PAUA (PAU 5A) – Fiordland
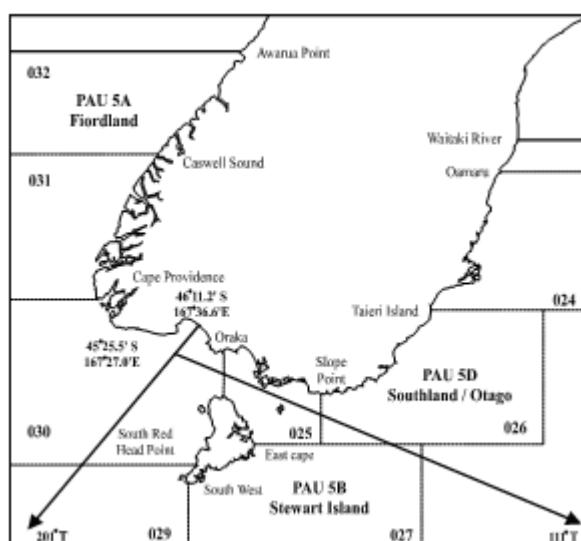
(Haliotis iris)
Paua

1. FISHERY SUMMARY

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

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

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

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

*PAU 5 TACC figures

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September.

On 1 October 2001 it became mandatory to report catch and effort on Paua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Paua Management Company for their voluntary logbook programme (Figure 1).
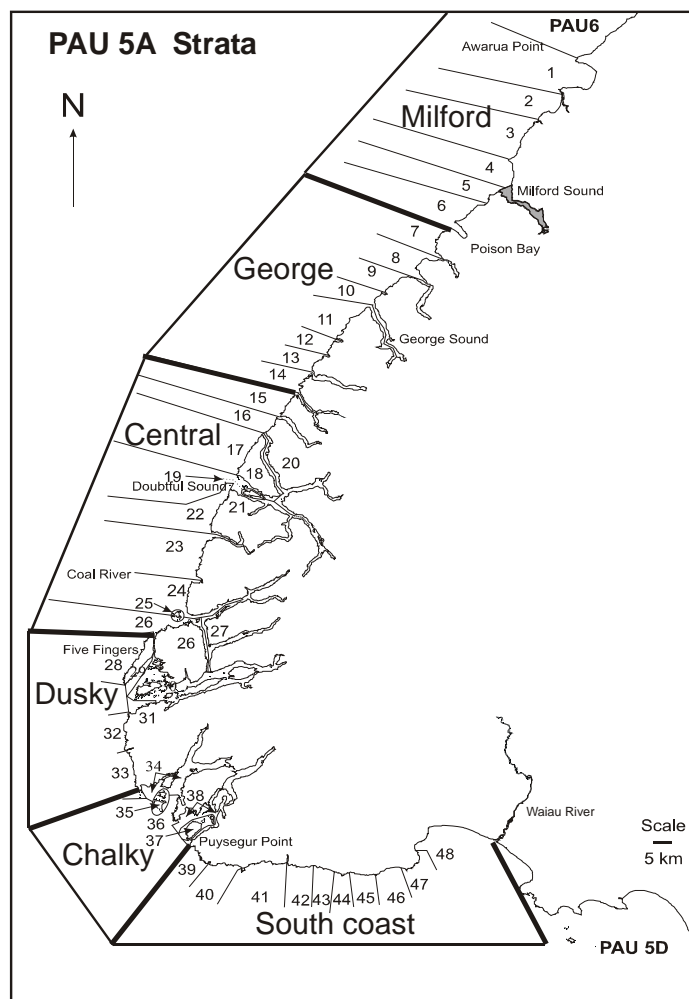
Figure 1: Map of paua statistical areas, and voluntary management strata in PAU 5A.

Landings for PAU 5A are shown in Table 2 and Figure 2. Landings for PAU 5 are reported in the introductory PAU Working Group Report.

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

Year	Landings	TACC
1995–96	139.53	148.98
1996–97	141.91	148.98
1997–98	145.22	148.98
1998–99	147.36	148.98
1999–00	143.91	148.98
2000–01	147.70	148.98
2001–02	148.53	148.98
2002–03	148.76	148.98
2003–04	148.98	148.98
2004–05	148.95	148.98
2005–06	148.92	148.98
2006–07	104.03	148.98
2007–08	105.13	148.98
2008–09	104.82	148.98
2009–10	105.74	148.98
2010–11	104.40	148.98
2011–12	106.23	148.98
2012–13	105.56	148.98
2013–14	102.30	148.98
2014–15	106.95	148.98
2015–16	106.84	148.98

1.2   Recreational fisheries

The National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates (2014), estimated about 0.42t of paua were harvested by recreational fishers in PAU 5A in 2011–12. For the purpose of the 2014 stock assessment, 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 2013.
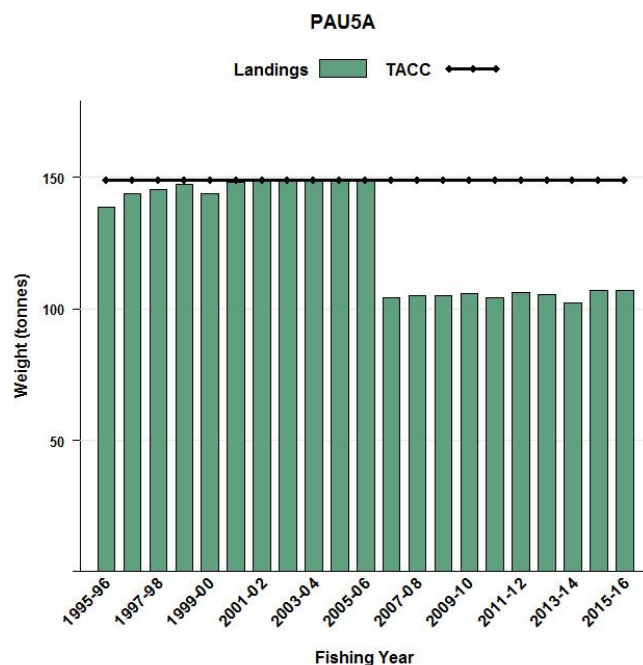

Figure 2: Landings and TACC for PAU 5A from 1995–96 to the present. For historical landings in PAU 5 prior to 1995–96, refer to Figure 1 and Table 1 in the introductory PAU Working Group Report.

1.3   Customary fisheries

Records of customary non-commercial catch taken under the South Island Regulations show that about 100 to 500 paua were collected each year from 2001–02 to 2012–13. For the purpose of the 2014 stock assessment model, the SFWG agreed to assume that customary catch has been constant at 1t.

1.4   Illegal catch

There are no estimates of illegal catch for PAU 5A. For the purpose of the 2014 stock assessment model, the SFWG agreed to assume that illegal catches have been a constant 5 t.

1.5   Other sources of mortality

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

2.   BIOLOGY

For further information on paua biology refer to the introductory PAU Working Group Report. Biological parameters derived using data collected from PAU 5A are summarised in Table 3. Size-at-maturity, natural mortality and annual growth increment parameters were estimated within the assessment model.

Table 3:   Estimates of biological parameters (*H. iris*). All estimates are external to the model.

Stock area	Estimate		Source
1. Weight = a (length)[b] (weight in kg, shell length in mm)			
PAU 5A	a = 2.99E-08	b = 3.303	Schiel & Breen (1991)
2. Size at maturity (shell length)			
PAU 5A	50% mature	93 mm	Samples from Dusky, George, and Milford
	95% mature	109 mm	areas (Fu et al 2010)
3. Estimated annual growth increments (both sexes combined)			Samples from Central, Dusky, George, Chalky and the South Coast (Fu et al 2010)
PAU 5A	At 75 mm	25.2 mm	
	At 120 mm	6.9 mm	

3.   STOCKS AND AREAS

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

4.   STOCK ASSESSMENT

Prior to 2010, stock assessments for PAU 5A had been carried out at the QMA level. In 2010 the Shellfish Working Group decided to split PAU 5A into two subareas (the southern area which included the Chalky and South Coast strata, and the northern area which included the Milford, George, Central, and Dusky strata (Figure 1)) and conduct separate stock assessments in each subarea. The division was based on the availability of data, differences in exploitation history and management initiatives. The 2014 assessment followed the same decision.

4.1   Estimates of fishery parameters and abundance

Parameters estimated in the base case model (for both the southern and northern areas) and their assumed Bayesian priors are 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	0.35	0.01	0.5
g_{max} (maximum growth increment)	U	–	–	1	50
$g_{50\%}$ (length at which the annual increment is half the maximum)	U	–	–	1	150
$g_{50-95\%}$ (difference in length at 50% and 95% of the maximum increment)	U	–	–	0.01	150
φ (CV of mean growth)	U	–	–	0.001	1
Ln(q^I) (catchability coefficient of CPUE)	U	–	–	-30	0
Ln(q^I) (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 for the commercial catch)	U	–	–	0.01	50
D_s(change in commercial diver selectivity for one unit change of MHS)	U	–	–	0.01	50

For both assessments, the following observational data were included:

1. Standardised CPUE series covering 1990–2001 based on CELR data.
   Standardised CPUE series covering 2002–2014 based on PCELR data.
2. Commercial catch sampling length frequency series for 1992–1994, 1998, 2001–2014
3. Tag-recapture length increment data (all areas combined).
4. Maturity at length data (all areas combined)

4.1.1   Relative abundance estimates from standardised CPUE analyses

The 2014 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2014. 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 identification. This process was followed 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 there is ambiguity in what is recorded for estimated daily fishing duration. On many CELR forms it is unclear if the hours of diving recorded is the total time each individual diver spent harvesting, or the total time spent harvesting by all divers. Because of this daily fishing duration 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 a new data set was generated for which the recorded fishing duration was less ambiguous. This was done by combining a subset of the data for which the recorded daily duration was predominantly total hours of diving *for all* divers, with the rest of the data in which the daily fishing duration was incorrectly recorded as hours *per diver* (and scaling the hours recorded by the number of divers to get the correct daily fishing duration *for all* divers). The criteria used to subset the data were: (i) just one diver or (ii) fishing duration >= 8 hours and number of divers >= 2. The new combined data set was used for the CELR standardisation using estimated daily catch, and effort as either number of divers or estimated fishing duration (both were offered to the standardisation model).

For the PCELR data 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 to qualify for the core fisher group that there be a minimum of 5 records per year for a minimum of 2 years (northern area), or a minimum of 5 records per year for a minimum of three years (southern area). In both cases 80% of the catch was retained 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 10 records per year for a minimum of 6 years (northern area), or a minimum of 10 records per year for a minimum of 4 years (southern area). This retained 83% (northern area) or 85% (southern area) of the catch over 2002–2014.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN, statistical area month, fishing duration (as a cubic polynomial), number of divers, and a month:area interaction. 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 northern area standardised CPUE shows fluctuation with no real trend from 1990 to 2001, and is flat from 2002 to 2014 (Figure 3-top). The southern area standardised CPUE shows a decline from 1990 to 2008, then an increase from 2009 to 2014 (Figure 3-bottom).

(a)

(b)

(c)

(d)
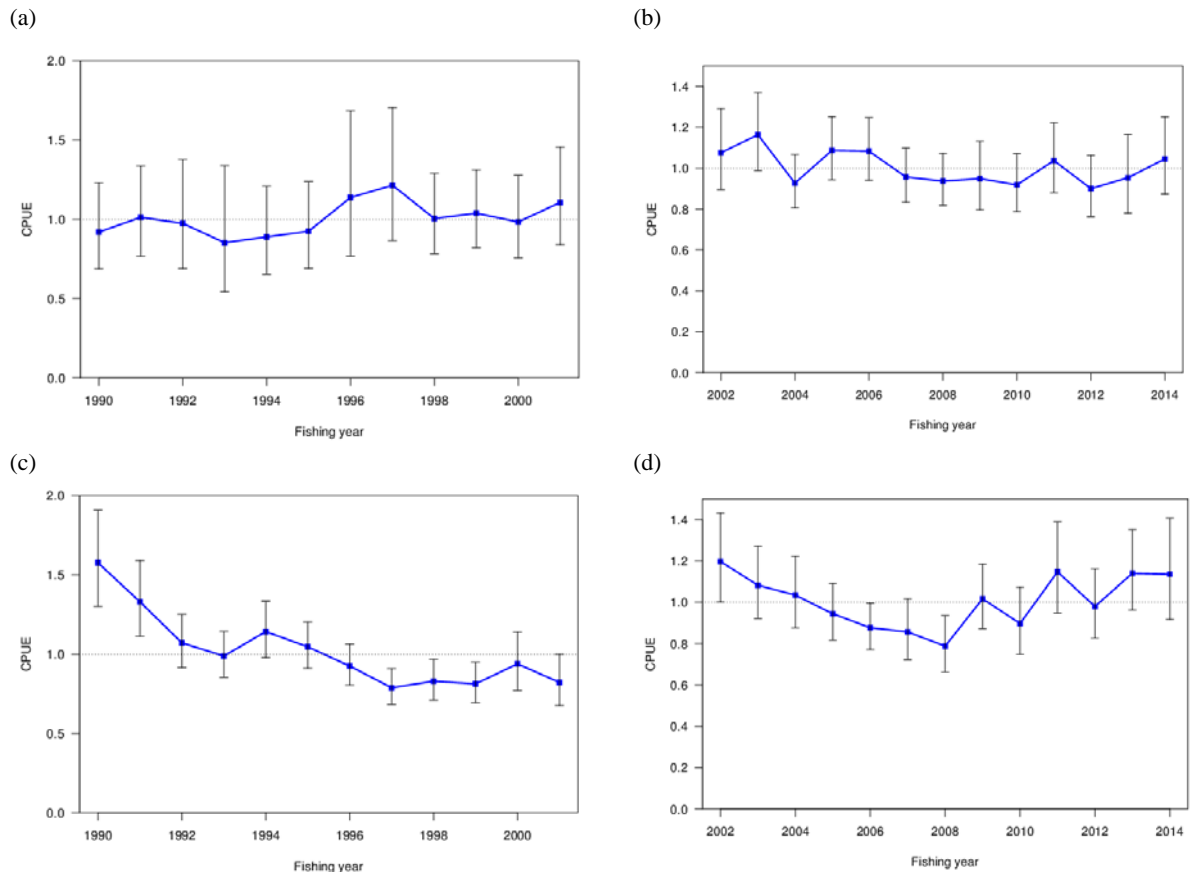
Figure 3:   Standardised CPUE indices for the northern area of PAU 5A based on the CELR 1990–2001 (a) and PCELR 2002–2014 (b) and for the southern area based on CELR 1990–2001 (c) and PCELR 2002–2014 (d).

4.1.2   Relative abundance estimates from research diver surveys

The abundance of paua in PAU 5A was also estimated from research diver surveys in 1996, 2002, 2003, 2006, and 2008−2010. Not every stratum was surveyed in each year, and before 2005–06 surveys were conducted only in the area from Dusky South. These data were not included in the assessment because there is concern that the data are not a reliable index of abundance

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

4.2   Stock assessment methods

The 2014 assessment for the southern and northern areas of PAU 5A (Fu 2015a, b) incorporated revision of the length-based model used in 2010 for PAU 5A (Fu & McKenzie 2010a, 2010b) and used in revised form for subsequent assessment in PAU 5D (Fu 2013) and PAU 5B (Fu 2014) For more information on the model structure and the data used refer to Fu et al. (2015) and Fu (2015a, b).

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 to change at each time step. Paua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2014. Catches were available for 1974–2014 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. It was assumed that 80% of the non-commercial catch was taken from the southern area of PAU 5A, with the remainder being taken from the northern area

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 to reach an asymptote. The increase in Minimum Harvest Size between since 2006 was modelled as an annual shift in fishing selectivity, which is equal to an annualised unit increase (estimated within the model), multiplied by the number of units associated with each year.

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). 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 to obtain a set of agreed indicators. Sensitivity trials were explored by comparing MPD fits made with alternative model assumptions.

For the Southern area the commercial catch history estimates were made under assumptions about the split of the catch between sub-stocks of PAU 5, and between subareas within PAU 5A. The base case model run has assumed 40% of the catch in Statistical Area 030 was taken from PAU 5A between 1985 and 1996. Estimates made under alternative assumptions (a lower bound of 18% and an upper bound of 61%) were used in sensitivity trials. The maturity and growth data included in the model were based on samples collected throughout PAU 5A, and the abundance and length frequency data were from Chalky and South Coast. Catch samples before 2002 (1992–1994, 1998, and 2001) were excluded from the base case, because the sample size is low and sampling coverage is dubious. The base case also used the methods recommended by Francis (2012) to determine the weight of the proportion-at-length and abundance data, and used the inverse-logistic growth model. The RDSI and RDLF were excluded from the base case, and the CPUE shape parameter was fixed at 1 assuming a linear

relationship between CPUE and abundance. Recruitment deviations were estimated for 1986–2010.

For the Northern area the commercial catch history estimates between 1984 and 2010 were based on reported catch from Statistical Area 031 and 032, and estimates before 1984 were made using assumptions about the split of the catch between subareas within PAU 5A. The split proportions were inferred from the total estimated catch between 1984 and 1995 from Statistical Areas 030, 031, and 032, assuming that 18% (upper bound), 40% (base case), or 61% (lower bound) of the annual catch in 030 was taken from PAU 5A. The catch vector estimated under the base case assumption was used in the base case model. The maturity and growth data included in the model were based on samples collected throughout PAU 5A, and the abundance and length frequency data were from Milford, George, Central, and Dusky. Catch samples collected before 2002 (1992, 1993, 1998, 2000, and 2001) were excluded from the base case. The base case also used the methods recommended by Francis (2012) to determine the weight of the proportion-at-length and abundance data, and used the inverse-logistic growth model. The RDSI and RDLF were excluded from the base case and the CPUE shape parameter was fixed at 1. Recruitment deviations were estimated for 1986–2010.

The following sensitivities were conducted for both the Southern and Northern areas. Run 1.6 used the SDNRs-based method to determine the weights of the proportion-at-length and abundance data; Run 1.7 included all the commercial length frequencies; Run 2.0 included the RDSI and RDLF data. For the Southern area, two additional sensitivities were conducted: Run 1.8 used commercial catch history that was estimated under "assumption 1" (between 1984 and 1996, 18% of the catch in Statistical Area 030 was taken from PAU 5A); Run 1.9 used commercial catch history estimated under "assumption 3" (between 1984 and 1996, 61% of the catch in Statistical Area 030 was taken from PAU 5A); For both assessments, The MCMC runs were carried out on models 1.5 (base case), 1.6, and 1.7.

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 2014 (B_{2014} and B_{2014}^r) and for the projection period (B_{proj} and B_{proj}^r). 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}
- $\Pr(B_{proj} > B_{2014})$ Probability that projected spawning biomass is greater than $B_{current}$
- $B\%B_0^r$ Current or projected recruited biomass as a percentage of B_0^r
- $B\%B_{msy}^r$ Current or projected recruited biomass as a percentage of B_{msy}^r
- Ucurrent   Current Exploitation
- $U_{40\%B0}$ Exploitation that will achieve 40%B0
- MSY   Maximum Sustainable Yield
- $\Pr(B_{proj} > B_{msy}^r)$ Probability that projected recruit-sized biomass is greater than B_{msy}^r
- $\Pr(B_{proj} > B_{2012}^r)$ Probability that projected recruit-sized biomass is greater than B_{2012}^r
- $\Pr(B_{proj} > 40\%B_0)$ 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 $U_{40\% B0}$

4.2.1   Stock assessment results

Southern Area

The base case fitted the two CPUE indices and the CSLF well, but the model predicted a broader distribution than the observed LF for a number of years. The use of the inverse-logistic growth model produced an adequate fit to the tag-recpature data. The estimates of recruitment deviations showed a period of relatively high recruitment in the mid-1990s and also in the 2000s. Estimated exploitation rates have declined since 2002, but have increased slightly over the last few years

The summaries of indicators from the base case are shown in Table 5. The median of the posterior of B_0 was estimated to be 1381 t. The posterior trajectory of spawning stock biomass is shown in Figure 4. Current estimates from the base case suggested that the spawning stock population in 2014 ($B_{current}$) was 41% (33–50%) B_0, and recruit-sized stock abundance ($B_{cureent}^{r}$) was 32% (24–41%) of the initial state (B_0^{r}).

When the CSLF data were up-weighted (MCMC 1.6), $B_{current}$ was estimated to be 35% (30–41%) of B_0. This model fitted less adequately to the tag-recapture data, with some negative bias for the larger size classes. Model results from the MCMC 1.7 were very similar to the base case and $B_{current}$ was estimated to be 42% (33–52%) B_0.

The assessment results were sensitive to the alternative catch history estimates. MPD estimates of $B_{current}$ were 34% and 46% B_0 when the upper and lower bound catch estimates were assumed, respectively.

Table 5: Summaries of the marginal posterior distributions of indicators for the base case of the southern area assessment. Columns show the 5th and 95th quantiles, median, minimum and maximum of each distribution. Biomass is in tonnes.

	Min	5%	Median	95%	Max
B_0	1135	1264	1381	1522	1765
B_{msy}	310	341	373	411	482
$B_{current}$	311	433	561	745	1153
$B_{current} / B_0$	0.25	0.33	0.41	0.50	0.68
$B_{current} / B_{msy}$	0.89	1.22	1.51	1.87	2.57
B_{msy} / B_0	0.26	0.26	0.27	0.28	0.28
B_0^{r}	975	1108	1228	1366	1559
B_{msy}^{r}	142	176	211	250	298
$B_{current}^{r}$	190	283	385	531	839
$B_{current}^{r} / B_0^{r}$	0.17	0.24	0.32	0.41	0.57

Table 5 [continued]

$B_{current}^r / B_{msy}^r$	0.87	1.34	1.83	2.53	3.95
B_{msy}^r / B_0^r	0.13	0.15	0.17	0.19	0.21
MSY	47	52	57	65	86
U_{msy}	0.15	0.19	0.23	0.30	0.40
$U_{40\% B_0}$	0.09	0.11	0.13	0.16	0.20
$U_{current}$	0.05	0.08	0.11	0.15	0.21
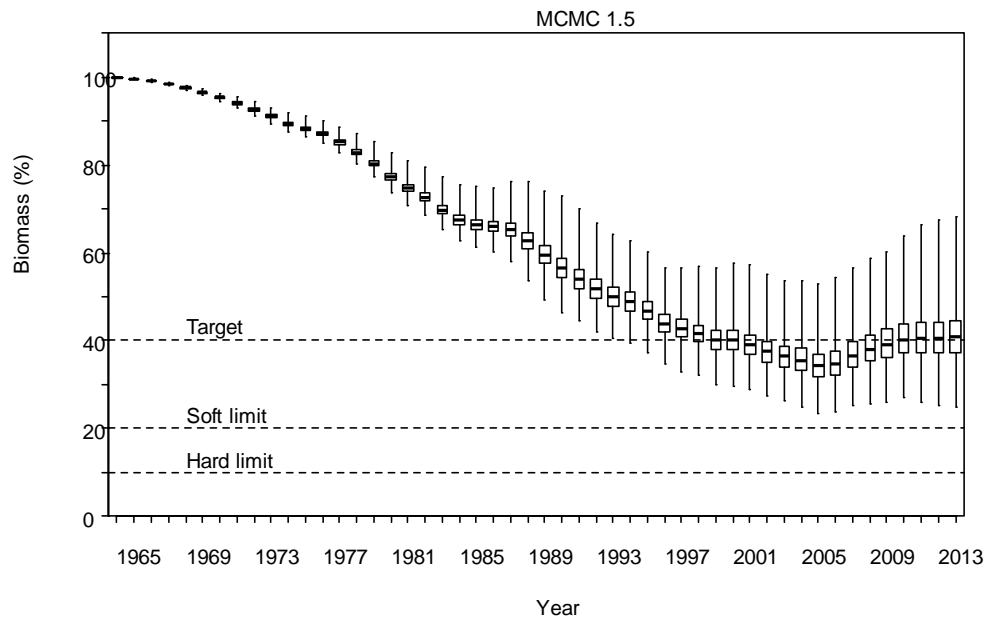
Figure 4: Posterior distributions of spawning stock biomass (including projection) as a percentage of B_0 for the southern area assessment base case model. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.
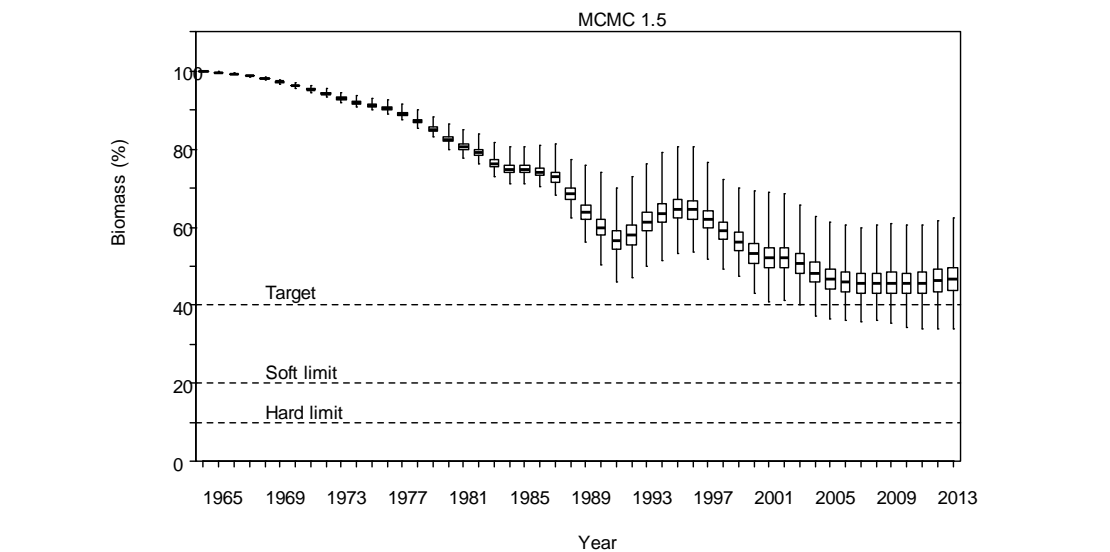
Northern area

The base case fitted the two CPUE indices well, but predicted more large paua in the length distributions than the observed LF for a number of years. The estimates of recruitment deviations showed a period of relatively high recruitment in the early 1990s and the early 2000s, but in most years, the recruitment was close to the long-term average. Estimated exploitation rates have declined since 2005.

The summaries of indicators from the base case for the northern area assessment are shown in Table 6. The median of the posterior of B_0 was estimated to be 1239 t. The posterior trajectory of spawning stock biomass is shown in Figure 5. Current estimates from the base case suggest that the spawning stock population in 2014 ($B_{current}$) was 47% (40–54%) B_0, and recruit-sized stock abundance ($B_{cureent}^r$) was 37% (31–45%) of the initial state (B_0^r).

When the CSLF data were up-weighted (MCMC 1.6), $B_{current}$ was estimated to be 39% (34–45%) B_0. Model results from MCMC 1.7 were very similar to the base case, and $B_{current}$ was estimated to be 47% (39–55%) B_0.

Table 6: Summaries of the marginal posterior distributions of indicators for the base case of the northern area assessment. Columns show the 5th and 95th quantiles, median, minimum and maximum of each distribution. Biomass is in tonnes.

	Min	5%	Median	95%	Max
B_0	1058	1144	1239	1359	1565
B_{msy}	286	307	332	363	413
$B_{current}$	383	472	576	717	958
$B_{current}/B_0$	0.34	0.40	0.47	0.54	0.62
$B_{current}/B_{msy}$	1.27	1.49	1.74	2.03	2.35
B_{msy}/B_0	0.26	0.26	0.27	0.27	0.27
B_0^r	844	935	1026	1132	1276
B_{msy}^r	104	130	158	187	219
$B_{current}^r$	246	300	380	489	669
$B_{current}^r/B_0^r$	0.25	0.31	0.37	0.45	0.54
$B_{current}^r/B_{msy}^r$	1.43	1.87	2.42	3.21	4.57
B_{msy}^r/B_0^r	0.11	0.14	0.15	0.17	0.19
MSY	62	66	73	83	101
U_{msy}	0.25	0.32	0.39	0.50	0.66
$U_{40\% B_0}$	0.14	0.17	0.21	0.25	0.31
$U_{current}$	0.09	0.12	0.16	0.20	0.24

Figure 5: Posterior distributions of spawning stock biomass as a percentage of B_0 for the northern area assessment base case model. 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   Yield estimates and projections

Southern Area

Assuming that the future catch remains at its current level, projections suggested that the spawning stock abundance will increase to 48% (0.38–0.61) over the next three years, and the probability of the spawning biomass being above the target (40%) will increase from 55% in 2014 to 67% in 2017 (Table 7). Assuming a 10% increase in the catch, the biomass will only increase slightly over the next three years; assuming a 20% increase in catch; the projected biomass will remain relatively stable.

Table 7: Summary of key indicators from the projection for the base case (1.5) MCMC of the southern area assessment with future commercial catch assumed to be the same the current catch: projected biomass as a percentage of the virgin and current stock status, for spawning stock and recruit-sized biomass.

	2014	2015	2016	2017
$B_{proj}\%B_0$	0.41 (0.32–0.53)	0.41 (0.32–0.54)	0.42 (0.32–0.55)	0.43 (0.32–0.56)
$B_{proj}\%B_{msy}$	1.51 (1.17–1.95)	1.53 (1.18–1.98)	1.56 (1.19–2.03)	1.58 (1.19–2.07)
$Pr(>B_{msy})$	1.00	1.00	1.00	1.00
$Pr(>B_{current})$	0.00	0.84	0.81	0.81
$Pr(>40\%B_0)$	0.55	0.60	0.64	0.67
$Pr(<20\%B_0)$	0.00	0.00	0.00	0.00
$Pr(<10\%B_0)$	0.00	0.00	0.00	0.00
$\%B_0^r$	0.32(0.23–0.43)	0.32 (0.23–0.44)	0.33 (0.24–0.44)	0.33 (0.24–0.45)
$\%B_{msy}^r$	1.83 (1.27–2.70)	1.86 (1.27–2.77)	1.89 (1.28–2.82)	1.92 (1.30–2.85)
$Pr(>B_{msy}^r)$	1.00	1.00	1.00	1.00
$Pr(>B_{current}^r)$	0.00	0.72	0.80	0.90
$Pr(U_{proj}>U_{40\%B0})$	0.14	0.08	0.04	0.02

Northern area

Assuming that the future catch remains at current level the projection suggested that the spawning stock abundance will remain relatively stable over the next three years, and the projected biomass in 2017 was 47% B_0 (Table 8). The probability of the spawning biomass in 2017 being above the target (40% B_0) was greater than 90%, and the stock status is very unlikely to be below the soft (20% B_0) or hard limit (10% B0) in the short term. Assuming a 10% increase in the annual catch, the projected biomass will decrease slightly over the next three years, and the projected biomass in 2017 was 46% B_0. Assuming a 20% increase in annual catch, the projected biomass decreased to 44% in 2017.

Table 8: Summary of key indicators from the projection for the base case (1.5) MCMC of the northern area assessment with future commercial catch assumed to be the same the current catch: projected biomass as a percentage of the virgin and current stock status, for spawning stock and recruit-sized biomass.

	2014	2015	2016	2017
$B_{proj} \% B_0$	0.47 (0.39–0.56)	0.47 (0.39–0.56)	0.47 (0.39–0.56)	0.47 (0.38–0.57)
$B_{proj} \% B_{msy}$	1.74 (1.46–2.08)	1.74 (1.45–2.08)	1.74 (1.44–2.10)	1.75 (1.41–2.13)
$\Pr(> B_{msy})$	1.00	1.00	1.00	1.00
$\Pr(> B_{current})$	0.00	0.48	0.47	0.50
$\Pr(> 40\% B_0)$	0.95	0.95	0.94	0.92
$\Pr(< 20\% B_0)$	0.00	0.00	0.00	0.00
$\Pr(< 10\% B_0)$	0.00	0.00	0.00	0.00
$\% B_0^r$	0.37 (0.30–0.47)	0.32 (0.25–0.41)	0.32 (0.25–0.41)	0.32 (0.24–0.41)
$\% B_{msy}^r$	2.42 (1.81–3.36)	2.10 (1.54–2.93)	2.10 (1.51–2.95)	2.09 (1.50–2.96)
$\Pr(> B_{msy}^r)$	1.00	1.00	1.00	1.00
$\Pr(> B_{current}^r)$	0.00	0.00	0.00	0.00
$\Pr(U_{proj} > U_{40\% B0})$	0.07	0.08	0.09	0.09

4.5   Other factors

A number of factors affected the overall validity of the assessment.

There were uncertainties in the estimated catch history for PAU 5A and its subareas before 1995. The results from the southern area assessment suggested that estimates of stock status are sensitive to the range of assumptions made for the estimated catch history. Between the lower-bound and upper-bound catch estimates, model estimates of current spawning stock status ranged from 34 to 46% B_0. For the northern area of PAU 5A, the commercial catch history is well determined back to 1984, although uncertainty exists for the pre-1984 catch, which is expected to have minor effects on the overall assessment. There is little information on the historical catches in Fiordland, but anecdotal evidence suggested that the catch between 1981 and 1984 was about 60–70 t annually (Storm Stanley pers. comm.). The lower and upper-bound catch estimates used in the assessment may have encompassed many of the uncertainties in the historical catches. In addition, non-commercial catch estimates are also very uncertain, and large differences may exist between the catches assumed and the catch actually taken. In both assessments, the modelled area is treated as if it were a single stock with homogeneous biology, habitat and fishing pressure. It is assumed that:

- recruitment affects the modelled area in the same way;
- natural mortality does not vary by length or year in the modelled area;
- growth has the same mean and variance in the modelled area, although in reality growth may be stunted in some areas and fast in others.

The models showed some conflicts between length frequencies and CPUE. The early CPUE for the southern area showed a declining trend, indicating that large fish were probably being removed from the stock, which would most likely have resulted in a decline of mean length in the commercial catch over time. But this is not consistent with trend in the observed length

distributions. A plausible explanation for this contradiction is that the commercial catch samples in the early years were unrepresentative of the fishery.

Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on increments observed in several different sites. Similarly, the length frequency data are integrated across samples from many places. An open question is whether a model fitted to data aggregated from a large area, within which smaller populations respond differently to fishing, results in credible estimates of the response of the aggregated sub-populations.

This effect is likely to make model results optimistic. For instance, if some local stocks are fished very hard and others are not fished, recruitment failure can result due to the depletion of spawners, because spawners must breed close to each other, and because the dispersal of larvae may be limited. Recruitment failure is a common observation in abalone fisheries internationally. Local processes may decrease recruitment, an effect that cannot be accounted for in the current model.

A significant source of uncertainty is that fishing may cause spatial contraction of populations or that some populations become relatively unproductive after initial fishing due, for example, to reductions in density that may impede successful spawning. If this happens, the model will overestimate productivity in the population as a whole. Historical catches may have been interpreted in the model as good recruitments, whereas they may actually have been the result of serial depletion.

5.   STATUS OF THE STOCKS

Stock Structure Assumptions
A genetic discontinuity between North Island and South Island paua populations was found approximately around the area of Cook Strait (Will & Gemmell 2008).
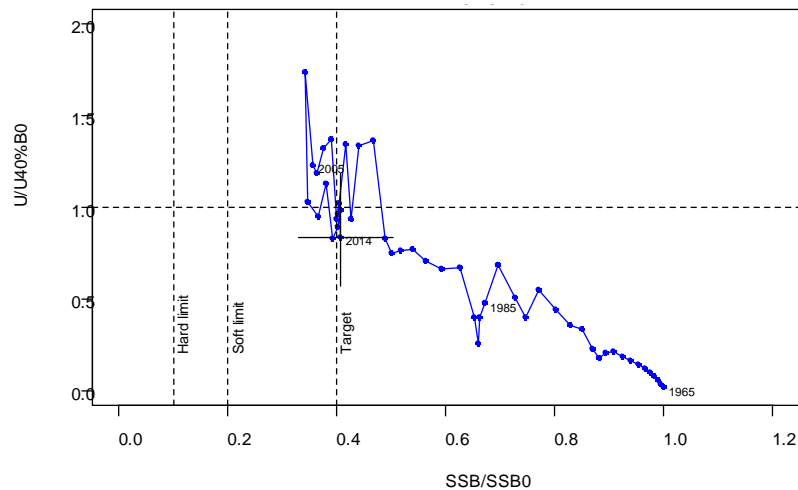
- **PAU 5A -** *Haliotis iris*

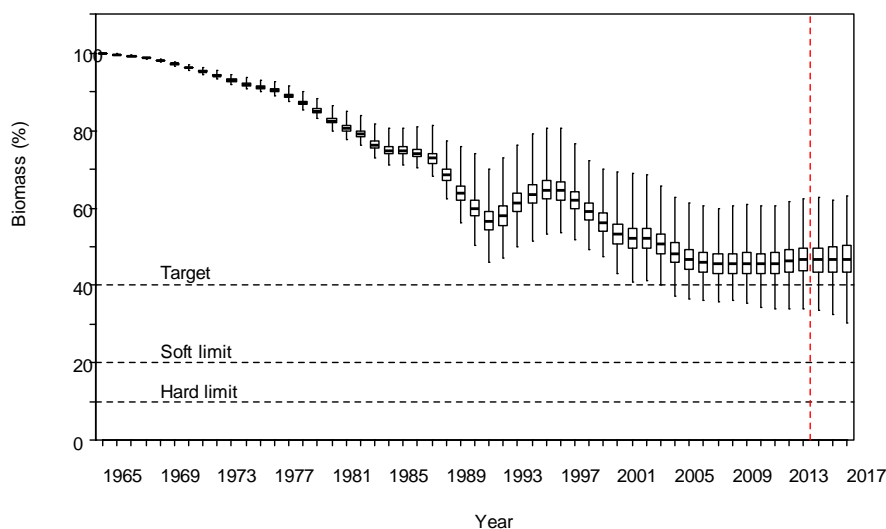| Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	Southern Area: base case model (run 1.5)
	Northern Area: base case model (run 1.5)
Reference Points	Target: 40% B_0 (Default as per HSS)
	Soft Limit: 20% B_0 (Default as per HSS)
	Hard Limit: 10% B_0 (Default as per HSS)
	Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Southern Area: B_{2014} was estimated at 41% (32–53%) B_0
	Northern Area: B_{2014} was estimated at 47% (39–56%) B_0
Status in relation to Limits	Southern Area: B_{2014} is Very Unlikely ($< 10\%$) to be below the soft and hard limits.
	Northern Area: B_{2014} is Very Unlikely ($< 10\%$) to be below the soft limit and hard limits.
Status in relation to Overfishing	Southern Area: The fishing intensity in 2014 was Unlikely ($< 40\%$) to be above the overfishing threshold
	Northern Area: The fishing intensity in 2014 was Very Unlikely ($< 10\%$) to be above the overfishing threshold

PAUA (PAU 5A)

Historical Stock Status Trajectory and Current Status
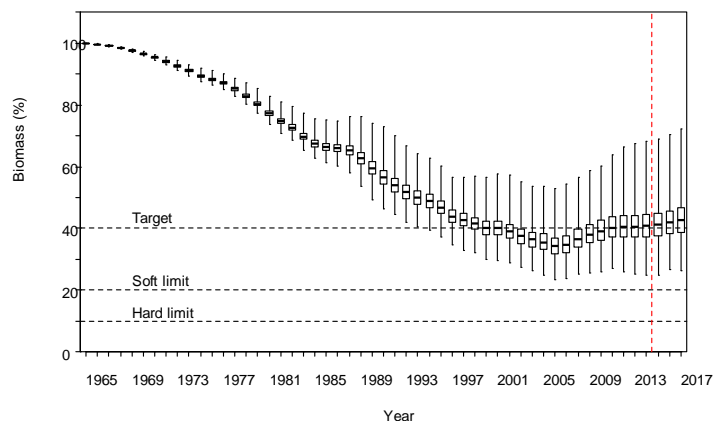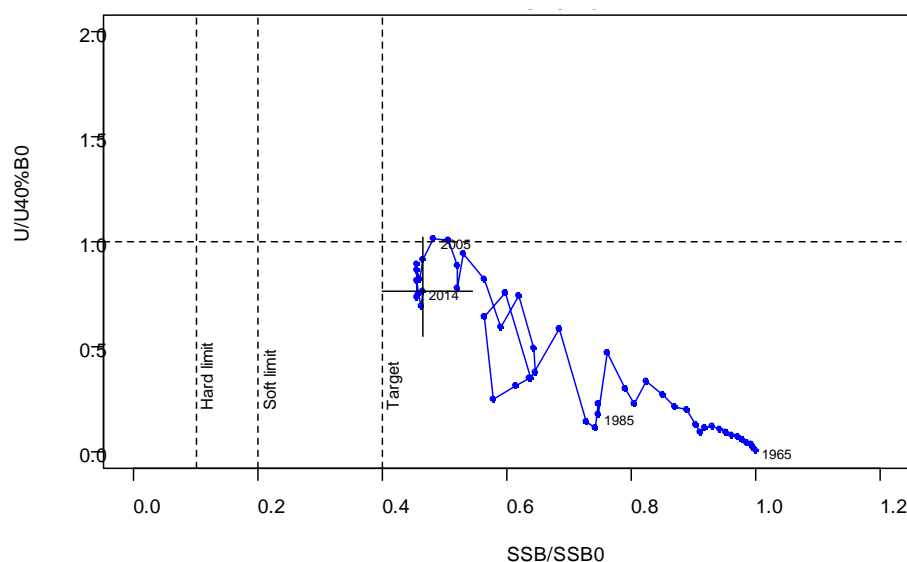

Posterior distributions from the base case model of spawning stock biomass (including projection) as a percentage of B_0 for the southern area assessment. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution. The boxes to the right of the dashed line indicate the projected spawning biomass to 2017 for each model assuming current catch level.

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 2014 for the southern area base case model. The vertical lines at 10%, 20%, and 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 estimates are based on MCMC medians and the 2014 90% CI is shown by the cross line.

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Posterior distributions from the base case model of spawning stock biomass (including projection) as a percentage of B_0 for the northern area assessment. 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 boxes to the right of the dashed line indicate the projected spawning biomass to 2017 for each model assuming current catch level.

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 2014 for the northern area base case model. The vertical lines at 10%, 20%, and 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 of $U_{\%40B0}$) for that year. The estimates are based on MCMC medians and the 2014 90% CI is shown by the cross line.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Southern Area: Spawning stock biomass has declined from the early years of the fishery up to 2007. Since 2007 biomass has been increasing. Northern Area: Spawning stock biomass has declined from the early years of the fishery up to 2007. Since 2007 the biomass has increased slightly.

Recent Trend in Fishing Intensity or Proxy	Southern Area: Exploitation rates have an overall declining trend since early 2000s, but have increased slightly over the last four years. Northern Area: Exploitation rates have declined since the mid-2000s.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Southern Area: At current levels of catch spawning stock biomass is projected to increase to 43% (32–56%) B_0 by 2017. If shelving is reduced by 20% spawning stock biomass is projected to remain stable at 41% (32–52%) of B_0 for the next 3 years. Northern Area: At current levels of catch spawning stock biomass is projected to remain unchanged at 47% (39–56%) B_0 for the next 3 years. If shelving is reduced by 10% spawning stock biomass is projected to decline to 46% (37–56%) B_0. If shelving is reduced by 20% spawning stock biomass is projected to decline to 44% (35–55%) B_0.

Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Southern Area:
	  Soft Limit: Very Unlikely (< 10%)
	  Hard Limit: Very Unlikely (< 10%)
	Northern Area current catch:
	  Soft Limit: Very Unlikely (< 10%)
	  Hard Limit: Very Unlikely (< 10%)

Probability of Current Catch or TACC causing Overfishing to continue or to commence	Southern Area: Unlikely (< 40%) at current catch levels
	  Unlikely (< 40%) if shelving reduced by 10%
	  About as Likely as Not (40–60%) if shelving reduced by 20%
	Northern Area: Very Unlikely (< 10%) at current catch levels
	  Unlikely (< 40%) if shelving reduced by 10%
	  About as Likely as Not (40–60%) if shelving reduced by 20%

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Latest assessment: 2014	Next assessment: 2019
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch history	1 – High Quality for commercial catch 2 – Mixed or Medium Quality for customary catch
	- CPUE indices early series	1. No data for recreational or illegal catch 2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA
	- CPUE indices later series	1 – High Quality
	- Commercial sampling	2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA

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	length frequencies	1 – High Quality
	- Tag recapture data (for growth estimation)	1 – High Quality
	- Maturity at length data	
Data not used (rank)	- Research Dive Survey Indices - Research Dive Length Frequencies	3 – Low Quality: not believed to index the stock 3 – Low Quality: not believed to be representative of the entire QMA
Changes to Model Structure and Assumptions	-	
Major sources of Uncertainty	- *M* may not be estimated accurately. There is information in the data that has informed the estimation of *M* and the prior has also strongly influenced the estimate. - CPUE may not be a reliable index of abundance. - Any effect of voluntary increases in MHS may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years.	
Qualifying Comments		
-		

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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