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Tini a Tangaroa

Pāua population monitoring in areas affected by the 2016 Kaikōura earthquake, April 2024 update

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PLAIN LANGUAGE SUMMARY

- The 2016 Kaikōura earthquake caused significant coastal uplift resulting in high mortality of marine life, including pāua. The pāua fishery is of high importance to customary, recreational and commercial fishers in the region.
- We undertook dive surveys to measure the recovery of the pāua populations on the affected coastline and have continued surveys since the fishery re-opening in 2021. This report provides an update of survey results that have now been undertaken annually over the last 7 years.
- Surveys have shown a steady increase of pāua abundance across the fishery until it was re-opened in 2021 after which there has been a slight decline. This shows the benefit of the surveys in detecting the effects of fishing on pāua abundance in the area.
- Data and outcomes from these surveys were used to inform the decision to re-open the fishery in 2021 and are now critical in informing future management decisions for the Kaikōura pāua fishery.

EXECUTIVE SUMMARY

McCowan, T.A.[1]; Neubauer, P.[2] (2024). Pāua population monitoring in areas affected by the November 2016 Kaikōura earthquake, April 2024 update.

***New Zealand Fisheries Assessment Report 2024/31.* 19 p.**

The November 2016 Kaikōura earthquake caused coastal uplift resulting in high pāua (*Haliotis iris*) mortality and extensive loss of critical pāua habitats. The uplift affected approximately 120 km of coastline that supports significant customary, recreational, and commercial pāua fisheries. There has been a closure of the pāua fishery from the Conway River in the south to Marfells Beach in the north (the 'closed area') since November 2016 to allow for recovery of affected pāua populations. The fishery was initially re-opened on the 1st of December 2021 and is now in its third successive annual fishing season since re-opening.

The objective of this project was to continue annual monitoring of pāua abundance and length frequency at the scale of the fishery closure at sites established initially in 2017. These surveys have employed a modified timed-swim methodology to estimate site and area-wide (Quota Management Area) trends in pāua abundance and length frequency. Results from these surveys had initially shown an overall increase in adult biomass, and widespread juvenile recruitment, which supported the decision to re-open the fishery.

Data analysis followed methods reported in previous updates, namely using generalised linear mixed models. Additional diagnostics to those presented for previous surveys were inspected to ensure that the model adequately captured variation in survey data across various strata (e.g., survey strata, quota management areas, survey periods, and covariates). These efforts suggested that multi-modality in the response within survey sites is a key driver of high variability (CVs) in survey estimates, a feature that arises from patchiness of pāua distribution and is largely irreducible with limited survey effort.

Analyses show that abundance of pāua increased from initial baseline surveys until the 2021–22 survey period, after which the fishery was re-opened. Since re-opening, abundance has declined in both PAU 3A and PAU 7 QMAs in the earthquake-affected areas, although there are some subtle differences in trends between QMAs. This decline is as expected and shows that the surveys have value in detecting changes in fishery wide pāua abundance in response to fishing effort. Analyses of abundance at the fine spatial scales (i.e., within 'management zones') can help to illustrate what specific areas may be driving overall fishery wide trends, although site bias in relation to where recent harvesting has taken place could influence this.

In PAU 3A, length frequency analyses showed that pāua are smaller in the latest surveys, which could be influenced by harvesting at sites over the last season. There were fewer pāua in smaller size classes in the last survey which is most likely reflective of general variability in recruitment. In PAU 7, pāua were overall larger in the last survey period, but this may be influenced by site bias.

The current Fisheries New Zealand project SEA2023-06 is testing the utility of the relative abundance trends from these surveys in estimating stock status and developing management procedures for determining future catch levels.

[1] Pāua Industry Council Ltd., New Zealand.
[2] Dragonfly Data Science, New Zealand.

1. INTRODUCTION

The fishery closure

The November 2016 earthquake caused coastal uplift of up to 6 m along approximately 120 km of coastline from Spyglass Point in the south to Marfells Beach in the north. This resulted in mass mortality of a range of species that inhabit the diverse shallow subtidal and intertidal habitats affected by the uplift. Pāua (*Haliotis iris*) populations in particular were severely impacted, with mass mortality at all life stages and significant loss of critical habitats. Of particular significance was the loss of intertidal and shallow subtidal rocky reef habitats (previously in less than 2 m of water) that support initial settlement and juvenile life stages. An initial assessment of the amount of the pāua fishery that was lost to the uplift was estimated at 21% of previously fished areas (Neubauer 2017). This initial finding and general observations of pāua mortality and habitat loss resulted in the emergency closure of the pāua fishery from the Conway River in the south to Marfells Beach in the north (‘the closed area’) under section 16 of the Fisheries Act.

The closed area contains pāua fisheries of high importance to recreational, customary, and commercial stakeholders. It spans two pāua Quota Management Areas (QMAs), PAU 7 (Marlborough) and PAU 3 (Kaikōura-Canterbury), that have historically accounted for 15 t of Total Allowable Commercial Catch (TACC) from PAU 7 and 47 t from PAU 3 (approximately 16% and 50% of each respective QMA TACC). After the closure, there was a reduction of 50% of the TACC in PAU 3 and an ongoing industry-initiated shelving of 12% of annual catch entitlement (ACE) in PAU 7. These effective reductions served to stop the spread of displaced fishing effort into the remaining open parts of these QMAs. In April 2021, PAU 3 was sub-divided into two new QMAs, PAU 3A and PAU 3B (with the Conway River as the boundary). This was to help facilitate the implementation of new management strategies upon re-opening of the closed area (PAU 3A).

Prior research

Following the earthquake and closure of the pāua fishery, the Ministry for Primary Industries (now Fisheries New Zealand) funded a range of projects to assess ecological impacts of the earthquake to inform future management options. Pāua were specifically included in projects undertaken by the University of Canterbury (monitoring juvenile pāua recruitment in the intertidal zone) and by the Pāua Industry Council Ltd. (monitoring the abundance of mature pāua).

McCowan & Neubauer (2018) estimated pāua abundance and length-frequency profiles at 35 sites in the closed area, and at an area-wide scale (QMA), to establish baselines for further monitoring. The continuation of this project has re-surveyed initially established monitoring sites and has generally showed an area-wide increase in pāua abundance, and evidence of post-earthquake recruitment into the shallow subtidal zone, with variability in trends between sites attributable to pre-earthquake abundance and the degree of uplift (McCowan & Neubauer 2021, 2022, 2023, 2024).

Fishery re-opening

The pāua fishery was re-opened for the first time since the closure on the 1st of December 2021 for a three-month period. The re-opening was initiated by a proposal by the Kaikoura Marine Guardians, recommending to the Minister that the fishery be re-opened based on the criteria that “widespread emergence of post-earthquake recruits is observed across the fishery; and a sustained increase in pāua biomass is observed across the fishery”. These criteria were adopted from the PāuaMAC3 Fisheries Plan and supported by previous results from this project (McCowan & Neubauer 2018, 2021) and monitoring of juvenile pāua recruitment (Gerrity et al. 2020).

In the first season, commercial fishing recommenced with a TACC of 23 t in PAU 3A and under an agreed catch cap of 6 t in the earthquake affected part of PAU 7. Industry management measures were in place under the PāuaMAC3 and PāuaMAC7 Fisheries Plans. Recreational fishing recommenced with a bag limit of 5 pāua per person per day and minimum harvest size of 125 mm shell length under a recreational allowance of 5 t.

A second fishing season since the closure opened from the 5th of January 2022 to the 30th of September for commercial fishing under the same TACC of 23 t; however the recreational fishery had a reduced bag limit of 3 pāua per person per day and a reduced season from the 15th of April to the 15th of June 2023 as an attempt to constrain recreational catch within the allowance of 5 t, which was significantly exceeded in the first open season.

The commercial fishery re-commenced under the same TACC on the 1st of October 2023, as business as usual and a recreational fishing season recommenced under the same management settings from 22 April to 22 June in 2024.

Project objectives

This project is a one-year continuation of the monitoring established earlier by McCowan & Neubauer (2018) and continued by McCowan & Neubauer (2021, 2022, 2023, 2024) with the following objectives:

i. Overall Objective: To complete pāua stock monitoring surveys to inform future management decisions at the scale of the earthquake fisheries closure in PAU 3A and PAU 7 areas.
ii. Objective 1: To monitor the abundance and length frequency distribution of adult pāua to estimate biomass trends to inform management actions relevant to the fishery closure area.
iii. Objective 2: To monitor the abundance and length frequency distribution of adult pāua to estimate biomass trends to inform management actions relevant to PAU 3A and PAU 7.

2. METHODS

The general survey design for this project is the same as that employed in earlier assessments of pāua abundance in the closed area (McCowan & Neubauer 2018, 2021), and data analyses were employed as given by McCowan & Neubauer (2022, 2023, 2024). The following is a summary of the methodologies employed.

2.1 Site selection

Site selection was based on data-driven stratification. Sampling points were allocated only within strata representing areas relevant to the fishery.

Stratification procedure

Survey sites were selected from within strata of high, medium, and low fishery utilisation. Stratification was undertaken using all available data-logger data (industry collected GPS-referenced fine-scale catch and effort data) from 2013 to 2016 from the closed area to calculate utilisation density using two-dimensional kernel-based smoothing of all available dive locations. The utilisation density was then intersected with the coastline to produce a 1-dimensional map of utilisation (Figure 1). The utilisation density was cut (within each QMA) at cumulative probability levels of 5–20% (low use), 20–80% (medium use), and 80–100% (high use) to define strata for sample allocation.

Assigning sampling points

A predetermined number of sampling points were allocated in each stratum, weighted towards more samples in high- and medium-use strata (Figure 1). The number of allocated sites was initially based on a realistic number of sites that could be surveyed over one season (from approximately November to February), equating to approximately 30 dive days. Three sites (one in PAU 7 and two in PAU 3A) were fixed to be aligned with intertidal juvenile pāua surveys being conducted by the University of

Canterbury. Back-up sites were also selected to give a sampling option when the primary site could not be surveyed due to poor diving conditions (i.e., swell over 1 m or visibility under 1 m). Based on the described criteria, 36 sites were allocated with 12 primary sites in PAU 3A and 6 in PAU 7, with an equivalent number of back-up sites. During initial baseline surveys, 35 sites (23 in PAU 3A and 12 in PAU 7) were surveyed (McCowan & Neubauer 2018). Over successive survey periods, attempts were made to re-survey these same sites to estimate longitudinal trends in pāua abundance at a site and an area-wide scale.

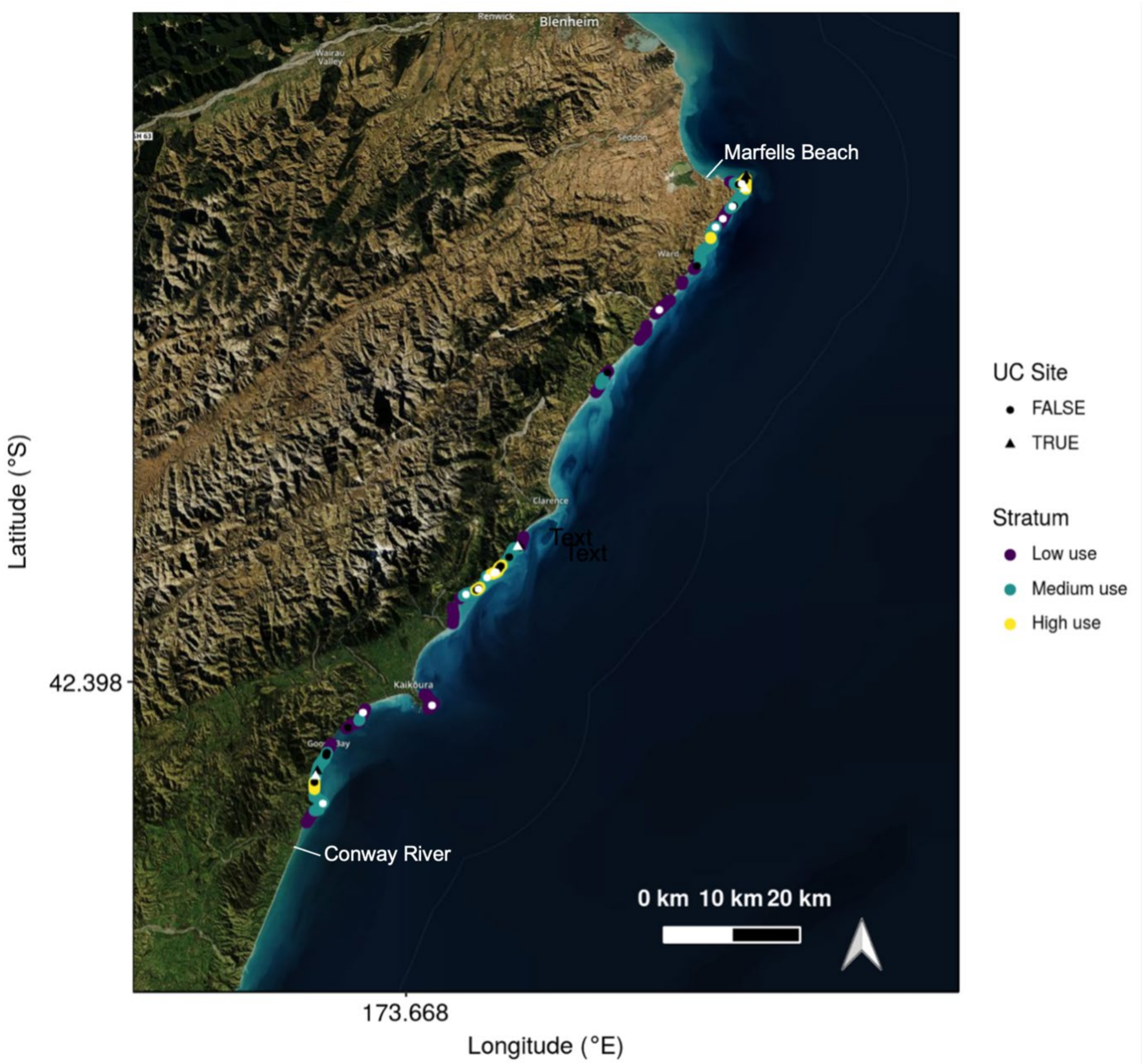

Figure 1: Extracted fishery use strata, established from the utilisation density by intersecting the density with the coastline to produce a 1-d line, and then dividing the cumulative 1-dimensional use distribution into inter-quantile ranges as described in the text. Selected sites (black) as well as fall-back points (white) for the Kaikōura pāua survey, in relation to fishery use strata. Note that many first-choice sites are nearly co-located with fall-back sites and therefore difficult to distinguish. UC sites are those that were fixed to coincide with University of Canterbury sites for juvenile monitoring.

2.2 Sampling procedure

Dive surveys were conducted by a crew of three snorkel divers with commercial pāua diving experience. As much as possible, the same divers were used for surveys in each QMA to maintain consistency. At each sampling point a length of approximately 100 m was haphazardly delimited using float-lines or obvious geographical boundaries set by a neutral advisor so prior knowledge about pāua abundance could not be used by divers to bias the selection of the survey area within each site. Each area was roughly divided into three smaller areas and allocated to each diver to survey. Divers swum for 45 minutes per site during which time they would measure (and log a count of) every pāua encountered using underwater electronic calipers. As pāua were measured they were marked with a yellow retsol marking crayon to ensure that they were not measured twice. In the first three surveys (i.e., McCowan & Neubauer 2018, 2021), each diver wore a GPS dive logger ('turtle unit') during the surveys to delimit the area swum to calculate pāua density estimates. However, due to issues with data quality from the turtle units, their use was discontinued during the fourth round of surveys and a proxy for density (measurements/biomass per unit time effort, or MPUE/BPUE) has been adopted (explained in detail under Section 2.3). At each site, swell, visibility, and a 'cryptic rating' (reflecting habitat complexity that can affect detection probability) were recorded.

Some sites additional to those allocated under the procedure described above were also surveyed. These sites were those of interest to commercial divers and were surveyed opportunistically when conditions were favourable at these sites but not at those allocated under the sampling procedure. Data from these sites were kept and used for observational purposes (e.g., in recruitment detection) but were not included in overall analyses.

2.3 Data analyses

Earlier stages of this project developed a novel survey design to overcome some of the issues associated with previously trialled timed-swim methodologies for estimating pāua abundance. These methods relied on estimating pāua densities at allocated sites using a modified timed-swim design, using GPS 'turtle loggers' worn by divers to account for areas swum by divers. However, after the initial round of surveys, a number of problems were encountered with the overall design. In summary, these problems were due to a large amount of survey data having to be discarded due to missing GPS positions from dive loggers and difficulties in accurately estimating detection probability and up-scaling density estimates to absolute biomass (see McCowan & Neubauer 2021).

To address these issues, McCowan & Neubauer (2021) tested the number of measurements per unit time effort (MPUE) as a potential proxy for relative density differences, similar to catch per unit effort being used as a proxy for biomass in fisheries stock assessments. That analysis confirmed MPUE as a suitable predictor, showing an approximate 1:1 relationship between density and MPUE (slope=1.00, se = 0.06; Figure A-1). MPUE was then converted to biomass per unit time effort (BPUE) as a more relatable index of abundance.

Trends between surveys were then assessed using a Bayesian generalised linear mixed model to estimate: i) the overall survey year effect, ii) a survey year within industry management areas (zones A-D in PAU 3A and zones A-D in PAU 7) (Figures B-1, B-2), iii) a survey year within QMA effect, and iv) a survey year within site effect. Note that ii) differs from previous analyses which considered *a priori* fishery use strata, which are less relevant since the re-opening of the fishery. Updated fishery management strata are now in use to determine catch caps and minimum harvest sizes, and these updated management strata (zones A-D) were therefore used. We used a truncated normal distribution to model the error in the (square root-transformed) response variable, with truncation to exclude negative numbers from the error distribution. We also included predictors for potential nuisance variables (swell, visibility, depth, and cryptic rating) to remove potentially confounding effects (e.g., those that would affect detection probability). Survey site, diver, and survey period within site were estimated as random effects; all other parameters were specified as fixed effects. The full model may be written in the R package brms (Bürkner 2018) as:

sqrt(BPUE) ~ depth + visibility + cryptic_rating + QMA_zone*survey_period + survey_period*QMA + survey_period:uplift + (1|diver) + (1|site_code) + (1|site_code:survey_period)

Additional diagnostics to those presented for previous surveys were inspected to ensure that the model adequately captured variation in survey data across various strata (e.g., survey strata, QMAs, survey periods) and covariates. For continuous covariates (here depth and cryptic rating as the two most influential variables), diagnostics were calculated as errors of posterior predictive means (residuals) which were plotted against the covariates to inspect for potentially non-linear relationships. For model strata, we plotted posterior predictive densities against raw densities to ensure that the model captures variability within all model strata.

3. RESULTS

3.1 Survey site coverage

The first round of surveys undertaken during the initial project (McCowan & Neubauer 2018) resulted in a total of 34 sites surveyed (23 in PAU 3A and 11 in PAU 7). The number of sites surveyed initially was higher than the proposed number of 'primary' sites because favourable survey conditions and efficient surveying times enabled several 'back-up' sites to be surveyed in both QMAs. Further, due to access and logistical constraints in some remote sites, additional sites were surveyed haphazardly when crews were in the area and where it was not possible to access sites further afield that day. Baseline estimates of pāua density and length-frequency distributions were made across all of these sites (as well as other descriptive statistics). Table 1 shows the number of sites that have since been surveyed over successive survey periods.

The occasions where fewer sites were surveyed in each QMA than the original baseline surveys of 2017–18 were due to consistently poor survey conditions (large swell or poor visibility) during the survey period and/or logistical constraints. This was particularly the case for the 2022 (post-fishing survey) which was attempted during April-May after the more favourable summer diving season.

Table 1: Number of sites surveyed during successive survey periods in earthquake affected areas of PAU 3A and PAU 7.

Survey Period	PAU 3A	PAU 7
2017–18 ('baseline')	23	12
2018–19	13	9
2019–20	22	12
2020–21	23	9
2021 (pre–fishing)	23	12
2022 (post–fishing)	6	0
2022–23	19	6
2023–24	20	9

3.2 Pāua abundance trends

Raw measurement data were used to model BPUE as proxies of pāua density. Models on square-root-transformed data had adequate fits (Figure A-2 and A-3). Estimates of coefficients are shown in Figure A-4. Coefficients for confounding variables were close to expectation, with lower visibility, higher cryptic rating, depth, and swell leading to lower measurements/biomass per unit time (Figures A-5 to A-8), noting that surveys only took place when conditions were acceptable for diving (i.e., swell less than 2 m).

Pāua abundance trends, as approximated by BPUE, have shown similar trends in both PAU 3A and PAU 7 (Figure 2). In both QMAs, there was no notable increase after the initial establishment of baseline abundance and the 2018–19 survey period. After 2018–19, abundance steadily increased in both QMAs until 2021–22. In PAU 3A, abundance was sustained through to the 2022–23 survey period and declined in the 2023–24 period. In PAU 7, the decline was observed to start one survey period earlier, in 2022–23.

As discussed in the introduction, the fishery re-opened for a three month period on the 1st of December 2021. It should be noted that the 2021–22 surveys were largely completed in October and November

2021 (i.e., before the re-opening). In previous reports (McCowan & Neubauer (2023) and McCowan & Neubauer (2024)), analyses of survey data collected immediately post-fishing season in 2022 were included and discussed. These have been excluded from these results due to the low number of sites surveyed during this period and the potential for site bias.

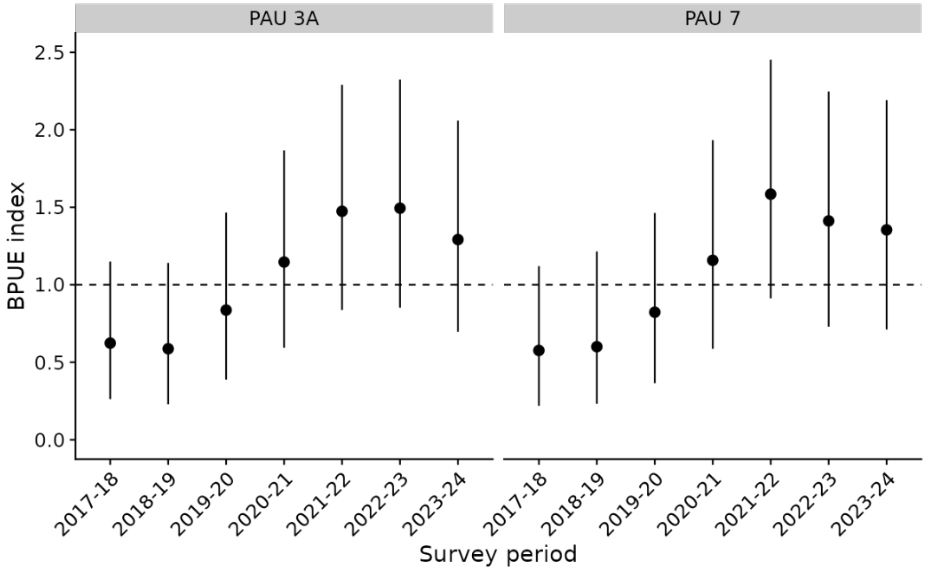

Figure 2: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for QMAs PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables.

There is notable variability in abundance trends across survey periods between individual sites. This could potentially be associated with the amount of uplift of sites after the earthquake. There is no apparent relationship between previous fishery use strata and abundance trends (Figure 3).

Figure 4 shows abundance trends estimated for management 'zones' that have been determined by industry (PāuaMAC3 and PāuaMAC7) for the ongoing management and monitoring of the fishery following the re-opening (Figures B-1 and B-2). These are illustrated as they are likely to be the most relevant scales for future management decisions. Similar trends were generally observed across all zones and at the QMA level however differences are observable between some zones. For example there is a larger decrease in abundance from the last survey period at 3AC-Omihi than in other zones. Differences in zone abundance trends are likely to be attributable to fishing effort, and this could be used to determine what parts of the fishery are most important for driving fishery wide abundance trends.

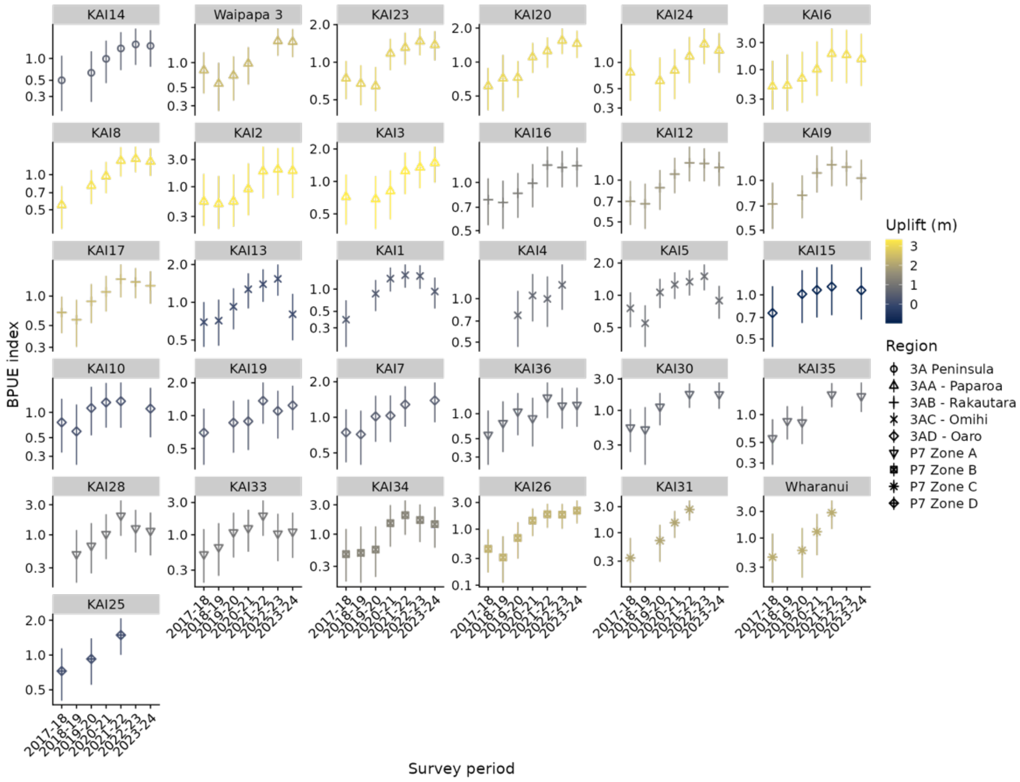

Figure 3: Marginal trend (relative to a geometric mean of 1 at each site) in biomass per unit effort (BPUE) across survey years for all sites (see McCowan & Neubauer 2018), plotted across industry management 'zones' ('Regions') in QMAs PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables.

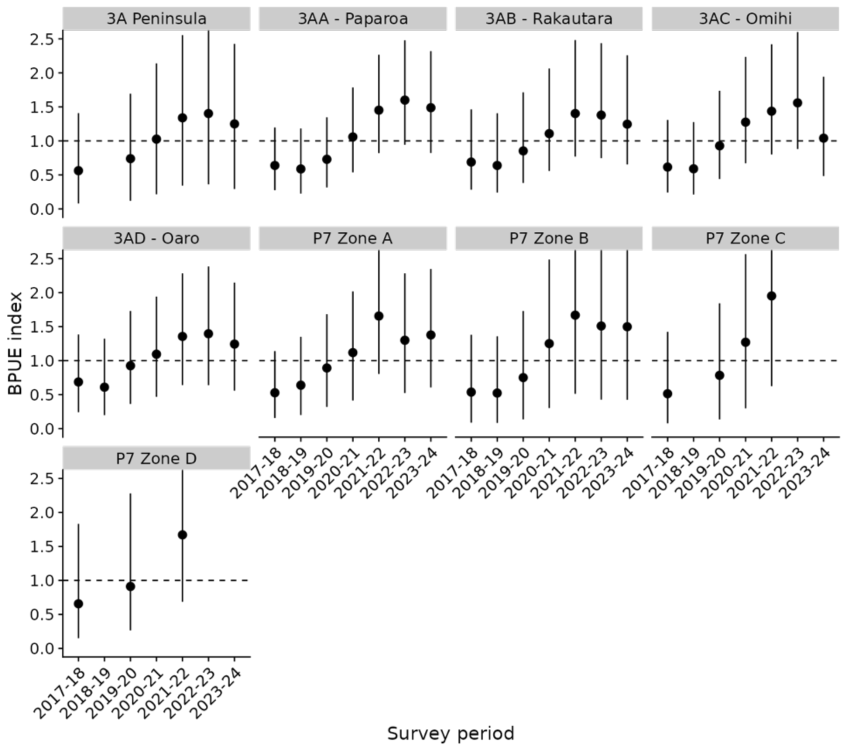

Figure 4: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for PAU 3A and PAU 7 management 'zones' from the BPUE model after accounting for confounding variables.

3.3 Length-frequency trends

Length-frequency data was analysed across survey periods to observe changes in size classes during the post-earthquake fishery closure and with the reintroduction of fishing. Figure 5 shows the cumulative length frequency plots for all pāua measured across all survey periods by QMA.

In PAU 3A the length frequency profiles have remained reasonably stable across all survey periods, especially across the larger size classes. In the most recent survey period, there was a slight decrease in the size of pāua overall, which was particularly noticeable in smaller size classes (<125 mm). Conversely, in PAU 7 there has been an overall increase in size of pāua measured overall, which was more evident in the smaller size classes (<125 mm).

Figure 6 shows the length-frequency profiles of pāua over all survey periods at each site, with the x-axis showing pāua less than 100 mm, which helps to visualise post-earthquake recruitment patterns at each site. Sites with 'spikes' shown in the most recent survey periods (light green in Figure 6) suggest detectable post-earthquake recruitment events. As with general patterns with pāua abundance across QMAs, trends in length-frequency profiles are highly variable between sites.

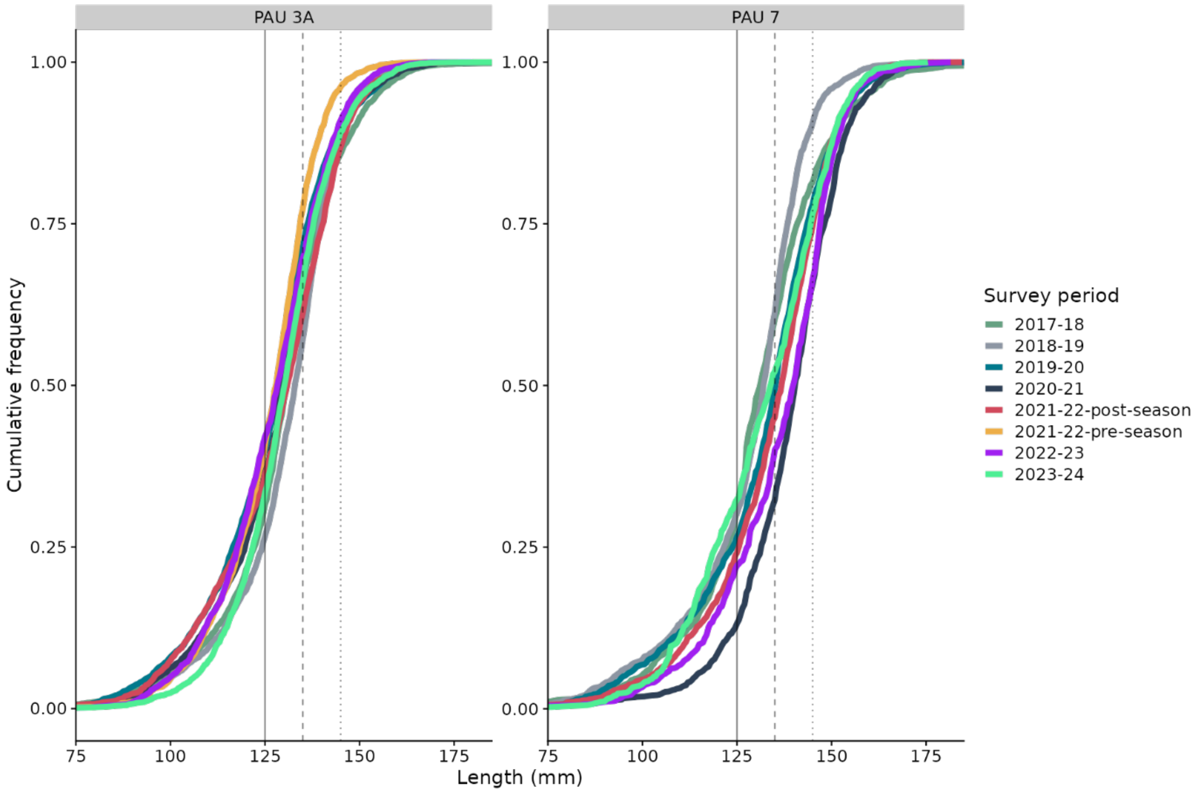

Figure 5: Cumulative length-frequency profiles for all pāua measured over seven survey periods in PAU 3A and PAU 7. Vertical lines show the legal size of 125 mm (minimum legal size; solid line), 135 mm (dashed line), and 145 mm (dotted line).

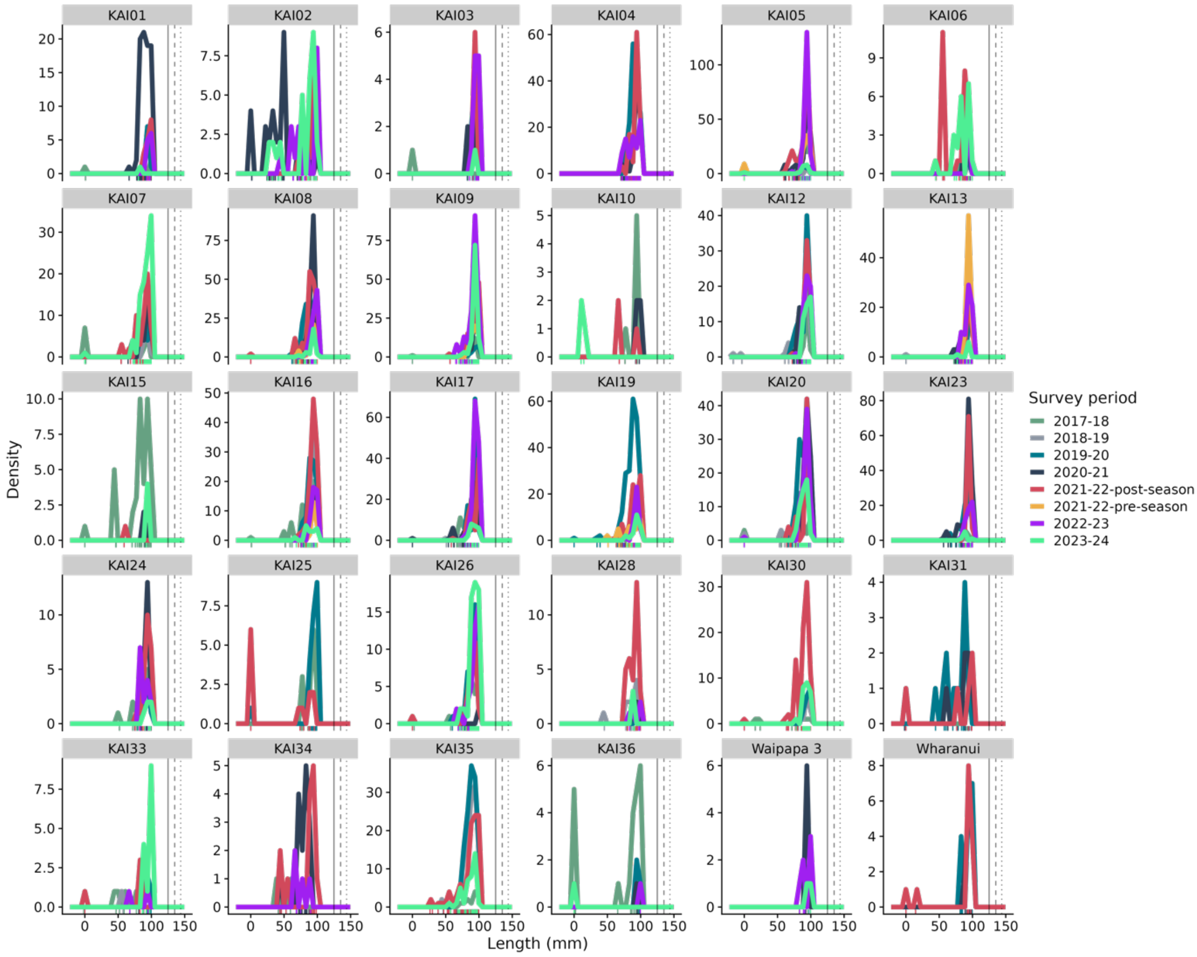

Figure 6: Length-frequency profiles (by number of pāua measured) for individual sites surveyed over seven survey periods. X-axis shows only individuals less than 100 mm.

4. DISCUSSION

4.1 Abundance trends

Comparable trends in abundance can be seen between PAU 3A and PAU 7, although there are some differences over the most recent survey periods. In both QMAs there is a steady increase in abundance from the 2017–18 survey periods until the 2021–22 period. There is a lag of approximately one year before initial abundance started to increase, which is most likely due to a delay in post-earthquake recruitment in the initial stages of recovery after the disruption. Increases in abundance can then be attributed to the population recovery and protection under the fisheries closure. Results from the surveys to the 2021–22 period were used in part to support the 're-opening criteria' discussed in the introductory material above. The increases in abundances until 2021–2022 can be attributed to the sustained increase in abundance of pāua across all size classes, with pāua in the < 100 mm size classes most likely to be post-earthquake recruits that have emerged into more open habitats and are now detectable in dive surveys.

The effects of the fishery re-opening are evident in the two most recent survey periods where estimated abundance has declined from its peak immediately before the fishery re-opening. This trend would be expected and shows that these surveys have value in detecting changes in abundance in response to fishing effort. In PAU 3A abundance appeared to plateau between 2021–22 and 2022–23, i.e., there was no detectable change in abundance after the first fishing season, but there has since been a slight decline in abundance after the second fishing season (Figure 2).

In PAU 7 there was a more obvious decline after the first fishing season (Figure 2). This steeper decline could have been influenced by the low number of sites that were able to be surveyed during the 2022–23 period (see Table 1) and the absence of some higher abundance sites meaning that estimated QMA abundance may be lower than expected.

Examination of the abundance trends within industry management zones can help explain what areas may be driving overall QMA trends. Figure 3 shows the abundance trends at the scale of industry management zones detailed in Appendices 2 and 3. For example, in PAU 3A, it can be seen that a slight decline in abundance at 3AB – Rakautara drove the 'plateau' effect that was observed between the 2021–22 and 2022–23 survey periods. Further, the steep decline at 3AC – Omihi has the overall most pronounced decline in abundance in PAU 3A. The same associations are harder to derive from the PAU 7 zones which have no representation in some survey periods where conditions do not allow for surveys to be undertaken at particular sites.

Site distribution is haphazard and sites are spatially discreet (generally 100–150 m of coast length). This means that site (and zone) abundances will be significantly affected by harvesting events that occur within sites. This is the most likely cause of relative decline in this zone rather than overall increased effort in particular zones as these are controlled through 'catch caps' via the PauaMAC3 Annual Operating Plan.

In PAU 3A most of the surveyed sites are likely to be more susceptible to commercial harvest than recreational as their random allocation was based on pre-earthquake commercial fishing data and were more heavily weighted towards higher commercial use strata. Sites are generally less accessible to recreational harvesters as few are proximate to major carparks or areas with easy coastal access. PauaMAC3 have also implemented increased minimum harvest sizes (MHS) of 130 mm or 135 mm depending on the zone, so decreases in estimated abundance are most likely due to reduction in >130 mm or >135 mm size classes, which is detectable in Figure 5. Similarly, PAU 7 has an implemented MHS of 145 mm meaning a much higher proportion of the biomass is protected from commercial harvest. However, much of the PAU 7 coastline is easily accessible to recreational fishers (e.g., via quad bike from Marfells Beach). This recreational harvest is noticeable in the decline in numbers of pāua in the 125 mm to 145 mm size range (Figure 5).

There is some variability in abundance trends between sites (Figure 3). Initially we attributed this variability to the different levels that sites were uplifted after the earthquake, which would influence the availability of recruitment habitat and overall mortality rates. However now that it is seven years after the earthquake, continuing variability is more likely to be related to suitability of habitat and the type of habitat which can influence the detectability of pāua of different size classes. Trends in some sites show that abundance may be starting to plateau (e.g., KAI33, KAI36), suggesting that these sites may be close to their maximum carrying capacity for pāua within the habitats surveyed.

4.2 Recruitment patterns

Cumulative length-frequency profiles illustrate that PAU 3A has maintained a relatively stable length-frequency profile of pāua over all the survey periods. There was a slight decrease in the overall size of pāua in the last survey period relative to the period before. In the larger size classes (>125 mm) this could be due to the effects of harvesting at some sites, although noting that sites subject to predominantly commercial harvest will be subject to a MHS of 130 mm or 135 mm depending on the management zone. There was a more noticeable decrease in the number of pāua in smaller size classes (<125 mm). This may be reflective of variability in recruitment that occurs in pāua generally. These pāua are those that have just recently emerged from their cryptic habitats. Detection of these pāua can be influenced by the type of habitat, i.e., it is easier to find them in medium boulder habitats as they emerge into the open, compared to large rock/shelf type habitats where they can remain undetectable in deep cracks.

In PAU 7 the overall sizes of pāua have increased. This may be reflective of fishing activity across seasons beginning to affect abundances at the site scale. For PAU 7 in particular, variability in length frequency patterns between survey periods also has the potential to be influenced by the specific set of sites that are surveyed during that period as pāua can exhibit fine scale demographic variability at small spatial scales.

The variability in post-earthquake recruitment across sites (Figure 6) can also be attributed to habitat related factors mentioned above and is also illustrative of the fine-scale annual variability in recruitment known to occur in pāua generally (Wilson & Schiel 1995). Overall, post-earthquake recruitment pulses in the last three years can be observed across the majority of sites. Generally, the observed recruitment signals are a positive sign that annual recruitment pulses are occurring across most sites each season. As with abundance, during the earlier stages of this project we attempted to attribute differences in recruitment in part to the amount of uplift experienced by each site. However, now that we are through the 'recovery' phase of the fishery rebuild, this influence seems less likely.

4.3 Use of the survey outputs

It has recently been proposed that BPUE will be used as an index of abundance (in conjunction with fisheries dependent data sources) to inform management procedures governed by a harvest control rule, to allow for the adaptive rebuild via TACC adjustments of the commercial fishery during the following seasons. These procedures have been tested as part of the current Fisheries New Zealand project SEA2023-06. It has been suggested that abundance represented by BPUE may be a more favourable metric than fisheries dependent indices (i.e., CPUE) as it is potentially more consistent and reliable, as it is not influenced by external factors such as fishing to larger harvest sizes.

5. FULFILLMENT OF BROADER OUTCOMES

This project has involved the training and employment of local commercial pāua harvesters to undertake survey diving. This has increased the research and skills capacity within industry The fisheries closure and the re-opening of the fishery at a reduced TACC has resulted in a significant loss of income for divers and others in the community for the past 7 years. This project has provided a small source of supplemental income for some of those divers.

6. ACKNOWLEDGEMENTS

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APPENDIX A – MODEL FIT AND SUPPLEMENTARY PLOTS

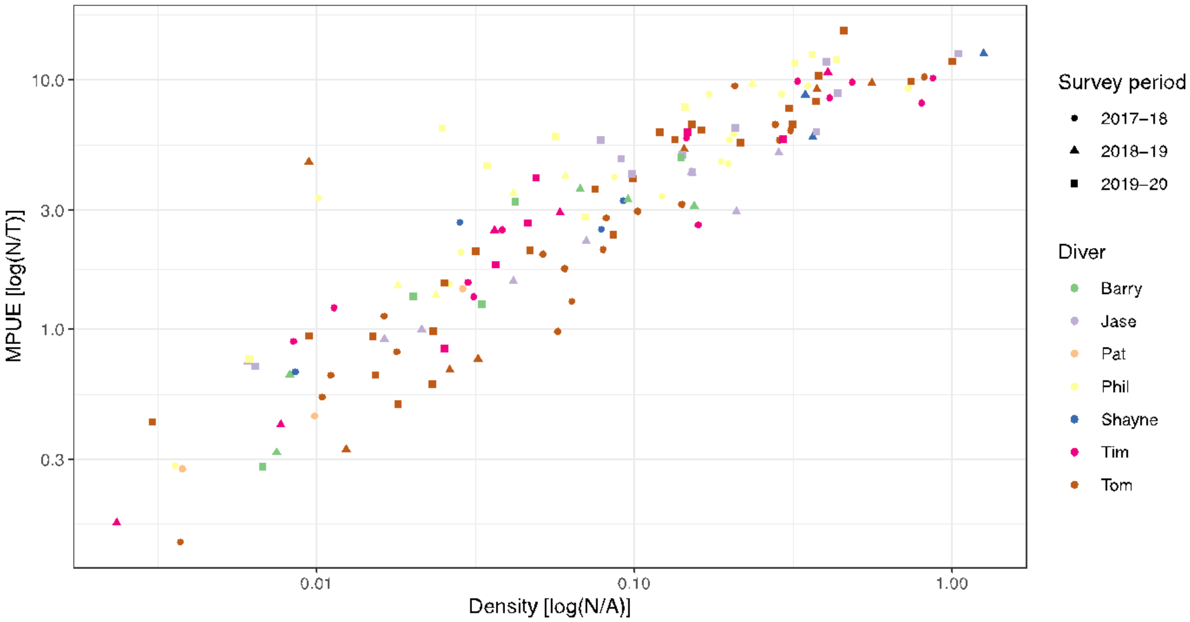

Figure A-1: Relationship between density in (log) individuals per unit area, and measurements per unit time (MPUE), for the three different survey periods (shapes) and divers (colours).

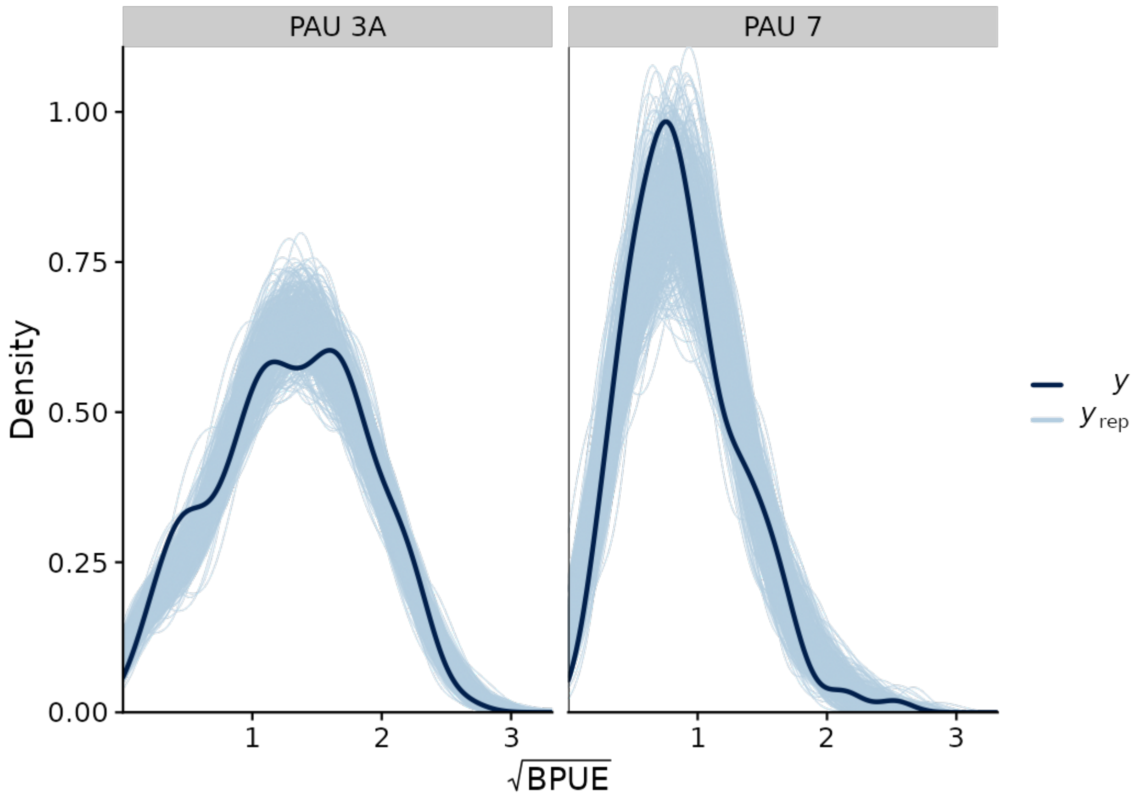

Figure A-2: Model fit by QMA for the model relating biomass per unit effort (BPUE) to predictors, as assessed by draws from the posterior predictive distribution (blue lines) compared with the empirical density for density data (black line).

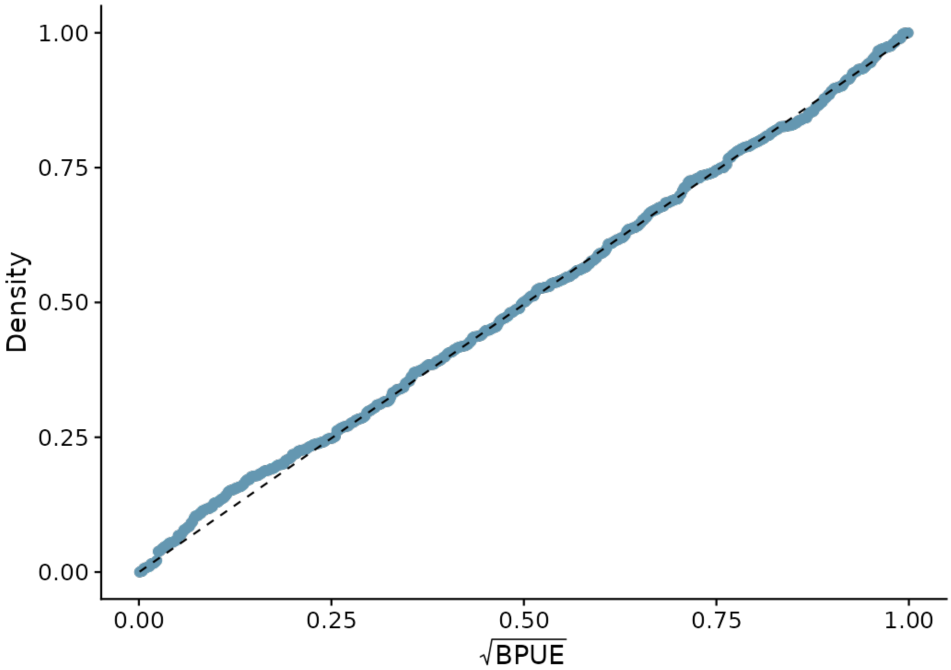

Figure A-3: Quantiles of residuals relative to expected quantiles, showing adequate fit of the model employed for survey analysis.

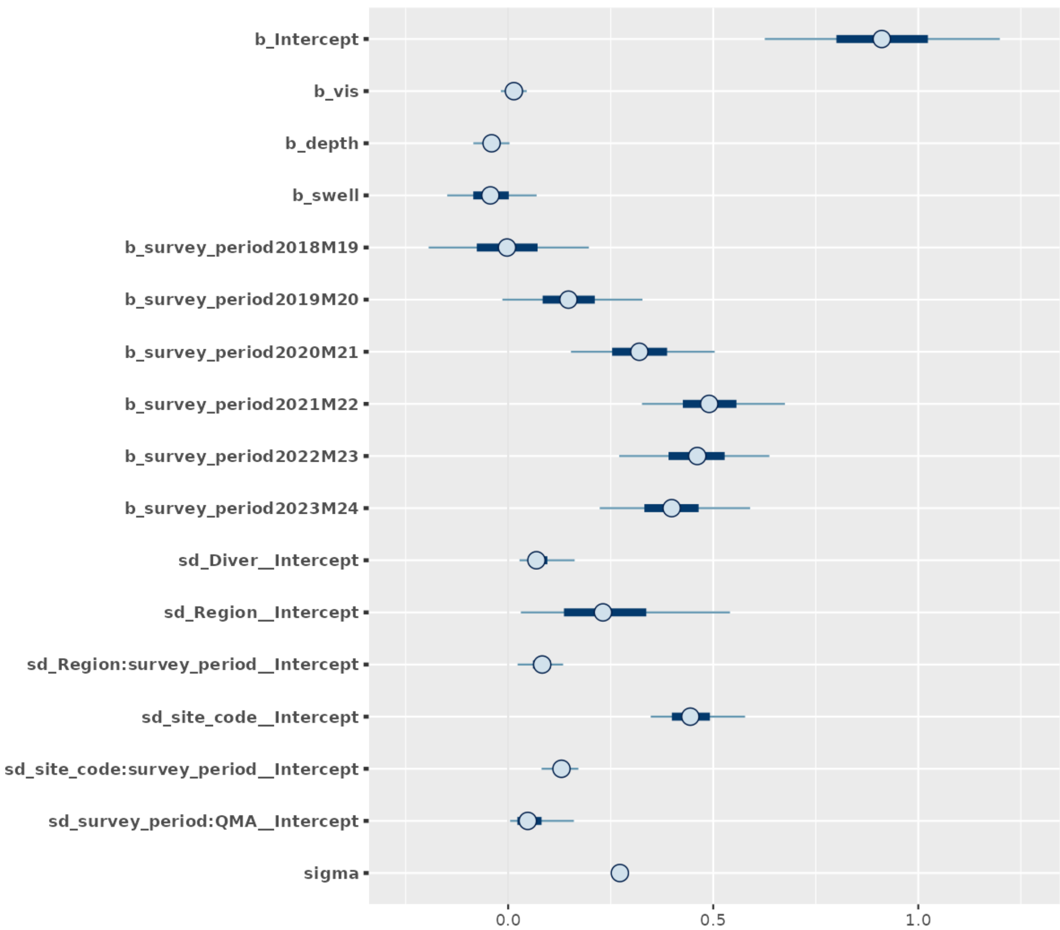

Figure A-4: Estimated coefficients in the biomass per unit effort (BPUE) model.

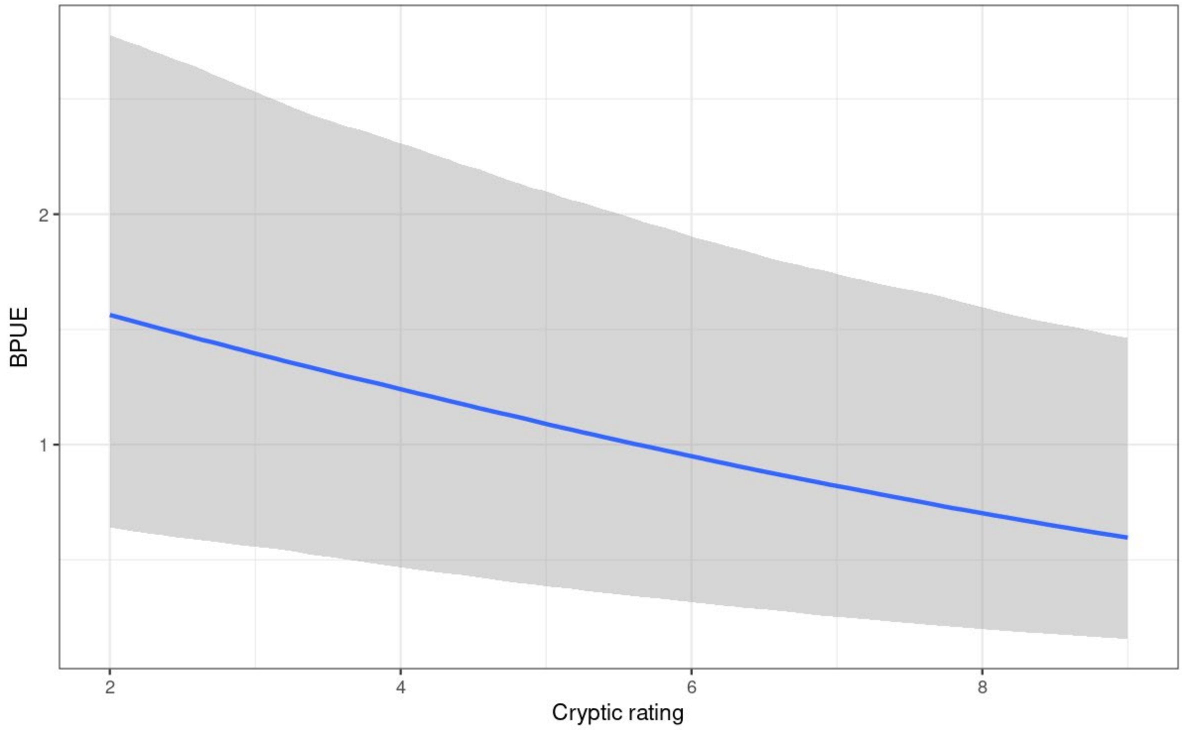

Figure A-5: Effect of cryptic rating in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

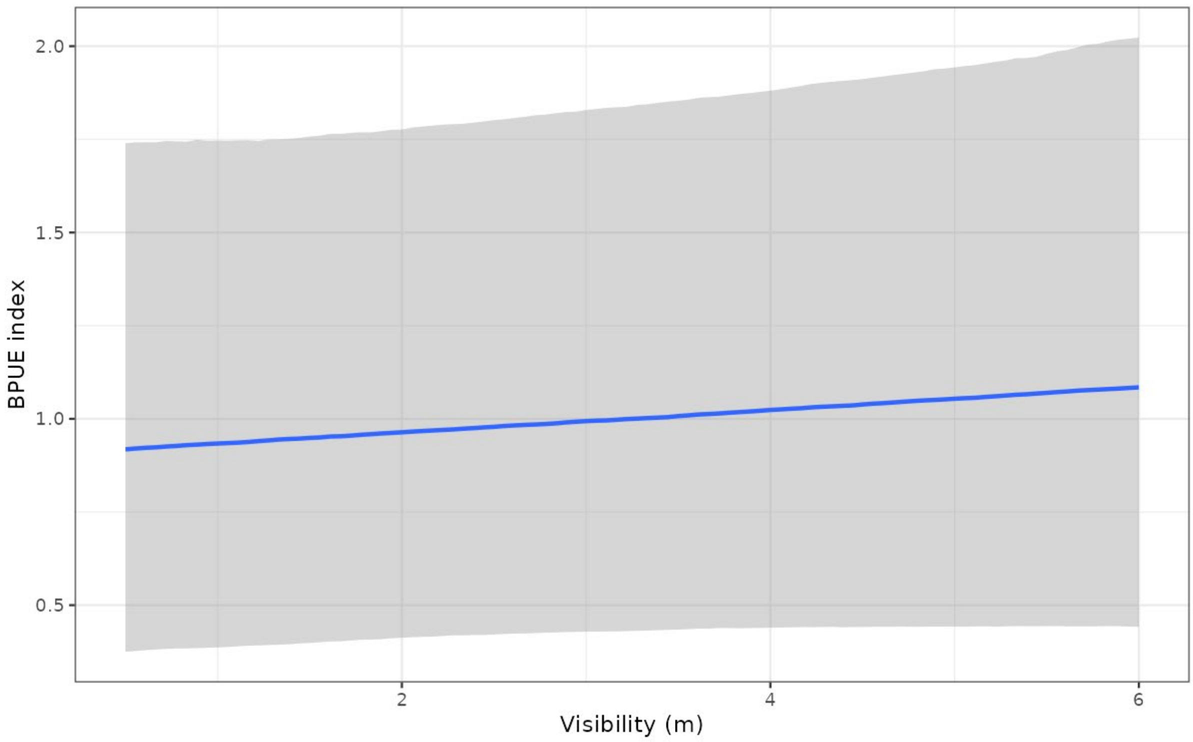

Figure A-6: Effect of visibility (metres) in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

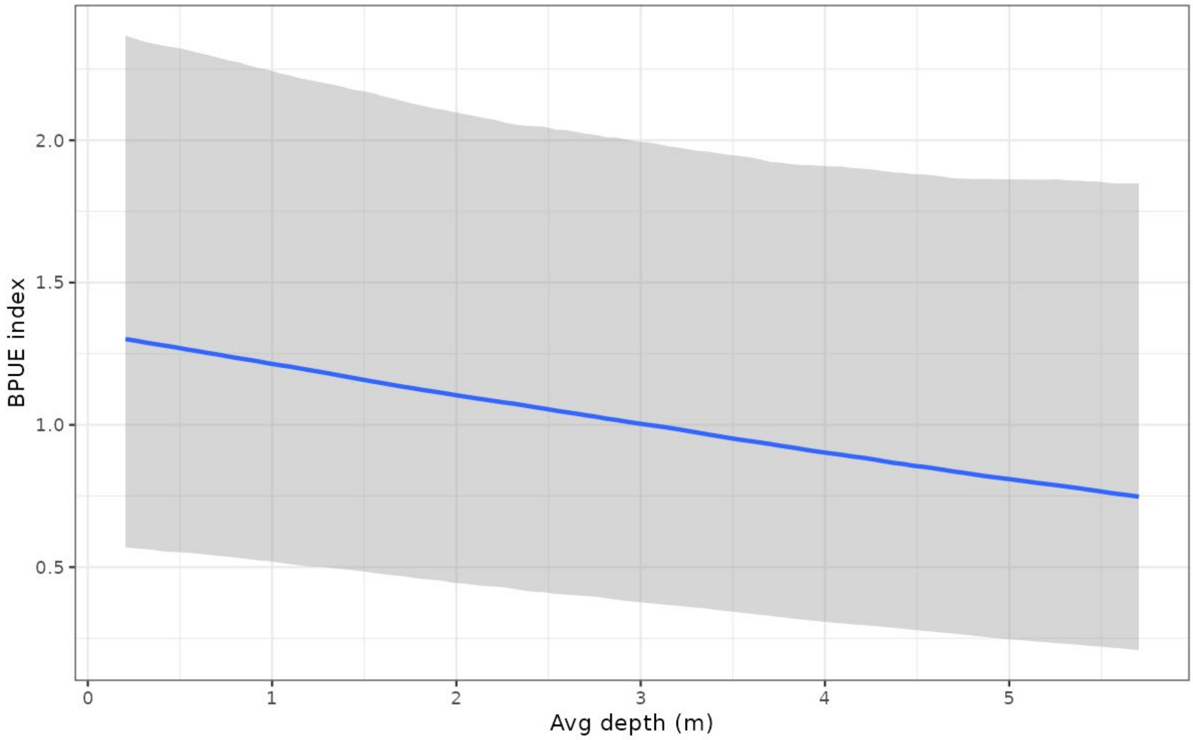

Figure A-7: Effect of depth (metres) in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

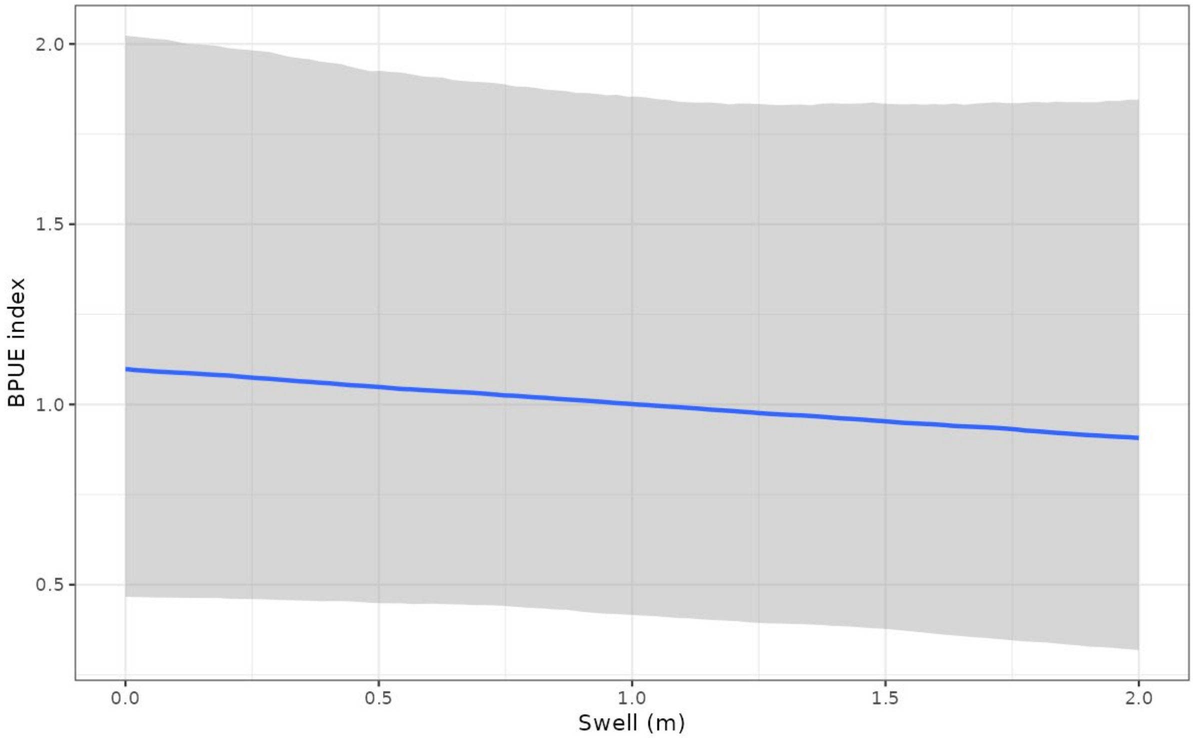

Figure A-8: Effect of swell (metres) in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

APPENDIX B – INDUSTRY MANAGEMENT 'ZONES'

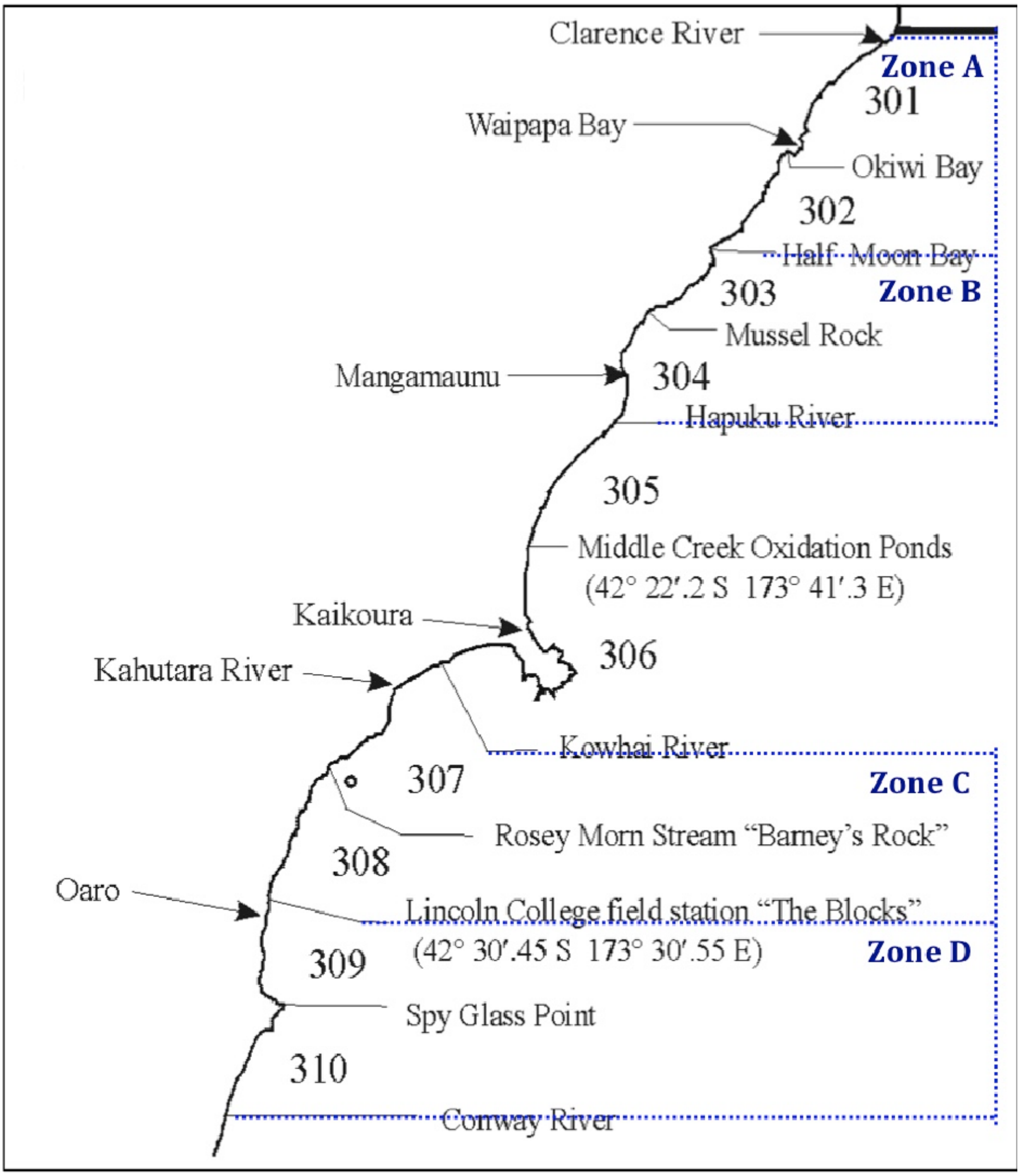

Figure B-1: Statistical area map showing PauaMAC3 management zones.

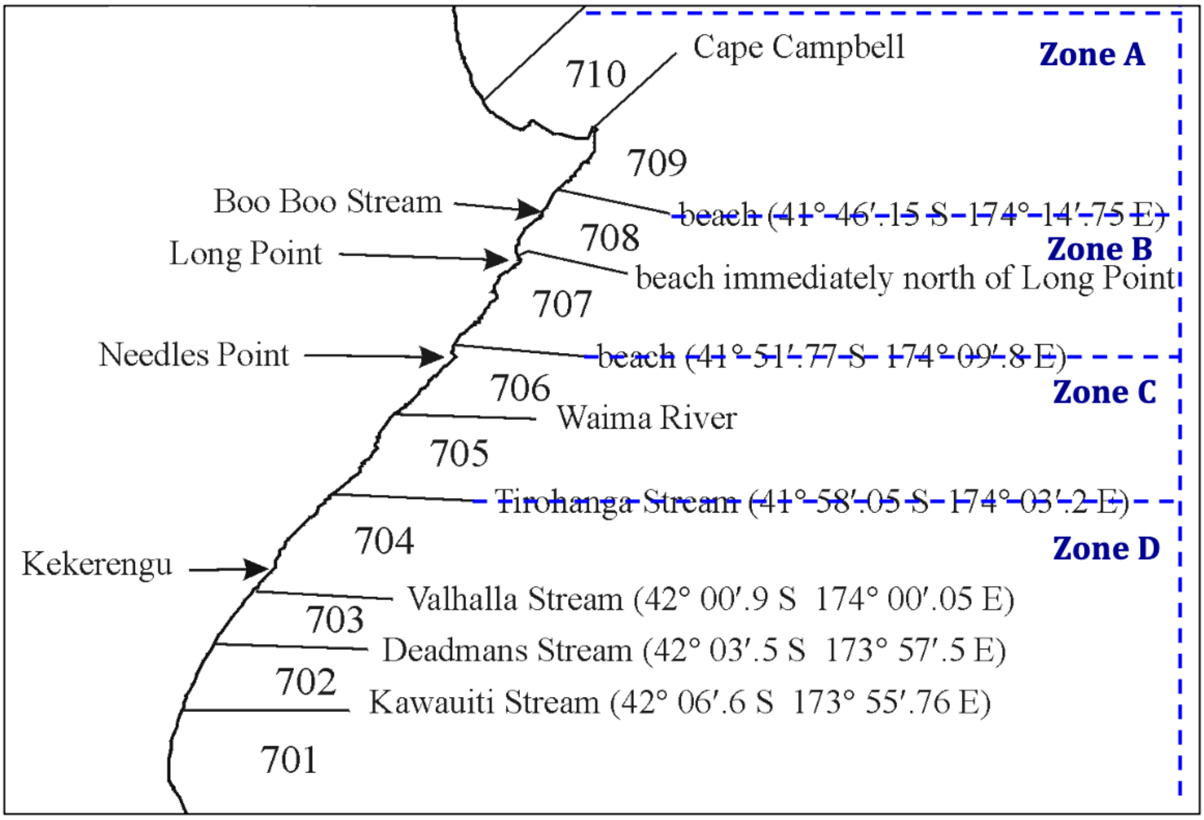

Figure B-2: Statistical area map showing PauaMAC7 management zones.