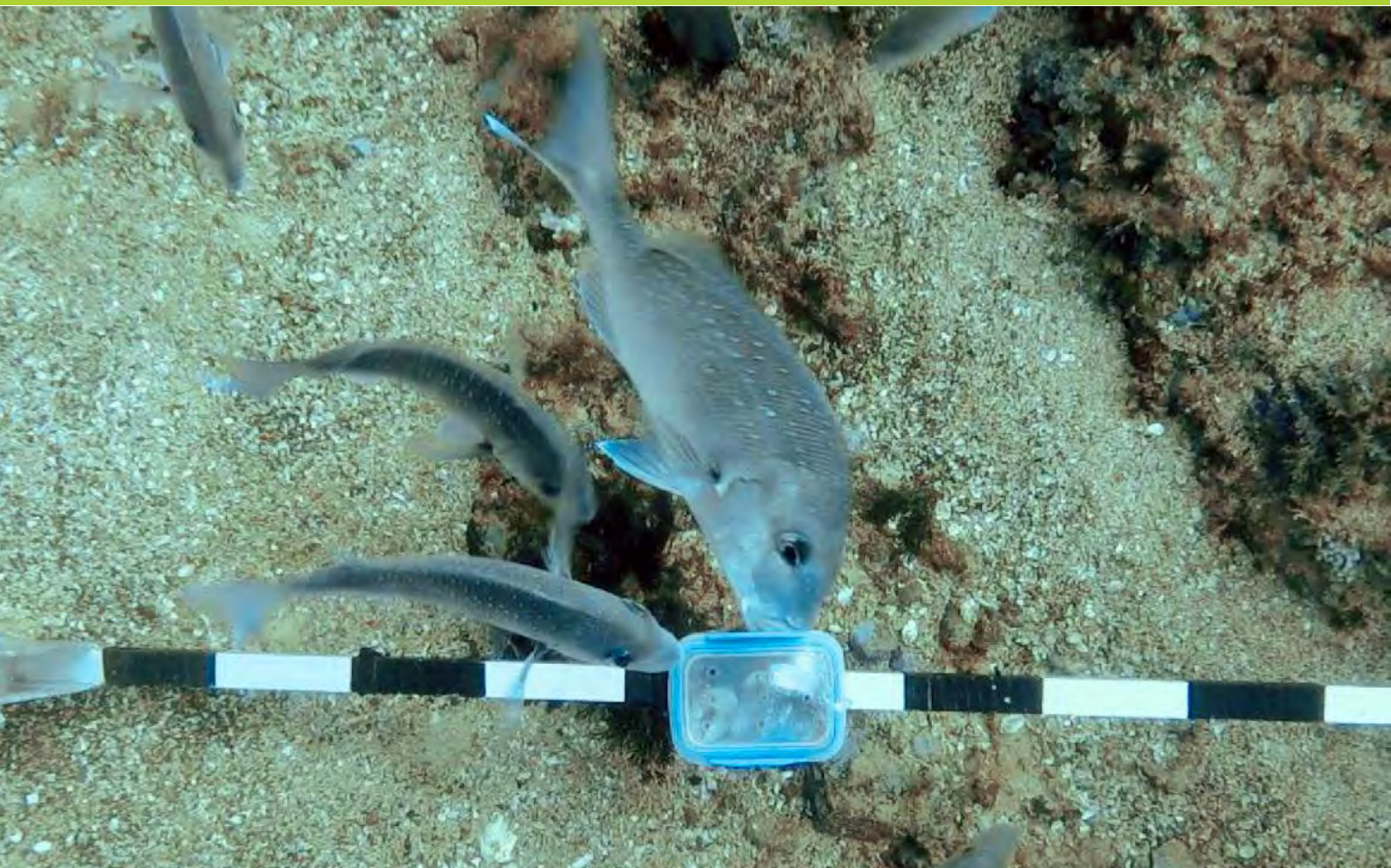


Pūrongo Tatauranga: Te Rangahau Ataata Raro Wai
Mamao ā-Mounu Takirua (BRUV) ki
Rākaumangamanga (Cape Brett), Te Pewhairangi |
Survey report: Stereo baited remote underwater video
(BRUV) survey of Rakaumangamanga (Cape Brett), Bay
of Islands

2025

Prepared by Dr Adam N. H. Smith (Director)



Survey Report

Stereo Baited Remote Underwater Video (BRUV) Survey of Rākaumangamanga (Cape Brett), Bay of Islands, 2025



Prepared by Dr Adam N. H. Smith (Director)



for the Northland Regional Council

2025-09-17

Contents

Executive summary	3
Glossary	4
1. Introduction	5
2. Methods	7
2.1. Stereo Baited Remote Underwater Video (BRUV)	8
2.2. Site locations	9
2.3. Video annotation	9
2.4. Data processing	9
2.5. Data analysis	10
3. Results	10
3.1. Survey outcomes	11
3.2. Fish species diversity	14
3.3. Snapper metrics	17
4. Discussion	22
4.1. Snapper abundance and size structure	23
4.2. Methodological considerations	24
4.3. Conclusions and Recommendations	25
Acknowledgements	25
Appendix 1: Data Structure	26
Overview	26
OpCodes	26
Video file system	26
Appendix 2: Table of sites	28
Appendix 3: Deployment quality	30
Appendix 4: Raw data	31
References	32



Executive summary

- Sea Through Science Limited was contracted by the Northland Regional Council to undertake a survey of fishes in and around the new marine protected areas at Rākaumangamanga (Cape Brett), Bay of Islands, using stereo Baited Remote Underwater Video (BRUV).
- Stereo BRUVs were deployed at 42 sites in May 2025, to depths of around 20-25 metres.
- The sites were distributed across the following four zones, with varying histories of marine protection:
 - **Fished:** North-facing coast between Waewaetorea Island, Urupukapuka Island, and Kohangaatara Point (open to fishing)
 - **Rāhui Tapu (2023):** Maunganui Bay (Deep Water Cove) to Opourua (Oke Bay) Rākaumangamanga Rāhui Tapu (no-take since November 2023)
 - **Rāhui Tapu (2010):** Maunganui Bay (Deep Water Cove) Rāhui Tapu (no-take since December 2010; incorporated into the Rākaumangamanga Rāhui Tapu since November 2023)
 - **Restricted (2023):** Ngā Au o Morunga Mai Rākaumangamanga Protection Area (restrictions based on specific fishing methods since November 2023)
- A total of 38 species from 22 families of fish were observed. Species richness ranged from 3 to 19, with an overall average of 9.2.
- Tāmure / snapper were dominant across the survey, with very high abundances observed in all zones. Maximum numbers of snapper on a single frame (MaxN) ranged from 12 to 105, with an overall average of 50.3. This average was close to the highest values recorded during surveys of the outer Hauraki Gulf in 2025 (though they were deeper, at 50-100 m).
- Snapper above the minimum legal size (300 mm fork length) were more abundant in rāhui tapu areas, especially Maunganui Bay, which has been closed since 2010. Very large snapper (>450 mm fork length) were observed only in Maunganui Bay, where they were very widespread.
- Other species such as trevally, wrasses, moray eels, rays, and sharks were also recorded, with patterns of diversity associated with local substratum type (sand vs reef).
- These results provide a strong baseline for monitoring. The most important long-term effects of marine protection are expected to be increases in the abundance of legal-sized and very large snapper, which play a key role in reproduction and recruitment. The results already suggest promising potential for recovery, and continued monitoring may reveal substantial benefits over time.

Glossary

Abundance — The quantity of a species present at a site or in a deployment, which can be measured as the number of individuals, biomass, or other indicators of population size or density.

Annotation — The process of reviewing video footage to identify, count, and record species, individuals, and other relevant observations. Annotations provide the data used for analyses of abundance, lengths, and biodiversity. Annotation is typically done with specialist software.

Bathymetry — The study and measurement of the depth and shape of underwater terrain.

Baited Remote Underwater Video (BRUV) — An underwater camera system deployed with a bait source to attract and record marine life, used to study fish abundance, diversity, and behaviour without extraction.

Calibration — The process of identifying the relative positions of a set of stereo cameras so that measurements of distance, size, and spatial relationships in the underwater footage are accurate. The process requires taking videos of a calibration cube which are then processed using specialist software.

Deployment — The placement of a stereo BRUV unit in the water at a site to record footage.

Field of view (FOV) — The area visible to the cameras, which affects what can be detected and measured.

Fork length (FL) — The straight-line distance from the tip of a fish's snout to the fork of its tail. It is commonly used as a standard measure of fish size.

Habitat — The environment or area where organisms live, including both the physical features (substratum, structure) and biological components (kelp, sponges, etc.) that provide shelter, food, and structure.

MaxN — The maximum number of individuals of a species observed simultaneously in a single video frame. It is used as a conservative measure of relative abundance to avoid double-counting animals that move in and out of the camera's view.

MaxN biomass — An estimate of the total weight of fish present in the single video frame where the maximum number of individuals (MaxN) of a species is observed.

Marine Protected Area (MPA) — A defined part of the ocean where activities are managed or restricted to conserve biodiversity and cultural or natural resources.

Observation period — The part of the video that is annotated, standardised to be 60 minutes beginning 5 minutes after the BRUV reaches the seafloor.

Rāhui Tapu — A traditional Māori form of restriction placed over an area or resource, often to protect it from harvesting or disturbance. In this work, rāhui tapu refers to no-take zones in the outer Bay of Islands. A no-take rāhui tapu was first established in Maunganui Bay (Deep Water Cove) in 2010. In 2023, the Rakaumangamanga Rāhui Tapu extended the rāhui tapu area further south to Opourua (Oke Bay). These rāhui tapu do not affect non-commercial Māori customary fishing rights guaranteed under Te Tiriti o Waitangi, although a permit is required.

Site — A specific location where one or more stereo BRUV deployments are made, usually defined by geographic coordinates. Sites are the basic units for comparing species presence, abundance, and habitat characteristics.

Species richness — A basic measure of diversity, measured as the number of species observed during the observation period.

Stereo BRUV — Stereo Baited Remote Underwater Video method used to survey fish. The “stereo” refers to the fact that there are two cameras in stereo that are calibrated to that distances and lengths of objects that appear on video can be measured.

Substratum — The physical material or surface on the seafloor, such as sand or rock. It describes what the bottom is made of, rather than the organisms living on it (*cf.* habitat).



(a) Trevally and snapper



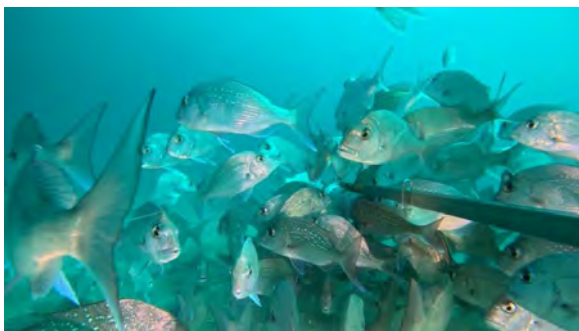
(b) Kingfish and snapper



(c) Small snapper



(d) A very large snapper



(e) 105 snapper



(f) Bronze whaler



(g) Mottled morays



(h) Combfish

Figure 1: Some screenshots from the 2025 stereo BRUV footage

1. Introduction

New marine protected areas (MPAs) were recently established in and around Rākaumangamanga (Cape Brett) in the Bay of Islands (Figure 2) as part of a broader regional strategy to protect and restore marine biodiversity. As with all new marine protection measures, ongoing monitoring is essential to evaluate their effectiveness and guide adaptive management.

A critical component of monitoring is the collection of baseline data, ideally before or shortly after protection is implemented. Fish populations can respond quickly to changes in fishing pressure [1,2], making them a priority for early monitoring. Accurate, repeatable measurements of fish diversity, abundance, and size structure are therefore central to understanding how protection affects ecosystem function.

Stereo Baited Remote Underwater Video (stereo BRUV) provides a robust, non-destructive, cost-effective, and standardised method to document fish abundance and size structure [3–5]. Compared with traditional visual or net-based surveys, stereo BRUVs allow simultaneous measurement of fish abundance and lengths at multiple sites, across habitats, with minimal disturbance to the ecosystem. This enables consistent, comparable data over time, making them particularly well suited for long-term monitoring programmes.

The focal species for this monitoring programme is tāmore / snapper (*Chrysophrys auratus*), the primary target for local fishers and species most likely to respond to protection. Previous studies in north-eastern New Zealand demonstrated strong responses of snapper to protection, particularly for individuals larger than the minimum legal size [6–9]. Notably, increases in large snapper can occur rapidly, within 1-2 years of protection [2]. This occurs because of the seasonal inshore migration of snapper [10] and the establishment of limited home ranges on rocky reefs [6,11]. Because some snapper are resident within small reef areas, even relatively small MPAs can encompass their home ranges, allowing them to grow large and live for several decades within protected areas.

Large, mature snapper are important for the recruitment of juveniles for surrounding areas. Snapper reach maturity at 2-5 years and fork lengths of 20-30 cm [12,13]. They are serial broadcast spawners [14]. Egg production increases exponentially with fish size [15], and a large, mature female is capable of producing millions of eggs during the summer spawning season [13]. Larvae can disperse tens of kilometres before settling in sheltered bays and estuaries [16]. Protected populations of large snapper can therefore contribute substantially to local recruitment, with studies showing up to 10% of snapper recruits within 55 km of a small marine reserve originating from protected fish [17].

This report presents the results of a baseline survey of the newly established MPAs in the Bay of Islands using stereo BRUVs. The objectives are to:

1. Present and summarise fish assemblage data, with a focus on snapper abundance and size structure.
2. Evaluate differences across zones with varying levels and histories of protection.
3. Identify limitations and recommendations for future monitoring.

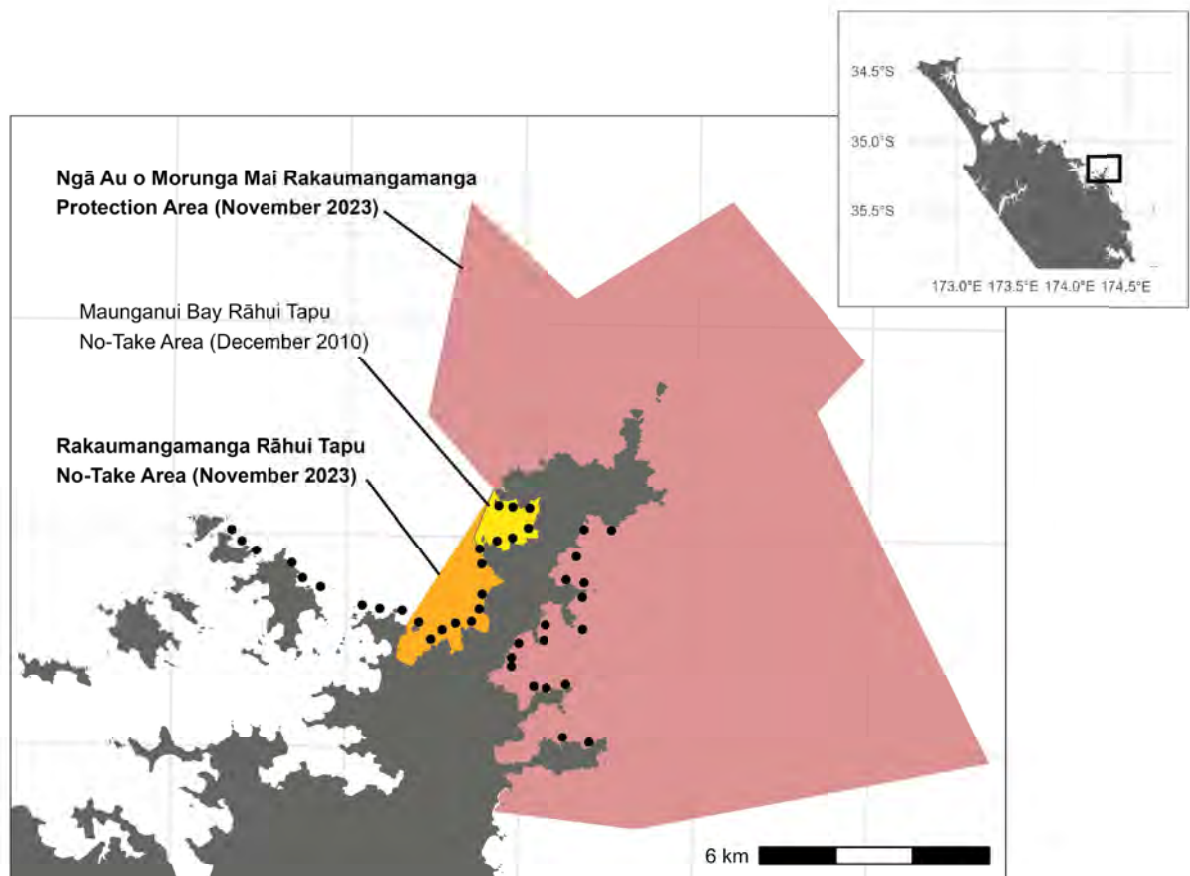


Figure 2: Map of marine protected areas around Cape Brett, with BRUV sampling sites shown as circles

2. Methods

2.1. Stereo Baited Remote Underwater Video (BRUV)

The stereo BRUV units comprised a stainless steel frame, two GoPro HERO 12 video cameras in specialised housings, lights, and a bait canister at the end of a stainless steel rod (Figure 3). The systems were attached by rope to a buoy and deployed to the seafloor for at least 70 minutes. We deployed six BRUV units simultaneously to achieve rapid replication, using 1 kg of fresh chopped pilchards for bait.

Each stereo BRUV unit was pre-calibrated to allow accurate measurements of the lengths of fish [18]. Calibration of each stereo unit involves taking synchronised left and right videos of a 1 x 1 m calibration cube (Figure 4) in various positions. The calibration cube has dozens of reflective points, and the distances between these points are known. The calibration is done by analysing the videos of the calibration cube using the specialised software ‘CAL’ (SeaGIS Ltd.).



Figure 3: A stereo BRUV unit ready for deployment

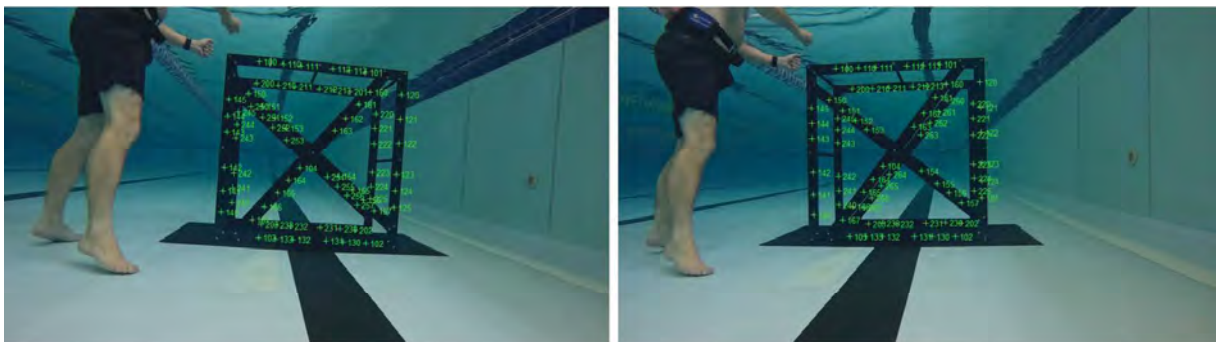


Figure 4: Left and right videos of a calibration cube

2.2. Site locations

An initial sampling plan was circulated to the stakeholders and discussed and agreed during a hui on the 16th of April 2025. The fieldwork was undertaken on the 2nd and 3rd of May, 2025. A total of 42 deployments were made over two days (Figure 5). On day 1, we made 18 deployments on the eastern side of Cape Brett, inside the Ngā Au o Morunga Mai Rākaumangamanga Protection Area. On day 2, we made 24 deployments between Waewaetorea Island and Putahataha Island, all on the western (Bay of Islands) side of Cape Brett. The survey area was divided into four “zones”, according to the history of protection, as shown in Table 1 and Figure 5.

The depths of the deployments ranged from 17 to 32 metres, with a median of 22. 37 out of 42 deployments were between 18 and 26 metres. Four out of the five outside this range were in the restricted, eastern zone.

2.3. Video annotation

‘Video annotation’ is the process of extracting biological data—such as species presence/absence, abundance, and individual lengths—from stereo BRUV footage (as distinct from ‘statistical analysis’ of the biological data). Annotation was conducted using EventMeasure software (SeaGIS Ltd.), the industry standard designed specifically for calibrated stereo BRUV video. Each annotation covered a 60-minute period, starting 5 min after the BRUV unit settled on the seafloor to allow sediment to clear, and included fish observed up to 7 m from the cameras.

To measure the relative abundance of each species, we used the standard metric, **MaxN**. MaxN is the maximum number of individuals of a species observed in a single frame [19,20]. This metric has the advantages of avoiding double counting, and allowing comparability across species for multivariate analyses of fish assemblage structure. From the MaxN data, we calculated species richness, a common measure of diversity given simply by the number of species observed during the observation period for each deployment.

Length measurements were collected for focal species, including snapper (*Chrysophrys auratus*), trevally (*Pseudocaranx georgianus*), john dory (*Zeus faber*), and kahawai (*Arripis trutta*). Lengths were taken from as many of the individuals that appeared in the MaxN frame as possible.

As well as the biological information, each deployment was classified as “Good”, “OK”, or “Bad”. The quality can limit what types of information can be reliably obtained from the deployment. Deployments deemed to be “good” can be reliably used for all information (abundance counts and lengths). Deployments deemed to be “bad” yield only very limited information, such as simple presence vs absence of species, and should not be used for abundance counts or lengths.

The sites were also classified into three broad substrata: **Sand**, where there was sand only (no reef); **Mixed**, a mixture of sand and rock (e.g., cobble or reef); and **Reef**, where there was rock only (no sand).

2.4. Data processing

The MaxN counts were obtained for all observed fish species. Species richness, a basic measure of diversity, was calculated for every site by counting the number of species present at every deployment.

The lengths were classified into four size classes (<150, 150-300, 300-450, and 450+ mm) and counted for each deployment. Where only a subset (n) of the total MaxN (N) count of fish were measured, the total size class counts for each deployment were estimated by multiplying N/n to take into account the unmeasured fish in the MaxN frame, assuming the measured lengths were a representative sample.

The total biomass of the fish observed in the MaxN frame was estimated by converting lengths to weights. The parameters for converting lengths to weights were taken from Walsh et al. [21], as these were specifically for the East Northland region. The conversion formula was:

$$W = 0.0349L^{2.8701}$$

where W is the estimated weight of the fish (kg) and L is the fork length of the snapper (cm).

Where only a subset (n) of the total MaxN (N) count of fish were measured, the estimated sum of the total numbers biomass for the subset of measured fish was multiplied by N/n to obtain an estimate of the total biomass for the MaxN fish, taking into account the unmeasured fish in the MaxN frame.

2.5. Data analysis

The key metrics—species richness and, for snapper, the MaxN counts, MaxN biomass, mean length, and estimated MaxN counts by size class—were summarised with dot charts, column charts, and boxplots, and also as bubbles on maps. R v4.5.1 [22] was used for all data manipulation, analysis, plotting, and mapping. To estimate means and 95% confidence intervals, we fit linear models using the ‘glmmTMB’ package [23] for R.

3. Results

3.1. Survey outcomes

3.1.1. Deployment quality

Of the 42 deployments, 31 were classified as “Good”, 10 as “OK”, and 1 as “Bad” (see Table 1 and Figure 6). In the case of the one bad deployment here, field of view was blocked by kelp. The 10 “OK” had some sort of malposition; 4 were tipped upside down, 2 were tilted upwards toward the surface, and for 5 the field of view of one or both cameras was partially occluded by rock or kelp. In most cases, the data from the ‘OK’ deployments can be used as normal; however, in future formal analysis of the dataset after multiple years’ surveys, it would be good to investigate the influence of the different deployment malpositions. Further details of the sites and specific quality issues are provided in Appendices 2 and 3, respectively.

Most of the OK deployments and the one bad deployment were made on the first day of sampling on the eastern side. This was because we had little information on the bathymetry and habitat for the eastern side, so many deployments were made on steep reefs and in dense kelp forests. On the second day, we added extra weights to the BRUV units which can make them less prone to tipping, and we had 22 good deployments and only 2 OK deployments.

3.1.2. Substrata

14 of the deployments were on sand, 18 were mixed, and 9 were on rocky reef (Figure 7), and these substrata were not well balanced across the four zones (Figure 8). For example, all but 1 of the reef sites were in the eastern, Restricted (2023) zone. Unfortunately, the substratum is difficult to know prior to deployment on the eastern side, due to a lack of detailed bathymetry information.

Table 1: Description of the four zones, and the number of BRUV sites surveyed in each. See also Figure 5

Zone	Description	Number of sites (Good, OK, Bad)
Fished	Western zone that is open to fishing, between Waewaetorea Island, Urupukapuka Island, and Kohangaatara Point.	9 (8, 1, 0)
Restricted (2023)	An area on the eastern side of Cape Brett in the Ngā Au o Morunga Mai Rākaumangamanga Protection Area, where specific fishing methods such as seining and trawling have been prohibited since November 2023.	18 (9, 8, 1)
Rāhui Tapu (2010)	Maunganui Bay, from Motuwheteke Island to Putahatahata Island, which has been a no-take rāhui tapu since December 2010. It is now the northern part of the Rākaumangamanga Rāhui Tapu no-take marine protected area (established November 2023).	7 (7, 0, 0)
Rāhui Tapu (2023)	The southern part of the Rākaumangamanga Rāhui Tapu marine protected area, from Moturahurahu Island and Oke Bay to Motuwheteke Island, which has been no-take since November 2023.	8 (7, 1, 0)



Figure 5: Sampling sites with labels and coloured by “Zone”, which indicates the protection status and duration. These colours are used in graphs throughout this report.

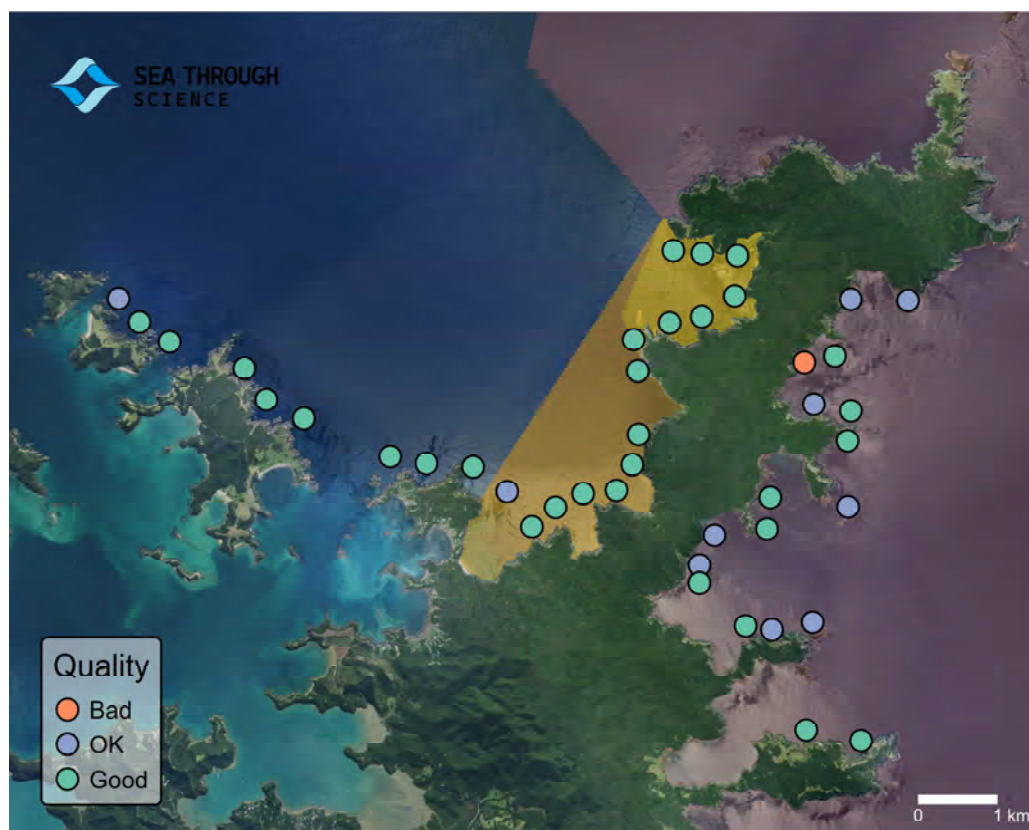
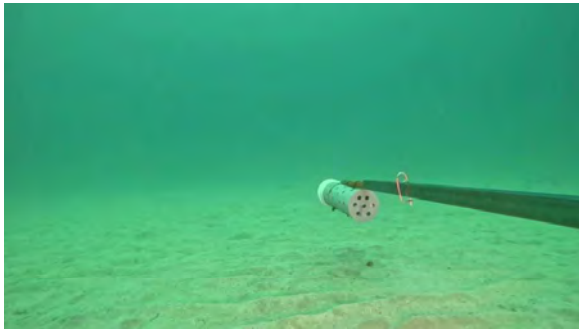


Figure 6: Quality of the BRUV deployments at each site



(a) Sand (MN060)



(b) Reef (CE126)



(c) Mixed (MC080)



(d) Mixed (CE129)

Figure 7: Example screenshots from 'Sand', 'Reef', and 'Mixed' substrata

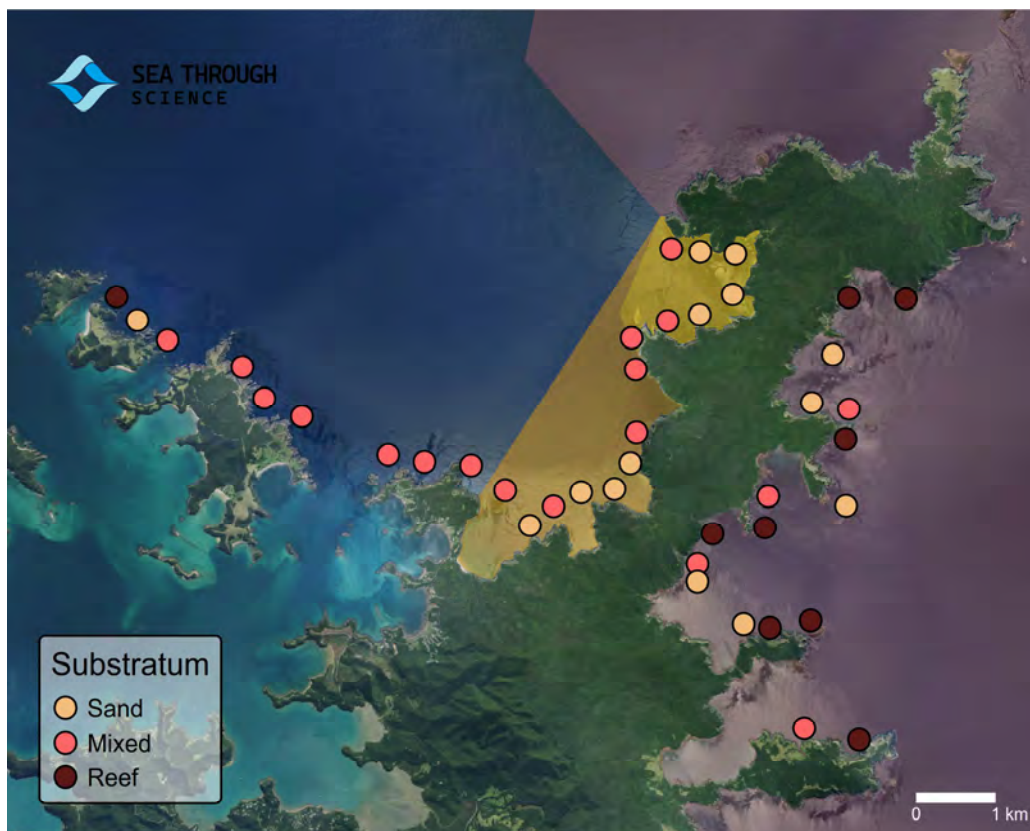


Figure 8: Sampling sites coloured by substratum

3.2. Fish species diversity

A total of 38 species from 22 families of fish were observed during this survey (Figure 10). Snapper were the most widespread species, observed at all 42 sites, followed by trevally (*Pseudocaranx georgianus*; 37 sites), kingfish (*Seriola lalandi*; 27 sites), red pigfish (*Bodianus unimaculatus*; 27 sites), and eagle ray (*Myliobatis tenuicaudatus*; 27 sites). Four species of moray eel were observed (yellow, grey, mottled, and mosaic), and five species of elasmobranchs (sharks and rays: eagle ray, short- and long-tailed stingray, bronze whaler, and smooth hammerhead). Ten species were each seen only at one site (Figure 10).

Species richness was not strongly related to Zone in this study (Figure 9, Figure 11). Species richness appeared to be more strongly related to the substratum, with sandy-only habitats being less diverse than mixed and reef substrata.

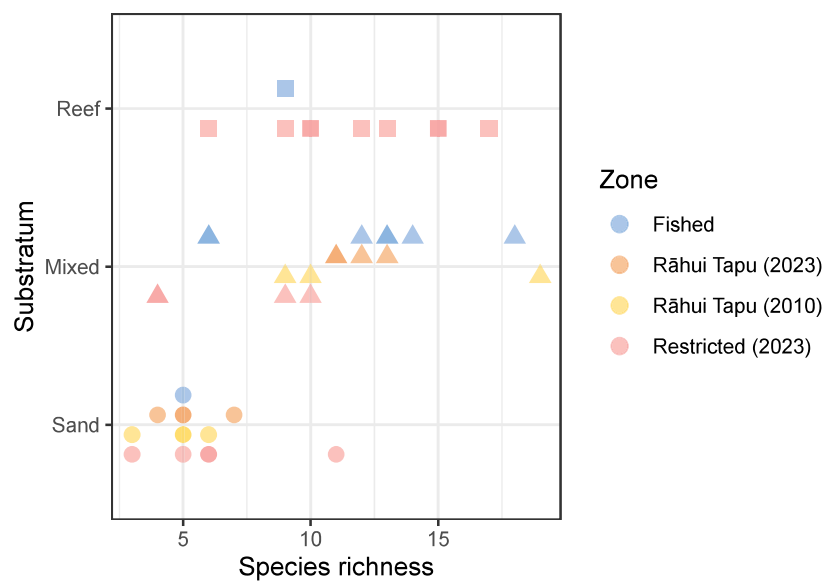


Figure 9: Species richness (number of species) observed in the different substrata. Points are coloured by Zone.

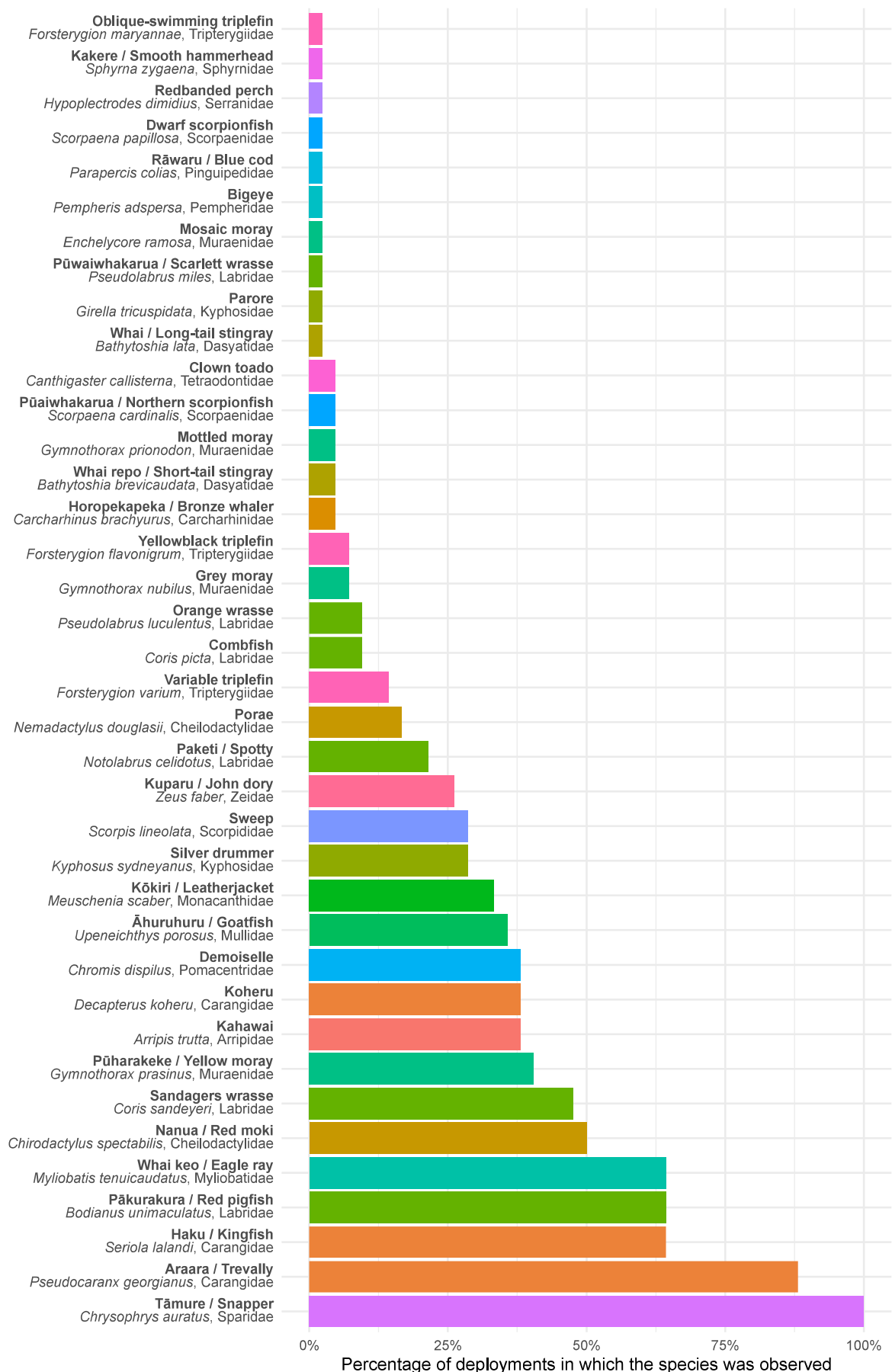


Figure 10: Prevalence of all 38 species observed during the survey. Bars are coloured according to Family.

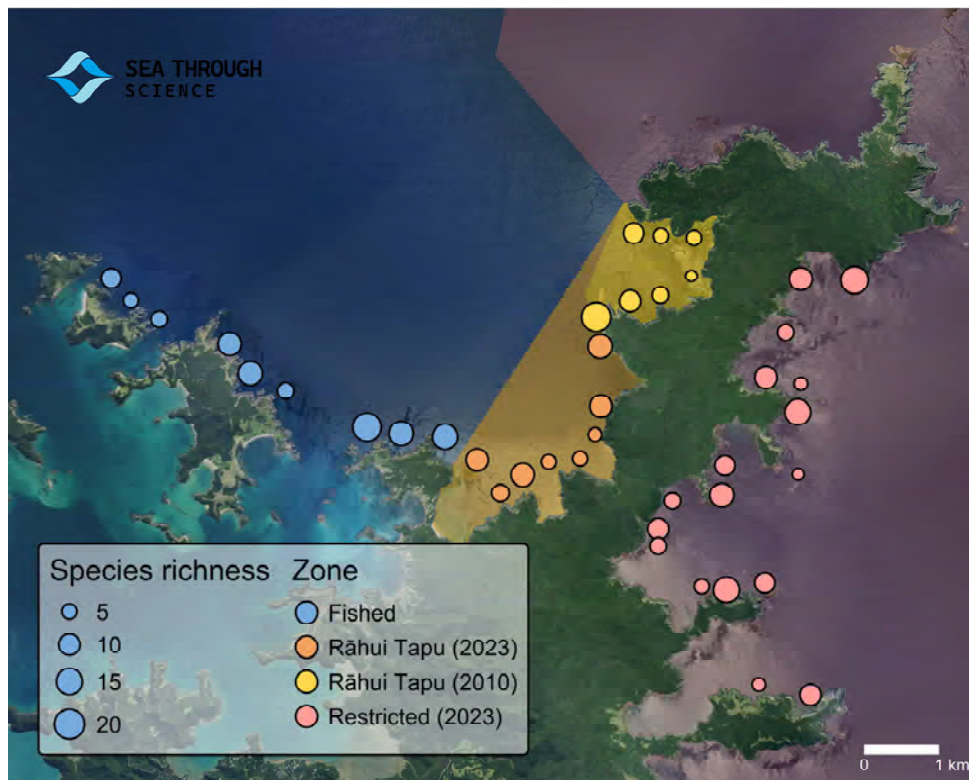


Figure 11: Map of sites with the size of the circle given by species richness (the number of species observed).

3.3. Snapper metrics

3.3.1. MaxN abundance

The numbers (MaxN counts) of snapper ranged from 12 to 105 (Figure 1e), with an overall average of 50.3. Counts were generally lower on the eastern (Restricted 2023) side of the peninsula than on the western, Bay of Islands side (Table 2, Figure 12a, Figure 13, Figure 16). There was little difference in overall average MaxN counts among the three western zones, but the fished zone was slightly lower than the two rāhui tapu zones.

3.3.2. MaxN biomass

The biomass in the MaxN frames ranged from 3.1 to 58.4 kg, with an overall average of 21.6 kg. The differences amongst the zones were more distinct for MaxN biomass than for MaxN counts (Table 2, Figure 12b, Figure 14). MaxN biomass was highest on average in the older, northern rāhui tapu (2010) zone than the southern, more recently protected rāhui tapu (2023) zone. Both rāhui tapu zones had higher average biomass than the fished and restricted-fishing zones (Figure 12b).

3.3.3. Size structure

The fork lengths of snapper ranged from 78 to 687 mm, with an overall average of 251 mm. The fact that the zones were more distinct for MaxN biomass than MaxN counts is due to differences in the size structure of fish among the zones. Snapper fork lengths were larger on average in the northern rāhui tapu zone than the southern rāhui tapu zone, and both were larger than the fished and restricted-fishing zones (Table 2, Figure 12c).

The differences in size structure across the zones are shown in the boxplots in Figure 15 and in a map in Figure 16. Snapper above the legal size of 300 mm fork length were more abundant in the rāhui tapu zones than the fished and restricted-fishing zones. Very large snapper (above 450 mm fork length) were only observed in the northern rāhui tapu zone (protected since 2010), where they were seen at most sites (Figure 15, Figure 16).

Table 2: Table of estimated means (and 95% confidence intervals) of three key metrics for snapper across the four zones. These estimates were obtained from linear models.

Zone	MaxN count	MaxN biomass (kg)	Length (mm)
Fished	52.9 (42.3, 63.5)	15.8 (9.7, 21.9)	225 (207, 242)
Rāhui Tapu (2023)	68.5 (57.3, 79.7)	29.8 (23.3, 36.2)	255 (236, 273)
Rāhui Tapu (2010)	62.7 (50.7, 74.7)	41.7 (34.8, 48.6)	296 (276, 315)
Restricted (2023)	35.4 (27.7, 43)	12 (7.5, 16.6)	231 (218, 244)

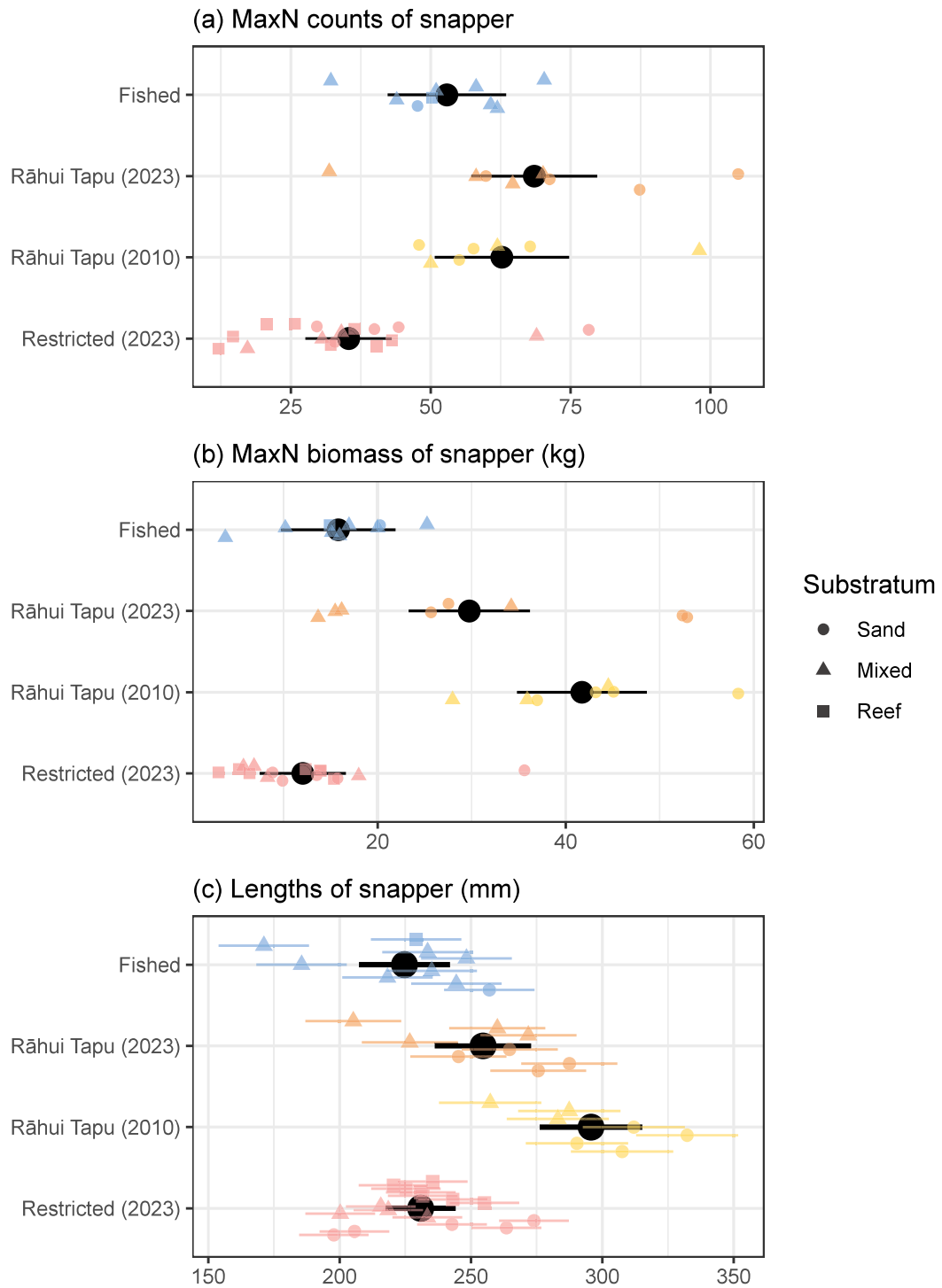


Figure 12: Three key metrics for snapper by zone. Each coloured point is a site (with the shape according to substratum), and the black circles are the means of each zone with 95% confidence intervals estimated from linear models, as given in Table 2.

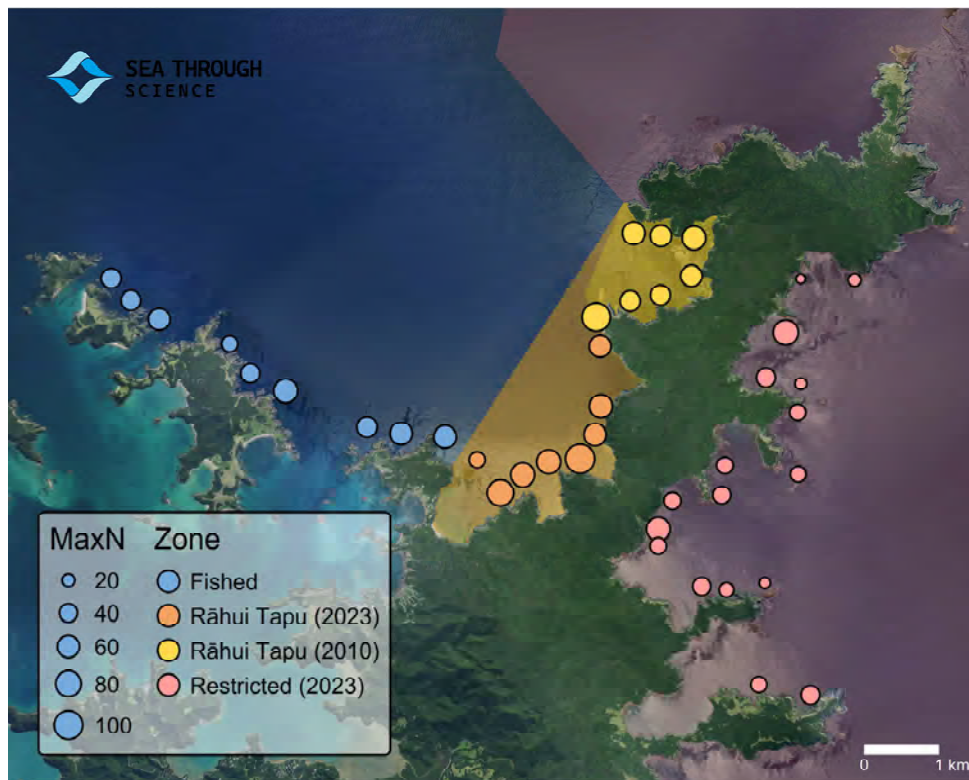


Figure 13: Map of sites with the size of the circle given by MaxN of snapper (the maximum number seen on a single frame of the BRUV deployment).

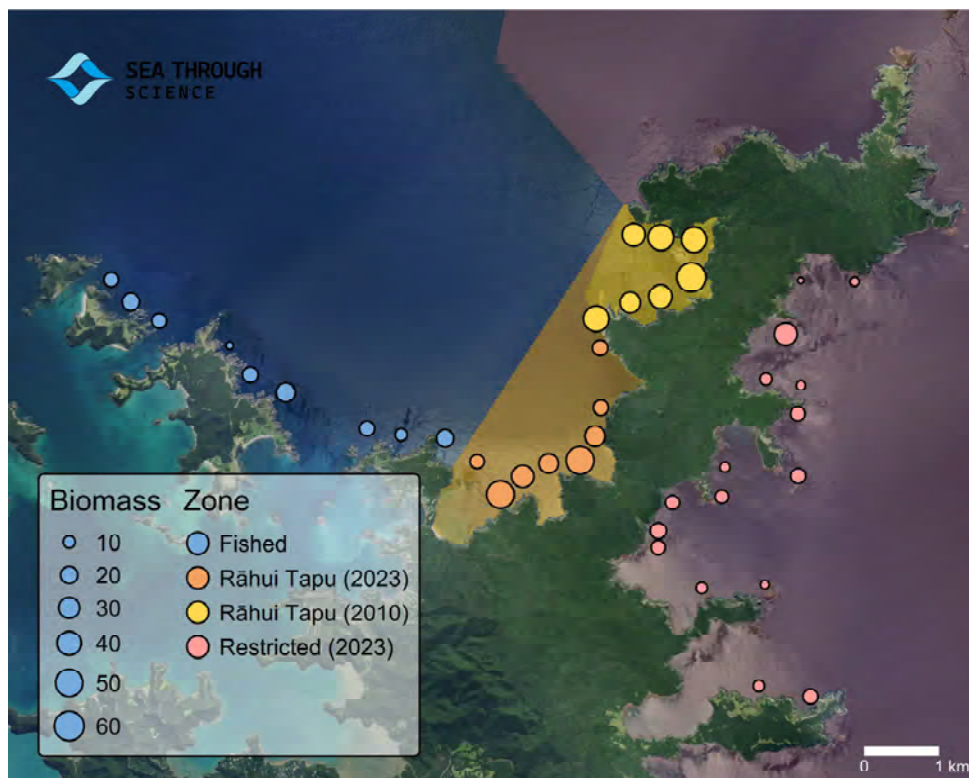


Figure 14: Map of sites with the size of the circle given by the estimated biomass of fish seen on the MaxN frame.

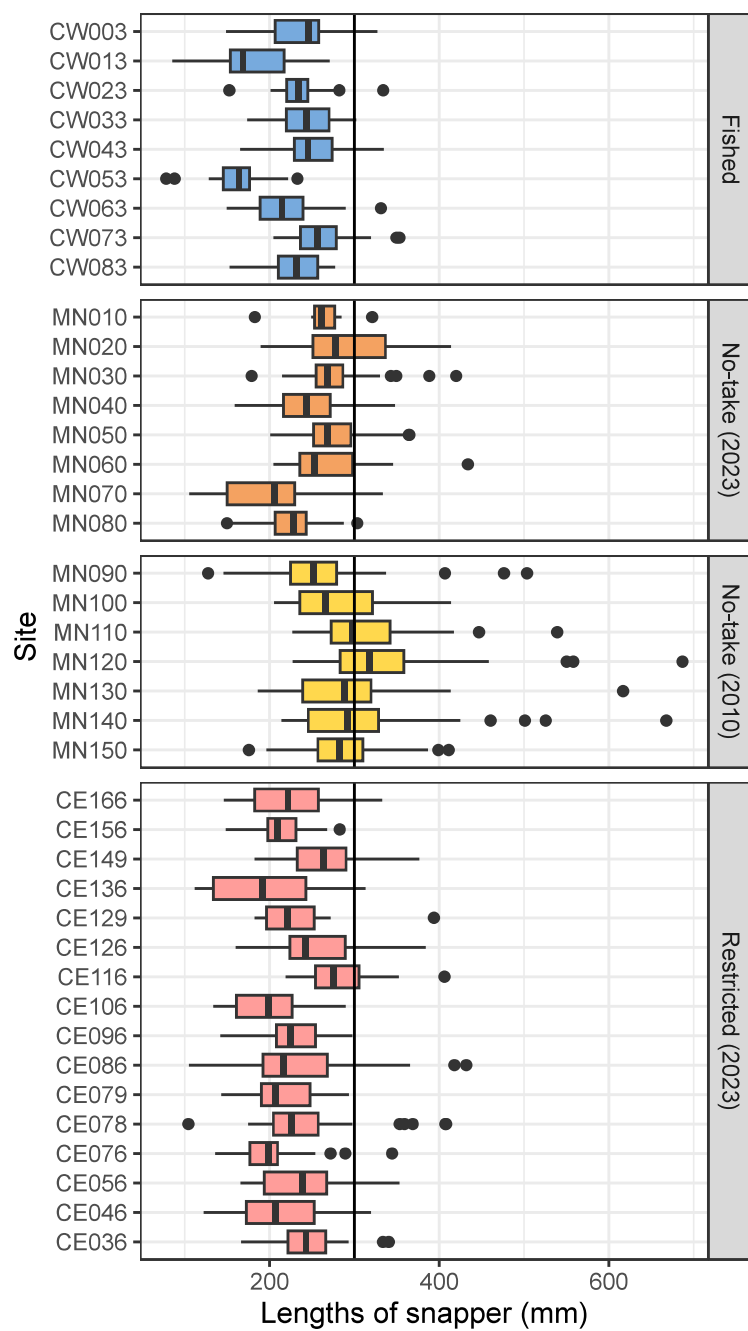


Figure 15: Boxplots showing the fork lengths of snapper recorded at each site in the four sampling areas. The black vertical line indicates the minimum legal size (300 mm).

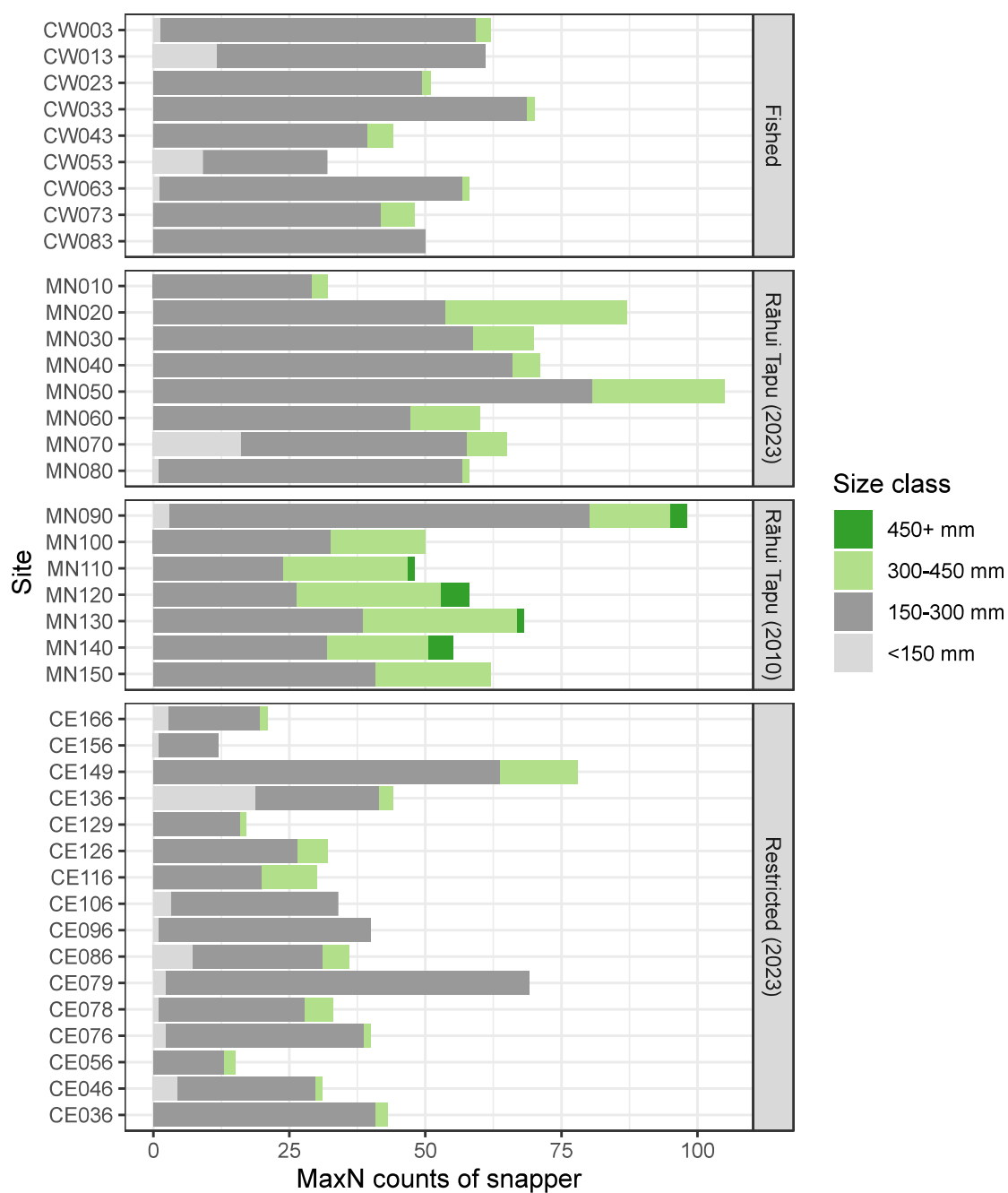


Figure 16: MaxN counts of snapper at each site, shown by zone, and coloured by four fork-length size classes. The grey and green colours show classes below and above the minimum legal size (300 mm fork length) respectively.

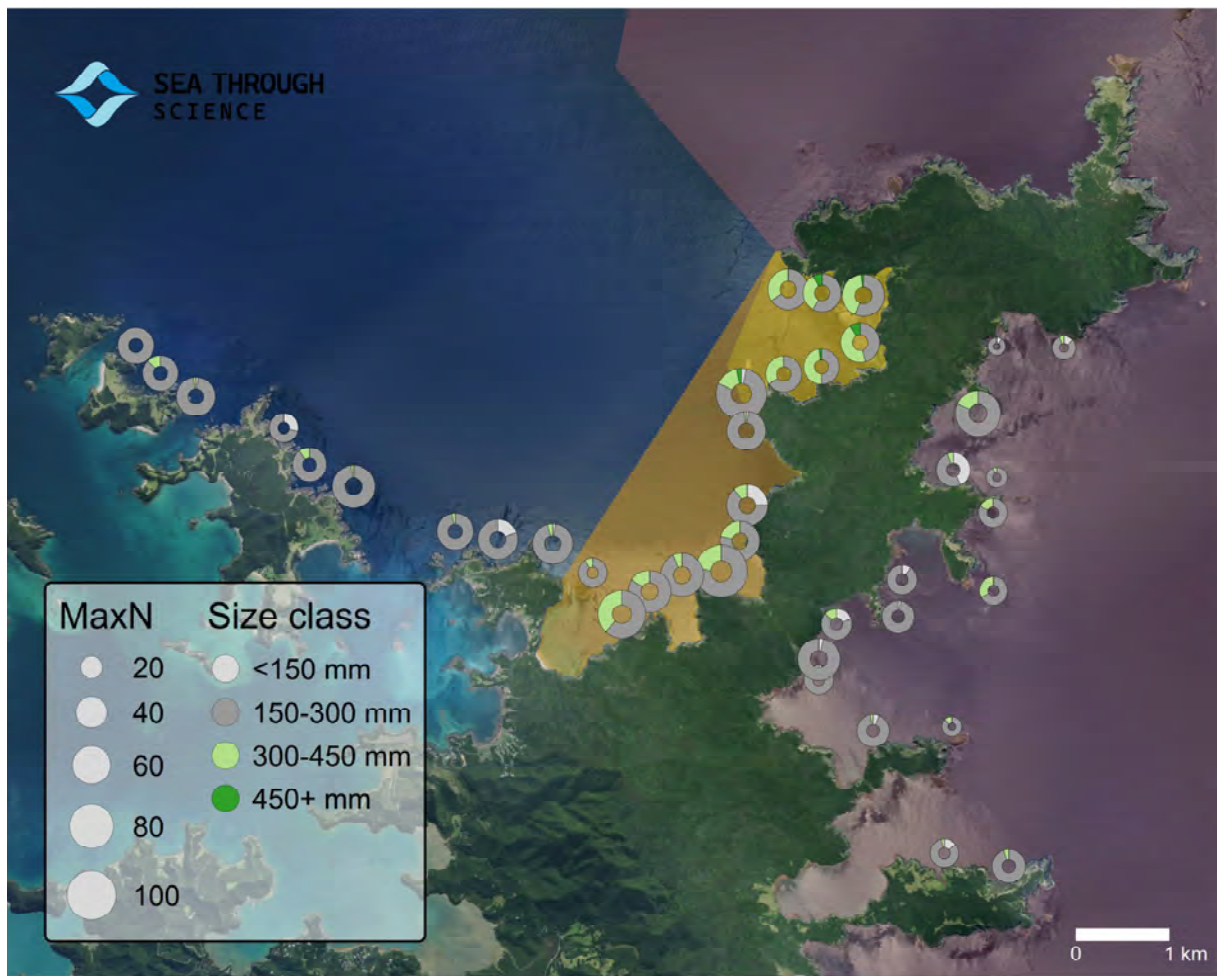


Figure 17: Map of sites with the size of the circle given by the MaxN – the maximum number of snapper seen on a single frame of the BRUV deployment, divided into four size classes.

4. Discussion

This survey provides a snapshot of fish assemblages across four zones with differing histories of protection around Rākaumangamanga/Cape Brett, with a particular focus on snapper abundance and size structure. This is the first year of monitoring with stereo BRUVs at this site, allowing us to collect accurate length measurements and high-quality data on fish assemblages. Overall, deployment quality was high, although some malpositioned BRUVs on the first day highlight the importance of learning from operational challenges, such as adjusting weights and placement to reduce tipping and occlusion in dense kelp or steep reef areas. These results provide a robust baseline for ongoing monitoring and management.

4.1. Snapper abundance and size structure

Snapper were ubiquitous across all sites, but both biomass and size structure varied strongly with protection status, reflecting the influence of historical and ongoing fishing pressure. In contrast, overall species richness appeared more closely tied to local substratum than to protection zone. Deployments on sand tended to have fewer species, because several species observed are obligatory reef-dwellers. These findings indicate that while protected zones are effective at supporting larger and more abundant snapper, broader patterns of fish diversity require consideration of both habitat and management history.

The abundance of snapper in the region was generally very high (e.g., Figure 16). Across the whole area surveyed, the maximum number seen on one frame (MaxN, the standard metric used to measure abundance from underwater video surveys) had an overall *mean* of 50.3, which is comparable to the *highest* values we have observed in our surveys of offshore islands in the Hauraki Gulf (though these surveys were deeper, at 50–90 m).

While overall MaxN counts did not substantially differ across the four protection zones (Figure 12a, Figure 13), there were some compelling differences in MaxN biomass (Figure 12b, Figure 14), lengths (Figure 12c, Figure 15), and counts of larger size classes (Figure 16, Figure 17). All of these metrics were highest in the northern rāhui tapu zone, which has been protected since 2010. In particular, very large snapper (>450 mm fork length) were observed only in the 2010 rāhui tapu zone, where most sites contained these individuals (Figure 16). The southern rāhui tapu zone, protected since November 2023, had smaller snapper on average but still higher numbers of legal-sized fish (>300 mm FL) than the fished and restricted-fishing zones.

The fact that large snapper were abundant in the northern zone protected since 2010 is not surprising, as the same has been found in several marine reserves in north-eastern New Zealand [2,6–9]. It may be more surprising that there were more legal-sized snapper in the southern zone—after all, snapper only attain legal size at around 3–4 years of age [24,25], and at the time of the survey the rāhui tapu had been in place there for less than two years. But rapid increases in legal-sized snapper after marine protection have been observed elsewhere. In the first few years after the Poor Knights Islands were made a marine reserve in 1998, numbers of large snapper and overall biomass increased several fold [2]. This can be explained by the fact that large snapper seasonally migrate to inshore waters [7,10,26], where some establish small home-ranges [6,11]. In heavily fished areas, most of these larger fish are caught. In protected areas, they remain, where they build up and grow larger in subsequent years [2,10]. So, any rapid increases in numbers of large snapper in a newly established marine protected area is likely due to recolonisation and subsequent protection of fish that have migrated inshore, rather than growth of smaller fish that live there already [2].

Large numbers of very small snapper (< 150 mm fork length) were observed at a few sites across the different zones (Figure 17). These included some fish less than 80 mm, which are likely to be young-of-the-year. This bodes well for the future population of snapper in the area, and may be a sign of strong breeding stock, perhaps bolstered by the reproductive output of very large snapper observed in Maunganui Bay. Like many fish, egg production of female snapper increases exponentially with size; a 50 cm female produces eight times as many eggs as one half her size [15]. A healthy population of so-called big old fat fecund female fish (BOFFFFs [27]) within a marine reserve can serve as a reproductive wellspring for nearby, fished areas. A recent study designated that female snapper achieve BOFFFF status at 370 mm [28]. Snapper egg production per unit of area is an estimated 23 times greater inside versus outside the marine reserve, meaning that the 5 km of protected coastline contributes the equivalent of 90 km of unprotected coastline [7]. Furthermore, an estimated 10% of young snapper within 55 km of the Cape Rodney to Okakari Point (CROP) Marine Reserve (near Leigh) were the offspring of fish inside the reserve [17], demonstrating that even small marine protected areas can contribute substantially to local populations, due to large numbers of very large fish. The fact that the new rāhui tapu area is already showing signs of building a larger breeding stock is encouraging, and as a result fishers might expect to see greater recruitment of snapper in the broader region in the coming years.

4.2. Methodological considerations

In this study, the standard approach to annotation was used, where the MaxN frame was identified for a given species, and lengths were taken only from the fish that appeared in the MaxN frame. Like any method, MaxN has limitations. Where snapper are extremely abundant, as was the case for many of the deployments in this survey, some individuals are undoubtedly obscured from view resulting in a ‘saturation’ effect, where the MaxN count stops increasing linearly with abundance. Another potential limitation is that the MaxN approach may not fully capture the abundance of each size class of snapper. For instance, if 20 small fish appear early in the video but are later displaced by 5 larger fish, the MaxN lengths would capture only the small fish, missing the larger individuals. Bias in the reverse direction is also possible; the 20 small snapper at the beginning of the video may be displaced by 30 larger fish that arrive later.

These two issues—biased measurements of the overall abundance and the abundance of some size classes—could be ameliorated by taking alternative approaches to video annotation. Specifically, if we counted and measured fish in the overall MaxN frame, and *also* at a set of time points systematically spread across the annotation period – say, at 0, 10, 20, 30, 40, 50, and 60 minutes. This would yield counts and lengths from eight frames: the one MaxN frame and the seven systematic frames. Others have suggested that the average of counts taken across these systematic frames, an index called **MeanCount**, might be more linearly related to true abundance than MaxN where true abundance is high [29–31]. Furthermore, to get the abundance of each size class, one could take the maximum count for the size class observed from any of the eight frames, avoiding any bias in the lengths of fish in the single, MaxN frame [32]. Then, the sum of the maximum counts across the size classes might yield an index of overall abundance less prone to saturation effects. The one drawback of this method is that annotation and statistical analysis would be more time consuming. As it was, annotation of only the MaxN frames took much longer than anticipated, due to the numbers of snapper being so high. However, given that the abundance of specific size classes will be the most important metric for the future of this monitoring programme, these alternative methods would potentially provide data more representative of the population, and therefore warrant further investigation.

The distribution of substrata (sand, mixed, and rocky reef) was uneven among zones. While it did not appear to strongly influence overall snapper abundance in the present study, substratum may

affect size classes differently (smaller fish might be more hesitant to leave the shelter provided by reef and kelp) and is expected to strongly influence the presence of other reef-associated species. This limits our ability to attribute differences in species richness to protection status [33]. While all sites were within tens of metres of reef (close enough for reef-resident snapper to move to the BRUV apparatus), future surveys could be improved by more balanced habitat representation to increase analytical power. Deployment quality, though generally high across most of the survey, can easily be improved by routinely adding weights the BRUV units and avoiding steep reef habitats, as was done successfully on the second day of sampling. At the end of the day, this study represents a single year of monitoring and a limited sample size. Repeated surveys over the coming years, with some adjustments to some of the sites, will allow us to build a more robust dataset and understand how snapper populations and fish assemblages more broadly are influenced by marine protection, substratum, and other factors.

4.3. Conclusions and Recommendations

This first year of stereo BRUV monitoring around Rākaumangamanga/Cape Brett represents an important step in establishing a long-term programme to evaluate the effects of rāhui tapu and other forms of marine protection. The survey has already yielded valuable insights, showing that snapper are abundant throughout the region, and that the largest individuals are concentrated in the northern rāhui tapu protected since 2010. The newer southern rāhui tapu also shows encouraging signs, with higher numbers of legal-sized snapper than in fished areas despite its short protection history. These findings underscore both the rapid potential for recolonisation and the longer-term benefits of sustained protection in rebuilding fish populations.

Looking ahead, the greatest effects of the rāhui tapu are expected to be increases in the abundance of snapper above the legal size (300 mm fork length) and very large individuals (>450 mm), which play a disproportionate role in reproduction and population replenishment. The use of calibrated stereo BRUVs provides a powerful means of monitoring these changes, particularly in capturing accurate length data. To strengthen the monitoring programme, we recommend:

- Repeating surveys in 2026 and 2027 to build a robust baseline and capture inter-annual variability.
- Adjusting some site locations to better balance substratum types and reduce habitat-driven biases.
- Incorporating systematic frame measurements in addition to MaxN, and developing statistical approaches that better represent population size structure, particularly where abundance is high.

By combining repeated surveys, methodological refinement, and improving habitat representation, this monitoring programme can provide robust evidence of how rāhui tapu contribute to rebuilding snapper populations and sustaining broader reef fish assemblages, while also informing adaptive management and community expectations.

Acknowledgements

The author thanks the Northland Regional Council (NRC), and in particular Nicola Hartwell and Richard Griffiths, for orchestrating and providing funding for this work. I am very grateful to Ngāti Kuta and Patukeha hapū for their support, and Robert Willoughby for accommodating me during the survey. I thank the skipper Bob Clarke, and Eli Sherman, Warren Matene, and Richard Griffiths for their help in the field – it was a pleasure to work with you! Thank you to Heidi Schlumpf for her many hours of annotation.

Appendix 1: Data Structure

Overview

The video files were provided to the client on a portable drive. Data files of deployment metadata were provided via email to the contract manager. Below is some information required to link the videos with the metadata.

OpCodes

Every deployment is given a unique identifier, known as an OpCode, that is used to link the videos, biological data, and the deployment metadata.

An OpCode comprises the following information:

- CampaignID (e.g., BOI25): Three letters indicating the broader geographic region (e.g., BOI for Bay of Islands), followed by the year in which the campaign began in YY format.
- SetNo: The 'set' number beginning with "S01". A set usually comprises six concurrent deployments, which are the 'replicates'.
- RepNo: The 'replicate' number of the deployment within the set. When using six BRUV systems, the RepNo would normally go from "R01" to "R06". The RepNo resets to R01 at the beginning of each Set.
- BRUVID: Identifies the BRUV unit that was used. This is essential to ensure the correct calibration files are used during annotation.
- Optional site label: an identifier for the site.

The full OpCode for any deployment will be made up of the following parts:

- CampaignID_SetNo_RepNo_BRUVID_(optional site label)

For example, the second replicate of the third set of the Fiordland 2025 campaign, at which BRUV unit number H12-02 was deployed at site CE129, has the OpCode B0I25_S03_R02_H12-02_CE129.

Video file system

The information from each campaign is stored within a single directory. Inside this campaign directory are some standard directories numbered 1 to 8, followed by directories containing the video files, arranged according to sets and replicates with a specific structure.

Below is a description of the directory system:

```
CampaignID
├── 1_Calibration files
├── 2_Data
├── 3_Measurement files_EMOB
├── 4_Database export
├── 5_Habitat screenshots
├── 6_Unidentified species
├── 7_Other screenshots
├── 8_Datasheets
├── 9_Report
└── CampaignID_SetNo
    └── CampaignID_SetNo_RepNo_BRUVID_SiteLabel
```

See explanations of the standard directories below. Some of these directories may be empty, depending on whether the videos have been annotated.

Folder Name	Description
1_Calibration files	Files exported by CAL for length measurements
2_Data	Data files
3_Measurement files_EMOB	EventMeasure annotation files
4_Database export	Biological data exported from EventMeasure
5_Habitat screenshots	Screenshots from each deployment
6_Unidentified species	Screenshots of any unknown species
7_Other screenshots	Other screenshots of interest
8_Datasheets	Photographs of field datasheets
9_Report	Report and figures

See below for an example of the directory structure for the video files:

```

B0I25
├── B0I25_S03
│   ├── B0I25_S03_R01_H12-01_CE149
│   ├── B0I25_S03_R02_H12-02_CE129
│   ├── B0I25_S03_R03_H12-03_CE079
│   ├── B0I25_S03_R04_H12-04_CE078
│   ├── B0I25_S03_R05_H12-04_CE046
│   └── B0I25_S03_R06_H12-06_CE036

```

The video files sit within the lowest level subdirectories. If multiple video files are in the folder, they will be in alphabetical sequence. However, prior to annotation, the left and right video files will be renamed and moved into the level above (i.e., CampaignID/CampaignID_SetNo/CampaignID_SetNo_RepNo_BRUVID_(optional-site-label)) and the lowest level subdirectories will be deleted.

Appendix 2: Table of sites

Site	Zone	Substratum	Quality	Depth (m)	Lat	Lon
CE036	Restricted (2023)	Reef	Good	21	35° 14.892' S	174° 19.214' E
CE046	Restricted (2023)	Mixed	Good	19	35° 14.822' S	174° 18.758' E
CE056	Restricted (2023)	Reef	OK	24	35° 14.087' S	174° 18.799' E
CE066	Restricted (2023)	Reef	OK	18	35° 14.141' S	174° 18.462' E
CE076	Restricted (2023)	Sand	Good	21	35° 14.118' S	174° 18.244' E
CE078	Restricted (2023)	Sand	Good	17	35° 13.829' S	174° 17.856' E
CE079	Restricted (2023)	Mixed	OK	19	35° 13.709' S	174° 17.855' E
CE086	Restricted (2023)	Reef	OK	19	35° 13.504' S	174° 17.976' E
CE096	Restricted (2023)	Reef	Good	21	35° 13.457' S	174° 18.410' E
CE106	Restricted (2023)	Mixed	Good	19	35° 13.241' S	174° 18.434' E
CE116	Restricted (2023)	Sand	OK	32	35° 13.298' S	174° 19.080' E
CE126	Restricted (2023)	Reef	Good	21	35° 12.848' S	174° 19.069' E
CE129	Restricted (2023)	Mixed	Good	31	35° 12.643' S	174° 19.093' E
CE136	Restricted (2023)	Sand	OK	24	35° 12.602' S	174° 18.785' E
CE146	Restricted (2023)	Reef	Bad	21	35° 12.319' S	174° 18.702' E
CE149	Restricted (2023)	Sand	Good	29	35° 12.273' S	174° 18.954' E
CE156	Restricted (2023)	Reef	OK	18	35° 11.884' S	174° 19.080' E
CE166	Restricted (2023)	Reef	OK	22	35° 11.887' S	174° 19.554' E
MN150	Rāhui Tapu (2010)	Mixed	Good	21	35° 11.569' S	174° 17.604' E
MN140	Rāhui Tapu (2010)	Sand	Good	24	35° 11.586' S	174° 17.844' E
MN130	Rāhui Tapu (2010)	Sand	Good	22	35° 11.598' S	174° 18.135' E
MN120	Rāhui Tapu (2010)	Sand	Good	23	35° 11.873' S	174° 18.117' E
MN110	Rāhui Tapu (2010)	Sand	Good	22	35° 12.015' S	174° 17.846' E
MN100	Rāhui Tapu (2010)	Mixed	Good	28	35° 12.060' S	174° 17.581' E
MN090	Rāhui Tapu (2010)	Mixed	Good	26	35° 12.179' S	174° 17.284' E
MN080	Rāhui Tapu (2023)	Mixed	Good	25	35° 12.391' S	174° 17.322' E
MN070	Rāhui Tapu (2023)	Mixed	Good	23	35° 12.823' S	174° 17.335' E
MN060	Rāhui Tapu (2023)	Sand	Good	23	35° 13.031' S	174° 17.287' E
MN050	Rāhui Tapu (2023)	Sand	Good	20	35° 13.206' S	174° 17.158' E
MN040	Rāhui Tapu (2023)	Sand	Good	24	35° 13.231' S	174° 16.882' E
MN030	Rāhui Tapu (2023)	Mixed	Good	23	35° 13.328' S	174° 16.655' E
MN020	Rāhui Tapu (2023)	Sand	Good	20	35° 13.462' S	174° 16.461' E
MN010	Rāhui Tapu (2023)	Mixed	OK	22	35° 13.224' S	174° 16.252' E

Site	Zone	Substratum	Quality	Depth (m)	Lat	Lon
CW083Fished		Reef	OK	24	35° 11.943' S	174° 13.011' E
CW073Fished		Sand	Good	23	35° 12.101' S	174° 13.186' E
CW063Fished		Mixed	Good	21	35° 12.234' S	174° 13.438' E
CW053Fished		Mixed	Good	22	35° 12.408' S	174° 14.061' E
CW043Fished		Mixed	Good	21	35° 12.619' S	174° 14.246' E
CW033Fished		Mixed	Good	23	35° 12.743' S	174° 14.559' E
CW023Fished		Mixed	Good	22	35° 12.996' S	174° 15.279' E
CW013Fished		Mixed	Good	21	35° 13.040' S	174° 15.580' E
CW003Fished		Mixed	Good	23	35° 13.060' S	174° 15.967' E

Appendix 3: Deployment quality

Table 3: Descriptions of the quality issues for each of the 'Bad' or 'OK' quality deployments

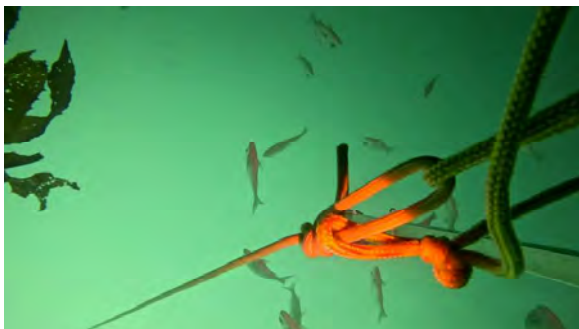
Site	Quality	Description of quality issue
CE146	Bad	Unit was upside down AND the fields of view of both cameras were obscured by kelp and/or rock
CE056, CE136, CE166	OK	Unit was upside down AND the field of view of at least one camera was partially obscured by kelp and/or rock
CE086, CE116	OK	Unit was facing upwards (towards the sky)
CE156	OK	Unit began facing upwards but then settled in correct position after 25 minutes
CE066	OK	Fields of view of both cameras at least partially obscured by kelp AND length measurements not possible
CE079, MN010, CW083	OK	Fields of view of both cameras at least partially obscured by kelp



(a) Upside down, very obscured (CE146)



(b) Upside down (CE136)



(c) Facing upwards (CE086)



(d) Partially obscured (MN010)

Figure 18: Screenshots from some 'Bad' or 'OK' deployments

Appendix 4: Raw data

Table 4: Table of MaxN counts for every species per site.

																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								</
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	----

References

- [1] Halpern BS, Warner RR. Marine reserves have rapid and lasting effects. *Ecology Letters* 2002;5:361–6. <https://doi.org/10.1046/j.1461-0248.2002.00326.x>.
- [2] Denny CM, Willis TJ, Babcock RC. Rapid recolonisation of snapper *Pagrus auratus*: Sparidae within an offshore island marine reserve after implementation of no-take status. *Marine Ecology Progress Series* 2004;272:183–90. <https://doi.org/10.3354/meps272183>.
- [3] Langlois TJ, Harvey ES, Fitzpatrick B, Meeuwig JJ, Shedrawi G, Watson DL. Cost-efficient sampling of fish assemblages: comparison of baited video stations and diver video transects. *Aquatic Biology* 2010;9:155–68. <https://doi.org/10.3354/ab00235>.
- [4] Whitmarsh SK, Fairweather PG, Huveneers C. What is Big BRUVver up to? Methods and uses of baited underwater video. *Reviews in Fish Biology and Fisheries* 2017;27:53–73. <https://doi.org/10.1007/s11160-016-9450-1>.
- [5] Langlois T, Goetze J, Bond T, Monk J, Abesamis RA, Asher J, et al. A field and video-annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages. *Methods in Ecology and Evolution* 2020;11:1401–9. <https://doi.org/10.1111/2041-210X.13470>.
- [6] Willis TJ, Parsons DM, Babcock RC. Evidence for long-term site fidelity of snapper (*Pagrus auratus*) within a marine reserve. *New Zealand Journal of Marine and Freshwater Research* 2001;35:581–90. <https://doi.org/10.1080/00288330.2001.9517024>.
- [7] Willis TJ, Millar RB, Babcock RC. Protection of exploited fish in temperate regions: High density and biomass of snapper *Pagrus auratus* (Sparidae) in northern New Zealand marine reserves. *Journal of Applied Ecology* 2003;40:214–27. <https://doi.org/10.2307/3505997>.
- [8] Smith ANH, Anderson MJ, Millar RB. Incorporating the intraspecific occupancy-abundance relationship into zero-inflated models. *Ecology* 2012;93:2526–32. <https://doi.org/10.1890/12-0460.1>.
- [9] Smith ANH, Anderson MJ, Millar RB, Willis TJ. Effects of marine reserves in the context of spatial and temporal variation: an analysis using Bayesian zero-inflated mixed models. *Marine Ecology Progress Series* 2014;499:203–16. <https://doi.org/10.3354/meps10653>.
- [10] Willis TJ, Millar RB. Using marine reserves to estimate fishing mortality. *Ecology Letters* 2005;8:47–52. <https://doi.org/10.1111/j.1461-0248.2004.00692.x>.
- [11] Parsons DM, Babcock RC, Hankin RKS, Willis TJ, Aitken JP, ODor RK, et al. Snapper *Pagrus auratus* (Sparidae) home range dynamics: acoustic tagging studies in a marine reserve. *Marine Ecology Progress Series* 2003;262:253–65. <https://doi.org/10.3354/meps262253>.
- [12] Francis MP, Pankhurst NW. Juvenile sex inversion in the New Zealand snapper *Chrysophrys auratus* (Bloch and Schneider, 1801) (Sparidae). *Marine and Freshwater Research* 1988;39:625–31. <https://doi.org/10.1071/mf9880625>.
- [13] Parsons D, Sim-Smith C, Cryer M, Francis M, Hartill B, Jones E, et al. Snapper (*Chrysophrys auratus*): a review of life history and key vulnerabilities in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 2014;0:1–28. <https://doi.org/10.1080/00288330.2014.892013>.
- [14] Scott SG, Zeldis JR, Pankhurst NW. Evidence of daily spawning in natural populations of the New Zealand snapper *Pagrus auratus* (Sparidae). *Environmental Biology of Fishes* 1993;36:149–56. <https://doi.org/10.1007/BF00002794>.

- [15] Crossland J. Fecundity of the snapper *Chrysophrys auratus* (Pisces: Sparidae) from the Hauraki Gulf. *New Zealand Journal of Marine and Freshwater Research* 1977;11:767–75. <https://doi.org/10.1080/00288330.1977.9515712>.
- [16] Le Port A, Montgomery JC, Croucher AE. Biophysical modelling of snapper *Pagrus auratus* larval dispersal from a temperate MPA. *Marine Ecology Progress Series* 2014;515:203–15. <https://doi.org/10.3354/meps10973>.
- [17] Le Port A, Montgomery JC, Smith ANH, Croucher AE, McLeod IM, Lavery SD. Temperate marine protected area provides recruitment subsidies to local fisheries. *Proceedings of the Royal Society B: Biological Sciences* 2017;284:20171300. <https://doi.org/10.1098/rspb.2017.1300>.
- [18] Harvey E, Fletcher D, Shortis M. Improving the statistical power of length estimates of reef fish: a comparison of estimates determined visually by divers with estimates produced by a stereo-video system. *Fishery Bulletin* 2001;99:72–80.
- [19] Willis TJ, Babcock RC. A baited underwater video system for the determination of relative density of carnivorous reef fish. *Marine and Freshwater Research* 2000;51:755–63. <https://doi.org/10.1071/MF00010>.
- [20] Willis TJ, Millar RB, Babcock RC. Detection of spatial variability in relative density of fishes: comparison of visual census, angling, and baited underwater video. *Marine Ecology Progress Series* 2000;198:249–60. <https://doi.org/10.3354/meps198249>.
- [21] Walsh C, Parsons DM, Bian R, McKenzie JR, Armiger H, Taylor R, et al. Age composition of commercial snapper landings in SNA 1 and SNA 2, 2019–20. Wellington, New Zealand: New Zealand Fisheries Assessment Report 2022/24. Fisheries New Zealand, Ministry for Primary Industries; 2022.
- [22] R Core Team. R: A Language and Environment for Statistical Computing 2025.
- [23] Brooks ME, Kristensen K, Benthem KJv, Magnusson A, Berg CW, Nielsen A, et al. glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. *The R Journal* 2017;9:378–400. <https://doi.org/10.32614/RJ-2017-066>.
- [24] Paul LJ. A study on age, growth, and population structure of the snapper, *Chrysophrys auratus* (Forster), in the Hauraki Gulf, New Zealand. *New Zealand Fisheries Research Bulletin* 13. Fisheries Research Division, New Zealand Ministry of Agriculture, Fisheries; 1976.
- [25] Paul LJ, Tarring SC. Growth rate and population structure of snapper, *Chrysophrys auratus*, in the East Cape region, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 1980;14:237–47. <https://doi.org/10.1080/00288330.1980.9515866>.
- [26] Francis MP. Spatial and seasonal variation in the abundance of juvenile snapper (*Pagrus auratus*) in the north-western Hauraki Gulf. *New Zealand Journal of Marine and Freshwater Research* 1995;29:565–79. <https://doi.org/10.1080/00288330.1995.9516688>.
- [27] Hixon MA, Johnson DW, Sogard SM. BOFFFFs: on the importance of conserving old-growth age structure in fishery populations. *ICES Journal of Marine Science: Journal Du Conseil* 2014;71:2171–85. <https://doi.org/10.1093/icesjms/fst200>.
- [28] Jefferson T, Hillman JR, Lundquist CJ. Prioritising multiple objectives in marine spatial planning for Aotearoa New Zealand. *Ocean & Coastal Management* 2023;246:106886. <https://doi.org/10.1016/j.ocecoaman.2023.106886>.

- [29] Conn PB. An evaluation and power analysis of fishery independent reef fish sampling in the Gulf of Mexico and U.S. south Atlantic. NOAA Tech. Memo. NMFS-SEFSC-610. National Oceanic, Atmospheric Administration, United States Department of Commerce; 2011.
- [30] Schobernd ZH, Bacheler NM, Conn PB. Examining the utility of alternative video monitoring metrics for indexing reef fish abundance. *Canadian Journal of Fisheries and Aquatic Sciences* 2013;71:464–71. <https://doi.org/10.1139/cjfas-2013-0086>.
- [31] Campbell MD, Pollack AG, Gledhill CT, Switzer TS, DeVries DA. Comparison of relative abundance indices calculated from two methods of generating video count data. *Fisheries Research* 2015;170:125–33. <https://doi.org/10.1016/j.fishres.2015.05.011>.
- [32] Williams EH, Shertzer KW, Bacheler N. Estimating length composition of fish observed with stereo-video cameras: A simulation study with application to red snapper (*Lutjanus campechanus*). *Fisheries Research* 2022;254:106424. <https://doi.org/10.1016/j.fishres.2022.106424>.
- [33] García-Charton JA, Ruzafa ÁP. Ecological heterogeneity and the evaluation of the effects of marine reserves. *Fisheries Research* 1999;42:1–20. [https://doi.org/10.1016/S0165-7836\(99\)00043-0](https://doi.org/10.1016/S0165-7836(99)00043-0).