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The 2022 stock assessment of pāua (*Haliotis iris*) for PAU 7

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EXECUTIVE SUMMARY

Neubauer, P.[1] (2023). The 2022 stock assessment of pāua (*Haliotis iris*) for PAU 7.

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Most pāua (*Haliotis iris*) fisheries in Aotearoa New Zealand are managed with regular stock assessments that determine the stock status of a particular quota management area (QMA). Stock assessments are based on statistical models that estimate the current and projected stock status, and the exploitation rate of the portion of the population that is impacted by fishing.

The present assessment provides an updated assessment for QMA PAU 7, which was last assessed in 2016. The previous assessment found the stock to be near or below the soft limit, and the Total Allowable Commercial Catch (TACC) was subsequently reduced by 50% to allow the stock to rebuild. Shortly following this reduction, a large earthquake struck the Kaikōura region, affecting areas on the east coast of Te Waipounamu South Island that are within QMA PAU 7 (although this area did not form part of previous assessments). Following the earthquake, which caused large areas of uplift of intertidal and subtidal reefs above the high tide mark, the fishery within the affected area was closed; a further 10% of quota was shelved pending re-opening of the affected coastline for pāua fisheries.

The present assessment was initially carried out as single and multi-area assessments over sub-areas within QMA PAU 7. Areas in the initial assessment model were Cook Strait, Northern Faces (north coast Marlborough Sounds), and D'Urville Island. Due to the spatial closure following the earthquake, the east-coast component of the fishery was not assessed and is currently being monitored using dive surveys.

Models for sub-areas Northern Faces and D'Urville Island were only technically feasible under the assumption of low stock resilience (steepness). There is anecdotal evidence, corroborated by initial model runs, that these sub-areas are in an enduring state of low recruitment and low biomass with little sign of recovery. Nevertheless, the Shellfish Working Group concluded that the models are likely insufficiently informed about the cause of the lack of recovery. Therefore, the models were considered to be inadequate to support management advice for these sub-areas. There is currently little commercial catch in the Northern Faces and D'Urville Island sub-areas, suggesting that the lack or recovery may be due to environmental conditions or allee effects related to low spawning biomass. Neither of these phenomena can currently be informed with data in the assessment model.

The fishery was largely concentrated in the Cook Strait area, which has consistently been the largest component of the PAU 7 fishery. Although there have been relatively large reductions in overall catch from PAU 7 in recent years (i.e., post-2016), the concentration of fishing effort in Cook Strait has meant that overall take from the area has not been reduced proportionally. Nevertheless, the current status was estimated to still be below target, but CPUE and the fitted assessment suggested strong signs of rebuilding in this component of the fishery. This aspect was evident in the projected biomass suggesting a rebuild to target levels by 2026 under current catch levels of near 75 t per year under the agreed base case model. All model sensitivities confirmed this trend, with varying status estimates and rebuilding timelines depending on productivity assumptions.

[1] Dragonfly Data Science, New Zealand.

1. INTRODUCTION

The management of most pāua (*Haliotis iris*) stocks in Aotearoa New Zealand relies on stock assessments to estimate their status across quota management areas (QMAs). Of the eight pāua (*Haliotis iris*) QMAs that support substantial commercial fisheries (PAU 2, PAU 3A, PAU 3B, PAU 4, PAU 5A, PAU 5B, PAU 5D, and PAU 7), five QMAs have had regular stock assessments. These QMAs include the northern areas of Te Waipounamu South Island that make up the PAU 7 QMA. This report presents an updated stock assessment for the main PAU 7 fishery (Cook Strait). Additional analyses supported qualitative inference about trends in other areas such as the Northern Faces (north coast Marlborough Sounds) and D'Urville Island.

The PAU 7 QMA has been one of the most intensely-fished areas of Aotearoa New Zealand's pāua fisheries for a considerable time. The QMA comprises the main fishing grounds on the Cook Strait face of the Marlborough Sounds region (Cook Strait, Northern Faces, D'Urville Island), and distinct areas on the north-west and north-east coast of Te Waipounamu South Island (Figure 1). Considerable areas in the north-western region of Golden Bay and Tasman Bay are not commercially fished.

The area on the north-east coast of Te Waipounamu South Island was strongly affected by the 2016 earthquake that occurred near Kaikōura and caused substantial coastal uplift and associated pāua mortality. The area was subsequently closed to all fishing for five years, while dive surveys were used to monitor the rebuild of biomass post-earthquake (McCowan & Neubauer 2021). Strong recovery led to the re-opening of the fishery for a period of three months between 1 December 2021 and 28 February 2022. Nevertheless, due to considerable uncertainties about the impact of the earthquake on resident populations, the earthquake-affected area was not included in the present assessment. In this context, it is worth noting that the area was also not represented in previous assessments of PAU 7, albeit for different reasons (Fu 2016). The west coast area has been sporadically fished due to difficult dive conditions; for this reason, it has also not been included in formal stock assessments. In the current report, this area is only mentioned in the context of stock characterisation.

The previous assessment of PAU 7 showed a strong and persistent decline in the fishery, which had supported as much as 400 t or more in early years (Fu 2016). The previous assessment estimated a biomass near the soft limit of 20% of unfished spawning stock, which led to a subsequent reduction in the Total Allowable Commercial Catch (TACC) for PAU 7 by 50% to below 90 t in 2016. An additional 10% of annual catch entitlement (ACE) was subsequently shelved by the commercial pāua fishery to account for fishing grounds that were lost due to the closure following the Kaikōura earthquake. The most recent reduction in TACC in 2016 followed a trend of shelving and TACC reductions in the fishery, starting from its introduction into the quota management system (QMS) at well over 300 t. For these reasons, the current assessment provides a significant monitoring tool to assess the effectiveness of recent management interventions for this fishery, which up to 2016 had a continually declining trend.

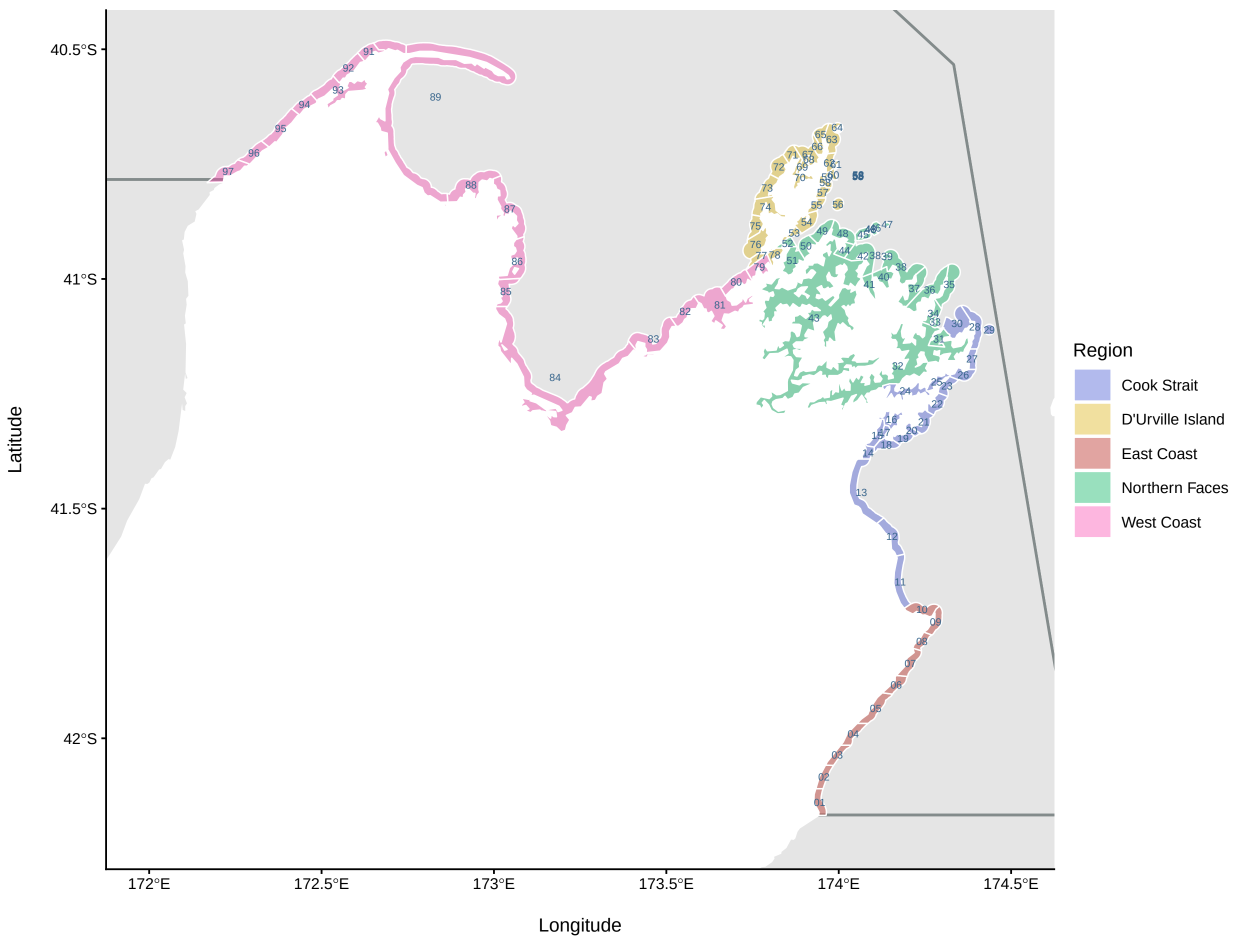

Figure 1: Pāua quota management area (QMA) PAU 7 at the top of Te Waipounamu South Island, including key spatial divisions (coloured). Catch reporting was initially at a lower spatial resolution of large statistical areas, and subsequently changed (in 2002) to finer-scale pāua statistical areas shown here (indicated by numbers).

2. METHODS

2.1 Inputs

Inputs for the PAU 7 stock assessment consisted of data of commercial catch, catch-per-unit-effort (CPUE) data from (Paua) Catch Effort Landing Return (PCELR) forms and the electronic reporting system (ERS), length-frequency data from commercial sampling (catch sampling length frequency, CSLF), and maturity and growth measurements from tagging by research divers. Catch assumptions for recreational, customary, and illegal take were agreed by the Shellfish Working Group (SFWG) and considered known.

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, therefore, had to be reconstructed for the assessment period from 1965 to 2021 (Table 1). Data sources for early catch included early reports of commercial pāua catch (Murray & Akroyd 1984), the Fisheries Statistical Unit (FSU) database (for the period 1983–1989), and catch effort data supplied by Fisheries New Zealand (Figure 2).

No data are available prior to 1974, and a simple linear ramp in catch was used between 1965, which was assumed to be the start of the commercial fishery, to the first catch data point in 1974. For some of the early part of the catch history (1974–1983), the commercial catch reconstruction used data reported by Murray & Akroyd (1984); however, catches in this period are considered to be uncertain: while examining export records, the report authors found that exports substantially exceeded reported catch (Murray & Akroyd 1984). Their same report also included a column of export weights per year that were not attributed to any QMA at the time. In previous stock assessments for PAU 7, estimates provided by Schiel (1992) were used for early catches, which in turn appeared to be derived from methodologies developed by Schiel (1989). These caches were treated as known without error. Schiel (1992) also attributed unknown catches to QMAs on the basis of reported area catch, which assumes that unreported catch was higher for areas with high reported catch. This assumption contrasts with recent assessments in other quota management areas (e.g., PAU 2, Neubauer 2022), for which an agreed proportion of these unknown or unreported catches was used to inflate early catch estimates. For this catch attribution, a smoothing window was applied with fixed weights, using 50% and 25% of the reported values in the following years and adding them to the reported values in each year. The smoothing window was applied forward in time: each year, reported values were successively adjusted for the amount attributed to the catch in previous years to account for exported catch potentially deriving from fishing that occurred in previous years; half of this backward-smoothed catch was arbitrarily added to PAU 7 to inflate early catches. This procedure produced catch estimates that are close to estimates by Schiel (1989) for that period and provides a reproducible template for exploring alternative catch assumptions in the future.

Catch reported by the FSU is included by Schiel (1989) and the FSU database. These sources are in agreement for all but the first year, for which estimates included by Schiel (1989) are higher and more in line with catches in preceding years. For 1985 and 1986, estimates from both sources appeared unrealistically low. For this reason, the SFWG agreed to use a linear interpolation between 1984 and QMR/MHR (Quota Management Report/Monthly Harvest Return) reporting in 1987 to generate catch estimates for these two years. From 1987 onwards, QMR/MHR catch estimates were used (see Table 1).

Table 1: Data source for pāua catch used in the current assessment by period. QMR/MHR, Quota Management Report/Monthly Harvest Return.

Period	Source	Sensitivity
1965–1973	Linear increase from 1 t to 1974 value	–
1974–1984	Murray & Akroyd (1984) (as cited by Schiel 1989)	Reported catch + 0.5· unknown catch
1985–1986	Linear interpolation between 1984 and 1987	–
1987–2022	QMR/MHR reporting	–

The present assessment was applied over fine-scale spatial areas (see Figure 1). These areas do not readily correspond with previous reporting strata, but reflect current understanding of regional stock dynamics and industry management. Importantly, Cook Strait (fine-scale Statistical areas 11 to 30), Northern Faces (Statistical areas 31–52), and D'Urville Island (Statistical areas 53–78) are used to manage the current fishery, with West Coast and East Coast strata forming separate areas that were not included in the present assessment. From 1984 to 1995, catch was reported at the unit of research strata (Statistical areas 017 (Cook Strait), 018 (East Coast), 036 (West Coast), and 038 & 039 (D'Urville Island West Coast)). Previous assessments used data from Statistical areas 017 and 038/039, and adjusted total catch for proportions of catch recorded in catch effort data (FSU, CELR, PCELR) from each area (Fu et al. 2016). The present subdivision of the greater Cook Strait area (Statistical areas 017 & 038) into smaller strata, however, means that early catches needed to be attributed based on more recent fine-scale reporting data. Catch has been reported at the level of fine-scale pāua statistical areas (on PCELR forms) since 2002. To attribute early catch to current assessment strata in years prior to the introduction of fine-scale reporting, catch pre-2002 was divided according to estimated catch proportions from PCELR forms. For this approach, only the first four years of PCELR data were used to avoid changing proportions due to a shift of catch and effort into Cook Strait over the latter period of PCELR catch.

Catch from the D'Urville Island and Northern Faces regions has declined continuously since the advent of PCELR data. Both regions changed from supporting nearly 40 t of catch annually to almost being absent from the fishery in recent years (Figure 3). By contrast, the Cook Strait region has been continuously fished, and in recent years has provided most of the commercial catch.

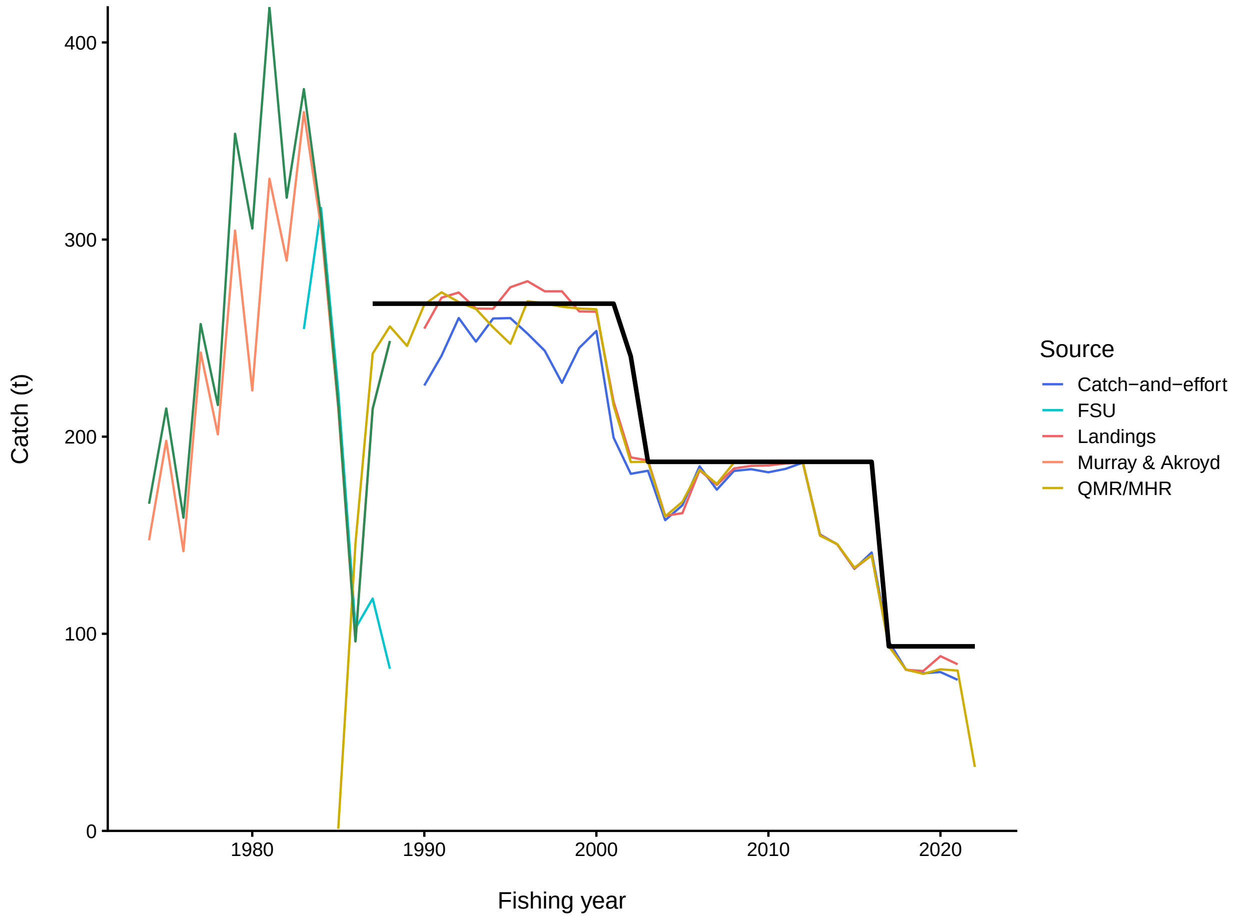

Figure 2: Commercial catch history for pāua quota management area PAU 7 from 1974 to 2021 and Total Allowable Commercial Catch (TACC; black line). Catch to 1983 was reconstructed from data reported by Murray & Akroyd (1984; light red line). The dark green line for the same period indicates the high catch scenario for the same period. Data for 1983–1989 were from the Fisheries Statistical Unit (FSU) database (teal line), but were not used in the assessment because catches were considered to be unrealistically low. Catch-effort data from 1989 were supplied by Fisheries New Zealand (catch-and-effort, blue; landings, dark red). Reported QMS (Quota Management System) harvest returns are shown in orange (QMR/MHR, Quota Management Report/Monthly Harvest Return).

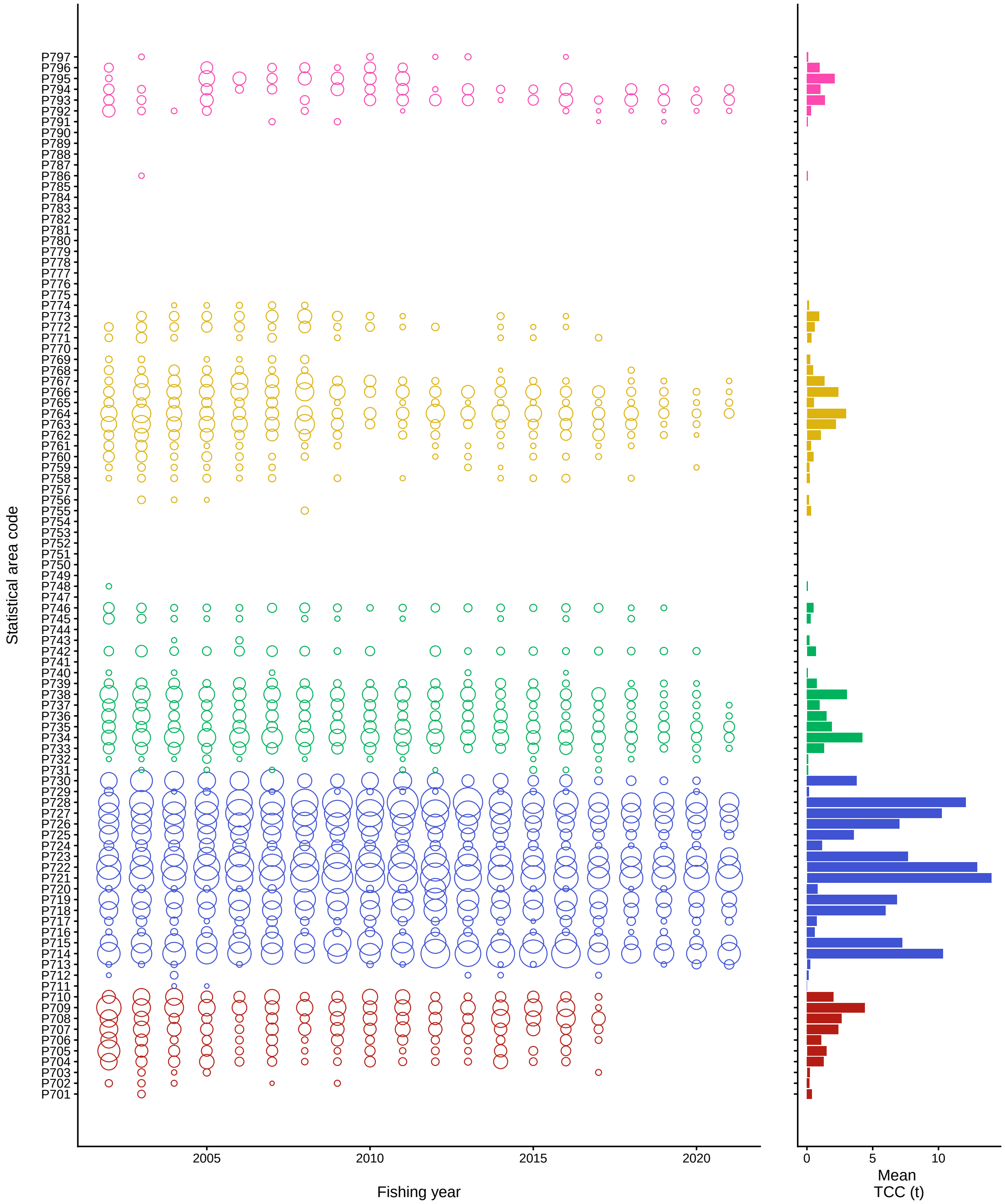

Figure 3: Relative trend in pāua catch (kg) over time by pāua statistical areas in quota management area PAU 7 for the period from 2002 to 2020, with total commercial catch (TCC) over the same time period right-hand side). Key spatial divisions within PAU 7 are colour-coded in accordance with Figure 1.

2.1.2 Recreational, customary and illegal catch

For recreational catch, two estimates from the National Panel Survey provide some, but limited, information (for pāua) for PAU 7 (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019). The survey estimated that about 50 534 individual pāua, or 14.13 t (CV of 34%) were taken by recreational fishers in PAU 7 in the 2011–12 fishing year. The National Panel Survey was repeated in 2017–18, when the estimated recreational catch was 3.02 t (CV of 36%). For the current stock assessment, the SFWG agreed to assume that recreational catch was 5 t in 1974, which increased linearly to 15 t in 2000, remained at 15 t until 2008, before subsequently declining to 2 t by 2018.

For customary catch, there has been no comprehensive information in recent years. Customary reporting suggested a relatively variable customary catch, with little or no reporting since 2012. For this stock assessment, the SFWG agreed to assume that customary catch was 1 t in 1974, increased linearly to 2 t between 1974 and 2000, then remained at 2 t until 2015, with recent catches around 1 t.

Illegal catch was thought to be high throughout the 1990s when pāua prices increased. Subsequent enforcement efforts are considered to have led to substantial reductions in illegal take since the early 2000s. The SFWG agreed to assume an increase in illegal catch from 1 t up to 1974 to 15 t annually by the 1999–2000 fishing year. Subsequent reductions from 15 t to 2.5 t between 2005 and 2010 reflected increasing enforcement, with steady illegal take at 2.5 t assumed for years since 2010.

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

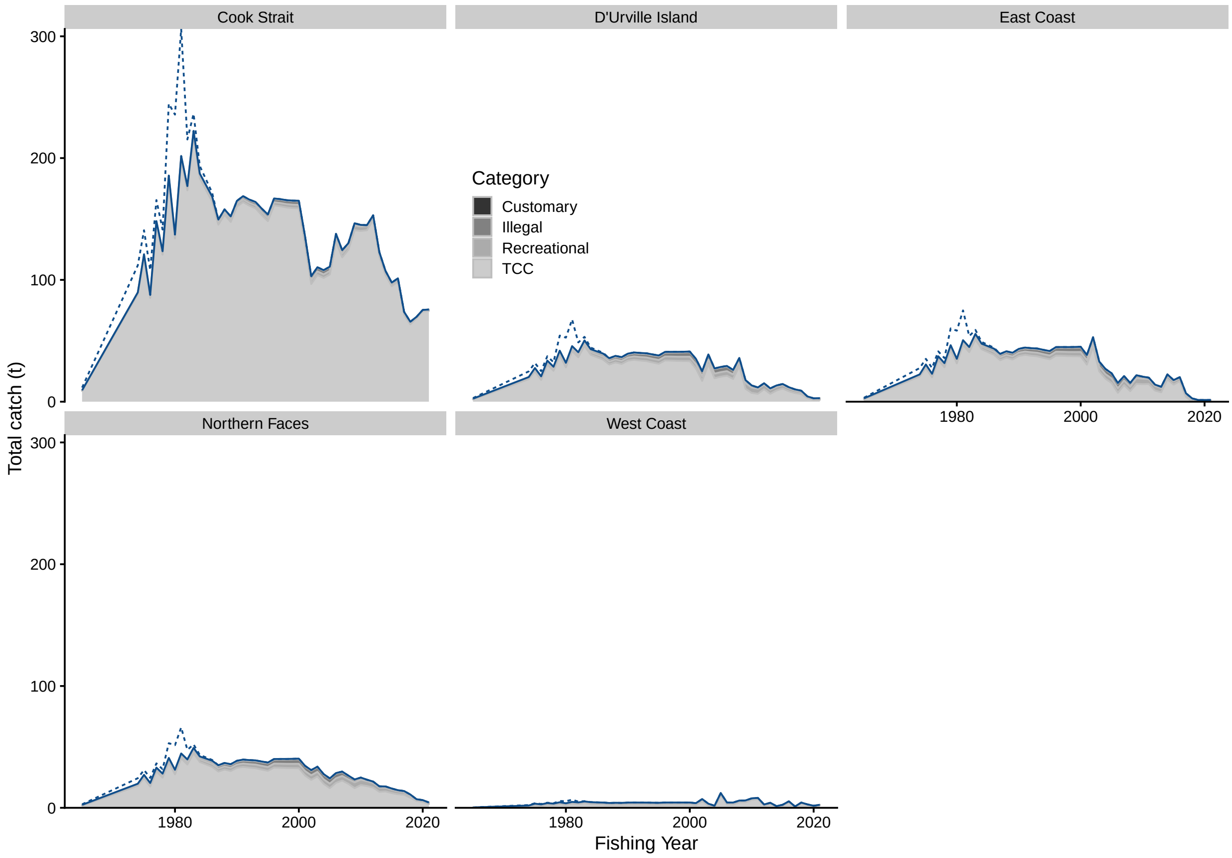

Figure 4: Estimated total catch history for quota management area (QMA) PAU 7 from 1974 to 2019 by fishery component and reporting area. Fishery categories were customary, illegal, recreational and commercial (Total Commercial Catch, TCC) catch. Commercial catch was reconstructed up to 1995, when the QMA was created, and based on landing records thereafter.

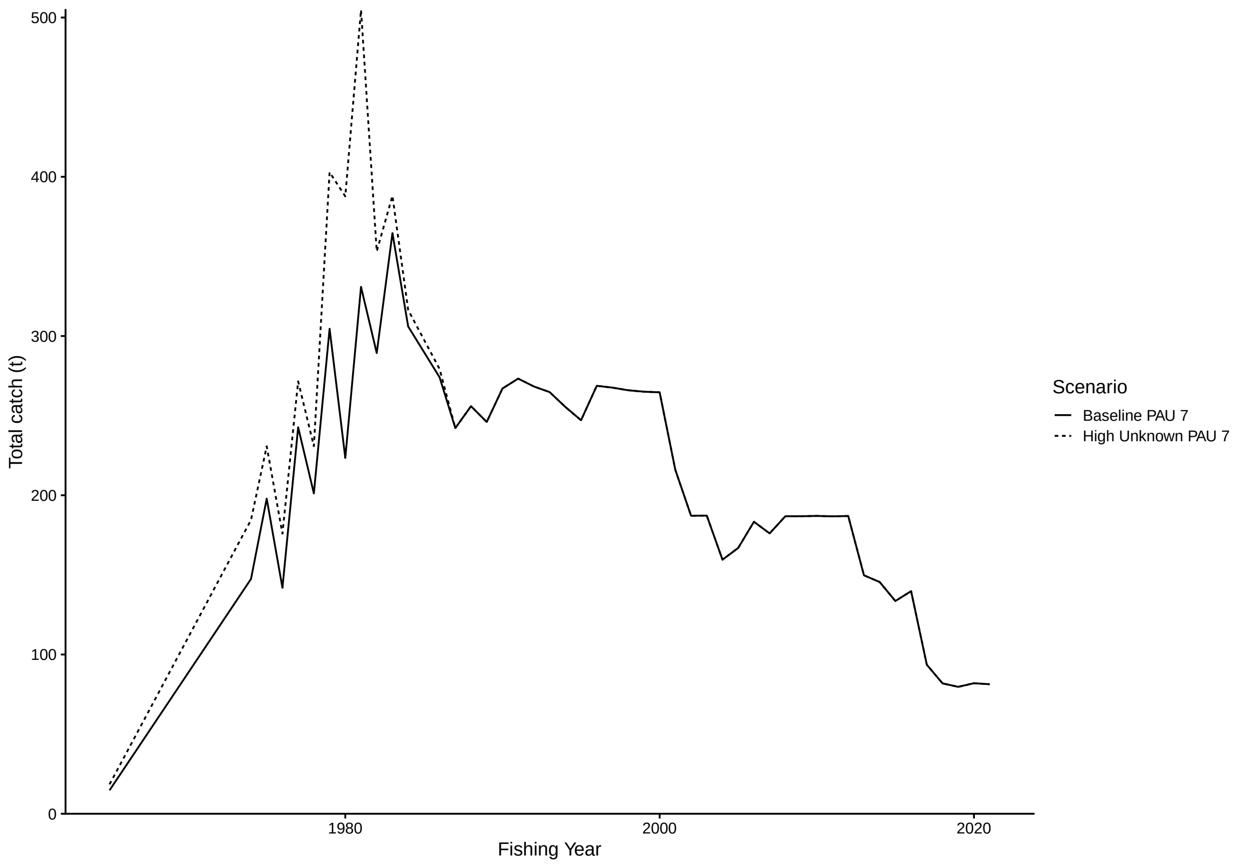

Figure 5: Total pāua catch history used in the single-area stock assessment for PAU 7 from 1965 to 2021 as the sum of all catch components (commercial, customary, recreational, and illegal catch). Dashed line shows catch scenario of highly unknown catch for PAU 7.

2.1.3 Catch-per-unit-effort (CPUE)

In contrast to previous analyses of CPUE in PAU 7, the present assessment only considered PCELR (2002 to 2019) and ERS data (2020–2021). Data from the FSU and CELR forms were used in previous assessments (CELR data were used up to 2020), but these data have been rejected because they are considered to be too unreliable to provide a proxy for trends of relative abundance in pāua QMAs. Poor reporting, considerable changes in the fishing fleet and operations (e.g., increases in fishing power) are considered likely to lead to an unknown degree of hyper-stability in these time series. These changes and reporting deficits had mostly disappeared and the fleet stabilised by the time PCELR reporting was introduced in 2002. The PCELR data are, therefore, considered to be robust indicators of abundance since the early 2000s.

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

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 (5 years), and divers with less than 3 years experience.
4. Retain only events with up to four recorded divers, and a recorded fishing duration of $\leq$10 h, and CPUE between 10 and 200 kg/h.

For recent electronic reporting system (ERS) data, the same procedure was followed (Table 3). Alternative data preparation procedures developed for ERS data (P. Neubauer, unpubl. data) were meant to correct for potential misreporting in ERS data or differences relative to data reported on PCELR forms. Nevertheless, these data preparation steps did not change the CPUE in areas of interest for the current assessment (Cook Strait) and were, therefore, not applied in the present analysis.

The PCELR and ERS data from 2002 were combined to derive a single standardised, fishery-dependent index of abundance. The 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 number, research stratum, and diver identification (PCELR). Previous standardisation models for PCELR data routinely used fine-scale statistical areas as a standardising variable. For the present assessment, this variable was not available with sufficient precision for recent (ERS) data, where it is inferred from position data; it was, therefore, omitted. Nevertheless, a follow-up examination of the quality of ERS data for pāua CPUE suggested limited effects of spatial reporting; in addition, the inclusion of statistical areas in the standardisation had little influence on the resulting indices for Cook Strait. Indices for other subareas were sensitive to the inclusion of statistical area.

Table 2: Data preparation steps and number of records removed for data from Paua Catch Effort Landing Return (PCELR) forms by year and in total (as number and percentage of records retained). FIN, 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	2018	2019	2020	Total	Retain (%)
All	180	182	157	165	184	173	182	183	182	183	186	149	145	128	133	94	82	71	1	2760	100.00
Missing fields	180	182	157	165	184	173	182	183	182	183	186	149	145	128	133	94	82	71	1	2760	100.00
FIN years ≥ 5	170	153	142	150	173	173	182	172	180	181	185	148	144	127	131	92	80	71	1	2655	96.20
Diver years ≥ 3	143	143	133	142	166	167	179	168	173	172	181	145	139	122	127	90	75	63	1	2529	91.63
No. of divers ≤ 4	143	143	133	142	166	167	179	168	173	172	181	145	139	122	127	90	75	63	1	2529	91.63
Fishing duration ≤ 10h	143	143	133	142	166	167	179	168	173	172	181	145	139	122	127	90	75	63	1	2529	91.63
10kg/h $\leq$CPUE $\leq$200kg/h	122	118	109	129	162	165	177	167	171	171	177	142	136	118	123	86	71	61	1	2406	87.17

Table 3: Data preparation steps and number of records removed for data from Electronic Reporting System (ERS) reports by year and in total (as number and percentage of records retained). FIN, fisher identification number, CPUE, catch-per-unit-effort.

Data preparation	2020	2021	2022	Total	% retained
All	80	77	47	204	100.00
FIN years ≥ 5	80	77	47	204	100.00
Diver years ≥ 3	68	68	43	179	87.75
No. of divers ≤ 4	68	68	43	179	87.75
Fishing duration ≤ 10h	68	68	43	179	87.75
10kg/h $\leq$CPUE $\leq$ 200kg/h	66	67	43	176	86.27

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. Standardised CPUE in all areas suggested increases in recent years, most notably in Cook Strait, and highly variable trends in raw CPUE in other areas (Figure 7). Although initial models were attempted for D'Urville Island and Northern Faces, the SFWG decided that CPUE may no longer be representative of these areas as a whole. This decision was based on recent reductions and spatial concentration of catch in these areas to a limited number of statistical areas.

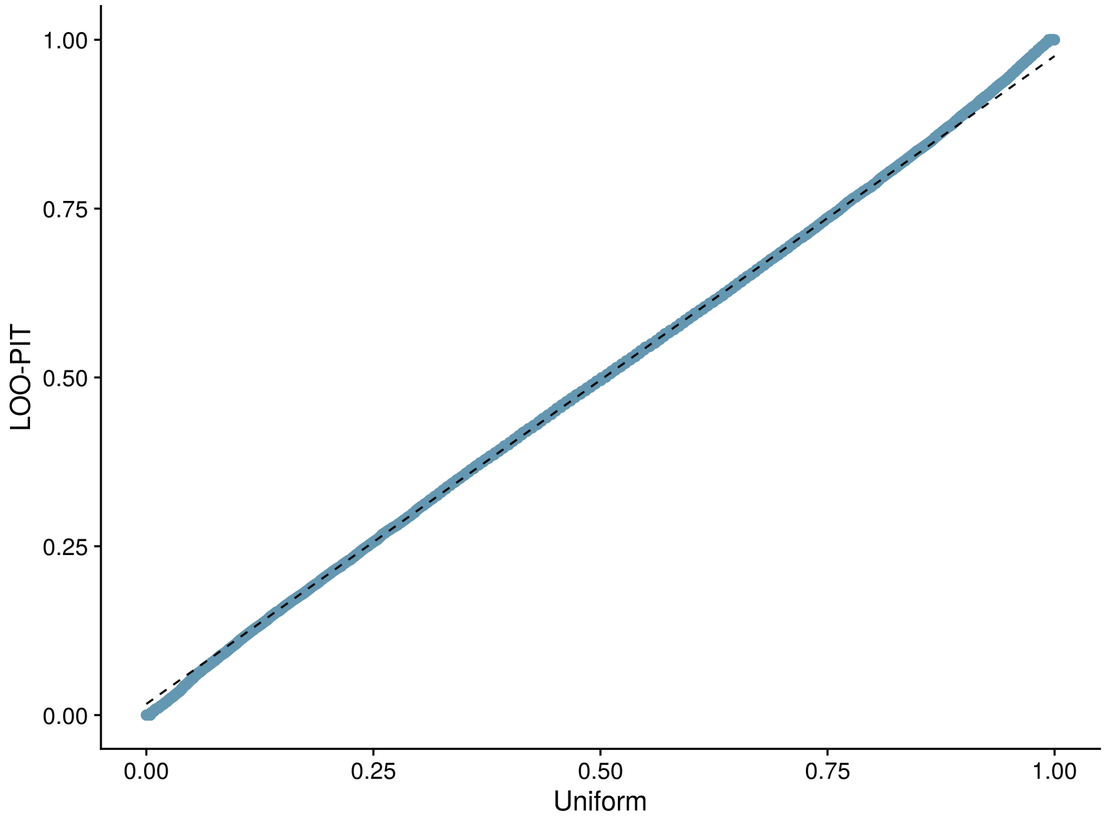

Figure 6: Fit of the log-normal generalised linear mixed model used for catch-per-unit-effort (CPUE) index standardisation. The quantile-quantile plot compares the PIT (Probability Integral Transform) of the leave-one-out (LOO) posterior predictive distribution to the theoretically expected uniform distribution.

For Cook Strait, the standardisation reduced the rate of recent increases relative to raw CPUE alone. Client (ACE holder) and diver identification had the strongest standardising effects for recent CPUE (Figure 8), due to the concentration of ACE into a smaller number of efficient fishing operations in recent years. Nevertheless, recent increases in standardised CPUE were of the order of 50% since the TACC was reduced in 2016–17.

The diver identification (from PCLER forms) had a negative standardising effect in the standardisation model (Figure 8); an increasing number of inexperienced divers entering the fishery reduced raw CPUE (Figure 9). In contrast, a reduction in the number of fishing crews, with mainly more efficient crews remaining in the fishery in most recent years, led to a slight increase in the CPUE (Figure 10). Combined, these adjustments had limited impact on the standardised CPUE relative to the raw series.

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

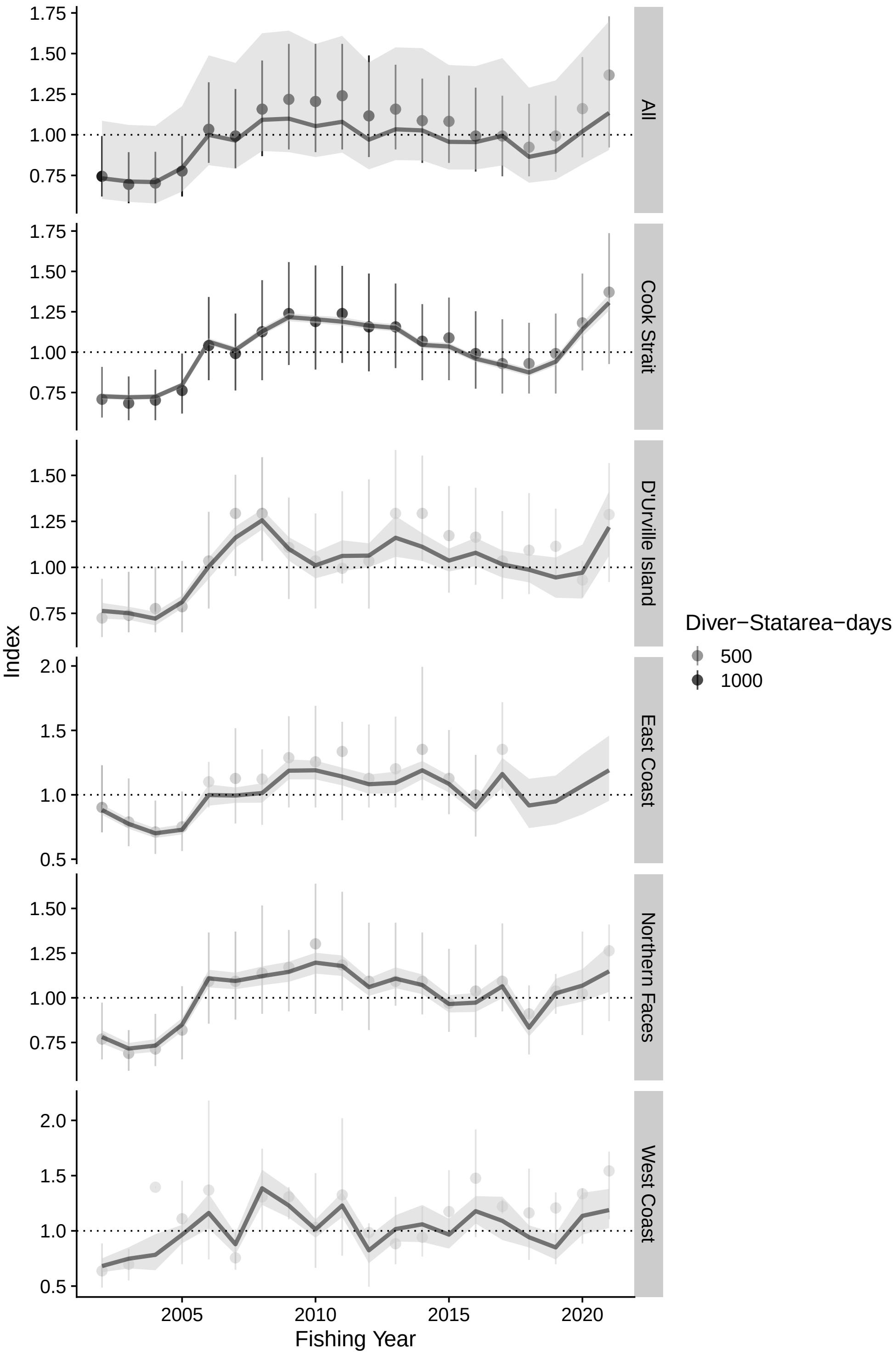

Figure 7: Standardisation of catch-per-unit-effort (CPUE) data using the generalised linear mixed model with area-year interaction; showing CPUE by area as ribbons (posterior median and 95% quantiles). Points with error bars show raw CPUE and 75% quantiles.

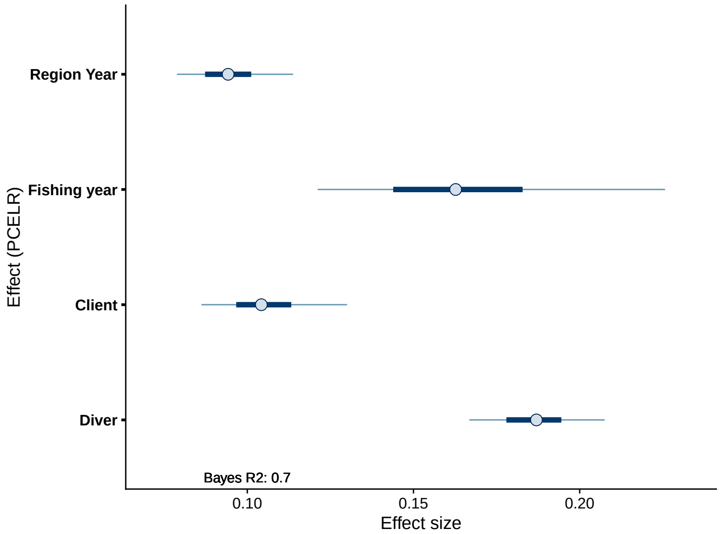

Figure 8: Effect size as variance explained for variables included in the random-effects standardisation model. PCELR, paua catch effort landing return.

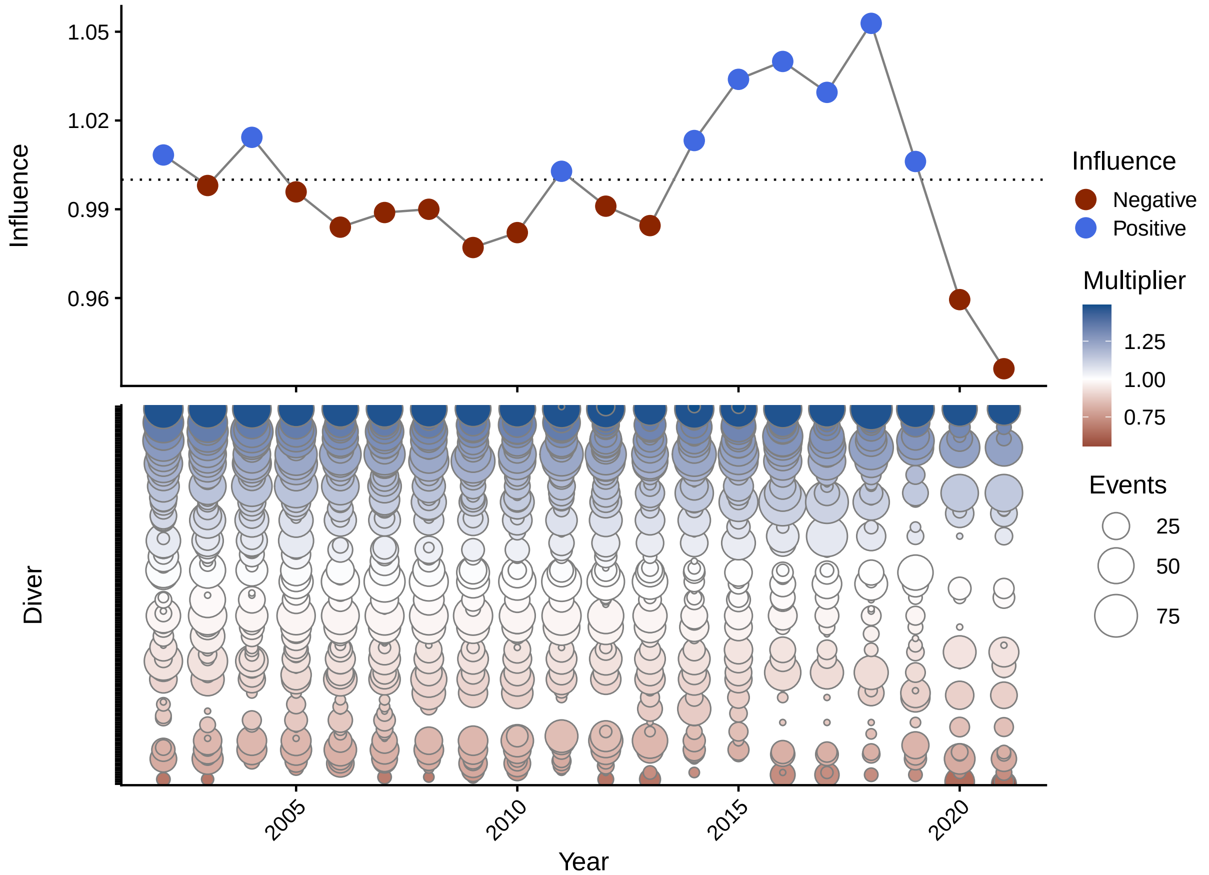

Figure 9: Influence plots for diver random effects, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised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

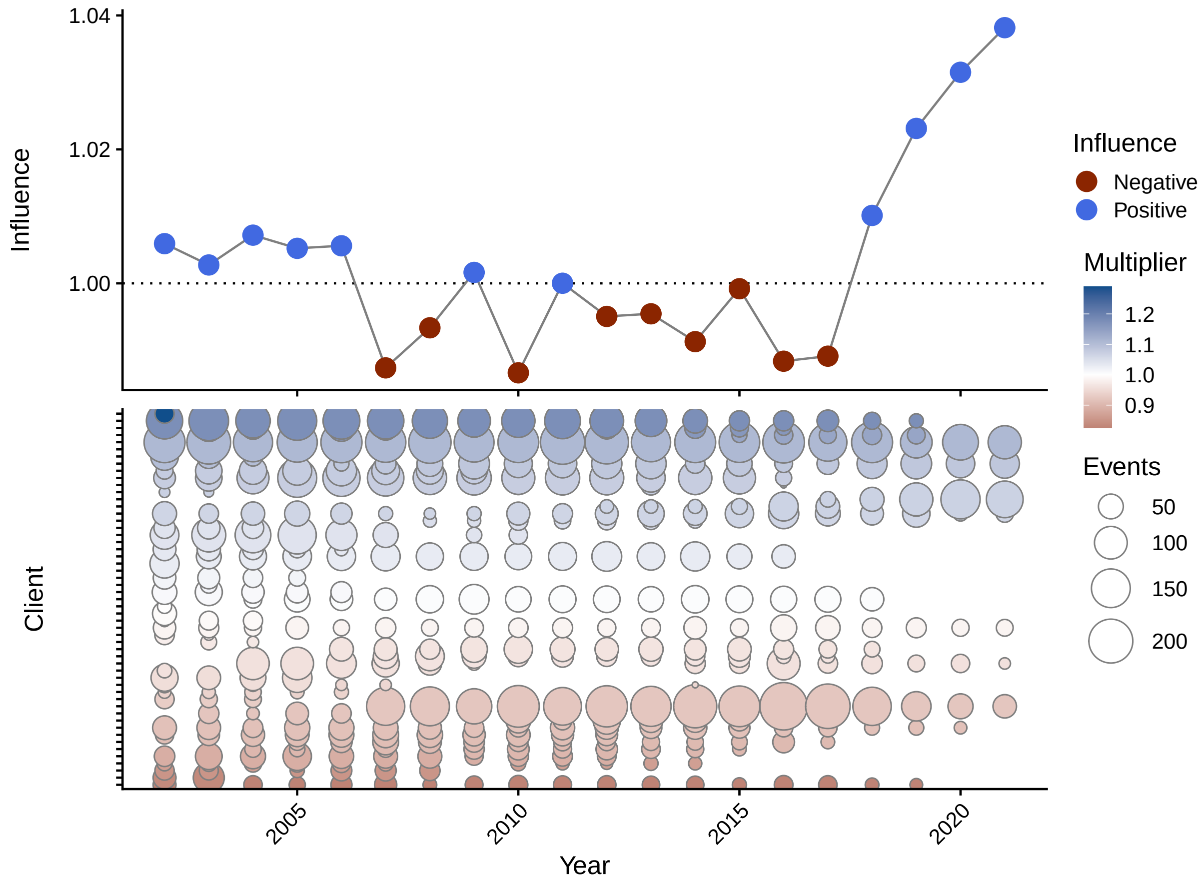

Figure 10: Influence plots for client number (FIN) effect, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised index was increased due to the relative distribution of the covariate.)

2.1.4 Catch sampling length-frequency (CSLF) data

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

Composition standardisation was performed for CSLF data from 1989–90, although there was a considerable gap between 1994 and 2005 when no CSLF samples were available. The model used statistical area, region (e.g., Cook Strait, Northern Faces, D'Urville Island), and region-year as standardising variables. Region and year were entered as fixed effects, and region-year and statistical area were entered as random effects.

The standardisation led to small adjustments relative to raw removal estimates based on statistical areas for the 1989–90, 1990–91, and 1991–92 fishing years (Figure 11). For these years, a higher number of pāua was from statistical areas that contained individuals at smaller-than-average length for that region. The model downward-adjusted the lower end of the LF distribution in those years (and, by extension, upward-adjusted the tail of the LF distribution; Figure 12). This adjustment is consistent with samples in 1992–93.

2.1.5 Growth and maturation

Similar to previous assessments since 2018, data were not fitted from individual growth tagging sites in PAU 7. Although growth data exist for a range of sites in PAU 7, the high spatial heterogeneity in the growth of pāua makes it unclear how representative the estimates of mean growth and variability are when based on a limited number of sites. Recent developments for 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 in pāua QMAs (Neubauer & Tremblay-Boyer 2019a).

For the present assessment (as in other recent stock assessments), an informed prior was used, derived from a meta-analysis of pāua growth. This prior 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 13). 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; see Figure 13). 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.

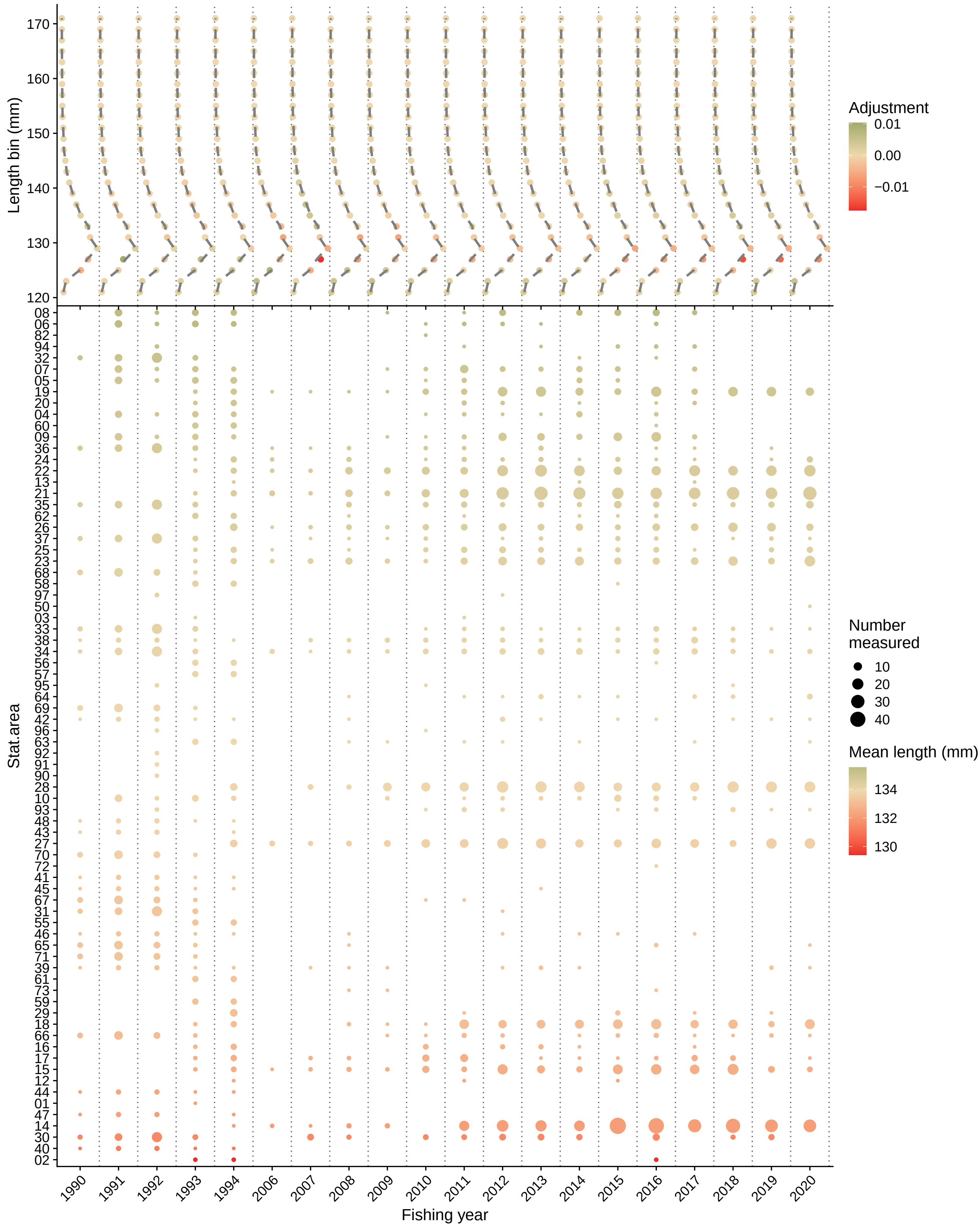

Figure 11: Effects plot for reporting area (top graph) and small-scale statistical area (bottom graph) for pāua management area PAU 7. For each graph, the top panel displays the direction of the adjustment from the raw catch sampling length frequency (LF; coloured points for LF classes) in each year and length class in relation to the fishing pattern (shown in the lower panel). Strata in the lower panel are sorted by the observed mean length to allow comparisons of their influence on estimated deviations in the upper panel.

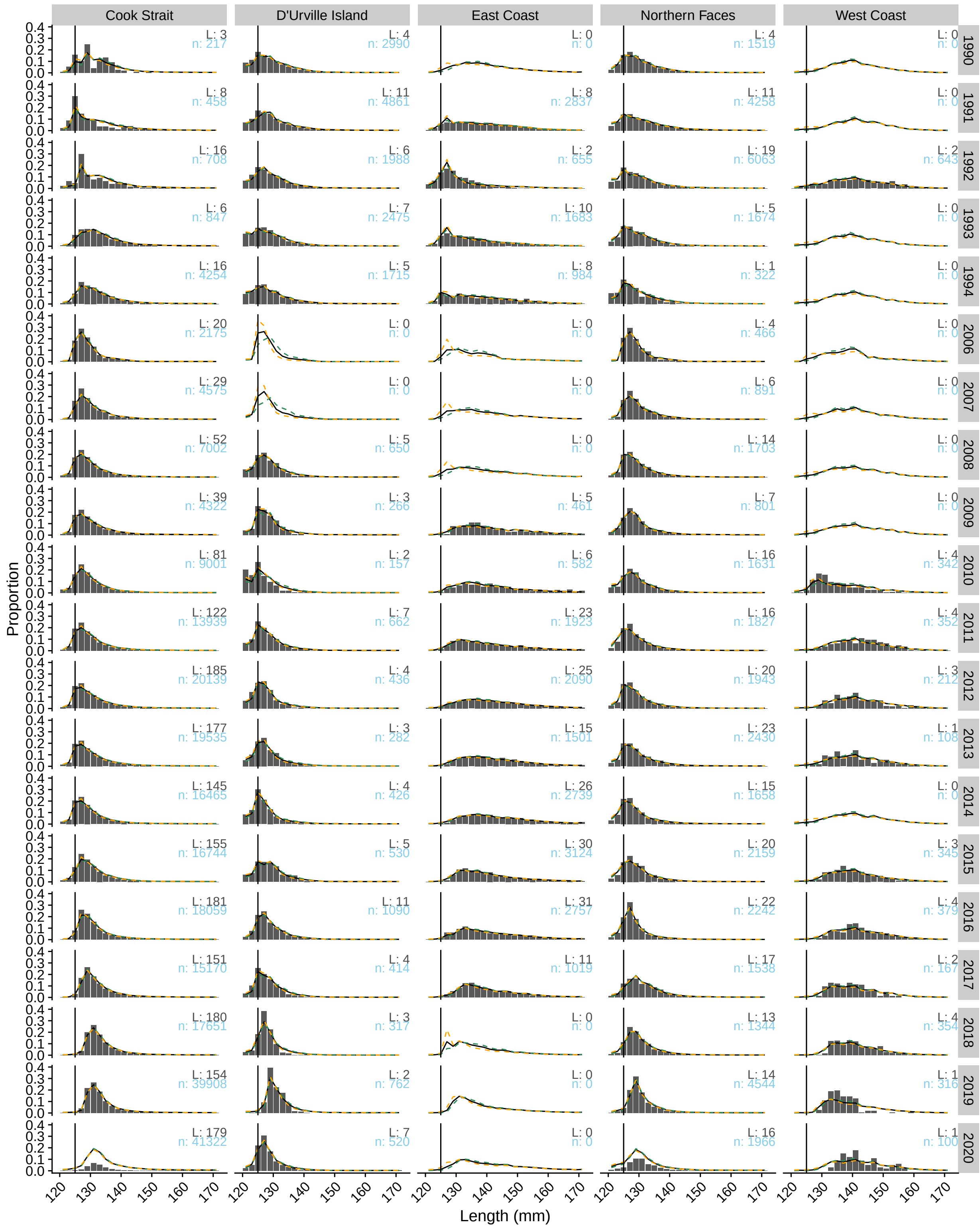

Figure 12: Dirichlet-Multinomial posterior distributions for yearly proportions $\pi_{r,y}$ (black line) in each of two geographical areas in pāua management area PAU 7, with 95% confidence intervals (dashed line). Raw catch sampling length-frequency proportions are in grey; number of landings (L) in black; number of measurements (n) in blue.

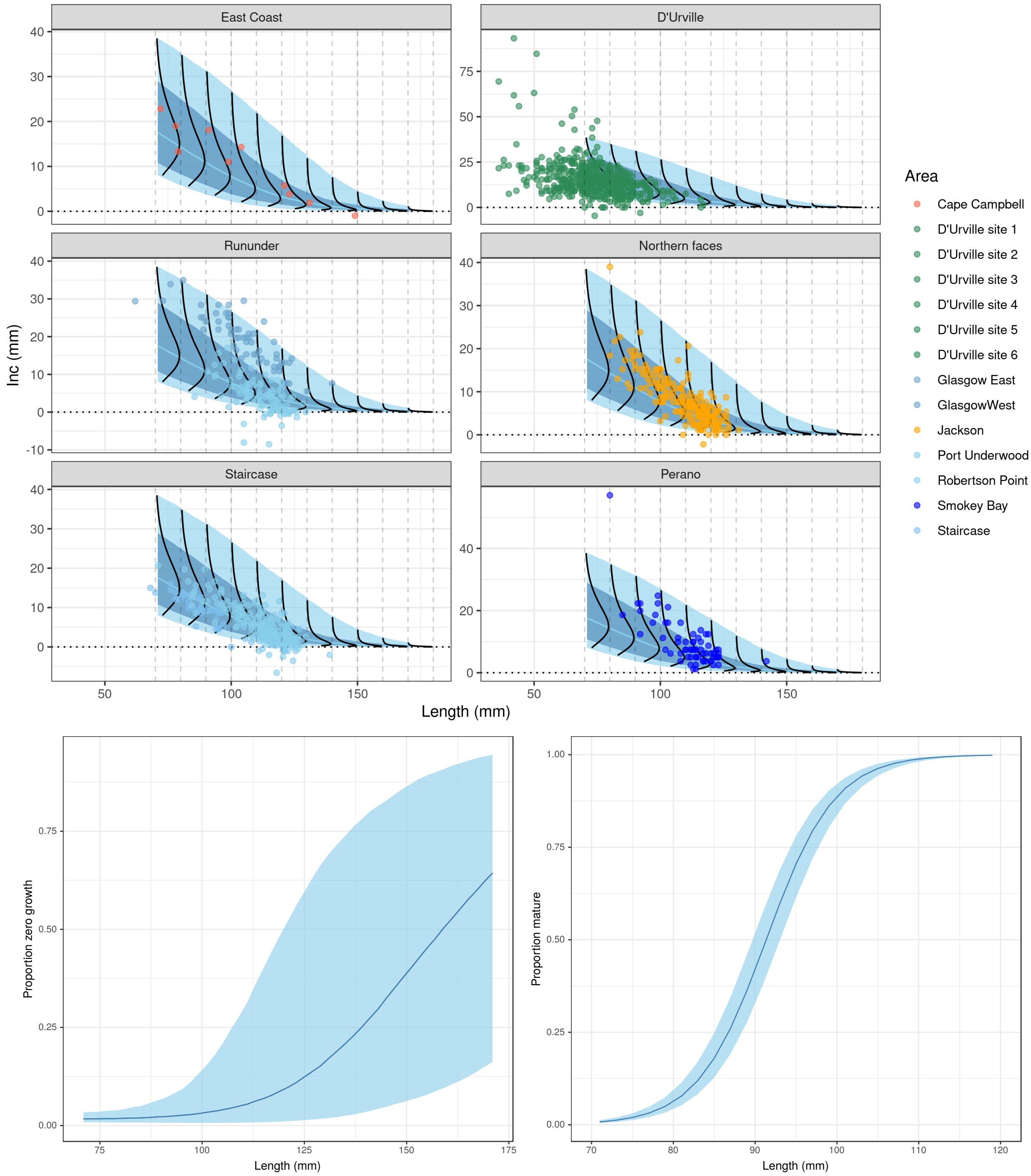

Figure 13: Priors implied from a meta-analysis of growth of pāua, based on model-fitting to all tag-increment data. Shown is the joint prior for positive growth increments and tag-recapture data, compared with data from sites in PAU 7. Top graph: Rununder, Staircase, and Perano, show the Cook Strait region; other panels show areas that were not considered in the final models. Bottom graph: proportion of local populations not growing at a particular size l (bottom-left graph); population level maturity (bottom-right graph). For positive increments, 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 line indicates the implied distribution of growth at the median of the prior.

2.2 Assessment model

2.2.1 Summary of changes from recent assessments

The stock assessment model in this assessment used the general length-based population dynamics model that was developed by Breen et al. (2003). This model was used in subsequent stock assessments (e.g., Marsh & Fu 2017), with changes introduced in the 2018 pāua stock assessment for PAU 5D (Neubauer & Tremblay-Boyer 2019b) and PAU 2 (Neubauer 2022).

2.2.2 Assessment specification

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

2.2.3 Prior distributions

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

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

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

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

Steepness h was estimated in this iteration of the assessment model, and was assigned a beta distribution prior with parameters a and b, with $a = 1$ and $b = 1$ the default prior (see Table 4 for other default priors).

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

Parameter	Symbol	Prior	Mean	SD	Mean (pos)	SD (pos)
Equilibrium recruitment	R_0	LN	13	5	1.19×10^{11}	3.19×10^{16}
Recruitment deviations	R_{dev}	LN	0	0.4	1.08	0.45
Natural mortality	M	LN	log(0.1)	0.2	0.1	0.02
Catchability	q	LN	-13	100	∞	∞
Length at 50% selectivity	D_{50}	LN	log(123)	0.05	123.15	6.16
95% selectivity offset	D_{95}	LN	log(5)	0.5	5.67	3.02
Steepness	h	Beta			0.5	0.29
CPUE process error	PE_{CPUE}	N^0(0.05)		0.04	0.03	
CSLF process error	PE_{CSLF}	N^0(1)		0.80	0.6	

The initial data weighting started with a set of weights that previous assessments identified as providing reasonable fits for both CPUE and CSLF data; these previous assessments were the spatial stock assessment model for pāua and the stock assessment for PAU 5D (Neubauer & Tremblay-Boyer 2019b, Neubauer 2020). Here, these weights were then varied to assess the effect of weighting of CSLF and CPUE data on model outcomes.

2.2.4 Technical model details

The model was initialised for a period of 60 years with constant recruitment at R_0 and no 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. For the final base case and sensitivity, eight independent chains were run over 6000 iterations, with the first 1000 samples discarded for each chain, and a further 5000 samples saved for inference and post-processing.

2.3 Stock assessment

The stock assessment included several sets of model runs, including an initial exploration. Initial exploration focused on spatial assessment models to split the area of the previous stock assessment (Statistical areas 017 and 038), comprising Cook Strait, Northern Faces, and D'Urville Island. Divers had raised concerns about the status of the latter areas in recent years, and catch has markedly declined in both areas in the past two decades. In particular, the D'Urville Island and Northern Faces fine-scale statistical areas accounted for approximately 40 t of catch throughout the early 2000s, with subsequent declines in catch to low levels in recent years. By contrast, fine-scale statistical areas in Cook Strait have continuously yielded between 70 and 150 t per year since the early 2000s. This area constitutes over 80% of the fishery in recent years.

The SFWG found that models for Northern Faces and D'Urville Island could not reconcile flat or declining CPUE with decreasing catch for these areas. The lack of increase in CPUE suggests that biomass in these areas is not rebuilding, despite the near absence of commercial fisheries at D'Urville Island. The SFWG decided to focus subsequent efforts on assessing the status of Cook Strait (i.e., a subset of Statistical area 017), because this area accounts for nearly all catch in recent years. Due to difficulties with assessments in other areas, the assessment was then run as a single-area assessment over Statistical areas 713 to 730. The final model structure assumed a single-sex population residing in a single homogeneous area within this region, with length classes from 70 to 170 mm in 2-mm groups.

Although the present stock assessment was similar to recent assessments conducted for PAU 2 and PAU 5A, it included a number of changes to better reflect different catches and their selectivity: illegal and recreational catches were, for the first time, split from commercial catch, and illegal catch was modelled as taking pāua in proportion to abundance rather than according to commercial selectivity. Although commercial minimum harvest size increased in recent years, recreational catch retained a logistic selectivity centred on the minimum legal size.

Recruitment was assumed to take place at the beginning of the annual cycle, with recruitment deviates estimated from 1984 to 2017; length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. Natural mortality in the base model was fixed at 0.12. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve, with increases in recent years due to changes in the minimum harvest size in some areas. The model was initiated with likelihood weights that had led to subjectively appropriate fits to both CPUE and CSLF inputs in other areas (PAU 5, PAU 2), and relative fits for CPUE and CSLF data were examined based on model fits and residuals.

The assessment calculated the following quantities from the marginal posterior distributions of various partitions of the biomass: the equilibrium (unfished) spawning stock biomass (SSB_0), assuming that recruitment is equal to the average recruitment, and the relative spawning and available biomass for 2021 (SSB_{2021}), and for the projection (Proj) period (SSB_{Proj}).

3. RESULTS

3.1 Base case results and agreed sensitivity runs

Model diagnostics and outcomes from the base model are provided in Appendix A. The base model with M=0.12 estimated a steady reduction in spawning biomass from the beginning of the fishing history (assumed to be 1965) to the early 2000s (Figure A-10). It estimated a subsequent increase in biomass determined by trends in CPUE (Figure A-4) after considerable (40%) reductions in catch between 2001 and 2004 that led to a slow reduction in exploitation rates (Figure A-13). The recovery largely slowed, and the stock started to decline again after a 15% shelving was lifted in 2007–08, which led to increases in exploitation rates again. Although subsequent shelving from 2012–13 to 2014–15 reduced fishing pressure to some extent, these reductions did not lead to the intended increases in biomass. Current fishing rates, following the 50% TACC reduction in 2016–17, have approached target levels, and have led to a recent rebuild of the biomass to levels approaching target biomass levels (Figure A-10).

The base model with M=0.12 and estimated growth provided a relatively close fit to CPUE and CSLF data (Figures A-4 and A-6). Although CPUE responded to reductions in catch in the early 2000s, leading to a strong subsequent increase in biomass, this initial increase in CPUE was partly explained by recruitment in the model (Figure A-9). The latter aspect suggests that the assumed productivity was insufficient to explain the level of increase in CPUE in the early 2000s. By contrast, recent recruitment estimates were only slightly above average, suggesting that more recent increases corresponded with assumed (and estimated) levels of productivity.

Alternative models (see Appendix B) investigated uncertainty in M, early (pre-PCELR) catch levels, steepness, and data weights. Despite different estimates of unfished recruitment (Figure B-1), all models estimated similar trends in biomass (Figure B-9), with slightly different outcomes in terms of recent stock status; low M and high early catch scenarios had the lowest estimates of recent biomass with 27% and 31% of unfished spawning biomass in 2021. Despite these differences, all models suggested recent increases in biomass, with relatively rapid expected rebuilding under the base model (by 2026; Table A-2).

4. DISCUSSION

The present assessment provided an attempt at splitting the PAU 7 assessment area into smaller subareas that align with commercial management areas rather than CELR reporting areas. In contrast, previous assessments were conducted across large spatial scales (i.e., across all areas around Marlborough Sounds). Nevertheless, there has been substantial evidence in recent years of change in smaller subareas that may have been un-accounted for by previous assessments; e.g., declines in catch and lack of recovery at D'Urville Island. The present assessment aimed to resolve these subarea trends by initially applying spatial assessment models to estimate stock status across smaller subareas. Although this approach showed the inadequacy of the current data and model to explain trends in north-western areas of PAU 7, it mainly resulted in the reduction of the assessment area to the "Cook Strait" region.

The Cook Strait region showed strong recovery from low biomass over most of the first two decades of the 2000s. Although this recovery was the intended outcome following the 50% TACC reduction in 2016, the scale of the recovery contrasts with an apparent lack of recovery in other areas, namely the Northern Faces and D'Urville Island. The lack of recovery in these areas may be the result of environmental factors, such as large storms affecting recruitment by causing large mortality of recruits, which tend to be in relatively shallow water. Other potential factors include warming water in the Tasman Sea leading to poor condition and lack of suitable thermal habitat to support populations that can sustain commercial fisheries.

In addition to these possible environmental explanations, alternative explanations include a lack of critical spawner densities to enable local recruitment. The stock assessment lacks information about pāua at sub-legal sizes, as these smaller pāua are not included in commercial fisheries data which are used in assessment models. Commercial fishing pressure was high in the decades around the early 2000s. Additionally, throughout most of the 1990s and early 2000s, illegal fishing is considered to have been important in many of these areas. The present assessment may have underestimated illegal take and its effect. For this reason, it may have underestimated the degree of biomass reduction in these areas, leading the assessment models to perform poorly. Although the commercial fishery tends to protect significant proportions of spawning biomass through a size limit, illegal fisheries have the potential to remove critical spawning biomass where populations are already small. These effects can, in theory, be explored in the assessment models; however, the lack of data on estimated volumes and sizes of illegal catch mean that any of these models would remain a hypothesis in line with other explanations. This aspect means that there is no conclusive reason for the lack of recovery in these areas.

While early and illegal catches remain a source of potential bias in models for most pāua fisheries, the current model appeared robust to removal of the CELR time series of CPUE, providing similar results to the previous assessment by Fu (2016) for the overlapping period. This result further confirms that CELR data do not contribute significant information to the assessment and should, therefore, be omitted. In addition, the similarity of results suggest that, despite substantial changes in the technical setup of the models and assumptions, including spatial stratification, selectivity for illegal and recreational fisheries, or likelihood for commercial length frequency data, the assessment for Cook Strait is largely determined by commercial fishing data. These data provide a consistent signal about the state of the fishery in Cook Strait.

In recent years, an increasing number of pāua have been exported live or frozen whole. For this reason, the shells of these animals have not been available for measurement at factories, and are not available for commercial length-frequency estimates. To mitigate this lack of measurements, a number of measuring boards were purchased by the Pāua Industry Council and trialled on a number of vessels in New Zealand. Although one vessel in the PAU 7 area has measured a large number of shells, these measurements are of overall length. In contrast, length data for the pāua stock assessment model are required to be basal length; however, overall and basal length are equivalent, unless there is a hump in the shell. Length data will likely be available for future assessments, but the lack of live export pāua, usually individuals of the largest size, may lead to a bias in recent length frequencies towards smaller individuals.

Despite potential biases and some remaining uncertainties in the present models, the strong recovery and projected further stock increase in Cook Strait indicates an optimistic outlook for this fishery. Combined with positive trends (McCowan & Neubauer 2021) and the recent re-opening of the east coast fishery, the current results showed that parts of PAU 7 have recovered well from past overfishing and earthquake effects. At the same time, other parts of this area may remain in a state of relatively low biomass for the foreseeable future. For these latter areas, alternative monitoring tools are needed, because commercial fisheries data are becoming sparse, limiting available information of these pāua populations. Recent surveys of the earthquake-affected areas in Kaikōura and the east coast area of PAU 7 have shown potential to track trends in these areas. As such, these surveys may provide a valuable monitoring tool for areas where commercial catch and effort data are becoming too limited to be used in formal assessments.

5. ACKNOWLEDGEMENTS

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APPENDIX A: MODEL DIAGNOSTICS AND RESULTS

A.1 Base case:

A.1.1 Markov chain Monte Carlo and posteriors

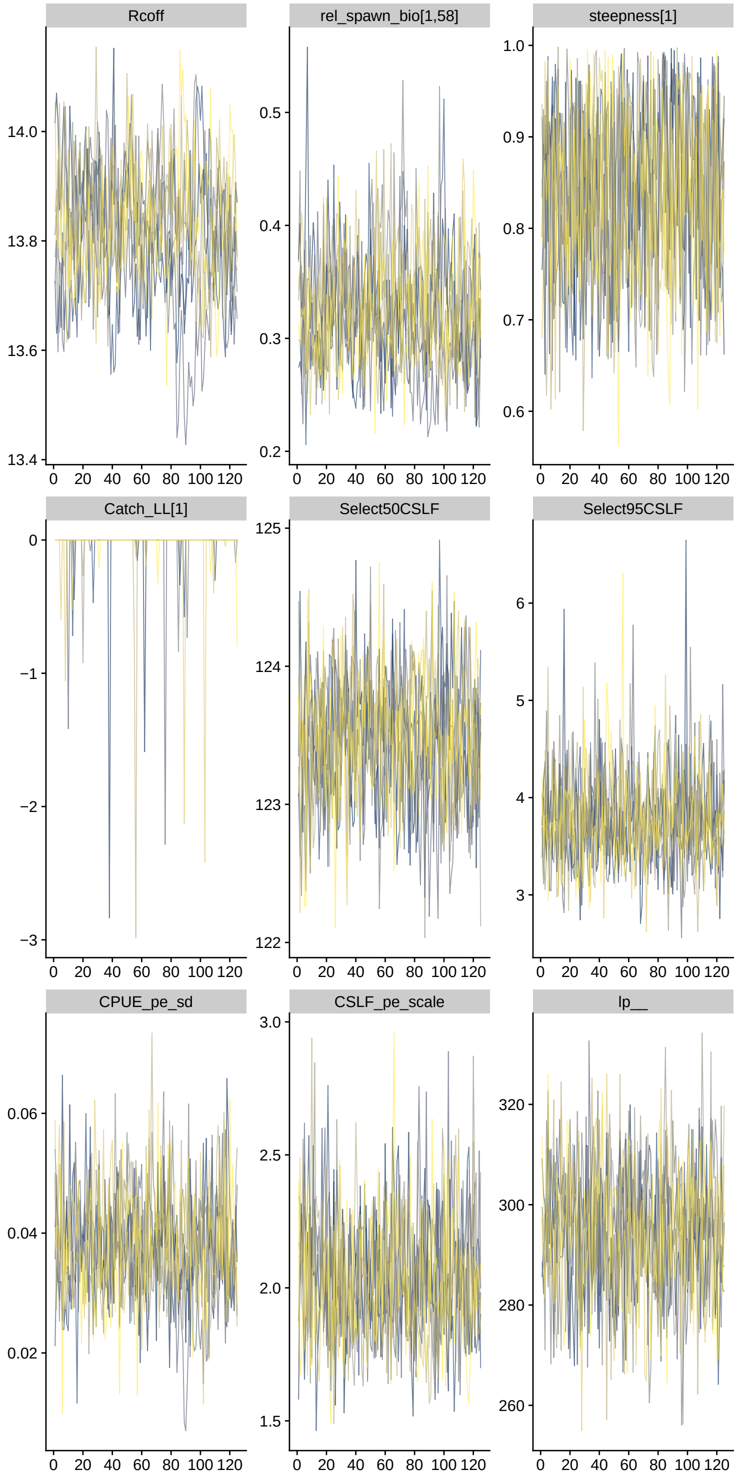

Figure A-1: Traces of Markov chain Monte Carlo estimation for the marginal posterior distribution of key model parameters for the base case stock assessment model of pāua in quota management area PAU 7.

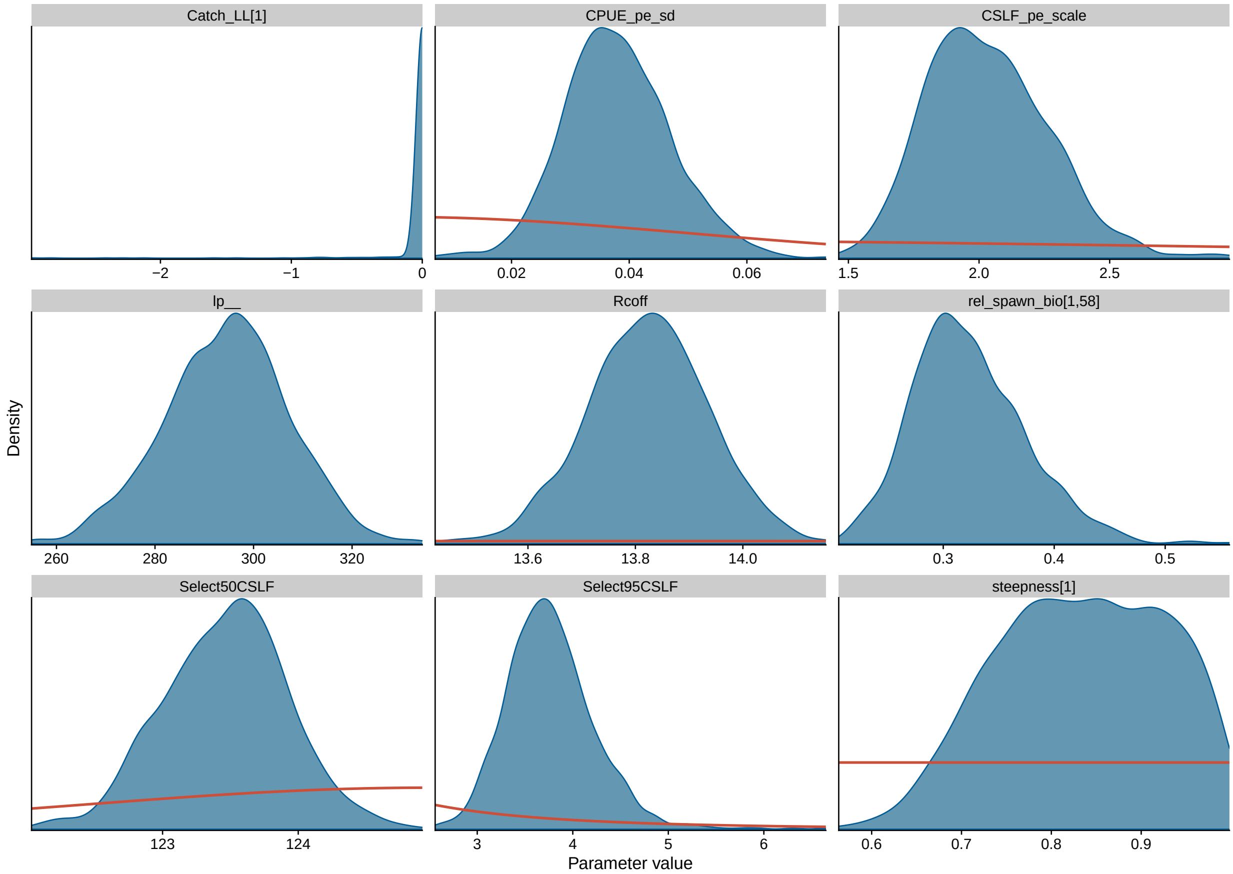

Figure A-2: Marginal posterior densities of key model parameters for the base case stock assessment model of pāua for quota management area PAU 7, with prior densities indicated in red.

Table A-1: Posterior quantities for key parameters in the base case pāua stock assessment model for quota management area PAU 7. R_0, equilibrium recruitment; D_{50} and D_{95}, size at which 50% and 95% of individuals are selected, respectively; $U_{40\%SSB_0}$, exploitation rate (U) leading to 40% of spawning stock biomass (SSB); PE, process error; CPUE, catch-per-unit-effort; CSLF, catch sampling length frequency; relative SSB_{2021}, relative spawning stock biomass in 2021.

Parameter	Posterior percentile				
	2.5%	25%	50%	75%	97.5%
$\log(R_0)$	13.60	13.75	13.82	13.90	14.04
D_{50}	122.57	123.16	123.49	123.77	124.36
D_{95}	3.00	3.46	3.73	4.02	4.78
$U_{40\%\mathrm{SSB}_0}$	0.21	0.26	0.30	0.36	0.57
Log catch penalty	-0.22	0.00	0.00	0.00	0.00
Log posterior	268.91	286.52	295.06	302.80	318.09
$\mathrm{PE}_{\mathrm{CPUE}}$	0.02	0.03	0.04	0.04	0.06
$\mathrm{PE}_{\mathrm{CSLF}}$	1.64	1.86	2.01	2.18	2.54
Relative SSB_{2021}	0.24	0.29	0.32	0.36	0.44
Steepness (h)	0.66	0.77	0.84	0.91	0.99

A.1.2 Growth

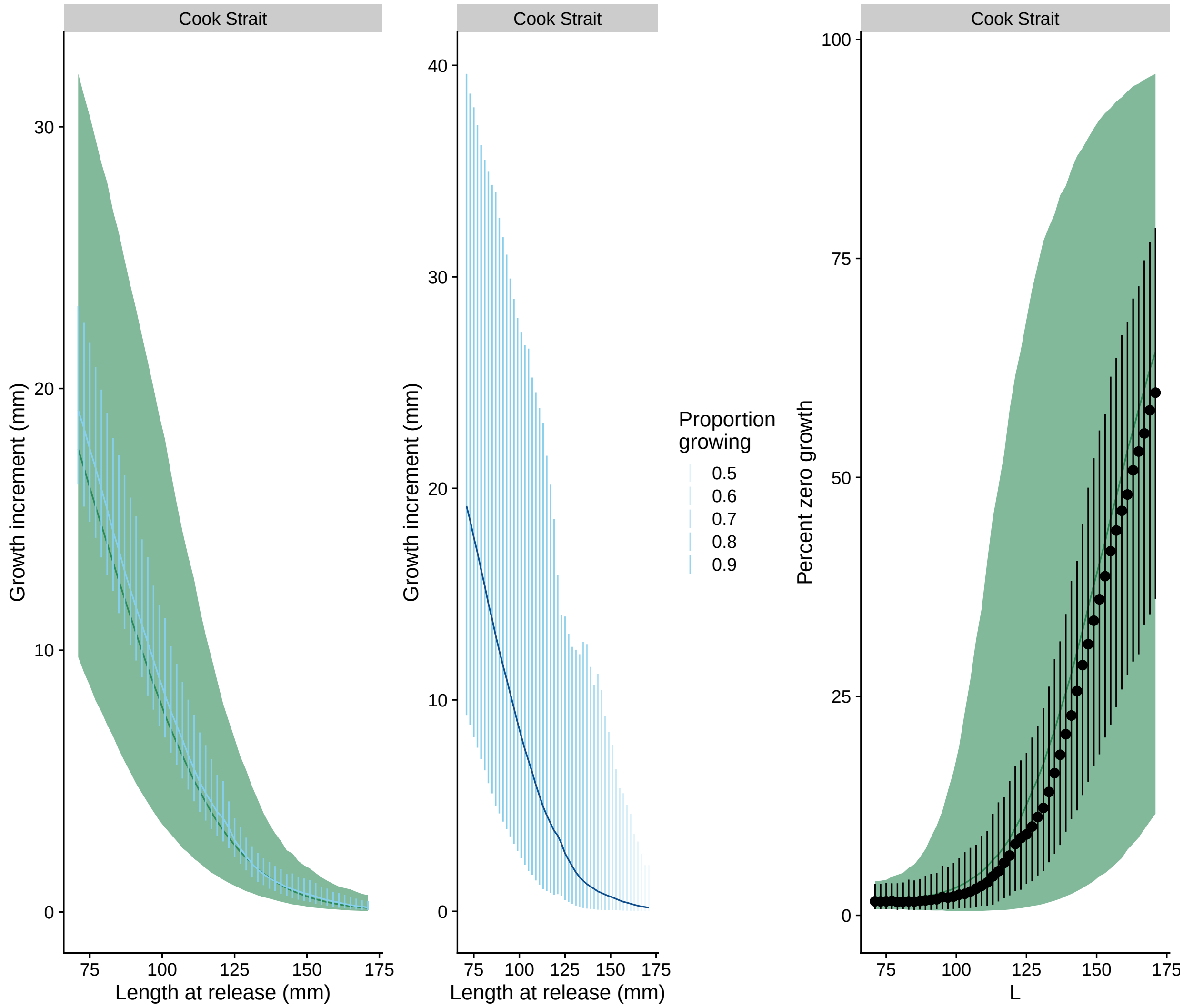

Figure A-3: Comparison of prior and posterior growth in thebase case stock assessment model of pāua for quota management area PAU 7. Left panel: Posterior mean growth (population mean (dark blue line) and standard deviation of the estimate (light blue ribbon)) relative to the prior (dark green). Middle panel: Estimated population standard deviation (posterior median; light blue) relative to estimated population mean (blue line). Right panel: Estimated proportion of pāua stock not growing at each length relative to the prior (green).

A.1.3 Catch-per-unit-effort fits

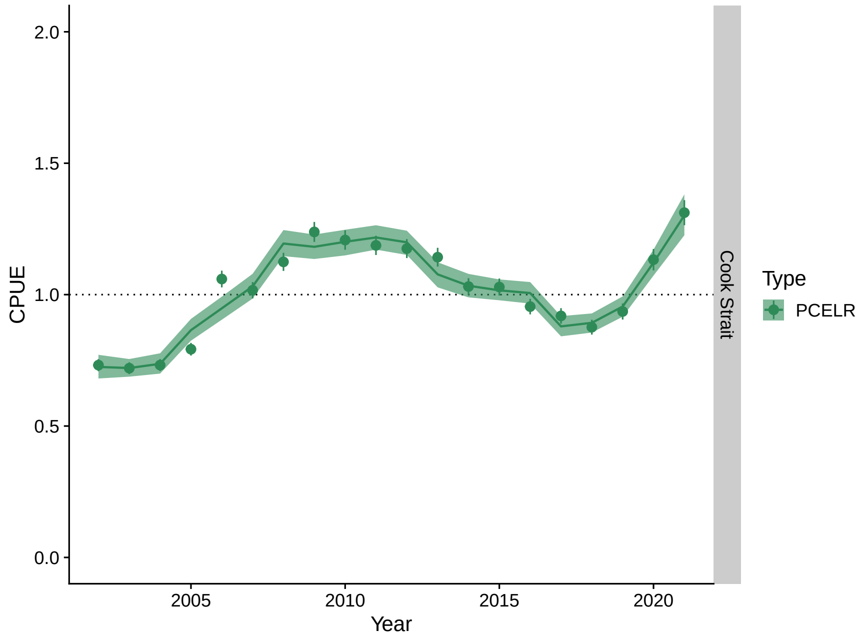

Figure A-4: Comparison of posterior predicted catch-per-unit-effort (CPUE; line and 95% confidence interval) with estimated CPUE index and observation error for the base case stock assessment model of pāua for quota management area PAU 7 (points and error bars).

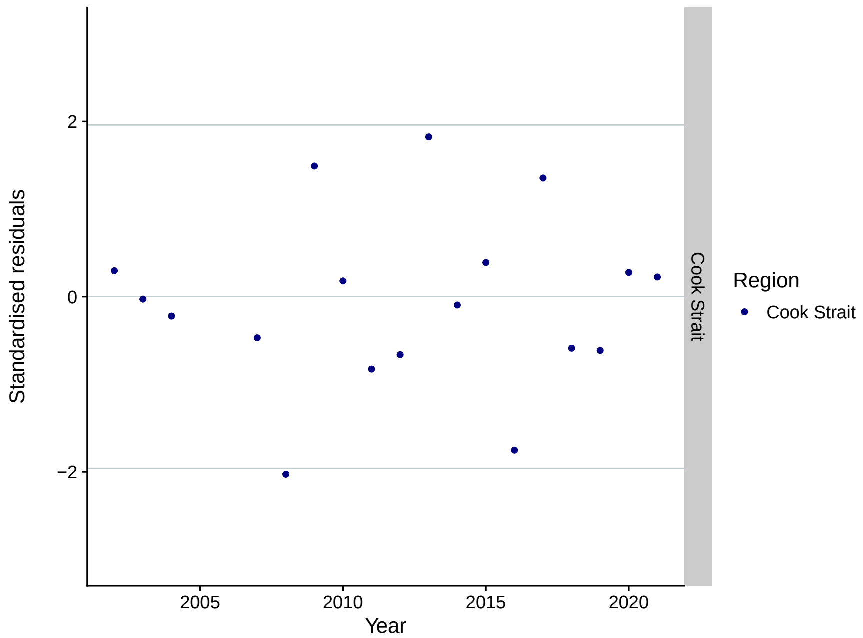

Figure A-5: Standardised residuals at the posterior median of predicted catch-per-unit-effort for the base case stock assessment model of pāua for quota management area PAU 7.

A.1.4 Catch sampling length frequency fits

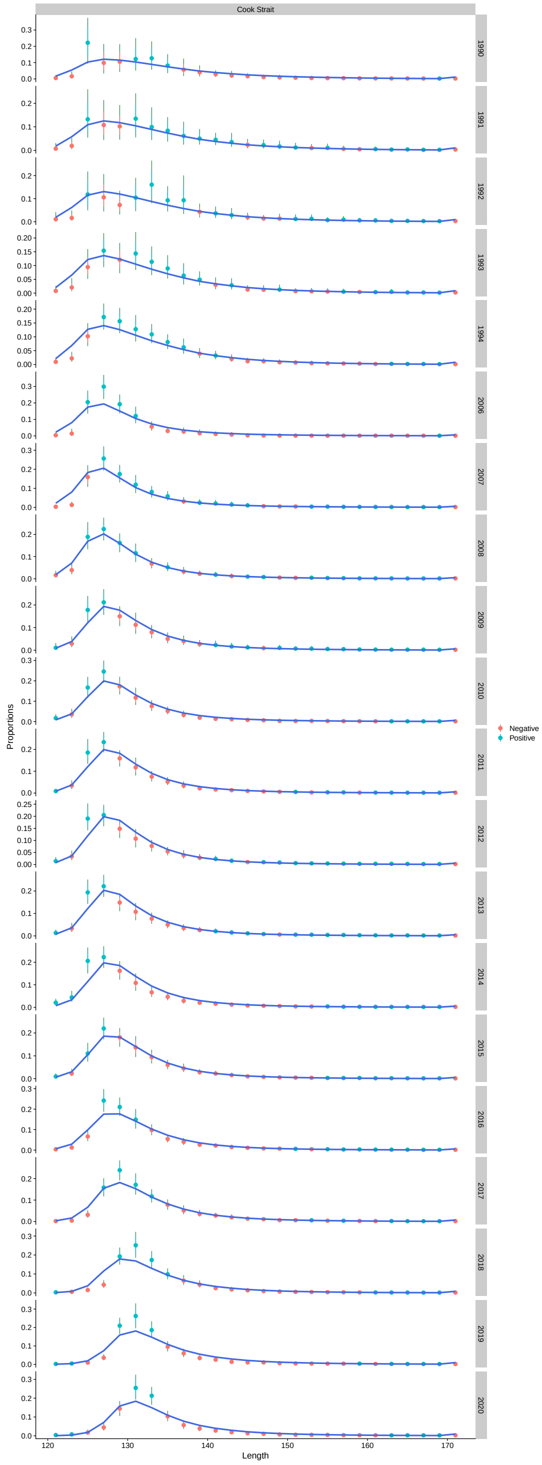

Figure A-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF) distribution with estimated CSLF proportions and observation error for the base case stock assessment model of pāua for quota management area PAU 7. Length classes (mm) with positive residuals in blue, with negative residuals in red.

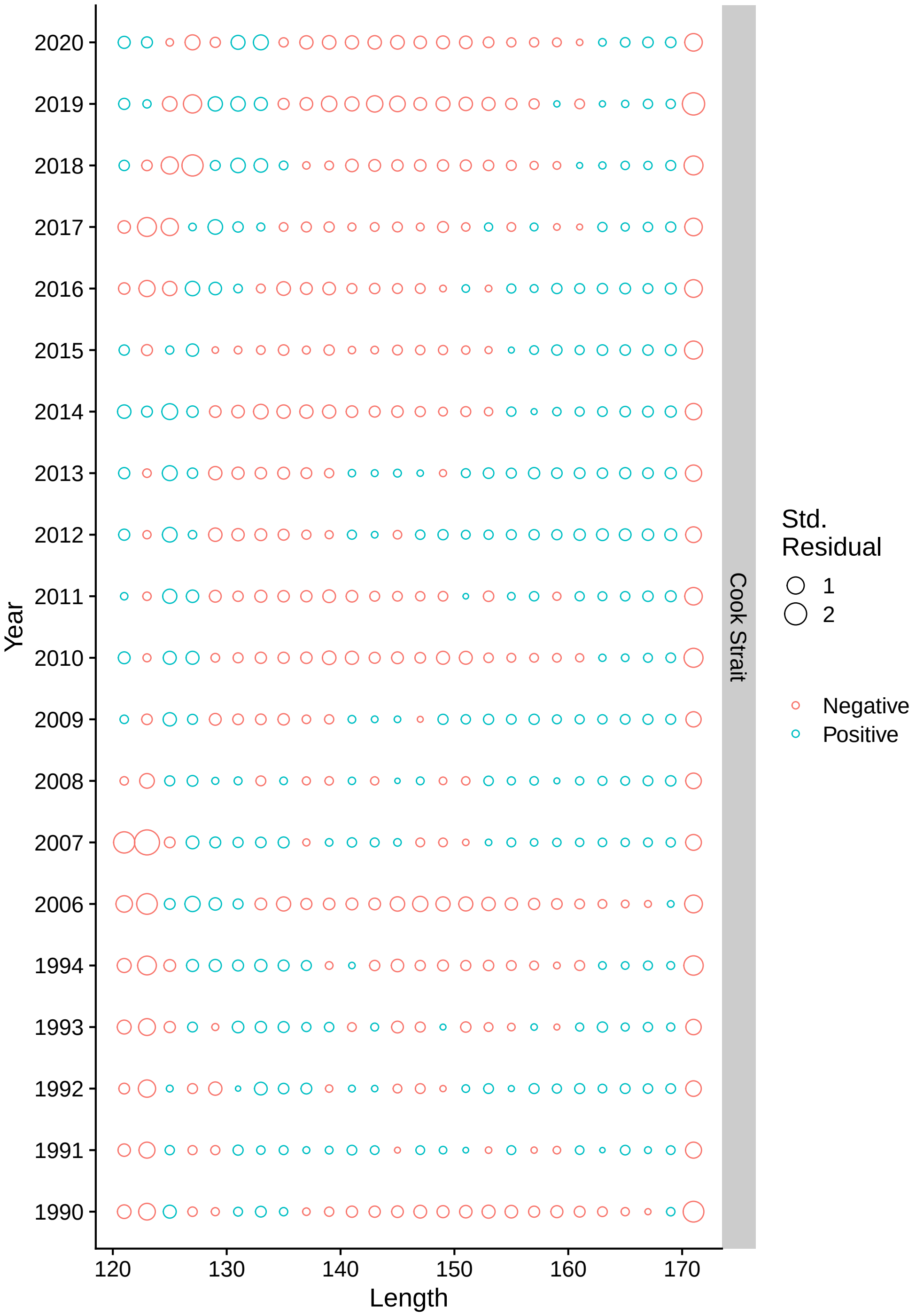

Figure A-7: Catch sampling length frequency model residuals for the base case stock assessment model of pāua for quota management area PAU 7. Length classes (mm) with positive residuals in blue, with negative residuals in red.

A.1.5 Selectivity

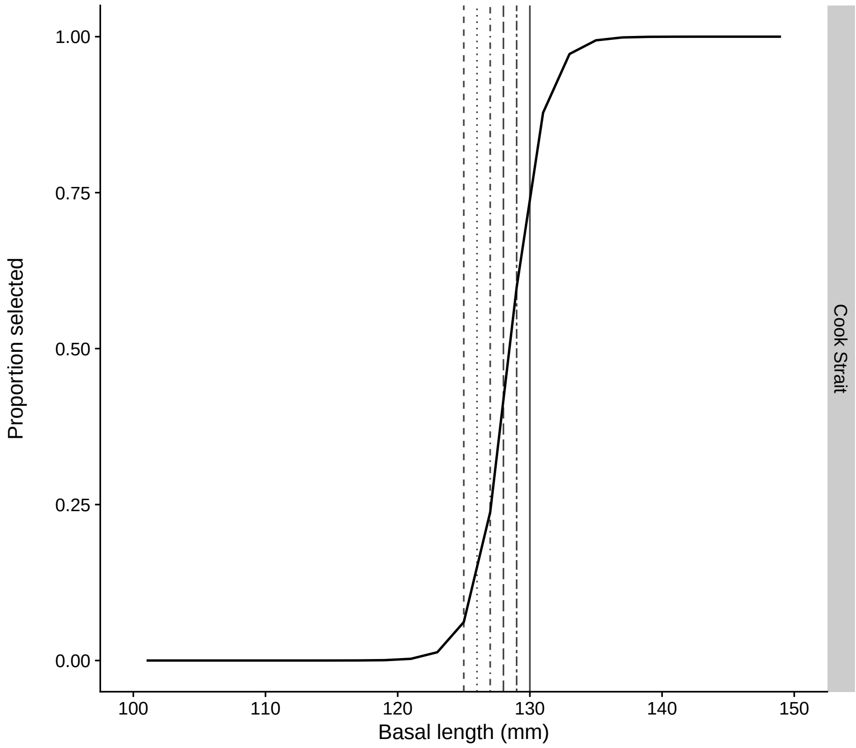

Figure A-8: Estimated selectivity (posterior mean) for the base case stock assessment model for pāua in quota management area PAU 7.

A.1.6 Recruitment and biomass trends

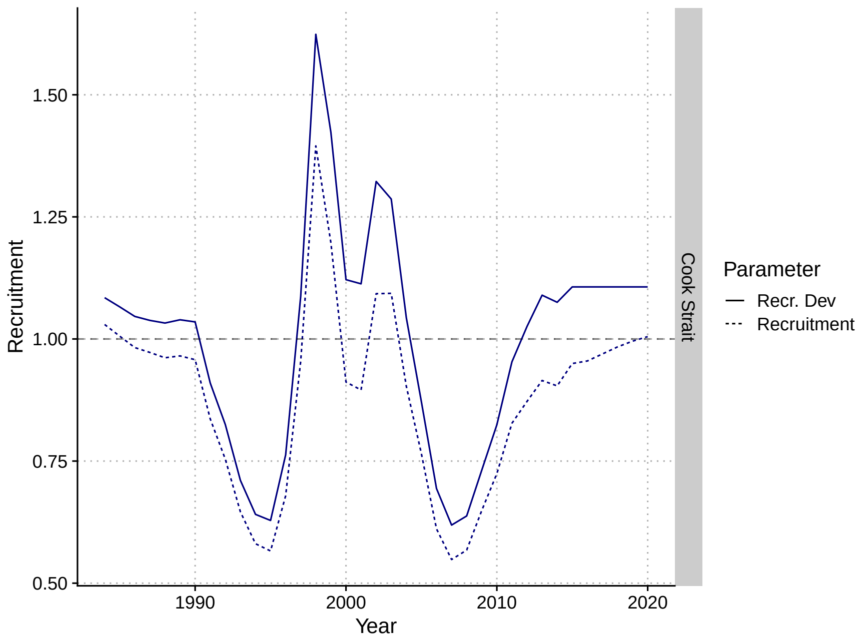

Figure A-9: Posterior mean recruitment for the base case stock assessment model of pāua for quota management area PAU 7 (R_{dev}, recruitment deviation).

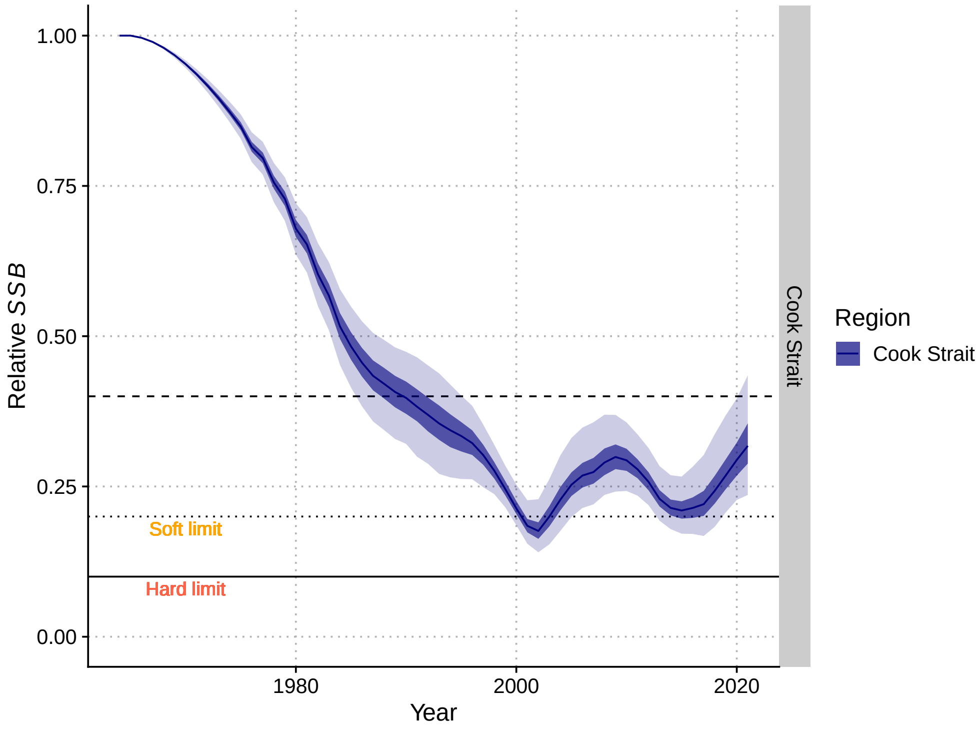

Figure A-10: Estimated trend of relative spawning stock biomass (SSB) for pāua for the base case stock assessment model for quota management area PAU 7 (black line, 75% (dark shade) and 95% (light shade) confidence interval).

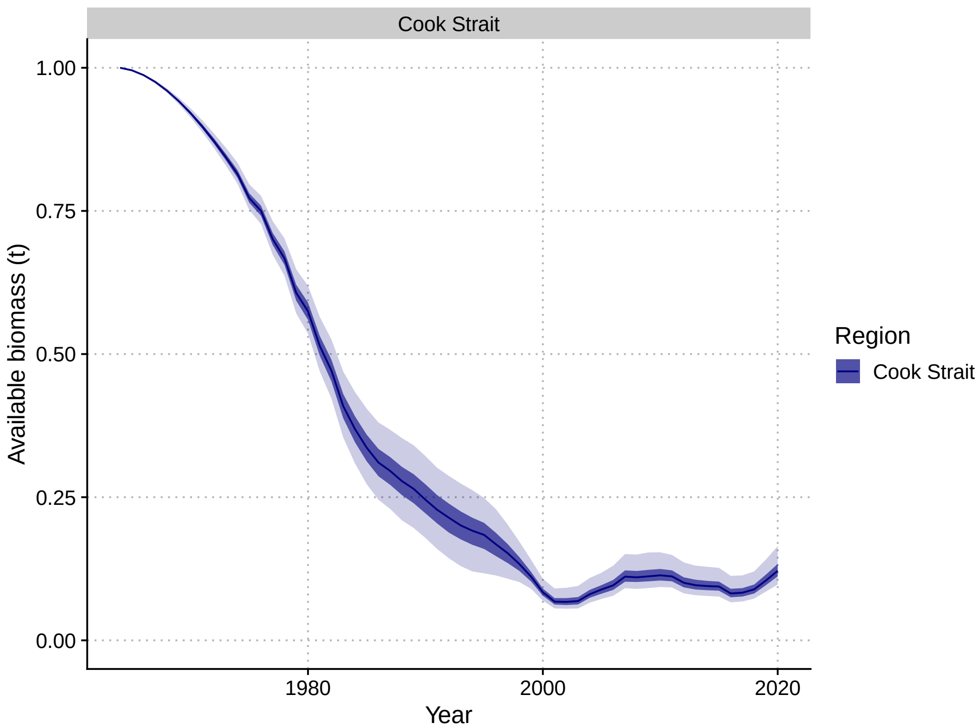

Figure A-11: Estimated relative available biomass trend for pāua for the base case stock assessment model for quota management area PAU 7 (black line, 75% (dark shade) and 95% (light shade) confidence interval).

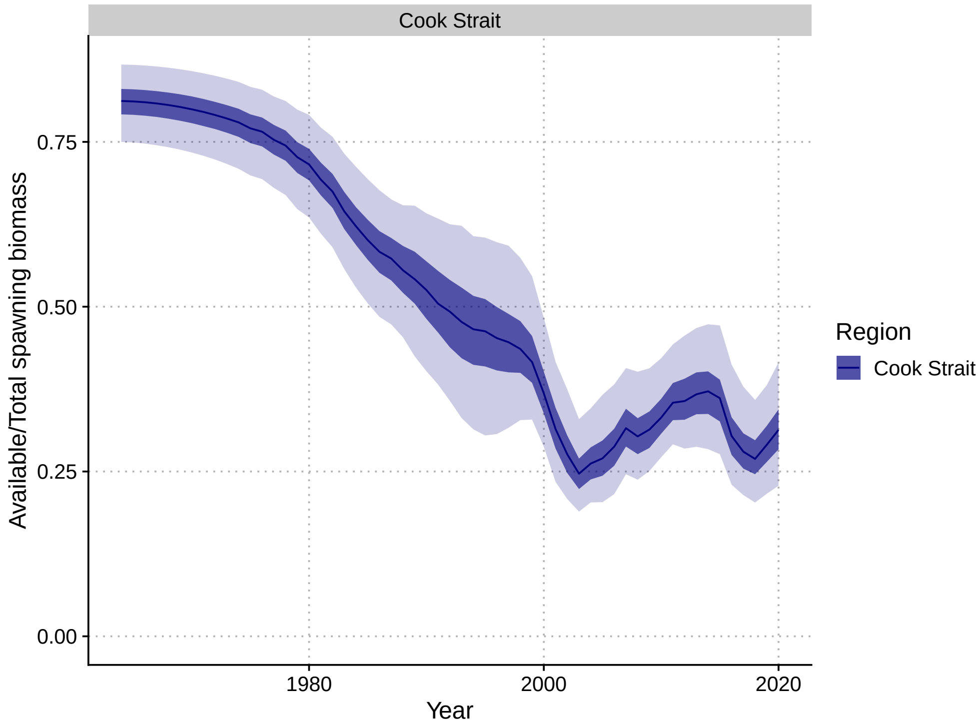

Figure A-12: Estimated relative available pāua biomass (relative to spawning stock) for the base case stock assessment model for quota management area PAU 7 (black line, 75% (dark shade) and 95% (light shade) confidence interval).

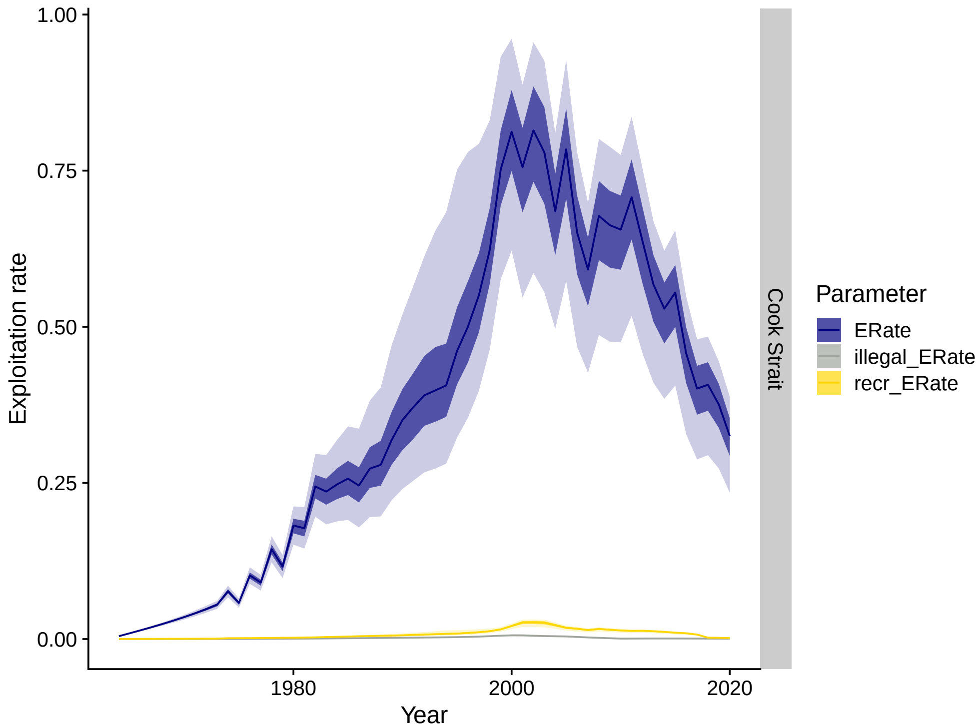

Figure A-13: Estimated exploitation rate (black line and 95% confidence interval) for the base case relative to the posterior median estimate of the exploitation rate (U) leading to 40% spawning stock biomass $U_{40\%SSB_0}$ (red line) of pāua for quota management area PAU 7.

A.1.7 Status and projections

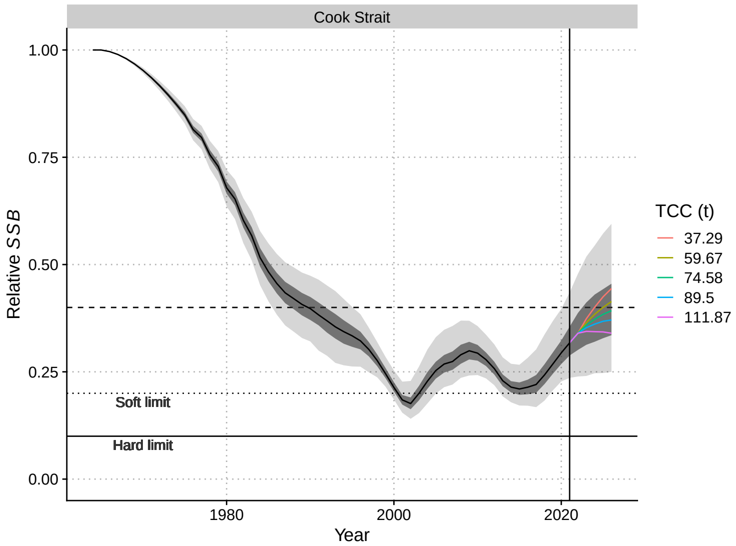

Figure A-14: Relative spawning stock biomass (SSB) trend for pāua for the base case stock assessment model for quota management area PAU 7. Estimated (left of solid vertical line) and projected (right of solid vertical line) relative SSB; black line, current/observed catch; shading, 95% confidence interval. Projections were for current catch (green line), 20% reduction or increase (olive or blue line) and 50% reduction or increase (red or pink line) from current catch (TCC, total commercial catch). Confidence interval corresponds to current catch projections (blue line) only.

Table A-2: Stock status and fishery indicators for the last fishing year considered in this assessment and projections for key fishery indicators from the base case stock assessment model of pāua for quota management area PAU 7. Shown are values for current catch (indicated by the asterisk), and 20% and 50% increases and reductions from current catch. Results at equilibrium (Eq.) are also included (assumed to be reached after 50 years). Columns are: probabilities of being above 40% (P(SSB>0.4SSB_0)) and 20% (P(SSB>0.2SSB_0)) of unfished spawning stock biomass (SSB), the probability that SSB in the projection year is above current SSB, the posterior median relative SSB, the posterior median relative available biomass (B^{avail}), the posterior median relative available spawning biomass (SSB^{avail}), the probability that B^{avail} in the projection year is above current B^{avail}, and the probability that the exploitation rate (U) is greater than the exploitation rate leading to 40% SSB (TACC, total allowable commercial catch).

		Fishery indicator							
TACC (t)	Year	P($SSB > 0.4SSB_0$)	P($SSB > 0.2SSB_0$)	P($SSB > SSB_{\text{current}}$)	Mean rel. SSB	Mean rel. B^{avail}	Mean rel. SSB^{avail}	P($B^{\text{avail}} > B^{\text{avail}}_{\text{current}}$)	P($U > U_{40\%\text{SSB}_0}$)
37.29	2021	0.09	1.00	1.00	0.33	0.12	0.31	0.00	0.56
	2022	0.21	1.00	0.92	0.35	0.14	0.34	0.00	0.00
	2023	0.40	1.00	0.99	0.39	0.18	0.39	0.01	0.00
	2024	0.54	1.00	1.00	0.41	0.22	0.44	0.06	0.00
	2025	0.65	1.00	1.00	0.44	0.26	0.49	0.23	0.00
	2026	0.73	1.00	1.00	0.46	0.29	0.52	0.40	0.00
	Eq.	1.00	1.00	1.00	0.69	0.58	0.68	1.00	0.00
59.67	2021	0.09	1.00	1.00	0.33	0.12	0.31	0.00	0.56
	2022	0.21	1.00	0.92	0.35	0.14	0.34	0.00	0.10
	2023	0.35	1.00	0.96	0.38	0.17	0.38	0.00	0.03
	2024	0.45	1.00	0.97	0.40	0.20	0.42	0.03	0.02
	2025	0.54	1.00	0.98	0.41	0.23	0.46	0.11	0.01
	2026	0.60	1.00	0.99	0.43	0.25	0.49	0.23	0.01
	Eq.	0.99	1.00	1.00	0.59	0.45	0.63	0.93	0.00
74.58*	2021	0.09	1.00	1.00	0.33	0.12	0.31	0.00	0.56
	2022	0.21	1.00	0.92	0.35	0.14	0.34	0.00	0.36
	2023	0.32	1.00	0.94	0.37	0.17	0.37	0.00	0.20
	2024	0.40	1.00	0.94	0.39	0.19	0.40	0.02	0.12
	2025	0.45	1.00	0.94	0.40	0.21	0.43	0.07	0.09
	2026	0.50	1.00	0.94	0.41	0.23	0.46	0.15	0.08
	Eq.	0.87	1.00	0.99	0.51	0.36	0.57	0.66	0.00

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Table A-2 – *Continued from previous page*

								Fishery indicator	
TACC (t)	Year	P($SSB > 0.4SSB_0$)	P($SSB > 0.2SSB_0$)	P($SSB > SSB_{\text{current}}$)	Mean rel. SSB	Mean rel. B^{avail}	Mean rel. SSB^{avail}	P($B^{\text{avail}} > B^{\text{avail}}_{\text{current}}$)	P($U > U_{40\%\text{SSB}_0}$)
89.5	2021	0.09	1.00	1.00	0.33	0.12	0.31	0.00	0.56
	2022	0.21	1.00	0.92	0.35	0.14	0.34	0.00	0.59
	2023	0.30	1.00	0.89	0.37	0.16	0.36	0.00	0.46
	2024	0.35	1.00	0.88	0.37	0.18	0.39	0.01	0.36
	2025	0.38	1.00	0.87	0.38	0.19	0.41	0.03	0.30
	2026	0.40	1.00	0.86	0.38	0.20	0.43	0.08	0.27
	Eq.	0.55	0.98	0.84	0.42	0.26	0.49	0.31	0.16
111.87	2021	0.09	1.00	1.00	0.33	0.12	0.31	0.00	0.56
	2022	0.21	1.00	0.92	0.35	0.14	0.34	0.00	0.82
	2023	0.26	1.00	0.81	0.36	0.15	0.35	0.00	0.77
	2024	0.28	0.99	0.74	0.36	0.16	0.36	0.00	0.72
	2025	0.28	0.99	0.70	0.35	0.16	0.37	0.01	0.67
	2026	0.28	0.98	0.64	0.35	0.16	0.38	0.03	0.63
	Eq.	0.13	0.78	0.22	0.28	0.11	0.29	0.04	0.81

APPENDIX B: MODEL SENSITIVITIES

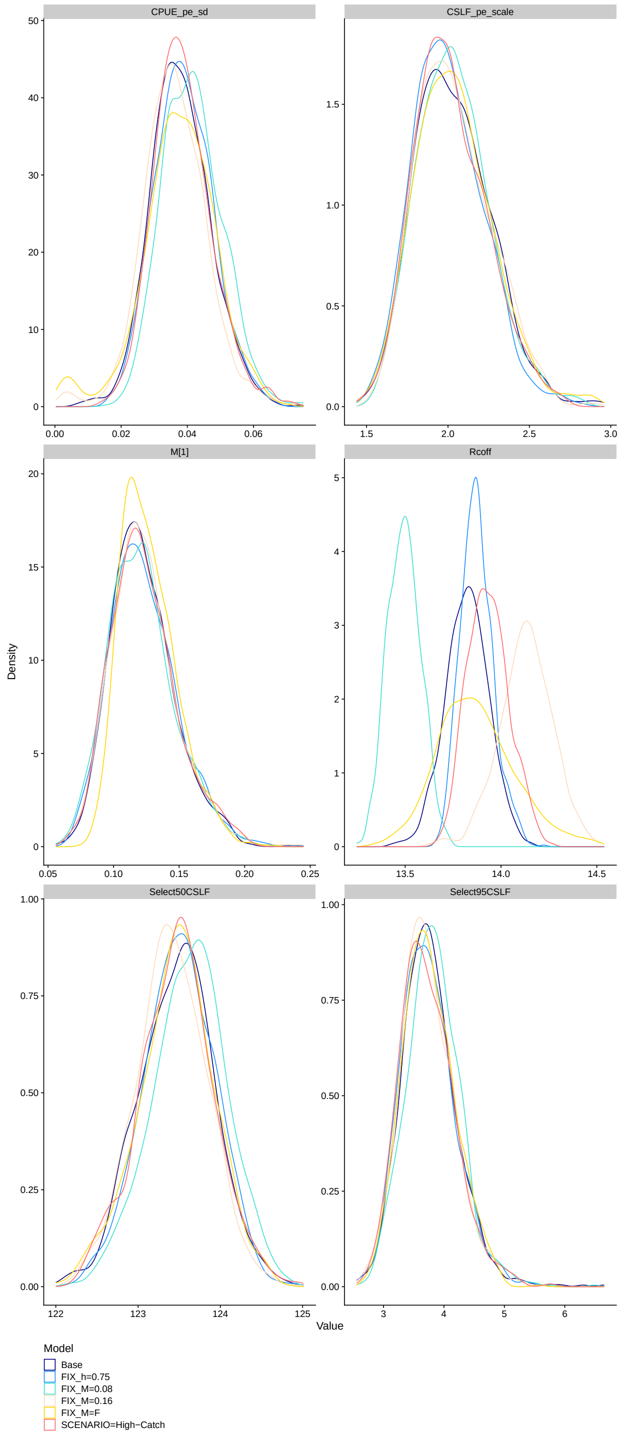

Figure B-1: Comparison of posterior densities for parameters in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.

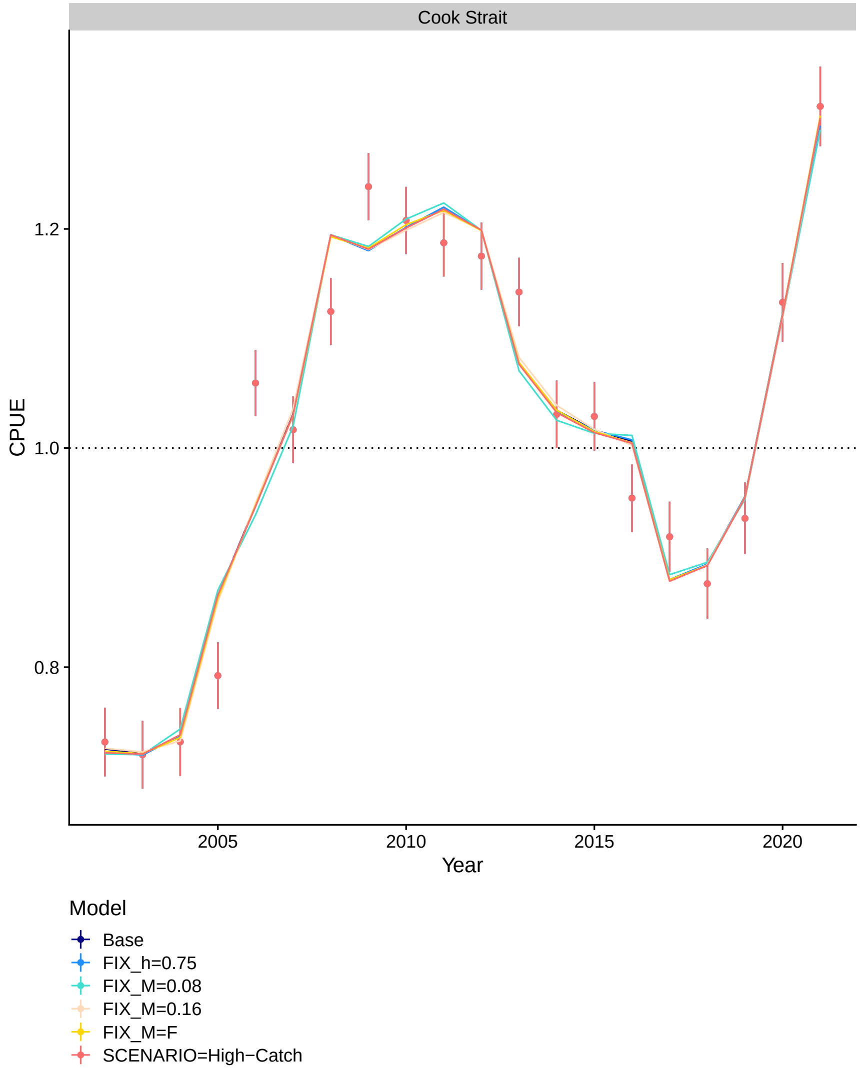

Figure B-2: Comparison of posterior median predicted catch-per-unit-effort (CPUE) in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.

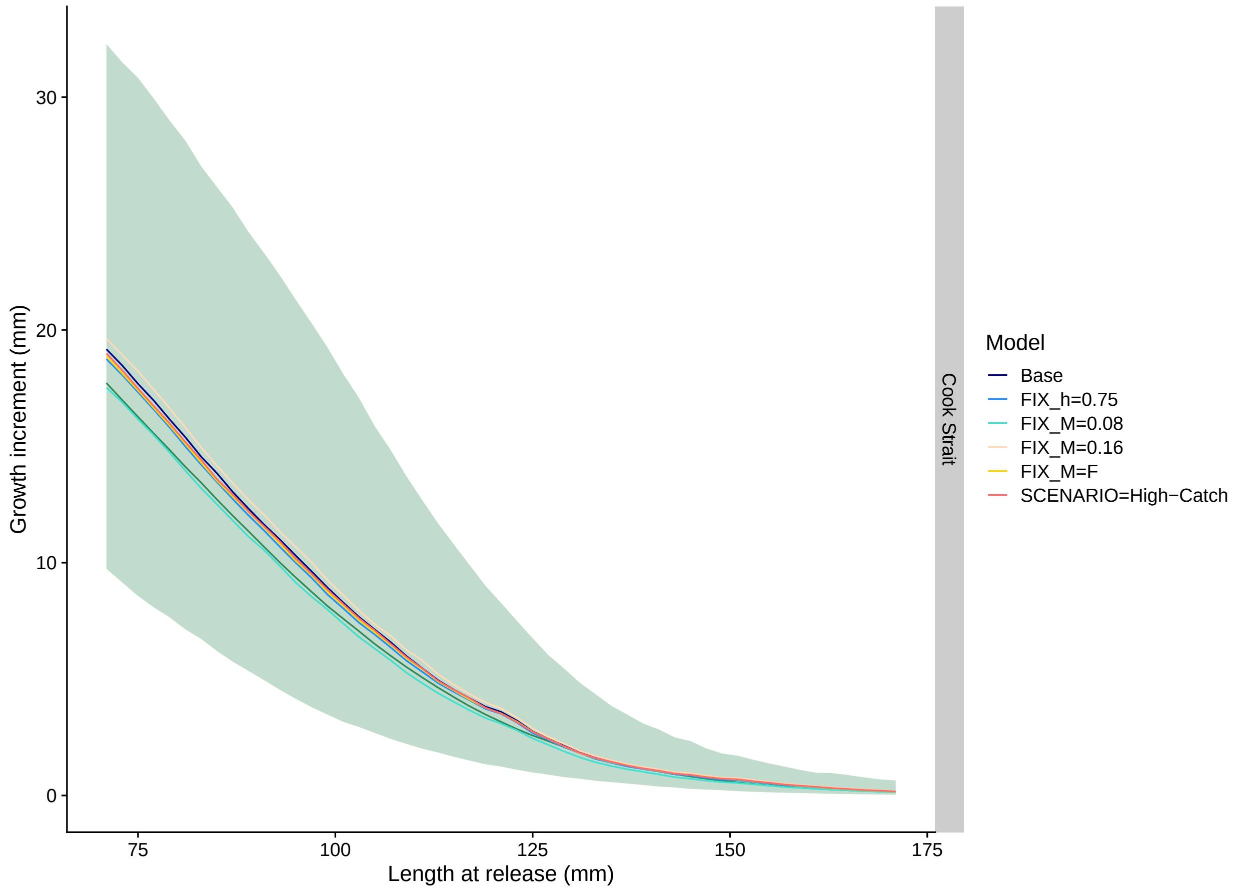

Figure B-3: Comparison of prior and posterior growth in the stock assessment model for key model sensitivities based on assumptions about productivity parameters. Prior for population mean growth (prior mean, green line; 95% prior interval, green shading), and posterior mean growth (light blue, posterior median and 95% posterior interval).

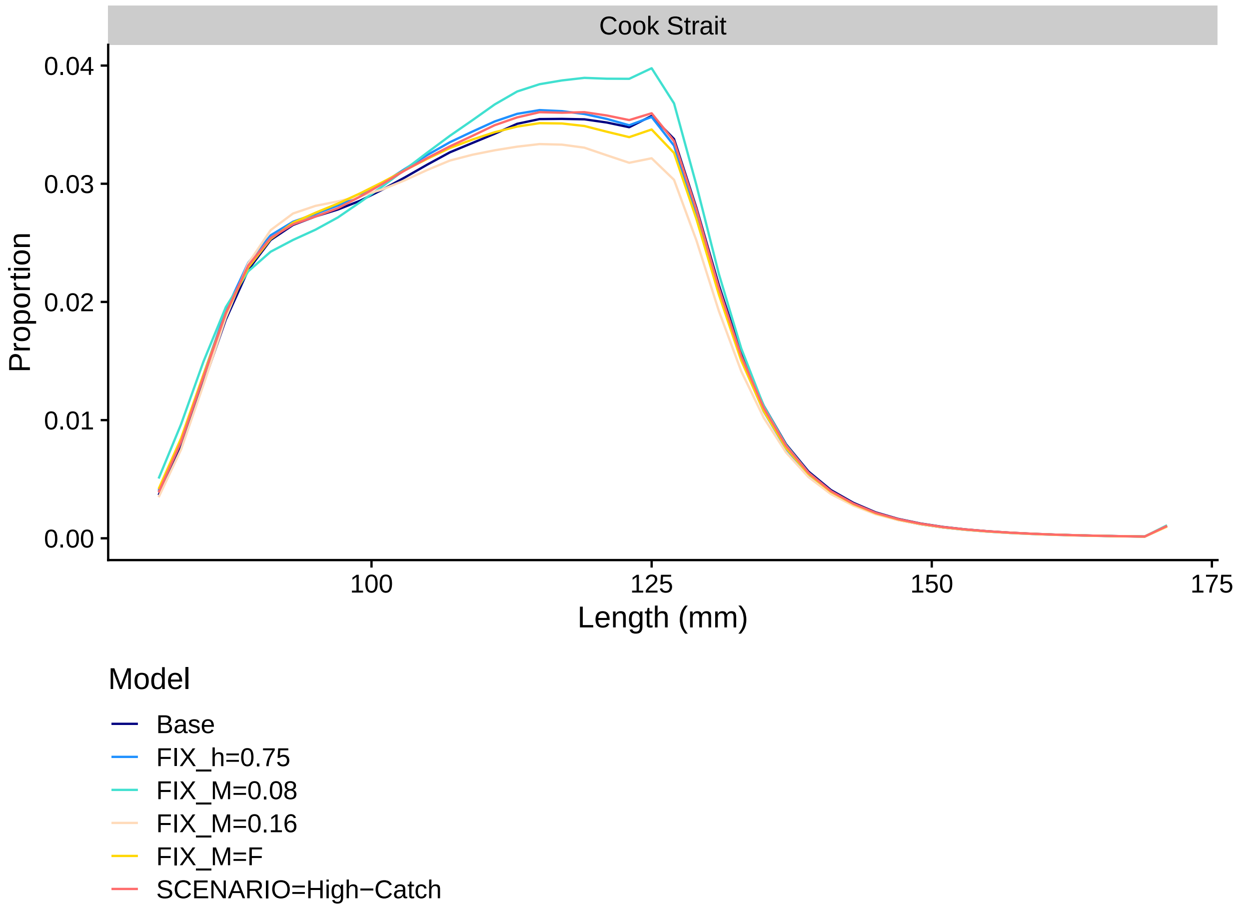

Figure B-4: Comparison of posterior mean proportions-at-length in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.

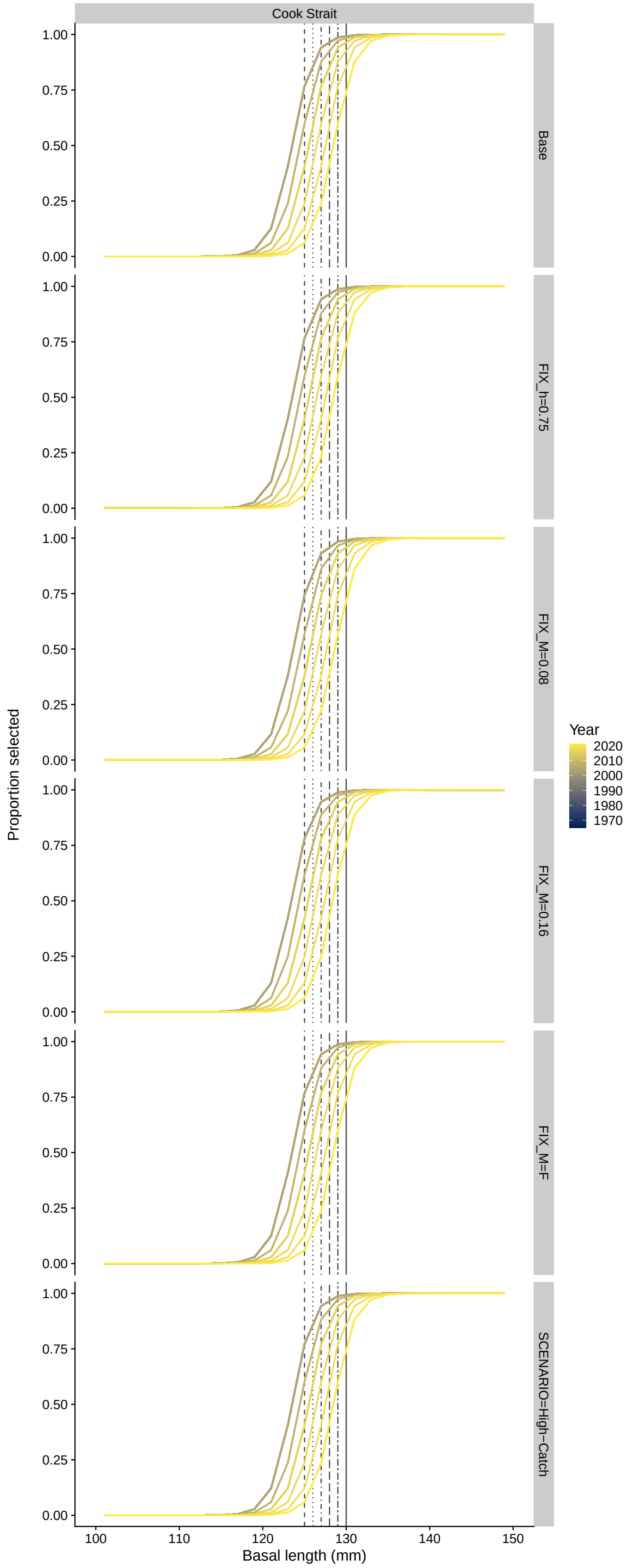

Figure B-5: Comparison of posterior mean selectivity-at-length in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.

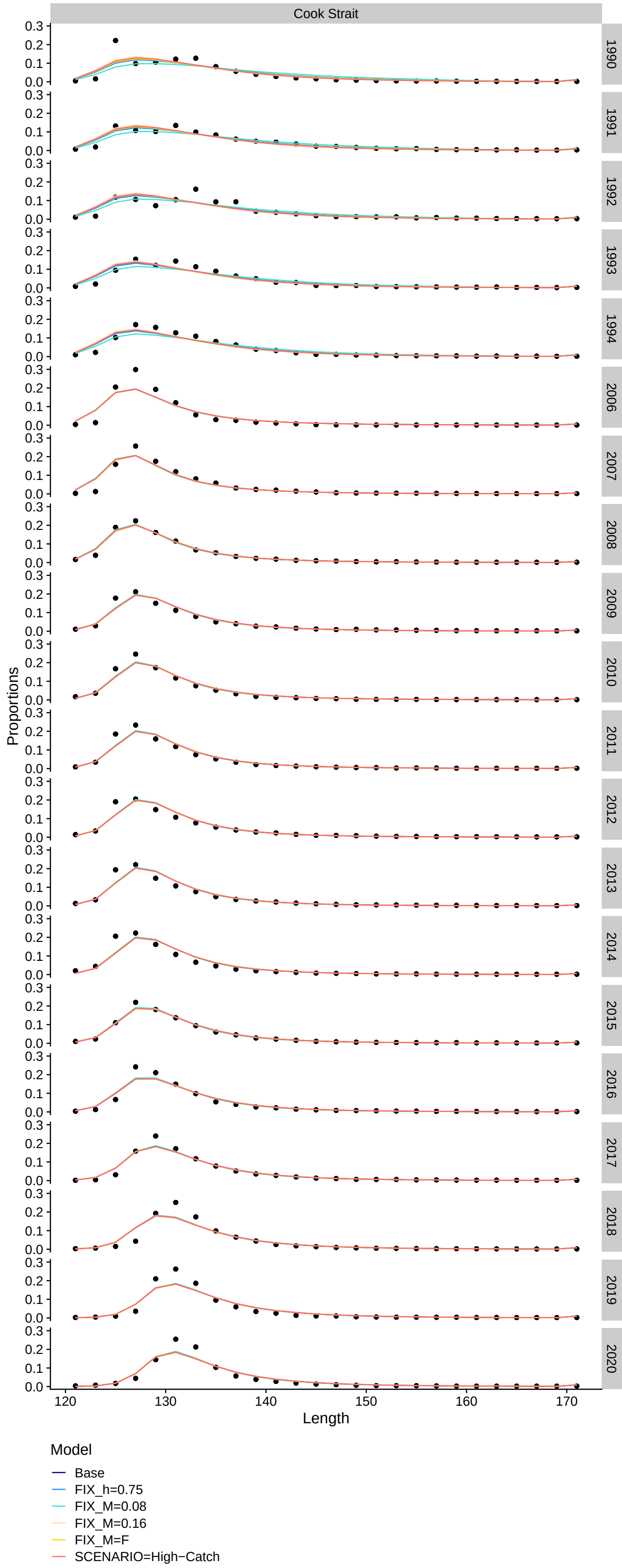

Figure B-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF) distribution with estimated CSLF proportions, in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.

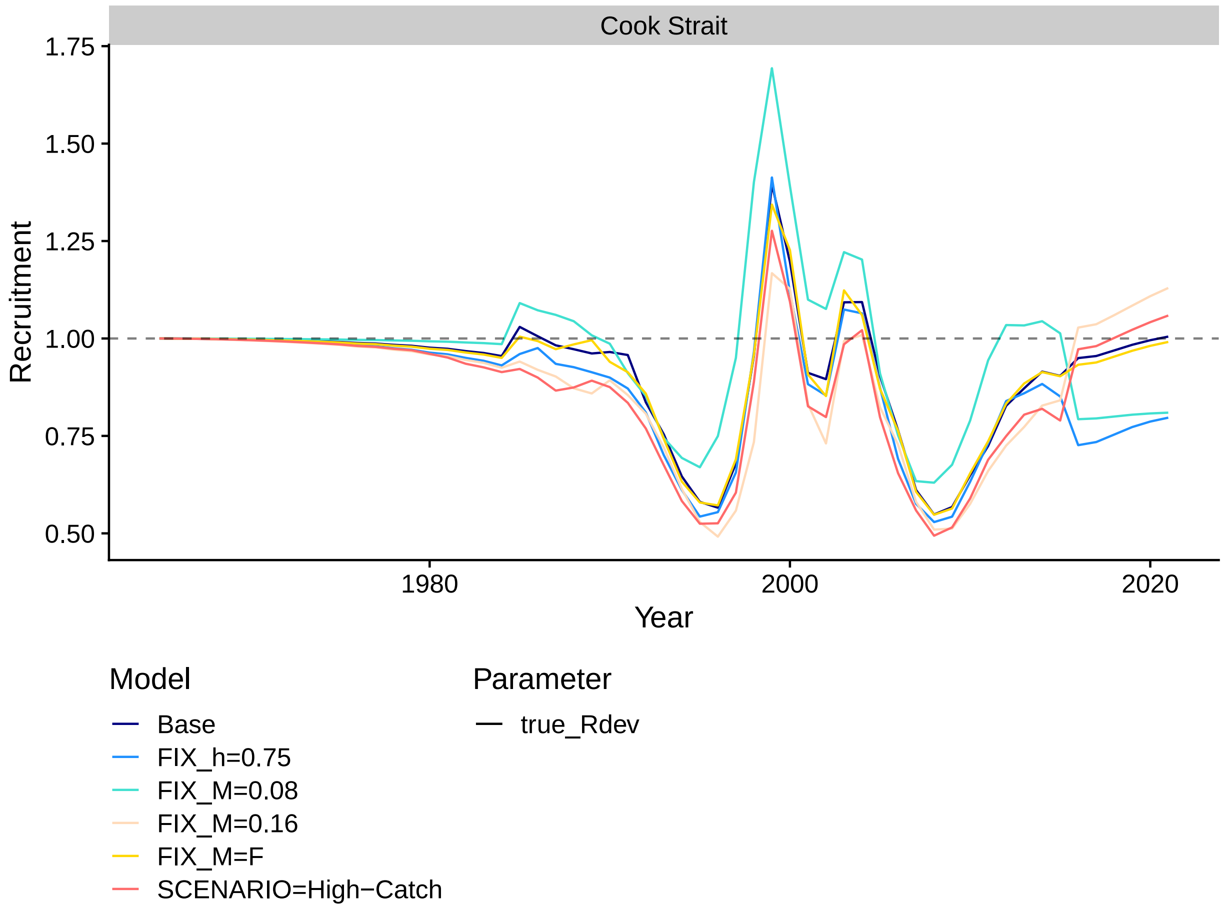

Figure B-7: Comparison of posterior mean recruitment deviations (R_{dev}) in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.

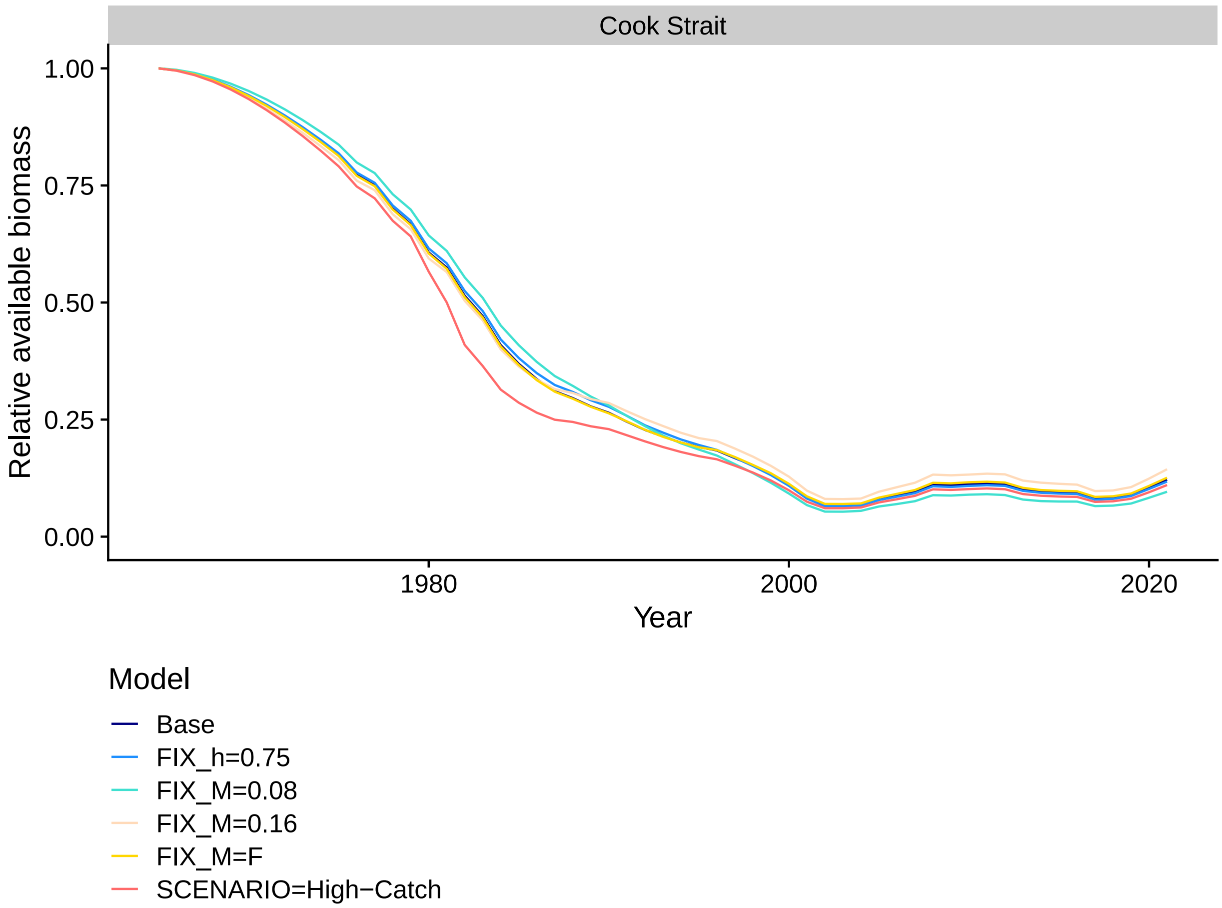

Figure B-8: Comparison of posterior median predicted relative available biomass trend in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.

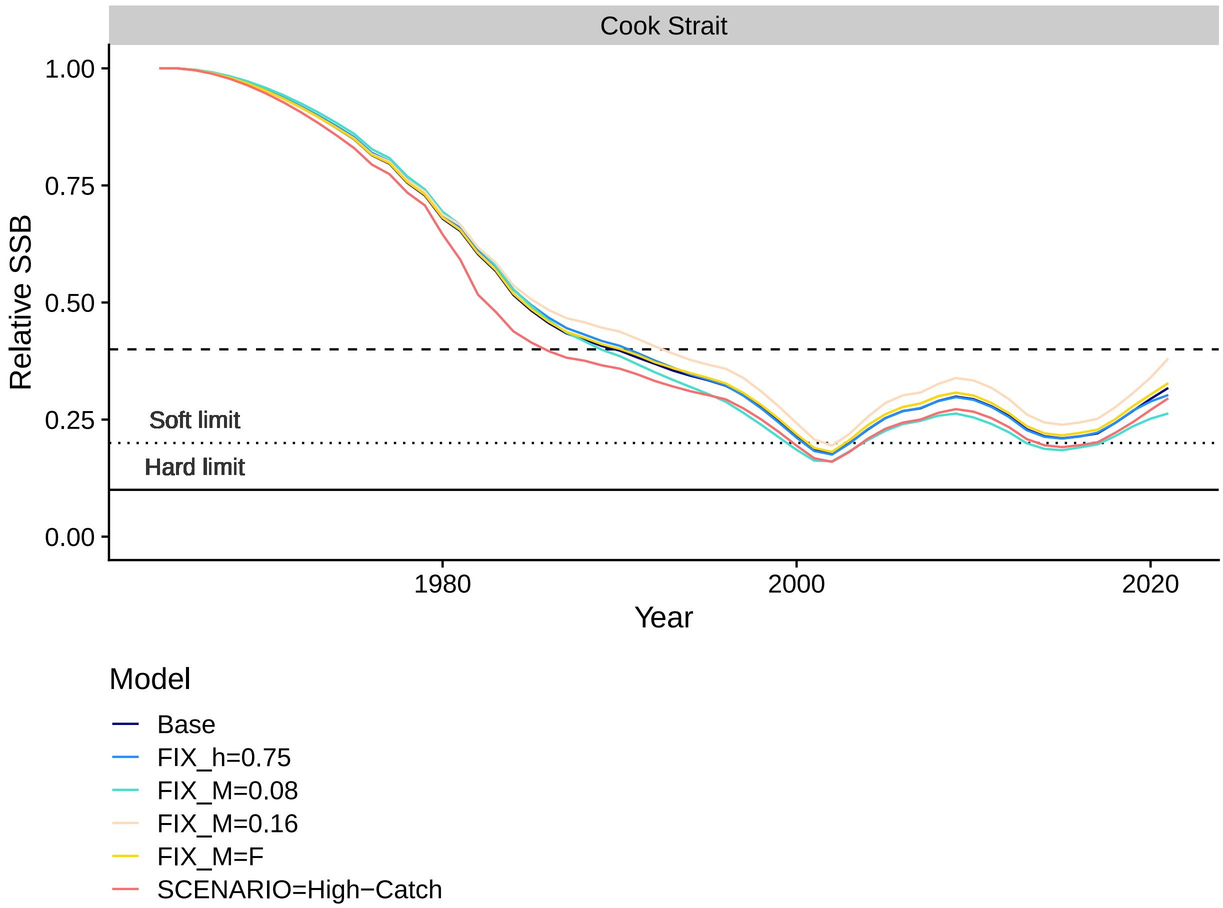

Figure B-9: Comparison of posterior median predicted relative spawning stock biomass (SSB) trend in the stock assessment model for key model sensitivities based on assumptions about productivity parameters.