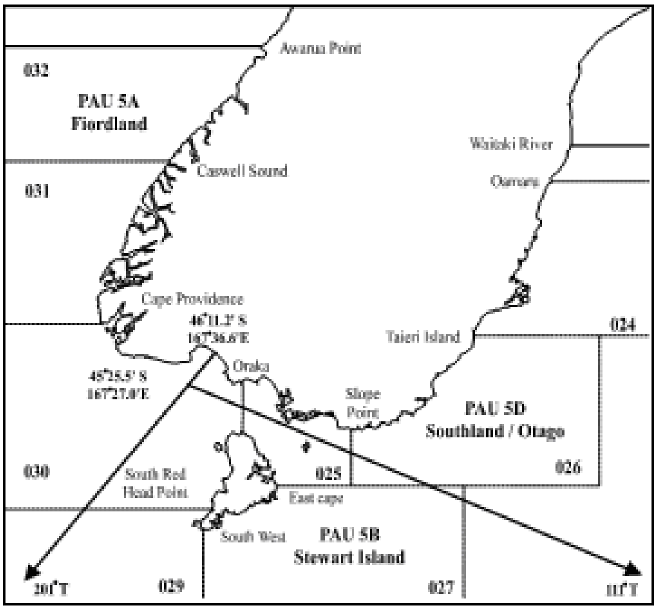
PAUA (PAU 5D) - Southland / Otago

(*Haliotis iris*)
Paua



1. FISHERY SUMMARY

Before 1995, PAU 5D 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 for 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 figure above) and the TACC was divided equally among them; the PAU 5D quota was set at 148.98 t.

On 1 October 2002 a TAC of 159 t was set for PAU 5D, comprising a TACC of 114 t, customary and recreational allowances of 3 t and 22 t respectively, and an allowance of 20 t for other mortality. The TAC and TACC have been changed since then but customary, recreational and other mortality allowances have remained unchanged (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 5D since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1991*	-	-	-	-	445
1991–1994*	-	-	-	-	492
1994–1995*	-	-	-	-	442.8
1995–2002	-	-	-	-	148.98
2002–2003	159	3	22	20	114
2003–present	134	3	22	20	89

*PAU 5 TACC figures

1.1 Commercial fishery

The fishing year runs from 1 October to 30 September. On 1 October 2001, it became mandatory to report catch and effort on Paua Catch Effort Landing Return (PCELR) forms using fine-scale reporting areas that had been developed by the New Zealand Paua Management Company for their voluntary logbook programme (Figure 1). Since 2010, the commercial industry has adopted some voluntary management initiatives which include raising the minimum harvest size for commercial fishers over specific statistical reporting areas. The industry has also voluntarily closed, to commercial harvesting, specific areas that are of high importance to recreational paua fishers. For the past three years commercial fishers have been voluntarily shelving a percentage of their Annual Catch Entitlement (ACE), which is reflected by the annual catch landings falling below the TACC (Figure 2, Table 2).

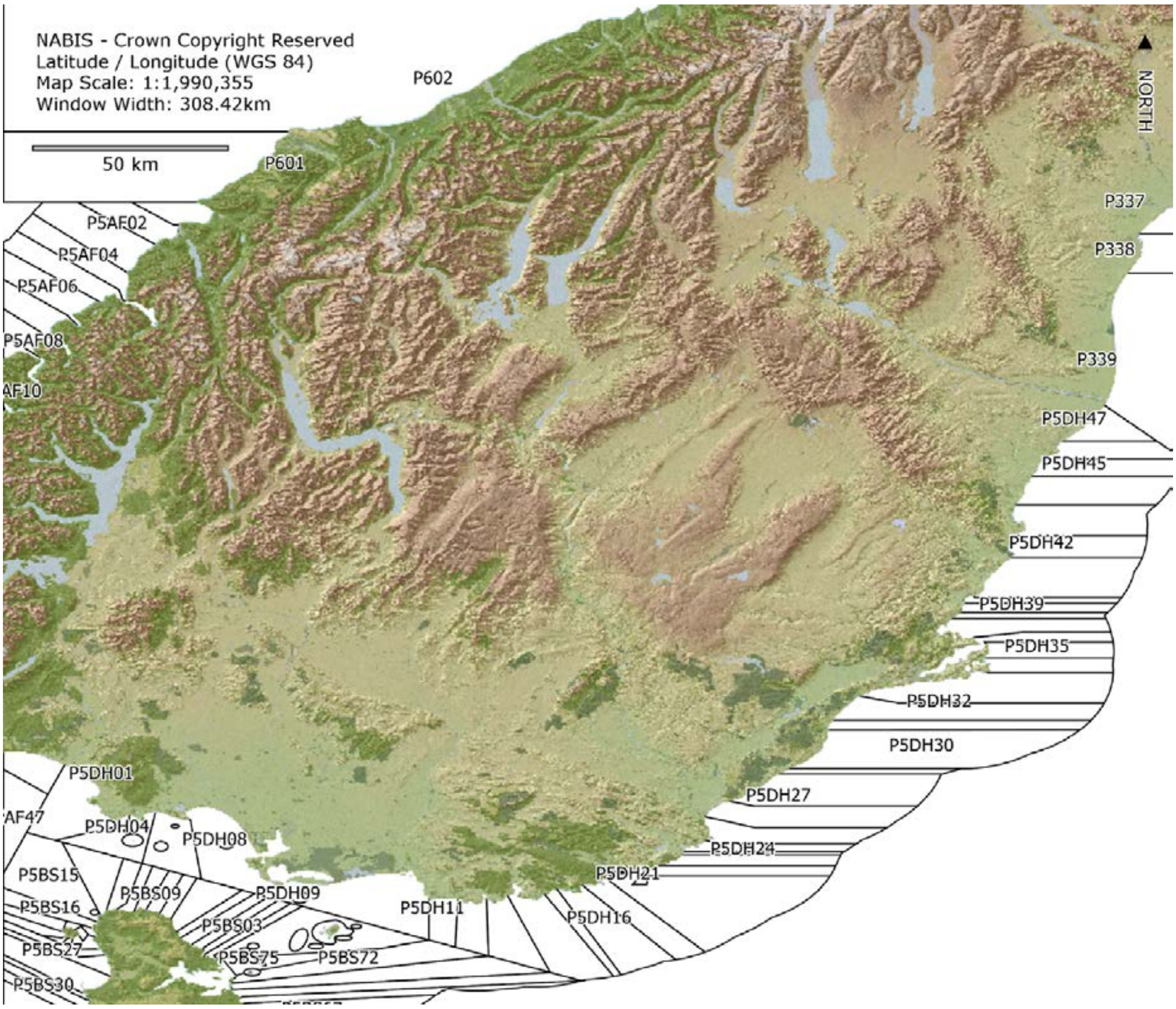


Figure 1: Map of fine scale statistical reporting areas for PAU 5D.

Commercial landings for PAU 5D are shown in Table 2 and Figure 2. Commercial landings for PAU 5 are reported in the introductory PAU Working Group Report.

Table 2: TACC and reported landings (t) of paua in PAU 5D from 1995–96 to the present. Data were estimated from CELR and QMR returns.

Year	Landings	TACC
1995–96	167.42	148.98
1996–97	146.6	148.98
1997–98	146.99	148.98
1998–99	148.78	148.98
1999–00	147.66	148.98
2000–01	149.00	148.98
2001–02	148.74	148.98
2002–03	111.69	114.00
2003–04	88.02	89.00
2004–05	88.82	89.00
2005–06	88.93	89.00
2006–07	88.97	89.00
2007–08	88.98	89.00

Table 2: [Continued]

Year	Landings	TACC
2008–09	88.77	89.00
2009–10	89.45	89.00
2010–11	88.70	89.00
2011–12	89.23	89.00
2012–13	87.91	89.00
2013–14	84.59	89.00
2014–15	71.87	89.00
2015–16	65.95	89.00

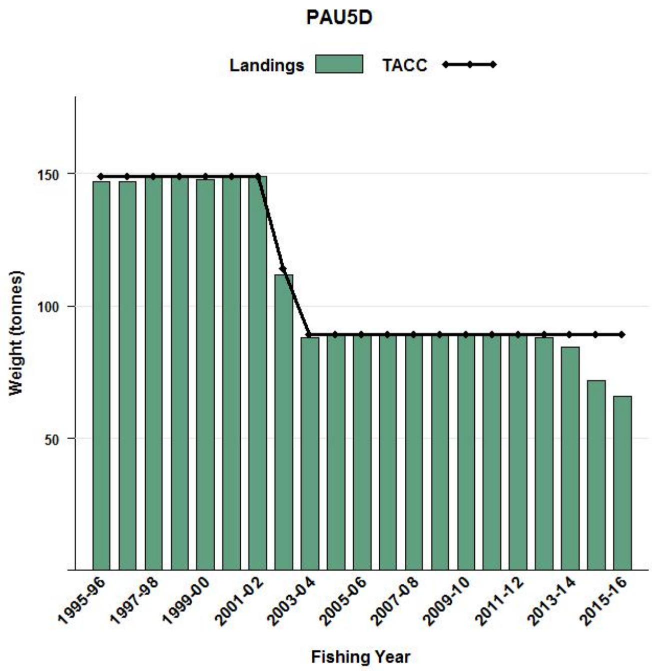


Figure 2: Reported commercial landings and TACC for PAU 5D from 1995–96 to present. For reported commercial landings in PAU 5 prior to 1995–96 refer to figure 1 and table 1 of the introductory PAU Working Group Report.

1.2 Recreational fisheries
For the purpose of the stock assessment model, the SFWG agreed to assume that the recreational catch in 1974 was 2 t and that it increased linearly to 10 t by 2005, where it has remained unchanged to date. For further information on recreational fisheries refer to the introductory PAU Working Group Report.

1.3 Customary fisheries
For the purpose of the stock assessment model, the SFWG agreed to assume that, for PAU 5D, the customary catch has been constant at 2 t from 1974 to the current stock assessment. For further information on customary fisheries refer to the introductory PAU Working Group Report.

1.4 Illegal catch
For the purpose of the stock assessment model, the SFWG agreed to assume that, for PAU 5D, illegal catches have been constant at 10 t from 1974 to the current stock assessment. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality
For further information on other sources of mortality refer to the introductory PAU Working Group Report.

2. BIOLOGY

For further information on paua biology refer to the introductory PAU Working Group Report. A summary of biological parameters used in the PAU 5D assessment is presented in Table 3.

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Working Group Report.

Table 3: Estimates of biological parameters (*H. iris*).

		Estimate	Source
1. Natural mortality (*M*)			
		0.14(0.12-0.16)	Median (5–95% range) of posterior estimated by the base case model
2. Weight = a(length)^b (Weight in g, length in mm shell length)			
All	a	b	
	2.99×10^{-5}	3.303	Schiel & Breen (1991)
3. Size at maturity (shell length)			
		50% maturity at 84 mm (83–85)	Median (5–95% range) of posterior estimated by the base case model
		95% maturity at 101 mm (103–106)	Median (5–95% range) of posterior estimated by the base case model
4. Estimated annual growth increments (both sexes combined)			
at 75 mm		at 120 mm	Median (5–95% range) of posteriors estimated by the base case model
28.8 (26.0-31.9)		6.8(6.3-7.2)	

4. STOCK ASSESSMENT

The stock assessment was implemented as a length-based Bayesian estimation model, with point estimates of parameters based on the mode of the joint posterior distribution, and uncertainty of model estimates investigated using the marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The most recent stock assessment was conducted for the fishing year ended 30 September 2016. A base case model (0.0 - referred to as the reference model henceforth) was chosen from the assessment. However, some data sets used in the model were from a limited number of locations and were most likely not representative of the whole QMA. Components of the stock assessment model that had the greatest uncertainty were the choice of mean and variance parameters on the prior of natural mortality (M), uncertainty associated with CPUE, and the proportionality assumption associated with CPUE and expected biomass.

4.1 Estimates of fishery parameters and abundance indices

Parameters estimated in the assessment model and their assumed Bayesian priors are summarized in Table 4.

Table 4: 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	Prior	*μ*	CV	Bounds	
				Lower	Upper
ln(*R0*)	U	–	–	5	50
M (Natural mortality)	LN	0.1	0.1	0.01	0.5
g_1*(Mean growth at 75 mm)*	U	–	–	1	50
g2(Mean growth at 120 mm)	U	–	–	0.01	50
φ (CV of mean growth)	U	–	–	0.001	1
$Ln(q^I)$ (catchability coefficient of CPUE)	U	–	–	-30	0
$Ln(q^J)$ (*catchability coefficient of PCPUE)*	U	–	–	-30	0
L_{50} (Length at 50% maturity)	U	–	–	70	145
L_{95-50}(Length between 50% and 95% maturity)	U	–	–	1	50

D_{50}(Length at 50% selectivity for the commercial catch)	U	–	–	70	145
D_{95-50}(Length between 50% and 95% selectivity the commercial catch)	U	–	–	0.01	50
ϵ (Recruitment deviations)	N	0	0.4	-2.3	2.3

The observational data were:
1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2016 based on PCELR data.
3. A commercial catch sampling length frequency series for 1998, 2002–04, 07, 2009–2015.
4. Tag-recapture length increment data.
5. Maturity at length data

4.1.1 Relative abundance estimates from standardised CPUE analyses

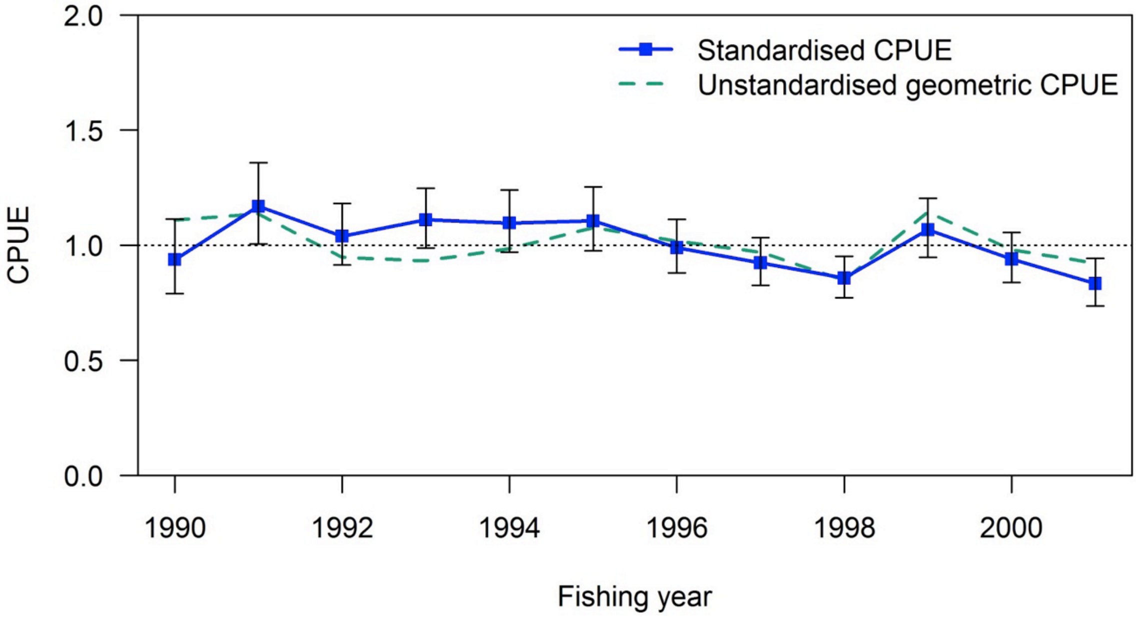
The 2016 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2016. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, and they were entered into the model in the order that gave the maximum decrease in the Akaike Information Criterion (AIC). Predictor variables were accepted into the model only if they explained at least 1% of the deviance.

For the CELR data, there is ambiguity in what is recorded for estimated daily fishing duration: either incorrectly recorded as hours per diver, or correctly as total hours for all divers. For PAU 5D, fishing duration appeared to have been predominantly recorded as hours per diver. The standardisation was therefore restricted to records where fishing duration was ≤ 10 hours. Another subset was applied where only a core group of records were selected based on the following criteria. Divers with a minimum of 5 records per year for a minimum of 4 years, Applying these criteria to the CELR data retained 82% of the catch over 1990–2001.

CELR CPUE was defined as daily catch, with year forced into the model at the start. Other predictor variables offered to the model were FIN (Fisher Identification Number), statistical area (024, 025, 026, 030), month, and total fishing duration (as a cubic polynomial). Total fishing duration is the recorded fishing duration multiplied by the number of divers for a record (recall fishing duration is incorrectly recorded as the diving duration per diver). The model explained 69% of the variability in CPUE with fishing duration (53%) explaining most of this followed by FIN (13%). The CELR data showed an overall stable to slight decline in CPUE from 1990 through to the early 2000s (Figure 3, upper panel).

For the PCELR data the following criteria was used to subset out a core group of records. The criteria of a minimum of 20 records per year for a minimum of 4 years was chosen. Applying these criteria retained 84% of the catch over 2002–2016. The dependent variable was modelled as log (diver catch) with a normal error distribution. Fishing year was forced into the model at the start. Variables offered to the model were month, diver key, FIN, statistical area, duration (third degree polynomial), and diving condition. Following previous standardisations, no interaction of fishing year with area was entered into the model, because the stock assessment for PAU 5D is a single area model. Except for FIN, all variables were accepted into the model, which explained 74% of the variability in CPUE. Most of the variability was explained by duration (55%) and diver (7%). The standardised index shows an increase from 2002 to 2011, then a decline after this (Figure 3, lower panel). There is little difference between the unstandardised and standardised CPUE, with most of the difference attributable to the fishing duration predictor.

In some circumstances, commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of paua despite a declining biomass. This occurs because paua 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.



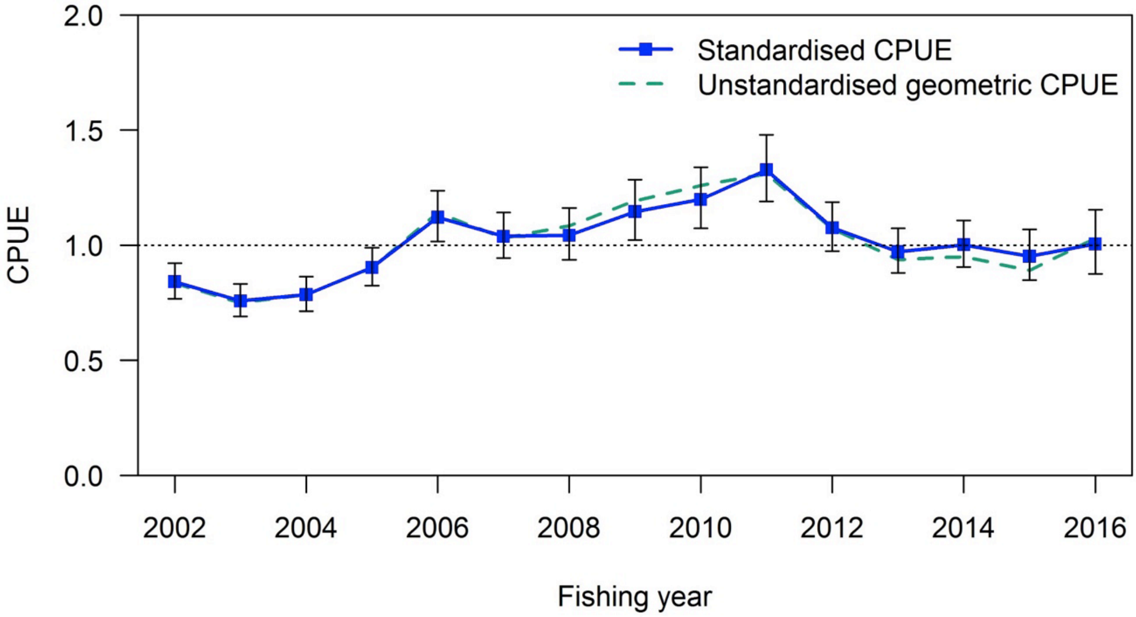


Figure 3: The standardised CPUE indices with 95% confidence intervals and unstandardized geometric CPUE for the early CELR series (upper panel) and the recent PCELR series (lower panel).

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of paua in PAU 5D has also been estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1994 and 2004. The survey strata (Catlins East and Catlins West) cover the areas that produced about 25% of the recent catches in PAU 5D. This data was not included in the assessment because there is concern that the data is not a reliable enough index of abundance and the data is not representative of the entire PAU 5D QMA.

Concerns about the ability of the data collected in the independent Research Dive surveys to reflect relative abundance instigated reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed the reliability of the research diver survey index as a proxy for abundance and whether the RDSI, when used in the paua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from paua stock assessments using the RDSI should be treated with caution. For a summary of the reviews conclusions refer to the introductory PAU Working Group Report

4.2 Stock assessment methods

The 2016 PAU 5D stock assessment used the same length-based model used for the 2015 PAU 7 assessment (Fu 2016). The model was described by Breen et al (2003). PAU 5D was last assessed using data up to the 2011–2012 fishing year (Fu 2013), and the most recent assessment uses data up to the 2015–2016 fishing year (Marsh & Fu in prep.). Changes to the stock assessment model between these two assessments include; 1) using a more flexible function form to describe the variance associated with the mean growth increment at length, 2) predicted CPUE was 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), and 3) changes to the likelihood function fitting the tag-recapture observations so that weights could be assigned to individual observations. These all follow suggestions from Butterworth et al (2015).

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. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class changing in each year. Paua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2016. Catches were available for 1974–2016 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.

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. The stock-recruitment relationship is unknown for paua. 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 the proportions of mature individuals from length-at-maturity data. Growth and natural mortalities were also estimated within the model. The model estimated the commercial fishing selectivity, which was assumed to follow a logistic curve and to reach an asymptote.

The assessment was conducted in several steps. First, the model was fitted to the data with arbitrary weights on the various data sets. The weights were then iteratively adjusted to produce balanced residuals among the datasets where the standardised deviation of the normalised residuals was close to one for each dataset. The length frequency data were further down-weighted using the method TA1.8 described by Francis (2011). The fit obtained is the mode of the joint posterior distribution of parameters (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 with a set of agreed indicators obtained. Sensitivity trials were explored by comparing MPD fits made with alternative model assumptions.

The reference model (0.0) excluded the RDSI and RDLF data, fitted the two CPUE series and the CSLF data, estimated growth parameters within the model using an exponential growth curve with estimated variance parameters α and β, and estimated M within the model.

The sensitivity trials carried out for the MCMC and used for projecting the stock included: run 0.0e, where both CPUE series had double the observation error (coefficient of variation) associated with them, and run 0.0h, where we assumed a hyper-stable relationship between stock biomass and CPUE. The sensitivity trials addressed uncertainties in CPUE.

The assessment calculates the following quantities from their posterior distributions: the equilibrium spawning stock biomass assuming that recruitment is equal to the average recruitment from the period for which recruitment deviation were estimated (B_0,), and the mid-season spawning and recruited biomass for 2016 (B_{2016} and B^r_{2016}) and for the projection period (B_{proj} and B^r_{proj}). This assessment also reports 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}
- $\Pr(B_{proj} > B_{2016})$ 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}
- $\Pr(B_{proj} > B^r_{2016})$ 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 reference case model (0.0) estimated that the unfished spawning stock biomass (B_0) was about 2457 t (2270 – 2672 t) (Table 5), and the spawning stock population in 2016 (B_{2016}) was about 35% (28–43%) of B_0 (Figure 4). The model projections, using recruitment re-sampled from the recent model estimates and assuming current catch levels (status quo, 2015–16 catch), suggested that the spawning stock abundance will increase to about 38% (28–52%) of B_0 over the next three years (Table 6). The projection also indicated that the probability of the spawning stock biomass being above the target (40% B_0) will increase from about 14% in 2016 to 40% by 2019.

The reference case model appeared to fit most data well, and there is no obvious indication of lack of fit. Natural mortality was estimated to be about 0.14. Estimated commercial catch selectivity was very steep with the 50% selectivity (D_{50}) being close to125 mm. The estimated recruitment was high in the early 2000s. The estimated exploitation rate peaked in 2002 and since then has been decreasing, with the U_{2016} estimated at 19% and the exploitation rate required to achieve the target of 40% B_0 ($U_{40\%B0}$) over the long term was 21%.

When the observation error on the early CPUE series was doubled (Run 0.0e), the model estimated the unfished spawning stock biomass (B_0) to be about 2597 t (2393 – 2825 t) and showed a slightly steeper decline in biomass between 1990 and 2002 (Figure 4, middle panel). Estimated B_{2016} was about 32% (25–41%) of B_0, current exploitation rate was 20% and $U_{40\%B0}$ was 18% (Table 5). The model projections (Table 7) suggested an increase in biomass over the next three years, with a 23% probability of being above the target of 40% B_0 by 2019.

When the early CPUE series was assumed to have a hyper-stable relationship with biomass (Run 0.0h), the unfished spawning stock biomass (B_0) was estimated at 2562 t (2355 – 2775 t) (Figure 4, lower panel). B_{2016} was 28% (22–37%) of B_0, U_{2016} was 23% and $U_{40\%B0}$ was 17% (Table 5). The model projections (Table 8) suggested an increase in biomass over the next three years, with a 12% probability of being above the target by 2015.

Deterministic B_{msy} was also calculated in the 2016 assessment with B_{msy} estimated at 703 t, 747 t and 738 t for the 0.0, 0.0e and 0.0h assessment runs respectively (Table 5). The corresponding exploitation rates (U_{msy}) were estimated at 38%, 32% and 30% (Table 5). Projections from the different assessment runs, with probability statements on current and future stock status are displayed in Tables 6, 7 and 8.

For a number of reasons (as outlined below) B_{msy} is not currently used as a reference point for managing paua stocks. However, because determining the most suitable target and limit reference points for managing paua stocks is still work in progress B_{msy} is among the indicators that are being estimated.

There are several reasons why B_{msy} is not considered a suitable target for management of the paua fishery. Firstly, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge of catch and biology and perfect stock assessments (because current biomass must be known exactly in order to calculate target catch), a constant-exploitation management strategy with annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders), and perfect management implementation of the TACC and catch splits with no under or over runs. Secondly, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known. Thirdly, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard. Thus, the actual target needs to be above this theoretical optimum; but the extent to which it needs to be above has not been determined.

Table 5: Summary of the marginal posterior distributions from the MCMC chain from Run 5.2 (base case), and sensitivity trials Run 5.5 (no early CPUE), 6.3 (fast growth), and 6.5 (slow growth). The columns show the median, the 5th and 95th percentiles values observed in the 1000 samples. Biomass is in tonnes.

	MCMC 0.0	MCMC 0.0e	MCMC 0.0h
B_0	2457 (2270–2672)	2597 (2393–2825)	2562 (2355–2775)
B_{msy}	703 (651–762)	747 (688–811)	738 (679–802)
$B_{current}$	866 (705–1098)	819 (647–1084)	722 (569–940)
$B_{current}$ (%B_0)	0.35 (0.29–0.43)	0.32 (0.25–0.41)	0.28 (0.22–0.37)
$B_{current}$ (%B_{msy})	1.24 (1.01–1.51)	1.11 (0.87–1.43)	0.98 (0.76–1.27)
B_{msy} (%B_0)	0.29 (0.28–0.29)	0.29 (0.28–0.29)	0.29 (0.28–0.3)
rB_0	2060 (1859–2280)	2227 (2005–2465)	2203 (1976–2430)
rB_{msy}	381 (313–453)	443 (365–528)	445 (365–525)
rBcurrent	534 (412–717)	516 (380–726)	435 (320–613)
$rB_{current}$ (rB_0)	0.26 (0.2–0.34)	0.23 (0.17–0.32)	0.2 (0.15–0.28)
$rB_{current}$ (rB_{msy})	1.41 (1.03–1.97)	1.17 (0.83–1.73)	0.98 (0.68–1.46)
rB_{msy} (%rB_0)	0.18 (0.16–0.2)	0.2 (0.18–0.22)	0.2 (0.18–0.22)
MSY	121 (114–131)	116 (109–127)	114 (107–123)
U_{msy}	0.38 (0.29–0.53)	0.32 (0.24–0.44)	0.3 (0.23–0.42)
$U_{\%40B0}$	0.18 (0.14–0.24)	0.34 (0.25–0.5)	0.17 (0.14–0.23)
$U_{current}$	0.2 (0.14–0.28)	0.19 (0.13–0.25)	0.23 (0.16–0.33)

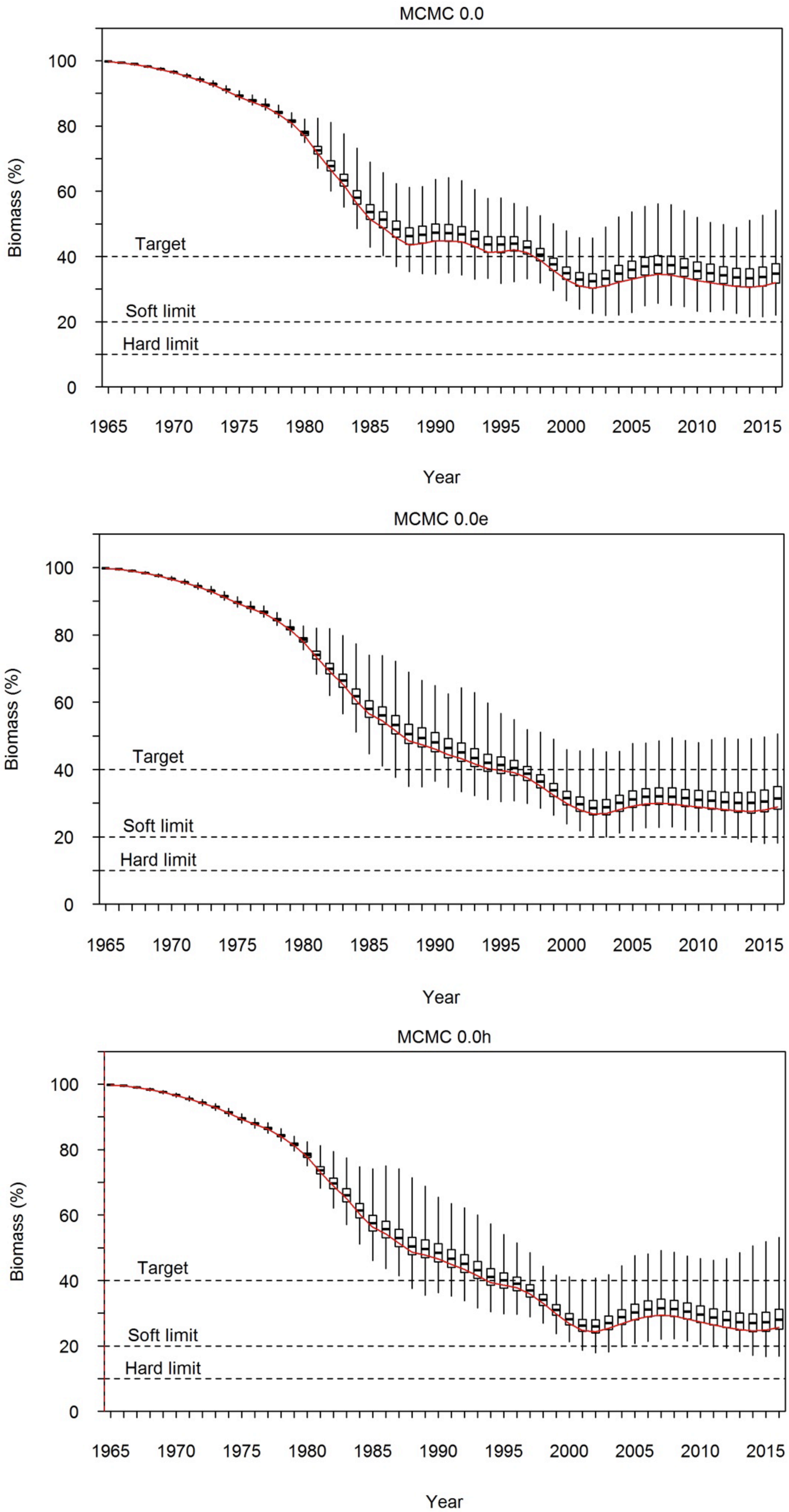


Figure 4: Posterior distributions of spawning stock biomass from MCMC 0.0 (base case), 0.0e (CPUE double observation error), and 0.0h (CPUE assumed hyperstable (*h* = 0.5)). The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution. The red line shows the MPD fit.

Table 6: Summary of current and projected indicators from the MCMCs for assessment run 0.0 with future commercial catch set to the current catch levels (status quo, 2015–16 fishing year) and non-commercial catch set to 22 t: biomass as a percentage of the virgin and current stock status, for spawning stock and recruit-sized biomass. B(current or projected biomass), U(current or projected exploitation rate).

	2016	2019
$B_{current}$	866 (705–1 098)	942 (680–1 315)
$B_{current}$ (%B_0)	0.35 (0.29–0.43)	0.38 (0.28–0.52)
$B_{current}$ (%B_{msy})	1.24 (1.01–1.51)	1.34 (0.97–1.82)
rBcurrent	534 (412–717)	608 (432–877)
$rB_{current}$ (%rB_0)	0.26 (0.2–0.34)	0.30 (0.21–0.41)
$rB_{current}$ (%rB_{msy})	1.41 (1.03–1.97)	1.6 (1.1–2.4)
Pr (>Bmsy)	0.94	0.96
Pr (>Bcurrent)	0.00	0.83
Pr (>40%B0)	0.14	0.40
Pr (<20%B0)	0.00	0.00
Pr (<10%B0)	0.00	0.00
Pr (>rBmsy)	0.96	0.99
Pr (>rBcurrent)	0.00	0.99
Pr (U>U40%B0)	0.32	0.14

Table 7: Summary of current and projected indicators from the MCMCs for assessment run 0.0e with future commercial set to the current catch levels (status quo, 2015–16 fishing year) and non-commercial catch set to 22 t: biomass as a percentage of the virgin and current stock status, for spawning stock and recruit-sized biomass. B (current or projected biomass), U (current or projected exploitation rate).

	2016	2019
B_t	819 (647 – 1 084)	910 (618 – 1 338)
%B_0	0.32 (0.25 – 0.41)	0.35 (0.24 – 0.50)
%B_{msy}	1.11 (0.87 – 1.43)	1.22 (0.83 – 1.76)
rB_t	516 (380 – 726)	593 (393 – 908)
%rB_0	0.23 (0.17 – 0.32)	0.27 (0.18 – 0.40)
%rB_{msy}	1.17 (0.83 – 1.73)	1.35 (0.84 – 2.17)
Pr (>Bmsy)	0.70	0.85
Pr (>Bcurrent)	0.00	0.87
Pr (>40%B0)	0.07	0.23
Pr (<20%B0)	0.00	0.00
Pr (<10%B0)	0.00	0.00
Pr (>rBmsy)	0.74	0.89
Pr (>rBcurrent)	0.00	0.99
Pr (U>U40%B0)	0.65	0.42

Table 8: Summary of current and projected indicators from the MCMCs for assessment run 0.0h with future commercial catch set to current catch levels (status quo, 2015–16 fishing year) and non-commercial catch set to 22 t: biomass as a percentage of the virgin and current stock status, for spawning stock and recruit-sized biomass. B (current or projected biomass), U (current or projected exploitation rate).

	2016	2019
B_t	722 (569 – 940)	807 (538 – 1202)
%B_0	0.28 (0.22 – 0.37)	0.32 (0.21 – 0.46)
%B_{msy}	0.98 (0.76 – 1.27)	1.10 (0.73 – 1.62)
rB_t	435 (320 – 613)	508 (328 – 784)
%rB_0	0.2 (0.15 – 0.28)	0.23 (0.15 – 0.35)
%rB_{msy}	0.98 (0.68 – 1.46)	1.15 (0.69 – 1.89)
Pr (>Bmsy)	0.43	0.68

Table 8: [Continued]

	2016	2019
Pr (>Bcurrent)	0.00	0.83
Pr (>40%B0)	0.02	0.12
Pr (<20%B0)	0.01	0.01
Pr (<10%B0)	0.00	0.00
Pr (>rBmsy)	0.46	0.71
Pr (>rBcurrent)	0.00	0.98
Pr (U>U40%B0)	0.85	0.68

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 paua 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 paua results in the timely re-colonisation of areas that have been fished down, as the cryptic paua, 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 making CPUE a poor proxy for abundance. How strong an effect serial depletion and aggregation behaviour have on the relationship between CPUE and abundance in PAU5D, is difficult to determine. However, because fishing has been consistent in PAU5D for a number of years and effort has been reasonably well spread, it could be assumed that CPUE, in more recent years, 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 PAU5D can also be upset by exploitation of spatially segregated populations of differing productivity. This can cause non-linearity in the CPUE-abundance relationship, making it difficult to track changes in abundance by using changes in CPUE as a proxy.

For PAU 5D, there is also some additional uncertainty associated with the early CPUE series: the standardisations suggested that there were different trends among statistical areas (the overall indices were unlikely to track abundance as the weights for each area cannot be easily determined); the level of decline in the CPUE indices appeared too small for the early stage of the fishery.

A major source of uncertainty in the model is the low confidence around the estimate of natural mortality. The current basis for the assumption of natural mortality is somewhat *ad hoc*, and the prior used is considered to be unduly informative (Butterworth et al 2015). Although sensitivities were run with different *a priori* assumptions of M, it was clear that the estimates were highly influenced by this assumption suggesting the data are not very informative for making strong statements about the status of the stocks and also suggesting that a better understanding of this parameter/dynamic would likely reduce a large component of uncertainty in this assessment.

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, including illegal catch, are poorly determined and could be substantially different from what was assumed.

Tag-recapture data were mainly from the Catlin areas and therefore may not reflect fully the average growth in the whole of the PAU 5D population. Model estimates of stock status were sensitive to the range of possible growth values examined. Maturity data were collected from Catlin West and may not represent the entire population either. Length frequency data collected from the commercial catch may not represent the commercial catch with high precision. The research diver survey covered only the Catlin Area, the abundance indices and associated length frequencies were unlikely to represent the trend in the whole population.

The model treats the whole of the assessed area of PAU 5D 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. However it is known that paua in some areas have stunted growth, and others are fast-growing.

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 depletion of spawners, because 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, so local processes may decrease recruitment, an effect that the current model cannot account for.

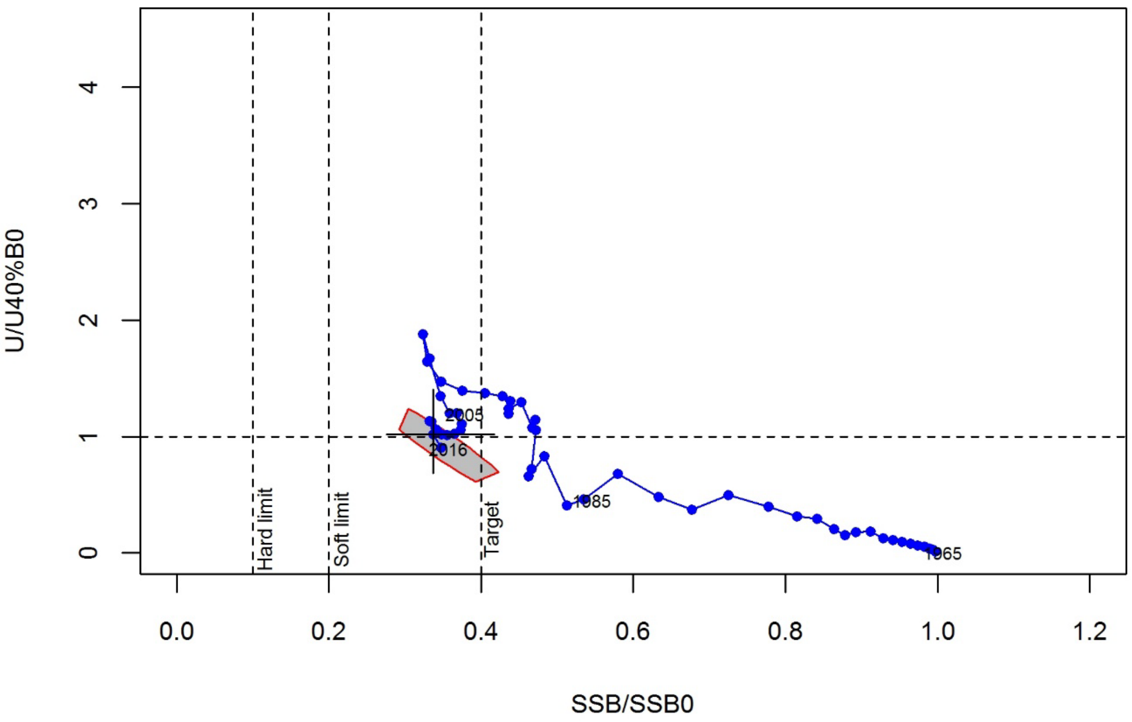
Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that some populations become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as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

5. STATUS OF THE STOCK

Stock Structure Assumptions
PAU 5D is assumed in the model to be a discrete and homogenous stock

- **PAU 5D - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2017
Assessment Runs Presented	Reference case MCMC
Reference Points	Interim Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2016} was estimated to be 35% B_0. The stock is Unlikely (< 40%) to be at or above the target.
Status in relation to Limits	Unlikely (< 40%) to be below the soft limit and Very Unlikely (< 10%) to be below the hard limit.
Status in Relation to Overfishing	Overfishing is About as Likely as Not (40-60%) to be occurring
Historical Stock Status Trajectory and Current Status	



Trajectory of exploitation rate as a ratio of $U_{\%40B0}$ and spawning stock biomass as a ratio of B_0 from the start of assessment period 1965 to 2016 for MCMC model run 0.0. The vertical lines at 10%, 20%, 40% B_0 represent the hard limit, the soft limit, and the target respectively. $U_{\%40B0}$ is the exploitation rate at which the spawning stock biomass would stabilise at 40% B_0 over the long term. Each point on the trajectory represents the estimated annual stock status: the value on the 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 $U_{\%40B0}$) for that year. The trajectory started in year 1965 when the SSB was close to B_0 and the exploitation rate was close to 0. The estimates are based on MCMC medians and the 2016 90% CI is shown by the cross line.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass decreased from 1965 to 2002 and has since been relatively stable.
Recent Trend in Fishing Mortality or Proxy	Exploitation rate peaked in 2002 and has since declined.
Other Abundance Indices	Standardised CPUE generally declined until the early 2000s, but has shown a gradual increase since.
Trends in Other Relevant Indicators or Variables	Estimated recruitment between 2002 and 2009 has decreased below the long term average and since then has been increasing to close to the long term average.

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch level biomass is expected to increase over the next 3 years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Results from all model assessment runs presented suggest it is Very Unlikely (< 10%) and Unlikely (< 40%) that current levels of catch or catch at the TACC, respectively, will cause a decline below the soft or hard limits.

Assessment Methodology and Evaluation		
Assessment Type	1- Full Quantitative Stock Assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest: 2017	Next: 2020
Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)		2 – Medium or Mixed Quality: not

	- Catch History	believed to be fully representative of catch in the QMA
	- CPUE Indices early series	2 – Medium or Mixed Quality: not believed to be fully representative of CPUE in the QMA
	- CPUE Indices later series	1– High Quality
	- Commercial sampling length frequencies	2 – Medium or Mixed Quality: not believed to be representative of the whole QMA
	- Tag recapture data	2 – Medium or Mixed Quality: not believed to be representative of the whole QMA
	- Maturity at length data	2 – Medium or Mixed Quality: not believed to be representative of the whole QMA
Data not used (rank)	- Research Dive survey indices	3 – Low Quality: not believed to be a reliable indicator of abundance in the whole QMA
	- Research Dive length frequencies	3 – Low Quality: not believed to be a reliable indicator of length frequency in the whole QMA
Changes to Model Structure and Assumptions	- Added a more flexible functional form to describe the variance associated with the mean growth increment at length - Mid-season abundance (and biomass) was calculated after half of the natural mortality and half of the fishing mortality was applied - Changed likelihood function for fitting the tag-recapture observations so that weights can be assigned to individual observations.	
Major Sources of Uncertainty	- Growth data were limited and may not be representative of growth within the whole QMA. This was explored through models with alternative growth assumptions, which show the high degree of uncertainty about current stock status associated with uncertainty about growth. - Assuming CPUE is a reliable index of abundance. - The model treats the whole of the assessed area of PAU 5D as if it were a single stock with homogeneous biology, habitat and fishing pressures. - Any effect of voluntary increases in MHS from 125mm to 132mm over the last five years may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years. - A major source of uncertainty in the model is the low confidence around the estimate of natural mortality. The current basis for the assumption of natural mortality is somewhat *ad hoc*, and the prior used is considered to be unduly informative (Butterworth et al 2015). Although sensitivities were run with different *a priori* assumptions of M, it was clear that the estimates were highly influenced by this assumption suggesting the data are not very informative for making strong statements about the status of the stocks and also suggesting that a better understanding of this parameter/dynamic would likely reduce a large component of uncertainty in this assessment.	
Qualifying Comments		
The uncertainty in the reliability of CPUE as a proxy for abundance and the uncertainty in estimates of M, require caution when deciding which level of probability best reflects the status of the fishery.		

Fishery Interactions
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6. FOR FURTHER INFORMATION

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