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Operating model and management procedure evaluation for pāua (*Haliotis iris*) fisheries in PAU 3A

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EXECUTIVE SUMMARY

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The pāua (*Haliotis iris*) stock in quota management area (QMA) PAU 3 was affected by a significant earthquake in November 2016, with coastal uplift of up to 6 m causing widespread mortality of all life stages of pāua and other intertidal and subtidal organisms. The northern part of the fishery (now PAU 3A) was subsequently closed for 5 years until 2021. It was also monitored using surveys to document the rebuild post-earthquake and develop indicators that could signal that re-opening the fishery would not negatively affect it long term.

Prior to the earthquake, the PAU 3 QMA was assessed on the basis of length-based statistical stock assessments up to 2016. The stock was considered to be in healthy condition, although considerable uncertainties about stock status remained, due to insufficient biological information to provide an understanding of local stock productivity. Dive surveys during the post-earthquake closure showed strong rebuilding of pāua numbers, and presence of all size classes. On the basis of this information, the fishery was reopened in December 2021 with a total allowable commercial catch (TACC) of 23 t. This catch weight was considered to be precautionary (catch prior to the earthquake was regularly in excess of 50 t). Nevertheless, monitoring of recreational catch suggested a take of 40 t for the first open season since the earthquake, owing to a high number of pāua that were easily accessible.

A fisheries plan for PAU 3 was developed following the earthquake, stipulating management strategies for re-opening and post re-opening. After the subdivision of the PAU 3 fishery into PAU 3A, the earthquake-affected area, and PAU 3B, the relatively unaffected area south of the Conway River, the fisheries plan suggested that both areas should be managed on the basis of harvest control rules for commercial catch. The present project attempted to develop models and test management options for PAU 3A as the fishery rebuilds. We focused on key uncertainties that remain for management of the fishery long term: modelling of earthquake impacts and recovery, and the developments of recreational catch over time.

Models used a range of simple assumptions about plausible earthquake impacts, and attempted to integrate survey data directly into stock assessments. While available data do not provide a basis for determining the likelihood of earthquake impact scenarios, a range of scenarios were tested in terms of their implications for management. Similarly, recreational catch cannot be precisely controlled, and alternative recreational catch scenarios were explored to understand the trade-off between long-term recreational catch and the commercial fishery in the long term.

The models were able to fit the fishery and aspects of survey data (indices), suggesting that models are able to represent the fishery development despite the earthquake. Although the simple assumptions were not able to capture more subtle trends in survey indices, and provided relatively poor fits to survey length-frequency data, they provided a starting point to modelling earthquake impacts in future assessments.

Depending on the model fitting strategy and earthquake impacts, tested commercial harvest strategies, combined with recreational harvest scenarios, led to relatively stable, or declining fisheries. The commercial fishery was especially affected by the trade-off with recreational take when recreational catch was not markedly reduced, leading to long-term reductions in commercial catch from re-opening levels. While differences between scenarios were minor in the short term, uncertainties were substantial over long periods, leading to non-negligible risk in some models. Given uncertainties about stock trajectories and risks, we recommend ongoing monitoring of commercial and recreational catch. Other recommendations include a review of management options in 2 to 3 years' time once trends and levels of

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recreational catch have stabilised and key uncertainties can be re-assessed to ensure fishery performance in the long term as the fishery develops post-closure.

1. INTRODUCTION

Pāua (*Haliotis iris*) stock in the PAU 3 quota management area was assessed on the basis of length-based statistical stock assessments (Fu 2014). The stock was considered to be in healthy condition, although large uncertainties about stock status remained due to insufficient biological information that provides an understanding of local stock productivity.

In November 2016, a substantial earthquake affected the northern area of PAU 3, with coastal uplift of up to 6 m causing widespread mortality of all life stages of pāua and other intertidal and subtidal organisms. The area of PAU 3 to the north of the Conway River was subsequently closed under section 11 of the Fisheries Act 1996 to all commercial and recreational pāua fishing for five years. Subsequent dive surveys have been used to monitor the rebuild of pāua biomass post-earthquake (McCowan & Neubauer 2021). At the same time, the southern part of the PAU 3 fishery remained open at a reduced (halved) Total Allowable Commercial Catch (TACC). To facilitate separate management of the earthquake-affected area and the remaining area of PAU 3, the quota management area (QMA) was divided into PAU 3A (Kaikōura) and PAU 3B (Canterbury coast and Banks Peninsula).

Evidence from dive surveys suggested substantial rebuilding and presence of post-earthquake recruitment. This evidence led to the re-opening of the PAU 3A fishery in December 2021 for a period of 3 months, at a TACC of 23 t with a commercial minimum harvest size of 135 mm shell length. During the three-month fishing season, nearly all taken pāua were measured, and catch-spreading was implemented to avoid overfishing of any particular area.

Recreational take was limited to five pāua per person per day, with a minimum harvest size set at the minimum legal size of 125 mm shell length. Two projects (Fisheries New Zealand project SEA2021-05 and University of Canterbury research) assessed the magnitude and impacts on shallow pāua populations, respectively. The recreational harvest from the PAU 3A area was estimated to be about 42 t (CV 17.5%), suggesting removals in excess of commercial removal, and at smaller sizes (Holdsworth 2022).

To inform ongoing management of the PAU 3 fisheries, a series of projects attempted to build models and evaluate management options for both of these areas. The development of management options followed the implementation of industry-determined control rules in the PAU 5 areas (Neubauer 2019, 2021). The perceived success of more formalised, responsive management rules led to their adoption as strategies for managing pāua fisheries in so-called “fisheries plans” for PAU 3, and other areas. These plans are strategic documents, which stipulate that fisheries ought to be managed on the basis of harvest control rules. To test these control rules, operating models were required for the newly subdivided QMAs of PAU 3.

The present project developed a stock assessment model for PAU 3A that included alternative hypotheses about earthquake impacts. The model served as an operating model to test harvest control rules, particularly to elucidate trade-offs between commercial and recreational take given the high estimated recreational take in the 2021–22 fishing season. The model was developed to align with management at the scale of industry management zones (Figure 1), which partition catch among spatial strata and allow the fishing industry to set area-specific minimum harvest sizes (MHSs).

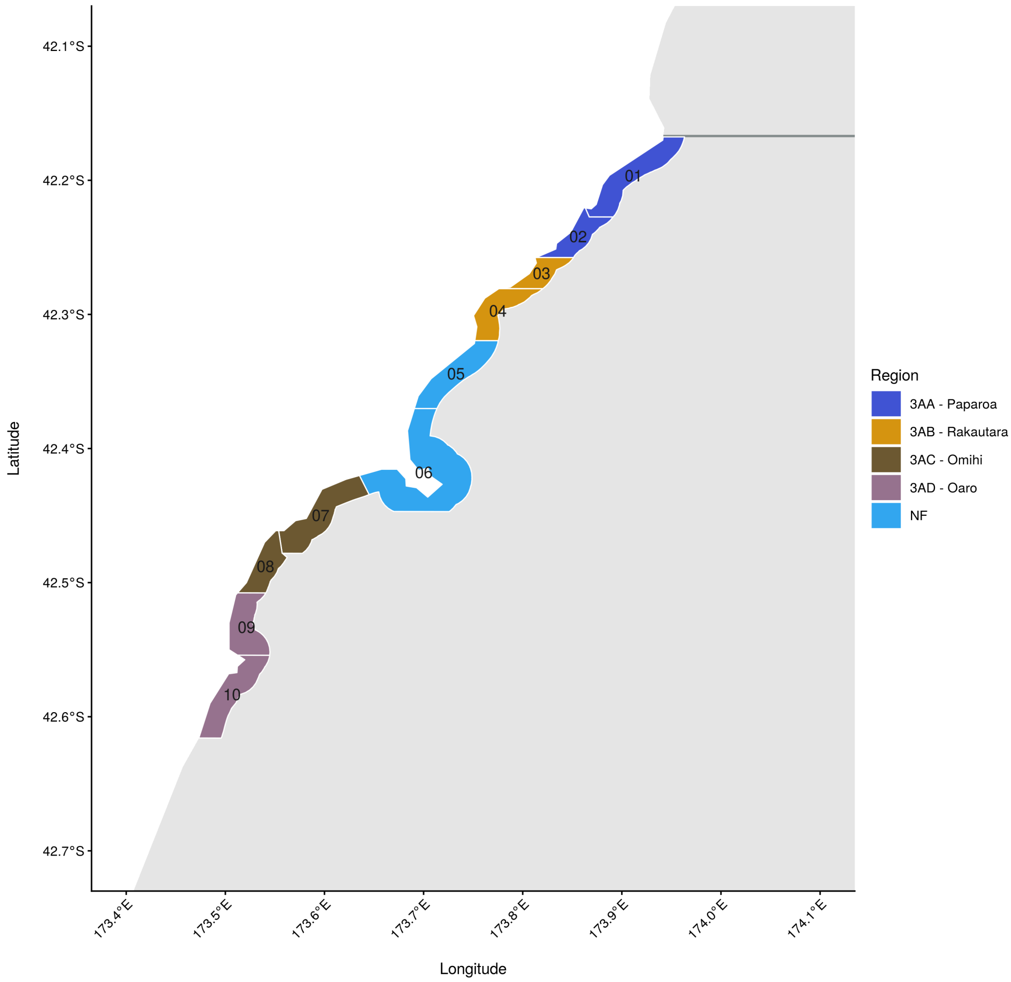

Figure 1: Pāua quota management area (QMA) PAU 3A, Kaikōura (centred on Kaikōura Peninsula). Pāua statistical areas shown here (coloured polygons) are grouped by colour according to current commercial management zones within PAU 3A. NF: zone without current commercial fishing.

2. METHODS

2.1 Inputs

Inputs for the PAU 3A model consisted of commercial catch data, catch-per-unit-effort (CPUE) data from (Pāua) Catch Effort Landing Return ((P)CELR) forms and electronic reporting systems submissions, and length-frequency data from commercial sampling (CSLF) up to 2016. Catch sampling length frequency (CSLF) data from the 2021–22 fishing year were not available at the time of the present model development. Catch assumptions for recreational, customary, and illegal take for the period prior to the earthquake were agreed by the Shellfish Working Group (SFWG), and treated as known. No representative biological data (i.e., growth data) were available for PAU 3A (Fu 2014, Fu et al. 2014); only distributions derived from meta-analyses were used in models for PAU 3A. Recent stock trends were informed by survey index and length-frequency information derived from McCowan & Neubauer (2023).

All data sources were prepared to align with current post-earthquake management zones. These zones were elicited based on abundance, length frequency and earthquake impact considerations. Although the waters surrounding Kaikōura Peninsula and adjacent areas are not fished commercially, there was some data available from prior fishing activity in this zone. These data were prepared with all other data sources, but were not included in the modelling.

All data sources were compiled and prepared through the Kahawai Collective reporting system, which implements reproducible and standardised prepared fisheries datasets for further analyses. Documentation for the Kahawai system is currently being developed (Middleton in prep.). For pāua in the current assessment, data preparation within the Kahawai database was minimal, consisting only of consistency assessments as part of database builds. Any substantial data preparation or analyses that were performed for individual analyses of datasets are detailed below.

2.1.1 Commercial catch

Commercial catch was assumed to be known without error in the assessment model, and was reconstructed from a range of sources for the model period from 1965 to 2022 (Table 1). Data sources for early catch included early reports on commercial pāua catch (Murray & Akroyd 1984), the Fisheries Statistical Unit (FSU) database (1983–1989), and catch and effort data supplied by Fisheries New Zealand (Figure 2).

Commercial catch for PAU 3A cannot be reconstructed with precision prior to the introduction of fine-scale statistical areas and PCELR forms in 2002. Prior reporting on non-pāua-specific CELR forms was at the level of large-scale statistical areas. The area with the majority of catch at the time, Statistical Area 018, straddled PAU 7, PAU 3A and PAU 3B. The majority of catch is considered to have been from areas north and south of Kaikōura peninsula, which currently encompasses PAU 3A. This assumption was supported by more recent data from the area, which showed between 85 to 95% of annual catch from Statistical Area 018 coming from PAU 3A. For all data prior to 2002, it was assumed here that 90% of catch reported from the PAU 3 part of Statistical Area 018 came from PAU 3A.

Between 2002 and the 2016 earthquake closure, catch was relatively stable spatially, with consistent catches from all commercially fished areas (Figure 3). For the early part (1974–1983) of the catch history, the commercial catch reconstruction used data from Murray & Akroyd (1984); the FSU data were used from 1983 to 1988, whereas from 1990 onwards, estimated catch data from CELR forms were used. Catch in 1989 was interpolated between 1988 and 1990. All catch sources were attributed to PAU 3A according to proportions described above (see Table 1).

Table 1: Sources of pāua catch data, by period. FSU, Fisheries Statistical Unit; (P)CELR, (Pāua) Catch Effort Landing Return.

Period	Source
1965–1973	Linear increase from 1 t to 1974 value.
1974–1983	Murray & Akroyd (1984) as cited by Schiel (1989).
1984–1988	FSU database.
1989	Interpolated.
1990–2019	Estimated catch from (P)CELR.
2020–2022	Estimated catch from the Electronic Reporting System (ERS).

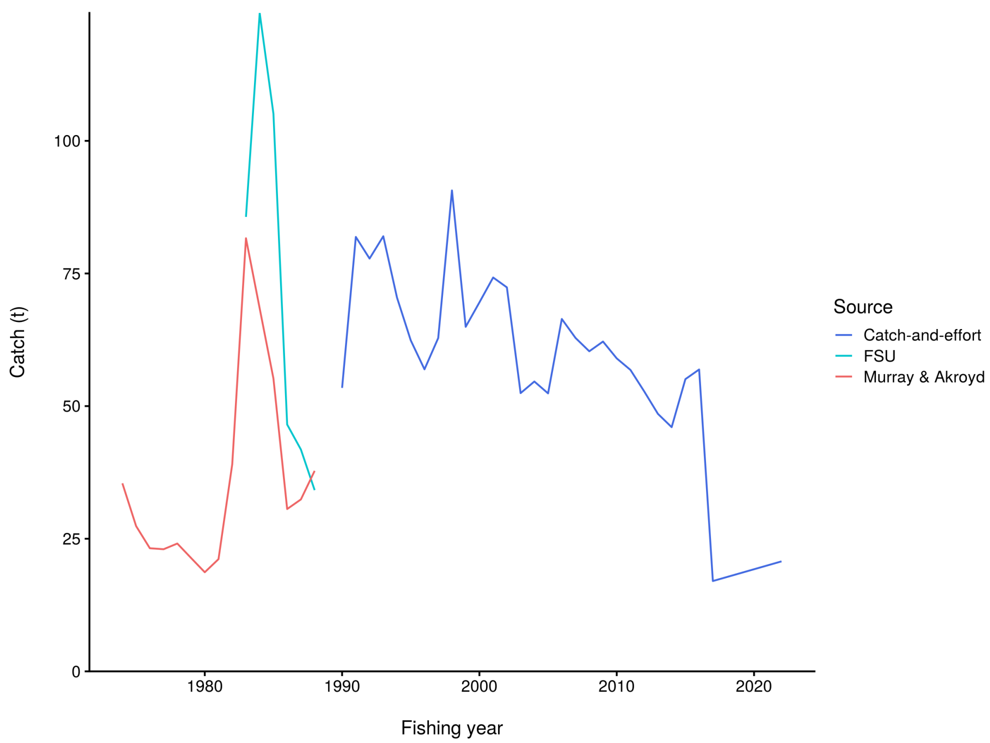

Figure 2: Commercial catch history for pāua quota management area (QMA) PAU 3A from 1974 to 2021. Catch to 1983 was reconstructed from data reported by Murray & Akroyd (1984; red line). Data for 1983–1986 were from the Fisheries Statistical Unit (FSU) database (teal line). Catch and effort data from 1989 was supplied by Fisheries New Zealand (catch-and-effort, blue). (Note, no other sources of catch were available at sufficient resolution due to the recent sub-division of QMA PAU 3.)

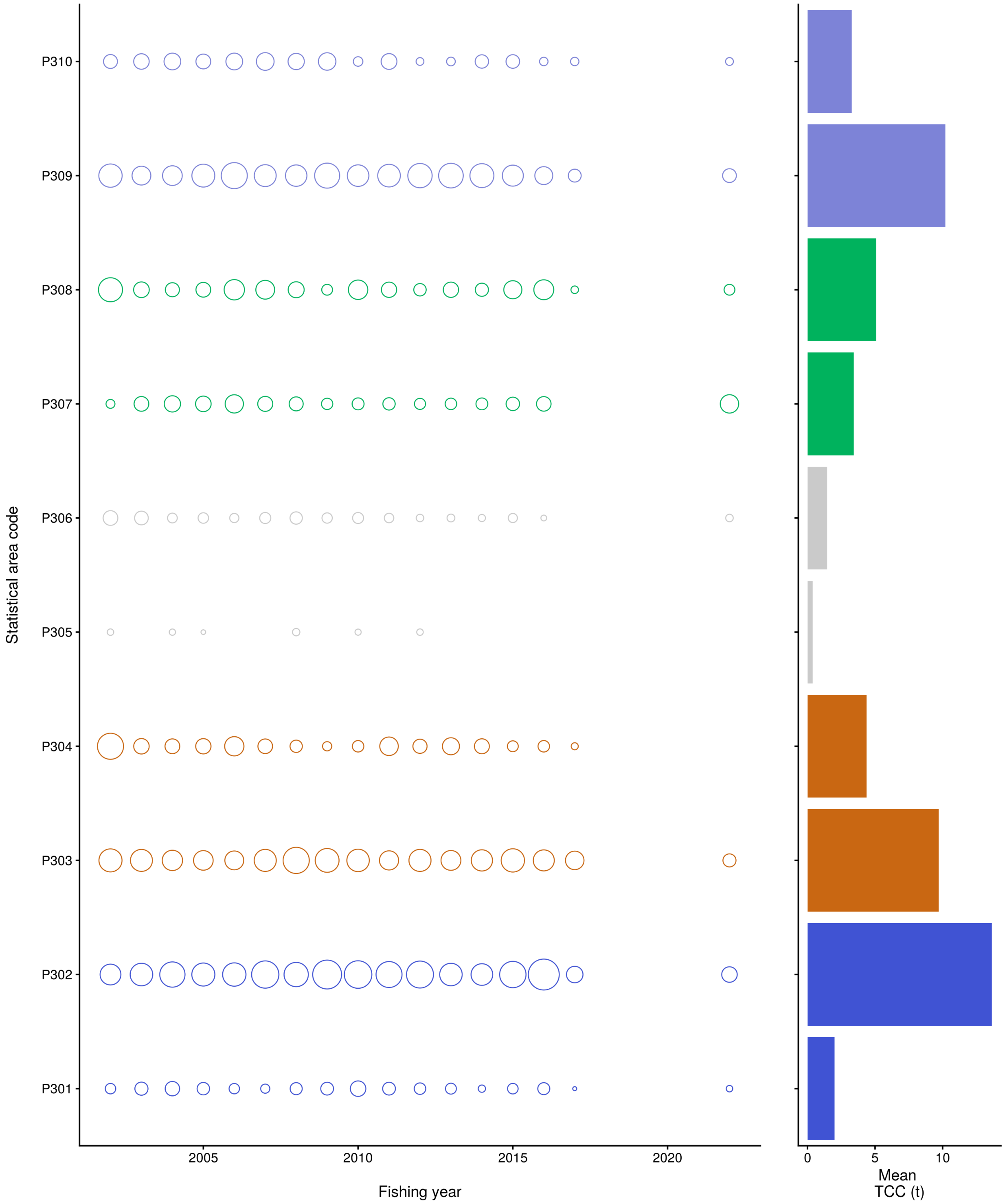

Figure 3: Relative trend in pāua catch (kg) over time by pāua statistical areas in quota management area PAU 3A for the period from 2002 to 2022, with total commercial catch over the same time period (right-hand side). Current commercial management zones within PAU 3A are colour coded (blue: zone A (Paparoa); orange: zone B (Rakautara); green: Zone C (Omihi); purple: zone D (Oaro); and grey: zone without current commercial fishing. (Note, any records in the latter zone likely originate from errors in determining the statistical area of fishing events from location data.)

2.1.2 Recreational, customary, and illegal catch

Two estimates from the national panel surveys provided some, if limited insight into recreational pāua fishing in the area (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019). The survey estimated that about 16.98 t (coefficient of variation, CV, of 31%) of pāua were taken by recreational fishers in the entire area of PAU 3 for 2011–12. This estimate was combined for all areas of PAU 3A and PAU 3B, and most of this take was considered to have been from PAU 3A. In 2017–18, the national panel survey was repeated and the estimated recreational catch was 8.79 t (CV of 35%) (Wynne-Jones et al. 2019). Due to the closure following the earthquake, this estimate was considered to represent only PAU 3B. The catch for the 2021–22 season was set at the estimate (42 t) reported by Holdsworth (2022).

Initial model runs used a weight of 12 t of recreational catch from 2012, with a linear increase from 3 t in 1974. Subsequent discussions in the Shellfish Working Group in view of the recent catch of around 42 t suggested that early estimates may have been low. For this reason, a weight of 20 t was used in models from 2012.

There is no comprehensive information available on customary take in recent years. The Shellfish Working Group agreed to assume that customary catch was 1 t in 1974, increasing linearly to 2 t between 1974 and 2012, and then remaining at 2 t prior to 2016. Customary fishing was the only form of fishing that was permitted during the earthquake closure of the PAU 3A area, and the Shellfish Working Group considered that substantial recreational effort likely shifted to customary harvest. Based on this consideration, models used an increased weight of 5 t for customary harvest in this period.

Illegal catch was considered to be high throughout the 1990s when pāua prices increased. Subsequent enforcement efforts since the early 2000s likely led to marked reductions in illegal take. For this catch component, the Shellfish Working Group agreed to assume an increase in illegal catch from 1 t per year up to 1974 to 10 t annually by the 1990 fishing year; subsequent illegal take was assumed to be remaining at 10 t throughout the 1990s. Subsequent reductions from 10 t to 2 t between 2000 and 2010 reflected increasing enforcement, with steady illegal take at 2 t assumed for years since 2010.

Based on the different catch components (Figure 4), estimates of the total catch by area were used in the spatial assessment (Figure 5).

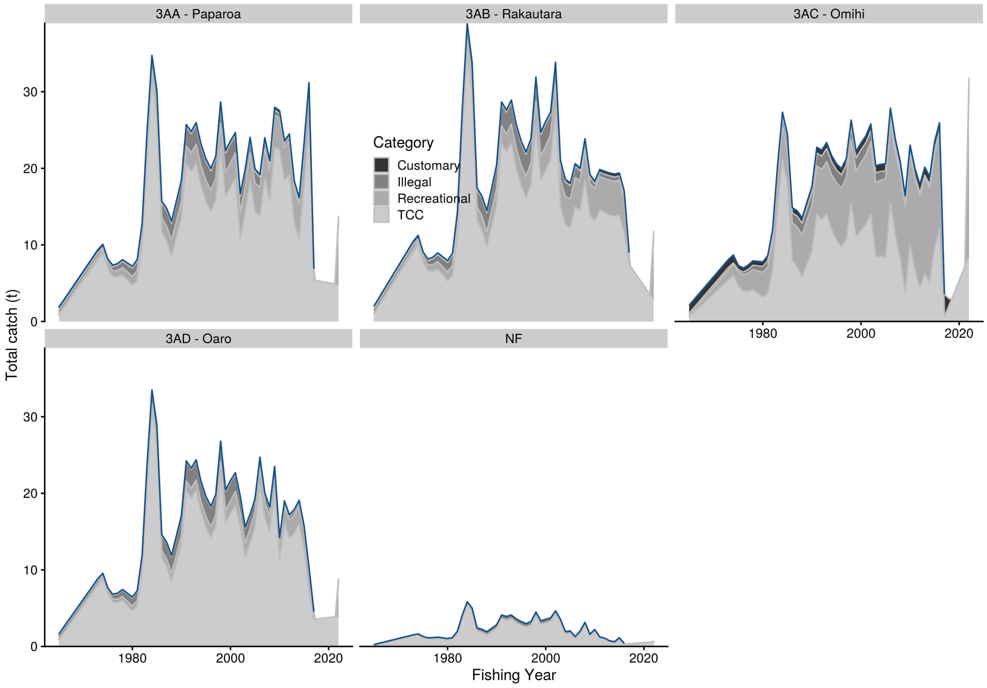

Figure 4: Estimated total pāua catch history for quota management area (QMA) PAU 3A from 1974 to 2022 by fishery component and reporting area. Fishery categories were commercial (Total Commercial Catch, TCC), customary, illegal, and recreational catch. Commercial catch was reconstructed up to 1995 when the QMA was created, and based on landing records thereafter. (Note, no commercial catch was taken between 2017 and 2022.)

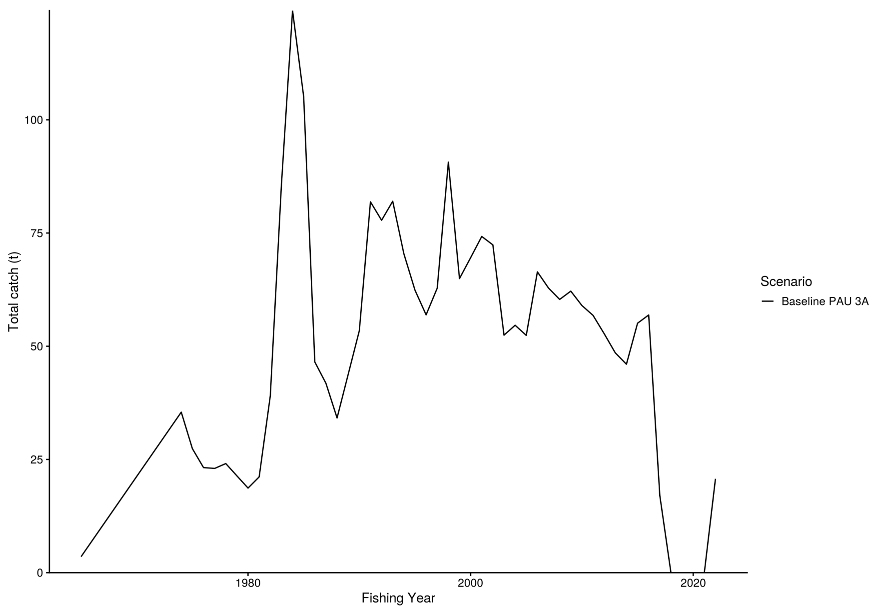

Figure 5: Total pāua catch history used in the single area stock assessment for PAU 3A from 1974 to 2022 as the sum of all catch components (commercial, customary, recreational, illegal).

2.1.3 Catch-per-unit-effort (CPUE)

The present assessment only considered CPUE data from PCELR forms (2002 to 2016). Although data from the FSU database and CELR forms were used in previous assessments (CELR data were used up to 2020), these data have been rejected as being too unreliable to be used as a proxy for trends of relative abundance in other pāua QMAs. Poor reporting, considerable changes in the fishing fleet, and operational changes (increases in fishing power) are likely to have led to an unknown degree of hyper-stability in these time series. In addition, the spatial resolution in pre-PCELR data is insufficient to partition the CPUE from CELR Statistical Area 018 to pāua QMAs, and does not allow partitioning of trends by industry management zones. These reporting deficits had mostly disappeared, and the fleet stabilised, by the time PCELR reporting was introduced in 2002. Therefore, CPUE based on PCELR has been considered a more robust indicator of abundance since the early 2000s.

Data preparation procedures for PCELR data generally followed established protocols detailed by Fu et al. (2017) (see details of the data preparation in Tables 2 and 3). Data preparation steps are summarised as follows:

1. Use only events with "diving" as method.
2. Remove items with missing fields needed for standardisation.
3. Remove clients who have not been active for extended periods of time (2 years), and divers with less than 2 years experience.
4. Retain only events with less than four recorded divers, and a recorded fishing duration of $\leq$10 h, and CPUE between 10 and 500 kg/h.

Table 2: Data preparation steps and total estimated catch weight (in t) for data from Pāua Catch Effort Landing Return (PCELR) forms by year and in total (as estimated catch weight and percentage retained). FIN, fisher (client) identification number; CPUE, catch-per-unit-effort.

Data preparation	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	% retained
All	72	52	54	52	66	63	60	62	59	56	53	49	46	55	57	17	873	100.00
Missing fields	72	52	54	52	66	63	60	62	59	56	53	49	46	55	57	17	873	100.00
FIN years ≥ 2	71	52	53	52	66	63	59	62	58	56	52	49	46	55	54	17	865	99.08
Diver years ≥ 2	63	49	51	51	64	61	58	61	57	56	50	48	45	52	51	16	833	95.42
No. of divers ≤ 4	63	49	51	51	64	61	58	61	57	56	50	48	45	52	51	16	833	95.42
Fishing duration $\leq$10h	63	49	51	51	64	61	58	61	57	56	50	48	45	52	51	16	833	95.42
10kg/h $\leq$CPUE $\leq$500kg/h	63	49	51	51	64	61	58	61	57	54	50	48	45	52	50	16	830	95.07

Table 3: Data preparation steps and number of records retained for data from Pāua Catch Effort Landing Return (PCELR) forms by year and in total (as record numbers retained and percentage retained). FIN, fisher (client) identification number; CPUE, catch-per-unit-effort.

Data preparation	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	% retained
All	404	355	323	332	380	367	383	370	400	319	292	279	253	329	288	69	5 143	100.00
Missing fields	404	355	323	332	380	367	383	370	400	319	292	279	253	329	288	69	5 143	100.00
FIN years ≥ 2	400	355	314	332	377	367	377	370	387	319	291	279	253	325	280	69	5 095	99.07
Diver years ≥ 2	331	333	298	317	364	359	366	359	382	314	270	271	248	305	266	63	4 846	94.23
No. of divers ≤ 4	331	333	298	317	364	359	366	359	382	314	270	271	248	305	266	63	4 846	94.23
Fishing duration $\leq$10h	331	333	298	317	364	359	366	359	382	314	270	271	248	305	266	63	4 846	94.23
10kg/h $\leq$CPUE $\leq$500kg/h	325	325	296	315	361	354	366	353	372	310	267	271	243	304	265	63	4 790	93.14

The PCELR CPUE standardisation was carried out using Bayesian Generalised Linear Mixed Models (GLMM) which partitioned variation among fixed (research strata) and random variables. The CPUE was defined as the log of daily catch. Variables in the model were fishing year, estimated fishing effort, client identification number, management zone, small-scale statistical area, and diver identification.

The fit of the log-normal CPUE index model was considered reasonable (Figure 6), with an index that was relatively similar to the raw data, suggesting minimal standardisation effect. Standardised CPUE in northern areas (Zone A, Paparoa; Zone B, Rakautara to a lesser degree) showed increases in years prior to the earthquake following a slight decline since 2006 (Figure 7). Southern zones (Zone C, Omihi; and zone D, Oaro) appeared stable and somewhat variable with no discernible trend prior to the earthquake. No variable had significant standardising effects: Client (Annual Catch Entitlement holder) and divers were relatively consistent over the period considered here (Figures 8, 9), despite explaining substantial proportions of variation (Figure 10).

The CPUE and estimated observation error (σ_{OBS}) were used as direct inputs to the attempted stock assessment model without further modifications, as process error is estimated within the model based on relative weights for CPUE and commercial sampling length-frequency (CSLF) data.

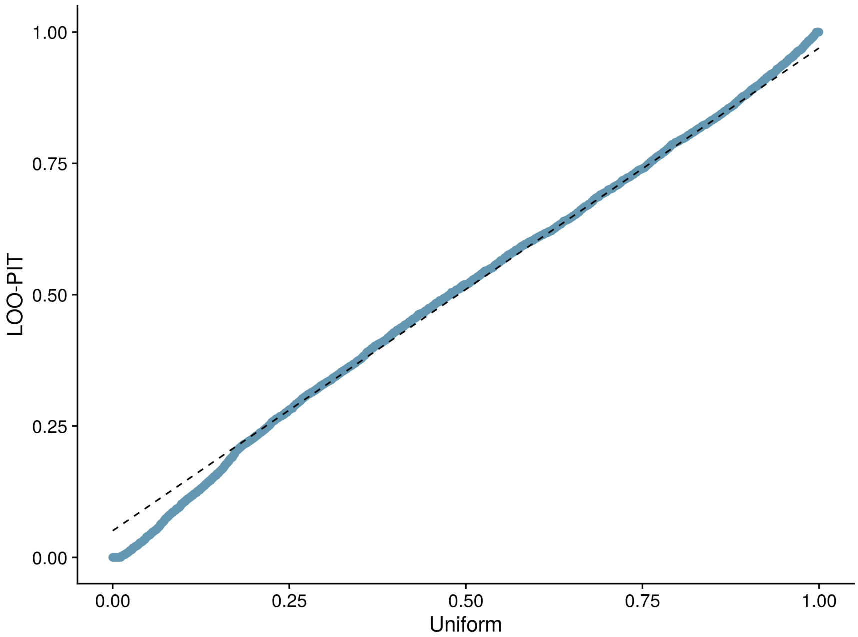

Figure 6: Fit of the log-normal generalised linear mixed model used for catch-per-unit-effort (CPUE) index standardisation. The quantile-quantile plot compares the PIT (Probability Integral Transform) of the leave-one-out (LOO) posterior predictive distribution to the theoretically expected uniform distribution.

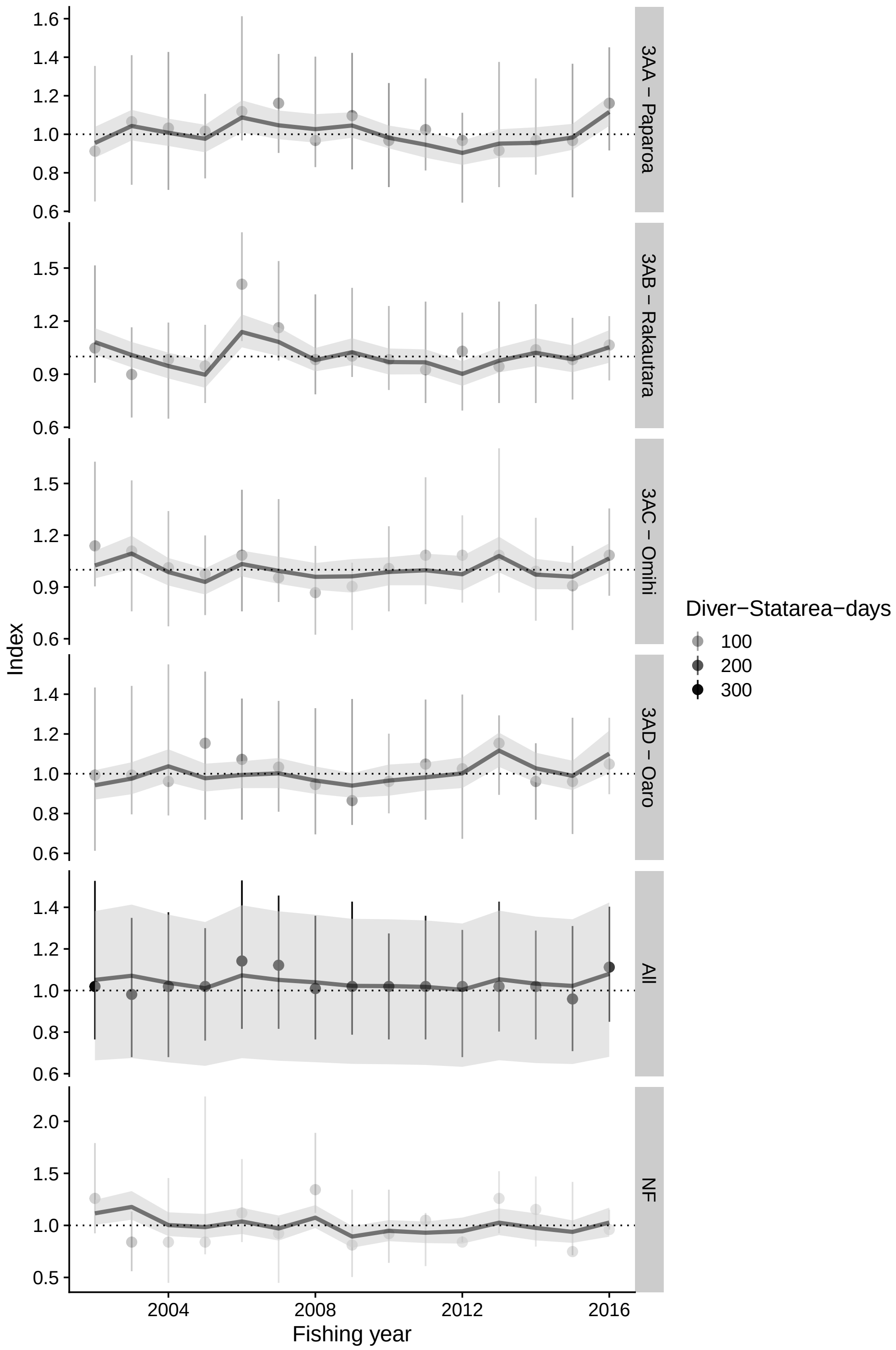

Figure 7: Standardised catch-per-unit-effort (CPUE) using a generalised linear mixed model with zone-year interaction; showing CPUE by zone (NF, zone without current commercial fishing). Black line and confidence interval show estimated CPUE index and 95% posterior quantiles, with data mean and inter-quartile range shown as points and error bars, respectively.

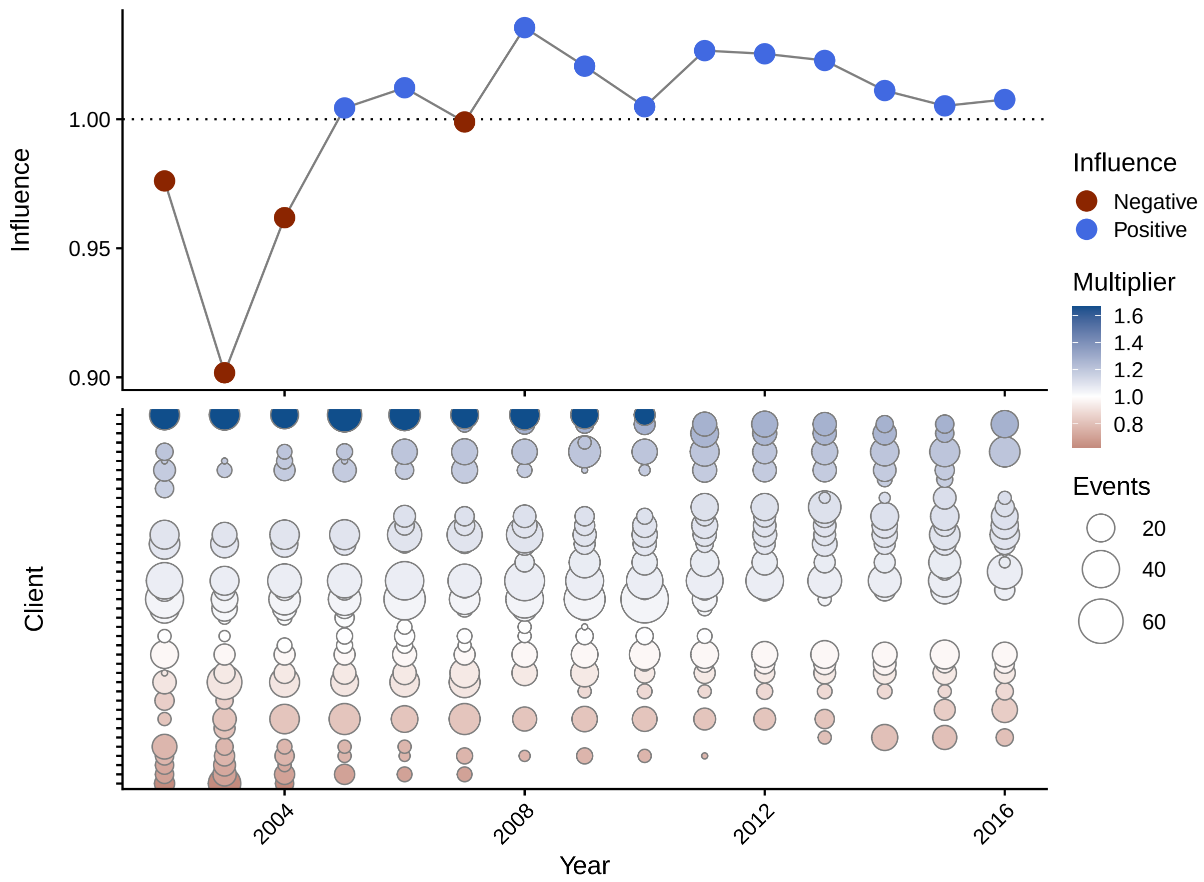

Figure 8: Influence plots for client number (FIN) effect, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised index was increased due to the relative distribution of the covariate.)

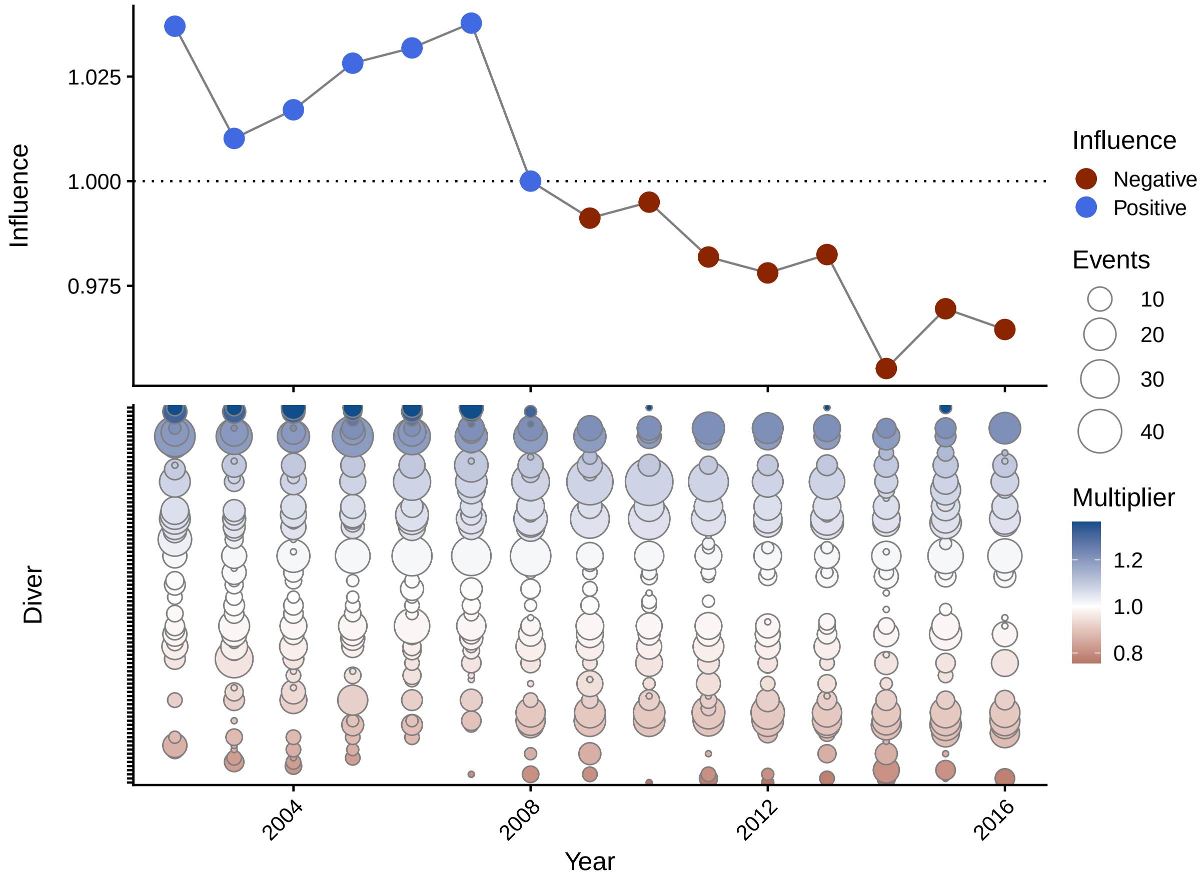

Figure 9: Influence plots for diver random effects, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised index was increased due to the relative distribution of the covariate.)

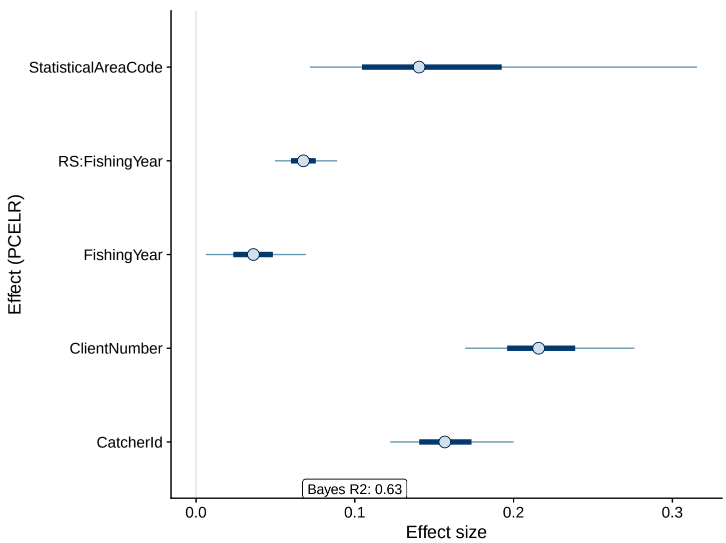

Figure 10: Effect size as variance explained for variables included in the random effects standardisation model. PCELR, Pāua Catch Effort Landing Return. RS:FishingYear is the magnitude of differences in year trends between management zones.

2.1.4 Commercial sampling length-frequency (CSLF) data

The present modelling used a standardisation model for composition data (developed by Neubauer 2020) that adjusts the length-frequency samples based on spatial and temporal variability. This adjustment is similar to adjustments in CPUE applied during the standardisation of CPUE, and effectively adjusts the estimated length-frequency of removals. This procedure has the advantage that reasonably smooth length-frequency distributions (i.e., filtering out variance from highly multi-modal length-frequency distributions that result from low sample numbers) for sparsely sampled strata can be extracted, even if individual samples in those strata are unlikely to provide a reliable estimate of the actual length frequencies. Random effects formulations ensure the sharing of information across strata (see more detail about the procedure provided by Neubauer 2020).

Composition standardisation was performed for CSLF data from 2005–06 to 2016–17. The model used statistical area and area-year as standardising variables. Area and year were entered as fixed effects, and area-year was entered as a random effect.

Raw CSLF data showed geographical patterns in length composition of removals (Figure 11). Measured pāua tended to be larger in the most northern and southern areas of Paparoa and Oaro, respectively, with relatively even sizes fished in all other statistical areas.

The standardisation led to minimal adjustments relative to raw removal estimates (Figures 12, 13), owing to consistent catch and relatively representative sampling patterns across statistical areas (Figure 14) since about 2008.

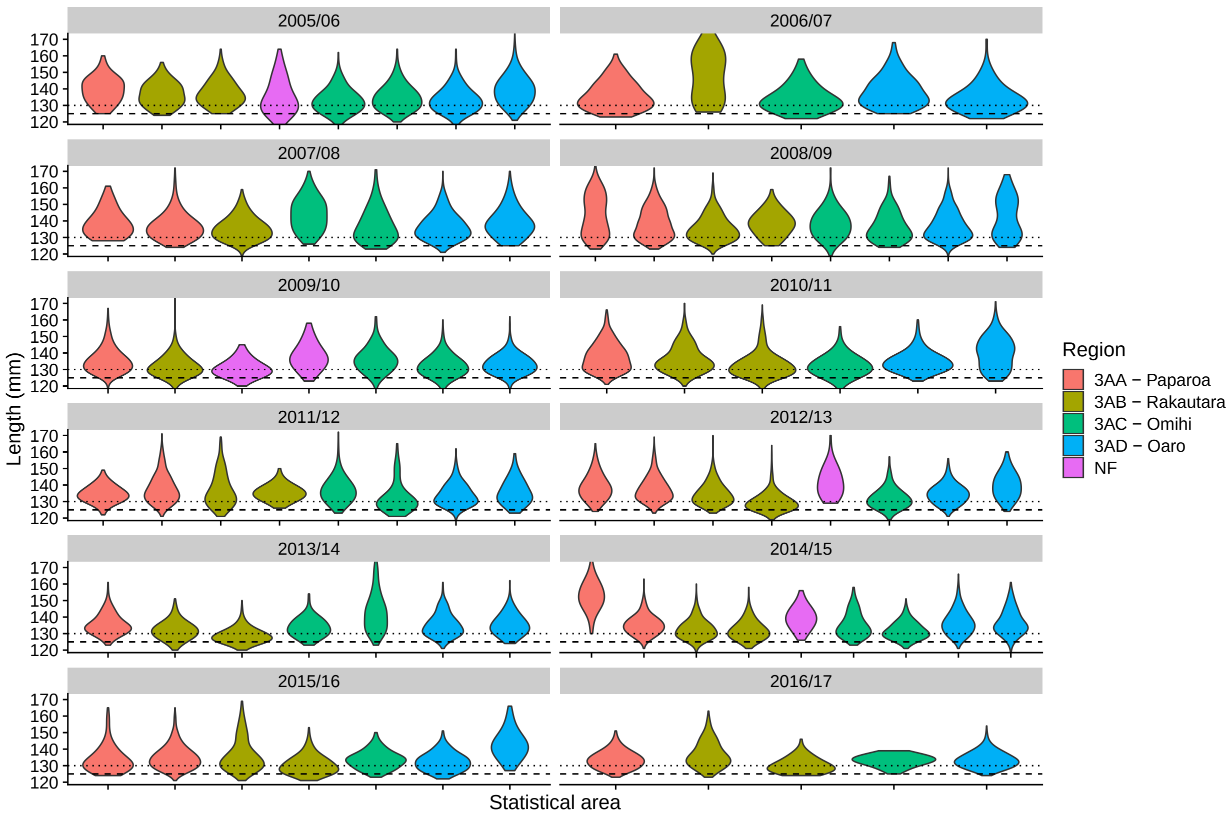

Figure 11: Catch sampling length frequency samples by statistical area (shapes long x-axis) and year; statistical areas are ordered north to south to show geographical trends. Region refers to management zones (NF, zone without current commercial fishing).

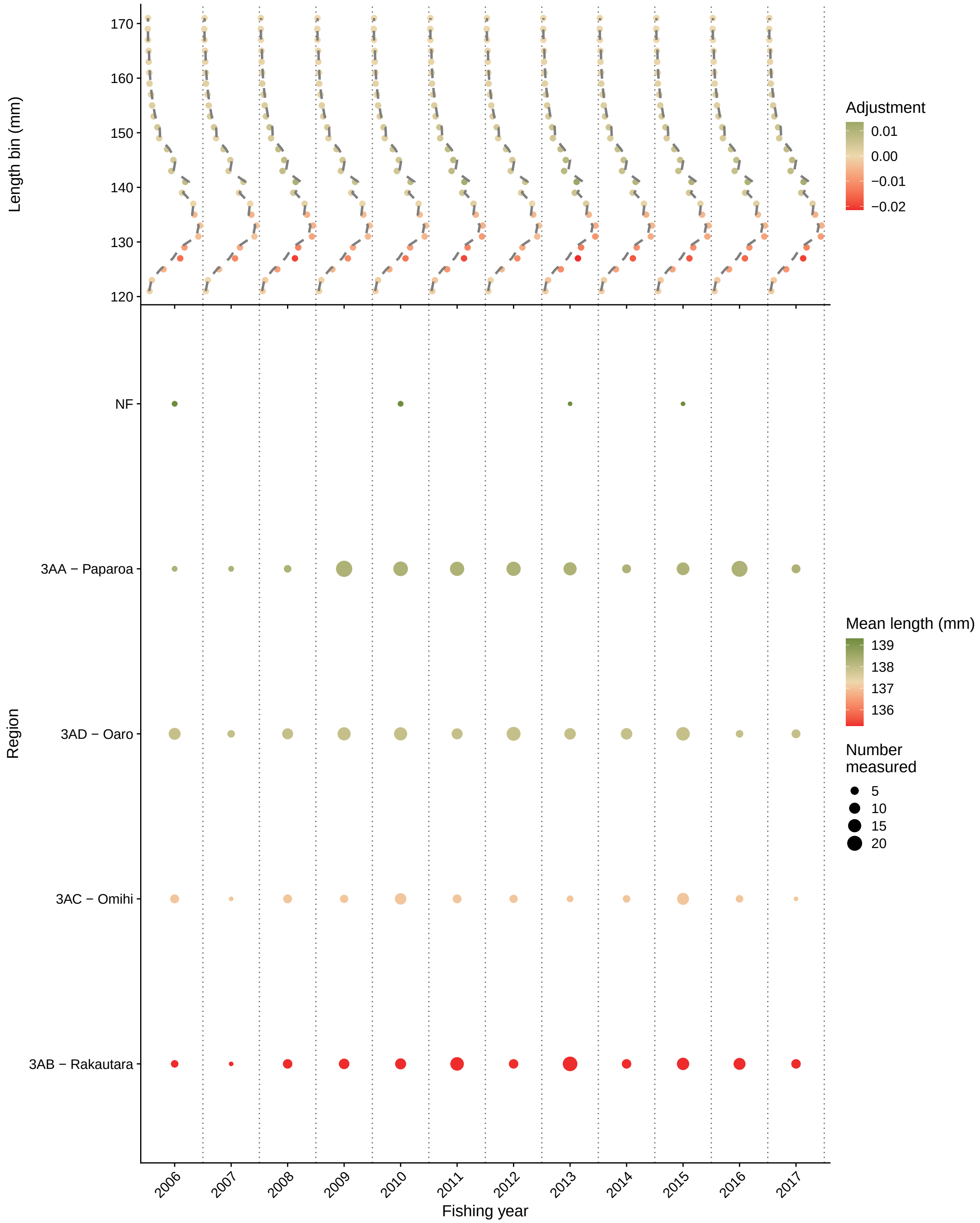

Figure 12: Effects plot for reporting small-scale statistical area (bottom graph) for pāua management area PAU 3A (NF, zone without current commercial fishing). The top panel displays the direction of the adjustment from the raw mean catch sampling length frequency (LF; coloured points for LF classes) in each year and length class in relation to the fishing pattern (shown in the lower panel). Strata in the lower panel are sorted by the observed mean length to allow comparisons of their influence on estimated deviations in the upper panel.

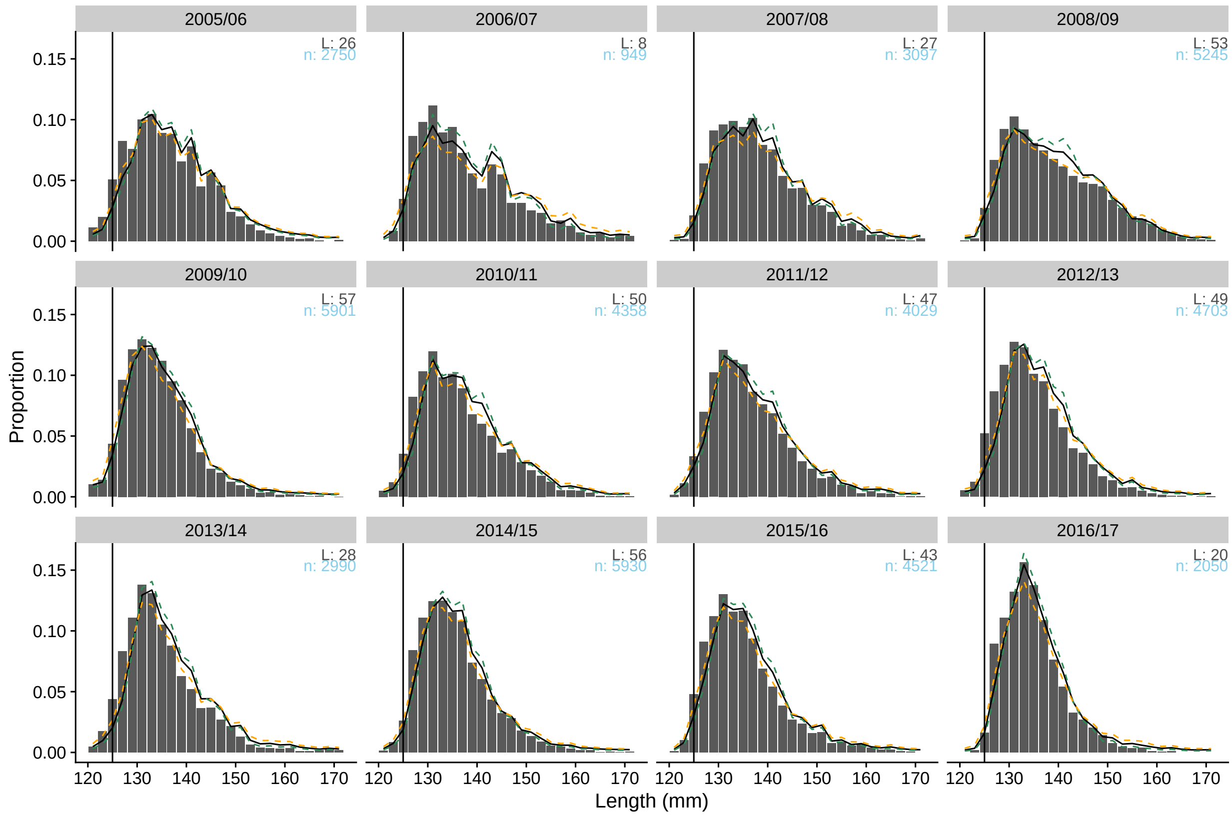

Figure 13: Dirichlet-Multinomial posterior distributions for yearly proportions $\pi_{r,y}$ (black line) in pāua management area PAU 3A, with 95% confidence intervals (green and orange dashed lines). Raw catch sampling length frequency proportions are in grey; number of landings (L) in black; number of measurements (n) in blue.

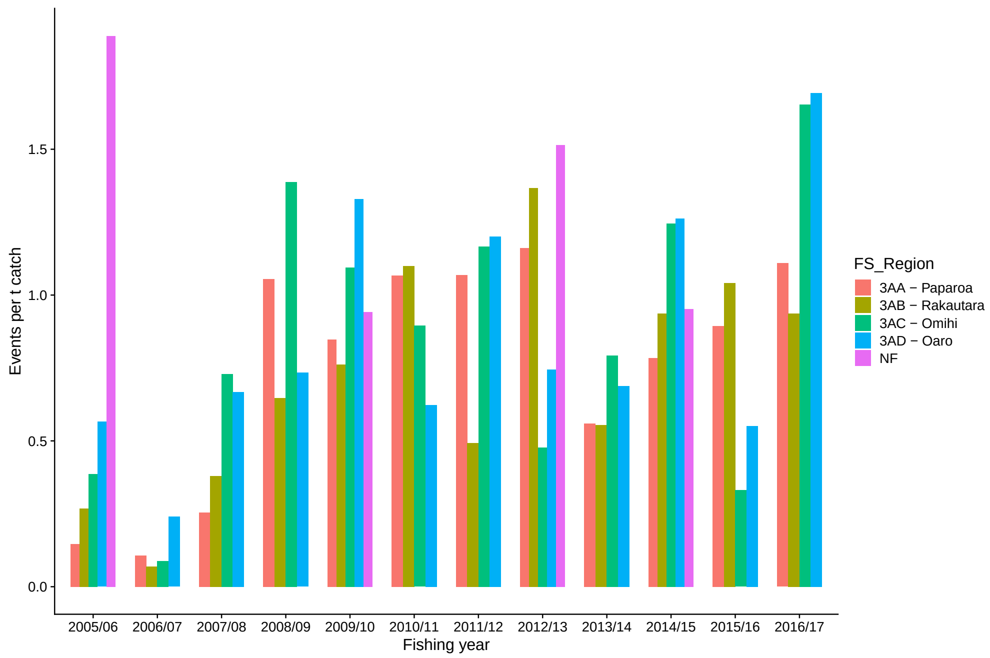

Figure 14: Length-frequency samples per tonne of commercial catch across management zones in PAU 3A since 2006 (NF, zone without current commercial fishing).

2.1.5 Growth and maturation

As for previous assessments and operating models since 2018, data were not fitted from individual growth tagging sites in PAU 3A. Recent developments in pāua growth models suggest that flexible growth models based on energy balance equations (e.g., Ohnishi et al. 2012) can describe observed growth and maturation differences across pāua QMAs (Neubauer & Tremblay-Boyer 2019a).

Similar to other recent stock assessments, an informed prior on growth across QMAs was used for the present models, which was derived from a meta-analysis of pāua growth. It allowed the model to adjust growth in accordance with other sources of information (priors on mortality M, CSLF and CPUE input)(see priors for mean growth and growth standard deviation in Figure 15). At each length l, a proportion $z(l)$ of the population grows according to a log-normal growth prior, and a proportion $(1 - z(l))$ of pāua is located in areas with no growth at length l (i.e., stunted growth at length l; Figures 15 and 16). Maturation was estimated simultaneously with growth in the meta-analysis, but was not found to be linked to growth in the meta-analysis based on available data (Figure 17).

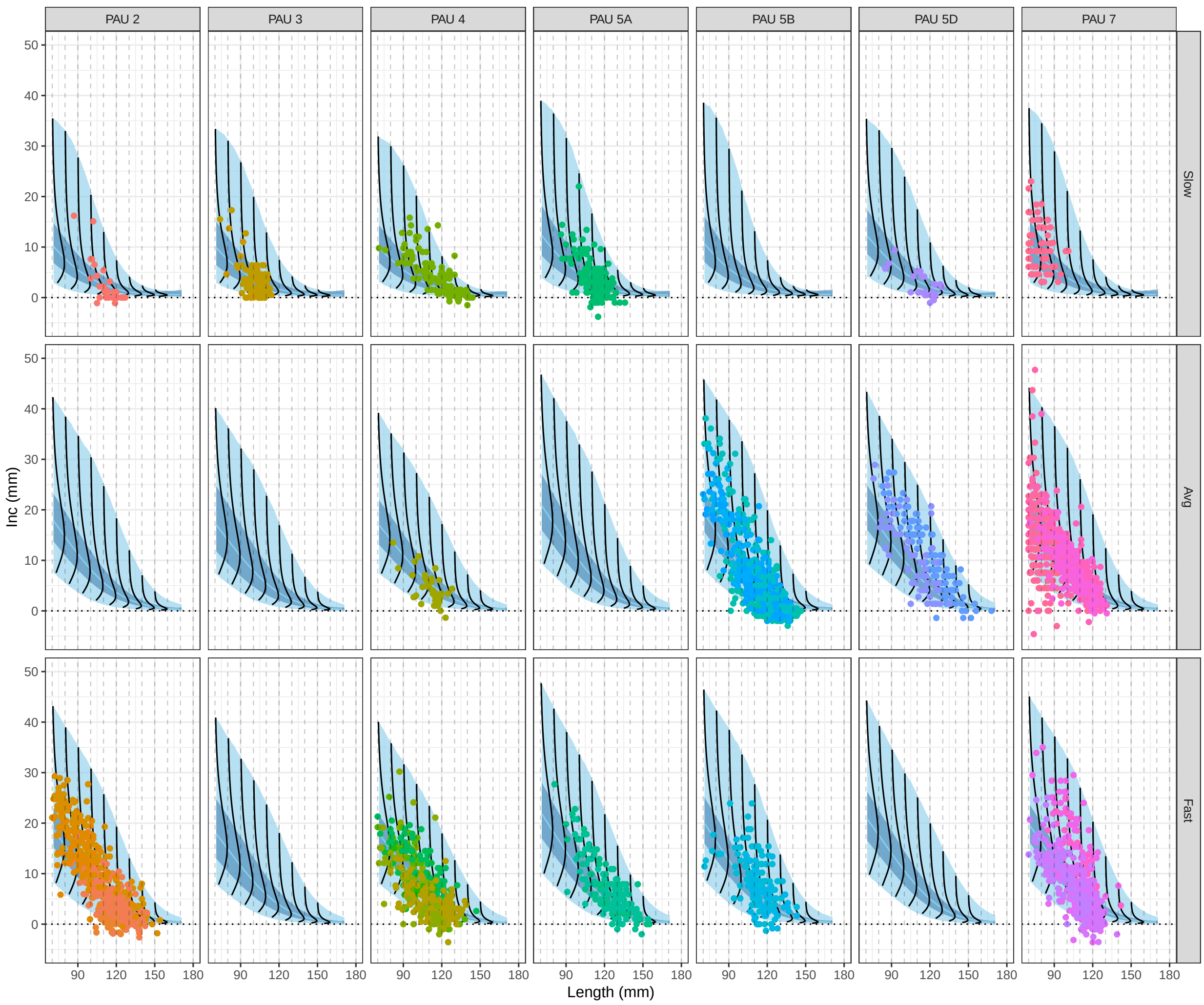

Figure 15: Priors derived from a meta-analysis of growth and maturity of pāua, based on model-fitting to all tag-increment and maturity data across quota management areas (QMAs). Shown is the joint prior for positive growth increments at size l by QMA and growth stratum. Dark blue shading shows uncertainty about mean growth; light blue line indicates posterior median for mean growth; light blue area shows the posterior median for the population standard deviation applied to mean growth; black lines indicate the implied distribution of growth at the median of the prior.

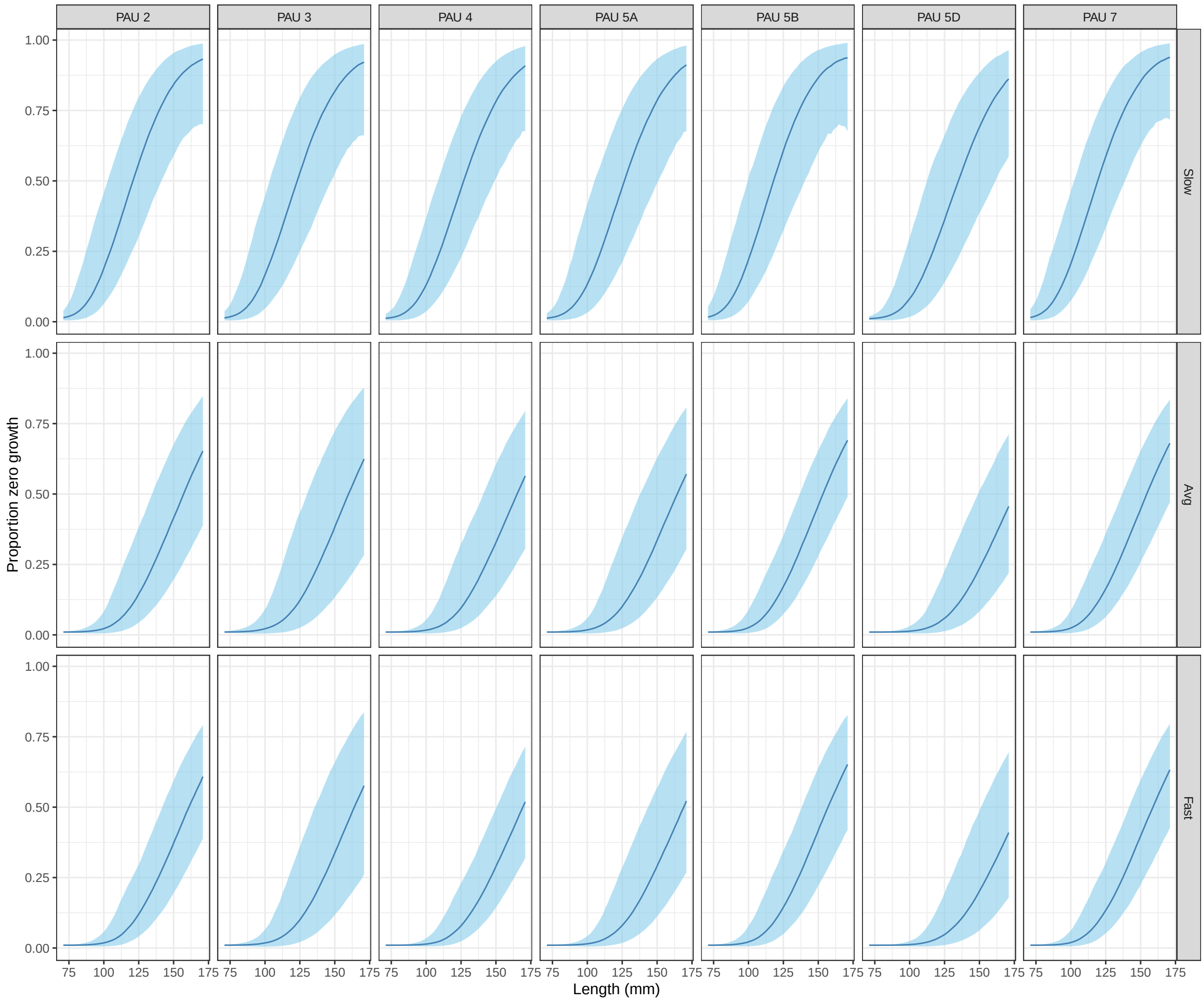

Figure 16: Priors derived from a meta-analysis of growth and maturity of pāua, based on model-fitting to all tag-increment and maturity data across quota management areas (QMAs). Shown is the expected proportion of local populations not growing at size l by QMA and growth stratum.

2.1.6 Survey index and length frequency

Trends during the earthquake closure were assessed using surveys, analysed by McCowan & Neubauer (2023). The analysis used a Bayesian generalised linear mixed model to estimate i) the overall survey year effect, ii) a survey year within management zones A-D, iii) a survey year within QMA effect, and iv) a survey year within site effect. A truncated normal distribution was used 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) in order 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 (BPUE, biomass per unit effort). The full model may be written in the R package brms (Bürkner 2018) as:

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

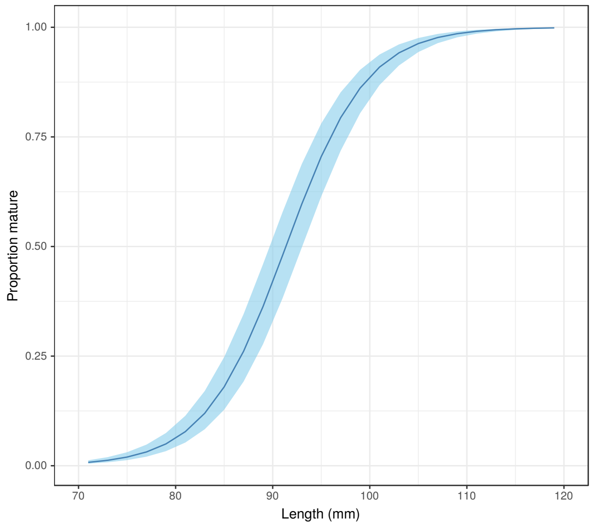

Figure 17: Priors derived from a meta-analysis of growth and maturity of pāua, based on model-fitting to all tag-increment and maturity data across quota management areas (QMAs). Shown is the population level maturity.

Overall pāua density, as approximated by BPUE, increased steadily between the first survey and the 2022 pre-season survey (Figures 18, 19). Although the estimates were uncertain, median estimates suggested an approximate increase of 75% in pāua abundance in PAU 3A zones between the initial and 2022 pre-season periods. The post-season survey recorded lower abundance, although this change may have been due to poor conditions, and may not reflect abundance trends (McCowan & Neubauer 2023).

Survey length frequencies (LFs) were analysed using an extension of the multinomial GLM, which was developed for estimating length frequencies of rock lobster removals (D. Webber, unpublished analysis). The extension here was achieved by factorising the multinomial distribution into independent Poisson distributions for total measurements (N_s) in sample s, and a second Poisson distribution with mean $\lambda_{i,s}$ over draws $n_{i,s}$ for the number of pāua in length category i in sample s. Length proportions π can then be recovered by setting $\pi_i = \lambda_i / \sum_j(\lambda_j)$. This setting allows the formulation as a straightforward Poisson GLM, using the total counts as an offset term. This model can be implemented in brms and efficiently run via:

```
bf(n_is ~ (1|Lcat:Zone:Year/site_code) +
        (1|Lcat:Zone/site_code) +
        (1|Lcat) +
        offset(log(N_s))).
```

The zone-year expected LFs can then be extracted from the model for each length category (Figure 20). The model provided a good fit to the data (Appendix A, Figures A-1 A-2), and provided smoothed estimates relative to raw proportions, which often showed high variability between adjacent length classes.

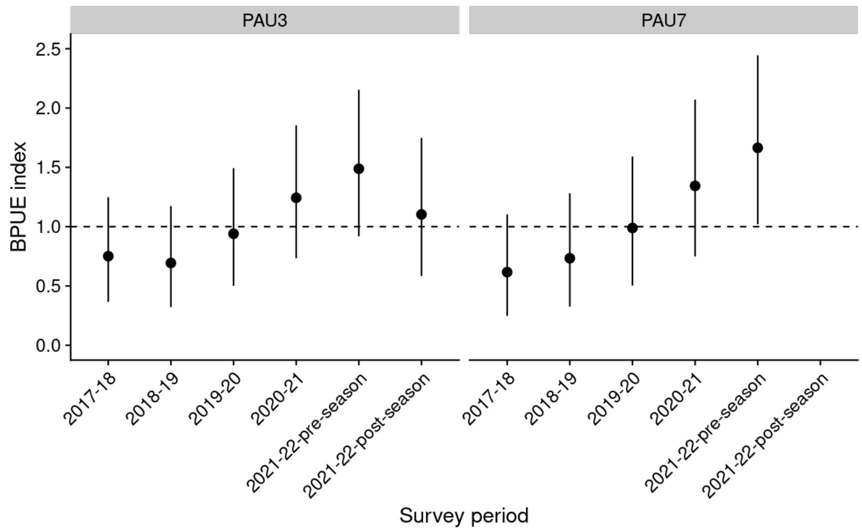

Figure 18: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables. PAU 7 could not be surveyed after the 2021–22 fishing season.

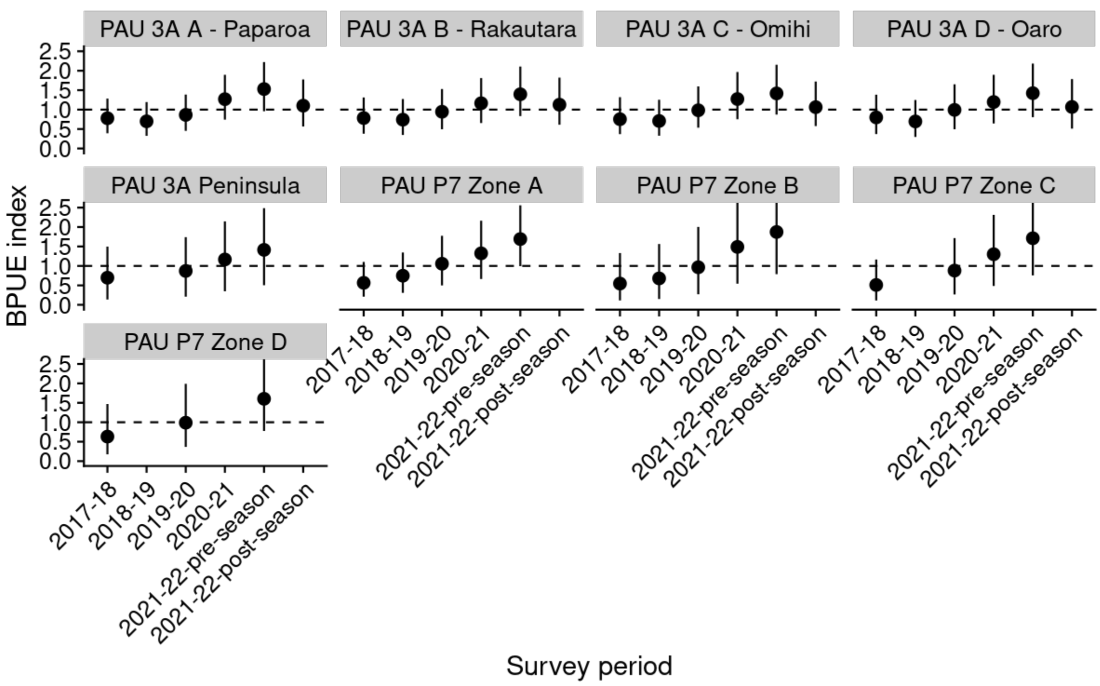

Figure 19: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for management zones in PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables.

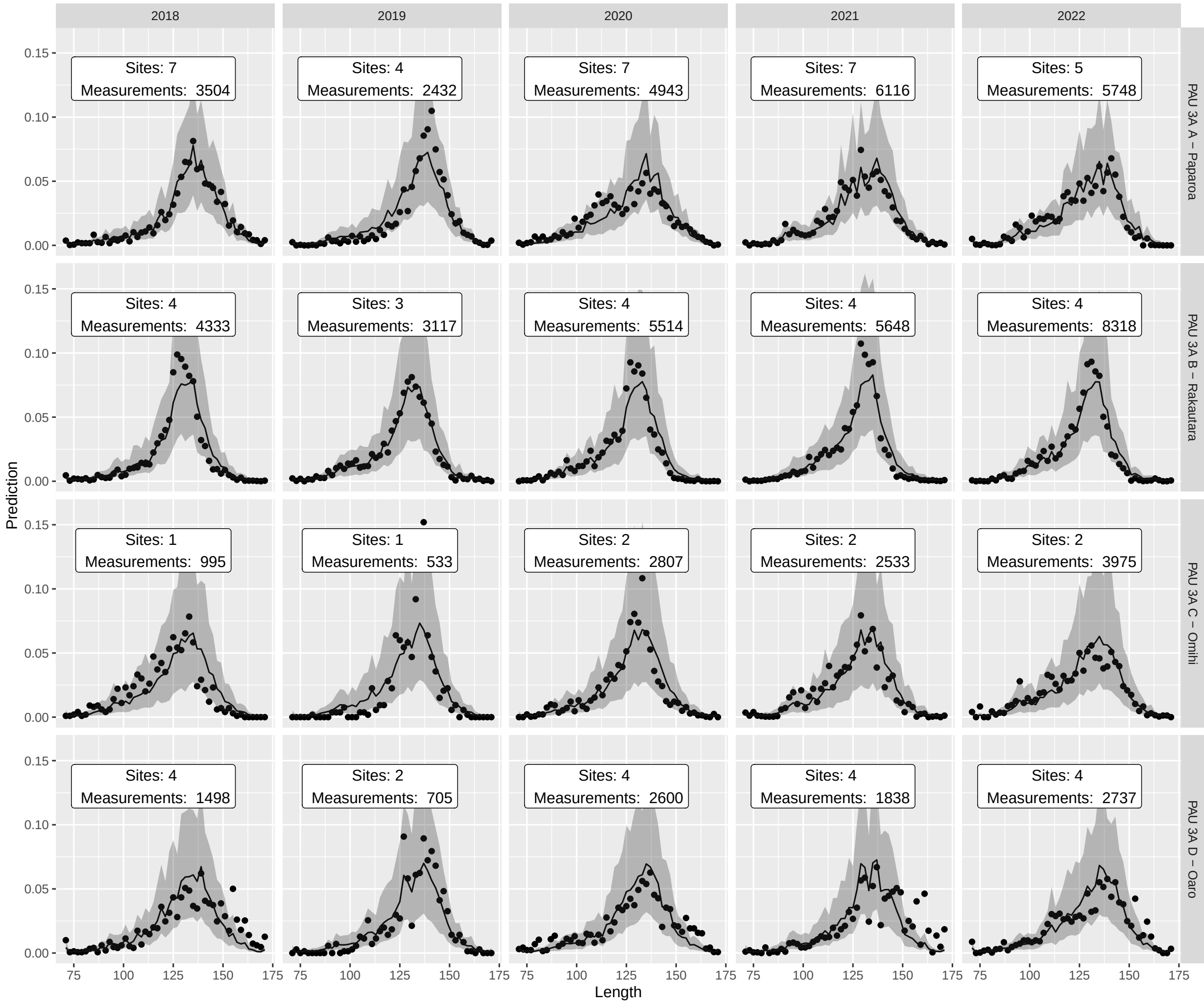

Figure 20: Estimated length distribution at the management zone level for survey years prior to re-opening of the pāua fishery in PAU 3A.

2.2 Assessment model

2.2.1 Model specification

The main pāua population dynamics are described by Breen et al. (2003), but some changes were recently implemented following recommendations by an international expert review panel for the stock assessment (Butterworth et al. 2015). Detailed equations for the most recent version of the population dynamics model are described by Neubauer & Tremblay-Boyer (2019b).

2.2.2 Prior distributions

The CPUE process error was estimated in the model using a half-normal prior distribution (N^0), with prior standard deviation $\tau_{PE_{CPUE}}$:

$$\mathrm{PE}_{\mathrm{CPUE}} \sim \mathrm{N}^0(\tau_{\mathrm{PE}_{\mathrm{CPUE}}}).$$

Similarly, the CSLF process error was estimated in the model using a half-normal prior distribution, with prior standard deviation $\tau_{\mathrm{PE}_{\mathrm{CSLF}}}$.

Recruitment deviations (R_{dev}), equilibrium recruitment (R_0), catchability (log(q)), length at 50% selectivity (D_{50}) and 95% selectivity offset (D_{95}) were assigned log-normal priors, parameterised in terms of mean and standard deviation (sd; on the log-scale), with the sample mean for R_{dev} forced to one (Table 4).

The initial data weighting started with a set of weights that had been found to provide reasonable fits for both CPUE and CSLF data in the spatial stock assessment model for pāua and the stock assessment for PAU 5D (Neubauer & Tremblay-Boyer 2019b, Neubauer 2020).

2.2.3 Technical model details

The model was initialised using equilibrium conditions calculated from the theoretical numbers at length in the absence of fishing. All Markov chain Monte Carlo algorithms (MCMCs) were run using the no-u-turn-sampler (NUTS) implemented in Stan (Stan Development Team 2018). The Stan language is more efficient than conventional Metropolis Hastings or Gibbs sampling for MCMC, and also provides diagnostics that can signal biased MCMC transitions (divergences) and potential bias in estimated quantities from these transitions. All MCMC chains were, therefore, monitored for divergent transitions to ensure that MCMCs

Table 4: Default priors used in the pāua stock assessment model (LN=Lognormal, N=Normal, N^0=half-normal), with prior mean and standard deviation (SD) shown on the log-scale and on the positive scale (CPUE, catch-per-unit-effort; CSLF, catch sampling length frequency).

Parameter	Symbol	Prior	Mean	SD	Mean (pos)	SD (pos)
Equilibrium recruitment	R_0	LN	13	5	1.19×10^{11}	3.19×10^{16}
Recruitment deviations	R_{dev}	LN	0	0.4	1.08	0.45
Natural mortality	M	fixed			0.12	
Catchability	q	LN	-13	100	∞	∞
Length at 50% selectivity	D_{50}	LN	log(123)	0.05	123.15	6.16
95% selectivity offset	D_{95}	LN	log(5)	0.5	5.67	3.02
Steepness	h	fixed				0.9
CPUE process error	$\mathrm{PE}_{\mathrm{CPUE}}$	N^0(0.05)		0.04	0.03	
CSLF process error	$\mathrm{PE}_{\mathrm{CSLF}}$	N^0(1)		0.80	0.6	

were not biased. Initial models were run with four independent chains for the MCMC, and 500 iterations were kept after discarding the initial 500 iterations.

2.3 Stock assessment setup

Stock assessment model runs for PAU 3A were set up using the most recent stock assessment model (Neubauer & Kim 2023). We implemented additional likelihoods for survey index and length-frequency data, which were handled identically to the CPUE index (log-normal likelihood) and catch length frequencies (logistic-normal likelihood), respectively, albeit with no applied selectivity. The model, therefore, assumed that all pāua above the recruitment size classes (70–80 mm) were available to be surveyed.

The model was run with two distinct assumptions: first, the model was run without fitting to the survey information, letting the model predict recovery under the earthquake closure (and under a range of earthquake impacts; see below). Second, the model was run with a large weight on survey observations. The survey length frequencies, in particular, were found to conflict with assumed growth and fishery length frequencies prior to the earthquake. These two model setups, therefore, provided alternative hypotheses about the stock.

2.4 Scenarios for earthquake impacts

The most difficult aspect of setting up a stock assessment model for PAU 3A was representing earthquake impacts and their short- and long-term consequences. Relevant impacts are those affecting productivity and/or its variability. The earthquake could have impacted natural mortality (M), un-fished recruitment (R_0), growth (growth transition matrix), steepness (h), and recruitment variability ($sigma_R$). A detailed evaluation of possible earthquake impacts (Appendix B), led to the representation of earthquake impacts as four scenarios:

1. **No impact**, impact is negligible at the population level. This scenario was included mainly to understand the impact of assumptions about earthquake impacts.

2. **Short-term mortality impact only**, no long-term impact. Mortality was taken as being equal to total uplift for each management zone, calculated as 0.44, 0.23, 0.20, and 0.01 for management zones A to D, respectively (Neubauer (2017)).

3. **Short-term mortality impact, long-term reduction in stock size (R_0).** Mortality was taken as being equal to total uplift, the reduction in R_0 was assumed to be half of total uplift.

4. **Short-term mortality impact, long-term reduction in stock size (R_0).** Mortality and reductions in R_0 were assumed to be half of total uplift.

In addition, all models assumed no connection between populations in management zones, essentially decoupling recruitment and assuming no possible recruitment subsidy from other management zones. From a management perspective, this assumption is prudent; however, to date no genetic differentiation of pāua stocks has been shown over distances such as the distances considered here (10s of km). Preliminary results from genomics (G. Trauzzi, pers. comm.) and particle tracking (P. Couto, pers. comm.) also support scenarios of mixing among sub-stocks along the Kaikōura coastline. For this reason, we added a contrasting model scenario of full mixing of recruitment (i.e., recruitment depends on total spawning stock in the area, rather than the local spawning stock).

2.5 Management procedure evaluation (MPE)

Potential management procedure approaches were determined with commercial fishers at a special meeting in 2021, and refined in conjunction with the Shellfish Working Group. Harvesters suggested that a long-term catch rate of 50kg/h was desirable. Initially, control rules were developed based on adjusting catch to meet the CPUE target. The process adjusted catch according to CPUE trends and absolute CPUE relative to the target. The process, therefore, aimed to find a harvest rate that is associated with a long-term biomass density that produces CPUE of 50kg/h: a constant fishing mortality (F) strategy. Depending on recreational catch levels, the fishing mortality was often zero in the long run, suggesting that commercial take was markedly impacted by recreational take, and high commercial catch rates cannot be achieved at high recreational take. Therefore, optimising commercial catch to achieve a given biomass density (and associated CPUE) is not possible independent of recreational catch control considerations. In addition, constant fishing mortality as a rule was difficult to visualise and explain, and requires annual changes in catch, which are difficult to implement.

To overcome initial difficulties with running MPEs using the constant F rule, the Shellfish Working Group suggested to explore rules which entail less change, based on outcomes of the constant fishing mortality rule. Step rules are part-way between constant F and constant catch control rules (in the limit of infinite plateaus/steps, the rule is a constant F rule, with 0 steps, and a single catch, it reflects constant catch). Therefore, a general proposal was to build control rules based on examples from PAU 5 QMAs, which adopted a set of three-step control rules, centred around a desired catch rate and corresponding catch (Table 5).

Table 5: Parameters used for initial PAU 3A management procedure evaluations: target total commercial catch (TCC) by management zone taken from 2021 PAU 3A annual operating plan, with associated assumed target catch-per-unit-effort (CPUE) and CPUE reference points (in kg/h) for fishery closure, and the CPUE at which a linear increase in catch is taken. All other parameters of the control rules were derived from the targets.

Stat area	Target TCC (t)	Target CPUE (kg/h)	Closure (kg/h)	Linear incr. from (kg/h)
3AA - Paparoa	4.60	50.00	15	80
3AB - Rakautara	6.90	50.00	15	80
3AC - Omihi	5.75	50.00	15	80
3AD - Oaro	5.75	50.00	15	80

The tested rule for PAU 3A was developed assuming a $\pm 20\%$ increment for steps around a 50kg/h target CPUE, with the agreed catch (23 t split into management zones) for the 2021–22 season set as the mid-plateau of the control rule for each management zone (see Figures 21, 22, Table 5). Control rules were scaled such that areas with low (high) CPUE (i.e., more than 20% deviation) relative to the target were placed on the low (high) plateau (see Figure 22 for an illustration). Given uncertainty about recreational catch developments (with recreational catch exceeding commercial catch), the tested control rules, therefore, respond to the question "if current settings remain unchanged over a range of CPUE plateaus, does the fishery incur risk over the time frame over which the rule is in place (e.g., 3 years)?".

Recreational catch developments were modelled using two sets of assumptions:

1. Recreational catch declines directly proportionally, or as a square or cube of available biomass (above the Minimum Legal Size of 125 mm). These scenarios explored the short-term trade-offs between recreational catch and commercial catch levels as the fishery develops.

2. Recreational catch is fixed at 0, 10, 15 and 20 tonnes. These scenarios explored the trade-off between commercial and recreational catch over longer timescales.

In all cases, recreational catch was allocated to management zones using proportions approximately reflecting area take found by Holdsworth (2022). The spatial allocation of this take did not change over the course of the simulations.

Due to considerable uncertainties about stock trajectories, recreational catch over the short-medium term, and earthquake impacts, only one set of commercial fishery control rules was evaluated. Catch splits between management zones were assumed to be consistent with control rules, with catch fully aligned with control-rule assigned catch (i.e., catch exactly matched the spatial allocation). Although this aspect is not the case in practice, the level of compliance with spatial control rule settings is difficult to predict. For this reason, it was assumed that the control rules were implemented without variation in spatial catch. The CV of CPUE observation error was based on the residual error in CPUE in recent stock assessments, and was assumed to be 10%. Applying the management procedure evaluation with a CV of 20% did not notably affect outcomes, other than slightly increasing long-term risk.

The control rule was tested for a validity period of three years, with simulations projecting the stock for 20 years to ascertain long-term performance of the control rule. In addition, all simulations assumed recruitment with no auto-correlation. Periods of prolonged below-average recruitment would significantly degrade fishery performance. For this reason, any indication of poor recruitment periods should lead to a review of the operating model assumptions and control rules. The evaluation performed here assumed a starting point based on recent conditions; however, implementation starting from a markedly different starting point (i.e., a lower starting point due to delayed implementation) would affect risk estimates, so that the control rule should be re-evaluated.

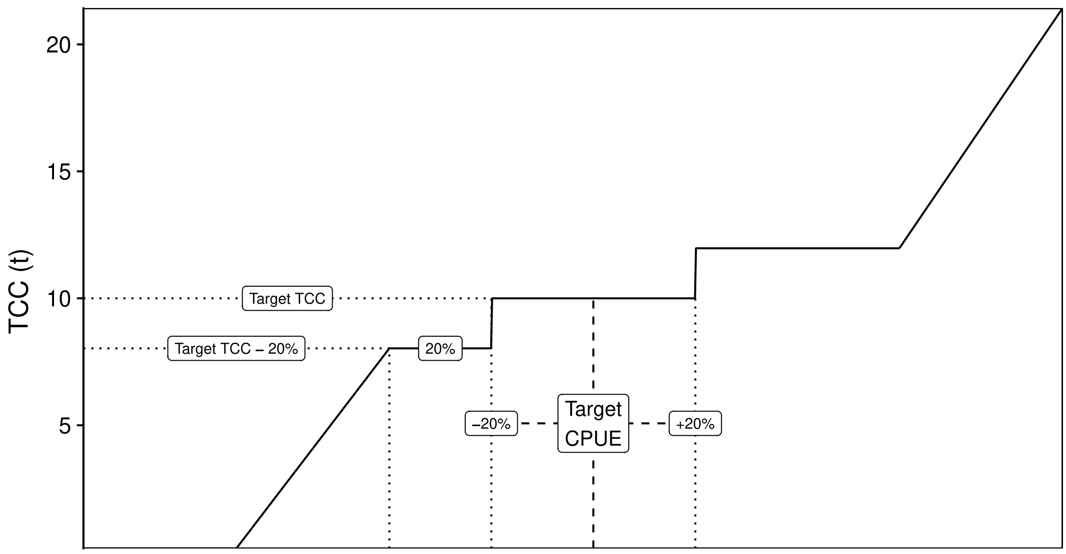

Figure 21: Conceptual graph of harvest control rules proposed for PAU 3A, illustrated for single arbitrary zone with a target catch of 10 t: control rules show total commercial catch (TCC) as a function of catch-per-unit-effort (CPUE), including key parameters. The latter include the width of the target plateau for expected CPUE and for natural variation around the target (here 20% of target), a lower buffer (20% of target), and catch and catch increments corresponding to the target and limit catch rates.

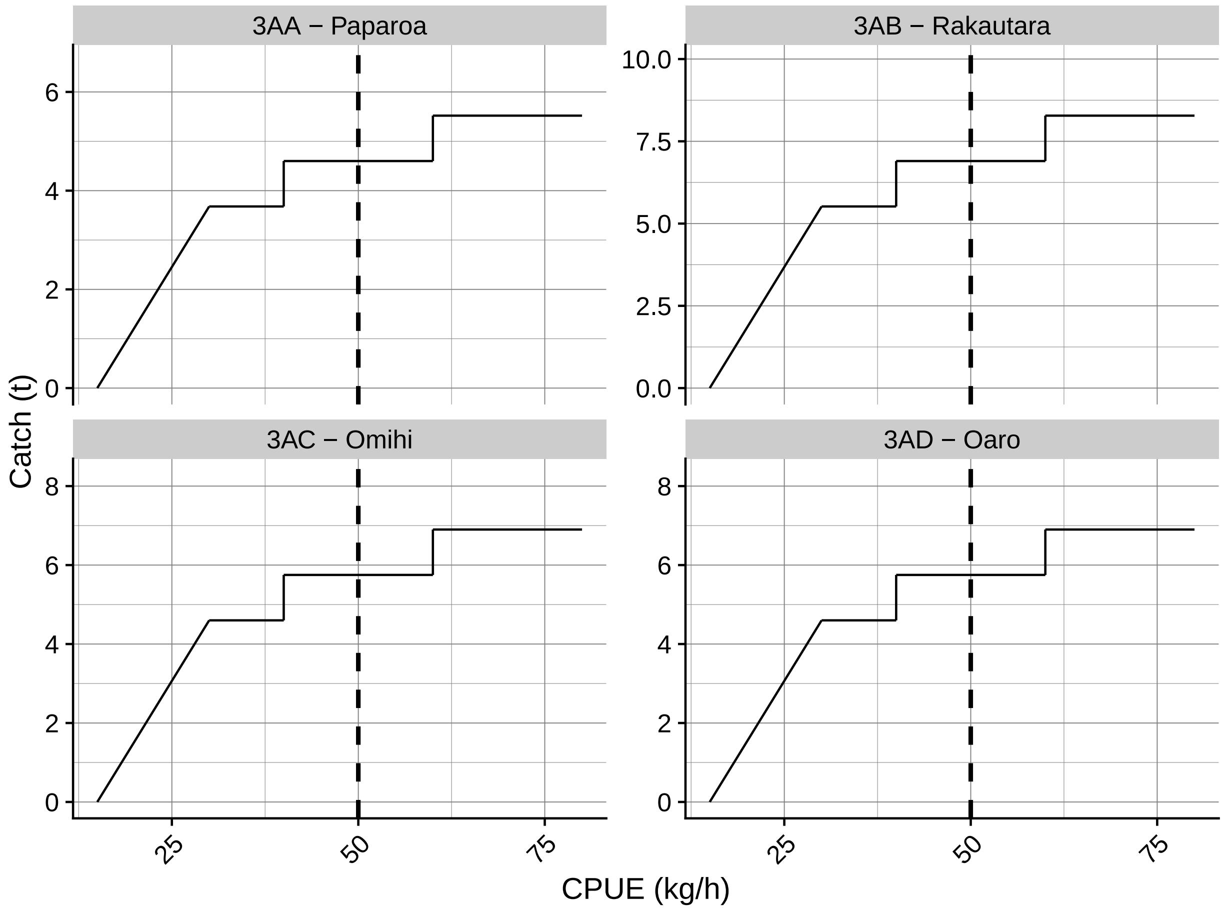

Figure 22: Harvest control rules proposed for PAU 3A (by management zone): total commercial catch (TCC) as a function of catch-per-unit-effort (CPUE). Target CPUE is shown as the dashed vertical line.

3. RESULTS

3.1 Stock assessment and earthquake impacts

Stock assessment models converged under all assumptions except for models with full connectivity between local stocks. These models are therefore not further considered here. While all remaining models were able to fit fishery observations, two key uncertainties were 1) fitting (or not) to survey observations and 2) the assumptions about earthquake impacts.

Survey information was used to compare between models not fitted and explicitly fitted to surveys. For the latter set of models, length frequencies from surveys were given great weight relative to fishery LFs (5x) to force a fit to survey length frequencies. As a result, models mainly differed in their fit to survey LFs (Figure 23), whereas fits to CPUE and commercial length frequency data were relatively similar (Figures 24, 25). Differences in survey fits were especially pronounced at Rakautara, where models not fitted to survey data were not able to predict survey LFs. The fit for models using survey information was achieved by adjusting productivity, estimating consistently lower growth than models without survey information (Figure 26). This adjustment led to estimates of higher total biomass in all areas (Figures 27, 28), as well as differing recovery trends since 2016: models not including survey LFs suggested a strong increase in biomass post-earthquake fishery closure, whereas models fitted to survey information showed a more dome-shaped response post earthquake, with little overall improvement. Post-earthquake biomass in these models remained below 2016 levels in aggregate (i.e., summed across management zones). This difference to models not using survey information was determined by the relatively subtle trends in survey

LFs (which were given high weight), and which did not match the survey indices showing strong recovery.

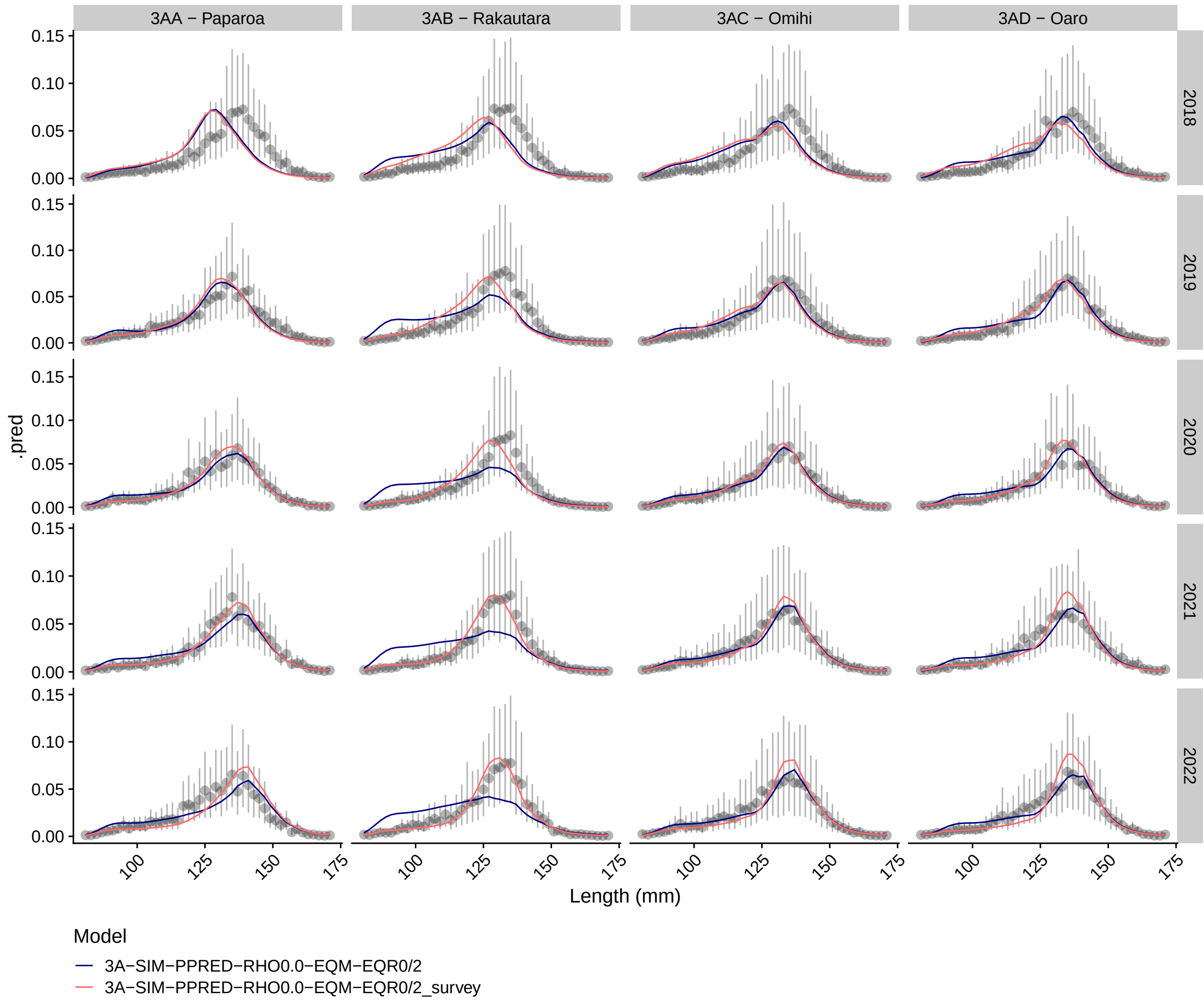

Figure 23: Fits to survey length-frequency data under two models by management zone in PAU 3A, fitted (or not) to survey observations (_survey; EQM - natural mortality from earthquake directly scaled with uplift; EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

Different assumptions about earthquake impacts had relatively small effects on fits in all areas except Paparoa, the area with the highest uplift and, therefore, the highest impacts. The model with no assumed impact was not able to fit the survey index of abundance (Figure 29), whereas different impact assumptions improved fits to survey indices (but did not change fits to survey LFs). Fits to survey LFs were poor in all areas in 2017–18 (Figure 30), with model expectations of smaller individuals contrasting with the size of individuals found in the surveys. Fits to commercial LFs were also hardly impacted by assumptions about earthquake impacts (Figure 31).

The main difference in assumptions about earthquake impacts was manifested in estimated growth (Figure 32), which was faster for models with higher assumed instantaneous mortality, especially in Paparoa and Rakautara. Consequentially, these models had lower spawning biomass and relative status at the final time step of the models in 2022 (Figures 33, 34).

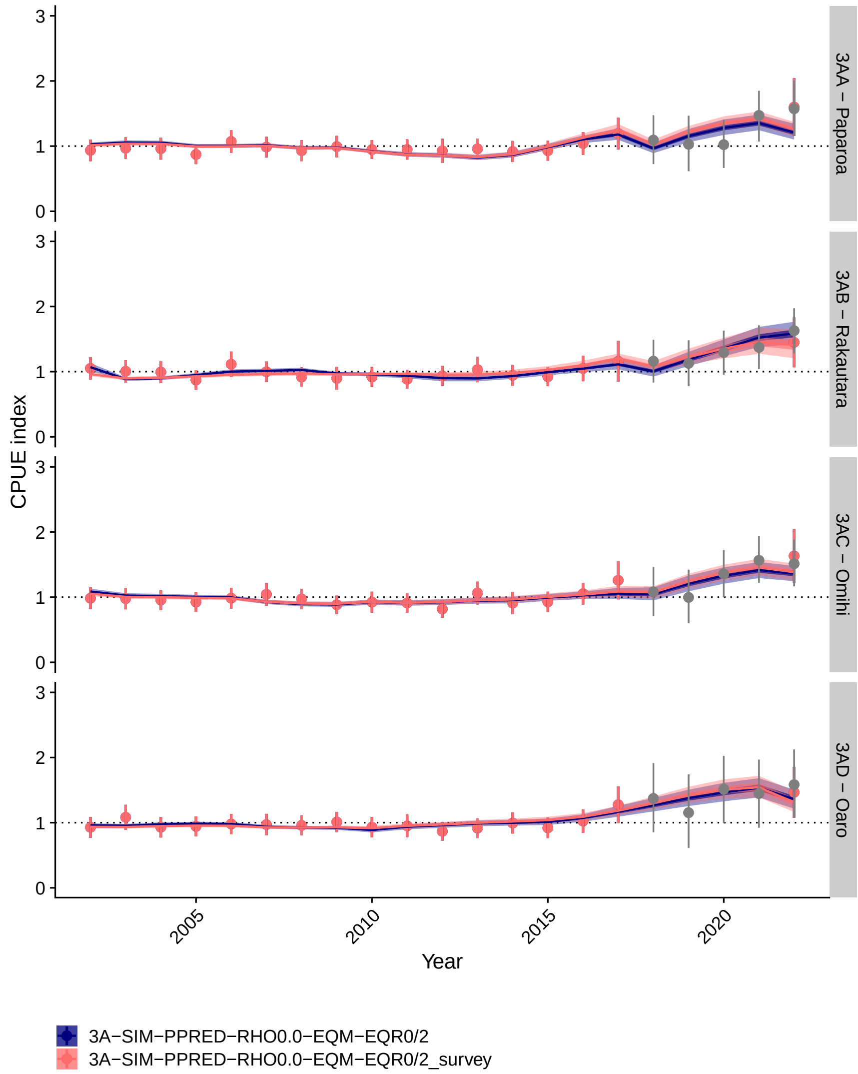

Figure 24: Fits to catch-per-unit-effort (CPUE) under two models by management zone in PAU 3A, fitted (or not) to survey observations (_survey; EQM - natural mortality from earthquake directly scaled with uplift; EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

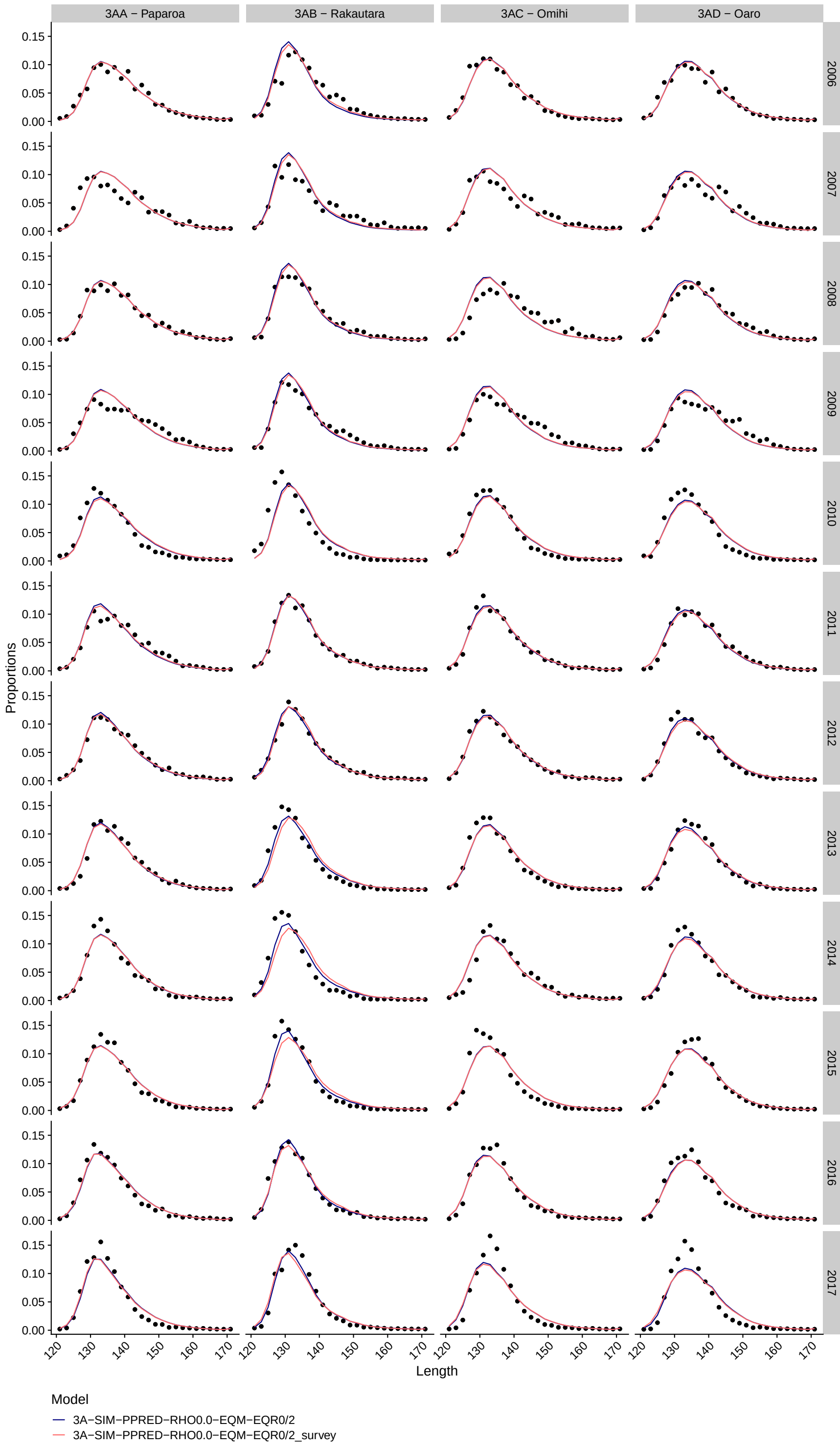

Figure 25: Fits to commercial catch sampling length frequencies under two models by management zone in PAU 3A, fitted (or not) to survey observations (_survey; EQM - natural mortality from earthquake directly scaled with uplift; EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

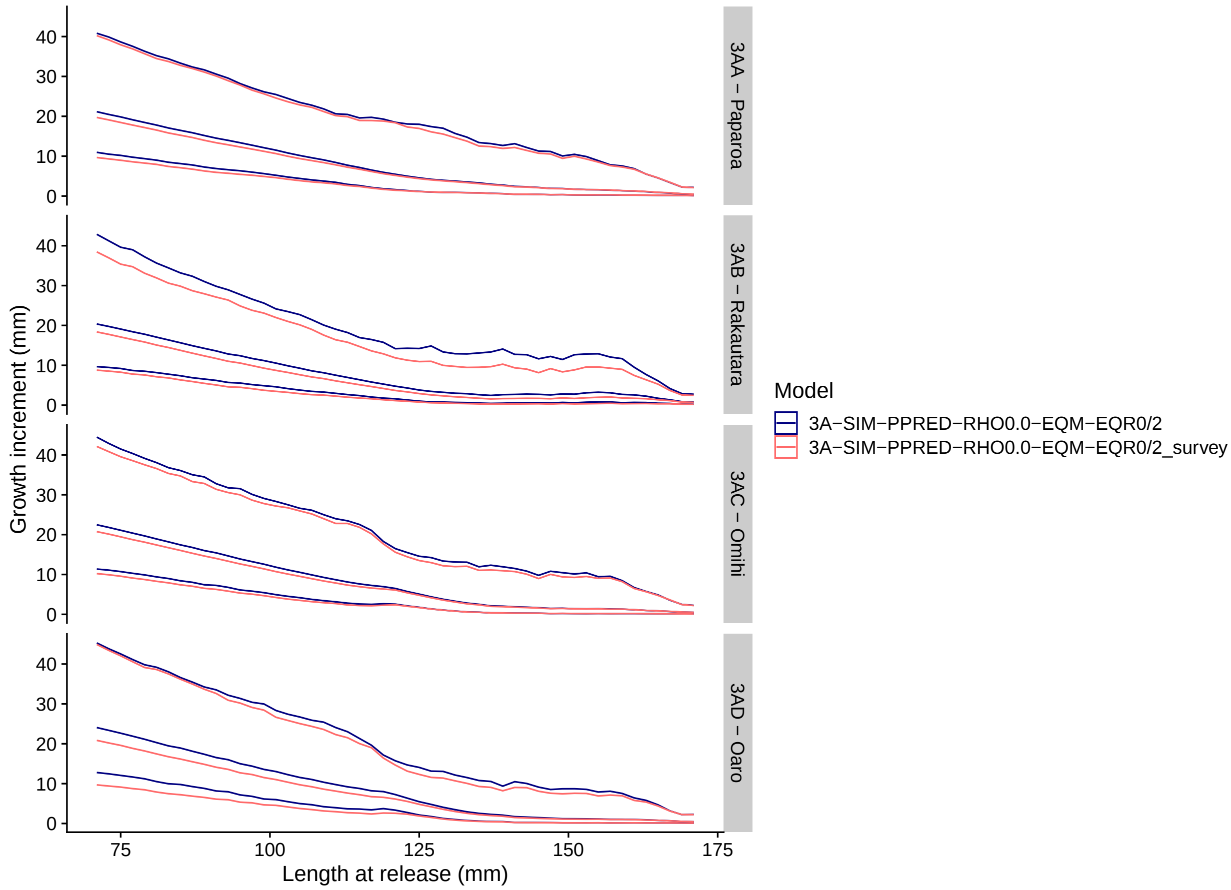

Figure 26: Estimated population level mean growth increment at length under two models by management zone in PAU 3A, fitted (or not) to survey observations (_survey; EQM - natural mortality from earthquake directly scaled with uplift; EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

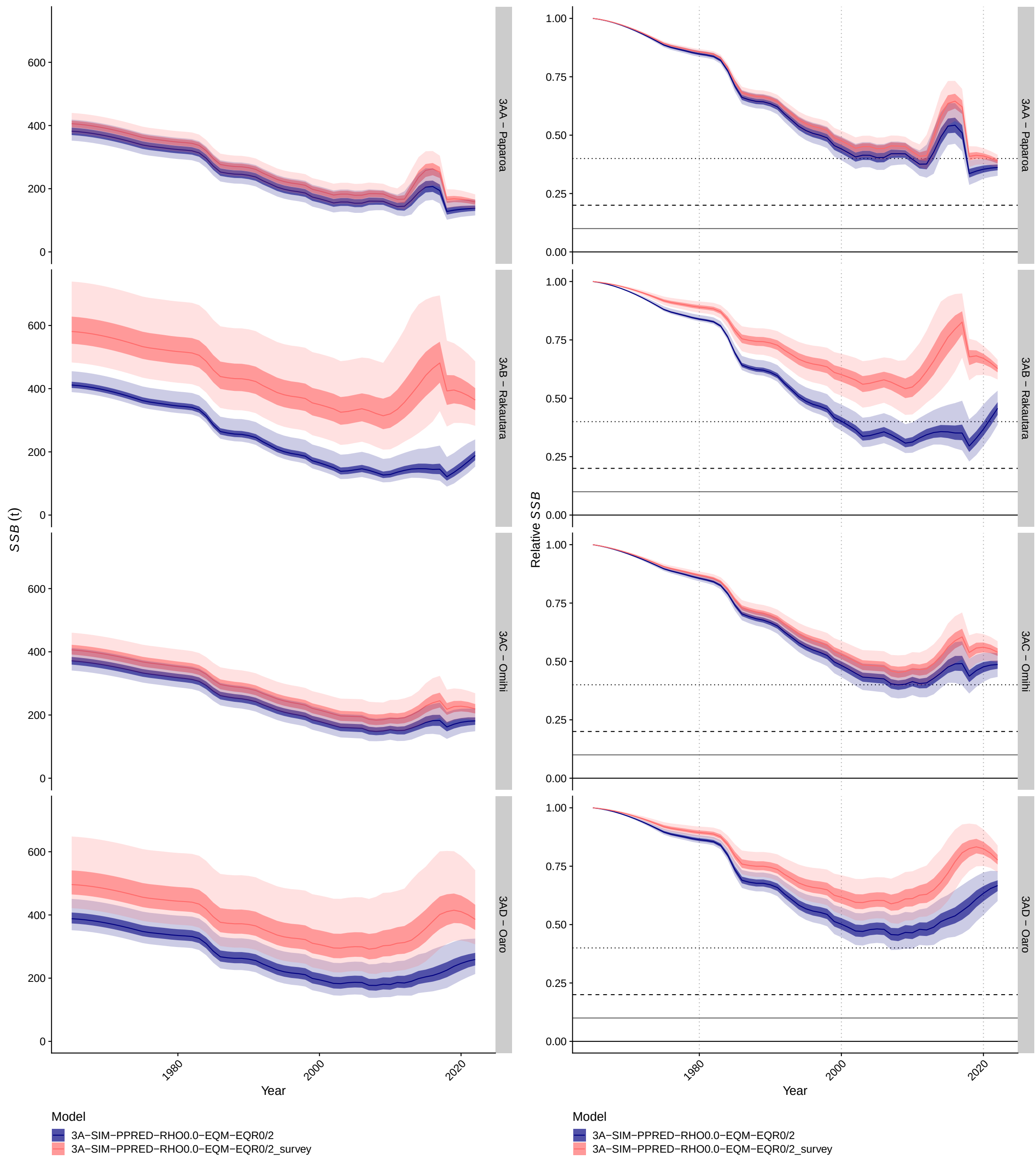

Figure 27: Spawning stock biomass (*SSB*), total (left) and relative (right) for two models by management zone in PAU 3A, fitted (or not) to survey observations (_survey; EQM - natural mortality from earthquake directly scaled with uplift; EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

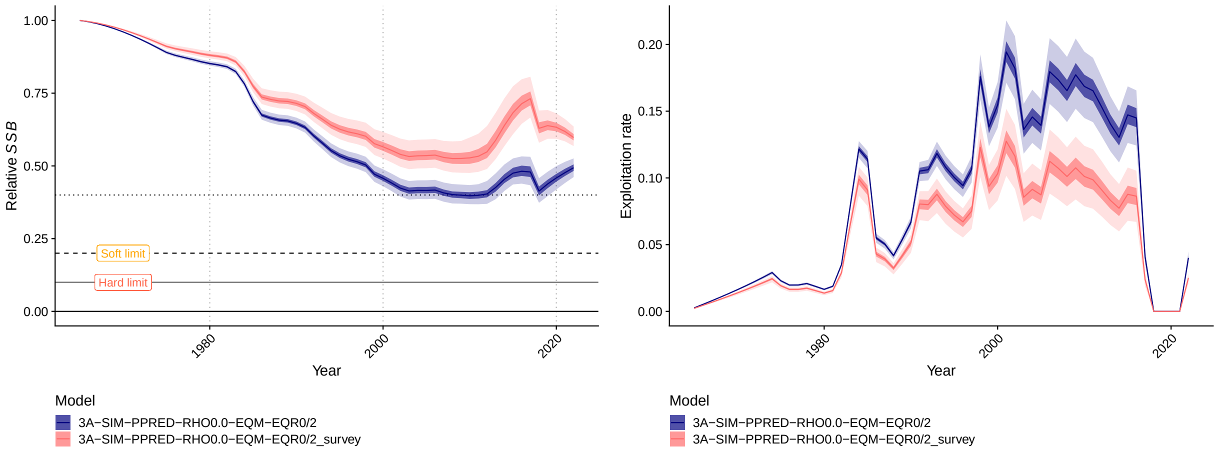

Figure 28: Relative spawning stock biomass (*SSB*) and exploitation rate for two models for PAU 3A, fitted (or not) to survey observations (_survey; EQM - natural mortality from earthquake directly scaled with uplift; EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

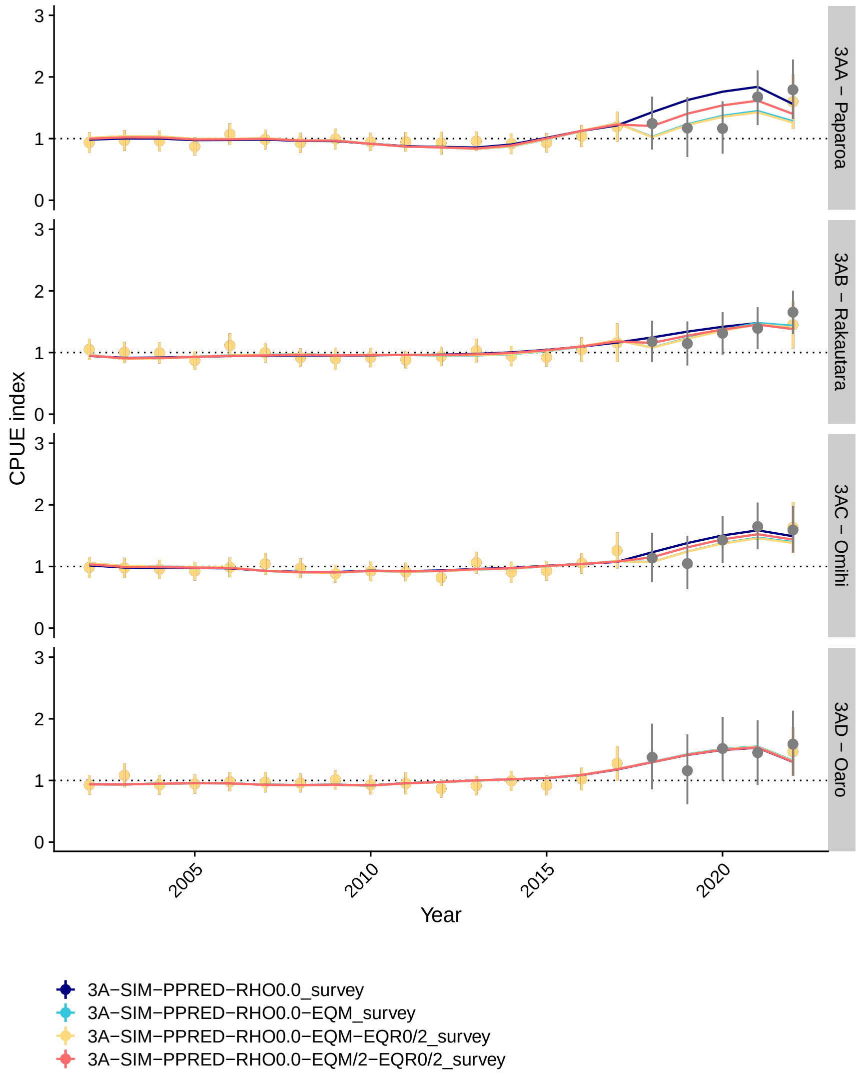

Figure 29: Fits to catch-per-unit-effort (CPUE) under models fitted to survey observations (_survey) under different assumptions about earthquake impacts by management zone in PAU 3A (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by two); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

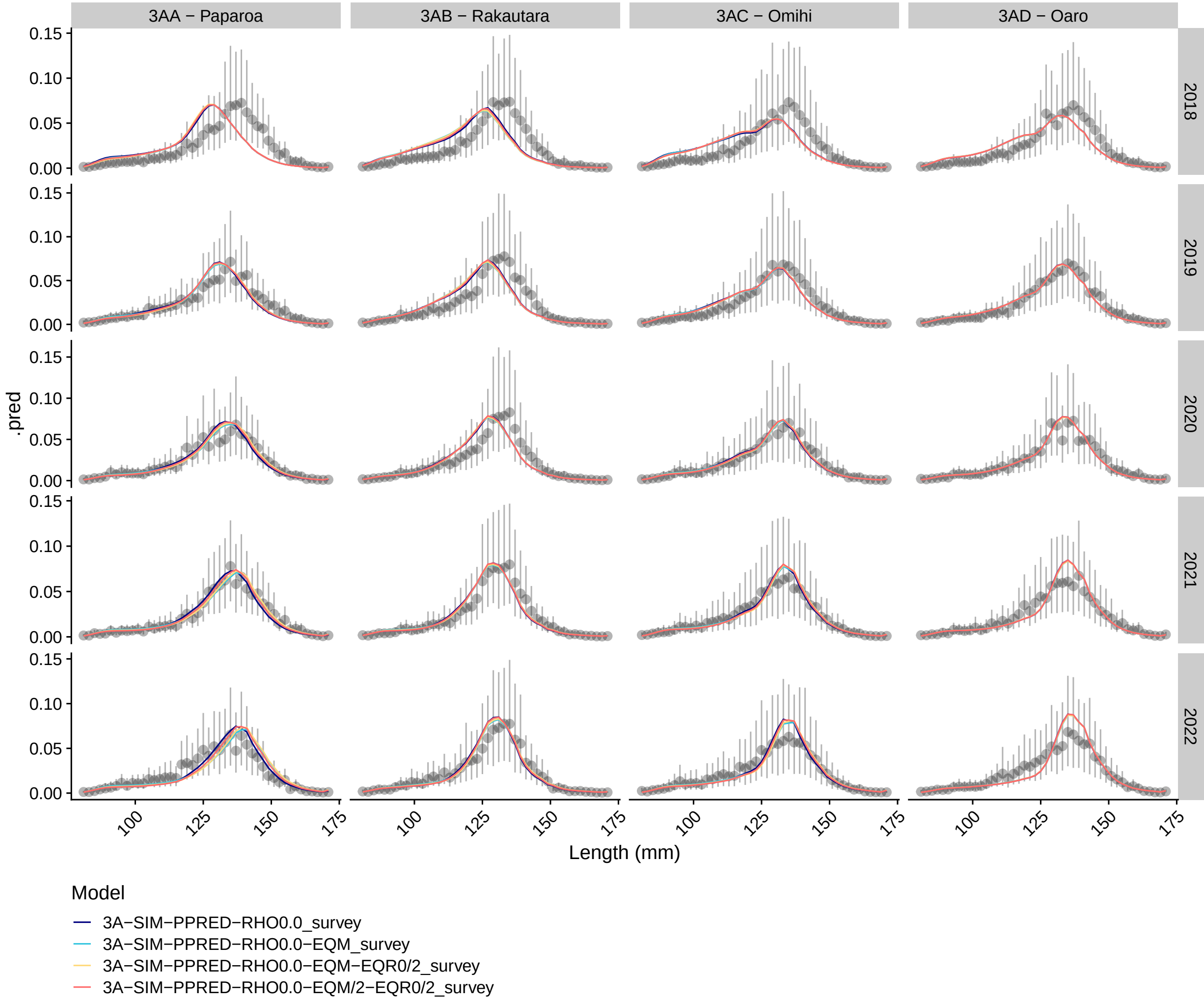

Figure 30: Fits to survey length frequency data under models fitted to survey observations (_survey) under different assumptions about earthquake impacts by management zone in PAU 3A (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by two); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

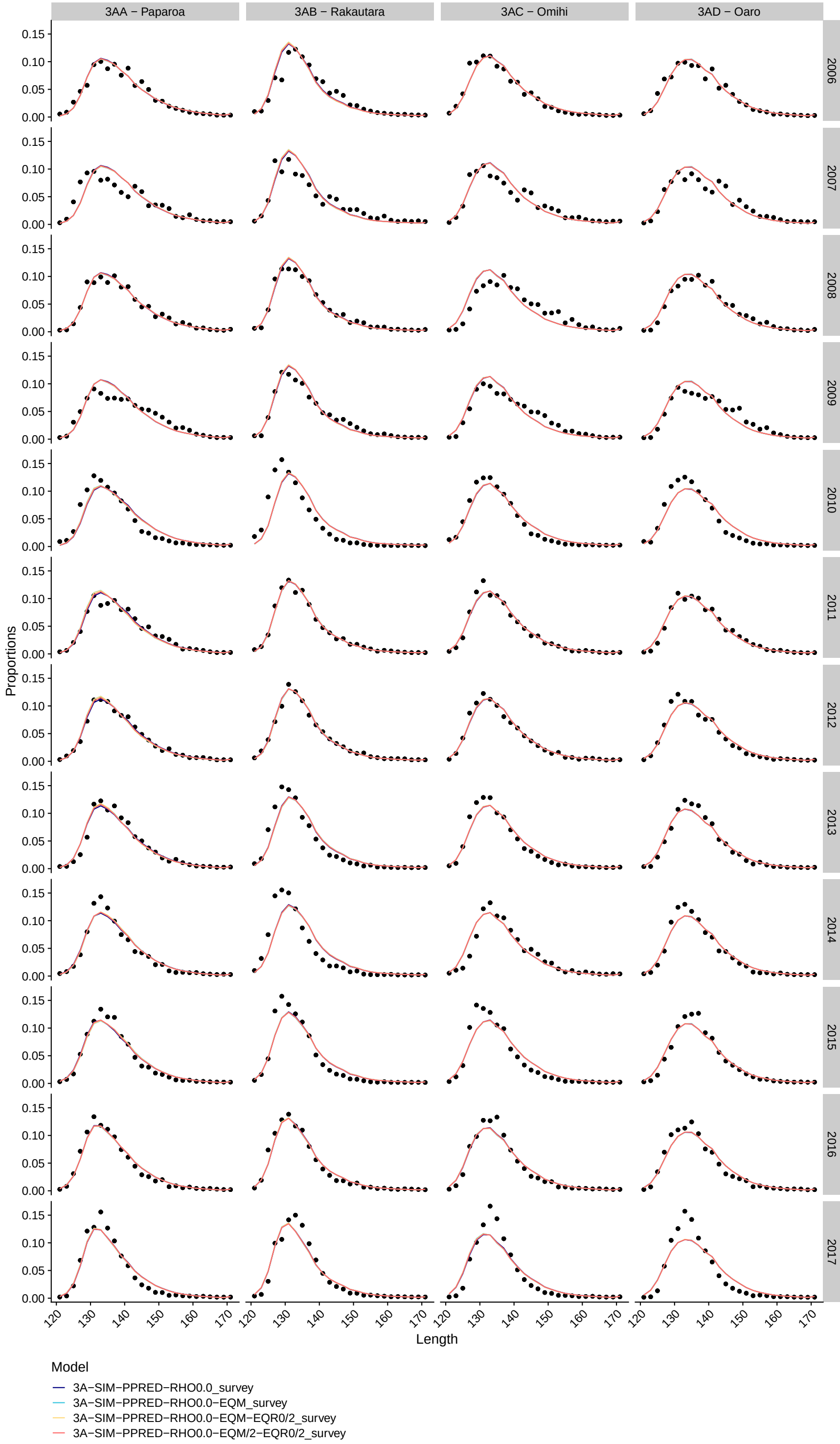

Figure 31: Fits to commercial catch sampling length frequencies under models fitted to survey observations (_survey) under different assumptions about earthquake impacts by management zone in PAU 3A (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by two); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

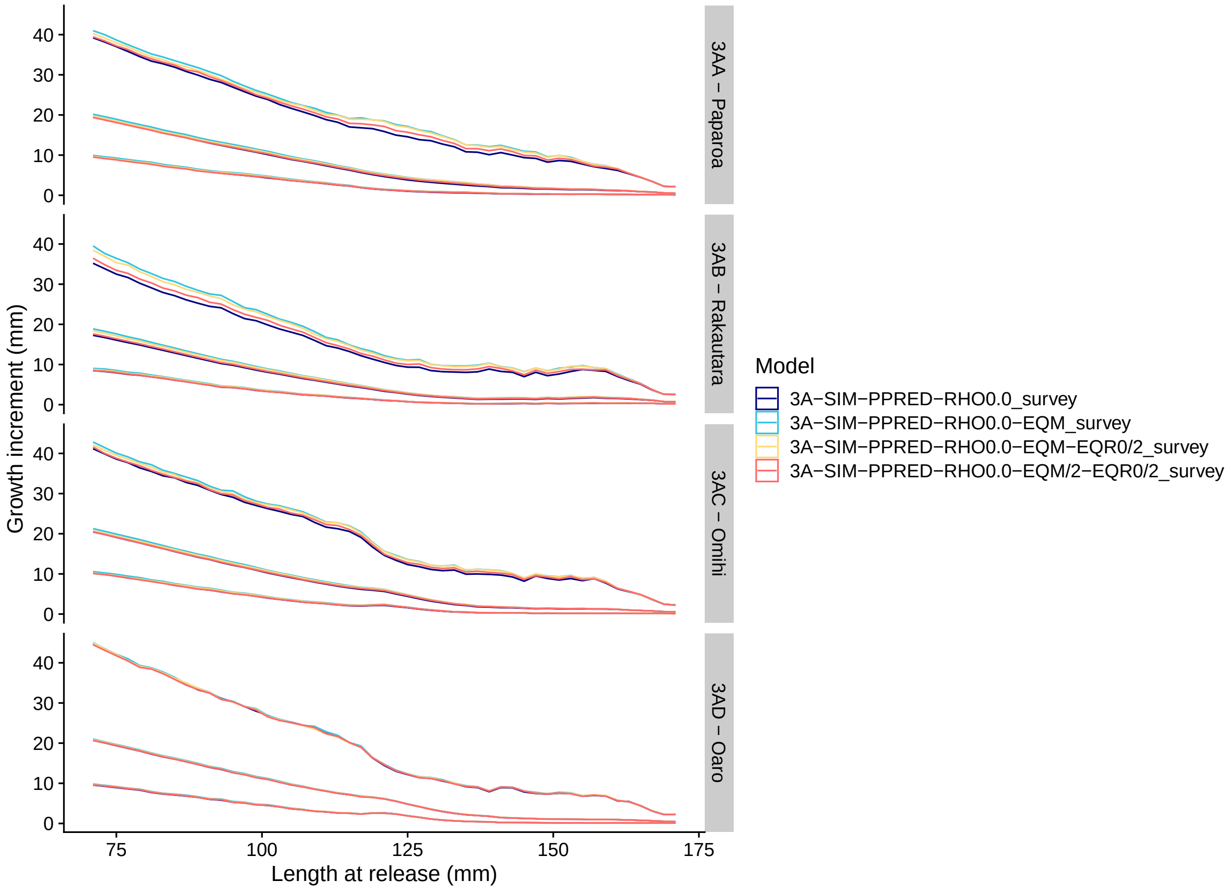

Figure 32: Estimated population level mean growth increment at length under models fitted to survey observations (_survey) under different assumptions about earthquake impacts by management zone in PAU 3A (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by two); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

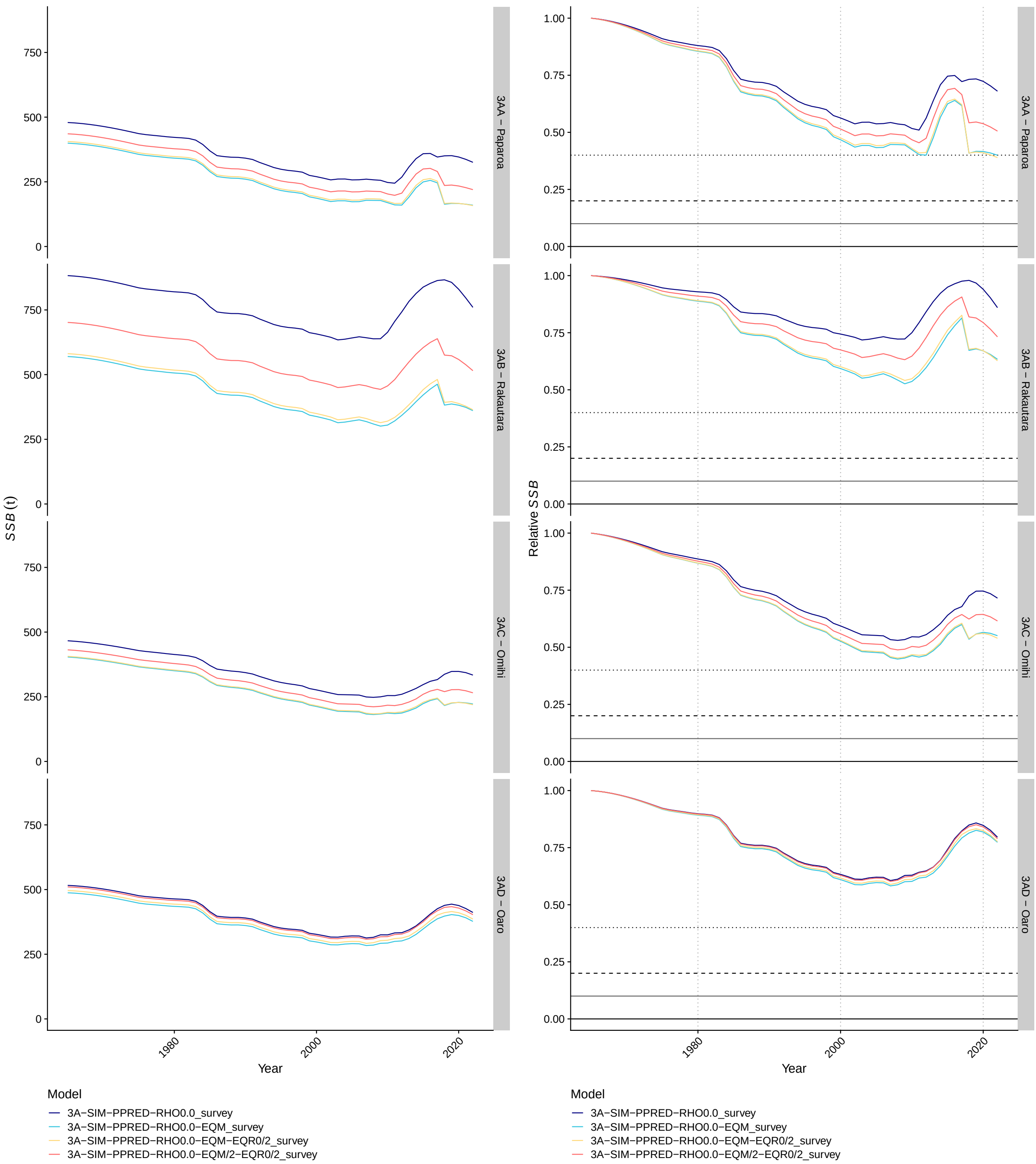

Figure 33: Spawning stock biomass (*SSB*), total (left) and relative (right) for models fitted to survey observations (_survey) under different assumptions about earthquake impacts by management zone in PAU 3A (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by two); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

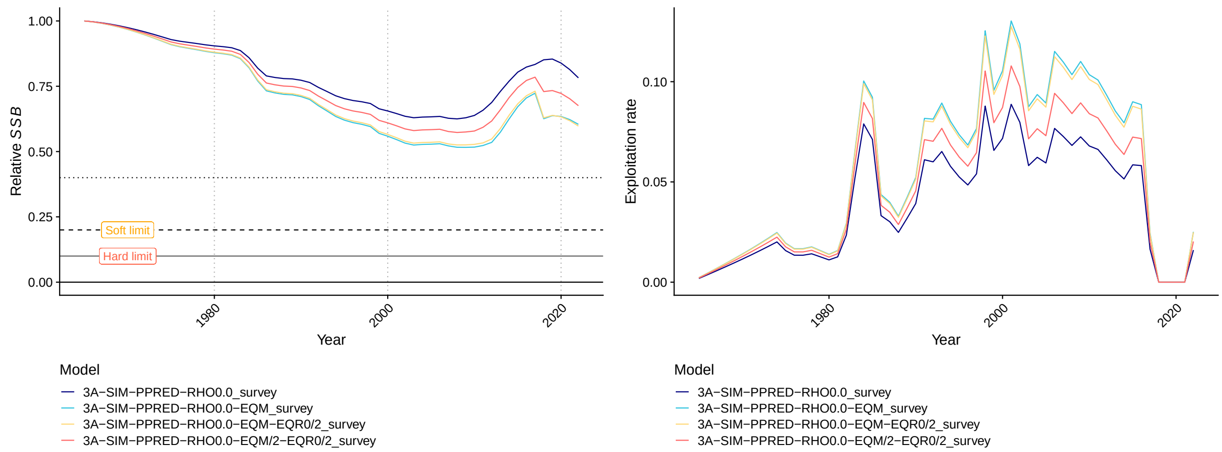

Figure 34: Relative spawning stock biomass (*SSB*) and expoitation rate for models fitted to survey observations (_survey) under different assumptions about earthquake impacts by management zone in PAU 3A (EQM - natural mortality from earthquake directly scaled with uplift,; EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2).

3.2 Operating models and management procedure evaluation

The model with high assumed instantaneous earthquake mortality (labelled EQM in figures), and ongoing reductions in unfished recruitment (R0/2) was used as the base operating model to explore management trade-offs, and explore management options under the highest assumed impacts (full diagnostics for these models, fitted and not fitted to survey indices, are provided in Appendices C and D). Robustness to alternative impact models was also tested, but key scenarios about recreational catch were explored on the basis of the high-impact models only.

Three key uncertainties were explored in the present project in terms of their impact on short-medium term (1–3 years) management, and also long-term outcomes: 1) fitting to survey indices, 2) earthquake impact scenarios, and 3) recreational catch scenarios. Summaries of simulation outcomes for each key uncertainty included totals summed across all management zones, and full outputs by management zone (Appendices E to H).

High-impact models fitted to survey information ended up with higher stock status in assessment runs (see “Stock assessment and earthquake impacts”) than models that did not include survey information; however, these former models could not sustain recent catch levels without substantial reductions in biomass in the short- to medium-term, even under assumptions of rapidly declining recreational catch (Figure 35). For this reason, commercial catch under these scenarios was steadily reduced over time across all areas (Figure E-6). In contrast, models that did not fit to survey information, did not show these marked reductions, but showed a slow decline with current catch, and maintained commercial catch levels close to levels in 2021–22 (for this scenario of rapidly declining recreational catch). Longer term, these scenarios led to marked differences in risk levels between models that fitted or did not fit to survey information (Table E-1): the risk of breaching limit reference points ($0.2 \cdot SSB_0$) were non-negligible (>0.1) for models fitted to survey data long term, whereas they remained low (<0.01) in aggregate for models that did not attempt to fit to surveys.

The differences in model fitting (using or not using surveys in model likelihoods) also overwhelmed any differences between earthquake assumptions, with the exception of models that did not consider any impacts (Figure 36): only models fitted to survey data showed risk of breaching limit reference points long term (Table F-1), with relatively low probability (0.31–0.49) to be above target levels in the long term. Models not forcing fits to survey LFs suggested limited risk to the stock, but also suggested stable commercial catch from 2021–22 levels, rather than rebuilding of commercial catch towards pre-earthquake levels. This limitation was largely determined by the assumed reduction in stock productivity, which may not occur in the long term.

Differences in stock performance from alternative assumptions and management options of recreational catch became discernible after a period of about three years (Figures 37, 38): initial reductions in recreational take with available biomass were similar across scenarios (Figure G-6). Long-term differences in scaling led to corresponding changes in overall commercial catch and risk levels (Table G-1), with slower reductions in recreational catch leading to higher risk. Commercial catch under the control rule, which aimed to maintain biomass levels to produce 50kg/h CPUE, was reduced in the long run from current (23 t) catch under all scenarios for models fitted to survey data. It was either maintained or reduced for models not fitted to surveys for all positive values of recreational catch trialled here. Similar differences were evident in assumed fixed catch levels for recreational take; however, differences were accentuated with regards to the responsive scaling models because recreational catch does not change with biomass and, therefore, exacerbates patterns of decline (Figure H-6; Table H-1).

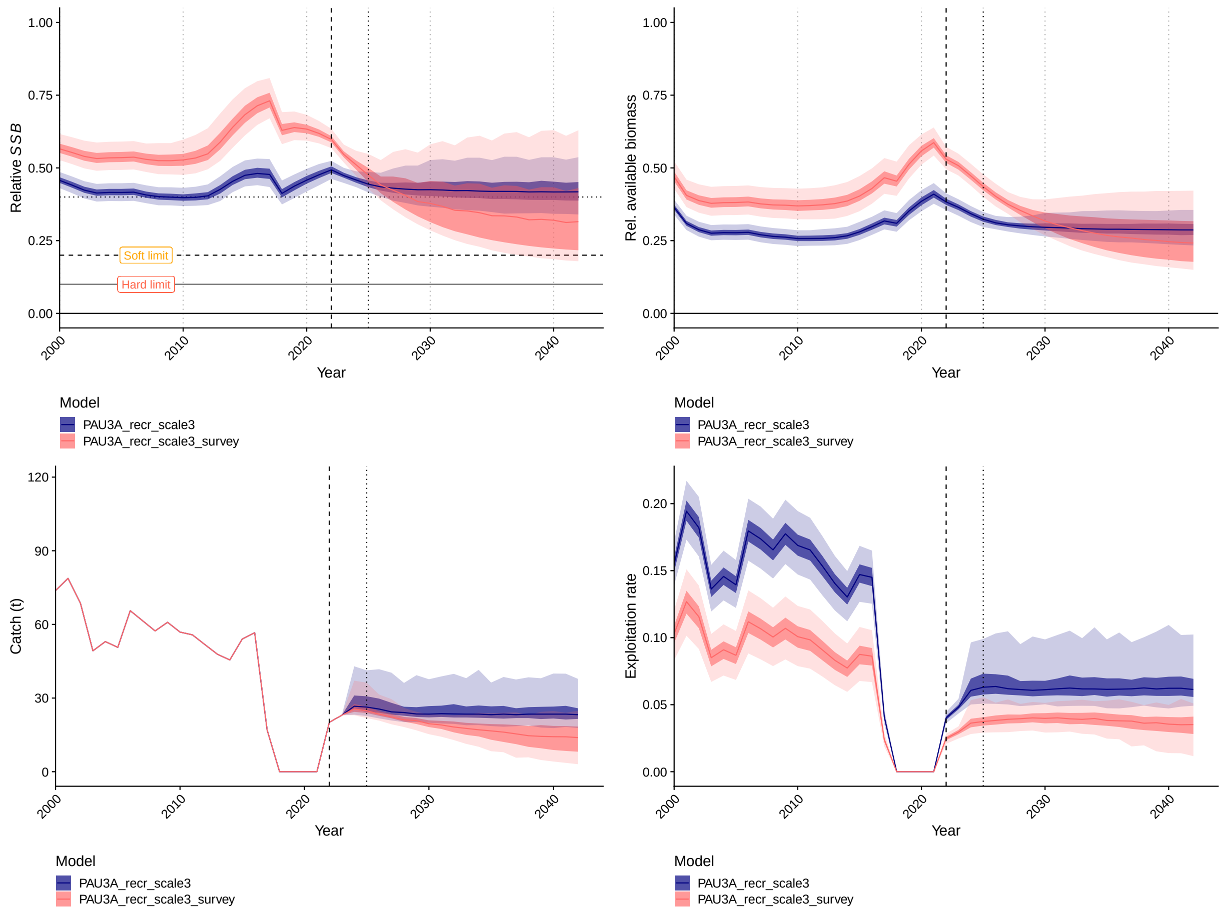

Figure 35: Projected relative spawning stock biomass (*SSB*), available biomass (at current minimum harvest size), long-term commercial catch and exploitation rate under two models for PAU 3A, fitted (or not) to survey observations, assuming rapidly declining recreational catch with available biomass (scale3).

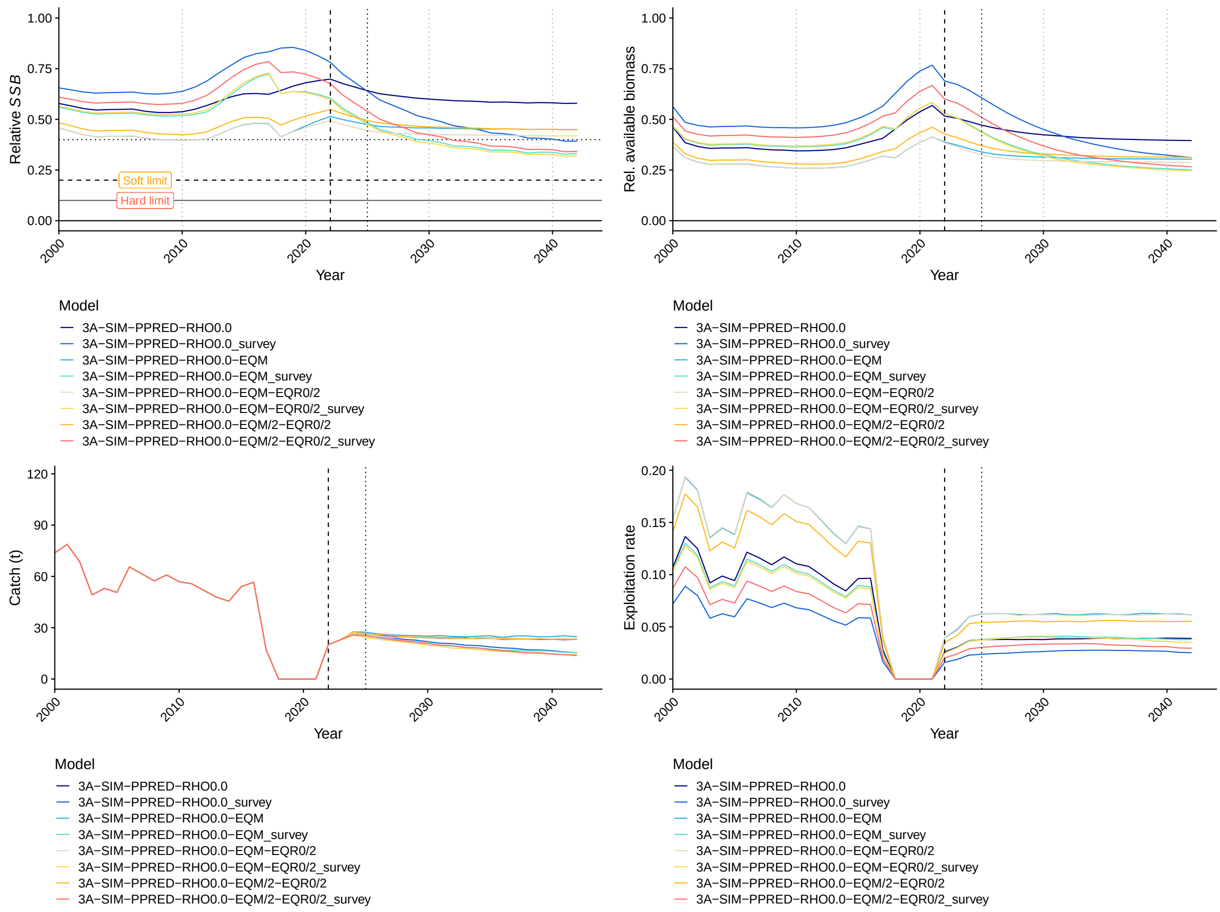

Figure 36: Projected relative spawning stock biomass (*SSB*), available biomass (at current minimum harvest size), long-term commercial catch and exploitation rate for models fitted to survey observations (_survey) or not, under different assumptions about earthquake impacts for PAU 3A (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2).

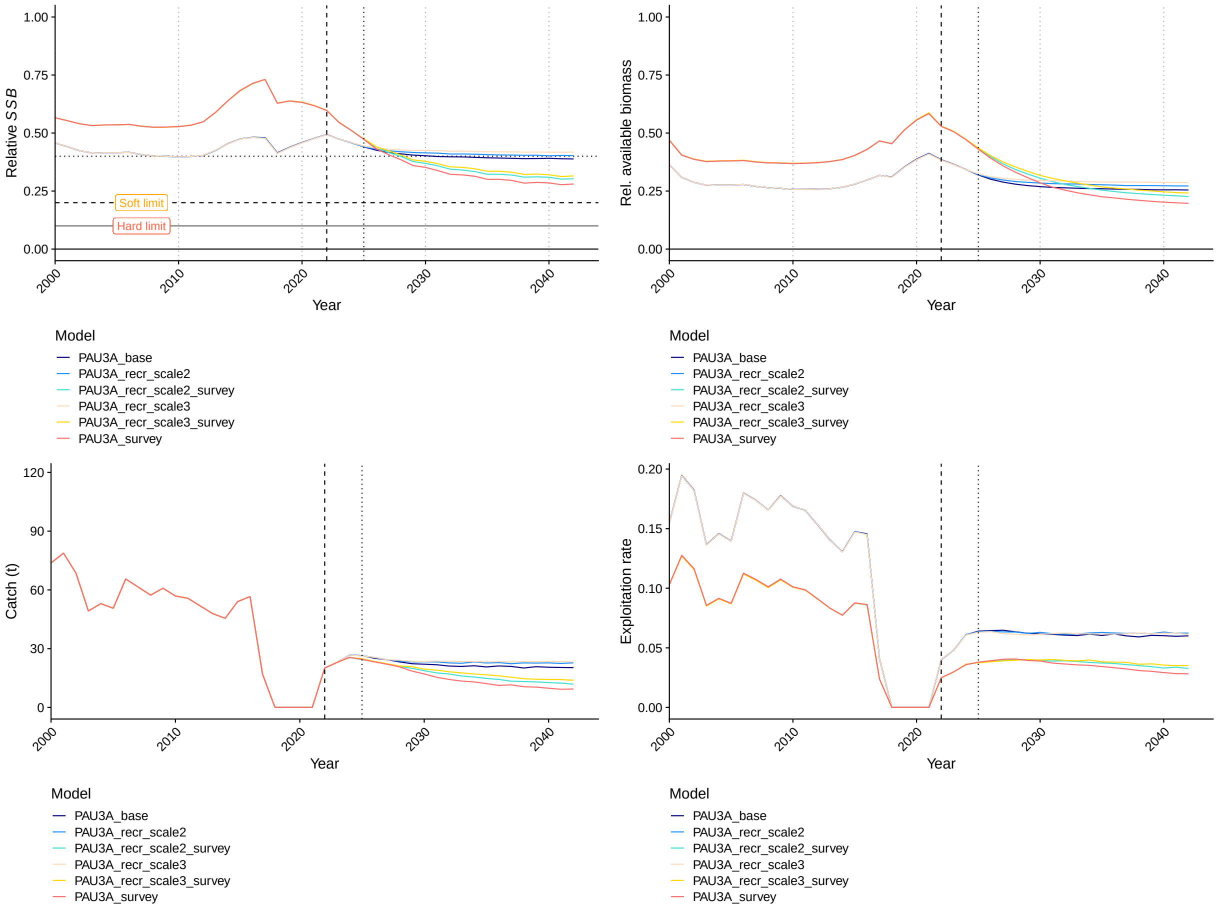

Figure 37: Projected relative spawning stock biomass (*SSB*), available biomass (at current minimum harvest size), long-term commercial catch and expoitation rate for models fitted to survey observations (_survey) or not for PAU 3A, using the model with maximum assumed earthquake impacts, and scaling recreational catch according to available biomass, either by scaling directly or as a square or cube of available biomass (scale2, scale3).

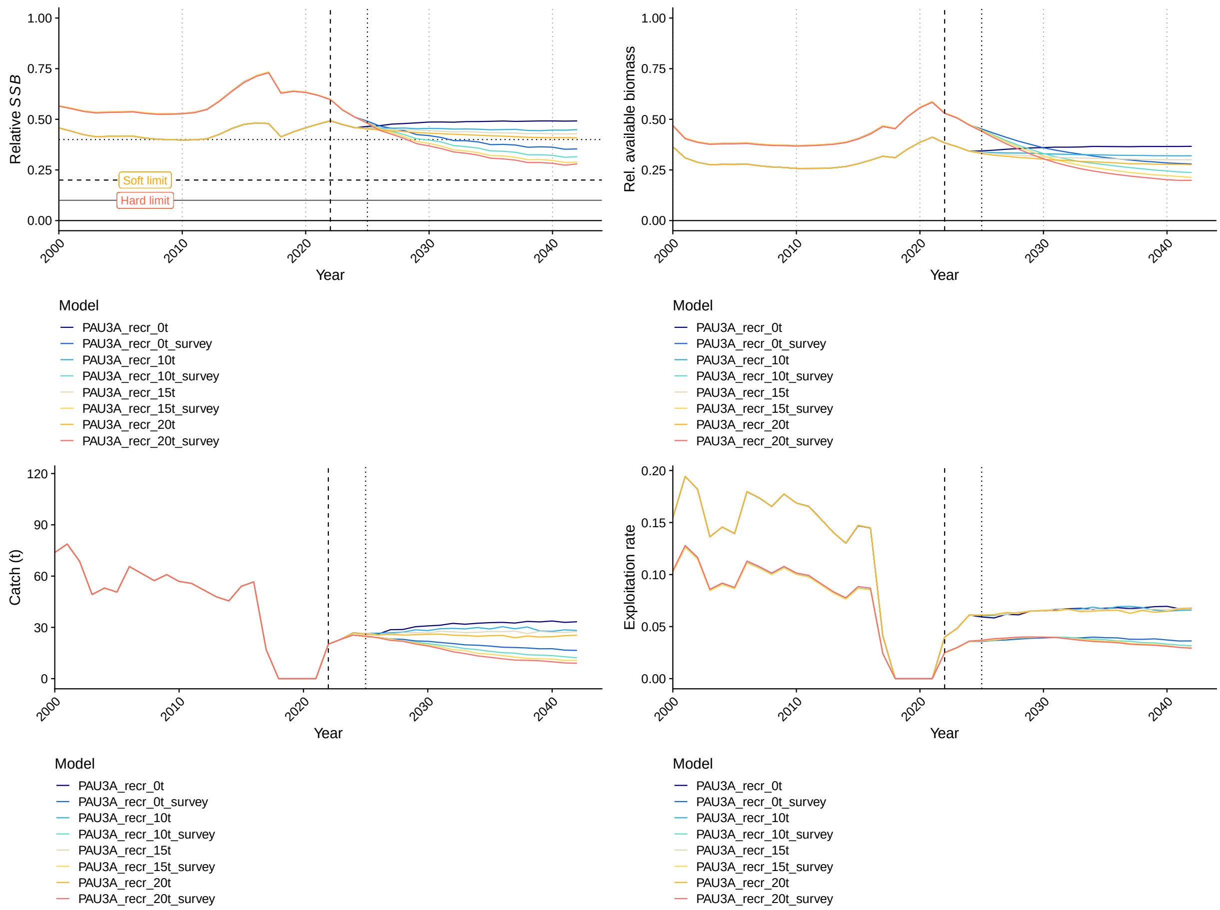

Figure 38: Projected relative spawning stock biomass (*SSB*), available biomass (at current minimum harvest size), long-term commercial catch and exploitation rate for models fitted to survey observations (_survey) or not for PAU 3A, using the model with maximum assumed earthquake impacts, and assuming fixed recreational catch to investigate impacts on commercial catch over time.

4. DISCUSSION

The present project presents a first attempt to explicitly integrate all available sources of information and data from PAU 3A to conduct a study of earthquake impact, and management options for the development of the fishery since its December 2021 re-opening. Post-earthquake discussions often focused on the fishery as a "new" fishery, with potentially large changes (P. Neubauer, pers. obs.); however, over the course of the present project, fitting assessment models across pre- and post-earthquake fisheries, with explicit representation of earthquake impacts, appeared to be the most sensible approach to derive useful operating models, which allow evaluation of different management options. The present approach allows estimation of the overall scale of the fishery pre-earthquake and made transparent (if likely simplistic) assumptions about earthquake impacts.

We assumed both immediate (via instantaneous natural mortality) and long-term (via reduced carrying capacity) impacts. Both of these assumptions are likely simplifications of a more complex reality: short-term impacts likely occurred over a number of years rather than being instantaneous, as the ecosystem continued to re-organise post-earthquake following uplift and intense sediment loads (McCowan & Neubauer 2021). Survey indices in highly-affected areas provide evidence for this medium-term re-organisation; survey indices in Paparoa, which had up to 42% of previously-fished area lifted above sea level, only showed significant recovery after four years post-earthquake. In addition, most parameters are unlikely to be permanently changed (at least not in a way can be implemented in a straightforward way). This aspect may mean that increases in commercial catch can be realised in the medium to long term relative to the initial 2021–22 re-opening TACC of 23 t. Nevertheless, in the context of evaluating management, it was considered important to evaluate management under possible long-term impact scenarios to safeguard against this possibility. Control rules should effectively adjust and take advantage of better-than-expected (by our models) conditions. In addition, improved scenarios for the "impact" period may be constructed and fitted to data by having a clearer statistical signal from the post-recovery fishery; for example, it may be possible to estimate the scale and period of earthquake impacts on natural mortality, or to accommodate more complex impact scenarios.

The focus for the present work was to understand key uncertainties and their impact on management. Many short-term earthquake impacts are unlikely to make a considerable difference with respect to control rule performance in the medium and long term. Nevertheless, the present study showed that these assumptions can affect estimated productivity levels for the stock, which impact on management options and risk levels. In this context, a greater array of biological productivity assumptions (natural mortality, growth) could be investigated in future iterations of this study.

Fitting to survey length frequencies was challenging, even for models that were weighted heavily towards fitting of survey length frequencies. Notably, there is a conflict between strong recovery trends in all areas, and an absence of strong trends in length frequencies: LFs showed an abundance of large individuals even in the first survey, and although overall pāua numbers increased during the earthquake closure, the LFs remained remarkably stable. The model interpretation for this relative absence of a trend in LFs was to fit a high biomass prior to the earthquake, with a low exploitation rate relative to models that do not attempt to fit these data. As a result, fitting to survey information led to higher stock status estimates; but even under this model, the first year of survey LFs was poorly reproduced by the model.

Alternative explanations for this pattern should be explored in future iterations of this modelling. The stability in survey LFs may be a product of dome-shaped selectivity in the pre-earthquake fishery. In an abundant pāua fishery, most diving is shallow (1 to 6 m water depth), and aggregations of large pāua may be regularly missed if they occur in relatively deep waters, especially in areas where visibility is frequently low, such as along the PAU 3A coastline. This aspect may in turn protect patches at greater depths, leading to fishing rates with pāua lengths that do not affect the overall size structure of the population. Alternatively, size-dependent earthquake mortality may have led to a disproportionate loss of smaller individuals, leading to a size structure that does not reflect depletion levels, but size-based earthquake impacts. This suggestion is supported by markedly worse initial (2018) model fits in areas with high impact, relative to fits for Oaro, which experienced little uplift from the earthquake.

In addition, although survey areas were allocated to reflect fishing areas, there are relatively few sites per management zone. For this reason, there is potential that these sites may not be representative of fished areas and, therefore, contrast with fisheries data. Forcing a fit to the survey data, therefore, may produce unwanted results; that the modelled status of post-closure fishery was lower than before the earthquake provides some evidence that fitting to survey data with the current model may produce overly pessimistic outcomes. Nevertheless, we retained models based on these fits because they provide a test of management procedures under different productivity assumptions. Trends in commercial CPUE as a function of total catch in the coming years may provide a more adequate basis to decide among competing hypotheses about current productivity and earthquake impacts.

In view of the high level of recreational take estimated for the 2021–22 season, the ongoing management of recreational effort and take is a key question for future commercial fishing and biomass levels. Because commercial take in the present simulations was adjusted by the control rule, most settings for recreational catch led to substantial long-term risk of decline in the fishery. These declines were both in terms of commercial catch and biomass status, for all models fitted to survey data. Although these models may be overly cautious, even models not fitted to survey data did not suggest that the fishery would grow substantially from the 2021–22 TACC, which was considered precautionary, under all but the most conservative recreational settings. The long-term catch for these models under a constant recreational catch of 10 t, for example, is approximately 30 t across PAU 3A. Ongoing monitoring and adjustments of recreational catch are, therefore, equally important as adjustments of commercial take in determining the long-term status and fishery performance of PAU 3A, regardless of the substantial uncertainties which remain with regards to models of earthquake impacts, status and future trends in PAU 3A.

Given remaining uncertainties, we recommend that the present study will be taken as a starting point, which, together with ongoing monitoring of commercial and recreational take, will provide a basis to make informed management decisions as the fishery develops in the coming years. We suggest that the status and trends in PAU 3A should be reviewed again in a relatively short time frame (e.g., after 2 to 3 years) to adjust management if necessary. The trajectory for recreational take may be more evident at that time, allowing a more thorough exploration of commercial control rules. The latter exploration will ideally be conducted under an expanded set of models that provide improvements to the present model in terms of fitting to survey data and earthquake scenarios.

5. ACKNOWLEDGEMENTS

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APPENDIX A: FIT OF THE SURVEY LENGTH-FREQUENCY MODELS

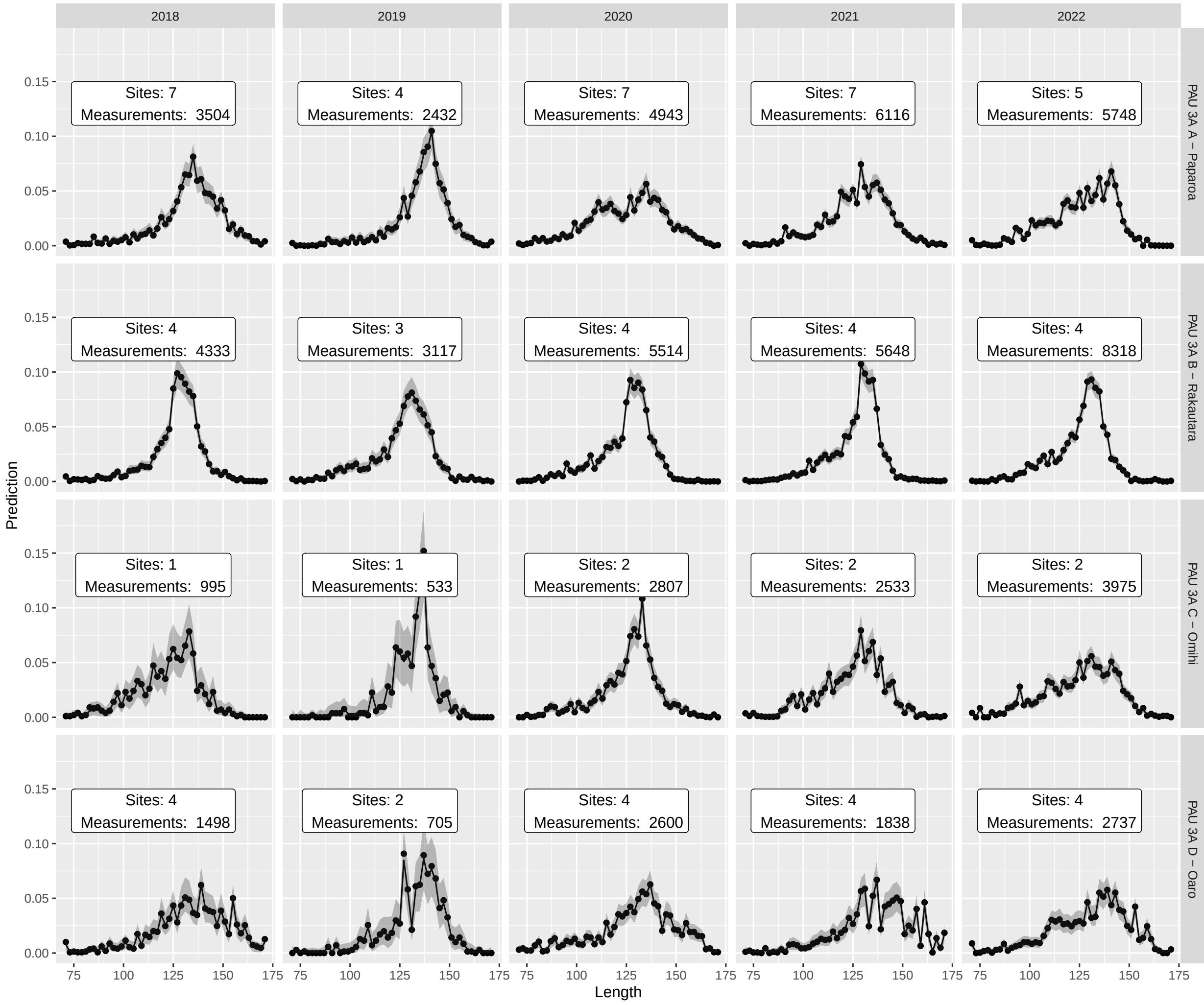

Figure A-1: Assessment of model fit at the management zone level in PAU 3A for the length-frequency (LF) standardisation model for Kaikōura survey LFs.

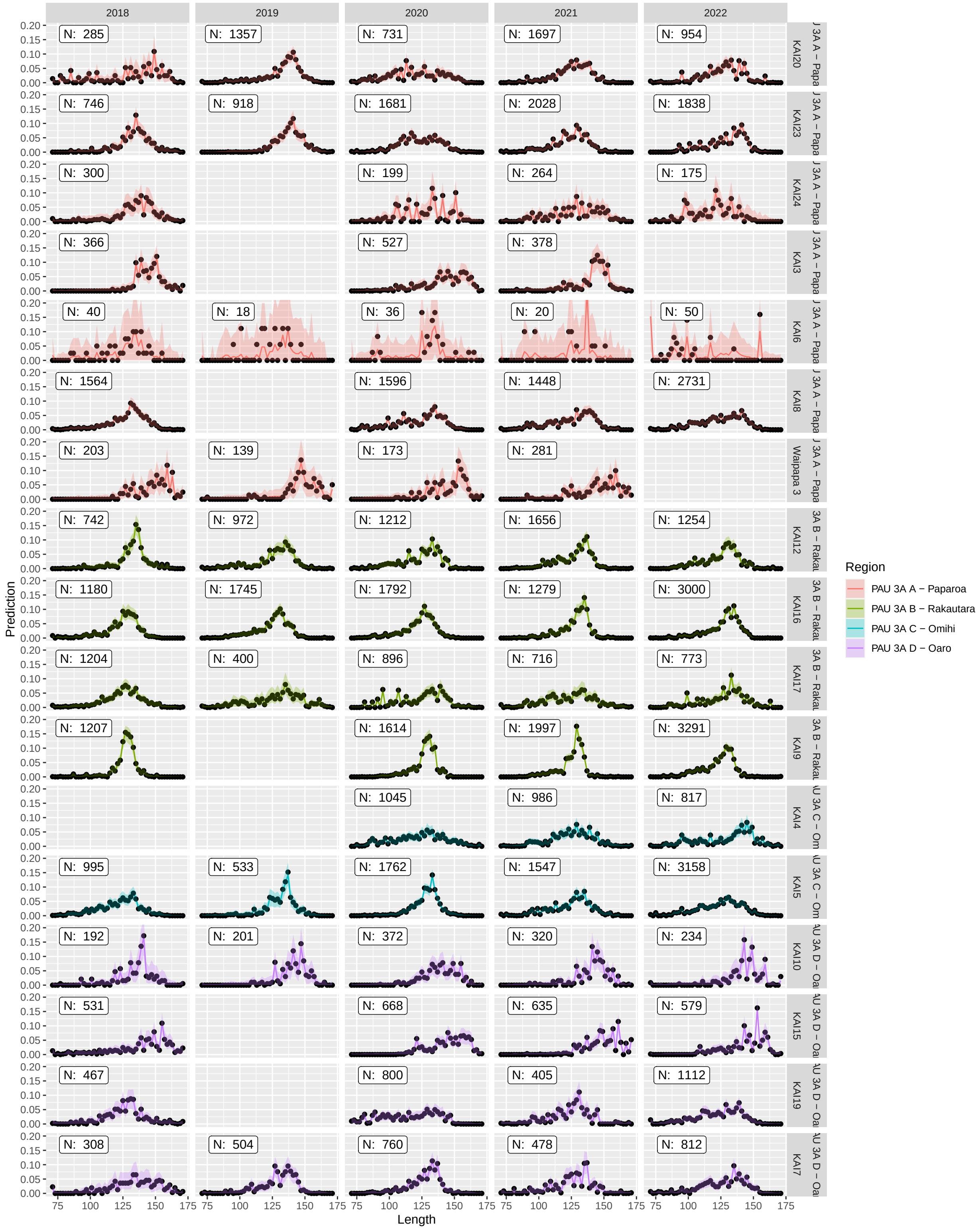

Figure A-2: Assessment of model fit at the site level in PAU 3A for the length-frequency (LF) standardisation model for Kaikōura survey LFs.

APPENDIX B: SCENARIOS FOR EARTHQUAKE IMPACTS

Table B-1: Hypotheses of earthquake (EQ) impacts considered for the stock assessment for PAU 3A, observations supporting (or not) each hypothesis, and considerations for representation in the present and future stock assessments.

Parameter	Hypothesis	Observations	Representation (or not)
Mortality M	Earthquake killed pāua in large numbers.	Large number of pāua found "stranded" in uplifted areas.	– High instant mortality in proportion to uplift. – Uplift % taken as mortality (assumed uniform distribution across uplifted and non-uplifted areas), or divided by 2.
	M equal across size spectrum.	Mortality observed across sizes.	– Mortality applied as single M.
	M affecting juveniles (pre-emergence) due to shallow distribution.	Uplift affecting shallow areas disproportionately.	– Pre-emergence pāua not modelled (model starts at 70 mm). – Large M for pre-emergence pāua manifests as low recruitment in the model.
	Higher M (decreasing) over some time (medium term).	Increased sedimentation, ecosystem effects.	– Not represented: adds additional, largely arbitrary parameters (scale of initial mortality versus attenuation coefficient), also probably limited impact on management procedure evaluation (MPE). – May be able to be estimated in future models.
Equilibrium recruitment R_0	(Semi-)permanent loss of pre-recruit habitat.	High uplift of shallow areas, long-term re-organisation of coastline.	– Lower R_0 over medium to long term. – Loss of R_0 proportional to uplift.
	Loss has only short-term impact on recruitment.	Evidence for post-EQ recruitment.	– Not represented (similar to short-term M assumption, but affecting only pre-recruits).
Steepness h	Slower recovery from low stock size due to allee effects, poor recruitment habitat.	Strong recovery observed in all areas, albeit with some lag in high uplift zone.	– Lower R_0 over medium to long term. Not represented: observed recovery suggests limited long-term effects: short-term effects more adequately represented via M. – Limited impact for MPs that avoid low stock size.

Continued on next page

Table B-1 – *Continued from previous page*

Parameter	Hypothesis	Observations	Representation (or not)
Recruitment variation σ_R	Higher recruitment variation due to unstable recruitment habitat for some time.	Increased sedimentation, ecosystem effects, ongoing ecosystem re-organisation.	– Implemented in MPE; most relevant for future management performance.
Growth	Growth impacted due to high sedimentation, ecosystem re-organisation.	None; apparent growth of surveyed pāua.	– Not represented, limited understanding of growth in assessment. – Potential to estimate growth impact as temporary deviation in growth in the future: difficult to parameterise. – Short-term effects likely have limited impact on future management performance.

APPENDIX C: BASE IMPACT MODEL DIAGNOSTICS: NO SURVEY FIT

C.1 Markov chain Monte Carlo and posteriors

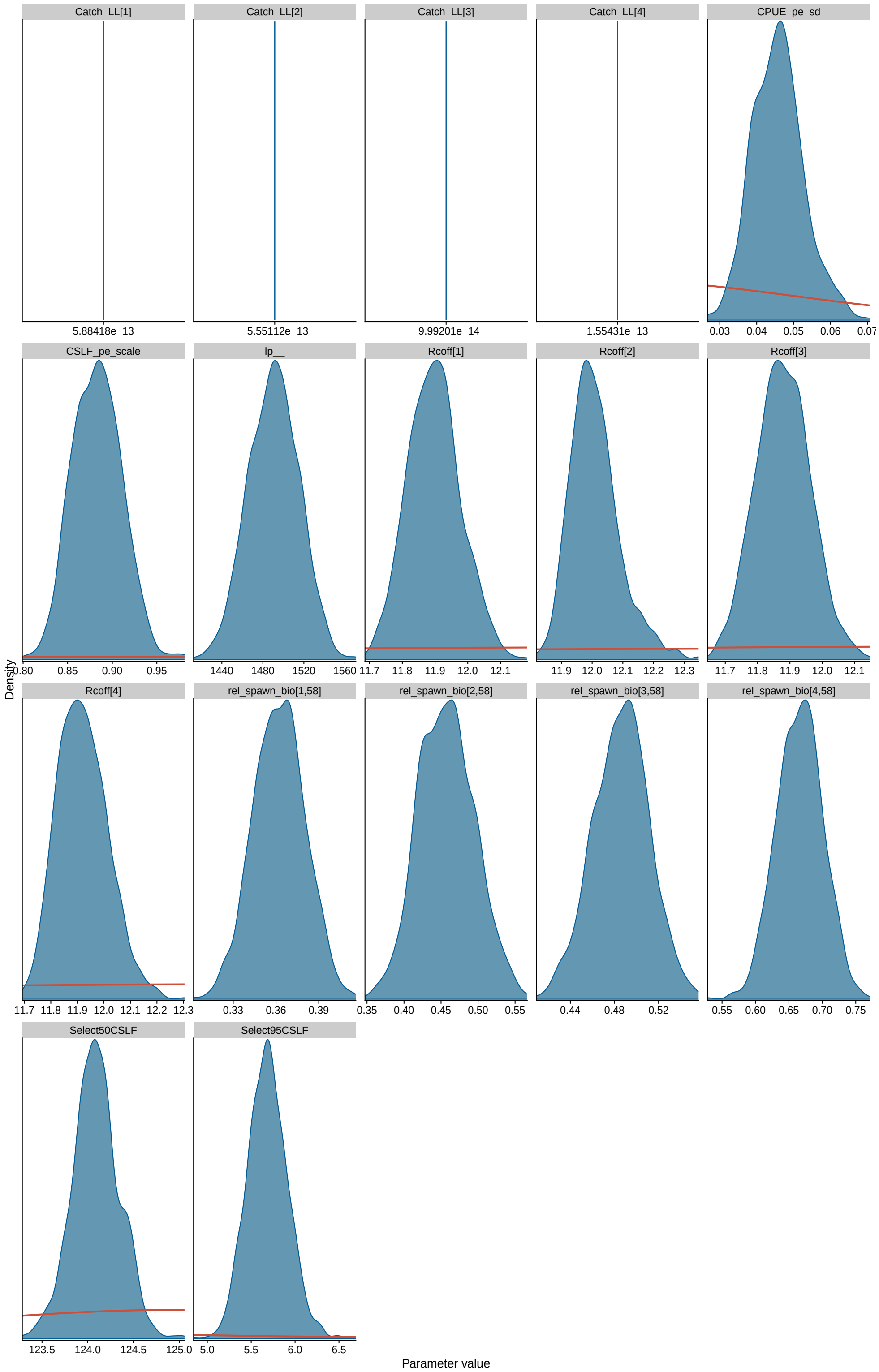

Figure C-1: Marginal posterior densities of key model parameters for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A, with prior densities indicated in red.

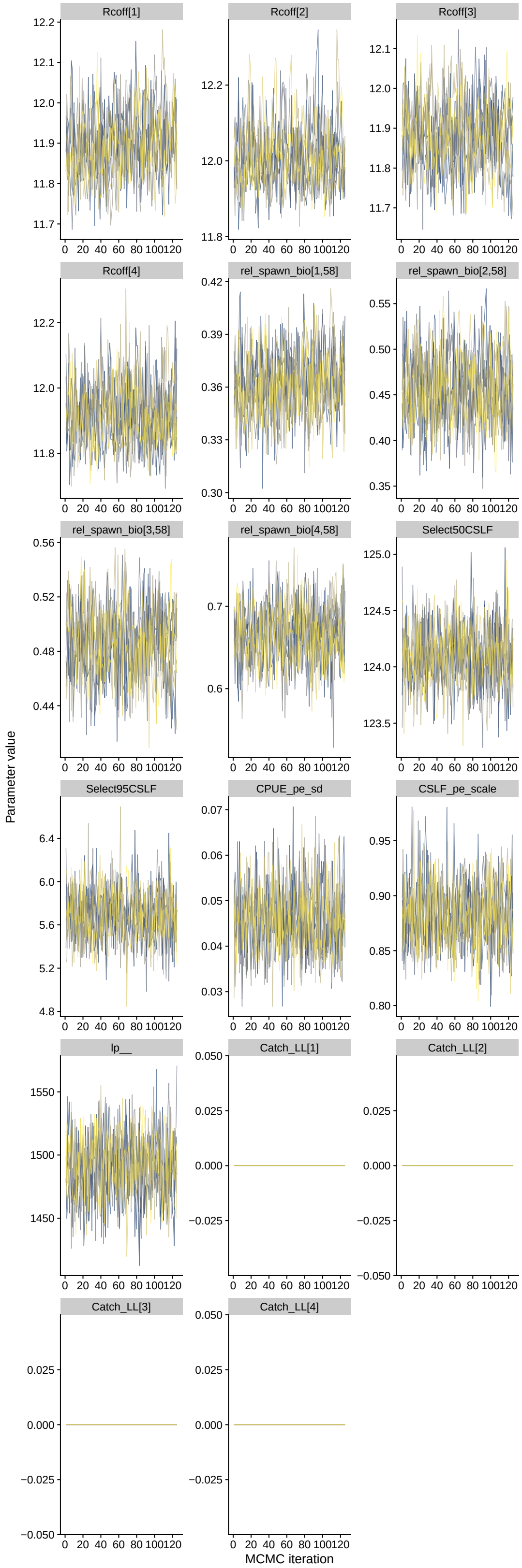

Figure C-2: Traces of Markov chain Monte Carlo (MCMC) estimation for the marginal posterior distribution of key model parameters for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua in quota management area PAU 3A.

C.2 Growth

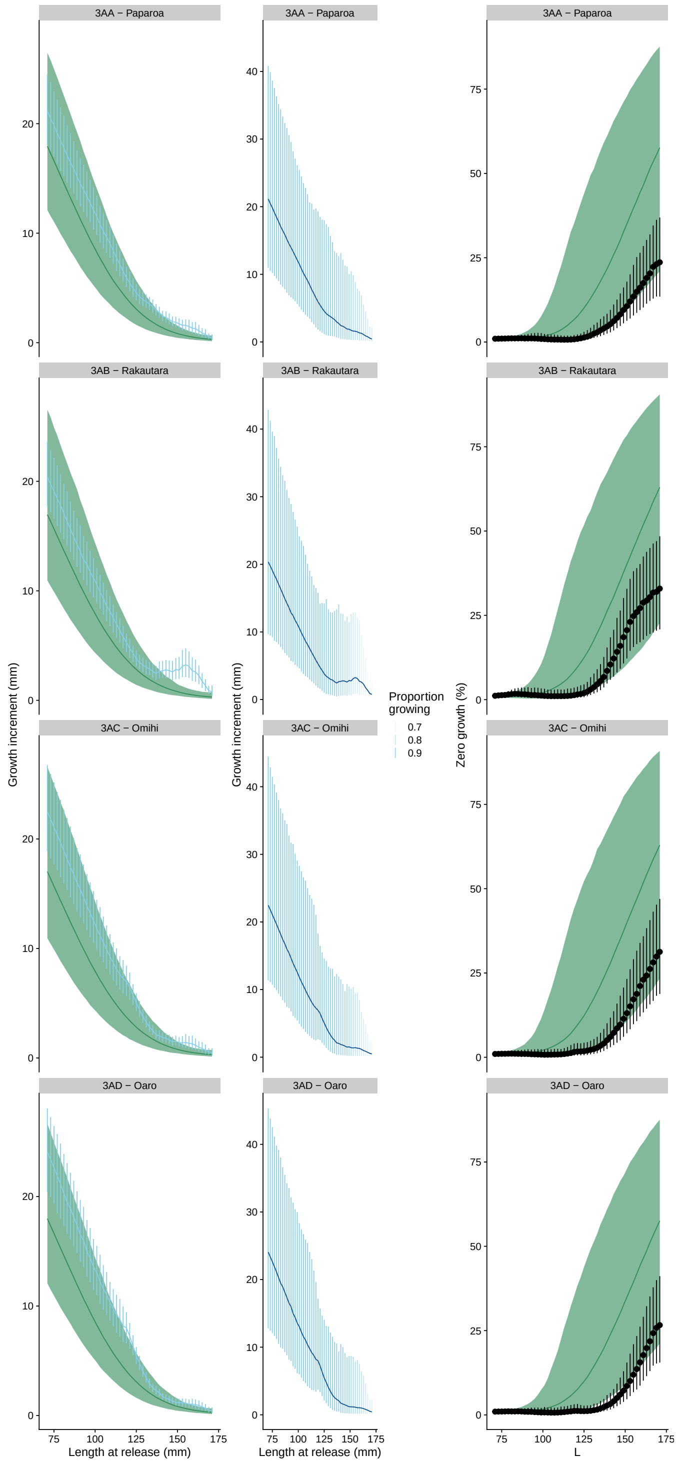

Figure C-3: Left: Posterior mean growth (population mean (dark blue line) and standard deviation of the estimate (light blue ribbon)), relative to the prior (dark green); middle: estimated population standard deviation (posterior median; light blue) relative to estimated population mean (blue line); right panel: estimated proportion of pāua stock not growing at each length relative to the prior (green) for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A.

C.3 Catch-per-unit-effort fits

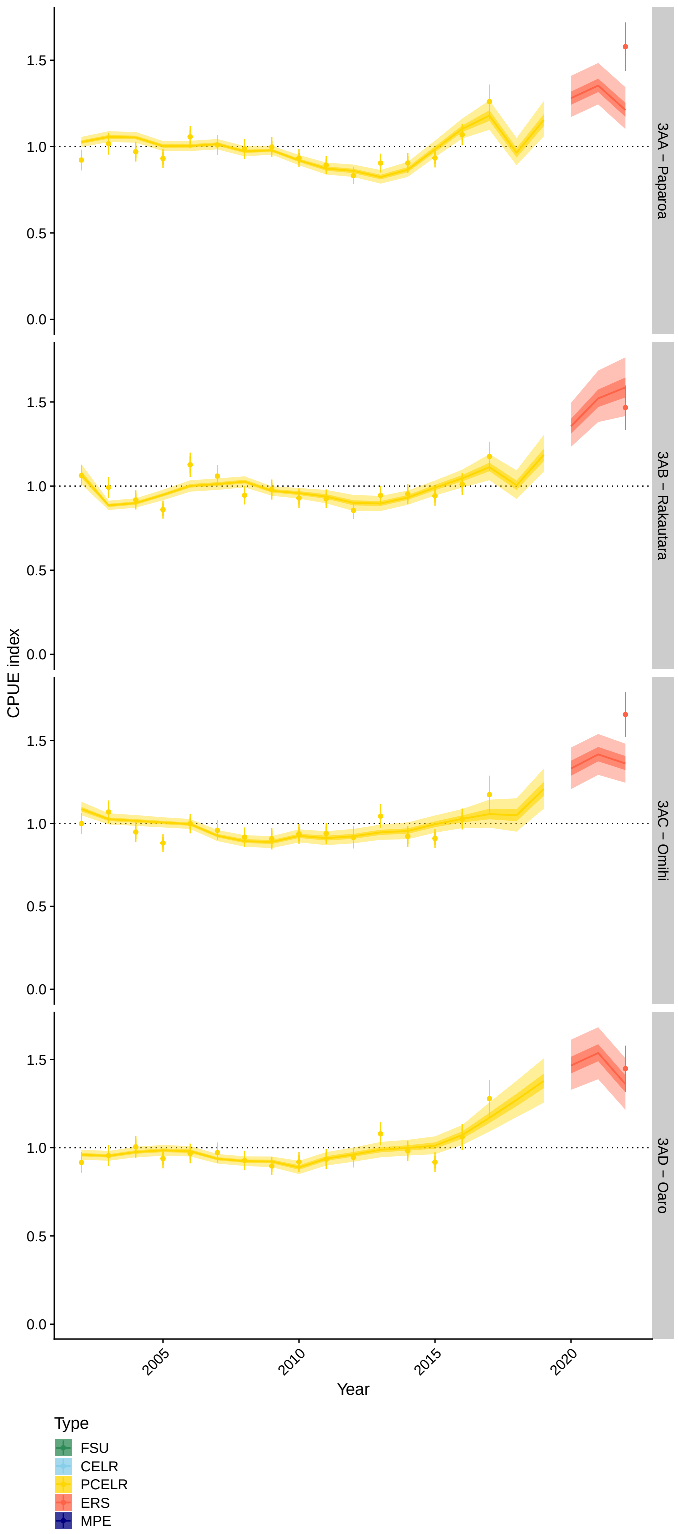

Figure C-4: Comparison of posterior median (line) and 95% confidence (shaded ribbon) predicted catch-per-unit-effort (CPUE) with estimated CPUE index and observation error for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A (points and error bars). FSU, Fisheries Statistical Unit; (P)CELR, (Pāua) Catch Effort Landing Return; ERS, electronic reporting system; MPE, management procedure evaluation.

C.4 Catch sampling length-frequency fits

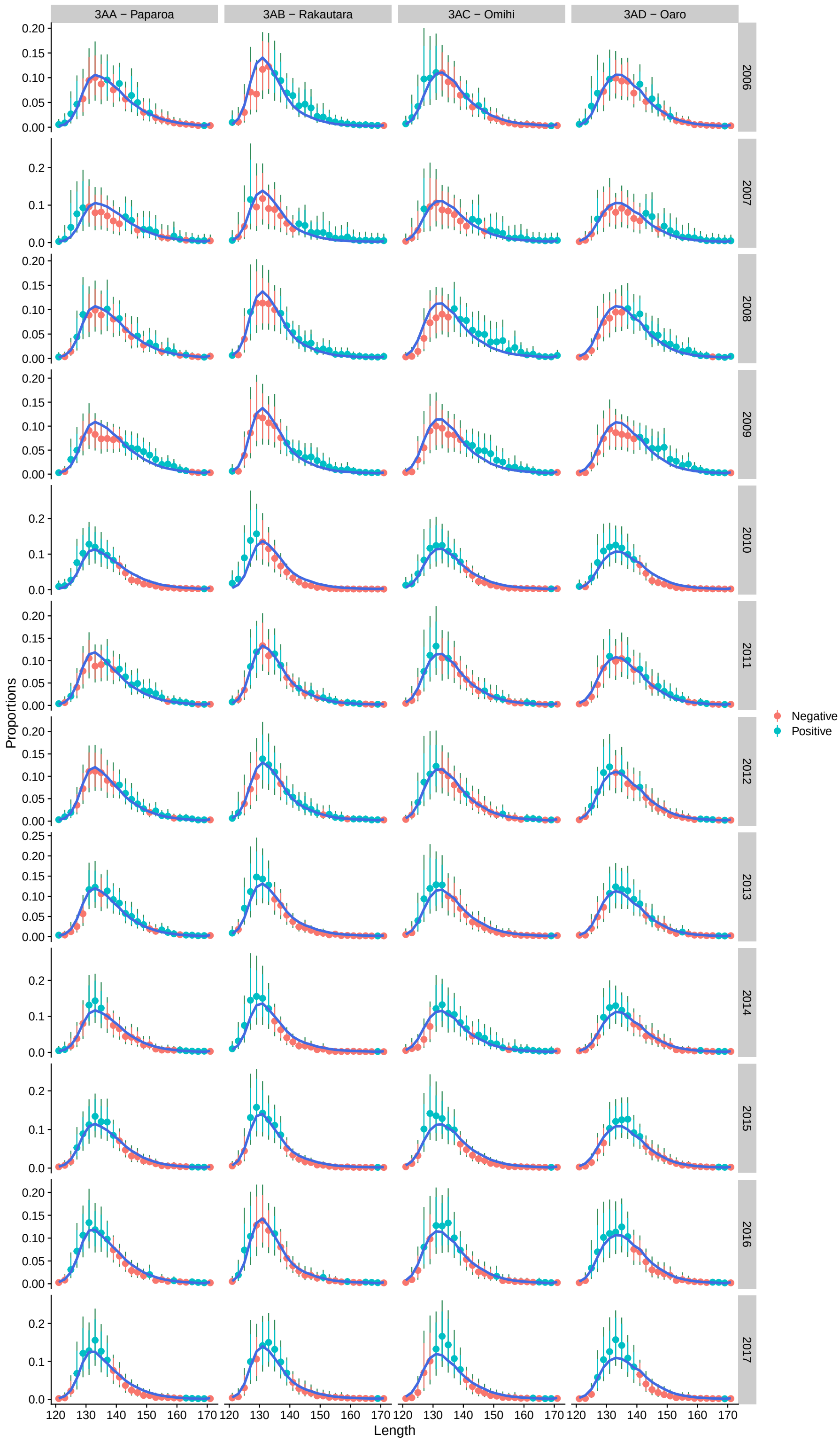

Figure C-5: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions and observation error for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A. Length classes with positive residuals in blue, with negative residuals in red.

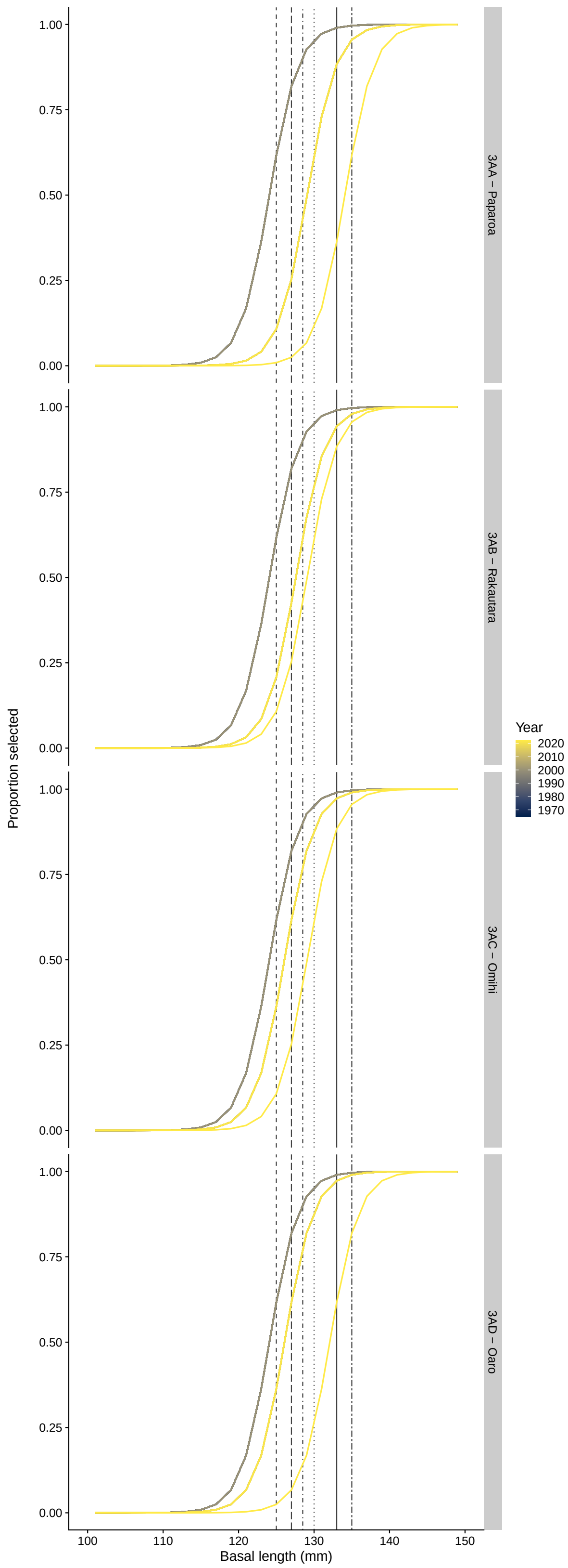

Figure C-6: Estimated selectivity (posterior mean) for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A.

C.5 Recruitment and biomass trends

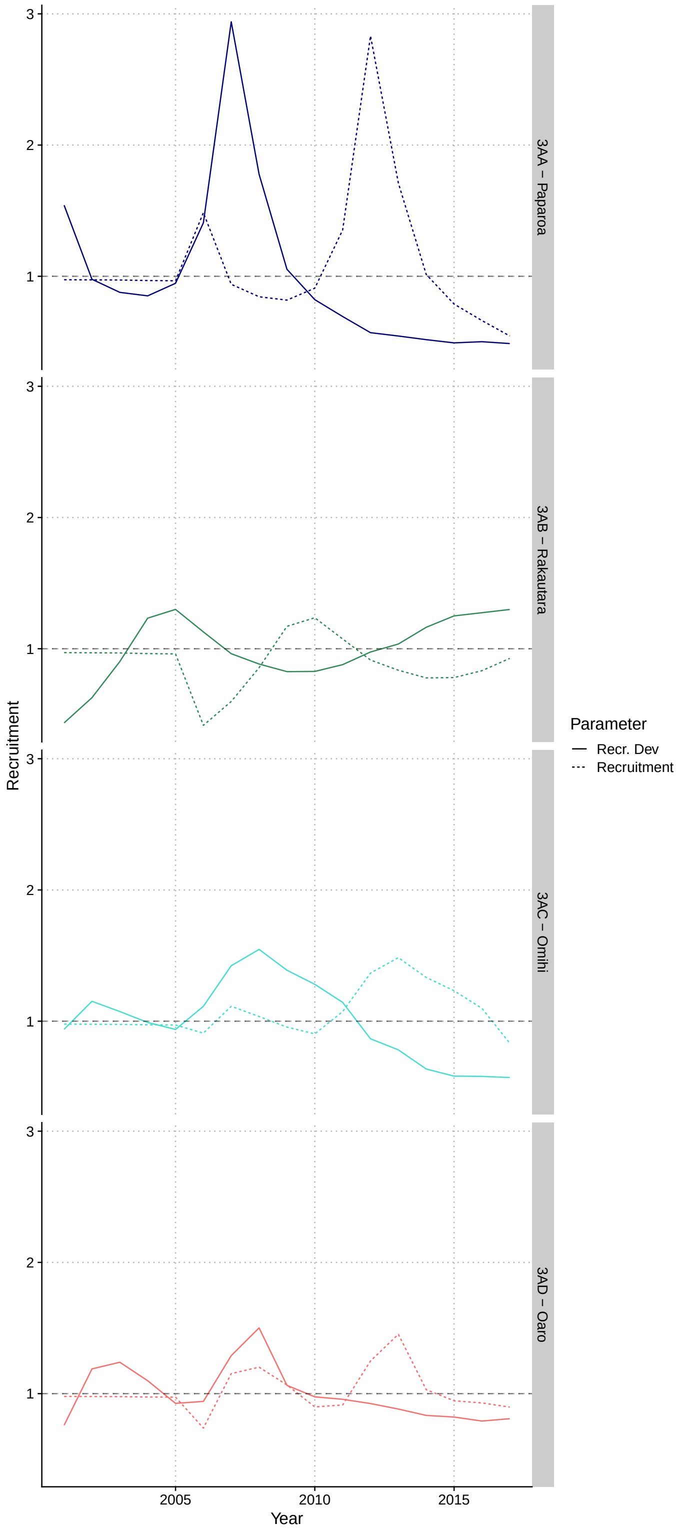

Figure C-7: Posterior mean recruitment for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A (Recr. Dev (R_{dev}), recruitment deviation).

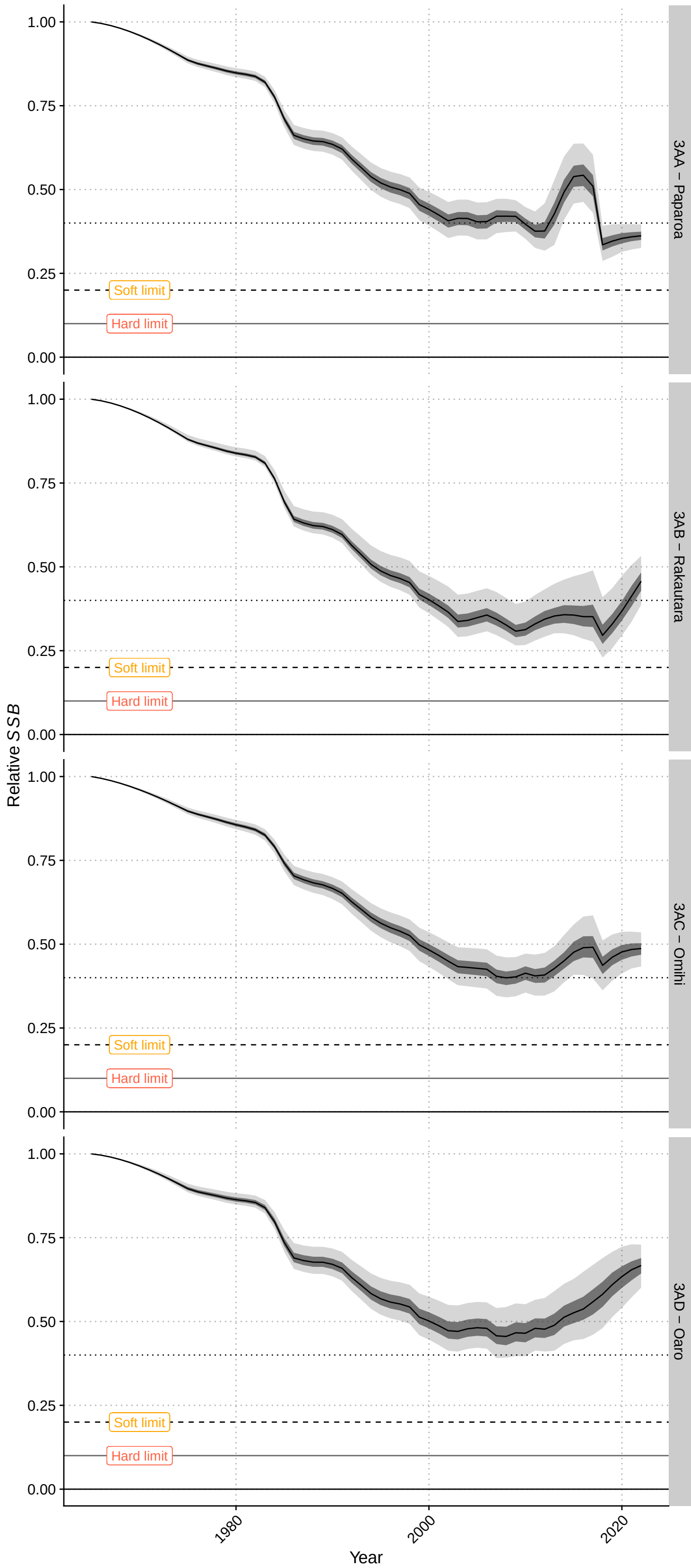

Figure C-8: Estimated relative spawning stock biomass (*SSB*) trend for pāua for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

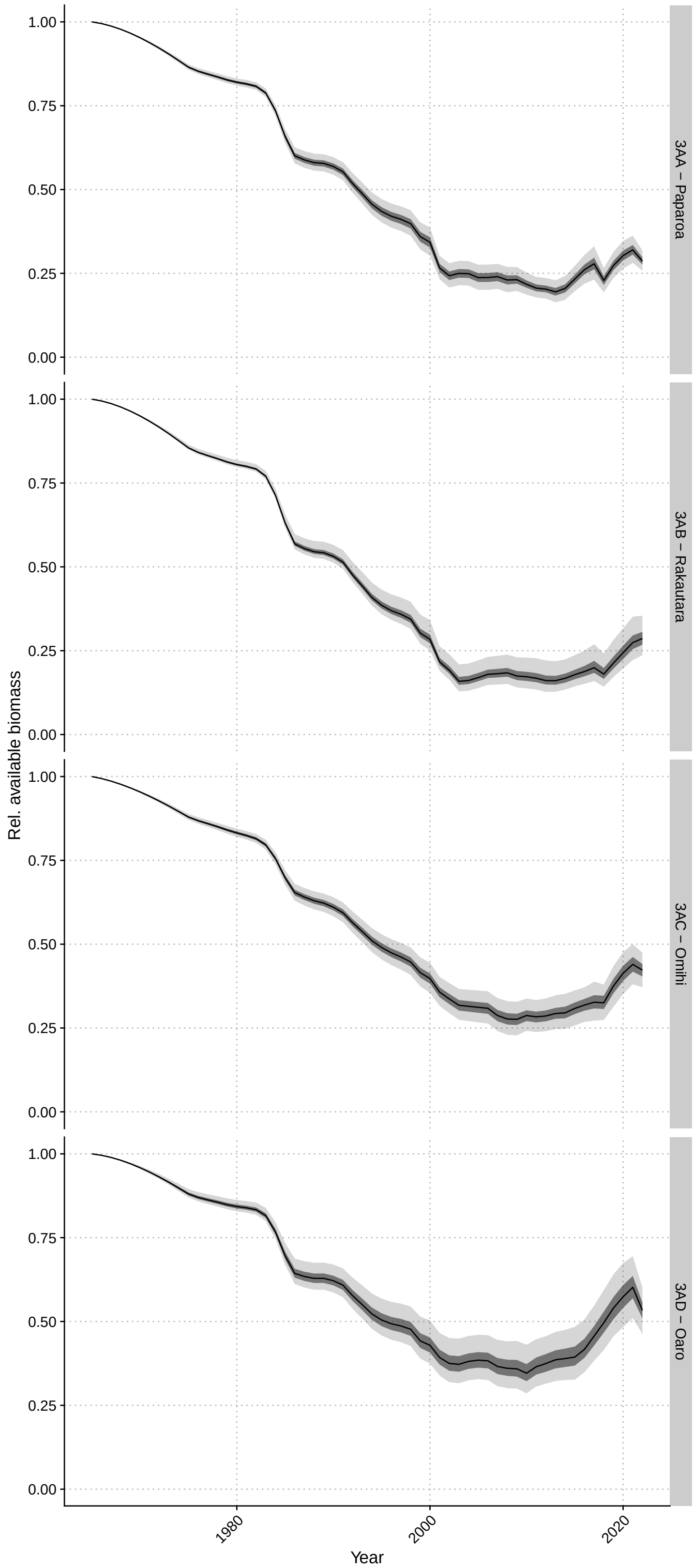

Figure C-9: Estimated relative available biomass trend for pāua for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

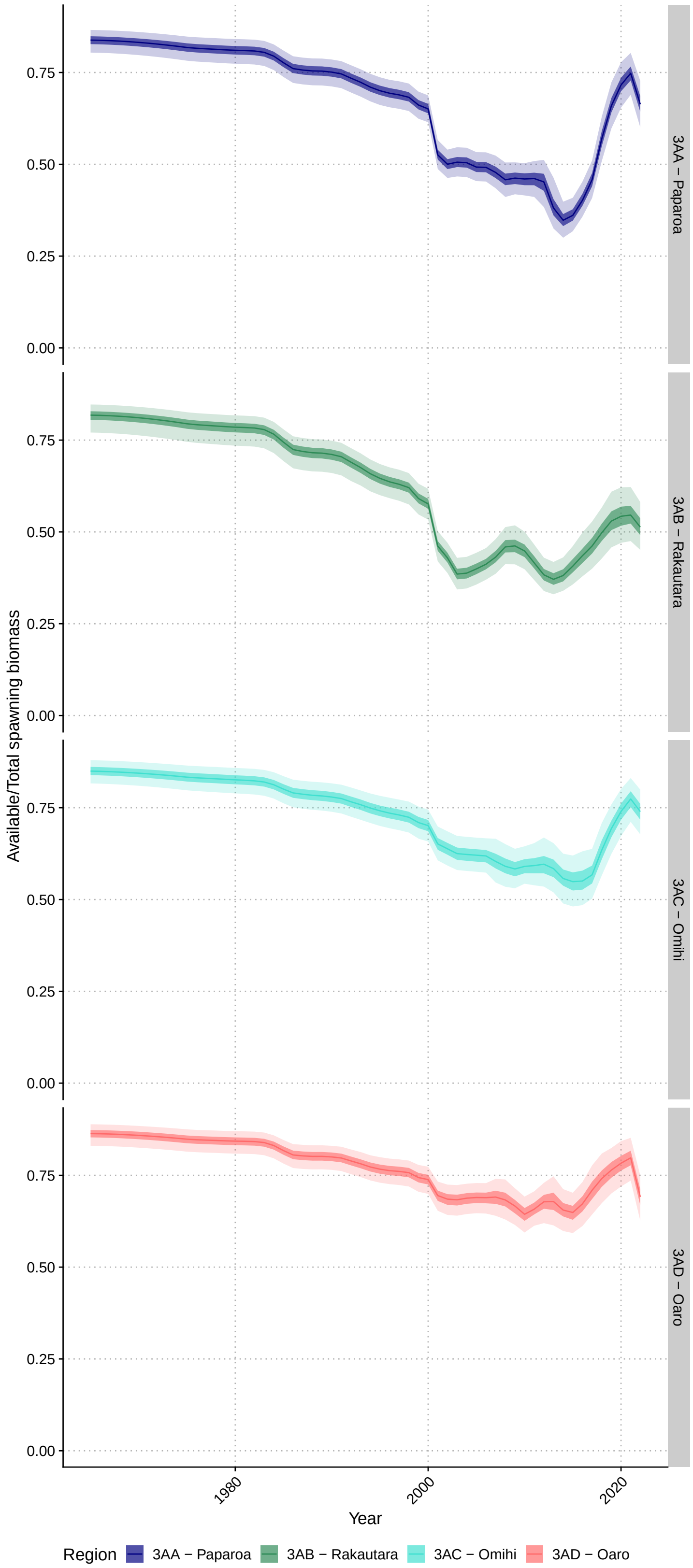

Figure C-10: Estimated relative available pāua biomass (relative to spawning stock) for the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

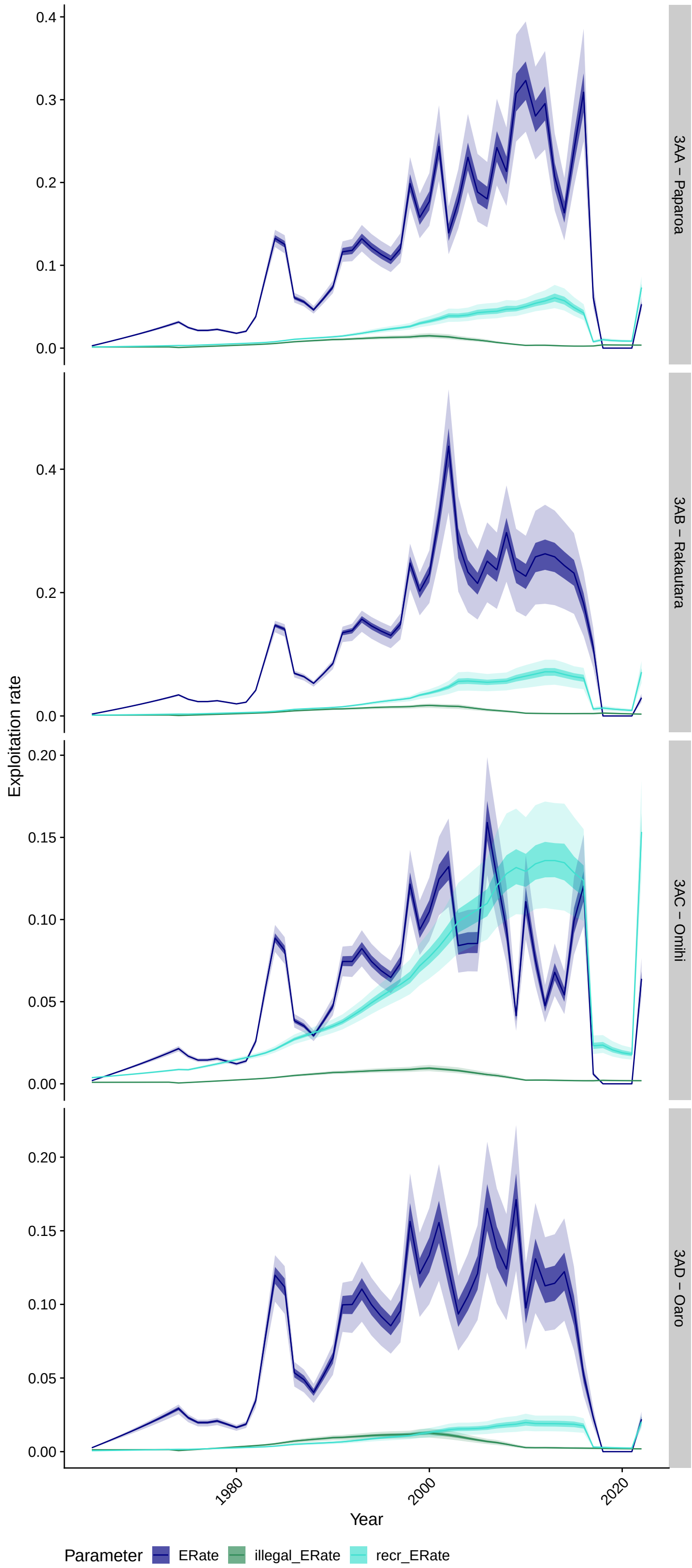

Figure C-11: Estimated exploitation rate (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)) for commercial (ERate), recreational (recr) and illegal components of the fishery in the base operating model, not fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A.

APPENDIX D: BASE IMPACT MODEL DIAGNOSTICS: SURVEY FIT

D.1 Markov chain Monte Carlo and posteriors

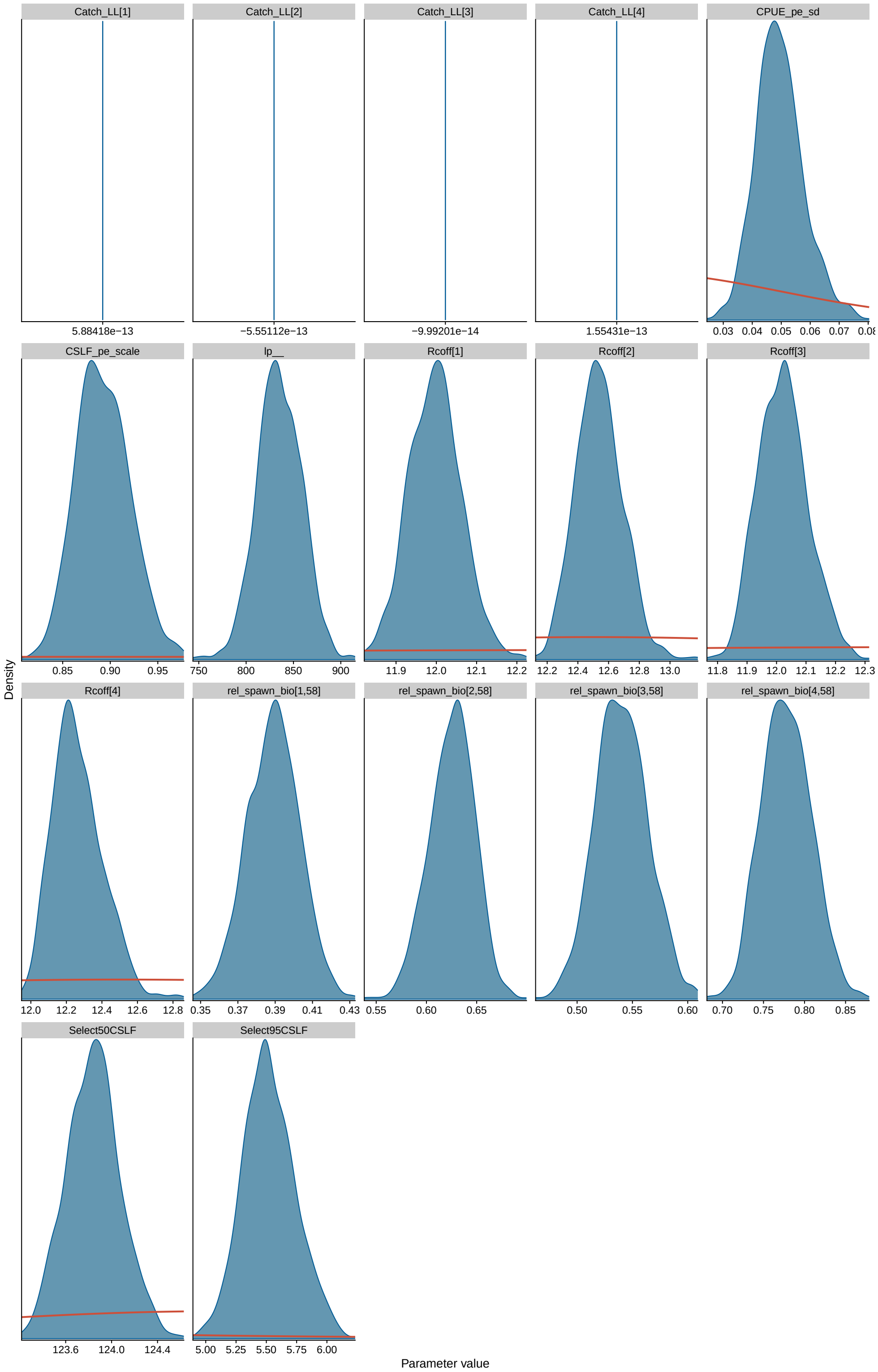

Figure D-1: Marginal posterior densities of key model parameters for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A, with prior densities indicated in red.

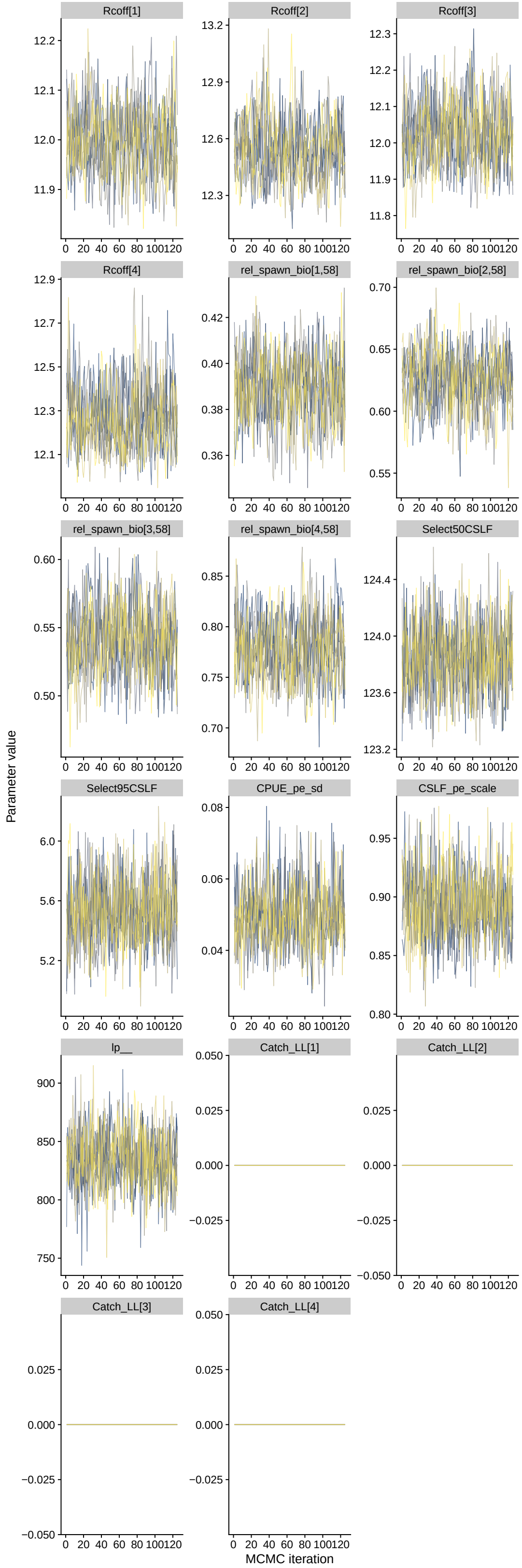

Figure D-2: Traces of Markov chain Monte Carlo (MCMC) estimation for the marginal posterior distribution of key model parameters for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua in quota management area PAU 3A.

D.2 Growth

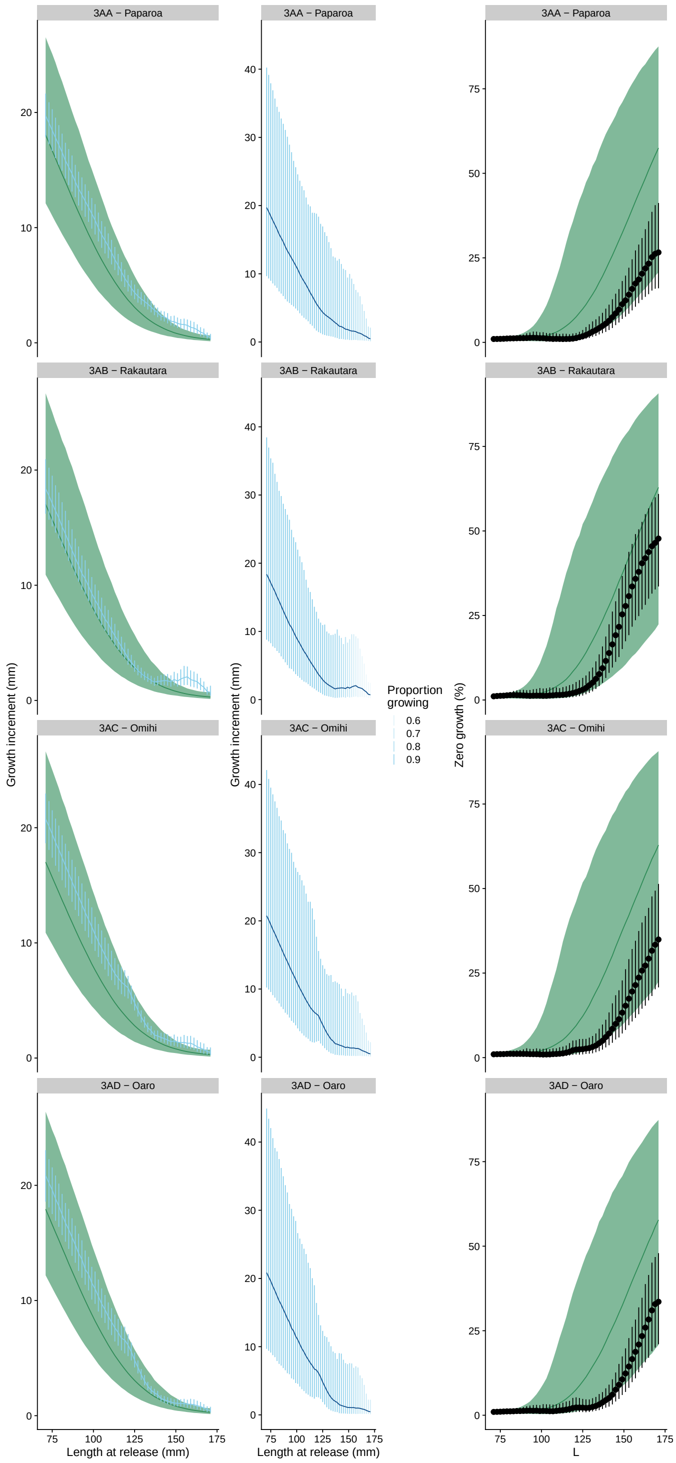

Figure D-3: Left: Posterior mean growth (population mean (dark blue line) and standard deviation of the estimate (light blue ribbon)), relative to the prior (dark green); middle: estimated population standard deviation (posterior median; light blue) relative to estimated population mean (blue line); right panel: estimated proportion of pāua stock not growing at each length relative to the prior (green) for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A.

D.3 Catch-per-unit-effort fits

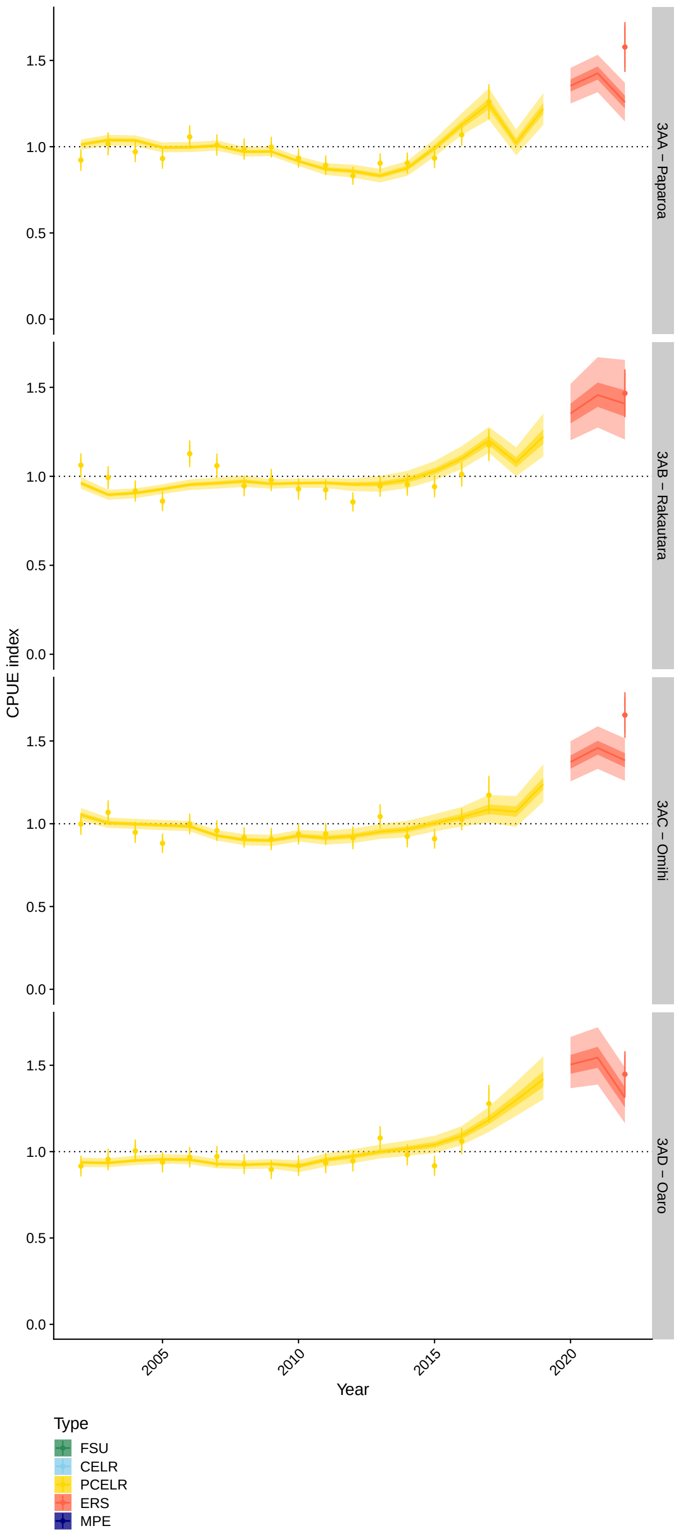

Figure D-4: Comparison of posterior median (line) and 95% confidence (shaded ribbon) predicted catch-per-unit-effort (CPUE) with estimated CPUE index and observation error for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A (points and error bars). FSU, Fisheries Statistical Unit; (P)CELR, (Pāua) Catch Effort Landing Return; ERS, electronic reporting system; MPE, management procedure evaluation.

D.4 Catch sampling length-frequency fits

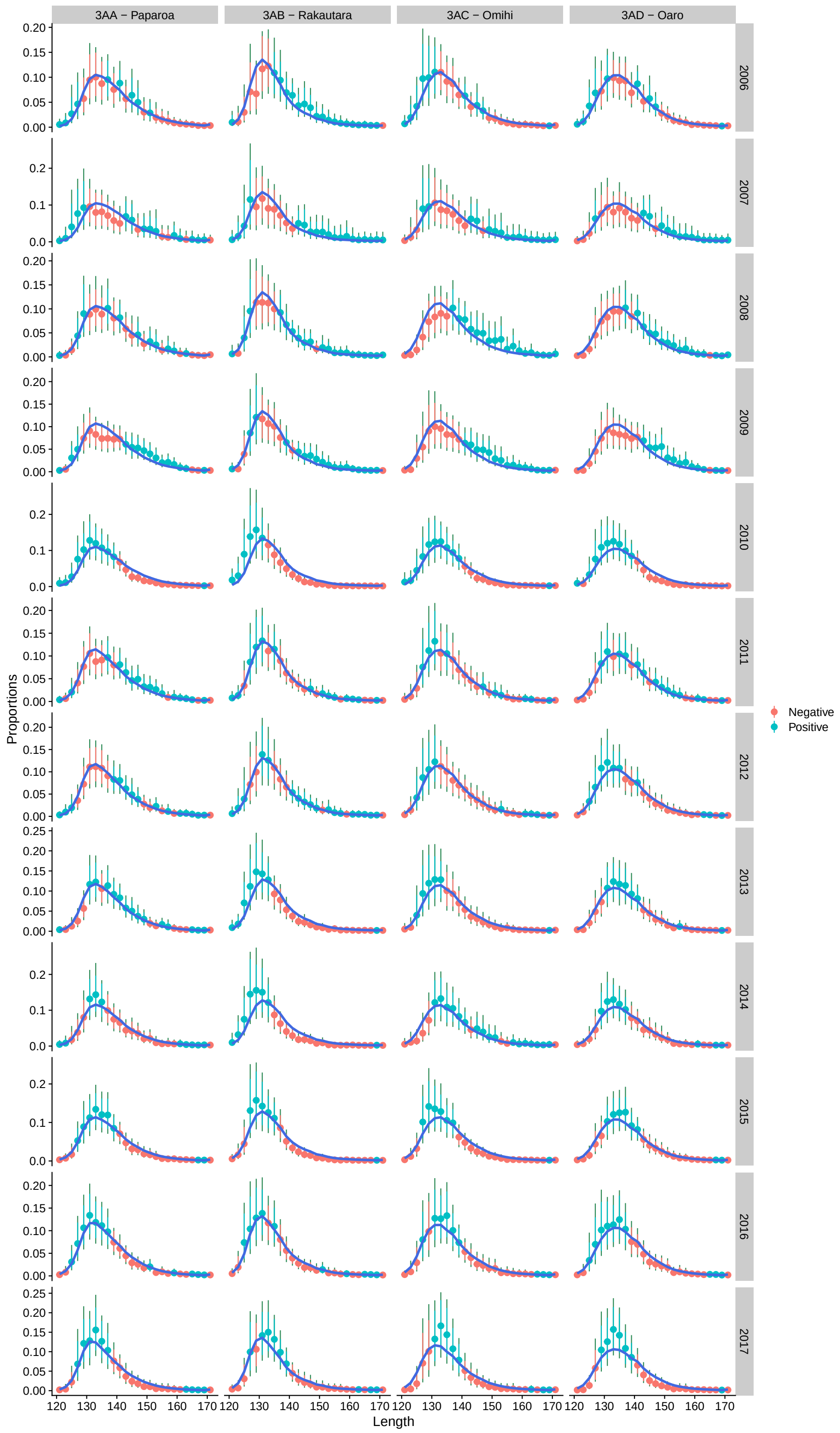

Figure D-5: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions and observation error for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A. Length classes with positive residuals in blue, with negative residuals in red.

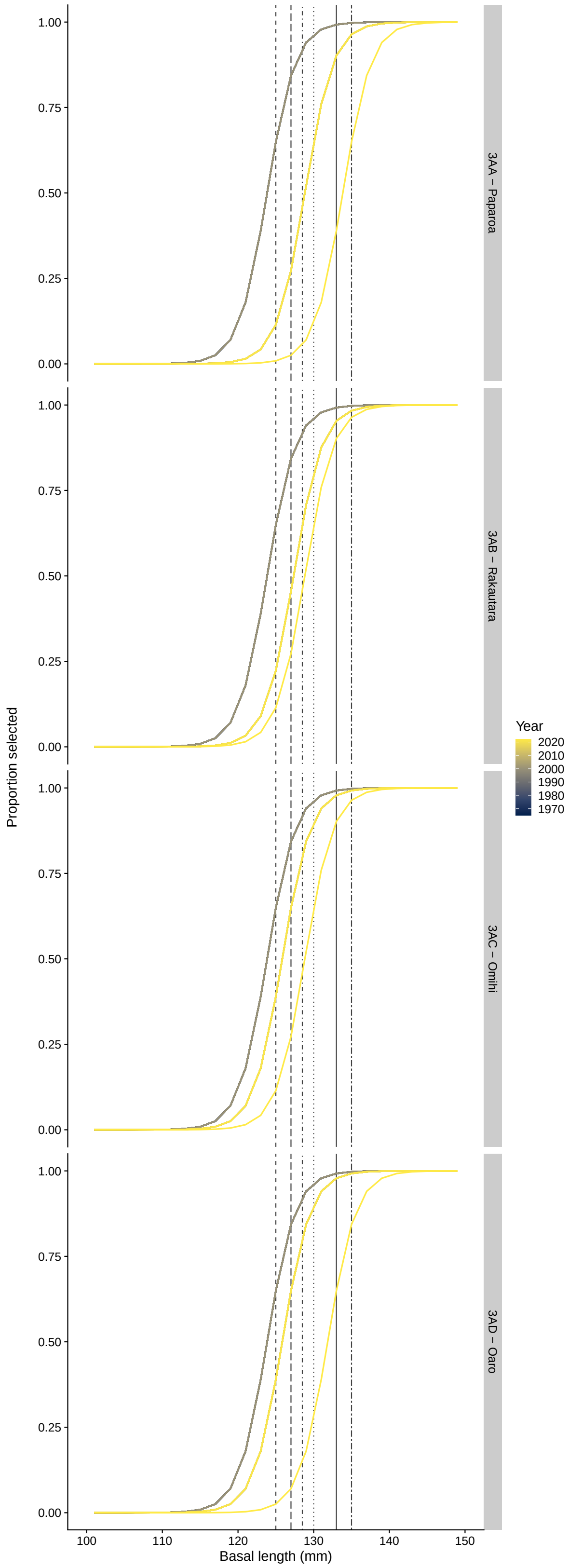

Figure D-6: Estimated selectivity (posterior mean) for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A.

D.5 Recruitment and biomass trends

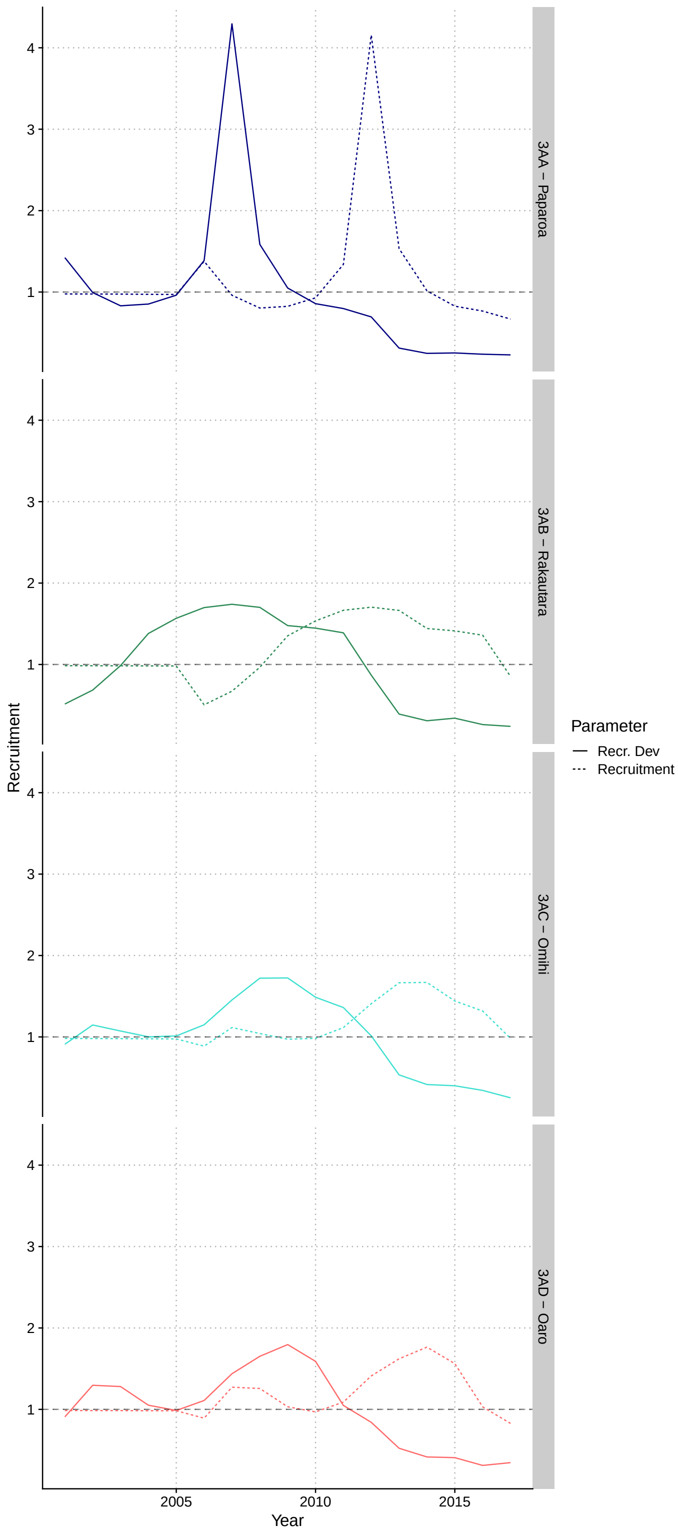

Figure D-7: Posterior mean recruitment for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model of pāua for quota management area PAU 3A (Recr. Dev (R_{dev}), recruitment deviation).

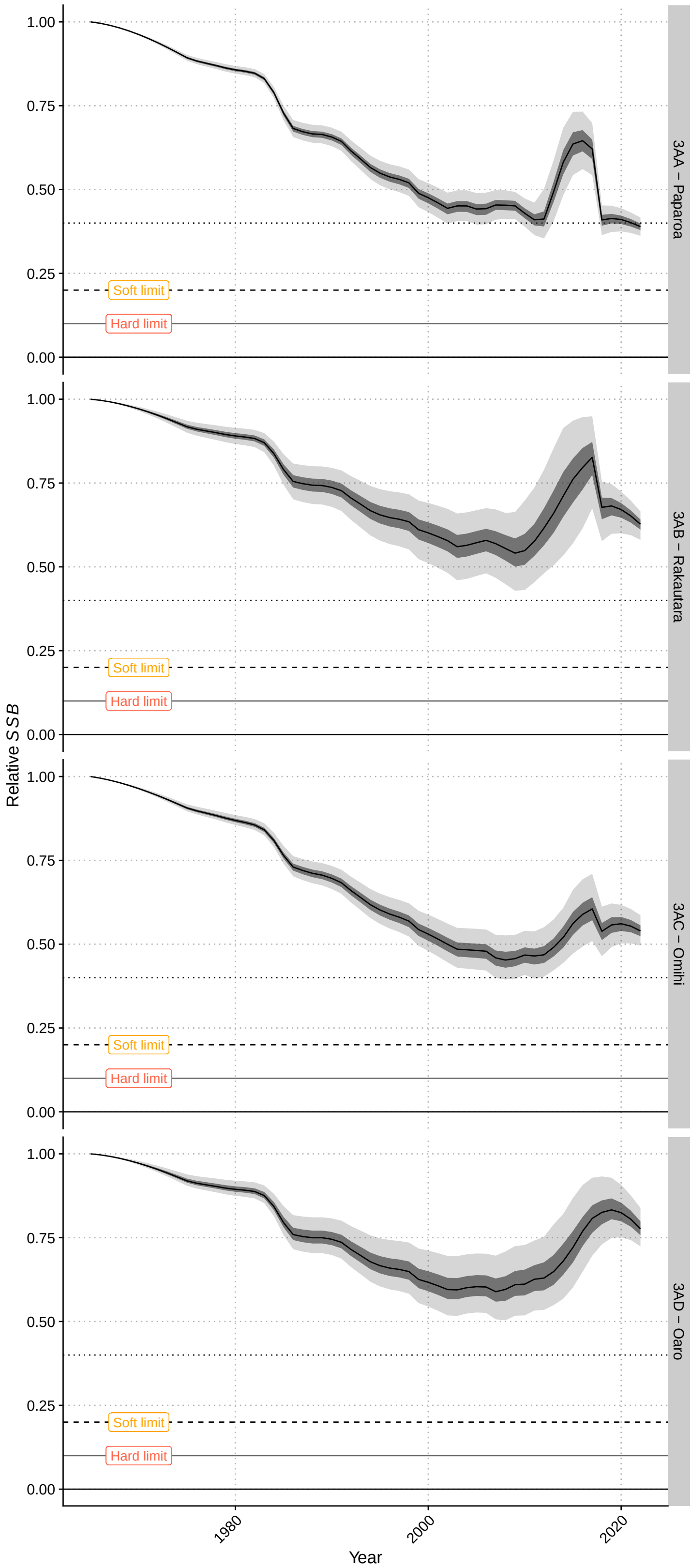

Figure D-8: Estimated relative spawning stock biomass (*SSB*) trend for pāua for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

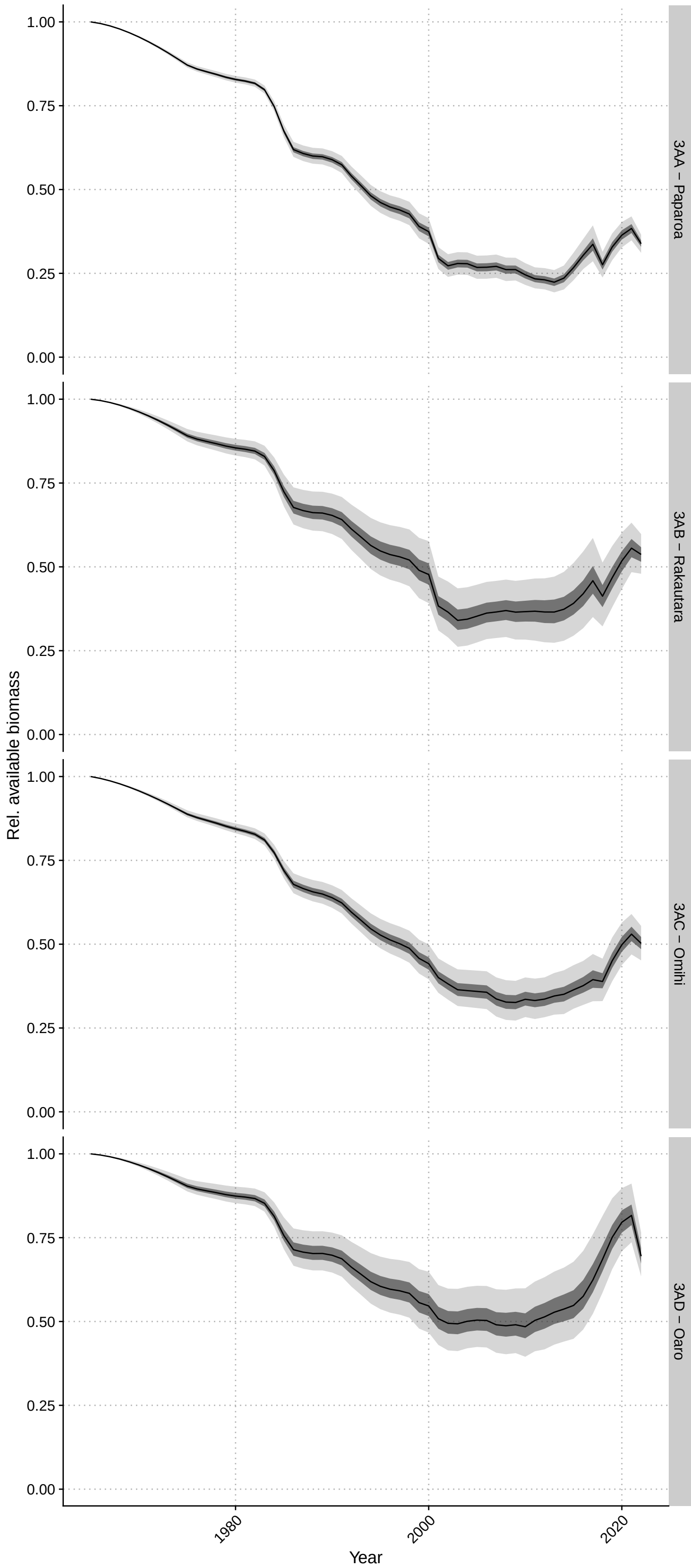

Figure D-9: Estimated relative available biomass trend for pāua for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

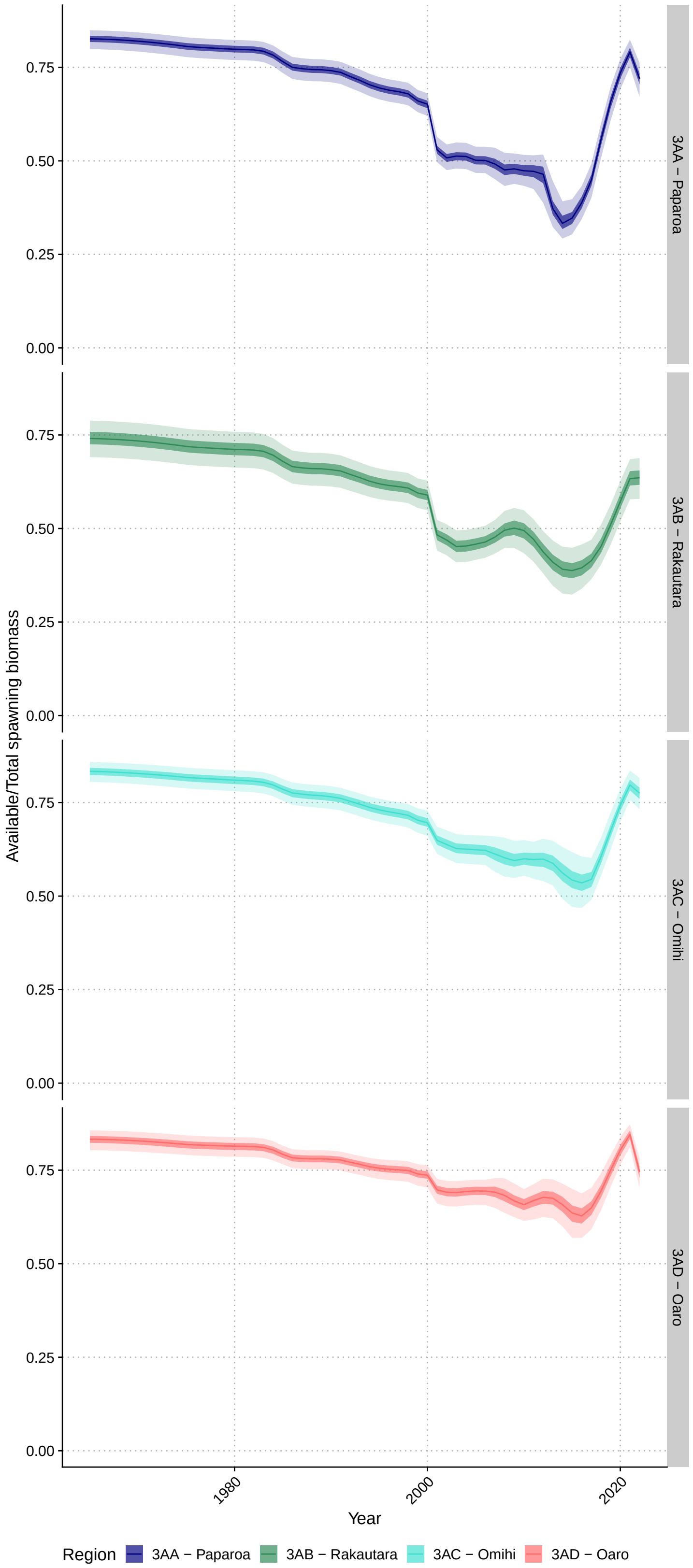

Figure D-10: Estimated relative available pāua biomass (relative to spawning stock) for the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

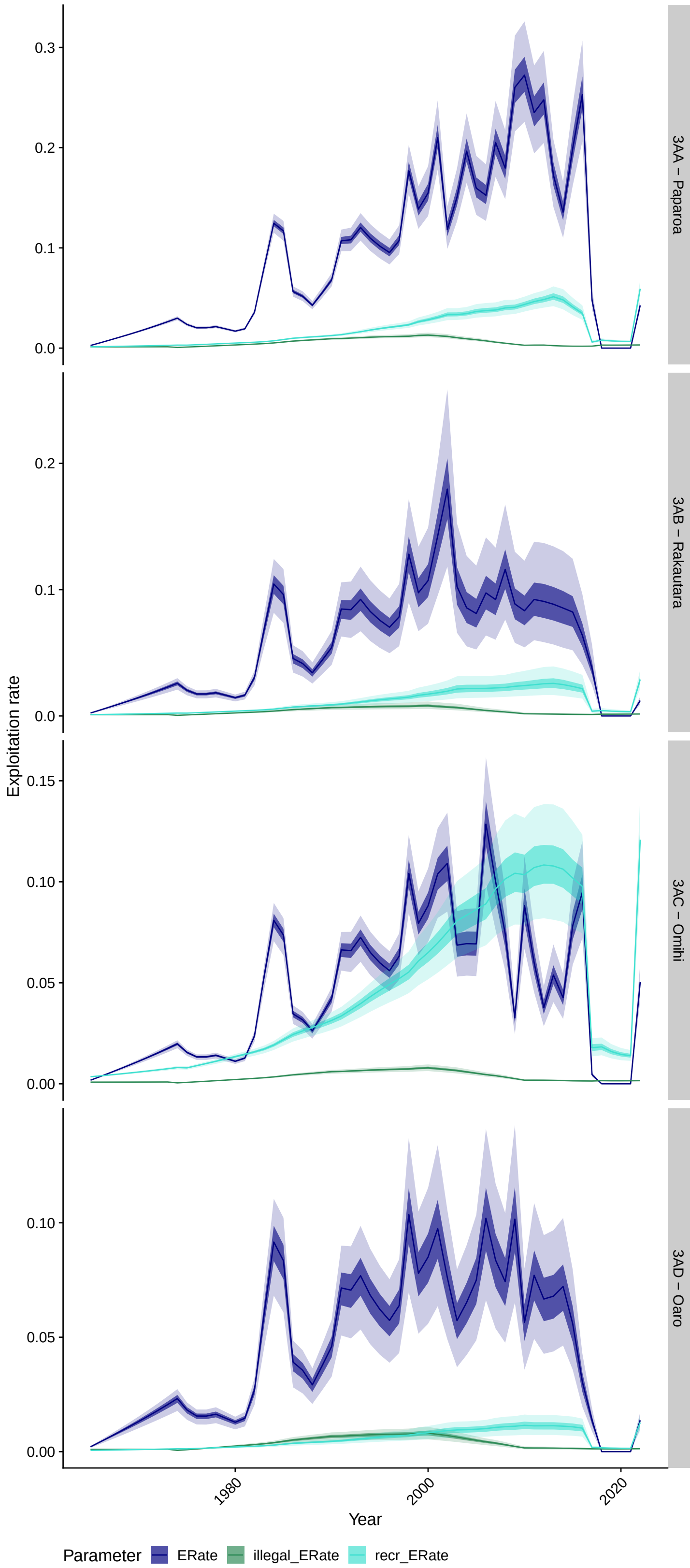

Figure D-11: Estimated exploitation rate (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)) for commercial (ERate), recreational (recr) and illegal components of the fishery in the base operating model, fitted to survey observations, including earthquake impacts modelled as instantaneous natural mortality (short term) and reduced recruitment (long term) proportional to uplift in each management zone in the model for quota management area PAU 3A.

APPENDIX E: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: SURVEY FIT

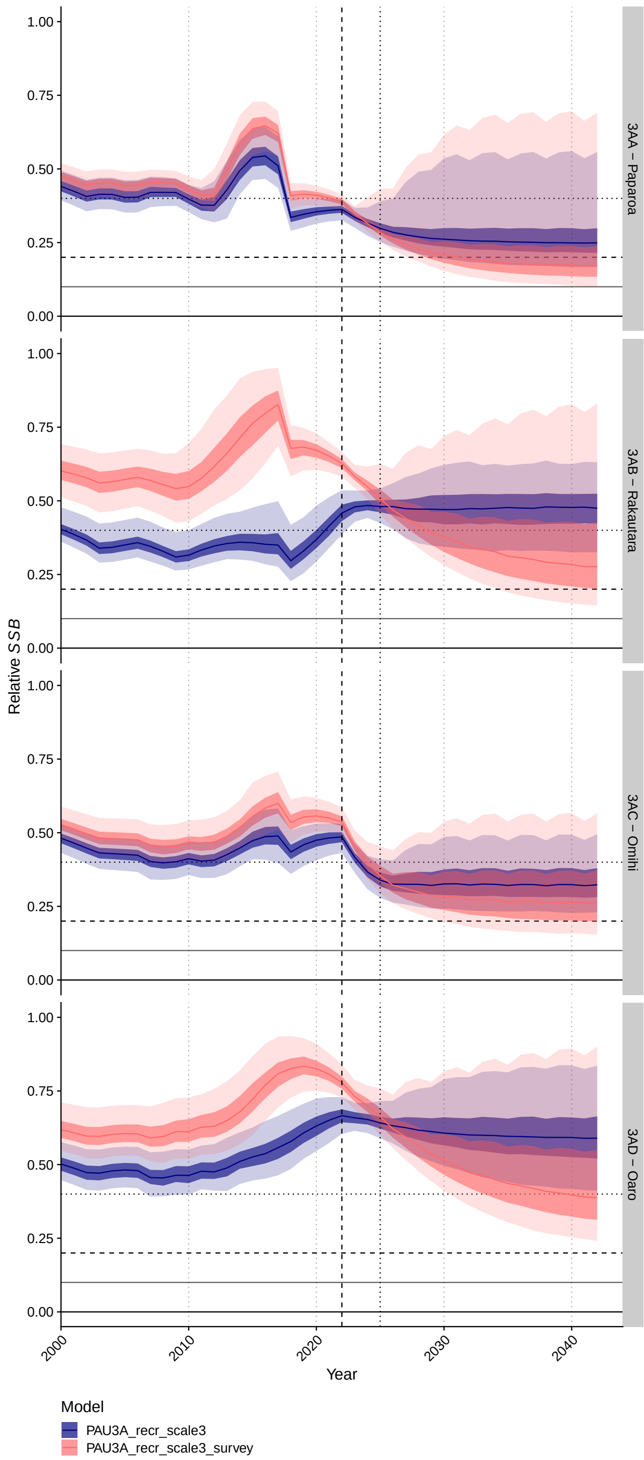

Figure E-1: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

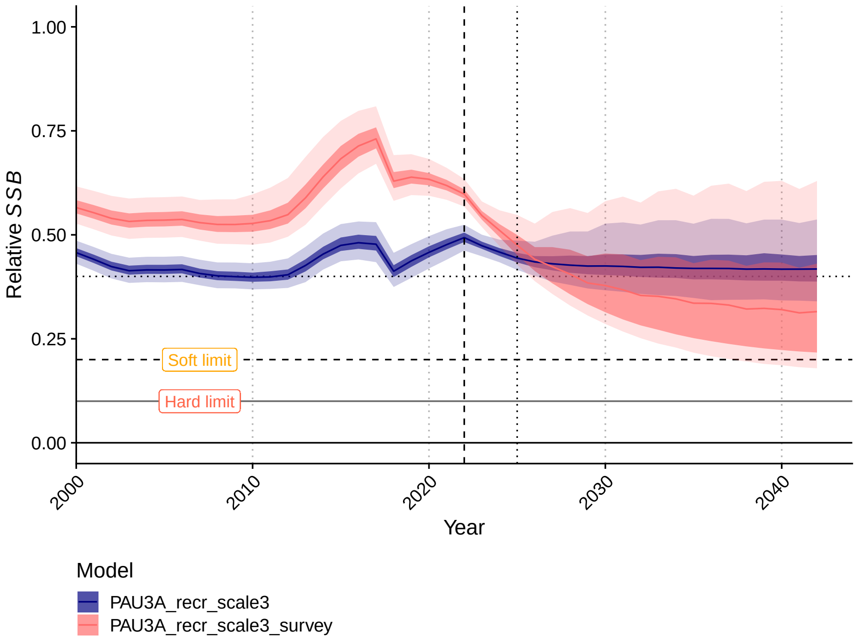

Figure E-2: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

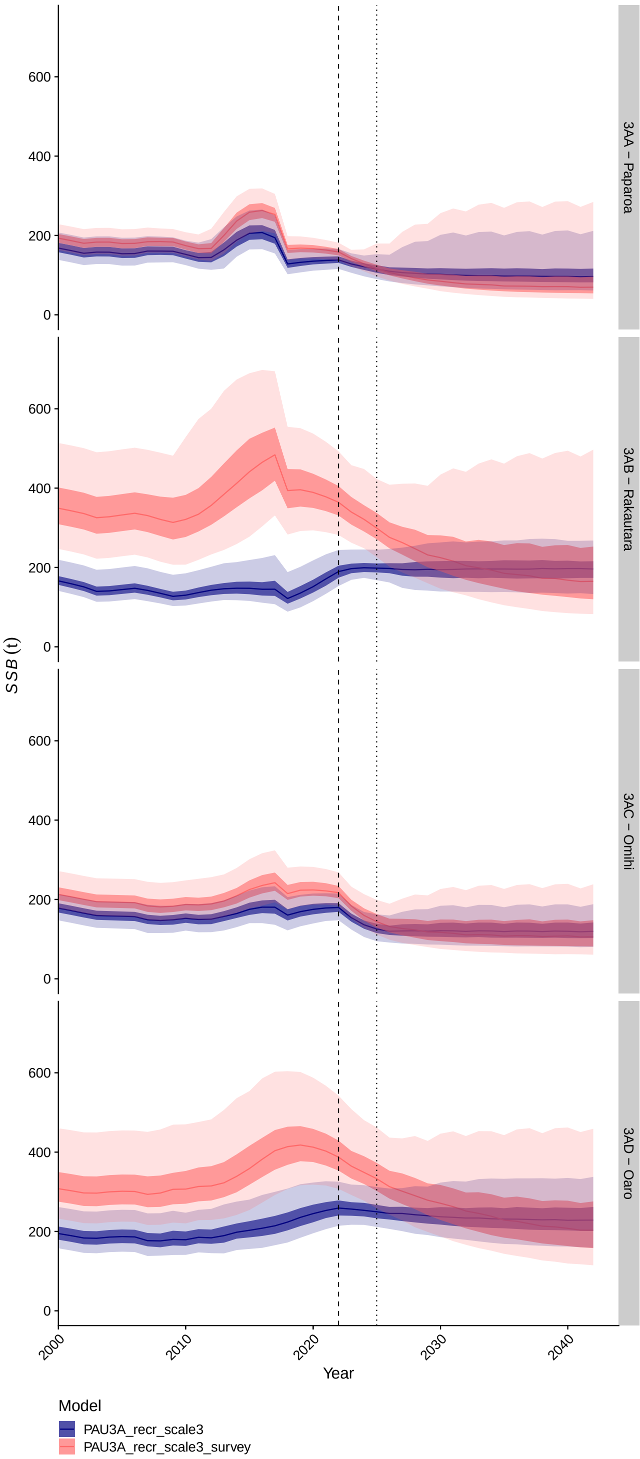

Figure E-3: Simulated spawning stock biomass (*SSB*; in tonnes) trend for pāua, comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

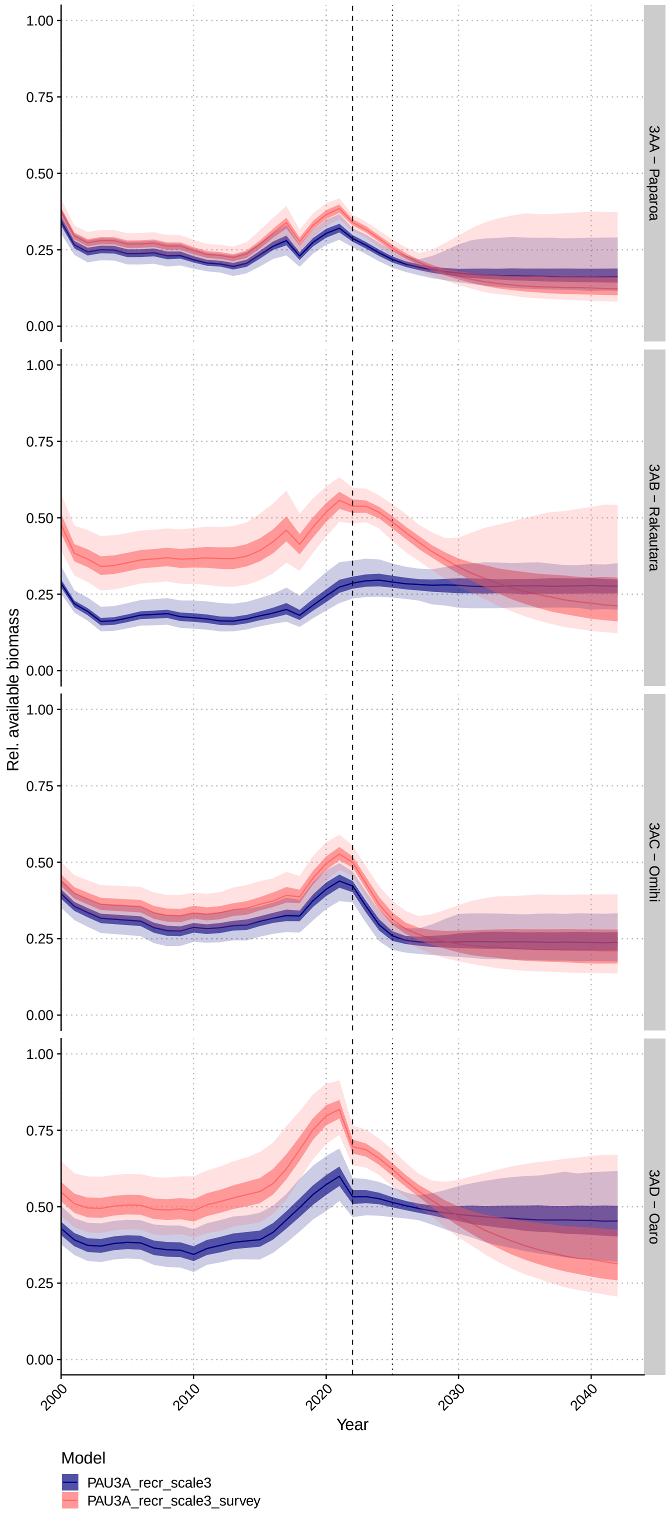

Figure E-4: Simulated relative available biomass trend for pāua, comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

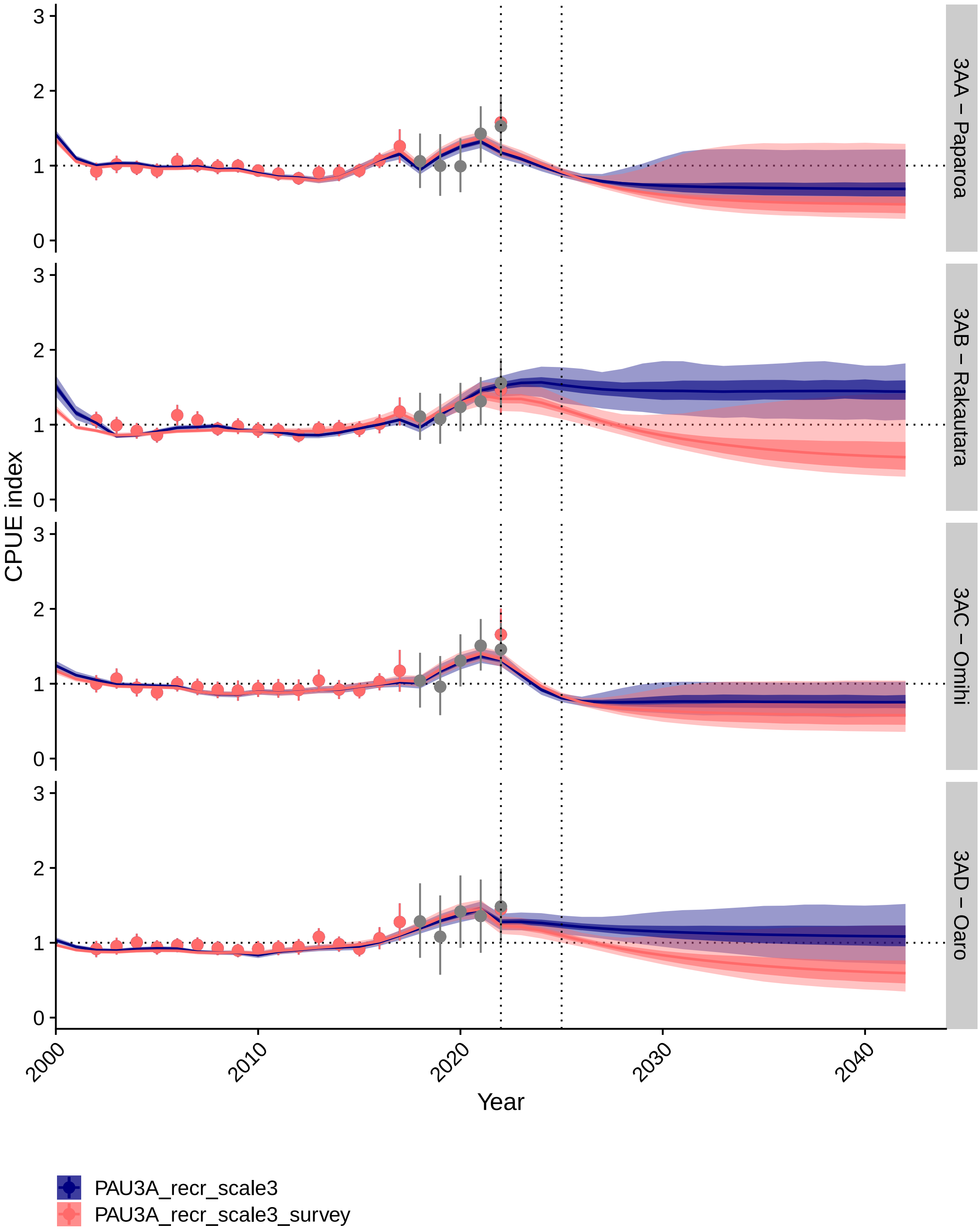

Figure E-5: Simulated catch-per-unit-effort (CPUE) trend for pāua, comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in quota management area PAU 3A. Left dotted vertical line shows the beginning of simulated trends based on the assessed harvest control rule, right dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

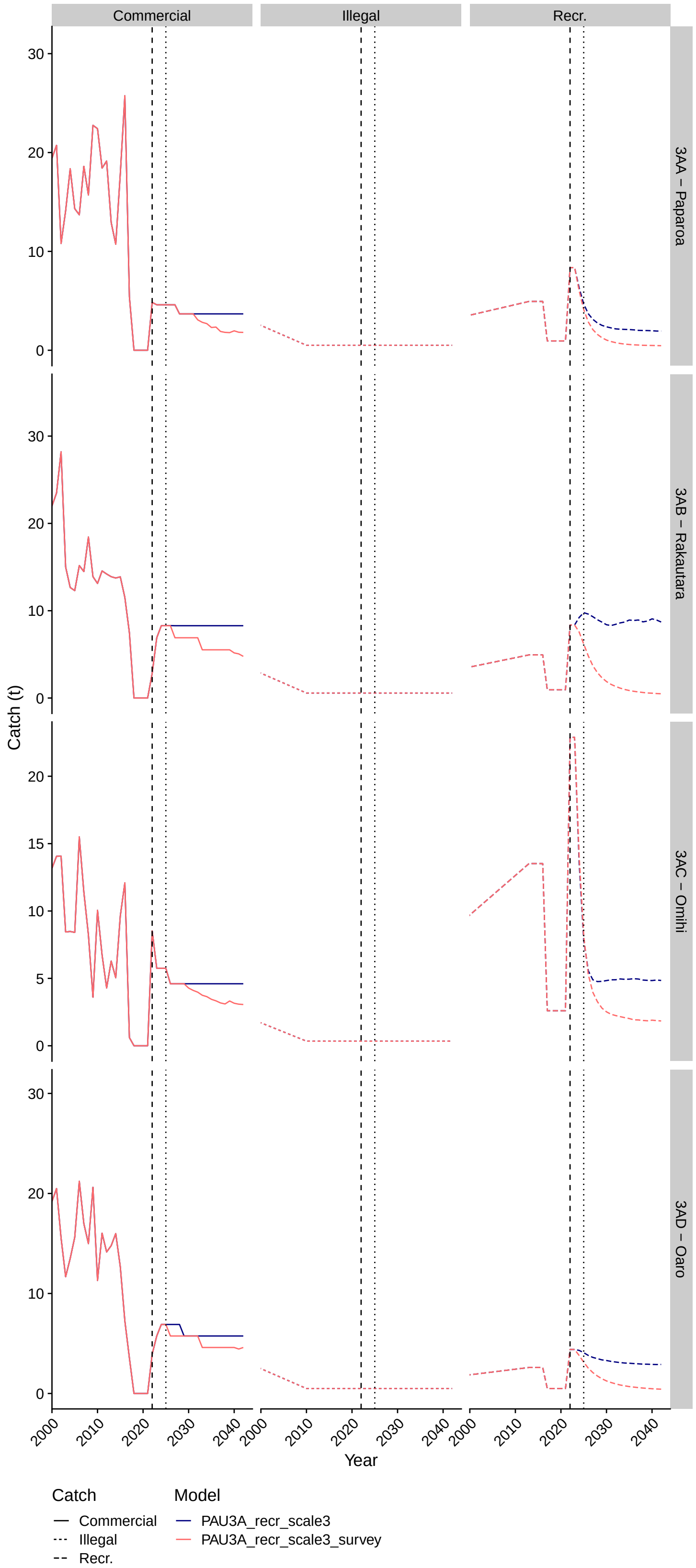

Figure E-6: Assumed and simulated catch by sector, comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

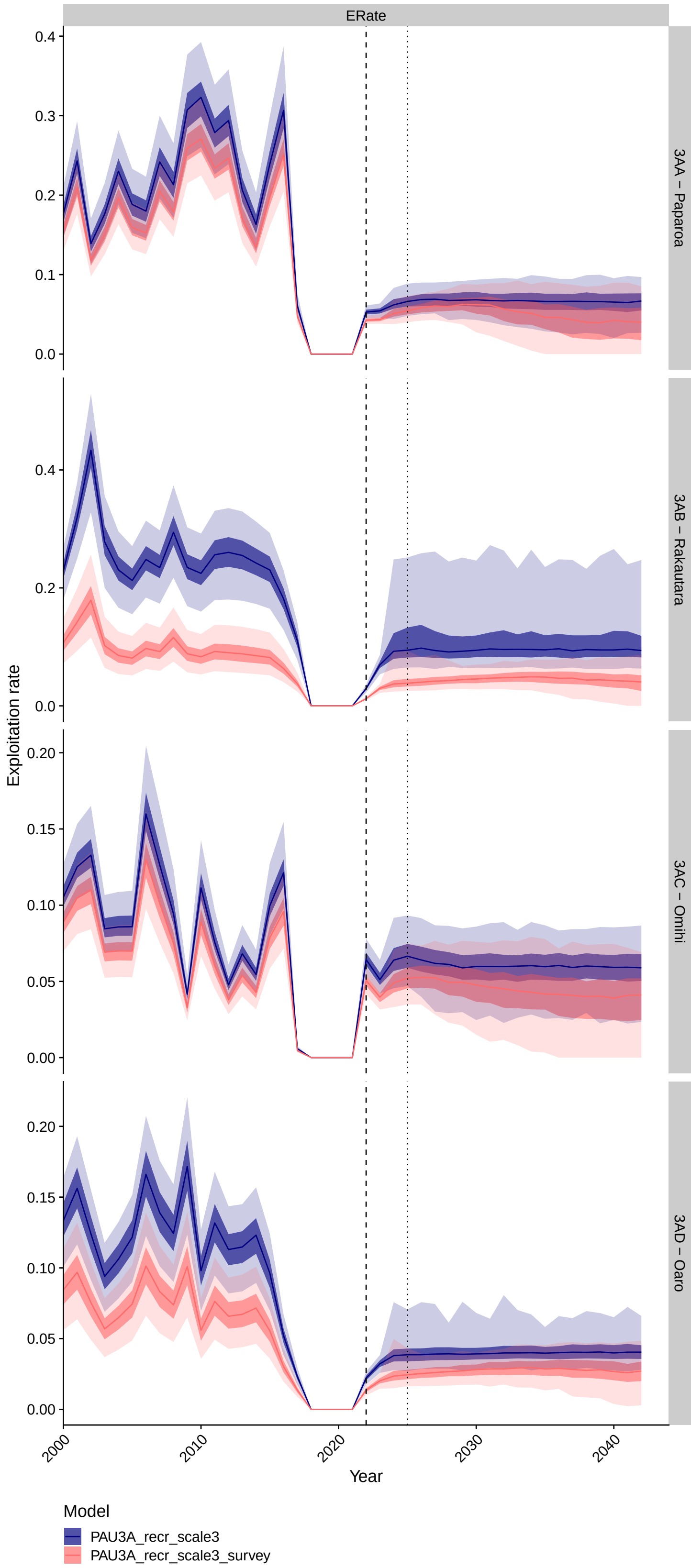

Figure E-7: Simulated exploitation rate (median line), comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

Table E-1: Performance of tested management procedures, comparing base operating models, fitted (or not) to survey observations, with management according to the tested control rules assuming recreational catch scaling according to the cube of available biomass (scale3) for each management zone in pāua for quota management area PAU 3A, by individual areas and across the overall QMA. MPE, management procedure evaluation; CPUE, catch-per-unit-effort.

Model	Region	Mean rel. *SSB* (2026)	Mean rel. *SSB* (2041)	P(rel*SSB* (2026)>0.4)	P(rel*SSB* (2041)>0.4)	P(rel*SSB* (2026)<0.2)	P(rel*SSB* (2041)<0.2)	P(rel*SSB* (2026)<0.1)	P(rel*SSB* (2041)<0.1)	Mean rel. *SSB* (2021–2041)	Mean catch (kg)	Mean CPUE (kg/h)
Base MPE, no survey fit	All Regions	0.45	0.42	1.00	0.65	0.00	0.00	0.00	0.00	0.43	25426.43	57.90
	3AA - Paparoa	0.30	0.27	0.02	0.09	0.00	0.16	0.00	0.00	0.29	3903.14	37.64
	3AB - Rakautara	0.48	0.47	1.00	0.83	0.00	0.00	0.00	0.00	0.48	10305.84	75.44
	3AC - Omihi	0.34	0.33	0.04	0.18	0.00	0.01	0.00	0.00	0.34	4709.01	35.22
	3AD - Oaro	0.64	0.60	1.00	0.99	0.00	0.00	0.00	0.00	0.62	6508.45	58.69
Base MPE, survey fit	All Regions	0.48	0.33	1.00	0.31	0.00	0.11	0.00	0.00	0.39	18662.94	38.50
	3AA - Paparoa	0.30	0.22	0.05	0.10	0.00	0.62	0.00	0.03	0.25	3170.76	32.09
	3AB - Rakautara	0.52	0.34	1.00	0.29	0.00	0.24	0.00	0.00	0.41	6367.00	43.71
	3AC - Omihi	0.36	0.30	0.18	0.20	0.00	0.25	0.00	0.00	0.32	3933.79	30.72
	3AD - Oaro	0.67	0.45	1.00	0.48	0.00	0.01	0.00	0.00	0.54	5191.40	41.92

APPENDIX F: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: EARTHQUAKE IMPACT ASSUMPTIONS

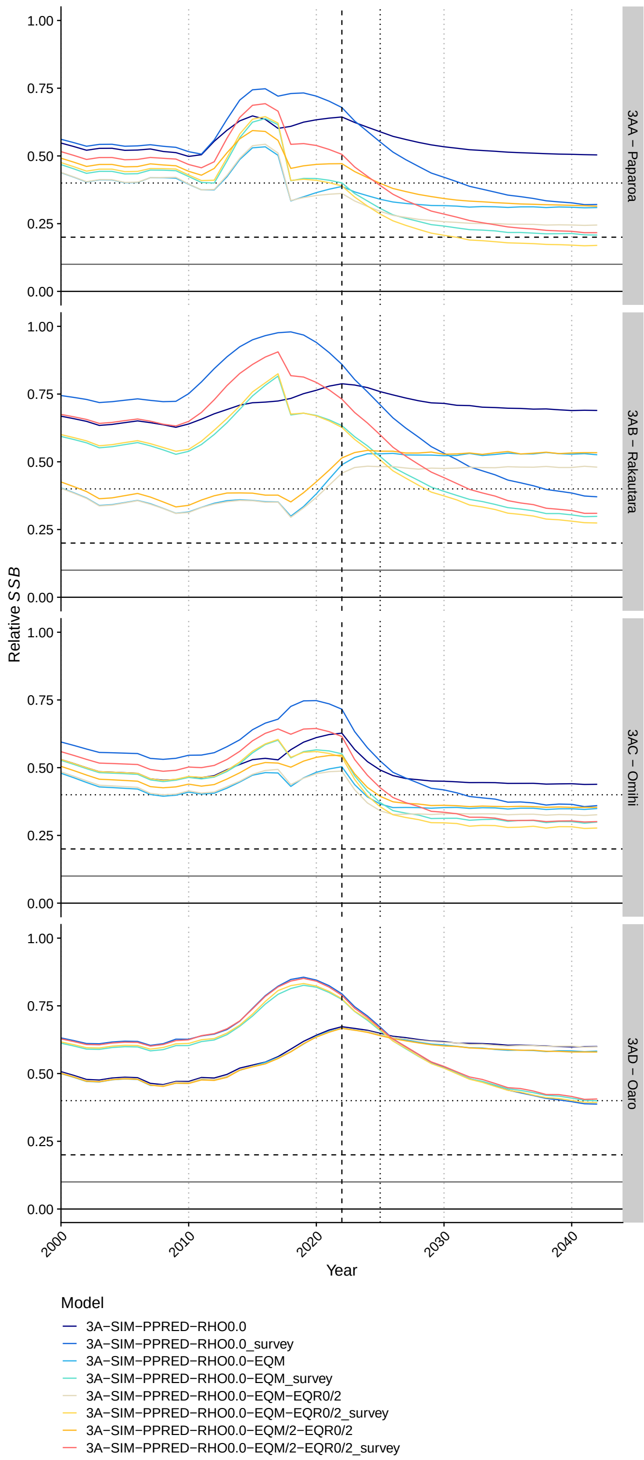

Figure F-1: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

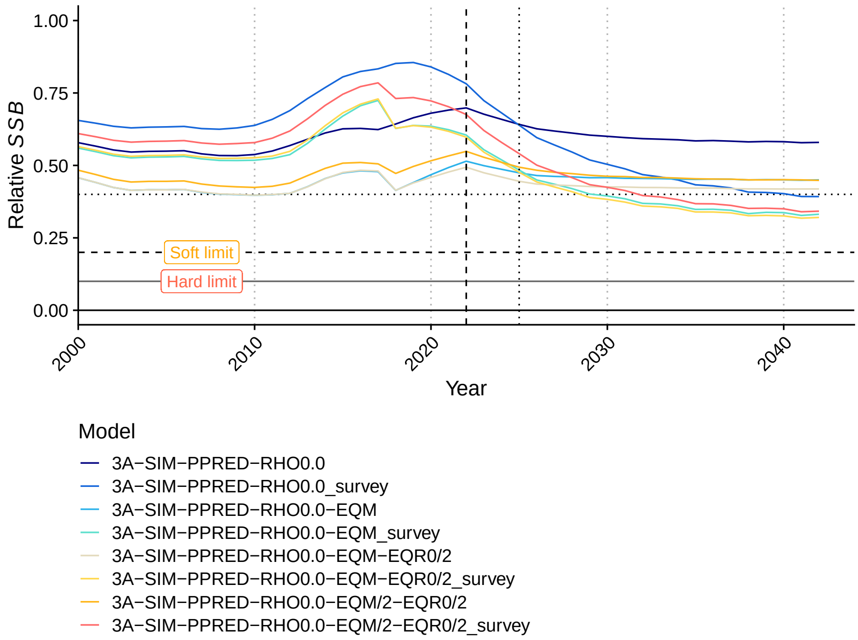

Figure F-2: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

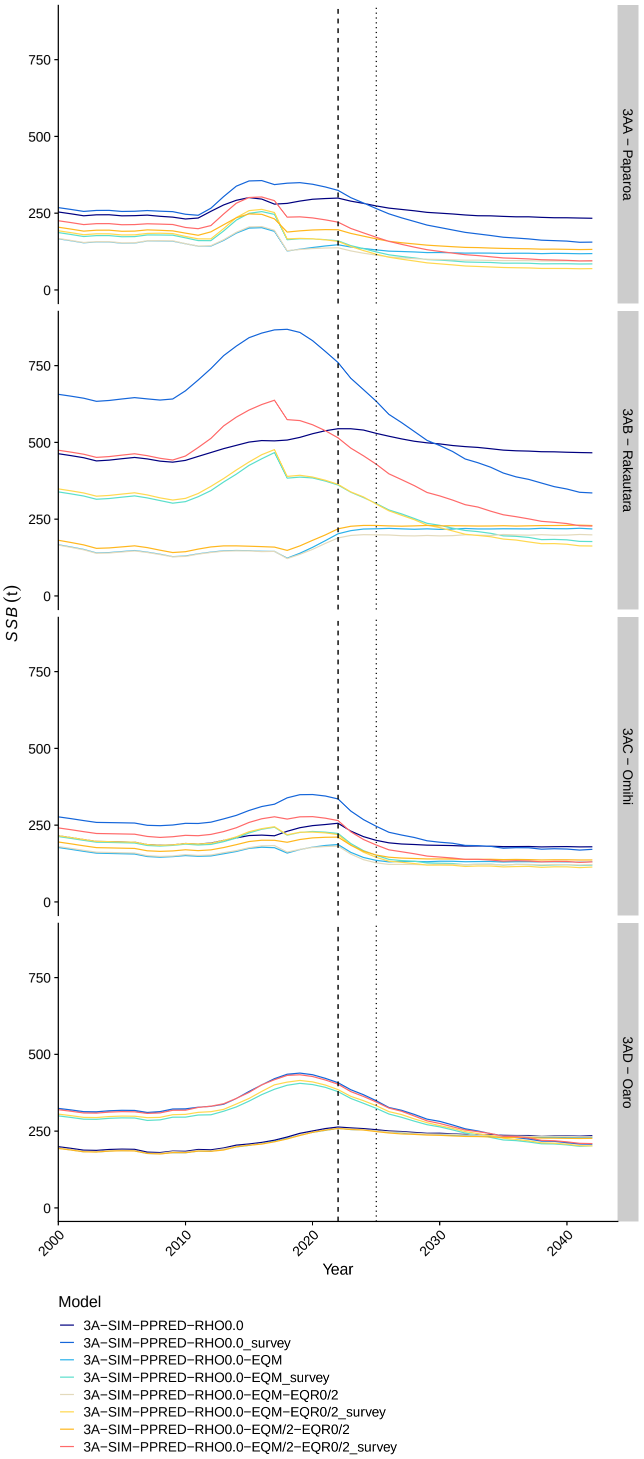

Figure F-3: Simulated spawning stock biomass (*SSB*; in tonnes) trend for pāua, comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

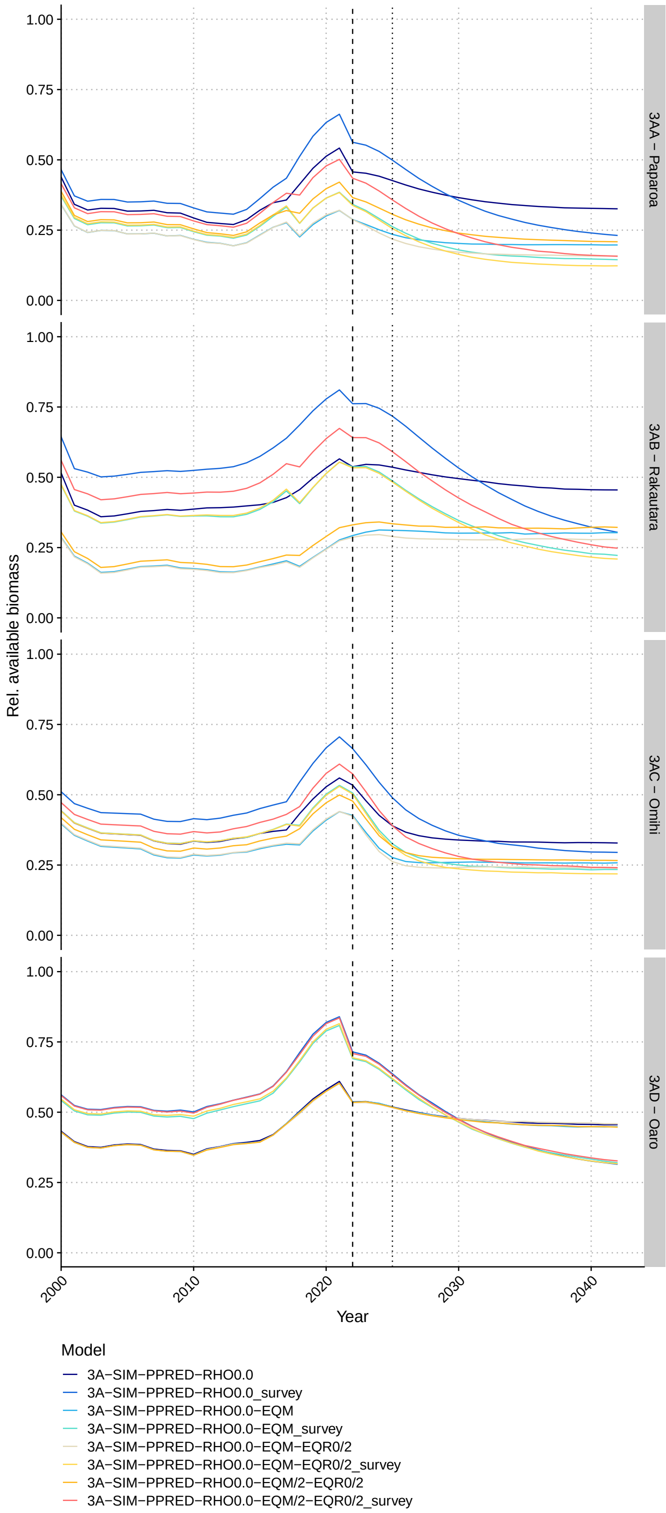

Figure F-4: Simulated relative available biomass trend for pāua, comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

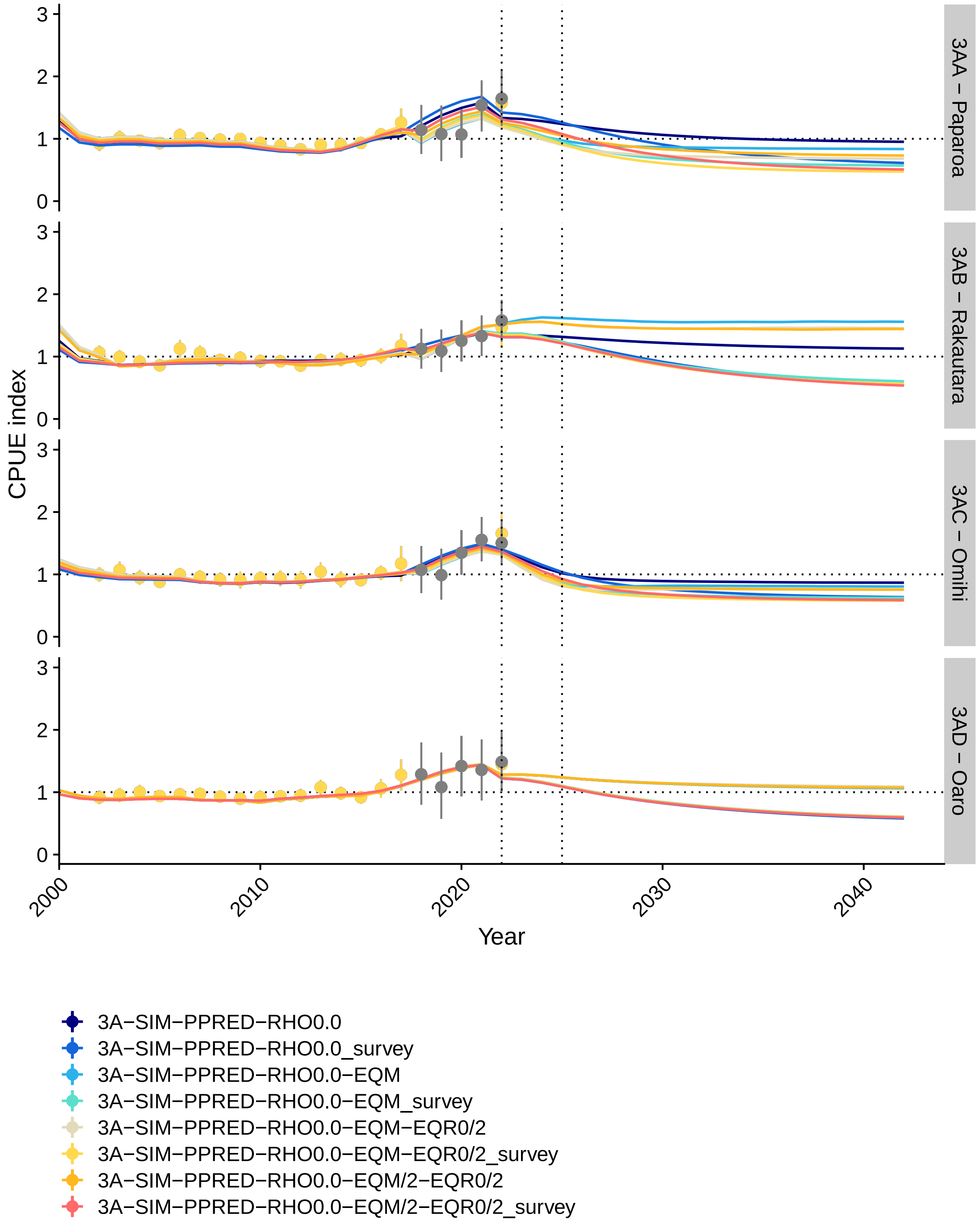

Figure F-5: Simulated catch-per-unit-effort (CPUE) trend for pāua, comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in quota management area PAU 3A. Left dotted vertical line shows the beginning of simulated trends based on the assessed harvest control rule, right dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

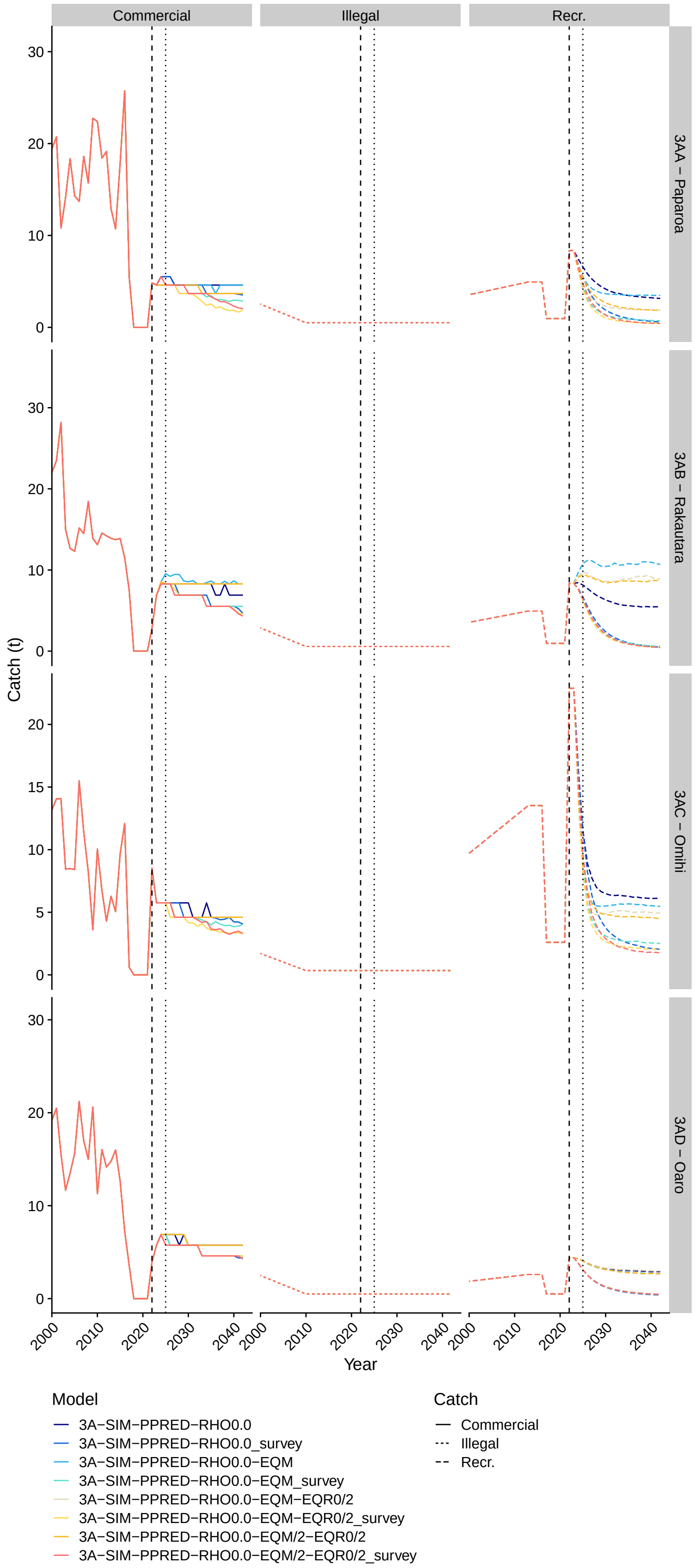

Figure F-6: Assumed and simulated catch by sector, comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

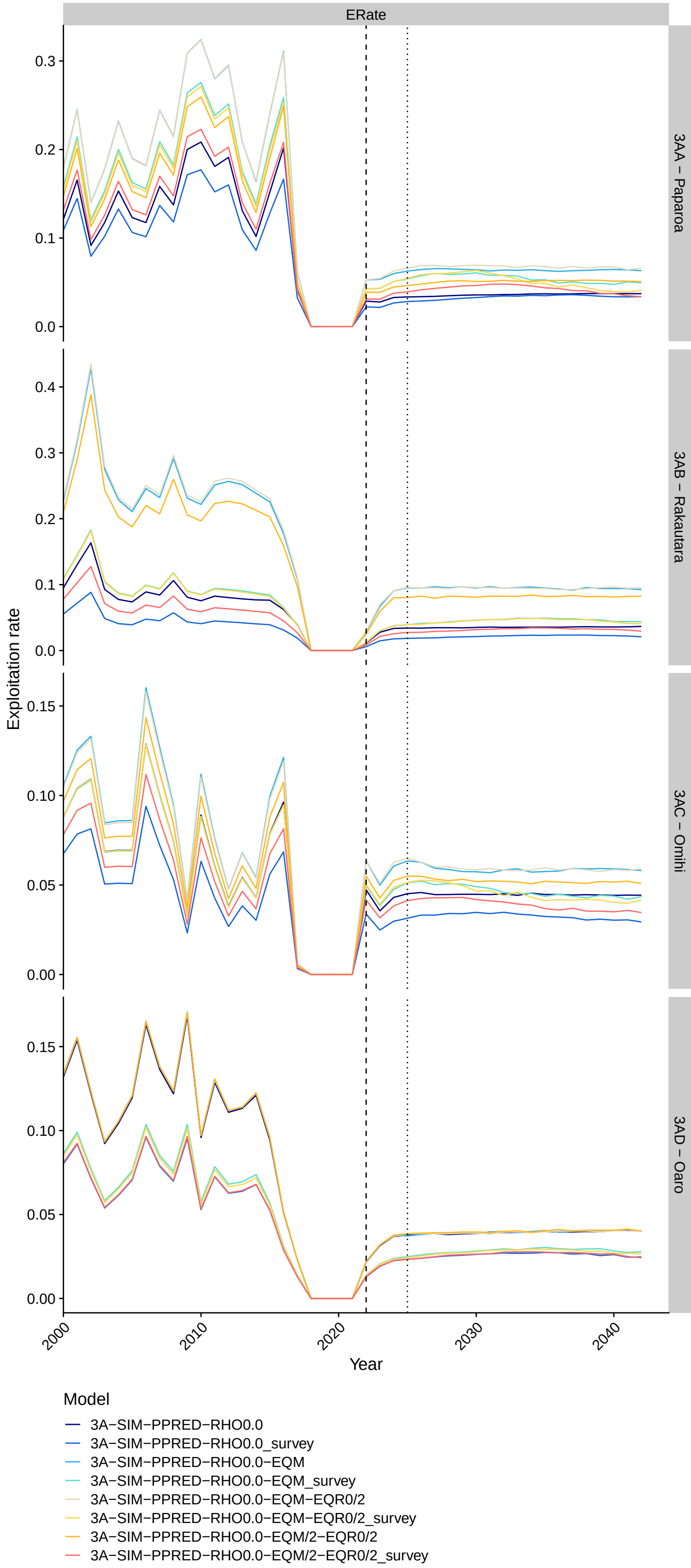

Figure F-7: Simulated exploitation rate (median line), comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

Table F-1: Performance of tested management procedures, comparing models (only medians from simulations are compared) assuming different levels of earthquake impacts (EQM - natural mortality from earthquake directly scaled with uplift (/2 refers to division by 2); EQR0/2 - unfished recruitment reduced by amount of uplift divided by 2), with management according to the tested control rules for each management zone in pāua for quota management area PAU 3A, by individual areas and across the overall QMA. MPE, management procedure evaluation; CPUE, catch-per-unit-effort.

Model	Region	Mean rel. *SSB* (2026)	Mean rel. *SSB* (2041)	P(rel*SSB* (2026)>0.4)	P(rel*SSB* (2041)>0.4)	P(rel*SSB* (2026)<0.2)	P(rel*SSB* (2041)<0.2)	P(rel*SSB* (2026)<0.1)	P(rel*SSB* (2041)<0.1)	Mean rel. *SSB* (2021–2041)	Mean catch (kg)	Mean CPUE (kg/h)
Base Model no survey fit	All Regions	0.64	0.58	1.00	1.00	0.00	0.00	0.00	0.00	0.61	24938.26	54.91
	3AA - Paparoa	0.59	0.52	1.00	0.90	0.00	0.00	0.00	0.00	0.54	4800.60	51.94
	3AB - Rakautara	0.75	0.70	1.00	1.00	0.00	0.00	0.00	0.00	0.72	8366.42	62.38
	3AC - Omihi	0.49	0.45	1.00	0.72	0.00	0.00	0.00	0.00	0.47	5268.88	41.30
	3AD - Oaro	0.65	0.60	1.00	0.96	0.00	0.00	0.00	0.00	0.62	6502.36	58.51
Base Model, EQM, no survey fit	All Regions	0.48	0.46	1.00	0.87	0.00	0.00	0.00	0.00	0.47	27276.67	61.68
	3AA - Paparoa	0.35	0.34	0.10	0.17	0.00	0.01	0.00	0.00	0.34	4326.41	43.64
	3AB - Rakautara	0.53	0.53	1.00	0.94	0.00	0.00	0.00	0.00	0.53	11535.09	80.68
	3AC - Omihi	0.37	0.36	0.20	0.28	0.00	0.00	0.00	0.00	0.37	4933.36	37.64
	3AD - Oaro	0.64	0.59	1.00	0.96	0.00	0.00	0.00	0.00	0.61	6481.80	58.19
Base Model, EQM/2-EQR0/2, no survey fit	All Regions	0.50	0.46	1.00	0.88	0.00	0.00	0.00	0.00	0.47	26054.30	58.50
	3AA - Paparoa	0.40	0.34	0.48	0.14	0.00	0.00	0.00	0.00	0.36	4204.01	41.71
	3AB - Rakautara	0.54	0.54	1.00	0.92	0.00	0.00	0.00	0.00	0.54	10519.14	75.42
	3AC - Omihi	0.40	0.36	0.43	0.27	0.00	0.00	0.00	0.00	0.38	4820.84	36.40
	3AD - Oaro	0.64	0.59	1.00	0.97	0.00	0.00	0.00	0.00	0.61	6510.30	58.37
Base Model, EQM-EQR0/2, no survey fit (Base MPE)	All Regions	0.45	0.43	1.00	0.64	0.00	0.00	0.00	0.00	0.43	25427.61	58.08
	3AA - Paparoa	0.30	0.27	0.02	0.09	0.00	0.17	0.00	0.00	0.28	3884.18	37.47
	3AB - Rakautara	0.48	0.48	1.00	0.85	0.00	0.00	0.00	0.00	0.48	10364.92	75.67
	3AC - Omihi	0.34	0.34	0.05	0.21	0.00	0.00	0.00	0.00	0.34	4685.64	35.24
	3AD - Oaro	0.65	0.60	1.00	0.99	0.00	0.00	0.00	0.00	0.62	6492.87	58.82
Base Model,	All Regions	0.64	0.41	1.00	0.49	0.00	0.00	0.00	0.00	0.50	20521.44	41.47

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Table F-1 – *Continued from previous page*

Model	Region	Mean rel. *SSB* (2026)	Mean rel. *SSB* (2041)	P(rel. *SSB* (2026)>0.4)	P(rel. *SSB* (2041)>0.4)	P(rel*SSB* (2026)<0.2)	P(rel *SSB* (2041)<0.2)	P(rel. *SSB* (2026)<0.1)	P(rel. *SSB* (2041)<0.1)	Mean rel. *SSB* (2021–2041)	Mean catch (kg)	Mean CPUE (kg/h)
survey fit	3AA - Paparoa	0.56	0.36	1.00	0.26	0.00	0.03	0.00	0.00	0.44	4302.01	43.59
	3AB - Rakautara	0.72	0.41	1.00	0.42	0.00	0.01	0.00	0.00	0.54	6506.53	44.19
	3AC - Omihi	0.53	0.39	1.00	0.43	0.00	0.03	0.00	0.00	0.45	4587.89	35.70
	3AD - Oaro	0.68	0.45	1.00	0.47	0.00	0.00	0.00	0.00	0.55	5125.01	41.40
Base Model,	All Regions	0.49	0.36	1.00	0.37	0.00	0.04	0.00	0.00	0.41	19638.08	40.13
EQM,	3AA - Paparoa	0.32	0.27	0.07	0.14	0.00	0.47	0.00	0.00	0.29	3574.18	35.81
survey fit	3AB - Rakautara	0.53	0.36	1.00	0.31	0.00	0.18	0.00	0.00	0.42	6613.63	45.56
	3AC - Omihi	0.38	0.32	0.27	0.21	0.00	0.13	0.00	0.00	0.34	4217.43	32.40
	3AD - Oaro	0.67	0.46	1.00	0.50	0.00	0.00	0.00	0.00	0.54	5232.84	42.45
Base Model,	All Regions	0.54	0.36	1.00	0.36	0.00	0.02	0.00	0.00	0.43	19280.40	39.14
EQM/2-EQR0/2,	3AA - Paparoa	0.40	0.26	0.34	0.11	0.00	0.42	0.00	0.00	0.32	3624.25	36.37
survey fit	3AB - Rakautara	0.60	0.36	1.00	0.32	0.00	0.11	0.00	0.00	0.46	6311.44	43.07
	3AC - Omihi	0.43	0.33	0.74	0.25	0.00	0.11	0.00	0.00	0.36	4175.31	32.38
	3AD - Oaro	0.68	0.46	1.00	0.52	0.00	0.00	0.00	0.00	0.55	5169.41	41.72
Base Model,	All Regions	0.48	0.33	1.00	0.31	0.00	0.11	0.00	0.00	0.39	18643.24	38.54
EQM-EQR0/2,	3AA - Paparoa	0.30	0.22	0.04	0.08	0.00	0.63	0.00	0.03	0.24	3145.06	31.80
survey fit	3AB - Rakautara	0.52	0.33	1.00	0.27	0.00	0.26	0.00	0.00	0.41	6343.81	43.78
(Base MPE)	3AC - Omihi	0.36	0.29	0.17	0.17	0.00	0.26	0.00	0.00	0.32	3951.98	30.68
	3AD - Oaro	0.67	0.46	1.00	0.49	0.00	0.00	0.00	0.00	0.54	5202.40	42.18

APPENDIX G: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: SCALING RECREATIONAL CATCH WITH AVAILABLE BIOMASS

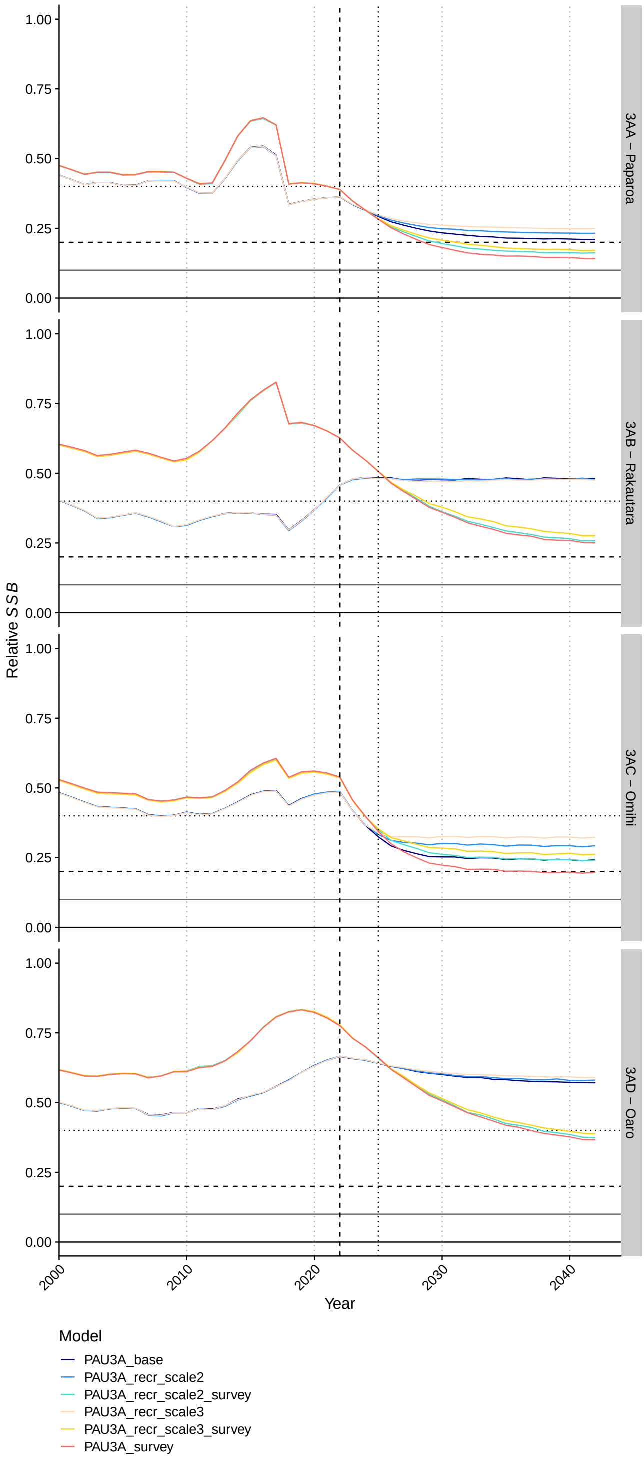

Figure G-1: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

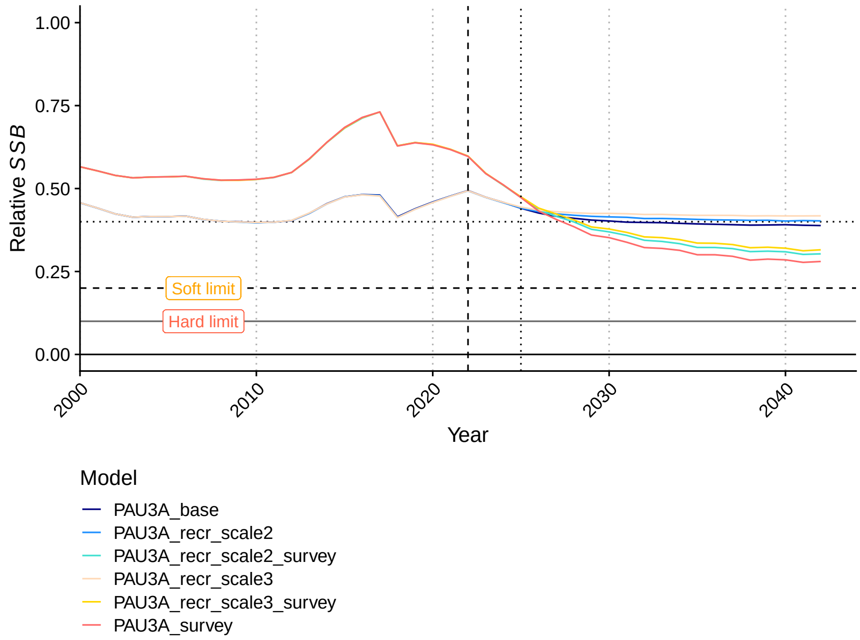

Figure G-2: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the tested harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

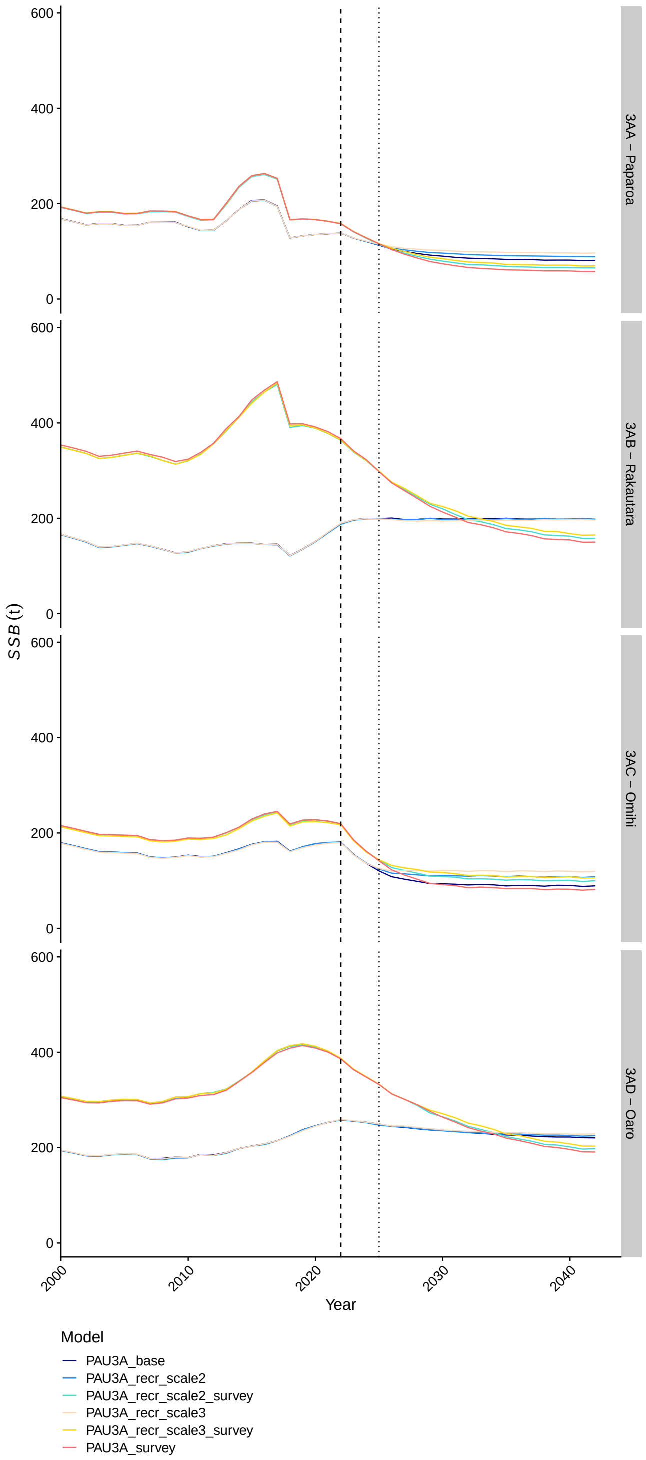

Figure G-3: Simulated spawning stock biomass (*SSB*; in tonnes) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

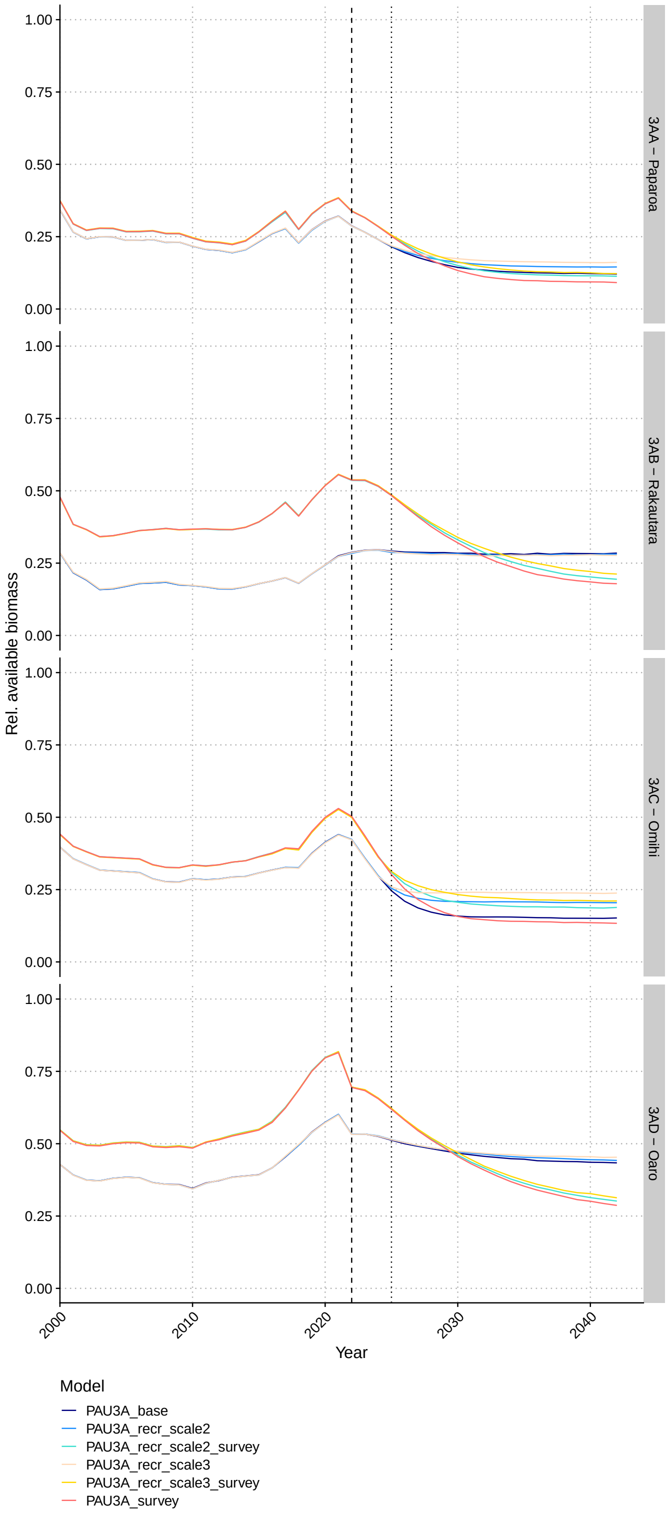

Figure G-4: Simulated relative available biomass trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

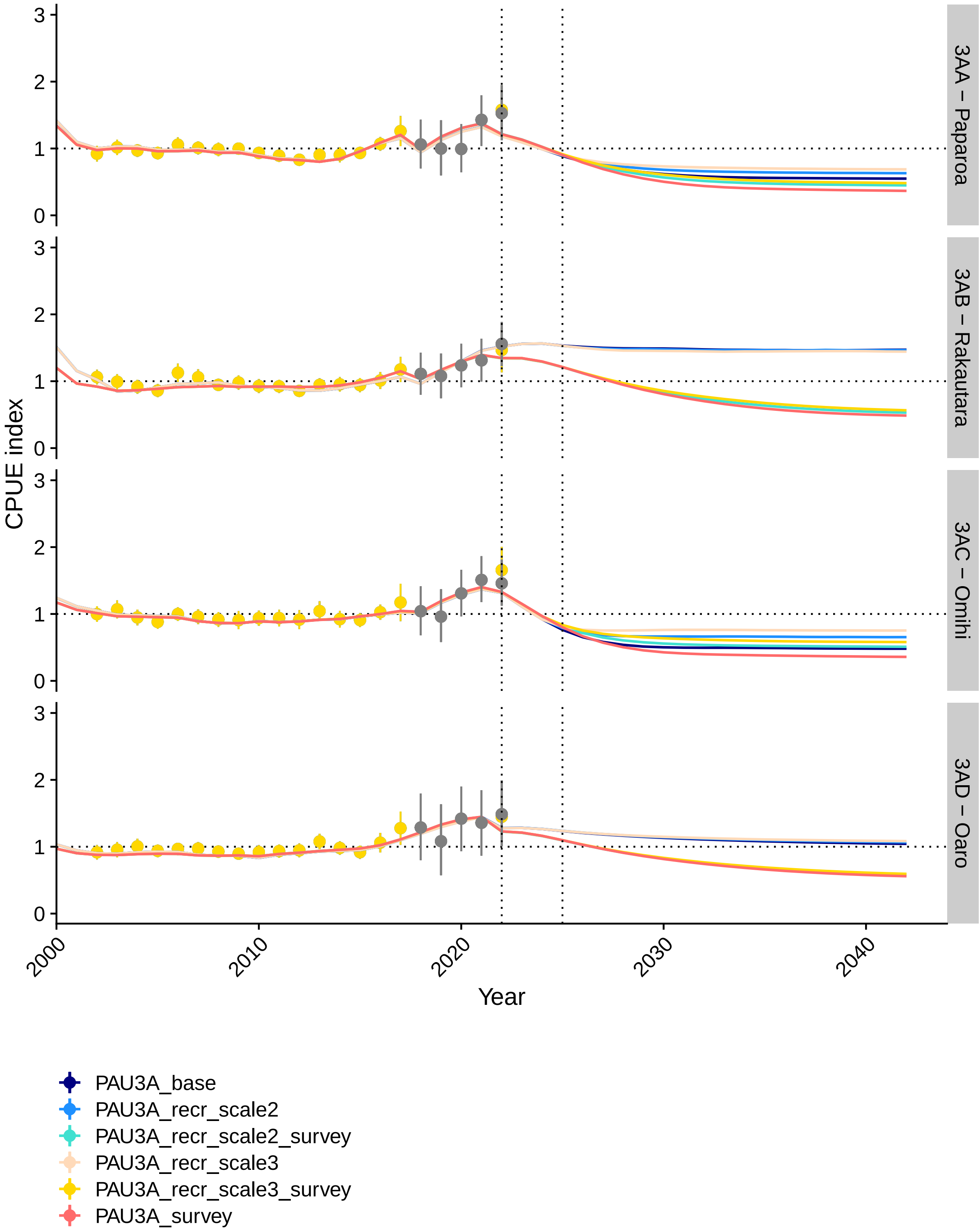

Figure G-5: Simulated catch-per-unit-effort (CPUE) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Left dotted vertical line shows the beginning of simulated trends based on the assessed harvest control rule, right dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

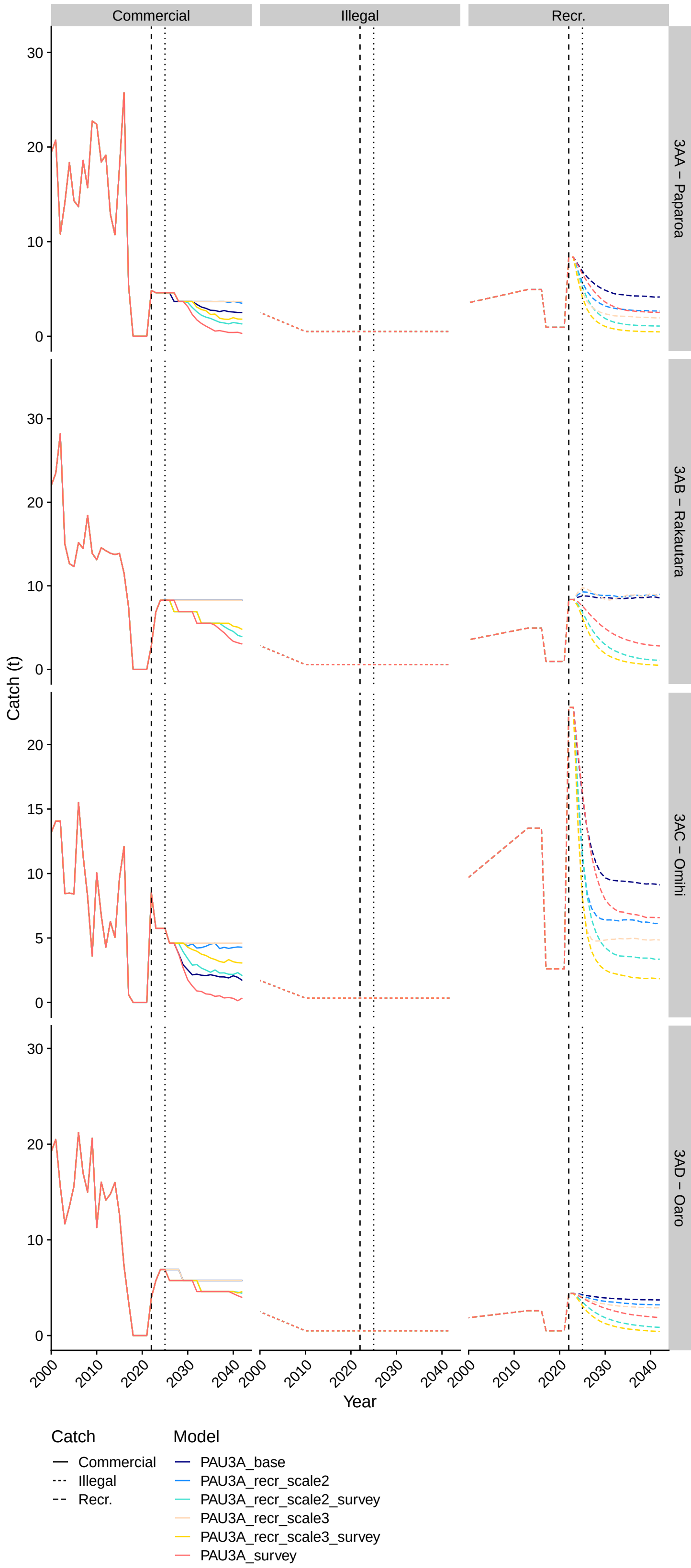

Figure G-6: Assumed and simulated catch by sector, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

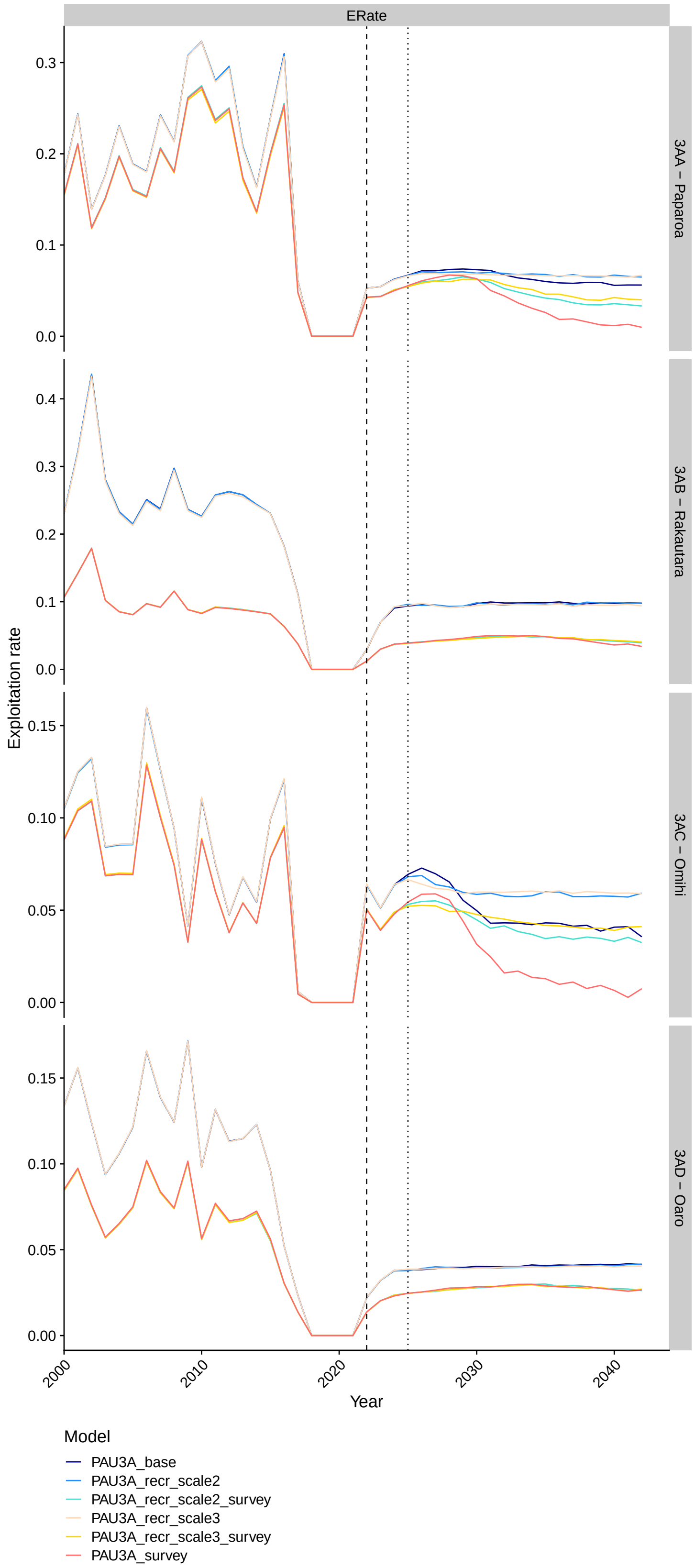

Figure G-7: Simulated exploitation rate (median line), comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

Table G-1: Performance of tested management procedures, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of scaling (red.: reduction) of recreational catch with available (above 125 mm) biomass. Management was applied according to the tested control rules for each management zone in pāua for quota management area PAU 3A, by individual areas and across the overall QMA. MPE, management procedure evaluation; CPUE, catch-per-unit-effort.

Model	Region	Mean rel. *SSB* (2026)	Mean rel. *SSB* (2041)	P(rel*SSB* (2026)>0.4)	P(rel*SSB* (2041)>0.4)	P(rel*SSB* (2026)<0.2)	P(rel*SSB* (2041)<0.2)	P(rel*SSB* (2026)<0.1)	P(rel*SSB* (2041)<0.1)	Mean rel. *SSB* (2021–2041)	Mean catch (kg)	Mean CPUE (kg/h)
Base MPE,	All Regions	0.45	0.42	1.00	0.65	0.00	0.00	0.00	0.00	0.43	25426.43	57.90
no survey fit	3AA - Paparoa	0.30	0.27	0.02	0.09	0.00	0.16	0.00	0.00	0.29	3903.14	37.64
	3AB - Rakautara	0.48	0.47	1.00	0.83	0.00	0.00	0.00	0.00	0.48	10305.84	75.44
	3AC - Omihi	0.34	0.33	0.04	0.18	0.00	0.01	0.00	0.00	0.34	4709.01	35.22
	3AD - Oaro	0.64	0.60	1.00	0.99	0.00	0.00	0.00	0.00	0.62	6508.45	58.69
Base MPE,	All Regions	0.44	0.41	0.99	0.53	0.00	0.00	0.00	0.00	0.42	25031.07	58.16
no survey fit,	3AA - Paparoa	0.30	0.26	0.03	0.08	0.00	0.25	0.00	0.00	0.27	3700.00	35.65
slow red.	3AB - Rakautara	0.48	0.48	1.00	0.83	0.00	0.00	0.00	0.00	0.48	10635.29	76.38
	3AC - Omihi	0.34	0.31	0.04	0.12	0.00	0.02	0.00	0.00	0.32	4222.43	31.73
	3AD - Oaro	0.64	0.59	1.00	0.97	0.00	0.00	0.00	0.00	0.61	6473.36	58.34
Base MPE,	All Regions	0.44	0.40	1.00	0.41	0.00	0.00	0.00	0.00	0.41	23821.18	59.02
no survey fit,	3AA - Paparoa	0.30	0.25	0.02	0.09	0.00	0.43	0.00	0.00	0.26	3342.92	33.19
slowest red.	3AB - Rakautara	0.48	0.49	0.99	0.79	0.00	0.00	0.00	0.00	0.48	10918.45	77.06
	3AC - Omihi	0.33	0.26	0.03	0.05	0.00	0.23	0.00	0.00	0.28	3103.24	25.85
	3AD - Oaro	0.64	0.58	1.00	0.95	0.00	0.00	0.00	0.00	0.61	6456.57	57.82
Base MPE,	All Regions	0.48	0.33	1.00	0.31	0.00	0.11	0.00	0.00	0.39	18662.94	38.50
survey fit	3AA - Paparoa	0.30	0.22	0.05	0.10	0.00	0.62	0.00	0.03	0.25	3170.76	32.09
	3AB - Rakautara	0.52	0.34	1.00	0.29	0.00	0.24	0.00	0.00	0.41	6367.00	43.71
	3AC - Omihi	0.36	0.30	0.18	0.20	0.00	0.25	0.00	0.00	0.32	3933.79	30.72
	3AD - Oaro	0.67	0.45	1.00	0.48	0.00	0.01	0.00	0.00	0.54	5191.40	41.92
Base MPE,	All Regions	0.48	0.32	1.00	0.27	0.00	0.17	0.00	0.00	0.38	17692.47	37.34
survey fit,	3AA - Paparoa	0.29	0.21	0.04	0.09	0.00	0.67	0.00	0.05	0.24	2941.29	30.74
slow red.	3AB - Rakautara	0.51	0.32	1.00	0.24	0.00	0.28	0.00	0.00	0.40	6184.66	42.32

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Table G-1 – *Continued from previous page*

Model	Region	Mean rel. *SSB* (2026)	Mean rel. *SSB* (2041)	P(rel. *SSB* (2026)>0.4)	P(rel. *SSB* (2041)>0.4)	P(rel*SSB* (2026)<0.2)	P(rel *SSB* (2041)<0.2)	P(rel. *SSB* (2026)<0.1)	P(rel. *SSB* (2041)<0.1)	Mean rel. *SSB* (2021–2041)	Mean catch (kg)	Mean CPUE (kg/h)
	3AC - Omihi	0.36	0.27	0.13	0.14	0.00	0.34	0.00	0.00	0.30	3431.82	28.00
	3AD - Oaro	0.67	0.44	1.00	0.46	0.00	0.00	0.00	0.00	0.54	5134.70	41.35
Base MPE,	All Regions	0.47	0.30	1.00	0.23	0.00	0.33	0.00	0.00	0.37	16138.41	36.13
survey fit,	3AA - Paparoa	0.29	0.20	0.05	0.09	0.00	0.76	0.00	0.21	0.23	2596.20	28.42
slowest red.	3AB - Rakautara	0.51	0.31	1.00	0.25	0.00	0.35	0.00	0.00	0.39	5917.32	41.01
	3AC - Omihi	0.35	0.22	0.11	0.08	0.00	0.51	0.00	0.05	0.26	2570.90	23.25
	3AD - Oaro	0.67	0.44	1.00	0.44	0.00	0.02	0.00	0.00	0.53	5053.99	40.95

APPENDIX H: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: FIXED RECREATIONAL CATCH

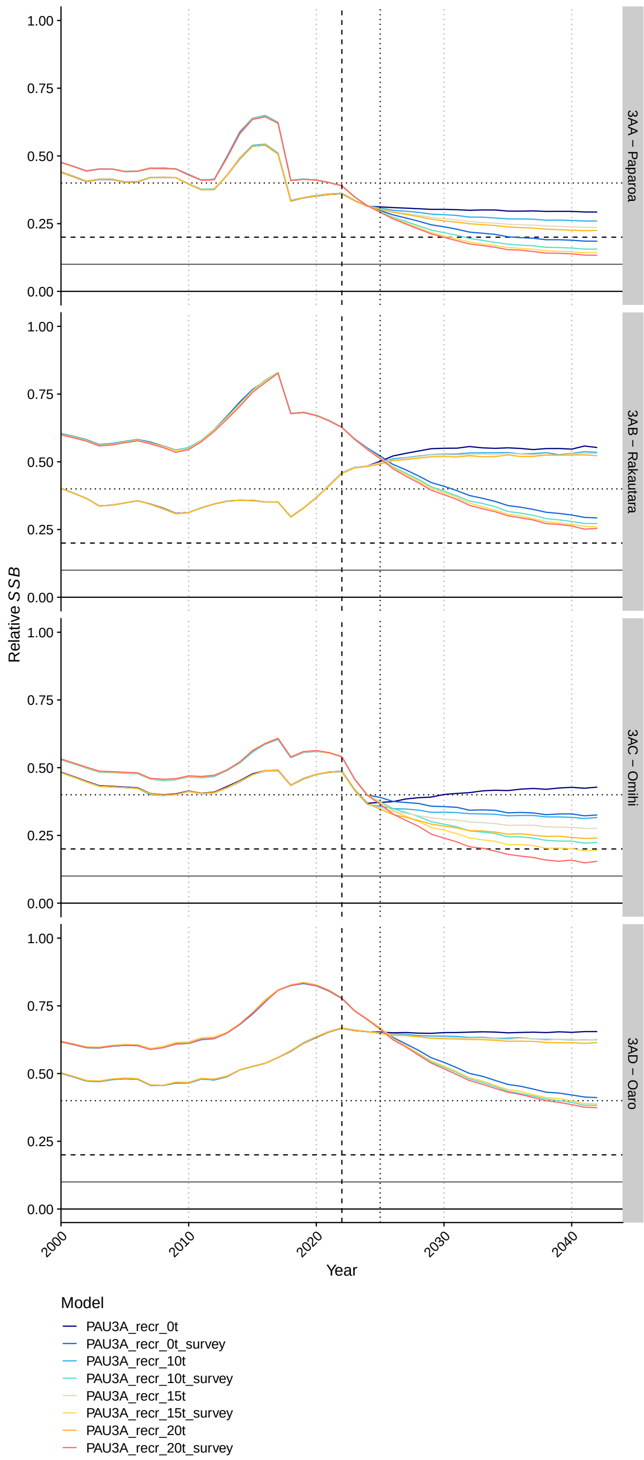

Figure H-1: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

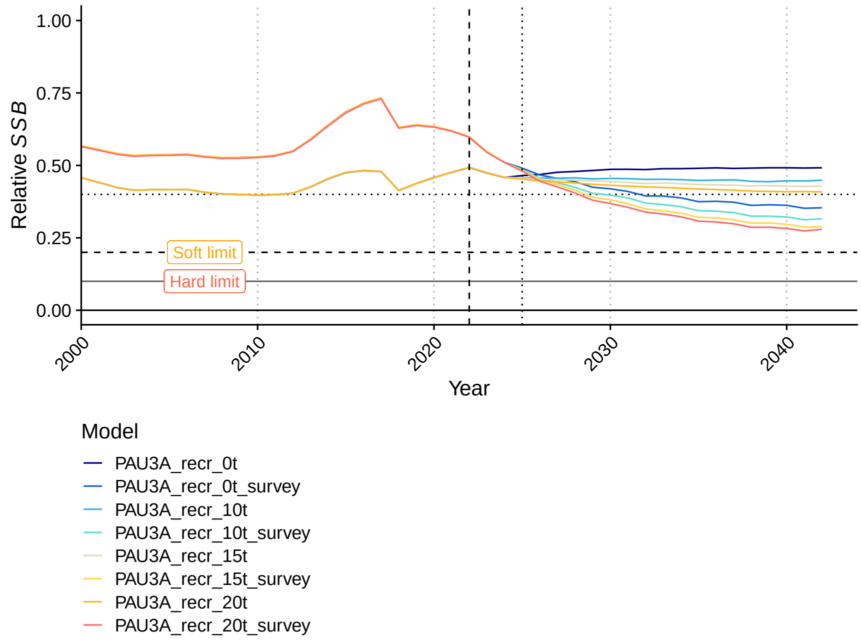

Figure H-2: Simulated relative spawning stock biomass (*SSB*) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

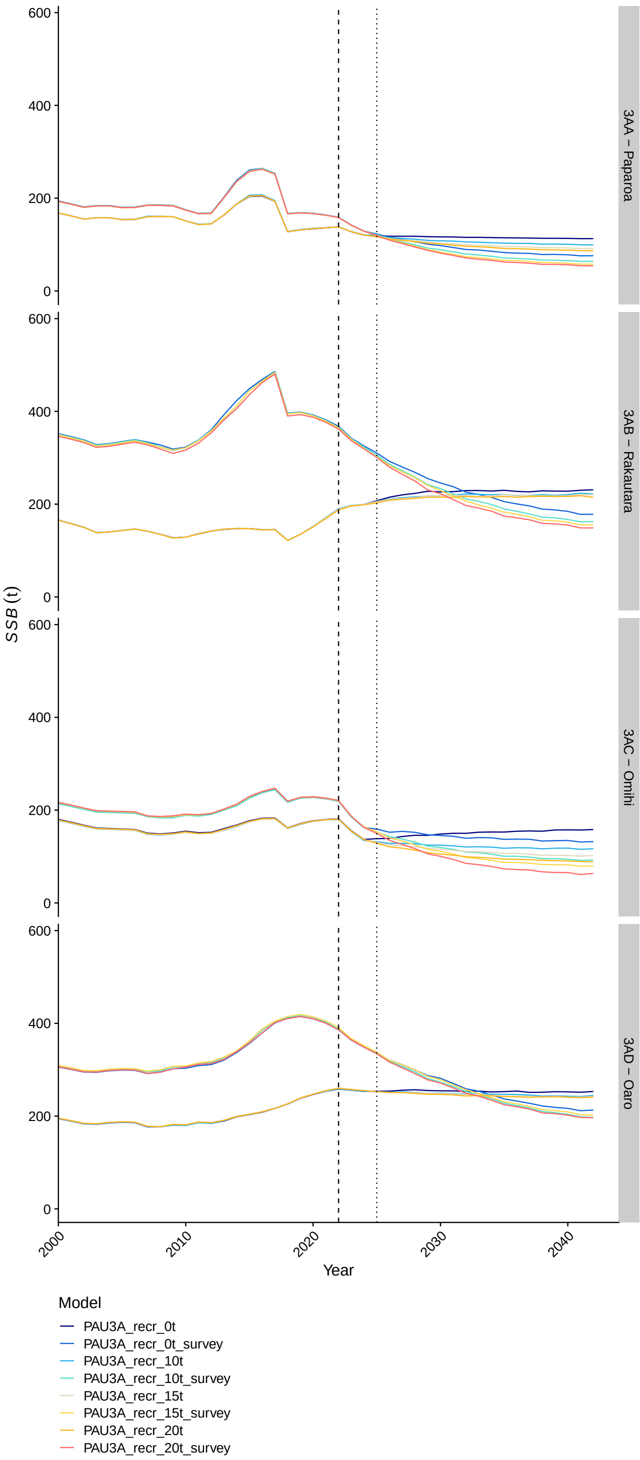

Figure H-3: Simulated spawning stock biomass (*SSB*; in tonnes) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

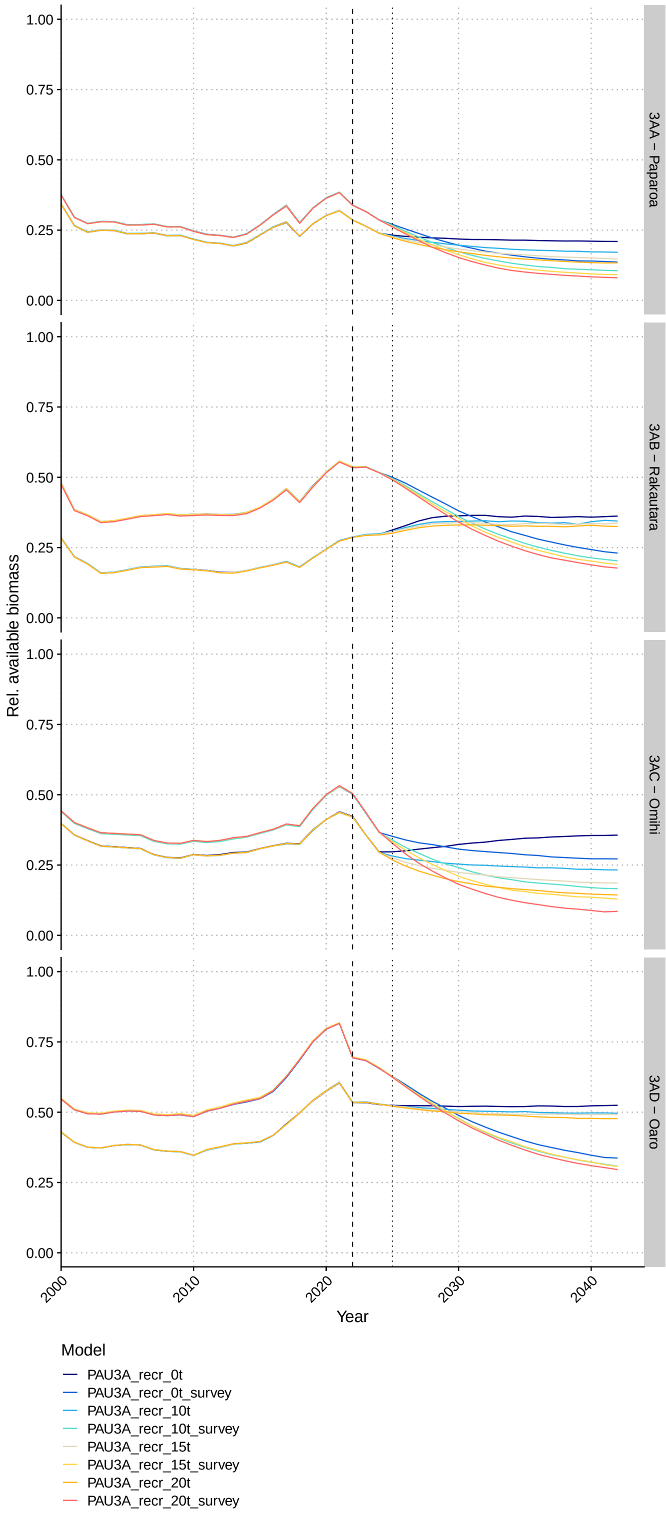

Figure H-4: Simulated relative available biomass trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

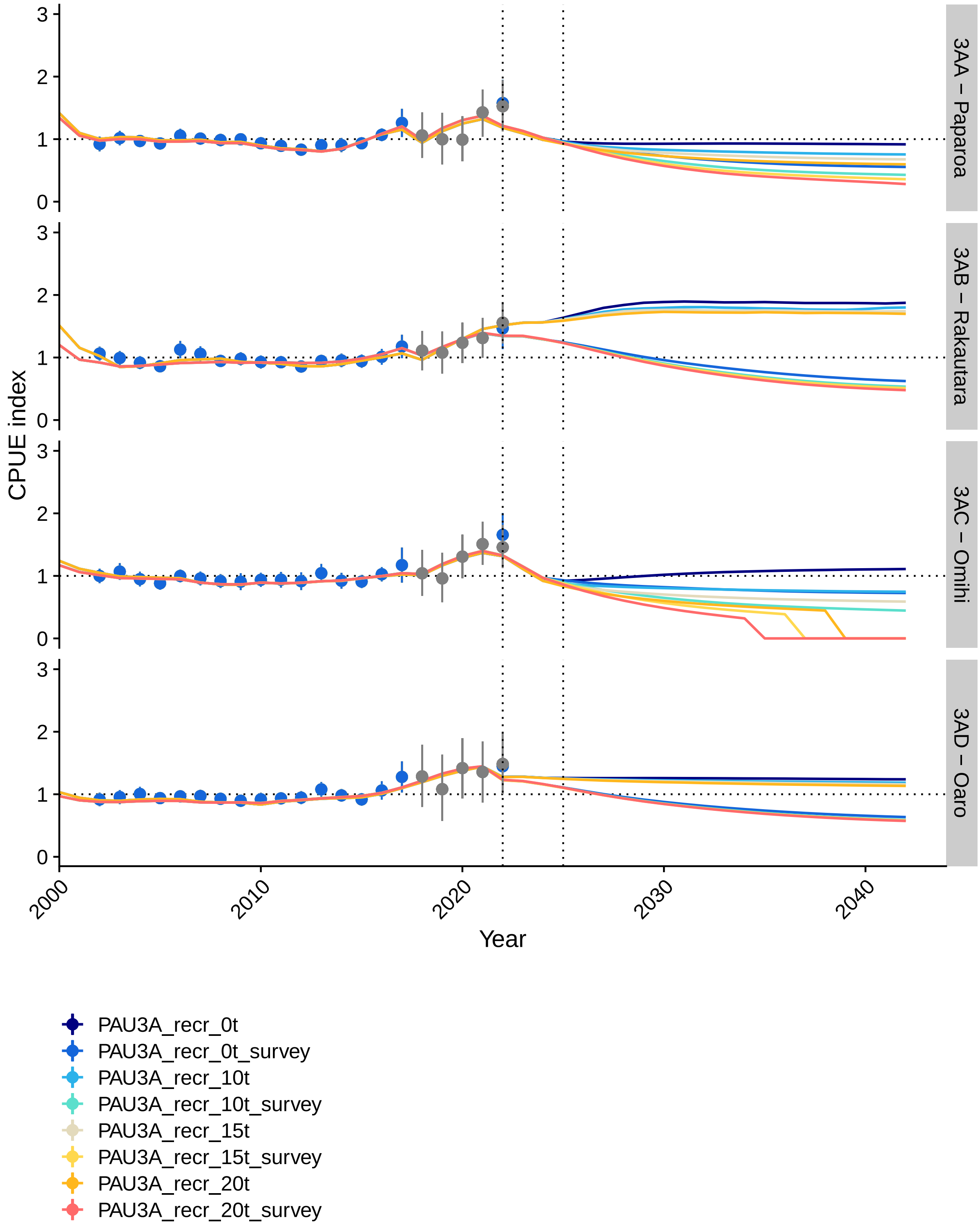

Figure H-5: Simulated catch-per-unit-effort (CPUE) trend for pāua, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. Left dotted vertical line shows the beginning of simulated trends based on the assessed harvest control rule, right dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

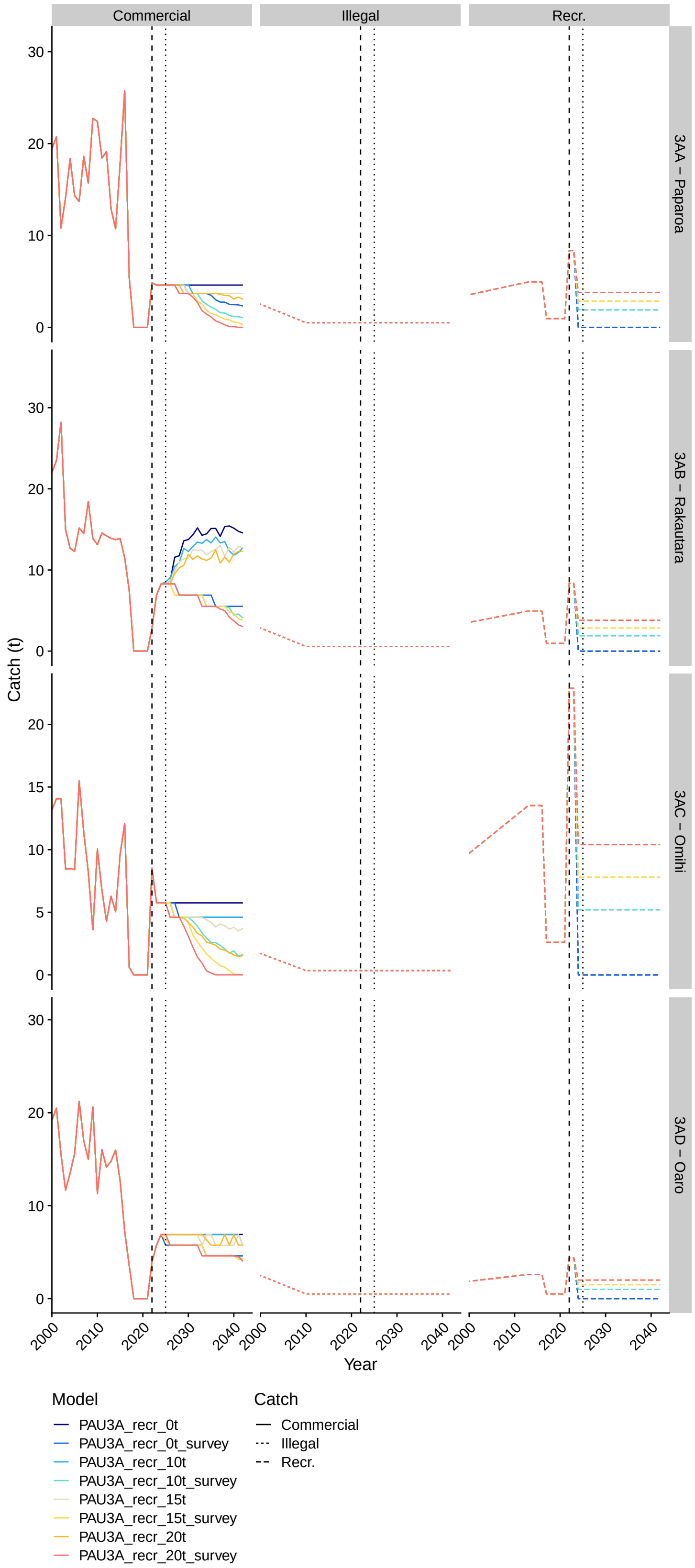

Figure H-6: Assumed and simulated catch by sector, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

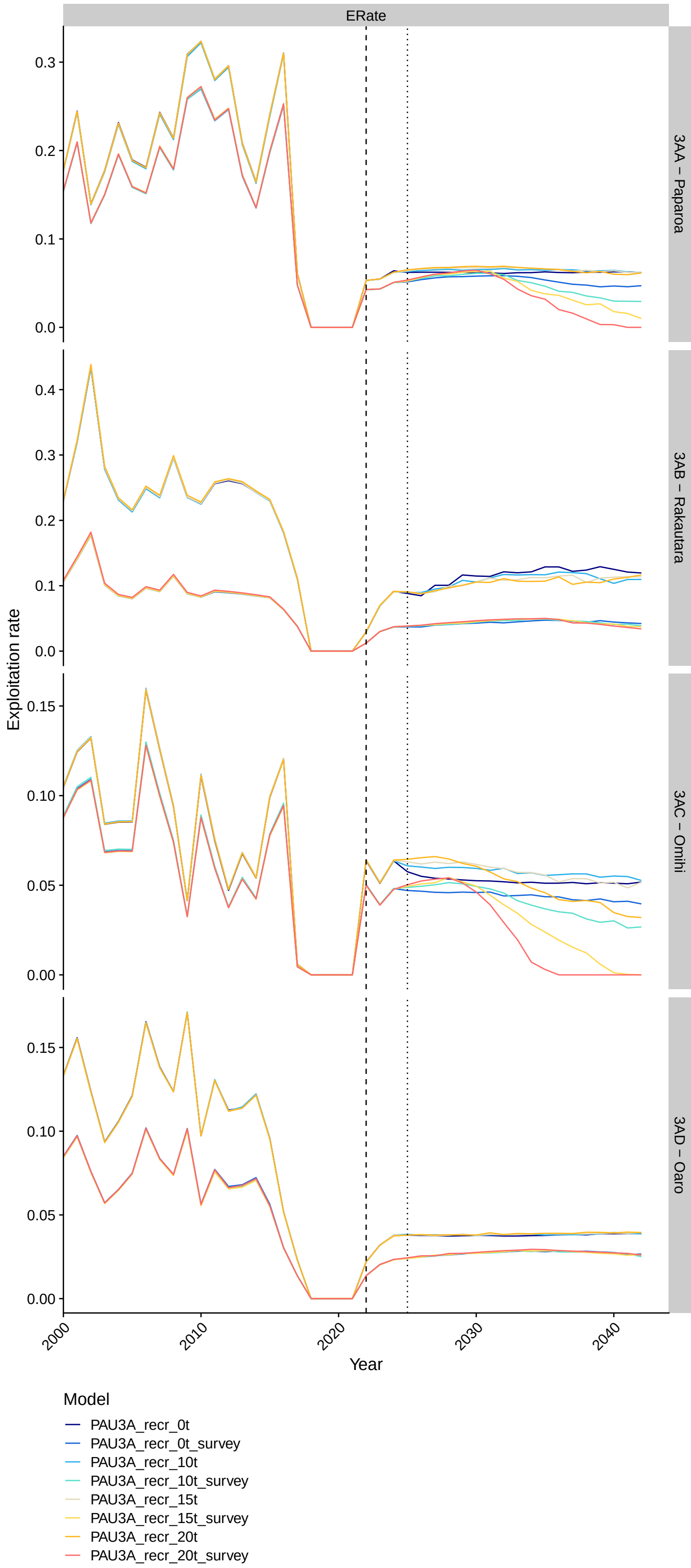

Figure H-7: Simulated exploitation rate (median line), comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in pāua for quota management area PAU 3A. Dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, dotted vertical line shows the tested limit of validity (3 years) of the tested rule.

Table H-1: Performance of tested management procedures, comparing base MPE model (EQM - natural mortality from earthquake directly scaled with uplift; R0/2 - unfished recruitment reduced by amount of uplift divided by 2), comparing different assumptions of constant recreational catch. Management was applied according to the tested control rules for each management zone in pāua for quota management area PAU 3A, by individual areas and across the overall QMA. MPE, management procedure evaluation; CPUE, catch-per-unit-effort.

Model	Region	Mean rel. *SSB* (2026)	Mean rel. *SSB* (2041)	P(rel*SSB* (2026)>0.4)	P(rel*SSB* (2041)>0.4)	P(rel*SSB* (2026)<0.2)	P(rel*SSB* (2041)<0.2)	P(rel*SSB* (2026)<0.1)	P(rel*SSB* (2041)<0.1)	Mean rel. *SSB* (2021–2041)	Mean catch (kg)	Mean CPUE (kg/h)
Base MPE, no survey fit, 20t Recr. catch	All Regions	0.45	0.42	1.00	0.57	0.00	0.00	0.00	0.00	0.44	27548.54	66.36
	3AA - Paparoa	0.31	0.26	0.03	0.10	0.00	0.35	0.00	0.00	0.28	3789.59	37.08
	3AB - Rakautara	0.49	0.52	1.00	0.90	0.00	0.00	0.00	0.00	0.52	13495.11	87.22
	3AC - Omihi	0.35	0.25	0.09	0.12	0.00	0.37	0.00	0.09	0.30	3503.31	28.17
	3AD - Oaro	0.65	0.62	1.00	0.98	0.00	0.00	0.00	0.00	0.64	6760.53	60.93
Base MPE no survey fit, 15t Recr. catch	All Regions	0.46	0.44	1.00	0.67	0.00	0.00	0.00	0.00	0.45	29038.40	67.47
	3AA - Paparoa	0.31	0.29	0.03	0.14	0.00	0.30	0.00	0.00	0.30	4060.56	39.98
	3AB - Rakautara	0.50	0.53	1.00	0.90	0.00	0.00	0.00	0.00	0.52	13966.87	88.68
	3AC - Omihi	0.36	0.30	0.11	0.18	0.00	0.18	0.00	0.00	0.32	4197.76	32.72
	3AD - Oaro	0.65	0.63	1.00	0.98	0.00	0.00	0.00	0.00	0.64	6813.21	61.79
Base MPE no survey fit, 10t Recr. catch	All Regions	0.46	0.46	1.00	0.79	0.00	0.00	0.00	0.00	0.46	30362.18	68.89
	3AA - Paparoa	0.31	0.30	0.03	0.14	0.00	0.22	0.00	0.00	0.31	4255.78	42.24
	3AB - Rakautara	0.50	0.54	1.00	0.91	0.00	0.00	0.00	0.00	0.53	14398.04	90.28
	3AC - Omihi	0.36	0.34	0.12	0.26	0.00	0.07	0.00	0.00	0.35	4764.17	37.21
	3AD - Oaro	0.65	0.64	1.00	0.98	0.00	0.00	0.00	0.00	0.65	6944.19	62.62
Base MPE no survey fit, 0t Recr. catch	All Regions	0.47	0.50	1.00	0.94	0.00	0.00	0.00	0.00	0.49	32843.70	72.82
	3AA - Paparoa	0.32	0.33	0.03	0.19	0.00	0.07	0.00	0.00	0.33	4620.87	47.05
	3AB - Rakautara	0.50	0.55	1.00	0.94	0.00	0.00	0.00	0.00	0.54	15386.76	93.95
	3AC - Omihi	0.38	0.45	0.25	0.57	0.00	0.00	0.00	0.00	0.42	5697.34	47.17
	3AD - Oaro	0.66	0.66	1.00	0.99	0.00	0.00	0.00	0.00	0.66	7138.73	64.40

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Table H-1 – *Continued from previous page*

Model	Region	Mean rel. *SSB* (2026)	Mean rel. *SSB* (2041)	P(rel. *SSB* (2026)>0.4)	P(rel. *SSB* (2041)>0.4)	P(rel*SSB* (2026)<0.2)	P(rel *SSB* (2041)<0.2)	P(rel. *SSB* (2026)<0.1)	P(rel. *SSB* (2041)<0.1)	Mean rel. *SSB* (2021–2041)	Mean catch (kg)	Mean CPUE (kg/h)
Base MPE survey fit, 20t Recr. catch	All Regions	0.48	0.30	1.00	0.27	0.00	0.40	0.00	0.00	0.38	17010.71	37.31
	3AA - Paparoa	0.30	0.20	0.05	0.11	0.00	0.75	0.00	0.35	0.24	2851.51	30.01
	3AB - Rakautara	0.52	0.32	1.00	0.24	0.00	0.37	0.00	0.01	0.40	6201.69	43.01
	3AC - Omihi	0.37	0.21	0.23	0.13	0.00	0.60	0.00	0.38	0.26	2798.84	23.33
	3AD - Oaro	0.67	0.45	1.00	0.46	0.00	0.00	0.00	0.00	0.54	5158.68	42.07
Base MPE survey fit, 15t Recr. catch	All Regions	0.49	0.31	1.00	0.29	0.00	0.35	0.00	0.00	0.38	17736.50	38.12
	3AA - Paparoa	0.30	0.20	0.04	0.10	0.00	0.73	0.00	0.26	0.24	2993.11	31.27
	3AB - Rakautara	0.52	0.32	1.00	0.27	0.00	0.34	0.00	0.00	0.41	6320.20	43.93
	3AC - Omihi	0.38	0.23	0.27	0.16	0.00	0.51	0.00	0.23	0.29	3230.64	26.64
	3AD - Oaro	0.67	0.45	1.00	0.48	0.00	0.01	0.00	0.00	0.55	5192.56	42.14
Base MPE, survey fit, 10t Recr. catch	All Regions	0.49	0.33	1.00	0.30	0.00	0.29	0.00	0.00	0.39	18626.61	39.20
	3AA - Paparoa	0.31	0.23	0.05	0.11	0.00	0.66	0.00	0.16	0.26	3268.64	33.52
	3AB - Rakautara	0.52	0.33	1.00	0.27	0.00	0.32	0.00	0.00	0.41	6417.91	44.61
	3AC - Omihi	0.38	0.27	0.29	0.19	0.00	0.43	0.00	0.06	0.32	3729.40	30.21
	3AD - Oaro	0.67	0.45	1.00	0.47	0.00	0.01	0.00	0.00	0.55	5210.66	42.53
Base MPE, survey fit, 0t Recr. catch	All Regions	0.49	0.37	1.00	0.38	0.00	0.06	0.00	0.00	0.42	20753.31	42.58
	3AA - Paparoa	0.31	0.26	0.06	0.12	0.00	0.56	0.00	0.02	0.28	3789.60	37.35
	3AB - Rakautara	0.53	0.36	1.00	0.32	0.00	0.21	0.00	0.00	0.43	6818.55	47.74
	3AC - Omihi	0.39	0.36	0.41	0.34	0.00	0.17	0.00	0.00	0.37	4771.49	37.82
	3AD - Oaro	0.67	0.48	1.00	0.53	0.00	0.00	0.00	0.00	0.56	5373.67	43.94