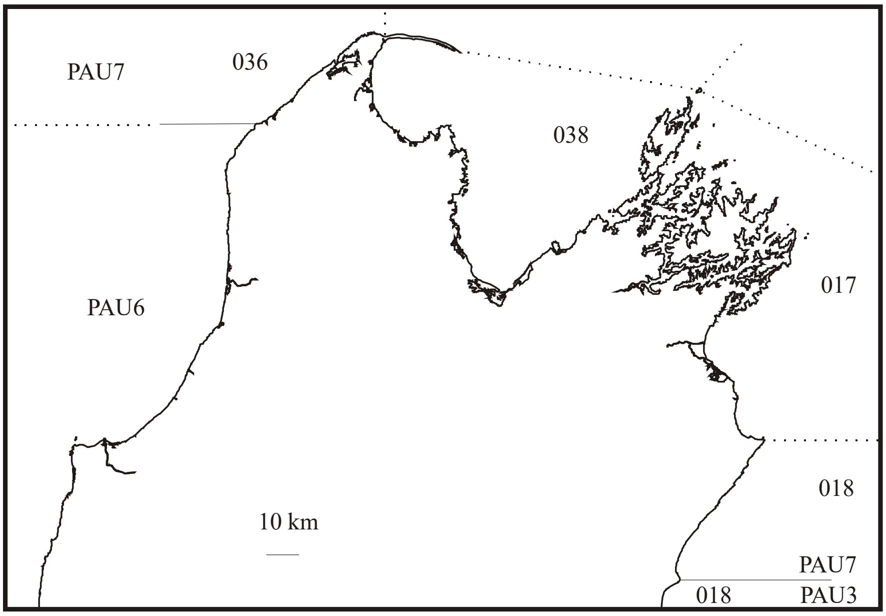
PĀUA (PAU 7) – Marlborough

(Haliotis iris)
Pāua



1. FISHERY SUMMARY

PAU 7 was introduced into the Quota Management System in 1986–87 with a TACC of 250 t. As a result of appeals to the Quota Appeal Authority the TACC increased to 267.48 t by 1989. On 1st October 2001 a TAC of 273.73 t was set with a TACC of 240.73 t, customary and recreational allowances of 15 t each and an allowance of 3 t for other mortality. On 1 October 2002 the TAC was reduced to 220.24 t and the TACC was set at 187.24 t; no changes were made to the customary, recreational or other mortality allowances. In 2016 the TACC was further reduced to 93.62 t, and the allowance for other mortality was increased to 10 t, setting the TAC to 133.62 (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 7 since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–89	–	–	–	–	250.00
1989–01	–	–	–	–	267.48
2001–02	273.73	15	15	3	240.73
2002–16	220.24	15	15	3	187.24
2016–Present	133.62	15	15	10	93.62

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. In 2000–01 concerns about the status of the PAU 7 fishery led to a decision by the commercial sector to voluntarily shelve 20% of the TACC for that fishing year. From the 2003–04 to the 2006–07 fishing years the industry proposed to shelve 15% of the TACC. In the 2012–13 and 2013–14, the industry shelved 20% of the 187.24 t TACC. In 2014–15, PAU 7 stakeholders again agreed to voluntarily shelve 30%. However some only shelved 20% and some shelved 30%; an average of 28% was shelved overall. In October 2016 the TACC was reduced by 50%. Almost immediately following this as a result of the Kaikōura earthquake of November 2016 the southern area of the fishery was closed under emergency provisions, this was later replaced by an official S11 closure. This area historically accounted for approximately 10% of the total PAU 7 catch. From 1 October 2017 the TAC was reduced a further 10%, but this decision was set aside by agreement following a court injunction so the TAC is still set at 133.63 t for PAU 7. However, PAU 7 stakeholders have agreed to a 10% shelving which they have maintained to date, and annual landings were about 81 t from 2017–18 to 2019–20. The customary and recreational allowances are still set at 15 t.

On 1 October 2001 it became mandatory to report catch and effort on PCELRs using fine-scale reporting areas (Figure 1) that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme. Reported landings and TACCs for PAU 7 are shown in Table 2 and Figure 2.

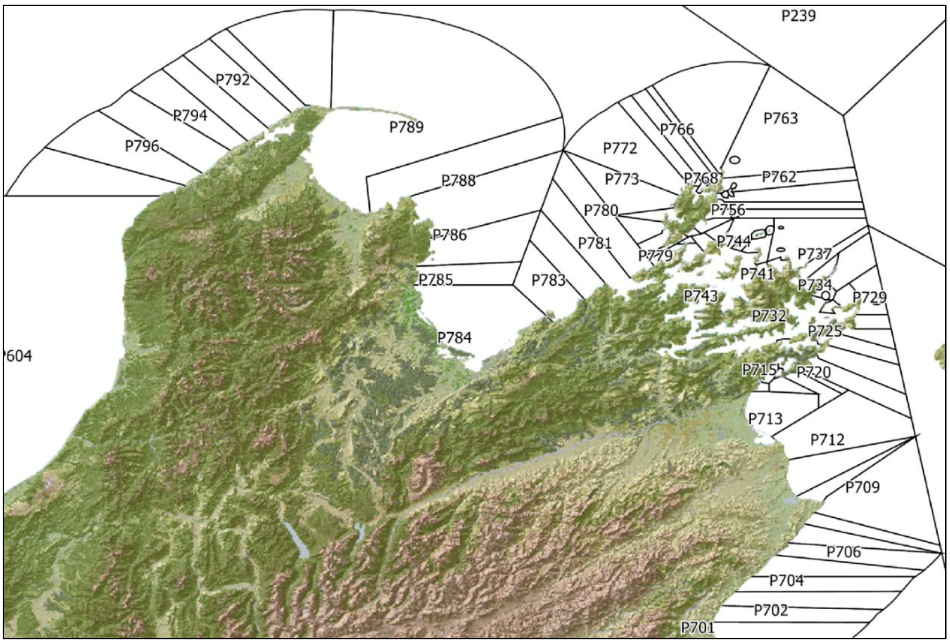


Figure 1: Map of fine scale statistical reporting areas for PAU 7.

Table 2: Reported landings and TACC in PAU 7 from 1983–84 to the present. The last column shows the TACC after shelving has been accounted for.

Year	Landings (kg)	TACC (t)	Shelving	Year	Landings (t)	TACC (t)	Shelving
1974–75	197 910	-	-	1997–98	266 655	267.48	267.48
1975–76	141 880	-	-	1998–99	265 050	267.48	267.48
1976–77	242 730	-	-	1999–00	264 642	267.48	267.48
1977–78	201 170	-	-	2000–01	215 920	267.48	*213.98
1978–79	304 570	-	-	2001–02	187 152	240.73	240.73
1979–80	223 430	-	-	2002–03	187 222	187.24	187.24
1980–81	490 000	-	-	2003–04	159 551	187.24	*159.15
1981–82	370 000	-	-	2004–05	166 940	187.24	*159.15
1982–83	400 000	-	-	2005–06	183 363	187.24	*159.15
1983–84	330 000	-	-	2006–07	176 052	187.24	*159.15
1984–85	230 000	-	-	2007–08	186 845	187.24	187.24
1985–86	236 090	-	-	2008–09	186 846	187.24	187.24
1986–87	242 180	250		2009–10	187 022	187.24	187.24
1987–88	255 944	250		2010–11	187 240	187.24	187.24
1988–89	246 029	250		2011–12	186 980	187.24	187.24
1989–90	267 052	267.48		2012–13	149 755	187.24	*149.80
1990–91	273 253	267.48		2013–14	145 523	187.24	*149.80
1991–92	268 309	267.48	267.48	2014–15	133 584	187.24	*134.80
1992–93	264 802	267.48	267.48	2015–16	138 790	187.24	187.24
1993–94	255 472	267.48	267.48	2016–17	93.610	93.620	93.620
1994–95	247.108	267.48	267.48	2017–18	81.880	93.620	*84.26
1995–96	268 742	267.48	267.48	2018–19	79.697	93.620	*84.26
1996–97	267 594	267.48	267.48	2019–20	81.983	93.620	*84.26

* Voluntary shelving

1.2 Recreational fisheries

A nationwide panel survey of over 7000 marine fishers who reported their fishing activity over the fishing year from 1 October 2011 to 30 September 2012 was conducted by The National Research Bureau Ltd in close consultation with Marine Amateur Fishing Working Group (Wynne-Jones et al 2014). The survey is based on an improved survey method developed to address issues and to reduce bias encountered in past surveys. The survey estimated that about 50 534 pāua, or 14.13 t (CV of 34%) were harvested by recreational fishers in PAU 7 for 2011–12. For this assessment, the SFWG agreed to assume that recreational catch was 5 t in 1974 and that it increased linearly to 15 t in 2000 and then remained at 15 t subsequently. In 2017–18, the National Panel Survey was repeated and the estimated recreational catch was 3.02 t (CV of 36%) (Wynne-Jones et al 2019). For further information on recreational fisheries refer to the introductory PAU Working Group Report.

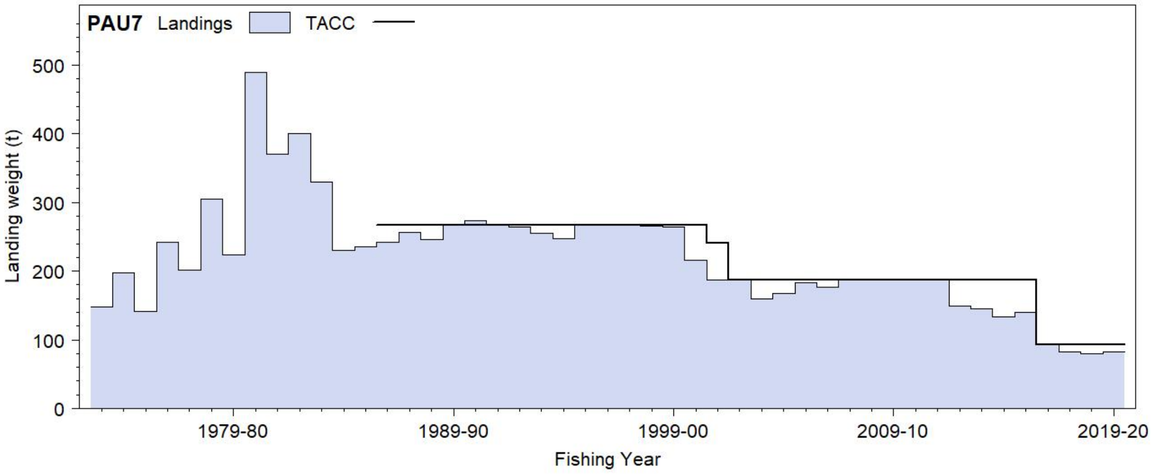


Figure 2: Reported commercial landings and TACC for PAU 7 from 1986–87 to present.

1.3 Customary fisheries

Customary catch was incorporated into the PAU 7 TAC in 2002 as an allowance of 15 t. Estimates of customary catch for PAU 7 are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in kilograms and numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kg) and numbers) of pāua in PAU 7 between 2007–08 and 2011–12. No reports since. – no data.

	Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**
2007–08	–	–	1 110	808
2008–09	–	–	1 270	1 014
2009–10	–	–	1 085	936
2010–11	–	–	60	31
2011–12	–	–	20	20

Records of customary catch taken under the South Island Regulations show that about 20 to 1014 pāua were reported to have been collected each year from 2007–08 to 2011–12, with an average of 449 pieces each year. Those numbers were substantially lower than the annual allowances. There has not been any reports since.

For the 2015 stock assessment, the Working Group agreed to assume that customary catch was 4 t in 1974, increasing linearly to 5 t between 1974 and 2000 and then remaining at 5 t subsequently.

For further information on customary fisheries refer to the introductory PAU Plenary chapter.

1.4 Illegal catch

There are no estimates of illegal catch for PAU 7.

For the 2015 stock assessment, the Working Group agreed to assume that illegal catch was 1 t in 1974 and that it increased linearly to 15 t between 1974 and 2000, remaining at 15 t from 2000 to 2005, then decreasing linearly to 7.5 t in 2008, and then remaining at 7.5 subsequently.

For further information on illegal catch refer to the introductory PAU Plenary chapter.

1.5 Other sources of mortality

The Working Group agreed that handling mortality would not be factored into the model. For further information on other sources of mortality refer to the introductory PAU Plenary chapter.

On November 16th 2016 a 7.8 magnitude earthquake hit the upper east coast of the South Island, uplifting areas of the coast by as much as 4 m. In the PAU 7 fishery, pāua statistical areas P701 to P710 were impacted to varying degrees by the earthquake. The earthquake caused direct mortality of a large number of juvenile and adult pāua that became exposed to the terrestrial environment with no means of being able to return to the water. More indirect mortality is also expected from the earthquake due to an immediate loss of pre-earthquake pāua habitat that now lies above the new post-earthquake high tide mark.

Impacts of the seabed uplift on pāua populations in PAU 7 will only become clear in the longer term. The immediate loss of area to the fishery, assumed to be good habitat for pāua, is only part of the impact that the seabed uplift associated with the earthquake will have on pāua populations. Juvenile pāua recruit in shallow water, and so the loss of juvenile habitat will have been higher than the loss of adult habitat. This will impact on the number of juvenile pāua growing into the fishery over the coming years. This impact will be difficult to quantify directly, but may affect pāua populations and fisheries over a span of multiple years.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Plenary chapter. A summary of biological parameters used in the PAU 7 stock assessment is presented in Table 4.

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

Fishstock		Estimate	Source
1. Natural mortality (*M*)			
All		0.02–0.25	Sainsbury (1982)
PAU 7	0.11 (0.10–0.13)	Median (5%–95% CI)	estimated from the base case assessment model
2. Weight = a (length)^b (weight in g, shell length in mm)			
	a = 2.59E–08	b = 3.322	Schiel & Breen (1991)
3. Size at maturity (shell length)			
50% mature	92 (91.3–92.7) mm	Median (5%–95% CI)	estimated by the assessment model
length at 95% mature - 50% mature	8.7 (9.6–13.4) mm	Median (5%–95% CI)	estimated by the assessment model
4. Exponential growth parameters (both sexes combined)			
l^g_{50}	104 (98.5–107.1) mm	Median (5%–95% CI)	estimated by the assessment model: length of animal at 50% maximum growth increment
$l^g_{95\text{-}50}$	30.9 (25.9–37.4) mm	Median (5%–95% CI)	estimated by the model: length of animal between at 50% and 95% maximum growth increment.
Δ_{max}	30 (26.3–36.1) mm	Median (5%–95% CI)	estimated by the model: maximum growth increment

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Plenary chapter.

4. STOCK ASSESSMENT

The stock assessment is 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 2015 assessment was restricted to Statistical Areas 017 and 038, which includes approximately 85–95% of the catch over the past 10 years.

4.1 Estimates of fishery parameters and abundance indices

Parameters estimated in the assessment model and their assumed Bayesian priors are summarised in Table 5.

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2015 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2015. 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.

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. FIN codes were used to select a core group of fishers from the CELR data, with the requirement to qualify for the core fisher group that there be a minimum of 15 records per year for a minimum of 3years. 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 8 years. For both periods, over 80% of catches were retained.

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	Definition	Phase	Prior	μ	CV	Lower	Upper
$\ln(R0)$	Natural log of base recruitment	1	U	–	–	5	50
M	Instantaneous rate of natural mortality	3	LN	0.1	0.1	0.01	0.5
Δ_{max}	Maximum growth increment	2	U	–	–	1	50
l^{g}_{50}	length at 50% maximum growth	2	U	–	–	0.01	150
l^{g}_{95-50}	length between 50% and 95% maximum growth	2	U	–	–	0.01	150
α	parameter that defines the variance of growth increment	2	U	–	–	0.001	5
β	parameter that defines the variance of growth increment		U	–	–	0.001	5
$Ln(q^{I})$	Catchability coefficient of CPUE	1	U	–	–	-30	0
$Ln(q^{J})$	Catchability coefficient of PCPUE	1	U	–	–	-30	0
L_{50}	Length at which maturity is 50%	1	U	–	–	70	145
L_{95-50}	Interval between L50 and L95	1	U	–	–	1	50
T_{50}	Length at which Fighting Bay length frequency selectivity is 50%	2	U	–	–	70	125
T_{95-50}	Difference between T50 and T95	2	U	–	–	0.001	50
D_{50}	Length at which commercial diver selectivity is 50%	2	U	–	–	70	145
D_{95-50}	Difference between D_{50} and D_{95}	2	U	–	–	0.01	50
ε	Vector of annual recruitment deviations from 1977 to 2013	1	N	0	0.4	-2.3	2.3
D_s	Change in commercial diver selectivity for one unit of change of MHS	1	U	–	–	0.01	10

The observational data were:

1. A standardised CPUE series covering 1983–2001 based on FSU/CELR data.
2. A standardised CPUE series covering 2002–2015 based on PCELR data.
3. A length frequency dataset from the Fighting Bay fish-down experiment (FBLF).
4. A commercial catch sampling length frequency series (CSLF).
5. Tag-recapture length increment data.
6. Maturity at length data

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 7, fishing duration appeared to have been predominantly recorded as hours per diver. The standardisation was therefore restricted to records where fishing duration ≤ 10 hours. This subset of data was used for the CELR standardisation using estimated daily catch, and effort as fishing duration.

For the PCELR data the unit of catch was diver catch, with effort as diver duration.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN 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 CELR index shows a decline from the early 1990s to 2001. The standardised PCELR index shows an increase from 2002 to 2008 with an overall slow decline since then (Figure 3).

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua in PAU 7 was also estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1992 and 2005. Concerns about the reliability of these data to estimate relative abundance instigated 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 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. For a summary of the conclusions from the reviews refer to the introductory PAU Plenary chapter.

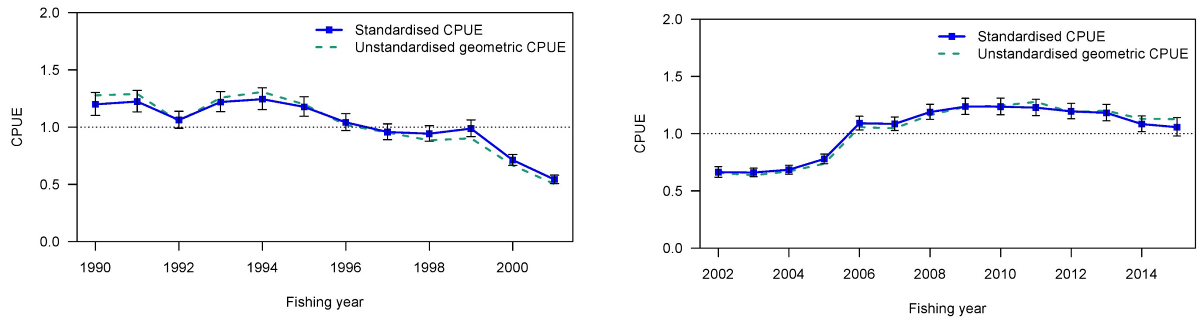


Figure 3: The standardised CPUE indices with 95% confidence intervals for the early CELR series (left) and the recent PCELR series (right).

4.2 Stock assessment methods

The 2015 PAU 7 stock assessment used the length-based model first used in 1999 for PAU 5B (Breen et al 2000) and revised for subsequent assessments in PAU 7 (Breen et al 2001, Breen & Kim 2003, 2005, McKenzie & Smith 2009b, Fu 2012). The model was described in Breen et al (2003). The assessment also addressed a number of recommendations made by the pāua review workshop held in Wellington in March 2015 (Butterworth et al 2015)

The model structure assumes 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 at each time step. Pāua enter the partition following recruitment and are removed by natural mortality and fishing mortality. The assessment addresses only Areas 017 and 038 within PAU 7. These areas have supported over 90% of the catch until recently, and all of the available data originate from these two areas, but the relationship between this subset of PAU 7 and the remainder of PAU 7 is uncertain.

The model simulates the population dynamics from 1965 to 2015. Catches were available for 1974–2015 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 pāua. A relationship may exist on small scales, but not be apparent when large-scale data are modelled (Breen et al 2003). No explicit stock-recruitment relationship was modelled in previous assessments; however, the SFWG 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. The model estimated proportions mature with the inclusion of length-at-maturity data. Growth and natural mortalities were also estimated within the model.
The models used two selectivities: the commercial fishing selectivity and the Fighting Bay catch sample selectivity, both 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 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.

A base case model (1.0) was chosen by the Shellfish Working Group for the assessment: The base case model is configured such that (a) predicted CPUE is calculated after half of the natural and fishing mortality has occurred; (b) Francis (2011) method was used to determine the weight of CSLF and CPUE; (c) growth was estimated using the inverse-logistic model; (d) tag-recapture observations from the Staircase were excluded; (e) tag-recapture observations were weighted by the catch in each area; (f) the CPUE shape parameter was fixed at 1 assuming a linear relationship between CPUE and abundance. The base case used a lognormal prior on M, with μ_M= 0.1 and σ_M= 0.1. The choice of CV was arbitrary, but generally chosen to be very informative to prevent obtaining unrealistic estimates. A sensitivity run (MCMC 1.4) used a prior (μ_M = 0.15 and σ_M = 0.25) developed from posterior estimates of M from assessments of PAU 5A and PAU 5B, based on the recommendation from the pāua review workshop (Butterworth et al 2015).

The SFWG also suggested the following sensitivity runs: using a smaller CV of 0.05 (model 1.1), or a larger CV of 0.12 (1.2); estimating the CPUE shape parameter assuming a uniform prior bounded between 0.5 and 1.5 (1.3), or fixing it at the lower (1.3a) and upper value (1.3b) respectively; using an alternative prior when estimating natural mortality; including tag-recapture observations from the Staircase (1.5). The base case and sensitivities are summarised in Table 6.

Table 6:Summary descriptions of base case and sensitivity model runs.

Model	Description
1.0	base case, Francis (2011) weighting, inverse logistic, excluded Staircase growth, growth data weighted
1.1	1.0, CV for CPUE2 = 0.5
1.2	1.0, CV for CPUE2 = 1.2
1.3	1.0, estimated CPUE shape parameter with a uniform prior [0.5,1.5]
1.3a	1.0, CPUE shape parameter = 0.5
1.3b	1.0, CPUE shape parameter = 1.5
1.4	1.0, M estimated with a prior developed using information from PAU 5A and PAU 5B.
1.5	1.0, included Staircase growth

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,), the mid-season spawning and recruited biomass for 2015 (B_{2015} and B^r_{2015}) 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}
$\Pr(B_{proj} > B_{2015})$	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}
$\Pr(B^r_{proj} > B^r_{msy})$	Probability that projected recruit-sized biomass is greater than B^r_{msy}
$\Pr(B^r_{proj} > B^r_{2015})$	Probability that projected recruit-sized biomass is greater than B^r_{2015}
$\Pr(B_{proj} > 40\%B_0)$	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 $U_{40\%B0}$

Forward projections (2016–2018) were made for the base case with a number of alternative future catch scenarios. Future recruitment deviations were resampled from model estimates either from 2002–2011 (a period with both high and low recruitment), or from 2010–2011 (a period with low recruitment). The total catch used in the projections was 142 717 kg (28% TACC reduction), 131 515 (35% TACC reduction), 123 514 kg (40% shelving), 107 511 kg (50% shelving) and 91 510 kg (60% TACC), and 27 500 kg (100% TACC reduction).

4.2.1 Stock assessment results

Current estimates from the base case suggested that spawning stock population in 2015 ($B_{current}$) was about 18% (16–21%) of the unfished level (B_0), or 69% (16–21%) of B_{msy} (Figure 4, Table 7). Estimated recent recruitment has been below average (recruitment in 2010 and 2011 was the lowest after 2002). The estimated exploitation rate has declined since 2003, and was further reduced after 2012. The exploitation rate in 2015 was estimated to be 0.46 (0.40–0.52).

The model projection made for three years using recruitment re-sampled from a period with both high and low recruitment (2002–2011), suggested that the spawning stock abundance will increase to 22% (16–29%) of B_0 in 2018 if the future catch remains at the current level (corresponding to a 28% TACC shelving), or 24% (18–31%) of B_0 if the future catch is reduced to 50% of the TACC (Figure 5). The projections using recruitment re-sampled from the recent period with low recruitment (2010–2011), suggested that the spawning stock abundance will only increase to 19% (14–25%) of B_0 in 2018 if the future catch remains at the current level, or 21% (16–27%) of B_0 with a 50% TACC reduction (Figure 6). It was extremely unlikely that the stock status will be above the target (40% B_0) in the short term.

The base case model matched very closely with the early CPUE and predicted CPUE indices were all well within the confidence bounds of the observed values. Predicted CPUE declined more than observed values between 2009 and 2013. However, the overall change in relative abundance between 2002 and 2015 is similar between the predicted and observed values. The standardised residuals show no apparent departure from the model's assumption of normality. Commercial catch length frequencies were well fitted for most years. The mean length of CSLF has increased since 2003, and has remained reasonably stable since 2007, except in 2014. The average fish size in the catch in recent years has been well below those in the early 1990s. The standardised residuals of the fits to CSLF revealed that in general the model predicted a slightly narrower distribution than what was observed in the catch. This might be because the fishery has been fished down to a low level and the chance of sampling pāua of large sizes has reduced. Estimated logistic selectivity was very close to knife-edge around the MLS, with a small increase in 2015. Fits to growth increment and maturity data appeared adequate. The relative weight assigned to tag-recapture observations from Perano and Rununder was about three times more than those from Northern Faces, and as a result, estimated mean growth was higher than if equal weights were assumed. The Fighting Bay length frequency fitted well, suggesting this length distribution was consistent with the estimated growth rates in the model.

Table 7: Summary of the marginal posterior distributions from the MCMC chain from the base case (1.0) and sensitivities. The columns show the medians and the 5th and 95th percentiles. Biomass is in tonnes.

	MCMC 1.0	MCMC 1.1	MCMC 1.2	MCMC 1.3	MCMC 1.4
B_0	4291 (3980–4584)	4296 (3963–4600)	4296 (3968–4610)	4322 (4011–4632)	3784 (3185–4359)
B_{msy}	1133 (1056–1209)	1133 (1051–1212)	1137 (1053–1216)	1137 (1060–1216)	1019 (913–1153)
$B_{current}$	780 (689–888)	763 (689–855)	786 (683–919)	804 (701–938)	821 (723–937)
$B_{current}/B_0$	0.18 (0.16–0.21)	0.18 (0.15–0.21)	0.18 (0.16–0.22)	0.19 (0.16–0.22)	0.22 (0.17–0.28)
$B_{current}/B_{msy}$	0.69 (0.59–0.81)	0.68 (0.58–0.79)	0.69 (0.59–0.83)	0.71 (0.6–0.85)	0.81 (0.65–0.98)
B_{msy}/B_0	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.27 (0.26–0.29)
rB_0	3532 (3185–3842)	3543 (3184–3876)	3538 (3179–3872)	3544 (3210–3876)	3019 (2395–3605)
rB_{msy}	544 (438–638)	546 (443–648)	547 (439–649)	539 (442–643)	414 (279–571)
$rBcurrent$	300 (260–349)	297 (265–336)	302 (251–364)	314 (265–382)	306 (266–351)
$rB_{current}/rB_0$	0.09 (0.07–0.1)	0.08 (0.07–0.1)	0.09 (0.07–0.11)	0.09 (0.07–0.11)	0.1 (0.08–0.13)
$rB_{current}/rB_{msy}$	0.55 (0.43–0.74)	0.55 (0.43–0.71)	0.55 (0.42–0.76)	0.59 (0.44–0.79)	0.74 (0.51–1.15)
rB_{msy}/rB_0	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.14 (0.11–0.16)
MSY	207 (202–214)	207 (201–213)	208 (202–215)	207 (201–214)	217 (206–234)
U_{msy}	0.37 (0.31–0.47)	0.37 (0.3–0.46)	0.37 (0.31–0.47)	0.37 (0.31–0.47)	0.51 (0.35–0.79)
$U_{\%40B0}$	0.19 (0.16–0.23)	0.18 (0.16–0.22)	0.19 (0.16–0.23)	0.19 (0.16–0.22)	0.25 (0.18–0.4)
$U_{current}$	0.46 (0.4–0.52)	0.46 (0.41–0.5)	0.46 (0.38–0.54)	0.44 (0.36–0.51)	0.46 (0.41–0.52)

Table 8: Summary of key indicators for projected biomass in 2018 from the projection for the base case MCMC with 28%, 35%, 40%, 50%, 60%, and 100% TACC reduction. The columns show the medians and the 5th and 95th percentiles. Biomass is in tonnes.

	28% reduction	35% reduction	40% reduction	50% reduction	60% reduction	100% reduction
B_{2018}	943 (711–1227)	971 (739–1255)	990 (759–1274)	1030 (799–1314)	1068 (8381353)	1225 (996–1508)
B_{2018}/B_0	0.22 (0.16–0.29)	0.23 (0.17–0.30)	0.23 (0.17–0.30)	0.24 (0.18–0.31)	0.25 (0.19–0.32)	0.29 (0.23–0.36)
B_{2018}/B_{msy}	0.83 (0.61–1.11)	0.86 (0.64–1.13)	0.88 (0.65–1.15)	0.91 (0.69–1.18)	0.95 (0.72–1.22)	1.08 (0.86–1.36)
Pr (B_{2018}>Bmsy)	0.10	0.14	0.17	0.24	0.3268	0.7546
Pr (B_{2018}>B_{2015})	0.94	0.97	0.98	0.99	0.9972	1
Pr (B_{2018}>40%B0)	0.00	0.00	0.00	0.00	0.0002	0.003
Pr (B_{2018}<20%B0)	0.26	0.19	0.15	0.09	0.05	0.0026
Pr (B_{2018}<10%B0)	0.00	0.00	0.00	0.00	0	0

Changes in stock size in response to fishing pressure over time are shown in Figure 7. This was done by plotting the annual spawning biomass and exploitation rate as a ratio of a reference value from 1965 to 2015. 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, the value on the y axis is the corresponding exploitation rate as a ratio of $U_{40\%B0}$ for that year. The trajectory started in 1965 when the SSB is close to B_0 and the exploitation rate is close to 0. The model indicated an early phase of the fishery where the exploitation rates were below $U_{40\%B0}$ and the SSBs were above 40% B_0 and a development phase where the exploitation rates increased and the SSBs decreased in relation to the target. The current exploitation rate is about twice of $U_{40\%B0}$ and the current spawning stock biomass is just below 20% B_0.

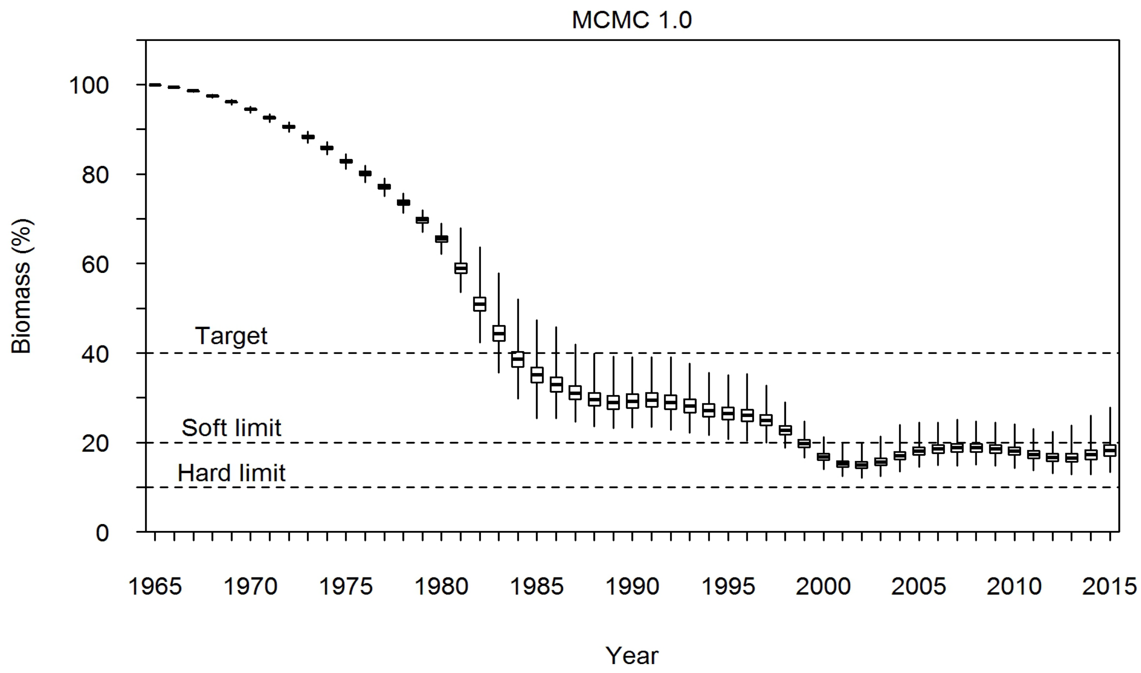


Figure 4: Posterior distribution of spawning stock biomass as a percentage of virgin level from MCMC 1.0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

4.3 Other factors

The stock assessment model assumed homogeneity in recruitment, and that natural mortality does not vary by size or year, and that growth has the same mean and variance throughout the entire area. However, it is known that pāua fisheries are spatially variable and that apparent growth and maturity in pāua populations can vary over very short distances. Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on tagging data collected from a range of different locations. Similarly, the length frequency data are integrated across samples from many places. The effect of this integration across local areas is likely to make model results optimistic.

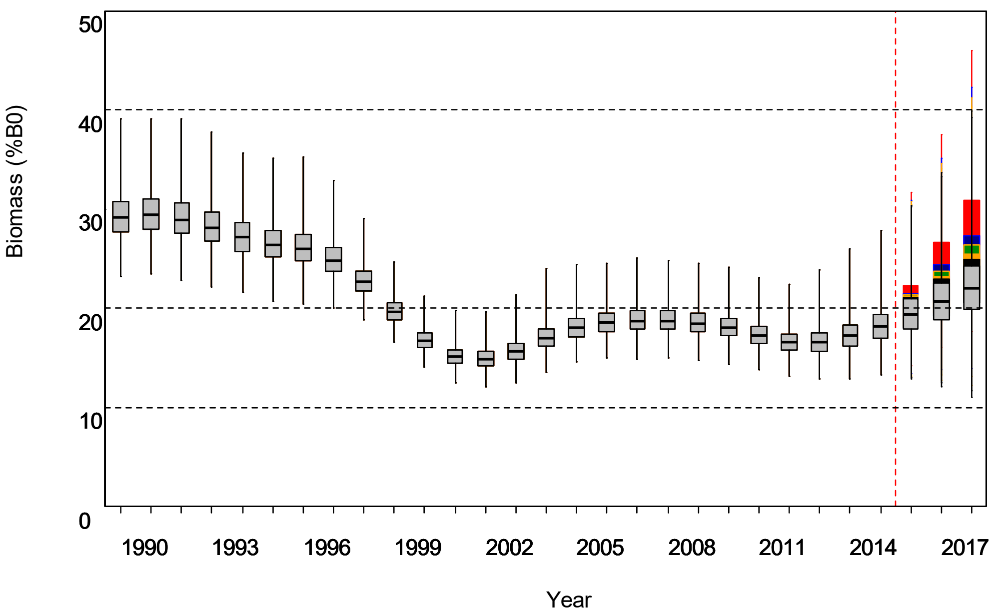


Figure 5: Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2002–2011 under six catch scenarios: 28% TACC reduction (gray), 35% TACC reduction (black), 40% TACC reduction (orange), 50% TACC reduction (green), 60% TACC reduction (blue), and 100% TACC reduction shelving (red). 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.

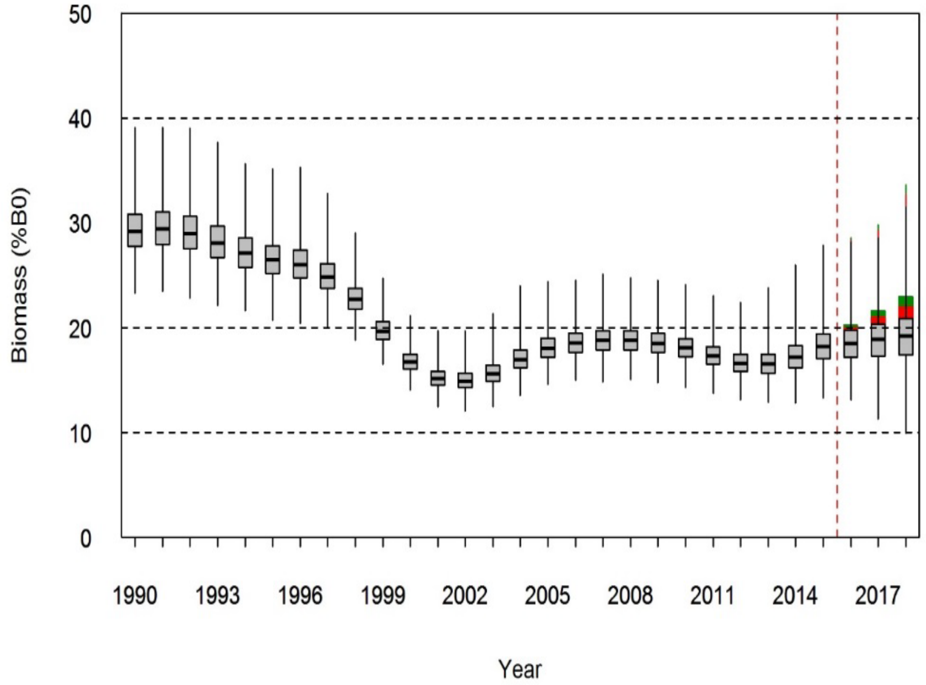


Figure 6: Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2010–2011 under three catch scenarios: 28% TACC reduction (gray), 40% TACC reduction (red), 50% TACC reduction (green), 60%. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

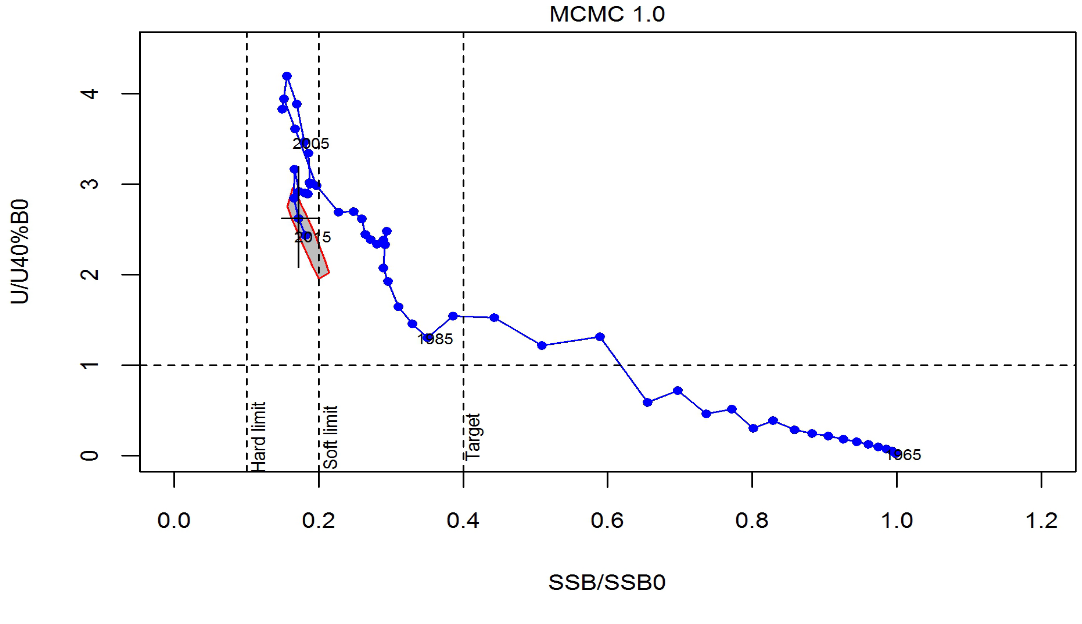


Figure 7: Trajectory of exploitation rate as a ratio of *$U_{\%40B0}$* and spawning stock biomass as a ratio of *B_0*, from the start of assessment period 1965 to 2015 for MCMC 1.0 (base case). The vertical lines at 10%, 20% and 40% *B_0* represent the soft limit, the hard limit, and the target. Estimates are based on MCMC median and the 2015 90% marginal CI is shown by the cross line, and joint CI is shown by the grey area.

For instance, if some local stocks are fished very hard and others not fished, local recruitment failure can result due to the limited dispersal range of this species. Recruitment failure is a common observation in overseas abalone fisheries. Fishing may also cause spatial contraction of populations (e.g., Shepherd & Partington 1995), and some populations appear to become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the assessment will overestimate productivity in the population as a whole. It is also possible that good recruitments estimated by the model might have been the result of serial depletion.

CPUE provides information on changes in relative abundance. However, CPUE is generally considered to be a poor index of stock abundance for pāua, due to divers' ability to maintain catch rates by moving from area to area despite a decreasing biomass (hyperstability). Breen & Kim (2003) argued that standardised CPUE might be able to relate to the changes of abundance in a fully exploited fishery such as PAU 7, and a large decline in the CPUE is most likely to reflect a decline in the fishery. Analysis of CPUE currently relies on Pāua Catch Effort Landing Return (PCELR) forms, which record daily fishing time and catch per diver on a relatively large spatial scale. These data will likely remain the basis for stock assessments and formal management in the medium term.

Since October 2010, a dive-logger data collection program has been initiated to achieve fine-scale monitoring of pāua fisheries (Neubauer et al 2014, Neubauer & Abraham 2014). The use of the data loggers by pāua divers and ACE holders has been steadily increasing over the last three years. Using fishing data logged at fine spatial and temporal scales can substantially improve effort calculations and the resulting CPUE indices and allow complex metrics such as spatial CPUE to be developed (Neubauer & Abraham 2014). Data from the loggers have been analysed to provide comprehensive descriptions of the spatial extent of the fisheries and insight on relationships between diver behavior, CPUE, and changes in abundance on various spatial and temporal scale (Neubauer et al 2014, Neubauer & Abraham 2014, Neubauer 2015). However the data-loggers can potentially change how the divers operate such that they may become more effective in their fishing operations (the divers become capable of avoiding areas that have been heavily fished or that have relatively low CPUE without them having to go there to discover this), therefore changing the meaning of diver CPUE (Butterworth 2015).

Commercial catch length frequencies provide information on changes in population structure under fishing pressure. However, if serial depletion has occurred and fishers have moved from area to area, samples from the commercial catch may not correctly represent the population of the entire stock. For PAU 7, there has been a long time-series of commercial catch sampling and the spatial coverage of the available samples is generally considered to be adequate throughout the years.

4.4 Future research needs

- Increased tagging to obtain better fine scale growth information.
- Consider including more of the east coast in the assessment, noting that this would need to be considered as a separate fishery due to differences in size limits.
- Examine the possibility of spatial patterns in length and growth.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

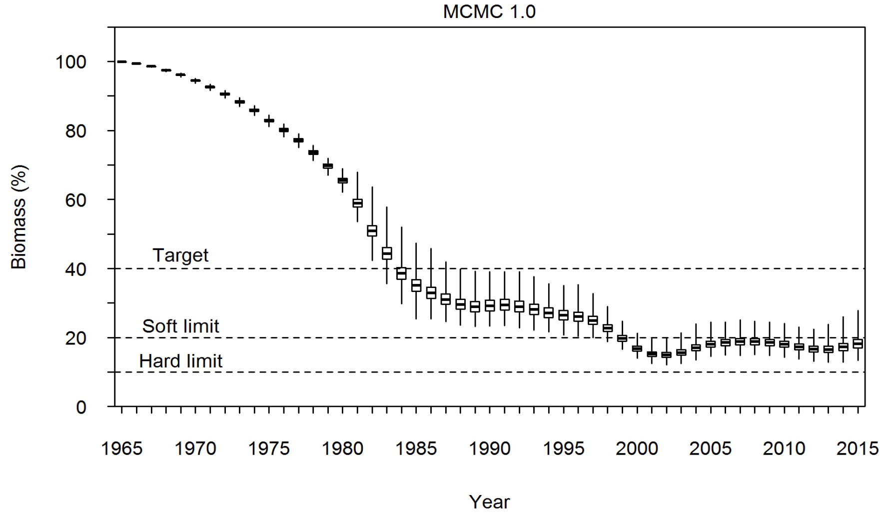
The 2015 assessment was conducted for Statistical Areas 017 and 038 only, but these include most (more than 90%) of the recent catch.

- **PAU 7**- *Haliotis iris*

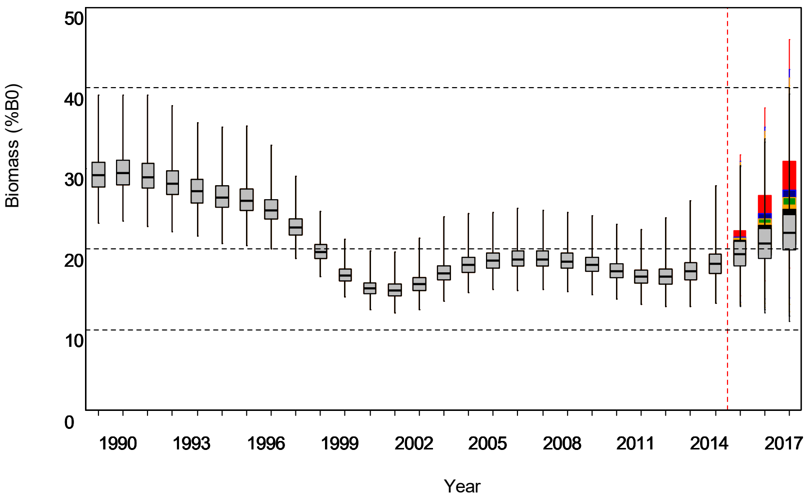
Stock Status	
Year of Most Recent Assessment	2015
Assessment Runs Presented	Base case MCMC
Reference Points	Interim Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Spawning stock biomass was estimated to be 18% B_0 and is Very Unlikely (< 10%) to be at or above the target

Status in relation to Limits	Spawning stock biomass was estimated to be 18% B_0, and is About as Likely as Not (40–60%) to be below the soft limit and Unlikely (< 40%) to be below the hard limit
Status in relation to Overfishing	In 2014–15 the fishing intensity was Very Likely (> 90%) to be above the overfishing threshold

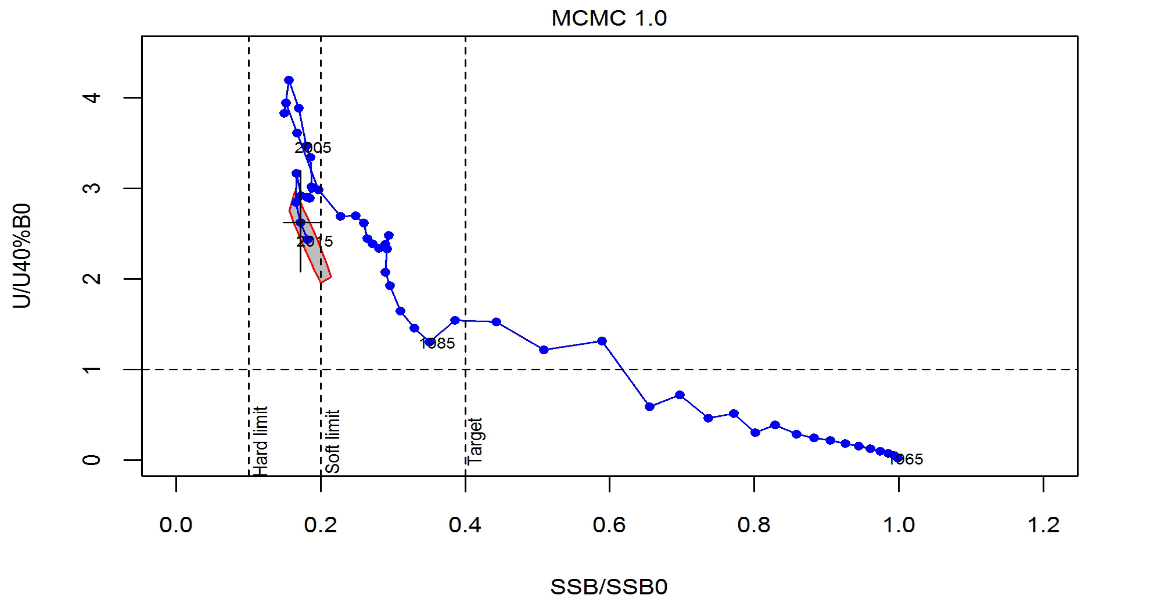
Historical Stock Status Trajectory and Current Status



Posterior distribution of spawning stock biomass as a percentage of virgin level from MCMC 1.0. 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.



Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2002–2011 under six catch scenarios: 28% TACC reduction (gray), 35% TACC reduction (black), 40% TACC reduction (orange), 50% TACC reduction (green), 60% TACC reduction (blue), and 100% TACC reduction shelving (red). 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 of $U_{\%40B0}$ and spawning stock biomass as a ratio of B_0, from the start of assessment period 1965 to 2015 for MCMC 1.0 (base case). The vertical lines at 10%, 20% and 40% B_0 represent the soft limit, the hard limit, and the target. Estimates are based on MCMC median and the 2015 90% marginal CI is shown by the cross line, and joint CI is shown by the grey area.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass reached its lowest point in 2002–03. It has since fluctuated at or just below the soft limit.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity peaked in 2003 but has subsequently declined.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-
Projections and Prognosis	
Stock Projections or Prognosis	Three year projections indicate that spawning biomass will increase slightly, to varying degrees, under different levels of catch when future recruitment is resampled from 2002–2011 but it is Very Unlikely (< 10%) to be at or above the target by this time.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: About as Likely as Not (40–60%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Very Likely (> 90%)

Assessment Methodology & Evaluation		
Assessment Type	Full quantitative stock assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2022
Overall assessment quality rank	1 – High Quality	

Qualifying Comments
-

Fishery Interactions
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6. FOR FURTHER INFORMATION

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