Baited Underwater Video (BUV) monitoring of the Motiti Protection Areas

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Executive summary

Baited Underwater Video (BUV) surveys were conducted across the Motiti Protection Areas and Motiti Island, to provide an assessment of relative fish abundance and populations prior to the implementation of fisheries restrictions. A total of 60 BUV deployments were conducted across five reef systems: Astrolabe (Otaiti), Okarapu, Schooner Rocks (Motuhaku), Motunau (Plate Island) and Motiti Island during late summer – early Autumn 2021. The relative abundances of identified key species and species richness/diversity metrics were compared to the reef location, depth, and biotic/abiotic factors to investigate species-habitat relationships. Additionally, this survey was used to investigate sampling effort (utilising rarefaction curves) and effectiveness of the BUV method for monitoring fish relative abundance, to inform future survey methods.

A total of 33 fish species were identified in the footage, which included a number of common reef fish such as snapper (*Pagrus auratus*), red pigfish (*Bodianus unimaculatus*), two-spot demoiselle (*Chromis dispilus*), scarlet wrasse (*Pseudolabrus miles*) and leatherjacket (*Meuschenia scaber*). The least common species included Sandagers wrasse (*Coris sandeyeri*), splendid perch (*Callanthias australis*), red fish/golden snapper (*Centroberyx affinis*), kingfish (*Seriola lalandi*) and the grey moray (*Gymnothorax nubilus*). Fish populations differed significantly across reef locations and depth strata and indicated higher species richness and diversity at the offshore reefs within the Motiti Protection Area compared to Motiti Island, which has no current protection in place.

Rarefaction curves indicated that for some locations, species richness metrics were still increasing, indicating that sampling intensity is required to be increased to capture some of the less common species, and provide a more robust indication of species richness. The results indicate that the BUV has been an effective method for measuring relative fish abundances, incorporated as part of a larger monitoring programme. The results will provide a baseline at the time of marine protection implementation, to track changes in fish populations over time. Regular annual surveys should be conducted to assess the effects of the protection measures on the fish assemblages.

Contents

1 Introduction

1.1 Marine protected areas

The latest Ministry for the Environment (MfE) report on our marine environment, indicates that human activities have had a significant impact on the health of our marine ecosystems (MfE, 2019). There has been a significant decline in biodiversity, habitat condition and extent due to our activities in the sea and on land (MfE, 2019). In addition to these stressors, climate change is also set to have a significant impact on marine ecosystems, due to increasing sea level, warming seas, and acidification of our oceans. The cumulative impacts of these stressors are one of the most urgent problems faced by our ocean environments (MfE, 2019).

In New Zealand a range of management tools are used to protect marine species and habitats. These tools can include restrictions that limit catch size and number of targeted fish species, restrictions on the use and development of marine areas, and temporary and permanent spatial closures. Marine protected areas are areas of the marine environment implemented to conserve or restore species, fisheries, populations, habitats, ecosystems, and ecological functions (Flournoy, 2003; Fox *et al.*, 2012). Under New Zealand's MPA Policy a marine protected area is defined as 'An area of the marine environment especially dedicated or, or achieving, through adequate protection, the maintenance and/or recovery of biological diversity at the habitat and ecosystem level in a healthy functioning state'. Marine reserves cover 9.8% of New Zealand's territorial sea, of which 0.4% is around the mainland and 9.4% around outlying islands. A further 2.6% of the territorial sea is protected in type 2 MPAs (Department of Conservation, 2019).

Many studies have examined the ecological impacts of marine protected areas and have demonstrated that marine protected areas are an effective tool to conserve biodiversity and improve ecosystem functioning (Grorud-Colvert *et al.,* 2021). No take protection generally results in increased organism size, density, biomass, and species richness within the marine protected area boundary (Lester *et al.*, 2009). However, time scales of species recovery can vary greatly, and initial detection of direct effects on target species can take up to ~5 years, with indirect effects on other taxa (often trait mediated) taking significantly longer (~16 years) (Babcock *et al.*, 2010; Edgar *et al.*, 2014).

1.2 Motiti Protection Areas

The reef ecosystems off the coast of the Bay of Plenty and Motiti Island support a wide range of biological diversity. In 2018 the Environment Court released an interim decision[1] that found the outstanding attributes and values of these reef ecosystems required greater protection. On 24 April 2020, the Environment Court released its final decision[2], which directed the Bay of Plenty Regional Council (BOPRC) to implement new rules within its Regional Coastal Environment Plan to protect three reef systems near Motiti Island and complete scientific monitoring to inform future integrated marine management solutions, in partnership with other government agencies and tangata whenua.

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[1] https://www.justice.govt.nz/assets/Documents/Publications/2018-NZEnvC-067-Motiti-Rohe-Moana- Trust-v-Bay-of-Plenty-Regional-Council2.pdf

[2] https://atlas.boprc.govt.nz/api/v1/edms/document/A3526046/content

The coastal ecosystems of the Motiti Protection Area are of significant cultural value to tangata whenua. Over the last two years, BOPRC have been talking with Te Patuwai Tribal Committee, Ngāti Awa, Tauwhao Te Ngare Trust and Ngāti Whakahemo to keep them informed and to establish processes to involve them in Council programme planning for policy, science, compliance and education. Our relationship with tangata whenua is a priority and we will continue to pursue all opportunities to enable collaborative processes.

The new rules have created three protection areas (called the Motiti Protection Areas) located offshore from Motiti Island (Figure 1), where the taking of all plants and animals is prohibited due to their significant marine biodiversity, landscape, and cultural values. These areas comprise of Otaiti (Astrolabe), including Te Papa (Brewis Shoal); Te Porotiti, and Okarapu Reef (MPA1, 46.3 km^2), Motuhaku (Schooner Rocks) (MPA2, 13.7 km^2), and Motunau (Plate Island) (MPA3, 24.7 km^2). The Motiti Protection Areas provides 84.7 km^2 of marine protection from extraction and benthic disturbance. These rules were implemented in August 2021. A summary of the marine ecological values of these protection areas is reported in De Luca (2020).

1.3 Baited Underwater Video (BUV)

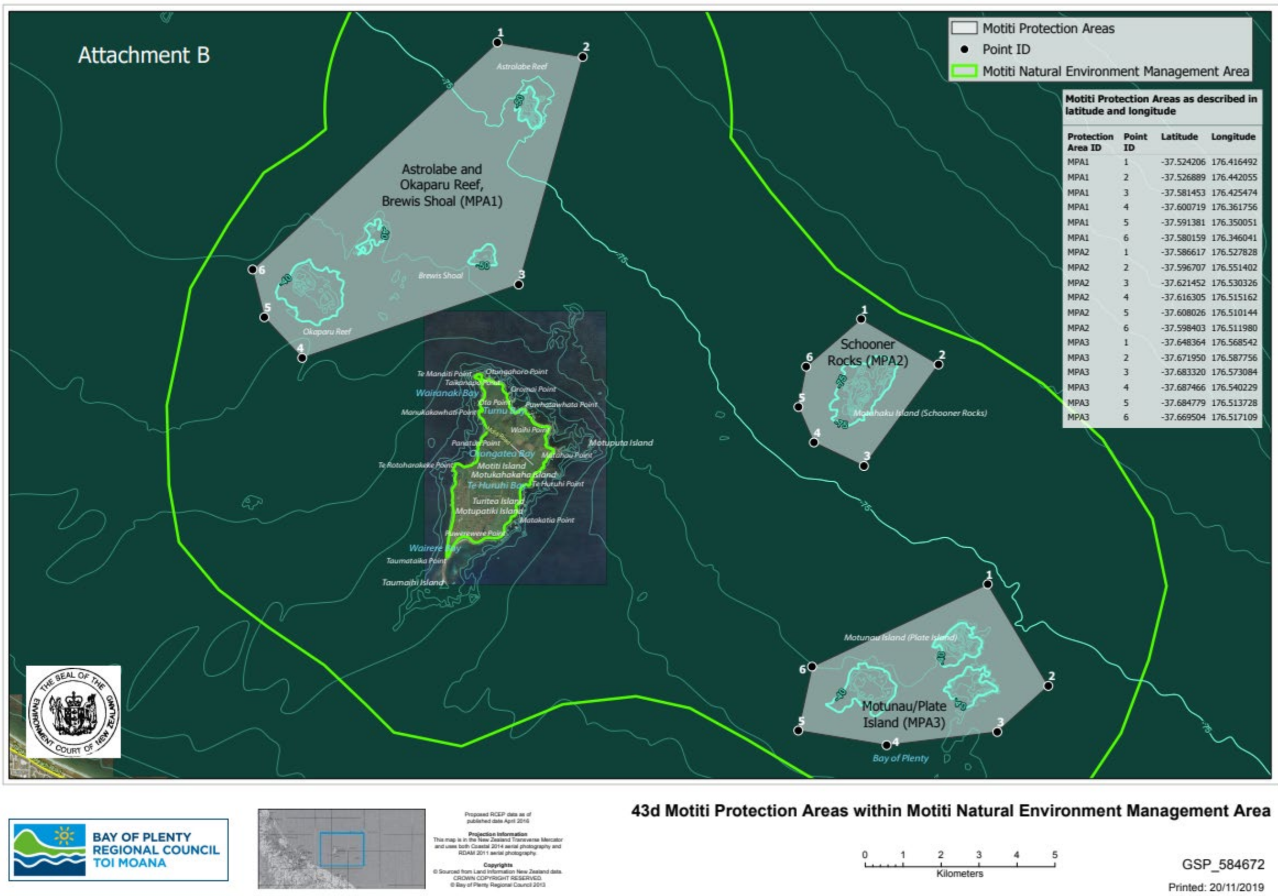
Baited Underwater Video is an unobtrusive sampling technique which is effective in providing abundance and size estimates of scavenger and carnivorous reef-fish species that often can be difficult to survey using divers (Willis & Babcock, 2000, Shortis *et al.*, 2009). Baited Underwater Video typically involves dropping a baited frame and video camera down onto the reef for a set period, to observe fish activity. Advantages of using BUV include collection of video footage that can be analysed by multiple observers, and it provides useful records of abundance, richness, size, and behaviour (Stobart *et al.*, 2007). It also reduces the requirement for scientific divers, can be deployed in a range of conditions and depths, and allows participation of non-scientific observers/non-divers (Mallet & Pelletier, 2014). Analysis can take place back in the office, reducing the costs and time of fieldwork. The Department of Conservation use BUV as one of the monitoring techniques in marine reserves across New Zealand and have developed a methodology toolbox that we utilise in this study[3].

1.4 Project Aims

Baited Underwater Video has not previously been used to monitor biological diversity at the Motiti Protection Areas, although some surveys have occurred around Motiti Island (De Luca, 2020). This project has several aims:

- Collect baseline information on fish species and populations (relative abundance) at the Motiti Protection Areas prior to the implementation of fisheries restrictions (August 2021).
- Investigate temporal variability in populations inside and outside the protected areas.
- Investigate variability in fish populations between the protection areas and Motiti Island, (currently excluded from marine protection).
- Investigate variability in fish populations between depth and habitat strata (both biotic and abiotic).
- Investigate method and sampling suitability for monitoring effectiveness of the marine protection.

[3] https://www.doc.govt.nz/globalassets/documents/science-and-technical/inventory-monitoring/im-toolbox-marine-baited-underwater-video-surveys-for-fish.pdf



Motiti Protection Areas as described in latitude and longitude

Protection Area ID	Point ID	Latitude	Longitude
MPA1	1	-37.524206	176.416492
MPA1	2	-37.526889	176.442055
MPA1	3	-37.581453	176.425474
MPA1	4	-37.600719	176.361756
MPA1	5	-37.591381	176.350051
MPA1	6	-37.580159	176.346041
MPA2	1	-37.586617	176.527828
MPA2	2	-37.596707	176.551402
MPA2	3	-37.621452	176.530326
MPA2	4	-37.616305	176.515162
MPA2	5	-37.608026	176.510144
MPA2	6	-37.598403	176.511980
MPA3	1	-37.648364	176.568542
MPA3	2	-37.671950	176.587756
MPA3	3	-37.683320	176.573084
MPA3	4	-37.687466	176.540229
MPA3	5	-37.684779	176.513728
MPA3	6	-37.669504	176.517109

Figure 1 Motiti Protection Areas (grey) within the Motiti Natural Environment Management Area (green outline).

2 Methods

2.1 Site location

Five sites were selected for preliminary investigations: Okarapu Reef, Astrolabe (Otaiti), Schooner Rocks (Motuhaku), Plate Island (Motunau), and Motiti Island (Figure 2). The Department of Conservation (DOC) baited remote video toolbox was utilised to develop the monitoring programme for the Motiti Protection Areas.

This survey is the first biodiversity survey by BUV in the Motiti Protection Areas, and limited information was available of habitat type and species distributions across the reef ecosystems. Sites were selected utilising knowledge of previous habitat surveys of Astrolabe Reef (which has a comparable ecology and geology to other reefs within the protection areas; De Luca, 2020) and bathymetry and reef rugosity available from previous bathymetric surveys.

Deployment sites were selected using a stratified random design, where a 100 m by 100 m grid was overlaid on each of the protected areas to the 40 m deep reef contour using ArcGIS Pro. Each point was given a unique site code and separated into three depth classes (A = 0 m-15 m, B = 15 m-25 m, C =25 m+). These depth classes were selected to represent the most common three habitat types on Astrolabe Reef - shallow mixed algae/urchins, *Ecklonia spp.* forest, and kelp-sponge transition (De Luca, 2020) which are expected to occur across the other reef systems. Each reef was split into 2-4 sections, to ensure even spatial coverage. A random number generator was used to select 12 sites across each reef, aiming for equal depth coverage where possible at each reef to try to capture the range of habitat types. Sites were located at a minimum separation distance of 150 m. Site locations are shown in Figure 2. The survey resulted in 60 complete videos, with a good coverage of the depth strata (Table 1).

Table 1 Summary table of depth strata and biotic habitat sampling coverage achieved over the 60 BUV drops.

Depth strata	Biotic Habitat			
	Algae	*Barren*	*Encrusting*	
Shallow (0-15 m)	14	3	-	17
Mid (15 - 25 m)	15	2	9	26
Deep (>25+ m)	7	4	6	17
Count of drops	36	9	15	60

2.2 Baited Underwater Video

2.2.1 Survey methods

The Department of Conservation purpose built “L Frames” were utilised for this study (Figure 3). The frame consists of an L shaped aluminium frame, with a Go Pro 8 mount attached at the top. It has a measurement scale marked at 100 mm intervals. The bait box was re-loaded for each drop with 300g of defrosted chopped pilchards (*Sardinops neopilchardus*). A small number of floats were attached to the camera bar to keep the camera oriented towards the sea floor. Baited Underwater Video surveys were conducted between late February to early May 2021, during periods of calm sea conditions (<1 m base swell). Difficult weather conditions and boat availability limited surveys being done closer together. Water temperature over the period ranged from 19°C to 21.5°C. All monitoring was conducted in daylight hours (generally between 8:30 – 13:00 NZST), at least 1 hour before dusk and after dawn. Recording sheets were filled out at each site utilising the DOC marine reserve monitoring toolbox.

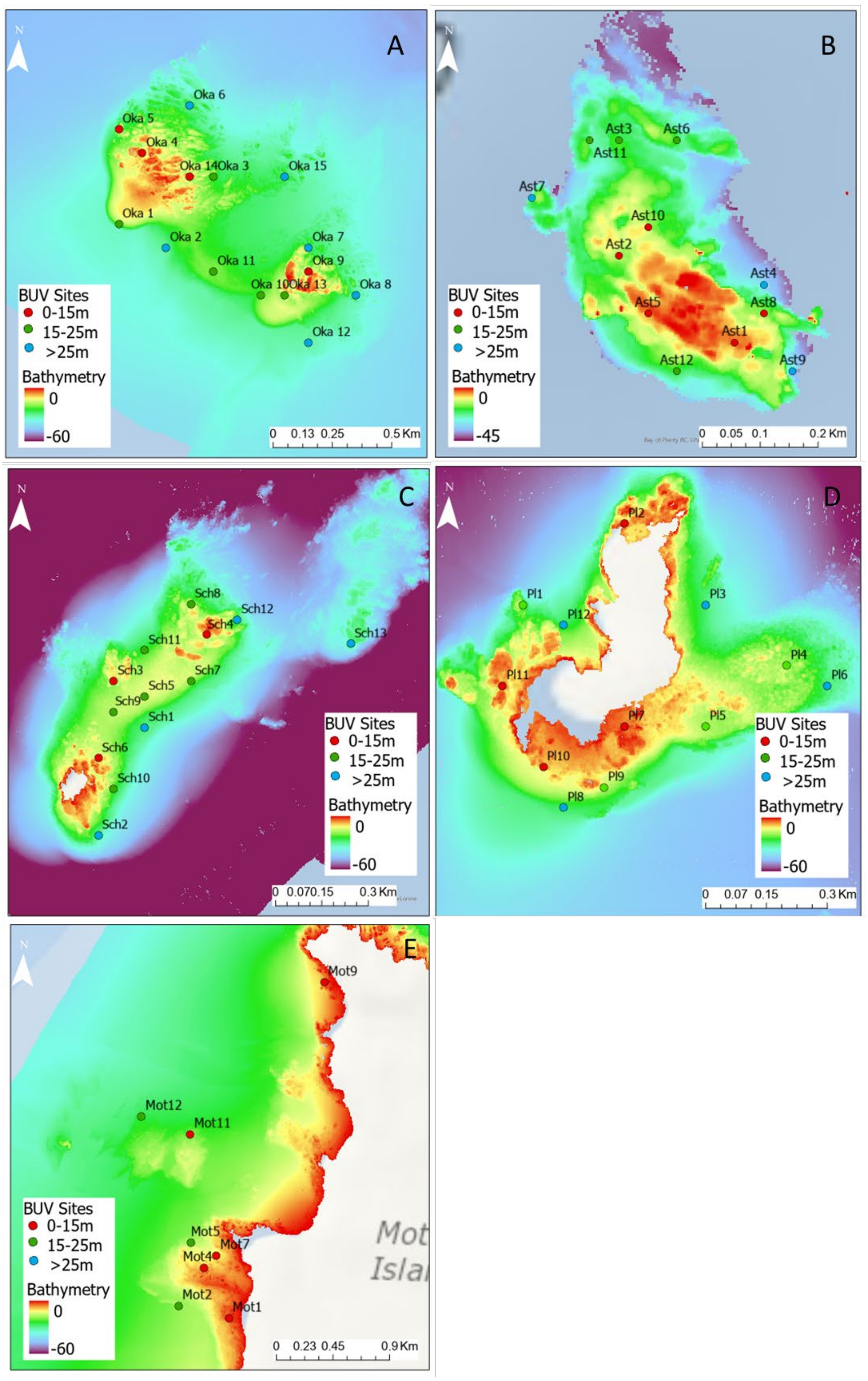


Figure 2 *BUV site locations within Okarapu Reef (A), Astrolabe (B), Schooner Rocks (C), Motunau (D), and Motiti Island (E). Coloured site points indicate the depth strata: Red = 0 m – 15 m, green = 15 m – 25 m, blue = > 25 m. Bathymetry is from multibeam echosounder (MBES) displayed as a continuous scale from 0 m depth to 60 m depth (exception of Astrolabe whose scale is limited to 45 m and remaining background is oceans basemap).*

Four BUV frames were deployed simultaneously at a reef location. Frames were deployed for 35-40 minutes, to ensure 30 minutes of video for analysis. Site deployments ranged from 4 m to 32.4 m depth. The maximum number of individuals of each species that was observed in any one frame of the BUV footage (MaxN) was recorded to give an estimate of species relative abundance for a particular deployment. A sampling window of 30 seconds was used to generate MaxN values, meaning that the MaxN of each species was evaluated for each 30-second interval in the BUV footage. The maximum value among the 30 minute, 30-second replicates was then used in the analysis.

All fish and invertebrate species were identified and counted, with the exception of triplefins (family Tripterygiidae) (due to difficulty identifying), butterfly perch (*Caesioperca lepidoptera*), and 2-spot demoiselles (*Chromis dispilus*) (due to high densities and difficulty counting when present). The latter two are noted in each video as presence/absence. Habitat type (biotic and abiotic) on deployment were classified. Where urchins (*Evechinus chloroticus* or *Centrostephanus rodgersii*) were present, the number visible in the field of view was counted.

All raw video footage is stored on external hard drives housed in the Tauranga BOPRC office. Field sheets and processed datasheets are stored in BOPRC's filing system (Objective ID: fA1401945).

Figure 3 Baited Underwater Video "L Shape" frame used for the deployments.

2.2.2 Data analysis

The data for each deployment were summarised in terms of the number of species, and the MaxN for each observed species. Four indicator fish species were selected for species specific analysis, including the commercial/recreationally important species snapper (*Pagrus auratus*), blue maomao (*Scorpis violacea)*, red pigfish (*Bodianus unimaculatus)* and scarlet wrasse (*Pseudolabrus miles)* which are common reef fish.

Data analysis was undertaken in R (R Development Core Team 2018). Generalised linear models (GLMs) were used to investigate the variation in relative abundance of the indicator species and species richness/diversity measures across reef locations, depth strata, and biotic habitat. Models were fitted with Poisson error distributions to account for the count data. All models were checked for violation of the model assumptions using appropriate diagnostic plots (Zuur et al. 2009). Where overdispersion was identified, standard errors were corrected using a quasi-GLM model. The nature and magnitude of the difference between tested parameters is given by the estimate and its standard error. The z value indicates how many standard deviations a particular value is from the mean and is used to derive the probability (statistical significance, P value). Pairwise Tukeys posthoc tests were performed on each model to test for differences between reef locations, depth strata and biotic habitat, using the ‘multcomp’ package in R. Shannon species diversity and richness were calculated, and assessed for variation across reef locations, depth strata and biotic habitat using generalised linear models with Gaussian distribution and Tukeys posthoc tests. The results of posthoc tests are detailed in Appendix 2 and noted briefly in text.

PRIMER (ver. 7, PRIMER-E Ltd, Plymouth, UK) with the PERMANOVA+ add-on was used to compare species assemblages between reef locations, depth and biotic habitat structure. A Bray-Curtis resemblance matrix was constructed from the dispersion-weighted, square root transformed abundances of the species observed in the BUV survey. To test for differences between species assemblages at each site, a three-factor model with Reef (random factor, five levels), Depth Strata (fixed factor, three levels) and Biotic Habitat (fixed factor, five levels) in a multivariate permutational multivariate analysis of variance (PERMANOVA) test. Similarity percentage (SIMPER) analysis was used to further investigate the similarity (or lack of) in assemblages observed from each Reef location, depth strata and biotic habitat. Non-metric multidimension scaling (nMDS) was used to visualise variation in species assemblages between the reef locations, depth strata and biotic habitat. The nMDS was based on the distance among site centroids in the Bray-Curtis resemblance matrix. Vectors were plotted with individual species Pearson correlations (> 0.3), showing the relationships between species abundances and site positions in multivariate space.

2.2.3 Validation of BUV method

MaxN represents an estimate of relative abundance of particular species. Discovery curves were used to validate the BUV method, which assumes the MaxN value for a given deployment will plateau by the end of the deployment period, indicating all fish individuals in the deployment area have visited the bait station. Discovery curves were plotted for two commonly occurring species across all sites (snapper and red pigfish), using the mean and standard error of count intervals across all deployments.

2.2.4 Rarefaction sampling curves

The iNEXT (iNterpolation and EXTrapolation) package in R was used to investigate rarefaction sampling curves for the BUV species data, based on Chao *et al.* (2014). iNEXT focuses on the three measures of Hill numbers of order. q = 0 is species richness, q = 1 is Shannon diversity, and q = 2 is Simpson diversity. For each diversity measure, iNEXT package in R uses the observed sample of incidence data (called the reference sample) to compute diversity estimates and the associated 95% confidence intervals. Three types of sampling curves are utilised:

1. Sample size (replication) based R/E sampling curves: iNEXT computes diversity estimates for rarefied and extrapolated samples up to double the reference sample size. This type of sampling curve plots the diversity estimates with respect to sample size. Same size refers to the number of sampling units (e.g. BUV drops) for incidence data.
2. Coverage based R/E sampling curves: iNEXT computes diversity estimates for rarefied and extrapolated samples with sample completeness (as measured by sample coverage) up to the coverage value of double the reference sample size. This type of sampling curve plots the diversity estimates with respect to sample coverage. Sample coverage gives the proportion of the total number of individuals in a community that belong to the species represented in the sample and provides an objective indicator of the completeness of the sample (Chao & Jost, 2012).
3. Completeness curve: iNEXT depicts how the sample coverage estimate varies as a function of sample size. It can be thought of as a bridge connecting the two previously mentioned types of curves.

3 Results

3.1 Sampling results

A total of 60 deployments were successfully completed across the study area. The sampling effort between areas and habitat strata were similar, however, some variance occurred due to issues with deployments (kelp obscuration, frame movement, camera failure).

A total of 35 fish species were recorded on the BUV footage over the entire study area (Table 2). The most observed species were snapper (*Pagrus auratus*), red pigfish (*Bodianus unimaculatus*), two-spot demoiselle (*Chromis dispilus*), scarlet wrasse (*Pseudolabrus miles*) and leatherjacket (*Meuschenia scaber*). The least common species included Sandagers wrasse (*Coris sandeyeri*), splendid perch (*Callanthias australis*), red fish/golden snapper (*Centroberyx affinis*), kingfish (*Seriola lalandi*) and the grey moray (*Gymnothorax nubilus*).

Several fish species important for recreational and/or commercial fishing were recorded including snapper, blue maomao (*Scorpis violacea*), blue cod (*Parapercis colias*), trevally (*Pseudocaranx dentex*), pink maomao (*Caprodon longimanus*), blue moki (*Latridopsis ciliaris*), and butterfish (*Odax pullus*). Several ray species were recorded including the short tail stingray (*Bathytoshia brevicaudata*) at 16 sites, and the eagle ray (*Myliobatis tenuicaudatus*) at three sites. Crayfish (*Jasus edwardsii*) were observed at three sites.

3.2 Habitat

There were six types of abiotic habitat identified in the BUV footage. These include small boulder complex (boulders of 25 cm-100 cm wide, 14 sites), large boulder complex (boulders of >100 cm, four sites), platform reef (22 sites), platform reef with vertical crevices (10 sites), sand (six sites) and shell (four sites) habitats. There were six types of biotic habitat identified in the BUV footage (Figure 4). These habitat types were barren (either urchin barren or barren landscape, e.g. bare rock, nine sites), crustose coralline algae (12 sites), *Ecklonia radiata* (kelp, 32 sites), shallow mixed algae (a high mix of shallow algae species in the high wave action zone, two sites), *Carpophyllum maschalocarpum* (the common flapjack, two sites), and sponge (three sites). For analysis, these were simplified into three categories due to the small number of some sites observed: Barren, Encrusting (crustose coralline algae and sponge), and Algae (*Ecklonia radiata*, shallow mixed algae, and *Carpophyllum maschalocarpum*).

Table 2 Frequency of occurrence of species observed during the baited underwater video (BUV) deployments. No. sites = the number of unique deployment sites where species were observed. The total number of deployments per reef is given in parentheses. Species are listed in order by species presence across all sites.

Scientific name	Common name	No sites	Okarapu (n=15)	Astrolabe (n=12)	Schooner (n=13)	Motiti (n=8)	Motunau (n=12)
Pagrus auratus	Snapper	52	15	10	10	8	9
Bodianus unimaculatus	Red pigfish	49	13	12	13	2	9
Chromis dispilus	Twospot demoiselle	47	14	12	10	1	10
Pseudolabrus miles	Scarlet wrasse	38	9	10	12	2	5
Meuschenia scaber	Leatherjacket	37	14	4	7	4	8
Gymnothorax prasinus	Yellow moray	28	8	5	6	4	5
Notolabrus celidotus	Spotty	27	6	8	7	1	5
Chironemus marmoratus	Hiwihiwi	24	9	7	3	1	4
Scorpis violacea	Blue maomao	24	11	6	4	0	3
Cheilodactylus spectabilis	Red moki	22	6	4	4	2	6
Caesioperca lepidoptera	Butterfly perch	21	7	6	4	0	4
Hypoplectrodes dimidius	Halfbanded perch	20	7	4	4	0	5
Bathytoshia brevicaudata	Short tail stingray	16	0	0	11	1	4
Parapercis colias	Blue cod	14	3	1	4	3	3
Upeneichthys lineatus	Goatfish	14	7	1	0	3	3
Pseudolabrus luculentus	Orange wrasse	11	0	4	6	0	1
Notolabrus fucicola	Banded wrasse	9	0	5	1	0	3
Pseudocaranx georgianus	Trevally	8	0	2	2	2	2
Scorpaena cardinalis	Scorpionfish	8	0	3	3	0	2
Optivus elongatus	Slender roughy	6	4	0	1	0	1
Pseudophycis bachus	Red cod	5	1	3	1	0	0
Nemadactylus douglasii	Porae	5	3	0	1	0	1
Aplodactylus arctidens	Marblefish	5	0	1	2	0	2
Decapterus koheru	Koheru	4	1	2	0	0	1
Bathytoshia brevicaudata	Black angelfish	4	0	0	1	0	3
Myliobatis tenuicaudatus	Eagle ray	3	0	1	1	1	0
Caprodon longimanus	Pink maomao	3	0	1	2	0	0
Hypoplectrodes huntii	Redbanded perch	3	0	1	2	0	0
Jasus edwardsii	Crayfish	3	0	1	1	0	1
Odax pullus	Butterfish	3	0	0	0	0	3
Latridopsis ciliaris	Blue moki	2	1	0	1	0	0
Suezichthys aylingi	Crimson cleanerfish	2	0	1	1	0	0
Gymnothorax nubilus	Grey moray	1	0	1	0	0	0
Seriola lalandi	Kingfish	1	1	0	0	0	0
Centroberyx affinis	Redfish	1	0	0	1	0	0
Callanthias australis	Splendid Perch	1	0	0	1	0	0
Coris sandeyeri	Sandagers Wrasse	1	0	0	0	0	1

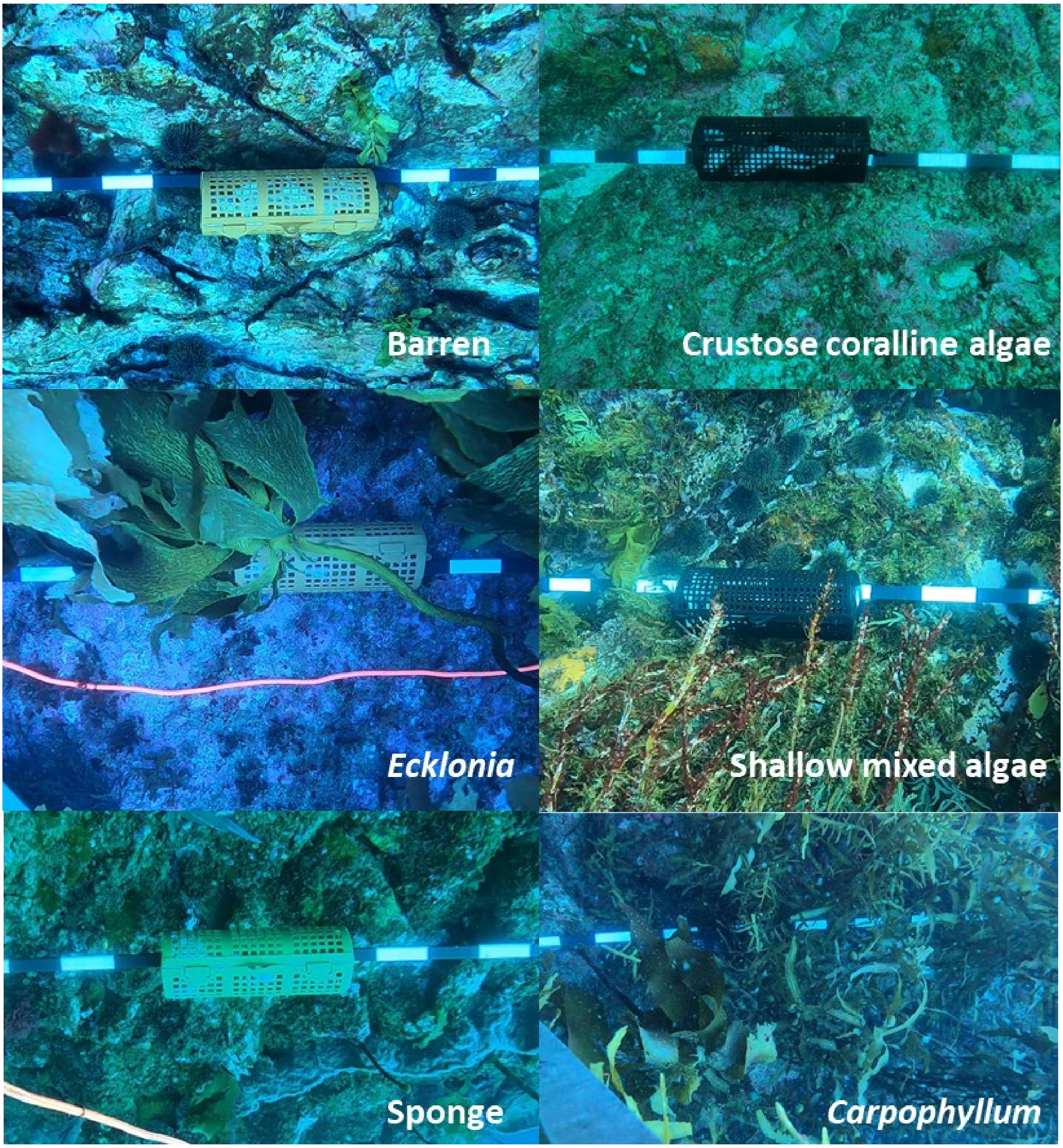


Figure 4 *Baited underwater video still images showing the six identified biotic habitat types.*

3.3 Relative abundance

Boxplots of the four indicator fish species across the monitored reefs are displayed in Figure 5. Snapper abundance was higher at the monitored sites at Motiti compared to Motunau (Est. = -1.54, z = -3.43, p<0.01), Okarapu (Est. = -1.02, z = -2.93, p<0.05) and Schooner Rocks (Est. = -1.28, z = -3.23, p<0.05). There was no statistically significant difference in blue maomao relative abundance across the reef ecosystems. The abundance of red pigfish was significantly different across the reefs, with lower relative abundance at Motiti compared to Astrolabe (Est. = -1.16, z = -2.94, p<0.05) and Schooner Rocks (Est. 2.22, z = 3.04, p<0.05). There was significantly higher relative abundance of scarlet wrasse at Schooner Rocks compared to Motunau (Est. = 1.57, z = 3.21, p<0.05) and Motiti (Est. = 2.08, z = 2.83, p<0.05).

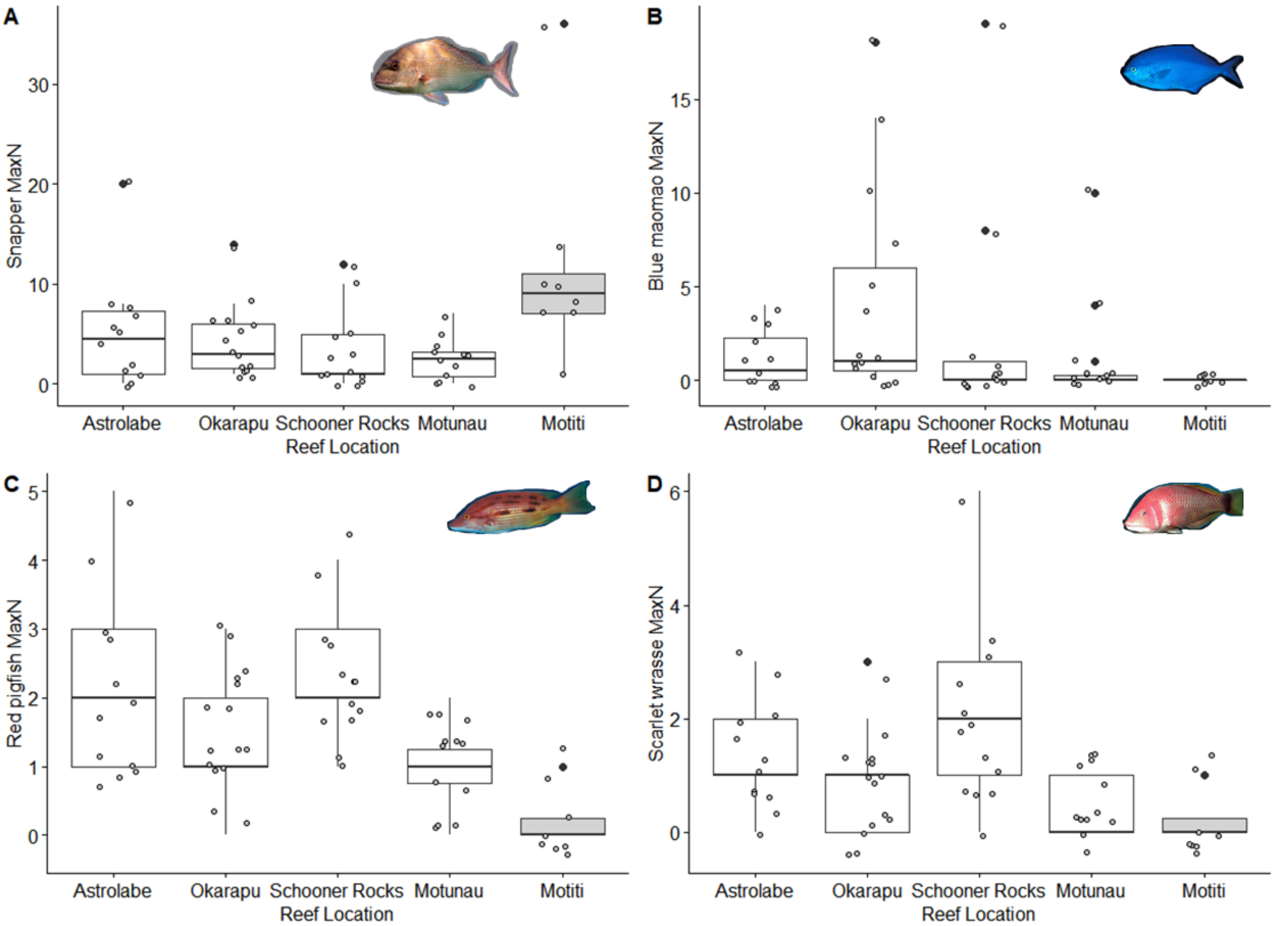


Figure 5 *Relative abundance (MaxN values) of four fish species across the surveyed reef locations. A = Snapper (Pagrus auratus), B = Blue maomao (Scorpis violacea), C = Red pigfish (Bodianus unimaculatus), D = Scarlet wrasse (Pseudolabrus miles). The lower and upper hinges represent the 25th and 75th percentiles and the middle line represents the median of the data. Points are jittered for easier visualisation (grey points). Outliers if present are displayed as black points. Marine protected sites are in white, and no protection sites in grey.*

The relative abundance of key fish species was compared among the biotic habitat types (Figure 6). There were statistically significant differences in snapper relative abundance between biotic habitats, with higher snapper relative abundance in barren habitats compared to algae (Est. = 0.71, z = 2.51, p<0.05) and encrusting (Est. = -1.51, z = -3.39, p<0.01). The scarlet wrasse relative abundance was higher in encrusting habitat compared to barren (Est. = 1.28, z = 2.37, p<0.05). There were no significant differences in blue maomao or red pigfish relative abundance compared to biotic habitat type.

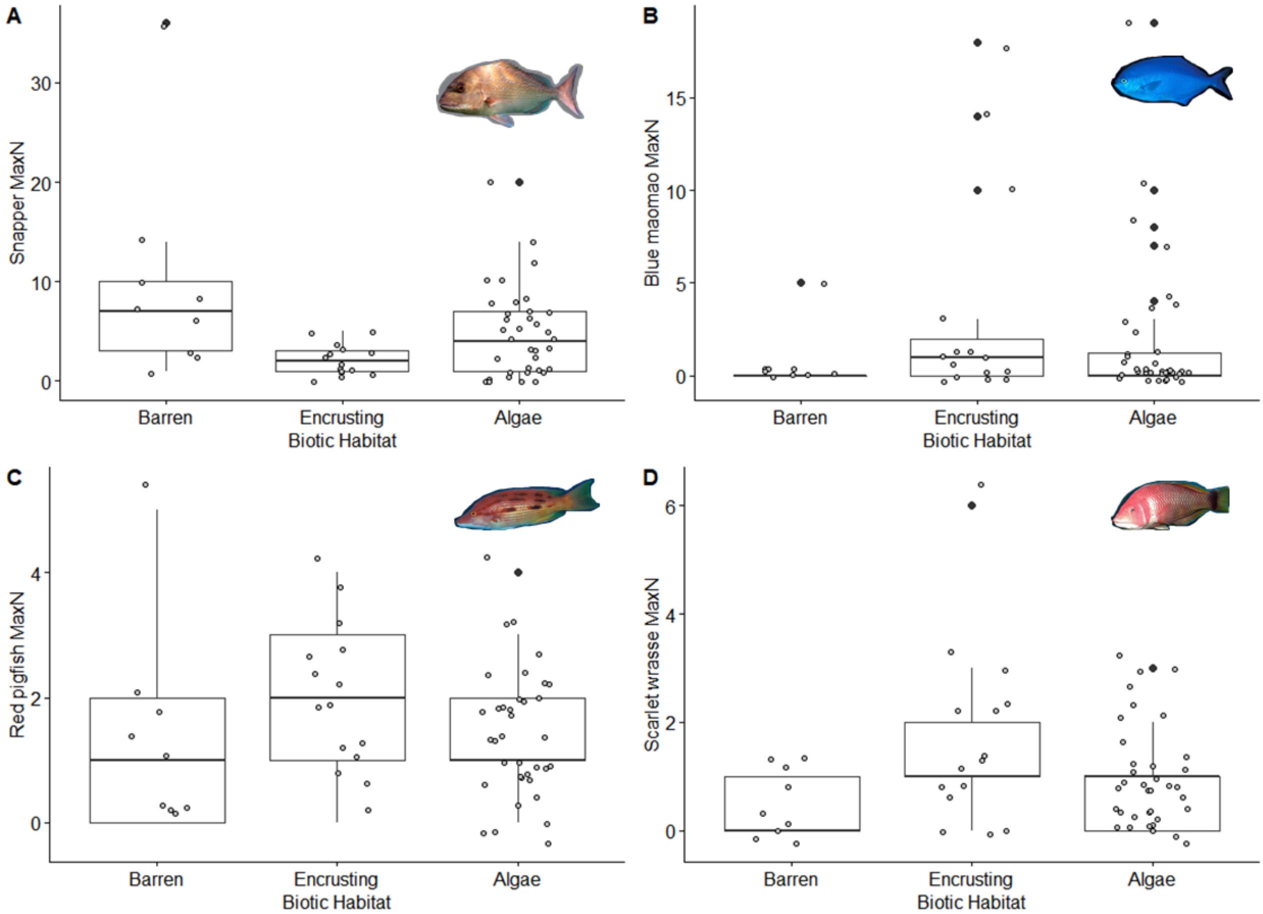


Figure 6 *Relative abundance (MaxN values) of four fish species across the identified biotic habitat types. A = Snapper (Pagrus auratus), B = Blue maomao (Scorpis violacea), C = Red pigfish (Bodianus unimaculatus), D = Scarlet wrasse (Pseudolabrus miles). The lower and upper hinges represent the 25th and 75th percentiles and the middle line represents the median of the data. Points are jittered for easier visualisation (grey points). Outliers if present are displayed as black points.*

The relative abundance of key fish species was compared among the depth strata (Figure 7). There was a significant difference in red pigfish abundance across the depth strata, with significantly higher abundance in the deep (25 m) strata compared to the shallow depth strata (5 m) (Est. = 0.80, z = 2.76, $p<0.05$). The scarlet wrasse relative abundance was higher in the mid (15 m) depth strata compared to the shallow (5 m) (Est. 1.02, z = 2.60, $p<0.05$). There was no significant difference in snapper or blue maomao relative abundance across depth strata.

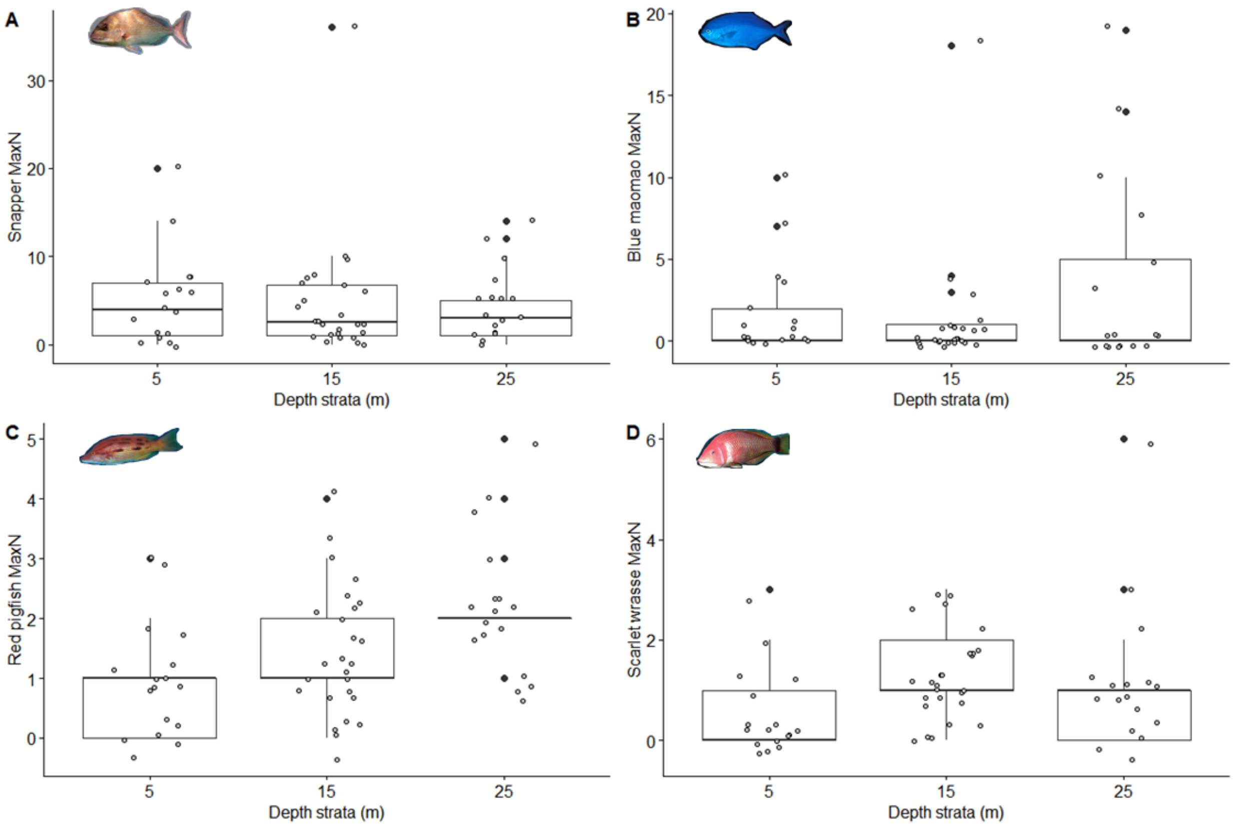


Figure 7 *Relative abundance (MaxN values) of four fish species across the three depth strata. A = Snapper (Pagrus auratus), B = Blue maomao (Scorpis violacea), C = Red pigfish (Bodianus unimaculatus), D = Scarlet wrasse (Pseudolabrus miles). The lower and upper hinges represent the 25th and 75th percentiles and the middle line represents the median of the data. Points are jittered for easier visualisation (grey points). Outliers if present are displayed as black points.*

3.4 Species diversity and richness

Mean species richness was calculated across each of the reef sites (Table 3, Figure 8). Species richness was significantly lower at the monitored Motiti sites compared to all other sites (Astrolabe, Est. = -1.04, z = -4.03, p<0.001; Okarapu, Est. = 1.01, z = 4.06, p<0.001; Schooner Rocks, Est. = 1.22, z = 4.82, p<0.001; Motunau, Est. = 1.04, z = 4.03, p<0.001). Mean species diversity (Shannon diversity index) was calculated across each of the reef sites monitored (Table 3). Mean species diversity at Astrolabe Reef was 1.91, Okarapu 1.88, Motunau 1.72, Schooner 2.02 and Motiti 0.85. Similarly, to species richness, species diversity was significantly lower at Motiti Island compared to the other sites (Astrolabe, Est. = -1.05, z = -5.05, p<0.001; Okarapu, Est. = 1.03, z = 5.13, p<0.001; Schooner Rocks, Est. = 1.17, z = 5.68, p<0.001; Motunau, Est. = 0.87, z = 4.16, p<0.001).

Table 3 Species richness and Shannon species diversity index across monitored sites.

		Richness		Shannon diversity	
Reef	**Count**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
Astrolabe	12	2.20	0.548	1.91	0.326
Okarapu	15	2.717	0.635	1.88	0.428
Motunau	12	2.20	0.587	1.72	0.598
Schooner	13	2.39	0.414	2.02	0.270
Motiti	8	1.16	0.633	0.85	0.649

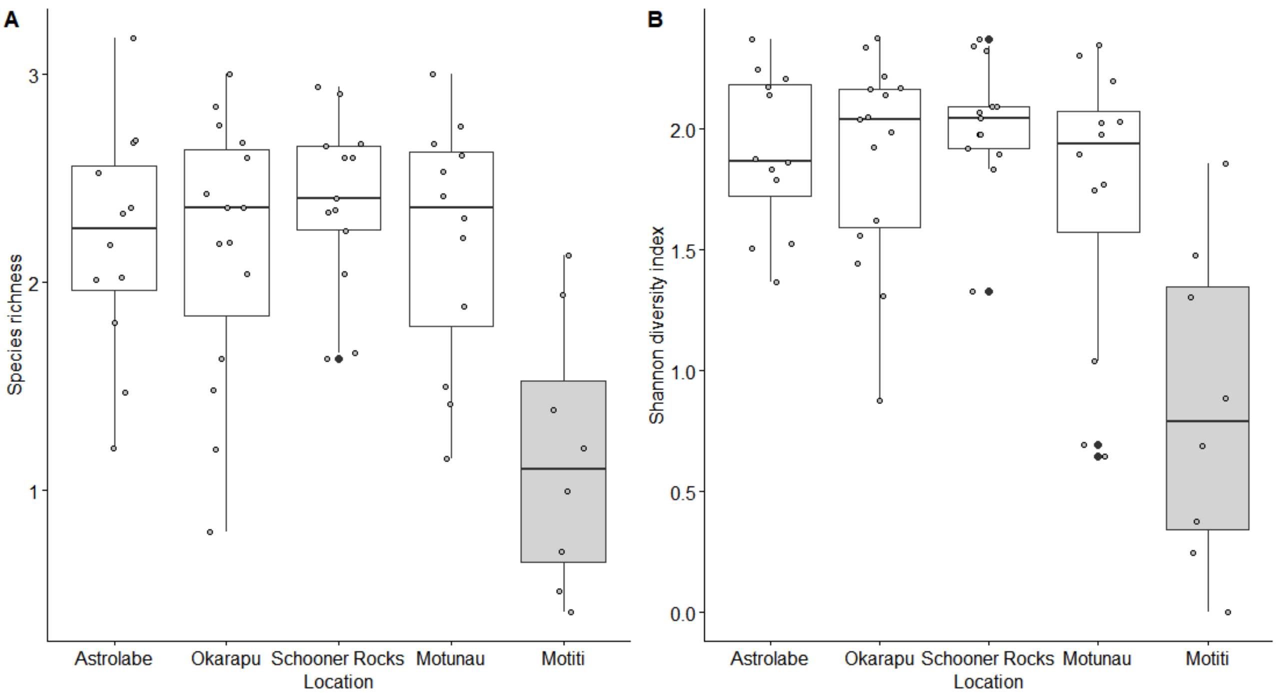


Figure 8 Boxplots of species richness (A) and Shannon diversity index (B) across the surveyed Reef locations. The lower and upper hinges represent the 25th and 75th percentiles and the middle line represents the median of the data. Points are jittered for easier visualisation (grey points). Outliers if present are displayed as black points. Marine protected sites are in white, and no protection sites in grey.

Mean species richness and species diversity was calculated across the biotic habitat types (Table 4, Figure 9). There was higher species diversity and species richness in the encrusting habitats compared to the barren (Shannon species diversity, Est. = 0.74, z = 3.27, p<0.01; Species richness, Est. = 0.73, z = 2.73, p<0.05). Species richness showed no differences across depth strata. Species diversity however showed higher diversity in the deeper and mid depth habitats compared to the shallow (Deep, Est. = 0.49, z = 2.62, p<0.05; Mid, Est. 0.40, z = 2.37, p<0.05).

Table 4 Species richness and Shannon species diversity index for the depth strata and biotic habitat classifications.

		Richness		Shannon diversity	
Depth strata	**Count**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
Shallow (0 – 15m)	17	1.93	0.73	1.43	0.73
Mid (15 – 25m)	26	2.06	0.51	1.84	0.51
Deep (25+ m)	17	2.31	0.35	1.92	0.35
Biotic habitat	**Count**	**Mean**	**Std dev.**	**Mean**	**Std dev.**
Barren	9	1.62	0.73	1.30	0.69
Encrusting	15	2.35	0.60	2.04	0.31
Algae	36	2.11	0.63	1.74	0.57

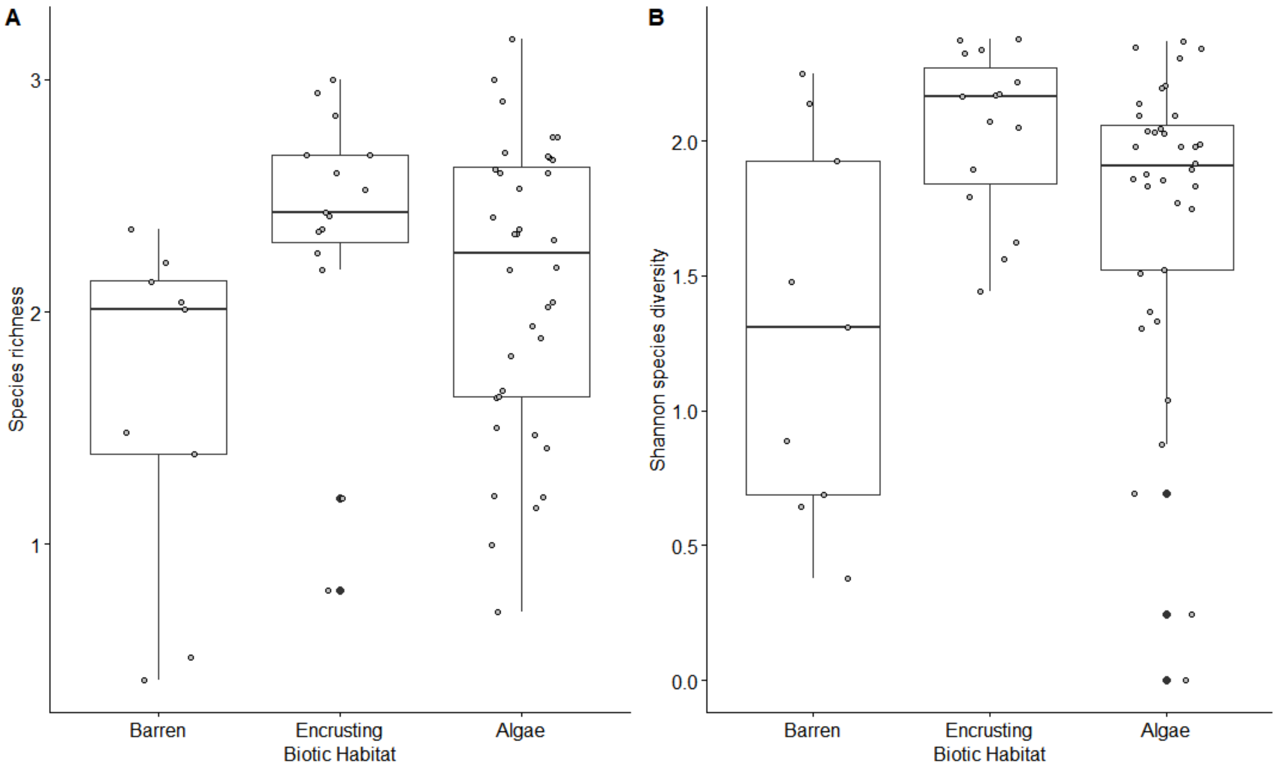


Figure 9 Boxplots of species richness (A) and Shannon species diversity (B) by biotic habitat. The lower and upper hinges represent the 25th and 75th percentiles and the middle line represents the median of the data. Points are jittered for easier visualisation (grey points). Outliers if present are displayed as black points.

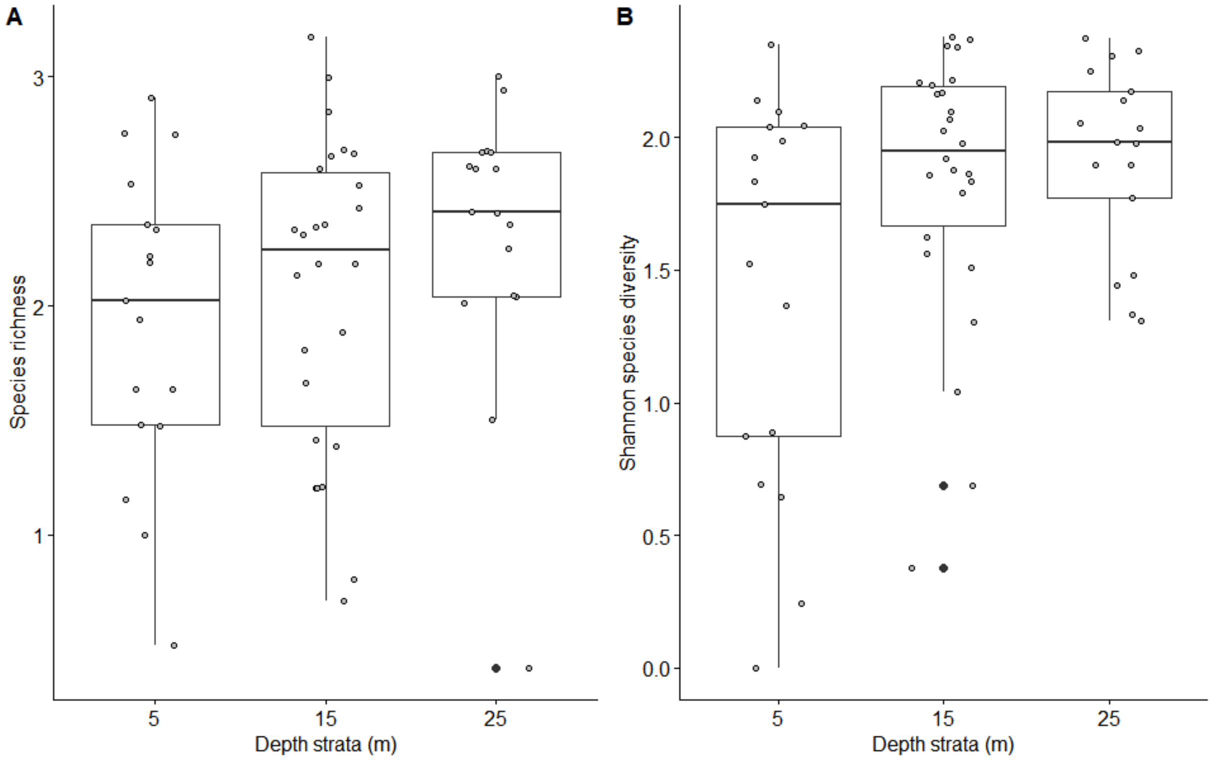


Figure 10 *Boxplots of species richness (A) and Shannon species diversity (B) by depth strata (m). The lower and upper hinges represent the 25th and 75th percentiles and the middle line represents the median of the data. Points are jittered for easier visualisation (grey points). Outliers if present are displayed as black points.*

3.5 Multivariate analyses

The nMDS plot for the species assemblage data, showed generally the MPA reefs (Astrolabe, Motunau, Okarapu and Schooner Rocks) were similar with relative clustering of the sites (Figure 11), however, the Motiti site was separated from the other reefs. A significant difference was found in the multivariate species assemblages between reef location (PERMANOVA: Pseudo-F = 3.18, P = 0.001) (Table 5). Pairwise, PERMANOVA tests of reef, indicated differences in the species assemblage data between Astrolabe and Schooner Rocks, and Astrolabe and Okarapu. There was a significant interaction between depth and reef for species assemblages (PERMANOVA: Pseudo-F = 1.47, P = 0.029) (Figure 12), and clustering appears evident in the depth nMDS (Figure 12). No difference in the species assemblages were identified between biotic habitats (PERMANOVA: Pseudo-F = 1.89, P = 0.105). (Figure 13).

Pearsons correlations were used to identify and plot significant species (correlation > 0.3) on the nMDS plots (Figure 11,12) which indicates some clustering between groups of fish, such as banded wrasse, spotty, black angelfish and hiwihiwi, indicating prevalence towards the lower depth strata locations (Figure 11,12). A mid-range depth group was evident with short-tail stingray, two-spot demoiselle, red pigfish and scorpionfish sitting in the mid depth strata. Perch and wrasse species such as scarlet wrasse, half-banded perch, butterfly perch and red cod were clustered towards the deeper site locations (Figure 11,12).

Table 5 *Results of the PERMANOVA for relative abundance (total MaxN) with significant differences indicated by bold font. df is degrees of freedom, MS is mean sum of squares, pseudo-F is F value by permutation. P (perm) is p value based on 9999 permutations.*

Source	df	MS	Pseudo-F	P (perm)
Reef	**3**	**4341**	**3.18**	**0.001**
Depth	1	2185	1.32	0.279
Biotic Habitat	1	2800	1.89	0.105
Reef x Depth	**7**	**2012**	**1.47**	**0.029**
Reef x Biotic Habitat	5	1652	1.21	0.2
Depth x Biotic Habitat	2	2332	1.71	0.057
Total	**59**			

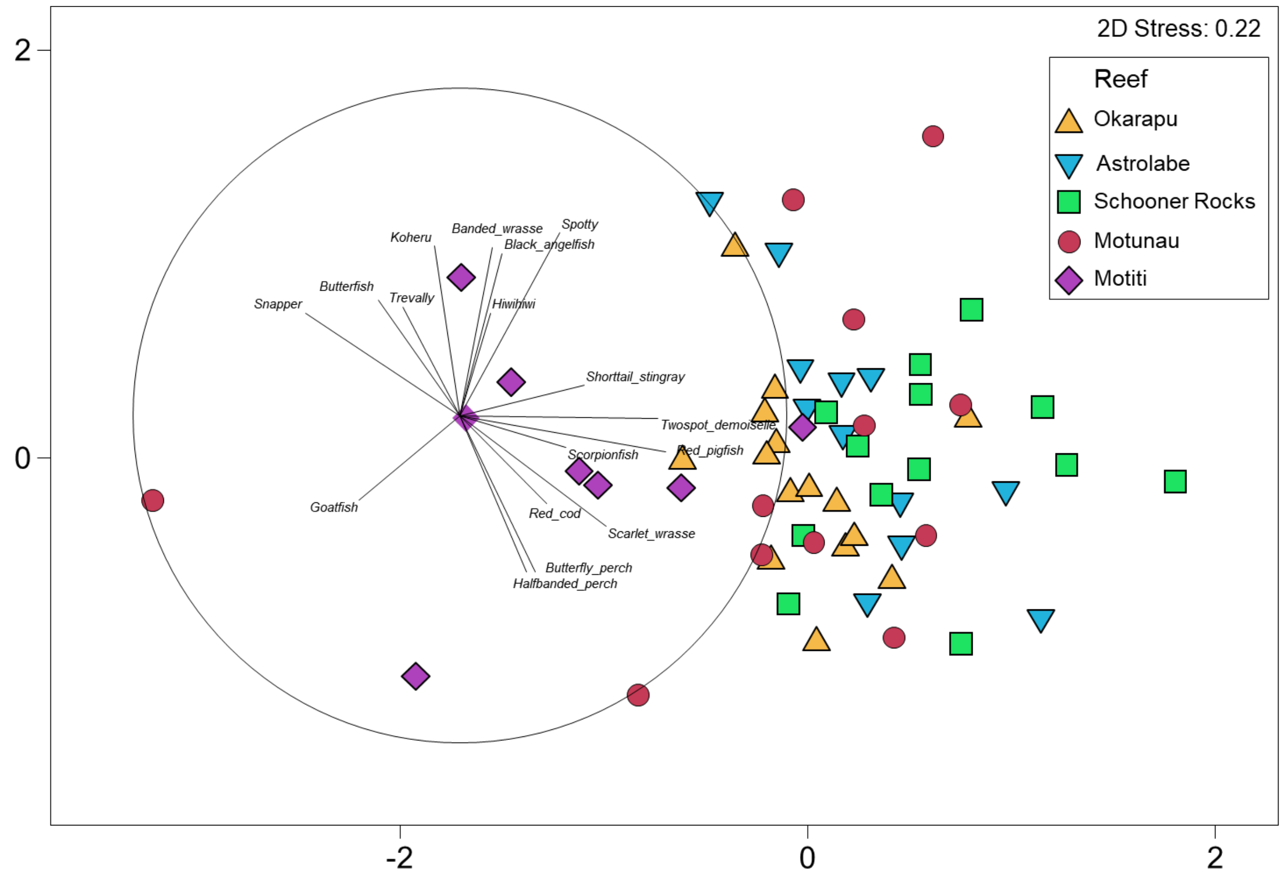


Figure 11 *Non-metric multidimensional scaling (nMDS) showing species assemblages between Reef locations. Species vectors are overlain in black text (Pearson correlations >0.3).*

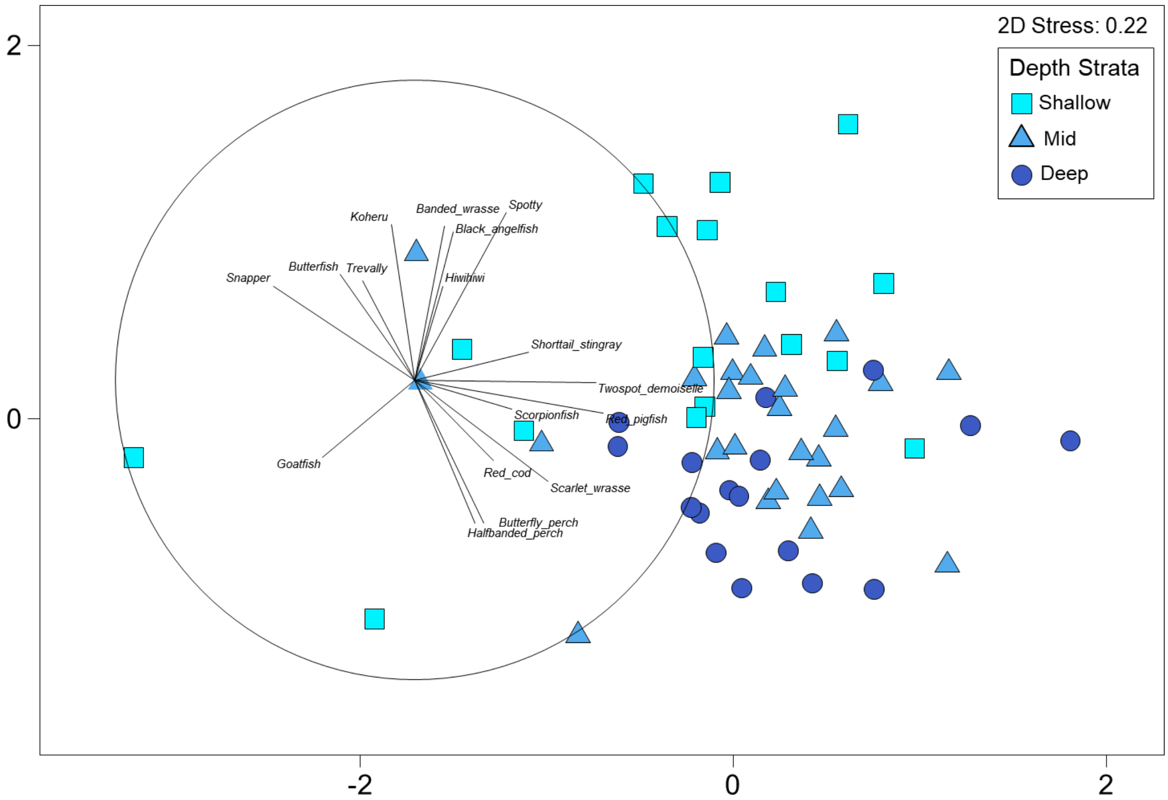


Figure 12 Non-metric multidimensional scaling (nMDS) showing species assemblages between depth strata. Species vectors are overlain in black text (Pearson correlations >0.3).

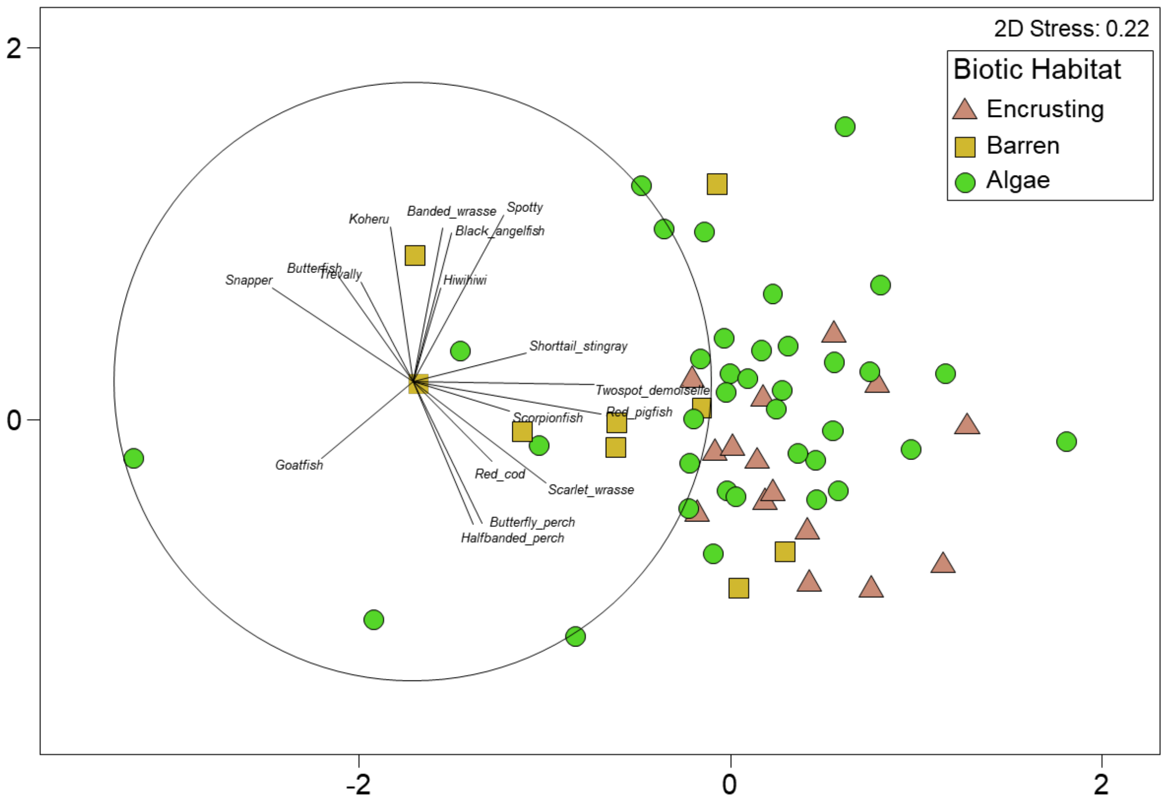


Figure 13 Non-metric multidimensional scaling (nMDS) showing species assemblages between biotic habitat. Species vectors are overlain in black text (Pearson correlations >0.3).

Similarity percentages (SIMPER) were estimated to determine which fish species contributed most to the variability observed in the fish community between reef sites and depth strata (and identified as significantly different in the post-hoc testing), and therefore were characteristic of those locations/habitats (Table 6).

The average similarity was 33% for the shallow depth strata, 45% for the mid depth strata, and 47% for the deep depth strata (Table 6), indicating that the shallow depth strata had the most dissimilar species communities. The average dissimilarity for the shallow to mid-depth strata is 63%, 67% dissimilarity for the shallow to deep strata, and 56% dissimilarity for the mid to deep. Snapper abundance was the most important contributor to both similarity and dissimilarity between the depth strata. Other species such as red pigfish, two-spot demoiselle, scarlet wrasse and leatherjacket were contributors to group similarity and dissimilarity.

For the reefs, the average similarity was 53% for Okarapu, 48% for Astrolabe, 47% for Schooner Rocks, 44% for Motiti and 33% for Motunau (Table 6). The most dissimilar reef sites were Motiti and Schooner Rocks (73%), Motiti and Motunau (73%), Motiti and Astrolabe (72%). Snapper abundance was again one of the key structuring fish species, identified to have a larger contribution compared to other species. For the sites identified as significantly different in the posthoc tests (Astrolabe compared to Schooner and Okarapu), they had similar key species, apart from one or two. Schooner Rocks had short-tail stingray contribute to the dissimilarity, and Astrolabe had spotty. Okarapu had both leatherjacket and blue maomao whilst Astrolabe had scarlet wrasse and spotty.

Table 6 Similarity percentages from SIMPER analysis of fish species contributions to depth strata and reef location similarities.

	Abundance	**Contribution**	**Cumulative**
Depth Strata			
Shallow	**Average similarity = 33.10**		
Snapper	1.92	28.93	28.93
Yellow moray	0.71	11.29	40.22
Spotty	0.67	8.80	49.02
Red pigfish	0.78	8.66	57.68
Two spot demoiselle	0.65	8.10	65.78
Hiwihiwi	0.81	6.35	72.13
Mid	**Average similarity = 45.48**		
Snapper	1.80	25.01	25.01
Red pigfish	1.04	14.36	39.37
Scarlet wrasse	1.00	14.28	53.65
Twospot demoiselle	0.81	13.02	66.67
Leatherjacket	0.77	7.67	74.34
Deep	**Average similarity = 47.18**		
Red pigfish	1.45	21.46	21.46
Snapper	1.86	20.06	41.53
Two spot demoiselle	0.88	12.97	54.50
Leatherjacket	0.90	9.62	64.11
Scarlet wrasse	0.86	7.34	71.46

Reef Location			
Okaparu	**Average similarity = 53.33**		
Snapper	1.90	21.34	21.34
Leatherjacket	1.26	14.08	35.42
Two spot demoiselle	0.93	13.04	48.46
Red pigfish	1.10	12.16	60.62
Blue maomao	1.54	9.69	70.31
Astrolabe	**Average similarity = 48.29**		
Red pigfish	1.41	19.38	19.38
Snapper	1.91	17.19	36.57
Two spot demoiselle	1.00	16.50	53.07
Scarlet wrasse	1.06	13.94	67.01
Spotty	0.67	7.18	74.18
Schooner Rocks	**Average similarity = 47.28**		
Red pigfish	1.49	23.81	23.81
Scarlet wrasse	1.30	16.39	40.20
Short-tail stingray	0.88	13.07	53.27
Snapper	1.43	12.73	66.00
Two spot demoiselle	0.77	9.94	75.94
Motiti	**Average similarity = 43.70**		
Snapper	3.15	80.05	80.05
Motunau	**Average similarity = 32.97**		
Snapper	1.33	21.08	21.08
Two spot demoiselle	0.83	17.50	38.59
Red pigfish	0.85	13.91	52.49
Leatherjacket	0.82	10.49	62.98
Half-banded perch	0.45	5.25	68.23
Scarlet wrasse	0.42	5.19	73.42

3.6 Rarefaction sampling curves

Species accumulation curves showed a fast increase in species identification over the first 10 sampling units (Figure 14). Species richness show the curves beginning to plateau at several sites at the end of the reference samples. Shannon diversity shows levelling off species accumulation after around 12-15 sampling units, similar to Simpson diversity (Figure 14). The species diversity measures were higher in three sites (Astrolabe, Motunau and Schooner). The sample coverages (sample completeness) for the five locations based on current sampling effort were estimated as: Astrolabe = 92.5%, Okaparu = 97.3%, Motiti = 88.4%, Schooner = 91.8%, Motunau = 94.7% respectively (Figure 15), indicating that sampling for completeness was limited at some of the sites. We can see that there is high overlap between the confidence intervals, noting the uncertainty in our estimates due to high variability in species abundances across the monitoring locations.

Figure 16 compares the coverage-based rarefaction and extrapolation curves up to double the reference sample size (replication) for each site. There is high overlap between the confidence intervals of Astrolabe, Motunau and Schooner, indicating similar species diversity across the sites and Hill numbers. Okaparu and Motiti appear similar at lower sample coverage, however Okaparu increases in dissimilarity as sample coverage increases.

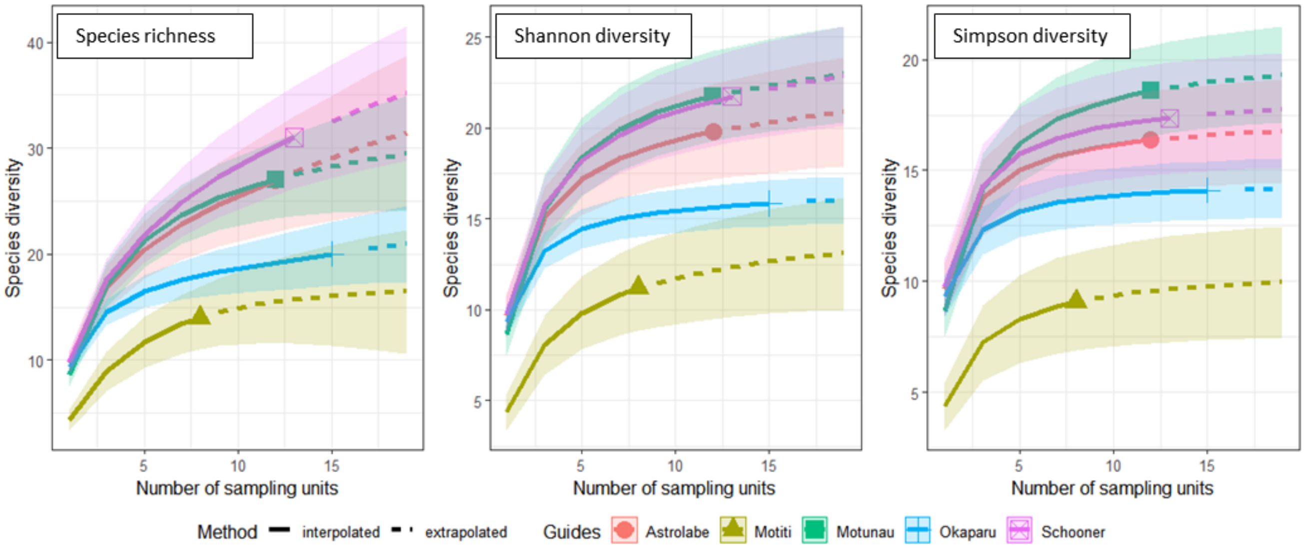


Figure 14 *Comparison of sample size-based rarefaction (solid line) and extrapolation (dashed line) curves with 95% confidence intervals using Hill numbers (Species richness, panel 1; Shannon diversity, panel 2; Simpson diversity, panel 3). All curves were extrapolated up to the base sample size of 15. Reference samples are denoted by solid dots.*

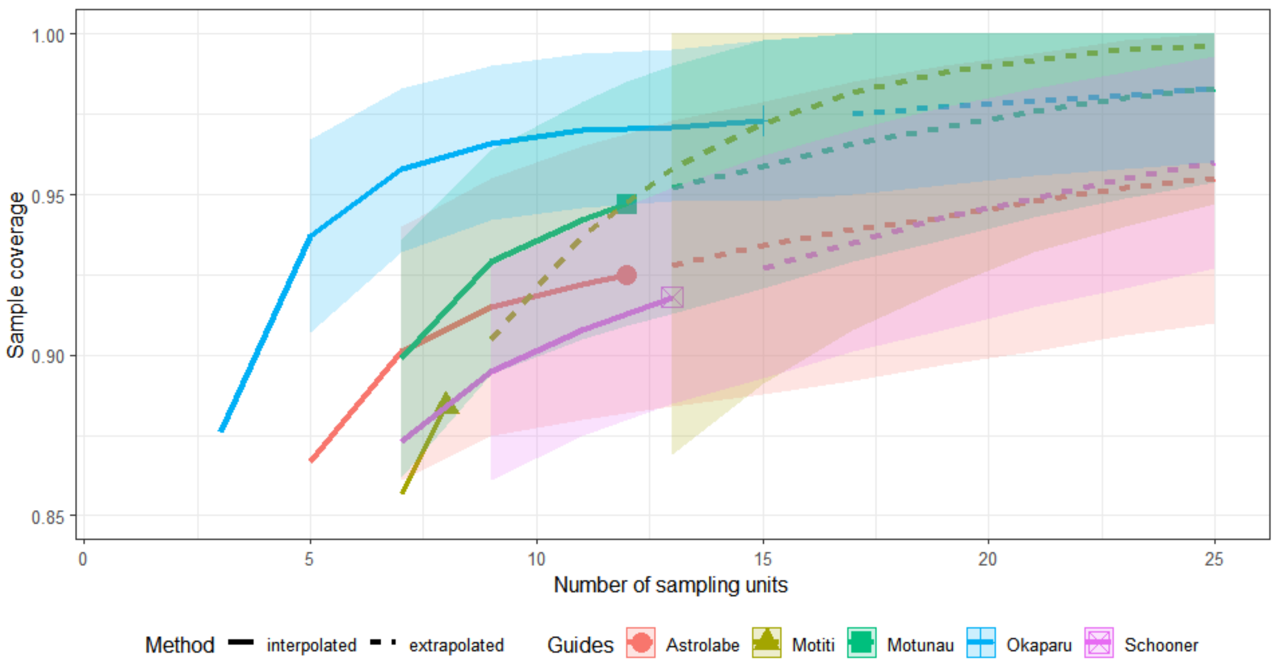


Figure 15 *Sample coverage for rarefied samples (solid lines) and extrapolated samples (dashed lines) with 95% confidence intervals for baited underwater video samples. Each curve was extrapolated up to double its reference sample size. Reference samples are denoted by solid dots.*

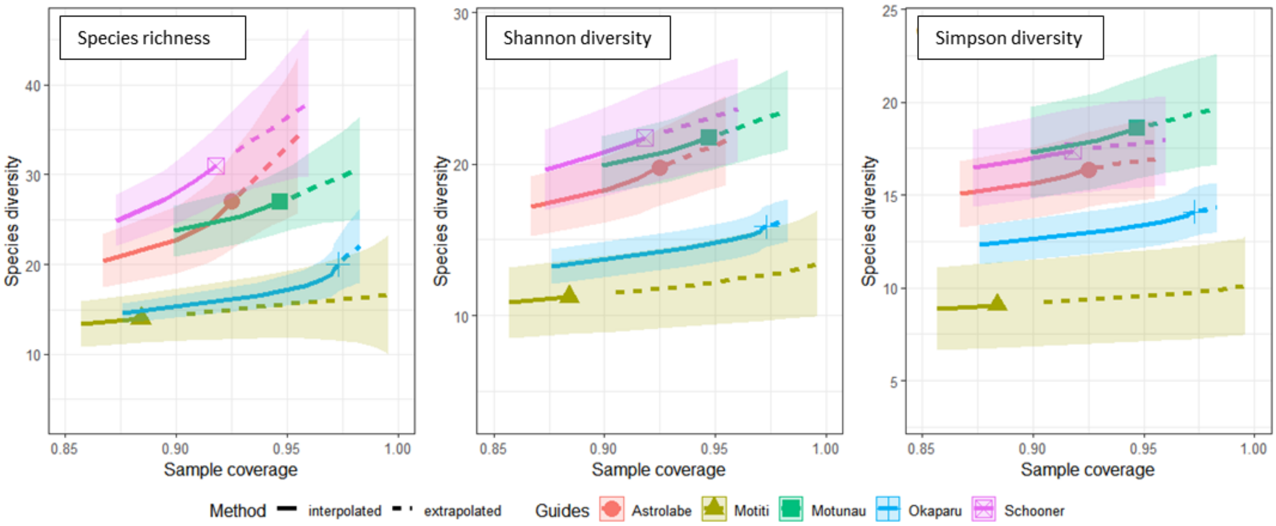


Figure 16 Comparison of the coverage-based rarefaction (solid lines) and extrapolation (dashed lines), up to a coverage of double the reference sample size, for species diversity from BUV using Hill numbers (Species richness, panel 1; Shannon diversity, panel 2; Simpson diversity, panel 3). Reference samples in each plot are denoted by solid dots.

Species diversity was estimated for 95% sample coverage (which correlates to around a doubling of sampling effort for many sites) (Table 7). The sites with a higher species diversity require a higher level of sampling to reach the sample coverage of 95%, whilst others could be reduced. This indicates that our sampling effort needs to be increased in future surveys to ensure we are getting a higher level of sampling coverage and a better representation of species diversity. Based on the species accumulation curves shown between Figures 14-16, increasing the average sample size of sites to a minimum of 15 will result in higher sample coverage (range of 92.7% - 97.3%). For the two sites with higher species discovery in the reference samples (Astrolabe and Schooner) it may be required to increase this sampling size even further (up to 22 samples).

Table 7 Output of the species diversity estimates of Hill numbers (Species richness, Shannon diversity, Simpson diversity) for a specified level of sample coverage (95%).

Site	Required sample size	Method	Sample coverage estimate	Species richness	Shannon diversity	Simpson diversity
Astrolabe	22	Extrapolated	0.950	33.071	21.267	16.853
Okaparu	6	Interpolated	0.950	17.086	14.757	13.369
Motiti	12	Extrapolated	0.949	15.534	12.172	9.563
Schooner	21	Extrapolated	0.949	36.242	23.127	17.801
Motunau	13	Extrapolated	0.952	27.458	21.967	18.734

3.7 BUV validation

Plots of the mean fish counts for two commonly observed species (snapper and red pigfish) indicate that generally the maximum fish counts were observed by 20-25 minutes, before the end of the 30-minute deployment (Figure 17). Snapper mean counts tended to occur later during the deployment time, indicating that the 30-minute deployment may be too short to capture the number of snapper present at a deployment site.

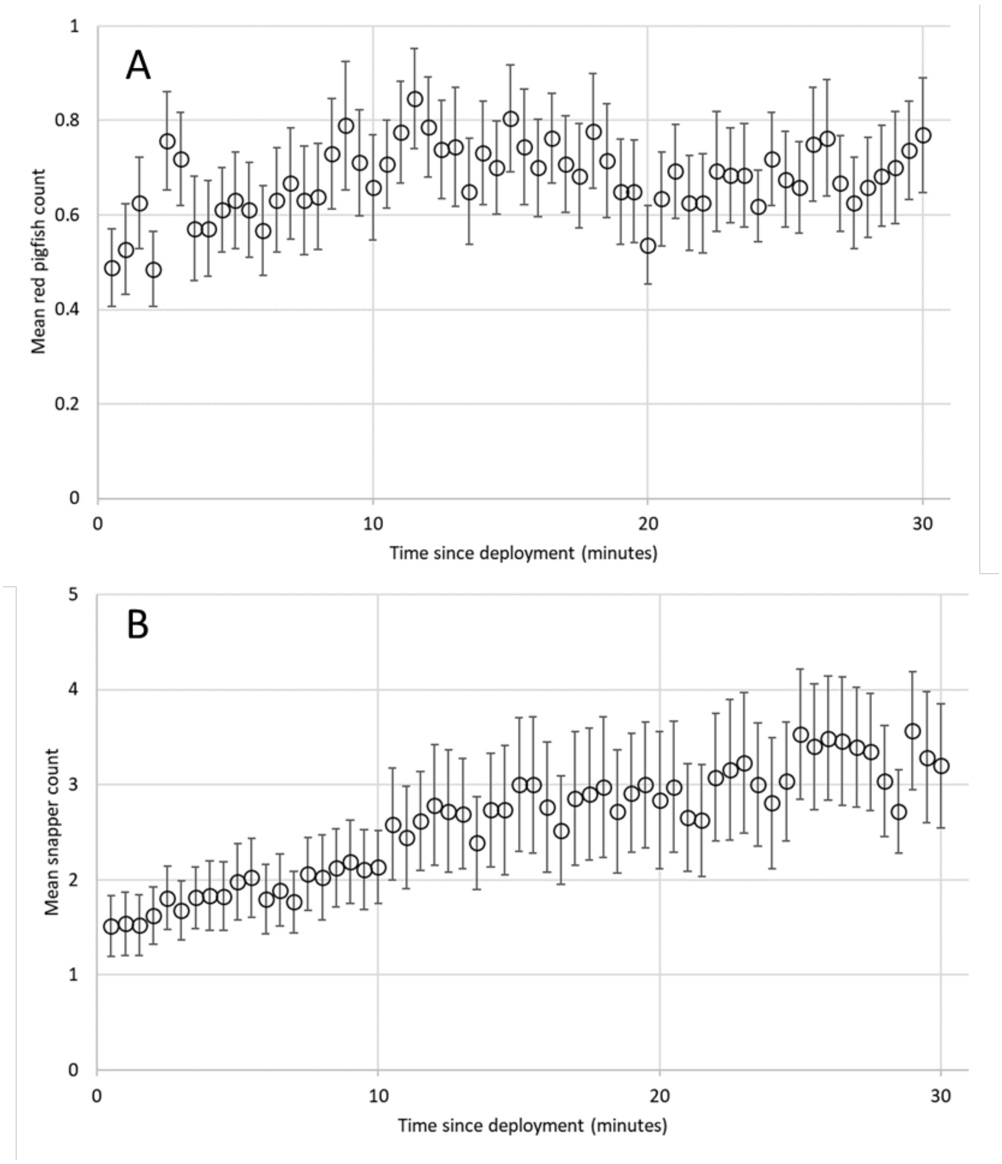


Figure 17 *Plots showing the effect of deployment time on the mean count values of red pigfish (Bodianus unimaculatus) (A) and snapper (Pagrus auratus) (B). The discovery curves show the influence of increasing numbers of 30 second count intervals on the MaxN value in a deployment.*

4 Discussion

4.1 Species inventory and population dynamics

This is the first known survey of fish populations in the Motiti Protection Areas using BUV. Baited Underwater Video is a well-recognised method to survey fish assemblages across a range of habitats and depths (Murphy & Jenkins, 2010, Harasti *et al.*, 2015, Whitmarsh *et al.*, 2017, Jones *et al.*, 2021). This survey represents a baseline of fish assemblages within the Motiti Protection Areas, at the time of the fishing restrictions being implemented (August 2021). It is expected that the marine protection will result in an increase of the number of fisheries targeted fish species (e.g. snapper), such as has been reported from other marine reserves around New Zealand (Denny *et al.*, 2003, Haggitt et al. 2021). These results will be used over time to track how the relative fish populations change in the protection areas after closure to fishing.

The BUV survey resulted in the observation of 35 species of fish across the Motiti Protection Areas and Motiti Island. The species occurrence is within the range that has been reported from BUV studies in protected areas across New Zealand: 10 fish species at Te Whanganui-a-Hei (Haggitt et al. 2021), 28 fish species Banks Peninsula (Brough *et al.*, 2018), 33 species at Tūhua (Shears & Usmar, 2006), with the exception of the Poor Knights marine reserve where BUV species was much higher at 61 species (Denny *et al.*, 2003). There has been many other BUV surveys in New Zealand marine reserves, however, these have mostly been analysed for key species e.g., snapper. The most common species observed in the Motiti Protection Areas were typical New Zealand rocky reef fish, such as snapper, red pigfish, two spot demoiselle, scarlet wrasse and leatherjacket. The species richness at the sites within the Motiti Protection Area (Astrolabe, Schooner, Okarapu, Motunau) were significantly greater than that recorded at the Motiti Island site. Species richness can be supported by habitats with high structural complexity (or rugosity)(Emslie *et al.*, 2008, Nash *et al.*, 2013, Graham *et al.*, 2015), such as presence of rock overhangs, boulders and rock crevices (Hall & Kingsford, 2021), providing a wider variety of microhabitats for fishes to shelter in (Jones, 2013). The reefs within the Motiti Protection Areas are subject to greater wave action and currents than the Motiti Island sites, due to their exposed locations, and are also located in deeper water (in particular Schooner Rocks and Astrolabe). Depth is an important characteristic in the structuring of fish communities in New Zealand rocky reef ecosystems (Jones, 2013). These attributes increase the likelihood of a more complex fish community. The multivariate analyses identified clear clustering of fish communities between the Motiti Protection Area sites (Astrolabe, Schooner, Okarapu and Motunau), suggesting similar species assemblages. It also identified some clustering of species assemblages across the depth strata, indicating the importance of including a range of depth gradients in the monitoring.

The offshore reefs that make up the Motiti Protection Areas are designated as Indigenous Biological Diversity Area A (IBDA-A)[4] due to their high indigenous biological diversity values. This formed part of the rationale that resulted in the marine protection provisions that were implemented by the Environment Court (to avoid adverse effects on biodiversity values). Thus, it was unsurprising that the Motiti Island sites had significantly lower species richness and diversity compared to the sites within the marine protection area. This initial survey only included a few locations and excluded some of the more complex rocky reef habitat on the northern and eastern sides of the island that will be included in future surveys. Although Motiti Island had a lower species richness, it appeared to have a higher relative abundance of snapper across the sites, compared to the other reefs where

[4] Regional Coastal Environment Plan 2019. Bay of Plenty Regional Council. https://www.boprc.govt.nz/your-council/plans-and-policies/plans/regional-plans/regional-coastal-environment-plan

there was higher variability. Juvenile snapper are known to distinguish between nursery areas, with preferences being identified in shallow bays and estuaries, in habitats such as seagrass beds, horse mussels and sponge gardens (Parsons *et al.*, 2014). The more sheltered bays of Motiti Island may provide a nursery area for snapper or identifies a preference for rocky habitat connected by sand, which is limited to much deeper waters at the offshore reefs (>40 m). Neither biotic nor abiotic habitat was a strong driver of fish population structure in the BUV study, which is unsurprising given the proximity of a range of habitats within each reef system.

4.2 BUV sampling suitability for monitoring

The BUV study complements the Underwater Visual Census (UVC) diver surveys that are also being conducted within the Motiti Protection Areas, providing sites at deeper depths, and allows the observation of diver shy species. Baited Underwater Video may be inherently biased towards predatory and scavenging species, due to attraction towards the bait plume, however this has been shown to not decrease the abundance of herbivorous species (Harvey *et al.*, 2007).

The BUV validation indicated that even at the 30-minute mark, we were occasionally seeing an increase in snapper numbers, indicating that the sampling time may be too short for some species. Many studies have been undertaken to determine the most appropriate set time (Gladstone *et al.*, 2012, Harasti *et al.*, 2015), and 30 minutes is generally accepted as a sufficient time for comparing species richness and fish assemblage patterns in marine protected areas (Harasti *et al.*, 2015). Increasing our set times would result in less ability to sample additional sites, thus it is recommended to continue with the 30-minute drop times to allow for additional sampling sites to be included.

The rarefaction sampling curves indicated that the sampling effort needs to be increased in future surveys to ensure a higher level of sampling coverage and a better representation of species diversity. Based on the species accumulation curves, increasing the average sample size of sites to a minimum of 15 will result in higher sample coverage (range of 92.7% - 97.3%). For the two sites with higher species diversity in the reference samples (Astrolabe and Schooner) it may be required to increase this sampling size even further (up to 20 samples).

Although not analysed in this study, it is possible to obtain length frequencies of commonly observed fish species, in particular snapper. It is assumed that over time the size frequencies within the Motiti Protection Areas will increase, such as been observed at other marine reserves in New Zealand (Haggitt et al. 2021).

The data collected in this BUV survey will form a baseline in time for which to track changes in relative fish populations due to the marine protection measures. Future reporting will provide an analysis of any changes observed over time and support future decision-making processes relating to marine protection.

Appendices

Appendix 1: Site Locations

Table 8 BUV site locations within the Motiti Protection Areas.

Reef	Site Name	Easting	Northing	Survey date	Boat Depth
Okaparu	Oka 1	1896737	5834935	22/02/2021	21.3
Okaparu	Oka 2	1896937	5834835	22/02/2021	30.2
Okaparu	Oka 3	1897137	5835135	22/02/2021	10.7
Okaparu	Oka 4	1896837	5835235	22/02/2021	11.6
Okaparu	Oka 5	1896737	5835335	22/02/2021	17.8
Okaparu	Oka 6	1897037	5835435	22/02/2021	24.3
Okaparu	Oka 7	1897537	5834835	22/02/2021	22.2
Okaparu	Oka 8	1897737	5834635	22/02/2021	26.3
Okaparu	Oka 9	1897537	5834735	22/02/2021	16.3
Okaparu	Oka 10	1897337	5834635	22/02/2021	21.1
Okaparu	Oka 11	1897137	5834735	22/02/2021	22.7
Okaparu	Oka 12	1897537	5834435	22/02/2021	32.4
Okaparu	Oka 13	1897437	5834635	22/02/2021	12.6
Okaparu	Oka 14	1897037	5835135	22/02/2021	9.8
Okaparu	Oka 14	1897037	5835135	22/02/2021	12.3
Okaparu	Oka 15	1897437	5835135	22/02/2021	29.3
Astrolabe (Otaiti)	Ast1	1902892	5839577	4/03/2021	6
Astrolabe (Otaiti)	Ast2	1902692	5839727	4/03/2021	14.3
Astrolabe (Otaiti)	Ast3	1902692	5839927	4/03/2021	19.7
Astrolabe (Otaiti)	Ast3	1902692	5839927	4/03/2021	18.5
Astrolabe (Otaiti)	Ast4	1902942	5839677	4/03/2021	31.2
Astrolabe (Otaiti)	Ast5	1902742	5839627	4/03/2021	5.7
Astrolabe (Otaiti)	Ast6	1902792	5839927	4/03/2021	20.2
Astrolabe (Otaiti)	Ast7	1902542	5839827	4/03/2021	18
Astrolabe (Otaiti)	Ast8	1902942	5839627	4/03/2021	15.8
Astrolabe (Otaiti)	Ast9	1902992	5839527	4/03/2021	29
Astrolabe (Otaiti)	Ast9	1902992	5839527	4/03/2021	23-28
Astrolabe (Otaiti)	Ast10	1902742	5839777	4/03/2021	12
Astrolabe (Otaiti)	Ast11	1902642	5839927	4/03/2021	24.2
Astrolabe (Otaiti)	Ast12	1902792	5839527	4/03/2021	19.6
Schooner Rocks (Motuhaku)	Sch1	1911556	5832004	23/04/2021	29
Schooner Rocks (Motuhaku)	Sch1	1911556	5832004	23/04/2021	30
Schooner Rocks (Motuhaku)	Sch2	1911406	5831654	23/04/2021	30
Schooner Rocks (Motuhaku)	Sch3	1911456	5832154	23/04/2021	14

Reef	Site Name	Easting	Northing	Survey date	Boat Depth
Schooner Rocks (Motuhaku)	Sch4	1911756	5832304	23/04/2021	15.2
Schooner Rocks (Motuhaku)	Sch5	1911556	5832104	23/04/2021	15
Schooner Rocks (Motuhaku)	Sch6	1911406	5831904	23/04/2021	14
Schooner Rocks (Motuhaku)	Sch7	1911706	5832154	23/04/2021	17
Schooner Rocks (Motuhaku)	Sch8	1911706	5832404	23/04/2021	20
Schooner Rocks (Motuhaku)	Sch9	1911456	5832054	23/04/2021	17
Schooner Rocks (Motuhaku)	Sch10	1911456	5831804	23/04/2021	22
Schooner Rocks (Motuhaku)	Sch11	1911556	5832254	23/04/2021	25
Schooner Rocks (Motuhaku)	Sch12	1911856	5832354	23/04/2021	30
Schooner Rocks (Motuhaku)	Sch13	1912223	5832275	23/04/2021	30
Orongatea (Motiti)	Mot1	1900580	5829728	29/04/2021	8
Orongatea (Motiti)	Mot2	1900180	5829828	29/04/2021	20
Orongatea (Motiti)	Mot4	1900380	5830128	29/04/2021	8
Orongatea (Motiti)	Mot5	1900280	5830328	29/04/2021	17
Orongatea (Motiti)	Mot7	1900480	5830228	29/04/2021	12
Wairanaki (Motiti)	Mot9	1901338	5832399	29/04/2021	9.7
Orongatea (Motiti)	Mot11	1900272	5831193	29/04/2021	15
Orongatea (Motiti)	Mot12	1899886	5831335	29/04/2021	25
Motunau (Plate Island)	Pl1	1913806	5825849	2/05/2021	26
Motunau (Plate Island)	Pl2	1914056	5826049	2/05/2021	12
Motunau (Plate Island)	Pl3	1914256	5825849	2/05/2021	26
Motunau (Plate Island)	Pl4	1914456	5825699	2/05/2021	22
Motunau (Plate Island)	Pl5	1914256	5825549	2/05/2021	20
Motunau (Plate Island)	Pl6	1914556	5825649	2/05/2021	26
Motunau (Plate Island)	Pl7	1914056	5825549	2/05/2021	5
Motunau (Plate Island)	Pl8	1913906	5825349	2/05/2021	27
Motunau (Plate Island)	Pl9	1914006	5825399	2/05/2021	17
Motunau (Plate Island)	Pl10	1913856	5825449	2/05/2021	14
Motunau (Plate Island)	Pl11	1913756	5825649	2/05/2021	10
Motunau (Plate Island)	Pl12	1913906	5825799	2/05/2021	27

Appendix 2: GLM Tukey Test Results

Effect of reef on relative abundance

Results of Tukey's post-hoc tests for the generalised linear models (GLMs with Poisson error distributions) testing the effects of Reef (fixed effect, 5 levels) on the relative abundances of snapper, blue maomao, red pigfish and scarlet wrasse. Overdispersion was detected in snapper and blue maomao and the standard errors were corrected using a quasi-GLM model. Relative abundance is the MaxN derived from baited underwater video deployments. The nature and magnitude of the difference between tested parameters is given by the estimate and its standard error. The z value indicates how many standard deviations a particular value is from the mean and is used to derive the probability (statistical significance, P value).

Snapper abundance	Estimate	Standard error	Z value	P value
Motiti - Astrolabe == 0	0.81	0.35	2.32	0.136
Motunau - Astrolabe == 0	-0.73	0.47	-1.53	0.537
Okarapu - Astrolabe == 0	-0.21	0.38	-0.54	0.982
Schooner Rocks - Astrolabe == 0	-0.47	0.43	-1.10	0.802
Motunau - Motiti == 0	-1.54	0.45	-3.43	0.005**
Okarapu - Motiti == 0	-1.02	0.35	-2.93	0.028*
Schooner Rocks - Motiti == 0	-1.28	0.40	-3.23	0.0104*
Okarapu - Motunau == 0	0.52	0.47	1.10	0.805
Schooner Rocks - Motunau == 0	0.26	0.51	0.50	0.987
Schooner Rocks - Okarapu == 0	-0.26	0.42	-0.62	0.972

Blue maomao abundance	Estimate	Standard error	Z value	P value
Motiti - Astrolabe == 0	-16.46	1924.99	-0.01	1.000
Motunau - Astrolabe == 0	0.069	0.96	0.07	1.000
Okarapu - Astrolabe == 0	1.28	0.76	1.67	0.392
Schooner Rocks - Astrolabe == 0	0.65	0.84	0.77	0.92
Motunau - Motiti == 0	16.53	1924.99	0.01	1.000
Okarapu - Motiti == 0	17.74	1924.99	0.01	1.000
Schooner Rocks - Motiti == 0	17.10	1924.99	0.01	1.000
Okarapu - Motunau == 0	1.21	0.74	1.63	0.420
Schooner Rocks - Motunau == 0	0.58	0.82	0.70	0.944
Schooner Rocks - Okarapu == 0	-0.63	0.58	-1.09	0.774

Red pigfish abundance	Estimate	Standard error	Z value	P value
Motiti - Astrolabe == 0	-1.16	0.73	-2.94	0.024*
Motunau - Astrolabe == 0	-0.77	0.35	-2.22	0.158
Okarapu - Astrolabe == 0	-0.39	0.29	-1.35	0.640
Schooner Rocks - Astrolabe == 0	0.06	0.27	0.24	0.999
Motunau - Motiti == 0	1.39	0.76	1.82	0.341
Okarapu - Motiti == 0	1.77	0.74	2.40	0.104
Schooner Rocks - Motiti == 0	2.22	0.73	3.04	0.017*
Okarapu - Motunau == 0	0.38	0.36	1.07	0.809
Schooner Rocks - Motunau == 0	0.84	0.34	2.45	0.092
Schooner Rocks - Okarapu == 0	0.45	0.28	1.62	0.463

Scarlet wrasse abundance	Estimate	Standard error	Z value	P value
Motiti - Astrolabe == 0	-1.73	0.75	-2.32	0.125
Motunau - Astrolabe == 0	-1.22	0.51	-2.41	0.103
Okarapu - Astrolabe == 0	-0.57	0.38	-1.52	0.529
Schooner Rocks - Astrolabe == 0	0.34	0.31	1.11	0.789
Motunau - Motiti == 0	0.51	0.84	0.61	0.971
Okarapu - Motiti == 0	1.16	0.76	1.52	0.524
Schooner Rocks - Motiti == 0	2.08	0.73	2.83	0.033*
Okarapu - Motunau == 0	0.65	0.53	1.23	0.718
Schooner Rocks - Motunau == 0	1.57	0.49	3.21	0.010*
Schooner Rocks - Okarapu == 0	0.92	0.35	2.63	0.059

Effect of biotic habitat on relative abundance

Results of Tukey's post-hoc tests for the generalised linear models (GLMs with Poisson error distributions) testing the effects of biotic habitat (fixed effect, three levels) on the relative abundances of snapper, blue maomao, red pigfish and scarlet wrasse. Overdispersion was detected in snapper and blue maomao and the standard errors were corrected using a quasi-GLM model. Relative abundance is the MaxN derived from baited underwater video deployments. The nature and magnitude of the difference between tested parameters is given by the estimate and its standard error. The z value indicates how many standard deviations a particular value is from the mean and is used to derive the probability (statistical significance, P value).

Red pigfish abundance	Estimate	Standard error	Z value	P value
Barren - Algae == 0	-0.15	0.33	-0.44	0.895
Encrusting - Algae == 0	0.34	0.23	1.50	0.285
Encrusting - Barren == 0	0.49	0.35	1.40	0.336

Scarlet wrasse abundance	Estimate	Standard error	Z value	P value
Barren - Algae == 0	-0.75	0.53	-1.43	0.314
Encrusting - Algae == 0	0.53	0.27	1.98	0.110
Encrusting - Barren == 0	1.28	0.54	2.37	0.043*

Snapper abundance	Estimate	Standard error	Z value	P value
Barren - Algae == 0	0.71	0.28	2.51	0.031*
Encrusting - Algae == 0	-0.80	0.41	-1.93	0.126
Encrusting - Barren == 0	-1.51	0.45	-3.39	0.002**

Blue maomao abundance	Estimate	Standard error	Z value	P value
Barren - Algae == 0	-1.19	1.32	-0.90	0.623
Encrusting - Algae == 0	0.60	0.53	1.12	0.484
Encrusting - Barren == 0	1.79	1.34	1.34	0.355

Effect of depth strata on relative abundance

Results of Tukey's post-hoc tests for the generalised linear models (GLMs with Poisson error distributions) testing the effects of depth strata (fixed effect, three levels) on the relative abundances of snapper, blue maomao, red pigfish and scarlet wrasse. Overdispersion was detected in snapper and blue maomao and the standard errors were corrected using a quasi-GLM model. Relative abundance is the MaxN derived from baited underwater video deployments. The nature and magnitude of the difference between tested parameters is given by the estimate and its standard error. The z value indicates how many standard deviations a particular value is from the mean and is used to derive the probability (statistical significance, P value).

Red pigfish abundance	Estimate	Standard error	Z value	P value
15 - 5 == 0	0.35	0.29	1.20	0.448
25 - 5 == 0	0.80	0.29	2.76	0.016*
25 - 15 == 0	0.45	0.23	1.96	0.122

Scarlet wrasse abundance	Estimate	Standard error	Z value	P value
15 - 5 == 0	1.02	0.39	2.60	0.024*
25 - 5 == 0	0.92	0.42	2.19	0.071
25 - 15 == 0	-0.11	0.28	-0.38	0.924

Snapper abundance	Estimate	Standard error	Z value	P value
15 - 5 == 0	-0.10	0.37	-0.25	0.966
25 - 5 == 0	-0.14	0.42	-0.35	0.936
25 - 15 == 0	-0.05	0.39	-0.13	0.990

Blue maomao abundance	Estimate	Standard error	Z value	P value
15 - 5 == 0	-0.36	0.75	-0.48	0.879
25 - 5 == 0	0.68	0.66	1.03	0.559
25 - 15 == 0	1.04	0.65	1.61	0.241

Effect of reef on species richness and Shannon diversity index

Results of Tukey's post-hoc tests for the generalised linear models (GLMs with Gaussian error distributions) testing the effects of Reef (fixed effect, five levels) on the species richness and Shannon diversity index. The nature and magnitude of the difference between tested parameters is given by the estimate and its standard error. The z value indicates how many standard deviations a particular value is from the mean and is used to derive the probability (statistical significance, P value).

Species Richness	Estimate	Standard error	Z value	P value
Motiti - Astrolabe == 0	-1.04	0.26	-4.03	0.0005***
Motunau - Astrolabe == 0	0.00	0.23	0.00	1.000
Okarapu - Astrolabe == 0	-0.03	0.22	-0.16	1.000
Schooner Rocks - Astrolabe == 0	0.18	0.23	0.81	0.927
Motunau - Motiti == 0	1.04	0.26	4.03	0.0005***
Okarapu - Motiti == 0	1.01	0.25	4.06	0.0004***
Schooner Rocks - Motiti == 0	1.22	0.25	4.82	<1e-4***
Okarapu - Motunau == 0	-0.03	0.22	-0.16	1.000
Schooner Rocks - Motunau == 0	0.18	0.23	0.81	0.928
Schooner Rocks - Okarapu == 0	0.22	0.21	1.02	0.847

Shannon diversity index	Estimate	Standard error	Z value	P value
Motiti - Astrolabe == 0	-1.05	0.21	-5.05	<0.001***
Motunau - Astrolabe == 0	-0.18	0.19	-0.99	0.860
Okarapu - Astrolabe == 0	-0.03	0.18	-0.15	1.000
Schooner Rocks - Astrolabe == 0	0.11	0.18	0.62	0.972
Motunau - Motiti == 0	0.87	0.21	4.16	<0.001***
Okarapu - Motiti == 0	1.03	0.20	5.13	<0.001***
Schooner Rocks - Motiti == 0	1.17	0.21	5.68	<0.001***
Okarapu - Motunau == 0	0.16	0.18	0.92	0.899
Schooner Rocks - Motunau == 0	0.30	0.18	1.63	0.478
Schooner Rocks - Okarapu == 0	0.14	0.17	0.81	0.928

Effect of depth strata on species richness and Shannon diversity index

Results of Tukey's post-hoc tests for the generalised linear models (GLMs with Gaussian error distributions) testing the effects of Depth (fixed effect, three levels) on the species richness and Shannon diversity index. The nature and magnitude of the difference between tested parameters is given by the estimate and its standard error. The z value indicates how many standard deviations a particular value is from the mean and is used to derive the probability (statistical significance, P value).

Species richness	Estimate	Standard error	Z value	P value
15 - 5 == 0	0.13	0.21	0.64	0.801
25 - 5 == 0	0.37	0.23	1.64	0.228
25 - 15 == 0	0.24	0.21	1.17	0.471

Shannon diversity index	Estimate	Standard error	Z value	P value
15 - 5 == 0	0.40	0.17	2.37	0.047*
25 - 5 == 0	0.49	0.19	2.62	0.024*
25 - 15 == 0	0.09	0.17	0.51	0.866

Effect of biotic habitat on species richness and Shannon diversity index

Results of Tukey's post-hoc tests for the generalised linear models (GLMs with Poisson error distributions) testing the effects of biotic habitat (fixed effect, three levels) on species richness and Shannon diversity index. The nature and magnitude of the difference between tested parameters is given by the estimate and its standard error. The z value indicates how many standard deviations a particular value is from the mean and is used to derive the probability (statistical significance, P value).

Species richness	Estimate	Standard error	Z value	P value
Barren - Algae == 0	-0.49	0.24	-2.09	0.091
Encrusting - Algae == 0	0.24	0.20	1.22	0.438
Encrusting - Barren == 0	0.73	0.27	2.73	0.017*

Shannon diversity index	Estimate	Standard error	Z value	P value
Barren - Algae == 0	-0.44	0.20	-2.21	0.0685
Encrusting - Algae == 0	0.30	0.16	1.81	0.162
Encrusting - Barren == 0	0.74	0.23	3.27	0.003**

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