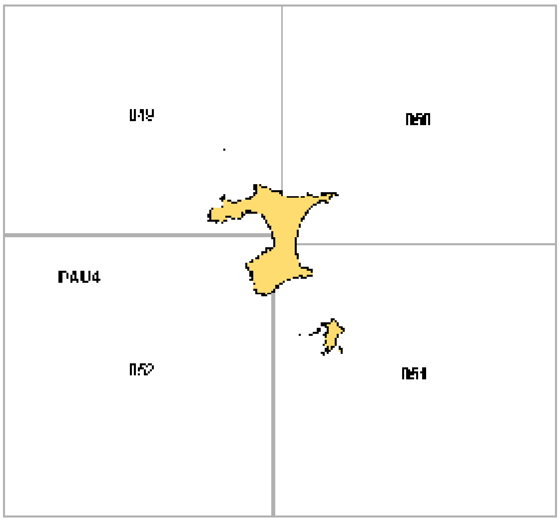
PAUA (PAU 4) - Chatham Islands

(*Haliotis iris*)



1. FISHERY SUMMARY

(a) Commercial fisheries

PAU 4 was introduced into the Quota Management System in 1986–87 with a TACC of 261 t. The TACC has since increased to 326 t as a result of the appeal process. The fishing year runs from 1 October through 30 September. In what follows, the fishing year is referred to using the second part, *viz* 2002-03 is termed “2003”.

Table 1: TACC and reported landings (t) of paua in PAU 4 from 1995–96 to 2004–05.

Year	Landings	TACC
1995–96	220.17	326.54
1996–97	251.71	326.54
1997–98	301.69	326.54
1998–99	281.76	326.54
1999–00	321.56	326.54
2000–01	326.89	326.54
2001–02	321.64	326.54
2002-03	325.62	326.54
2003-04	325.85	326.54
2004-05	319.24	326.54

(b) Recreational fisheries

There are no estimates of recreational catch for PAU 4. The 1996, 1999/2000 and 2000/2001 national marine recreational fishing surveys did not included the Chatham Islands. For the assessment this catch was assumed to be zero.

(c) Maori customary fisheries

There are no estimates of customary catch for PAU 4. For the assessment this catch was assumed to be zero.

(d) Illegal catch

There are no estimates of illegal catch for PAU 4. For the assessment this catch was assumed to be zero.

(e) Other sources of mortality

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 et al. (2003) estimated that in PAU 7, 27% 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

Growth, morphometrics and recruitment can vary over short distances and may be influenced by factors such as wave exposure, predation and food availability. A summary of values for biological parameters used in the PAU 4 assessment is presented in Table 2. Natural mortality was estimated in the assessment.

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

	Estimate		Source
1. Natural mortality (M)			
All	0.02–0.25		Sainsbury (1982)
PAU 4	0.19 (0.13–0.29) Median (5%–95% quantiles)		Estimated by the model
2. Weight = a (length)^b (weight in kg, shell length in mm)			
	a = 2.99E-08	b = 3.303	Schiel and Breen (1991)
3. Size at maturity (shell length)			
50% mature	95 mm		Assumed
95% mature	102 mm		Assumed

3. STOCKS AND AREAS

The present Fishstock boundaries may not represent a single discrete paua stock for PAU 4.

4. STOCK ASSESSMENT

(a) Estimates of fishery parameters and abundance

The 2004 assessment is based on information and catches from Statistical Areas 049 through 052. The catch vector used comprises PAU 4 catch from 1983 through 2003 and assumed that the TACC is caught for 2004. Catches for the years 1973 to 1982 is assumed to have increased linearly from zero in 1981 to the mean of 1983 and 1984 catches in 1982 (Figure 1).

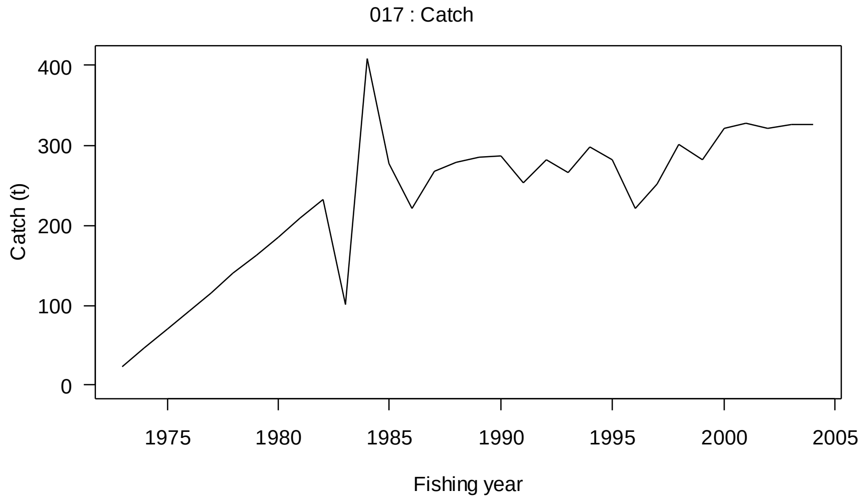


Figure 1: Assumed catch series (t) used in the PAU 4 assessment.

Catch rates from CELR records (Table 3) show a sharp increase from 1983–86 to 1987–88, a decline to a low in 1994, then a gradual increase. Commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of paua despite a falling biomass. This occurs because paua tend to aggregate and divers move among areas to maximise their catch rates. Changes in CPUE should therefore be interpreted with caution.

Table 3: Raw and standardised catch per unit effort (CPUE) in PAU 4 from 1983 to 2003, shown as kg per diver-day.

Year	Raw	Standardised	Year	Raw	Standardised
1983	163.5	187.9	1994	242.0	221.0
1984	261.2	290.4	1995	303.6	273.5
1985	314.1	337.6	1996	365.8	320.3
1986	264.3	340.2	1997	358.1	332.0
1987	380.6	498.3	1998	296.2	254.4
1988	426.2	462.4	1999	358.2	340.6
1990	312.2	404.1	2000	339.4	300.7
1991	347.1	394.9	2001	394.0	308.5
1992	325.4	387.2	2002	450.1	382.8
1993	248.7	249.2	2003	475.0	334.7

The relative abundance of paua in PAU 4 was estimated from research diver surveys in 1994 and 2002 in four research strata matching the statistical areas (Figure 2, Table 4).

Table 4: Mean paua abundance (standardised research diver survey index, RDSI) and its standard error for PAU 4.

	Index	S.E.
1994	0.862	0.126
2002	1.160	0.126

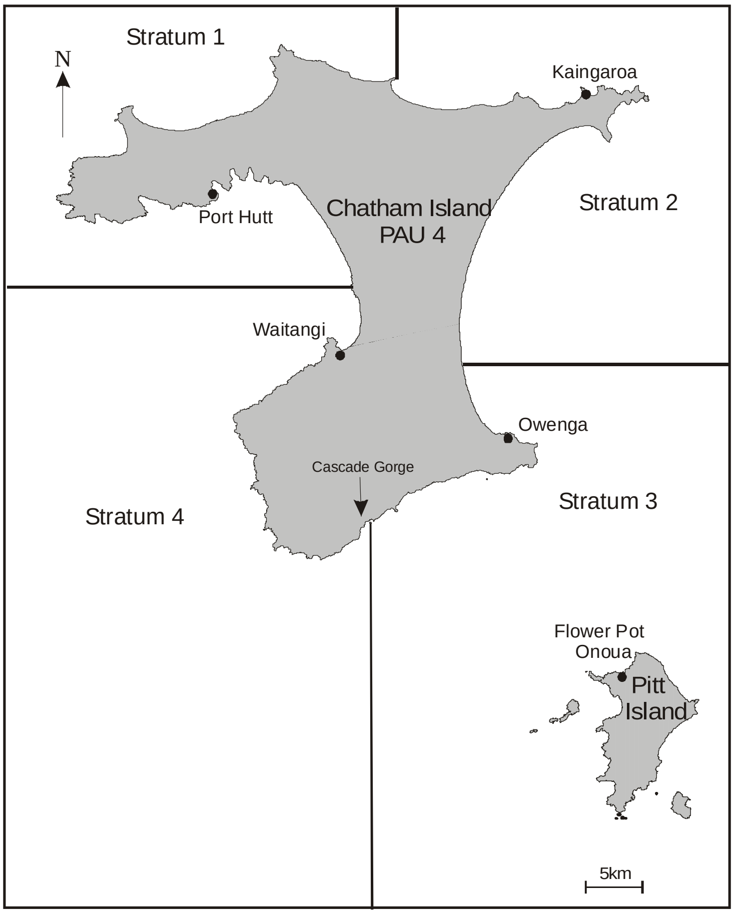


Figure 2: Strata used for independent surveys in PAU 4.

(b) Stock assessment 2004

i) Model structure

The integrated length-based model used for the 2003 assessment of PAU 7 (Breen et al. 2003) was revised for the 2004 assessments. These changes included a generalisation of the growth model, revision of the plus group and addition of alternative likelihood functions. The integrated model can estimate maturity parameters but data were insufficient in PAU 4 for this to be done.

The model generates a population and simulates its dynamics through 25 years of fishing, growth, natural mortality and recruitment. The model’s mid-season recruited biomass is fitted to observed CPUE, and an index of numbers above 90 mm shell length is fitted to the analogous observed index from population surveys (RDSI). The model’s mid-season population length structure is fitted to observed length distributions from catch sampling and population surveys. Outputs are the present and projected states of the stock. The assessment is based on the marginal posterior distributions of the parameters and derived parameters of interest, in turn based on Monte Carlo – Markov chain (MCMC) simulations. Males and females are not modelled separately.

Growth is modelled as a stochastic transition matrix calculated from three growth parameters estimated by the integrated model from the length frequency and tag-recapture data.

Recruitment is modelled as an estimated base value with estimated annual deviations (in log space) that have an assumed prior distribution; this assumption and a prior on natural mortality rate make the model Bayesian. No stock–recruit relation is estimated and projections are made by re-sampling recruitment from the past 10 years. Diver selectivity is estimated for both the commercial and research divers.

The model is driven by catch – exploitation rate is calculated 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 (a new base case was chosen from the results of sensitivity trials). Monte Carlo – Markov chain simulations were used to estimate the marginal posterior distributions of model parameters, indicators and state of the stock.

Sensitivity tests involved exploring alternative likelihood functions for length frequencies, fitting only to one data set, removing each of the five data sets in turn, using a Cauchy prior for *M*, and estimating the shape of the relations between CPUE and biomass and the shape of the growth curve.

ii) Data used in the assessment

The model was applied to five data sets from PAU 4: standardised CPUE, standardised research diver survey index (RDSI), length frequencies from catch sampling and population surveys, and tag-recapture data. The fishery-independent survey and population length frequency data are presented in Naylor et al. (submitted).

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 28.7% of the total variation in observed CPUE and deviated only slightly from the pattern of raw CPUE (Figure 3).

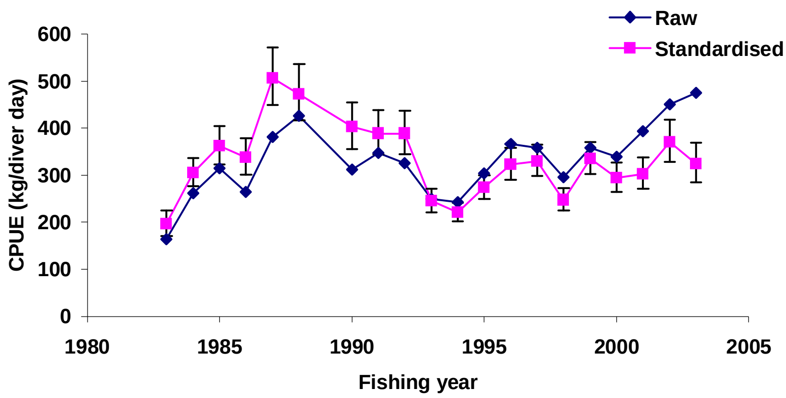


Figure 3: Raw and standardised CPUE (kg per diver-day) for PAU 4.

Assessment model parameters and their priors and bounds are given in Table 5. The length–weight relationship and maturity parameters were as shown in Table 3. Vulnerability to the fishery and to research diver sampling of paua are estimated inside the model.

Table 5: PAU 7 model parameters and their priors and bounds.

Model parameters	Definition	Priors and bounds
$\ln(R0)$	Natural log (virgin recruitment)	Uniform Bounds 0.01 and 50
T_{50}	Length at which research diver selectivity is 50%	Uniform Bounds 70 and 125
T_{95-50}	Distance between lengths at which research diver selectivity is 95% and 50%	Uniform Bounds 70.001 and 175
D_{50}	Length at which commercial diver selectivity is 50%	Uniform Bounds 70 and 145
D_{95-50}	Distance between lengths at which commercial selectivity is 95% and 50%	Uniform Bounds 70.001 and 195
M	Natural mortality	Lognormal mean 0.1, cv 0.35 Bounds 0.01 and 0.50
$\ln(q^I)$	Scalar between recruited biomass and CPUE	Uniform Bounds -30 and 0

Table 5 ***(Continued)***

Model parameters	Definition	Priors and bounds
$\ln(q^J)$	Scalar between numbers and the RDSI	Uniform Bounds -30 and 0
h	Relation between biomass and CPUE	Uniform Bounds 0.01 and 2
g_{75}	Expected annual growth at length 75mm	Uniform Bounds 1 and 50
g_{120}	Expected annual growth at length 120mm	Uniform Bounds 0.01 and 50
gshape	Shape of the growth curve	Uniform Bounds 0.001 and 5
e_t	Vector of recruitment deviations in log space	Normal, mean 0, cv 0.4 Bounds –2.3 and 2.3
$\ln(\tilde{\sigma})$	Logarithm of the common standard deviation of observation error	Uniform Bounds -10 and 1.0
f	CV of expected growth increments	Uniform Bounds 0.001 and 1

iii) Results

The sensitivities of model outputs to inputs and assumptions (Table) were explored using the MPD point estimates. Projections from the MCMC simulations (Table 7), which used re-sampling of previous recruitment, were stochastic.

Results were not especially sensitive to the removal of data sets (Table). The MPD retrospective analyses were reasonably stable except for one year; iterative re-weighting would likely have led to similar estimates.

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

Sensitivity test	Outcomes
To likelihood functions:	
Changing the function used for length frequencies	• Results were sensitive, but the functions change the weighting, and re-weighting to perform fair comparisons was not performed.
***To data sets*:**	
Fitting to single data sets	• Reasonable results were obtained only when CPUE was used
Removing each of the five data sets in turn from the fitting procedure	• Generally robust to indicators;
To the prior:	
Changing to a Cauchy prior for *M*	• *M* went to its upper bound
To additional parameters	
Estimating the shape of the CPUE - abundance relation	• Better fit
Estimating the shape of the growth curve	• Better fit
Estimating both shapes	• Better fit; chosen as the base case

The assessment was based on 5000 samples from 6 million MCMC simulations in one long chain started from the MPD estimate. Diagnostics on the MCMC chains were mixed. The model provided good fits to most data sets except for the first few CPUE data, and growth of large paua was estimated as higher than that suggested by the tag-recapture data.

Only three-year projections were made. These assume the same catch as the current TACC.

Estimates of population ratios from the base case posterior distributions are given in Table 7. The assessment results suggest that current recruited biomass is 1450 t (5% to 95% range 770 to 2330 t), and that the current exploitation rate is 19% (12% to 33%). This is a relatively wide range of uncertainty. Optimum exploitation rate is unknown.

An arbitrary reference period, 1991-93, was chosen by inspecting the biomass and exploitation rate trajectories from the MPD. This was a period after which exploitation rates increased and then levelled off, and after which biomass declined somewhat and then stabilised.

The assessment suggests that current recruitment biomass is just above *Bav*, but with high uncertainty (83% to 125%). Current spawning biomass appears more certainly high than *Sav*, but the uncertainty is artificially low with maturity parameters not estimated, and the conclusion may be sensitive to maturity ogives. More maturity data are obviously required with a high priority.

Projections suggest an increasing recruited biomass, with a median of 20% increase (1.5% to 38%) and a more uncertain spawning biomass (median 4% decrease, 90% range of 18% decrease to 16% increase. The 2007 recruited biomass could be above *Bav* (median 26% increase), but is uncertain (12% decrease to 60% increase). The 2007 spawning biomass is similar.

(c) Biomass estimates

Biomass estimates from posterior distributions are given in Table 7. The median mid-season biomass of paua larger than 125 mm in 2004 was estimated to be 1457 t (with 5^{th} and 95^{th} percentiles of 769 and 2338 respectively). This is slightly greater than estimates from the reference period. Median spawning biomass in 2004 was estimated to be 3875 t (with 5^{th} and 95^{th} percentiles of 2184 and 6675 respectively). This is also higher than the reference level.

Table 7: Performance indicators derived from posterior distributions generated from the base case assessment of PAU 4. *B* is mid-season recruited biomass (paua greater than 125 mm shell length) in tonnes, *S* is mid-season spawning biomass (based on numbers–at–size and maturity–at–size) in tonnes, *ERate* is exploitation rate. *Sav* and *Bav* are the mean mid-season biomass estimates for 1991-93. The table shows median, 5th and 95th quantiles from the posterior distributions for the parameters indicated, taken from the distribution of 5000 samples from 6 million MCMC simulations. The last four lines of the table show the percentages of runs in which the criterion was true.

	0.05	median	0.95	% runs
ERate04	12.1%	18.8%	33.4%	
ERate07	10.3%	16.6%	31.8%	
Sav	1858	3006	4743	
S04	2184	3875	6675	
S07	1989	3760	6726	
Bav	820	1393	2107	
B04	769	1457	2338	
B07	836	1741	2901	
S04/Sav	106.0%	129.6%	155.7%	
S07/Sav	93.2%	124.5%	165.4%	
S07/S04	81.7%	96.2%	115.7%	
B04/Bav	82.5%	105.0%	124.9%	
B07/Bav	88.4%	125.8%	160.5%	
B07/B04	101.4%	119.1%	138.1%	
S07<S04				64.0%
S07<Sav				10.1%
B07<B04				4.1%
B07<Bav				12.5%

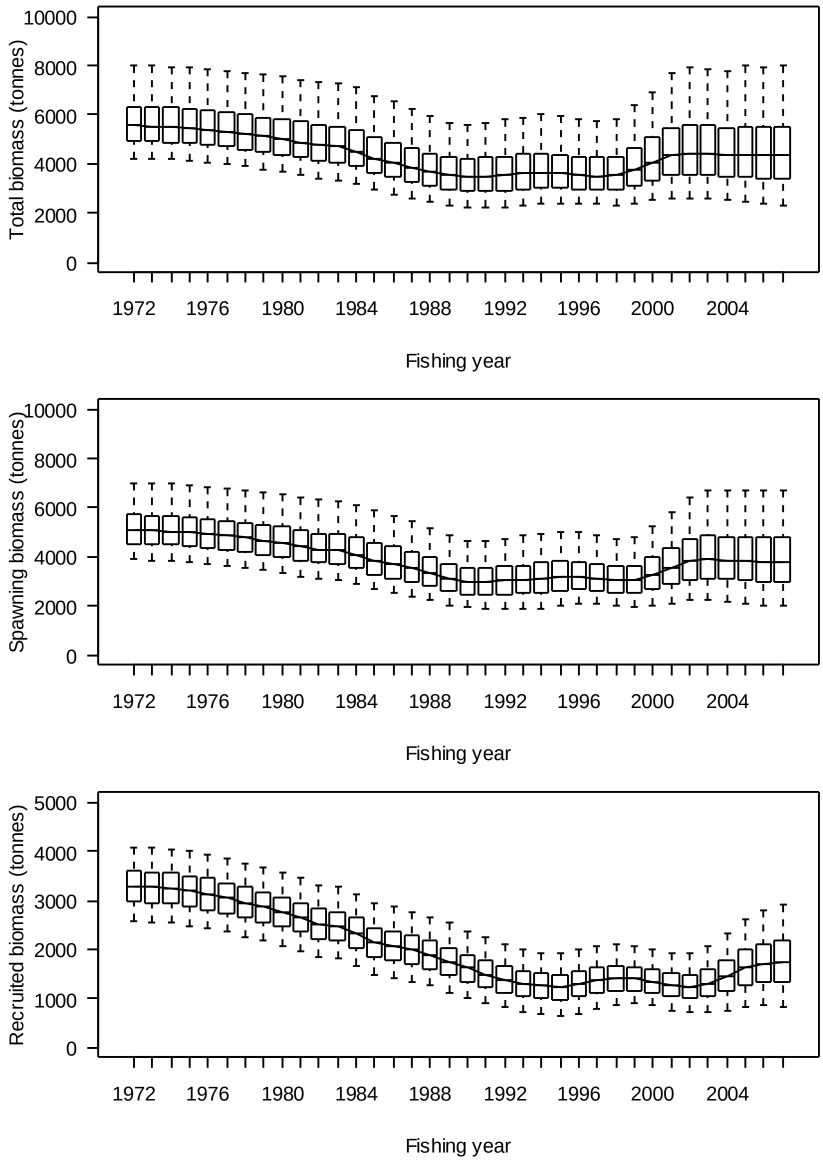


Figure 4: Posterior biomass trajectories for total (upper), spawning (middle) and recruited biomass for PAU 4. For each year, the figure shows the median of the posterior (horizontal bar), the 25th and 75th percentiles (box) and 5th and 95th percentiles of the posterior.

(d) Estimation of Maximum Constant Yield (MCY)

No estimate of MCY has been made for PAU 4. A range of more robust performance indicators that cover a range of management alternatives (TACCs) is presented.

(e) Estimation of Current Annual Yield (CAY)

No estimate of CAY has been made for PAU 4. Current surplus production is estimated by the model with a median of 481.7 t (5% to 95% range 377.4 to 632.4).

(f) Other factors

i) The MCMC process underestimates uncertainty

The assessment results just described have more uncertainty than tat reflected in the distributions of posterior distributions of parameters. These results come from a single base case chosen from a wide range of possibilities, although we used as objective a process in choosing one as we could. Sensitivity trials on the MPD suggest that data weighting has an effect on the MPD results. Choice of likelihoods may also have an effect, and we did not explore this avenue fully. The effect of assuming maturity parameters has already been discussed.

ii) The data are not completely accurate

The next source of uncertainty comes from the data. The commercial catch data show large fluctuations in 1983 to 1986 that suggest anomalies in data capture. The period before 1983 is unknown, and although we think the effect is minor, major differences may exist between the catches we assume and what was taken. On top of this, non-commercial catch estimates are unavailable but could be substantial.

The tagging data are from only three locations, which may not reflect fully the average growth and range of growth in this population. Similarly, length frequency data collected from the commercial catch may not represent the commercial catch with much precision: only 110 days have been sampled in five years and only 1000 paua were measured in total from some areas.

The research diver data are sparse. Only two surveys have been conducted, and the indices were uncertain and sensitive to standardisation. It is difficult to sample heterogeneous populations to obtain estimates that are representative of the whole population. The 148 sites may not be fully representative of Chatham Islands paua habitat, and thus length frequencies may not be representative.

iii) The model is homogeneous

The model treats the whole of PAU 4 as if it were a single stock with homogeneous biology, habitat and fishing pressures. This means: in the model, recruitment affects all areas of PAU 4 in the same way. Natural mortality, which does not vary by size or year, is the same in all areas of PAU 4. Growth has the same mean and variance in all parts of PAU 4, but some areas are stunted and some are fast-growing.

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

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

iv) The model assumptions may be violated

The most suspect assumption made by the model is that CPUE is an index of abundance. There is a large literature for abalone that suggests CPUE is difficult to use in abalone stock assessments because of serial depletion. This happens when fishers can deplete unfished or lightly fished beds and maintain their catch rates. So CPUE stays high while the biomass is actually decreasing.

In fully developed fisheries such as PAU 7 this is not such a serious problem, at least if Cape Campbell and the West Coast strata are excluded. The difference is illustrated by CPUE itself: for PAU 7 it was 64 kg per diver day in 2002; for PAU 4 it was 335 kg in 2003 (both are standardised estimates).

If CPUE is not an index of abundance, it may mislead the model, although this assessment was not grossly changed when CPUE was excluded. However, the same problem occurs in the commercial length frequencies, CSLF. If the fishery depletes areas serially, the size structure of the commercial catch does not reflect the population size structure. The PAU 4 length frequencies show only small changes among the years sampled if the suspect 1999 is excluded, although the 2004 frequency does show fewer large paua and more small paua.

If serial depletion occurs in the current PAU 4 fishery, then these assessment results may be misleading. Biomass may be declining much faster than CPUE indicates, and the size structure may be changing to smaller paua much faster than the CSLFs indicate. The research diver data are somewhat sparse to overcome these other data sources.

Whether serial depletion is a problem cannot be determined with the current data. Statistical area catches show no obvious pattern. Another significant source of uncertainty in this assessment is that fishing may cause spatial contraction of populations or that some populations become relatively unproductive after initial fishing. If this happens, the model will overestimate productivity in the population as a whole. Past recruitments estimated by the model might instead have been the result of serial depletion.

5. STATUS OF THE STOCKS

A Bayesian length-based stock assessment model was applied to PAU 4 to estimate stock status and yield. A reference period from 1991–1993 was chosen by inspecting the biomass and exploitation rate trajectories from the MPD. This was a period after which exploitation rates increased and then levelled off, and after which biomass declined somewhat and then stabilised. It is not intended as a target.

Assessment results suggest that current recruited biomass is 1450 t (5% to 95% range 770 to 2330 t), and that the current exploitation rate is 19% (12% to 33%). Current recruitment biomass is estimated to be just above *Bav*, but with high uncertainty (83% to 125%). Current spawning biomass appears higher than *Sav*, (130%), but this conclusion may be sensitive to maturity ogives.

Projections suggest stable recruited biomass, with a median of 20% increase (1.5% to 38%) and a more uncertain spawning biomass (median 4% decrease, 90% range of 18% decrease to 16% increase. The 2007 recruited biomass could be above *Bav* (median 26% increase), but is uncertain (12% decrease to 40% increase). The 2007 spawning biomass is similar.

These results suggest that the current catch level is sustainable, but with considerable uncertainty. Major uncertainties not reflected in the model's uncertainty estimates are described above and require this assessment to be treated with great caution.

Summary of TACC (t) and reported landings (t) of paua 4 for 2004-05 fishing year

QMA	Actual TACC	Reported landings
PAU 4	326.54	319.24

6. FOR FURTHER INFORMATION

Andrew, N.L.; Naylor, J.R.; Gerring, P. (1999). A modified timed–swim method for paua stock assessment. N.Z. Fisheries Assessment Report 2000/4. 23 p.

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

Chen, Y.; Breen, P.A.; Andrew, N.L. (2000). Impacts of outliers and mis–specification of priors on Bayesian fish stock assessment. *Canadian Journal of Fisheries and Aquatic Science*. 57: 2293–2305.

Gerring, P.K.; Andrew, N.L.; Naylor, J.R. (2003). Incidental fishing mortality of paua (*Haliotis iris*) in the PAU 7 commercial fishery. *New Zealand Fisheries Assessment Report 2003/56:* 13 pp.

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

Naylor, J.R.; Andrew, N.L.; Kim, S.W. (submitted). Fishery independent surveys of the relative abundance, size-structure, and growth of paua (*Haliotis iris*) in PAU 4. *New Zealand Fisheries Assessment Report*

Pirker, J.G. (1992). Growth, shell–ring deposition and mortality of paua (*Haliotis iris* Martyn) in the Kaikoura region. MSc thesis, University of Canterbury. 165 p.

Sainsbury, K.J. (1982). Population dynamics and fishery management of the paua, *Haliotis iris*. 1. Population structure, growth, reproduction and mortality. *N.Z. Journal of Marine and Freshwater Research 16*: 147–161.

Schiel, D.R. (1992). The paua (abalone) fishery of New Zealand. *In* Shepherd, S.A.; Tegner, M.J.; Guzman del Proo, S. (eds.), Abalone of the World: Biology, fisheries, and culture. Blackwell Scientific, Oxford.

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

Vignaux M. (1993). Catch per unit effort (CPUE) analysis of the hoki fishery, 1987–92. N.Z. Fisheries Assessment Research Document 93/14. 23 p.