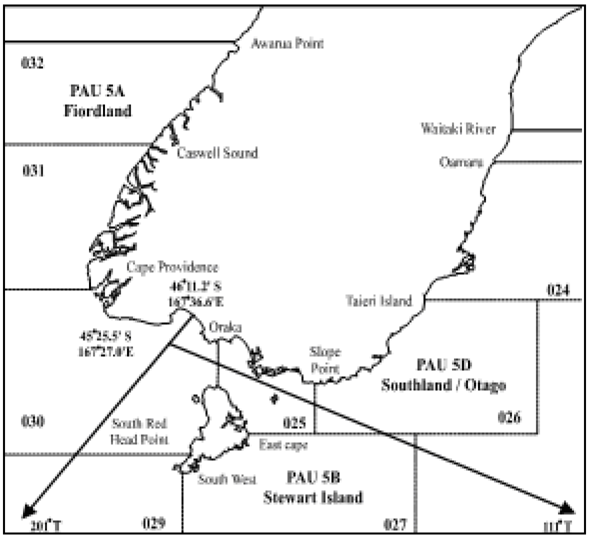
PĀUA (PAU 5A) – Fiordland

(Haliotis iris)
Pāua



1. FISHERY SUMMARY

Prior to 1995, PAU 5A was part of the PAU 5 QMA, which was introduced into the QMS in 1986 with a TACC of 445 t. As a result of appeals to the Quota Appeal Authority, the TACC increased to 492 t in the 1991–92 fishing year; PAU 5 was then the largest QMA by number of quota holders and TACC. Concerns about the status of the PAU 5 stock led to a voluntary 10% reduction in the TACC in 1994–95. On 1 October 1995, PAU 5 was divided into three QMAs (PAU 5A, PAU 5B, and PAU 5D; see the figure above) and the TACC was divided equally among them; the PAU 5A quota was set at 148.98 t.

There is no TAC for PAU 5A (Table 1): before the Fisheries Act (1996) a TAC was not required. When changes have been made to a TACC after 1996, stocks have been assigned a TAC. No allowances have been made for customary, recreational or other mortality.

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 5 and PAU 5A since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1991*	-	-	-	-	445
1991–1994*	-	-	-	-	492
1994–1995*	-	-	-	-	442.8
1995–present	-	-	-	-	148.98

*PAU 5 TACC figures

1.1 Commercial fisheries
The fishing year runs from 1 October to 30 September.

On 1 October 2001 it became mandatory to report catch and effort on Pāua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1).

PAU 5A landings were close to the TACC from the fishing year 1995–96 to 2005–06, but dropped to an average of 105 t a year from 2006–07 onwards (Table 2 and Figure 2). Landings for PAU 5 prior to 1995–96 are reported in the Introduction – Pāua chapter.

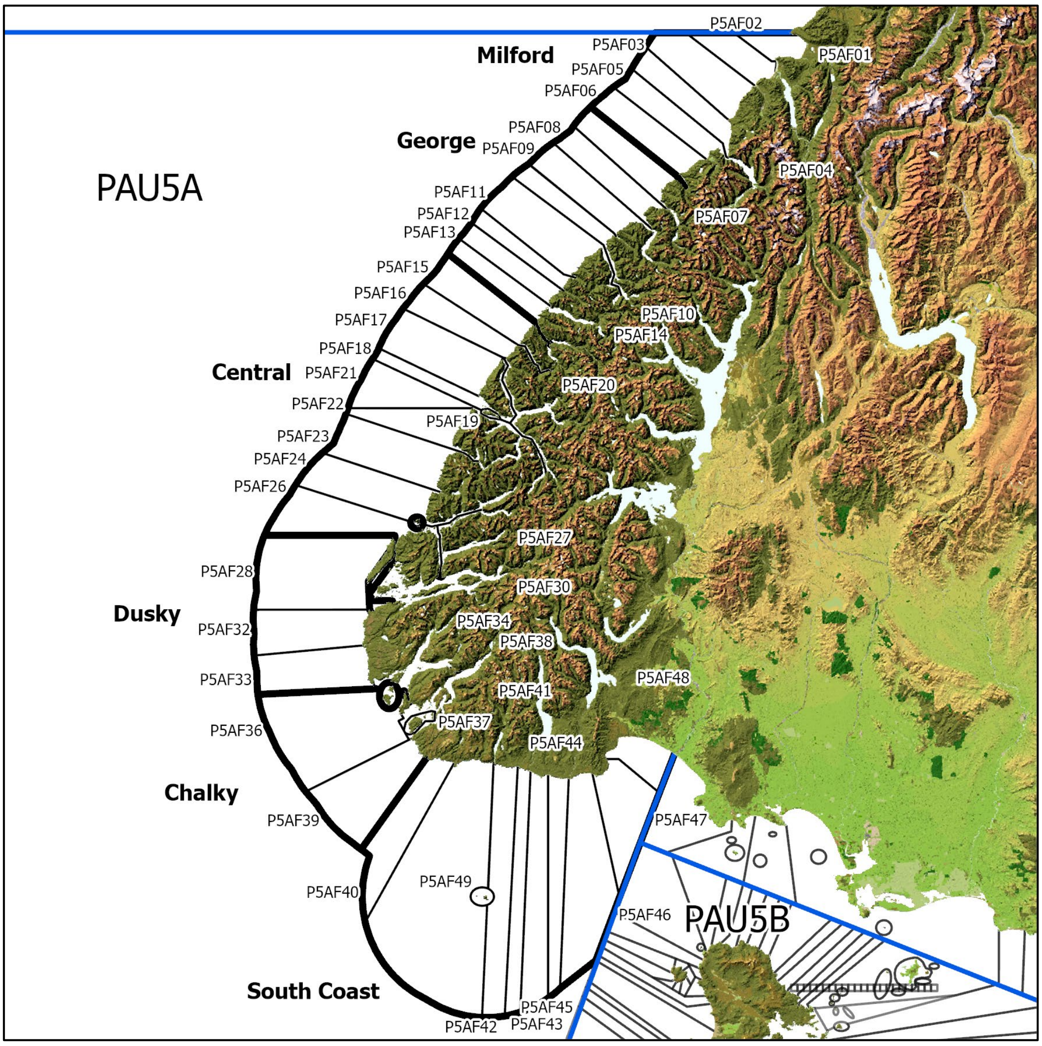


Figure 1: Map of Pāua Statistical Areas, and voluntary management strata in PAU 5A.

Table 2: TACC and reported landings (t) of pāua in PAU 5A from 1995–96 to the present from MHR returns.

Year	Landings	TACC	Year	Landings	TACC
1995–96	139.53	148.98	2009–10	105.74	148.98
1996–97	141.91	148.98	2010–11	104.40	148.98
1997–98	145.22	148.98	2011–12	106.23	148.98
1998–99	147.36	148.98	2012–13	105.56	148.98
1999–00	143.91	148.98	2013–14	102.30	148.98
2000–01	147.70	148.98	2014–15	106.95	148.98
2001–02	148.53	148.98	2015–16	106.84	148.98
2002–03	148.76	148.98	2016–17	106.50	148.98
2003–04	148.98	148.98	2017–18	107.45	148.98
2004–05	148.95	148.98	2018–19	99.66	148.98
2005–06	148.92	148.98	2019–20	103.03	148.98
2006–07	104.03	148.98	2020–21	106.02	148.98
2007–08	105.13	148.98	2021–22	114.88	148.98
2008–09	104.82	148.98	2022–23	111.51	148.98

1.2 Recreational fisheries

The National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates Wynne-Jones et al (2014), estimated that about 0.42 t (CV 0.76) of pāua were harvested by recreational fishers in PAU 5A in 2011–12.

The national panel survey was repeated in 2017–18 (Wynne-Jones et al 2019) and the estimated harvest for PAU 5A was 0.71 t (CV 0.81). For the purpose of the 2020 stock assessment, the SFWG agreed to assume that the recreational catch rose linearly from 1965 to 1 t in 1974, and has remained at 1 t since 1974.

The most recent national panel survey harvest estimate for PAU 5A is 1.58 t (CV 0.68) for 2022–23 (Heinemann & Gray in prep).

For further information on recreational fisheries refer to the Introduction – Pāua chapter.

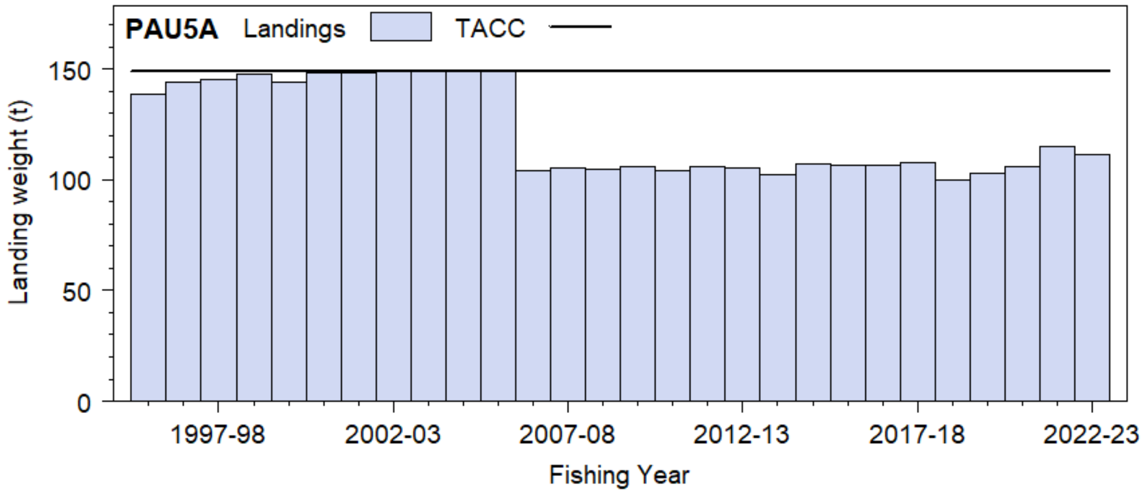


Figure 2: Landings and TACC for PAU 5A from 1995–96 to the present. For historical landings in PAU 5 prior to 1995–96, refer to figure 1 and table 1 in the Introduction – Pāua chapter.

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

Estimates of customary catch for PAU 5A are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch approved and harvested in numbers is reported in the table. In addition, many tangata whenua also harvest pāua under their recreational allowance and these are not included in records of customary catch.

Table 3: Fisheries New Zealand records of customary harvest of pāua (approved and reported in numbers) in PAU 5A since 2001–02. – no data.

	Numbers	
Fishing year	**Approved**	**Harvested**
2001–02	80	70
2002–03	–	–
2003–04	–	–
2004–05	–	–
2005–06	–	–
2006–07	–	–
2007–08	100	100
2008–09	100	100
2009–10	150	150
2010–11	150	150
2011–12	512	462
2012–13	590	527
2013–14	–	–
2014–15	–	–
2015–16	255	50
2016–17	–	–
2017–18	200	200
2018–19	–	–
2019–20	–	–
2020–21	850	820
2021–22	–	–
2022–23	–	–

Records of customary non-commercial catch taken under the South Island Regulations show that about 70 pāua were taken in 2001–2002, then nothing until 2007–08. From 2007–08 to 2012–13, 100 to 500 pāua were collected each year. Since then, less pāua have been reported as caught (maximum 200 t in 2017–18).

For the purpose of the 2020 stock assessment model, the SFWG agreed to assume that customary catch has been constant at 1 t.

For further information on customary fisheries refer to the Introduction – Pāua chapter.

1.4 Illegal catch

There is qualitative data to suggest Illegal, unreported, unregulated (IUU) activity in this Fishery. There are no quantitative estimates of illegal catch for PAU 5A. For the purpose of the 2020 stock assessment model, the SFWG agreed to assume that illegal catches have been a constant 5 t.

1.5 Other sources of mortality

For further information on other sources of mortality refer to the Introduction – Pāua chapter.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter. Biological parameters derived using data collected from PAU 5A are summarised in Table 4. Size-at-maturity, natural mortality and annual growth increment parameters were estimated within the assessment model.

Table 4: Estimates of biological parameters (*H. iris*). All estimates are external to the model.

Stock area		Estimate	Source
1. Weight = a (length)^b (weight in kg, shell length in mm)			
PAU 5A	a = 2.99E-08	b = 3.303	Schiel & Breen (1991)
2. Size at maturity (shell length)			
PAU 5A	50% mature	91 mm (89–93)	Median (5–95% range) estimated outside of the assessment
	95% mature	103 mm (101–105)	
3. Estimated annual growth increments (both sexes combined)			
PAU 5A	At 75 mm	16.65 mm (15.96–24.29)	Median (5–95% range) estimated outside of the assessment
	At 120 mm	4.57 mm (3.27–6.40)	

3. STOCKS AND AREAS

For further information on stocks and areas refer to the Introduction – Pāua chapter.

4. STOCK ASSESSMENT

For 2010 and 2014, the stock assessments for PAU 5A had split PAU 5A into two subareas; the southern area which included the Chalky and South Coast strata, and the northern area which included the Milford, George, Central, and Dusky strata (Figure 1). Separate stock assessments were conducted in each subarea. The division was based on the availability of data, differences in exploitation history and management initiatives. Prior to 2010 the area was assessed as a single area. The 2020 assessment re-evaluated the split of PAU 5A into two subareas, and concluded that the data used for the separate assessments did not adequately reflect the differences in these areas, and the 2020 assessment was therefore run in two configurations: as a single area assessment over all of PAU 5A, and by splitting the area into three areas (statistical areas around Milford Sound (large scale Statistical Area 032) were separated from the previously defined Northern area due to slower growth) and fitting a spatial version of the assessment model (Neubauer 2020). Initial assessment runs suggested no difference in key estimated quantities between the spatial and single-area models, and the SFWG decided to proceed with the more parsimonious single area model.

4.1 Estimates of fishery parameters and abundance

Parameters estimated in the base case model (for both the southern and northern areas) and their assumed Bayesian priors are summarised in Table 5.

Table 5: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U=uniform; N= normal; LN=lognormal; Beta = beta distribution), mean and CV of the prior.

Parameter	Prior	μ	sd	Bounds	
				Lower	Upper
ln(*R0*)	LN	13.5	0.5	10	20
D_{50}(Length at 50% selectivity for the commercial catch)	LN	123	0.05	100	145
D_{95-50}(Length between 50% and 95% selectivity the commercial catch)	LN	5	0.5	0.01	50
Steepness (h)	Beta	0.8	0.17	0	1
ϵ (Recruitment deviations)	LN	0	2	0	-

The observational data were:

1. A standardised CPUE series covering 1989–2018 based on combined CELR and PCELR data.
2. A commercial catch sampling length frequency

4.1.1 Relative abundance estimates from standardised CPUE analyses

A combined series of standardised CPUE indices that included FSU (1983–1989), CELR data covering 1990–2001, and PCELR data covering 2002–2019 was used for the 2020 stock assessment (Figure 3). CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among fixed (research strata) and random variables, and between fine-scale reporting (PCELR) and larger scale variables (CELR). The FSU data contained no standardising variables. The variation explained by fine-scale variables (e.g. fine scale statistical areas or divers) in PCELR data was considered unexplained in the CELR and FSU portion of the model and therefore added to observation error.

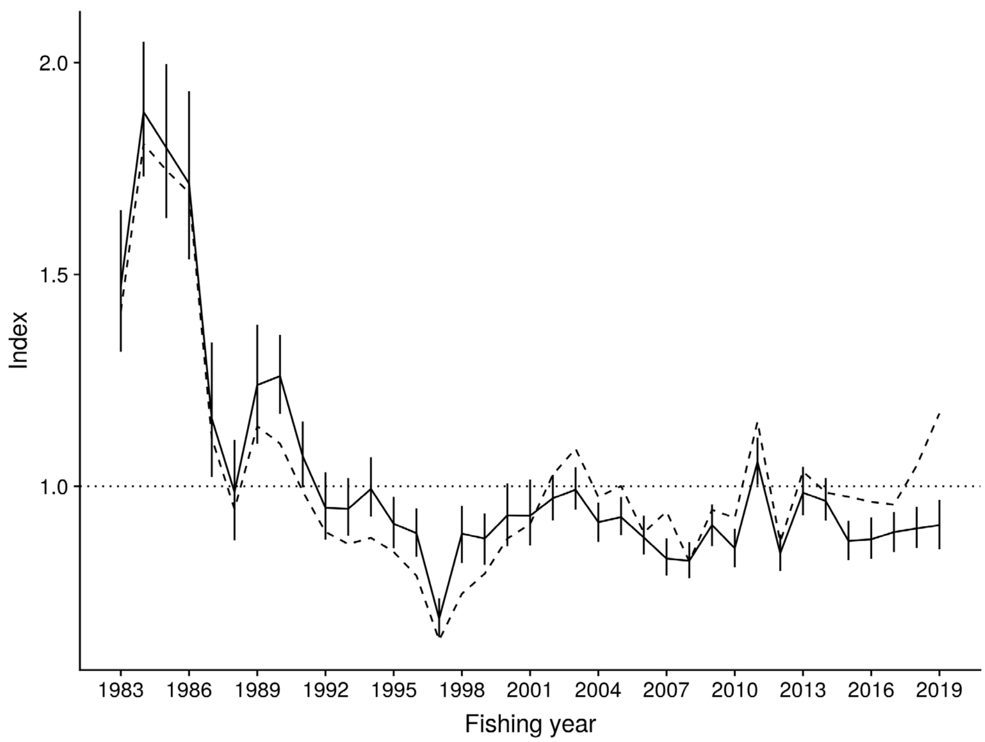


Figure 3: The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardised geometric CPUE (dashed line) for the combined CELR and the PCELR series.

There was ambiguity in the CELR data about what was recorded for estimated daily fishing duration: either incorrectly recorded as hours per diver, or correctly as total hours for all divers. For PAU 5A, fishing duration appeared to have been predominantly recorded as hours per diver. A model-based correction procedure was developed to detect and correct for misreporting, using a mixture model that determines the characteristics of each reporting type by fishing crew and assigns years to correct (reporting for all divers) or incorrect (by diver) reporting regimes with some probability. Only records with greater than 95% certainty of belonging to one or the other reporting type were retained for further analysis.
CPUE was defined as the log of daily catch-per-unit-effort. Variables in the model were fishing year, FIN (Fisher Identification Number), Statistical Area, dive condition, diver ID, and fine-scale statistical area. Variability in CPUE was mostly explained by differences among crews (FINs), with dive conditions also strongly affecting CPUE. The CPUE data showed initially high CPUE in the 1980s, followed by a rapid decline and subsequent increase in the late 1980s. A further decline in the early 1990s was evident, with relatively stable but fluctuating CPUE since 1992. In some circumstances, commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of pāua despite a declining biomass. This occurs because pāua tend to aggregate and divers move among areas to maximise their catch rates. Apparent stability in CPUE should therefore be interpreted with caution. The assumption of CPUE being proportional to biomass was investigated using the assessment model.

4.1.2 Relative abundance estimates from research diver surveys

Relative abundance of pāua in PAU 5A has previously been estimated from research diver surveys conducted in 1996, 2002, 2003, 2006, and 2008–2010. Not every stratum was surveyed in each year, and before 2005–06 surveys were conducted only in the area south of Dusky Sound.

Concerns about the reliability of this data as an estimate of relative abundance instigated several reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed i) the reliability of the research diver survey index as a proxy for abundance and ii) whether the Research Diver Survey Index (RDSI), when used in the pāua stock assessment models, results in model outputs that do not adequately reflect the status of the stocks. Both reviews suggest that outputs from pāua stock assessments using the RDSI should be treated with caution. Consequently, these data were not included in the assessment. For a summary of the conclusions from the reviews refer to the Introduction – Pāua chapter.

4.2 Stock assessment methods

The 2020 stock assessment for PAU 5A used an updated version of the length-based population dynamics model described by Breen et al (2003). The stock was last assessed using data up to the 2014 fishing year (Fu 2015a, b) and the most recent assessment uses data up to the 2018–2019 fishing year (Neubauer 2022). Although the overall population-dynamics model remained unchanged, the most recent iteration of the PAU 5A stock assessment incorporates changes to the previous methodology (first introduced in the 2019 assessment of Pau 5D; Neubauer & Tremblay-Boyer 2019):

1. The base case model considered the entire area of PAU 5A, rather than conducting separate assessments for the PAU 5A northern and PAU 5A southern areas.
2. CPUE likelihood calculations reverted to predicting CPUE from beginning of year biomass since the previous change to mid-year predictions did not affect the assessment and caused potential for error and an increased computational burden.
3. A Bayesian statistical framework across all data inputs and assessments (MPD runs were not performed; all exploration was performed using full Markov chain Monte Carlo runs).
4. The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB).
5. Catch sampling length-frequency (CSLF) data handling was modified to a model-based estimation of observation error with partitioning between observation and process error for CSLF and CPUE, and use of a multivariate normal model for centred-log-ratio-transformed mean CSLF and observation error.

6. The data weighting procedure was to use a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF.
7. Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.

The model structure assumed a single-sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm in groups of 2 mm, although a spatial version of the assessment model (Neubauer 2020) was also tried. For the latter, the model assumed three areas, with the Southern area identical to the previously assessed Southern stock area, and the Northern areas splitting the previous Northern assessment area south of Milford Sound to account for growth differences to the north of Milford Sound.

Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class to change at each time step. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2019. Catches were available for 1974–2019 although catches before 1995 must be estimated from the combined PAU 5 catch, and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step. For the spatial model, it was assumed that 80% of the non-commercial catch was taken from the southern area of PAU 5A, with the remainder being taken from the northern areas.

Recruitment was assumed to take place at the beginning of the annual cycle, and length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. Growth and natural mortalities were estimated within the model from informed prior distributions. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and to reach an asymptote. Dome-shaped selectivity curves were also investigated for the present assessment. The increase in Minimum Harvest Size since 2006 was modelled as a shift in fishing selectivity.

The commercial catch history estimates were made under assumptions about the split of the catch between sub-stocks of PAU 5, and between subareas within PAU 5A. The base case model run assumed that 40% of the catch in Statistical Area 030 was taken from PAU 5A between 1985 and 1996. Estimates made under alternative assumptions (a lower bound of 18% and an upper bound of 61%) were used in sensitivity trials. Commercial catch sampling length-frequency samples before 2002 (1992–1994, 1998, and 2001) were excluded from the base case, because the sample size is low and sampling coverage is dubious. The model was initiated with likelihood weights that were found to lead to subjectively appropriate fits to both CPUE and CSLF inputs in other areas (PAU 5D and PAU 5B) The RDSI and RDLF were excluded from all models, and the CPUE shape parameter was fixed at 1 assuming a linear relationship between CPUE and abundance except for one scenario assuming a hyper-stable CPUE-abundance relationship. The assessment proceeded in three stages (sets):

A first set of model runs explored:

- Including the FSU CPUE index or excluding it.
- Estimating a trend in catchability, and forcing hyper-stable CPUE.
- High and Low Statistical Area 030 catch scenarios prior to 1996.
- Lower recruitment variability.

The trend in catchability was implemented as a linear trend in log-space. Data weight parameters were set to values that produced reasonable fits in other assessments.

A variation of the first set of model runs explored running the same scenarios as described above, but using the spatial model described in Neubauer (2020) for each of the three large scale reporting strata

(Statistical Areas 030, 031, 032). Natural mortality and steepness were shared parameters, whereas recruitment was estimated independently for each region, and total (PAU 5A-wide) unfished recruitment was partitioned into each of the three regions using a composition vector that was estimated within the model using an informed prior based on relative catch levels.

After running the first set of models it was evident that models were using recruitment to adjust the biomass for increases in CPUE after an initial decline in the late 1980s and early 1990s. However, this period of CPUE increase coincides with a period of rapidly increasing efficiency (dive gear, operational aspects, weather forecasts) in all PAU fisheries around the country, which all show some degree of CPUE increase during this period. The SFWG therefore decided to fix recruitment for the years until CSLF information became available (2000–01), and to instead use variable catchability by i) splitting catchability into reporting epochs (FSU, CELR and PCELR) and ii) estimating increase in catchability for each epoch.

In addition to fixing early recruitment, models using variable selectivity were trialled to account for spatially variable fishing patterns that are likely to drive some of the CPUE variation (rather than variation being recruitment driven): if fishers only fish a subset of available areas in any given year (due to weather or market constraints), variable (and potentially dome-shaped) selectivity would be expected given small scale variation in growth and fishing pressure. Both variable logistic selectivity (variable length at 50% selection), and fixed and variable dome-shaped selectivity (with variable right-hand limb of the inverted quadratic curve used for the dome-shaped selectivity) were implemented. Models with variable dome-shaped selectivity did not converge and were therefore excluded.

Lastly, given doubts about accuracy in early FSU reporting, in conjunction with implausible scenarios from excluding FSU data altogether, the working group decided to trial estimating initial depletion in 1984 (and ignoring both catch and CPUE prior to 1984), as well as starting CPUE in 1984 instead of 1983 (reported CPUE was high from 1984, but lower in 1983), but maintaining the catch time-series from 1965. In summary, the second set of models were set up as follows:

- Including the FSU CPUE index, but starting CPUE in 1984, or estimating initial depletion in 1984 (starting catch and CPUE in 1984).
- Estimating a trend in catchability by CPUE reporting period (using separate initial q for FSU, CELR and PCELR).
- Baseline Statistical Area 030 catch scenarios prior to 1996.
- Fixed recruitment prior to CSLF data availability (estimated from three years prior to first year of CSLF data).
- Variable logistic selectivity and dome-shaped selectivity (fixed - variable dome-shape did not converge).

The robustness of models from the first two sets that were judged plausible (Baseline catch with FSU CPUE from 1984, with or without recruitment deviations for pre-CSLF period, with variable selectivity or not) was investigated by varying model weights. Three sets of weights were trialled in addition to weights used in sets 1 & 2: all sets down-weight CPUE by a factor of 2 relative to sets 1 & 2, and either doubled (0.2) or halved (0.05) CSLF weights.

The assessment calculates 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 2018 (SSB_{2018} and B_{2018}^{Avail} $\mathrm{B}_{\mathrm{Proj}}^{\mathrm{Avail}}$) and for the projection (*Proj*) period (SSB_{Proj} and B_{proj}^{Avail}).

This assessment also reports the following fishery indictors:

Relative *SSB*	Estimated spawning stock biomass in the final year relative to unfished spawning stock biomass
Relative B^{Avail}	Estimated available biomass in the final year relative to unfished available stock biomass
P(SSB_{2018} > 40% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 40% of the unfished spawning stock
P(SSB_{2018} > 20% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 20% of the unfished spawning stock (soft limit)
P(SSB_{Proj} > 40% SSB_0)	Probability that projected future spawning stock biomass will be greater than 40% of the unfished spawning stock given assumed future catches
P(SSB_{Proj} > 20% SSB_0)	Probability that projected future spawning stock biomass will be greater than 20% of the unfished spawning stock given assumed future catches
P(B_{Proj} > B_{2018})	Probability that projected future biomass (spawning stock or available biomass) is greater than estimated biomass for the 2018 fishing year given assumed future catches

4.3 Stock assessment results

The initial set of model runs produced three distinct outcomes: models that did not include FSU data suggested very little depletion since the start of the fishery (final stock status above 60% of SSB_0), whereas models with forced hyper-depletion in the CPUE index or estimated increase in catchability lead to higher depletion levels (final stock status near 40% of SSB_0).

The baseline model with FSU data included, as well as scenarios with low or high catch from Statistical Area 030 all produced intermediate status estimates, as did the model with reduced recruitment variability. The latter model stood out as a model that estimated both much faster growth as well as high M (M>0.1; with M<0.1 for all other runs).

Based on these runs the working group decided that model scenarios without FSU data most likely did not adequately capture biomass declines over the initial phase of the fishery, as the estimate of a stock near 75% of un-fished biomass in the early 2000s did not appear compatible with a voluntary 30% shelving of the quota in 2006. Given that models with estimated increase in q produced similar results to those with forced hyper-depletion, the latter were not pursued further.

Spatial model runs were able to partition the initial biomass decline and demographic variability into the three regions. The Northern region (north of Milford) had the lowest depletion level owing to sporadic fishing in the region, which has significantly slower growth than the other regions but a similar share of overall recruitment. Overall, aggregate values from the spatial model were nearly identical to the non-spatial model and the more parsimonious single-area model was therefore preferred by the working group.

All models in the second set of model runs produced similar outcomes, with the exception of the model with variable selectivity, which appeared to over-fit and produce implausible selectivity patterns. Starting CPUE in 1984 (ignoring the low 1983 year) produced very similar results to model runs that include the first year. It was nevertheless excluded from subsequent model runs given concerns about early CPUE reporting. Estimating initial depletion in 1984 invariably led to low estimated initial depletion (i.e., the mode of the posterior distribution for initial depletion near zero). This depletion level was judged implausible by the working group. As models with estimated initial depletion led to similar inferences about stock status and productivity as models with a longer catch time-series, these models were not explored further.

Estimated selectivity in the dome-shaped selectivity model was only slightly domed, with a slight increase in doming after 2006. The (invariable) left-hand limb of the curve was estimated near post-

2006 selectivity for models with logistic selectivity. The model with variable logistic selectivity suggested very highly variable selectivity with selection of large individuals in early years to allow the model to fit a steep CPUE decline in the FSU years. However, this pattern was judged implausible by the working group, as it appeared that selectivity was taking the role of other, unknown process error and allowed the model to over-fit.

Models with no time-varying process error (i.e., no yearly variable selectivity or recruitment) prior to availability of CSLF data nevertheless provided reasonable fits to CPUE (which shows some high inter-annual variability).

Changing the weights for CSLF and CPUE data had comparatively little impact on the stock trajectory: Reducing CSLF weights generally led to a lower stock status, but all estimates remained near or above 40% or B_0. A reduction in CSLF weight also led to less extreme variation in estimated selectivity for the variable logistic selectivity model, but the selectivity still suggested selection of large individuals in the early years of the fishery, and a decrease in the fully selected size in more recent years, which is contrary to estimates from a model with a single shift in selectivity in 2006, which suggests a shift in the size-at-50% selection in 2006 in line with an increase in the MHS.

The difference from data weights was altogether small compared with differences introduced by estimating (or not) recruitment for pre-CSLF years. Models that included variable recruitment for all CPUE years as well as trends in q suggested a strong recent increase in q over the PCELR period, and a continued decline of the fishery to below 40% of B_0. However, this recent increase in catchability was judged less likely by the working group, especially since most of the significant innovations in the fishery (better boats, improved wetsuits and fins, and other gear) took place in the CELR period (1990s), and most likely not in the more recent PCELR period.

As a suitable base case, the working group selected a model with:

- CPUE starting in 1984, therefore removing the initial FSU record;
- estimated recruitment from 2001;
- separate catchability for three reporting periods.

The base case suggested a relatively slow but steady downward trend in spawning stock biomass since the 1990s (Figure 4), with a more recent downward trend that was attributed to estimates of recruitment being forced low to compensate for early estimated above-average recruitment (CPUE is slowly increasing most recently). The base case also indicated that the stock is currently above target spawning stock biomass with a high probability, with little to no probability that it is below the soft limit of 0.2 SSB_0. This inference was supported by the agreed sensitivity run, which included an estimated trend in catchability (Figure 4).

Projections from the base case model (Table 5) suggested little movement in spawning stock biomass over the coming years at current catch levels. The tested sensitivity led to lower recent stock status, but with a slight recent increase, providing a better fit to recent CPUE. In addition, projections from this model were slightly more optimistic about future stock trajectory, even at increased catch levels (Table 6).

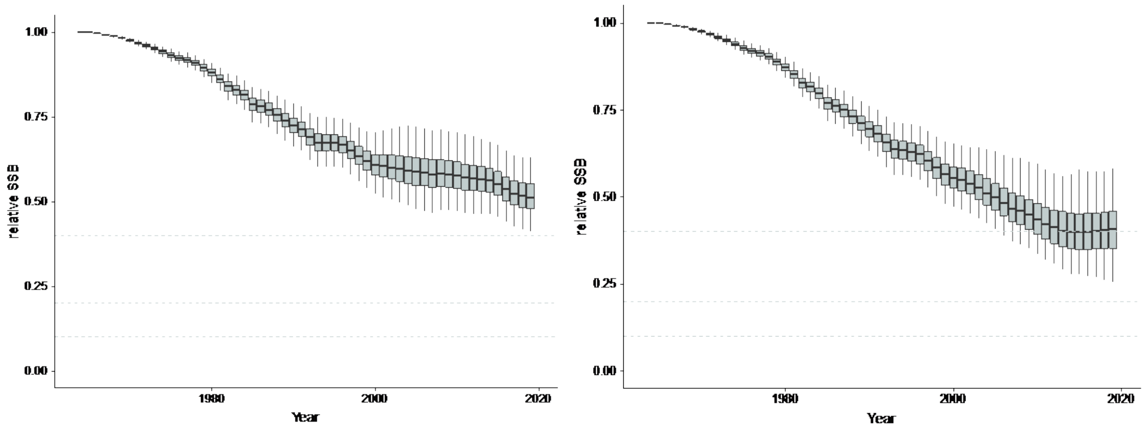


Figure 4: Posterior distributions of spawning stock biomass from the base case model, the sensitivity scenario with increasing catchability. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence range of the distribution.

Table 6: Projections for key fishery indicators from the base case model: probabilities of being above 40% and 20% of unfished spawning biomass (SSB) [P(SSB_{Proj} > 40% SSB_0) and P(SSB_{Proj} > 20% SSB_0)], the probability that SSB in the projection year is above current SSB, the posterior median relative to SSB, the posterior median relative available spawning biomass B_{Proj}^{Avail}, and the probability that the exploitation rate (U) in the projection year is above $U_{40\%\ SSB0}$, the exploitation rate that leads to 40% SSB_0. The total commercial catch (TCC) marked with * corresponds to current commercial catch under 30% shelving of the current TACC (149 t). Other TACC scenarios show 50% shelving (83.4 t), 10% shelving (125.1 t) and fishing at the current TACC. Simulation to equilibrium (assumed to have been reached after 50 projection years) are indicated with Eq. in the year column.

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2018})	Median rel. SSB_{Proj}	Median rel. B_{Proj}^{Avail}	P(U > $U_{40\%\ SSB0}$)
83.4	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.98	1	0.39	0.52	0.4	0.58
	2022	0.98	1	0.46	0.52	0.4	0.57
	Eq.	0.85	0.99	0.63	0.59	0.46	0.59
104.3*	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.98	1	0.27	0.51	0.39	0.58
	2022	0.96	1	0.34	0.51	0.39	0.57
	Eq.	0.68	0.95	0.43	0.5	0.36	0.51
125.1	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.97	1	0.19	0.51	0.39	0.57
	2022	0.95	1	0.25	0.5	0.37	0.56
	Eq.	0.48	0.87	0.24	0.41	0.25	0.42

4.4 Other factors

To run the stock assessment model a number of assumptions must be made, one of these being that CPUE is a reliable index of abundance. The literature on abalone fisheries suggests that this assumption is questionable and that CPUE is difficult to use in abalone stock assessments due to the serial depletion behaviour of fishers along with the aggregating behaviour of abalone. Serial depletion is when fishers consecutively fish-down beds of pāua but maintain their catch rates by moving to new unfished beds; thus CPUE stays high while the overall population biomass is actually decreasing. The aggregating behaviour of pāua results in the timely re-colonisation of areas that have been fished down, as the cryptic pāua that were unavailable at the first fishing event, move to and aggregate within the recently depleted area. Both serial depletion and aggregation behaviour cause CPUE to have a hyperstable relationship with abundance (i.e. abundance is decreasing at a faster rate than CPUE) thus potentially making CPUE a poor proxy for abundance. The strength of the effect that serial depletion and aggregating behaviour have on the relationship between CPUE and abundance in PAU 5A is difficult to determine. However, because fishing has been consistent in for a number of years and effort has been reasonably well spread, it could be assumed that CPUE is not as strongly influenced by these factors, relative to the early CPUE series.

The assumption of CPUE being a reliable index of abundance in PAU 5A can also be upset by exploitation of spatially segregated populations of differing productivity. This can conversely cause non-linearity and hyper-depletion in the CPUE-abundance relationship, making it difficult to accurately track changes in abundance by using changes in CPUE as a proxy.

Another source of uncertainty is the data. The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Major differences may exist between the catches assumed in the model and what was actually taken. Non-commercial catch trends, including illegal catch, are also relatively poorly determined and could be substantially different from what was assumed.

The model treats the whole of the assessed area of PAU 5A as if it were a single stock with homogeneous biology, habitat and fishing pressure. The model assumes homogeneity in recruitment and natural mortality. Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Nevertheless, the spatial-three area model showed nearly identical trends to the single area model, and variation in growth is most likely addressed to some extent by having a stochastic growth transition matrix based on increments observed in several different places; similarly the length frequency data are integrated across samples from many places. Nevertheless, length frequency data collected from the commercial catch may not represent the available biomass represented in the model with high precision.

The effect of these factors is likely to make model results optimistic. For instance, if some local stocks are fished very hard and others not fished, recruitment failure can result because of the depletion of spawners, as spawners must breed close to each other, and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, and the current model does not account for such local processes that may decrease recruitment.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that it may result in some populations becoming relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole.

5. STATUS OF THE STOCKS

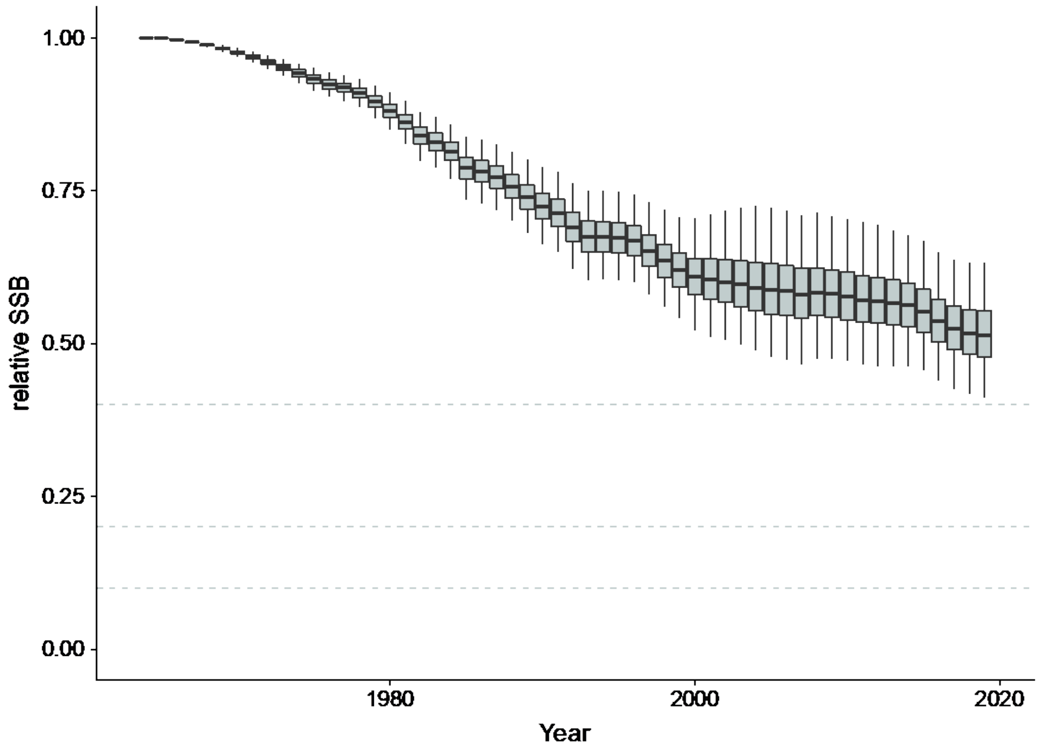
Stock Structure Assumptions
A genetic discontinuity between North Island and South Island pāua populations was found approximately around the area of Cook Strait (Will & Gemmell 2008).

- **PAU 5A - Fiordland**

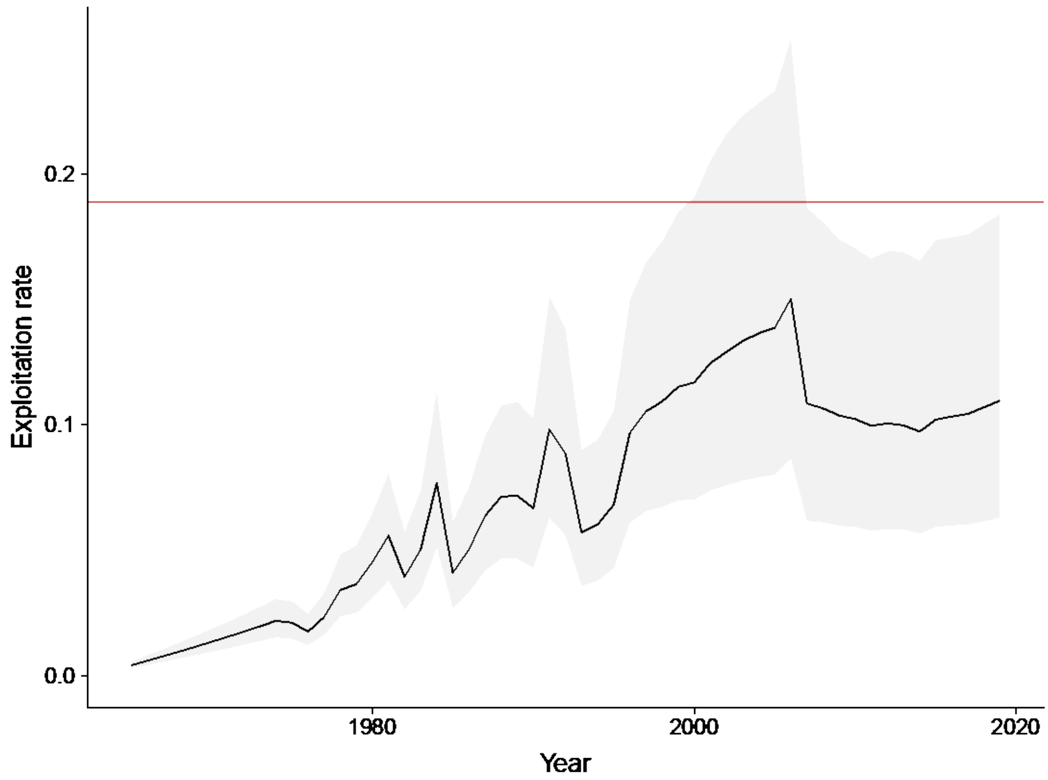
Stock Status		
Most Recent Assessment Plenary Publication Year	2020	
Catch in most recent year of assessment	Year: 2018–19	Catch: 100 t
Assessment Runs Presented	Base case Sensitivity with linearly increasing catchability	
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: $U_{40\%B0}$	
Status in relation to Target	Base case: B_{2019} was estimated at 51% (41–63%) B_0	

	Sensitivity: B_{2019} was estimated at 40% (26–57%) B_0 For both cases combined, B_{2019} was Likely (> 60%) to be at or above the target
Status in relation to Limits	B_{2019} was Very Unlikely (< 10%) to be below both the soft and hard limits.
Status in relation to Overfishing	The fishing intensity in 2019 was Very Unlikely (< 10%) to be above the overfishing threshold.

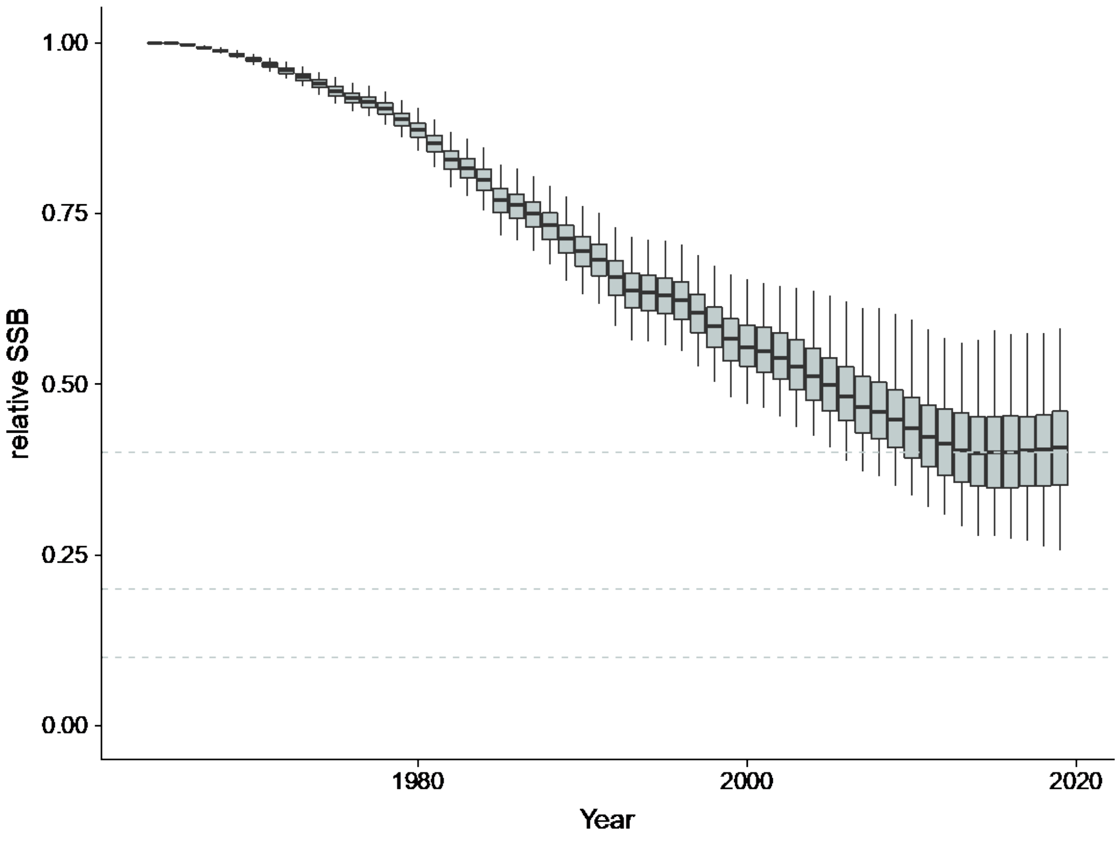
Historical Stock Status Trajectory and Current Status



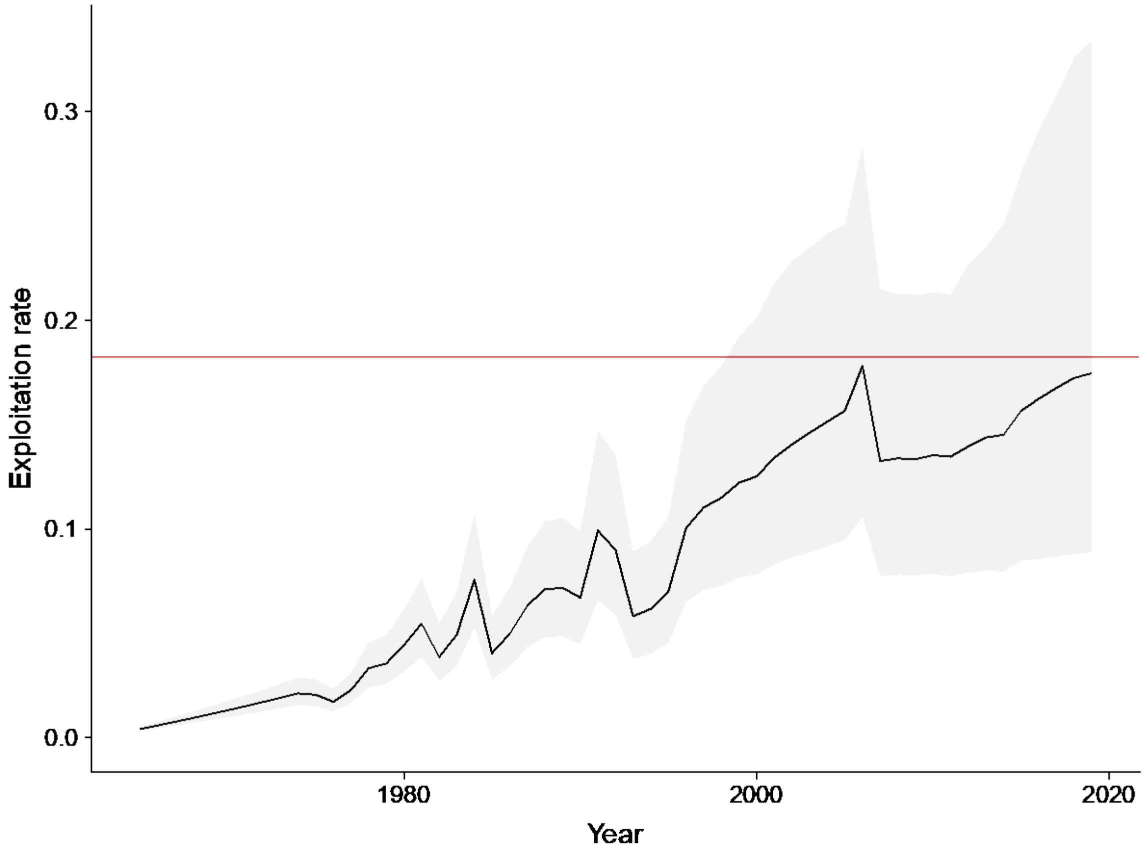
Posterior distributions from the base case model of spawning stock biomass as a percentage of *SSB₀*. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 2.5th and 97.5th percentiles of the distribution. Dashed horizontal lines show target (40% of *SSB₀*), soft-limit (20% of *SSB₀*) and hard-limit (10% of *SSB₀*) reference points.



Posterior distributions from the base case model of exploitation rate (posterior median and 95% confidence interval) relative to the exploitation rate that leads to a relative spawning stock biomass of 40% of SSB_0.



Posterior distributions from the main sensitivity (increasing catchability) model of spawning stock biomass as a percentage of SSB_0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 2.5th and 97.5th percentiles of the distribution. Dashed horizontal lines show target (40% of SSB_0) soft-limit (20% of SSB_0) and hard-limit (10% of SSB_0) reference points.



Posterior distributions from the main sensitivity (increasing catchability) of exploitation rate (posterior median and 95% confidence interval) relative to the exploitation rate that leads to a relative spawning stock biomass of 40% of SSB_0.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	For the base case, spawning stock biomass declined steeply from the early years up to the early 2000s, with a slow decline since. The more recent trend (since 2015) suggests that biomass remained above 40% SSB_0 but trending slightly downward. The latter conflicts with the CPUE index for the most recent years. The decline in the main sensitivity model is more gradual until about 2015, with a slight increase since 2015 from near 40% SSB_0. The latter trend is more compatible with recent (standardised) CPUE.
Recent Trend in Fishing Intensity or Proxy	For both the base case and the main sensitivity, the exploitation rate reached a peak near 2006, at which point ACE shelving reduced the exploitation rates significantly. For the base case, the exploitation rate remained well below the exploitation rate that leads to a relative spawning stock biomass of 40% SSB_0. In the main sensitivity, the recent exploitation rate has trended upwards in recent years towards the exploitation rate that leads to a relative spawning stock biomass of 40% SSB_0.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At current levels of catch spawning stock biomass is projected to remain nearly unchanged at 51% B_0 after 3 years, with an equilibrium value of 50% B_0. If shelving is reduced to 10%, spawning stock biomass is projected to decline to 50% B_0 over 3 years, and to 41% B_0 in the long term
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) at current catch levels Unlikely (< 40%) if shelving reduced by 10% About as Likely as Not (40–60%) if shelving reduced by 20%

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Latest assessment Plenary publication year: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch history - CPUE indices early series - CPUE indices later series - Commercial sampling length frequencies - Tag recapture data (for growth estimation) - Maturity at length data	1 – High Quality for commercial catch 2 – Mixed or Medium Quality for customary catch 1. No data for recreational or illegal catch 2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA 1 – High Quality 2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA 1 – High Quality 1 – High Quality
Data not used (rank)	- Research Dive Survey Indices - Research Dive Length Frequencies	3 – Low Quality: not believed to index the stock 3 – Low Quality: not believed to be representative of the entire QMA
Changes to Model Structure and Assumptions	- The base case model was implemented as a single area model rather than the separate PAU 5A northern and PAU 5A southern models of previous years. - A three-area spatial model was also developed to corroborate findings from the single area model. - MPD runs were not performed; all exploration was performed using full Markov Chain Monte Carlo runs. - The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB). - A multivariate normal model was used for centred-log-ratio-transformed mean CSLF and observation error.	

	- The data weighting procedure was based on a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF. - Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.
Major Sources of Uncertainty	- CPUE may not be a reliable index of abundance. - Any effect of voluntary increases in MHS may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years.

Qualifying Comments
-

Fishery Interactions
-

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