = 15.576$, $p < 0.001$, Fig. 13). *Vana* were recorded in all sites except for Pacific Resort Control and the largest densities were recorded in Long Reef Rā'ui and Akaiami Rā'ui (mean ± 1 S.E. = 41.98 ± 12.39 ind./100 m^2 and 34.79 ± 12.67 ind./100 m^2 respectively). Across sites, Akaiami Rā'ui and Long Reef Rā'ui had significantly greater densities of *vana* than Pacific Resort Control, Runway Control, Papau Bonefish Reserve, Papau Control, and Takitaki Bonefish Reserve (*Designation/Survey:* $F_{(8,261)} = 3.784$, $p < 0.001$). Densities in Long Reef Rā'ui were also significantly greater than in Long Reef Control.

Within the Akaiami Rā'ui and Long Reef Rā'ui, the majority of *vana* were observed within the RFT habitat, driving significant variability among habitats and designations (*Habitat/Designation:* $F_{(6,271)} = 3.620$, $p < 0.001$). Densities in the RFT habitat were, on average, eight times greater than within other habitats where *vana* were observed. No *vana* were observed in MLT or ORT habitats.

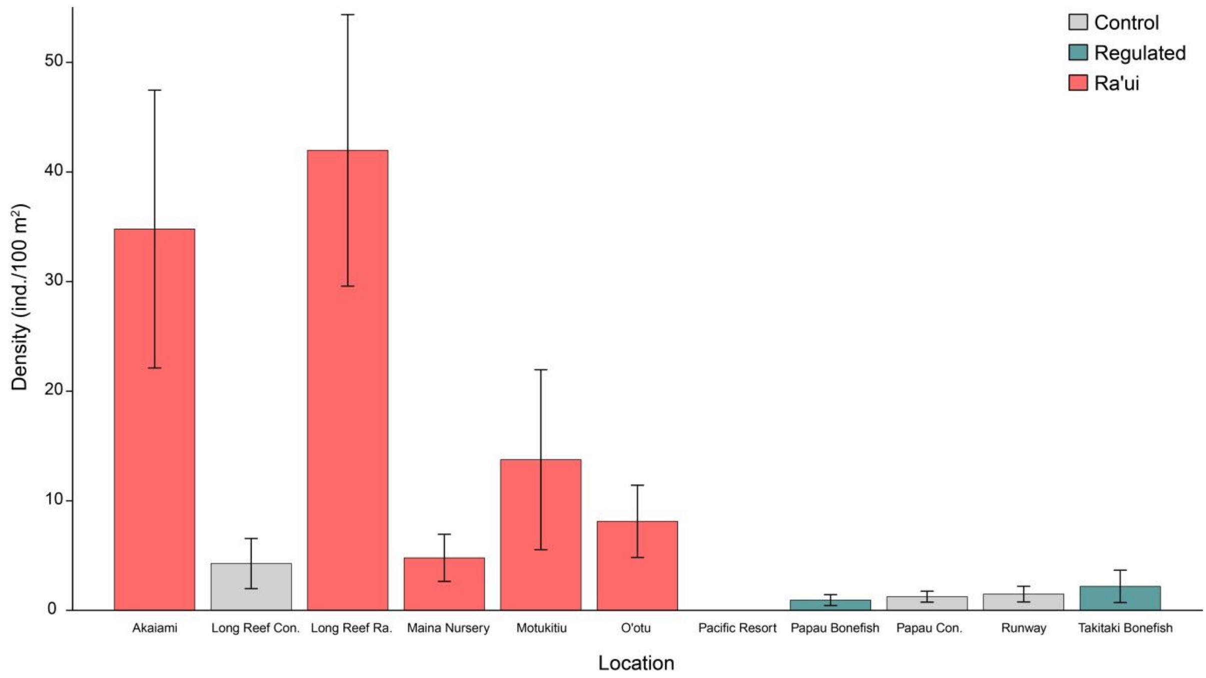

Fig. 13. Mean density (± 1 S.E.) of *vana* in 11 survey sites within Aitutaki.

3.1.16 'Atuke (Heterocentrotus mammillatus)

No *'atuke* were recorded.

3.1.17 Taramea (Acanthaster planci)

Low densities (approximately 0.05 ind./100 m^2 across all transects) of *taramea* were observed. Despite this, the survey sites where *taramea* were observed were all within the *rā'ui* designation. However, no significant differences in density were detected. Two *taramea* were observed within the SBT habitat of Long Reef Rā'ui, one within the SBT habitat of Maina Nursery Rā'ui and two within the RFT habitat of Akaiami Rā'ui.

3.2 Aitutaki: Finfish

A total of 13,710 individuals were observed across 42 transects, representing 169 different genera/species during the finfish surveys in Aitutaki. The most frequently observed species of finfish was *Chromis acares,* where a total of 4,782 individuals were recorded.

3.2.1 Total Abundance

Finfish densities were greatest in ORT habitats compared to FT habitats, particularly for ORT habitats on the western side of Aitutaki. Significant differences between ORT and FT habitats accounted for a large proportion of variability in the data and there was no apparent distinction of designation (*Habitat:* $F_{(7,21)} = 4.23$, $p < 0.01$, Fig. 14).

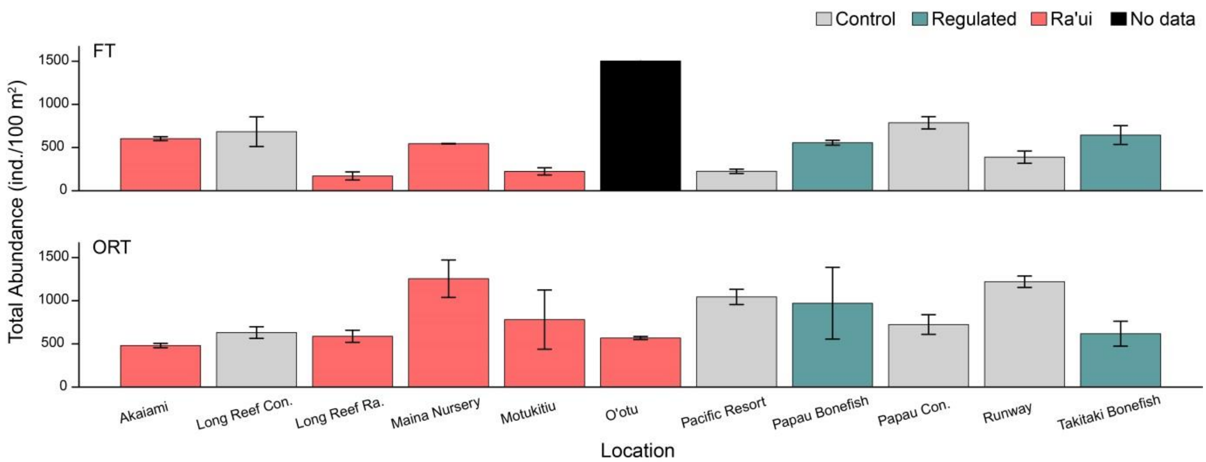

Fig. 14. Mean abundance (± 1 S.E.) of all finfish observed in 11 survey sites and 2 habitats within Aitutaki.

3.2.2 Total Richness

The greatest species diversity was observed within the ORT habitat of Maina Nursery Rā'ui (mean ± 1 S.E. = 75 ± 15 ind./100 m^2) and overall, high diversity was concentrated outside of the lagoon, driving significant differences between habitats (*Habitat:* $F_{(1,21)} = 19.50$, $p < 0.001$, Fig. 15).

On average, finfish richness was approximately 53 species across all sites. Compared to the total number of species identified (n = 169), this average diversity indicates that the community composition has potentially greater differences/meaning/variability than species diversity alone.

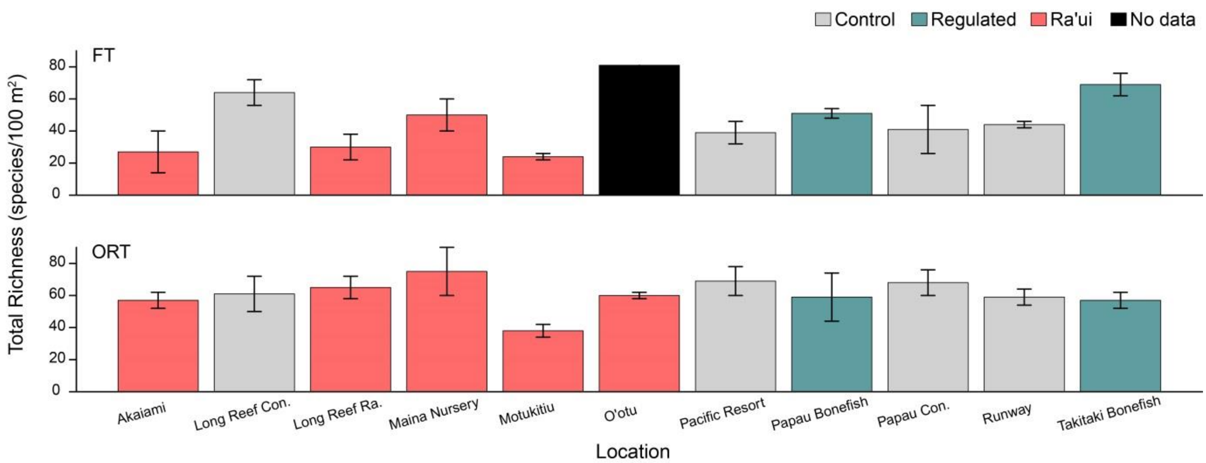

Fig. 15. Mean richness (± 1 S.E.) of all finfish species observed in 11 survey sites and 2 habitats within Aitutaki.

3.2.3 'Iku-toto (Acanthurus achilles)

Observations of *'iku-toto* were confined to DFT habitats, driving significant differences (*Habitat:* $F_{(1,21)} = 11.01$, $p = 0.003$), particularly in Papau Control, O'otu Rā'ui, Runway Control, Pacific Resort Control and Akaiami Rā'ui.

3.2.4 Urua (Caranx ignobilis)

The only *urua* observation was of a single animal within the FT habitat of the Maina Nursery Rā'ui. There were no significant differences in *urua* densities between sites.

3.2.5 Ava (Chanos chanos)

Only three *ava* were observed, all within the ORT habitat of Papau Bonefish Reserve. There were no significant differences in *ava* densities between sites.

3.2.6 Maratea (Cheilinus undulatus)

Maratea were only observed in ORT habitats, particularly within Motukitiu Rā'ui (n = 6), Papau Bonefish Reserve (n = 8), Papau Control (n = 4) and Takitaki Bonefish Reserve (n = 2). Significant differences were detected at the habitat scale (*Habitat:* $F_{(1,21)} = 6.49$, $p = 0.019$), but there were no significant differences in *maratea* densities between sites.

3.2.7 Pipi (Kyphosus **spp.***)*

Low numbers of *pipi* were observed within the FT habitat of Long Reef Control (n = 1) and within the ORT habitat of Maina Nursery Rā'ui (n = 1) and Papau Bonefish Reserve (n = 2). There were no significant differences in *pipi* densities between sites, designations or habitats.

3.2.8 'Īroa (Lethrinus xanthochilus)

Observations of *'īroa* were primarily limited to the ORT habitat of Papau Control, which had significantly higher densities than all other sites in Aitutaki (*Habitat/Designation/Survey:* $F_{(7,21)} = 68.63$, $p < 0.0001$). The only other location where *'īroa* were observed was within the ORT habitat of Long Reef Rā'ui (n = 2).

3.2.9 Mū (Monotaxis grandoculis)

The greatest densities of *mū* were observed within the ORT habitats of Papau Bonefish Reserve and Pacific Resort Control (mean ± 1 S.E. = 21 ± 9 ind./100 m^2 and 11 ± 5 ind./100 m^2 respectively), as well as the FT habitat of Maina Nursery Rā'ui (n = 8). However, there were no significant differences in *mū* densities between sites or habitats.

3.2.10 Vete and Takua (Mulloidichthys spp.*)*

The only observations of *vete* and/or *takua* were within the Takitaki Bonefish Rā'ui (n = 30). There were no significant differences in *vete* and/or *takua* densities between sites.

3.2.11 Umeume (Naso lituratus)

Significant differences in *umeume* densities were detected, where average densities in ORT habitats were 4.5 times greater than those in FT habitats (*Habitat:* $F_{(1,21)} = 6.38$, $p = 0.020$). The greatest densities of *umeume* were observed in ORT habitats of the similarly designated sites of Maina Nursery Rā'ui, Akaiami Rā'ui, Motukitiu Rā'ui and O'otu Rā'ui.

3.2.12 Ume (Naso unicornis)

Ume were only observed in the ORT habitats of the Motukitiu Rā'ui (n = 16), O'otu Rā'ui (n = 8) and Papau Bonefish Reserve (n = 2). There were no significant differences in *ume* densities between sites.

3.2.13 U'u (Scaridae)

The greatest densities of *u'u* were observed in the FT habitat of Long Reef Control (mean ± 1 S.E. = 77 ± 17 ind./100 m^2) and were significantly greater than all other sites and habitats except the FT habitat of Maina Nursery Rā'ui (*Habitat/Designation/Survey:* $F_{(7,21)} = 6.96$, $p < 0.001$, Fig. 16).

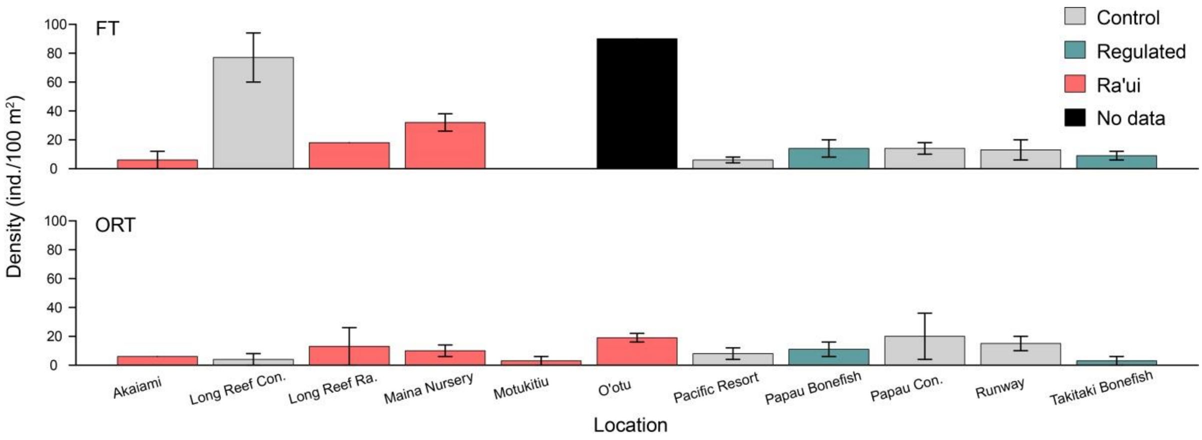

Fig. 16. Mean density (± 1 S.E.) of all Scaridae species observed in 11 survey sites and 2 habitats within Aitutaki.

3.2.14 Maemae (Siganus spp.)

Maemae were only observed within the ORT habitat of Maina Nursery Rā'ui (n = 2). There were no significant differences in *maemae* densities between sites, designations or habitats.

3.2.15 Mango (Carcharhinidae)

No sharks were recorded on transects, however, one whitetip reef shark (*Triaenodon obesus*) and one grey reef shark (*Carcharhinus amblyrhynchos*) were observed off transect.

3.3 Manuae: Invertebrates

A total of 15,021 individuals were observed across 84 transects, representing 22 different genera/species during the invertebrate surveys in Manuae. The most frequently observed species of invertebrates were *Holothuria atra* and *Tridacna* spp., where a total of 7,218 and 5,763 individuals were recorded across all transects, respectively.

3.3.1 Total abundance

The largest values for total abundance were recorded at Site 2 (mean ± 1 S.E. = 949.84 ± 204.96 ind./100 m^2). These values were 10 times greater than the lowest values at Site 2A (mean ± 1 S.E. = 94.38 ± 34.13 ind./100 m^2) and accounted for significant overall variation between survey sites (*Survey:* $F_{(5,78)} = 5.65$, $p < 0.001$). Total abundance was similarly low in Site 1 (mean ± 1 S.E. = 118.91 ± 25.26 ind./100 m^2, Fig. 17).

High invertebrate abundance was concentrated in the MLT and RBT habitats of Site 2 (mean ± 1 S.E. = 1341.88 ± 577.08 and 1295.63 ± 401.46 ind./100 m^2 respectively). Despite this, differences among habitats were primarily driven by low abundances in RFT and ORT habitats (*Habitat:* $F_{(4,63)} = 4.402$, $p = 0.003$).

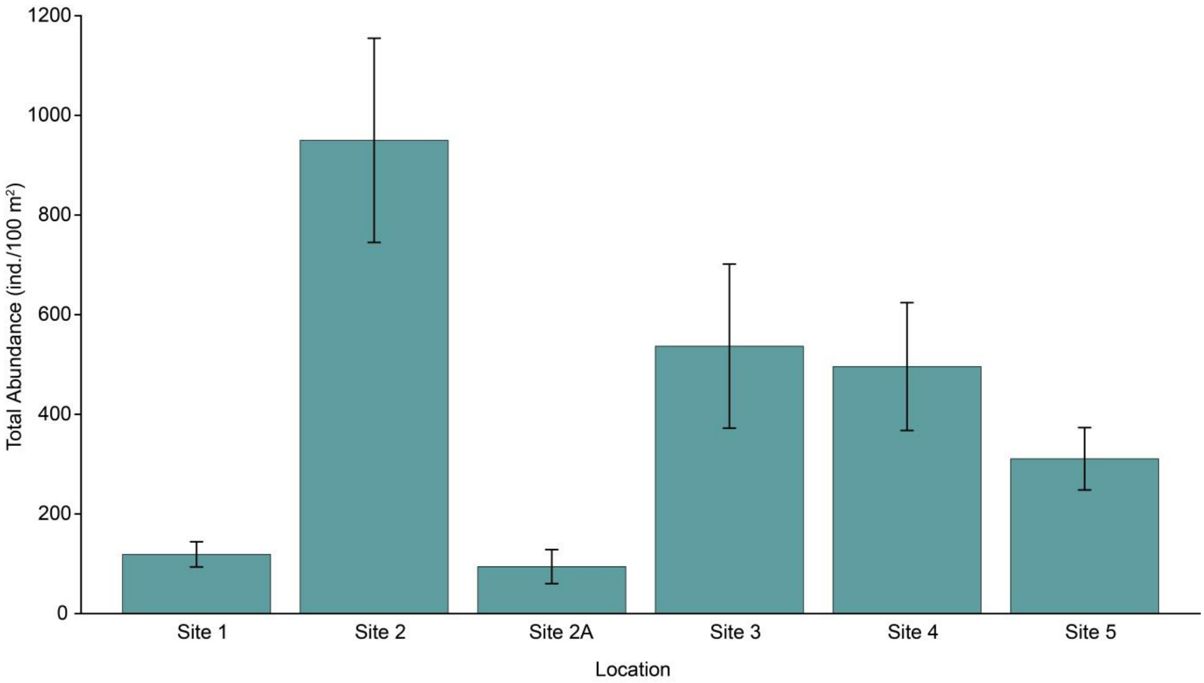

Fig. 17. Mean abundance (± 1 S.E.) of all finfish observed in 6 survey sites within Manuae.

3.3.2 Total richness

Overall, the greatest diversity of species identified were recorded at Site 2 (mean ± 1 S.E. = 9.38 ± 0.84 species/100 m^2), particularly within the RBT, RFT and MLT habitats. Total richness in the RBT and RFT habitats of Site 5 were similarly high, driving significant differences between sites and habitats (*Habitat/Survey:* $F_{(16,63)} = 2.357$, $p = 0.008$).

3.3.3 Paua (Tridacna **spp.***)*

Overall, densities of *paua* were relatively high, particularly compared to Aitutaki, and were greatest in Site 2 and Site 3 (mean ± 1 S.E. = 488.13 ± 163.48 and 282.97 ± 118.90 ind./100 m^2 respectively). Furthermore, greater densities of *paua* were generally observed in the MLT and RBT habitats, particularly of Site 2, Site 3 and Site 5. Significant differences between both survey sites and habitats were detected (*Habitat/Survey:* $F_{(16,63)} = 2.317$, $p = 0.009$). Greater densities of *paua* were recorded in the RBT habitat of Site 2 than most other habitat and sites. Within the MLT habitat, densities recorded at Site 2 were significantly greater than those at Site 1, Site 2A and Site 5 (Fig. 18).

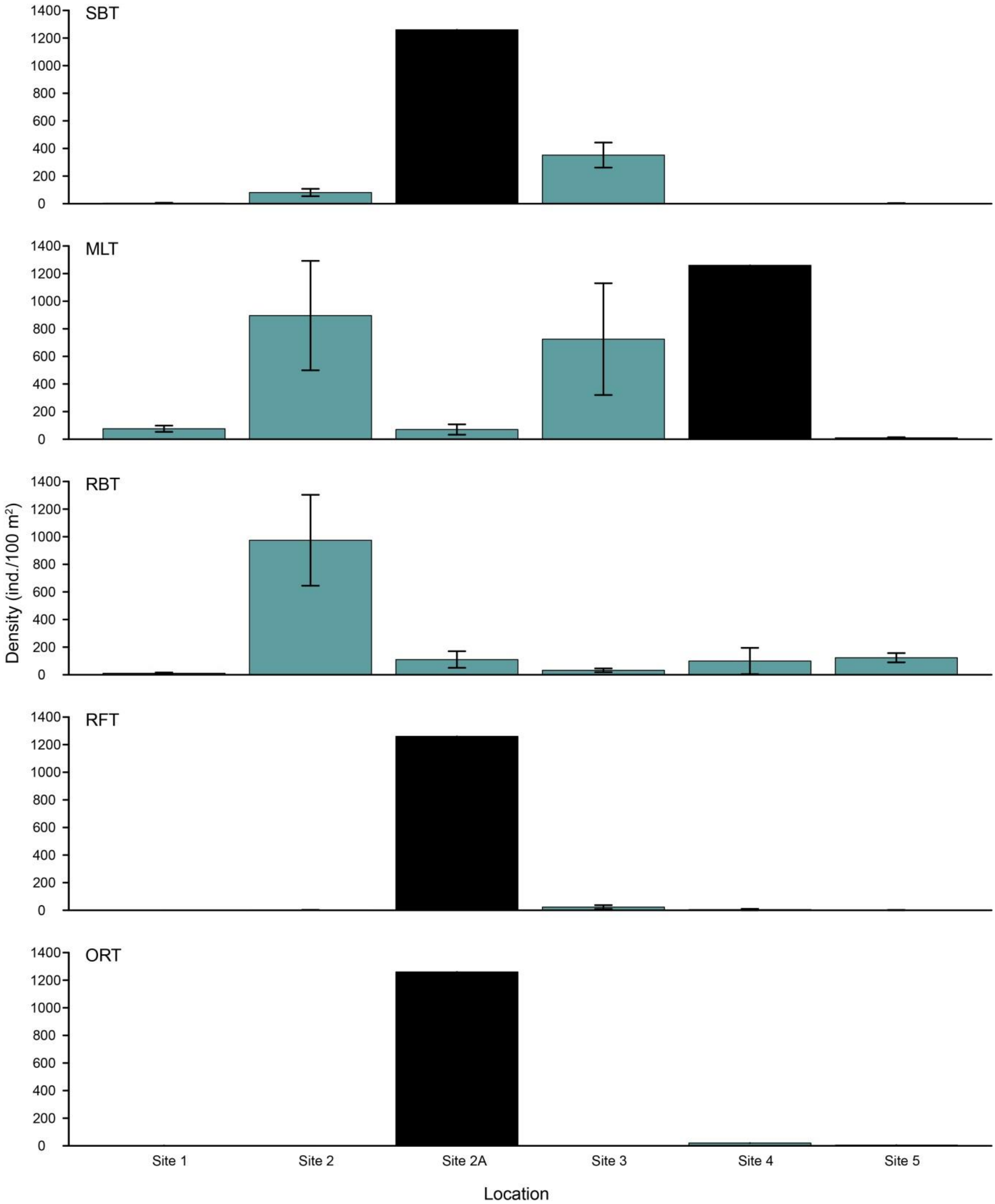

Fig. 18. Mean density (± 1 S.E.) of *paua* observed in 6 survey sites and 5 habitats within Manuae.

On average, *paua* were largest in Site 2A (mean ± 1 S.E. = 176.79 ± 8.32 mm), despite having lower overall densities. The smallest *paua* were recorded in Site 4 (mean ± 1 S.E. = 101.74 ± 11.19 mm), contributing to the significant differences between sites (*Survey:* $F_{(5,443)}$

= *11.483, p < 0.001*). Across all sites, the length-frequency distribution was significantly different from a normal distribution and skewed right with the majority of lengths above the 75 mm minimum size allowable for harvest (Fig. 19).

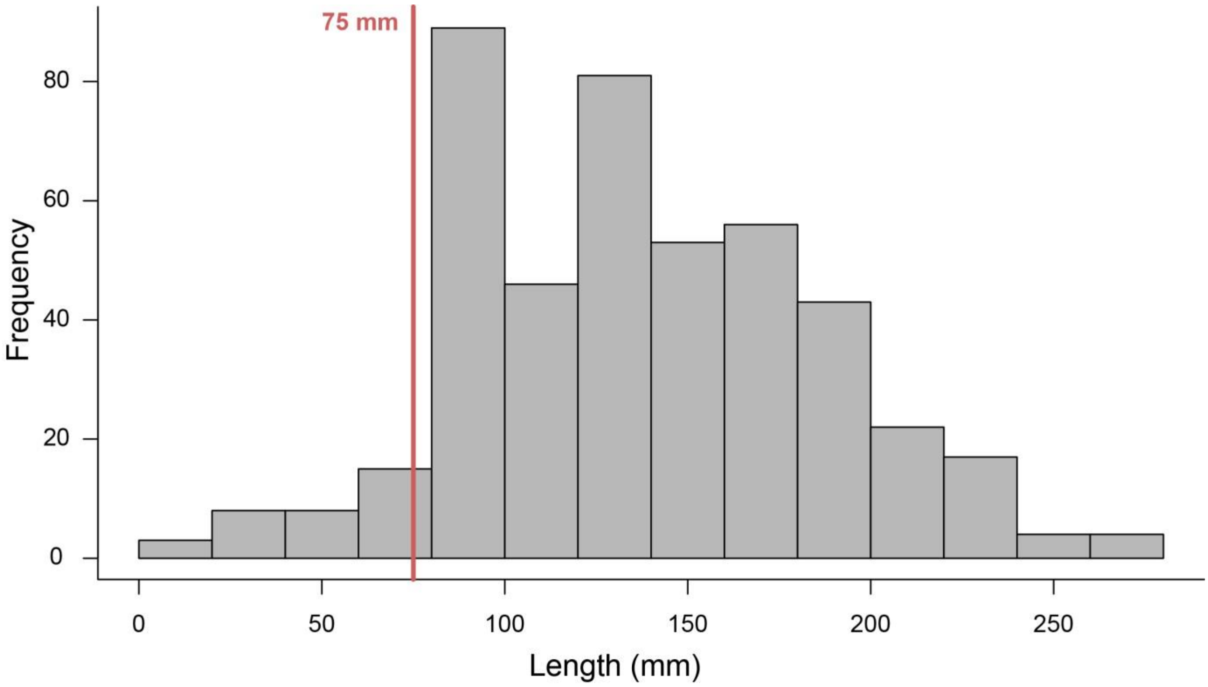

Fig. 19. Length-frequency histogram of *paua* within Manuae with 75 mm minimum allowable harvest size indicated.

3.3.4 Pipi (Pinctada maculata)

No *pipi* were recorded.

3.3.5 Pārau (Pinctada margaritifera)

Only a single *pārau*, with a length of 220 mm, was recorded. This observation was made within the RBT habitat of Site 2A.

3.3.6 Trochus (Tectus niloticus)

No *trochus* were recorded.

3.3.7 Ariri (Turbo setosus)

Ariri were observed in four of the six sites. The greatest densities of *ariri* were recorded in Site 4 and were concentrated within the RBT habitat (mean ± 1 S.E. = 296.25 ± 171.05 ind./100 m^2). Densities here were significantly greater than those of any other location (*Survey:* $F_{(5,63)} = 3.706$, $p = 0.005$). No *ariri* were recorded in SBT, MLT or ORT habitats, or Site 3.

3.3.8 Ungakoa (Denropoma maximum)

There were significantly greater densities of *ungakoa* in Site 2 and Site 1 (mean ± 1 S.E. = 49.38 ± 15.68 and 42.19 ± 19.36 ind./100 m^2 respectively) than Site 3, Site 4 and Site 5 (*Survey:* $F_{(5,63)} = 3.436$, $p = 0.008$, Fig. 20). *Ungakoa* were not recorded in Site 2A. High densities of *ungakoa* were present within the RFT habitat of Site 1 and Site 2, within the ORT habitat of Site 4 and SBT habitat of Site 2.

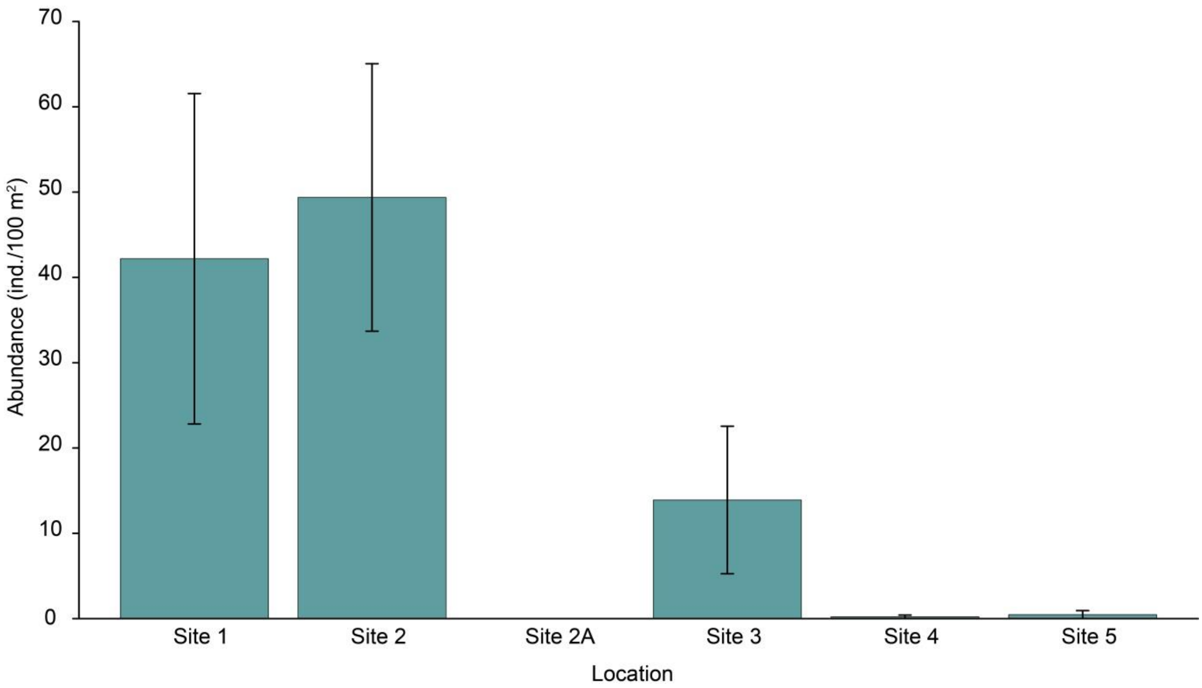

Fig. 20. Mean density (± 1 S.E.) of *ungakoa* observed in 6 survey sites within Manuae

3.3.9 Rori Toto (Holothuria atra)

The greatest densities of *rori toto* were recorded in the SBT habitats of Site 2 (mean ± 1 S.E. = 835.63 ± 245.89 ind./100 m^2) and Site 4 (mean ± 1 S.E. = 827.50 ± 257.01 ind./100 m^2). Overall, there were significantly higher densities of *rori toto* in Site 2 than in Site 1 and Site 2A (*Survey:* $F_{(5,78)} = 2.943$, $p = 0.017$). Densities of *rori toto* were significantly greater in the SBT habitat than MLT, RBT or RFT habitats (*Habitat:* $F_{(4,63)} = 10.23$, $p < 0.001$). No *rori toto* were observed in the ORT habitat.

On average, lengths of *rori toto* ranged from 106.64 ± 3.57 mm at Site 2, to 193.33 ± 2.36 mm at Site 2A, driving significant differences between survey sites (*Survey:* $F_{(5,485)} = 10.568$, $p < 0.001$, Fig. 21). The length-frequency distribution indicates that the majority of individuals of *rori toto* are 80-100 mm in length.

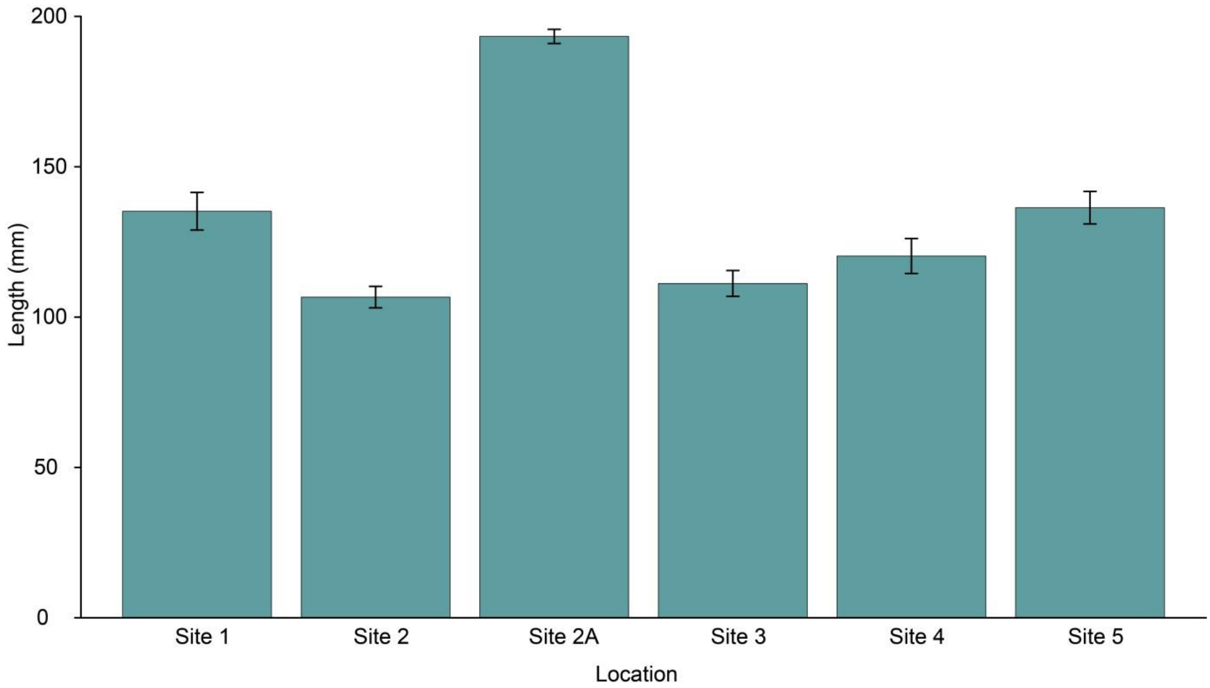

Fig. 21. Mean length (± 1 S.E.) of *rori toto* observed in 6 survey sites within Manuae

3.3.10 Rori Pirpiri (Holothuria leucospilota)

Rori piripiri were recorded in two of the 26 sites. Densities of *rori piripiri* were significantly greater in the RFT habitat of Site 4 (mean ± 1 S.E. = 27.50 ± 16.01 ind./100 m^2) compared to the MLT habitat of Site 1 (mean ± 1 S.E. = 1.25± 0.72 ind./100 m^2, *Habitat/Survey:* $F_{(16,63)} = 2.154$, $p = 0.016$).

3.3.11 Black Teatfish (Holothuria whitmaei)

No black teatfish were recorded.

3.3.12 Rori Rimu (Stichopus chloronotus)

No *rori rimu* were recorded.

3.3.13 Rori Puakatoro (Actinopyga mauritiana)

There were significantly greater densities of *rori puakatoro* in Site 5 than Site 2 (*Survey:* $F_{(5,78)} = 2.563$, $p = 0.034$, Fig. 22). *Rori puakatoro* were only observed in RBT and RFT habitats. Within the RBT habitat, greatest densities of *rori puakatoro* were recorded in Site 5 and Site 1 (mean ± 1 S.E. = 6.25 ± 1.61 and 4.38 ± 1.20 ind./100 m^2 respectively). Within the RFT habitat, greatest densities of *rori puakatoro* were recorded in Site 5 and Site 3 (mean ± 1 S.E. = 9.38 ± 1.88 and 8.75 ± 2.60 ind./100 m^2 respectively). There were no *rori puakatoro* observed in Site 2A.

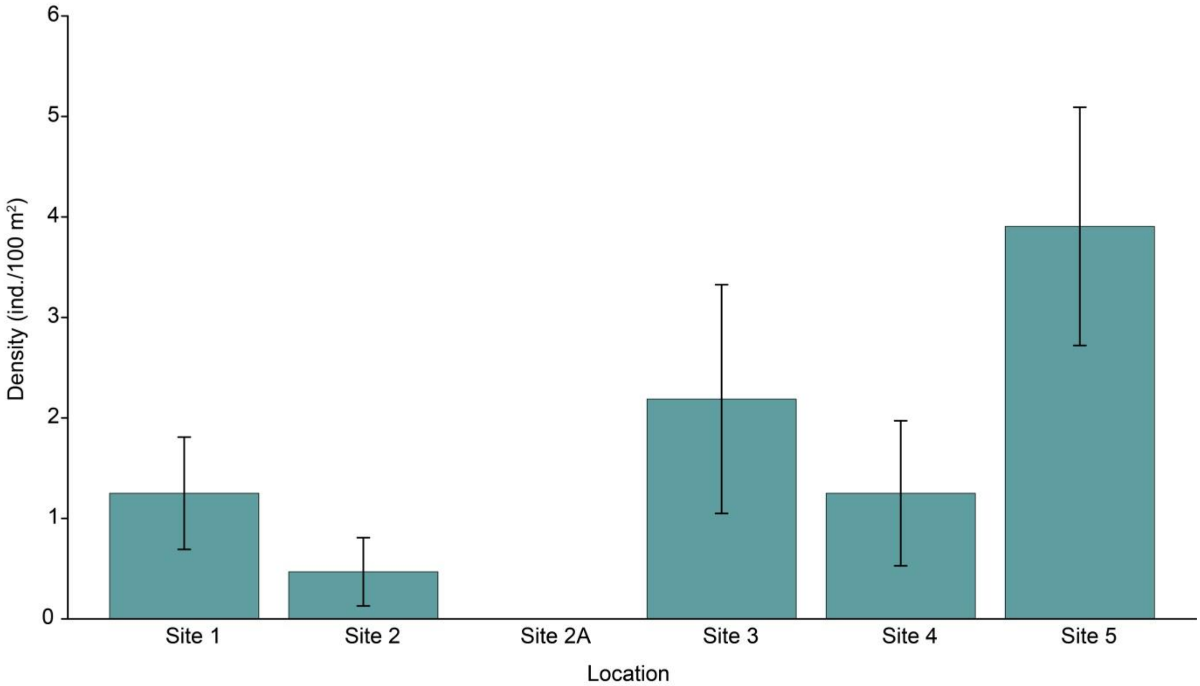

Fig. 22. Mean density (± 1 S.E.) of *rori puakatoro* observed in 6 survey sites within Manuae.

3.3.14 Vana (Echinothrix diadema)

Low densities of *vana* were observed, however, the greatest densities were recorded in Site 5 (mean ± 1 S.E. = 2.66 ± 1.24 ind./100 m^2, *Survey:* $F_{(5,78)} = 2.487$, $p = 0.038$) and were concentrated in the RBT habitat. Vana were only observed in five of the 26 habitats within sites.

3.3.15 Āvake (Tripneustes gratilla)

No *āvake* were recorded.

3.3.16 'Atuke (Heterocentrotus mammillatus)

No *'atuke* were recorded.

3.3.17 Taramea (Acanthaster planci)

No *taramea* were recorded on transect, however, several were noted off-transect both within and outside of the lagoon.

3.4 Manuae: Finfish

A total of 3,759 individuals were observed across 10 transects, representing 84 different genera/species during the finfish surveys in Manuae. The most frequently observed species was *Chromis acares* where a total of 2,140 individuals were recorded.

3.4.1 Total Abundance

Finfish densities were greatest in ORT habitats compared to FT habitats, particularly for ORT habitats of leeward sites of Site 1 and Site 2 (mean = 2,220 and 1,862 ind./100 m^2 respectively). In general, total finfish abundances were approximately 4 times greater in ORT than FT habitats.

3.4.2 Total richness

On average, species diversity (total richness) did not vary greatly between sites or habitats, ranging from 36 species in the ORT habitat of Site 3, to 62 species in the FT habitat of Site 2A. The FT habitat of Site 5 is an exception, where a relatively low diversity of 6 species was recorded. Of the 84 total species identified in Manuae, only 24% were common to both FT and ORT habitats, suggesting that finfish communities may differ between habitats in terms of composition.

3.4.3 'Iku-toto (Acanthurus achilles)

'Iku-toto was observed in ORT habitats at all sites within Manuae. The largest numbers of *'iku-toto* were recorded in the ORT habitats of Site 4 (n = 26) and Site 2 (n = 22). No *'iku-toto* were observed inside the lagoon (Fig. 23).

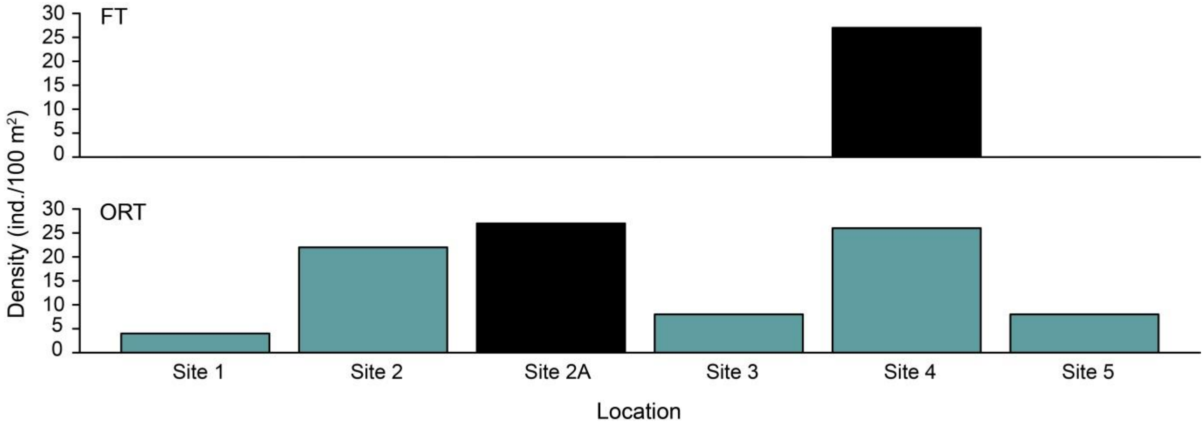

Fig. 23. Mean density (± 1 S.E.) of *'iku-toto* observed in 6 survey sites and 2 habitats within Manuae.

3.4.4 Urua (Caranx ignobilis)

No *urua* were observed in Manuae on-transect. However, this species was observed while transiting the lagoon by boat, near the SBT habitat of Site 4 and near the FT and ORT habitats of Site 3. One hour of fishing by two anglers yielded one ~15 kg *urua* and two other fish, presumably *urua,* which were hooked but lost before boating.

3.4.5 Ava (Chanos chanos)

No *ava* were recorded on-transect, but multiple were observed off-transect near the SBT habitat of Site 4.

3.4.6 Maratea (Cheilinus undulatus)

The only *maratea* observation was of a single individual, made off transect in the ORT habitat of Site 3.

3.4.7 Pipi (Kyphosus spp.*)*

Pipi were only observed within the FT habitat of Site 1 (n = 2). No other observations of *pipi* were made.

3.4.8 'Īroa (Lethrinus xanthochilus)

'Īroa were only observed in the FT habitat of Site 2. No significant differences in densities between sites existed. The only *'īroa* observed was within the FT habitat of Site 2 (n = 4). No observations of *'īroa* were recorded outside the lagoon.

3.4.9 Mū (Monotaxis grandoculis)

Mū were observed within the FT habitat of Site 2 (n = 8) and Site 2A (n = 2). No *mū* were observed outside the lagoon.

3.4.10 Vete and/or Takua (Mulloidichthys spp.*)*

No vete and/or Takua were recorded.

3.4.11 Umeume (Naso lituratus)

Umeume were observed in the FT habitat of Site 2 (n = 2) and the ORT habitat of Site 3 (n = 6). There were no other *umeume* observed.

3.4.12 Ume (Naso unicornis)

The only *ume* observed were off-transect near the FT habitat of site 2A.

3.4.13 U'u (Scaridae)

U'u were observed in both the ORT and FT habitats, however, greater numbers were recorded for the FT habitats (approximately 10 times greater). Observations of *u'u* were made in both habitats of Site 2 (FT n = 52, ORT n = 6) and Site 3 (FT n = 36, ORT n = 2), in the FT habitat of site 2A (n =94) and the ORT habitat of Site 1 (n = 10).

3.4.14 Maemae (Siganus spp.*)*

No *maemae* were recorded.

3.4.15 Mango (Carcharhinidae)

A grey reef shark (*Carcharhinus amblyrhynchos*) was observed within the ORT habitat of Site 5 (n =1).

3.5 Manuae: Coral and Substrate

Within the lagoon, FT photoquadrats were mainly composed of hard and soft substrates (Fig. 24). Macroalgae, hard corals and dead coral were also observed but in low percent coverage. Site 5 was mainly composed of a hard pavement substrate which was unique between FT sites.

ORT substrate was mainly composed of hard coral, dead coral, crustose coralline algae, macroalgae and pavement substrate (Fig. 25).

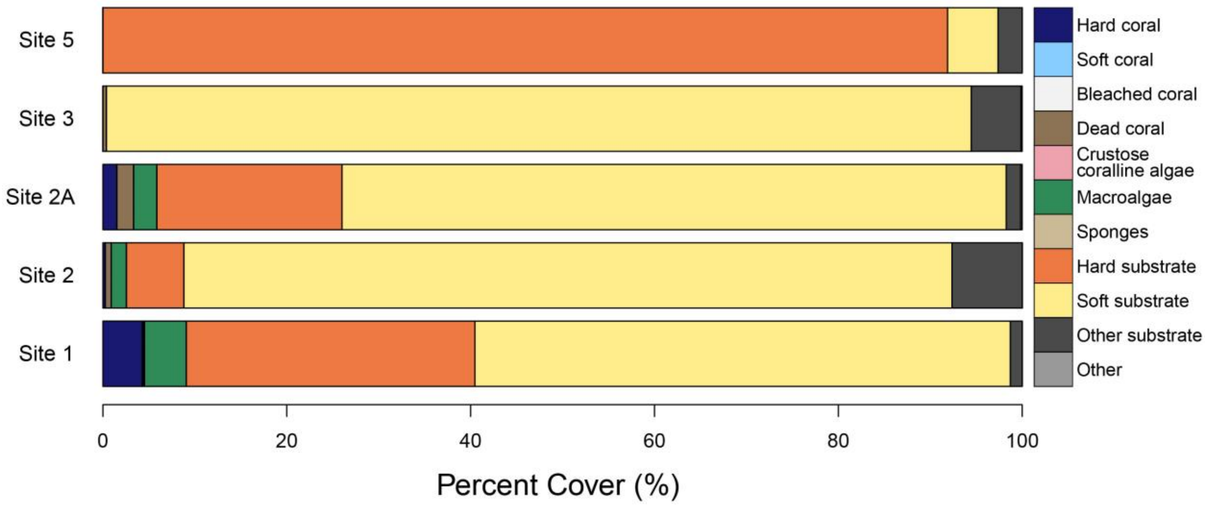

Fig. 24. Mean percent cover of major coral and substrate groups for FT sites within Manuae.

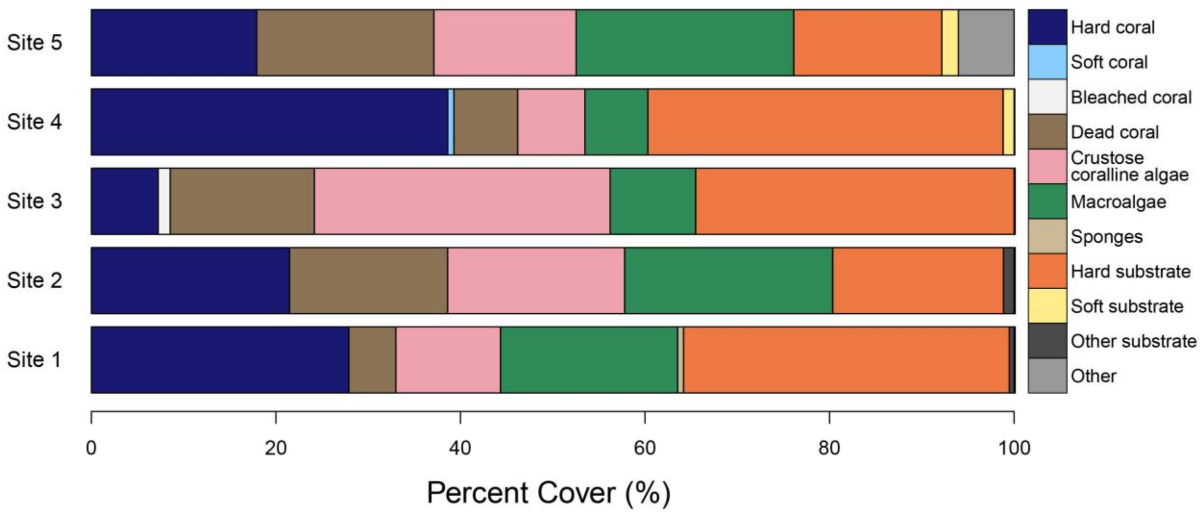

Fig. 25. Mean percent cover of major coral and substrate groups for ORT sites within Manuae.

3.6 Aitutaki: Coral and Substrate

Within the lagoon, FT photoquadrats were mainly composed of soft and hard substrates. Live coral cover was low (Fig. 26). In all ORT sites, hard substrates including those covered in crustose coralline algae dominated. Soft coral was also abundant at many sites (Fig. 27).

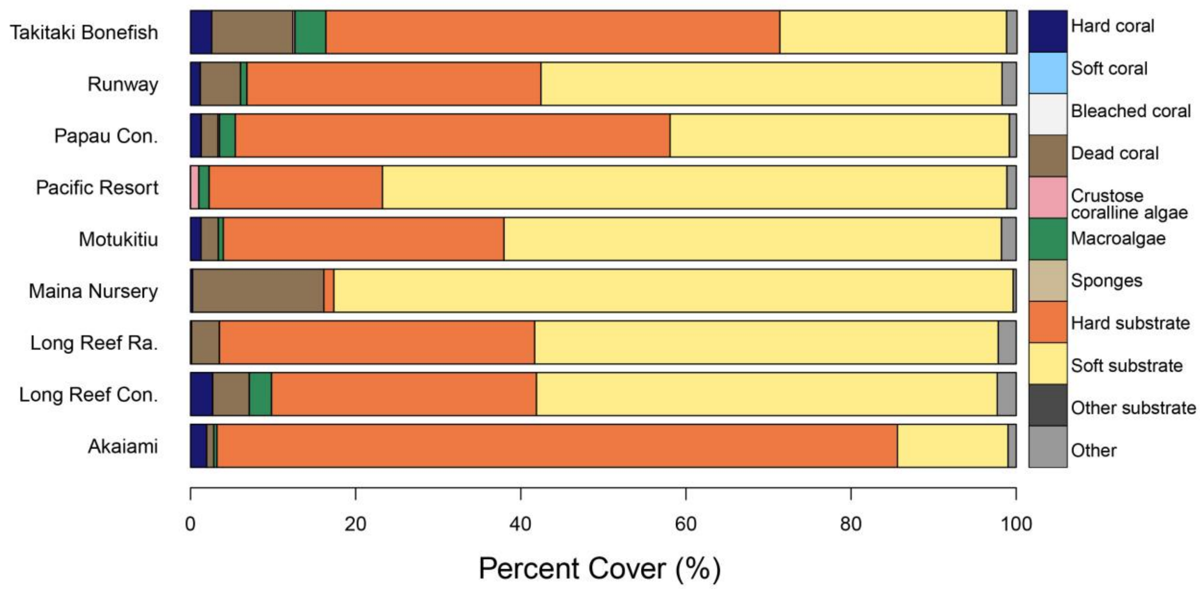

Fig. 26. Mean percent cover of major coral and substrate groups for FT sites within Aitutaki.

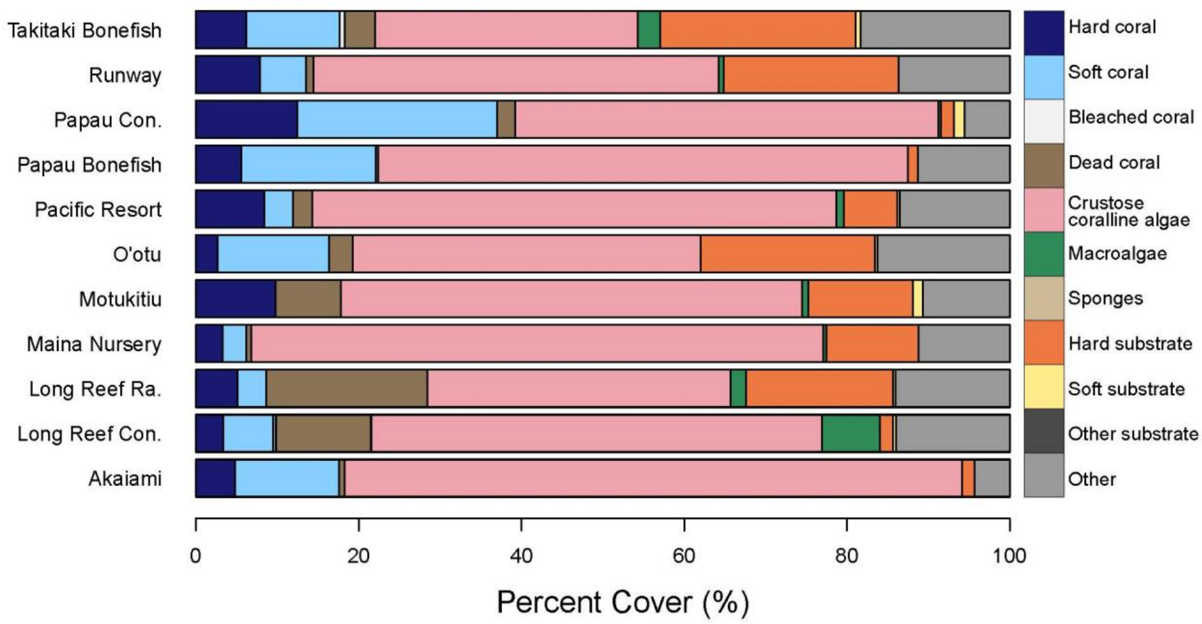

Fig. 27. Mean percent cover of major coral and substrate groups for ORT sites within Aitutaki.

3.7 Island Comparisons

3.7.1 Paua (Tridacna spp.*) in Aitutaki and Manuae*

Paua densities in Manuae were significantly greater than in Aitutaki ($p < 0.001$, Fig. 28). On average, *paua* densities in Manuae were 45 times greater than in Aitutaki.

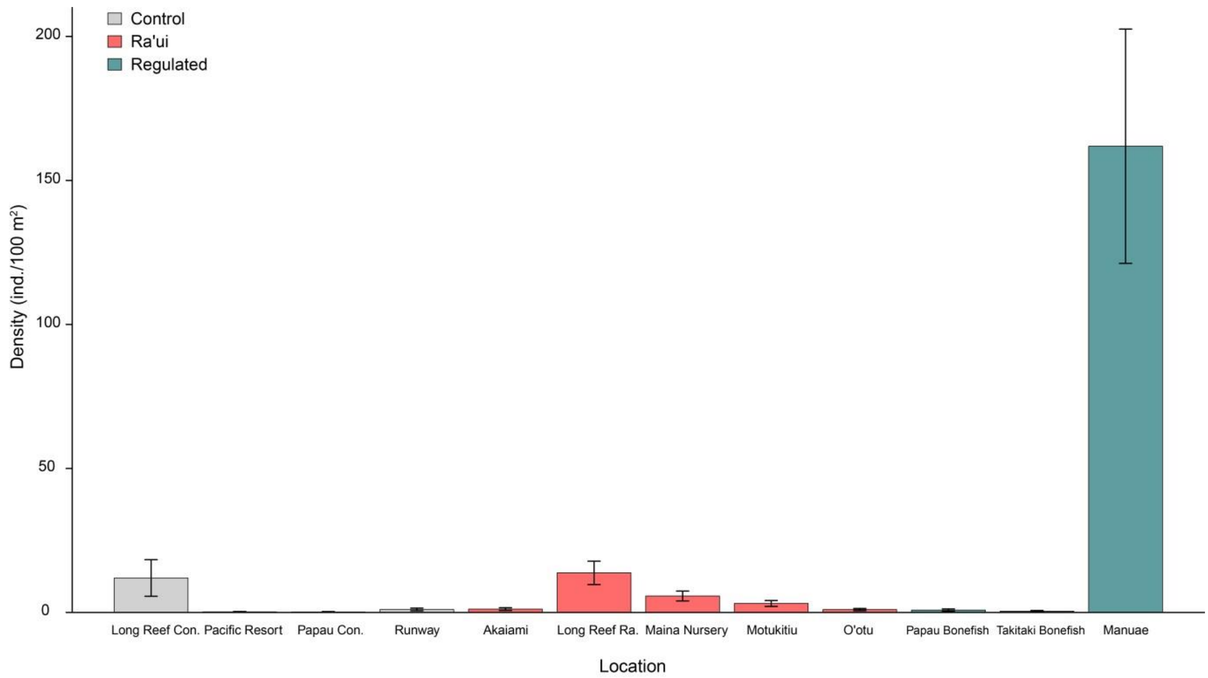

Fig. 28. Mean density (± 1 S.E.) of *paua* observed in 11 survey sites within Aitutaki and overall in Manuae.

3.8 Turtles

In Aitutaki, turtles were only observed in ORT habitats. All turtles identified to species were endangered (IUCN) green sea turtles (*Chelonia mydas*). There were no turtle tracks observed along the shoreline.

In Manuae, turtle tracks leading to nests were observed on both Manuae and Te Au O Tu islets. On the Manuae islet, 7.7 kilometres of beach were surveyed and 26 nests were recorded (Fig. 27). Nests were concentrated on southwest and northwest, ocean facing beaches. No nests were found along surveyed lagoon facing beaches on Manuae. Two randomly chosen nests on the southwest side of Manuae islet were excavated revealing unhatched eggs.

On Te Au O Tu, 5.8 kilometres of beach were surveyed and 31 turtle nests were recorded. Nests were concentrated on east, south and southwest, ocean and lagoon facing beaches.

Turtles were observed off transect in lagoon waters and along the outer reef slope. All turtles observed were identified as endangered (IUCN) green sea turtles (*Chelonia mydas*).

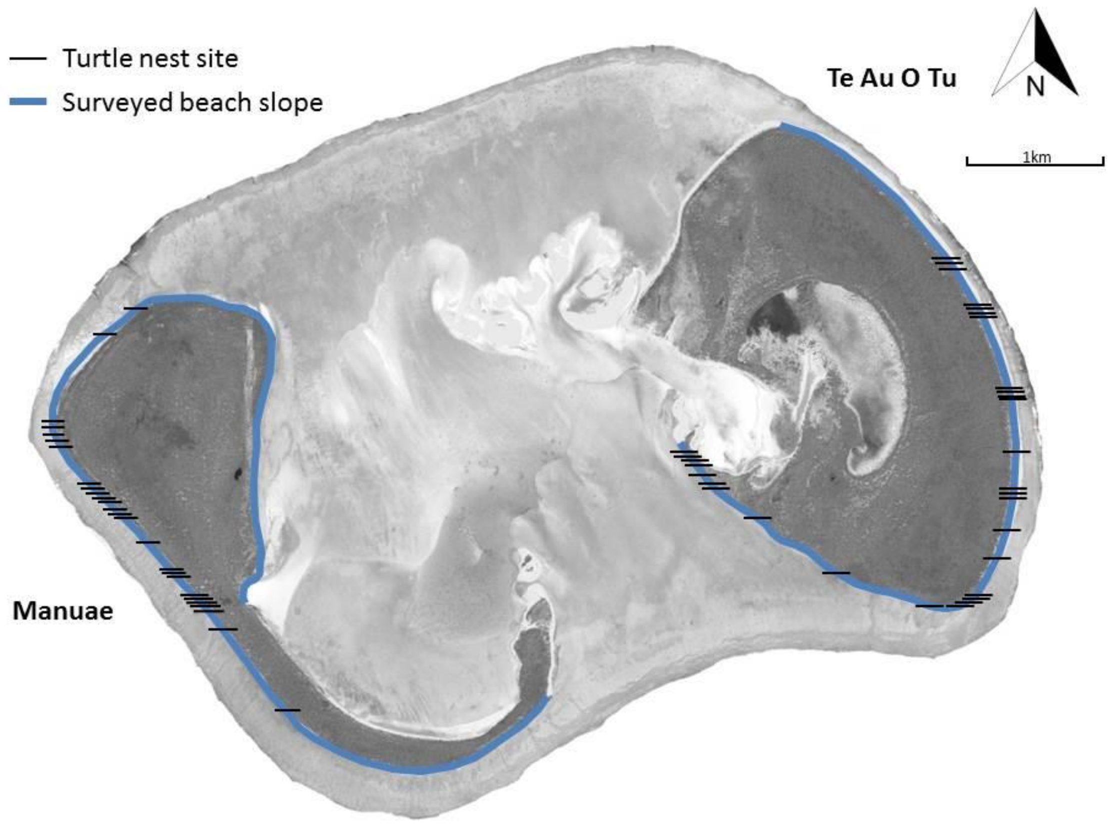

Fig. 29. Turtle nest locations and beaches surveyed on islets of Manuae and Te Au O Tu, Manuae. Map source: Google DigitalGlobe.

4. DISCUSSION AND BIOLOGICAL INFORMATION

4.1 Invertebrates

4.1.1 Paua (Tridacna **spp.***)*

In both Aitutaki and Manuae, *paua* is a valuable resource and highly sought after by fishers and local communities for consumption. The *paua* populations, primarily of Aitutaki, have been severely over-harvested and population densities are now only a fraction of what they once were.

Overall *paua* densities in Aitutaki were 2.8 ind./100 m^2. *Paua* densities were the highest within RBT and SBT habitats, with an average density of 5 ind./100 m^2. These values are lower than that observed on the last assessment of *paua* densities in Aitutaki (Ponia 1998a, Ponia et al. 1999). Looking further into the past, historical data show a steep decline in *paua* densities since the mid-1980's (Fig. 30). Typically, high densities of *paua* would be expected in *rā'ui* designated areas. In this study, the lack of significant differences between *rā'ui* and control sites and overall low densities of *paua* may indicate active *paua* harvest within *rā'ui* areas and/or low levels of successful reproduction.

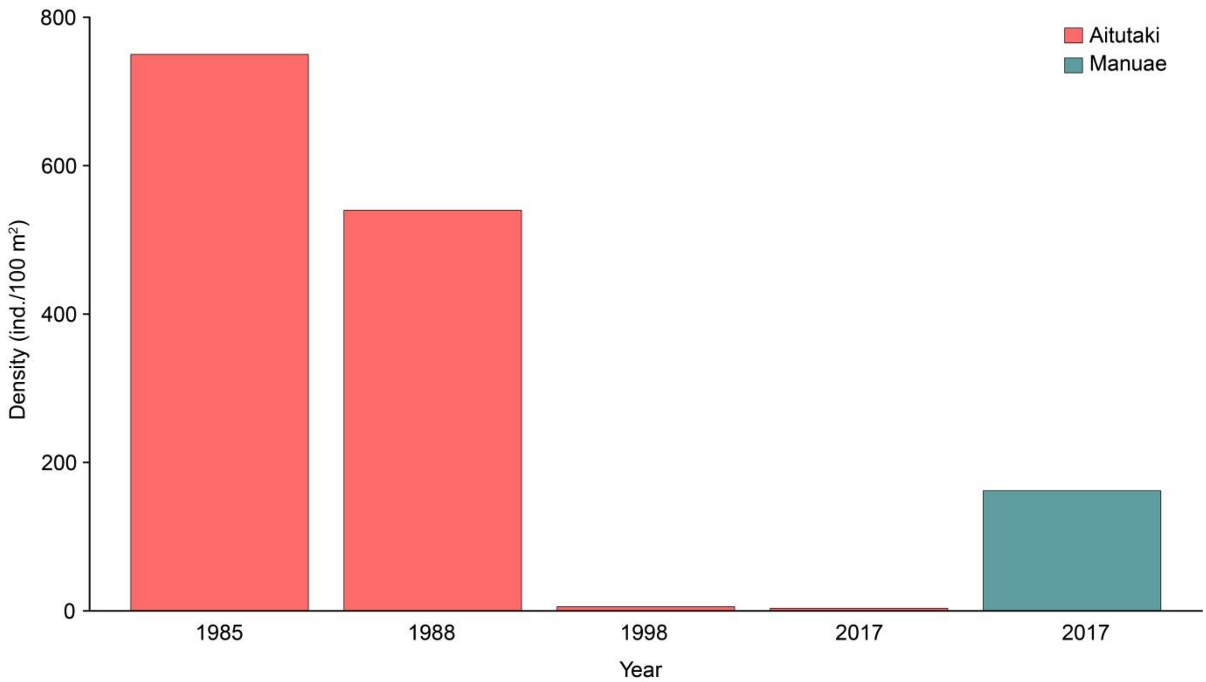

Fig. 30. Historical comparison of *paua* mean density (± 1 S.E.) for Aitutaki and Manuae.

In Manuae, *paua* were observed in remarkably high densities (Fig. 28). These densities were greatest on shallow reefs of the MLT and RBT habitats with combined *paua* densities of 290 ind./100 m^2. Despite overall averages for Manuae, within the some sites, *paua* densities were much higher and nearly equal to those previously reported for Aitutaki in the 1980s.

Adult *paua* are sessile organisms and once settled, are unable to move from their location on the reef. They are broadcast spawners and release sperm and eggs into the water to reproduce. Reproduction occurs where sperm and eggs meet in the water and result in the development of *paua* larvae. *Paua* that are near each other have significantly higher chances of successfully reproducing than those which are further apart. This means that high densities of *paua* are necessary for successful reproduction to occur. Furthermore, chemical cues released by adult *paua* encourage drifting *paua* larvae to settle nearby, thus, high *paua* densities can perpetuate high *paua* densities (Dumas et al. 2013).

Paua larvae are able to survive in the water for up to ten days before settling onto a hard surface. Therefore, it is possible that *paua* larvae from Manuae may be drifting to Aitutaki, however, genetic studies would be necessary to confirm this assumption (Jameson 1976).

Average *paua* length in Manuae was greater than in Aitutaki. The majority of *paua* in Aitutaki were below the 75 mm minimum size limit, and well below average lengths of 79-124 mm found by Sims and Howard in 1988. In contrast, the majority of *paua* in Manuae were larger than the 75 mm minimum size allowable for harvest.

Manuae represents a unique ecosystem where the dependence of fishers and local communities on the marine resources is minimal. Manuae *paua* populations appear healthy and could possibly support an effectively managed fishery. However, the failure of effective *paua* management in Aitutaki is a reminder that sustainable management and enforcement is difficult, but essential. Management decisions may be best directed towards protection and conservation of *paua* in Manuae rather than spurring a fishery.

4.1.2 Other bivalves

No significant differences in densities of *pipi,* and *pārau*, were found between sites and overall densities of these species were low. Harvest of these species is reportedly opportunistic and rare, indicating low densities are not likely a result of current overexploitation.

4.1.3 Trochus (Tectus niloticus)

Trochus densities in Aitutaki were significantly higher within the Akaiami Rā'ui. The Akaiami Rā'ui is permanently closed to trochus harvest for the purpose of creating high densities of spawn. These densities indicate successful *rā'ui* compliance.

4.1.4 Sea cucumbers

In Aitutaki, significantly higher *Rori toto* densities were found within Pacific Resort Control and Runway Control than within most other sites. Motukitiu Rā'ui also had notably high densities. Near shore densities were highest and decreased towards the reef crest. Other than the Motukitiu Rā'ui, the highest densities were found in easily accessible areas open to harvest which suggests that factors other than harvest were likely the main contributor to variances in species density. Furthermore, harvest of *rori toto* involves the removal of gonadal tissue through an incision in the body wall and leaving the animal in the water. Because nearshore *rori toto* generally reproduce via transverse fission, animals are thought to easily survive both incision and gonad harvest, and harvest presumably should not have negative impacts on density. *Rori toto* were one of the most frequently recorded invertebrate species.

Rori piripiri were found in significantly higher densities within O'otu Rā'ui and Runway Control than in most other sites. Considering the high densities within Runway Control, factors other than harvest are likely the main contributors to species density. *Rori piripiri* are a shallow water species usually confined to reef crests, reef flats and lagoons. Like the *rori toto, rori piripiri* can reproduce by means of transverse fission, harvest involves the removal of gonadal tissue through a small incision and harvested animals are left to heal in the water. *Rori piripiri* gonad harvest presumably should also not negatively impact species density.

Rori rimu and *rori puakatoro* were found in significantly higher numbers in Papau Control and Runway Control, respectively, than the majority of other sites. To harvest *rori rimu* and *rori puakatoro,* the whole animals are taken for consumption and harvest would presumably have a negative effect on population densities. High densities recorded in control areas compared to regulated and *rā'ui* areas, suggest that current harvest is not occurring.

4.1.5 Sea urchins

Āvake densities were significantly greater in Papau Bonefish Reserve than in all other sites. The only legal restrictions within the Papau Bonefish Reserve are for bonefish, therefore, these higher densities are not likely a direct result of protective measures.

Vana were found in significantly higher densities within the Akaiami Rā'ui and Long Reef Rā'ui than in the majority of other sites. The *rā'ui* areas in general were found to support moderately greater diversity and may explain high densities of many species observed.

4.1.6 Crown of thorns seastar (Taramea)

In Aitutaki, *Taramea* were observed in Long Reef Rā'ui, Maina Nursery Rā'ui and Akaiami Rā'ui. Overall densities in Aitutaki are generally considered below those which may raise concern and result in an outbreak. While not captured in our analysis, *taramea* were observed off transect more frequently in Manuae than in Aitutaki. The majority of observations of *taramea* were made in 15-30 meter depths, beyond the ORT habitats of the eastern and north eastern reefs. The presence of *taramea* is normal in many coral reef ecosystems throughout the Indo-Pacific. However, this does not currently seem to be an issue for Aitutaki or Manuae.

4.2 Finfish

The data recognise a difference between the types of species that primarily utilise either of the two habitats surveyed in both Aitutaki and Manuae, and a small proportion of species that occupy both. Further, there were several species that were observed in some parts of the islands and not others. In general, these trends support basic knowledge on habitat preferences for fish.

In Aitutaki, densities of *'iku-toto, mū, vete and takua, pipi-nanue, umeume-poko-toki, ume* and *maemae* were not significantly different between sites. Along with many other species, *'iku-toto* were found only in the ORT habitat, outside the lagoon. *Vete and/or takua* were only observed within the Takitaki Bonefish Rā'ui. *Umeume* were observed in the ORT habitat of all sites as well as within the FT habitat of Long Reef Control and Maina Nursery Rā'ui. *Ume* were only observed in the ORT habitat of the Motukitiu Rā'ui, O'otu Rā'ui and Papau Bonefish Reserve.

Urua were more frequently observed in Manuae.

4.2.1 Bonefish

Large bonefish (*Albula glossodonta* - IUCN threatened) were observed in the shallow 'bay' on the western side of Te Au O Tu. Along with bonefish, drummer (*Kyphosis* sp.), milkfish (*Chanos chanos*) and small Carangids were also present.

4.2.2 Maratea **(Napoleon Wrasse)**

Maratea densities in Aitutaki were 0.48 per 100 m^2. This density is staggeringly high, and greater than recorded in published literature (Sadovy *et al.* 2003). However, such high densities are quite rare and observational results can be biased when working with relatively small transect lengths (50 m in this study, compared to 25 km used in other studies). Densities of *maratea* in Manuae were comparatively low. No fish were recorded on-transect within any site. The only *maratea* observation was of a single fish near the ORT transect of Site 3. These low densities are likely natural as fishing effort in Manuae is reportedly very low.

Maratea are a long lived, slow to mature species and in areas with even low levels of fishing pressure, populations have declined dramatically. *Maratea* are an endangered species (IUCN) and listed under Appendix II of CITES which restricts any form of trade between CITES nations.

4.3 Sharks

Higher densities of grey reef sharks (*Carcharhinus amblyrhynchos*) and whitetip reef sharks (*Triaenodon obesus*) were observed in Manuae than in Aitutaki despite the nearly four times greater sampling effort that occurred in Aitutaki. While only one fell into our sample, grey reef sharks were observed outside the reef at most sites in Manuae. Multiple grey reef sharks and a whitetip reef shark (*Triaenodon obesus*) were observed by divers off-transect, outside of the reef passage, directly north of Manuae, and a large, female whitetip reef shark was observed off-transect at site 2A.

4.4 Turtles

All turtles identified to species-level in both Aitutaki and Manuae were endangered (IUCN) green sea turtles (*Chelonia mydas*). Interestingly, critically endangered (IUCN) hawksbill sea turtles (*Eretmochelys imbricata*), often observed in lagoon and ocean waters around Rarotonga, were not observed in Aitutaki or Manuae.

While no nest surveys were conducted in Aitutaki, there were reports from lagoon cruise operators of active turtle nesting occurring on the south side of the Maina islet. Mating green sea turtles were observed by our team in ocean waters just south of the mouth of Arutanga Passage.

4.5 Coral and Substrate

4.5.1 Manuae: Coral and Substrate

Within the lagoon, the benthos was mainly composed of hard and soft substrates (Fig. 24). Soft substrates were often observed as a thin layer covering a solid, underlying pavement. These thin layers of soft substrates inflated our soft substrate percent covers which has available habitat implications for sessile organisms such as *paua* to (Fig 31). Macroalgae, hard corals and dead coral were also observed but in low percent covers within the FT habitat.

ORT habitats were mainly composed of hard substrates and crustose coralline algae. The most common macroalgae on the fore reef was *Halimeda spp.*, however, *Caulerpa racemosa* was observed at sites 2 and 5. Soft coral was only observed in Site 4 and at a low percent cover.

Fig. 31. MMR fisheries officer Tua Matepi recording *paua* densities in FT habitat of site 2 in Manuae. Photo Copyright of Kirby Morejohn

4.5.2 Aitutaki: Coral and Substrate

Within the Aitutaki lagoon, the benthos was mainly composed of hard and soft substrates. Unlike our lagoon substrate observations from Manuae, soft substrates in Aitutaki were deep and not ideal for growth of sessile organisms that require hard substrates for settlement (e.g. *paua*). Hard substrates, however, were more frequently observed in Aitutaki lagoons than in Manuae.

Within ORT sites in Aitutaki, live coral cover was roughly 20%, similar to that of Manuae. Live coral cover in Aitutaki, however, was mainly composed of soft corals whereas in Manuae, soft corals were infrequently observed (Fig. 26).

4.6 Other

The 'bays' on the inward-facing sides of both motu had warm, shallow waters and a fine sediment substrates. Nearby beaches were littered with cockle (*Fragum fragum*) and cerith (*Rhinoclavis aspera*) shells, suggesting that this silty habitat may be important for these filter and deposit feeding Molluscs. The pen shell (*Pinna* sp.) and unidentified, spiral gastropod egg cases were also observed in this habitat.

Bristle-thighed curlew (*Numenius tahitiensis*) were observed on beaches of both Manuae and Te Au O Tu. These birds are considered a vulnerable species (IUCN) that overwinter on tropical Pacific islands.

5. RECOMMENDATIONS

Paua in Aitutaki are in need of functional protective measures. Current management strategies have been insufficient at stalling the population decline over the last 30 years. The *rā'ui* system may still be effective if proper enforcement occurs, but in the long term, for the purpose of growing and maintaining a healthy, wild stock of reproductive *paua,* we recommended that specific areas be permanently closed, implementation of minimum harvestable size limits and daily bag limits, and a ban of the sale of *paua* meat, shell, and other parts. Permanently closed areas are important safety nets if mismanagement of a species occurs in areas open to harvest. Closed areas with high densities of adult *paua* will drastically increase the number of young *paua* that 'spill over' into areas where harvest occurs. Minimum size limits ensure that *paua* in areas open to harvest can spawn before reaching harvestable size (minimum harvestable size limits are used in Tonga – 155 mm, Samoa – 160 mm, Niue - 180 mm, Guam – 180 mm, and French Polynesia – 120 mm [SPC 2005]). A daily bag limit prevents fishers from taking more than they can reasonably consume. The sale of *paua* causes harvest size and money to become proportional which encourages fishers to take more than they can use to maximize their profits (Johannes 1978).

In an attempt to protect the remaining wild stock of *paua* in Aitutaki*,* we recommend an immediate island-wide closure to *paua* harvest until populations increase to levels which may support a healthy fishery.

In Manuae, *paua* are in high numbers and in what appear to be healthy densities. Although not observed on transect, our team noted lower densities near the main camp and passage which may indicate an effort shift from Aitutaki to Manuae and inter-island serial depletion. It is important to approach *paua* management very carefully and consider the long term protection and conservation of these populations before assessing any possibility for a sustainable *paua* fishery. *Paua* habitat in Manuae is roughly 1/6 the size to that of Aitutaki. The small size of Manuae and therefore available *paua* habitat puts Manuae at risk of overharvest due to mismanagement. We recommend a closure to all *paua* harvest in Manuae until Aitutaki *paua* populations recover and a well-managed, functional fishery in Aitutaki is formed. Only after healthy *paua* stocks are rebuilt and a functional, sustainable *paua* fishery is formed in Aitutaki, should any actions be made taken to form a *paua* fishery in Manuae.

Trochus densities on Aitutaki were highest in the Akaiami Rā'ui, which was formed to protect an introduced broodstock of trochus. Located on the windward side, trochus in the Akaiami Rā'ui are thought to replenish stocks via larval transport to downwind and down-current areas of the Aitutaki reef. At the time of our survey, trochus management appears to be effectively sustaining healthy harvests. We recommend maintaining current trochus monitoring and management practices.

In Aitutaki, *maratea* (*Cheilinus undulatus*) were observed in high numbers. Fishing and spearfishing for these fish is currently reportedly uncommon and discouraged by locals. *Maratea* are a slow growing, long lived species which are easily overfished; global populations are currently endangered (IUCN). *Maratea* are important reef predators of *taramea* (*Acanthaster planci*) and a charismatic species for SCUBA and freedivers to encounter. We recommend restriction of take of these fish and encourage tour operators to include these fish as a component in ecotourism.

Densities of reef sharks in Aitutaki were lower than expected. We heard multiple reports of fishermen killing and wasting sharks as a measure to reduce depredation. Sharks have slow growth rates and low reproductive outputs which put them at risk of overfishing. As high level reef carnivores, reef sharks are a vital component of the nearshore marine ecosystem. The top down pressure that sharks apply cause reef fish to reproduce and grow faster. We recommend that fishermen cease any targeted capturing of sharks and any incidentally captured sharks are released unharmed.

All species of sea turtles are globally endangered and local protection is necessary for their survival. Sea turtles were observed in both Aitutaki and Manuae and nesting was reported on Aitutaki and observed in Manuae. We recommend increasing efforts into turtle conservation activities such as reducing light pollution on nesting beaches, reducing plastic pollution, avoiding unnecessary interactions and eliminating turtle take and consumption.

In some cases (e.g. *paua* management in Aitutaki), *rā'ui* has not been successful for species conservation. We recommend a review of management practices to assess an effective and sustainable way forward.

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