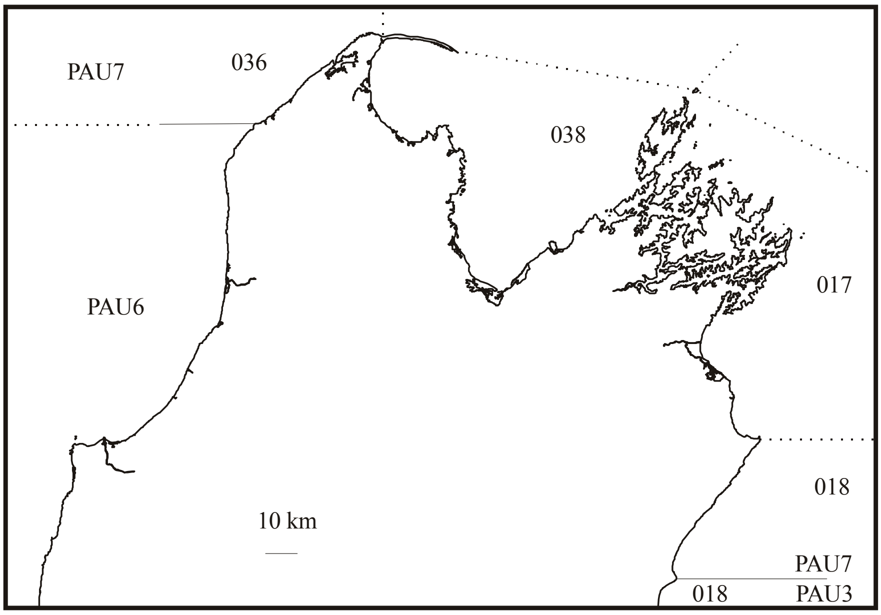
PAUA (PAU 7) – Marlborough

(*Haliotis iris*)
Paua



1. FISHERY SUMMARY

1.1 Commercial fisheries

PAU 7 was introduced into the Quota Management System in 1986–87 with a TACC of 250 t, which increased to 267.48 t as a result of the appeal process. For 2000–01 the commercial sector voluntarily shelved 20% of the TACC. In 2001–02 the TACC was reduced by 10%, and in 2002–03 the TACC was reduced to 187.24 t. For 2003–04 to 2006–07, the industry shelved 15% of the TACC. Estimated landings for PAU 7 are shown in Table 1.

Table 1: TACC and reported landings (t) of paua in PAU 7 from 1995–96 to 2007–08. The last column shows the TACC after shelving has been accounted for.

Year	Landings	TACC	TACC after shelving
1995–96	268.7	267.48	267.48
1996–97	267.6	267.48	267.48
1997–98	266.7	267.48	267.48
1998–99	265.1	267.48	267.48
1999–00	264.6	267.48	267.48
2000–01	215.9	*267.48	213.98
2001–02	187.1	240.73	240.73
2002–03	187.2	187.24	187.24
2003–04	159.6	*187.24	159.15
2004–05	166.9	*187.24	159.15
2005–06	183.4	*187.24	159.15
2006–07	176.0	*187.24	159.15
2007–08	186.9	187.24	–

*voluntary shelving in place

1.2 Recreational fisheries

The 1996 National Marine Recreational Fishing Survey estimated 23,000 paua taken in PAU 7. The 1999-2000 and 2000-01 national surveys estimated 15.8 t and 7.7 t respectively. The Marine Recreational Fisheries Technical Working Group (RFTWG) has considered the harvest estimates from the national surveys and concluded that the estimates from the 1996 survey are unreliable due to a methodological error. The RFTWG also concluded that some harvest estimates from the 1999-2000 and 2000-01 surveys for some fish stocks were unbelievably high. For the purpose of the stock assessment, the Shellfish Fisheries Assessment Working Group agreed to assume that recreational catch was 5 t in 1974 and that it increased linearly to 15 t in 2000, and then remained at 15 t.

1.3 Customary non-commercial fisheries

Customary non-commercial catch was incorporated into the PAU 7 TAC in 2002 as an allowance of 15 t. No historical estimates are available. The Working Group agreed to assume that customary non-commercial catch was 4 t in 1974, increasing linearly to 10 t between 1974 and 2000, and then remained at 10 t.

1.4 Illegal catch

Current illegal catch was estimated by the Ministry of Fisheries to be 10–20 t. No historical estimates are available. The Working Group agreed to assume that illegal catch was 1 t in 1974 and that it increased linearly to 15 t between 1974 and 2000, remaining at 15 t from 2000 through 2005, and then decreased linearly to 7.5 t in 2008. For projections the Working Group agreed to assume that illegal catch would remain at 7.5 t.

1.5 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.

Previously the Working Group has discussed handling mortality, with some suggesting that handling mortality in the past could have been between 15% and 40%. It is difficult to model past handling mortality without more information on selectivity and mortality rates of returned animals. The Working group agreed that handling mortality would not be factored into the model.

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 7 assessment is presented in Table 2. Natural mortality was estimated in the assessment but used a lognormal prior.

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

	Estimate		Source
1. Natural mortality (*M*)			
All	0.02–0.25		Sainsbury (1982)
PAU 7	0.15 (0.12–0.21)	Median (5%–95% C.L.)	estimated by the assessment model
2. Weight = a (length)^b (weight in g, shell length in mm)			
	a = 2.59E–08	b = 3.322	Schiel & Breen (1991)
3. Size at maturity (shell length)			
50% mature	90.7(89.9–91.5) mm Median (5%–95% C.L.)		estimated by the assessment model
length at 95% mature - 50% mature	11.6(9.6–13.4) mm Median (5%–95% C.L.)		estimated by the assessment model
4. Exponential growth parameters (both sexes combined)			
g_{75}	15.4(14.6–16.2) mm Median (5%–95% C.L.)		estimated by the assessment model: growth increment of animal with initial length of 75 mm.
g_{120}	5.7 (5.5–5.9) mm Median (5%–95% C.L.)		estimated by the model: growth increment of animal with initial length of 120 mm.

3. STOCKS AND AREAS

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

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

The 2005 assessment is based on information and catches from Statistical Areas 17 and 38 only. These areas have accounted for an average of 88% (range 65.2% to 99.8%) of the annual commercial catch in PAU 7 since 1990. The catch vector used is composed of all PAU 7 catch prior to 1990, and the percentage of that catch estimated from CELR and PCELR records to have come from areas 17 and 38 between 1990 and 2007. For 2002–03 to 2006–07 the mean percentage of catch from areas 17 and 38 at the time of the assessment was 90.6%, and this percentage of the TACC plus the estimated non-commercial catch was used in projections. A sensitivity was done with zero assumed non-commercial catch.

Better quality of CPUE data became available after 2001, when the old catch and effort landing returns (CELRs) were replaced by paua-specific forms (PCELRs) with much more detailed area information. The two series were standardised separately, using catch per diver-day as the unit for the earlier data and catch per diver-hour for the later.

Catch rates from CELR records (Table 3) were relatively stable through much of the 1990s, although there has been an overall decline since records began in 1982–83. Catch rates from 2001 onwards (Table 4) show a slow increase in the first four years, with significantly higher catch rates for the last two years.

In some circumstances commercial CPUE may not be proportional to abundance (the model suggests it is not directly proportional) 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. Apparent stability in CPUE should therefore be interpreted with caution.

Table 3: Standardised catch per unit effort (CPUE) in PAU 7 from the CELR forms, 1995–96 through 2000–01, shown as kg per diver-day.

Year	CPUE
1982–83	228.8
1983–84	225.5
1984–85	220.2
1985–86	199.7
1986–87	185.2
1987–88	196.4
1988–89	163.0
1989–90	137.7
1990–91	136.3
1991–92	115.6
1992–93	133.0
1993–94	130.9
1994–95	126.0
1995–96	124.6
1996–97	109.9
1997–98	111.1
1998–99	118.8
1999–2000	80.7
2000–01	60.0

Table 4: Standardised catch per unit effort (CPUE) in PAU 7 from the PCELR forms, 2001–02 through 2006–07, shown as kg per diver-hour.

Year	CPUE
2001–02	11.4
2002–03	11.7
2003–04	12.2
2004–05	14.8
2005–06	21.0
2006–07	21.1

The relative abundance of paua in PAU 7 was estimated from research diver surveys in five research strata (Figure 1, Table 5). Surveys made in the West Coasts and Campbell strata were not used.

Table 5: Mean paua abundance (research diver survey index, RDSI) and its standard error for PAU 7.

Year	RDSI	S.E.
1992–93	0.863	0.120
1994–95	1.508	0.191
1995–96	1.363	0.140
1998–99	0.689	0.104
2000–01	0.621	0.103
2002–03	1.062	0.119
2004–05	1.239	0.109

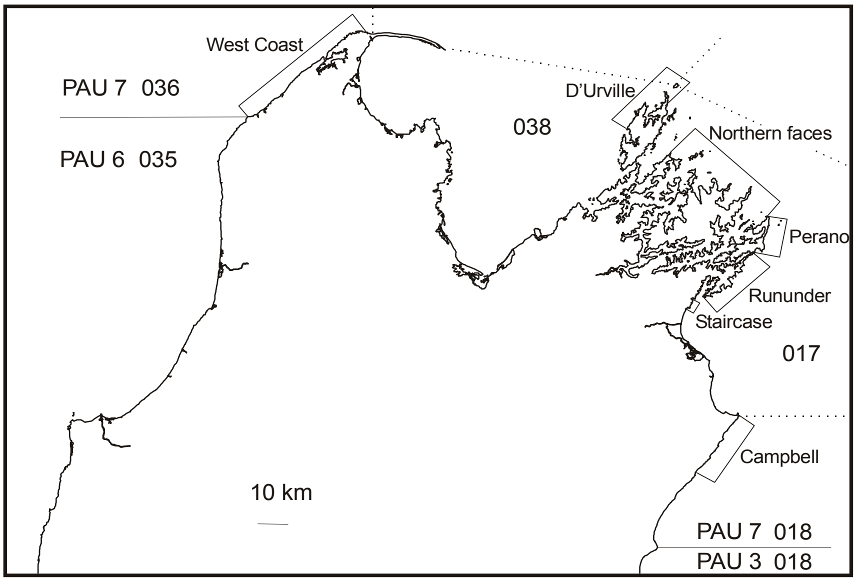


Figure 1: Strata used for independent surveys in PAU 7.

4.2 Assessment model for 2008

4.2.1 Model structure

The length–based model used for the 2005 PAU 7 assessment was slightly revised for the 2008 assessment (Breen & Kim 2005) by incorporating for the tag-recapture data set the common observation error term, which is present for all other data sets. The 2003 model was published by Breen *et al.* (2003).

The model generates a population and simulates its dynamics through 43 years of fishing, growth, natural mortality and recruitment. The model recruited biomass (mid-season biomass in this assessment) is fitted to the observed CPUE indices, and an index of numbers above 90 mm shell length is fitted to the analogous observed index from research diver surveys. The model's mid-season population length structure is fitted to observed length distributions from commercial catch sampling and research diver 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 the von Bertalanffy growth parameters, which are estimated as parameters of the model, and an estimated relation between expected increment and its standard deviation, based on tagging data. A contribution to the total likelihood function comes from comparison of observed and expected increments in the tagging data.

Recruitment is modelled as an estimated baseline value with estimated annual deviations. These have an assumed mean and standard deviation; this and other assumptions 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 modelled for both the commercial and research divers.

The model was applied to seven data sets from statistical areas 17 and 38 in PAU 7: two standardised CPUE series, the standardised research diver survey index, length frequencies from catch sampling and population surveys, tag–recapture data and maturity data.

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) serves as the starting point for the Bayesian estimations and as the basis for some sensitivity tests. Markov chain Monte Carlo (MCMC) simulations were used to estimate the marginal posterior distributions of model parameters, indicators and state of the stock.

Sensitivity tests involved removing each of the seven data sets in turn, using one continuous CPUE series and using an alternative growth model, all based on the MPD estimates, and retrospective and other trials based on full sets of MCMC simulations.

4.2.2 Data used in the assessment

Breen & Kim (2005) summarise the 2005 assessment and the data used. The catch history was estimated by Murray & Akroyd (1984) for 1974–1983, who stated that landings before 1974 were unreliable. Schiel (1989) presented estimates for 1984–1988. Schiel (1992) re-visited the estimates for 1981–85, and previous PAU 7 assessments have used the Schiel (1992) estimates as a base case. The effect of this change (affecting mostly the 1981 and 1982 catches) was explored by Andrew *et al.* (2000) and found to be small. The catch vector used in the assessment (Figure 2) includes a ten-year segment of assumed catches that increase from zero to the first estimated catch: this is to avoid assuming an unfished equilibrium in the first year with a catch estimate.

Figure 2: Assumed catch series used in the assessment. Only catches from Statistical Areas 17 and 38 were used.

Vectors of standardised CPUE from the CELR forms (Table 3) were generated using a multiple regression model (Vignaux 1993). Records from only the vessels that landed the top 75% of the catch in each year were used. The standardisation model accounted for 43% of the total variation in observed CPUE and deviated little from the pattern of decline in raw CPUE through time (Figure 3). Similarly, a standardised index was generated from the PCPUE forms (Table 4). For this the standardisation model accounted for 52% of the total variation and showed a slightly stronger increase than the raw data (Figure 4).

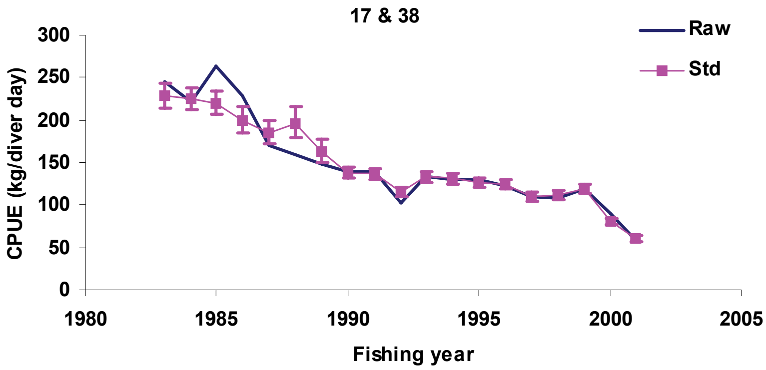


Figure 3: Raw and standardised (with 95% confidence intervals) CPUE (kg per diver day) from CELR forms, from statistical areas 17 and 38 combined.

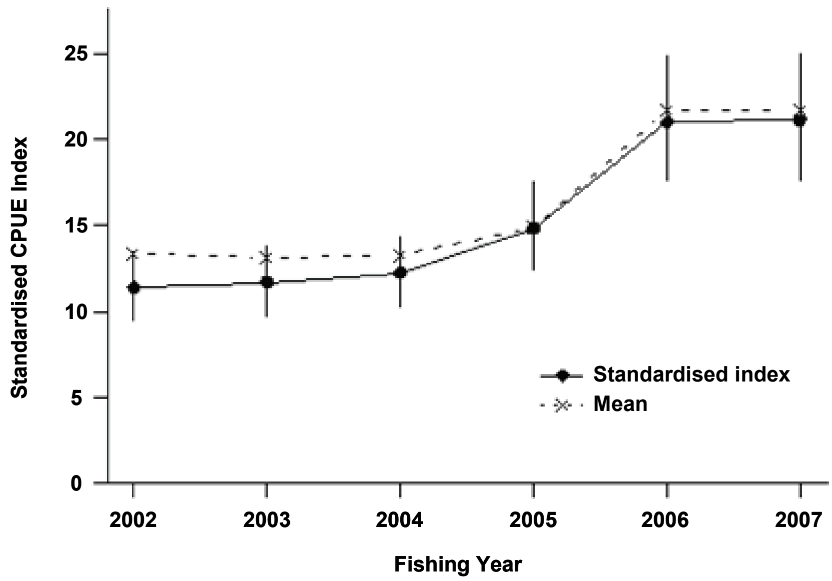


Figure 4: Standardised (with 95% confidence intervals) and unstandardised mean PCPUE (kg per diver hour) from PCELR forms, from statistical areas 17 and 18 combined.

The research diver survey index (RDSI) (Figure 5) was also standardised with a model that accounted for 23% of the variation.

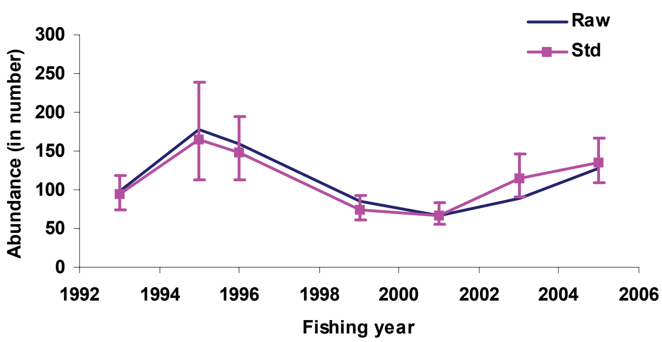


Figure 5: Raw and standardised RDSI from areas 17 and 38 combined. Vertical bars show the 95% confidence intervals.

Assessment model parameters and their priors and bounds are given in Table 6. Other biological assumptions were as follows: The length–weight relationship is as shown in Table 2. Vulnerability to the fishery and vulnerability to sampling of small paua are estimated by the model.

Table 6: PAU 7 model parameters and their priors and bounds and weights.

Model parameters	Definition	Priors and bounds
$\ln(R0)$	Natural log of base recruitment	Uniform in log space Bounds 5 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 0.001 and 50
L_{50}	length at which maturity is 50%	Uniform Bounds 70 and 145
L_{95-50}	distance between lengths at which maturity is 95% and 50%	Uniform Bounds 1 and 50
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 0.01 and 50
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
X	multiplier applied to $\ln(q^I)$ used to produce the scalar for PCPUE	Uniform bounds 0.05 and 1
$\ln(q^J)$	scalar between numbers and the RDSI	Uniform bounds -30 and 0
h	shape of the 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
ε_t	A vector of recruitment deviations in log space	normal, mean 0, cv 0.4 Bounds –2.3 and 2.3
$\tilde{\sigma}$	common standard deviation of observation error	Uniform Bounds 0.01 and 1.0
ϕ	CV of expected growth increments	Uniform Bounds 0.001 and 1

4.2.3 Projections

Because of the high uncertainty associated with projections, the Working group agreed that three year projections would be made. Recruitment for projections was obtained by re-sampling the model estimates from 1997 through 2006.

4.2.4 Fishery indicators

The assessment is based on the following indicators calculated from their posterior distributions: the model's mid-season recruited and spawning biomass from 2008 (current biomass), from 2011 (projected biomass), from the nadir of the population trajectory (B_{MIN} and S_{MIN}) and from a reference period, 1985–87 (B_{REF} 85-87). This was a period when the biomass was relatively stable, production was good and there was a subsequent period when the fishery flourished. The means of values from the three years were called S_{AV} and B_{AV} for spawning and recruited biomass respectively. We also used annual exploitation rate in 2005, U05, and in 2008, U08. Ratios of these reference points are also used.

Six additional indicators are calculated as the percentage of runs in which:

- spawning biomass in 2011 had decreased from 2008: $S_{11} < S_{08}$
- spawning biomass in 2011 was less than the reference level: S11 < S_{AV}
- spawning biomass in 2011 was less than the nadir: $S_{11} < S_{MIN}$
- recruited biomass in 2011 had decreased from 2004: $B_{11} < B_{08}$
- recruited biomass in 2011 was less than the reference level: $B_{11} < B_{AV}$
- recruited biomass in 2011 was less than the nadir: $B_{11} < B_{MIN}$

4.2.5 Stock assessment results

The procedure of iteratively re-weighting the data sets to obtain normalised residuals with a standard deviation of unity worked well in this assessment and was used for the base case. This eliminated the arbitrary weights assigned in previous assessments.

The sensitivity of the model results to individual datasets, and choice of growth model was explored in MPD trials. Sensitivity of the MPD indicators was not great. *M* was sensitive to removal of the CPUE series (the longest abundance index series), but the indicators were not greatly affected. Growth estimates were sensitive to removal of the tag-recapture data set: the model estimated much slower growth when these data were absent, but again the indicators did not change much. Lack of sensitivity to dataset removal suggests redundancy of information among datasets.

Diagnostic plots of the single long MCMC chain suggested that the base case was acceptable. The model provided good fits to most data sets, with some systematic trends in the residuals for proportions-at-length. Other indications were that the model fit the data well. MCMC retrospective analyses had good stability. Trials with different values for the assumed maximum exploitation rate, $U^{\max}$, showed that the model was sensitive to this assumption. When the value was changed from 0.80, the base case, to 0.90, there was little effect, but a decrease to 0.65 produced unrealistic estimates of *M*, made the biomass trajectories very different (Figure 7) and made the projections less optimistic.

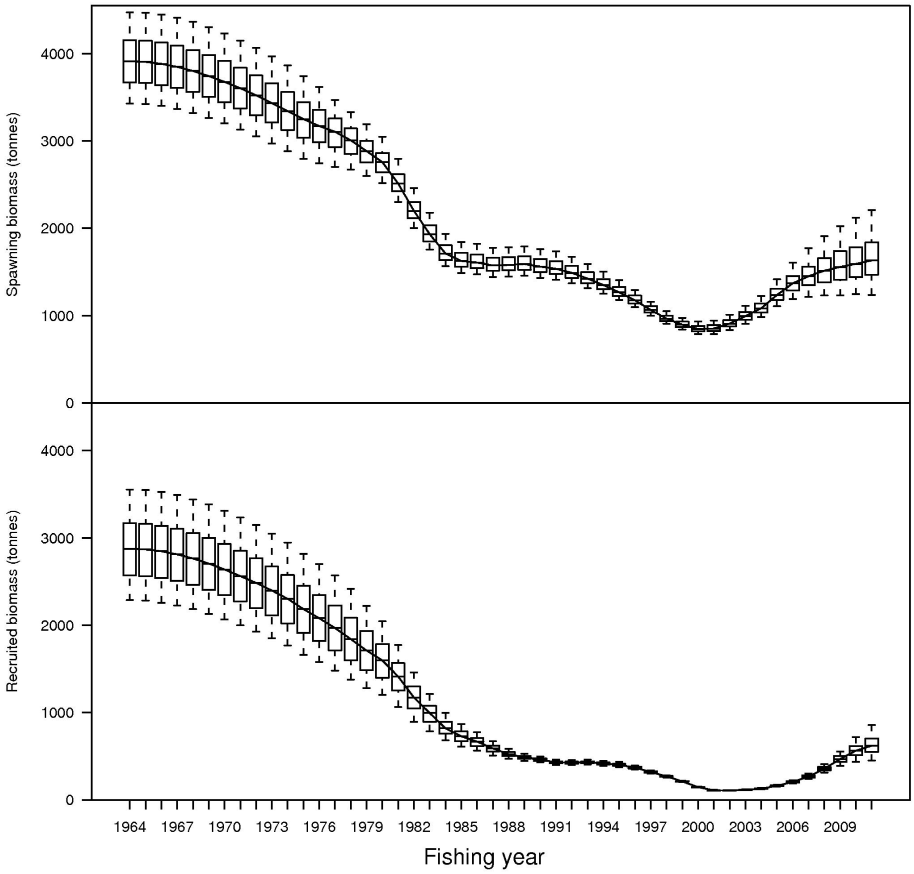


Figure 6: The posterior biomass trajectories for spawning (upper) and recruited (lower) biomass for the base case for PAU 7. For each year, the figure shows the median of the posterior (horizontal bar), the 25th and 75th percentiles (box) and 5th and 95th percentiles of the posterior.

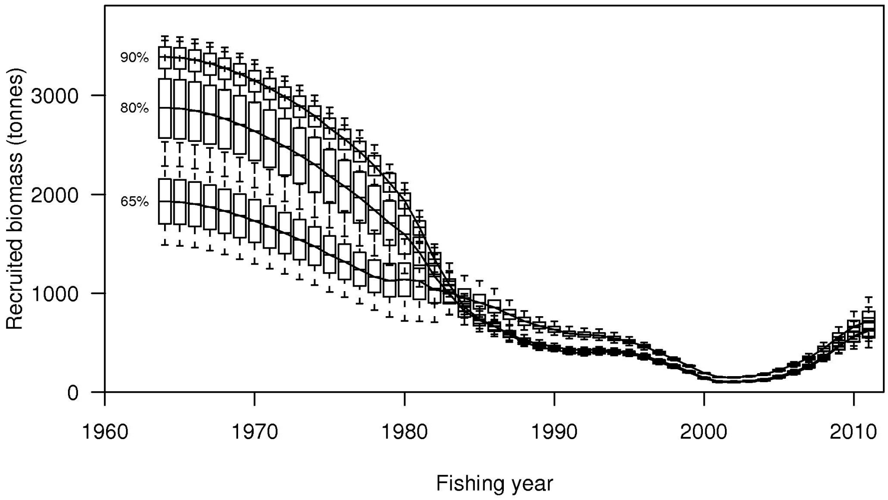


Figure 7: Recruited biomass trajectories from the MCMC sensitivity trials in which maximum allowed exploitation rate was varied from 80% in the base case to 65% and 90%. The 65% trial is the line that is lowest on the left and highest in the early 2000s.

Indicators based on the base case posterior distributions are given in Table 7. These projections assume the current catch estimates. Current spawning biomass is estimated to be 1513 t, 77% greater than the historical minimum spawning biomass and 93% of the reference level. Current recruited biomass (the mid-season biomass of paua larger than 125 mm) was estimated to be 357 t. This is 234% larger than the historical minimum, but only 54% of the reference level. Current exploitation rate is 37%, but this estimate is poorly determined because it depends on the assumed $U^{\max}$.

Projections made at the estimated current catch level (202.0 t) show that the stock will rebuild under catch levels. Biomass in the projections almost always increased, reaching reference levels about 50% of time. Spawning biomass increased by a median 8%, and recruited biomass by a median 73%. Exploitation rate declined to a median 25%. The speed of rebuilding towards reference levels depends on catch levels. At no level of catch does median recruited biomass reach the reference level in three years, and for spawning biomass this happens only with very large catch reductions. Three years is an unrealistic time for reaching the reference levels, given the dynamics of this species and the current levels of depletion.

Table 7: Summary of the marginal posterior distributions from the MCMC chain from the base case for PAU 7. The columns show the 5th and 95th percentiles and the medians of posterior distributions. The last six rows show the percentage of runs for which the indicator was true. Biomass is in tonnes.

	5%	median	95%
U08	33%	37%	42%
U11	19%	25%	33%
Smin	785	845	929
Sav	1 465	1 603	1 812
S08	1 230	1 513	1 908
S09	1 230	1 555	2 021
S10	1 245	1 591	2 120
S11	1 237	1 630	2 206
Bmin	103	107	112
Bav	564	662	764
B08	311	357	412
B09	389	467	554
B10	437	563	717
B11	450	619	859
S08/S_{AV}	79%	93%	114%
S08/S_{MIN}	149%	177%	217%
S11/S_{AV}	78%	101%	133%
S11/S08	95%	108%	124%
B08/B_{AV}	46%	54%	65%
B08/B_{MIN}	288%	334%	385%
B11/B_{AV}	67%	94%	132%
B11/B08	134%	173%	229%
S11<S08		18%	
S11<S_{AV}		48%	
B11<B_{AV}		62%	

Table 8: Total catches (kg) used for projections with alternative catches for the non-commercial catch. For the zero scenario the non-commercial catch is taken to be zero in the projection years (2009, 2010, 2011). In the base scenario the non-commercial catch in the projection years is taken to equal that in 2008. For the ramp scenario the linear ramp in the non-commercial catch from 1974 to 2000 is continued to 2011. For all scenarios the commercial catch in the projection years is equal to the estimated commercial catch in 2008.

Fishing Year	base	zero	ramp
2000	238 419	238 419	238 419
2001	180 731	180 731	184 056
2002	178 492	178 492	185 142
2003	204 755	204 755	214 730
2004	185 191	185 191	198 491
2005	183 568	183 568	200 193
2006	211 695	211 695	234 145
2007	196 968	196 968	225 243
2008	202 065	202 065	236 165
2009	202 065	169 565	237 365
2010	202 065	169 565	238 365
2011	202 065	169 565	239 565

Table 9: Summary of results from projections using alternative maximum exploitation rates and non-commercial catches. Numbers shown for the exploitation rate in 2011 (U11) and biomass ratios are median values. In all runs, the median biomass exceeded B_{MIN} and S_{MIN}. MaxER65 denotes a maximum exploitation rate of 0.65.

	U11	S11/Sav	S11/S08	P(S11 < S_{AV})	P(S11 < S08)	B11/B_{AV}	B11/B08	P(B11 < B_{AV})
base	0.25	1.01	1.08	0.48	0.18	0.94	1.73	0.62
MaxER65	0.22	0.93	1.02	0.67	0.43	0.85	1.65	0.81
MaxER90	0.25	1.04	1.08	0.39	0.11	0.99	1.88	0.51
zero	0.20	1.06	1.13	0.35	0.05	1.05	1.94	0.41
ramp	0.30	1.04	1.04	0.38	0.32	0.92	1.63	0.63

4.3 Biomass estimates

Biomass estimates from posterior distributions are given in Table 7 and shown in Figure 6. The median mid-season biomass for paua larger than 125 mm in 2004–05 was estimated to be 357 t (with 5^{th} and 95^{th} percentiles of 311 and 412 respectively). This represents a decrease from the biomass (662 t) estimated for the period between 1985–87 (a period when, the model suggests, exploitation rates were moderate and the biomass had just entered a period of relative stability). The median spawning biomass in 2007–08 was estimated to be 1513 t (with 5^{th} and 95^{th} percentiles of 1230 and 1908 respectively). This is a decrease from the spawning biomass (1603 t) estimated for the period 1985–87.

4.4 Sensitivities

The base case assessment results described above have more uncertainty than that reflected in the posterior distributions. These results come from a single base case chosen from a wide range of possibilities, although the choice of a base case was reasonably objective. The most important uncertainty is the choice of $U^{\max}$, affecting both the estimated current status of the stock and the strength of rebuilding.

The tight ranges for most model estimates derive from the model's exploitation rate reaching its bound, $U^{\max}$. Sensitivity trials show that assuming other values for $U^{\max}$ has little effect on recent biomass estimates and trends, but assuming 0.65 leads to unrealistic M estimates and quite different biomass trajectories. The target reference points are sensitive to $U^{\max}$ but the limit reference points are not. This is the major uncertainty of the assessment.

4.5 Estimation of Maximum Constant Yield (MCY)

No estimate of MCY has been made for PAU 7. A range of more robust performance indicators that cover a range of management alternatives (TACCs) is presented.

4.6 Estimation of Current Annual Yield (CAY)

No estimate of CAY has been made for PAU 7. A range of more robust performance indicators that cover a range of management alternatives (TACCs) is presented.

4.7 Other yield estimates and stock assessment results

The assessment model was used to predict the likely effects of alternative catch levels between 2006 and 2008 and these (Table 9) suggest that lower catch levels increase the speed of rebuilding.

4.8 Other factors

Another source of uncertainty outside the model is the 2008 catch. The assessment uses a value based on the TACC, and uses an estimate of the proportion of PAU 7 catch that comes from areas 17 and 38 for the previous five years. Differences between the estimated and actual catch for 2008 in areas 17 and 38 could affect the strength of rebuilding predicted by the assessment.

The next source of uncertainty comes from the data. The commercial catch before 1974 is unknown and, although we think the effect is minor. Major differences may exist between the catches we assume and what was taken. In addition, non-commercial catch estimates are poorly determined and could be substantially different from what was assumed, although generally non-commercial catches appear to relatively small compared with commercial catch. The illegal catch is particularly questionable.

The tagging data may not fully reflect 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 high precision: after 1999 the number of paua measured from area 38 has been only 500 or less.

The research diver data comprise seven surveys, but for some the standard errors are quite large and length frequencies may not be fully representative of the population.

The model treats the sub-stock of PAU 7 as if it were a single stock with homogeneous biology, habitat and fishing pressures. This mean the model assumes homogeneity in recruitment, natural mortality, which does not vary by size or year and growth has the same mean and variance (we know this is violated because some areas are stunted and some are fast-growing).

It is unknown to what extent a homogenous model makes biased predictions about a heterogeneous stock. Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on increments observed in several different places; similarly the length frequency data are integrated across samples from many places.

The effect 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. Therefore, local processes may decrease recruitment, an effect that the current model cannot account for. The assumption made by the model that CPUE is an index of abundance could be suspect. There is a large literature for abalone that suggests CPUE is difficult to use in abalone stock assessments because of serial depletion. This can happen 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. In areas 17 and 38 the exploitation rate has been high and few undepleted areas are likely to remain. The main problem affects the model's estimates of the early fishery, but in this assessment, the degree of hyperstability appeared reasonably well determined.

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

5. STATUS OF THE STOCKS

A Bayesian length-based stock assessment model was applied to PAU 7 to estimate stock status and yield. 1985–87 was chosen as a reference period, because the model suggests that in these years biomass had stabilised following a 'fishing down' period that started in the 1970s, and the exploitation rate was moderate compared to later years.

The assessment shows a depleted stock. The current spawning and recruited biomass levels are both much lower than they were when the catch data begin in 1974 or CPUE data begin in 1983. Both are lower than the agreed reference levels from 1985–87: spawning biomass has a median of 93%, with 5–95% range of 79–114%; recruited biomass has a median of 54% (46–65%). Both medians are below the agreed limit biomass reference points. Current exploitation (poorly determined because it depends on the assumed value for $U^{\max}$) is estimated to be 37% (33–42%).

Under the base case the model predicts that the stock may reach the reference level within 3 years.

Assessment results suggest that the current catch level is sustainable and the stock is likely to increase over three years. The list of cautions discussed above under "other factors" should be read in conjunction with this statement. Potential problems with the model are likely to cause model results to be optimistic.

Table 10: Summary of TACC (t) and reported landings (t) of paua in PAU 7 for 2007–08 fishing year.

QMA	Actual TACC	Reported landings
PAU 7	187.24	186.85

6. FOR FURTHER INFORMATION

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