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Stock assessment and spawning potential ratio-based management procedures for pāua (*Haliotis iris*) fisheries in PAU 3A

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Plain language summary

Stock assessments support the sustainable management of fisheries resources, such as pāua, throughout New Zealand. This study assessed pāua stocks in the area around Kaikōura, which was affected by the 2016 earthquake (now quota management area PAU 3A). The current project aimed to assess the status and management options for pāua stocks there by developing stock assessment models for pāua. The models were informed by fisheries, biological and survey data, and performed well based on data from the periods before and after the earthquake. Although there were some uncertainties about the representativeness of the survey data and about recreational take of pāua, the modelling estimated that the pāua stock in PAU 3A was at or above target levels in 2023. In addition, this study also evaluated management strategies for supporting sustainable pāua fisheries following the earthquake. This part of the study considered different limitations, known as harvest control rules, for pāua fisheries in this area. Different scenarios of limitations were assessed, associated with reproductive output of pāua. Based on the exploration of different strategies, the harvest control rules proposed here indicated that their implementation would maintain the PAU 3A fishery in a healthy state.

EXECUTIVE SUMMARY

Neubauer, P.[1]; Kim, K.[1]; A'mar, T.[1]; Prince, J.[2] (2025). Stock assessment and spawning potential ratio-based management procedures for pāua (*Haliotis iris*) fisheries in PAU 3A.

***New Zealand Fisheries Assessment Report 2025/01*. 139 p.**

In November 2016, a strong earthquake struck the core area of the PAU 3 pāua (*Haliotis iris*) fishery, particularly impacting areas surrounding Kaikōura peninsula. The earthquake caused coastal uplift of up to 6 metres, and widespread mortality across various marine organisms, including pāua. For this reason, a fishery closure was imposed on the northern part of PAU 3 for five years, whereas the southern section remained open with a reduced Total Allowable Commercial Catch (TACC).

To manage the earthquake-affected area separately, quota management area PAU 3 was divided into PAU 3A (Kaikōura) and PAU 3B (Canterbury coast and Banks Peninsula). Dive surveys post-earthquake revealed significant recovery and new recruitment in PAU 3A, leading to the reopening of the fishery in December 2021, albeit with cautious restrictions and monitoring measures.

Before the earthquake, stock assessments in PAU 3 relied on length-based statistical methods, which posed challenges due to limited biological data. The current project aimed to develop a new stock assessment model based on updated fisheries, biological and survey data, and to evaluate management strategies that enable sustainable harvest post-earthquake. While acknowledging the complexities of earthquake impacts, the focus of this project was on developing parsimonious assessment models and robust harvest control rules for the commercial fishery to ensure the fishery's long-term sustainability.

Assessment models were able to fit both pre- and post-earthquake data well, including survey indices, which provided evidence of the strong rebuild post-earthquake. The selected base-case model did not appear to require strong assumptions about earthquake impacts to fit these data, suggesting that the assessment model is inherently flexible enough to represent dynamics pre- and post-earthquake in a relatively straightforward way. Despite some remaining uncertainties, including uncertainties regarding recreational harvest levels and survey representation, the base-case model consistently estimated that the stock was at or above default target levels in 2023.

New harvest control rules were based on a target spawning potential ratio (SPR) of 50% (i.e., the ratio of reproductive output estimated from fishery length data relative to unfished reproductive output), and used CPUE to gauge the "direction of travel" when the stock is outside of the SPR target zone to adjust catches and return the stock spawning potential towards the target level. This semi-empirical control rule was tested against the base-case assessment and a range of models and management options for immediate increases in total catch. Proposed harvest control rules based on spawning potential ratio targets appeared to maintain the fishery in a healthy state.

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1. INTRODUCTION

In November 2016, a significant earthquake impacted the core area of the pāua (*Haliotis iris*) fishery in quota management area (QMA) PAU 3 around Kaikōura peninsula. The earthquake resulted in coastal uplift of up to 6 metres, and widespread mortality across all life stages of pāua and other intertidal and subtidal organisms. For this reason, the area north of Conway River in PAU 3 was closed to all commercial and recreational pāua fishing for five years under section 11 of the Fisheries Act 1996.Post-earthquake recovery of pāua biomass was monitored through dive surveys (McCowan & Neubauer 2021, 2023). At the same time, the southern part of PAU 3 remained open, with a reduced Total Allowable Commercial Catch (TACC), i.e., the TACC was cut in half.

To manage the earthquake-affected area separately from the rest of PAU 3, the quota management area was divided into PAU 3A (Kaikōura) and PAU 3B (Canterbury coast and Banks Peninsula). Evidence from dive surveys indicated substantial recovery and new recruitment post-earthquake (McCowan & Neubauer 2021). The recovery led to the reopening of the PAU 3A fishery in December 2021 for three months, with a TACC of 23 t and a commercial minimum harvest size of 130 to 135 mm shell length. During this period, a considerable number of harvested pāua were measured, and commercial catch-spreading was implemented to prevent overfishing in any specific area. The subsequent season was opened for the full fishing year for commercial fishers, albeit at the same TACC of 23 t.

During the initial season, recreational harvests were limited to five pāua per person per day, with a minimum harvest 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. The recreational harvest from PAU 3A was estimated to be about 42 t (coefficient of variation, CV: 17.5%), indicating removals that exceeded commercial take and included smaller sizes (Holdsworth 2022). Recreational harvest was subsequently reduced to three pāua per person, and the season was moved to autumn to reduce recreational fishing effort in the summer period (i.e., by holiday makers), which resulted in a reduction of recreational take to approximately 11.5 t (Holdsworth et al. 2023).

Prior to the earthquake, the stock in the PAU 3 quota management area was assessed using length-based statistical stock assessments (Fu 2014). The stock was deemed “healthy”; however, significant uncertainties about stock status persisted due to a lack of sufficient biological information necessary to understand local stock productivity. To support ongoing management of PAU 3 fisheries, a series of projects aimed to develop models and evaluate management options for PAU 3A. These projects followed the implementation of industry-determined control rules in the PAU 5 areas (Neubauer 2019, 2021). The success of these control rules prompted their adoption in fisheries plans for PAU 3 and other areas. These strategic plans emphasise the management of fisheries based on harvest control rules, which require operating models for the newly-subdivided QMAs of PAU 3.

Initial operating models and management procedures were developed by Neubauer & Kim (2023a); highlighting potential trade-offs between recent high recreational harvest levels and long-term commercial harvest potential. Nevertheless, these models did not consider post-reopening data from the commercial fishery; in addition, they only used a significantly shorter survey time series, and significant uncertainties remained about the stock status and long-term performance.

The current project developed a new stock assessment model for PAU 3A that included different hypotheses about earthquake impacts. The model was used to assess the likely current status of the stock, and at the same time as an operating model to test harvest control rules. The latter were developed based on simple measures of spawning potential ratio derived from commercial length data, and also CPUE. The model was designed to align with management at the scale of industry management zones (Figure 1). These zones partition catch among spatial strata, and allow the industry to set an area-specific minimum harvest size (MHS). By zoning management procedures, the model allows for area specific adjustments that can be summed to a QMA-wide TACC.

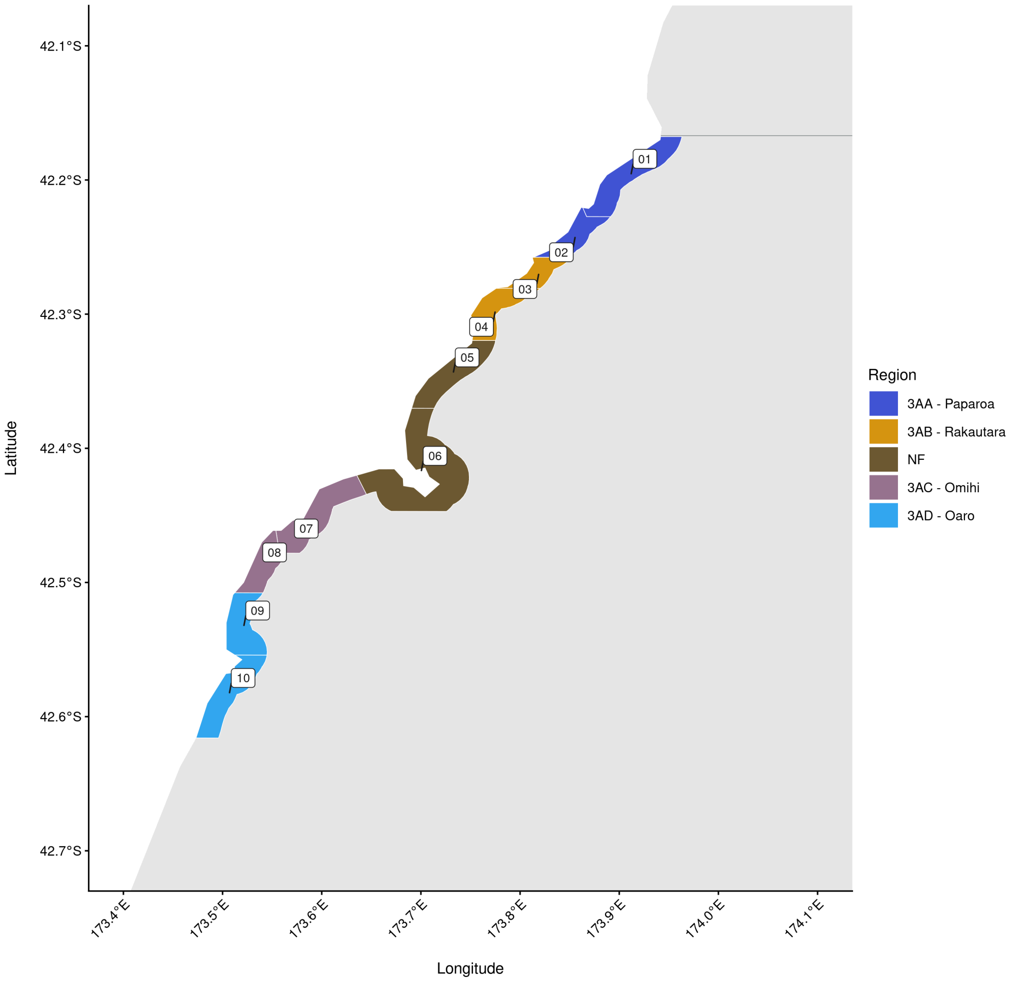

Figure 1: Pāua Quota Management Area (QMA) PAU 3A, Kaikōura (centred on Kaikōura peninsula). Pāua statistical areas shown here (coloured polygons) are grouped by colour according to current commercial management zones within PAU 3A. NF: zone without current commercial fishing.

2. METHODS

2.1 Inputs

All data sources were prepared to align with current post-earthquake management zones. These zones were defined by industry (T. McCowan, Paua Industry Council), based on abundance, length frequency, and earthquake impact considerations. Although the waters surrounding Kaikōura Peninsula and adjacent areas are not fished commercially, there were 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.

Inputs for the PAU 3A model consisted of commercial catch data, catch-per-unit-effort (CPUE) data from Paua Catch Effort and Landing Returns (PCELR) forms and electronic reporting systems submissions. Length-frequency data from commercial sampling (CSLF) up to 2016, and for 2022 and 2023 fishing seasons were included. 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 the survey index and length-frequency information derived from McCowan & Neubauer (2023).

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 2023 (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 General 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 (Neubauer & Kim 2023a). 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; PCELR, (Paua Catch Effort and 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 PCELR.
2020–2023	Estimated catch from the Electronic Reporting System (ERS).

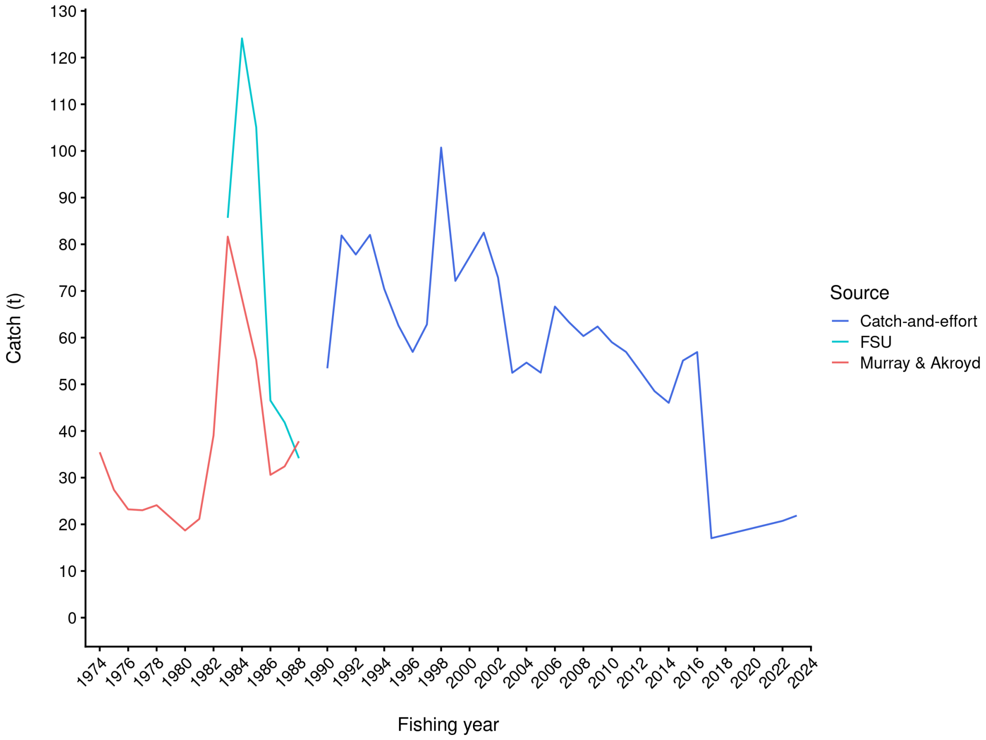

Figure 2: Commercial catch history for pāua Quota Management Area (QMA) PAU 3A from 1974 to 2023. Catch to 1983 was reconstructed from data reported by Murray & Akroyd (1984; red line). Data for 1983–1986 were from the Fisheries Statistical Unit (FSU) database (teal line). Catch and effort data from 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.)

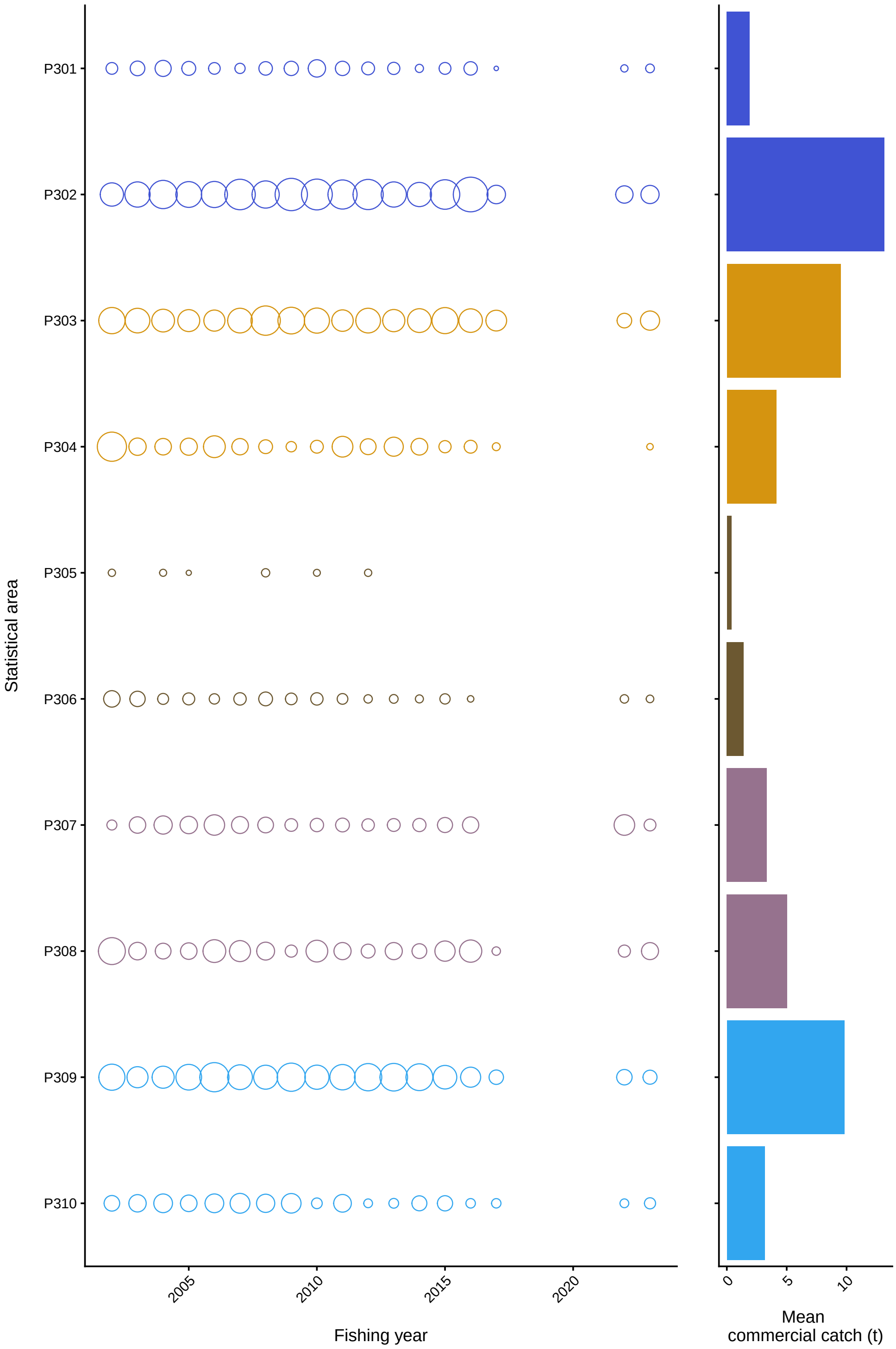

Figure 3: Relative trend in pāua catch (kg) over time by pāua statistical area in Quota Management Area PAU 3A for the period from 2002 to 2023, with total commercial catch over the same time period (right-hand side). Current commercial management zones within PAU 3A are colour-coded (blue: zone A (Paparoa); orange: zone B (Rakautara); purple: Zone C (Omihi); light blue: zone D (Oaro); brown: zone without current commercial fishing (P305 and P306). (Note, any records in the latter zone likely originate from errors in the statistical area of fishing events.)

2.1.2 Recreational, customary, and illegal catch

Two estimates from the national panel surveys (NPSs) 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 (CV: 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 NPS was repeated and the estimated recreational catch was 8.79 t (CV: 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, and highlighted that the NPS estimates are probably of limited use for the area and pāua in general. For this reason, a weight of 24 t was used in models from 2012 onwards, with either a linear increase from 12 t to 24 t between 1974 and 2012, or a flat assumption of 24 t since 1974 (base assumption).

There is no comprehensive information available on customary take in recent years. The Shellfish Working Group agreed to assume that customary catch was about 2 t between 1974 and 2017. 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 increase 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), with catch splits derived from PCELR-estimated catch.

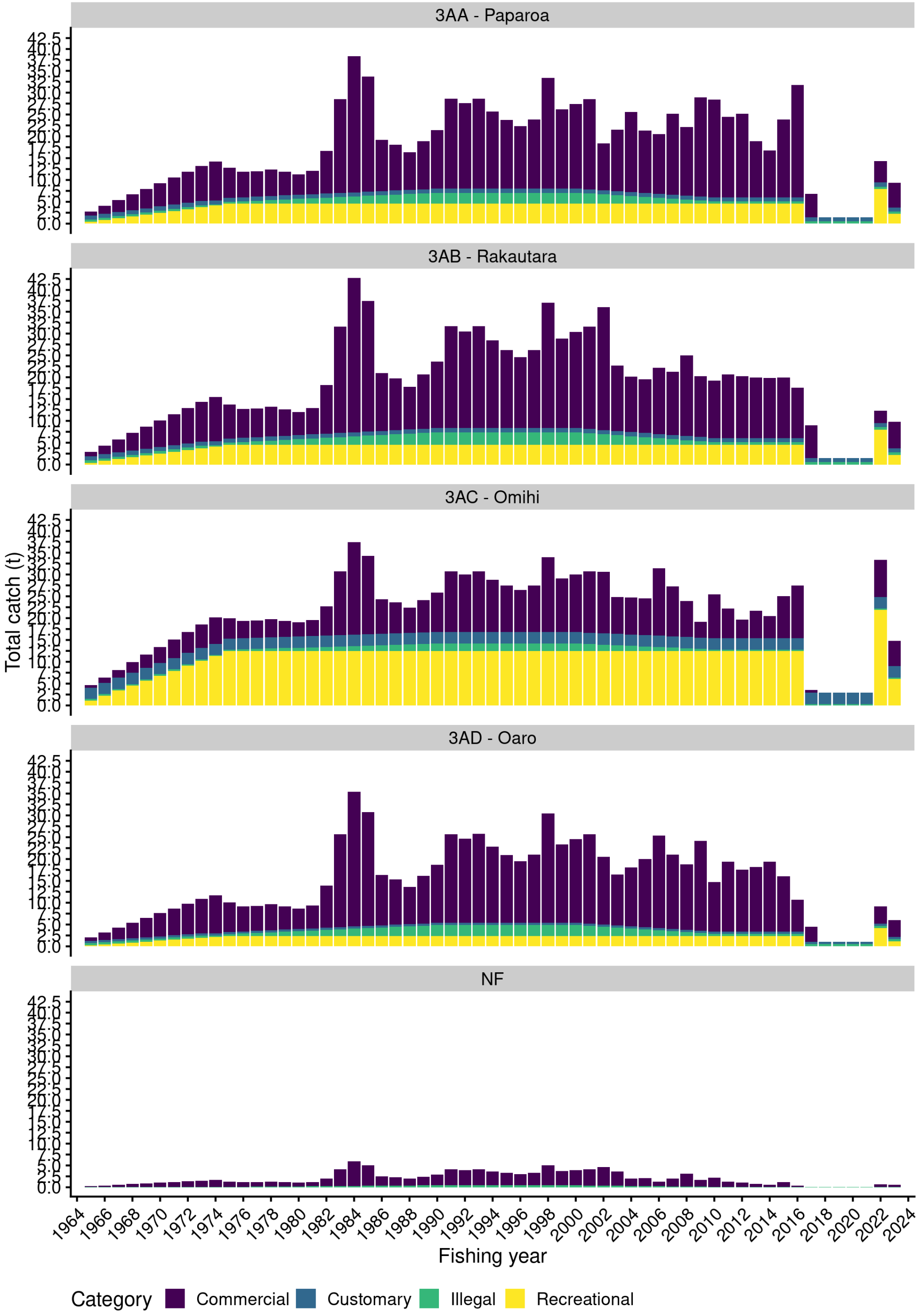

Figure 4: Estimated total pāua catch history for Quota Management Area (QMA) PAU 3A from 1974 to 2023 by fishery component and reporting area. Fishery categories were commercial (Total Commercial Catch, TCC), customary, illegal, and recreational catch. Commercial catch was reconstructed up to 1995 when the QMA was created, and based on landing records thereafter. (Note, no commercial catch was taken between 2017 and 2022.)

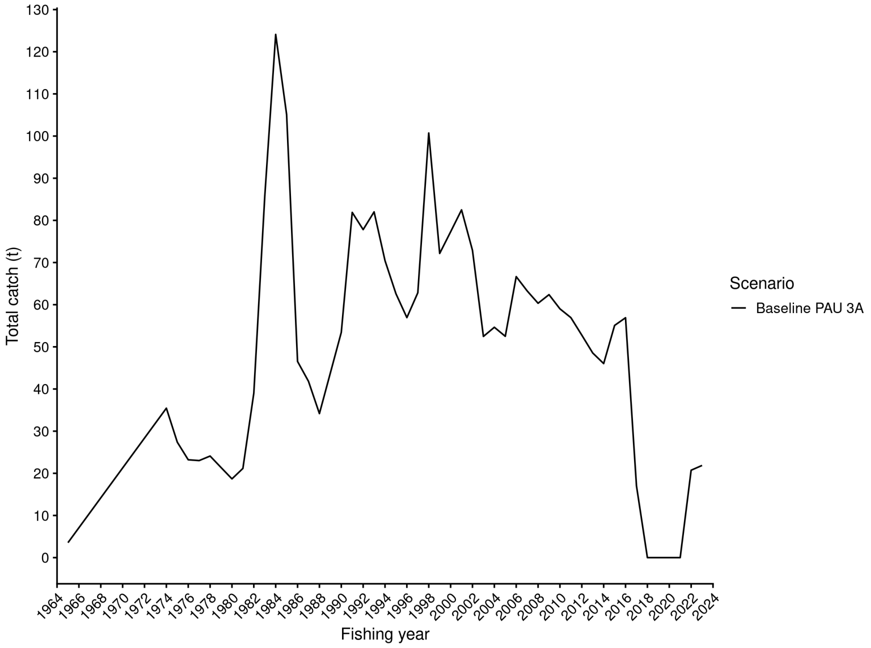

Figure 5: Total pāua catch history used in the single area stock assessment for PAU 3A from 1974 to 2023 as the sum of all catch components (commercial, customary, recreational, illegal).

2.1.3 Catch-per-unit-effort (CPUE)

The present assessment only considered CPUE data from PCELR forms (2002–2016) and ERS (2021–2023). The spatial resolution in pre-PCELR data was 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 were corrected with the introduction of PCELR reporting in 2002. Therefore, CPUE based on PCELR has been considered as an 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, and for ERS data in Tables 4 and 5). 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 Paua Catch Effort and 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 Paua Catch Effort and 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$10 h	331	333	298	317	364	359	366	359	382	314	270	271	248	305	266	63	4 846	94.23
10 kg/h $\leq$CPUE $\leq$500 kg/h	325	325	296	315	361	354	366	353	372	310	267	271	243	304	265	63	4 790	93.14

Table 4: Data preparation steps and total estimated catch weight (in t) for data from pāua Electronic Reporting System (ERS) returns by year and in total (as estimated catch weight and percentage retained). FIN, fisher (client) identification number; CPUE, catch-per-unit-effort.

Data preparation	2022	2023	2024	Total	% retained
All	21	22	3	46	100.00
Missing fields	21	22	3	46	100.00
FIN years ≥2	21	22	3	46	100.00
Diver years ≥2	20	20	2	42	91.30
No. of divers ≤4	20	20	2	42	91.30
Fishing duration ≤10 h	20	20	2	42	91.30
10 kg/h ≤CPUE ≤500 kg/h	20	20	2	42	91.30

Table 5: Data preparation steps and total estimated catch weight (in t) for data from pāua Electronic Reporting System (ERS) returns by year and in total (as record numbers retained and percentage retained). FIN, fisher (client) identification number; CPUE, catch-per-unit-effort.

Data preparation	2022	2023	2024	Total	% retained
All	106	100	12	218	100.00
Missing fields	106	100	12	218	100.00
FIN years ≥2	106	100	12	218	100.00
Diver years ≥2	96	90	8	194	88.99
No. of divers ≤4	96	90	8	194	88.99
Fishing duration ≤10 h	96	90	8	194	88.99
10 kg/h ≤CPUE ≤500 kg/h	94	89	8	191	87.61

A combined PCELR-ERS 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 except in the two recent years. 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 prior to the earthquake (Figures 8, 9), with these variables explaining substantial proportions of variation (Figure 10). Since the earthquake, only a subset of more effective, higher CPUE clients remained (Figure 8), which led to a downward adjustment in the standardised CPUE.

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

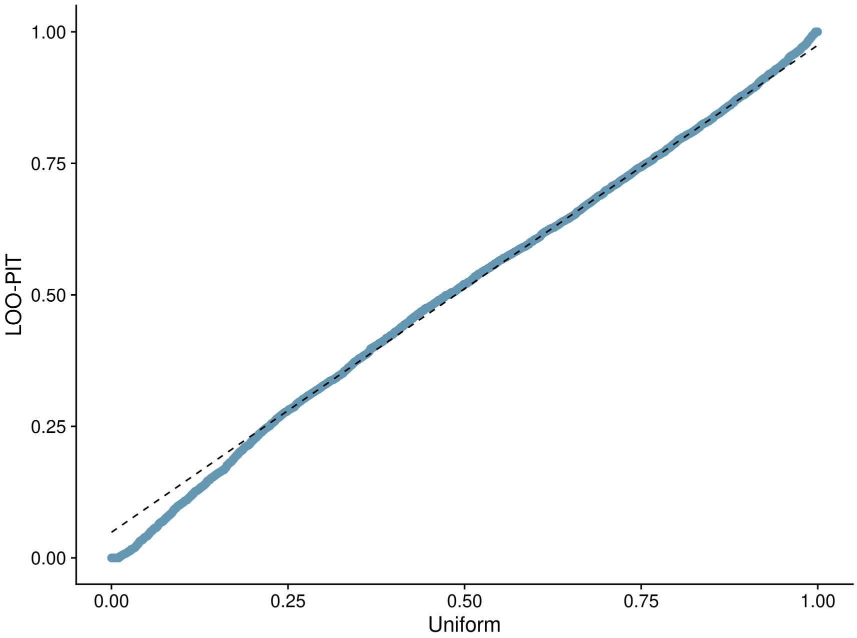

Figure 6: Fit of the log-normal generalised linear mixed model used for catch-per-unit-effort (CPUE) index standardisation. The quantile-quantile plot compares the PIT (Probability Integral Transform) of the leave-one-out (LOO) posterior predictive distribution to the theoretically expected uniform distribution.

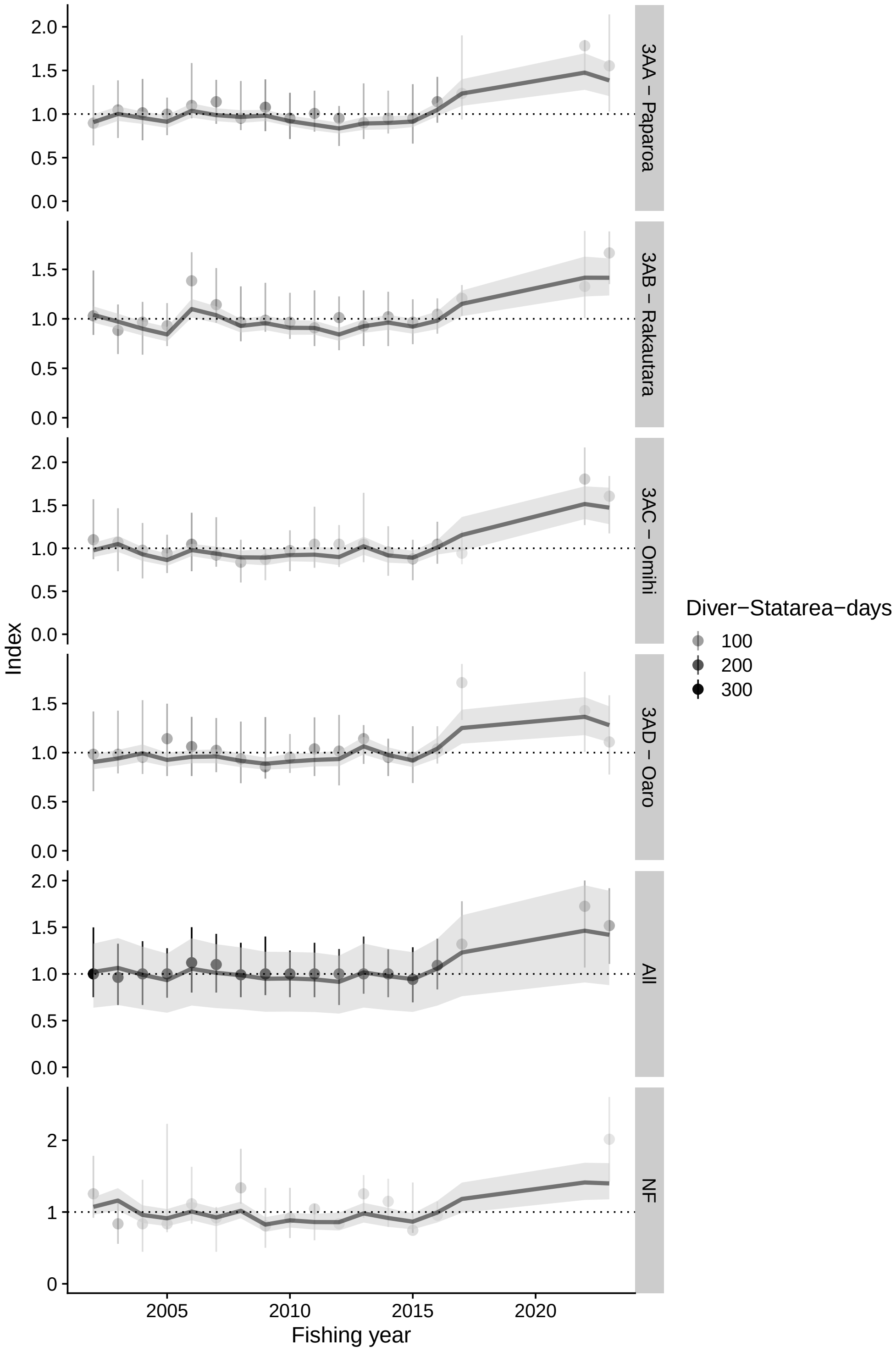

Figure 7: Standardised catch-per-unit-effort (CPUE) using a generalised linear mixed model with zone-year interaction; showing CPUE by zone (NF, zone without current commercial fishing). Black line and confidence interval show estimated CPUE index and 95% posterior quantiles, with data mean and inter-quartile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

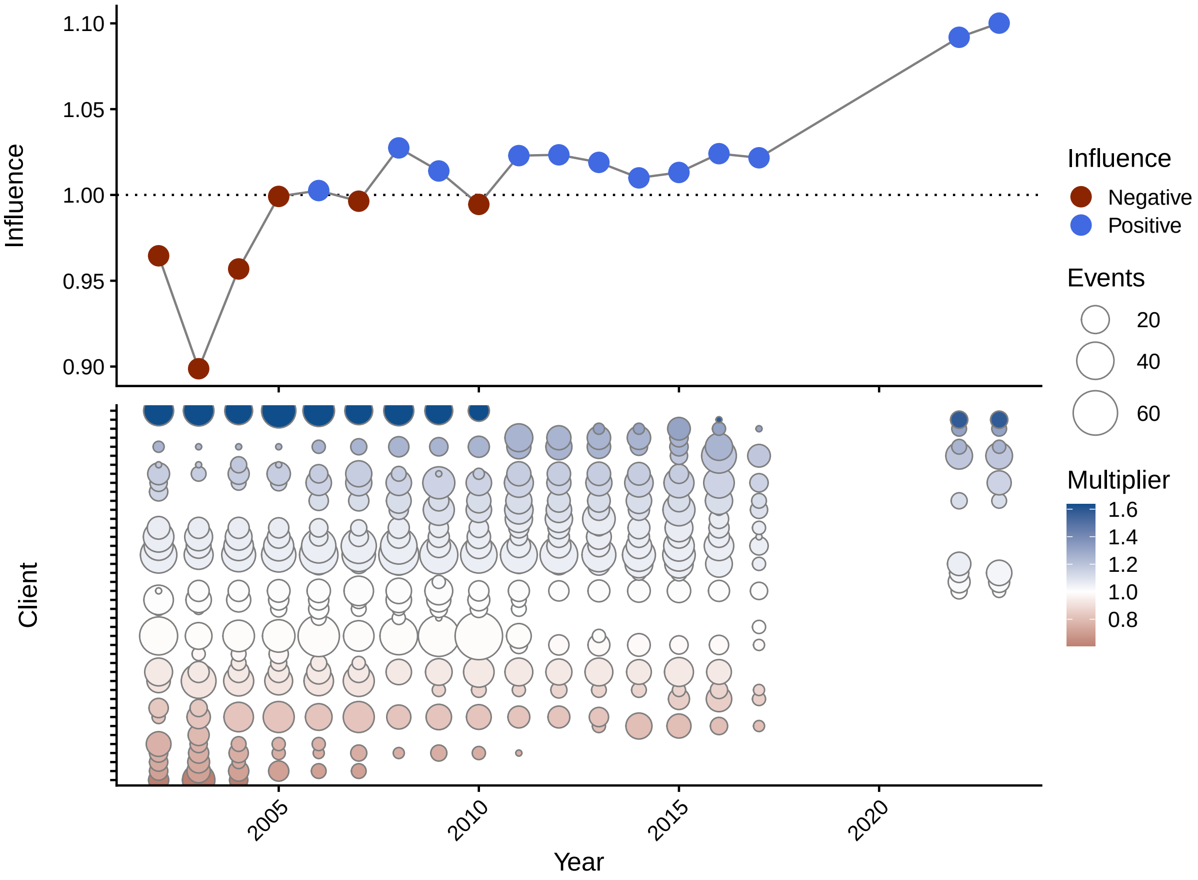

Figure 8: Influence plots for client number (FIN) effect, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised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

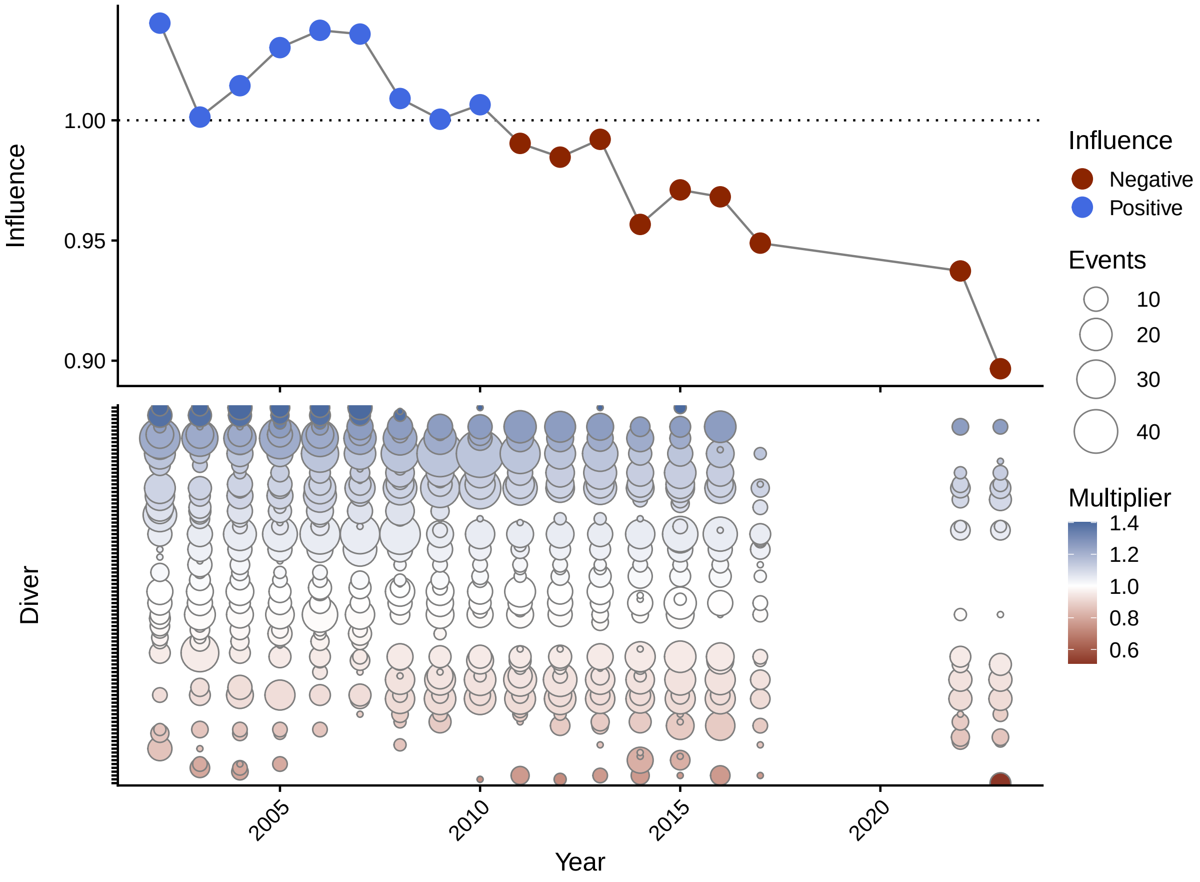

Figure 9: Influence plots for diver random effects, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised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

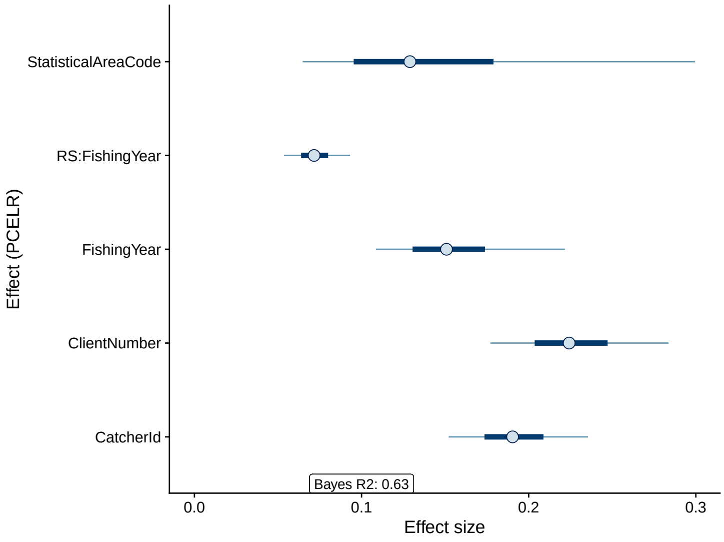

Figure 10: Effect size as variance explained for variables included in the random effects standardisation model. PCELR, Paua Catch Effort and Landing Return. RS:FishingYear is the magnitude of differences in year trends between management zones.

2.1.4 Commercial sampling length-frequency (CSLF) data

Length-composition data have been regularly sampled at factories since the early 2000s, and since 2021, electronic measuring boards on vessels have been used to measure catch. A model-based approach for length compositions for pāua stocks was developed for this area to account for differences in measurement type between factory-measured shells (basal length) and onboard measurements (overall length).

The present modelling used a standardisation model for composition data. The model is similar to the model developed by Neubauer (2020), and used in previous assessments, but it included a marked improvement in that it fits to measured numbers-at-length rather than proportions. The procedure 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 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 length frequencies. In addition, the method can be used to combine estimates from the two different measurement systems by including a factor for measurement type that varies by area, reflecting area-specific differences in conversion factors (e.g., area specific differences between basal and overall length due to different growth types).

The updated formulation was 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 GLMM, using the total counts as an offset term. Random effects formulations ensure the sharing of information across strata. This model can be implemented in *brms* and efficiently run via:

```
bf(n_i,s ~ (1|Lcat:Area:Year/site_code) +
        (1|Lcat:Area/site_code) +
        (1|Lcat:Area/measure-type) +
        (1|Lcat) +
        offset(log(N_s))).
```

The length-composition standardisation model converged well (Figure 11) and provided a good fit to the data (Figure 12). Estimates for standard deviation parameters suggested that annual differences in the composition of removed pāua were seen at regional and statistical-area scales (Figure 13), while static differences between statistical areas within regions were larger than differences between regions. Standardised length compositions reflected samples in most cases (Figure 14), suggesting reasonable coverage of the sampling programme.

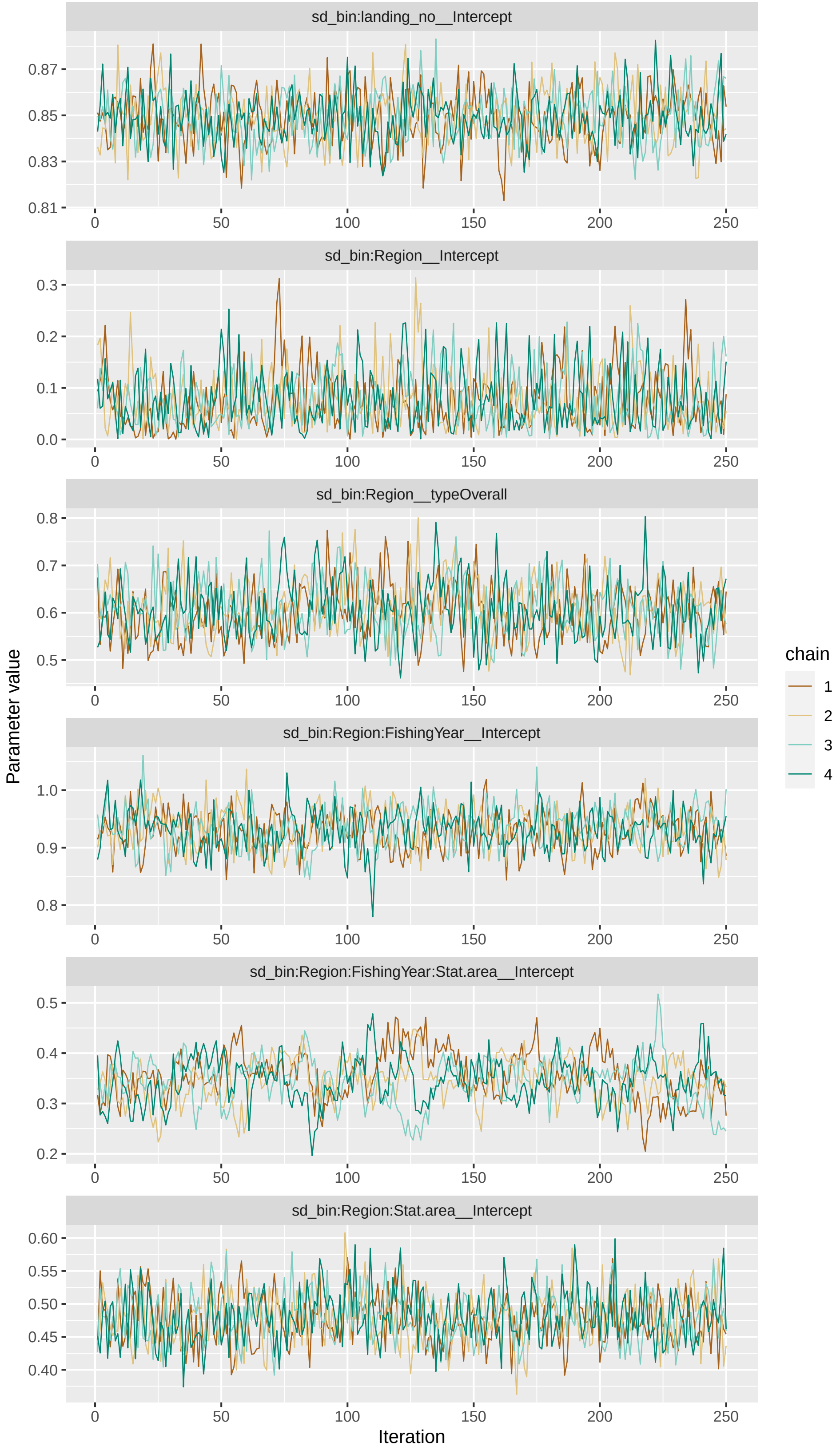

Figure 11: Length-composition standardisation model Markov Chain Monte Carlo trace-plots for key parameters.

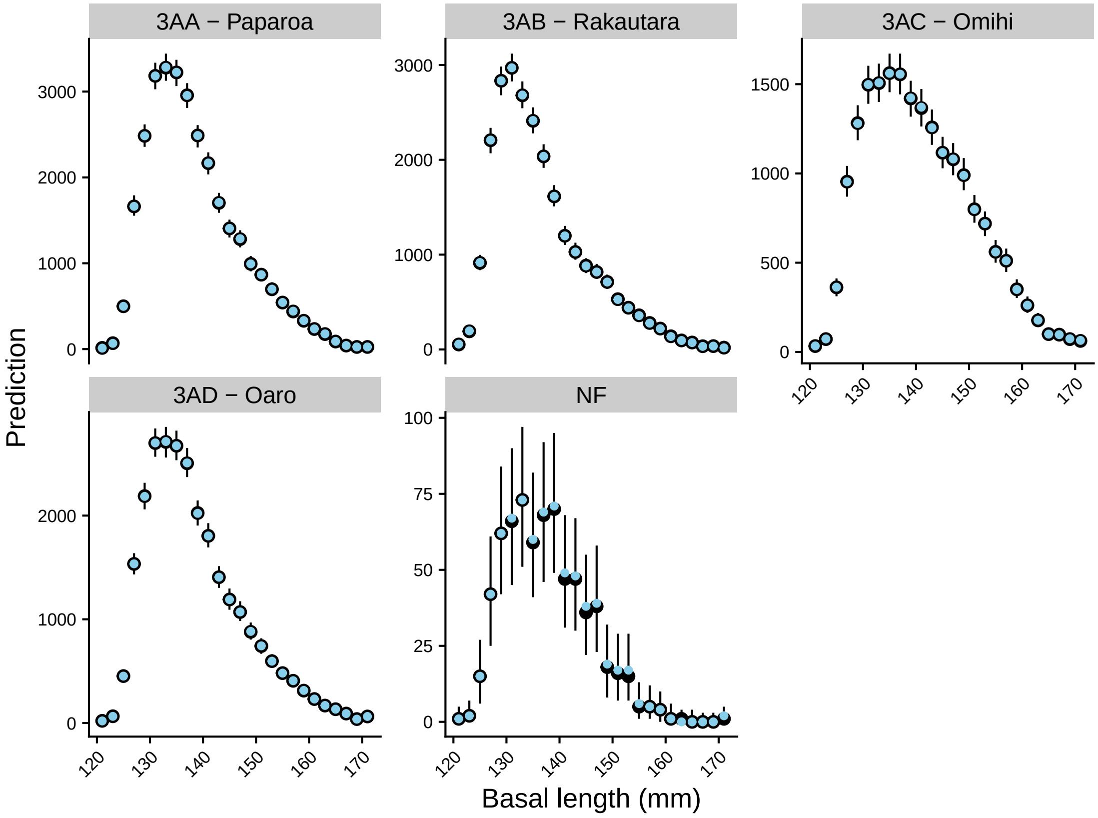

Figure 12: Length-composition standardisation model fit (black posterior median and 95% prediction interval) to the observed numbers in each model length bin, by region.

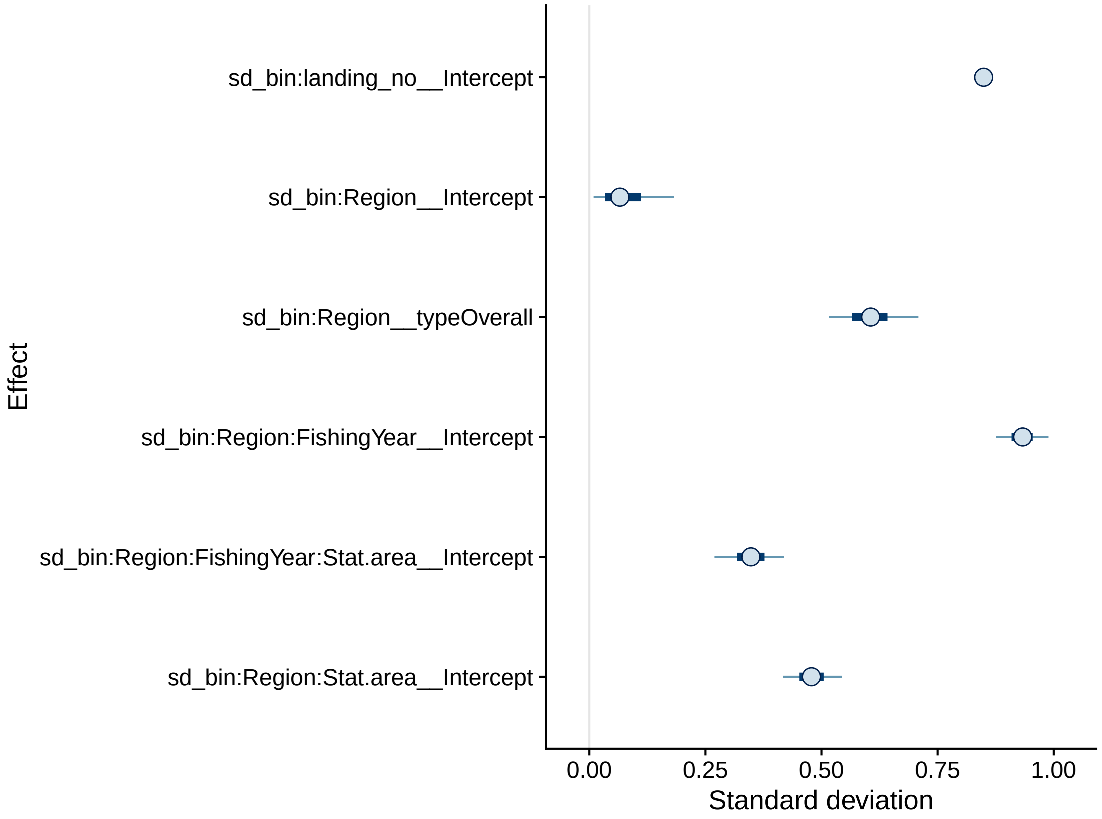

Figure 13: Length-composition standardisation model estimates (posterior median and 95% confidence interval) for standard deviation parameters associated with standardising effects.

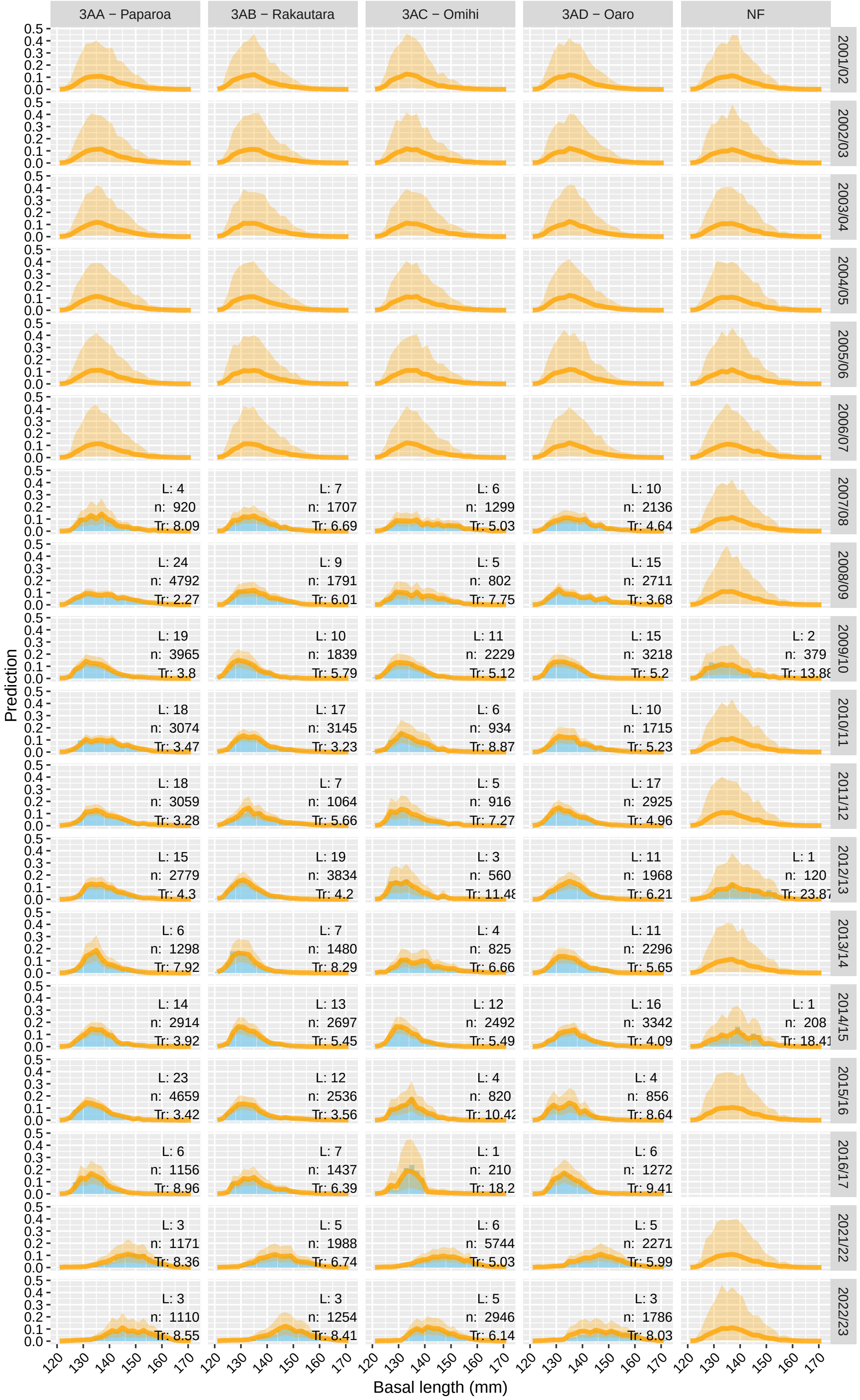

Figure 14: Sampled length compositions (blue histogram) and catch-scaled standardisation model estimates (orange posterior median and 95% confidence interval) by area and year. L: number of landings; n: number of pāua sampled, tr: trace of the covariance matrix for estimated compositions (i.e., sum of standard deviations).

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).

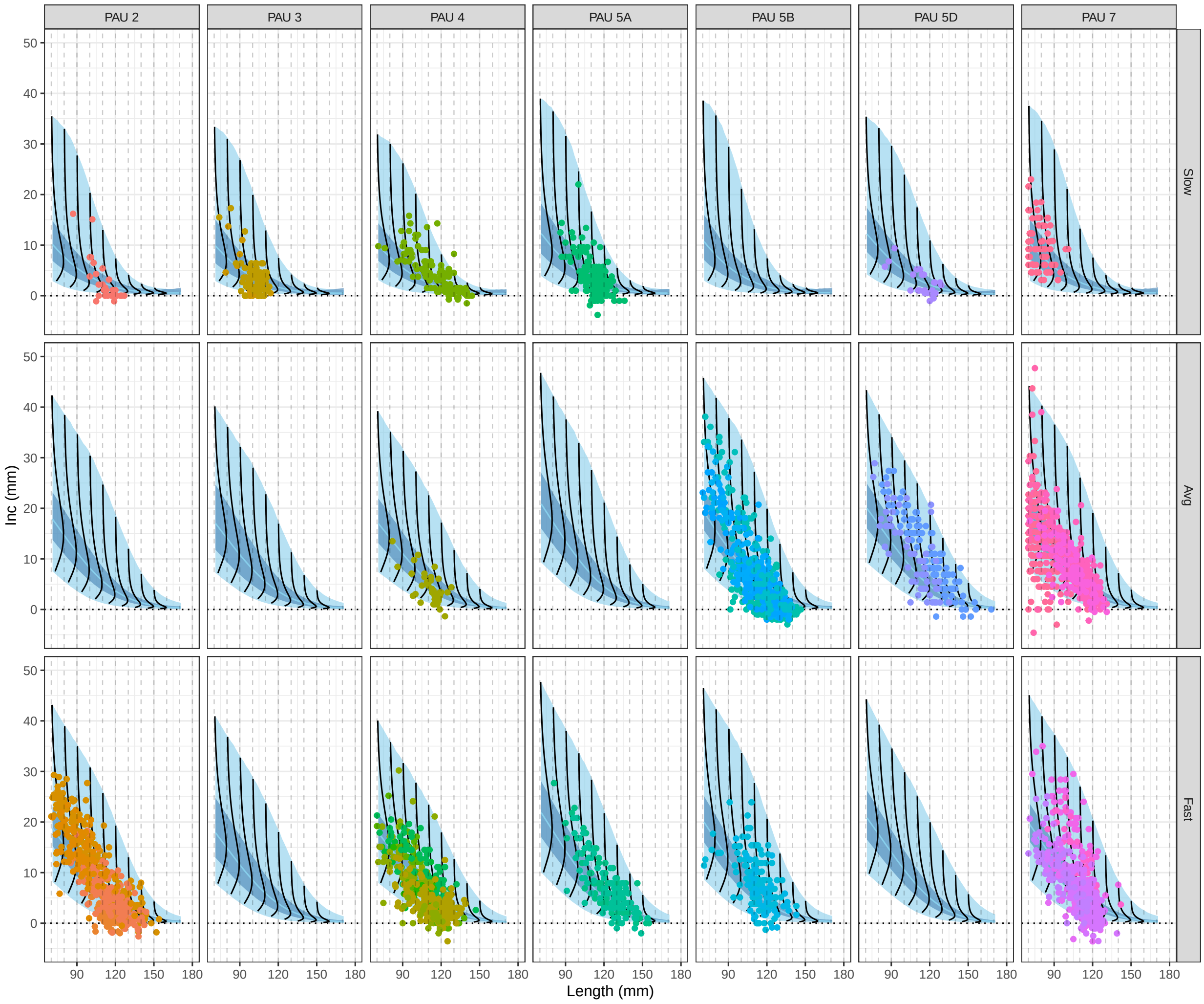

Figure 15: Priors derived from a meta-analysis of growth and maturity of pāua, based on model-fitting to all tag-increment and maturity data across quota management areas (QMAs). Shown is the joint prior for positive growth increments at size l by QMA and growth stratum. Dark blue shading shows uncertainty 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.

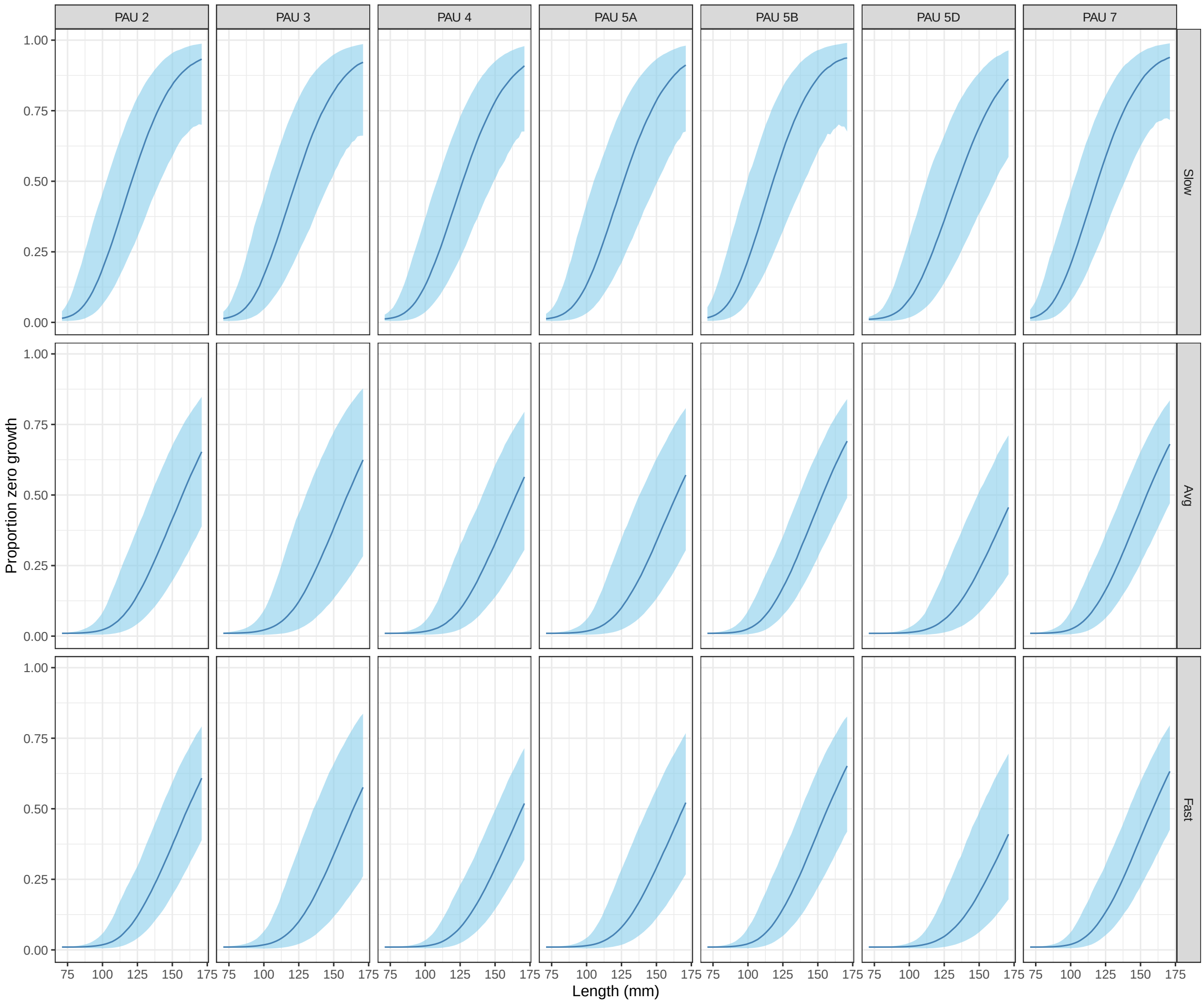

Figure 16: Priors derived from a meta-analysis of growth and maturity of pāua, based on model-fitting to all tag-increment and maturity data across quota management areas (QMAs). Shown is the expected proportion of local populations not growing at size *l* by QMA and growth stratum.

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) to remove potentially confounding effects (e.g., effects 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).
```

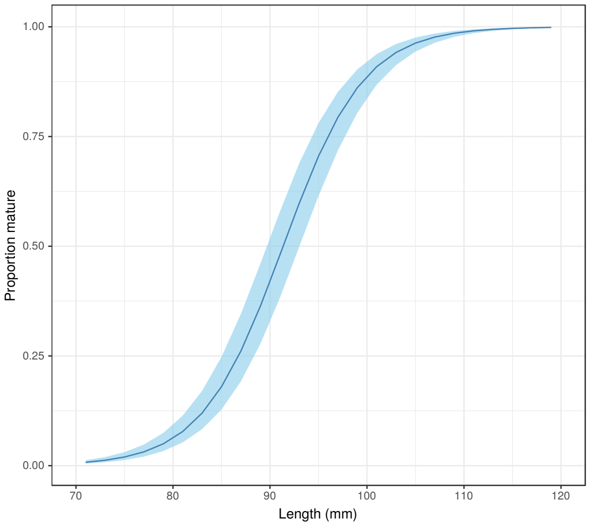

Figure 17: Priors derived from a meta-analysis of growth and maturity of pāua, based on model-fitting to all tag-increment and maturity data across quota management areas (QMAs). Shown is the population level maturity.

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 21). Contrary to the survey index, survey length frequencies showed relatively little variation by year (Figures 20 and 21), with relatively right-skewed length distributions.

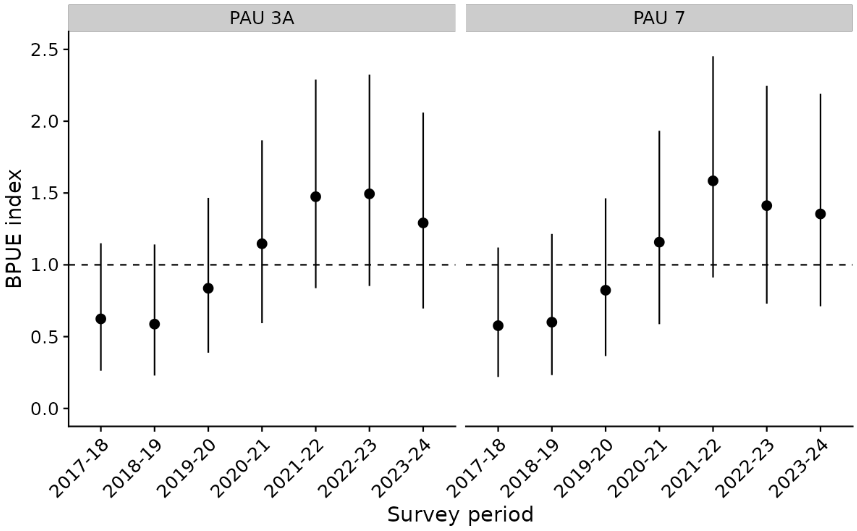

Figure 18: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables.

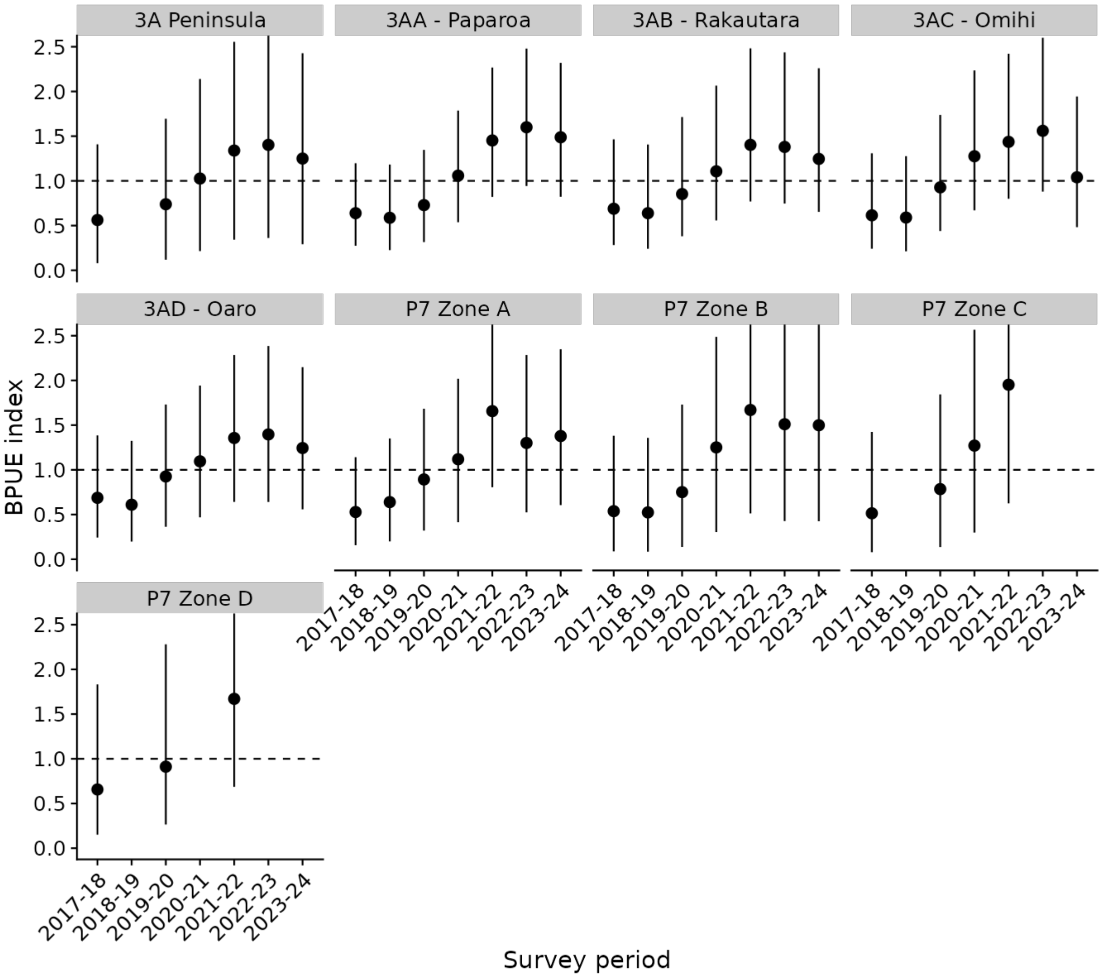

Figure 19: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for management zones in PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables.

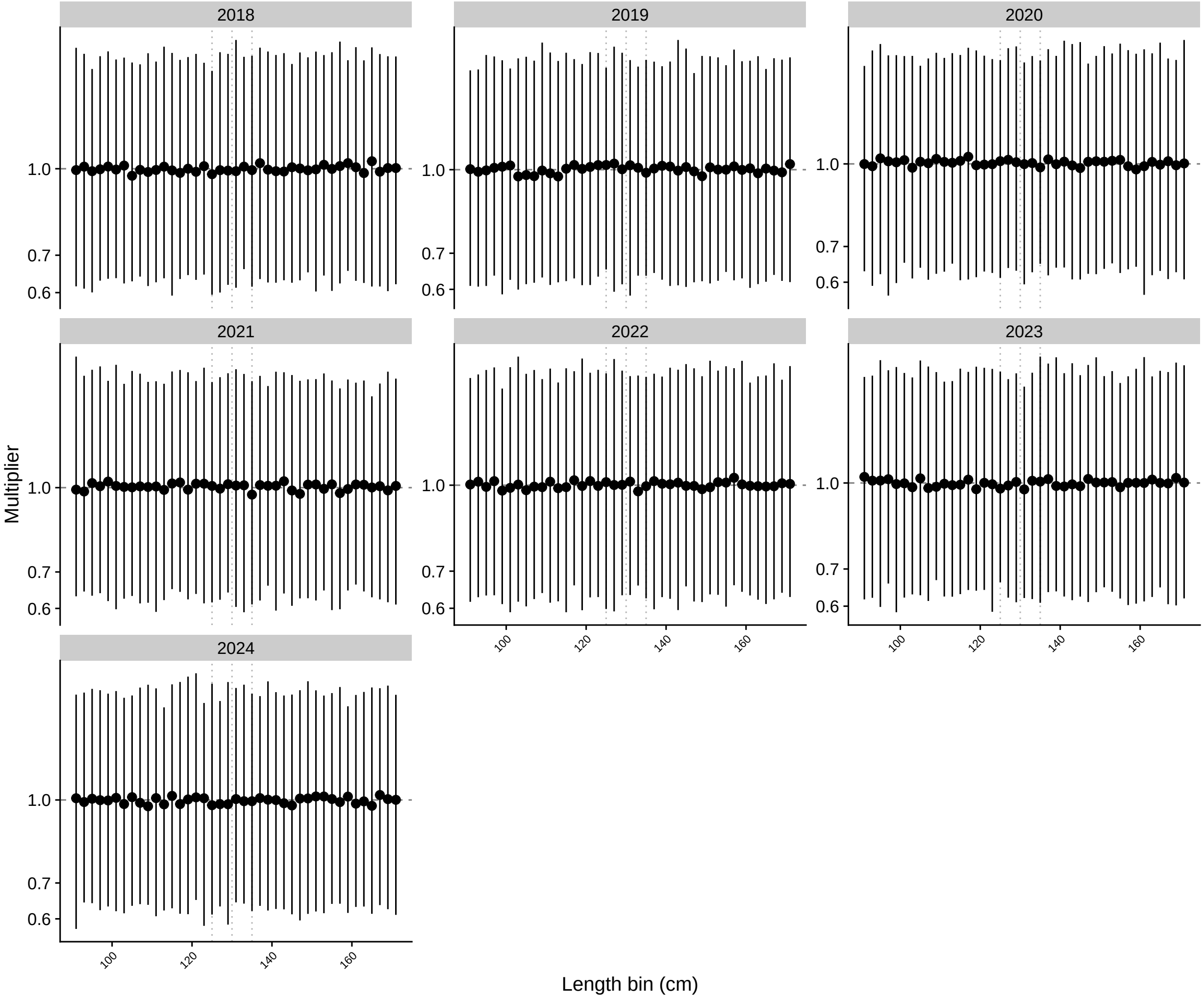

Figure 20: Estimated effect of year by length bin for survey years post-earthquake in the pāua fishery in PAU 3A.

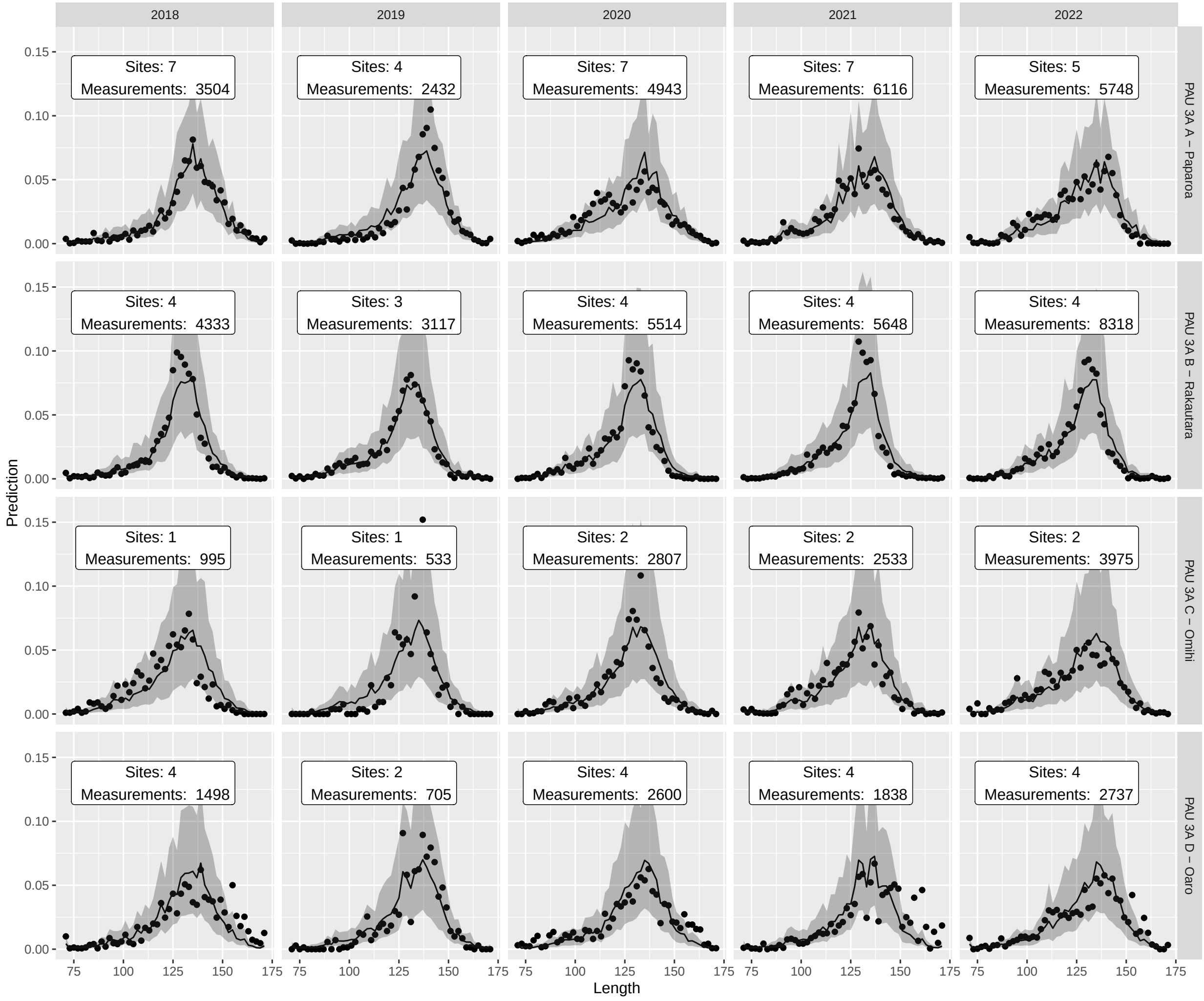

Figure 21: Estimated length distribution at the management zone level for survey years prior to re-opening of the pāua fishery in PAU 3A.

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 subsequently 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 $\tau_{PE_{CPUE}}$:

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

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

Recruitment deviations (R_{dev}), equilibrium recruitment (R_0), catchability ($\log(q)$), length at 5% selectivity (D_5) and 95% selectivity offset (D_{95}) were assigned log-normal priors, parameterised in terms of mean and standard deviation, with the sample mean for R_{dev} forced to one (Table 6).

Table 6: Default priors used in the pāua stock assessment model (LN=Lognormal, N=Normal (with log indicating the parameter is given on a log scale), 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
Equilibrium recruitment	R_0	N(log)	12	3
Recruitment deviations	R_{dev}	N (log)	0	0.4
Natural mortality	M	LN	0.12	0.2
Length at 5% selectivity	D_{50}	LN	125	5
95% selectivity offset	D_{95}	LN	5	5
Survey length at 50% selectivity	S_{50}	LN	90	50
Survey 95% selectivity offset	S_{95}	LN	10	50
Steepness	h	fixed	0.7	
CPUE process error	$\mathrm{PE_{CPUE}}$	N^0	0.05	0.05
CSLF process error	$\mathrm{PE_{CSLF}}$	gamma	1	3

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 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 2023b). 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). In addition, a logistic selectivity function was implemented for survey selectivity by region. This avoids the previous assumption that all pāua above the recruitment size classes (70–80 mm) were available to be surveyed.

The model was run with two distinct assumptions for the CSLF weight, which tended to impact fits to recent CSLF data. The first set of weights (0.1) has been used as a standard assumption in other assessments, but leads to a poor fit recent CSLF data as well as pre-earthquake LFs in Rakautara. Increasing the weight to 0.5 leads to improved fits, but also impacts stock status and the biomass trajectory, and slightly degrades fit to CPUE.

2.4 Scenarios for earthquake impacts

Plausible consequences of earthquake impacts on pāua population dynamics were first explored in Neubauer & Kim (2023a). 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 review of earthquake impacts in the working group based on recent information about stock recovery based on survey outcomes and fishery information, led to the representation of earthquake impacts as three scenarios (see also Appendix A):

1. **No impact:** The medium–long term impact is negligible at the population level, and the model will represent short term impacts via recruitment estimates.
2. **Short-term mortality impact only:** No long-term impact. An instantaneous mortality was taken as being equal to half of 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)). This mortality was attenuated through time as $M^t_{Tot} = M + M_{EQ}^{t-t_{EQ}+1}$, where M^t_{Tot} is total mortality at time t, M_{EQ} is the assumed earthquake mortality and t_{EQ} is the timing of the mortality.
3. **Short-term mortality impact, short-term reduction in mean recruitment (R_0).** The mortality assumption was the same as in 2, and this assumption was mirrored for a reduction in R_0 (mean/unfished recruitment) in proportion to earthquake uplift, with a similar exponential reduction of the impact over time as $R_0 * (1 - r_{EQ})^{t-t_{EQ}+1}$, where r_{EQ} is the reduction in mean recruitment.

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 the distances considered here (i.e., 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.

2.5 Alternative selectivity and mortality assumptions

A range of selectivity and mortality assumptions were tried in the process of developing the assessment model.

1. Initial models assumed that the survey "sees" all modelled pāua (i.e., there is no cryptic biomass above 70 mm, the size at which pāua enter the model partition). However, this assumption led to poor model fits for survey length compositions. In addition, size at emergence is related to the L_{50} for maturity and growth (onset of maturation defines inflection point on growth curve), and we would, therefore, expect differences in the initial sizes that are available to be surveyed. The model was modified to estimate survey selectivity to resolve the discrepancy between model assumptions and observations.
2. Added logistic selectivity parameterised in terms of 5 and 95% selectivity with time-varying 95% selectivity to account for variable minimum harvest sizes and targeting of large pāua.
3. Length-based mortality, especially during the earthquake, may have led to length distributions that were not easily fitted by the model assuming size-indiscriminate mortality. Pāua are often vertically stratified, with small individuals in shallow areas, and large individuals in deeper waters, where the latter size class would have been less susceptible to earthquake-related mortality from uplift. Length-based mortality was implemented in the model to investigate this possibility, with a base mortality estimated at 125 mm length, and an exponential scaling of mortality with size to the power of -2.

2.6 Management procedure evaluation (MPE)

2.6.1 Initial CPUE-based control rules

Initial control rules developed for Neubauer & Kim (2023a) were based on adjusting catch to meet the CPUE target. The process adjusted catch according to CPUE trends and absolute CPUE relative to a target CPUE (identified as 50 kg/h). The process, therefore, aimed to find a harvest rate that is associated with a long-term biomass density that produces CPUE of 50kg/h. The tested rule for PAU 3A was developed assuming a $\pm 20\%$ increment for steps around a 50 kg/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 22 and 23, Table 7). Control rules were scaled so 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 23 for an illustration).

Depending on recreational catch levels, the commercial catch was often zero in the long term, 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) was not possible independent of recreational catch control considerations. 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)?" (Neubauer & Kim 2023a).

Table 7: 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

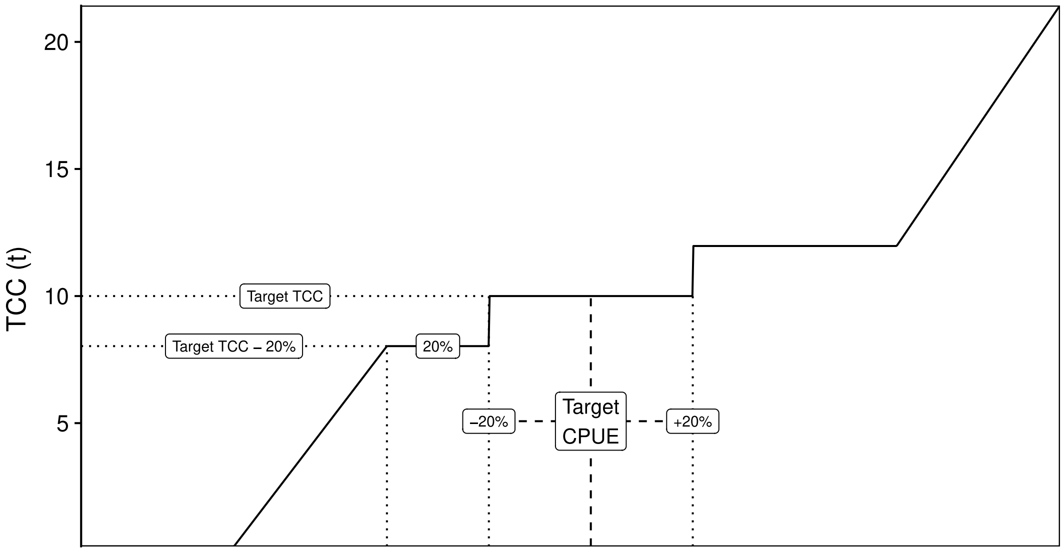

Figure 22: Conceptual graph of harvest control rules used in most PAU stocks, illustrated for single arbitrary zone with a target catch of 10 t: control rules show total commercial catch (TCC) as a function of catch-per-unit-effort (CPUE), including key parameters. The latter include the width of the 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.

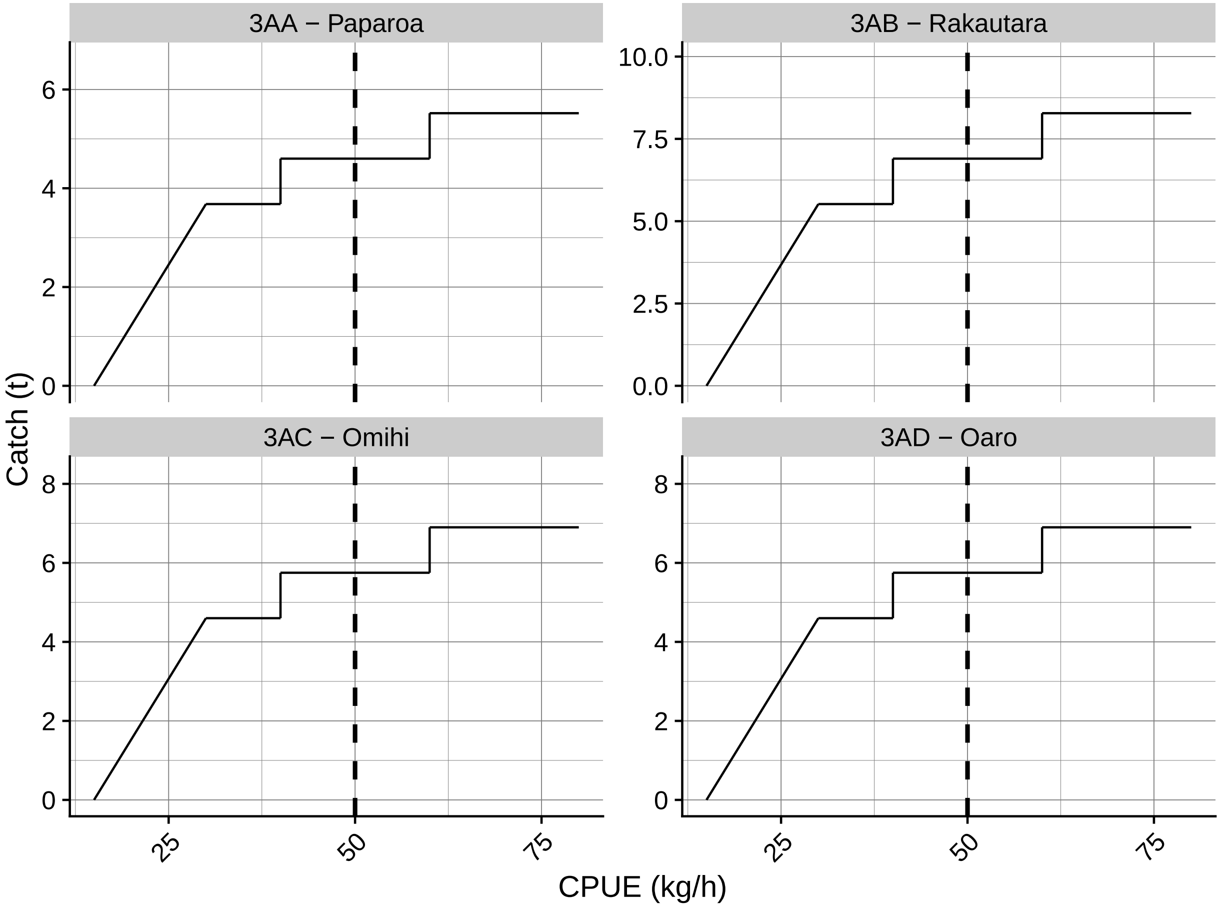

Figure 23: Initial harvest control rules proposed for PAU 3A (by management zone) under project PAU2021-02 by Neubauer & Kim (2023a): total commercial catch (TCC) as a function of catch-per-unit-effort (CPUE). Target CPUE is shown as the dashed vertical line.

2.6.2 Updated control rules based on spawning potential ratio (SPR) target and CPUE trends

A key drawback of CPUE-based rules has been that the catch plateau and limits may not directly correspond to sustainability criteria outlined by the New Zealand Harvest Strategy Standard. While the compliance with this standard is a key element of testing management procedures, the lack of direct correspondence is difficult to communicate. In addition, using CPUE alone for a control rule can be difficult when minimum harvest sizes and overall catch allowances are changed, as both will impact on where and how fishing occurs, with repercussions on CPUE.

Recently-developed methods that can incorporate length measurements from fished populations as a status indicator for fisheries have the potential to provide additional (Hordyk et al. 2015, Hordyk et al. 2016), and more direct information on the state of and changes in the fishery. The idea behind the method is that conditional on life history, the length composition of the fishery can be used to estimate both selectivity and fishing mortality on an annual basis to derive an equilibrium measure of stock status in terms of the spawning potential ratio (i.e., the ratio of current spawning potential in the fishery relative to unfished spawning potential; Figure 24). Management strategy evaluation based on this and related concepts has shown the utility in a management context (Prince et al. 2011).

The length-based spawning potential ratio (LB-SPR) can be linked to assessment-based metrics of spawning biomass, such as relative spawning biomass (see Figure 24), and can be readily implemented based on efficient implementation of the algorithm (Figure 25; Hordyk & Mardones 2019).

The LB-SPR rule was tested using a target of 50% SPR, with an M/K ratio of 0.6 derived from New Zealand data from a recent meta-analysis (Prince et al. 2023). Other required parameters are L_∞ (asymptotic length) and L_M (length-at-maturity) which were derived from survey data as the 95th percentile of length distributions for L_∞, and $L_M = 0.6L_\infty$. Alternative simulations were tried with higher M/K (assuming more productive stock) and higher L_∞ (+10%), but these settings tended to over (under) estimate spawning potential relative to the stock assessment model.

Recreational catch developments were modelled by setting an initial catch (assuming a set of measures to constrain recreational catch within those limits given currently available biomass), and assuming that recreational catch evolved directly proportionally to available biomass (above the Minimum Legal Size of 125 mm). 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.

Commercial 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 assumed to be 20%. For simulated length distributions, the length at 50% selectivity was assumed to fluctuate randomly with a CV of 10%, introducing “noise” (variability) in length compositions and resulting SPR estimates. This noise is often seen in regional distributions due to weather-constrained access to fishing areas with different length distributions.

The control rule was tested for a validity period of five years, with simulations projecting the stock for 25 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.

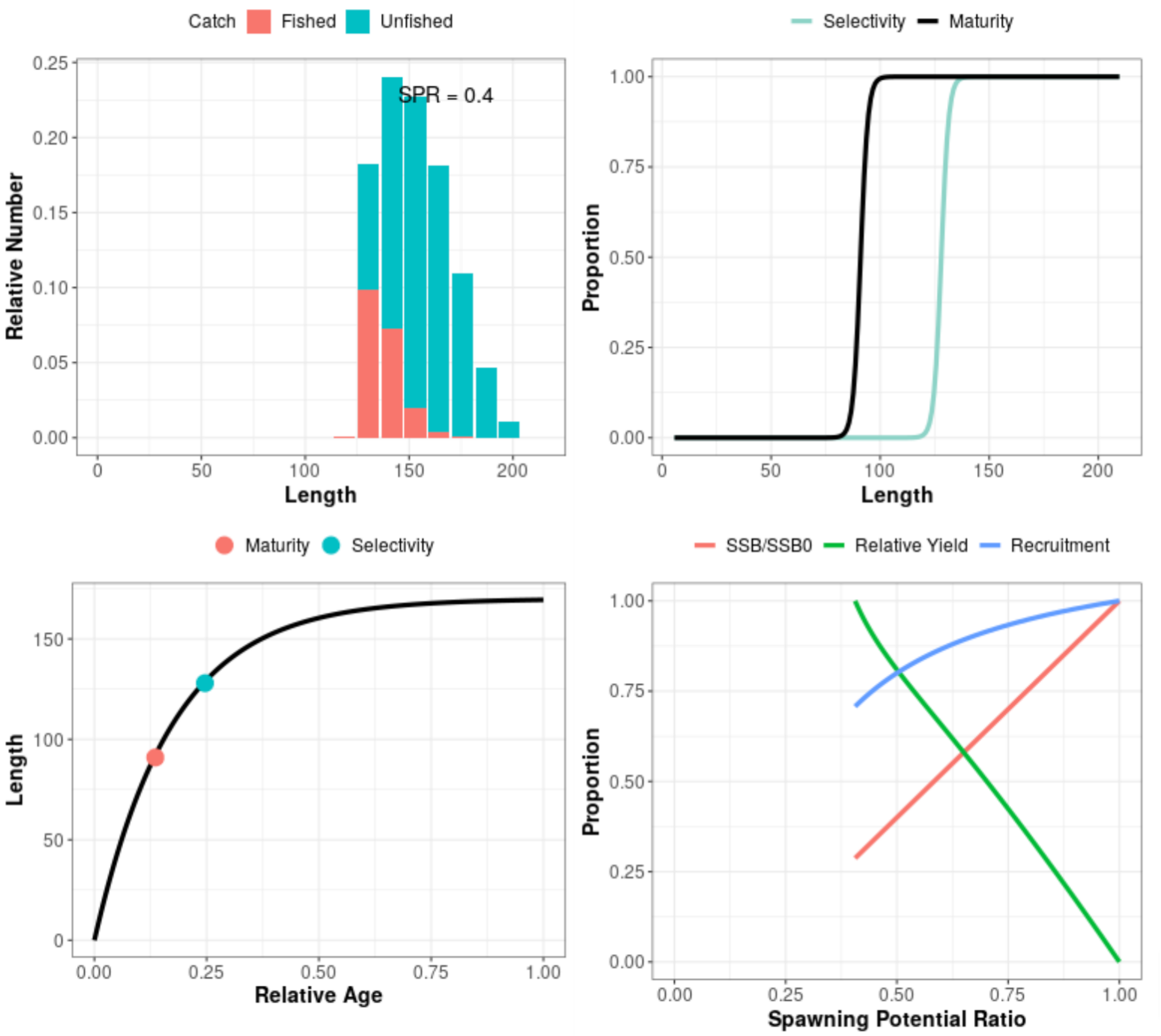

Figure 24: Illustration of the length-based (LB) spawning potential ratio (SPR), based on assumptions about maturation, *K* (growth rate) relative to natural mortality (*M*) and selectivity. The ratio *M*/*K* is generally estimated from meta-analysis. Assumed link to (relative) age is shown on the bottom left, relationships to other stock metrics (*SSB*: spawning stock biomass) are shown on the bottom right.

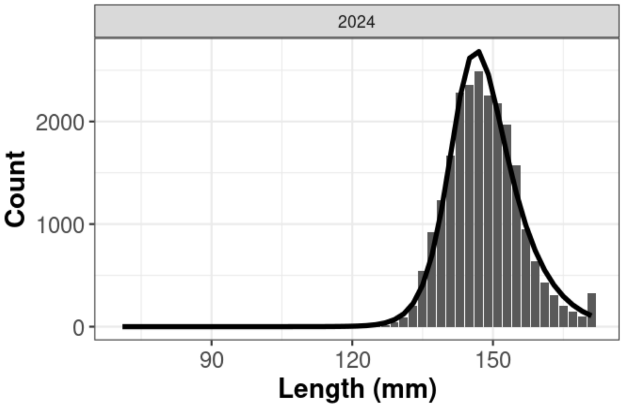

Figure 25: Illustrated fit of the length-based spawning potential ratio (LB-SPR) method to simulated length frequencies in PAU 3A for 2024.

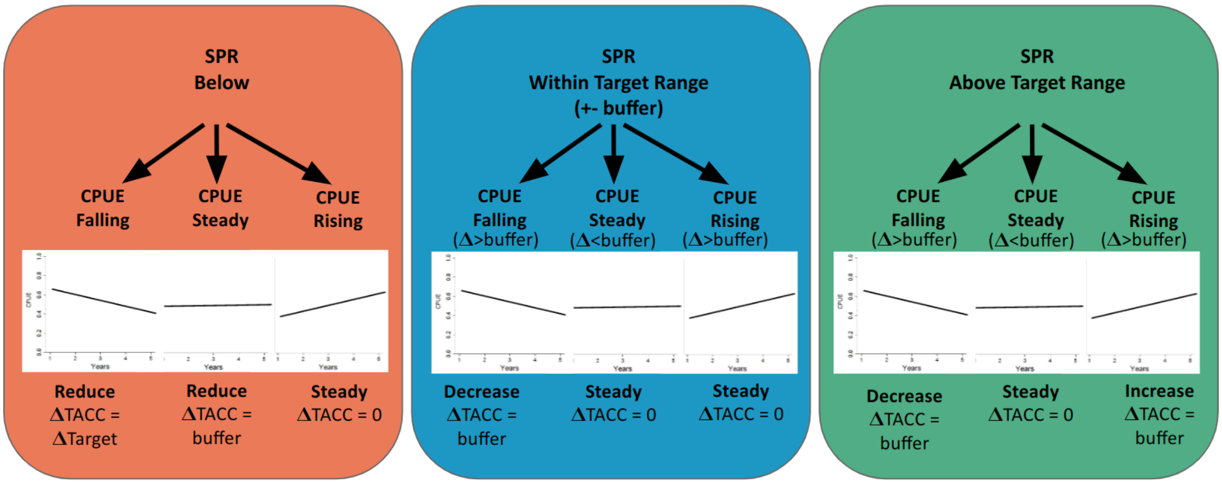

Figure 26: Length-based spawning potential ratio (LB-SPR-based harvest control rule proposed for PAU 3A: A target spawning potential ratio (SPR) is first set (e.g., 50% of unfished spawning potential). Given a buffer (e.g., 10%) around this target, the SPR is estimated from length data for each management area. If the estimated SPR is within the target zone, and catch-per-unit-effort (CPUE) is not declining, no further action is required. If CPUE is declining (e.g., 2 years of CPUE declines in a row), then catch is reduced by 10%. If the SPR is below target by more than the specified buffer, correcting action is taken by reducing the catch by the ratio of SPR to the target (i.e., the reduction is at minimum equal to the buffer). If the SPR is above the target buffer zone, catch is maintained unless CPUE drops rapidly (by >buffer).

3. RESULTS

3.1 Stock assessment and earthquake impacts

Stock assessment models converged and were able to fit fishery observations. Two key uncertainties were: 1) the weight to be applied to commercial catch sampling length frequencies (CSLF), and 2) the assumption about short-term earthquake impacts.

Using low CSLF weights led to poor fits to CSLF data prior to the earthquake (Figure 27), but to slightly better fits in survey length composition fits (Figure 28) and CPUE (Figure 29). The model with low CSLF weights had a higher stock status and did not go as low as the high CSLF weight model historically (Figures 30 and 31). Due to the small differences in CPUE fit but markedly better CSLF data fits, the high CSLF weight model was preferred by Shellfish Working Group and Fisheries Assessment Plenary, especially in light of evaluation management procedures that include length data. The base case model (highCSLFw;

Appendix B) had a stock status of 45% of unfished spawning biomass, with a very low risk of the stock being below limit reference points. The alternative weighting with lower weight placed on CSLF data led to a higher status estimate (Appendix C).

Different assumptions about earthquake impacts had relatively small effects on fits in all areas except Paparoa (Appendix D); Paparoa was the area with the highest uplift and, therefore, the highest impacts. The model with forced recruitment reductions could not fit the survey index well in the most impacted region (Figure 32), leading the Shellfish Working Group to conclude that this model was not useful. The model with a pulse-mortality event could fit these data, but could not fit recent commercial CPUE as they estimated too small an available biomass level (Figure 33). This low biomass was also reflected in the assessed status in models with forced earthquake impacts (Figures 34 and 35). The base case model was able to fit survey and commercial data best, and may be able to do so by estimating low recruitment for the earthquake year (Figure 36). The Shellfish Working Group decided that this model was likely to be the most parsimonious way to represent earthquake impacts in the short term.

Alternative life history assumptions, such as length-based natural mortality or fixed natural mortality, had limited impact on estimated stock status or fits, given M was estimated to be near 0.13 (Appendix E). Similarly, alternative assumptions about recreational catch prior to the earthquake had a relatively minor impact (Appendix F), but were identified by the Fisheries Assessment Plenary as a main uncertainty in the catch history.

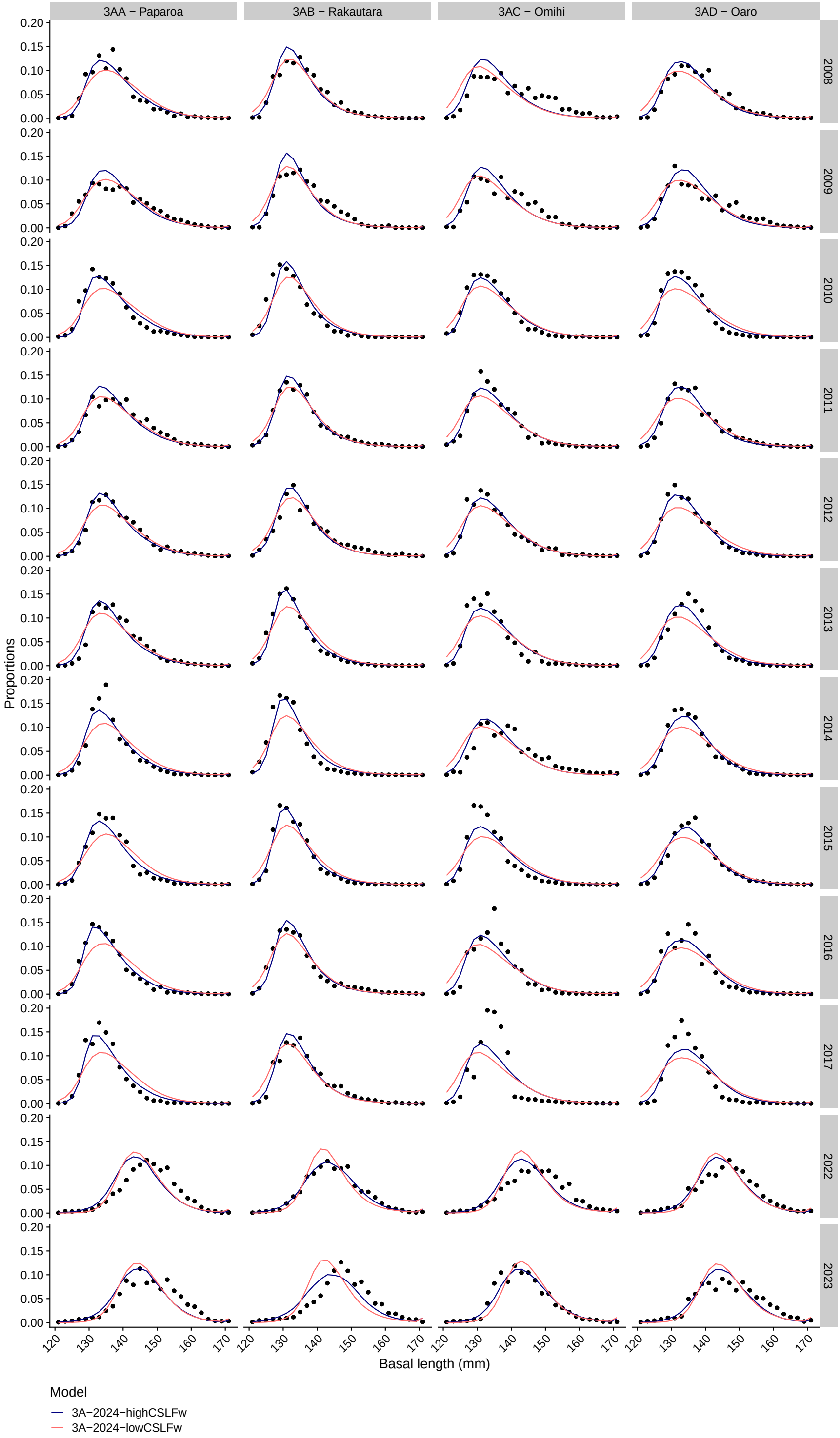

Figure 27: Fits to commercial catch sampling length frequencies (CSLFs) under two models with differing weights for CSLF data (high CSLF weight (w) versus low CSLF weight) by management zone in PAU 3A.

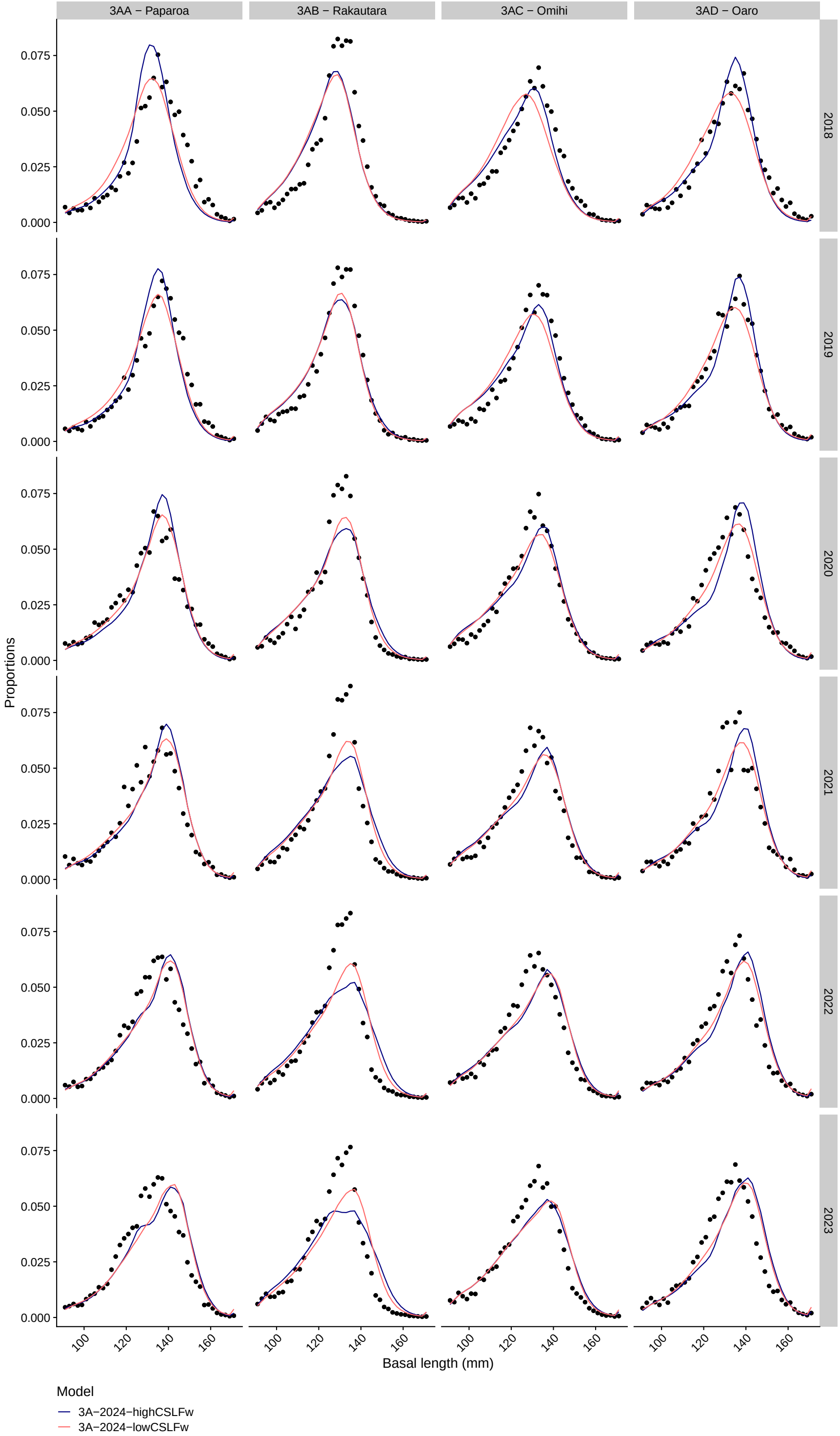

Figure 28: Fits to survey length frequency data under two models with differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versus low CSLF weight) by management zone in PAU 3A.

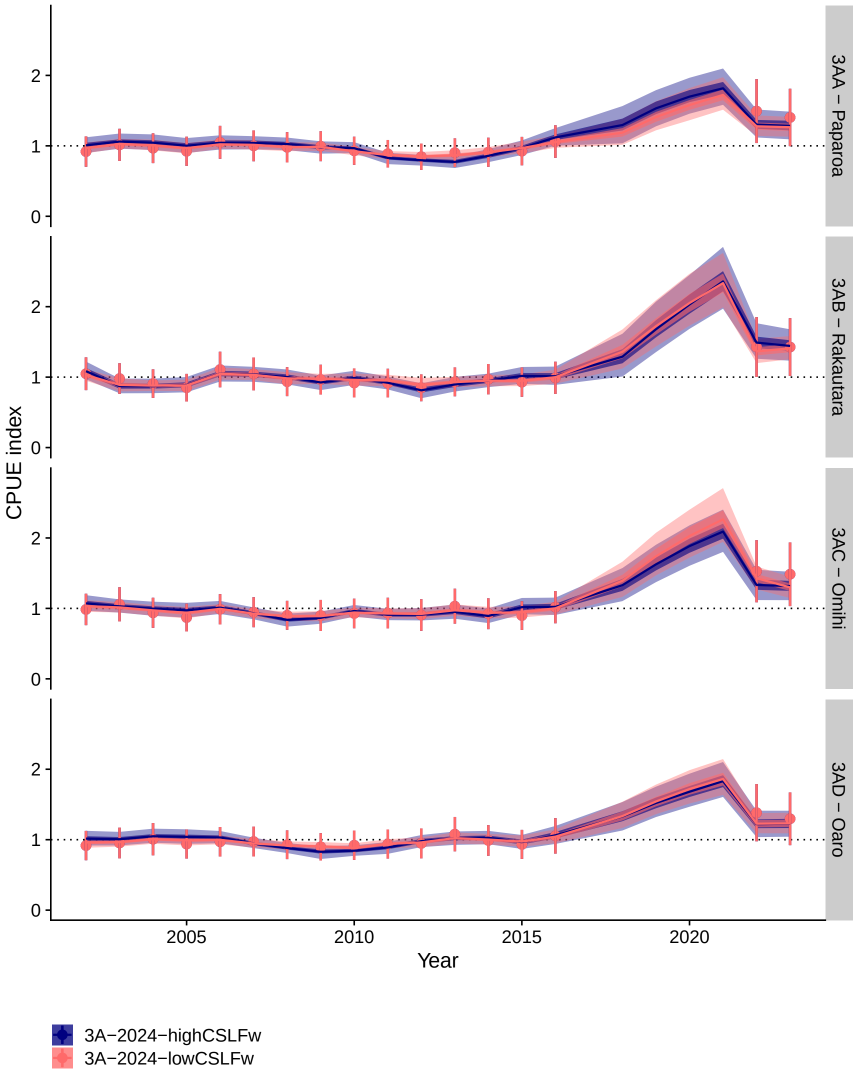

Figure 29: Fits to catch-per-unit-effort (CPUE; posterior median (line) and 95% confidence (shaded ribbon)) under two models with differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versus low CSLF weight) by management zone in PAU 3A.

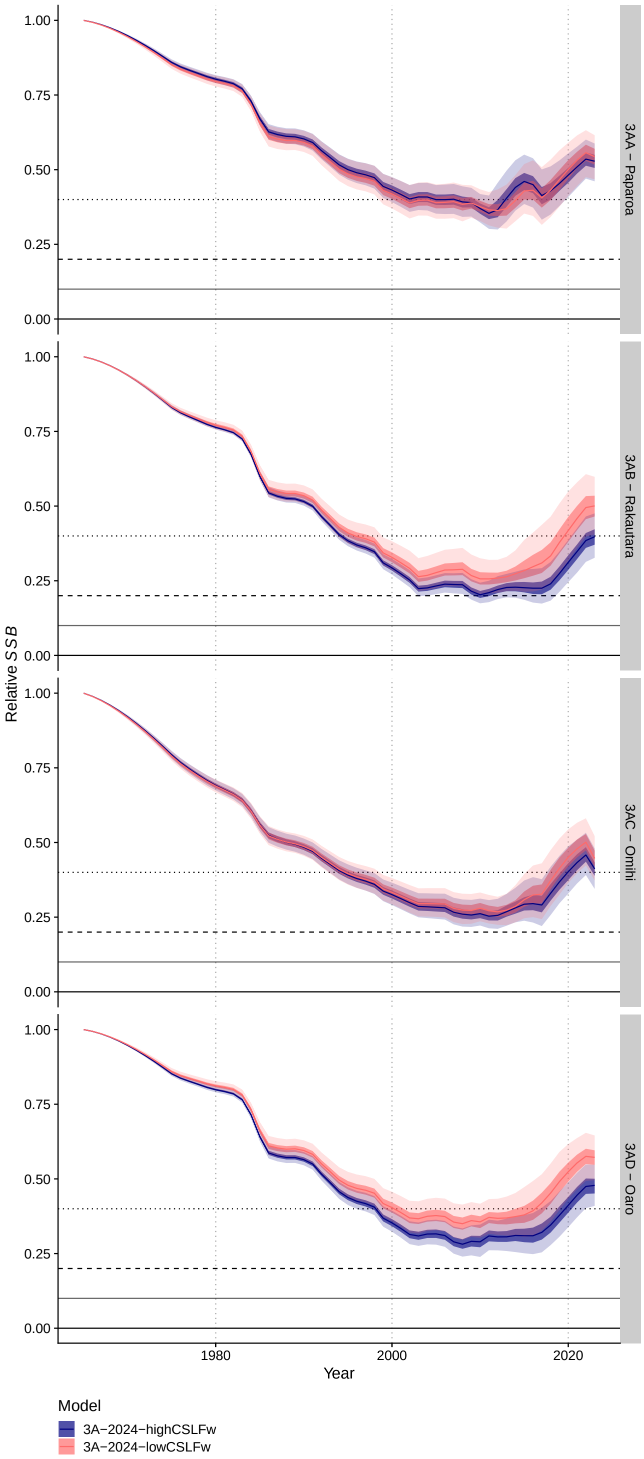

Figure 30: Estimated stock status (relative spawning stock biomass; *SSB*; posterior median (line) and 95% confidence (shaded ribbon)) under two models with differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versus low CSLF weight) by management zone in PAU 3A.

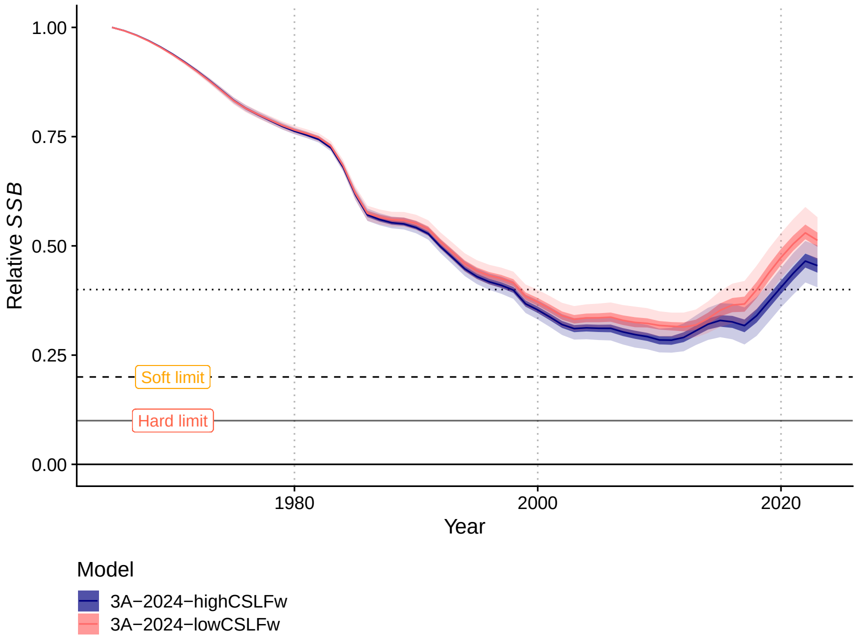

Figure 31: Estimated stock status (relative spawning stock biomass; *SSB*; posterior median (line) and 95% confidence (shaded ribbon)) under two models with differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versus low CSLF weight) in PAU 3A.

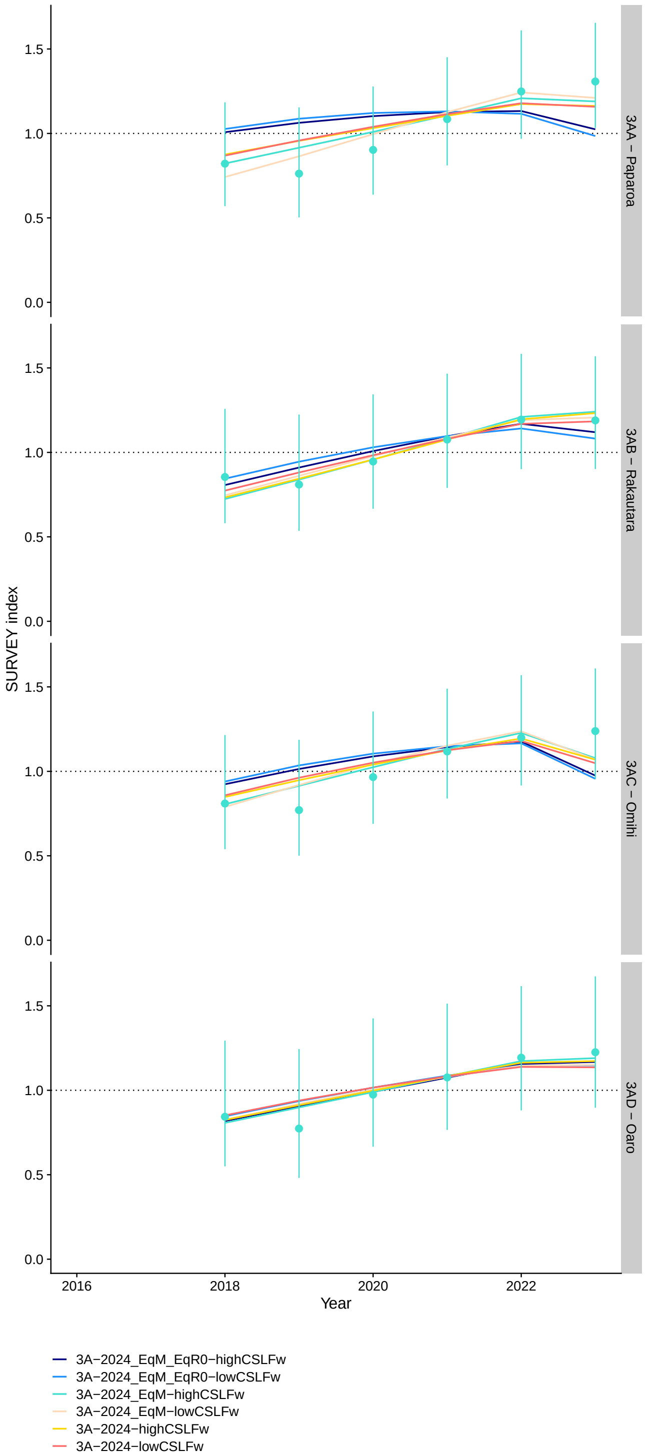

Figure 32: Fits to survey indices under models fitted to survey observations (_survey) under different assumptions about earthquake impacts (EqM: natural mortality from earthquake directly scaled with uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2) and differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versuss low CSLF weight) by management zone in PAU 3A.

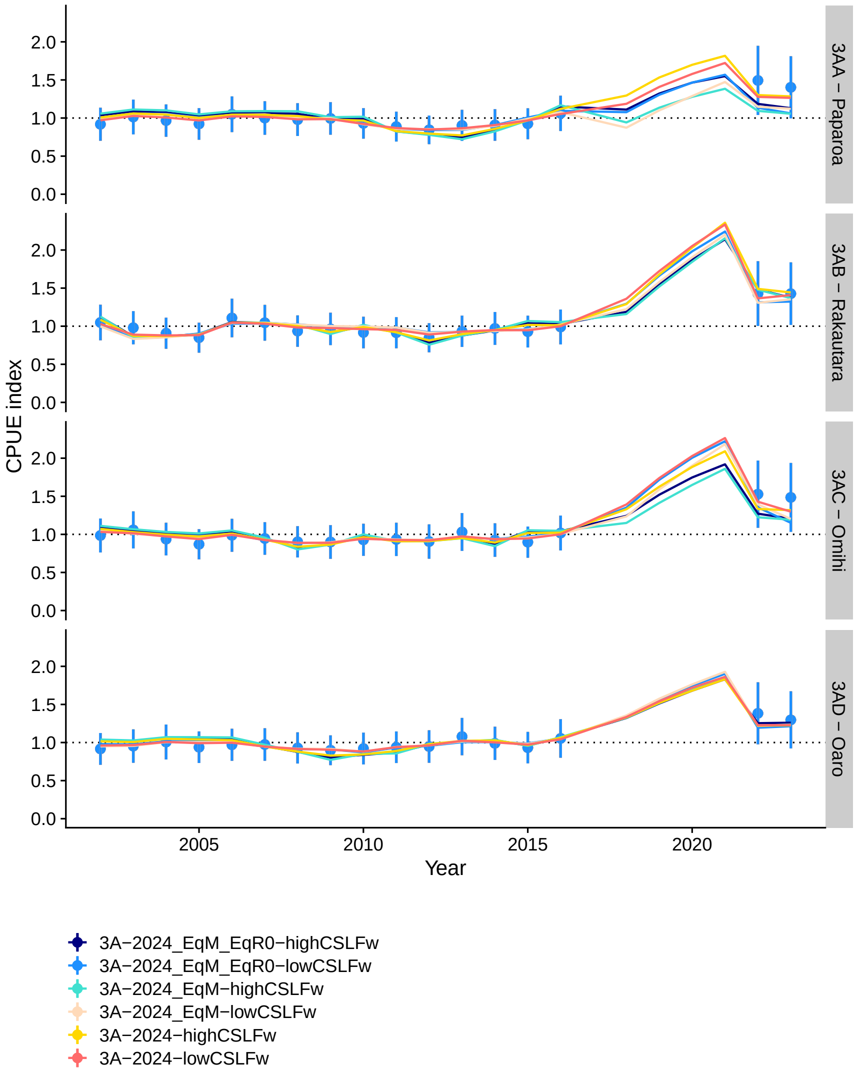

Figure 33: Fits to catch-per-unit-effort (CPUE) under models fitted to survey observations (_survey) under different assumptions about earthquake impacts (EqM: natural mortality from earthquake directly scaled with uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2) and differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versus low CSLF weight) by management zone in PAU 3A.

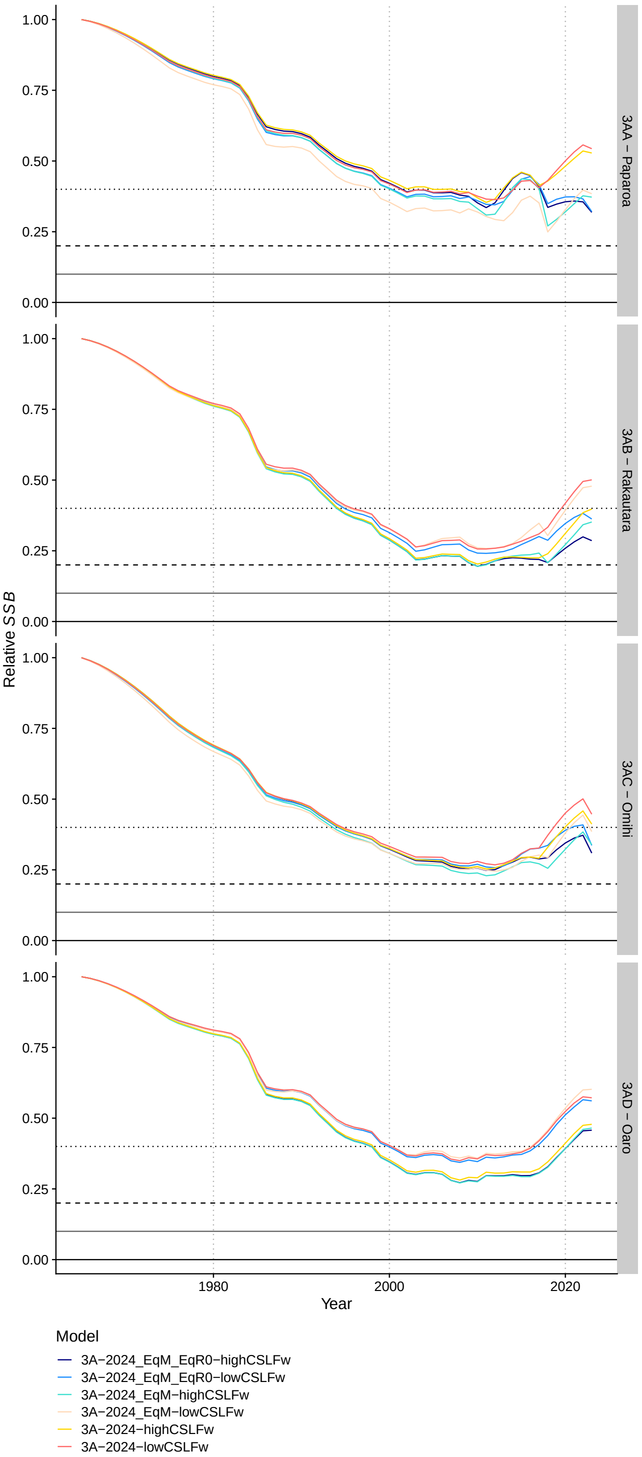

Figure 34: Estimated stock status (relative spawning stock biomass; *SSB*) under models fitted to survey observations (_survey) under different assumptions about earthquake impacts (EqM: natural mortality from earthquake directly scaled with uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2) and differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versus low CSLF weight) by management zone in PAU 3A.

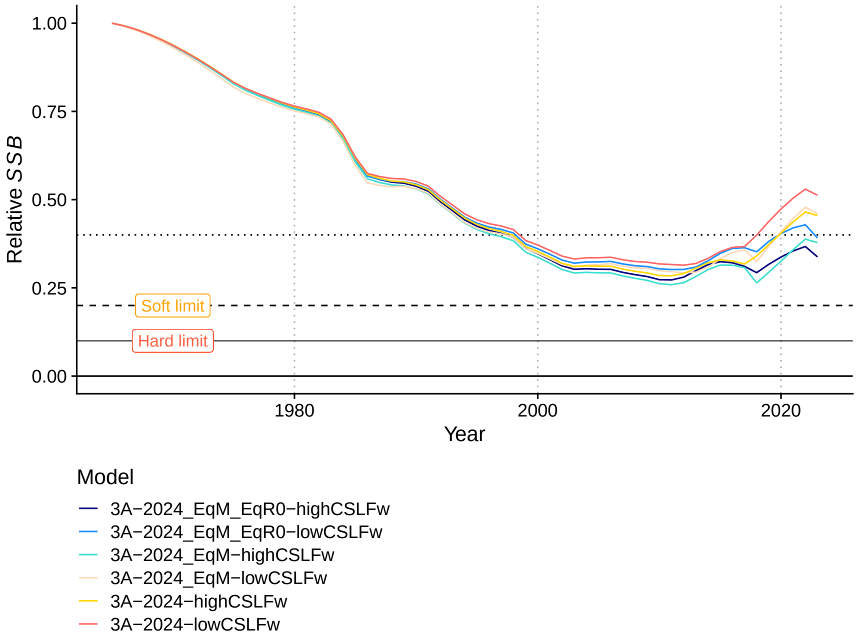

Figure 35: Estimated stock status (relative spawning stock biomass; *SSB*) under models fitted to survey observations (_survey) under different assumptions about earthquake impacts (EqM: natural mortality from earthquake directly scaled with uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2) and differing weights for catch sampling length frequency (CSLF) data (high CSLF weight (w) versus low CSLF weight) by management zone in PAU 3A.

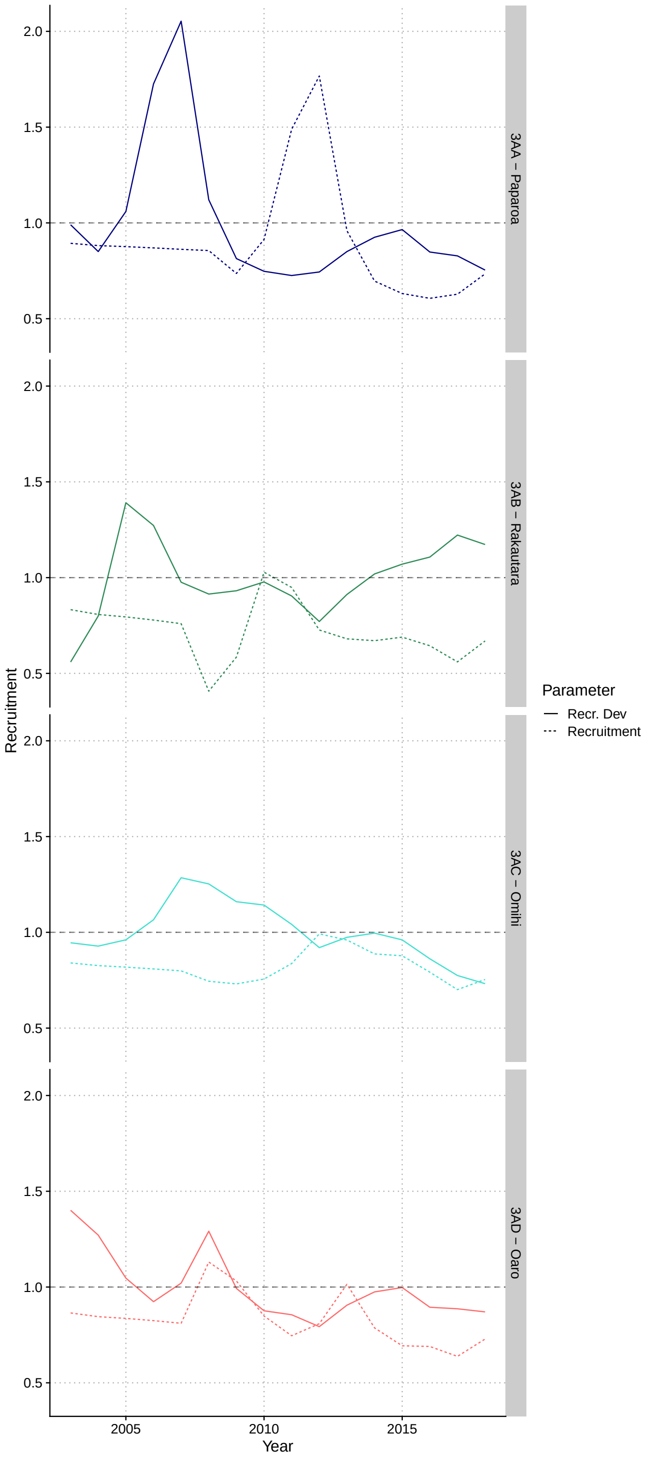

Figure 36: Estimated recruitment deviation (Dev.) and actual resulting recruitment for the base case model for PAU 3A.

3.2 Management procedure evaluation

Overall, the management procedure evaluation showed little risk for all options considered within the evaluation. MLS changes had a minor impact on projected stock trajectories (Appendix G), largely because the management procedure prevented the stock from reaching low levels when protection of a minimum spawning biomass was important. In the long-term, there was a trade-off between recreational and commercial catch settings, with high recreational allowance (e.g., 25 t) leading to a slow but steady reduction of commercial catch under the control rule when it is set to 46 t initially (Appendix H). With a lower starting catch for the commercial sector, the TACC was slowly increased by the control rule. Overall, the suggested control rule managed to maintain the stock at or above the default target of 40% of unfished biomass in all cases when the base model was used.

Only when alternative models, with lower estimated status—such as assuming high earthquake-related mortality—were used, did the stock stay below target, with the control rule leading to a slow but steady rebuilding towards target levels (Appendix I). Assuming alternative *M*/*K* settings for the LB-SPR performance indicators leads to variable performance (Appendix J), with high catches under the base model leading to a decline in stock status. However, these settings were not proposed to be used, as they lead to an LB-SPR estimate that is not aligned with the underlying operating model output (i.e., it overestimates SPR).

4. DISCUSSION

The current project represents an endeavour to systematically incorporate all available information and data from PAU 3A to estimate fishery status and evaluate management options post-earthquake. Within the assessment approach, we attempted to estimate the fishery's overall scale before the earthquake, while also making transparent, albeit possibly oversimplified, assumptions regarding earthquake repercussions. We considered both immediate impacts (via instantaneous natural mortality) and long-term effects (via reduced carrying capacity), recognising these assumptions as likely simplifications of a multi-faceted reality. Short-term impacts likely extended over several years rather than occurring instantly, as the ecosystem continued to adapt post-earthquake, following uplift and sediment influxes. Nevertheless, the most parsimonious approach throughout this project appeared to be the development of assessment models encompassing both pre- and post-earthquake fisheries, and allowing the assessment model to adjust recruitment to represent earthquake impacts.

It is too early to conclusively state whether the chosen implicit representation of earthquake impacts is fully justified. Nevertheless, there is currently strong evidence of a rapid and widespread re-build of the pāua populations in the PAU 3A area. For example, survey indices in Paparoa, where up to 42% of the previously-fished area was uplifted, have displayed significant recovery, albeit with a certain lag. In addition, current CPUE is high, despite high harvest sizes of at least 135 mm in all areas. It appears unlikely that productivity parameters such as growth or natural mortality would experience permanent alteration. It may, therefore, be reasonable to maintain an implicit representation of the earthquake, and assume that the scale of the fishery remained unchanged.

Despite these considerations, control rules should be robust with respect to potential other representations of earthquake impacts, such as forced earthquake mortality; they should also allow the fishery to build on conditions better than the conditions expected by the present models. We found that SPR-based control rules were robust, as long as the parameters of the LB-SPR assessment mirrored the true model. Choosing an *M*/*K* ratio that is too high will lead to an overly-optimistic assessment of SPR and long-term overfishing. For this reason, we propose a ratio of 0.6 that is on the low end of data obtained for *H. iris*. In addition, an SPR target of 0.5 will maintain the stock at or above the default target of 40% of unfished biomass. For this reason, we suggest that the current settings provide in themselves a safety buffer.

Key uncertainties still remain in the scale and variability of the pre-earthquake recreational fishery. It is unlikely that this uncertainty can be resolved *post-hoc*, highlighting the importance of ongoing monitoring of recreational catch levels. Another uncertainty lies in the degree of spatial overlap and representation of the survey and commercial fishery. It was difficult for the model to simultaneously represent both survey and commercial length compositions. Although the survey was designed to represent the commercial fishery, it covered relatively few sites within each management zone; it is unlikely to cover the demographic variability of pāua populations in each zone. Nevertheless, the model fitted the survey indices relatively well, and the relatively poor fit to some survey length compositions may have been due to more complex post-earthquake dynamics than were represented in the models. We attempted to fit a model with length-dependent natural mortality to represent potential length-dependent mortality, but this process did not lead to improved fits. It is possible that other temporary processes, such as short-term changes in growth, are responsible for the patterns seen in survey length compositions.

Despite these uncertainties, the model consistently estimated that the stock is at or above the target, and that management under the proposed harvest control rule should maintain the fishery in a healthy state.

5. ACKNOWLEDGEMENTS

This research was funded by Fisheries New Zealand projects SEA2023-06. Many thanks to Marine Pomarède, Storm Stanley, Jeremy Cooper and Tom McCowan and the members of the Shellfish Working Group for helpful discussion.

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APPENDIX A: SCENARIOS FOR EARTHQUAKE IMPACTS

Table A-1: Hypotheses of earthquake (EQ) impacts considered for the pāua 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.
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.

Continued on next page

Table A-1 – *Continued from previous page*

Parameter	Hypothesis	Observations	Representation (or not)
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 B: BASE MODEL DIAGNOSTICS: HIGH CSLF WEIGHT

B.1 Markov Chain Monte Carlo and posteriors

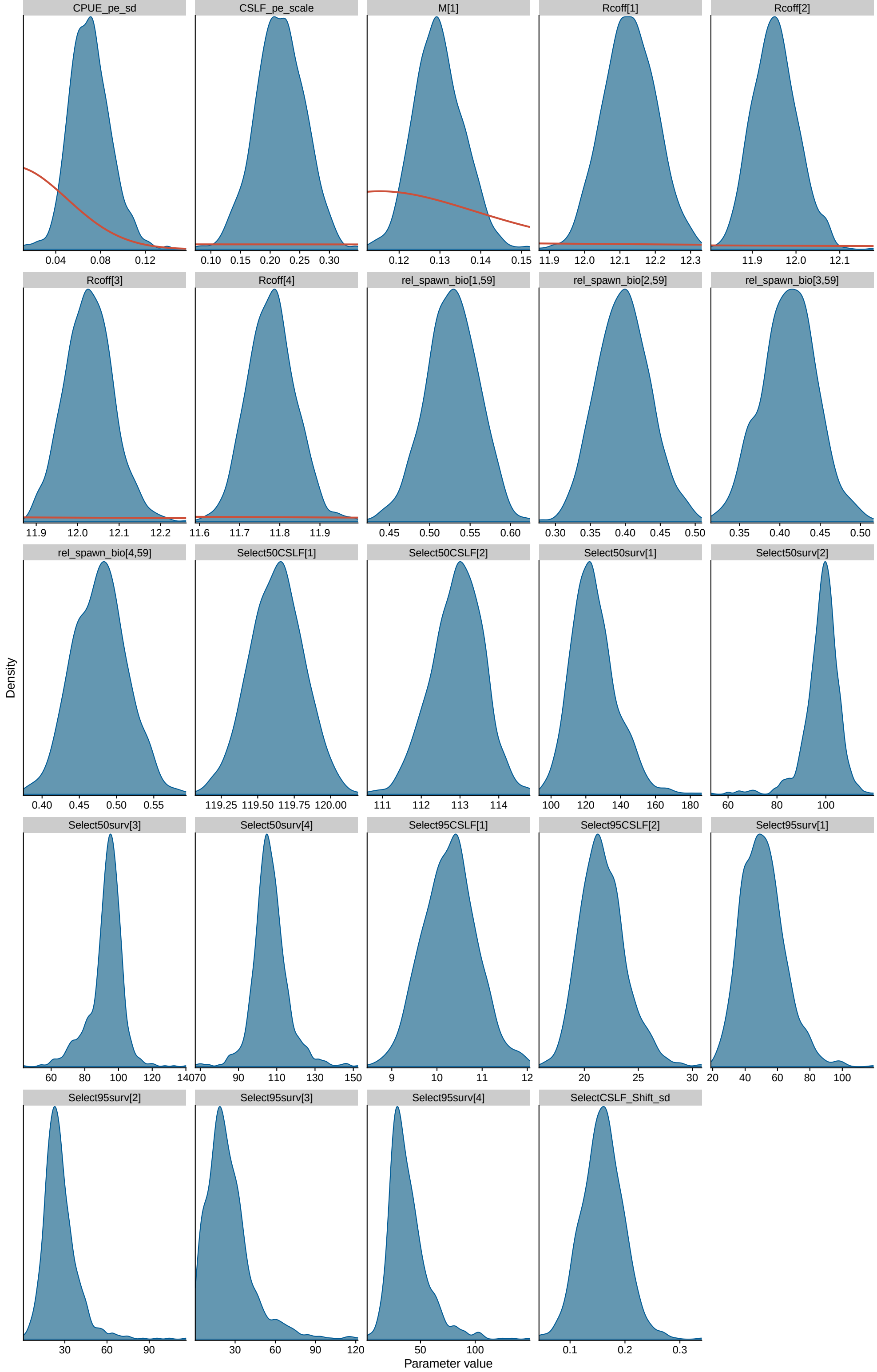

Figure B-1: Marginal posterior densities of key model parameters for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A, with prior densities indicated in red.

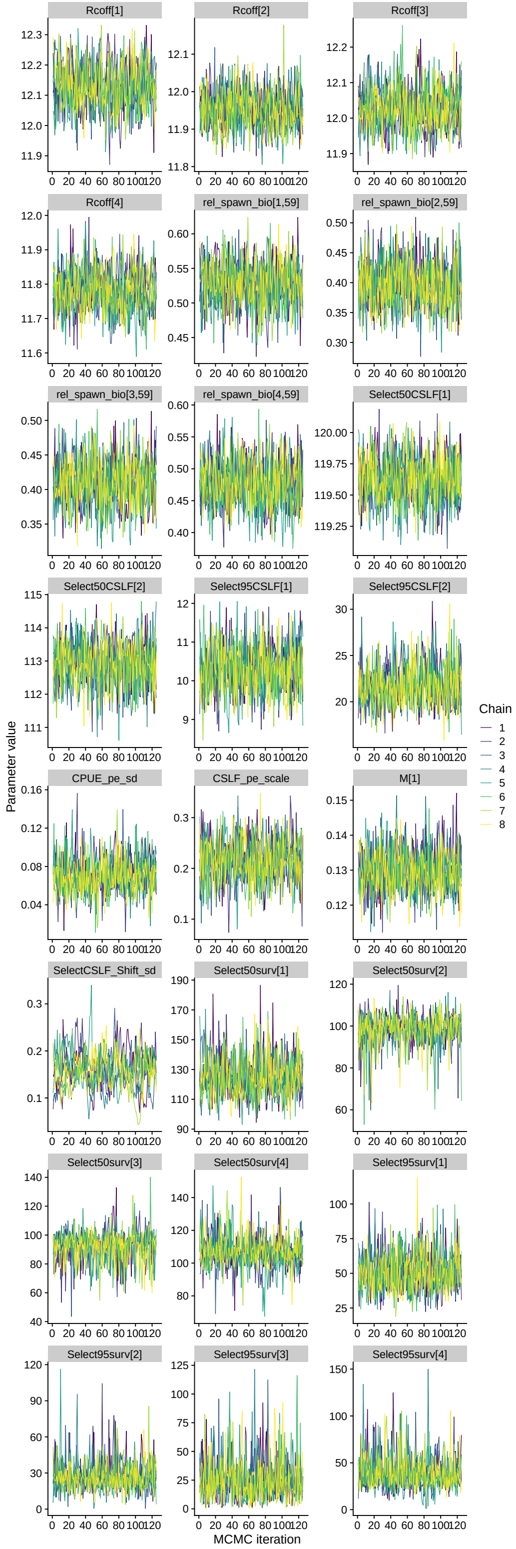

Figure B-2: Traces of Markov Chain Monte Carlo estimation for the marginal posterior distribution of key model parameters for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A.

Table B-1: Posterior quantities for key parameters in the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A. Logarithm of unfished recruitment, $log(R_0)$; size at which 5% of individuals are selected, D_5; (offset) size at which 95% of individuals are selected, D_{95}; natural mortality M, process error, PE; stock status (relative spawning stock biomass (*SSB*)); size at which 50% of individuals are surveyed, $Select50surv$; (offset) size at which 95% of individuals are surveyed, $Select95surv$.

Parameter	Posterior percentile				
	2.5%	25%	50%	75%	97.5%
D_5	111.78	112.97	116.94	119.63	119.93
D_{95}	9.36	10.30	13.93	21.54	25.60
$\log(R_0)$	11.70	11.88	11.98	12.07	12.22
M	0.12	0.13	0.13	0.13	0.14
PE_{CPUE}	0.04	0.06	0.07	0.08	0.11
PE_{CSLF}	0.13	0.19	0.22	0.25	0.30
SD Selectivity	0.09	0.13	0.16	0.18	0.24
Select50surv	77.15	96.27	102.68	113.47	143.11
Select95surv	5.87	22.26	32.31	46.57	77.47
relative SSB_{2023}	0.34	0.40	0.45	0.50	0.57

B.2 Catch-per-unit-effort

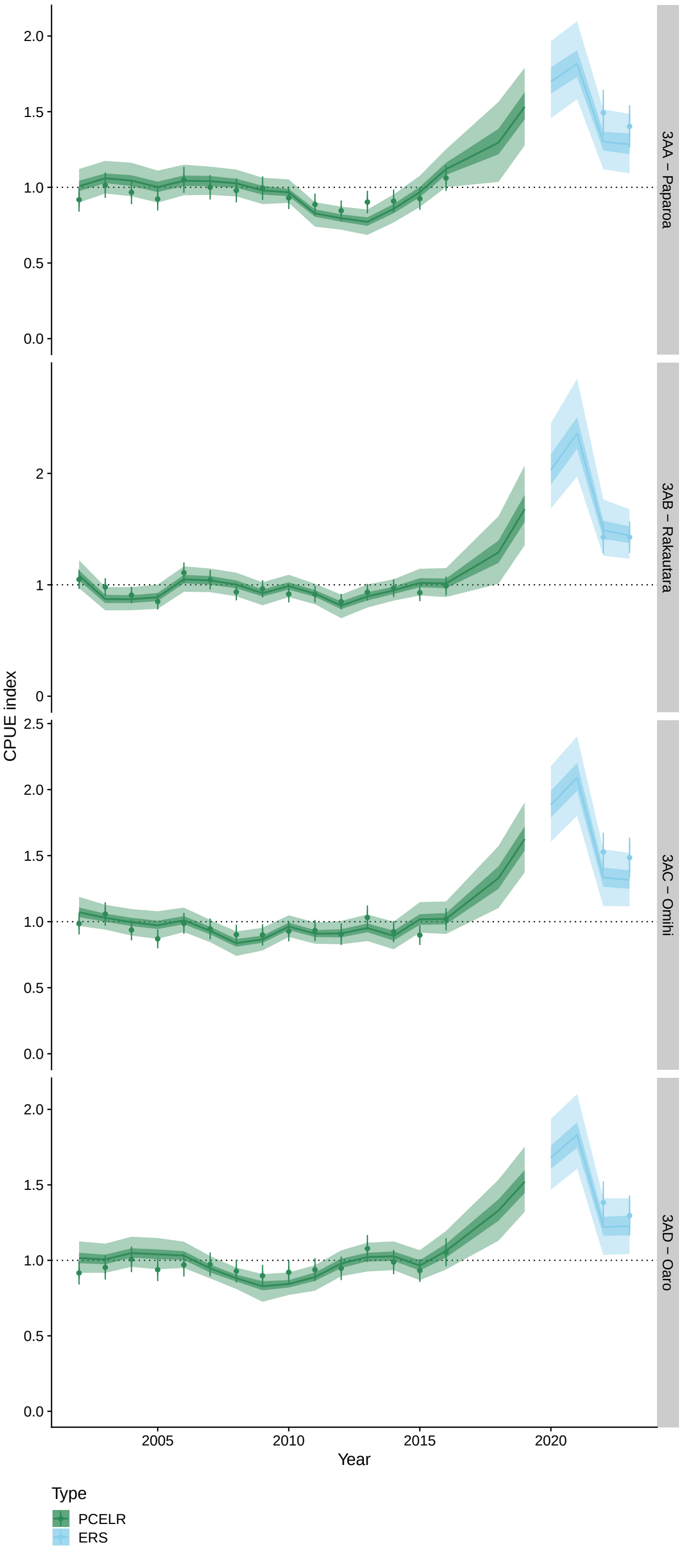

Figure B-3: Comparison of posterior median (line) and 95% confidence (shaded ribbon) predicted catch-per-unit-effort (CPUE) with estimated CPUE index and observation error for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A (points and error bars; PCELR data from Paua Catch Effort and Landing Return forms; ERS data from Electronic Reporting System).

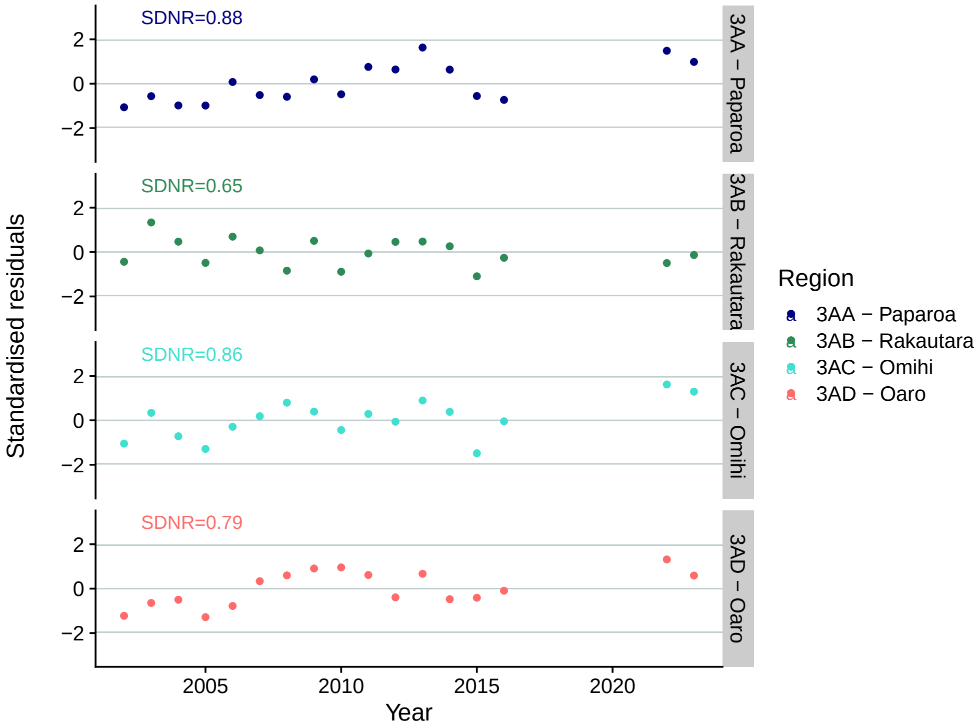

Figure B-4: Standardised residuals at the posterior median of predicted catch-per-unit-effort for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A. SDNR: Standard deviation of normalised residuals.

B.3 Survey index

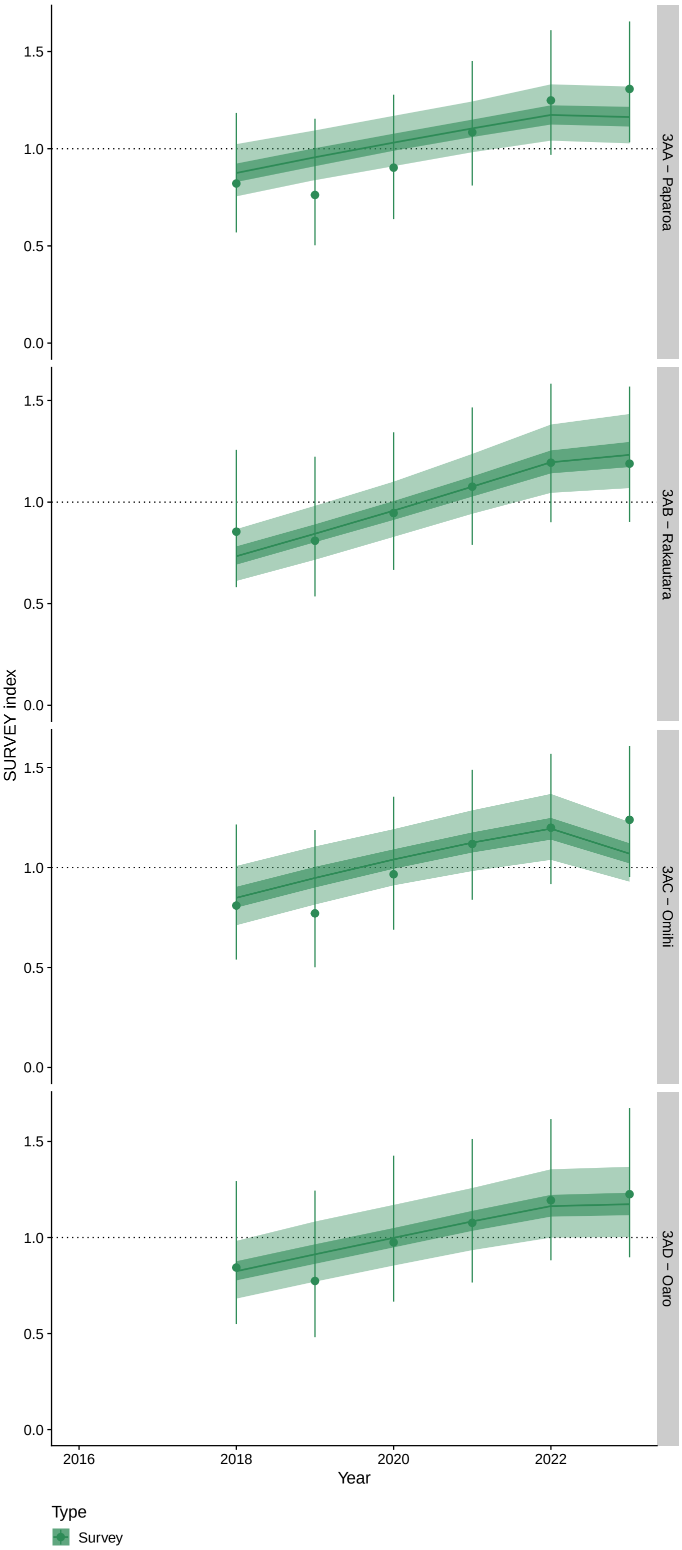

Figure B-5: Comparison of posterior median (line) and 95% confidence (shaded ribbon) model-predicted survey index with the estimated survey index and observation error for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A (points and error bars).

B.4 Commercial fishery length frequency

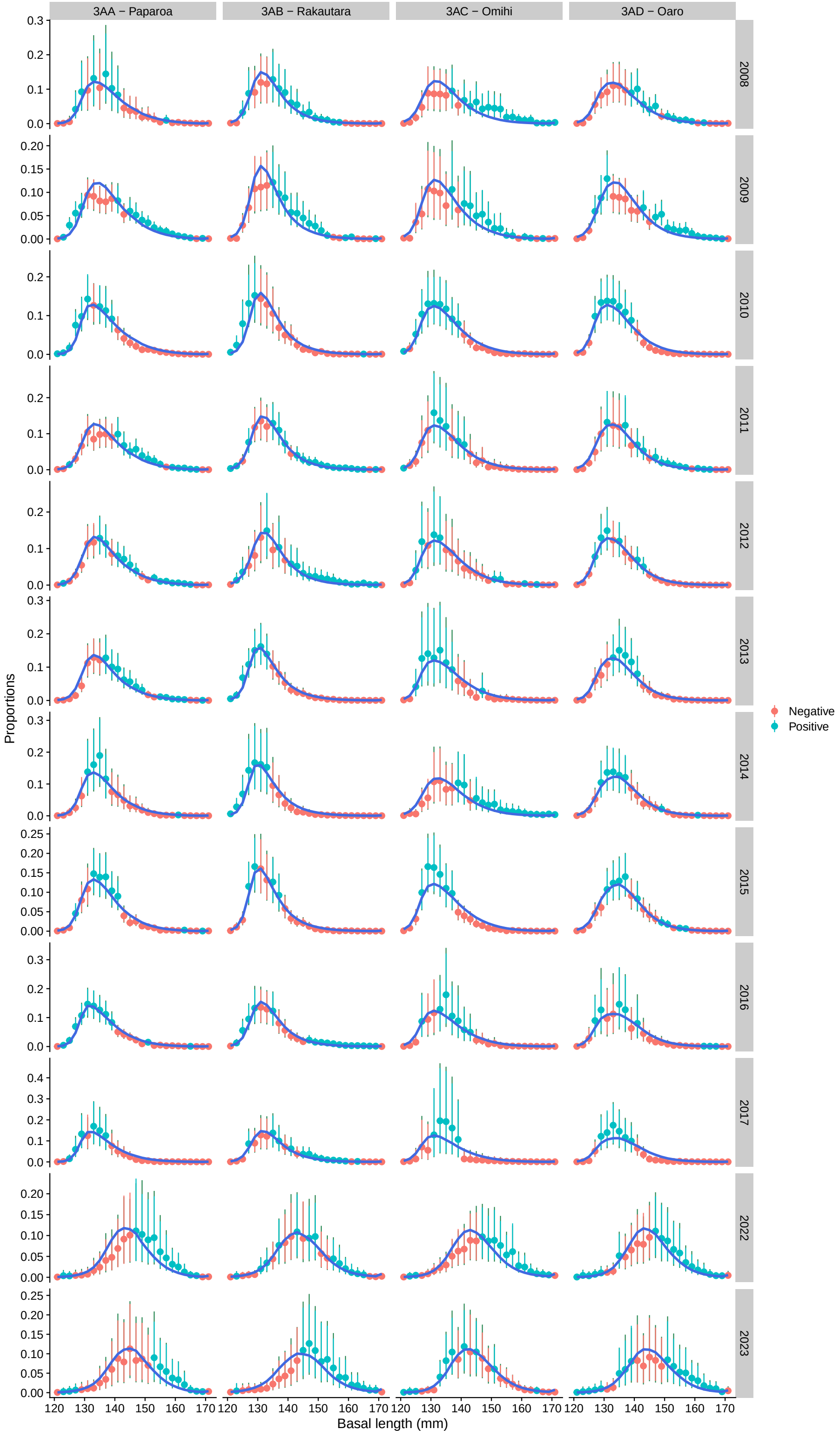

Figure B-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions and observation error for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A. Length classes with positive residuals in blue, with negative residuals in red.

Figure B-7: Catch sampling length frequency model residuals for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A. Length classes with positive residuals in blue, with negative residuals in red.

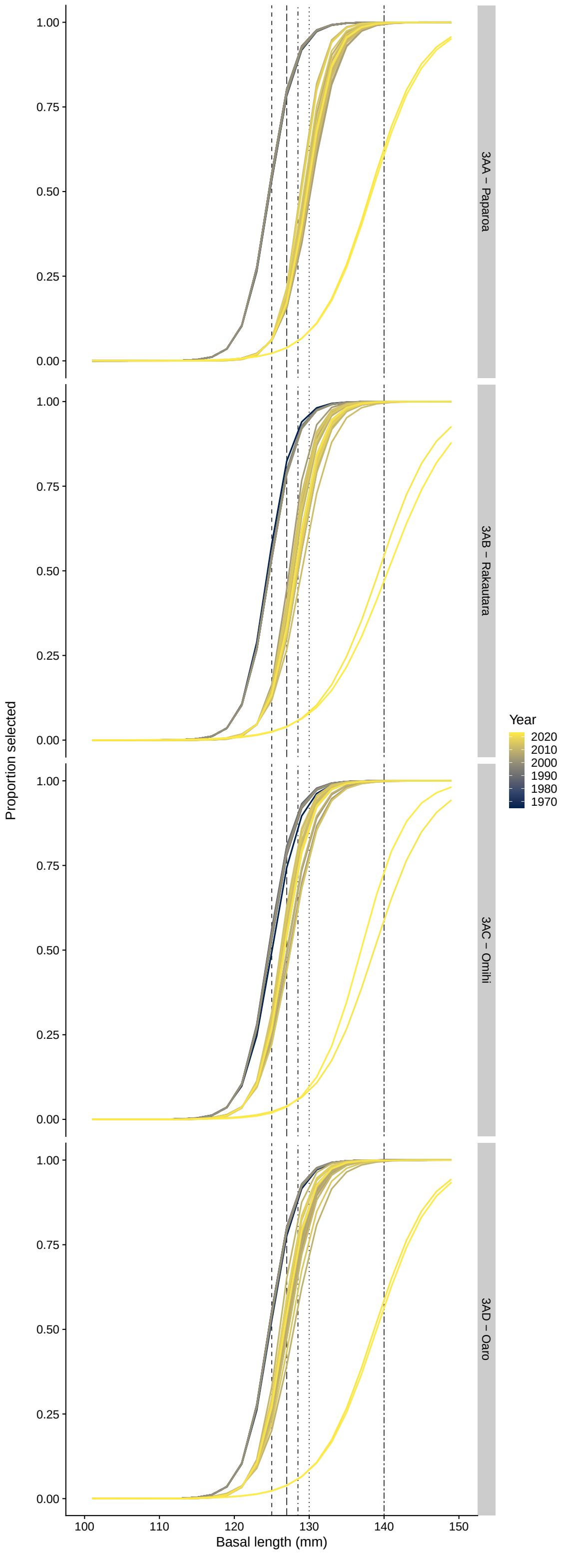

Figure B-8: Estimated selectivity (posterior mean) for pāua for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A.

B.5 Survey length frequency

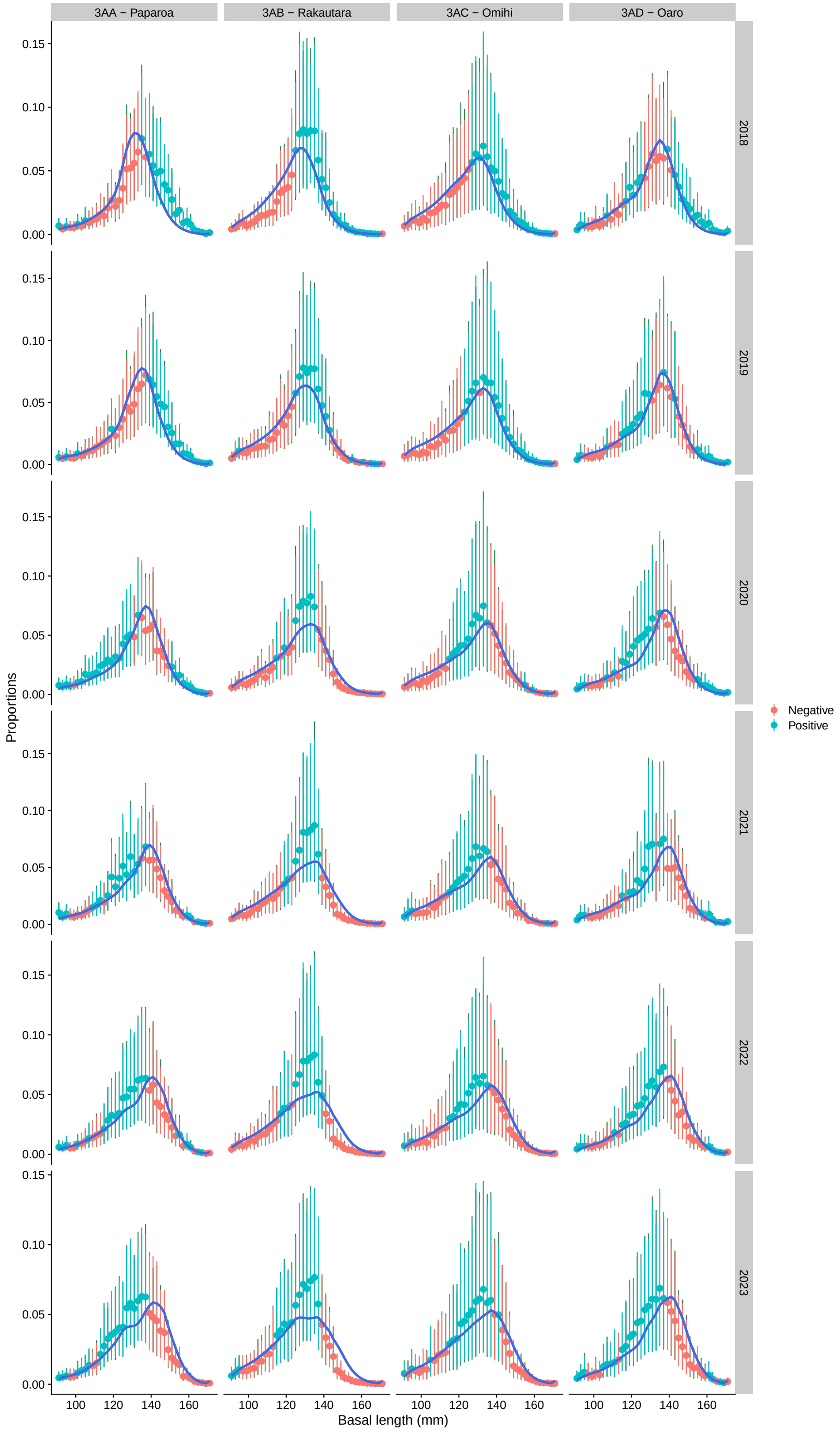

Figure B-9: Comparison of posterior mean predicted survey length frequency with estimated proportions and observation error for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A.

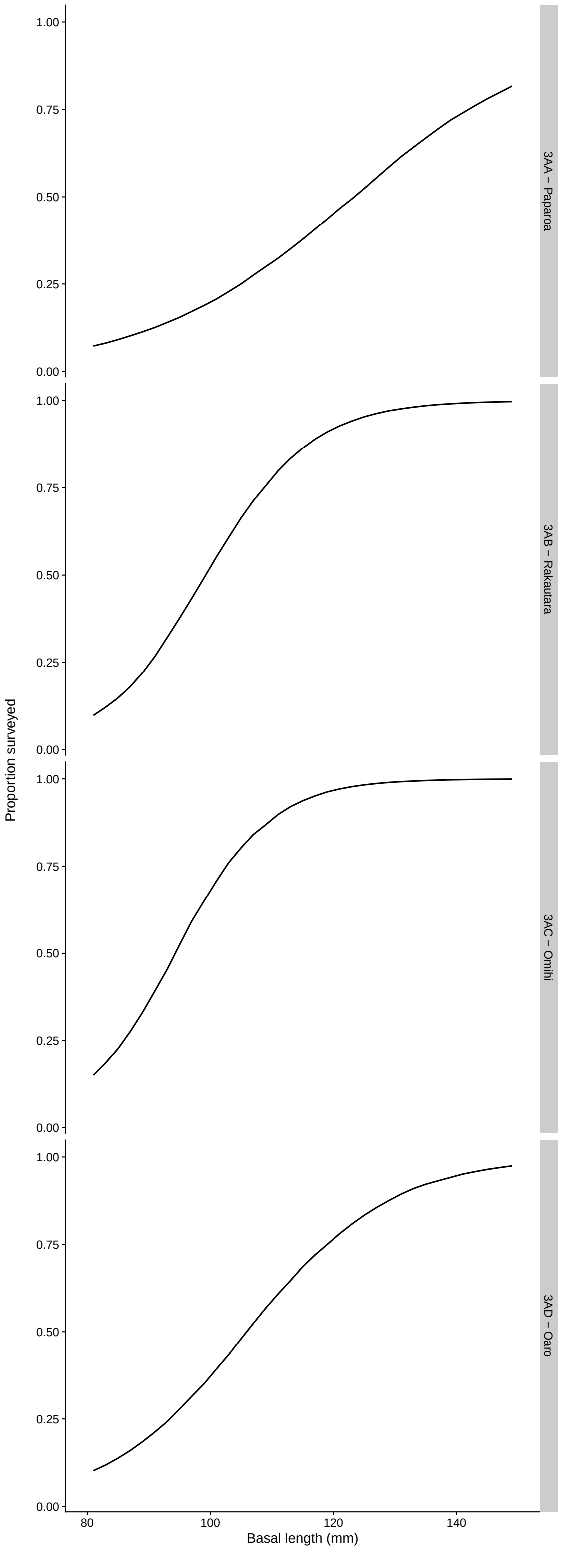

Figure B-10: Estimated survey selectivity (posterior mean) for pāua for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A.

B.6 Growth

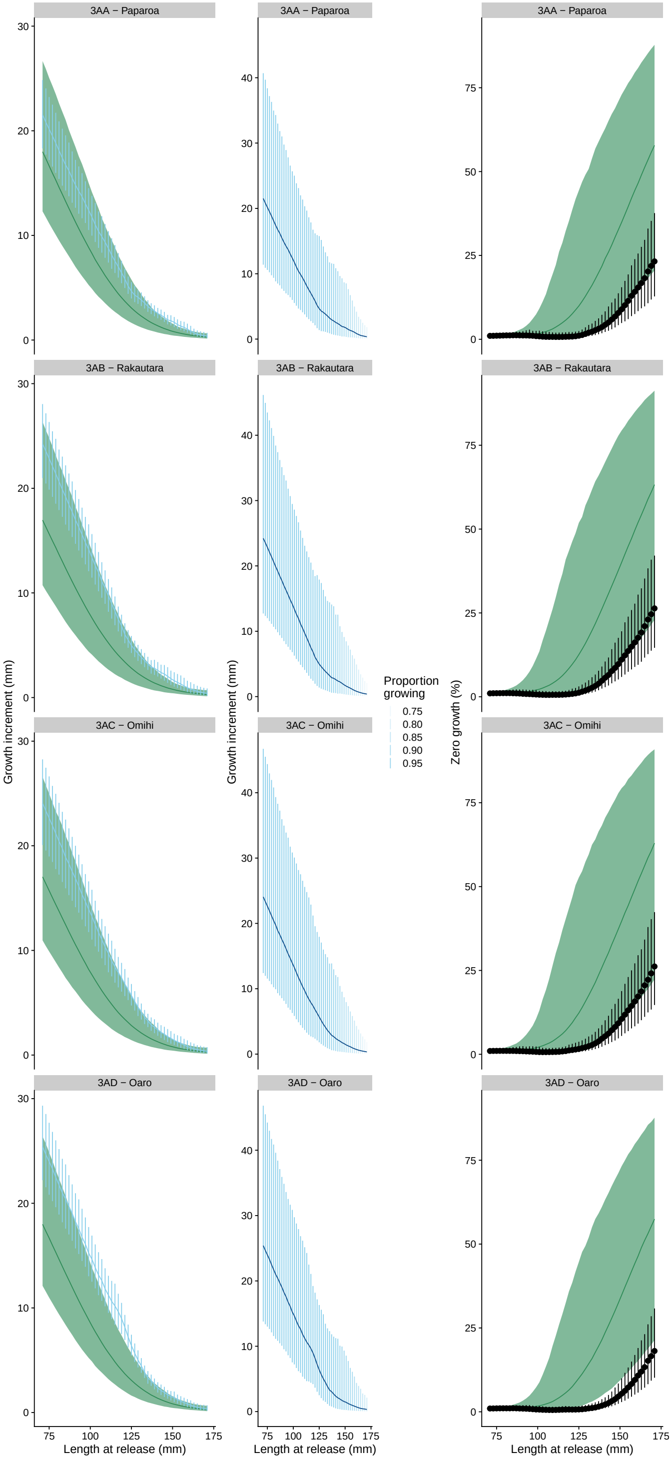

Figure B-11: Pāua growth for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A. Left: Posterior mean growth (population mean (dark blue line) and standard deviation of the estimate (light blue ribbon)), relative to the prior (dark green); middle: estimated population standard deviation (posterior median; light blue) relative to estimated population mean (blue line); right: estimated proportion of pāua stock not growing at each length (black points and 95% confidence interval) relative to the prior (green).

B.7 Recruitment and biomass trends

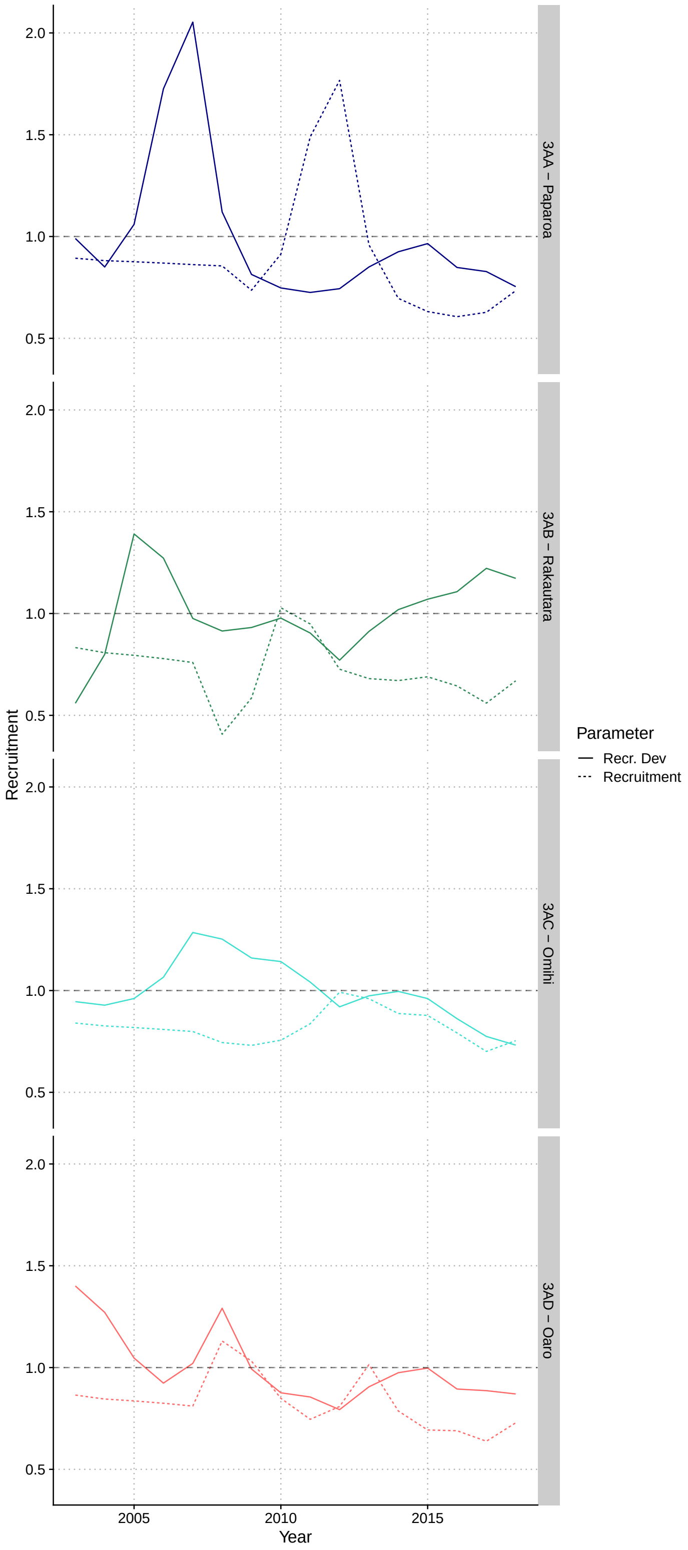

Figure B-12: Posterior mean recruitment for pāua for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A (R_{dev}, recruitment deviation).

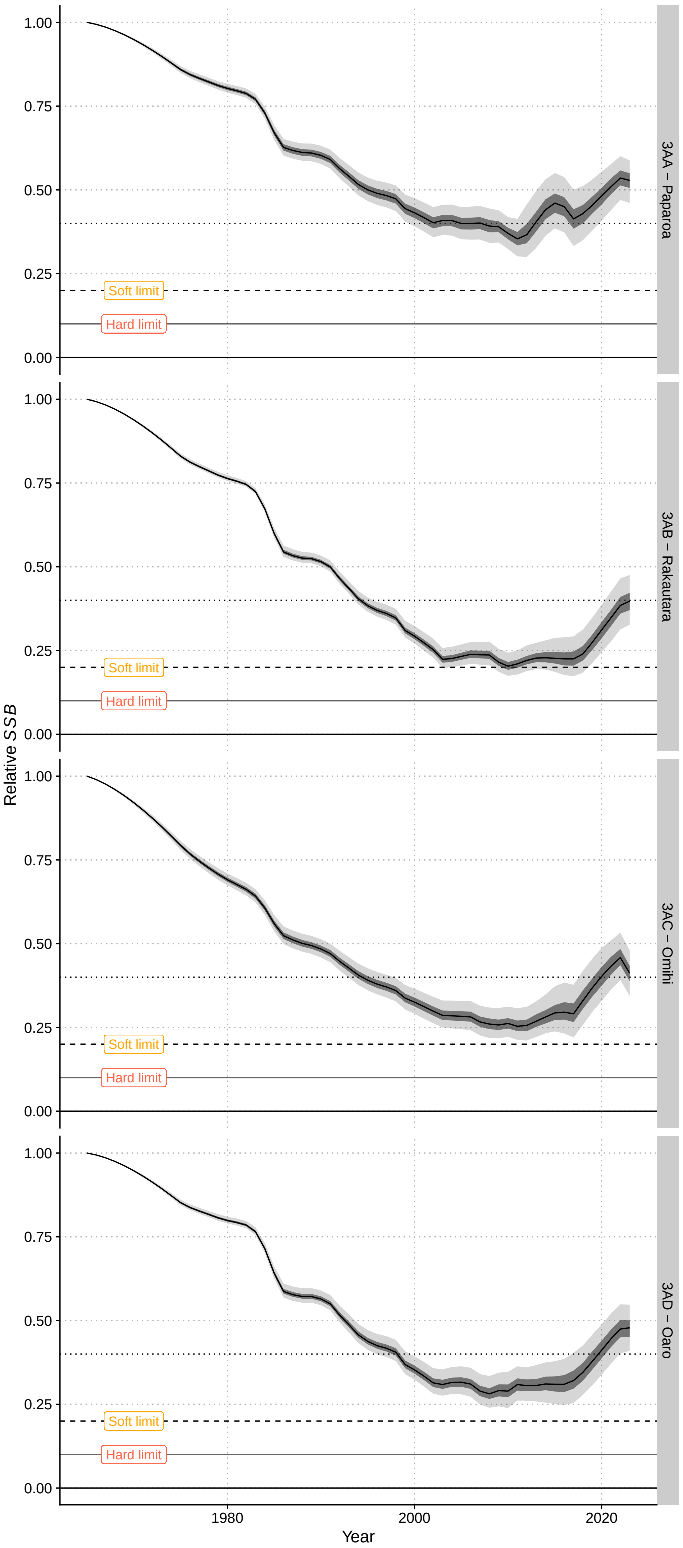

Figure B-13: Estimated relative spawning stock biomass (*SSB*) trend for pāua for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

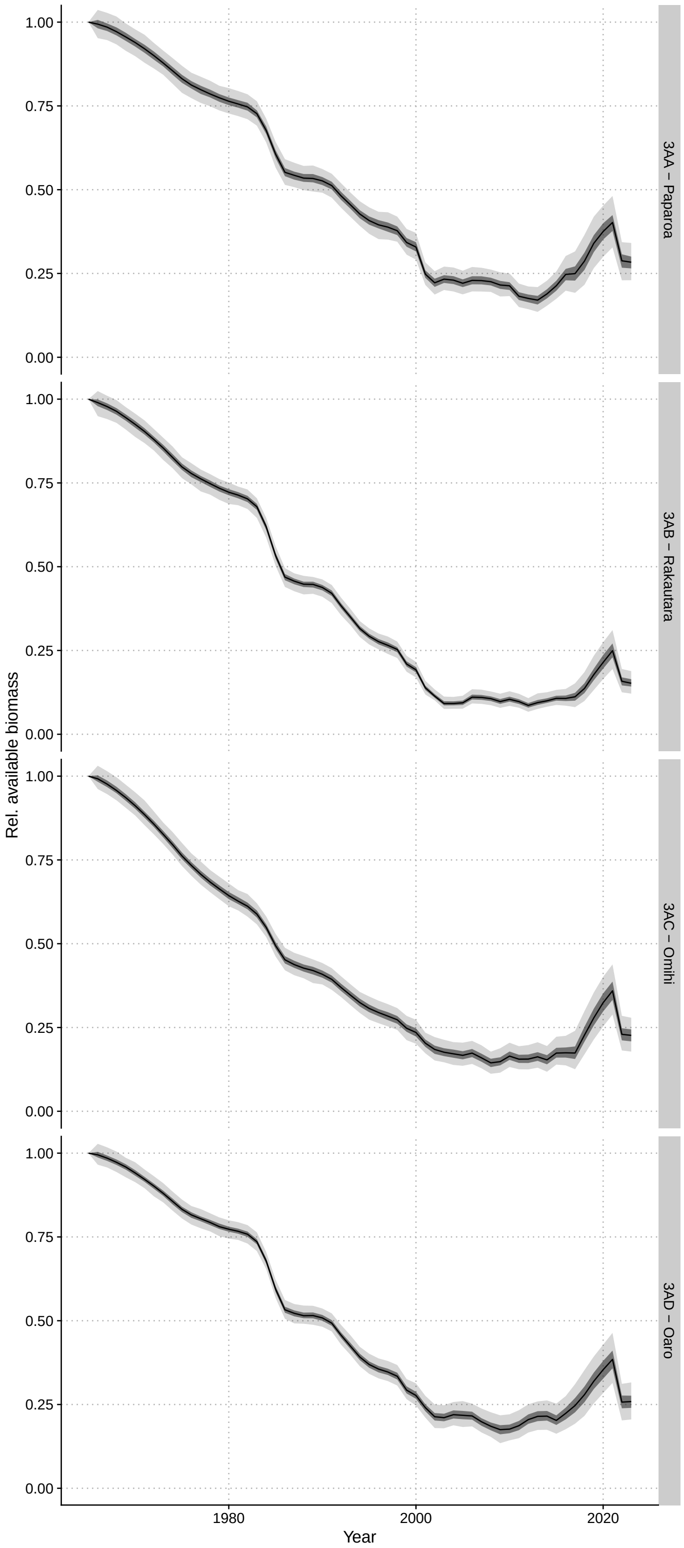

Figure B-14: Estimated relative available biomass trend for pāua for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

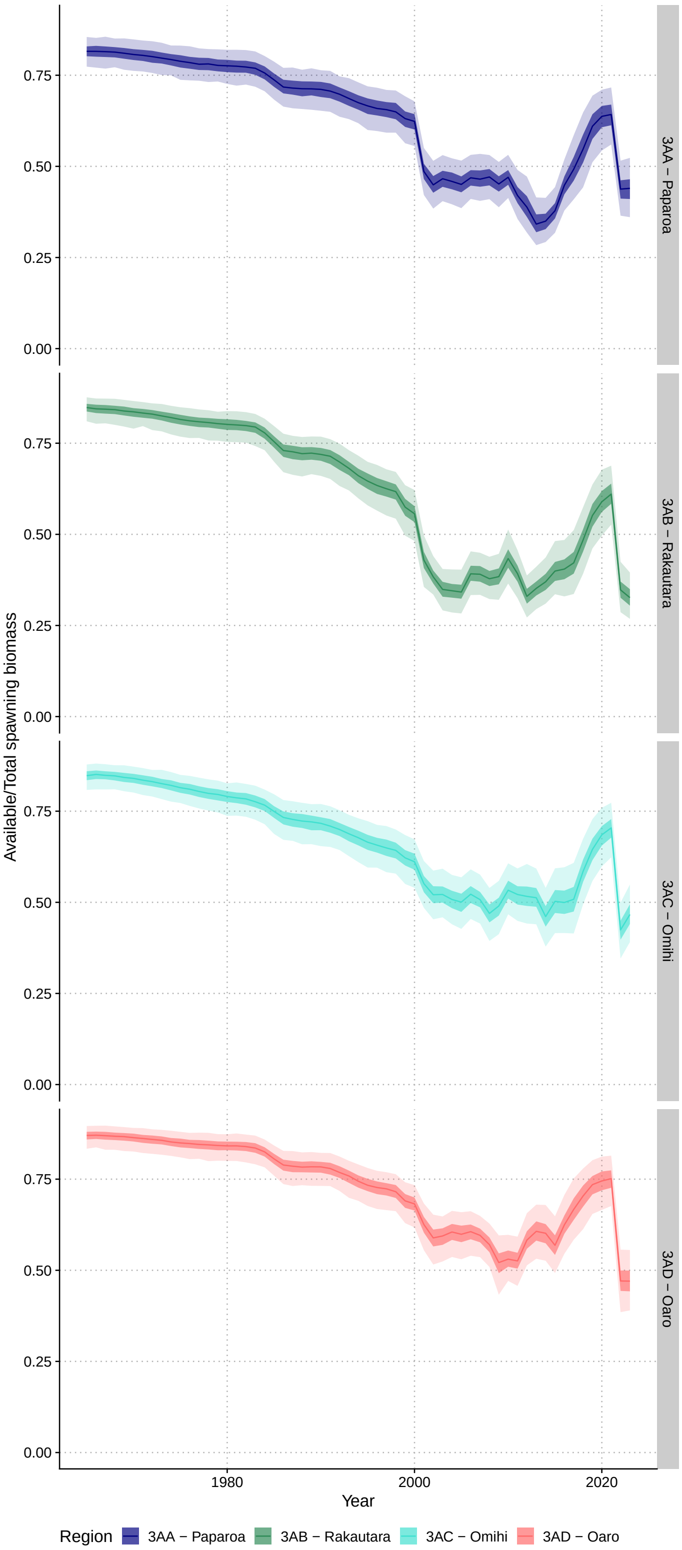

Figure B-15: Estimated relative available pāua biomass (relative to spawning stock) for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)).

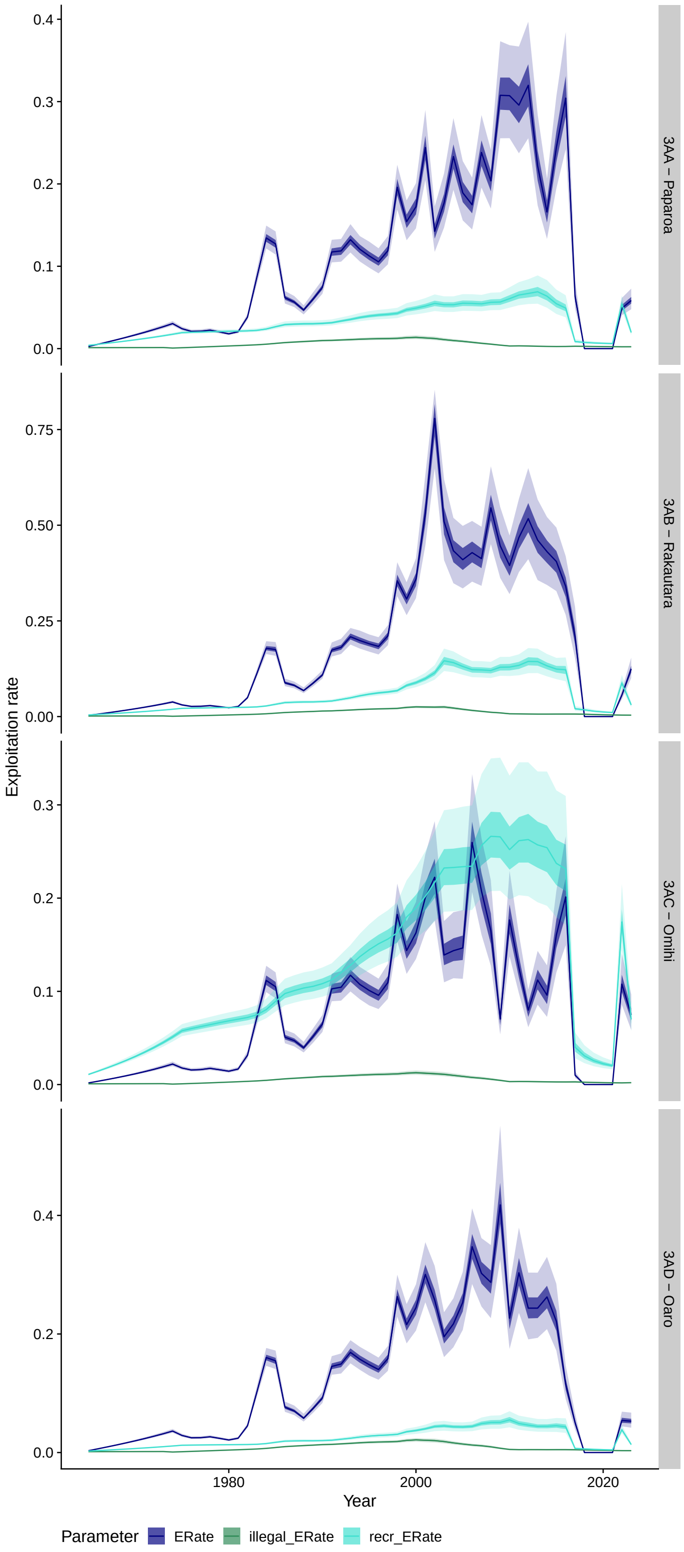

Figure B-16: Estimated exploitation rates for commercial (ERate), illegal and recreational (recr.) catch components (median line, inter-quartile range (dark shaded area) and 95% confidence interval (lighter shading)) for the base-case assessment model, fitted to survey and fishery observations in Quota Management Area PAU 3A.

APPENDIX C: ASSESSMENT MODEL COMPARISON: CSLF WEIGHT

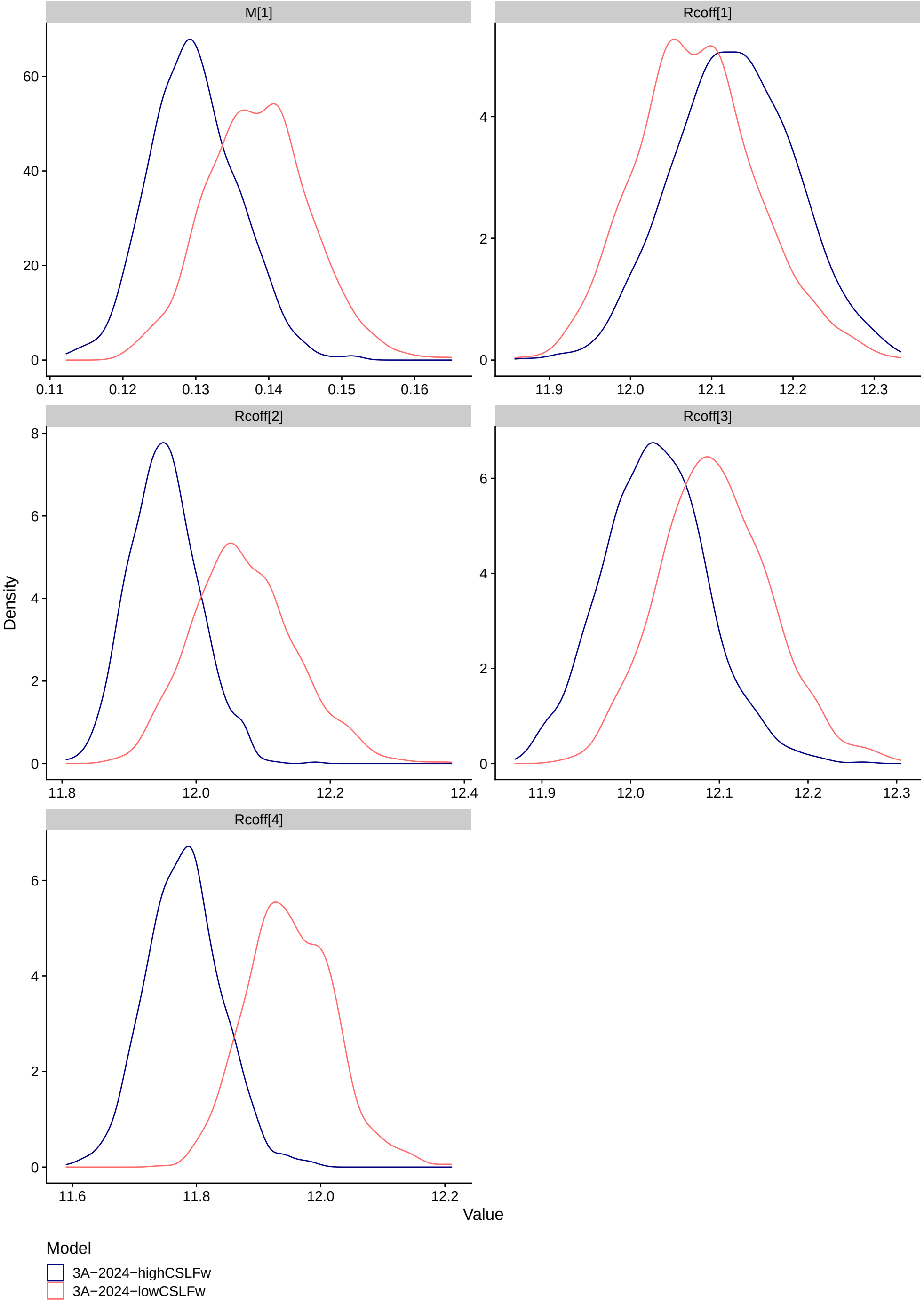

Figure C-1: Comparison of posterior densities for parameters for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

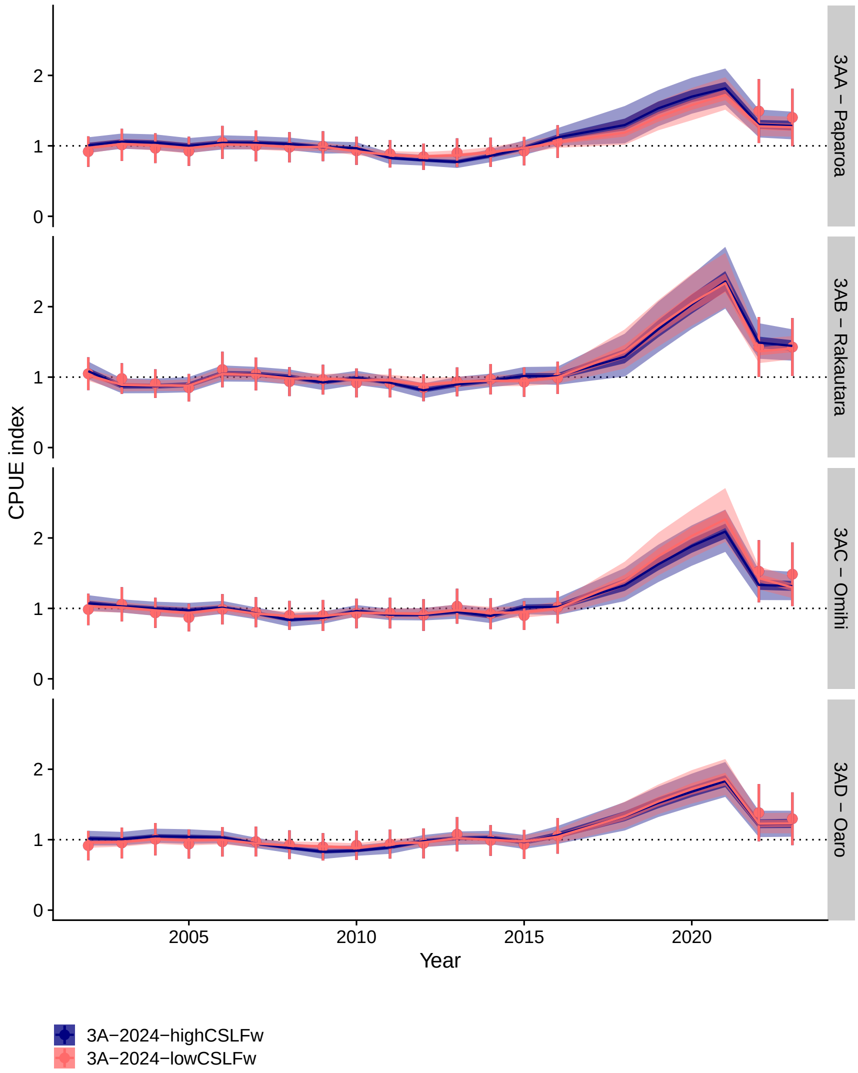

Figure C-2: Comparison of posterior median predicted catch-per-unit-effort (CPUE) for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

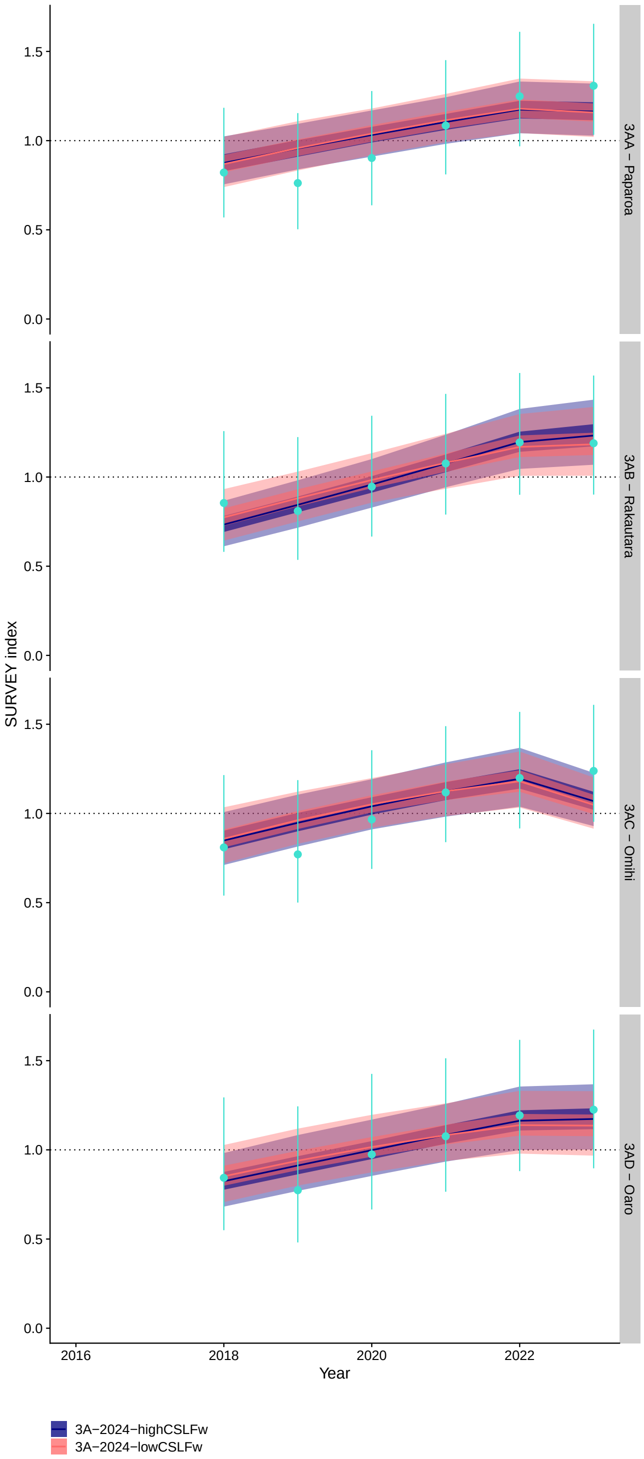

Figure C-3: Comparison of posterior median (line) model-predicted survey index with the estimated survey index and observation error for the models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A (points and error bars).

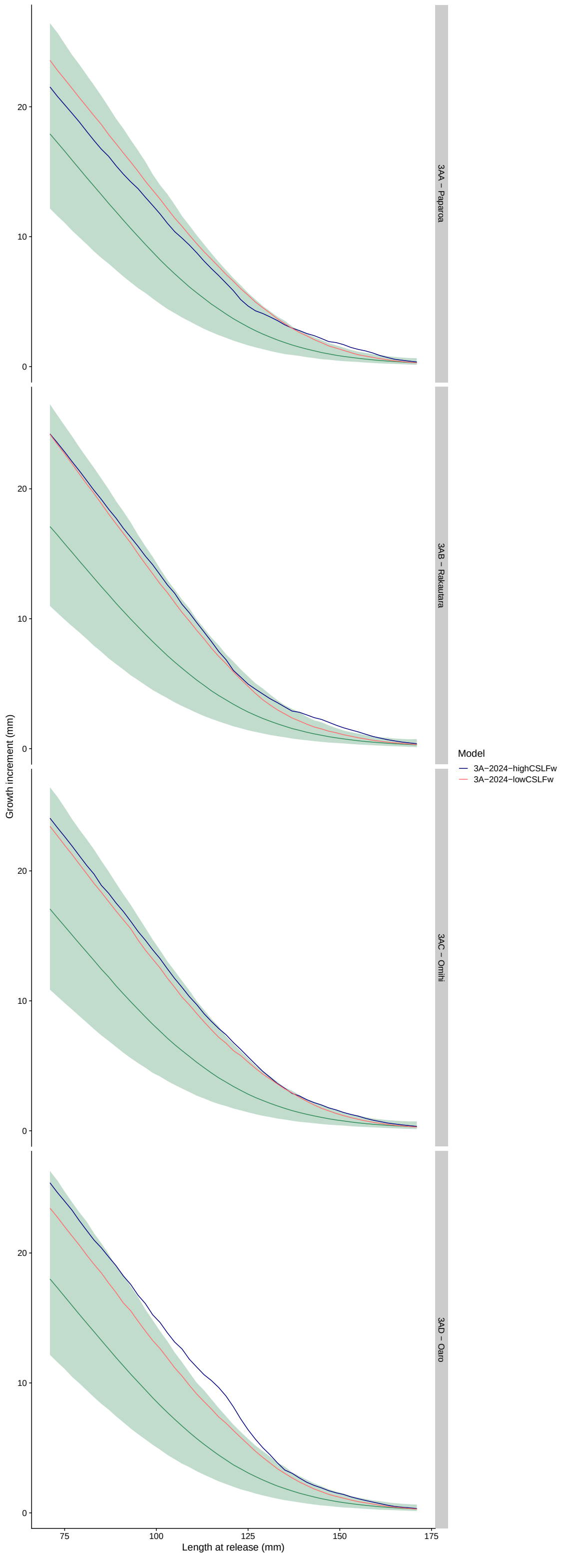

Figure C-4: Comparison of prior and median posterior growth for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A. Prior for population mean growth (prior mean, green line; 95% prior interval, green shading), and posterior mean growth.

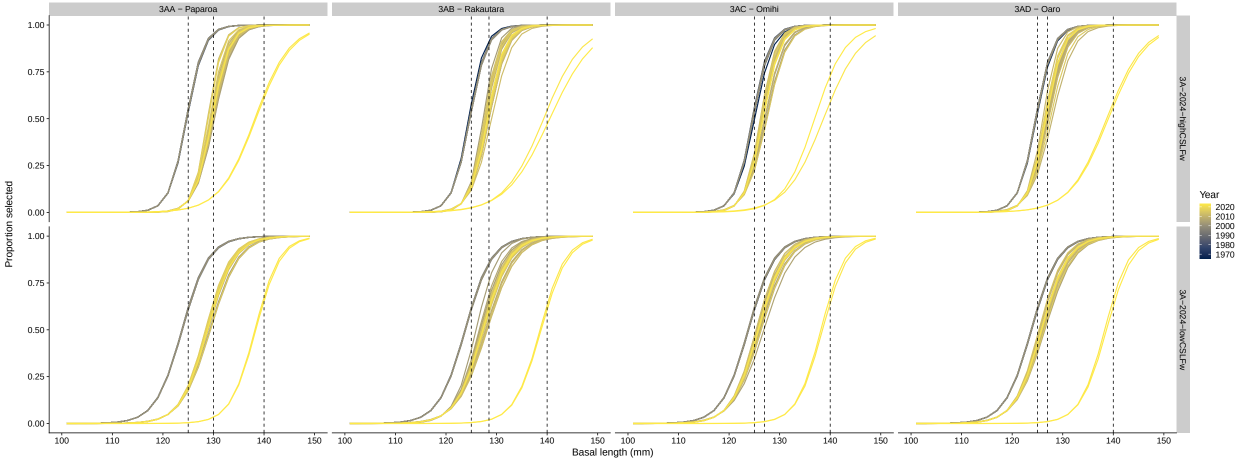

Figure C-5: Comparison of posterior mean selectivity-at-length for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

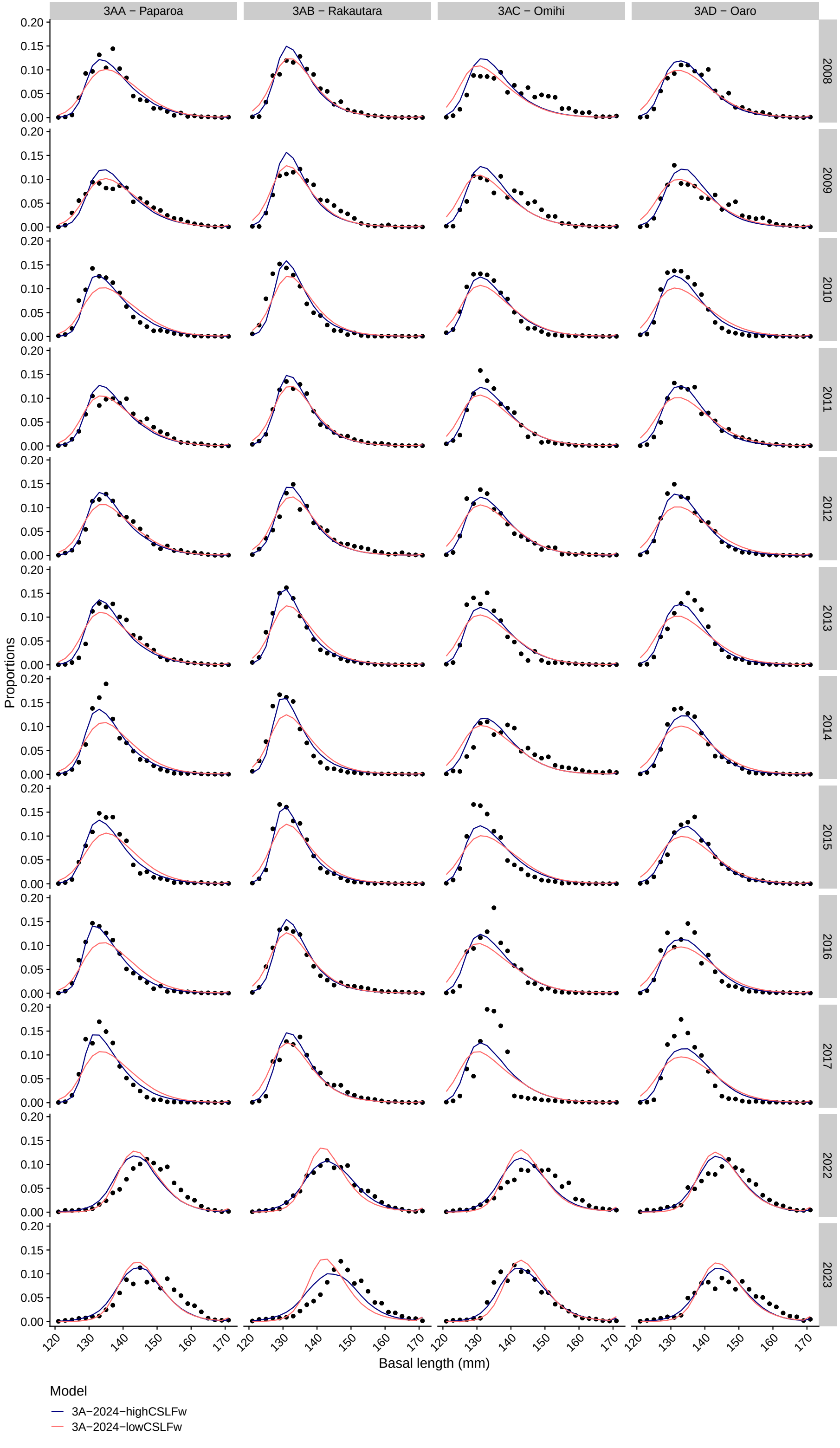

Figure C-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions, for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for quota management area PAU 3A.

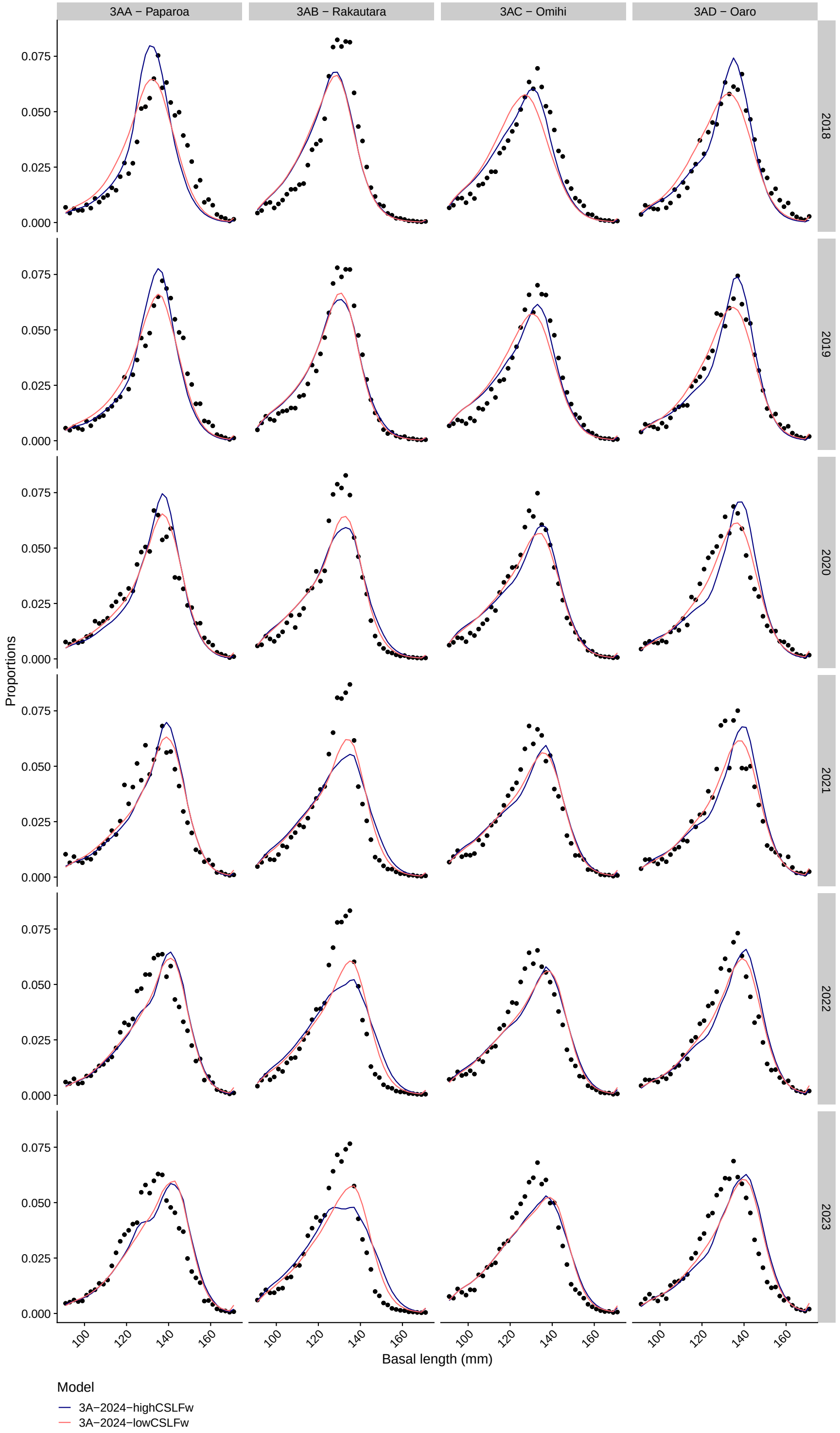

Figure C-7: Comparison of posterior mean predicted survey length frequency with estimated proportions and observation error for the models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

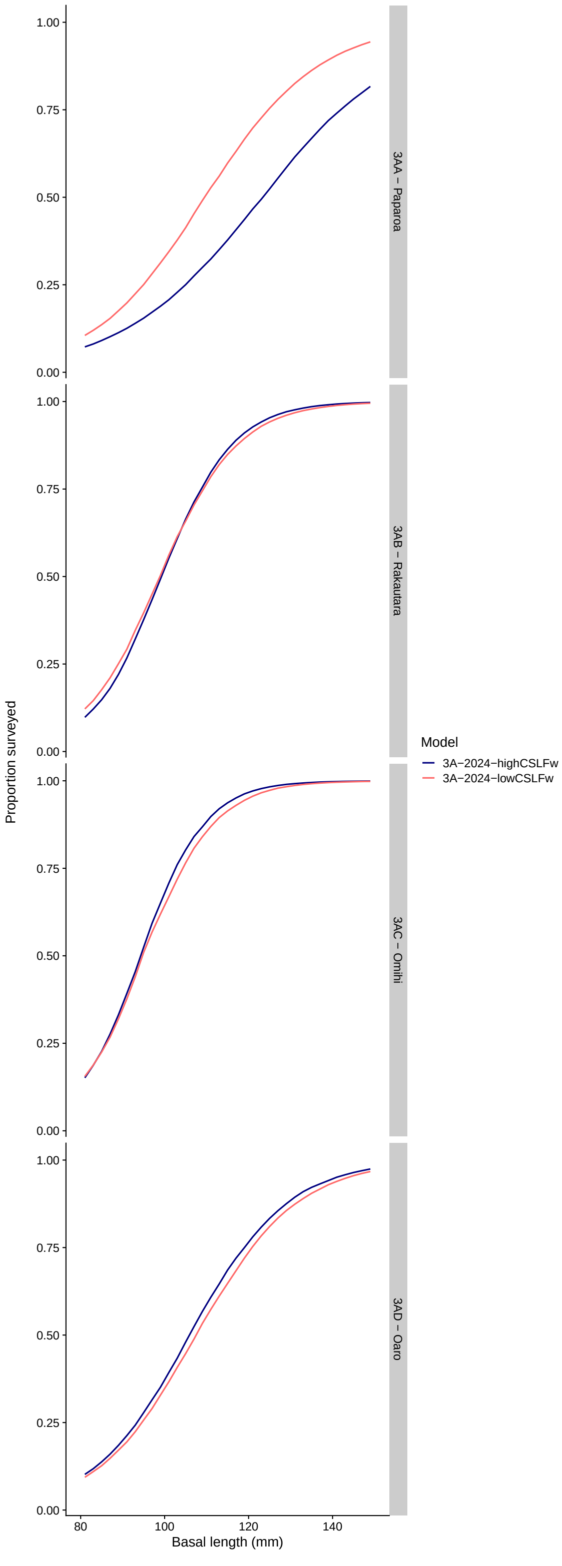

Figure C-8: Estimated survey selectivity (posterior mean) for pāua for the models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

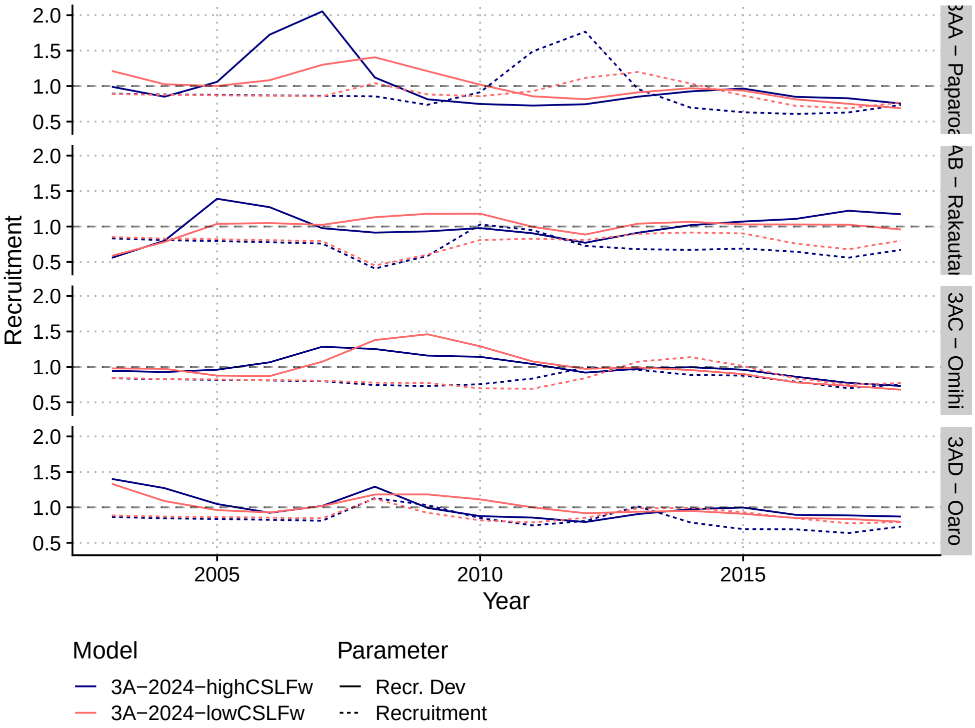

Figure C-9: Comparison of posterior mean recruitment deviations (*Rdev*) for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

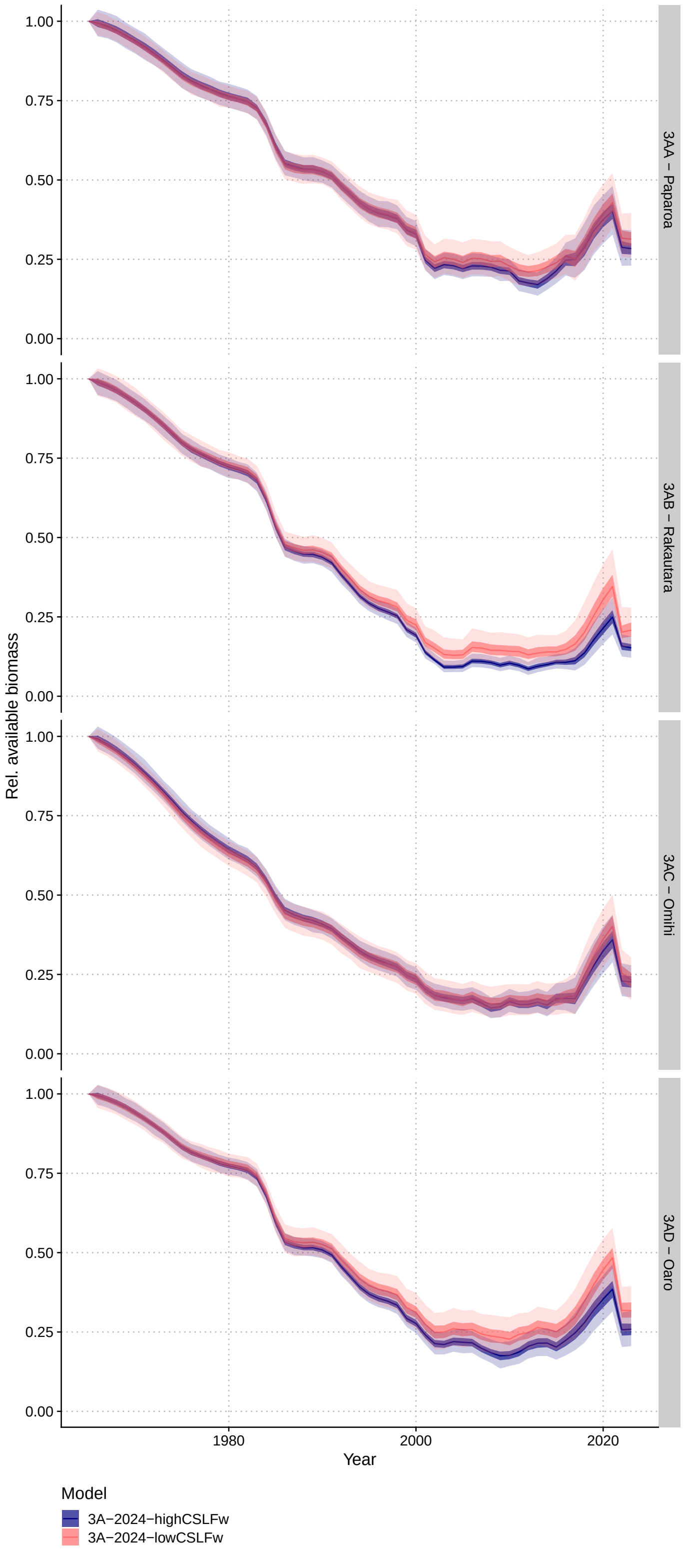

Figure C-10: Comparison of posterior median predicted relative available biomass trend for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

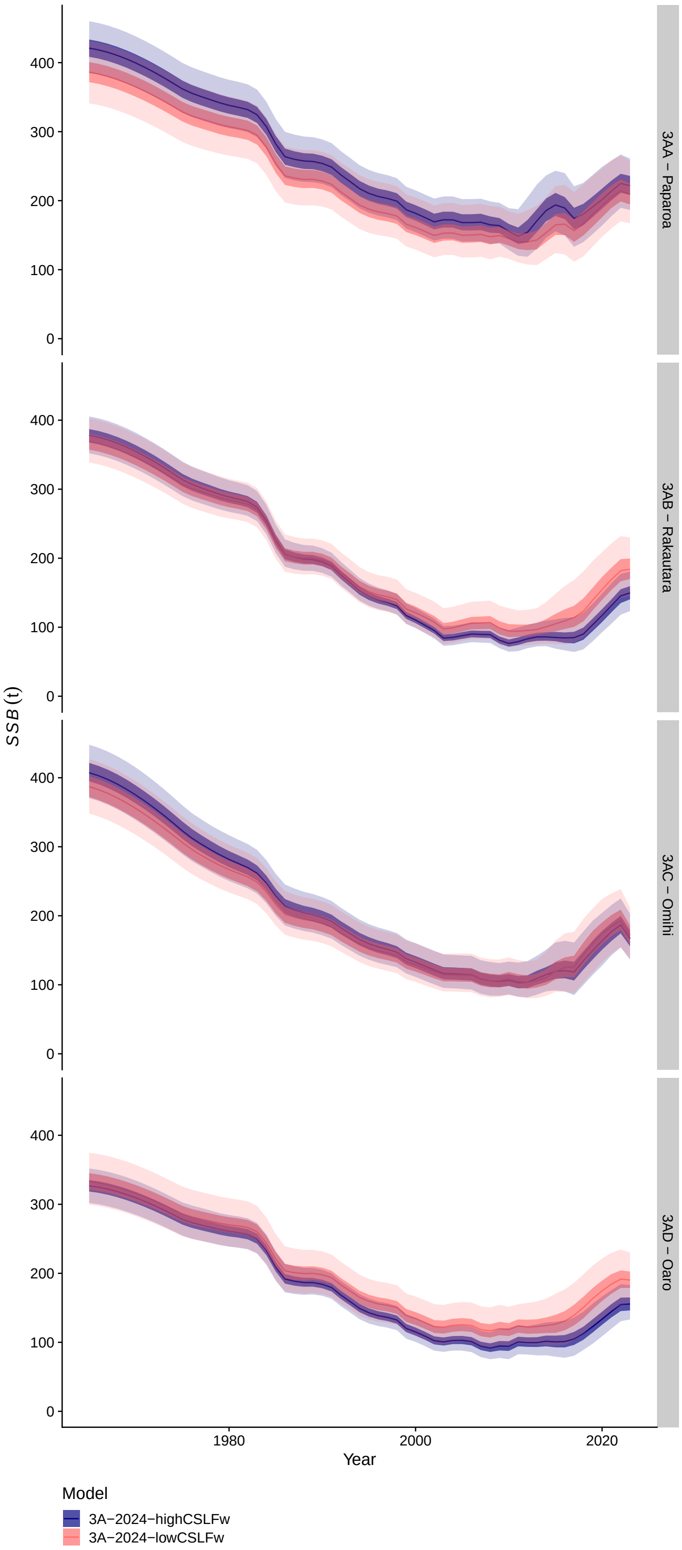

Figure C-11: Comparison of posterior median predicted spawning stock biomass (*SSB*) trend for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

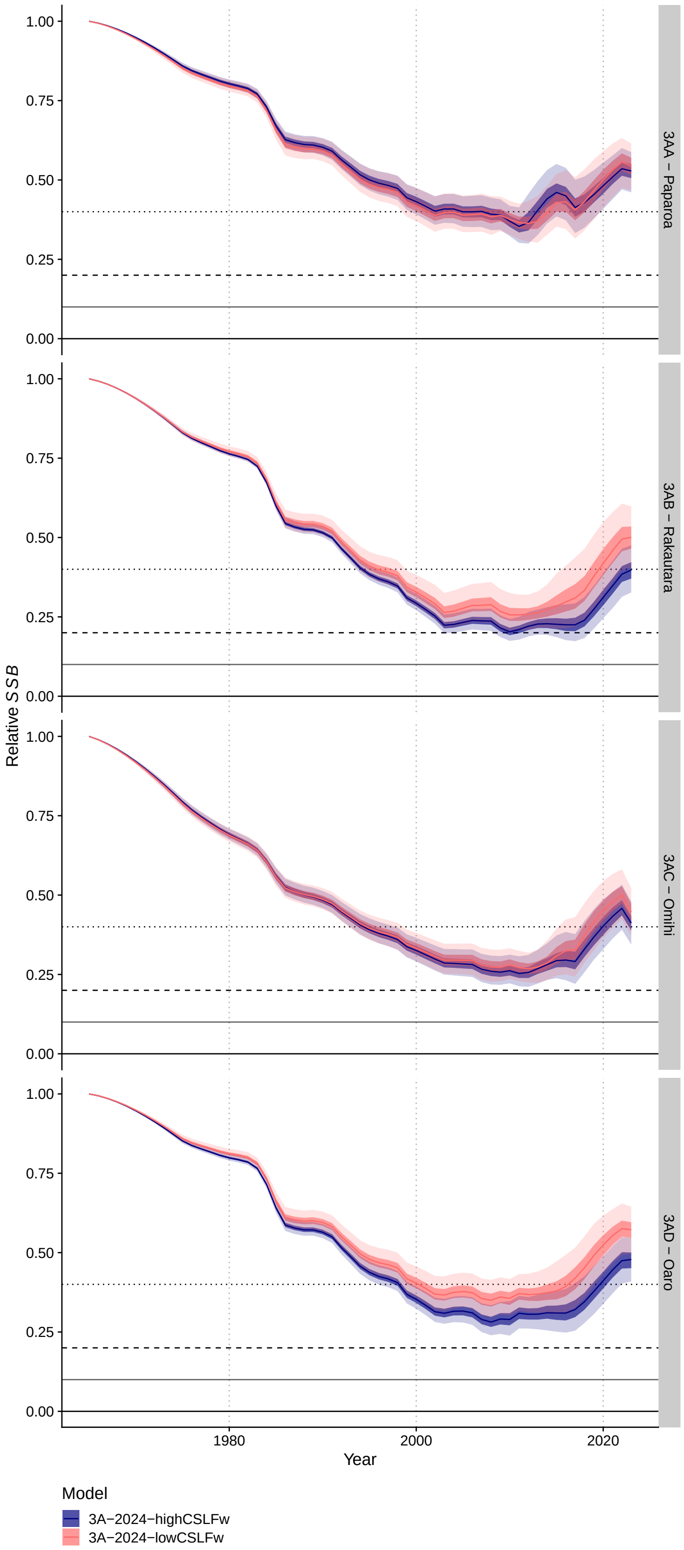

Figure C-12: Comparison of posterior median predicted relative spawning stock biomass (*SSB*) trend for models with alternative (high and low) weight for catch sampling length frequency (CSLF) used in the stock assessment for Quota Management Area PAU 3A.

APPENDIX D: ASSESSMENT MODEL COMPARISON: EARTHQUAKE IMPACT ASSUMPTIONS

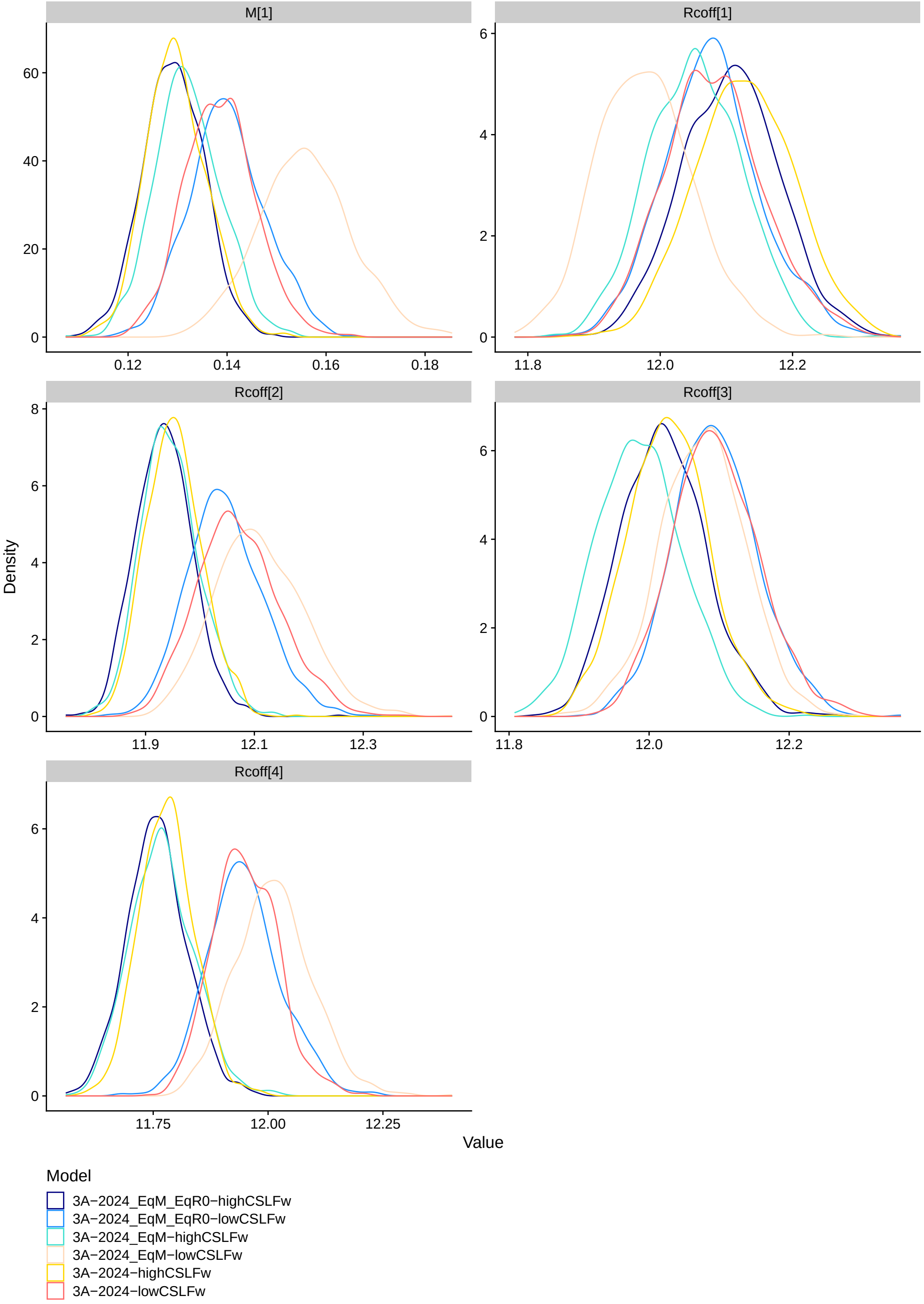

Figure D-1: Comparison of posterior densities for parameters for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

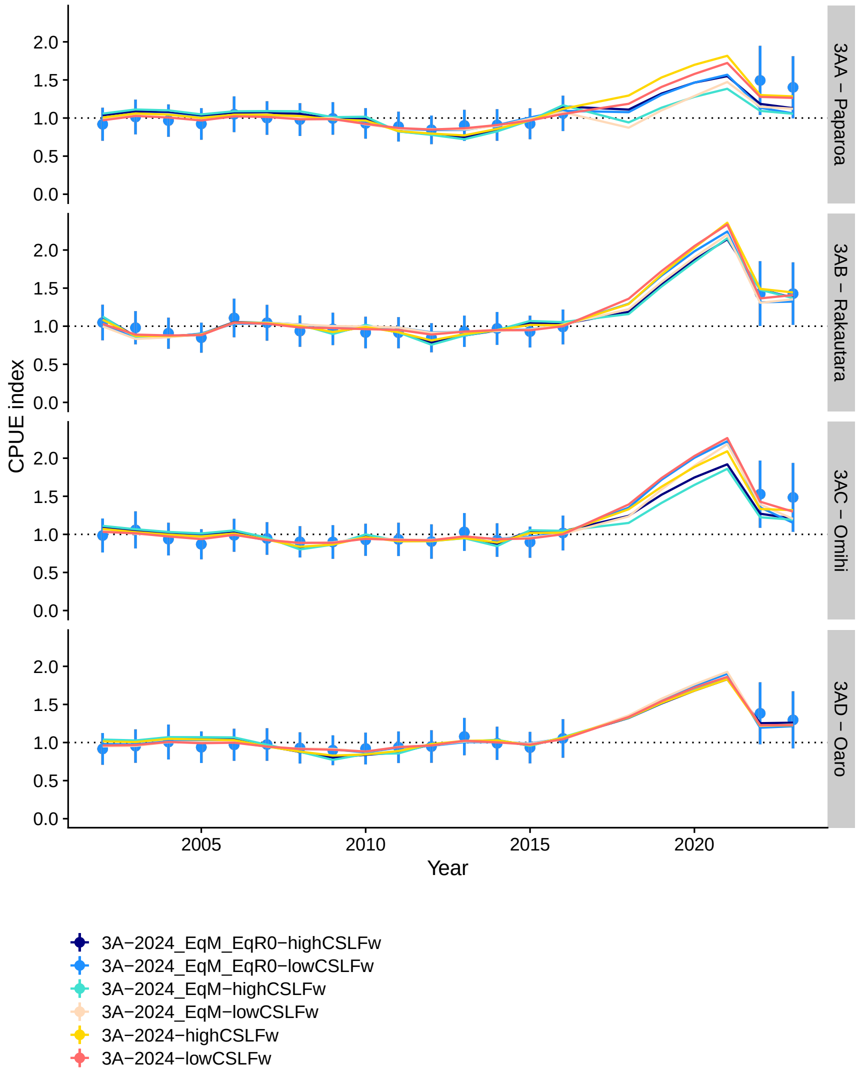

Figure D-2: Comparison of posterior median predicted catch-per-unit-effort (CPUE) for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

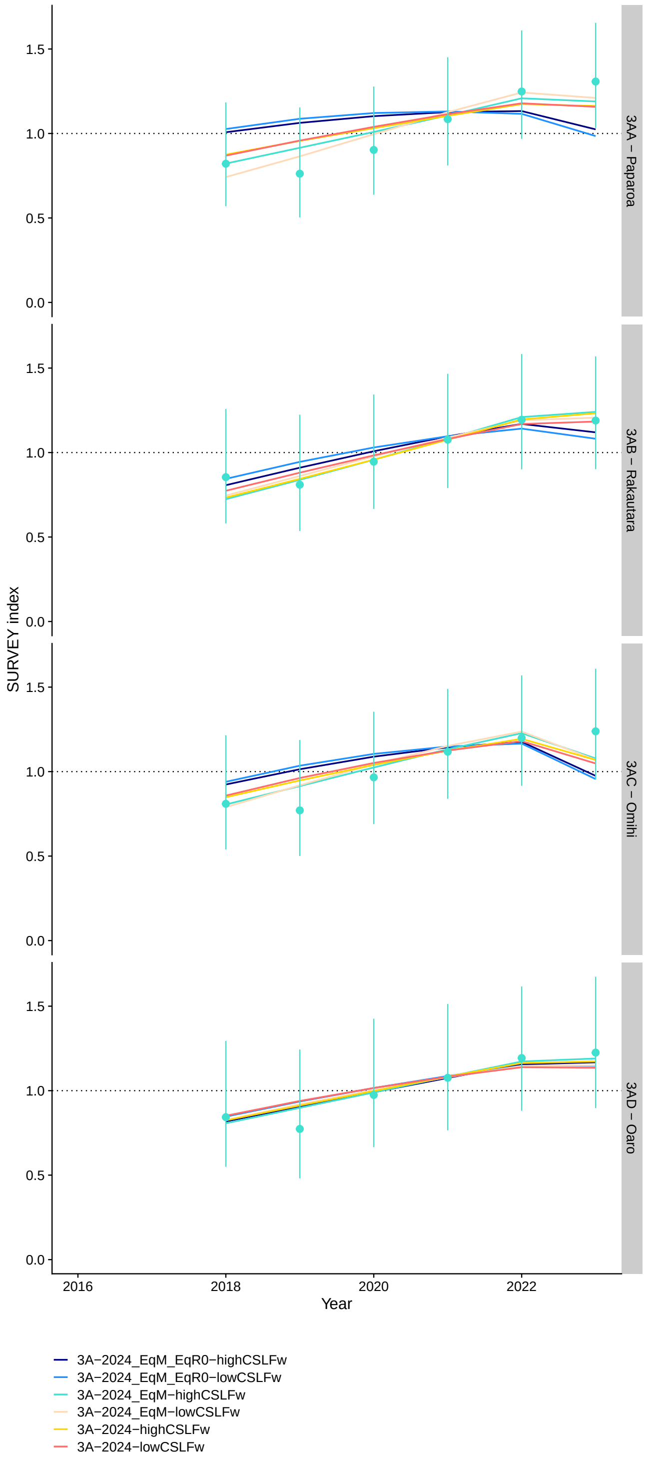

Figure D-3: Comparison of posterior median (line) model-predicted survey index with the estimated survey index and observation error for the models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A (points and error bars).

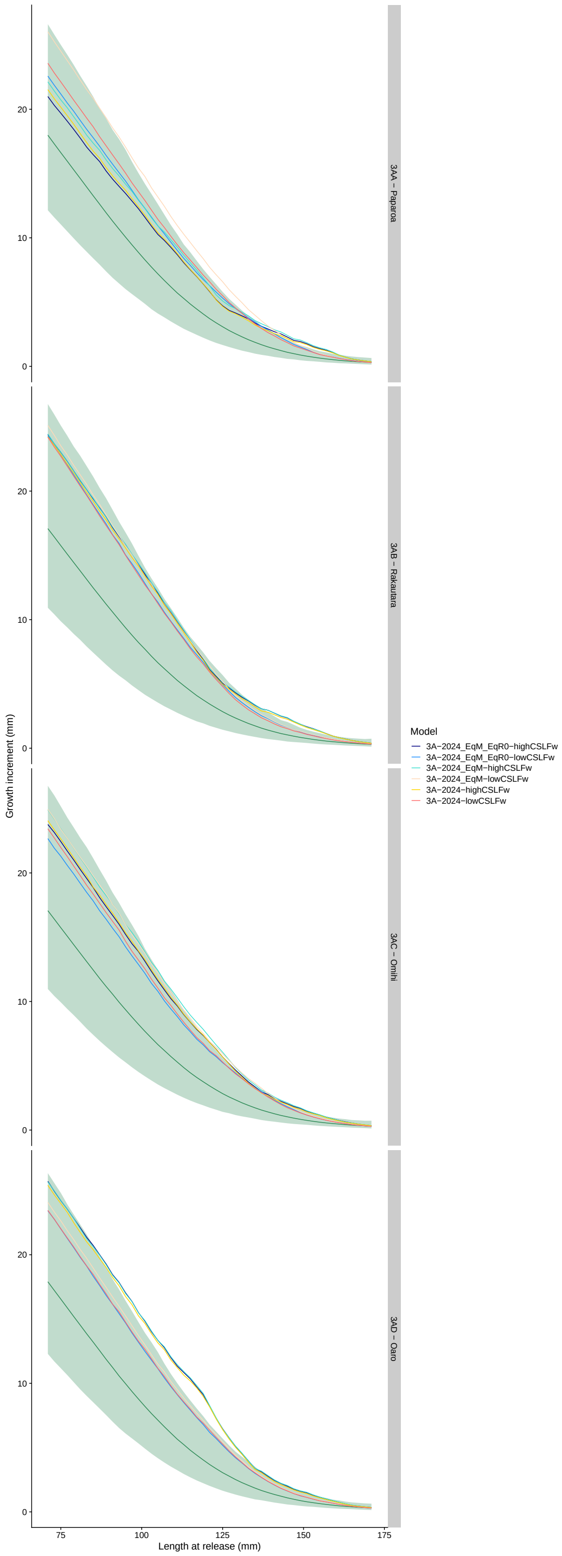

Figure D-4: Comparison of prior and median posterior growth for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A. Prior for population mean growth (prior mean, green line; 95% prior interval, green shading), and posterior mean growth.

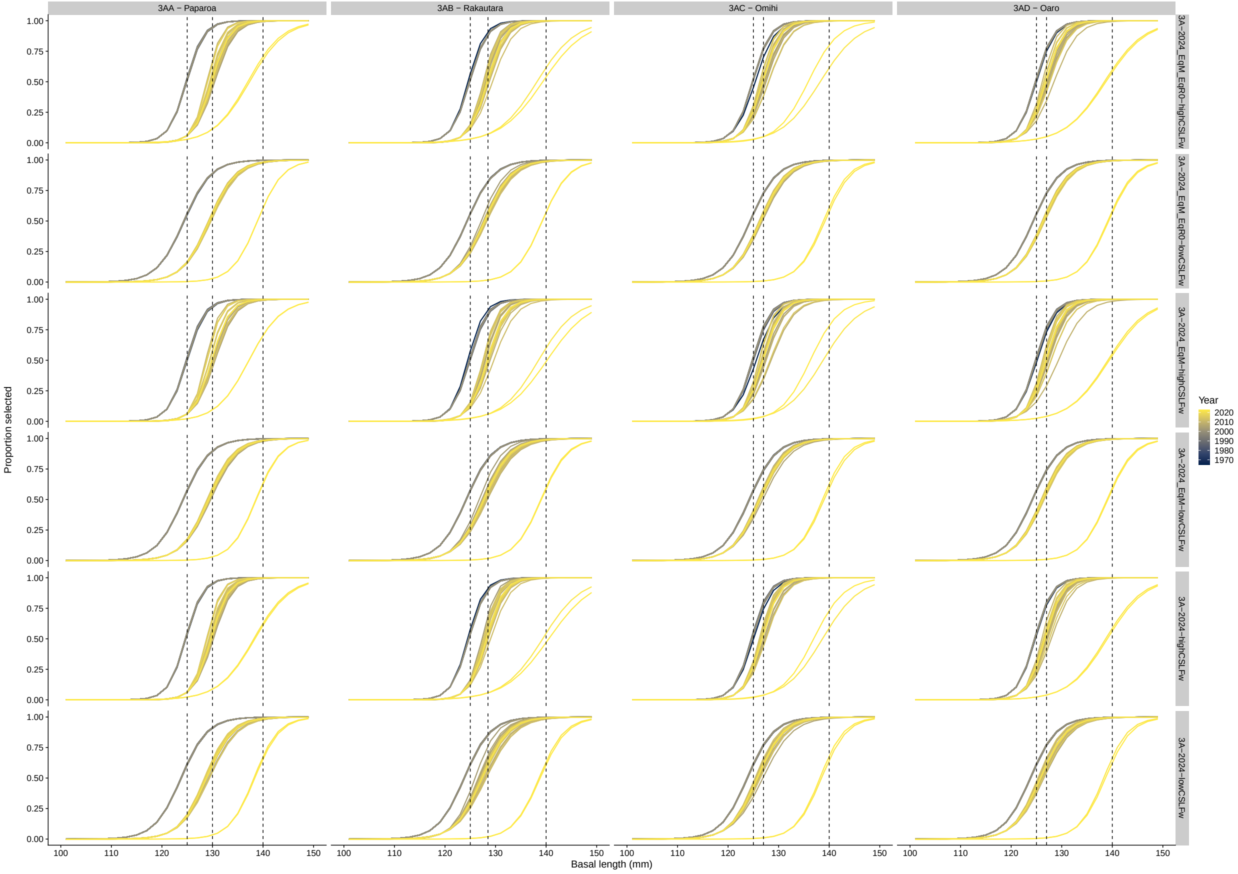

Figure D-5: Comparison of posterior mean selectivity-at-length for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

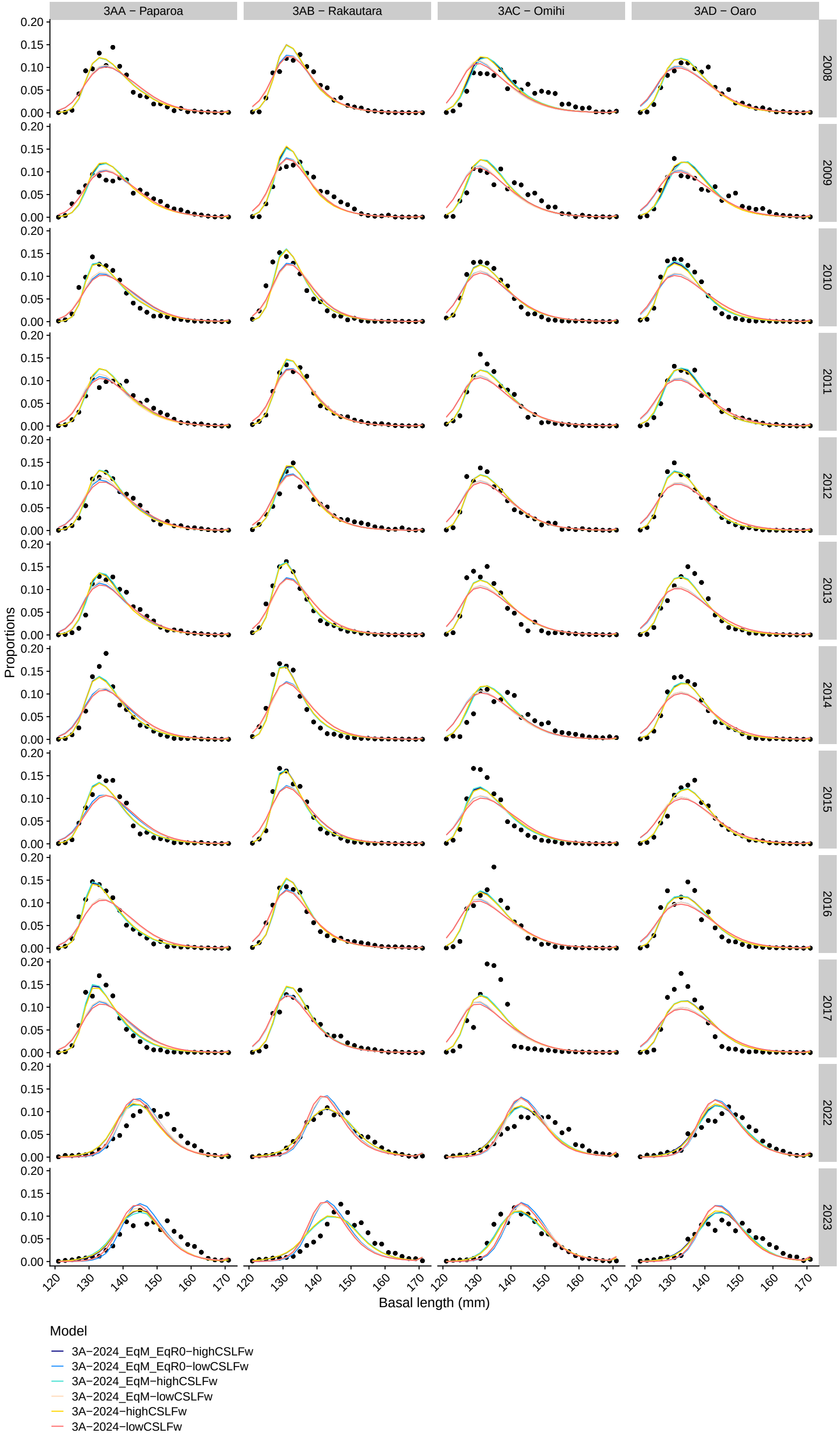

Figure D-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions, for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for quota management area PAU 3A.

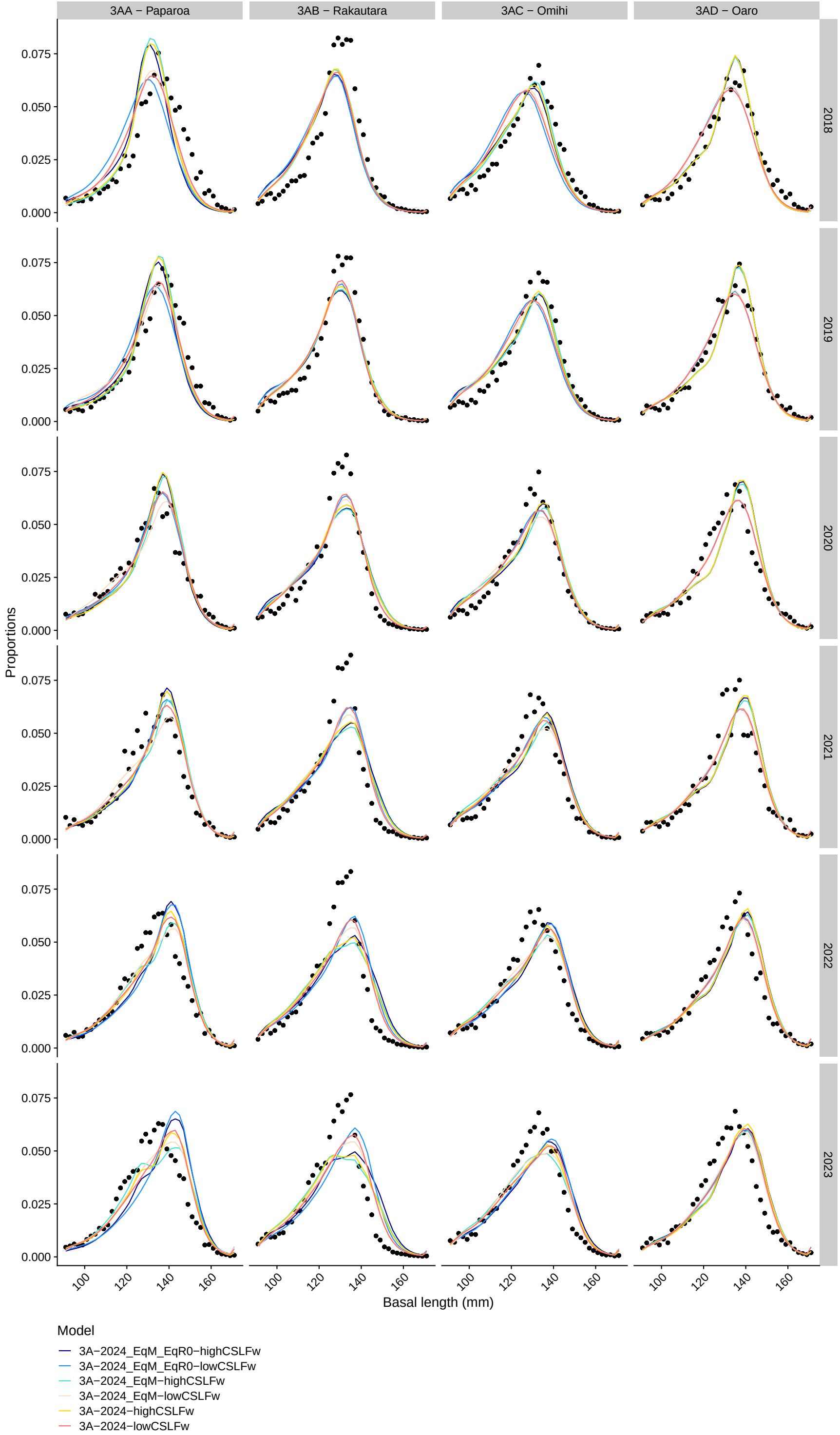

Figure D-7: Comparison of posterior mean predicted survey length frequency with estimated proportions and observation error for the models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

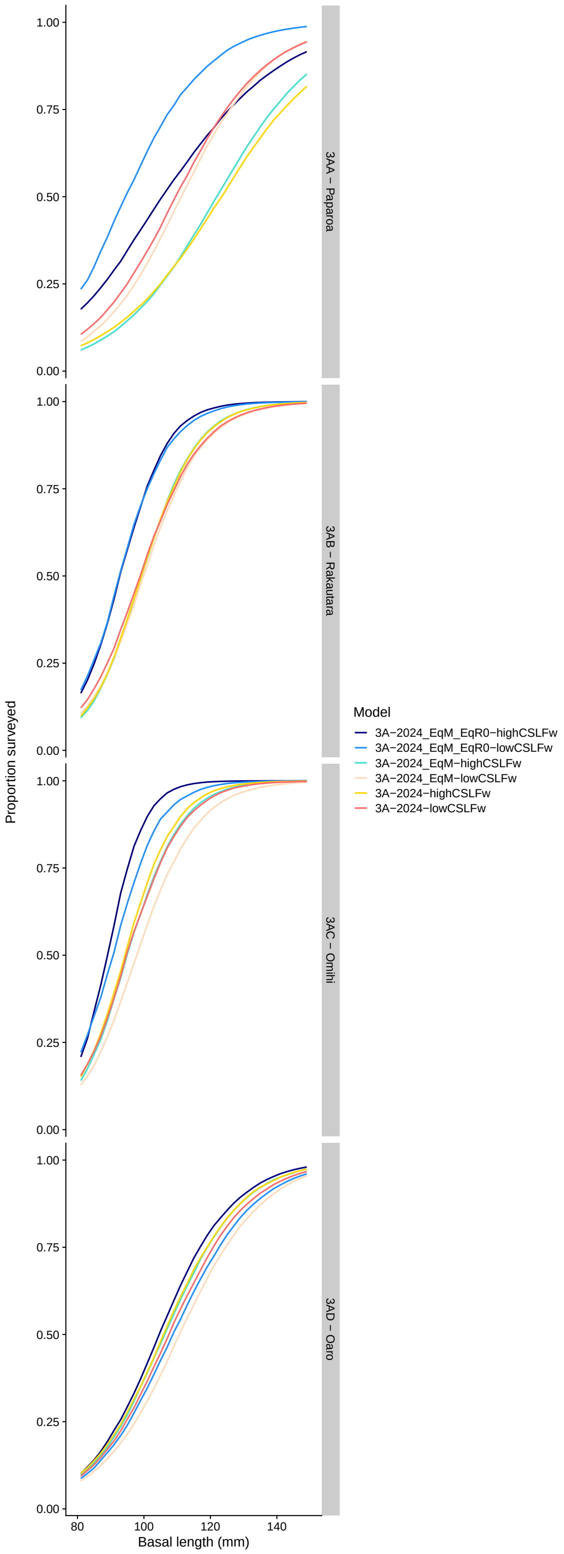

Figure D-8: Estimated survey selectivity (posterior mean) for pāua for the models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

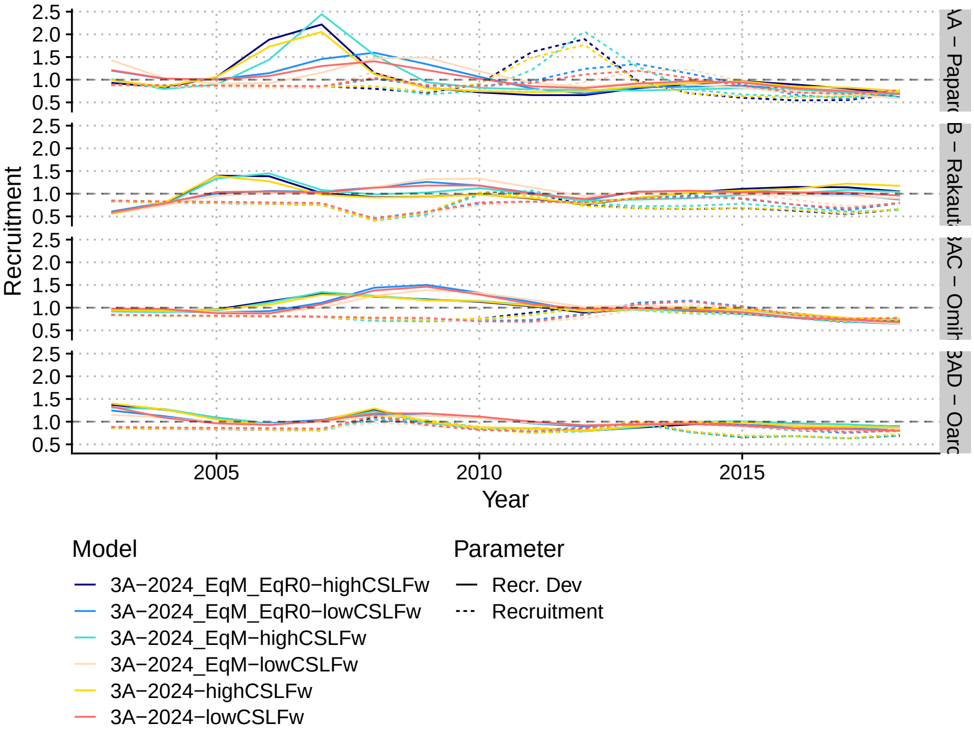

Figure D-9: Comparison of posterior mean recruitment deviations (*Rdev*) for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

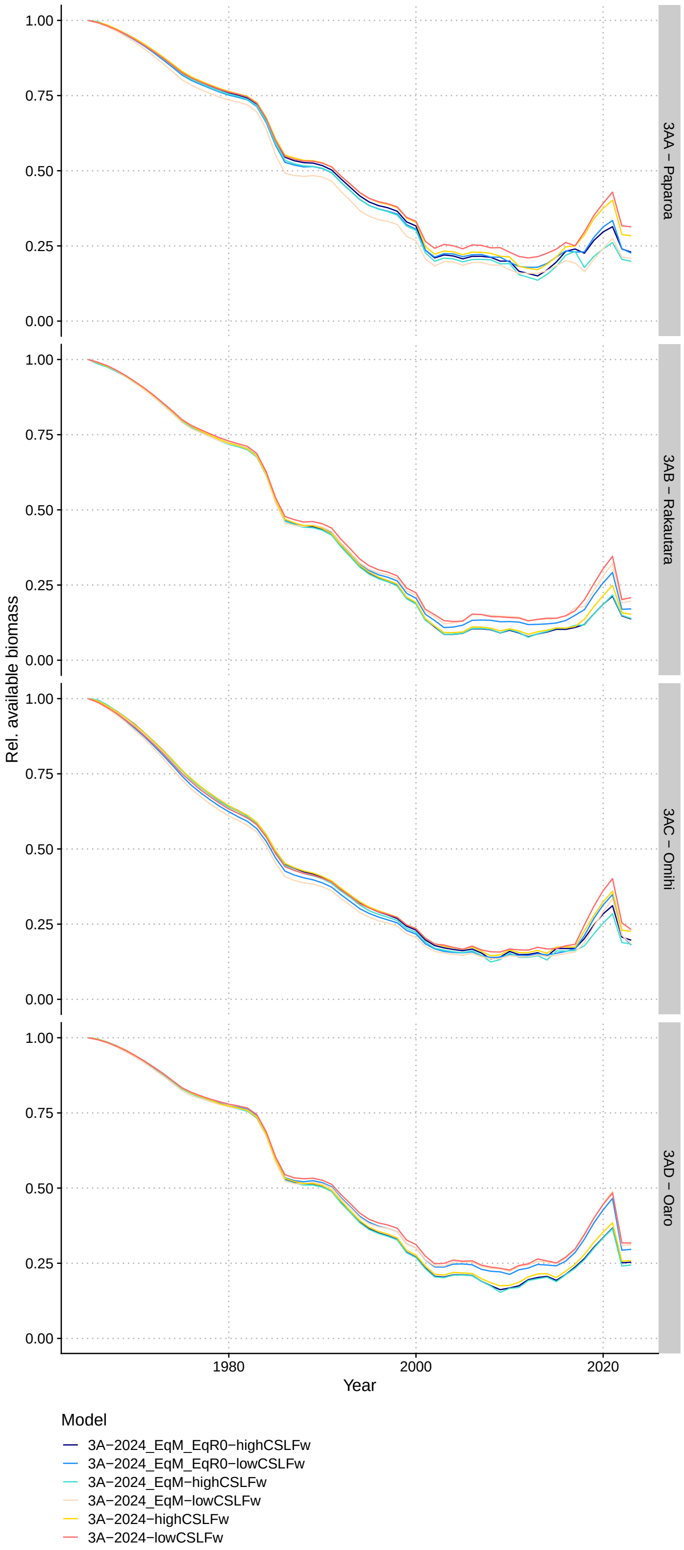

Figure D-10: Comparison of posterior median predicted relative available biomass trend for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

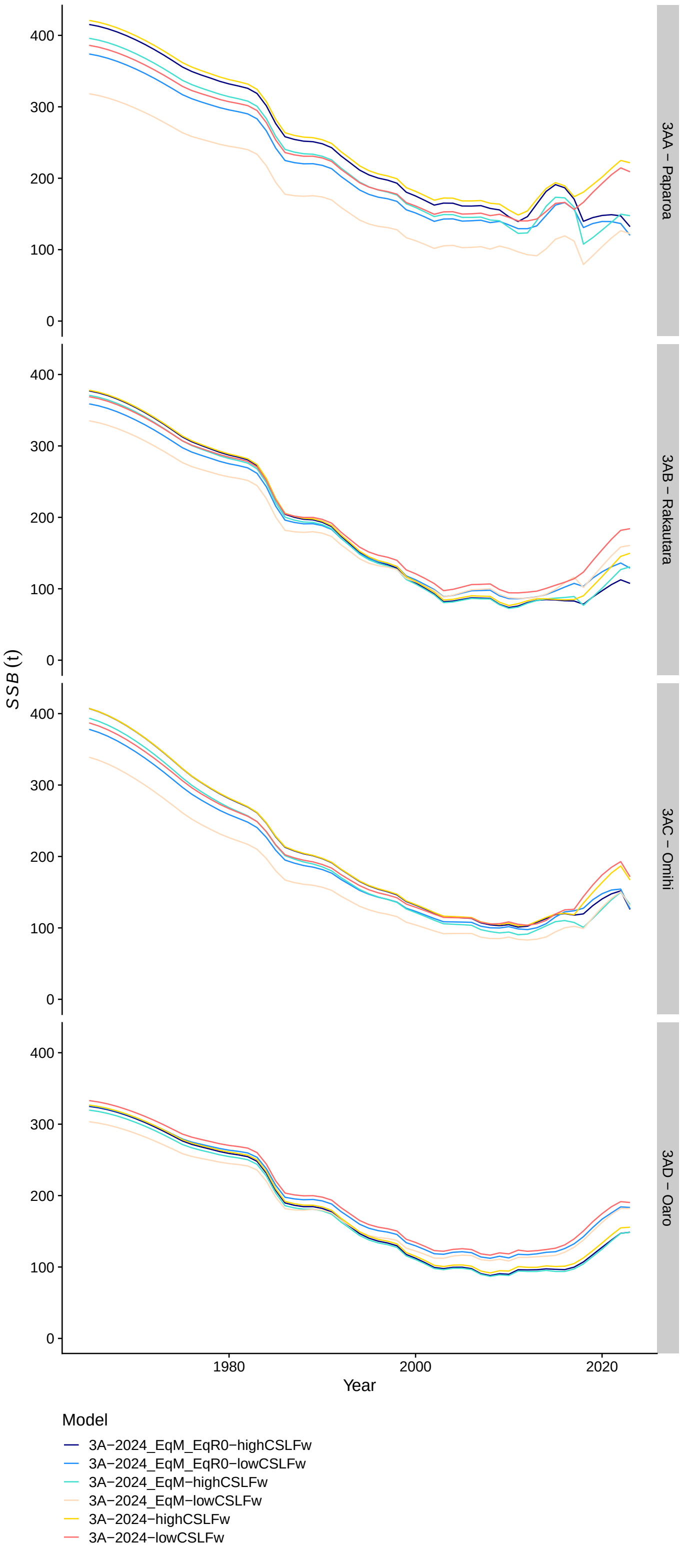

Figure D-11: Comparison of posterior median predicted spawning stock biomass (*SSB*) trend for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

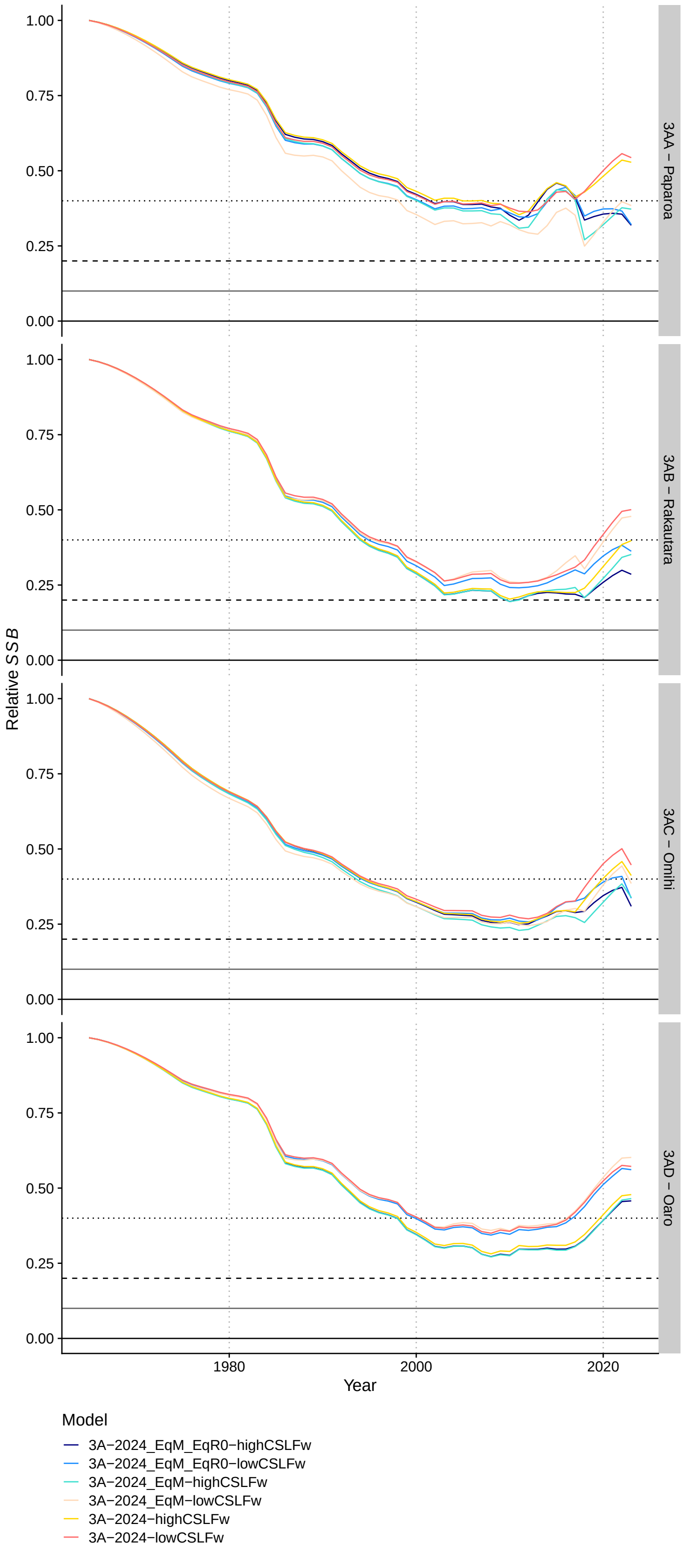

Figure D-12: Comparison of posterior median predicted relative spawning stock biomass (*SSB*) trend for models assuming different levels of model weights for commercial length frequencies (CSLFw, high versus low weight); earthquake impacts (EqM: natural mortality from earthquake scaled with local uplift; EqR0: unfished recruitment reduced by amount of uplift divided by 2), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

APPENDIX E: ASSESSMENT MODEL COMPARISON: NATURAL MORTALITY ASSUMPTIONS

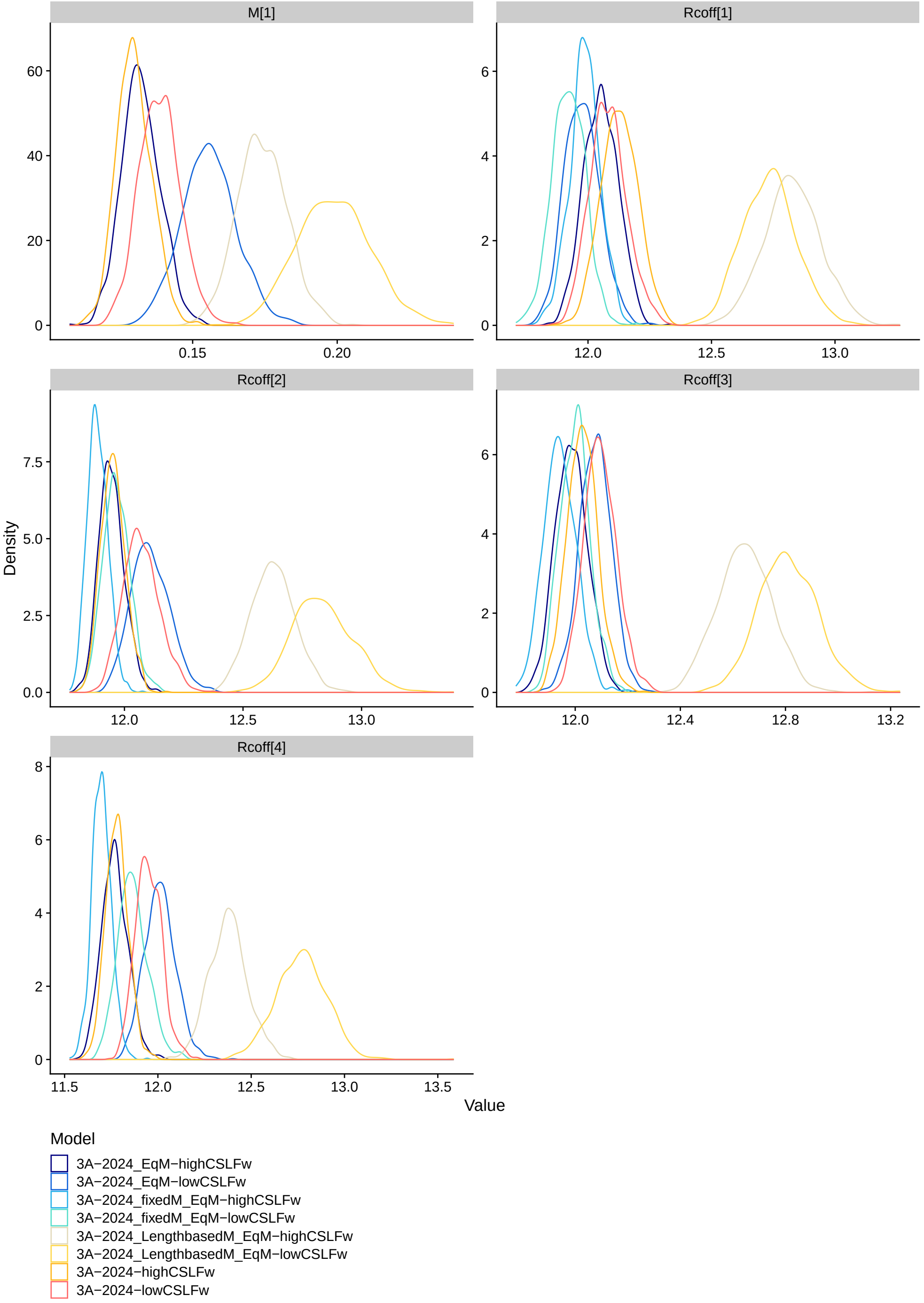

Figure E-1: Comparison of posterior densities for parameters for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

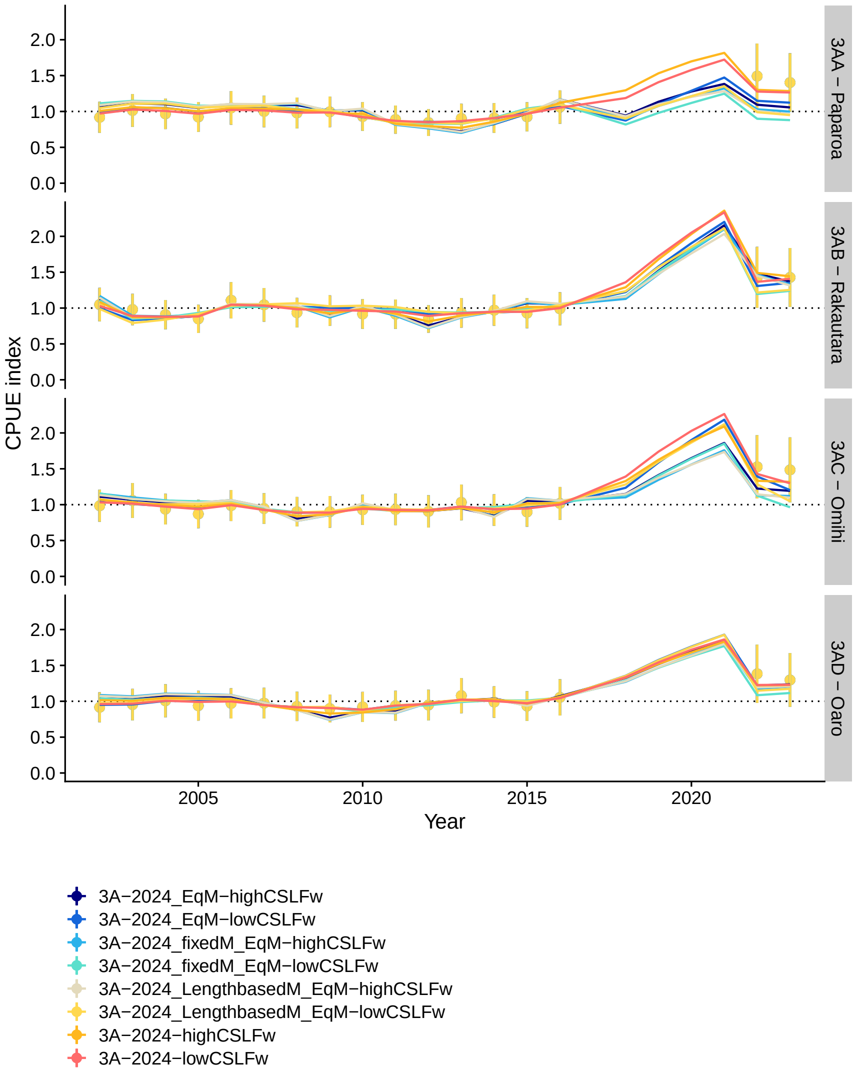

Figure E-2: Comparison of posterior median predicted catch-per-unit-effort (CPUE) for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

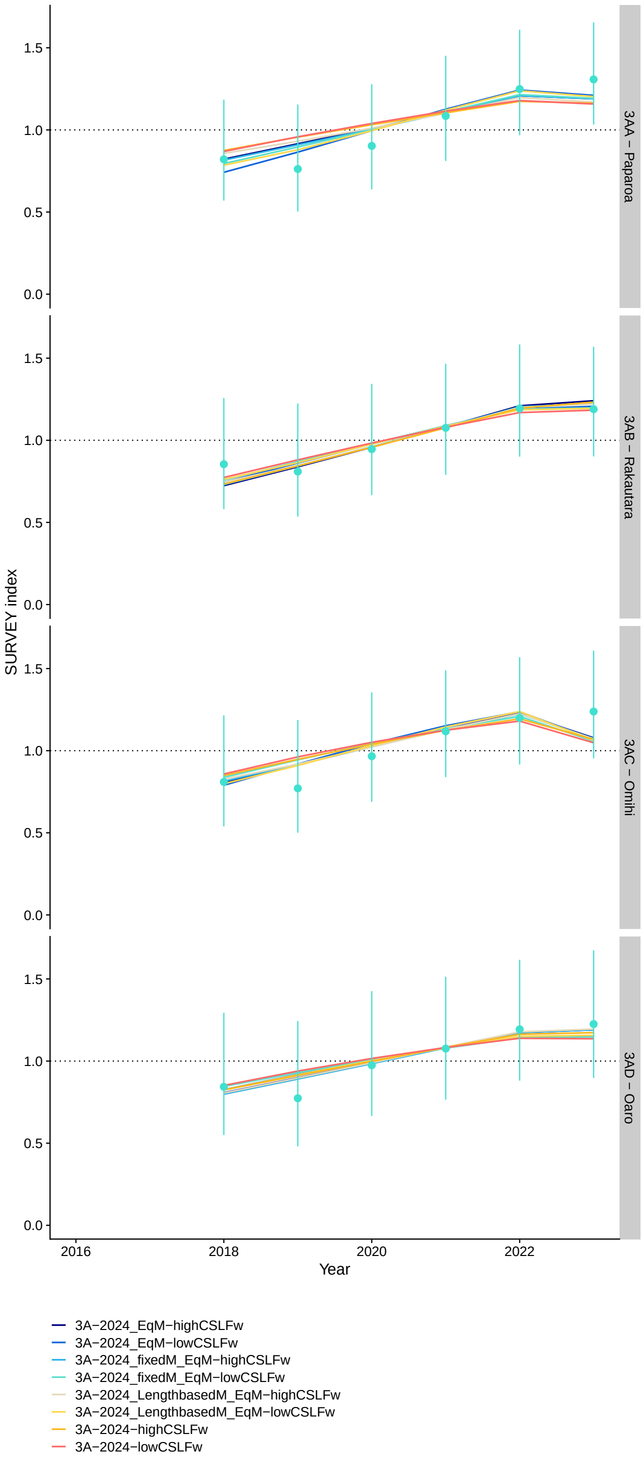

Figure E-3: Comparison of posterior median (line) model-predicted survey index with the estimated survey index and observation error for the models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A (points and error bars).

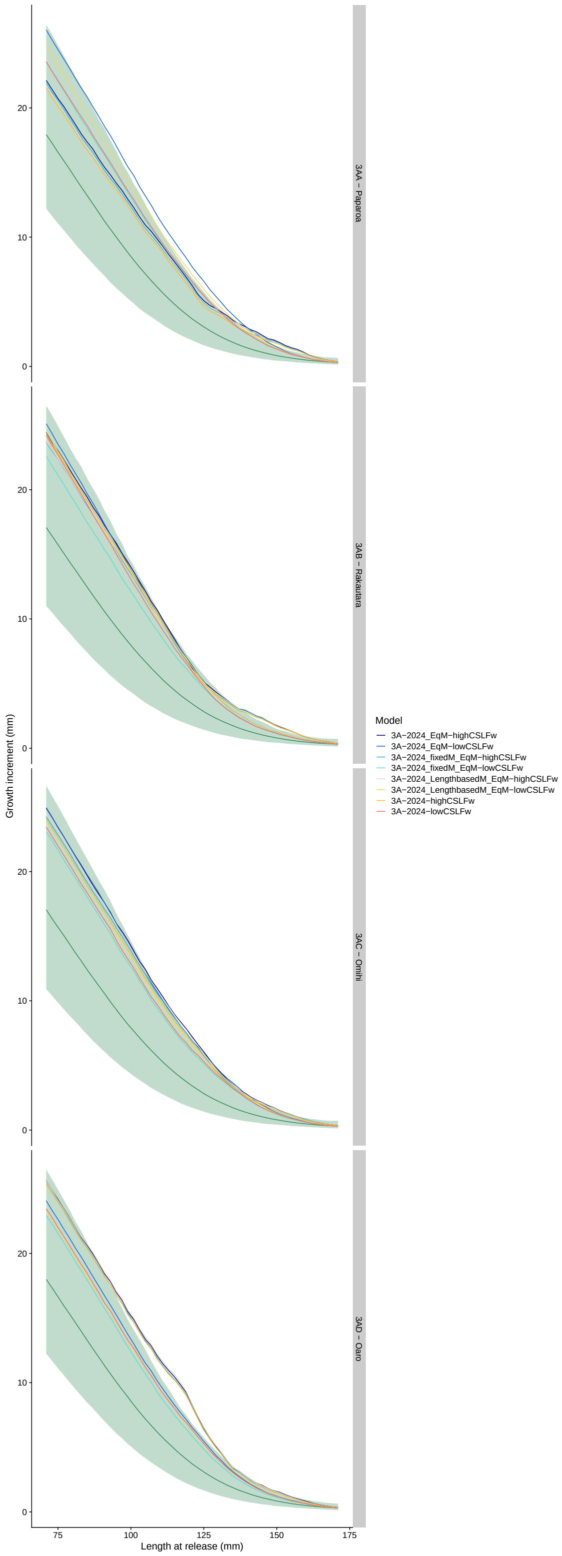

Figure E-4: Comparison of prior and median posterior growth for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A. Prior for population mean growth (prior mean, green line; 95% prior interval, green shading), and posterior mean growth.

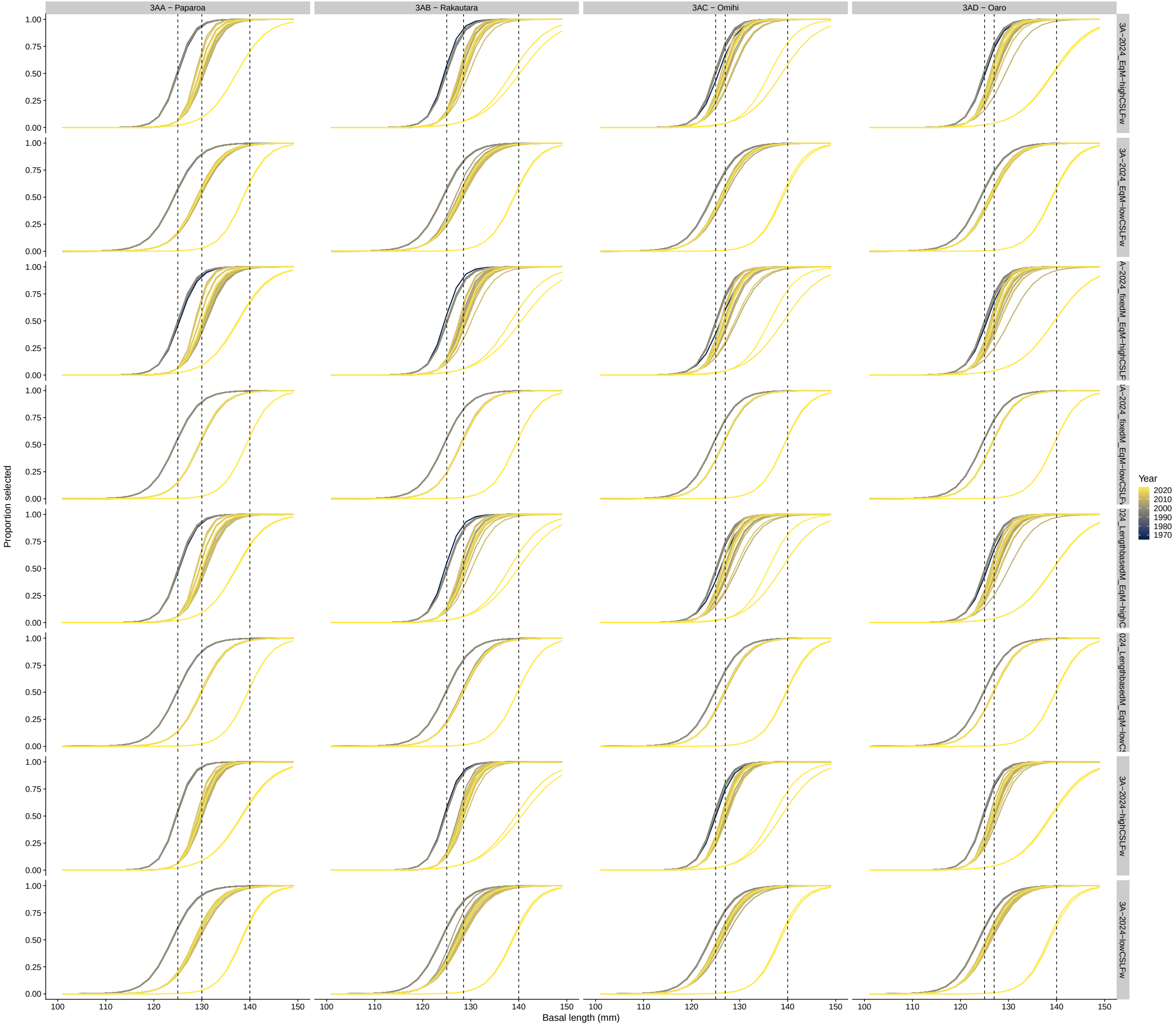

Figure E-5: Comparison of posterior mean selectivity-at-length for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

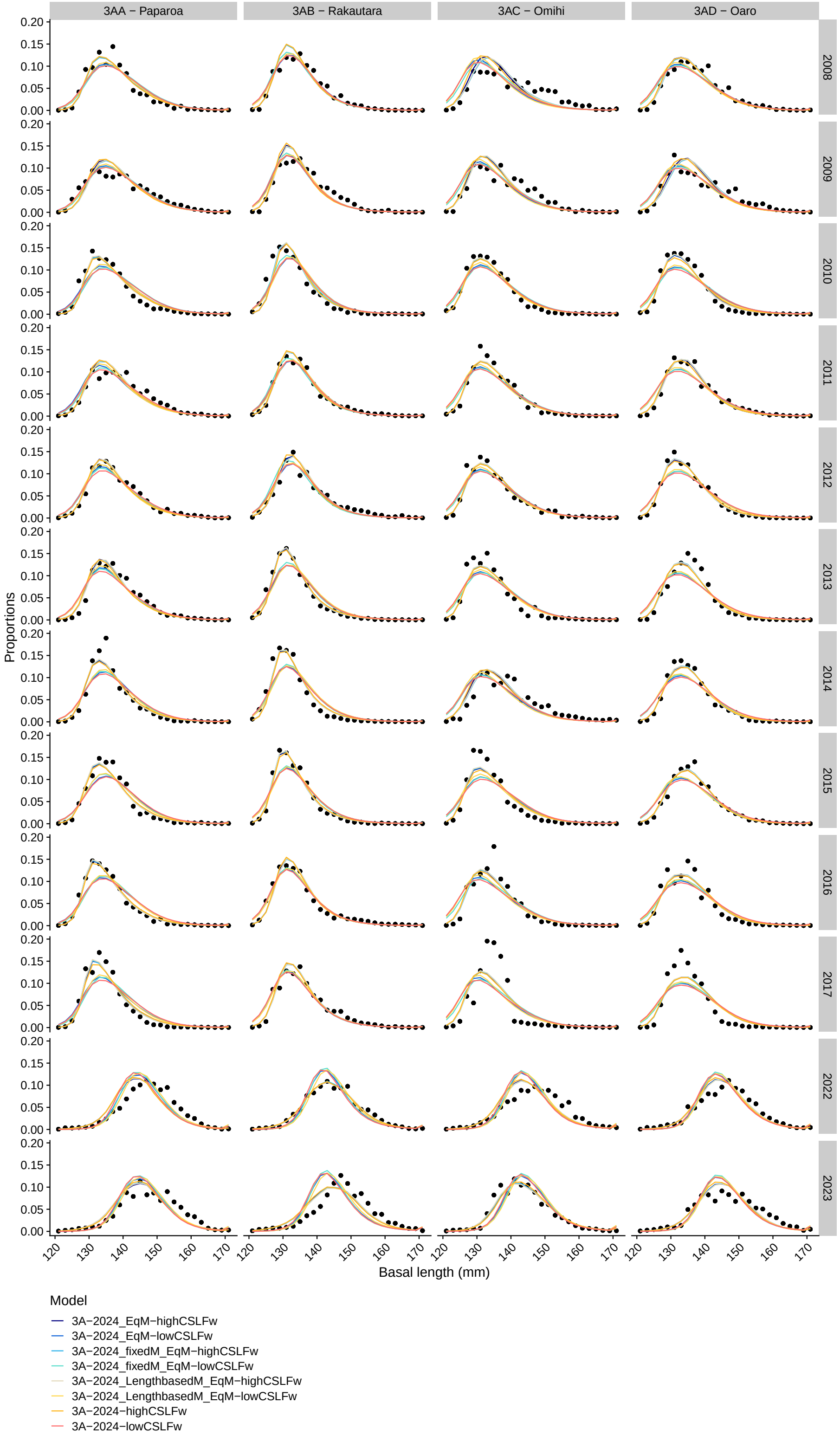

Figure E-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions, for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for quota management area PAU 3A.

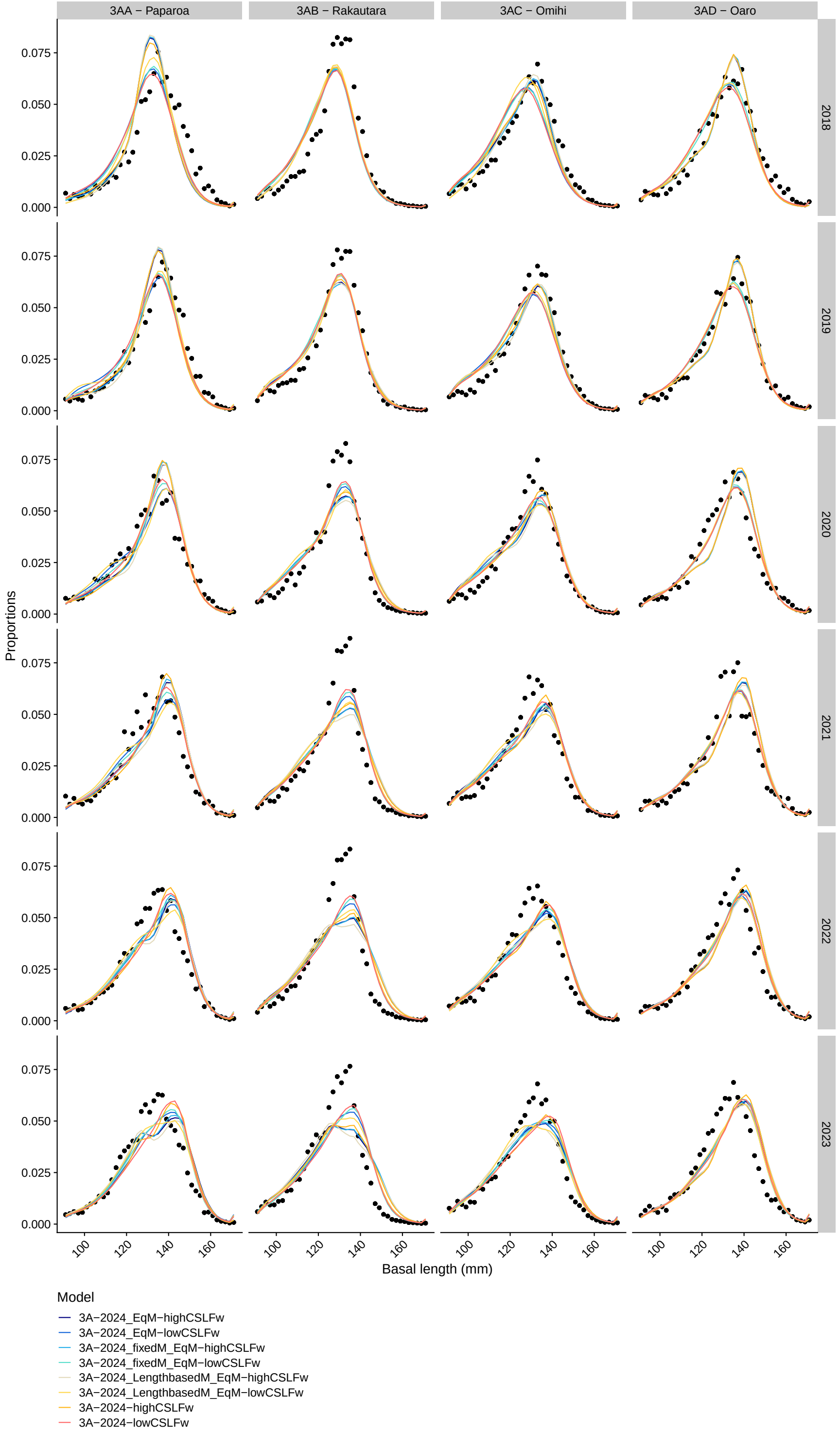

Figure E-7: Comparison of posterior mean predicted survey length frequency with estimated proportions and observation error for the models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

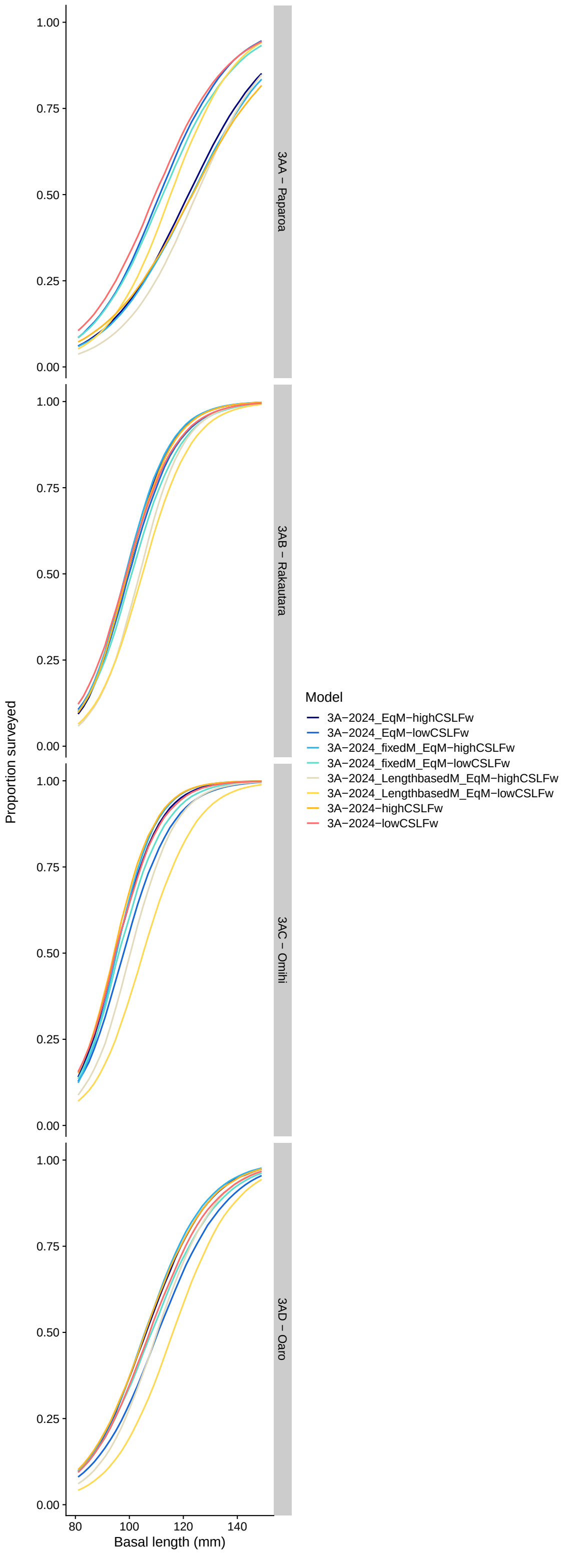

Figure E-8: Estimated survey selectivity (posterior mean) for pāua for the models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

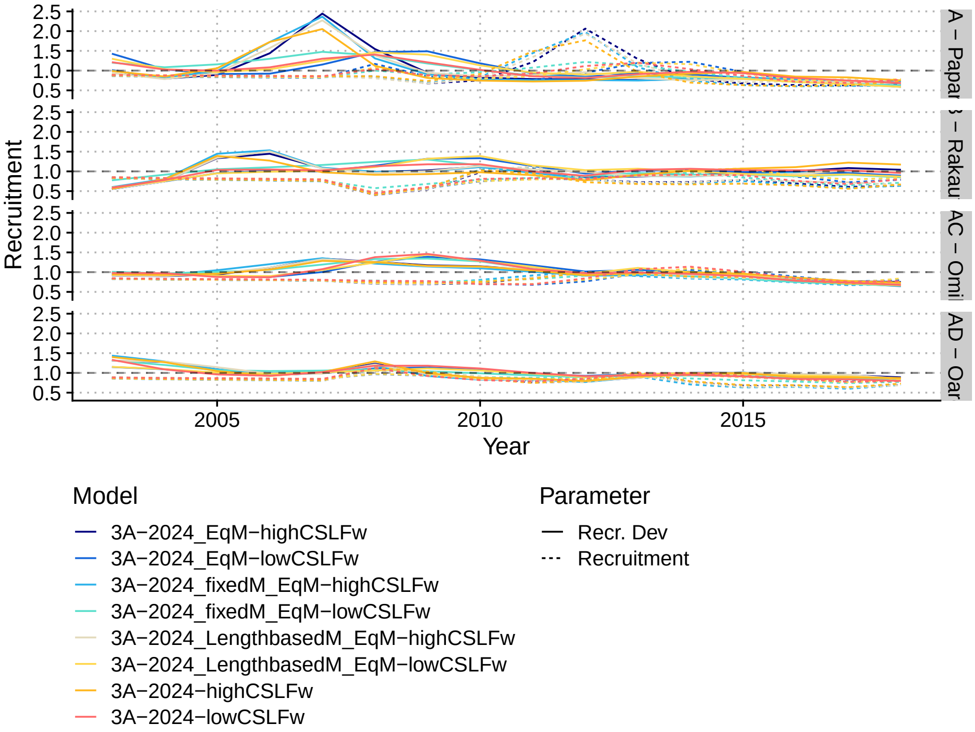

Figure E-9: Comparison of posterior mean recruitment deviations (*Rdev*) for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

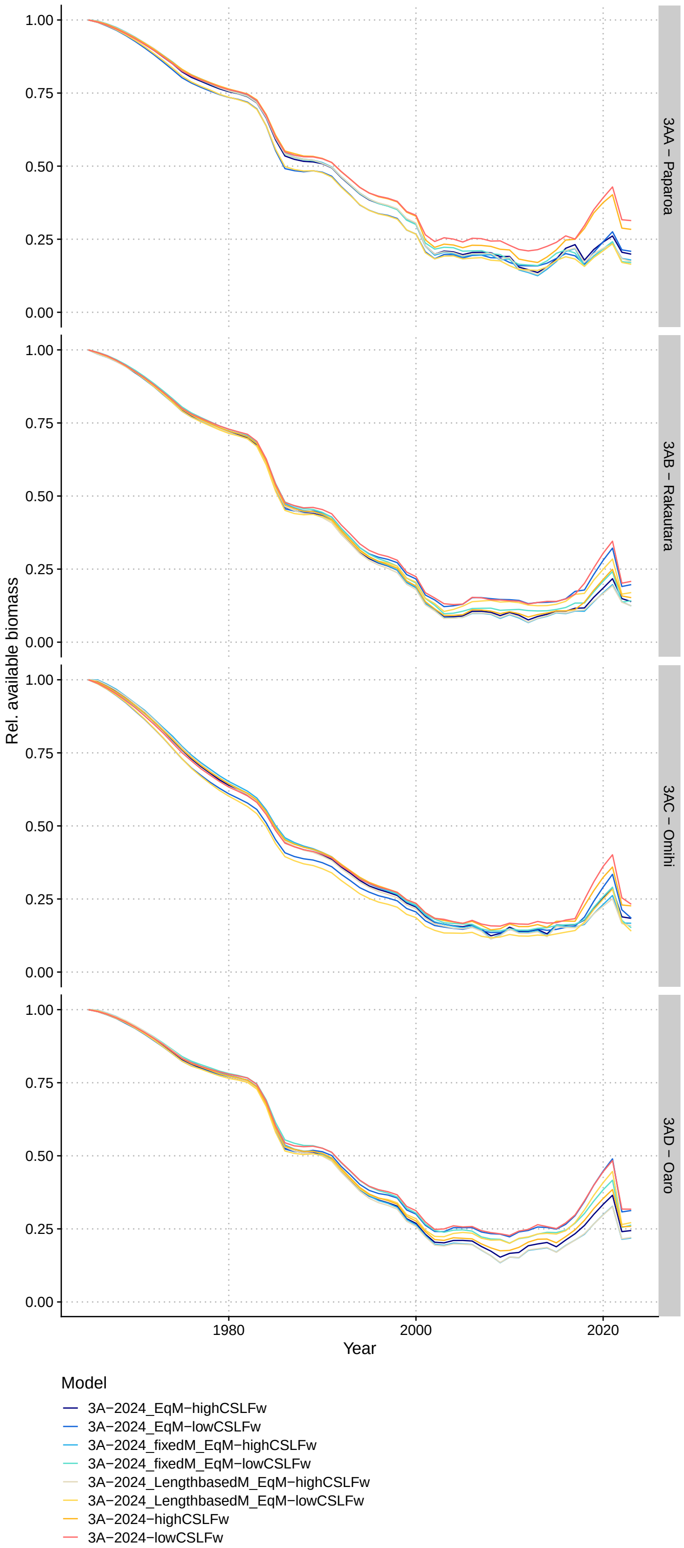

Figure E-10: Comparison of posterior median predicted relative available biomass trend for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

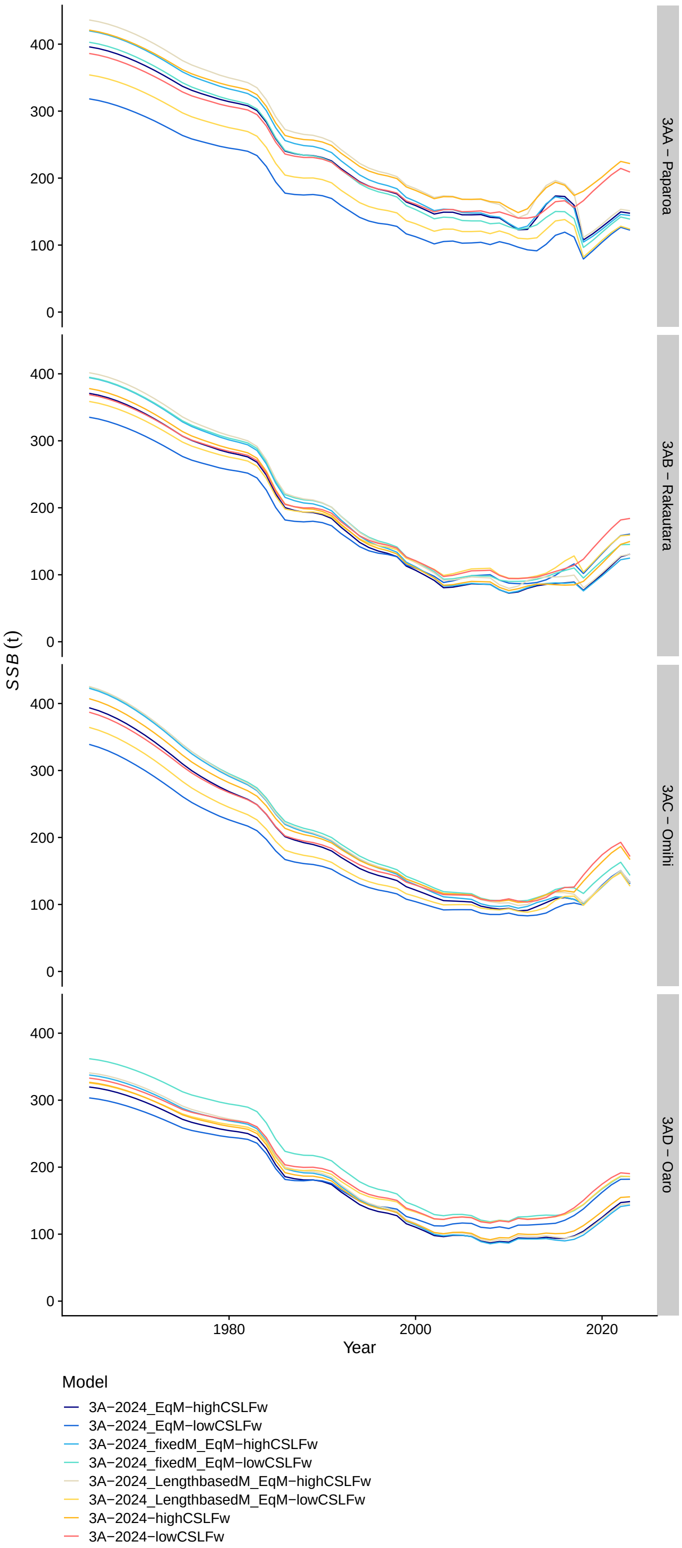

Figure E-11: Comparison of posterior median predicted spawning stock biomass (*SSB*) trend for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

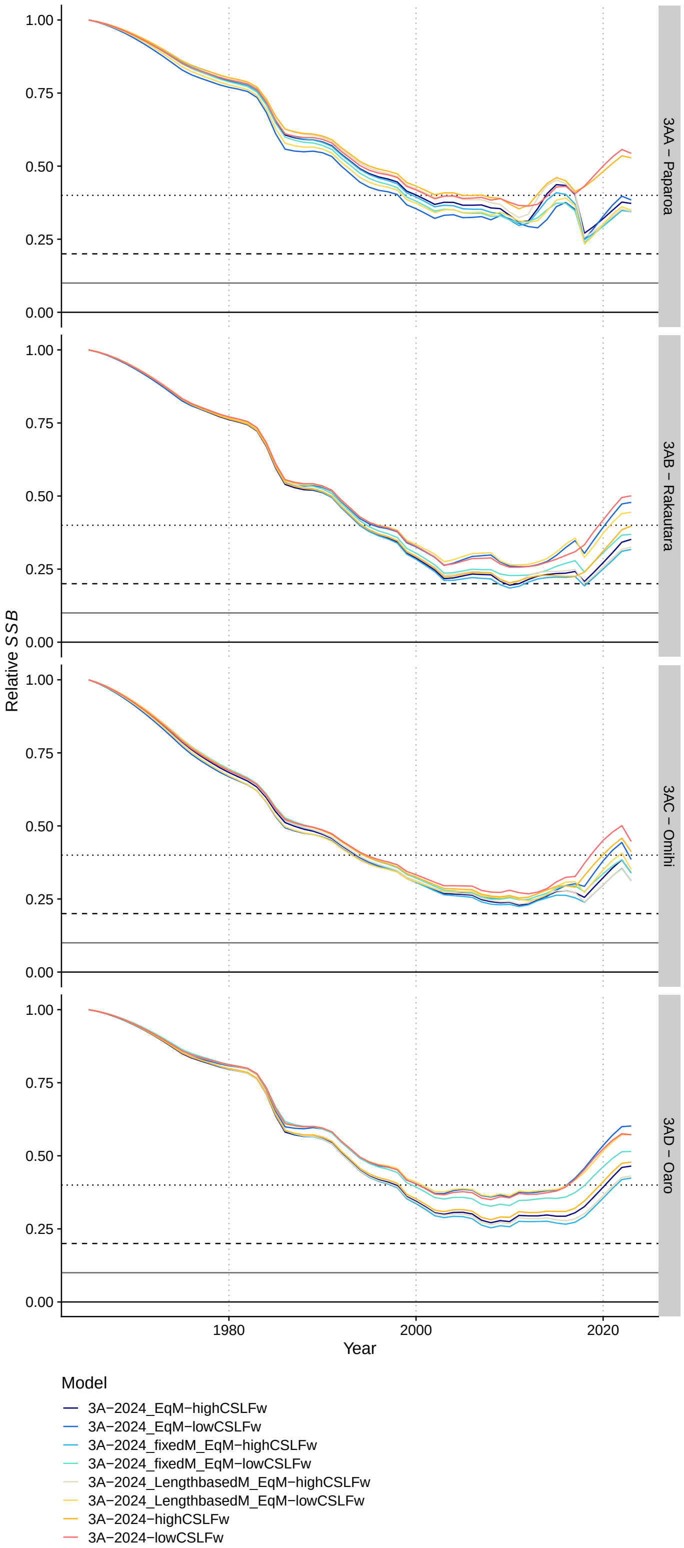

Figure E-12: Comparison of posterior median predicted relative spawning stock biomass (*SSB*) trend for models with different assumptions about model weights for commercial length frequency (CSLFw, high versus low weight); natural mortality, fixed at 0.12 (fixedM, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), used for sensitivities in the stock assessment for Quota Management Area PAU 3A.

APPENDIX F: ASSESSMENT MODEL COMPARISON: RECREATIONAL CATCH ASSUMPTION

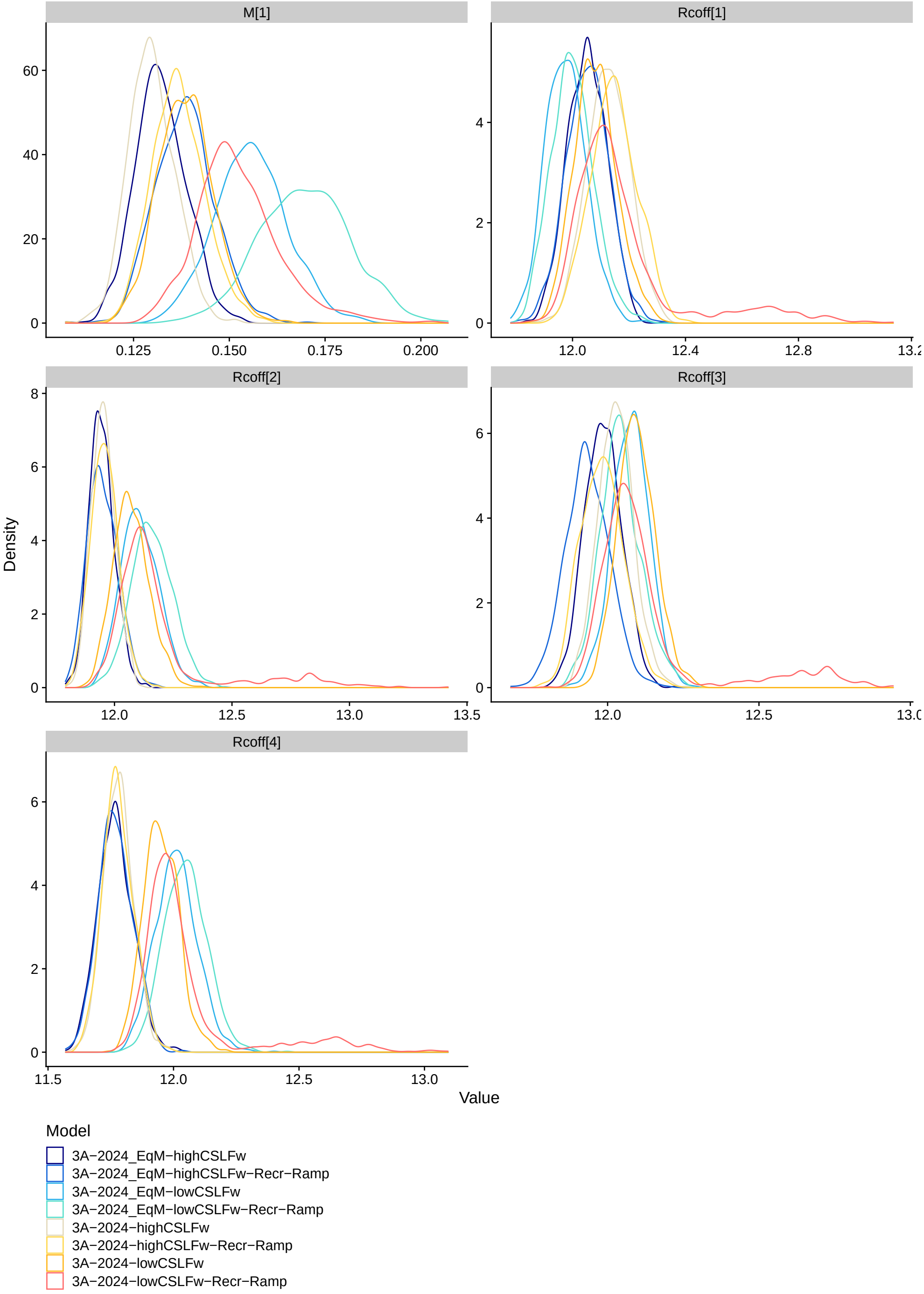

Figure F-1: Comparison of posterior densities for parameters for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

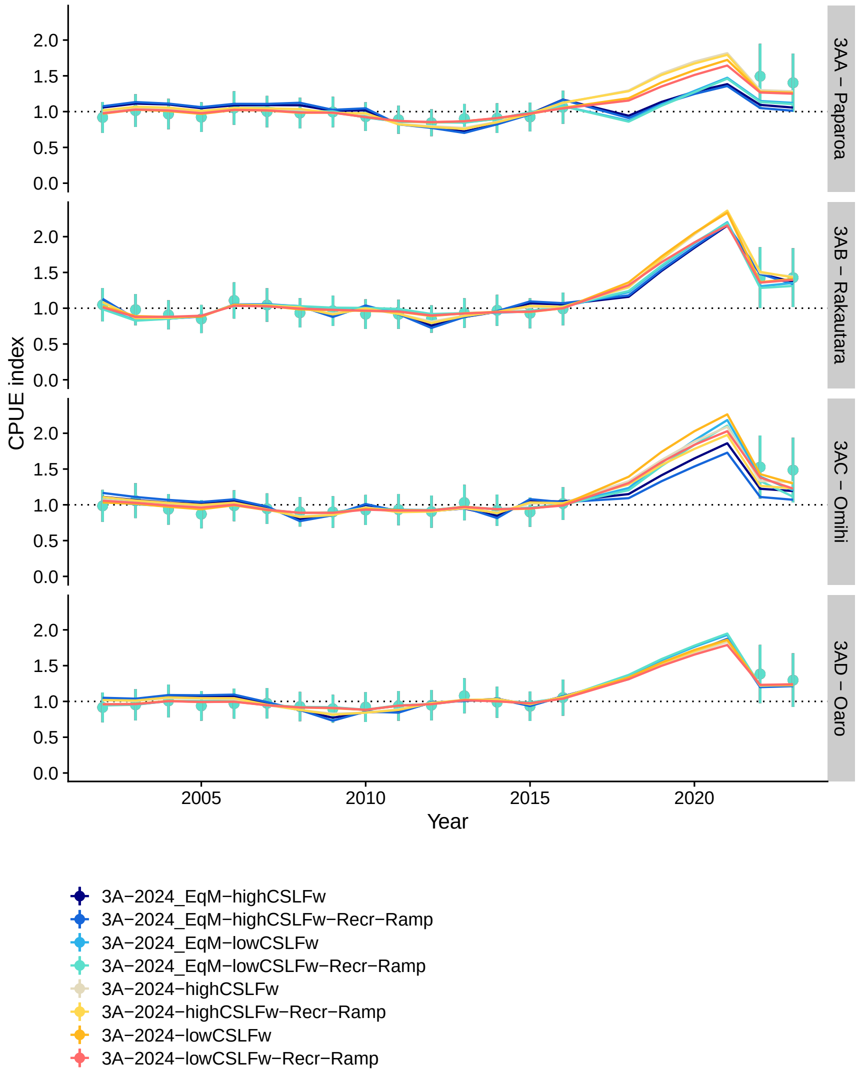

Figure F-2: Comparison of posterior median predicted catch-per-unit-effort (CPUE) for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

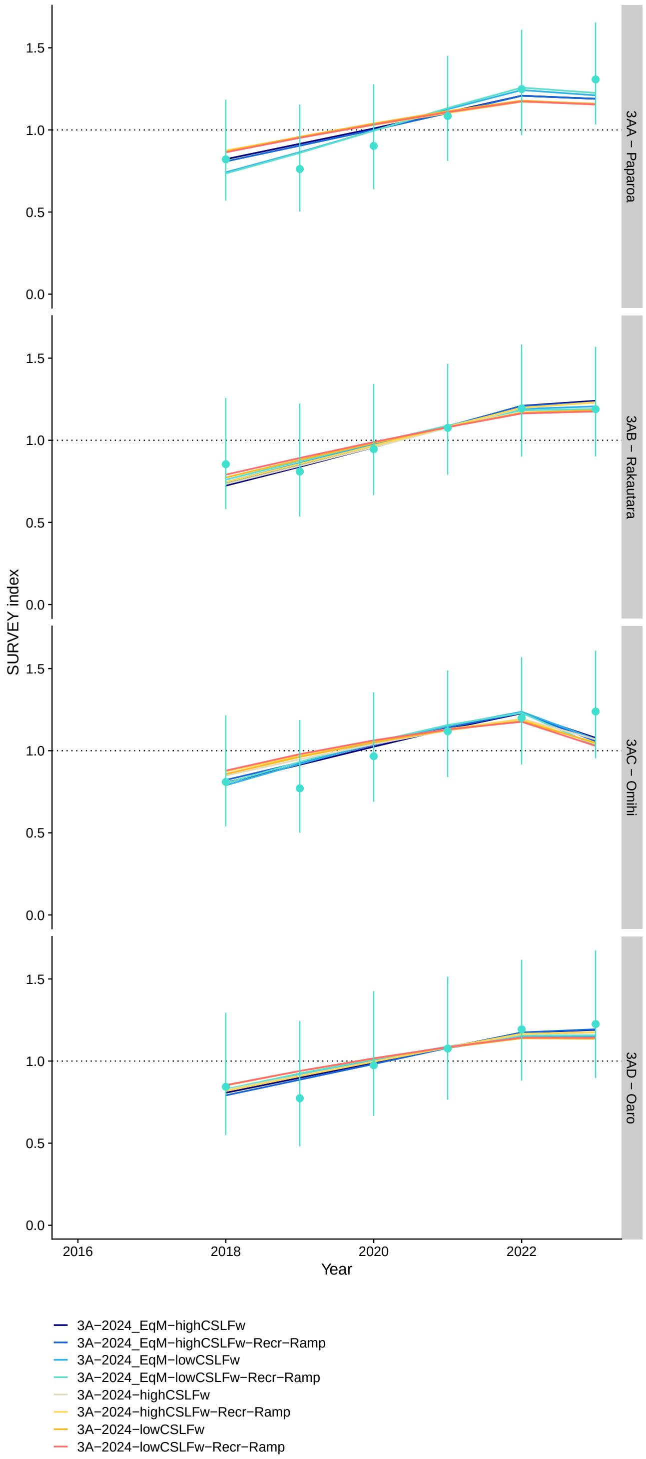

Figure F-3: Comparison of posterior median (line) model-predicted survey index with the estimated survey index and observation error for the models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A (points and error bars).

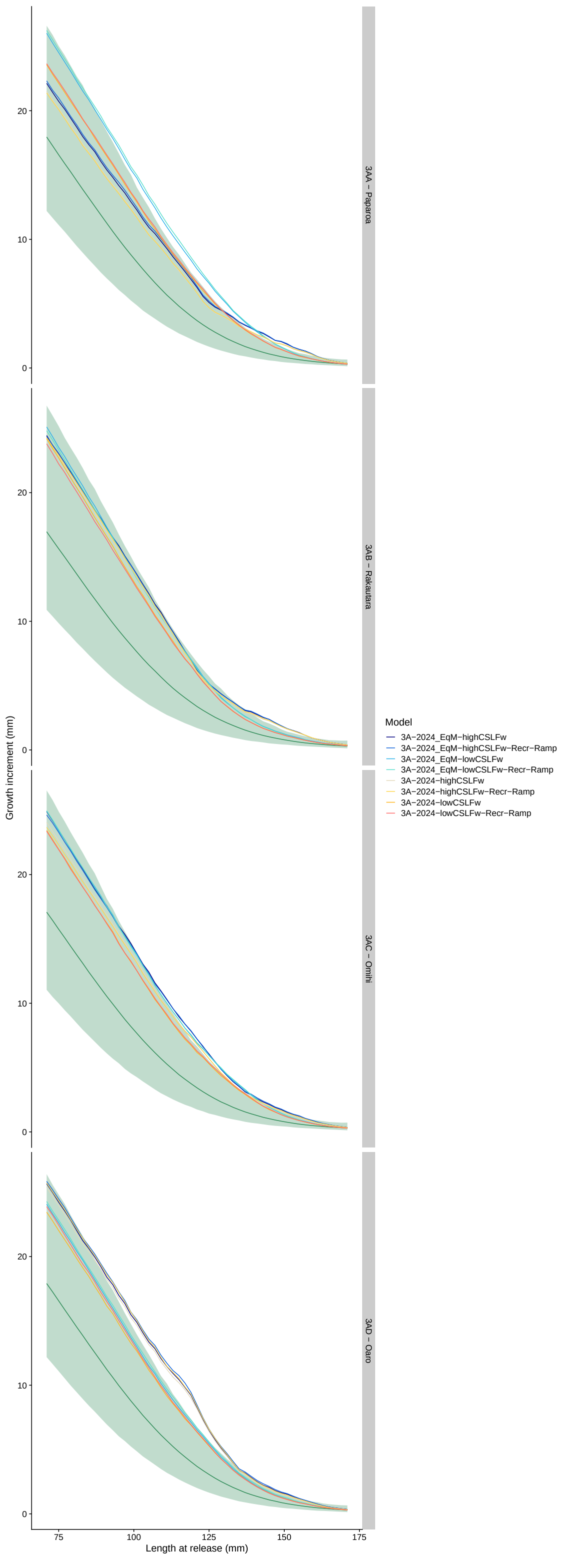

Figure F-4: Comparison of prior and median posterior growth for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A. Prior for population mean growth (prior mean, green line; 95% prior interval, green shading), and posterior mean growth.

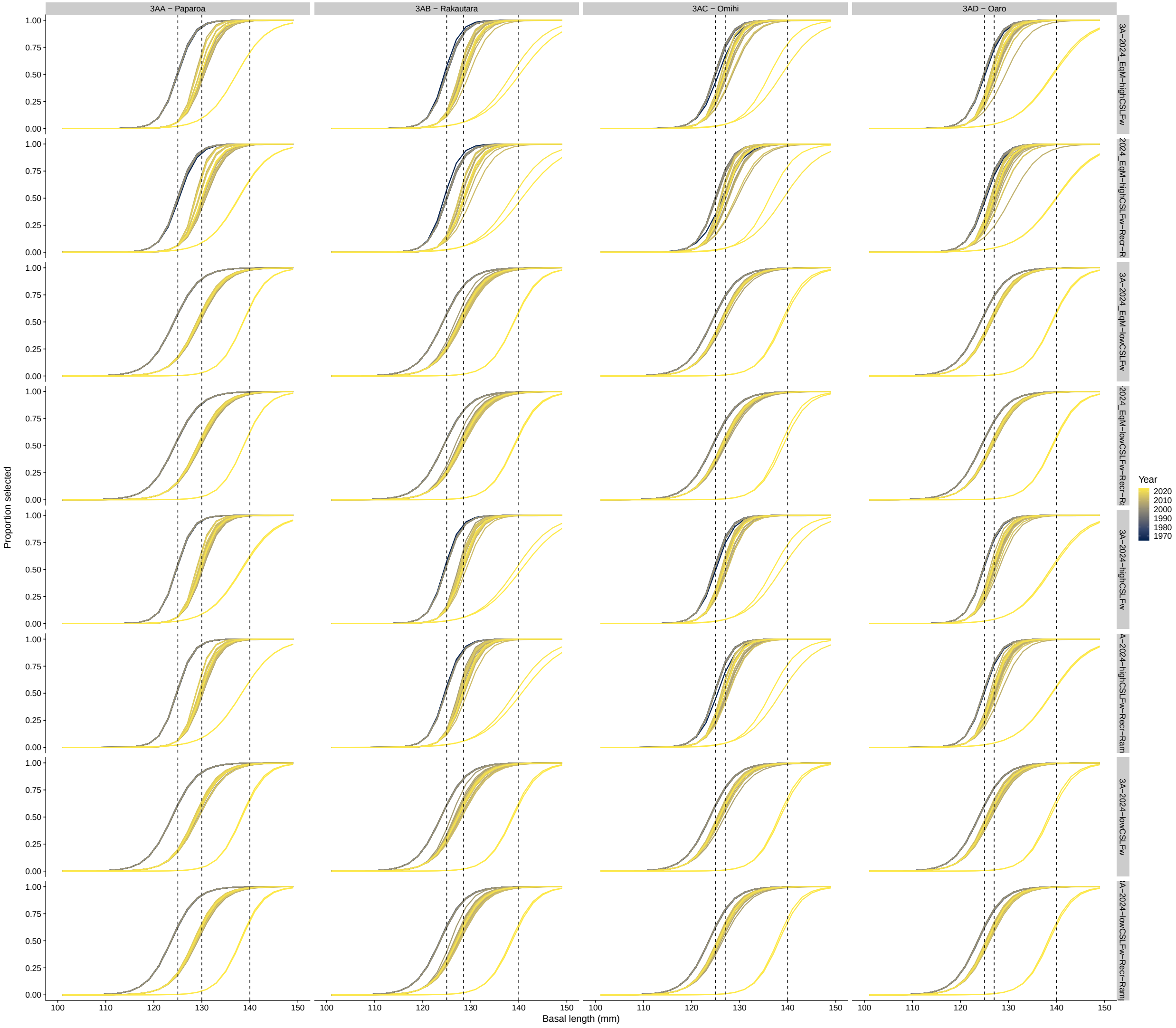

Figure F-5: Comparison of posterior mean selectivity-at-length for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

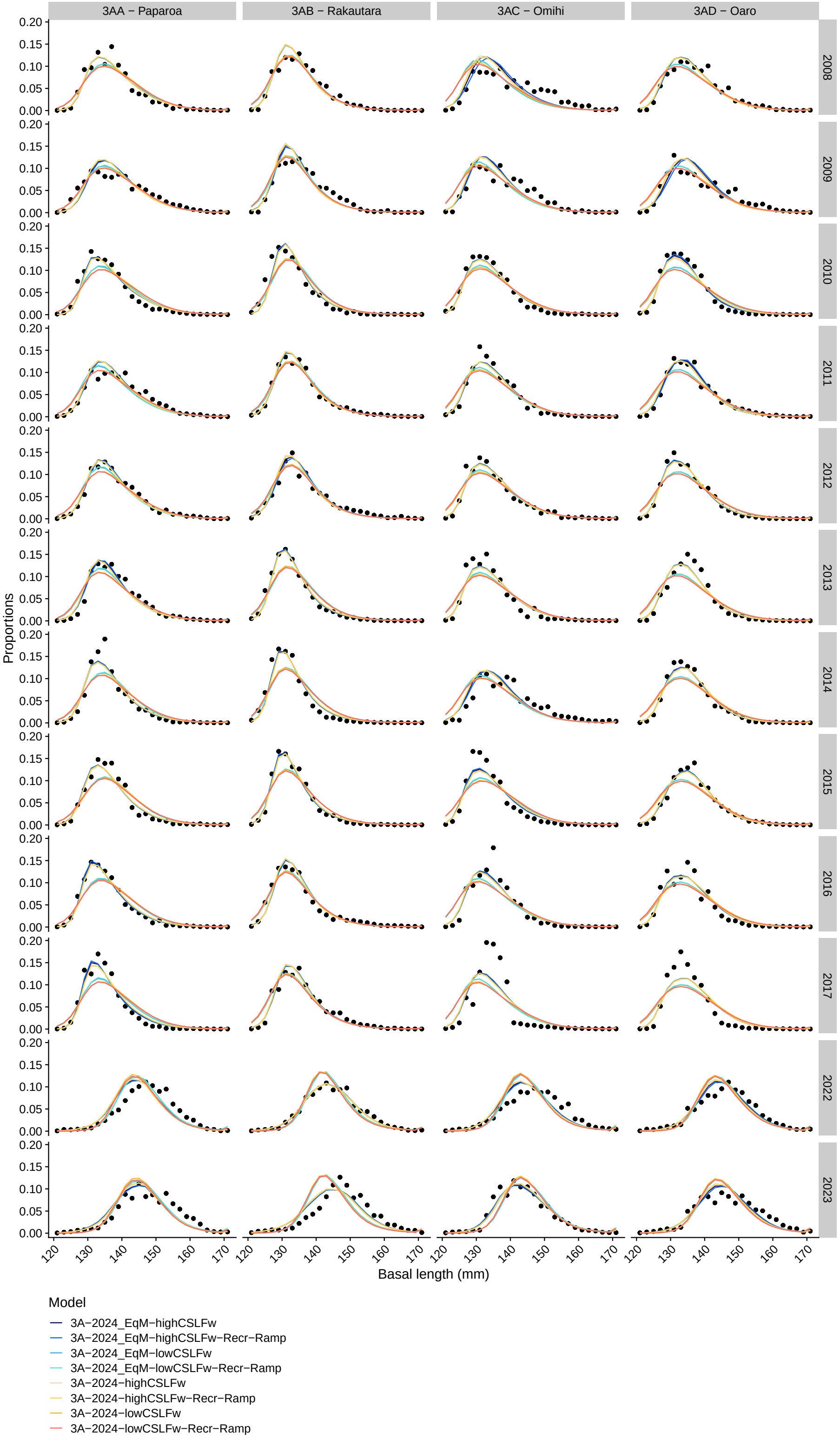

Figure F-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions, for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for quota management area PAU 3A.

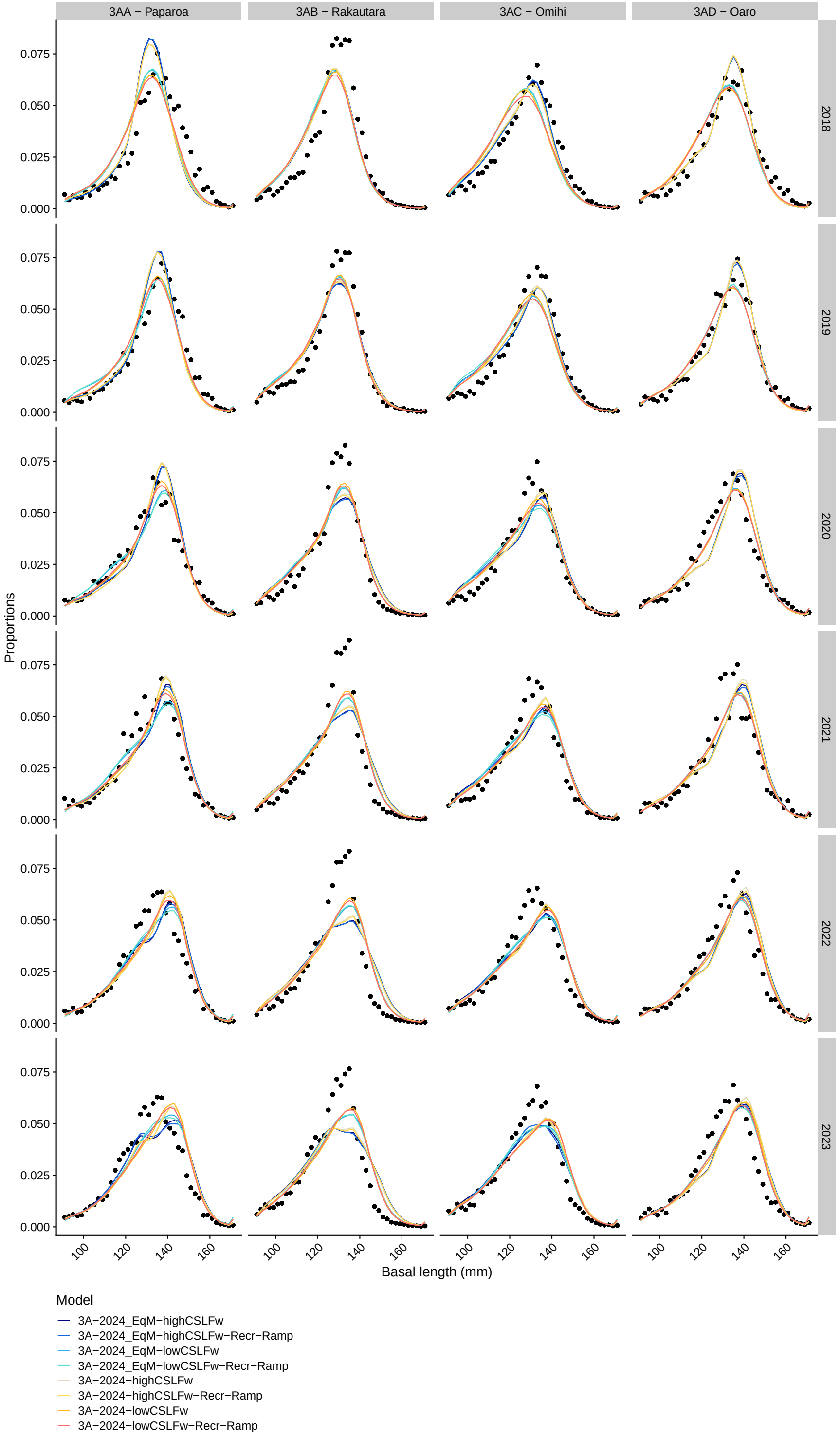

Figure F-7: Comparison of posterior mean predicted survey length frequency with estimated proportions and observation error for the models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

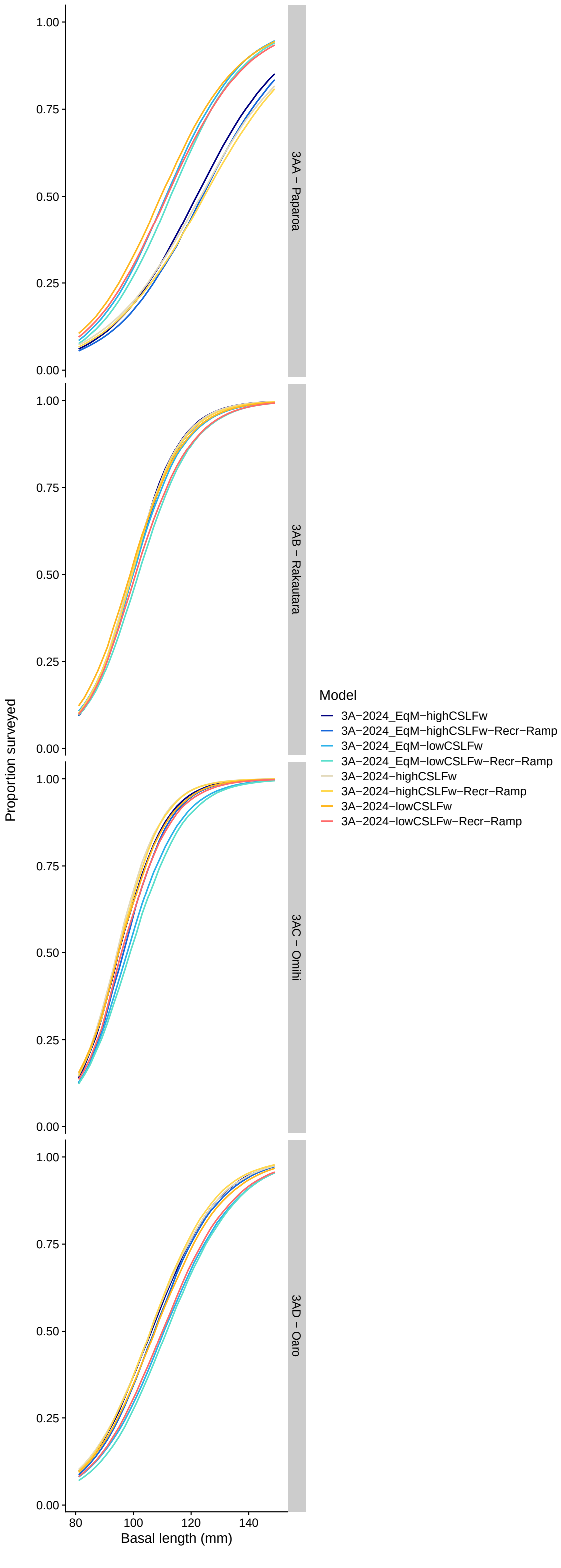

Figure F-8: Estimated survey selectivity (posterior mean) for pāua for the models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

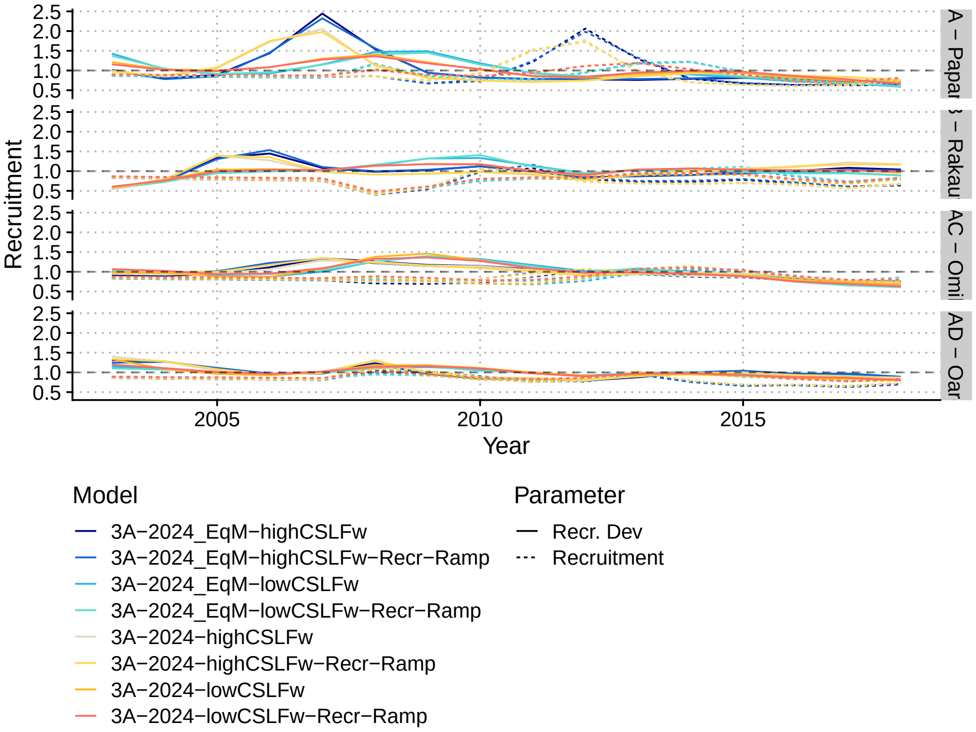

Figure F-9: Comparison of posterior mean recruitment deviations (*Rdev*) for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

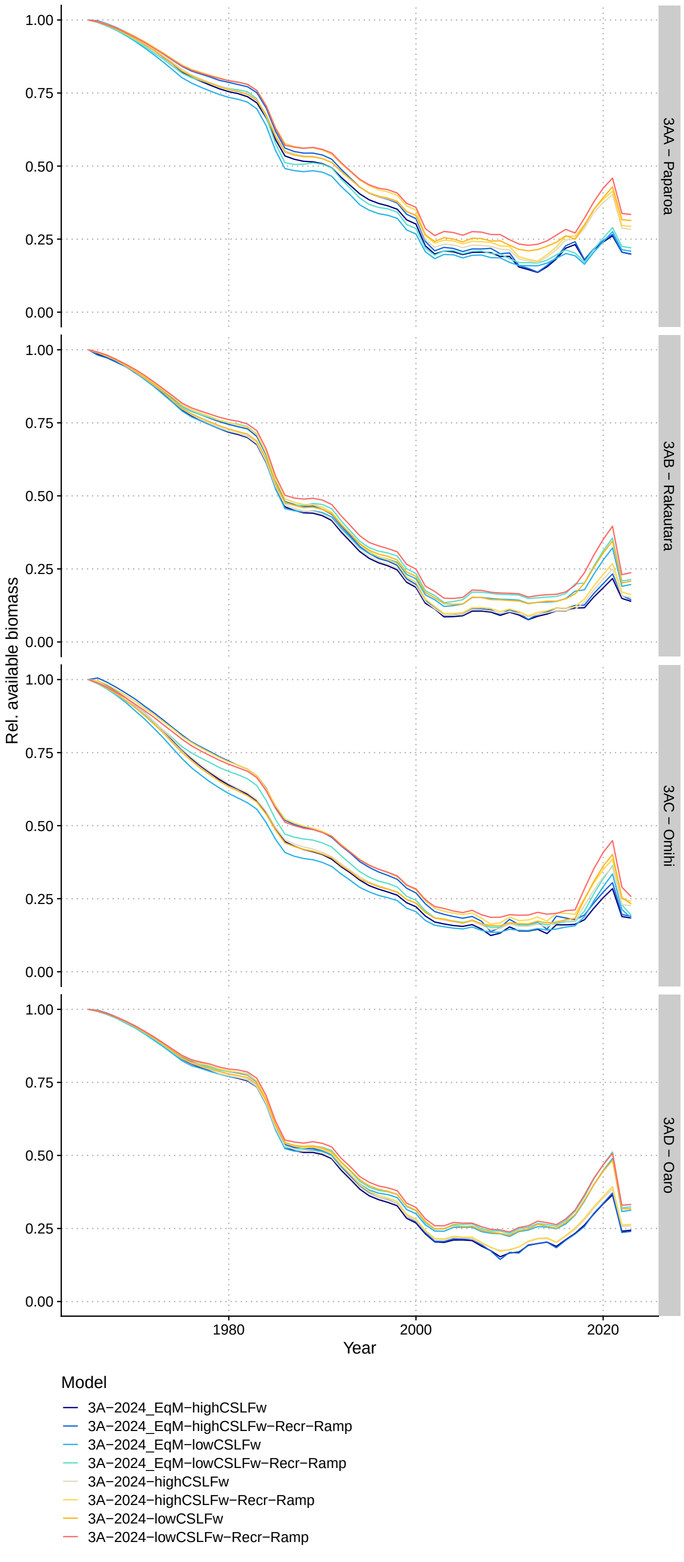

Figure F-10: Comparison of posterior median predicted relative available biomass trend for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

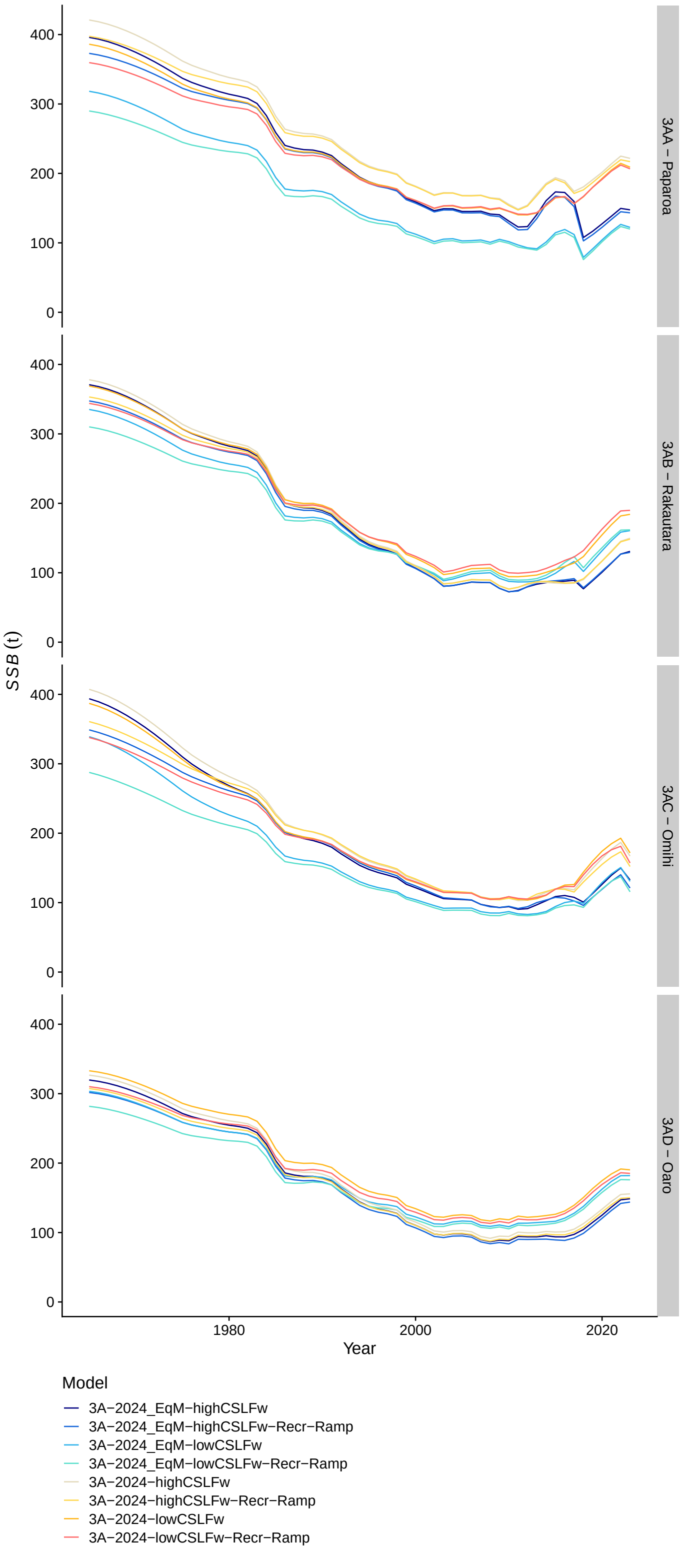

Figure F-11: Comparison of posterior median predicted spawning stock biomass (*SSB*) trend for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

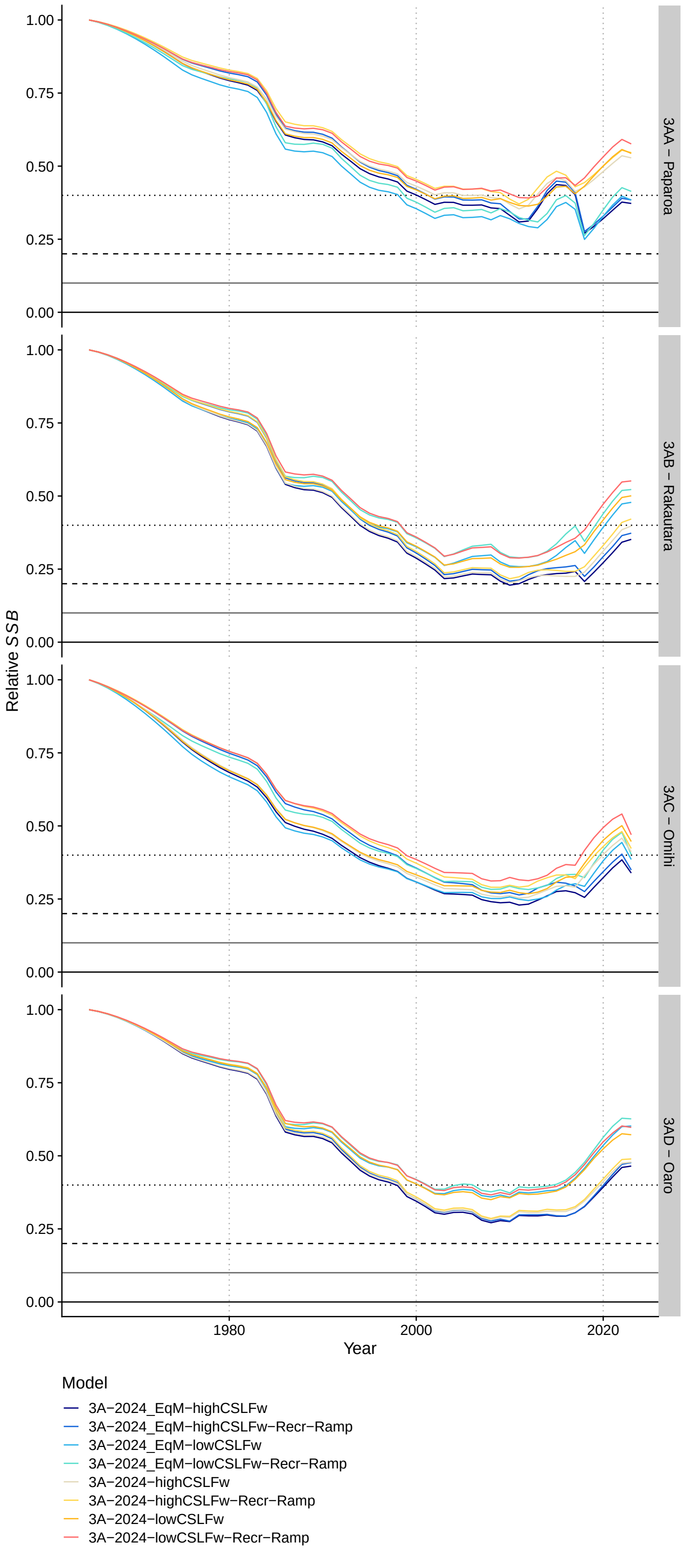

Figure F-12: Comparison of posterior median predicted relative spawning stock biomass (*SSB*) trend for models with alternative scenarios for recreational catch using either 24 t constant catch pre-earthquake, or a ramp (suffix Ramp) from 12 t of recreational catch in 1974 to 24 t in 2012. These assumptions were run across alternative models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); and explicit earthquake mortality (EqM), used as sensitivities in the stock assessment for Quota Management Area PAU 3A.

APPENDIX G: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: COMPARING ALTERNATIVE MINIMUM LEGAL SIZE (MLS) SETTINGS

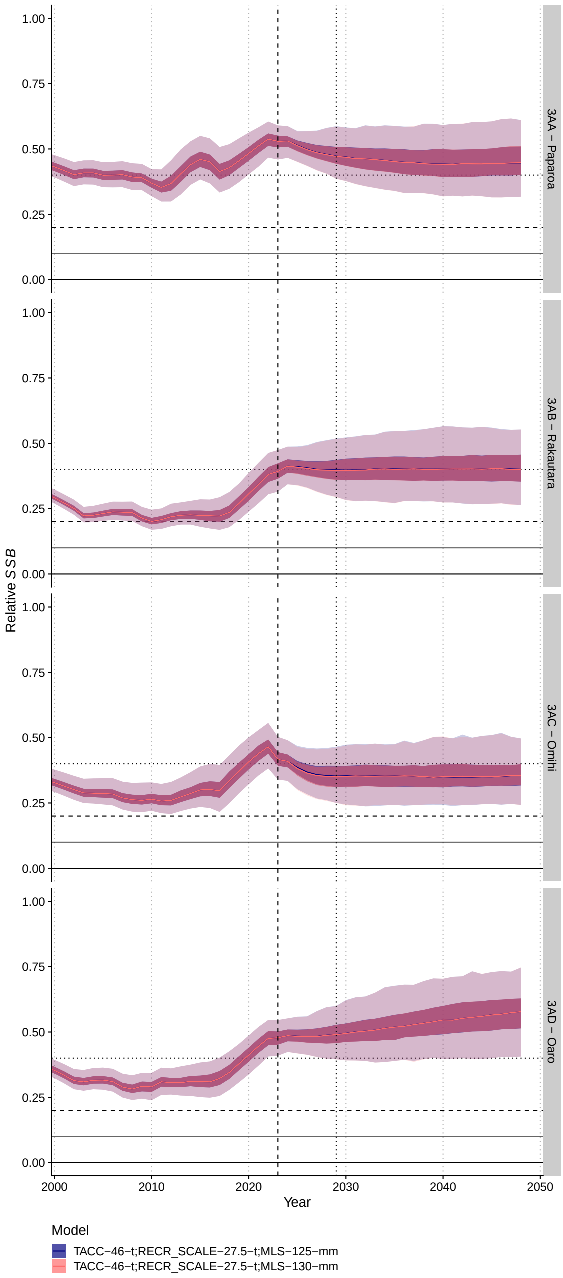

Figure G-1: Estimated and projected relative spawning stock biomass (*SSB*) trend for pāua, comparing simulations from the base assessment model under different assumptions of minimum legal size (MLS), assuming an increase in commercial catch (TACC) to 46 t in 2024 and a recreational allowance of 20 t combined with a customary allowance of 7.5 t (together shown as RECR-SCALE). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

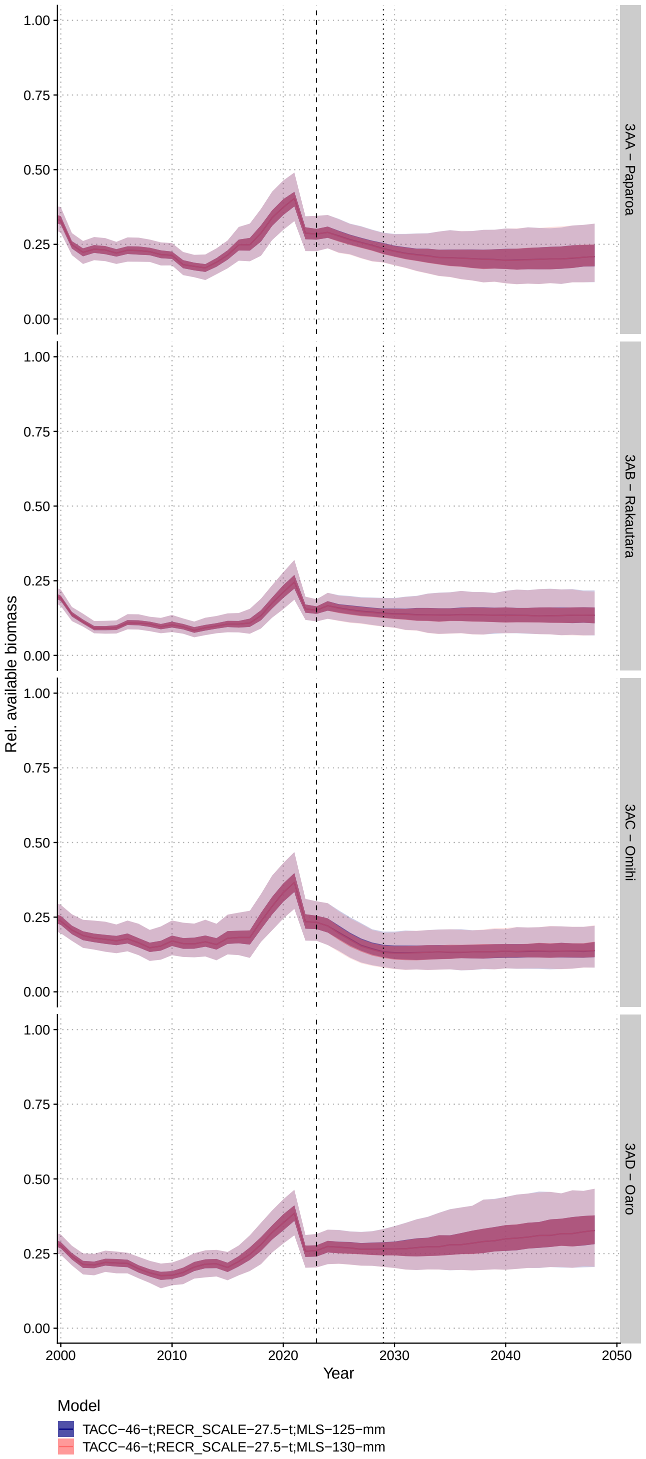

Figure G-2: Estimated and projected relative available biomass trend for pāua, comparing simulations from the base assessment model under different assumptions of minimum legal size (MLS), assuming an increase in commercial catch (TACC) to 46 t in 2024 and a recreational allowance of 20 t combined with a customary allowance of 7.5 t (together shown as RECR-SCALE). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

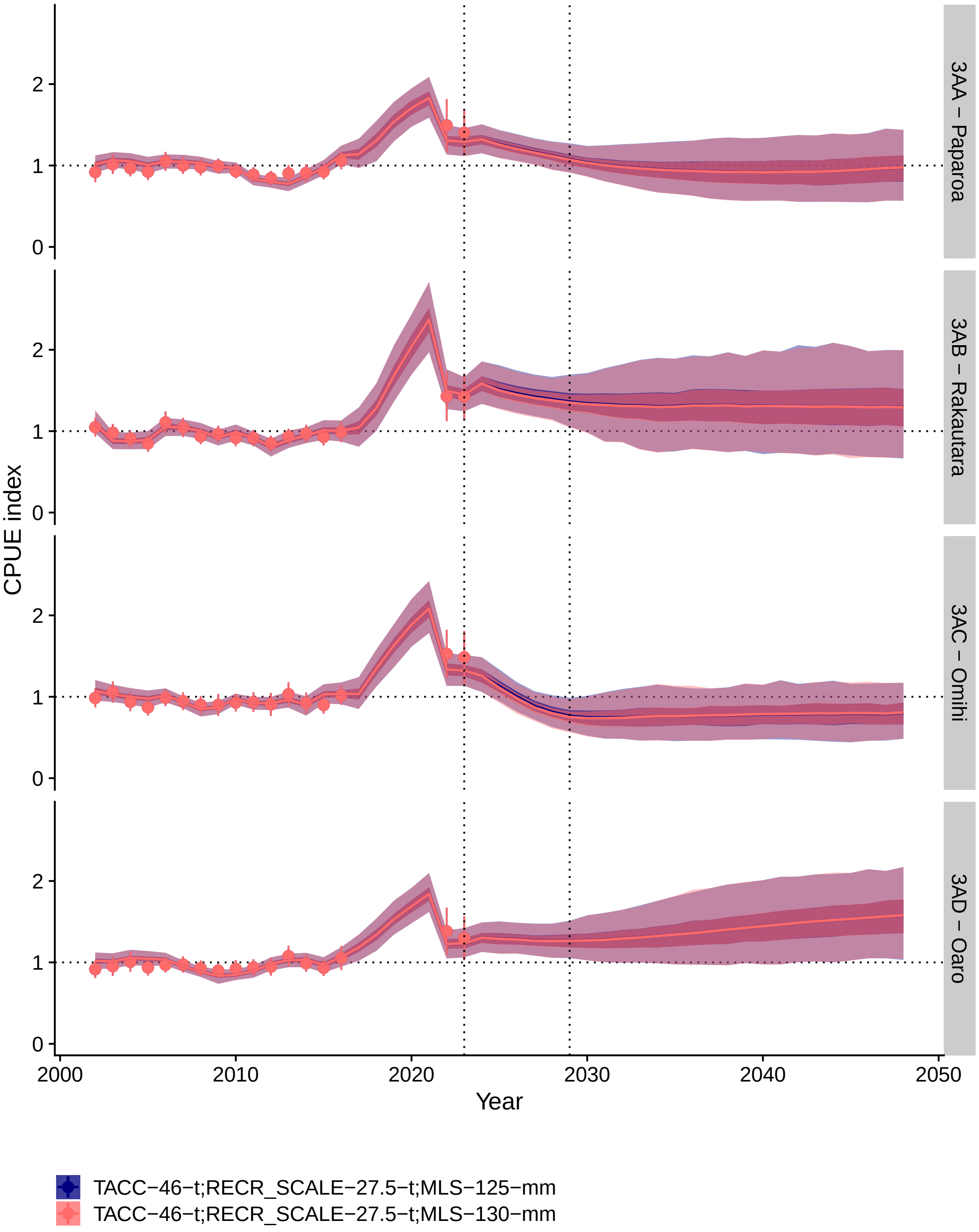

Figure G-3: Estimated and projected catch-per-unit-effort (CPUE) trend for pāua, comparing simulations from the base assessment model under different assumptions of minimum legal size (MLS), assuming an increase in commercial catch (TACC) to 46 t in 2024 and a recreational allowance of 20 t combined with a customary allowance of 7.5 t (together shown as RECR-SCALE). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

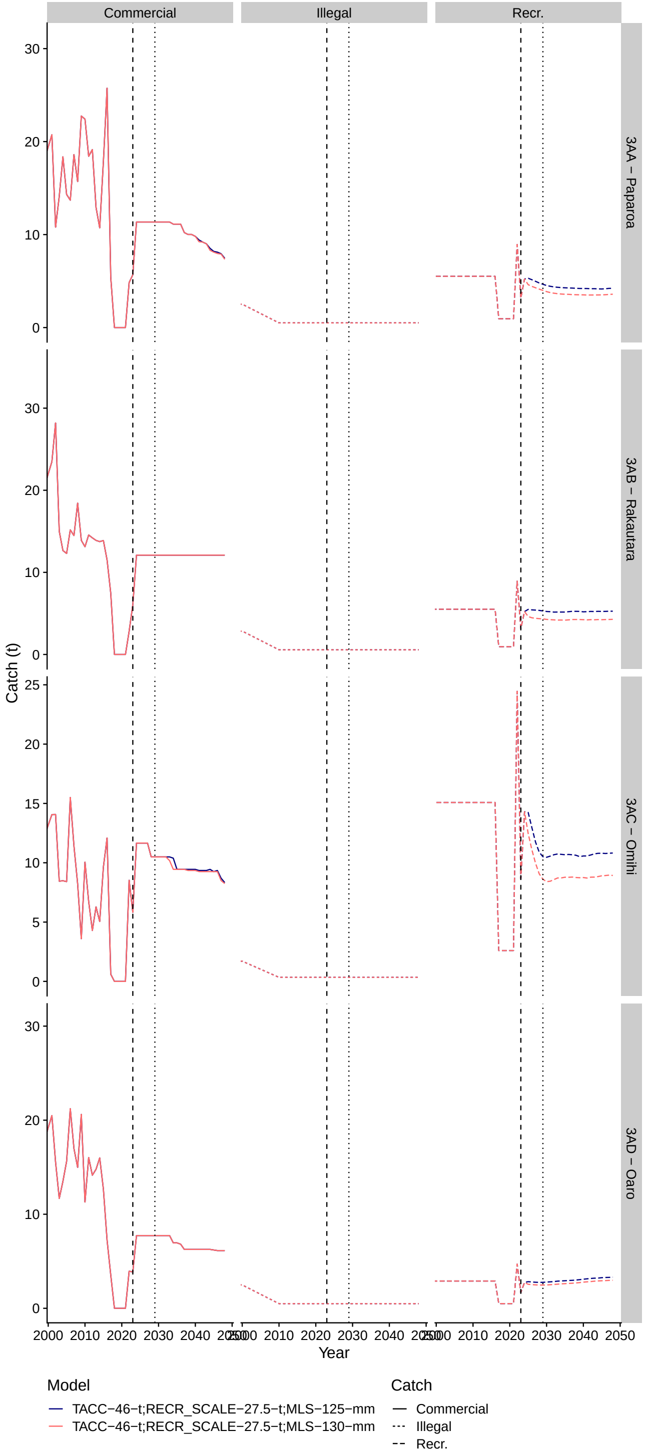

Figure G-4: Assumed and projected catch by sector, comparing simulations from the base assessment model under different assumptions of minimum legal size (MLS), assuming an increase in commercial catch (TACC) to 46 t in 2024 and a recreational allowance of 20 t combined with a customary allowance of 7.5 t (together shown as RECR-SCALE). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations were compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

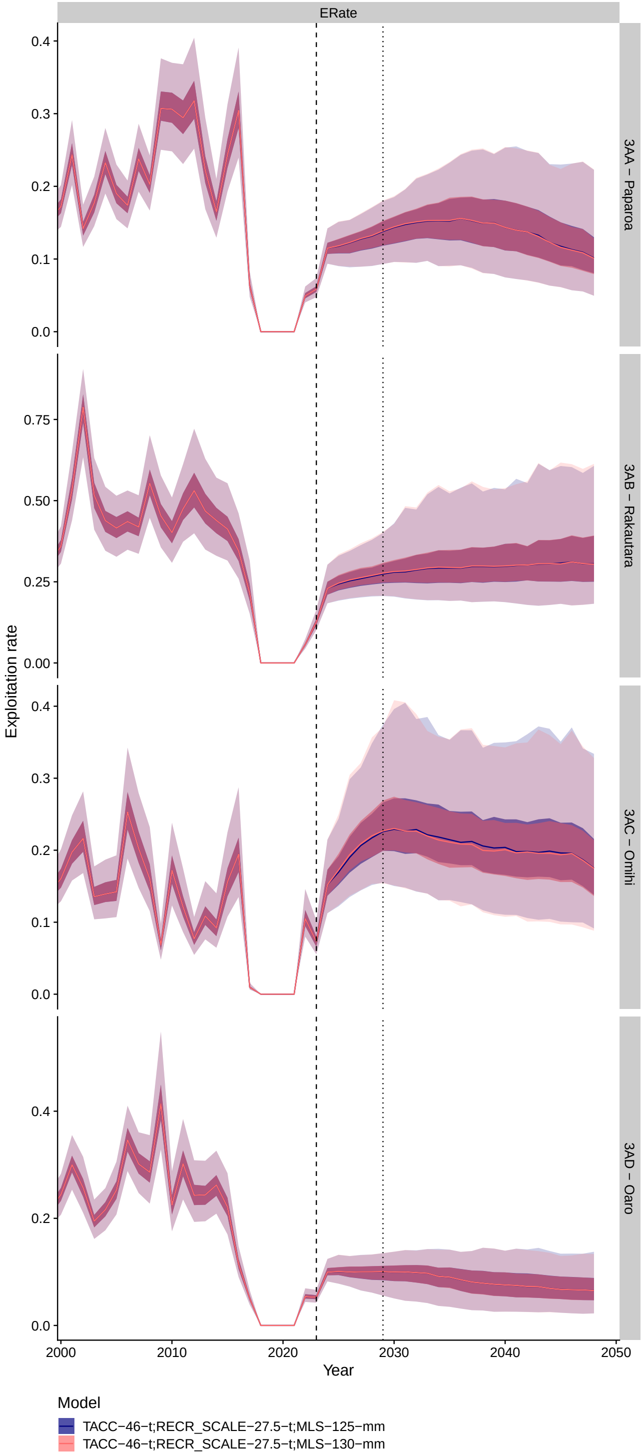

Figure G-5: Estimated and projected exploitation rate for the commercial pāua fishery (median line), comparing simulations from the base assessment model under different assumptions of minimum legal size (MLS), assuming an increase in commercial catch (TACC) to 46 t in 2024 and a recreational allowance of 20 t combined with a customary allowance of 7.5 t (together shown as RECR-SCALE). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

Table G-1: Performance of tested management procedures, comparing simulations from the base assessment model under different assumptions of minimum legal size (MLS), assuming an increase in commercial catch (TACC) to 46 t in 2024 and a recreational allowance of 20 t combined with a customary allowance of 7.5 t (together shown as RECR-SCALE). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in quota management area PAU 3A. *SSB*, spawning stock biomass; CPUE, catch-per-unit-effort; TACC, Total Allowable Commercial Catch.

Model	Area	Mean rel. *SSB* (2029)	Mean rel. *SSB* (2048)	P(rel. *SSB* (2029) > 0.4)	P(rel. *SSB* (2048) > 0.4)	P(rel. *SSB* (2029) < 0.2)	P(rel. *SSB* (2048) < 0.2)	P(rel. *SSB* (2029) < 0.1)	P(rel. *SSB* (2048) < 0.1)	Mean rel. *SSB* (2024–2048)	Mean catch (t)	Mean CPUE (kg/h)
TACC-46-t;R&C-27.5-t;MLS-125-mm	All Regions	0.43	0.44	0.83	0.84	0.00	0.00	0.00	0.00	0.44	39381.05	56.79
TACC-46-t;R&C-27.5-t;MLS-125-mm	3AA - Paparoa	0.48	0.46	0.98	0.76	0.00	0.00	0.00	0.00	0.47	9941.14	50.44
TACC-46-t;R&C-27.5-t;MLS-125-mm	3AB - Rakautara	0.40	0.41	0.49	0.51	0.00	0.00	0.00	0.00	0.41	12775.86	67.34
TACC-46-t;R&C-27.5-t;MLS-125-mm	3AC - Omihi	0.35	0.36	0.20	0.25	0.00	0.00	0.00	0.00	0.36	9983.80	41.15
TACC-46-t;R&C-27.5-t;MLS-125-mm	3AD - Oaro	0.49	0.57	0.97	0.98	0.00	0.00	0.00	0.00	0.53	6680.25	69.43
TACC-46-t;R&C-27.5-t;MLS-130-mm	All Regions	0.43	0.44	0.82	0.84	0.00	0.00	0.00	0.00	0.44	39262.95	56.65
TACC-46-t;R&C-27.5-t;MLS-130-mm	3AA - Paparoa	0.48	0.46	0.98	0.76	0.00	0.00	0.00	0.00	0.46	9922.07	50.31
TACC-46-t;R&C-27.5-t;MLS-130-mm	3AB - Rakautara	0.40	0.41	0.47	0.50	0.00	0.00	0.00	0.00	0.40	12773.85	67.01
TACC-46-t;R&C-27.5-t;MLS-130-mm	3AC - Omihi	0.35	0.36	0.19	0.25	0.00	0.00	0.00	0.00	0.36	9896.93	41.03
TACC-46-t;R&C-27.5-t;MLS-130-mm	3AD - Oaro	0.49	0.57	0.97	0.98	0.00	0.00	0.00	0.00	0.53	6670.10	69.40

APPENDIX H: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: CATCH SETTINGS

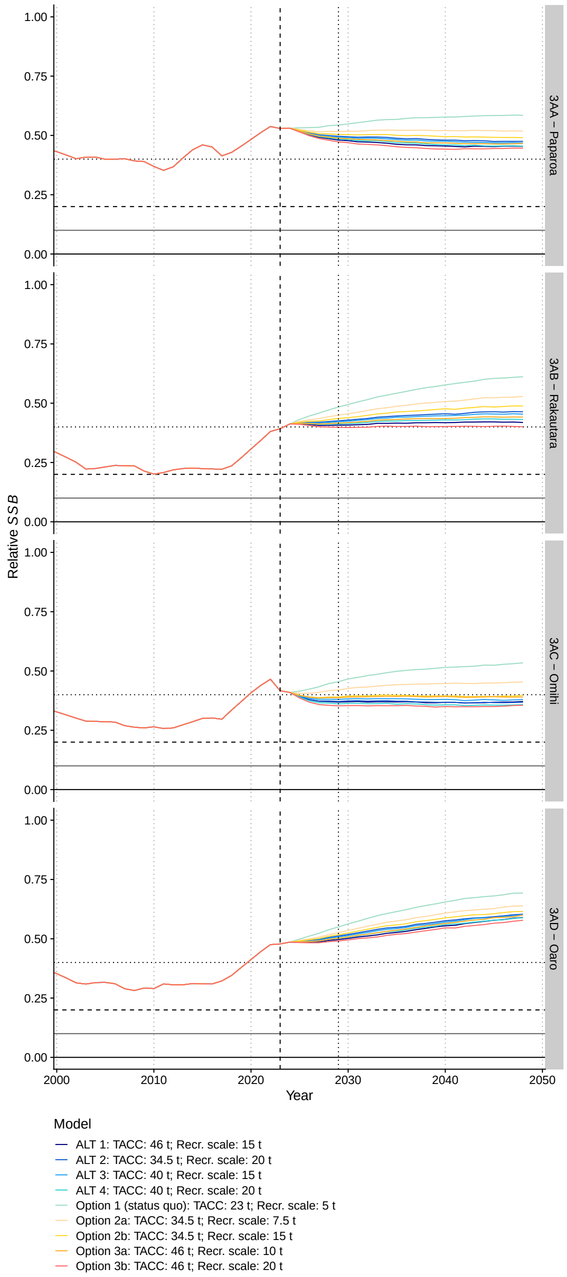

Figure H-1: Estimated and projected relative spawning stock biomass (*SSB*) trend for pāua, comparing simulations from the base assessment model with alternative assumptions about the base level of recreational (Recr.) catch and commercial catch from 2024–2025 (TACC: Total Allowable Commercial Catch). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

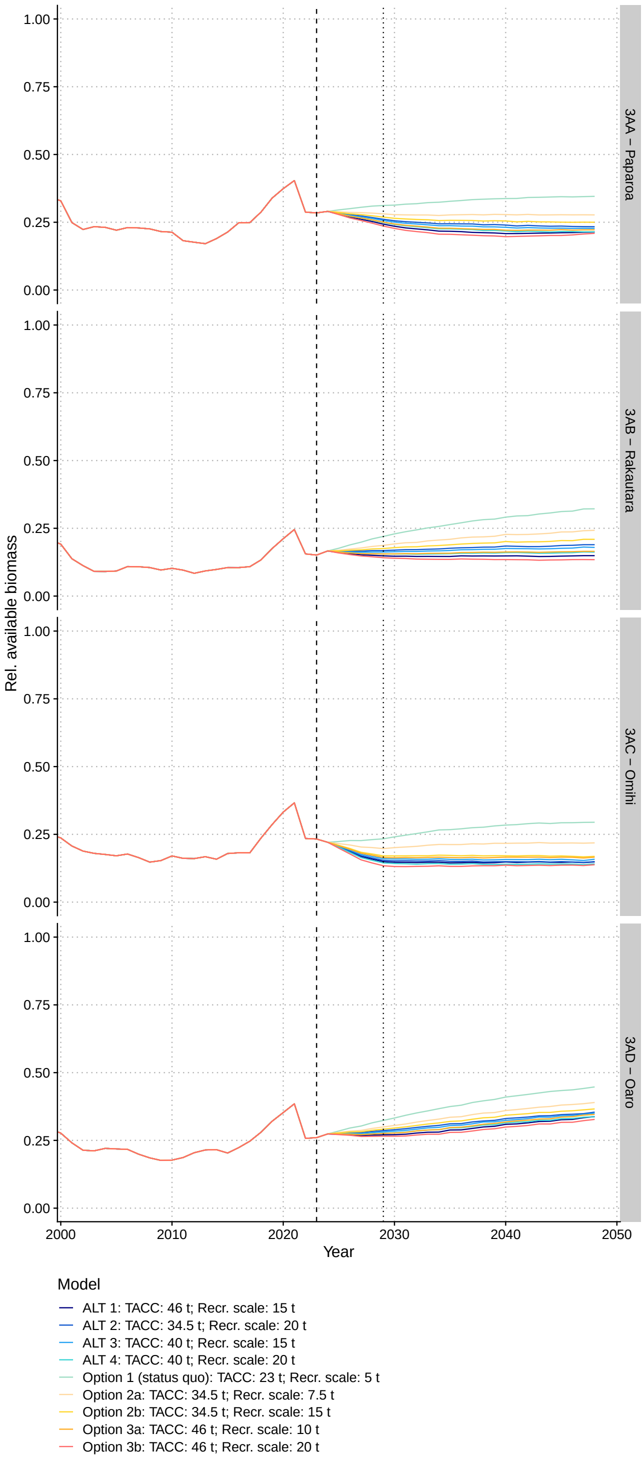

Figure H-2: Estimated and projected relative available biomass trend for pāua, comparing simulations from the base assessment model with alternative assumptions about the base level of recreational (Recr.) catch and commercial catch from 2024–2025 (TACC: Total Allowable Commercial Catch). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

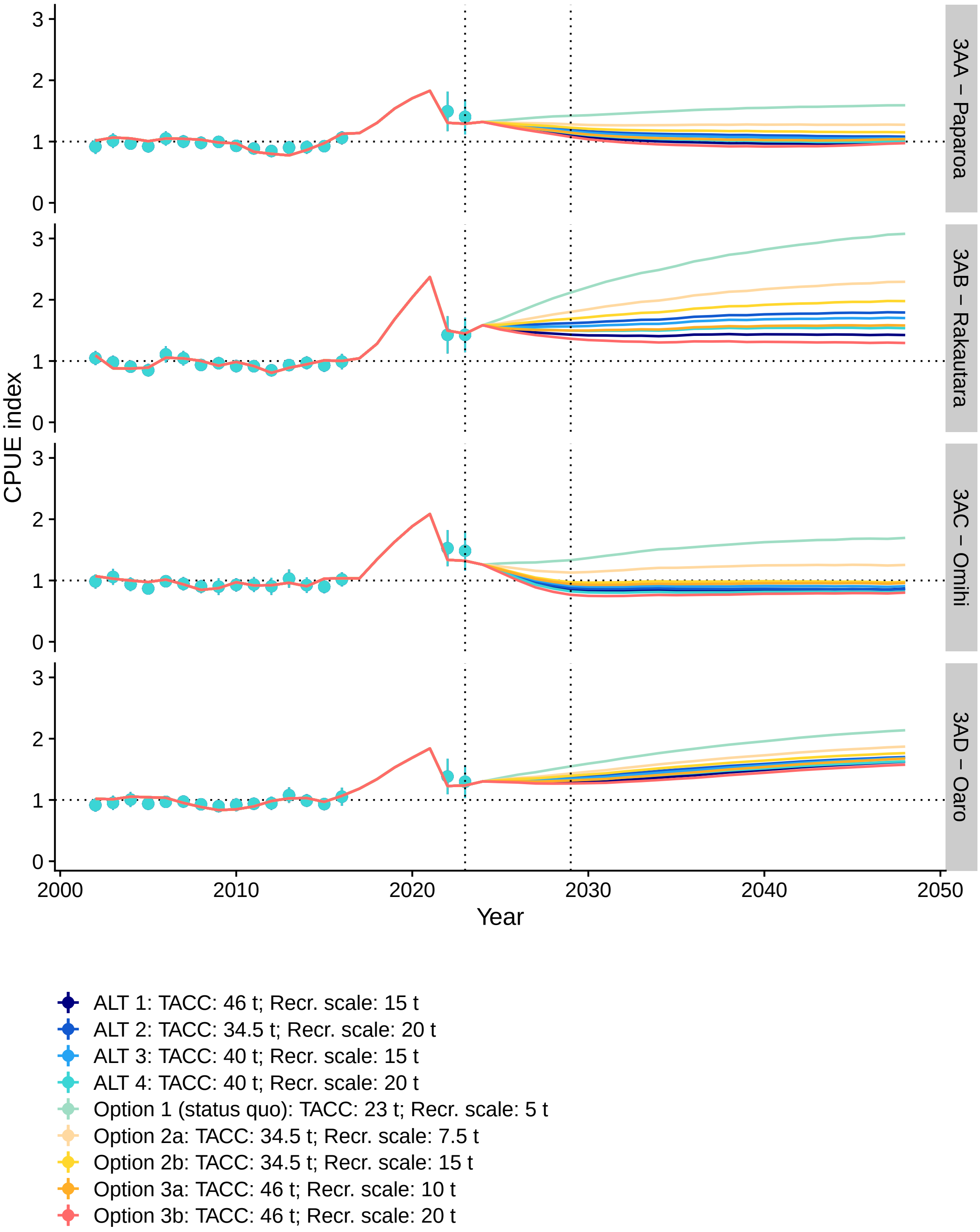

Figure H-3: Estimated and projected catch-per-unit-effort (CPUE) trend for pāua, comparing simulations from the base assessment model with alternative assumptions about the base level of recreational (Recr.) catch and commercial catch from 2024–2025 (TACC: Total Allowable Commercial Catch). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

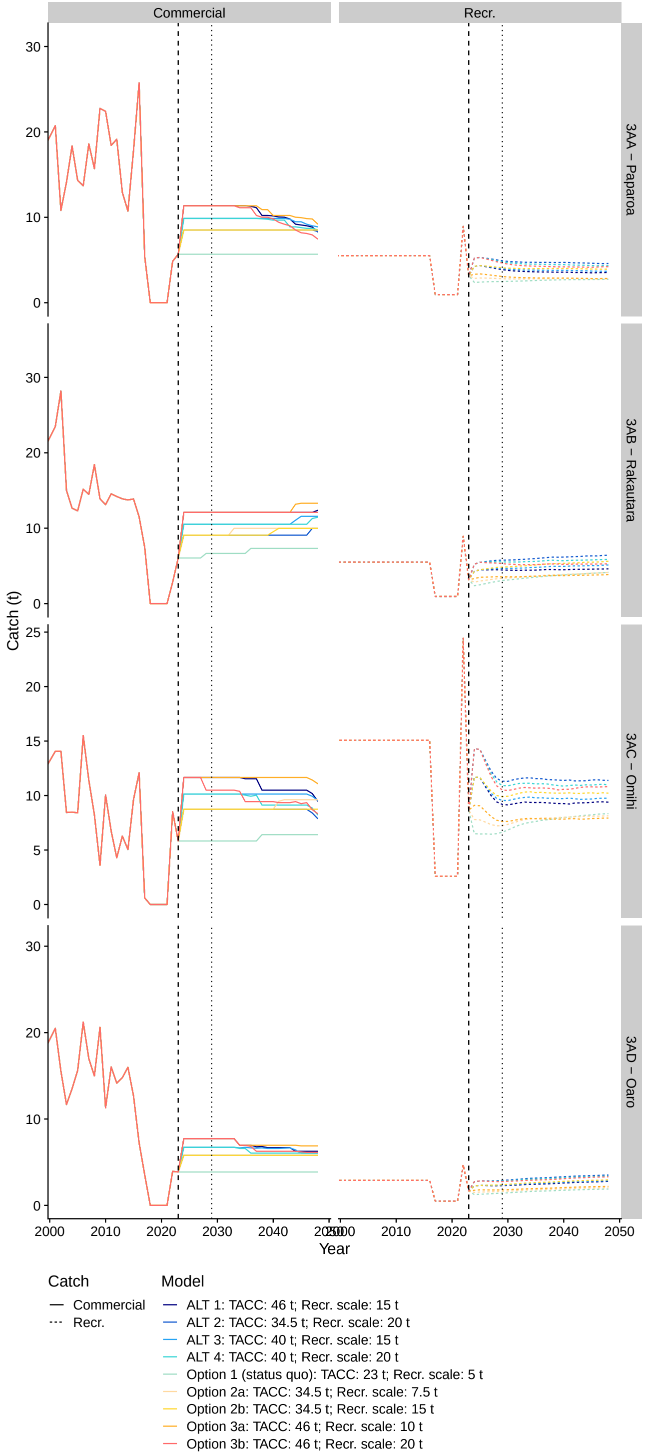

Figure H-4: Assumed and projected catch by sector, comparing simulations from the base assessment model with alternative assumptions about the base level of recreational (Recr.) catch and commercial catch from 2024–2025 (TACC: Total Allowable Commercial Catch). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Only medians from simulations were compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

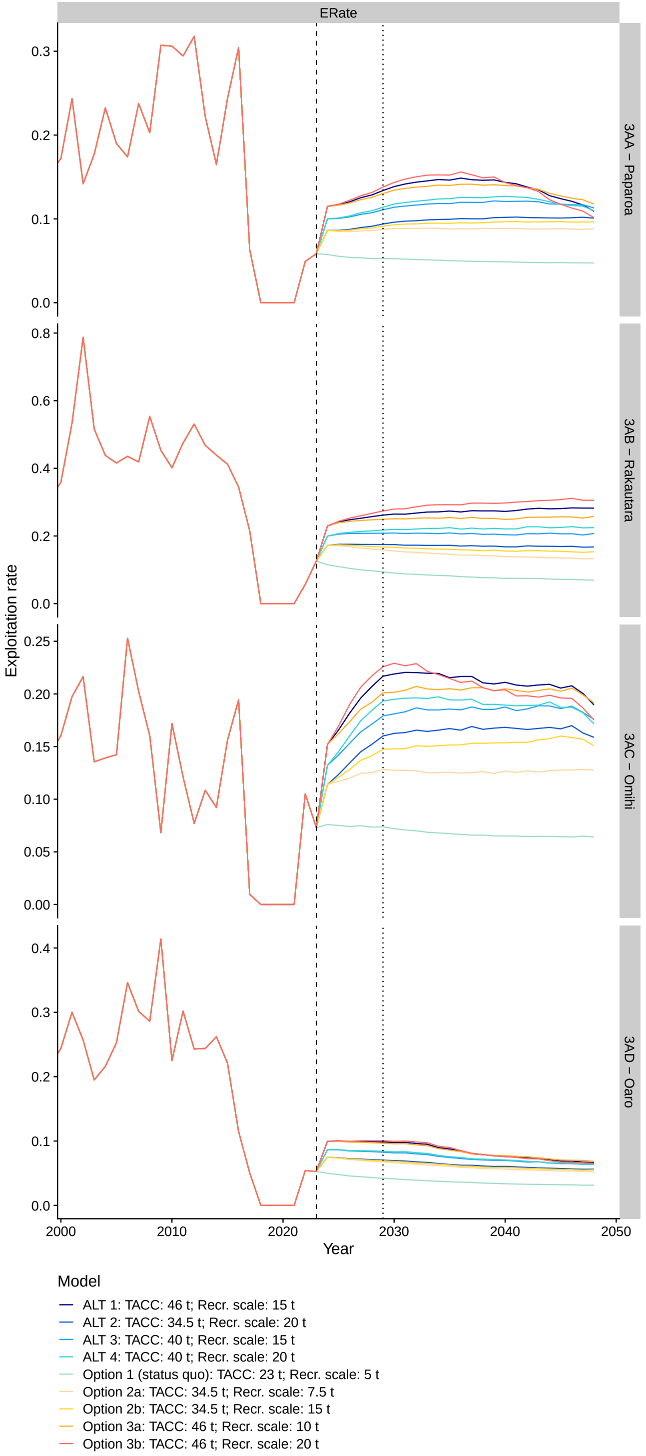

Figure H-5: Estimated and projected exploitation rate for the commercial pāua fishery (median line), comparing simulations from the base assessment model with alternative assumptions about the base level of recreational (Recr.) catch and commercial catch from 2024–2025 (TACC: Total Allowable Commercial Catch). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in Quota Management Area PAU 3A. Model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

Table H-1: Performance of tested management procedures, comparing simulations from the base assessment model with alternative assumptions about the base level of recreational (Recr.) catch and commercial catch from 2024–2025 (TACC: Total Allowable Commercial Catch). Management after 2025 was applied according to the tested spawning-potential-ratio target control rule for each management zone in quota management area PAU 3A. *SSB*, spawning stock biomass; CPUE, catch-per-unit-effort; TACC, Total Allowable Commercial Catch.

Model	Area	Mean rel. *SSB* (2029)	Mean rel. *SSB* (2048)	P(rel. *SSB* (2029) > 0.4)	P(rel. *SSB* (2048) > 0.4)	P(rel. *SSB* (2029) < 0.2)	P(rel. *SSB* (2048) < 0.2)	P(rel. *SSB* (2029) < 0.1)	P(rel. *SSB* (2048) < 0.1)	Mean rel. *SSB* (2024–2048)	Mean catch (t)	Mean CPUE (kg/h)
Option 1 (status quo): TACC: 23 t; Recr. scale: 5 t	All Regions	0.50	0.60	1.00	1.00	0.00	0.00	0.00	0.00	0.55	22803.42	93.33
Option 2a: TACC: 34.5 t; Recr. scale: 7.5 t	All Regions	0.47	0.53	1.00	1.00	0.00	0.00	0.00	0.00	0.50	33220.12	77.05
Option 2b: TACC: 34.5 t; Recr. scale: 15 t	All Regions	0.46	0.50	0.97	0.98	0.00	0.00	0.00	0.00	0.48	32660.63	69.69
Option 3a: TACC: 46 t; Recr. scale: 10 t	All Regions	0.45	0.47	0.93	0.95	0.00	0.00	0.00	0.00	0.46	41984.00	63.11
Option 3b: TACC: 46 t; Recr. scale: 20 t	All Regions	0.43	0.44	0.83	0.84	0.00	0.00	0.00	0.00	0.44	39381.05	56.79
ALT 1: TACC: 46 t; Recr. scale: 15 t	All Regions	0.44	0.46	0.89	0.90	0.00	0.00	0.00	0.00	0.45	40801.60	59.64
ALT 2: TACC: 34.5 t; Recr. scale: 20 t	All Regions	0.45	0.47	0.94	0.96	0.00	0.00	0.00	0.00	0.46	32103.27	65.66
ALT 3: TACC: 40 t; Recr. scale: 15 t	All Regions	0.45	0.47	0.93	0.95	0.00	0.00	0.00	0.00	0.46	37003.60	64.56
ALT 4: TACC: 40 t; Recr. scale: 20 t	All Regions	0.44	0.46	0.90	0.90	0.00	0.00	0.00	0.00	0.45	36076.29	61.11

APPENDIX I: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: NATURAL MORTALITY

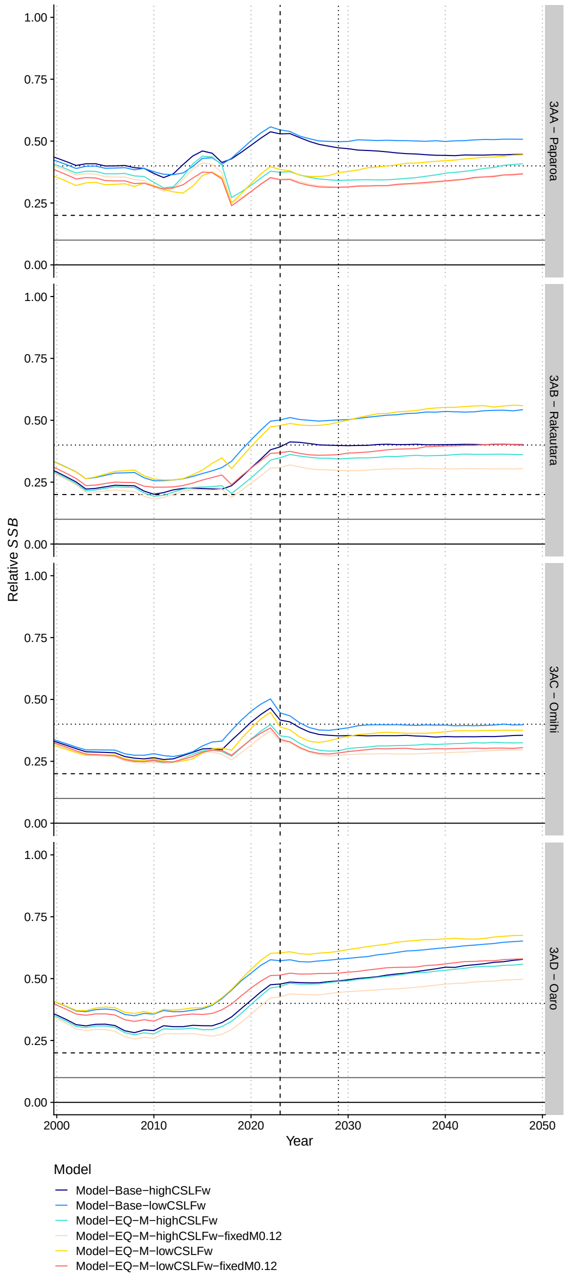

Figure I-1: Estimated and projected relative spawning stock biomass (*SSB*) trend for pāua, comparing plausible operating models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); natural mortality (fixed at 0.12, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), with management according to the tested spawning-potential-ratio target control rule assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

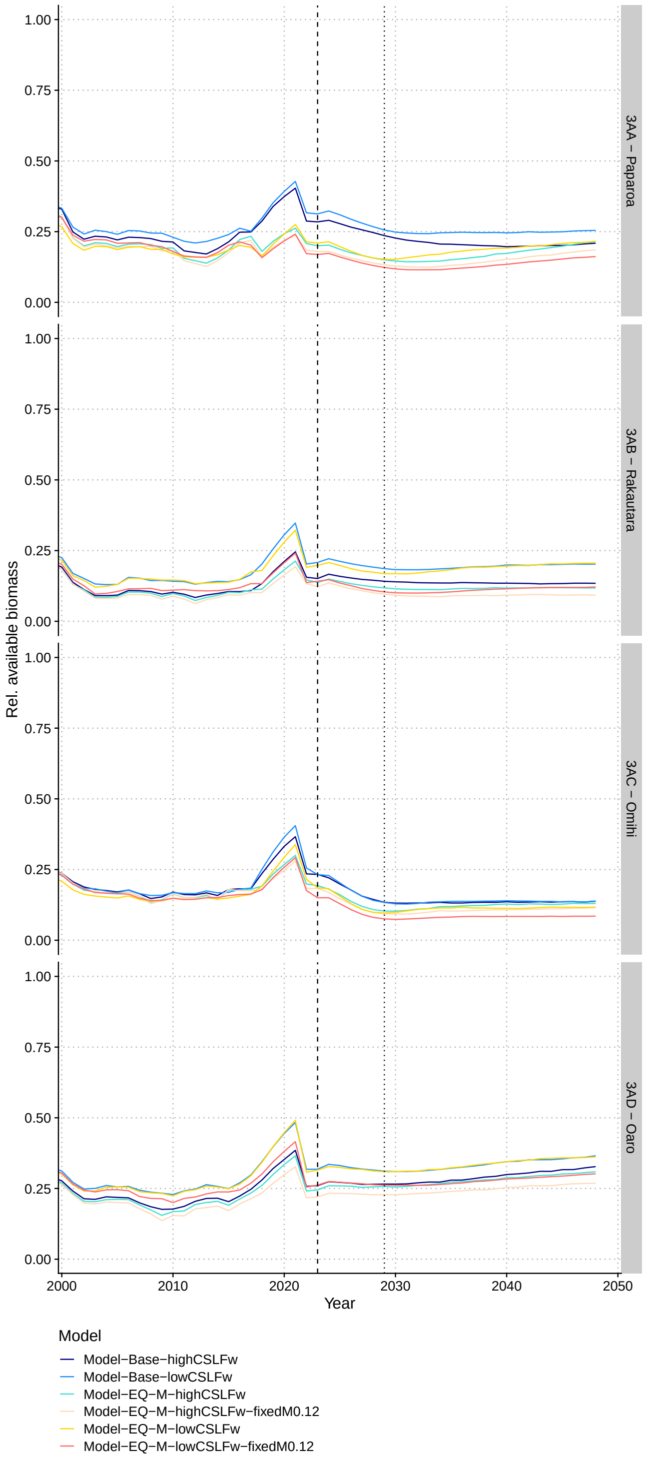

Figure I-2: Estimated and projected relative available biomass trend for pāua, comparing plausible operating models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); natural mortality (fixed at 0.12, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), with management according to the tested spawning-potential-ratio target control rule assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

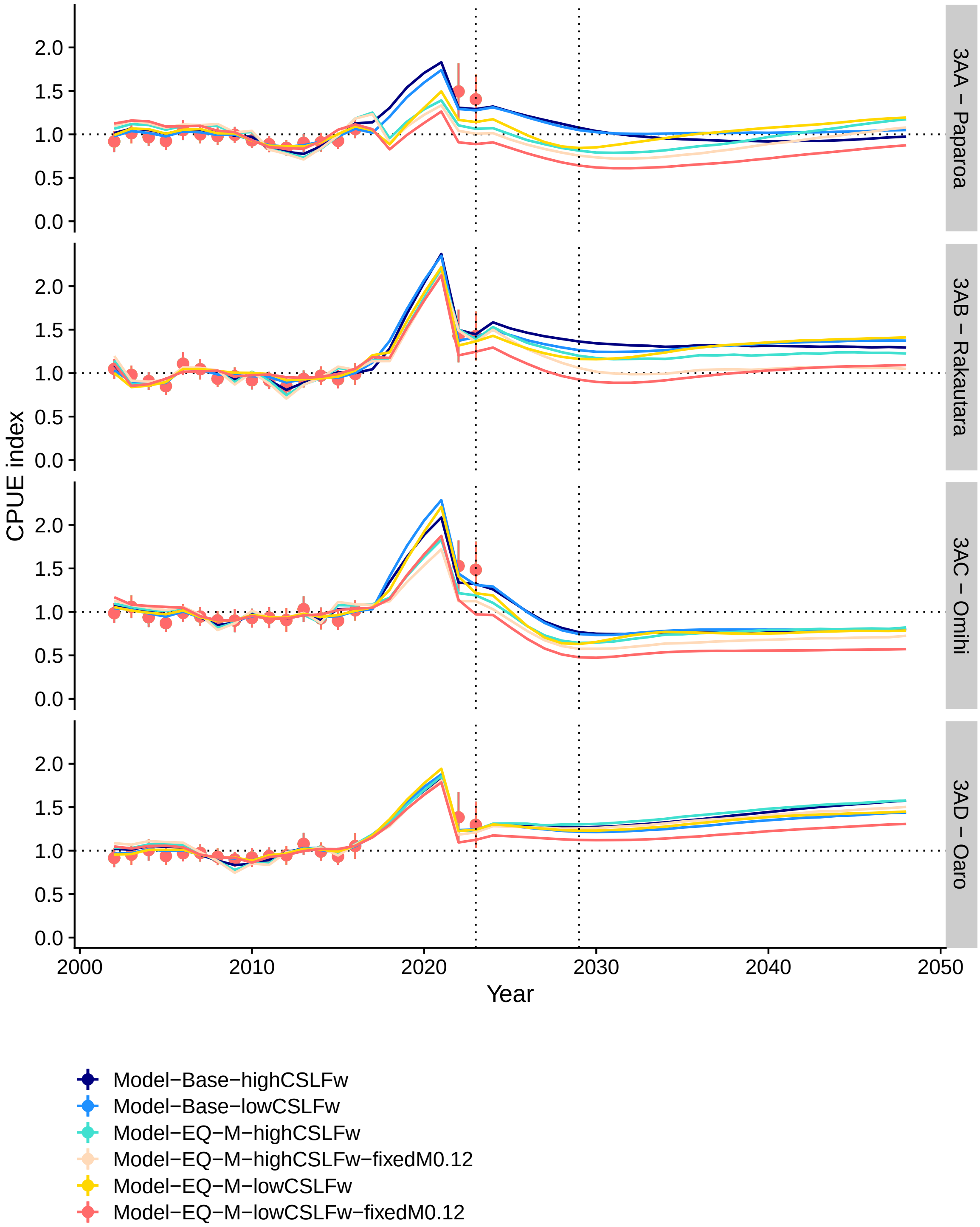

Figure I-3: Estimated and projected catch-per-unit-effort (CPUE) trend for pāua, comparing plausible operating models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); natural mortality (fixed at 0.12, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), with management according to the tested spawning-potential-ratio target control rule assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

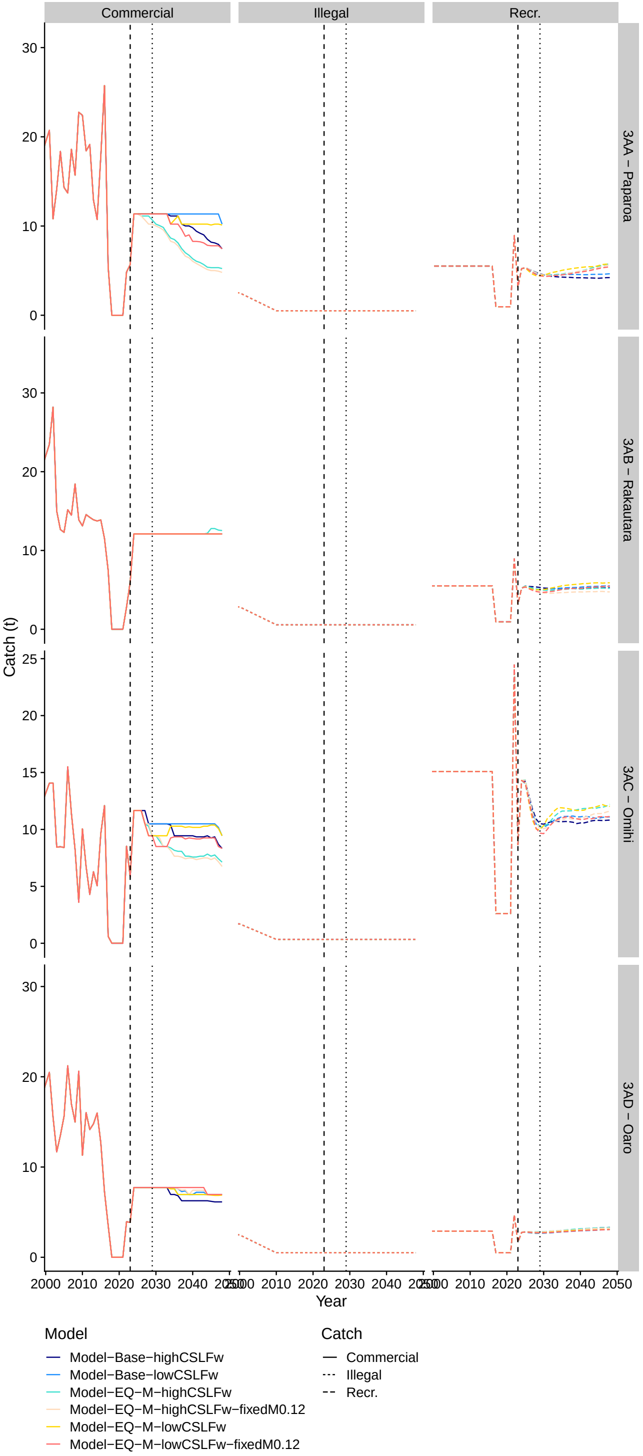

Figure I-4: Assumed and projected catch by sector, comparing plausible operating models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); natural mortality (fixed at 0.12, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), with management according to the tested spawning-potential-ratio target control rule assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations were compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

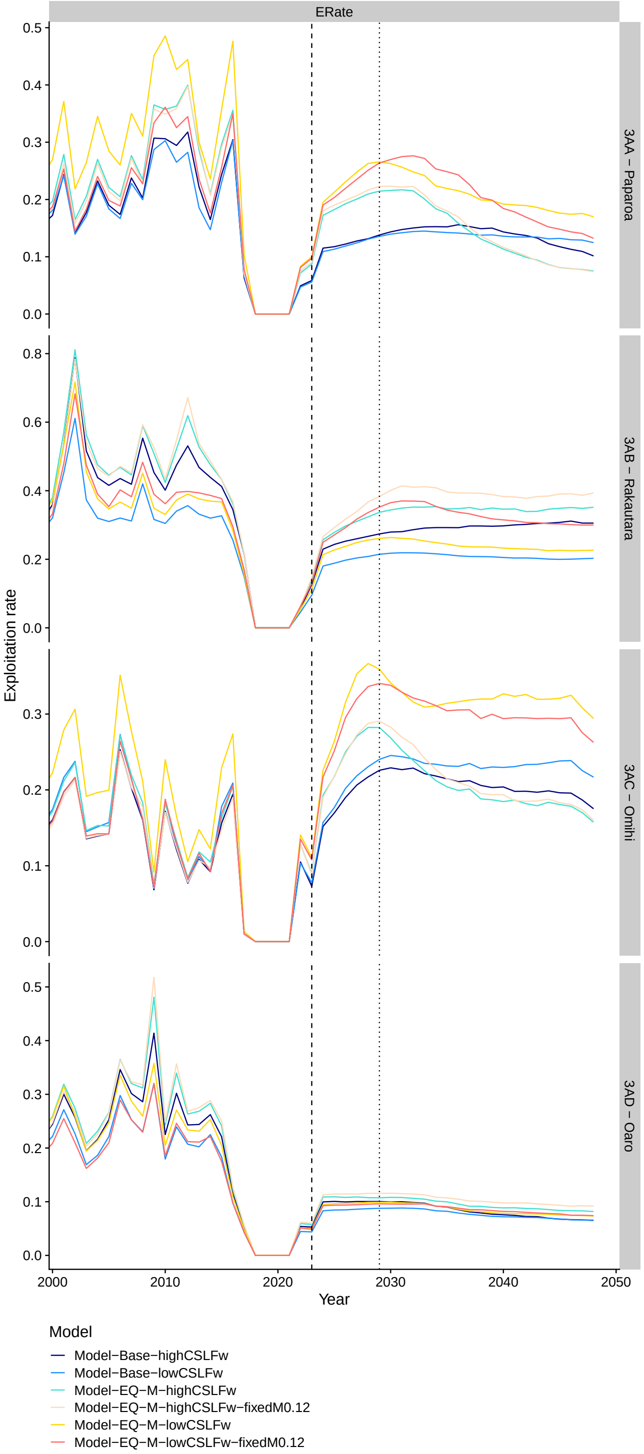

Figure I-5: Estimated and projected exploitation rate for the commercial pāua fishery (median line), comparing plausible operating models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); natural mortality (fixed at 0.12, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), with management according to the tested spawning-potential-ratio target control rule assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

Table I-1: Performance of tested management procedures, comparing plausible operating models with different assumptions about model weights for commercial length frequencies (CSLFw, high versus low weight); natural mortality (fixed at 0.12, length-based (estimated) or length-invariant (estimated); all other models); and explicit earthquake mortality (EqM), with management according to the tested spawning-potential-ratio target control rule assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in quota management area PAU 3A. *SSB*, spawning stock biomass; CPUE, catch-per-unit-effort; TACC, Total Allowable Commercial Catch.

Model	Area	Mean rel. *SSB* (2029)	Mean rel. *SSB* (2048)	P(rel. *SSB* (2029) > 0.4)	P(rel. *SSB* (2048) > 0.4)	P(rel. *SSB* (2029) < 0.2)	P(rel. *SSB* (2048) < 0.2)	P(rel. *SSB* (2029) < 0.1)	P(rel. *SSB* (2048) < 0.1)	Mean rel. *SSB* (2024–2048)	Mean catch (t)	Mean CPUE (kg/h)
Model-Base-highCSLFw	All Regions	0.43	0.44	0.83	0.84	0.00	0.00	0.00	0.00	0.44	39381.05	56.79
Model-Base-lowCSLFw	All Regions	0.49	0.53	1.00	1.00	0.00	0.00	0.00	0.00	0.51	40745.16	56.25
Model-EQ-M-highCSLFw	All Regions	0.37	0.41	0.14	0.61	0.00	0.00	0.00	0.00	0.39	36764.19	54.79
Model-EQ-M-highCSLFw-fixedM0.12	All Regions	0.33	0.37	0.00	0.14	0.00	0.00	0.00	0.00	0.35	36129.87	49.92
Model-EQ-M-lowCSLFw	All Regions	0.45	0.52	0.88	0.97	0.00	0.00	0.00	0.00	0.49	40324.64	55.00
Model-EQ-M-lowCSLFw-fixedM0.12	All Regions	0.37	0.42	0.13	0.62	0.00	0.00	0.00	0.00	0.39	38254.40	43.41

APPENDIX J: MANAGEMENT PROCEDURE EVALUATION MODEL COMPARISON: MPE PERFORMANCE INDICATOR ASSUMPTIONS

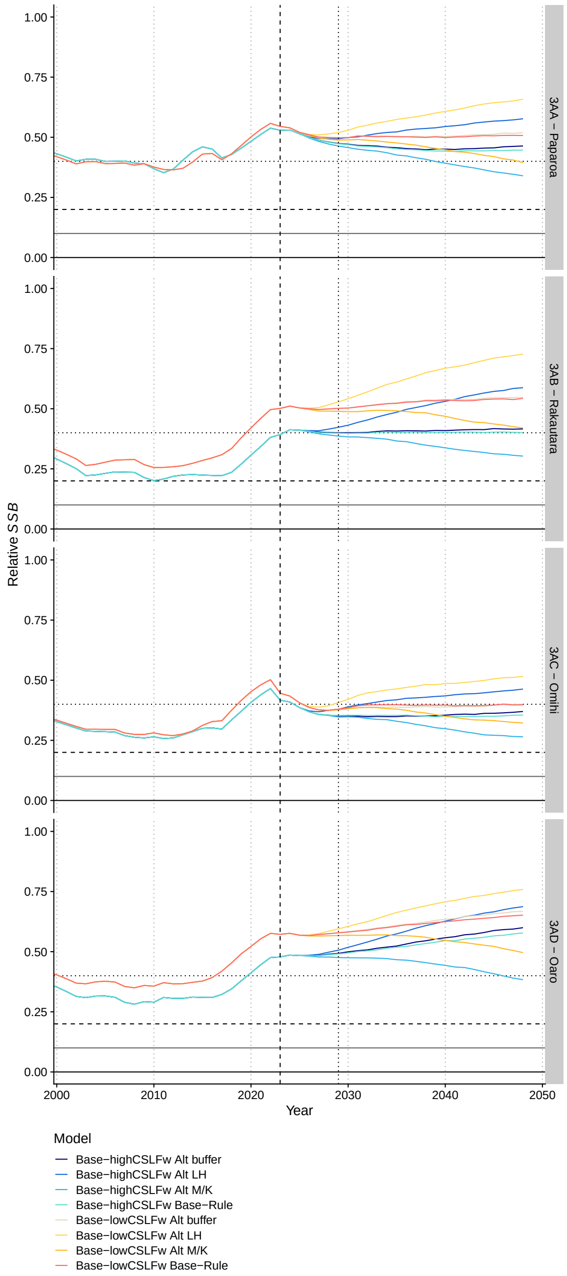

Figure J-1: Estimated and projected relative spawning stock biomass (*SSB*) trend for pāua, comparing comparing alternative assumptions for performance indicators (alternative buffer [20 instead of 10 percent], alternative M/K estimates for length-based spawning-potential-ratio estimators (0.9 instead of 0.6), and alternative life history LH; 10 percent increase in length-at-maturity and asymptotic length), assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

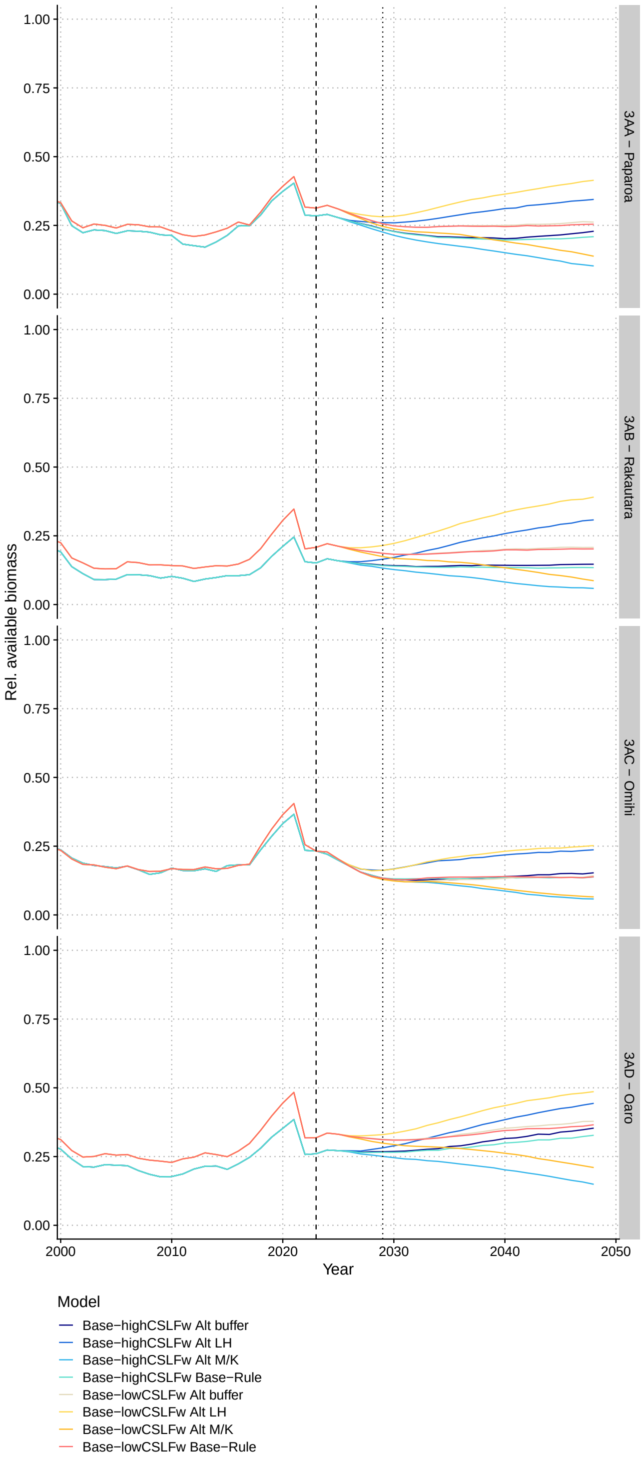

Figure J-2: Estimated and projected relative available biomass trend for pāua, comparing comparing alternative assumptions for performance indicators (alternative buffer [20 instead of 10 percent], alternative M/K estimates for length-based spawning-potential-ratio estimators (0.9 instead of 0.6), and alternative life history LH; 10 percent increase in length-at-maturity and asymptotic length), assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

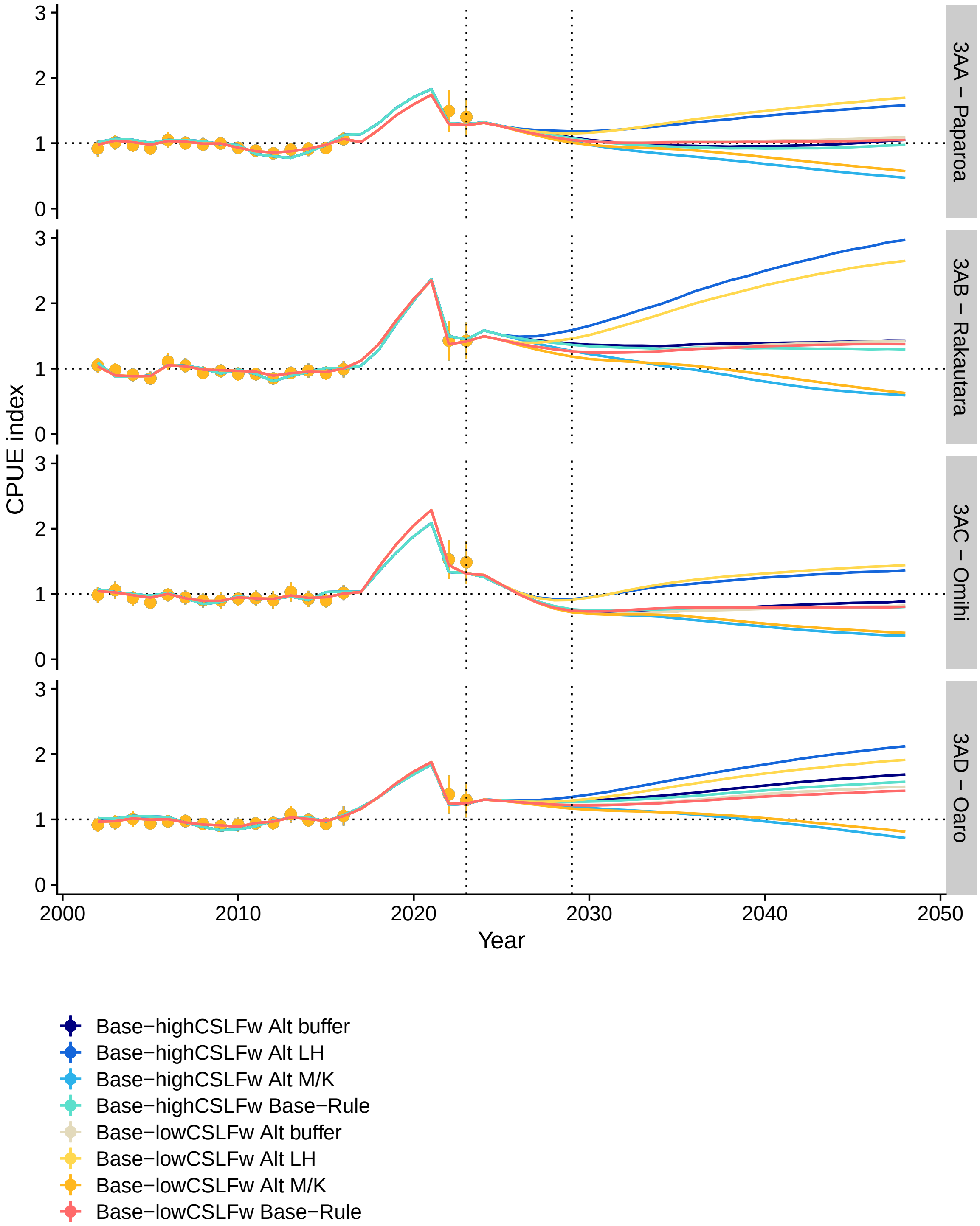

Figure J-3: Estimated and projected catch-per-unit-effort (CPUE) trend for pāua, comparing comparing alternative assumptions for performance indicators (alternative buffer [20 instead of 10 percent], alternative M/K estimates for length-based spawning-potential-ratio estimators (0.9 instead of 0.6), and alternative life history LH; 10 percent increase in length-at-maturity and asymptotic length), assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations are compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

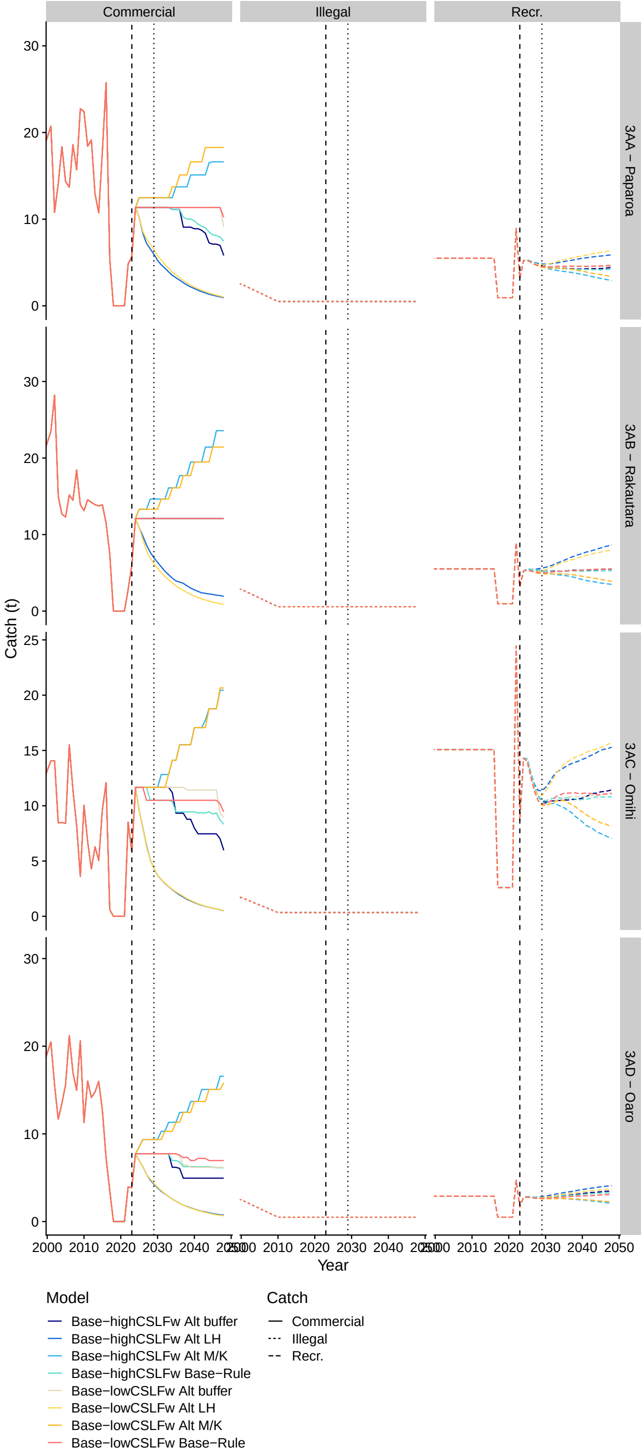

Figure J-4: Assumed and projected catch by sector, comparing comparing alternative assumptions for performance indicators (alternative buffer [20 instead of 10 percent], alternative M/K estimates for length-based spawning-potential-ratio estimators (0.9 instead of 0.6), and alternative life history LH; 10 percent increase in length-at-maturity and asymptotic length), assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Only medians from simulations were compared, and model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

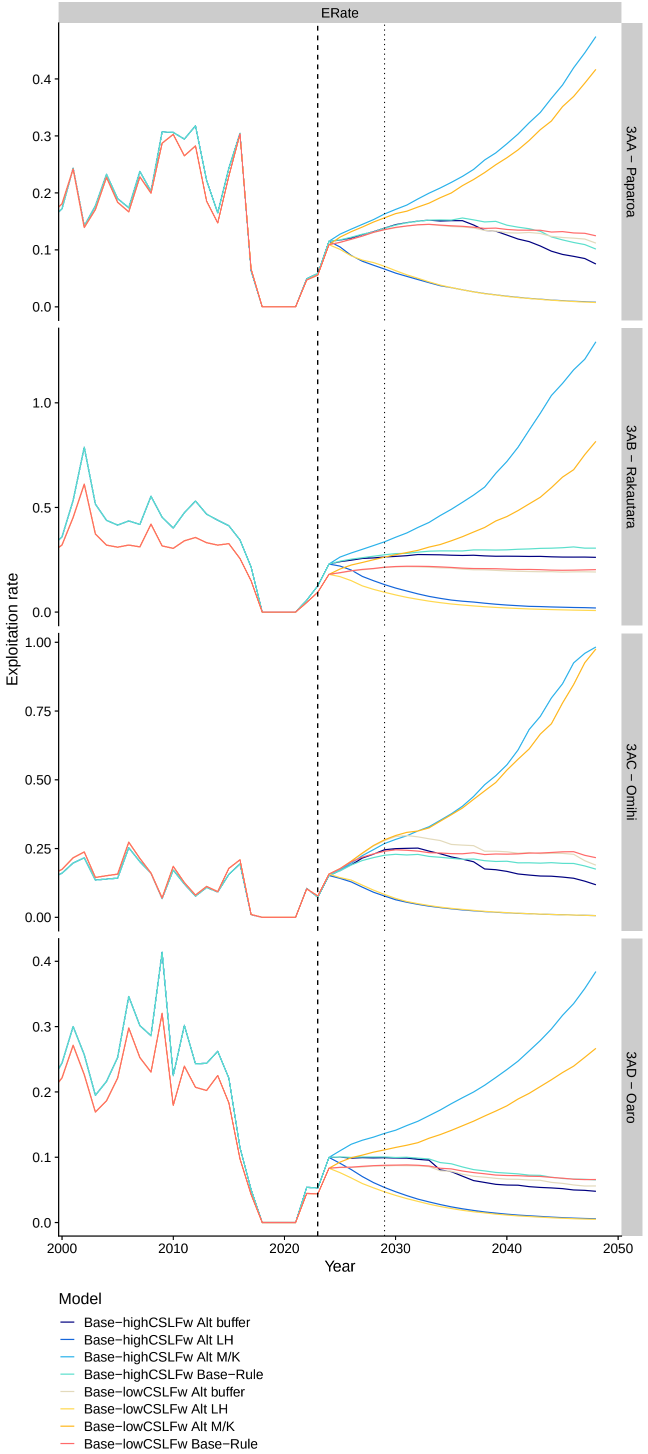

Figure J-5: Estimated and projected exploitation rate for the commercial pāua fishery (median line), comparing comparing alternative assumptions for performance indicators (alternative buffer [20 instead of 10 percent], alternative M/K estimates for length-based spawning-potential-ratio estimators (0.9 instead of 0.6), and alternative life history LH; 10 percent increase in length-at-maturity and asymptotic length), assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in Quota Management Area PAU 3A. Model trajectories may overlap over parts or all of the time series, so that only one realisation may be visible. 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 (5 years) of the tested rule. The final projection year was 2048.

Table J-1: Performance of tested management procedures, comparing comparing alternative assumptions for performance indicators (alternative buffer [20 instead of 10 percent], alternative M/K estimates for length-based spawning-potential-ratio estimators (0.9 instead of 0.6), and alternative life history LH; 10 percent increase in length-at-maturity and asymptotic length), assuming an increase in commercial catch to 46 t for the 2025 fishing year and a recreational allowance of 20 t, with allocation spread across each management zone proportionally to current catch for each management zone in quota management area PAU 3A. *SSB*, spawning stock biomass; CPUE, catch-per-unit-effort; TACC, Total Allowable Commercial Catch.

Model	Area	Mean rel. *SSB* (2029)	Mean rel. *SSB* (2048)	P(rel. *SSB* (2029) > 0.4)	P(rel. *SSB* (2048) > 0.4)	P(rel. *SSB* (2029) < 0.2)	P(rel. *SSB* (2048) < 0.2)	P(rel. *SSB* (2029) < 0.1)	P(rel. *SSB* (2048) < 0.1)	Mean rel. *SSB* (2024–2048)	Mean catch (t)	Mean CPUE (kg/h)
Base-highCSLFw Base-Rule	All Regions	0.43	0.44	0.83	0.84	0.00	0.00	0.00	0.00	0.44	39381.05	56.79
Base-lowCSLFw Base-Rule	All Regions	0.49	0.53	1.00	1.00	0.00	0.00	0.00	0.00	0.51	40745.16	56.25
Base-highCSLFw Alt LH	All Regions	0.45	0.58	0.92	1.00	0.00	0.00	0.00	0.00	0.51	14956.76	82.34
Base-lowCSLFw Alt LH	All Regions	0.50	0.67	1.00	1.00	0.00	0.00	0.00	0.00	0.58	14484.91	77.67
Base-highCSLFw Alt buffer	All Regions	0.43	0.46	0.84	0.90	0.00	0.00	0.00	0.00	0.44	36854.92	58.63
Base-lowCSLFw Alt buffer	All Regions	0.49	0.53	1.00	1.00	0.00	0.00	0.00	0.00	0.51	39849.08	56.40
Base-highCSLFw Alt M/K	All Regions	0.42	0.32	0.79	0.02	0.00	0.00	0.00	0.00	0.39	59354.31	43.62
Base-lowCSLFw Alt M/K	All Regions	0.48	0.41	1.00	0.58	0.00	0.00	0.00	0.00	0.47	59024.89	45.16