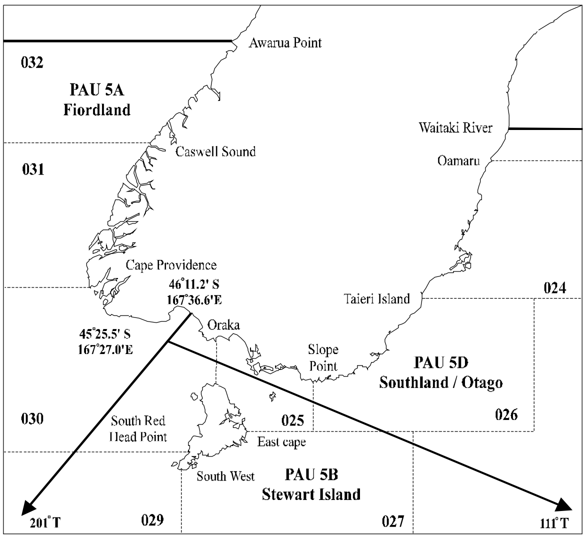
PAUA (PAU 5D) – Southland / Otago

(*Haliotis iris*)



1. FISHERY SUMMARY

(a) Commercial fishery

Before 1995–96, PAU 5 was the most important QMA by number of quota holders and TACC. The TACC peaked in PAU 5 in 1991–92 at 492 t, having grown steadily from a provisional TACC of 390 t in 1985–86 as a result of the quota appeal process. Concerns about the status of the PAU 5 fishery led to a voluntary 10% reduction in the TACC in 1994–95. On 1 October 1995, PAU 5 was divided into three QMAs (5A, 5B, and 5D; see Figure above) and the TACC was subdivided equally among them. It is widely considered that this led to a large redistribution of catch from Stewart Island to Fiordland and the Catlins/Otago coast (Elvey et al., 1997). The exact increase in catch in the new PAU 5D caused by subdivision cannot be determined with certainty because several Statistical Areas used to report catch and effort straddled 5B and 5D (Figure above; Kendrick and Andrew 2000).

Table 1: TACC and reported landings (t) of paua in PAU 5D from 1995-96 to 2004–05. Data reported from CELR returns.

Year	Landings	TACC
1995–96	167.42	148.81
1996–97	146.60	148.81
1997–98	146.99	148.81
1998–99	148.78	148.81
1999–00	147.66	148.81
2000–01	149.00	148.81
2001–02	148.74	148.81
2002–03	111.69	114.00
2003-04	88.02	89.00
2004-05	88.82	89.00

(b) Recreational fisheries

The Ministry of Fisheries estimated that 87 000 paua were harvested by recreational divers in PAU 5D. This number was converted into weight using length-weight relationship by assuming a mean length of 125 mm. The estimate of recreational catch used in this assessment was 22 016 kg. This catch estimate was used for the whole period modelled.

The 1996 national telephone diary survey estimated that 105,000 paua (27 t) were taken by recreational fishers in PAU 5. The 1999/2000 and 2000/2001 national recreational fishing surveys estimated 120,000 and 191,000 paua respectively were harvested by recreational fishers in PAU 5D. At an average weight of 357g, these numbers equate to a recreational harvest of 42.8 t in 1999/2000 and 68.2 t in 2000/2001. The Marine Recreational Fisheries Technical Working Group (RFTWG) has reviewed the harvest estimates from the national surveys. The RFTWG concluded that the 1996 harvest estimates were unreliable due to a methodological error. Harvest estimates from the 1999/2000 and 2000/2001 surveys for some fish stocks were considered to be unbelievably high. The Shellfish Fisheries Assessment Working Group accepted a harvest estimate of 87,000 paua for PAU 5D. This number was converted into weight using length-weight relationship by assuming a mean length of 125 mm. The estimate of recreational catch used in this assessment was 22.016 t. This catch estimate was used for the whole period modelled.

(c) <u>Maori customary fisheries</u>

There is an important customary use of paua by Maori for food, and the shells have been used extensively for decorations and fishing devices. Estimates of customary catch for the 2002 assessment were provided as numbers of paua by the Ministry of Fisheries. Estimates were provided for 1999 to 2001 and the mean of these estimates, 2505, was used in the assessment for the whole period modelled. This estimate was converted into 835 kg weight by assuming a mean individual weight of 333 g.

(d) <u>Illegal catch</u>

Illegal catch was estimated by the Ministry of Fisheries to be 20 t. No historical estimates are available so these estimates were used for the whole period modelled.

The catch vector (sum of all these components) is shown in Figure 1.

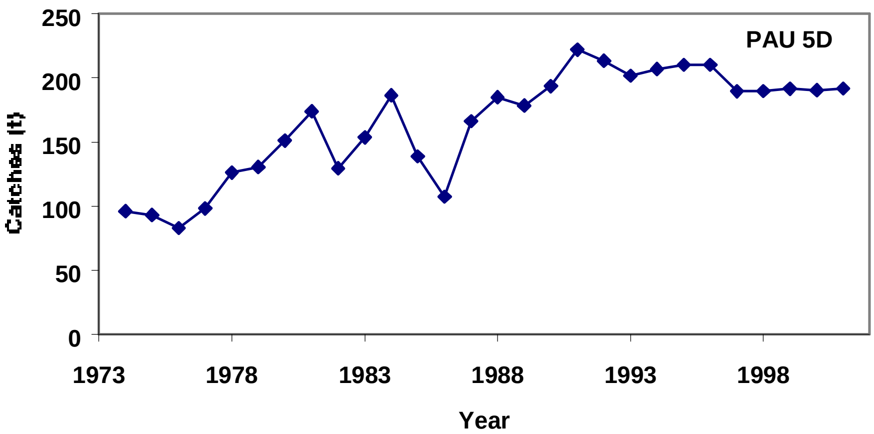


Figure 1: Assumed catch (t) used in the assessment.

(e) <u>Other sources of mortality</u>

Sub-legal paua may be subject to handling mortality by the fishery if they are removed from the substrate to be measured. Paua may die from wounds caused by removal, desiccation or osmotic and temperature stress at the surface or indirectly from being returned to unsuitable habitat or being lost to predators or bacterial infection. Gerring (2003) estimated that in PAU 7, 37% of paua removed from the reef by commercial divers were undersize and were returned to the reef. Their estimate of incidental mortality associated with fishing in PAU 7 was 0.3% of the landed catch. The low estimate was attributed to improved handling behaviour by divers and their use of a benign removal tool. Incidental fishing mortality may be higher in other areas where these practices have not been adopted. Pirker (1992) reported that in some fisheries, as much as 54% of paua removed from the reef may be undersize. Of these paua, up to 13% were damaged in some way and field estimates suggest up to 80% of these may fall victim to predation by wrasses or starfishes following their return to the reef. No attempt has been made to incorporate this source of mortality in the stock assessment.

2. BIOLOGY

A summary of biological parameters used in the PAU 5D assessment is presented in Table 2.

Table 2: Estimates of biological parameters (*H. iris*).

		Estimate	Source
1. Natural mortality (M)			
		0.13 (0.10–0.16)	Median (5–95% range) of posterior estimated by the model
2. Weight = a (length)^b (weight in g, shell length in mm)			
		a = 2.99 x 10^{-5} b = 3.303	Schiel and Breen (1991)
3. Size at maturity (shell length)			
		50% maturity at 91 mm	
		95% maturity at 105 mm	R. Naylor (NIWA) unpub. data
4. von Bertalanffy growth parameters (both sexes combined)			
	K	**L_∞ (mm)**	
	0.34 (0.32–0.36)	154.5 (152.3–157.0)	Median (5–95% range) of posteriors estimated by the model

3. STOCKS AND AREAS

PAU 5D was created in 1995 when PAU 5 was divided into three sub-areas, each with a TACC of 147.66 t. From 1 November 1997 catch in PAU 5D was reported in 11 statistical areas, and further subdivided from 1 October 2001, when it became mandatory to report catch and effort from the 47 small zones developed by the New Zealand Paua Management Company for their voluntary logbook and subsequently adopted on MFish CELR's.

4. STOCK ASSESSMENT

(a) Estimates of fishery parameters and abundance

Catch rates (CPUE data from CELR records – Table 3) in PAU 5 declined for the first 15 years after the introduction of the QMS , but appear relatively stable since the creation of PAU 5D (Table 3). 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.

Table 3: Unstandardised and standardised catch per unit effort (CPUE) in PAU 5D (kg per diver-day) (Breen et al. 2002b).

Year	Unstandardised CPUE	Standardised CPUE
1982–83	159.11	353.56
1983–84	177.02	297.70
1984–85	287.59	308.30
1985–86	299.12	318.78
1986–87	260.34	237.25
1987–88	227.68	250.28
1988–89	179.34	171.84
1989–90	151.79	148.64
1990–91	159.15	143.77
1991–92	142.58	134.62
1992–93	144.34	142.15
1993–94	131.92	132.81
1994–95	134.54	126.72
1995–96	133.07	115.80
1996–97	132.42	115.20
1997–98	117.48	98.19
1998–99	164.83	132.07
1999–00	139.92	116.10

2000–01	146.33	108.82

The relative abundance of paua in PAU 5D has been estimated from research surveys (Andrew et al., 2000a, 2000b, 2002) (Table 4). Relative abundance has declined between each of the four years surveys have been done.

Table 4: Standardised research diver survey indices and 95% confidence limits (1.96 standard errors) for sites surveyed in PAU 5D. – indicates no data collected.

Year	2.5%	mean	97.5%
1993–94	26.89	42.30	66.55
1994–95	–	–	–
1995–96	–	–	–
1996–97	19.13	38.02	75.57
1997–98	–	–	–
1998–99	18.92	31.83	53.54
1999–00	–	–	–
2000–01	16.39	26.79	43.81

(b) Revised assessment model for PAU 5D

i) Model structure

This assessment is made with a revision of the length-based model first used in 1999 for PAU 5B (Breen et al., 2000a), and used in revised form for subsequent assessments in PAU 5B and PAU 7 (Marlborough) (Breen et al., 2000b, Breen et al., 2001). This model is driven by reported commercial catches from 1974 through 2001 and is fitted to five sets of data: standardised CPUE, standardised research diver survey index (Andrew et al., 2000a, 2000b, 2002), proportion-at-length data from commercial catch sampling and from research diver surveys (Andrew *et* error for each set. Iterative re-weighting is used to obtain standard deviations of standardised residuals equal to unity; this replaces the arbitrary weighting of previous assessments.

Exploitation rate is estimated from observed catch and model biomass. A point estimate of the mode of the joint posterior distribution (MPD) served as the starting point for the Bayesian estimations, and as the basis for sensitivity tests. The assessment is based on the marginal posterior distributions of estimated and derived parameters of interest, in turn based on Markov chain - Monte Carlo (McMC) simulations.

In addition to model parameters, derived parameters such as population size and exploitation rate were calculated and their posterior distributions summarised. In the assessment of PAU 7 in 2001, indicators using virgin recruited and spawning biomass, as well as B_{ref} were poorly determined (Breen et al., 2001). These indicators were replaced with those from a reference period, in (Breen et al., 2000a. 2000b, 2002), and a set of growth increment data (Naylor unpub. data).

Growth is modelled as a stochastic transition matrix calculated from the von Bertalanffy growth parameters, which are estimated as parameters of the model, and the estimated relation between expected increment and its standard deviation. A contribution to the total likelihood function comes from comparison of observed and expected increments in the tagging data.

Recruitment is modelled as a fixed mean with annual deviations, estimated as a vector of parameters. These have an assumed mean and standard deviation; this assumption makes the model Bayesian. No stock-recruit relation is estimated, but projections are made using the mean of the 1991–2000 recruitments as the assumed mean recruitment. Research diver selectivity-at-size is modelled with two estimated parameters.

The model estimates a standard deviation of observation error common to all data sets, which necessitated changing the likelihood functions used in previous assessments. The weights for data sets were adjusted with a term acting acted on the standard deviation of observation which the fishery appeared to be operating at a sustainable level. For this assessment spawning and recruited biomass indicators S_{ref} and B_{ref} are also used. The period from which to take these means was chosen after examining various trajectories from preliminary results. 1985–87 was chosen as a reference period because estimates of recruited and spawning biomass were higher than they are currently (Figure 3), and the period coincided with paua's entry to the QMS and a concomitant improvement in data quality. The 1985–87 period is a reference against which current and projected stock sizes and exploitation rates can be compared and should not be considered as a management target.

Performance indicators were provided for current (2002) and 5 year projections (2007). The indicators for current and projected recruited biomass, B_{02} and B_{07}, were the values for recruited biomass in those years. Spawning biomass indicators for the current and projected populations were called S_{02} and S_{07} and were calculated as the product of the maturity vector and numbers in each size class for each year. Exploitation rates in 2001 and 2007 were also used as indicators, and called U_{01} and U_{07}.

For the McMC simulations used in projections, additional indicators were the percentages of runs in which spawning biomass decreased during projections, recruited biomass decreased during projections, spawning biomass remained less than S_{ref}, and recruited biomass remained below B_{ref}.

Sensitivity tests involved removing each of the five data sets in turn, then removing all length data or all population index data in turn, changing the relative weights for data sets, using an alternative prior on M, and estimating the shape of the relation between CPUE and biomass. Retrospective analyses, in which years of data were sequentially removed and the model refitted were also used to analyse the sensitivity of the model to data.

ii) Data used in the assessment

The data used in this assessment of PAU 5D are summarised in a series of FARs. The fishery-independent survey and population length frequency data are presented in Andrew et al. (2000a, 2000b, 2002); Breen et al. (2002b) present the assessment for PAU 5D. Catch rate and catch history are presented in Kendrick & Andrew (2000) and Breen et al. (2002a, 2002b).

Generation of a catch vector required assumptions to be made about the division of catch from statistical areas 25 and 30 to PAU 5B prior to 1995. For this purpose, the fishery was divided into three periods: pre-1984, 1984–1995, and post-1995. In this assessment we used the following series:

1974–1983 25% of PAU 5 landings.
1984–1995 25% of Area 25 and 7% of Area 30.
1996–2001 As allocated to subdivided QMAs.

A vector of standardised CPUE was generated using the raw catch rates as catch per diver-day (Kendrick and Andrew 2000) and a multiple regression model (Vignaux 1993). The standardisation model accounted for 33% of the total variation in observed CPUE and deviated little from the pattern of decline in raw CPUE through time (Figure 2).

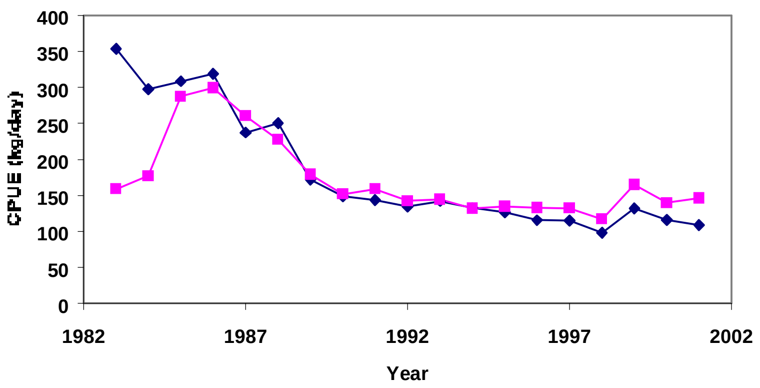


Figure 2: Raw (diamonds) and standardised (squares) CPUE (kg per diver-day) for PAU 5D.

Assessment model parameters and their priors and bounds are given in Table 5. Other biological assumptions were as follows: The length-weight relationship, growth parameters (derived from the model) are given in Table 2. Maturity is knife-edged at 90 mm. Vulnerability to the fishery is knife-edged at 126 mm. Selectivity parameters were fixed in this assessment, to the MPD values obtained for PAU 5B, because estimation gave unrealistic results for these parameters.

Table 5: Parameters estimated in the model and their prior distributions.

Model parameters	Definition	Priors and bounds
$\ln(R0)$	Natural log(recruitment)	Uniform, 5, 50
M	Natural mortality	Cauchy with mean 0.1, CV 0.5, bounds 0.01, 0.50
L_{∞}	Asymptotic length	Uniform, 100, 250
K	Brody coefficient	Uniform, 0.01, 0.80
$S50$	Size at 50% selectivity by research divers	Fixed in this assessment
$S95$	Difference in size between 95% and 50% selectivity	Fixed in this assessment
ε_t	Vector of recruitment deviations in log space	Normal, mean 0 Bounds –2.3 and 2.3, CV 0.4
$\tilde{\sigma}$	Common standard deviation of observation error	Uniform, 0.01, 1.0
α	CV of expected growth increments	Uniform, 0.001,1
σ_{MIN}	Minimum standard deviation of growth increment	Uniform, 0.001,5

iii) Stock assessment results

The sensitivities of model outputs to inputs and assumptions (Table 6) were explored using the MLE point estimates.

Table 6: Results of sensitivity tests on MPD estimates to model inputs and assumptions.

Sensitivity test	Outcomes
***To datasets*:** Removing each of the five data sets in turn from the fitting procedure, removing both abundance indices, and removing both length frequency data sets	• Sensitive to removal of CPUE and tagging data • Otherwise robust
Alternative weighting of datasets	• Reasonably robust
To the prior on M (natural mortality): changed the mean from 0.10 to 0.12	• Little change
Estimating the shape of the CPUE – abundance relation	• Little change

The model was reasonably robust to these trials; major sensitivities were to removal of tagging and CPUE data sets. When CPUE was removed, the current exploitation rate went to the upper bound of 80%, probably because the model fitted the steeper decline in the research diver survey index. Removing the research diver survey index had little effect. Removing the proportion-at-length data from commercial catch sampling made the estimated current exploitation rate lower, while removing proportions-at-length from the research surveys had little effect. Removing the growth increment data set caused a large increase in current exploitation rate.

Some sensitivity was seen to data set weighting, but the base case was arrived at by an analytical process, whereas it was arbitrary in previous assessments. *M* and the growth parameters changed from the base case estimates when weights were altered, and this also caused distortion in the standard deviations of standardised residuals. The indicators examined in these trials, however, showed less sensitivity to the weights than did the parameters.

A set of retrospective analyses suggested that bias or model mis-specification were not problems with this assessment.

The model provided reasonably good fits to the proportions-at-length from commercial catch sampling and CPUE, but not as good a fit to proportions-at-length from the research diver survey, and a poor fit to the research diver survey index. Where fits were not good, differences between data sets could be found as the causes. For instance, proportions-at-length from the commercial catch sampling and research diver survey were different when compared in the same year. The research diver survey index declined more steeply than the CPUE index. With such differences in data sets, the model cannot fit all data sets well.

The posterior summaries (Table 7) suggest that current spawning and recruited biomass are both significantly less than they were in the reference period (1985–87), and that current exploitation rate is in the range 51–64%. Projections from the McMC simulations used recruitment that varied randomly around the recent 10-year mean. Projections made with the current catch and MLS suggest that both biomass indicators have some chance of increasing: 42% for spawning and 38% for recruited biomass; the median expectations are for decreases, with much uncertainty as seen in the trajectories. At the current catch and MLS, there is little chance that the indicators will above the reference values in 5 years.

Table 7: Performance indicators derived from posterior distributions generated from the base case assessment. B is recruited biomass (paua greater than 125 mm shell length) in tonnes, S is spawning biomass (based on numbers-at-size and maturity-at-size) in tonnes, U is exploitation rate. Sref and Bref are the mean biomass estimates for 1985-87. Biomass estimates in t. The table shows 5th percentile, median and 95th percentile for the parameters indicated, taken from the distribution of 5000 samples from 10 million simulations.

	0.05	median	0.95
U_{01}	51%	57%	64%
U_{07}	18.3%	78.6%	98.3%
S_{ref}	948	1 028	1 130
S_{02}	522	633	760
S_{07}	203	555	1 596
B_{ref}	801	869	944
B_{02}	274	329	387
B_{07}	65	244	1 047
S_{02}/S_{ref}	52.1%	61.2%	71.7%
S_{07}/S_{ref}	20.1%	53.7%	153.1%
S_{07}/S_{02}	33.4%	88.0%	246.7%
B_{02}/B_{ref}	32.0%	37.8%	43.8%
B_{07}/B_{ref}	7.6%	28.0%	118.5%
B_{07}/B_{02}	19.9%	74.6%	313.0%
Percentage of runs where:			
$S_{07}<S_{02}$			58.2%
$S_{07}<S_{ref}$			83.9%
$B_{07}<B_{02}$			62.8%
$B_{07}<B_{ref}$			92.3%

(c) Biomass Estimates

The posterior summaries (Table 7) suggest that current spawning and recruited biomass are both significantly less than they were in the reference period, and that current exploitation rate is in the range 51–64%. Projections made with the current catch and MLS (Table 7) suggest that both biomass indicators have some chance of increasing: 42% for spawning and 38% for recruited biomass; the median expectations are for decreases, with much uncertainty in the projections (Figure 3). At the current catch and MLS, there is little chance that the indicators will be above the reference values in 5 years.

(d) Estimation of Maximum Constant Yield (MCY)

No estimate of MCY has been made for PAU 5D.

(e) Estimation of Current Annual Yield (CAY)

No estimate of CAY has been made for PAU 5D.

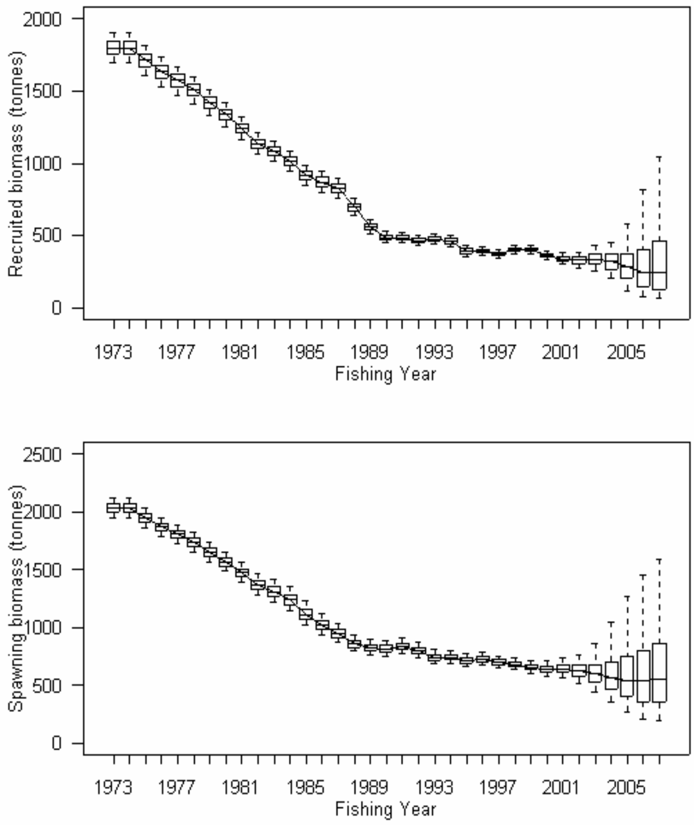


Figure 3: The posterior biomass trajectories for recruited (upper) and spawning (lower) biomass for the base case for PAU 5D. For each year, the figure shows the median of the posterior (horizontal bar), the 25th and 75th percentiles (box) and 5th and 95th percentiles of the posterior.

(f) Other yield estimates and stock assessment results

The assessment model was used to predict the likely impact of five alternative catch levels between 2002 and 2007 and these suggest lower catch levels increase the probability and speed of rebuilding (Table 8).

Table 8: Summaries of posterior distributions of derived parameters generated from the base case assessment of PAU 5D for five alternative catch levels for projections to 2007, including the current catch of 192 t. B is recruited biomass (paua greater than 125 mm shell length), S is spawning biomass (paua greater than 90 mm shell length), U is exploitation rate. Values for the first seven indicators are the medians of 5000 samples from the McMC simulations. Percentages indicated for the last four indicators are the percentage of the 5000 samples in which the indicator was true.

Projected Catch (t)	115	134	154	173	192
U_{07} (%)	19.9	27.4	38.2	54.9	78.6
S_{02}/S_{ref} (%)	61.2	61.2	61.2	61.2	61.2
S_{07}/S_{ref} (%)	85.4	77.0	68.6	60.4	53.7
S_{07}/S_{02} (%)	138.5	124.7	110.7	98.4	88.0
B_{02}/B_{ref} (%)	37.8	37.8	37.8	37.8	37.8
B_{07}/B_{ref} (%)	66.4	56.5	46.4	36.4	28.0
B_{07}/B_{02} (%)	175.8	149.6	123.1	96.0	74.6
$S_{07}<S_{02}$ (%)	20.6	31.8	42.5	51.2	58.2
$S_{07}<S_{ref}$ (%)	64.3	70.9	75.7	80.5	83.9
$B_{07}<B_{02}$ (%)	9.3	22.5	39.0	52.1	62.8
$B_{07}<B_{ref}$ (%)	79.6	84.8	88.0	90.3	92.3

(g) Other factors

The model treats the whole of PAU 5D as if it were a single stock with homogeneous biology, habitat and fishing pressures. The PAU 5D stock in reality is highly heterogeneous with respect to all these factors. In particular, the extreme weather typical of the Catlins coast make it probable that fishing pressure is concentrated in sections of the coast that are easier to access, causing large difference in exploitation rate within the QMA. The effect of this simplification in the model, especially with respect to predictions, is unknown. This is a common problem in abalone fisheries, where the effective unit stock may be small, and typically much smaller than the scale at which the fishery is managed. Local stocks may be disproportionately depleted compared with the average depletion; in paua or abalone this can result in small-scale recruitment failure. Further, it is difficult to sample heterogeneous populations to obtain estimates that are representative of the whole population. These problems result from the mismatch between the spatial scales at which abalone fisheries can be practically managed and the much smaller scales at which population dynamics are thought to operate.

Serial depletion, if it occurs, may cause model results to be overly optimistic with respect to the part of the population that is being fished or surveyed. Hyperstability in CPUE could also cause model results to be overly optimistic. The research diver survey index in fact declined at a greater than CPUE.

5. STATUS OF THE STOCK

The assessment was not updated in 2005; the results from the 2002 assessment are reported below. The TACC was reduced to 89 t from 1 October 2003.

A Bayesian length-based stock assessment model was applied to PAU 5D to estimate stock status and yield. 1985–87 was chosen as a reference period because recruited and spawning biomass was higher than it is currently, and it coincided with the entry of paua to the QMS and a concomitant jump in data quality.

The current median recruited biomass estimate was 329 t (5th and 95th percentiles equal to 274–387 t, respectively); the current median spawning biomass estimate was 633 t (522–760 t). The median and upper percentiles for both current recruited and spawning biomass are less than the reference years 1985–87. The assessment indicated that the current median exploitation rate is about 57 % (51–64%).

Projections show that at the current levels of catch and MLS, in 2007 there is a 37.2% probability that recruited biomass will be greater than current biomass, and a 7.7% probability that it will be greater than the recruited biomass estimated for the period between 1985–87. Similarly, in 2007 there is a 41.8% probability that spawning biomass will be greater than current spawning biomass, and a 16.1% probability that it will be greater than the spawning biomass estimated for the period between 1985–87. Projections also indicate that the exploitation rate will increase to around 79% (18–98%) by the end of 2007.

At the current catch levels and minimum legal size, the biomass is likely to decrease further and is unlikely to move toward the reference levels. These results suggest that the current catch level is not sustainable and will likely cause the stock to decrease further from reference levels of biomass in the next five years. Model projections with five alternative catch levels indicate that lower catch levels increase the chance and speed of rebuilding the stock.

Sensitivities to data and uncertainties not explicitly addressed by the model were tested and indicate that these conclusions are robust to the range of assumptions tested.

Summary of TACC (t) and reported landings (t) of paua 5D for the 2004-05 fishing year.

QMA	Actual TACC	Reported commercial landings
PAU 5D	89.00	88.82

6. FOR FURTHER INFORMATION

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