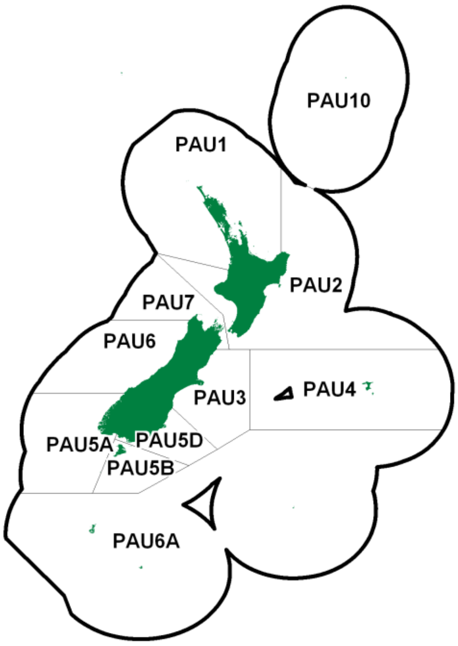
PAUA (PAU)

(*Haliotis iris, Haliotis australis*)
Paua



1. INTRODUCTION

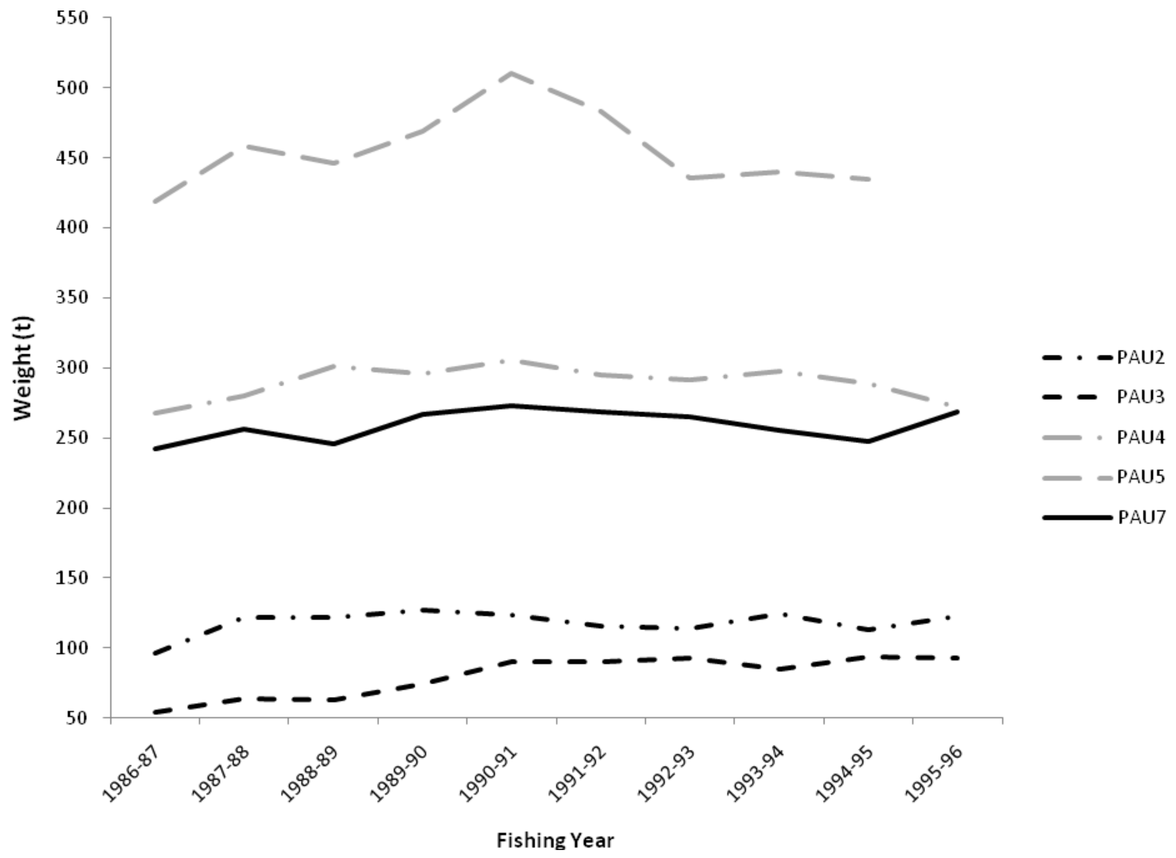
Specific Working Group reports are given separately for PAU 2, PAU 3, PAU 4, PAU 5A, PAU 5B, PAU 5D and PAU 7. The TACC for PAU 1, PAU 6 and PAU 10 is 1.93 t, 1 t and 1 t respectively. Commercial landings for PAU 10 since 1983 have been 0 t.

1.1 Commercial fisheries

The commercial fishery for paua dates from the mid-1940s. In the early years of this commercial fishery the meat was generally discarded and only the shell was marketed, however by the late 1950s both meat and shell were being sold. Since the 1986–87 fishing season, the eight Quota Management Areas have been managed with an individual transferable quota system and a total allowable catch (TAC) that is made up of; total allowed commercial catch (TACC), recreational and customary catch and other sources of mortality.

Fishers gather paua by hand while free diving (use of underwater breathing apparatus is not permitted). Most of the catch is from the Wairarapa coast southwards: the major fishing areas are in the South Island, Marlborough (PAU 7), Stewart Island (PAU 5A, 5B and 5D) and the Chatham Islands (PAU 4). Virtually the entire commercial fishery is for the black-foot paua, *Haliotis iris*, with a minimum legal size for harvesting of 125 mm shell length. The yellow-foot paua, *H. australis* is less abundant than *H. iris* and is caught only in small quantities; it has a minimum legal size of 80 mm. Catch statistics include both *H. iris* and *H. australis*.

Up until the 2002 fishing year, catch was reported by general statistical areas, however from 2002 onwards, a more finely scaled system of paua specific statistical areas were put in place throughout each QMA (refer to the QMA specific Working Group reports). Figure 1 shows the historical landings for the main PAU stocks. On 1 October 1995 PAU 5 was divided into three separate QMAs: PAU 5A, PAU 5B and PAU 5D.



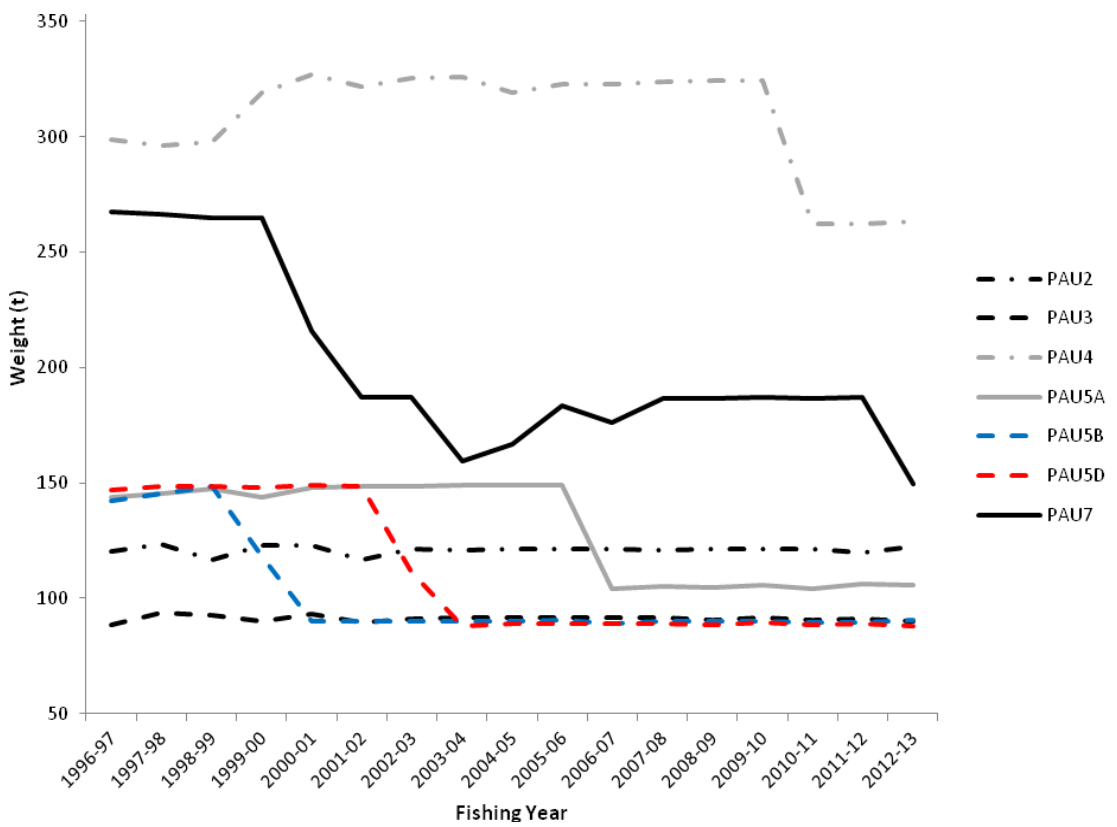


Figure 1: Historic landings for the major paua QMAs from 1983–84 to 1995–96 (top) and from 1996–97 to present (lower).

Landings for PAU 1, PAU 6, PAU 10 and PAU 5 (prior to 1995) are shown in Table 1. For information on landings specific to other paua QMAs refer to the specific Working Group reports.

Table 1: TACCs and reported landings (t) of paua by Fishstock from 1983–84 to present.

	PAU 1		PAU 5		PAU 6		PAU 10	
PAU	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	1	-	550	-	0.00	-	0.00	-
1984–85*	0	-	353	-	3.00	-	0.00	-
1985–86*	0	-	228	-	0.00	-	0.00	-
1986–87*	0.01	1.00	418.9	445	0.00	1.00	0.00	1.00
1987–88*	0.98	1.00	465	448.98	0.00	1.00	0.00	1.00
1988–89*	0.05	1.93	427.97	449.64	0.00	1.00	0.00	1.00
1989–90	0.28	1.93	459.46	459.48	0.00	1.00	0.00	1.00
1990–91	0.16	1.93	528.16	484.94	0.23	1.00	0.00	1.00
1991–92	0.27	1.93	486.76	492.06	0.00	1.00	0.00	1.00
1992–93	1.37	1.93	440.15	442.85	0.88	1.00	0.00	1.00
1993–94	1.05	1.93	440.39	442.85	0.10	1.00	0.00	1.00
1994–95	0.26	1.93	436.13	442.85	18.21H	1.00	0.00	1.00
1995–96	0.99	1.93	-	-	28.62H	1.00	0.00	1.00
1996–97	1.28	1.93	-	-	0.11	1.00	0.00	1.00
1997–98	1.28	1.93	-	-	0.00	1.00	0.00	1.00
1998–99	1.13	1.93	-	-	0.00	1.00	0.00	1.00
1999–00	0.69	1.93	-	-	1.04	1.00	0.00	1.00
2000–01	1.00	1.93	-	-	0.00	1.00	0.00	1.00
2001–02	0.32	1.93	-	-	0.00	1.00	0.00	1.00
2002–03	0.00	1.93	-	-	0.00	1.00	0.00	1.00
2003–04	0.05	1.93	-	-	0.00	1.00	0.00	1.00
2004–05	0.27	1.93	-	-	0.00	1.00	0.00	1.00
2005–06	0.45	1.93	-	-	0.00	1.00	0.00	1.00
2006–07	0.76	1.93	-	-	1.00	1.00	0.00	1.00
2007–08	1.14	1.93	-	-	1.00	1.00	0.00	1.00
2008–09	0.47	1.93	-	-	1.00	1.00	0.00	1.00
2009–10	0.20	1.93	-	-	1.00	1.00	0.00	1.00
2010–11	0.12	1.93	-	-	1.00	1.00	0.00	1.00
2011–12	0.77	1.93	-	-	1.00	1.00	0.00	1.00
2012-13	1.06	1.93	-	-	1.00	1.00	0.00	1.00
2013-14	0.71	1.93	-	-	1.00	1.00	0.00	1.00

H experimental landings
* FSU data

1.2 Recreational fisheries

There is a large recreational fishery for paua. Estimated catches from telephone and diary surveys of recreational fishers (Teirney et al 1997, Bradford 1998, Boyd & Reilly 2004, Boyd et al 2004, Wynne-Jones et al 2014) are shown in Table 2. In 1996–97 sufficient diary data were available for an estimate in PAU 5D only (Bradford 1998, NIWA unpublished data). The Marine Recreational Fisheries Technical Working Group (RFTWG) has reviewed the harvest estimates from the national surveys. Due to a methodological error in the methodology, the harvest estimates for 1991–92 to 1993–94 and 1996–97 are not considered to be reliable. The harvest estimates for the 1999–2000 and 2000–01 surveys may be very inaccurate and some implausibly high. This may be due to a number of factors including the accuracy of the mean weight used to derive total harvest weight from the estimated numbers of paua caught by diarists, and the small number of diarists harvesting the stock in some areas. However relative comparisons can be made between stocks within the surveys.

Table 2: Estimated annual harvest of paua (t) by recreational fishers*.

Fishstock	PAU 1	PAU 2	PAU 3	PAU 5	PAU5A	PAU5B	PAU 5D	PAU 6	PAU 7
1991–92	-	-	35–60	50–80	-	-	-	-	-
1992–93	-	37–89	-	-	-	-	-	0–1	2–7
1993–94	29–32	-	-	-	-	-	-	-	-
1995–96	10–20	45–65	-	20–35	-	-	-	-	-
1996–97	-	-	-	N/A	-	-	22.5	-	-
1999–00	40–78	224–606	26–46	36–70	-	-	26–50	2–14	8–23
2000–01	16–37	152–248	31–61	70–121	-	-	43–79	0–3	4–11
2011-12	12.6	81.85	16.98	-	0.42	0.82	22.45	-	14.13

*1991–1995 Regional telephone/diary estimates, 1995/96, 1999/00 and 2000/01 National Maine Recreational Fishing Surveys.

1.3 Customary fisheries

There is an important customary use of paua by Maori for food, and the shells have been used extensively for decorations and fishing devices. Limited data is available for reported customary landings in PAU 3; however no information is available for current levels of customary take for any other paua QMA. Kaitiaki are now in place in many areas and estimates of customary harvest can be expected in the future.

1.4 Illegal catch

Current levels of illegal harvests are not known. In the past, annual estimates of illegal harvest for some Fishstocks were provided by MFish Compliance based on seizures. In the current paua stock assessments, nominal illegal catches are used.

1.5 Other sources of mortality

Paua may die from wounds caused by removal desiccation or osmotic and temperature stress if they are bought to the surface. Sub-legal paua may be subject to handling mortality by the fishery if they are removed from the substrate to be measured. Further mortality may result indirectly from being returned to unsuitable habitat or being lost to predators or bacterial infection. Gerring (2003) observed paua (from PAU 7) with a range of wounds in the laboratory and found that only a deep cut in the foot caused significant mortality (40% over 70 days). In the field this injury reduced the ability of paua to right themselves and clamp securely onto the reef, and consequently made them more vulnerable to predators. The tool generally used by divers in PAU 7 is a custom made stainless steel knife with a rounded tip and no sharp edges. This design makes cutting the paua very unlikely (although abrasions and shell damage may occur). 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. His estimate of incidental mortality associated with fishing in PAU 7 was 0.3% of the landed catch. Incidental fishing mortality may be higher in areas where other types of tools and fishing practices are used. Mortality may increase if paua are kept out of the water for a prolonged period or returned onto sand. To date, the stock assessments developed for paua have assumed that there is no mortality associated with capture of undersize animals.

2. BIOLOGY

Paua are herbivores which can form large aggregations on reefs in shallow subtidal coastal habitats. Movement is over a sufficiently small spatial scale that the species may be considered sedentary. Paua are broadcast spawners and spawning is thought to be annual. Habitat related factors are an important source of variation in the post-settlement survival of paua. Growth, morphometrics, and recruitment can vary over short distances and may be influenced by factors such as wave exposure, habitat structure, availability of food and population density. A summary of generic estimates for biological parameters for paua are presented in Table 3. Parameters specific to individual paua QMAs are reported in the specific Working Group reports.

Table 3: Estimates of biological parameters for paua (H. *iris*).

Fishstock		Estimate	Source
1. Natural mortality (*M*)			
All		0.02–0.25	Sainsbury (1982)
2. Weight = a (length)^b (weight in kg, shell length in mm)			
	a = 2.99E^{-08}	b = 3.303	Schiel & Breen (1991)

3. STOCKS AND AREAS

Using both mitochondrial and microsatellite markers Will & Gemmell (2008) found high levels of genetic variation within samples of *H. Iris* taken from 25 locations spread throughout New Zealand. They also found two patterns of weak but significant population genetic structure. Firstly, *H. iris* individuals collected from the Chatham Islands were found to be genetically distinct from those collected from coastal sites around the North and South Islands. Secondly a genetic discontinuity was found loosely associated with the Cook Strait region. Genetic discontinuities within the Cook Strait region have previously been identified in sea stars, mussels, limpets, and chitons and are possibly related to contemporary and/or past oceanographic and geological conditions of the region. This split may have some implications for management of the paua stocks, with populations on the south of the North Island, and the north of the South Island potentially warranting management as separate entities; a status they already receive under the zonation of the current fisheries regions, PAU 2 in the North Island, and PAU 7 on the South Island.

4. STOCK ASSESSMENT

The dates of the most recent survey or stock assessment for each QMA are listed in Table 4.

Table 4: Recent survey and stock assessment information for each paua QMA

QMA	Type of survey or assessment	Date	Comments
PAU 1	No surveys or assessments have been undertaken		
PAU 2	Relative abundance estimate using standardised CPUE index based on commercial catch	2014	Standardised CPUE showed slight oscillation without trend between 1992 and 2001 and has remained flat from 2002 until 2014.
PAU 3	Quantitative assessment using a Bayesian length based model	2013	For the 2013 stock assessment nine model runs where conducted. The Shellfish Working Group agreed on a base case model which estimated M within the model but fixed the growth parameters as providing a reliable estimate of the status of the stocks in PAU 3 with the caveat that the model most likely underestimated uncertainty in growth but adequately estimated uncertainty in natural mortality.
PAU 4	Quantitative assessment using a Bayesian length based model	2004	In February 2010 the Shellfish Working Group (SFWG) agreed that due to the lack of adequate data as input into the Bayesian length-based model, a stock assessment for PAU 4 using this model was not appropriate. Other performance indicators that could be used as reference points around which to assess the status of the stocks are being evaluated for use in PAU 4
PAU 5A	Quantitative assessment using a Bayesian length based model	2010	The 2014 stock assessment was conducted over two subareas of the QMA. The SFWG was satisfied that the stock assessment for both the Southern and Northern areas was reliable based on the available data.
PAU 5B	Quantitative assessment using a Bayesian length based model	2013	The SFWG were satisfied that the stock assessment provided a reliable estimate of the status of the stocks in PAU 5B. Sensitivity trials addressed uncertainties associated with various aspects of the input data and model assumptions.
PAU 5D	Quantitative assessment using a Bayesian length based model	2012	Four assessment runs were presented and all considered to be equally plausible. All runs showed that it was Very Unlikely the stock will fall below the soft or hard limits over the next three years at current levels of catch, and suggested that biomass would increase. However, the four runs differed in their assessment of the status of the stock relative to the target.
PAU 6	Biomass estimate	1996	This fishery has a TACC of 1 t
PAU 7	Quantitative assessment using a Bayesian length based model	2012	The SFWG agreed that the stock assessment was reliable based on the available data. Currently, spawning stock biomass is estimated at 22% B_0 Results suggest an increase to 23.4% B_0 in over the next three years at current levels of catch.
PAU 10	No surveys or assessments have been undertaken		

4.1 Estimates of fishery parameters and abundance

For further information on fishery parameters and abundance specific to each paua QMA refer to the specific Working Group report.

In 2008 standardised CPUE indices were constructed to assess relative abundance in PAU 2. In QMAs where quantitative stock assessments have been undertaken, standardised CPUE is also used as input data for the Bayesian length-based stock assessment model. There is however a large amount of literature on abalone which suggests that any apparent stability in CPUE should be interpreted with caution and CPUE may not be proportional to abundance as it is possible to maintain high catch rates despite a falling biomass. This occurs because paua tend to aggregate and in order to maximise their catch rates divers' move from areas that have been depleted of paua, to areas with higher density. The consequence of this fishing behaviour is that overall abundance is decreasing while CPUE is remaining stable. This process of hyperstability is believed to be of less concern in PAU 3, PAU 5D and PAU 7 because fishing in these QMAs is consistent across all fishable areas.

In PAU 4, 5A, 5B, 5D and 7 the relative abundance of paua has also been estimated from independent research diver surveys (RDS). In PAU 7, seven surveys have been completed over a number of years but only two surveys have been conducted in PAU 4. In 2009 and 2010 several reviews were conducted (Cordue (2009) and Haist V (2010 MPI .FRR) to assess; i) the reliability of the research diver survey index as a proxy for abundance; and ii) whether the RDS data, when used in the paua stock assessment models, results in model outputs that do not adequately reflect the status of the stocks. The reviews concluded that:

- Due to inappropriate survey design the RDS data appear to be of very limited use for constructing relative abundance indices.
- There was clear non-linearity in the RDS index, the form of which is unclear and could be potentially complex.
- CVs of RDS index 'year' effects are likely to be underestimated, especially at low densities.
- Different abundance trends among strata reduces the reliability of RDS indices, and the CVs are likely not to be informative about this.
- It is unlikely that the assessment model can determine the true non-linearity of the RDS index-abundance relationship because of the high variability in the RDS indices.
- The non-linearity observed in the RDS indices is likely to be more extreme at low densities, so the RDSI is likely to mask trends when it is most critical to observe them.
- Existing RDS data is likely to be most useful at the research stratum level.

4.2 Biomass estimates

Biomass was estimated for PAU 6 in 1996 (McShane et al 1996). However the survey area was only from Kahurangi Point to the Heaphy River.

Biomass has been estimated, as part of the stock assessments, for PAU 4, 5A, 5B, 5D and 7 (Table 4). For further information on biomass estimates specific to each paua QMA refer to the specific Working Group report.

4.3 Yield Estimates and Projections

Yield estimates and projections are estimated as part of the stock assessment process. Both are available for PAU 5A, 5D and 7. For further information on yield estimates and projections specific to each paua QMA refer to the specific Working Group report.

4.4 Other factors

In the last few years the commercial fishery have been implementing voluntary management actions in the main QMAs. These management actions include raising the minimum harvest size and subdividing QMAs into smaller management areas and capping catch in the different areas

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

5.1. Ecosystem role

Paua are eaten by a range of predators, and smaller paua are generally more vulnerable to predation. Smaller paua are consumed by blue cod (Carbines and Beentjes 2003), snapper (Francis 2003), banded wrasse (Russell 1983), spotties (McCardle 1983), triplefins (McCardle 1983) and octopus (Andrew & Naylor 2003). Large paua are generally well protected by their strong shells, but are still vulnerable to rock lobsters (McCardle 1983), the large predatory starfishes *Astrostole scabra* and *Coscinasterias muricata* (Andrew & Naylor 2003). Large paua are also vulnerable to predation by eagle rays (McCardle 1983), but Ayling & Cox (1982) suggested that eagle rays feed almost exclusively on Cook's turban. There are no known predators that feed exclusively on paua.

Paua feed preferentially on drift algae but at high densities they also feed by grazing attached algae. They are not generally considered to have a large structural impact upon algal communities but at high densities they may reduce the abundance of algae. There are no recognised interactions with paua abundance and the abundance or distribution of other species, with the exception of kina which, at very high densities, appear to exclude paua (Andrew et al 2000). Research at D'Urville Island and on Wellington's south coast suggests that there is some negative association between paua and kina (Andrew & MacDiarmid 1999).

5.2. Fish and invertebrate bycatch

Because paua are harvested by hand gathering, incidental bycatch is limited to epibiota attached to, or within the shell. The most common epibiont on paua shell is non-geniculate coralline algae, which, along with most other plants and animals which settle and grow on the shell, such as barnacles, oysters, sponges, bryozoans, and algae, appears to have general habitat requirements (i.e. these organisms are not restricted to the shells of paua). Several boring and spiral-shelled polychaete worms are commonly found in and on the shells of paua. Most of these are found on several shellfish species, although within New Zealand's shellfish, the onuphid polychaete *Brevibrachium maculatum* has been found only in paua shell Handley, S. (2004). This species; however, has been reported to burrow into limestone, or attach its tube to the holdfasts of algae (Read 2004). It is also not uncommon for paua harvesters to collect predators of paua (mainly large predatory starfish) while fishing and to effectively remove these from the ecosystem. The levels of these removals are unlikely to have a significant effect on starfish populations (nor, in fact, on the mortality of paua caused by predation).

5.3. Incidental catch (seabirds, mammals, and protected fish)

There is no known bycatch of threatened, endangered, or protected species associated with the hand gathering of paua.

5.44. Benthic interactions

The environmental impact of paua harvesting is likely to be minimal because paua are selectively hand gathered by free divers. Habitat contact by divers at the time of harvest is limited to the area of paua foot attachment, and paua are usually removed with a blunt tool to minimise damage to the flesh. The diver's body is also seldom in full contact with the benthos. Vessels anchoring during or after fishing have the potential to cause damage to the reef depending on the type of diving operation (in many cases, vessels do not anchor during fishing). Damage from anchoring is likely to be greater in areas with fragile species such as corals than it is on shallow temperate rocky reefs. Corals are relatively abundant at shallow depths within Fiordland, but there are seven areas within the sounds with significant populations of fragile species where anchoring is prohibited.

5.5. Other considerations

5.5.1 Genetic effects

Fishing, environmental changes, including those caused by climate change or pollution, could alter the genetic composition or diversity of a species and there is some evidence to suggest that genetic changes may occur in response to fishing of abalones. Miller et al (2009) suggested that, in *Haliotis rubra* in Tasmania, localised depletion will lead to reduced local reproductive output which may, in turn, lead to an increase in genetic diversity because migrant larval recruitment will contribute more to total larval recruitment. Enhancement of paua stocks with artificially-reared juveniles has the potential to lead to genetic effects if inappropriate broodstocks are used.

5.5.2 Biosecurity issues

Undaria pinnatifida is a highly invasive opportunistic kelp which spreads mainly via fouling on boat hulls. It can form dense stands underwater, potentially resulting in competition for light and space which may lead to the exclusion or displacement of native plant and animal species. *Undaria* may be transported on the hulls of paua dive tenders to unaffected areas. Bluff Harbour, for example, supports a large population of *Undaria*, and is one of the main ports of departure for fishing vessels harvesting paua in Fiordland, which appears to be devoid of *Undaria* (R. Naylor, personal observation). In 2010, a small population of *Undaria* was found in Sunday Cove in Breaksea Sound, and attempts to eradicate it appear to have been successful (see http://www.biosecurity.govt.nz/pests/undaria).

6. STATUS OF THE STOCKS

The status of paua stocks PAU 2, PAU 3, PAU 4, PAU 5A, PAU 5B, PAU 5D and PAU 7 are given in the relevant Working Group reports.

7. FOR FURTHER INFORMATION

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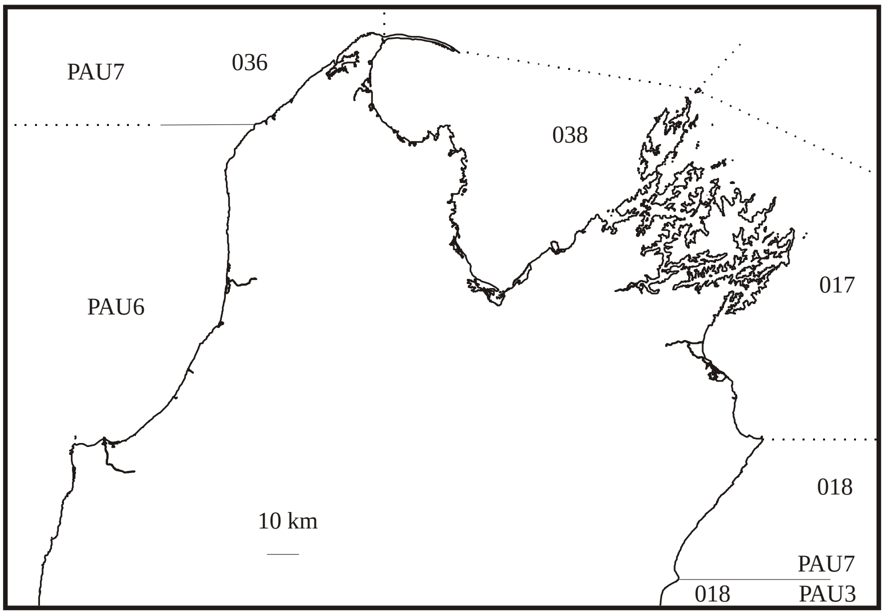
PAUA (PAU 7) – Marlborough

(Haliotis iris)
Paua



1. FISHERY SUMMARY

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

Table 1: Total allowable catches (TAC, t) allowances for customary fishing, recreational fishing, and other sources of mortality (t) and Total Allowable Commercial Catches (TACC, t) declared for PAU 7 since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–89	-	-	-	-	250.00
1989–2001					267.48
2001–02	273.73	15	15	3	240.73
2002–present	220.24	15	15	3	187.24

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. In 2001–02 concerns about the status of the PAU 7 fishery led to a decision by the commercial sector to voluntarily shelve 20% of the TACC for that fishing year. From the 2003–04 to the 2006–07 fishing years the industry proposed to shelve 15% of the TACC. The proposal met with varying success, with less than 15% of the ACE being shelved in three of the four years.

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

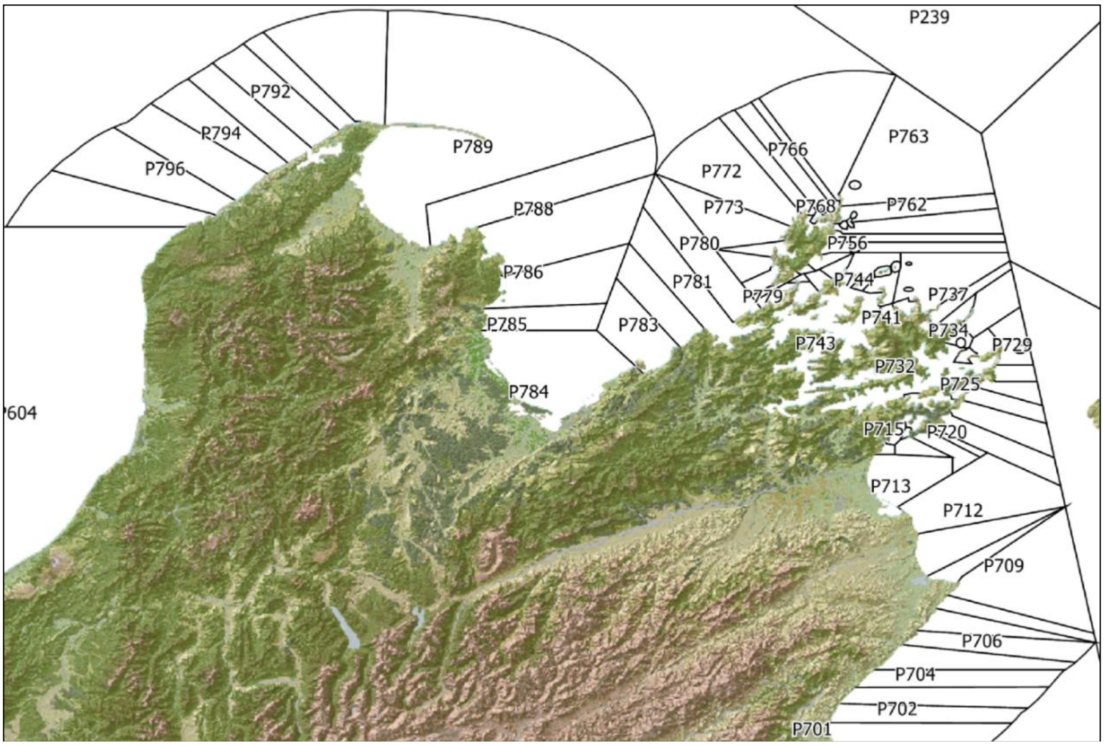


Figure 1: Map of fine scale statistical reporting areas for PAU 7.

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

Year	Landings (kg)	TACC (t)	After shelving	Year	Landings (kg)	TACC (t)	After shelving
1973–74	147 440	-	-	1994–95	247 108	266.17	266.17
1974–75	197 910	-	-	1995–96	268 742	267.48	267.48
1975–76	141 880	-	-	1996–97	267 594	267.48	267.48
1976–77	242 730	-	-	1997–98	266 655	267.48	267.48
1977–78	201 170	-	-	1998–99	265 050	267.48	267.48
1978–79	304 570	-	-	1999–00	264 642	267.48	267.48
1979–80	223 430	-	-	2000–01	215 920	267.48	*213.98
1980–81	490 000	-	-	2001–02	187 152	240.73	240.73
1981–82	370 000	-	-	2002–03	187 222	187.24	187.24
1982–83	400 000	-	-	2003–04	159 551	187.24	*159.15
1983–84	330 000	-	-	2004–05	166 940	187.24	*159.15
1984–85	230 000	-	-	2005–06	183 363	187.24	*159.15
1985–86	236 090	-	-	2006–07	176 052	187.24	*159.15
1986–87	242 180	250	250	2007–08	186 845	187.24	187.24
1987–88	255 944	250	250	2008–09	186 846	187.24	187.24
1988–89	246 029	250	250	2009–10	187 022	187.24	187.24
1989–90	267 052	263.53	263.53	2010–11	187 240	187.24	187.24
1990–91	273 253	266.24	266.24	2011–12	186 980	187.24	187.24
1991–92	268 309	266.17	266.17	2012-13	149 755	187.24	187.24
1992–93	264 802	266.17	266.17	2013-14	145 523	187.24	187.24
1993–94	255 472	266.17	266.17				

* Voluntary shelving

1.2 Recreational fisheries

For the purpose of the stock assessment, the Shellfish Working Group (SFWG) agreed to assume that recreational catch was 5 t in 1974 and that it increased linearly to 15 t in 2000, and then remained at 15 t. For further information on recreational fisheries refer to the introductory PAU Working Group Report.

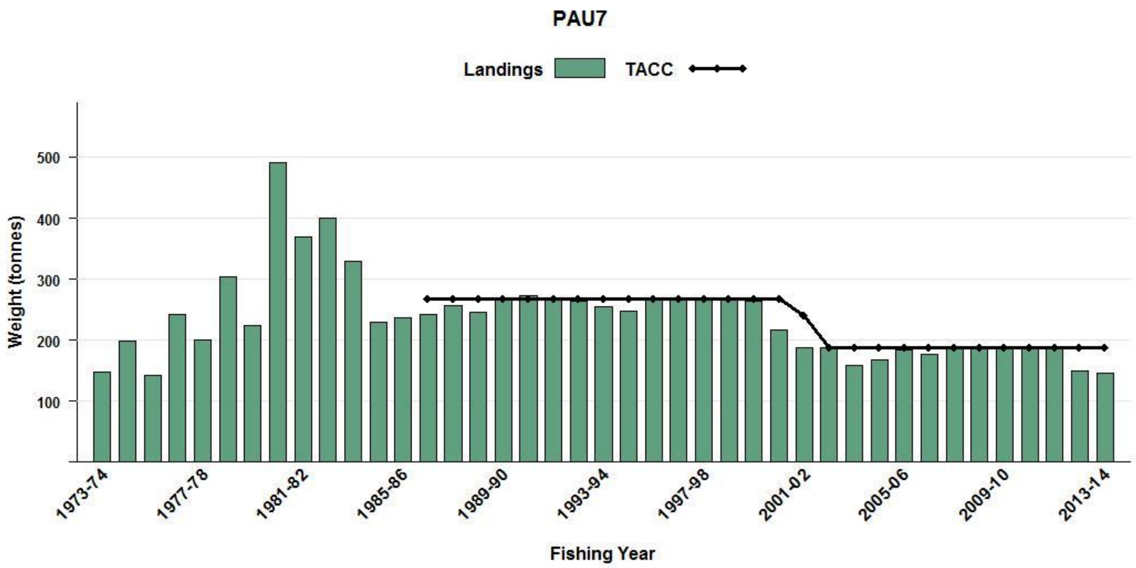


Figure 2: Reported commercial landings and TACC for PAU 7 from 1986–87 to present.

1.3 Customary fisheries

For the purpose of the stock assessment the SFWG agreed to assume that customary catch was 4 t in 1974, increasing linearly to 10 t between 1974 and 2000, and then remaining at 10 t. For further information on customary fisheries refer to the introductory PAU Working Group Report.

1.4 Illegal catch

For the purpose of the stock assessment the SFWG 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 to 2005, and then decreasing linearly to 7.5 t in 2008. For projections the Working Group agreed to assume that illegal catch would remain at 7.5 t. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality

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

2. BIOLOGY

For further information on paua biology refer to the introductory PAU Working Group Report. A summary of biological parameters used in the PAU 7 stock assessment is presented in Table 3.

Table 3: Estimates of biological parameters (*H. iris*).

		Estimate	Source
1. Natural mortality (*M*)			
All		0.02–0.25	Sainsbury (1982)
PAU 7	0.14 (0.13–0.15)	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}	25.8(23.0–28.7) mm	Median (5%–95% C.L.)	estimated by the assessment model: growth increment of animal with initial length of 75 mm.
g_{120}	5.5 (5.1–5.8) mm	Median (5%–95% C.L.)	estimated by the model: growth increment

of animal with initial length of 120 mm.

3. STOCKS AND AREAS

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

4. STOCK ASSESSMENT

The stock assessment is implemented as a length-based Bayesian estimation model, with point estimates of parameters based on the mode of the joint posterior distribution, and uncertainty of model estimates investigated using the marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The 2011 assessment was restricted to Statistical Areas 017 and 038 which includes most (over 90%) of the recent catch**.**

4.1 Estimates of fishery parameters and abundance indices

Parameters estimated in the assessment model 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	C.V.	Bounds	
				Lower	Upper
ln(*R0*)	*U*	–	–	5	50
M (Natural mortality)	*LN*	0.1	0.35	0.01	0.5
g_1*(Mean growth at 75 mm)*	*U*	–	–	1	50
g2(Mean growth at 75 mm)	*U*	–	–	0.01	50
φ *(cv of mean growth)*	*U*	–	–	0.001	1
$Ln(q^I)$ (catchability cofficient of CPUE)	*U*	–	–	-30	0
$Ln(q^J)$ *(catchability cofficient of PCPUE)*	*U*	–	–	-30	0
$Ln(q^k)$ (catchability cofficient of RDSI)	*U*	–	–	-30	0
L_{50} (Length at 50% maturity)	*U*	–	–	70	145
$L_{95\text{-}50}$(Length beteen 50% and 95% maturity)	*U*	–	–	1	50
T_{50}(Length at 50% selectivty for the divery survey)	*U*	–	–	70	125
$T_{95\text{-}50}$(Length between 50% and 95% selectivty for the divery survey)	*U*	–	–	0.001	50
D_{50}(Length at 50% selectivty for the divery survey)	*U*	–	–	70	145
$D_{95\text{-}50}$(Length between 50% and 95% selectivty for the divery survey)	*U*	–	–	0.01	50
ϵ (Recruiment deviations)	*N*	0	0.4	-2.3	2.3
h (CPUE shape parameter)	*U*	–	–	0.01	2

The observational data were:

1. A standardised CPUE series covering 1983–2001 based on FSU/CELR data.
2. A standardised CPUE series covering 2002–2011 based on PCELR data.
3. A standardised research diver survey index (RDSI).
4. A research diver survey proportions-at-lengths series (RDLF).
5. A commercial catch sampling length frequency series (CSLF).
6. Tag-recapture length increment data.
7. Maturity at length data.

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2011 stock assessement used two sets of standardised CPUE indices: one based on FSU/CELR data covering 1983–2001, and another based on PCELR data covering 2002–2011. For both series, standardised catch per unit effort (CPUE) analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, and they were entered into the model in the order that gave the maximum decrease in the Akaike Information Criterion (AIC). Predictor variables were accepted into the model only if they explained at least 1% of the deviance.

The standardised index of FSU/CELR series from the 2005 assessment is re-presented here, as the SFWG agreed that it was not necessary to update this series. The unit of catch used was the total estimated daily catch for a vessel. As the diver-hours field on the CELR forms contains a high number of errors, the unit of effort used was the total number of diver days (total number of divers on a vessel for a day). Records were restricted to those from vessels that fished the top 75% of catch in any given year, and from areas 017 and 038. The standardised index is shown in the left panel of Figure 3.

PCELR data were extracted in October 2011 for the time frame 1 October 2001 to 30 September 2011.The Shellfish Working Group suggested that the Fisher Identification Number (FIN) be used in the standardisation instead of vessel. The reason for this is that 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. It was decided to use criteria which specified a minimum number of records (PCELRs and CELRs) per year for a minimum number of years for selecting FIN permit holders for the model. The selected criteria were at least 40 records per year for a minimum of four years. This reduced the number of FIN permit holders from 72 to 20, but retained 76% of the original catch over 2002–2011.

To ensure that there were sufficient data to estimate fine scale statistical area and diver effects in the standardisation, only those fine scale statistical areas and divers with at least 10 diver days were retained. This dropped the number of fine scale statistical areas from 54 to 45, and the number of divers from 379 to 82 (51% of divers have just one dive-day).

The standardisation was done on the natural log of catch per diver day. Variables offered to the model were diver, diving condition, fishing duration FIN (Fisher identification number), fishing year, month and statistical area; no interactions were included in the model and fishing year was forced to be in the model as an explanatory variable. The standardised index is shown in the right panel of Figure 3.

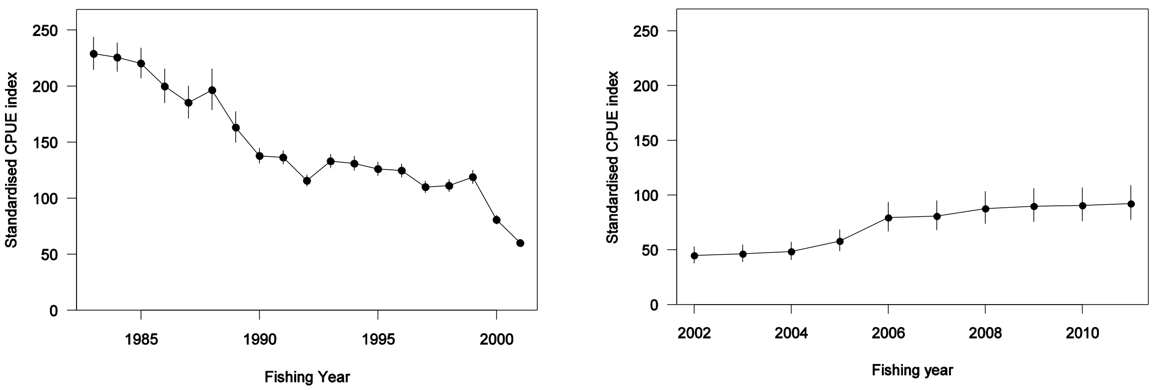


Figure 3: The standardised CPUE indices with 95% confidence intervals for the early CELR/FSU series (left) and the recent PCELR series (right).

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of paua in PAU 7 was also estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1992 and 2005. Concerns about the reliability of these data to estimate relative abundance instigated reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed i) the reliability of the research diver survey index as a proxy for abundance and ii) whether the RDSI, when used in the paua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested 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. Relative abundance estimates from research diver surveys are shown in Figure 4.

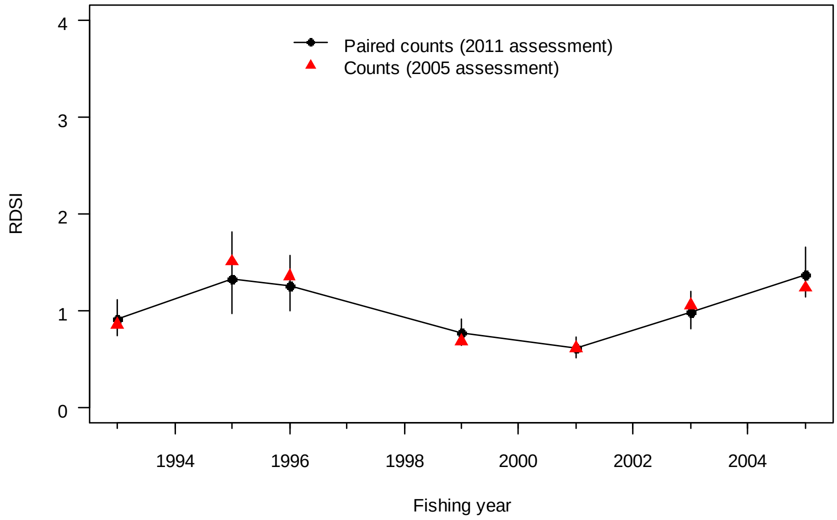


Figure 4: The standardised RDSI from the negative-binomial GLM models fitted to paired diver counts for surveys in Statistical Areas 017 and 038 within PAU 7.

4.2 Stock assessment methods

The 2012 PAU 7 stock assessment (Fu 2012, Fu et al 2012) used the length-based model first implemented in 1999 for PAU 5B (Breen et al 2000 and revised for subsequent assessments in PAU 7 (Andrew et al 2000, Breen & Kim 2003, Breen & Kim 2005 and Fu 2012). The model is described in Breen et al (2003).

The model structure assumes a single sex population residing in a single homgeneous area, with length classes from 70 mm to 170 mm, in groups of 2 mm. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class changing at each time step. Paua enter the partition following recruitment and are removed by natural mortality and fishing mortality. The assessment addresses only Areas 017 and 038 within PAU 7. These areas have supported most (more than 90%) of the catch until recently, and all of the available data originate from these two areas, but the relationship between this subset of PAU 7 and the remainder of PAU 7 is uncertain.

The model simulates the population dynamics from 1965 to 2011. Catches were available for 1974–2011, and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step.

Recruitment was assumed to take place at the beginning of the annual cycle, and length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. The stock-recruitment relationship is unknown for paua. A relationship may exist on small scales, but not be apparent when large-scale data are modelled (Breen et al 2003). No explicit stock-recruitment relationship was modelled in previous assessments; however, the SFWG agreed to use a Beverton-Holt stock-recruitment relationship with steepness (h) of 0.75 for this assessment.

Maturity is not required in the population partition. The model estimated proportions mature with the inclusion of length-at-maturity data. Growth and natural mortalities were also estimated within the model.

The models used two selectivities: the commercial fishing selectivity and research diver survey selectivity, both assumed to follow a logistic curve and to reach an asymptote.

The assessment was conducted in several steps. First, the model was fitted to the data with arbitrary weights on the various data sets. The weights were then iteratively adjusted to produce balanced residuals among the datasets where the standardised deviation of the normalised residuals was close to one for each dataset. The fit obtained is the mode of the joint posterior distribution of parameters (MPD). Next, from the resulting fit, Markov chain-Monte Carlo (MCMC) simulations were made to obtain a large set of samples from the joint posterior distribution. From this set of samples, forward projections were made with a set of agreed indicators obtained. Sensitivity trials were explored by comparing MPD fits made with alternative model assumptions.

A base case model (1.0) was chosen by the SFWG for the assessment: the tag-recapture data from all areas (except for D'Urville) were included, growth parameters were estimated within the model using an exponential growth curve, the weighting of the proportion-at-length data was determined using the TA1.8 method (Francis 2011), and maturity data from Northern faces were excluded. The base case model also assumed a steepness of 0.75 for the stock-recruitment relationship and estimated the CPUE shape parameter. The base case and sensitivities are summarised in Table 5.

The assessment reported:

- B_0 (the equilibrium spawning stock biomass assuming that recruitment is equal to the average recruitment from the period for which recruitment deviation were estimated).
- The mid-season spawning and recruited biomass for 2011 ($B_{current}$ and $B^r_{current}$), and for the projected period (B_{proj} and B^r_{proj}), and from a reference period, 1985–87. The latter was a period that had been previously chosen because the biomass was relatively stable. The means of values from the three years were called B_{ref} and B^r_{ref} for spawning and legal biomass respectively. Legal biomass is the biomass of paua above the legal size limit (currently 125 mm).
- % B_0 Ratio of current and projected spawning biomass to B_0.
- % B_{ref} Ratio of current and projected spawning biomass to B_{ref}.
- Pr(>B_{ref}) Probabilities that current and projected spawning biomass greater than B_{ref}.
- Pr(>$B_{current}$) Probabilities that projected spawning biomass greater than $B_{current}$.
- Pr(<20% B_0) Probabilities that projected spawning biomass is less than 20% B_0.
- Pr(<10% B_0) Probabilities that projected spawning biomass is less than 10% B_0.
- %B^r_0 Ratio of current and projected legal biomass to B^r_0.
- %B^r_{ref} Ratio of current and projected legal biomass to B^r_{ref}.
- Pr(>B^r_{ref}) Probabilities that current and projected legal biomass greater than B^r_{ref}.
- Pr(>$B^r_{current}$) Probabilities that projected legal biomass greater than $B^r_{current}$.

Recruitments for projections were obtained by randomly re-sampling model estimates from 1996 to 2006. Projections were run at four different levels of catch: the current TACC, and reductions of 10%, 15% and 20%.

4.2.1 Stock assessment results

Current estimates from the base case suggested that spawning stock population in 2011 ($B_{current}$) was about 22% (19–26%) of the unfished level (B_0), and vulnerable biomass ($B^r_{current}$) was about 10% (8–12%) of the initial state (B^r_0) (Figure 5, Table 6). Model projections made for three years, assuming current catch levels and using recruitments re-sampled from the recent model estimates, suggested that the spawning stock biomass will slightly increase to about 23.4% (17–32%) B_0 over the next three years (Table 7). Projections made with alternative catch levels showed that the spawning stock biomass will increase to about 24.4%, 25.0%, and 25.5% B_0 respectively, if the current TACC was to be reduced by 10%, 15% and 20% respectively (Table 7).

Table 5: Summary descriptions for base case and sensitivity model runs.

Model runs	Descriptions
0.0 (Initial model)	Iterative reweighting, assumed *h* of 0.75 and U^{max} of 0.8, estimated *h*
1.0 (Base case)	TA1.8 weighting method, assumed *h* of 0.75 and U^{max} of 0.8, estimated *h*
1.1	1.0, but fixed CPUE shape parameter (*??*) at 1
1.2	1.0, but assuming steepness (*h*) of 1
1.3	1.0, but assuming steepness (*h*) of 0.5
1.4	1.0, but assuming maximum exploitation rate (U^{max}) of 0.9
1.5	1.0, but assuming maximum exploitation rate (U^{max}) of 0.65
2.0	1.0, fixed growth parameters at low values
3.0	1.0, fixed growth parameters at high values

The base case model appeared to have represented most observational data well, and there is no obvious indication of lack of fit. The CPUE shape parameter was estimated to be less than 1, suggesting possible hyper-stability in the relationship between CPUE and abundance. However, model results changed very little when a linear relationship between CPUE and abundance was assumed.

Model sensitivity runs which assumed different values for the stock-recruitment steepness (*h*) parameter appeared to compensate for the differences in the stock-recruitment relationship with changes in R_0, recruitment deviations, and natural mortality. Estimates of current stock status were similar between these model runs, although there were some differences in the size of the estimated B_0.

Table 6: Summary of the marginal posterior distributions from the MCMC chain from the base case (1.0). The columns show the 5th and 95th percentiles, and the medians. Biomass is in tonnes.

	5%	Median	95%	MPD estimate
B_0	3905	4242	4541	4156
B_{ref}	1299	1426	1561	1359
$B_{current}$	790	933	1115	877
$B_{current}/B_0$	0.19	0.22	0.26	0.21
$B_{current}/B_{ref}$	0.56	0.66	0.78	0.65
B_0^r	3063	3417	3719	3368
B_{ref}^r	669	816	971	777
$B_{current}^r$	261	334	428	313
$B_{current}^r/B_0^r$	0.08	0.10	0.12	0.09
$B_{current}^r/B_{ref}^r$	0.32	0.41	0.54	0.40
$U_{current}$	0.33	0.41	0.49	0.43

The base case assumed a maximum exploitation rate (U_{max}) of 0.8 and there were two years (2001 and 2003) in which the exploitation rate was estimated to be at this bound. When U_{max} was assumed to be 0.65, the estimated exploitation rates for 2001 and 2003 were also at the bound; when U_{max} was assumed to be 0.9, the estimated exploitation rate for 2003 was at the bound. However, biomass estimates were similar among all these runs.

The base case assessment estimated growth parameters within the model using the tag-recapture data. The fits to the tag-recapture data appear adequate, but are likely to have been influenced by the proportion-at-length data as well. Sensitivity runs, which assumed alternative growth parameters (fixed at values representing either a fast or slow growth rate), led to significant changes to the estimates of abundance, but had poor fits to the proportion-at-length data.

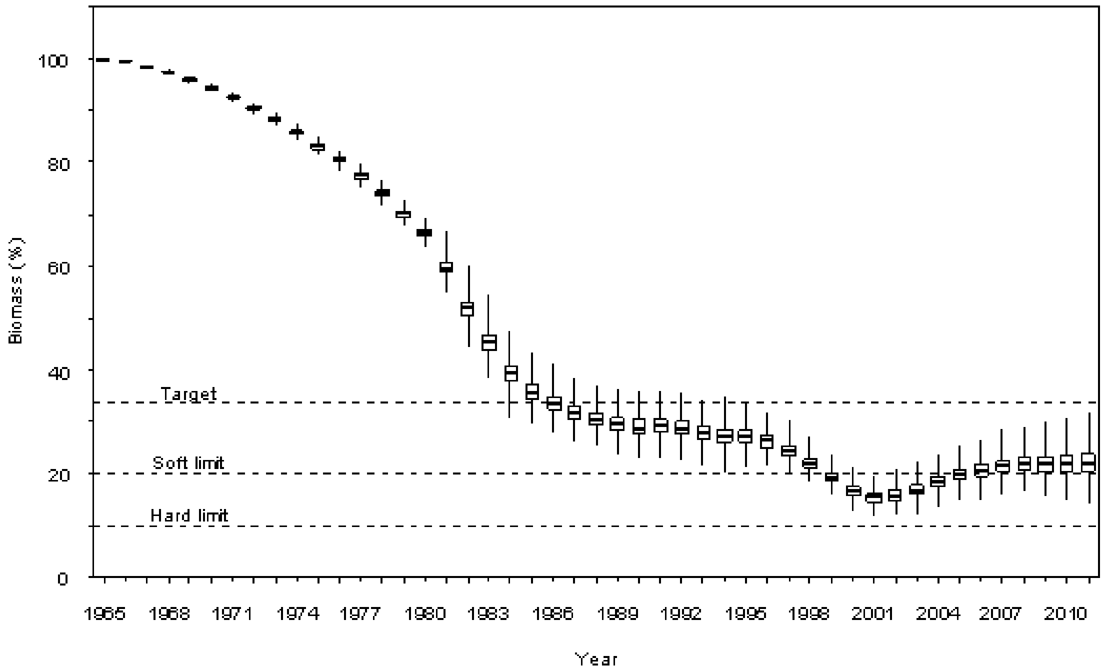


Figure 5: Posterior distributions of spawning stock biomass as a percentage of virgin level from MCMC 1.0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution. The target is the median reference biomass (33.6% B_0).

The base case estimated growth parameters within the model incorporating the tag-recapture data. The fits to the tag-recapture data appear adequate, but are likely to have been influenced by the proportion-at-length data. Sensitivity runs assuming alternative growth parameters (fixed at values representing either a fast or slow growth rate) led to significant changes to the estimates of abundance, but had poor fits to the proportion-at-length data.

4.5 Yield estimates and projections

No estimate of *MCY* has been made for PAU 7.

No estimate of *CAY* has been made for PAU 7.

4.6 Other factors

The stock assessment model assumed homogeneity in recruitment, that natural mortality does not vary by size or year, and that growth has the same mean and variance throughout the entire area. However, it is known that paua fisheries are spatially variable and that apparent growth and maturity in paua populations can vary over very short distances. Variation in growth is addressed to some extent by having a stochastic growth transition matrix based on tagging data collected from a range of different locations. Similarly, the length frequency data are integrated across samples from many places. The effect of this integraion across local areas is likely to make model results optimistic. For instance, if some local stocks are fished very hard and others not fished, local recruitment failure can result due to the limited dispersal range of this species. Recruitment failure is a common observation in overseas abalone fisheries. Fishing may also cause spatial contraction of populations (e.g., Shepherd & Partington 1995), and some populations appear to become relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the assessment will overestimate productivity in the population as a whole. It is also possible that good recruitments estimated by the model might have been the result of serial depletion.

Table 7: Projections to 2014 of the key indicators (from the base case MCMC) with future commercial catch set to 100%, 90%, 85%, and 80% of the TACC. Key indicators are spawning stock biomass (*B*) and recruited biomass (*rB*) and include % of virgin biomass and % biomass from a reference period (B_{ref}) and the probability of being above current biomass or below default limits.

	2011	2014			
Projection		Current TACC	90% TACC	85% TACC	80% TACC
$\%B_0$	22.1 (18.0–27.2)	23.4 (16.5–31.5)	24.4 (17.5–32.6)	25.0(18.0–33.1)	25.5 (18.5–33.6)
$\%B_{ref}$	65.5 (53.7–80.5)	69.3 (49.4–942)	72.4 (52.5–97.4)	74.0(54.1–99.0)	75.6 (55.7–100.6)
$Pr(> B_{ref})$	0.000	0.008	0.015	0.021	0.029
$Pr(>B_{current})$		0.671	0.796	0.854	0.897
$Pr(<20\%B_0)$	0.173	0.176	0.112	0.086	0.063
$Pr(<10\%B_0)$	0.000	0.000	0.000	0	0
$\%rB_0$	9.8 (0.073–0.130)	10.5 (6.2–15.9)	11.7 (7.4–17.1)	12.3(8.0–17.7)	12.9 (8.6–18.4)
$\%rB_{ref}$	41.2 (30.0–56.6)	43.9 (26.3–67.6)	49.0 (30.9–73.2)	51.6(33.3–76.1)	54.2 (35.6–79.0)
$Pr(> rB_{ref})$	0.000	0.000	0.000	0.000	0.000
$Pr(>rB_{current})$		0.679	0.926	0.975	0.995

CPUE provides information in the model on changes in relative abundance. However, CPUE is generally considered to be a poor index of stock abundance for paua, due to divers' ability to maintain catch rates by moving from area to area despite a decreasing biomass (hyperstability). Breen et al (2003) argued that standardised CPUE might monitor changes of abundance in a fully exploited fishery, and that declines in the CPUE most likely reflected a decline in the population. PAU 7 is generally considered to be a fully developed fishery: the exploitation rate in Statistical Areas 017 and 038 is known to have been high and there are unlikely to be many unfished areas within the area.

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

The utility of research diver survey indices to provide relative abundance information has been an ongoing concern in the SFWG. Cordue (2009) identified issues associated with diver surveys based on the timed swim approach and questioned their adequacy as indices of relative abundance. Haist (2010) suggested that the existing RDSI data were likely to be more useful at a stratum level. The general consensus is that the index-abundance relationship from the research diver survey is likely to be nonlinear, and cannot easily be quantified in a stock assessment.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

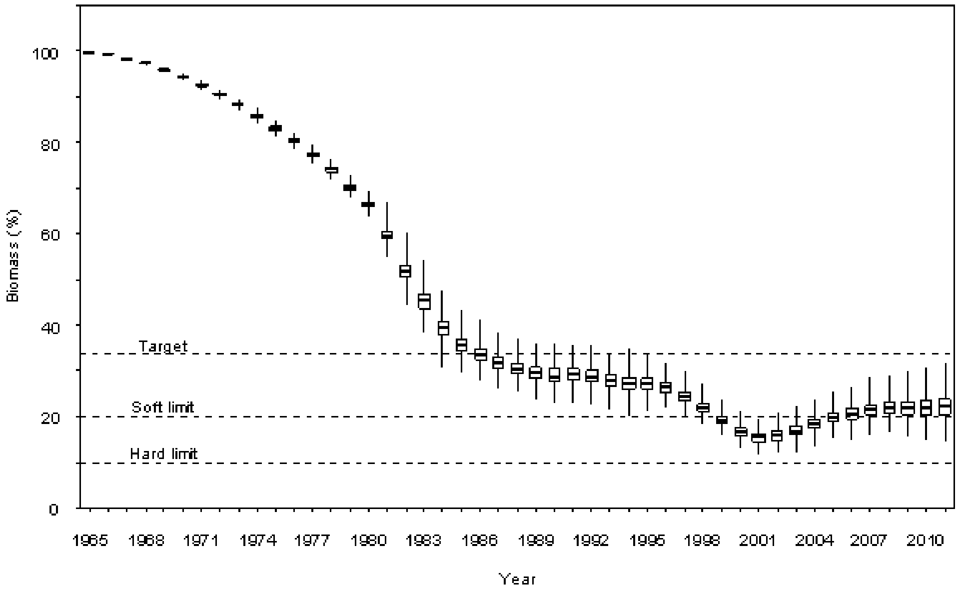
The 2012 assessment was conducted for Statistical Areas 017 and 038 only, but these include most (more than 90%) of the recent catch.

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

Stock Status	
Year of Most Recent Assessment	2012
Assessment Runs Presented	Base case MCMC

Reference Points	Interim Target: B_{ref} (average spawning biomass from 1985–1987) = 33.6% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Target	Spawning stock biomass was estimated to be 66% B_{ref} and is Very Unlikely (< 10%) to be at or above the interim target
Status in relation to Limits	Spawning stock biomass was estimated to be 22% B_0, and is About as Likely as Not (40–60%) to be below the soft limit and Unlikely (< 40%) to be below the hard limit

Historical Stock Status Trajectory and Current Status



Posterior distributions of spawning stock biomass as a percentage of virgin level from MCMC 1.0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution. The target is the median reference biomass (33.6% B_0).

Projections and Prognosis	
Stock Projections or Prognosis	Three year projections indicate that spawning and recruited biomass are likely to increase but are Very Unlikely (< 10%) to be at or above the target by this time.
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: About as Likely as Not (40–60%) Hard Limit: Unlikely (< 40%)

Assessment Methodology & Evaluation		
Assessment Type	Full quantitative stock assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest: 2012	Next: 2015
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE	1 – High Quality
	- Research diver survey indices	2 – Medium or Mixed Quality: it is suggested that the RDSI do not provide a reliable index of abundance
	- Commercial catch length frequency	1 – High Quality
	- Research diver length frequency	1 – High Quality

	- Tag-recapture data - Maturity at length data	1 – High Quality 1 – High Quality
Data not used (rank)	-	
Changes to Model Structure and Assumptions	- Data weighting (LF only) and steepness	
Major Sources of Uncertainty	- Spatial heterogeneity not incorporated - Potential hyperstability in CPUE - Potential for localised recruitment failure	

Qualifying Comments
No account has been taken of the voluntary closure of areas affected by "greening". Stock projections also do not account for reduced production due to potential closed areas in the future, which are likely to slow or reverse projected increases in stock size.

Fishery Interactions
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6. FOR FURTHER INFORMATION

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