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Pāua population monitoring in areas affected by the 2016 Kaikōura earthquake, November 2023 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 6 years.

Surveys have shown a steady increase of pāua abundance across the fishery and an increasing abundance of smaller pāua suggesting successful post-earthquake recruitment (appearance of juveniles in the population).

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, November 2023 update.

***New Zealand Fisheries Assessment Report 2024/22.* 18 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 re-opened for the first time for a three-month period on the 1st of December 2021.

The objective of this project was to monitor annually (since 2017) the abundance and length frequency of adult pāua populations in the closed area to estimate biomass trends to inform management actions at the scale of the closed fishery until mid-2023. This was achieved by continuing to monitor baseline estimates of pāua abundance and length-frequency profiles at selected sites within the closed area since 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 have 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 has increased from initial baseline surveys until the most recent surveys undertaken during the summer of 2022–23 in the PAU 3A section of the earthquake affected area. In PAU 7 there was a decrease in abundance shown during the most recent survey period, which is suspected to be due to the low number of sites surveyed in this area for this period and potential biases away from sites with higher densities. Decreases in abundance were also observed immediately post fishing season in 2021–22 in PAU 3A; however, as above for PAU 7, this was suspected to be due to the low number of sites covered, as most recent surveys showed abundance was higher than it was immediately before the fishery re-opening.

General trends of increasing biomass are driven by the emergence of post-earthquake recruitment of small (<100 mm) pāua that are now visible during dive surveys, which is more consistently apparent in PAU 3A. In PAU 7, increasing biomass is more strongly driven by the increasing abundance of larger (>140 mm) pāua. There is high variability in abundance and recruitment trends across surveyed sites which could be attributed to site-specific variability in uplift and habitat related factors.

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1. INTRODUCTION

1.1 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 serve 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).

1.2 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).

1.3 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 for commercial on the 5th of January 2022 until the 30th of September 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 recommenced under the same TACC on the 1st of October 2023, as business as usual, and no decisions have been made about the recreational management settings.

1.4 Project objectives

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

i. To complete pāua stock monitoring surveys to inform future management decisions at the scale of the earthquake fisheries closure in PAU 3 and PAU 7.
ii. To monitor the abundance and length frequency of adult pāua populations to estimate biomass trends to inform management actions at the scale of the fishery closure until mid-2023.

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). 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.

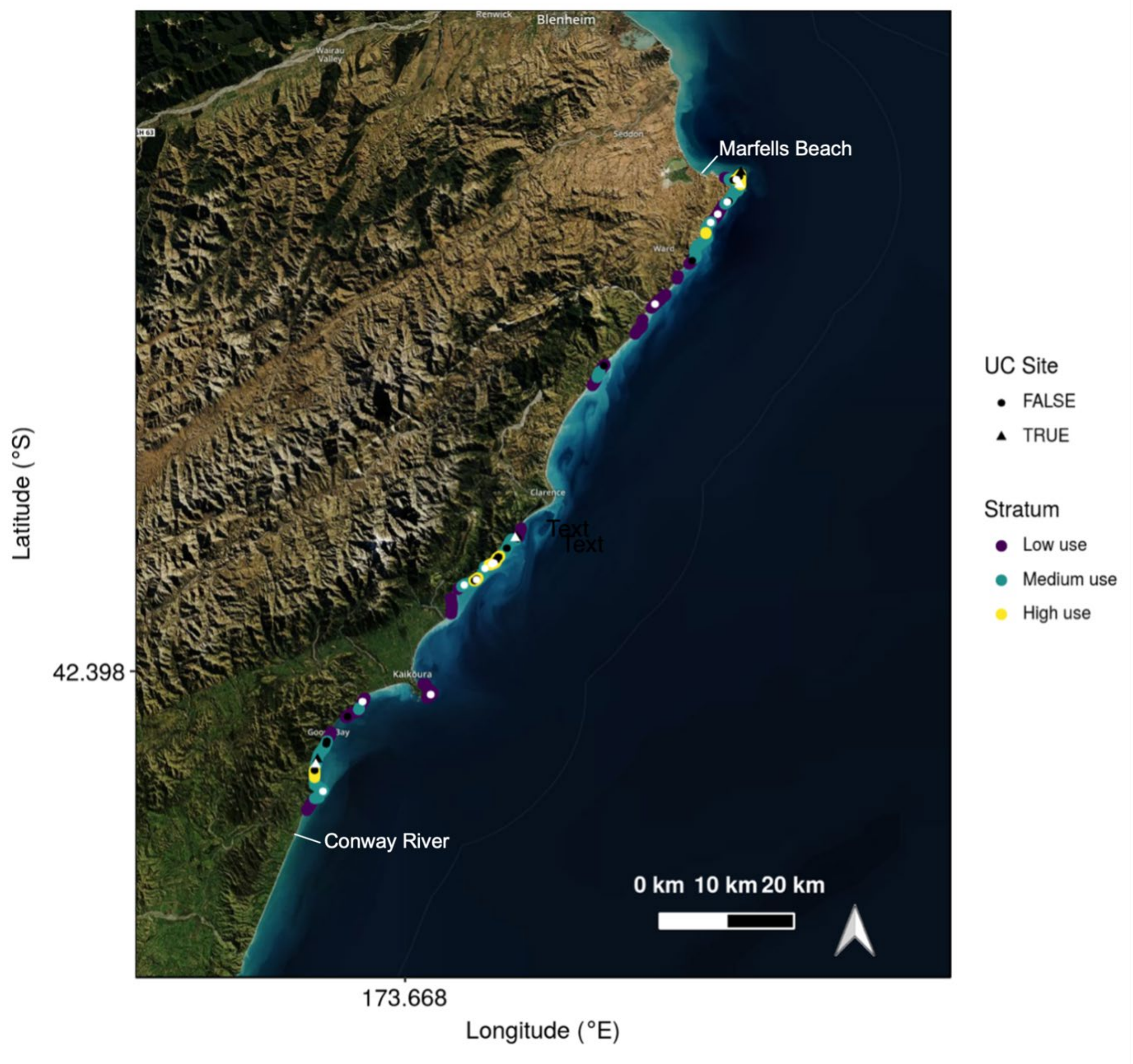

Figure 1: Extracted fishery use strata, established from the utilisation density by intersecting the density with the coastline to produce a 1-d line, and then dividing the cumulative 1-dimensional use distribution into inter-quantile ranges as described in the text. Selected sites (black) as well as 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 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 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 support of 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 less 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

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 less 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).

In PAU 7, overall pāua abundance, as approximated by BPUE increased from the 2017–18 survey period to the 2021–22 pre-season period (Figure 2). No sites were surveyed as part of the attempt to survey immediately after the first fishing season in 2022. In the most recent 2022–23 fishing season there was a slight decrease in estimated pāua abundance in PAU 7 sites.

In PAU 3A, a similar increase in abundance was observed until the 2021–22 pre-fishing survey period, with a notable decrease observed after the first fishing season, and a continued increase to the highest recorded abundance levels in the most recent survey period in 2022–23. Overall increases in abundances at the QMA level up until the 2021–22 pre-fishing survey were slightly more pronounced in PAU 7 (Figure 2).

There was high variability in abundance trends across survey periods between all surveyed sites. This variability was related in part to the variability in the amount of uplift at each site, as those with a larger increase in abundance were generally those with less uplift. There was 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 scales across which stock assessment or management procedures are applied. Similar trends were observed across all zones as what was observed at the QMA level, with the decreases in abundance between the 2021–22 pre- and post-fishing survey periods in PAU 3A also reflected across the PAU 3A zones. Decreases in abundance in PAU 7 zones were also observed where sites were surveyed in the most recent survey period (2022–23)

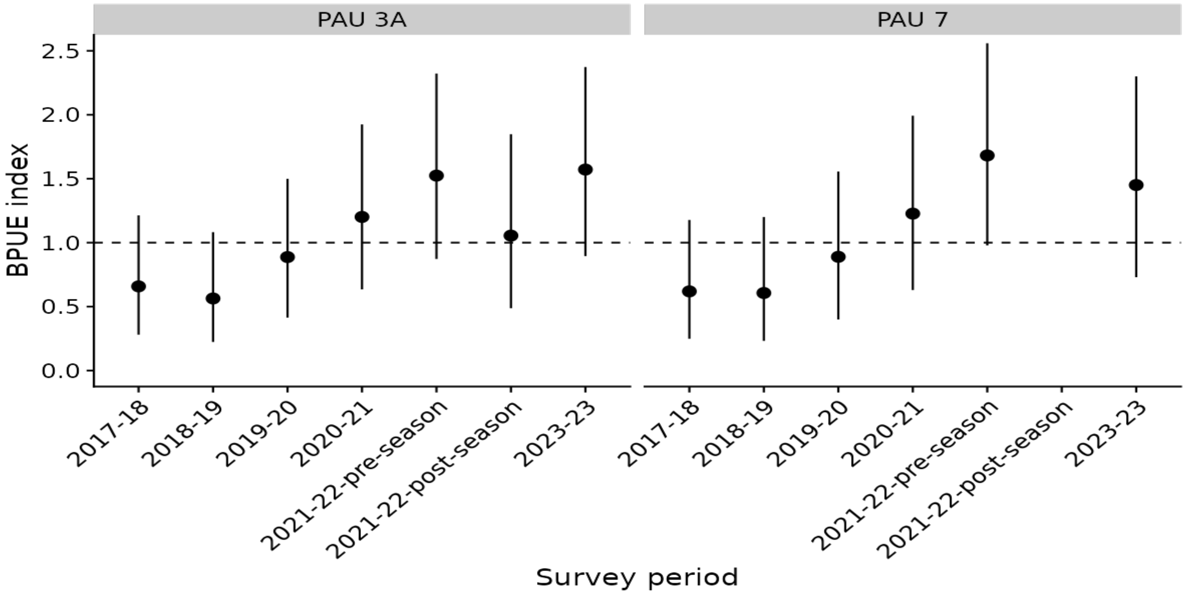

Figure 2: **Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for QMAs PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables.**

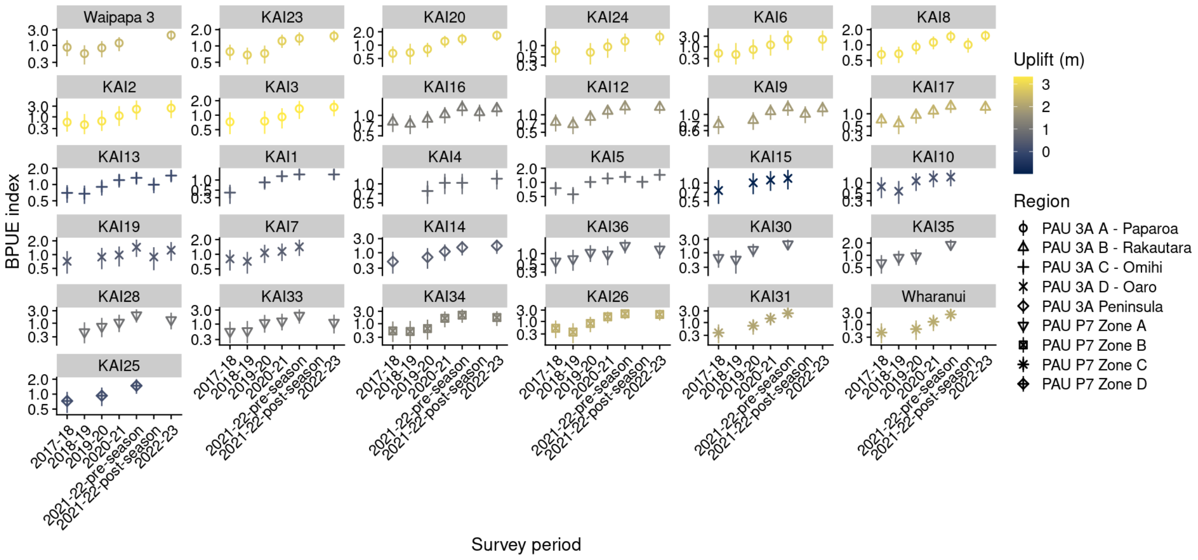

Figure 3: **Marginal trend (relative to a geometric mean of 1 at each site) in biomass per unit effort (BPUE) across survey years for all sites (see McCowan & Neubauer 2018), plotted across industry management ‘zones’ (‘Regions’) in QMAs PAU 3A and PAU 7 from the BPUE model after accounting for confounding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

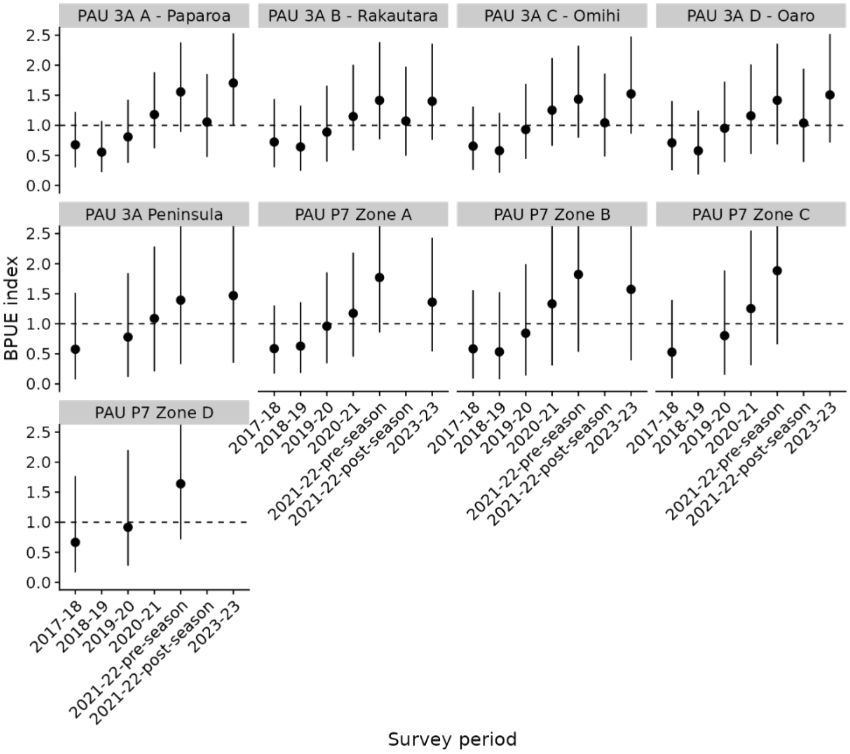

Figure 4: **Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for PAU 3A and PAU 7 management 'zones' from the BPUE model after accounting for confounding variables.**

3.3 Length-frequency trends

Length frequencies of pāua were analysed across all sites and survey periods to make size class and recruitment observations at QMA levels. Cumulative length-frequency plots of all pāua measured during each survey period in each QMA show that profiles have been reasonably stable across the larger size classes (125–150 mm) in PAU 3A, whereas in PAU 7 there has been an observable increase in large pāua (>140 mm) in the recent survey periods (Figure 5).

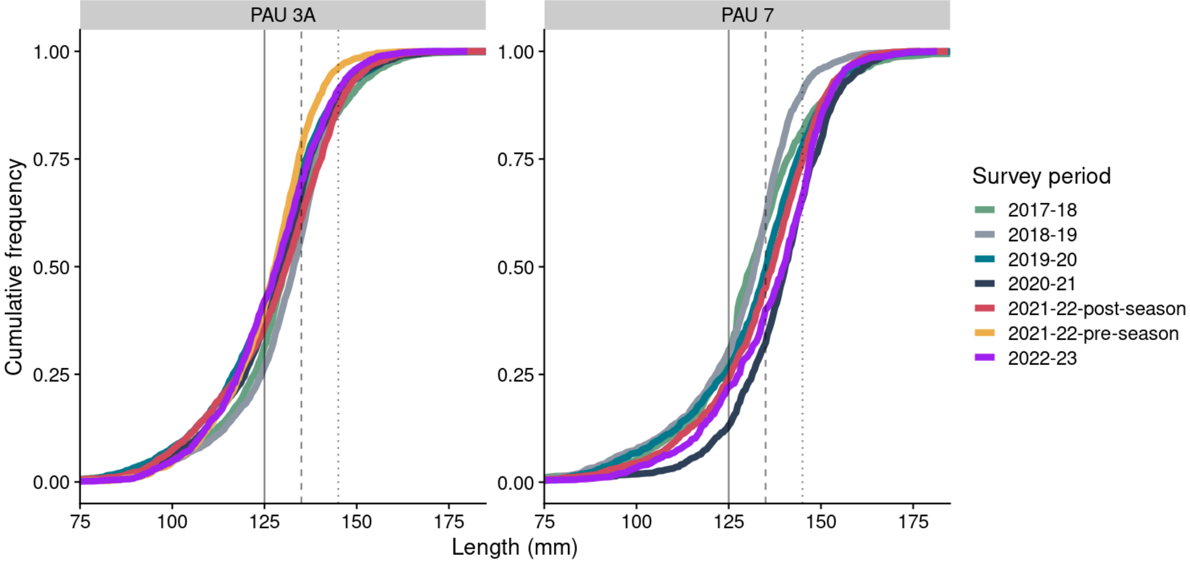

Figure 5: **Cumulative length-frequency profiles for all pāua measured over seven survey periods in PAU 3A and PAU 7. Vertical lines show the legal size of 125 mm (minimum legal size; solid line), 135 mm (dashed line), and 145 mm (dotted line).**

There has generally been an increase in the number of individuals in the 80–100mm size class across survey periods in PAU 3A. This trend also exists for PAU 7; however, there was a noticeable decrease in small size classes during the 2020–21 survey period and, to a lesser extent, in the 2022–23 survey period.

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 suggest detectable post-earthquake recruitment events. As with general patterns with pāua abundance across QMAs, trends in length-frequency profiles are subject to considerable variation between sites. Differences are most apparent in the changes in abundance of pāua in smaller size classes (80–100 mm) and the overall number of pāua being measured at each site.

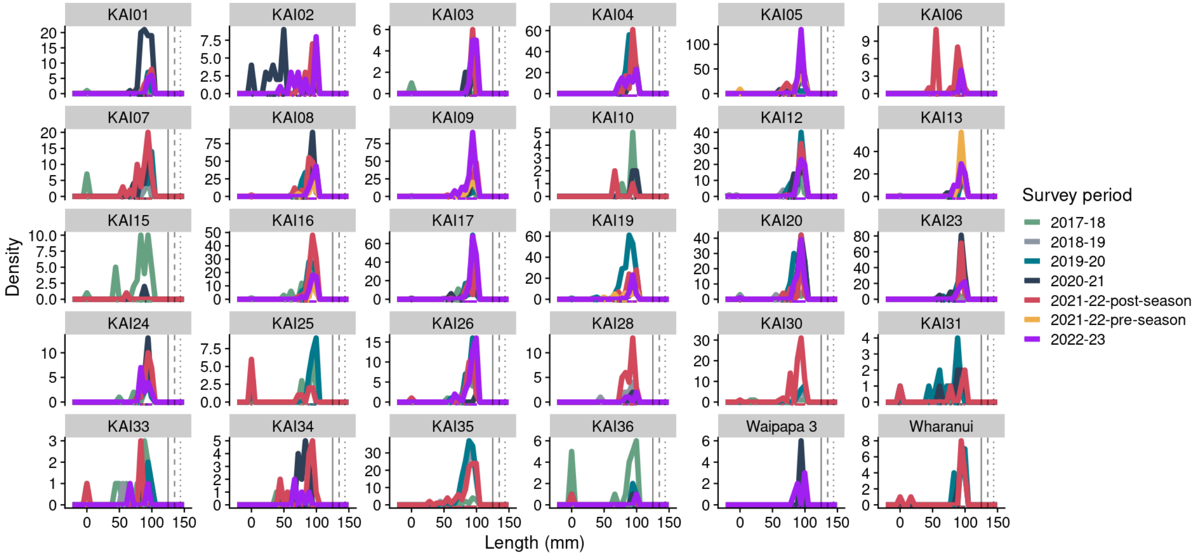

Figure 6: Length-frequency profiles (by number of pāua measured) for individual sites surveyed over seven survey periods. X-axis shows only individuals less than 100 mm.

4. DISCUSSION

4.1 Abundance trends

Abundance as represented by BPUE shows slightly different trends in each QMA surveyed. In PAU 3A overall abundance has increased from the initial 2017–18 surveys to the most recent survey period. There was about a one-year lag before initial abundance started to increase, which is likely to be due to the initial impacts of the earthquake causing a delay before post-earthquake emergent recruitment could be detected. Abundance then steadily increases in PAU 3A until the 2021–22 pre-fishing with biomass increasing due to population recovery and protection under the fisheries closure. Results from these surveys were used in part to support the ‘re-opening criteria’ mentioned above.

Across these survey periods, increases in abundance 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.

A survey was attempted immediately after the three-month fishing season (2021–22 post–fishing period) and portrayed a notable decrease in abundance. During this period, only six sites were able to be surveyed due to consistently poor survey conditions. The conditions were generally worse than what had been typically experienced during the more settled spring-summer period when previous surveys have been undertaken. While visibility and swell conditions are recorded and accounted for in estimated

BPUE, the previous ability to target much more optimum conditions may mean that these factors were not enough to accurately be accounted for in these much poorer conditions. Further, the small number of sampling sites means that abundance estimates may have been biased if sites were of low abundance, or if they had been subjected to higher fishing pressure than other areas during the fishing season.

The most recent surveys (2022–23) where much greater site coverage was achieved indicated a further increase in abundance from what was detected immediately after the fishing season in 2021–22, back to the same approximate levels as immediately before the first fishery re-opening in 2022–23. This suggests that the first fishing season had no detectable impact on pāua abundance across the surveyed sites. The first fishing season saw 23 t of pāua harvested commercially and an estimated 42 t of pāua harvested recreationally (Holdsworth 2022). The surveyed sites are more likely to be susceptible to commercial than recreational harvest because their random allocation was based on pre-earthquake commercial fishing data and, thus, they are generally less accessible (to car parks or easy coastal access). Given the substantially reduced TACC (relative to historical equivalents in the area) and the increased harvest sizes implemented by commercial divers, impacts on overall estimated abundance would be expected to be relatively small.

In PAU 7, the same general trends in abundance as described above for PAU 3A can be observed from 2017–18 to 2021–22 pre-fishing season. In PAU 7, increases in BPUE could be explained by increasing abundance of large pāua growing to larger size classes (> 130 mm); however, this does not appear to be due to significant increases in recruitment of emergent pāua. Differences in overall abundance over survey periods between PAU 3A and PAU 7 are likely to be attributable to pre-earthquake stock status; it is anecdotally accepted that PAU 7 was under high fishing pressure relative to PAU 3A.

No sites were able to be surveyed in PAU 7 immediately post-fishing in 2021–22 due to poor diving conditions. In the most recent survey period in 2022–23, there was a noticeable decline in BPUE. This may be due to decreased abundance as a result of the first fishing season. However, it is more likely to be due to the low numbers of sites that were surveyed during this period (6 out of 12) and the fact that some sites which were not able to be surveyed were very high abundance sites, meaning overall estimated abundance is lower than expected. It is unlikely that fishing impact would have had a significant impact on biomass in PAU 7 across this 3-month fishing season. As with PAU 3, most sites are likely to be subjected to commercial harvest rather than recreational. The commercial harvest size in this area was set at 140 mm so if decreases in abundance were due to fishing it would be expected that the numbers of 140 mm+ pāua would be lower, which is not evident in Figure 5.

There is notable variability in abundance trends between sites (Figure 3). This could be attributed to variability in the amount of uplift at sites and habitat related factors which make it harder to detect pāua of smaller size classes during dive surveys. Trends in some sites show that abundance may be starting to plateau (e.g., KAI33, KAI36), suggesting these sites may be close to their maximum carrying capacity for pāua within the habitats surveyed. Results from surveys for the remainder of this project will help to determine this. Figure 3 also indicates that sites that experienced higher uplift have shown weaker positive abundance trends than lower uplift sites. This is expected, because monitoring in sites with little to no uplift is really showing a 'marine reserve' effect, rather than population recovery post-earthquake.

Variability in abundance and uplift across sites has been considered by PāuaMAC3 in the development of their management tools with the re-opening, initially formalised in their 2021–22 annual operating plan and again in the 2022–23 plan. Specifically, catch spreading has been implemented to take fishing effort away from areas with higher uplift and lower pāua abundance.

4.2 Recruitment patterns

Cumulative length-frequency profiles illustrate that PAU 3A has maintained a relatively stable length-frequency profile of mature pāua over all the survey periods (Figure 5). The decrease in the number of larger pāua in the 2021–22 post-fishing survey is likely to be due to bias in the low number of sites sampled. In PAU 7, there is evidence of an increase in larger pāua (> 140 mm) across survey periods. This could be explained by the pre-earthquake stock status of PAU 7, relative to PAU 3A (described above), and the growth of pāua into larger size classes in PAU 7 following the closure, where pāua are anecdotally known to grow larger.

The general pattern of increasing numbers of 80–100 mm pāua in PAU 3A is indicative of post-earthquake recruitment. In PAU 7, there is a noticeable decrease in the numbers of smaller pāua during the 2020–21 survey period, and the trend of increasing abundance of smaller pāua observed in PAU 3A does not appear to exist. This may be due to individual variability in the sites that were able to be surveyed during these later periods, with potential bias towards sites with a lower abundance of smaller size classes, or sites where the habitat does not favour the emergence and detection of smaller size classes, and may also be reflective of variation in recruitment generally. Sites in PAU 7 also tend to be more shelf/gutter type habitats rather than boulder habitats more characteristic of PAU 3A sites where smaller pāua are more readily detectable.

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 two years can be observed across the majority of sites, meaning these results continue to support one of the agreed criteria for re-opening, that “widespread emergence of post-earthquake recruits is observed across the fishery”. Generally, the observed recruitment signals are a positive sign that annual recruitment pulses are occurring across most sites each season.

4.3 Management implications

It is now seven years since the Kaikōura earthquake and the initial resulting fishery closure. Results from these surveys and widespread anecdotal observation is that the pāua fishery has recovered well, with the biomass in many areas being higher than it was before the earthquake. Pāua fishing has recommenced under different precautionary management settings for previous two fishing seasons. While challenges remain for how the recreational fishery is to be managed in the future, the commercial fishery has a plan for how this can be achieved in the PAU 3 Fisheries Plan approved by the Minister in April 2021.

The PAU3 Fisheries Plan makes provision for an ‘Adaptive rebuild programme’ (Strategy 2.4) to adopt harvest control rules to inform recommendations on commercial harvest levels (Strategy 2.4.4) to then recommend to the Minister of Oceans and Fisheries that the TACC should be reviewed on an annual basis (Strategy 2.4.5). It has recently been proposed that BPUE will be used as an index of abundance (in conjunction with fisheries dependent data) 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.

5. ACKNOWLEDGEMENTS

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APPENDIX A – MODEL FIT AND SUPPLEMENTARY PLOTS

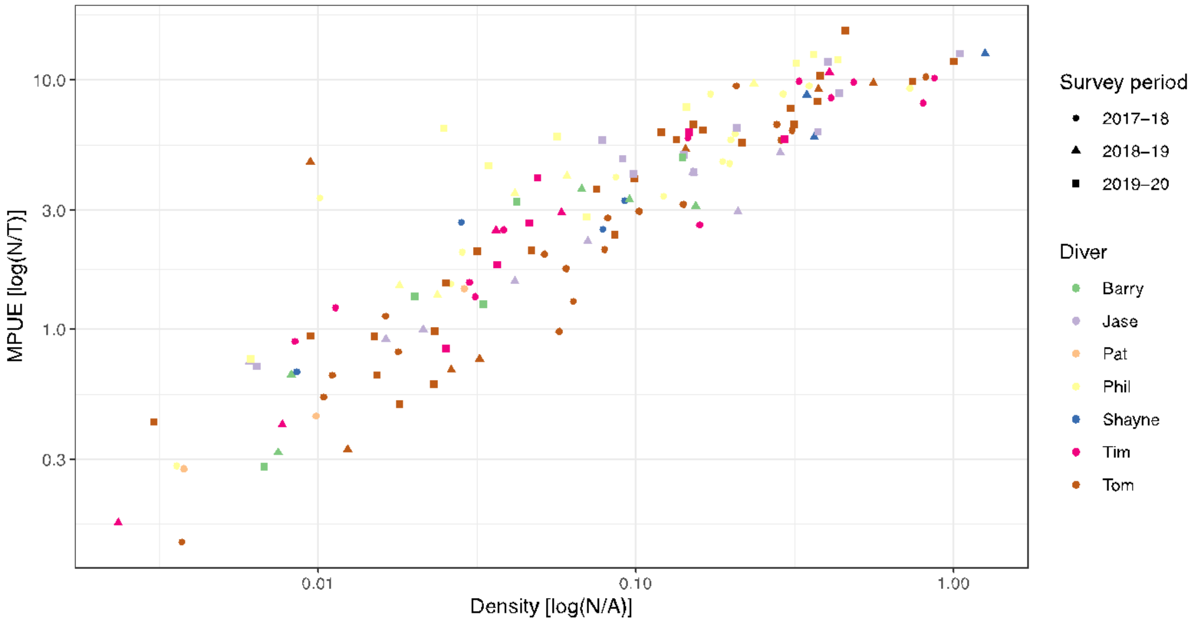

Figure A-1: Relationship between density in (log) individuals per unit area, and measurements per unit time (MPUE), for the three different survey periods (shapes) and divers (colours).

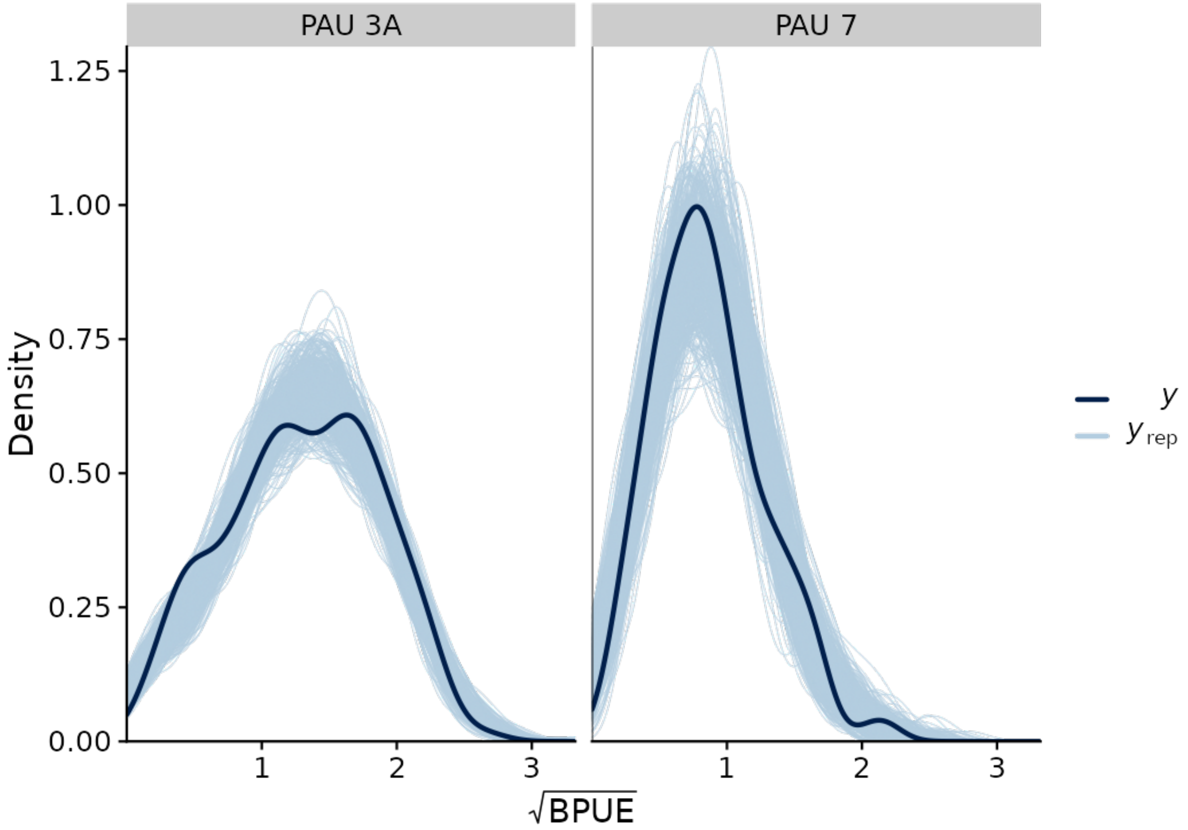

Figure A-2: Model fit by QMA for the model relating biomass per unit effort (BPUE) to predictors, as assessed by draws from the posterior predictive distribution (blue lines) compared with the empirical density for density data (black line).

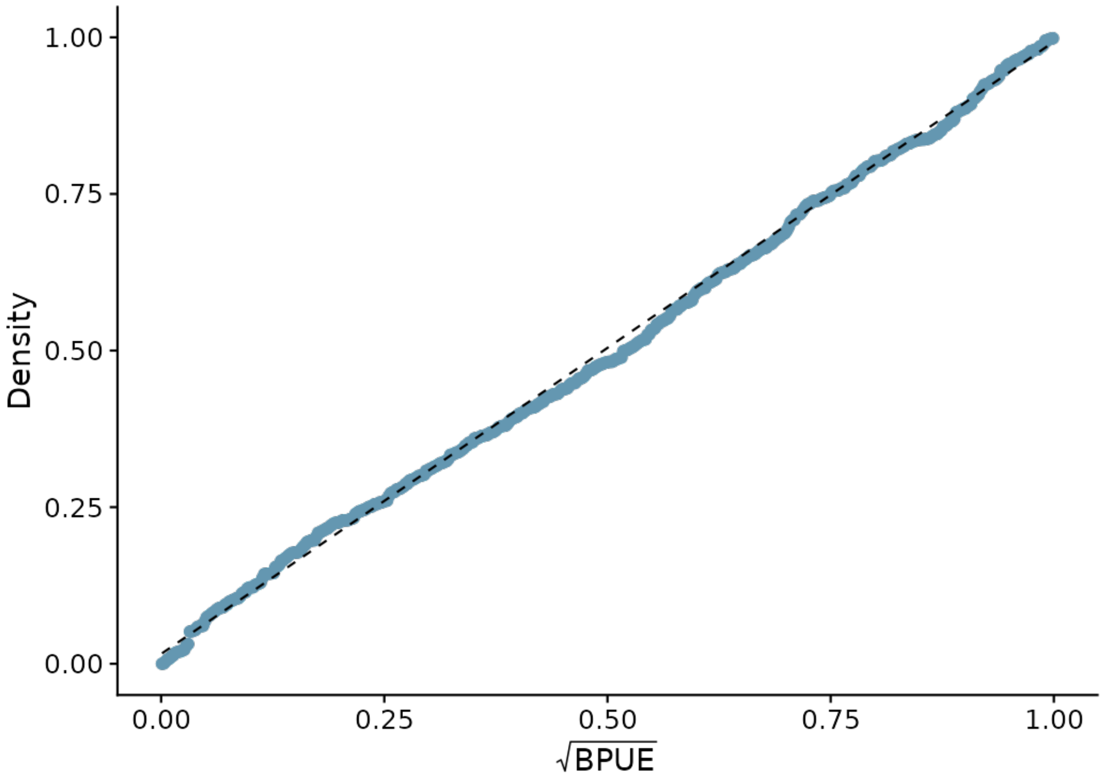

Figure A-3: Quantiles of residuals relative to expected quantiles, showing adequate fit of the model employed for survey analysis.

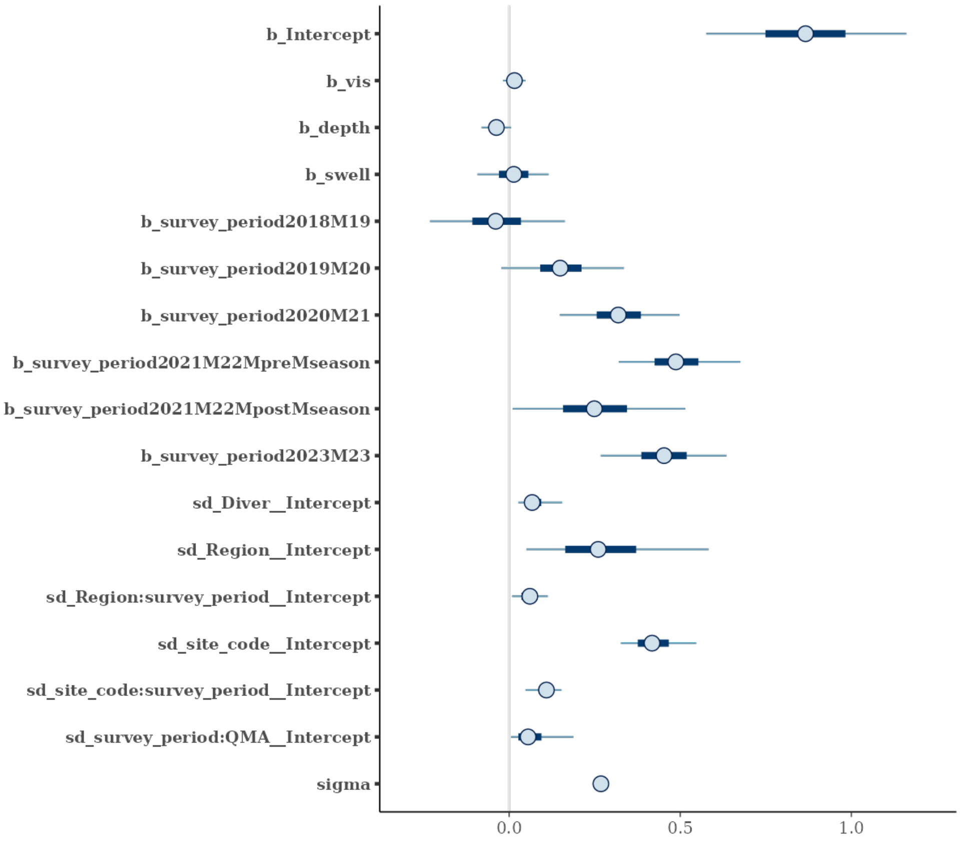

Figure A-4: Estimated coefficients in the biomass per unit effort (BPUE) model.

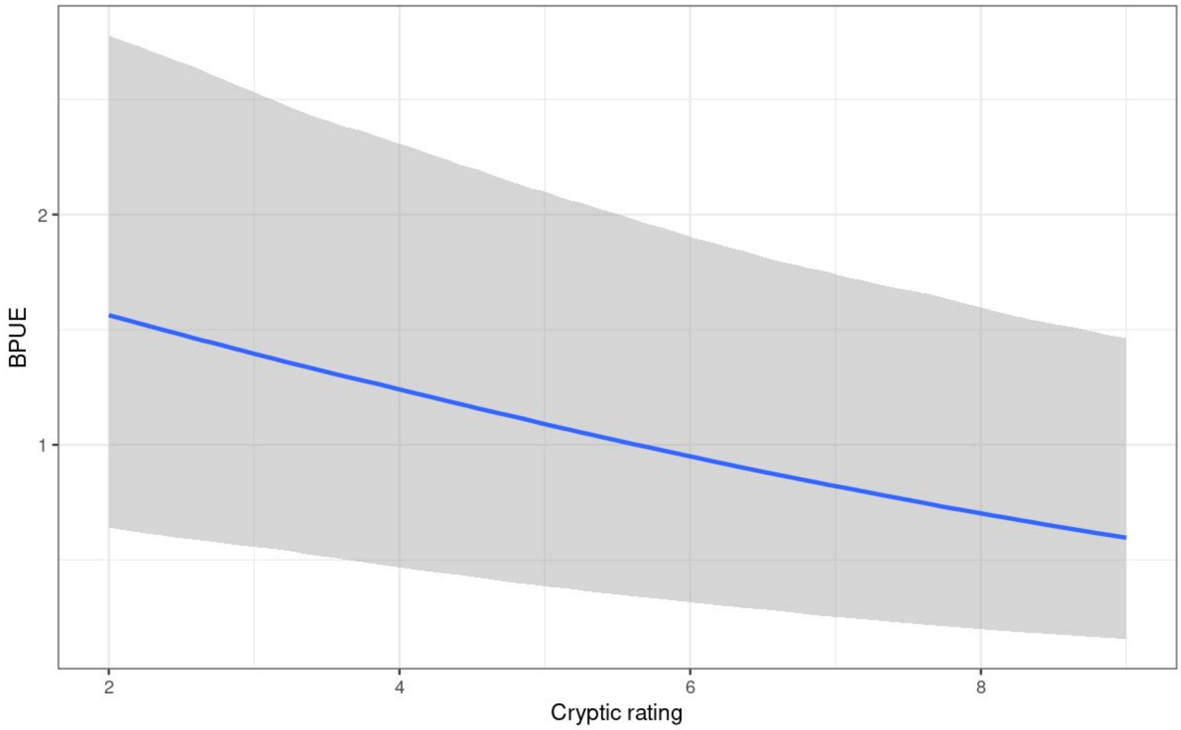

Figure A-5: Effect of cryptic rating in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

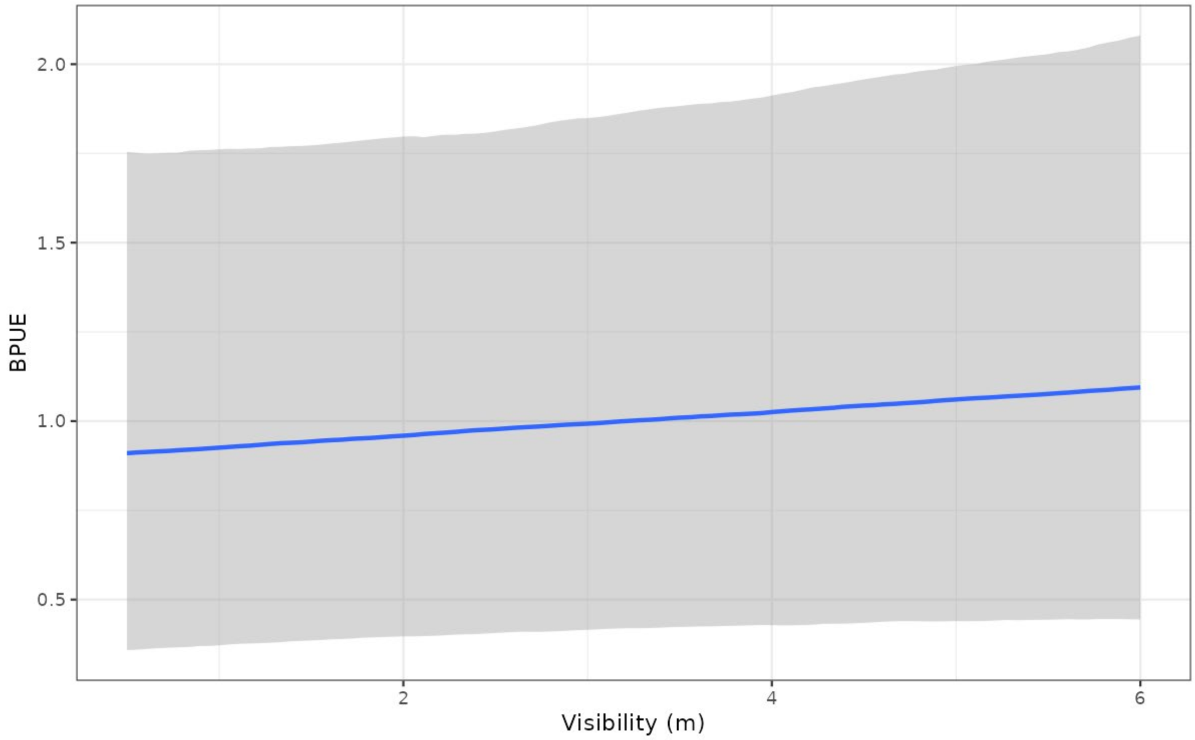

Figure A-6: Effect of visibility in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

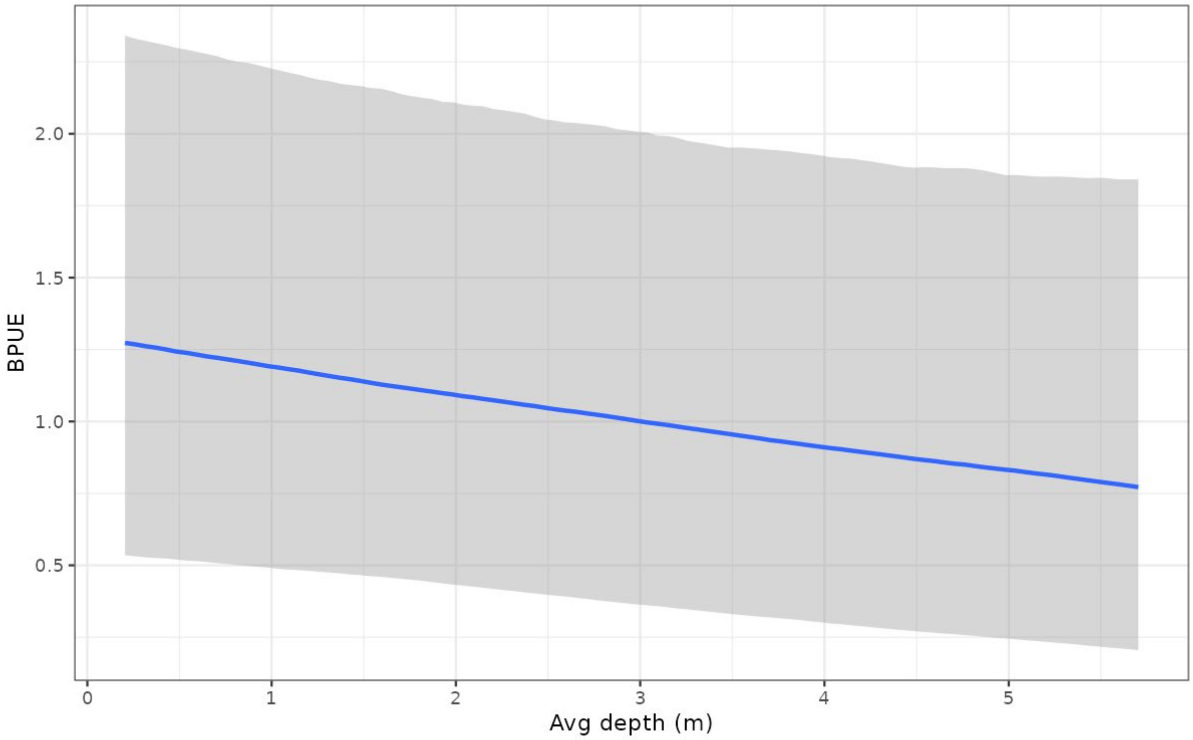

Figure A-7: Effect of depth in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

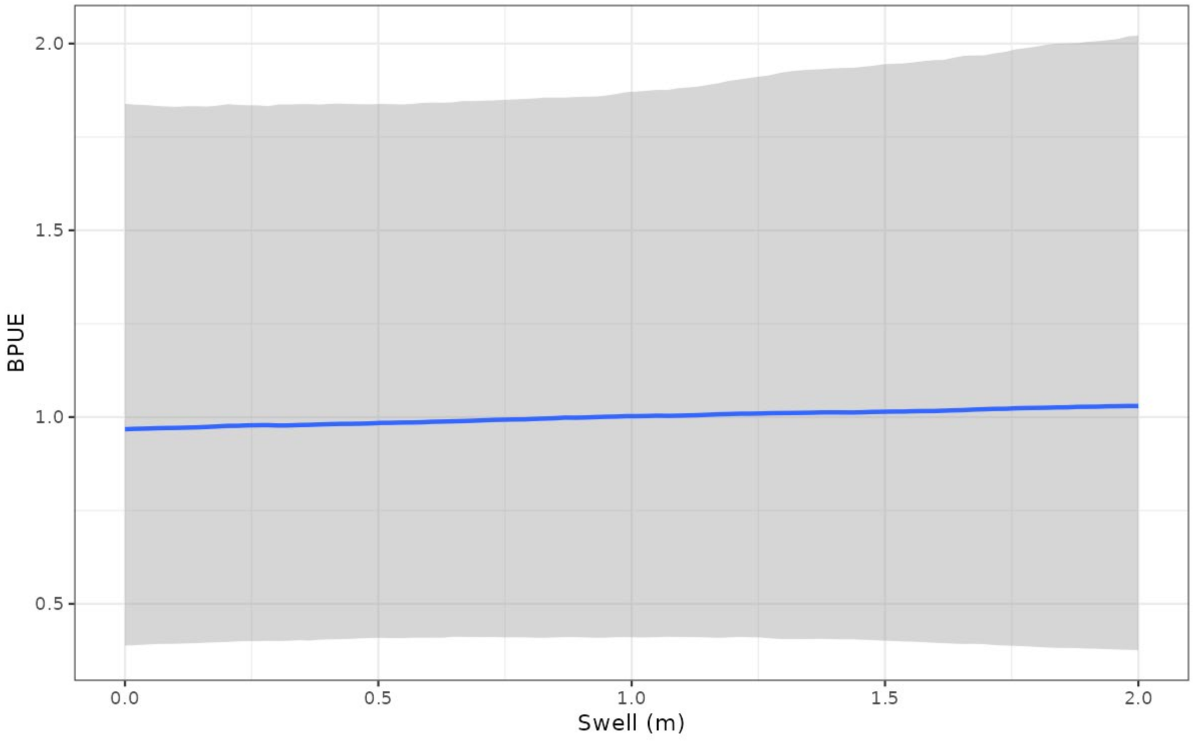

Figure A-8: Effect of swell in the biomass per unit effort (BPUE) model, as assessed by its marginal impact on BPUE.

APPENDIX B – INDUSTRY MANAGEMENT ‘ZONES’

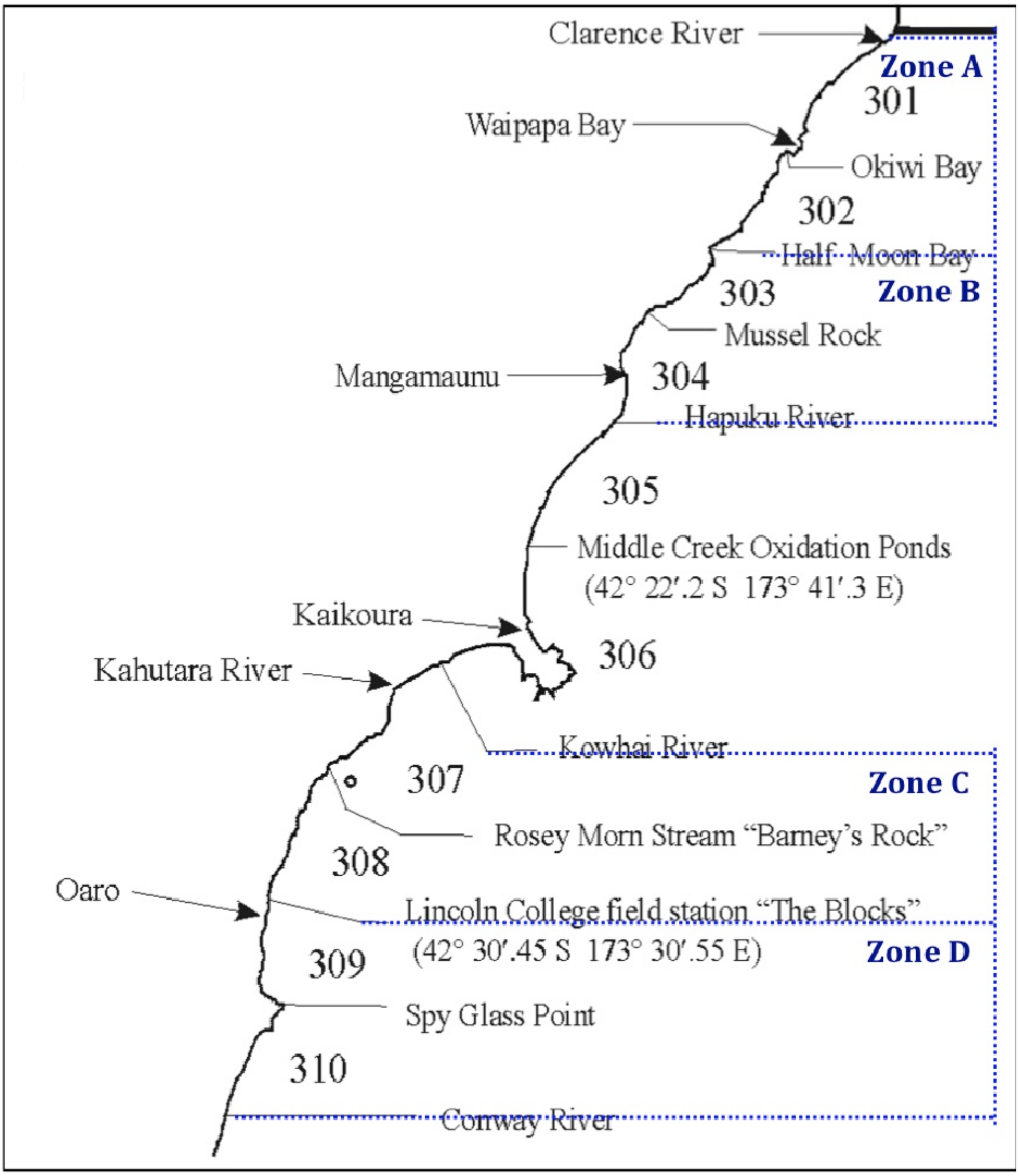

Figure B-1: Statistical area map showing PauaMAC3 management zones.

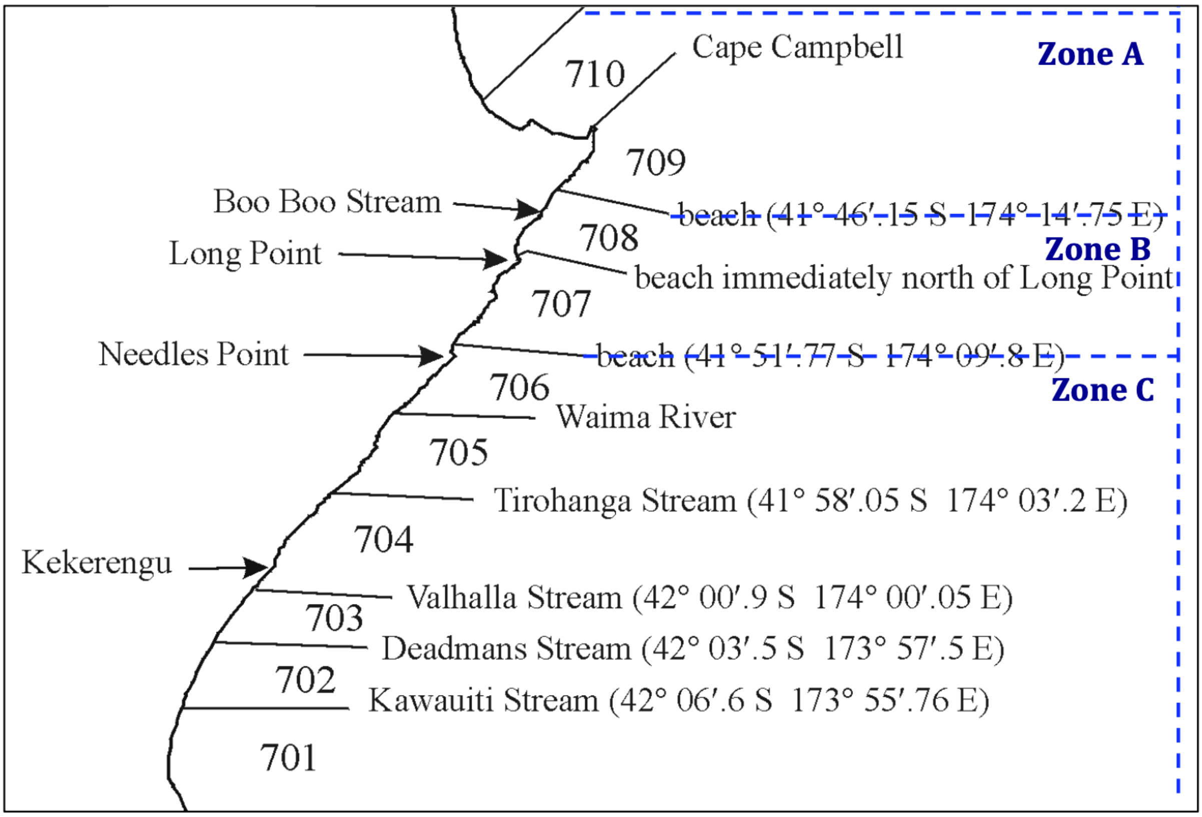

Figure B-2: Statistical area map showing PauaMAC7 management zones.