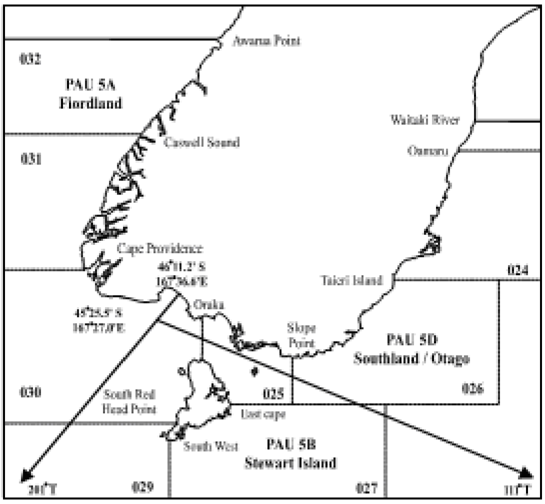
# PĀUA (PAU 5B) - Stewart Island

(*Haliotis iris*)
Pāua



## 1. FISHERY SUMMARY

Before 1995, PAU 5B 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 pāua 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 5B TACC was set at 148.98 t.

On 1 October 1999 a TAC of 155.98 t was set for PAU 5B, comprising a TACC of 143.98 t (a 5 t reduction) and customary and recreational allowances of 6 t each. The TAC and TACC were subsequently reduced twice, and TAC was set at 105 t in 2002–2018, with a TACC of 90 t, customary and recreational allowances at 6 t each and an allowance of 3 t for other mortality. In 2018 the PAU5B TACC was increased to 107 t, and the customary allowance to 7 t, bringing the TAC to 123 t. Prior to the increase being triggered however an injunction was filed by parties concerned about the possible impact on s.28N rights in the fishery. Subsequently, in 2022, the 28N Rights in question were extinguished and the injunction withdrawn, which allowed the TAC increase to proceed at the start of the October 2022 season (Table 1).

**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 5B since introduction into the QMS. † The decision to increase the PAU5B TACC and customary allowance on 1 October 2018 was not implemented due to a High Court issued interim order. That order was discharged on 30 September 2022 and the increase actioned on 1 October 2022.**

| Year | TAC | Customary | Recreational | Other mortality | TACC |
|---|---|---|---|---|---|
| 1986–1991* | - | - | - | - | 445 |
| 1991–1994* | - | - | - | - | 492 |
| 1994–1995* | - | - | - | - | 442.8 |
| 1995–1999 | - | - | - | - | 148.98 |
| 1999–2000 | 155.9 | 6 | 6 | - | 143.98 |
| 2000–2002 | 124.87 | 6 | 6 | - | 112.187 |
| 2002–2018 | 105 | 6 | 6 | 3 | 90 |
| 2018–Present | 123† | 7† | 6 | 3 | 107† |

*PAU 5 TACC figures

## 1.1 Commercial fishery

The fishing year runs from 1 October to 30 September.

Concerns about the status of the stock led to the commercial fishers agreeing to voluntarily reduce their Annual Catch Entitlement (ACE) by 25 t for the 1999/00 fishing year. This shelving continued for the 2000/01and 2001/02 fishing years at a level of 22 t, but was discontinued at the beginning of the 2002/03 fishing year (Table 2).
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).

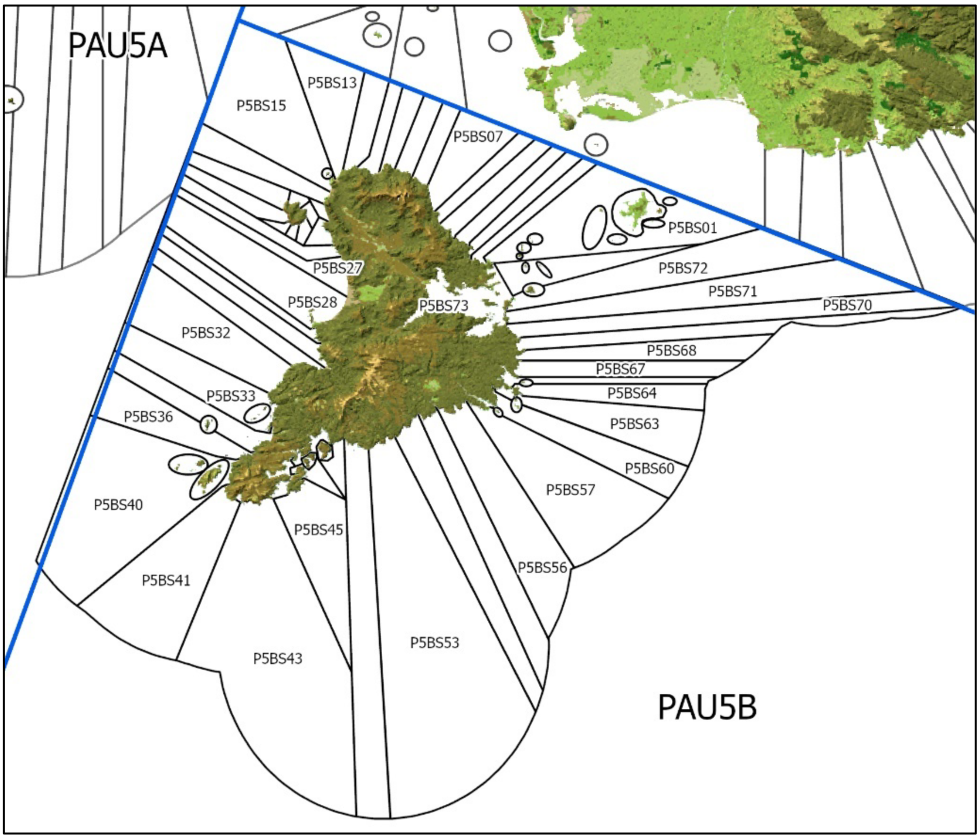


**Figure 1: Map of fine scale statistical reporting areas for PAU 5B.**

**Table 2: TACC and reported commercial landings (t) of pāua in PAU 5B, 1995–96 to present, from QMR and MHR returns.**

| Year | Landings | TACC |
|---|---|---|
| 1995–96 | 144.66 | 148.98 |
| 1996–97 | 142.36 | 148.98 |
| 1997–98 | 145.34 | 148.98 |
| 1998–99 | 148.55 | 148.98 |
| 1999–00 | 118.07 | 143.98 |
| 2000–01 | 89.92 | 112.19 |
| 2001–02 | 89.96 | 112.19 |
| 2002–03 | 89.86 | 90.00 |
| 2003–04 | 90.00 | 90.00 |
| 2004–05 | 89.97 | 90.00 |
| 2005–06 | 90.47 | 90.00 |
| 2006–07 | 89.16 | 90.00 |
| 2007–08 | 90.21 | 90.00 |
| 2008–09 | 90.00 | 90.00 |
| 2009–10 | 90.23 | 90.00 |
| 2010–11 | 89.67 | 90.00 |
| 2011–12 | 89.59 | 90.00 |
| 2012–13 | 90.58 | 90.00 |
| 2013–14 | 88.84 | 90.00 |
| 2014–15 | 89.45 | 90.00 |
| 2015–16 | 88.39 | 90.00 |
| 2016–17 | 92.99 | 90.00 |
| 2017–18 | 89.33 | 90.00 |
| 2018–19 | 89.03 | 90.00 |
| 2019–20 | 87.19 | 107.00 |
| 2020–21 | 89.60 | 107.00 |
| 2021–22 | 92.97 | 107.00 |
| 2022–23 | 105.06 | 107.00 |

PAU 5B commercial landings have been close to the TACC in most fishing years since 1995, with the exception of the fishing years 1999–00, 2000–01, and 2001–02, when the TACC was not reached (Table 2 and Figure 2). Landings for PAU 5 prior to 1995 are reported in the Introduction – Pāua chapter.

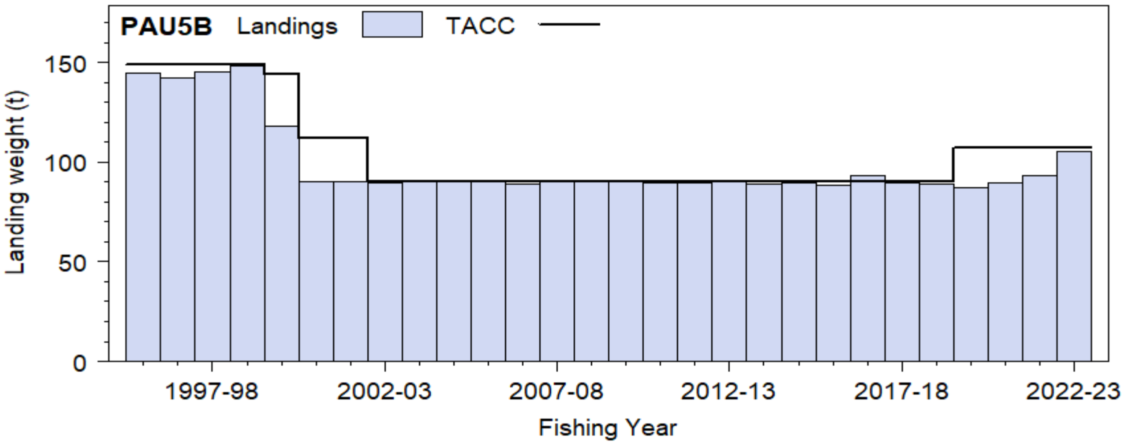


**Figure 2: Reported commercial landings and TACC for PAU 5B from 1995–96 to present. For reported commercial landings in PAU 5 before 1995–96 refer to figure 1 and table 1 in the Introduction – Pāua chapter.**

## 1.2 Recreational fisheries

The 'National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates' estimated that the recreational harvest for PAU 5B was 0.76 t with a CV of 54%. For the 2017 assessment model, the SFWG agreed to assume that the recreational catch rose linearly from 1 t in 1974 to 5 t in 2006, and remained at 5 t between 2007 and 2017. The National Panel Survey was repeated in the 2017–18 fishing year (Wynne-Jones et al 2019). The estimated recreational catch for that year was 4.88 tonnes (CV 0.45). The most recent national panel survey harvest estimate for PAU 5B is 3.46 t (CV 0.33) for 2022–23 (Heinemann & Gray in prep). For further information on recreational fisheries refer to 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 5B 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.

For the 2017 assessment model the SFWG agreed to assume that customary catch was equal to 1 t from 1974–2017.

## 1.4 Illegal catch

There is qualitative data to suggest significant illegal, unreported, unregulated (IUU) activity in this Fishery. Illegal catch was estimated by the Ministry of Fisheries to be 15 t, but "Compliance express extreme reservations about the accuracy of this figure." The SFWG agreed to assume for the 2013 assessment that illegal catch was zero before 1986, then rose linearly from 1 t in 1986 to 5 t in 2006 and remained constant at 5 t between 2007 and 2013. For further information on illegal catch refer to the Introduction – Pāua chapter.

**Table 3: Fisheries New Zealand records of customary harvest of pāua (approved and reported in numbers) in PAU 5B since 2000–01. – no data.**

| | Numbers | |
|---|---|---|
| **Fishing year** | **Approved** | **Harvested** |
| 2000–01 | 50 | 50 |
| 2001–02 | 610 | 590 |
| 2002–03 | – | – |
| 2003–04 | – | – |
| 2004–05 | – | – |
| 2005–06 | 140 | 90 |
| 2006–07 | 485 | 483 |
| 2007–08 | 2 685 | 2 684 |
| 2008–09 | 3 520 | 3 444 |
| 2009–10 | 2 680 | 2 043 |
| 2010–11 | 2 053 | 1 978 |
| 2011–12 | 495 | 495 |
| 2012–13 | 1 875 | 1 828 |
| 2013–14 | 130 | 130 |
| 2014–15 | – | – |
| 2015–16 | 2 195 | 2 003 |
| 2016–17 | 75 | 75 |
| 2017–18 | 2 245 | 2 245 |
| 2018–19 | 1 405 | 1 337 |
| 2019–20 | 835 | 815 |
| 2020–21 | 2 645 | 2495 |
| 2021–22 | 70 | 70 |
| 2022–23 | – | – |

### 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. A summary of biological parameters used in the PAU 5B assessment is presented in Table 4.

## 3. STOCKS AND AREAS

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

**Table 4: Estimates of biological parameters (*H. iris*).**

| | | **Estimate** | **Source** |
|---|---|---|---|
| 1. Natural mortality (*M*) | | 0.10 (CV 0.10) | Assumed prior probability distribution |
| 2. Weight = a(length)$^b$ (Weight in g, length in mm shell length). | | | |
| | | All | |
| | a | b | |
| | 2.99 x 10$^{-5}$ | 3.303 | Schiel & Breen (1991) |
| 3. Size at maturity (shell length) | | | |
| | | 50% maturity at 91 mm | Naylor (NIWA unpub. data) |
| | | 95% maturity at 133 mm | Naylor (NIWA unpub. data) |
| 4. Growth parameters (both sexes combined) | | | |
| | Growth at 75 mm | Growth at 120 mm | Median (5–95% range) of posterior distributions estimated by the assessment model |
| | 26.1 mm (24.8 to 27.2) | 6.9 mm (6.5–7.3) | |

## 4. STOCK ASSESSMENT

The stock assessment was done with a length-based Bayesian estimation model, with parameter point estimates based on the mode of the joint posterior distribution and uncertainty estimated from marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The most recent stock assessment was conducted in 2017 for the fishing year ended 30 September 2017. A base case model (0.1) was chosen from the assessment. The SFWG also suggested several sensitivity runs; model 0.4 which assumed an alternate catch history and model 0.6 where a time varying catchability was estimated.

### 4.1 Estimates of fishery parameters and abundance

Parameters estimated in the assessment model and their Bayesian prior distributions are summarized in Table 5.

### 4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2017 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2017. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, with variables entering the model in the order that gave the maximum decrease in the residual deviance. Predictor variables were accepted in the model only if they explained at least 1% of the deviance.

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

| Parameter | Phase | Prior | $\mu$ | CV | Lower | Upper |
|---|---|---|---|---|---|---|
| $\ln(R_0)$ | 1 | U | – | – | 5 | 50 |
| $M$ (natural mortality) | 3 | U | – | – | 0.01 | 0.5 |
| $g_1$(Mean growth at 75 mm) | 2 | U | – | – | 0.01 | 150 |
| $g2$(Mean growth at 120 mm) | 2 | U | – | – | 0.01 | 150 |
| $g_{50}$ | 2 | U | – | – | 0.01 | 150 |
| $g_{50\text{-}95\%}$ | 2 | U | – | – | 0.01 | 150 |
| $g_{max}$ | 1 | U | – | – | 0.01 | 50 |
| $\alpha$ | 2 | U | – | – | 0.01 | 10 |
| $\beta$ | 2 | U | – | – | 0.01 | 10 |
| Ln$(q^I)$ (catchability coefficient of CPUE) | 1 | U | – | – | -30 | 0 |
| Ln$(q^J)$ (catchability coefficient of PCPUE) | 1 | U | – | – | -30 | 0 |
| $L_{50}$ (Length at 50% maturity) | 1 | U | – | – | 70 | 145 |
| $L_{95\text{-}50}$(Length between 50% and 95% maturity) | 1 | U | – | – | 1 | 50 |
| $D_{50}$(Length at 50% selectivity for the commercial catch) | 2 | U | – | – | 70 | 145 |
| $D_{95\text{-}50}$(Length between 50% and 95% selectivity for the commercial catch) | 2 | U | – | – | 0.01 | 50 |
| $D_s$ | 1 | U | – | – | 0.01 | 10 |
| $\epsilon$ (Recruitment deviations) | 1 | N | 0 | 0.4 | -2.3 | 2.3 |

The observational data were:

1. A 1990–2001 standardised CPUE series based on CELR data.
2. A 2002–2017 standardised CPUE series based on PCELR data.
3. A commercial catch sampling length frequency series for 1998, 2002–04, 07, 2009–2012.
4. Tag-recapture length increment data.
5. Maturity at length data

For both the CELR and PCELR data, the Fisher Identification Number (FIN) was used in the standardisations instead of vessel, because the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN.

For the CELR data (1990–2001) there is ambiguity in what is recorded for estimated daily fishing duration (total fishing duration for all divers), and it has not been used in past standardisations as a measure of effort; instead the number of divers has been used. However, there is evidence that the fishing duration for a diver changes over time, and because of this, criteria were used to identify records for which the recorded fishing duration should predominantly be recorded correctly. The criteria used to subset the data were: (i) just one diver or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2. For the other records

the recorded fishing duration was multiplied by the number of divers. The data set consisting of predominantly correct records for the recorded fishing duration, and others with the recorded fishing duration scaled up by the number of divers was used for the CELR standardisation using estimated daily catch and effort as estimated fishing duration.
For the PCELR data (2002–2017) the unit of catch was diver catch, with effort as diver duration.

FIN codes were used to select a core group of fishers from the CELR data, with the requirement that there be a minimum of 7 records per year for a minimum of 2 years to qualify for the core fisher group. This retained 84% of the catch over 1990–2001. For the PCELR data the FIN was also used to select a core group of fishers, with the requirement that there be a minimum of 20 records per year for a minimum of 3 years. This retained 87% of the catch over 2002–2017.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN, Statistical Area (025, 027, 029, 030), month and fishing duration (as a cubic polynomial),. For the PCELR data, fishing year was forced into the model and variables offered to the model were month, diver key, FIN statistical area, diver duration (third degree polynomial), and diving conditions.

The standardised CPUE from the CELR data shows an increase from 1990 to 1991 followed by a steady decline through to 2001 at which point it is 49% of its initial 1990 level (Figure 3-top). The standardised CPUE from the PCELR data shows a 74% increase from 2002 to 2014 then a slight decline from 2014 to 2017. This 13% decline between 2014 and 2017 is not unexpected and is most likely due to the commercial fishers voluntarily increasing the minimum harvest size (Figure 3-bottom).

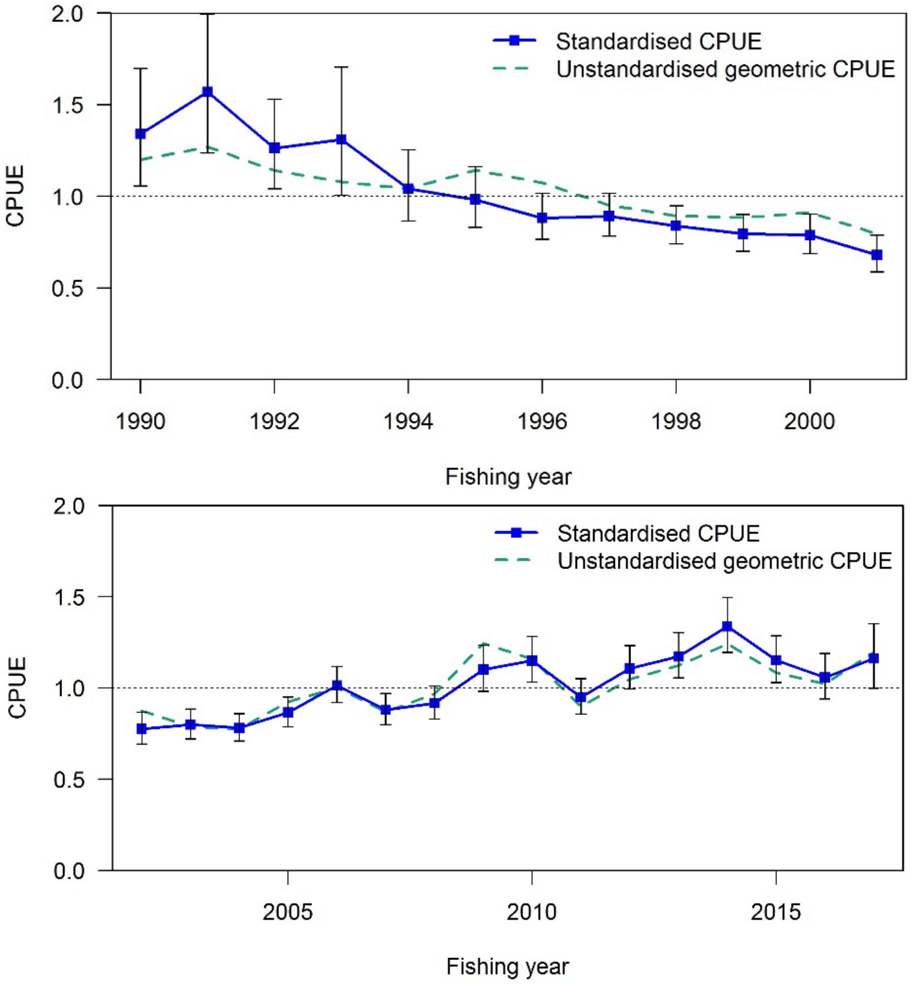


**Figure 3: The standardised CPUE indices with 95% confidence intervals for the CELR series covering 1990–2001 (blue line for top-figure). The standardised CPUE indices with 95% confidence intervals for the PCELR series covering 2002–2017 (blue line for bottom-figure). For both indices the unstandardised geometric CPUE is calculated as catch divided by fishing duration.**

### 4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua in PAU 5B has also been estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1993 and 2007. The survey strata included Ruggedy, Waituna, Codfish, Pegasus, Lords, and East Cape. These data were included in the assessment although there is concern that the data are not a reliable index of abundance.

Concerns about the ability of the data collected in the independent Research Dive surveys to reflect relative abundance instigated several reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed the reliability of the research diver survey index as an index of abundance and whether the RDSI, when used in the pāua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from pāua stock assessments using the RDSI should be treated with caution however this data was included in the 2017 assessment based on recommendations arising from the pāua stock assessment review workshop (Butterworth et al 2015).

### 4.2 Stock assessment methods

The 2017 PAU 5B stock assessment used the same length-based model as the 2017 PAU 5D assessment (Marsh & Fu 2017). The model was described by Breen et al (2003). PAU 5B was last assessed in 2013 (Fu 2014 and Fu et al 2014a).

The model structure assumed a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm in 2 mm bins. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of transitions among length class at each time step. Pāua enter the model following recruitment and are removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2017. Catches were available for 1974–2017 although catches before 1995 must be estimated from the combined PAU 5 catch. Catches 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.

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. No explicit stock-recruitment relationship was modelled in previous assessments; however, the Shellfish Working Group agreed to use a Beverton-Holt stock-recruitment relationship with steepness ($h$) of 0.75 for this assessment.

Maturity is not required in the population partition but is necessary for estimating spawning biomass. The model estimated proportions mature from length-at-maturity data. Growth and natural mortalities were also estimated within the model. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and asymptote at 1. The increase in Minimum Harvest Size between 2006 and 2017 was modelled as an annual shift in fishing selectivity.

The assessment was conducted in several steps. First, the model was fitted to the data with parameters estimated at the mode of their joint posterior distribution (MPD). Next, from the resulting fit, Markov chain-Monte Carlo (MCMC) simulations were made to obtain a large set of samples from the joint posterior distribution. From this set of samples, forward projections were made and an agreed set of biological indicators obtained. Model sensitivity was explored by comparing MPD fits made under alternative model assumptions.

The base case incorporated a number of changes since the last assessment of PAU 5B in 2013. First, a more flexible functional form (inverse logistic) was used to describe the variance associated with the mean growth increment at length. Second, the predicted CPUE is now calculated after 50% of the fishing and natural mortality have occurred (previously the CPUE indices were fitted to the vulnerable biomass calculated after 50% of the catch was taken). This is considered to be appropriate if fishing occurs throughout a year (Schnute 1985). The change was recommended by the pāua review workshop held in Wellington in March 2015 (Butterworth et al. 2015). Accordingly, mid-season numbers (and biomass) was calculated after half of the natural mortality and half of the fishing mortality was applied.

The third change was made to the likelihood function, fitting the tag-recapture observations so that weights could be assigned to individual data sets. This also followed the pāua review workshop's recommendation that "the tagging data should be weighted by the relative contribution of average yield from the different areas so that the estimates could better reflect the growth rates from the more productive areas" (Butterworth et al 2015). Two smaller changes were added in this iteration of the assessment model, including: 1) adding a lag between recruitment and spawning for models where the partition was started at > 2 mm; and 2) adding a time varying parameter on the catchability coefficient of the CPUE observations.

The base case model (0.1) and the six sensitivities (0.1all and 0.2–0.6) were considered (Table 6): two separate CPUE series (0.2), excluding research diver observations (0.3), alternative catch history (0.4), modelling the partition at 2 mm (0.5), and estimating a time varying catchability (0.6). MCMCs were carried out for the base case and model runs 0.4 and 0.6.

**Table 6: Summary descriptions of base case (0.1) and sensitivity model runs.**

| Model | Description |
|---|---|
| **0.1** | inverse logistic growth model, tag-recapture weighted, CSLF data up to 2016, M prior Uniform, tag data > 70 mm, RDLF and RDSI included, Combined CPUE series, Catch history assumption 3 |
| **0.1 all** | The same as model 0.1 with CSLF data up to and including the 2017 fishing year. |
| **0.2** | Model 0.1 with split CPUE series, one for the CELR and another for the PCELR |
| **0.3** | Model 0.1 but with the RDLF and RDSI data excluded |
| **0.4** | Model 0.1 but with catch history assumption 1 |
| **0.5** | Model 0.1 but start modelling at 2 mm instead of 70 mm |
| **0.6** | Model 0.1 but with a time varying catchability coefficient, with an estimated drift parameter ~ Uniform(-0.05, 0.05) |

The assessment calculated the following quantities from their posterior distributions: the equilibrium spawning stock biomass with recruitment equal to the average recruitment from the period for which recruitment deviation were estimated ($B_0$,), the mid-season spawning and recruited biomass for 2013 ($B_{2013}$ and $B^r_{proj2013}$) and for the projection period ($B_{proj}$ and $B^r_{proj}$). This assessment also reported the following fishery indictors:

- $B\%B_0$ Current or projected spawning biomass as a percentage of $B_0$
- $B\%B_{msy}$ Current or projected spawning biomass as a percentage of $B_{msy}$
- $\Pr(B_{proj} > B_{msy})$ Probability that projected spawning biomass is greater than $B_{msy}$
- $\Pr(B_{proj} > B_{2012})$ Probability that projected spawning biomass is greater than $B_{current}$
- $B\%B^r_0$ Current or projected recruited biomass as a percentage of $B^r_0$
- $B\%B^r_{msy}$ Current or projected recruited biomass as a percentage of $B^r_{msy}$
- $\Pr(B_{proj} > B^r_{msy})$ Probability that projected recruit-sized biomass is greater than $B^r_{msy}$
- $\Pr(B_{proj} > B^r_{2012})$ Probability that projected recruit-sized biomass is greater than $B^r_{2012}$
- $\Pr(B_{proj} > 40\%B_0)$ Probability that projected spawning biomass is greater than 40% $B_0$
- $\Pr(B_{proj} < 20\%B_0)$ Probability that projected spawning biomass is less than 20% $B_0$
- $\Pr(B_{proj} < 10\%B_0)$ Probability that projected spawning biomass is less than 10% $B_0$
- $\Pr(U_{proj} > U_{40\%B0})$ Probability that projected exploitation rate is greater than $U_{40\%B0}$

### 4.3 Stock assessment results

The base case model (0.1) estimated that the unfished spawning stock biomass ($B_0$) was about 3948 t (3630–4271 t) (Figure 4), and the spawning stock population in 2017 ($B_{2017}$) was about 47% (39–58%) of $B_0$ (Table 7). The base case indicated that spawning biomass increased rapidly after 2002 when the stock was at its lowest level.

Three-year projections (2018–2020) were run for two alternative recruitment assumptions, with the period of recruitment sampled from the past 10 years of estimates and from the past 5 years of estimates (explored due to recent lower-than-average recruitment), and with four different future harvest levels based on changes to the total allowable catch (TACC), with the TACC increasing by 5% (94.5 t), 10% (99 t), 15% (103.5 t) and 20% (108 t) (Tables 8–11). The base case model suggested that the current stock status was very unlikely to fall below the target of 40% $B_0$. The projections suggested that with an increase of 20% of the current TACC, future biomass was likely to remain constant over the next 3 years. The conclusion was similar across all sensitivity runs.

The MCMC simulation started at the MPD parameter values and the traces show good mixing. MCMC chains starting at either higher or lower parameter values also converged after the initial burn-in phase. The base case model estimated an $M$ of 0.10 with a 90% credible interval between 0.08 and 0.12. The midpoint of the commercial fishery selectivity (pre-2006), where selectivity is 50% of the maximum, was estimated to be about 125 mm and the selectivity ogive was very steep. The model estimated an annual shift of about 1.9 mm in selectivity, with a total increase of about 10 mm between 2006 and 2011.

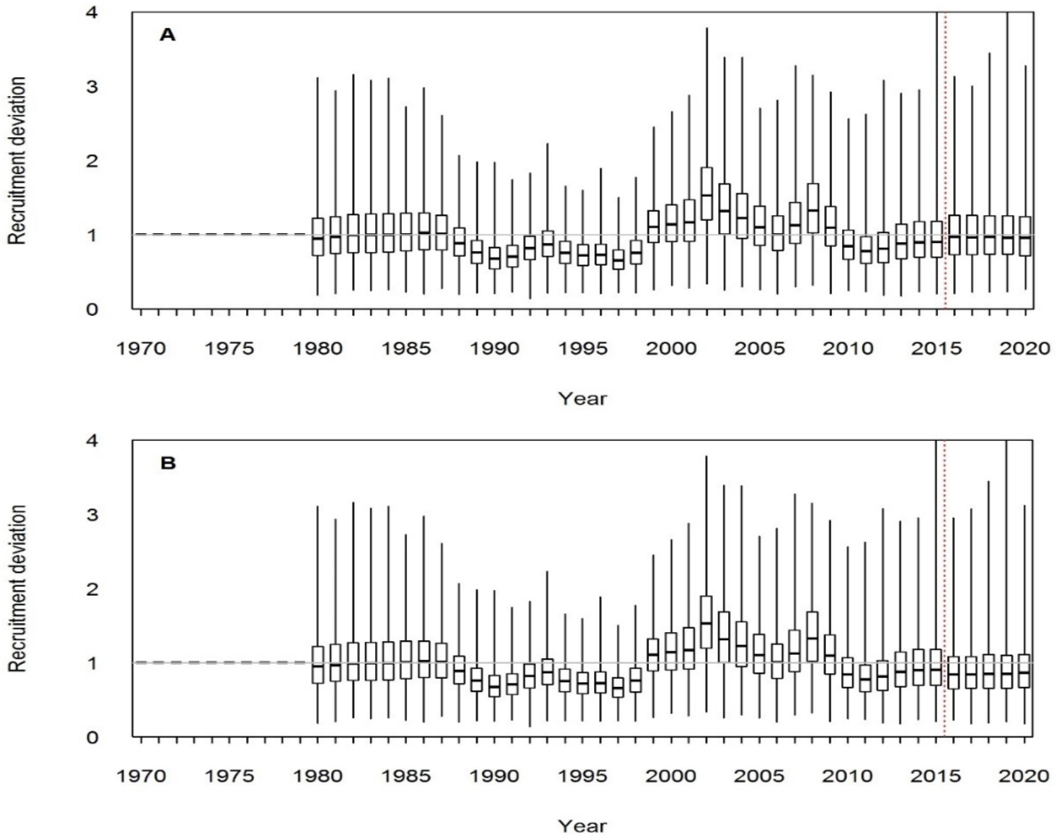


**Figure 4: Recruitment deviations around the stock recruitment relationship estimated and forecasted for model 0.1. The red line is the time up to where recruitment deviations were resampled from. The top figure (A) is when we resample from the last 10 years. The bottom figure (B) is when we resample from the last 5 years.**

The estimated recruitment deviations showed a period of relatively low recruitment through the 1990s to the early 2000s. From the early 2000s to 2010 recruitment was above the average however, from 2011 until 2015 recruitment has been lower than the long-term average. (Figure 5). Exploitation rates peaked around 2002, but have decreased since then. The base case estimated exploitation rate in 2017 to be about 0.09 (0.07–0.11) (Table 7).

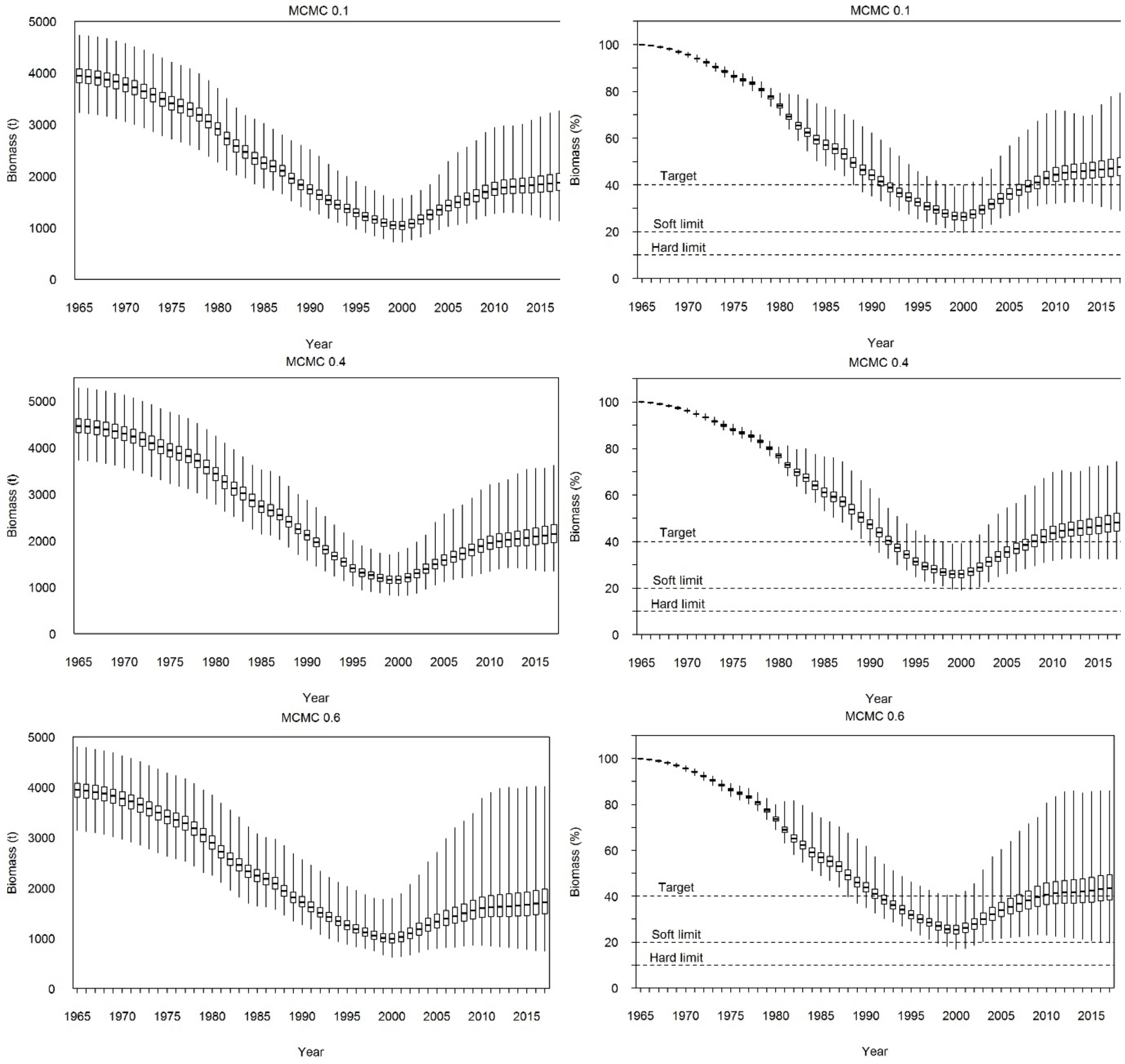


**Figure 5: Posterior distributions of spawning stock biomass and spawning stock biomass as a percentage of the unfished level from MCMC for models 0.1, 0.4 and 06. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.**

**Table 7: Summary of the marginal posterior distributions from the MCMC chain from the base case (Model 0.1), and the sensitivity trials (models 0.4 and 0.6). The columns show the median, the 5th and 95th percentiles values observed in the 1000 samples. Biomass is in tonnes.**

| | **MCMC 0.1** | **MCMC 0.4** | **MCMC 0.6** |
|---|---|---|---|
| $B_0$ | 3948 (3630–4271) | 4470 (4112–4841) | 3947 (3608–4287) |
| $B_{2017}$ | 1873 (1513–2360) | 2144 (1750–2686) | 1711 (1223–2410) |
| $B_{2017}\%B_0$ | 47 (39–58) | 48 (40–59) | 44 (32–59) |
| $rB_0$ | 3553 (3221–3876) | 4029 (3655–4400) | 3569 (3223–3882) |
| $rB_{2017}$ | 1524 (1230–1906) | 1755 (1435–2178) | 1374 (964–1970) |
| $rB_{2017}/rB_0$ | 0.43 (0.35–0.53) | 0.44 (0.36–0.53) | 0.39 (0.27–0.54) |
| $U_{40\%B0}$ | 16 (13–23) | 13 (10–17) | 6 (5–9) |
| $U_{msy}$ | 33 (24–53) | 33 (24–53) | 30 (21–51) |
| $U_{2017}$ | 9 (7–11) | 8 (6–9) | 10 (7–14) |

## 4.4 Other factors

The assessment used CPUE as an index of abundance. The assumption that CPUE indexes abundance is questionable. The literature on abalone fisheries suggests that CPUE is problematic for stock assessments because of serial depletion. This can happen when fishers deplete unfished or lightly fished beds and maintain their catch rates by moving to new areas. Thus CPUE stays high while the biomass is actually decreasing. For PAU 5B, the model estimate of stock status was strongly driven by the trend in the recent CPUE indices. It is unknown to what extent the CPUE series tracks stock abundance. The SFWG believed that the increasing trend in recent CPUE series are credible, corroborating anecdotal evidence from the commercial divers in PAU 5B that the stock has been in good shape in recent years.

Natural mortality is an important productivity parameter. It is often difficult to estimate *M* reliably within a stock assessment model and the estimate is strongly influenced by the assumed prior. For the pāua assessment, the choice of prior has been based on current belief on the plausible range of the natural mortality for pāua, and therefore it is reasonable to incorporate available evidence to inform the estimation of *M*. The sensitivity of model results to the assumptions on *M* could be assessed through the use of alternative priors.

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 we assume and what was actually taken. In addition, non-commercial catch estimates are poorly determined and could be substantially different from what was assumed, although generally non-commercial catches appear to be relatively small compared with commercial catch. The estimate of illegal catch in particular is uncertain.

**Table 8: Projected quantities for the Base model with an assumed 5% TACC increase and recruitment based on the past 10 years.**

| | 2018 | 2019 | 2020 |
|---|---|---|---|
| **Bt** | 1898 (1460–2528) | 1916 (1451–2594) | 1936 (1439–2655) |
| **%*B0*** | 0.48 (0.38–0.63) | 0.49 (0.38–0.64) | 0.49 (0.37–0.65) |
| ***rBt*** | 1536 (1176–2031) | 1550 (1176–2077) | 1569 (1177–2124) |
| **%*rB0*** | 0.43 (0.34–0.56) | 0.44 (0.34–0.58) | 0.44 (0.34–0.59) |
| **Pr (>*Bcurrent*)** | 0.65 | 0.69 | 0.71 |
| **Pr (>40%$B_0$)** | 0.93 | 0.93 | 0.93 |
| **Pr (<20% $B_0$)** | 0 | 0 | 0 |
| **Pr (<10% $B_0$)** | 0 | 0 | 0 |
| **Pr (>*rBcurrent*)** | 0.61 | 0.64 | 0.69 |
| **Pr (U>U40% $B_0$)** | 0 | 0 | 0.01 |

**Table 9: Projected quantities for the Base model with an assumed 20% TACC increase and recruitment based on the past 10 years.**

| | 2018 | 2019 | 2020 |
|---|---|---|---|
| ***Bt*** | 1892 (1453–2521) | 1896 (1431–2574) | 1904 (1407–2624) |
| **% $B_0$** | 0.48 (0.38–0.62) | 0.48 (0.37–0.63) | 0.48 (0.37–0.64) |
| ***rBt*** | 1529 (1169–2024) | 1530 (1156–2057) | 1537 (1144–2092) |
| **%*r*$B_0$** | 0.43 (0.34–0.56) | 0.43 (0.33–0.57) | 0.43 (0.33–0.58) |
| **Pr (>*Bcurrent*)** | 0.58 | 0.59 | 0.59 |
| **Pr (>40% $B_0$)** | 0.93 | 0.92 | 0.91 |
| **Pr (<20% $B_0$)** | 0 | 0 | 0 |
| **Pr (<10% $B_0$)** | 0 | 0 | 0 |
| **Pr (>*rBcurrent*)** | 0.53 | 0.51 | 0.53 |
| **Pr (U>U40% $B_0$)** | 0.02 | 0.02 | 0.03 |

**Table 10: Projected quantities for the Base model with an assumed 5% TACC increase and recruitment based on the past 5 years. [Continued on next page]**

| | 2018 | 2019 | 2020 |
|---|---|---|---|
| ***Bt*** | 1876 (1434–2530) | 1879 (1406–2571) | 1876 (1373–2646) |
| **% $B_0$** | 0.48 (0.37–0.62) | 0.48 (0.37–0.64) | 0.48 (0.36–0.65) |
| ***rBt*** | 1536 (1175–2032) | 1545 (1167–2073) | 1551 (1154–2119) |
| **%*r*$B_0$** | 0.43 (0.34–0.56) | 0.44 (0.34–0.58) | 0.44 (0.33–0.59) |
| **Pr (>*Bcurrent*)** | 0.47 | 0.49 | 0.48 |

**Table 10 [Continued]:**

| | 2018 | 2019 | 2020 |
|---|---|---|---|
| **Pr (>40% $B_0$)** | 0.92 | 0.9 | 0.88 |
| **Pr (<20% $B_0$)** | 0 | 0 | 0 |
| **Pr (<10% $B_0$)** | 0 | 0 | 0 |
| **Pr (>*rBcurrent*)** | 0.6 | 0.6 | 0.59 |
| **Pr (U>U40% $B_0$)** | 0 | 0 | 0.01 |

**Table 11: Projected quantities for the Base model with an assumed 20% TACC increase and recruitment based on the past 5 years.**

| | 2018 | 2019 | 2020 |
|---|---|---|---|
| ***Bt*** | 1869 (1427–2523) | 1859 (1386–2551) | 1844 (1341–2614) |
| **% $B_0$** | 0.47 (0.37–0.62) | 0.47 (0.36–0.63) | 0.47 (0.35–0.65) |
| ***rBt*** | 1529 (1168–2025) | 1525 (1147–2053) | 1519 (1121–2087) |
| **%$rB_0$** | 0.43 (0.34–0.56) | 0.43 (0.33–0.57) | 0.43 (0.32–0.58) |
| **Pr (>*Bcurrent*)** | 0.41 | 0.39 | 0.37 |
| **Pr (>40% $B_0$)** | 0.91 | 0.89 | 0.85 |
| **Pr (<20% $B_0$)** | 0 | 0 | 0 |
| **Pr (<10% $B_0$)** | 0 | 0 | 0 |
| **Pr (>*rBcurrent*)** | 0.52 | 0.48 | 0.44 |
| **Pr (U>U40% $B_0$)** | 0.02 | 0.02 | 0.03 |

The model treats the whole of the assessed area of PAU 5B as if it were a single stock with homogeneous biology, habitat and fishing pressures. The model assumes homogeneity in recruitment and natural mortality, and assumes that growth has the same mean and variance throughout. Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Variation in growth is 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.

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 localized depletion of spawners. Spawners must be close to each other to breed and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, so local processes may decrease recruitment, an effect that the current model cannot account for.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that some populations become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole. Past recruitments estimated by the model might instead have been the result of serial depletion.

### 4.5 Future research considerations

- Continue to develop fisheries-independent survey methodologies that are representative of the PAU 5B area;
- Further investigate *q*-drift to determine how to quantify it and its implications for assessment outcomes;
- Ensure models are robust to assumptions about, or estimates of, natural mortality and stock-recruitment parameters;
- Review the commercial catch sampling programme in light of the increasing trend of live or frozen-in-shell exports.

## 5. STATUS OF THE STOCK

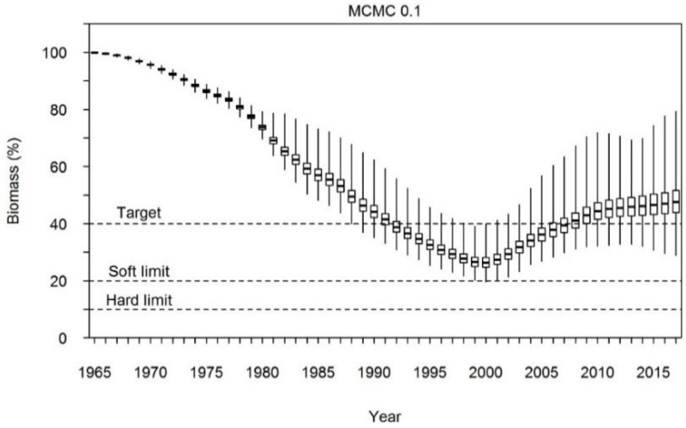
### Stock Structure Assumptions

PAU 5B is assumed to be a homogenous stock for purposes of the stock assessment.

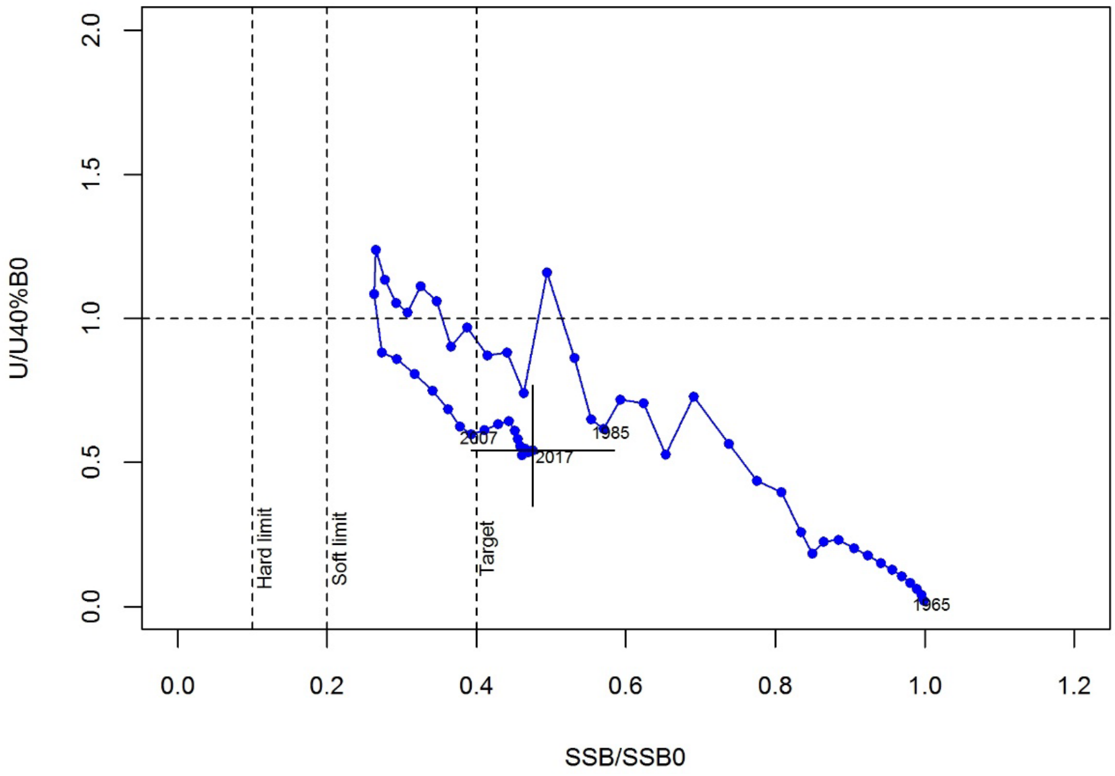
- **PAU 5B - Stewart Island**

| **Stock Status** | | |
|---|---|---|
| Most Recent Assessment Plenary Publication | 2018 | |
| Catch in most recent year of assessment | Year: 2016–17 | Catch: 93 t |
| Assessment Runs Presented | MCMC 0.1 (base case) | |
| Reference Points | Target: 40% $B_0$ (Default as per HSS)<br>Soft Limit: 20% $B_0$ (Default as per HSS)<br>Hard Limit: 10% $B_0$ (Default as per HSS)<br>Overfishing threshold: $U_{40\%B0}$ | |
| Status in relation to Target | $B_{2017}$ was estimated to be 47% $B_0$ for the base case; Likely (> 60%) to be at or above the target | |
| Status in relation to Limits | Very Unlikely (< 10%) to be below the soft and hard limits | |
| Status in Relation to Overfishing | Overfishing is Very Unlikely (< 10%) to be occurring | |

**Historical Stock Status Trajectory and Current Status**



**Posterior distributions of spawning stock biomass as a percentage of the unfished level from MCMC 0.1. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.**



**Trajectory of exploitation rate as a ratio $U_{40\%B0}$ and spawning stock biomass as a ratio of $B_0$ from the start of assessment period 1965 to 2017 for MCMC 0.1 (base case). The vertical lines at 10%, 20% and 40% $B_0$ represent the hard limit, the soft limit, and the target respectively. $U_{40\%B0}$ is the exploitation rate at which the spawning stock biomass would stabilise at 40% $B_0$ over the long term. Each point on trajectory represents the estimated annual stock status: the value on x axis is the mid-season spawning stock biomass (as a ratio of $B_0$) and the value on the y axis is the corresponding exploitation rate (as a ratio $U_{40\%B0}$) for that year. The estimates are based on MCMC medians and the 2017 90% CI is shown by the crossed line.**

| **Fishery and Stock Trends** | |
|---|---|
| Recent Trend in Biomass or Proxy | Biomass decreased to its lowest level in 2002 but has increased since then. |
| Recent Trend in Fishing Intensity or Proxy | Exploitation rate peaked in late 1990s and has since declined. |
| Other Abundance Indices | Standardised CPUE generally declined until the early 2000s, but has shown an overall increase since then. |
| Trends in Other Relevant Indicators or Variables | Estimated recruitment was relatively low through the 1990s to the early 2000s, increased from 2002 until 2010 and has since fallen below the long-term average. |

| **Projections and Prognosis** | |
|---|---|
| Stock Projections or Prognosis | At the current catch level biomass is expected to remain at or above the target over the next 3 years. |
| Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits | Results from all models suggest it is Very Unlikely (< 10%) that current catch or TACC will cause a decline below the limits. |
| Probability of Current Catch or TACC to cause Overfishing to continue or to commence | Very Unlikely (< 10%) |

| **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: 2018 | Next: 2021 |
|---|---|---|
| Overall assessment quality (rank) | 1 – High Quality | |
| Main data inputs (rank) | - Catch history | 1 – High Quality for commercial catch<br>2 – Medium or Mixed Quality for recreational, customary and illegal as catch histories are not believed to be fully representative of the QMA |
| | - CPUE indices early series | 2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA |
| | - CPUE indices later series | 1 – High Quality |
| | - Commercial sampling length frequencies | 2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA |
| | - Tag recapture data (for growth estimation) | 1 – High Quality |
| | - Maturity at length data | 1 – High Quality |
| | - Research Dive Survey Indices | 2 – Medium or Mixed Quality: uncertain whether it indexes the stock |
| Data not used (rank) | - Research Dive Length Frequencies | 2 – Medium or Mixed Quality: not believed to be representative of the entire QMA |
| Changes to Model Structure and Assumptions | New model | |
| Major Sources of Uncertainty | - *M* may not be estimated accurately<br>- CPUE may not be a reliable index of abundance and it is unclear whether catchability has changed over time<br>- The model treats the whole of the assessed area of PAU 5B as if it were a single stock with homogeneous biology, habitat and fishing pressure<br>- Any effect of voluntary increases in MHS from 125 mm to 137 mm between 2006 and 2017 may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years | |

| **Qualifying Comments:** |
|---|
| - |

| **Fishery Interactions** |
|---|
| - |

## 6. FOR FURTHER INFORMATION

Andrew, N L; Naylor, J R; Gerring, P (2000a) A modified timed-swim method for paua stock assessment. *New Zealand Fisheries Assessment Report 2000/4*. 23 p.

Andrew, N L; Naylor, J R; Gerring, P; Notman, P R (2000b) Fishery independent surveys of paua (*Haliotis iris*) in PAU 5B and 5D. *New Zealand Fisheries Assessment Report 2000/3*. 21 p.

Andrew, N L; Naylor, J R; Kim, S W; Doonan, I J (2002) Fishery independent surveys of the relative abundance and size-structure of paua (*Haliotis iris*) in PAU 5B and PAU 5D. *New Zealand Fisheries Assessment Report 2002/41*. 25 p.

Bradford, E (1998) Harvest estimates from the 1996 national recreational fishing surveys. New Zealand Fisheries Assessment Research Document. 1998/16. 27 p. (Unpublished document held by NIWA library, Wellington.)

Breen, P A; Andrew, N L; Kendrick, T H (2000a) Stock assessment of paua (*Haliotis iris*) in PAU 5B and PAU 5D using a new length-based model. *New Zealand Fisheries Assessment Report 2000/33*. 37 p.

Breen, P A; Andrew, N L; Kendrick, T H (2000b) The 2000 stock assessment of paua (*Haliotis iris*) in PAU 5B using an improved Bayesian length-based model. *New Zealand Fisheries Assessment Report 2000/48*. 36 p.

Breen, P A; Andrew, N L; Kim, S W (2001) The 2001 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2001/55*. 53 p.

Breen, P A; Kim, S W (2005) The 2005 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2005/47*. 114 p.

Breen, P A; Kim, S W; Andrew, N L (2003) A length-based Bayesian stock assessment model for abalone. *Marine and Freshwater Research 54(5): 619–634.*

Breen, P A; Smith, A N H (2008) The 2007 assessment for paua (*Haliotis iris)* stock PAU 5B (Stewart Island). *New Zealand Fisheries Assessment Report 2008/05*. 64 p.

Butterworth, D; Haddon, M; Haist, V; Helidoniotis, F (2015) Report on the New Zealand Paua stock assessment model; 2015. *New Zealand Fisheries Science Review 2015/4*. 31 p.

Cordue, P L (2009) Analysis of PAU 5A diver survey data and PCELR catch and effort data. SeaFic and PAUMac 5. (Unpublished report held by Fisheries New Zealand, Wellington.) 45 p.

Fu, D (2013) The 2012 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2013/57.*

Fu, D (2014) The 2013 stock assessment of paua (*Haliotis iris*) for PAU 5B. *New Zealand Fisheries Assessment Report 2014/45*. 51 p.

Fu, D; McKenzie, A; Naylor, R (2014) Summary of input data for the 2013 PAU 5B stock assessment. *New Zealand Fisheries Assessment Report 2014/43*. 61 p.

Gerring, P K (2003) Incidental fishing mortality of paua (*Haliotis iris*) in the PAU 7 commercial fishery. *New Zealand Fisheries Assessment Report 2003/56*.

Gorfine, H K; Dixon, C D (2000) A behavioural rather than resource-focused approach may be needed to ensure sustainability of quota managed abalone fisheries. *Journal of Shellfish Research 19*: 515–516.

Haist, V (2010) Paua research diver surveys: review of data collected and simulation study of survey method. *New Zealand Fisheries Assessment Report 2010/38*. 54 p.

Heinemann A; Gray, A. (in prep.) National Panel Survey of Recreational Marine Fishers 2022-23.

Kendrick, T H; Andrew, N L (2000) Catch and effort statistics and a summary of standardised CPUE indices for paua (*Haliotis iris*) in PAU 5A, 5B, and 5D. *New Zealand Fisheries Assessment Report 2000/47*. 25 p.

Marsh, C; Fu, D (2017) The 2016 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2017/33*.

Punt, A E (2003) The performance of a size-structured stock assessment method in the face of spatial heterogeneity in growth. *Fisheries Research 65*: 391–409.

Schiel, D R; Breen, P A (1991) Population structure, ageing and fishing mortality of the New Zealand abalone *Haliotis iris*. *Fishery Bulletin 89*: 681–691.

Schnute, J (1985) A General Theory for Analysis of Catch and Effort Data. *Canadian Journal of Fisheries and Aquatic Sciences, 42(3)*: 414–429.

Shepherd, S A; Partington, D (1995) Studies on Southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. *Marine and Freshwater Research 46*: 669–680.

Teirney, L D; Kilner, A R; Millar, R E; Bradford, E; Bell, J D (1997) Estimation of recreational catch from 1991/92 to 1993/94. New Zealand Fisheries Assessment Research Document 1997/15. 43 p. (Unpublished report held by NIWA library, Wellington.)

Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. New Zealand Fisheries Research Report. GEN2007A: 37 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

Wynne-Jones, J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 p.