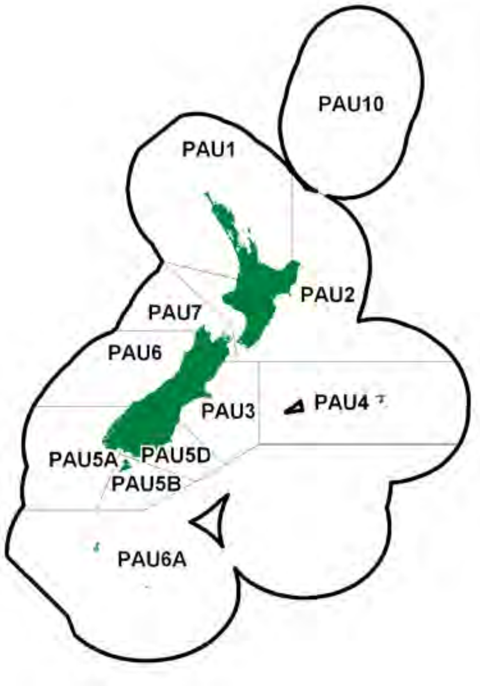
PĀUA (PAU)

(*Haliotis iris, Haliotis australis*)



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

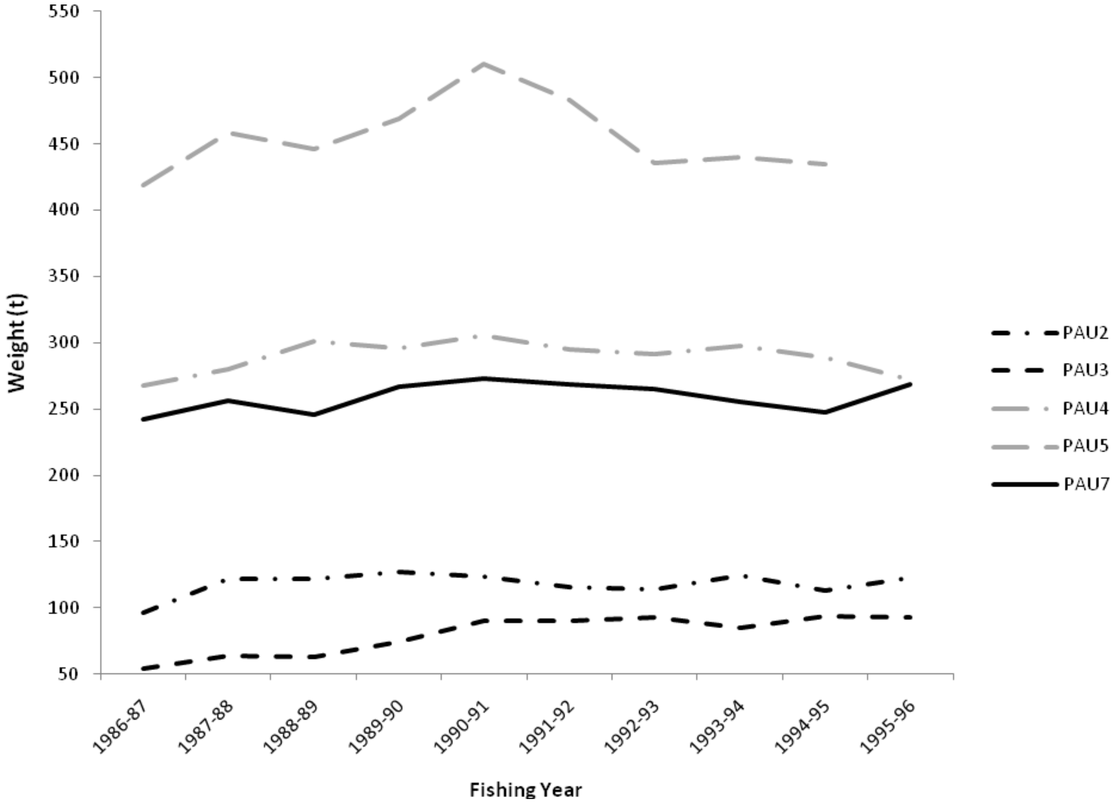
The commercial fishery for pāua dates from the mid-1940s. In the early years of this commercial fishery the meat was generally discarded and only the shell was marketed, however by the late 1950s both meat and shell were being sold. Since the 1986–87 fishing season, the eight Quota Management Areas have 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 pāua by hand while free diving. The use of underwater breathing apparatus (UBA) is not permitted except in the PAU 4 fishery. Due to safety concerns concerning great white shark interactions, the use of UBAs has been permitted in the Chatham Island pāua fishery (PAU 4) since 2012. 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 pāua, *Haliotis iris*, with a minimum legal size for harvesting of 125 mm shell length. The yellow-foot pāua, *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*.

2016 saw PAU 7 TACC reductions and voluntary ACE shelving by quota owners forgoing catching a portion of their quota, by 50 percent. A further 10% of the PAU 7 TACC was shelved in 2017 to remove any excess commercial fishing effort in areas either side of the earthquake closure; this shelving is still current for the 2018–19 fishing year.

Up until the 2002 fishing year, catch was reported by general statistical areas, however from 2002 onwards, a more fine scale system of pāua specific statistical areas were put in place throughout each QMA (refer to the QMA specific Plenary chapters). 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.



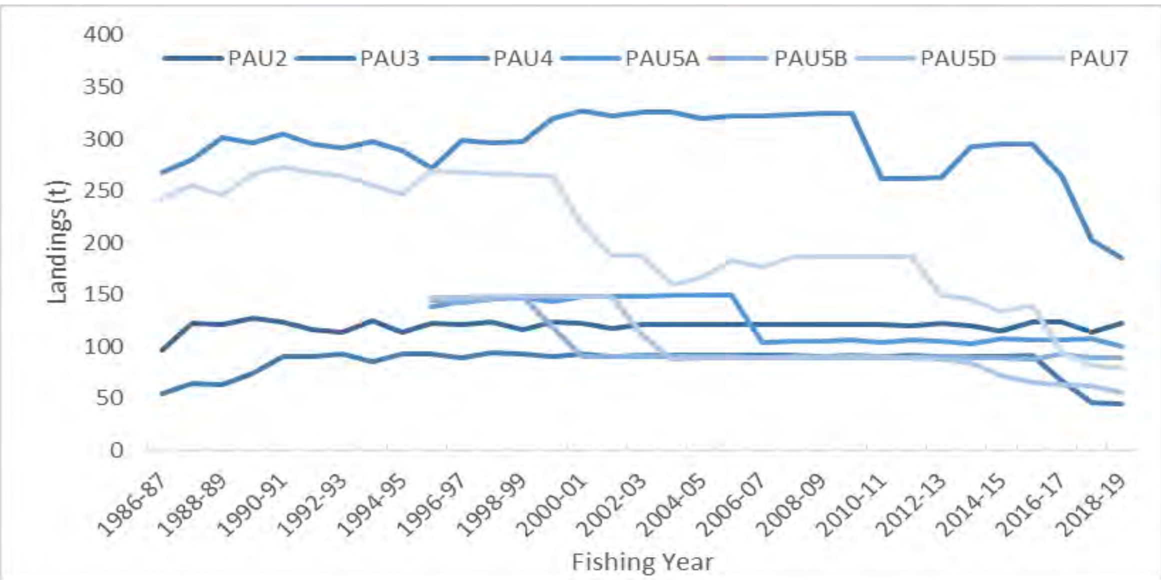


Figure 1: Historic landings for the major pāua QMAs from 1983–84 to 1995–96 (top) and from 1996–97 to 2018-19 (lower).

Landings for PAU 1, PAU 6, PAU 10 and PAU 5 (prior to 1995) are shown in Table 1. PAU 1 landings have been below the TACC since its introduction in 1986–87, with no landings recorded for 2017–18 and just 0.22 t recorded in 2018–19. In contrast PAU 6 landings have been close to the TACC since the fishing year 2006–07. For information on landings specific to other pāua QMAs refer to the specific Working Group reports.

1.2 Recreational fisheries

There is a large recreational fishery for pāua. Estimated catches from telephone and diary surveys of recreational fishers (Teirney et al 1997, Bradford 1998, Boyd & Reilly 2004, Boyd et al 2004) are shown in Table 2.

The harvest estimates provided by telephone-diary surveys between 1993 and 2001 are no longer considered reliable for various reasons. A Recreational Technical Working Group concluded that these harvest estimates should be used only with the following qualifications: a) they may be very inaccurate; b) the 1996 and earlier surveys contain a methodological error; and c) the 2000 and 2001 estimates are implausibly high for many important fisheries. In response to these problems and the cost and scale challenges associated with onsite methods, a National Panel Survey was conducted for the first time throughout the 2011–12 fishing year. The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information collected in standardised phone interviews. The panel survey was repeated in 2017–18 (Wynne-Jones et al 2019). Harvest estimates for pāua are given in Table 3 (from Wynne-Jones et al 2014 using mean weights from Hartill & Davey 2015 and from Wynne-Jones et al 2019).

Table 1: TACCs and reported landings (t) of pāua 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
2014–15	0.47	1.93	-	-	1.00	1.00	0.00	1.00
2015–16	0.13	1.93	-	-	0.84	1.00	0.00	1.00
2016–17	0.25	1.93	-	-	1.06	1.00	0.00	1.00
2017–18	0.00	1.93	-	-	1.04	1.00	0.00	1.00
2018–19	0.22	1.93	-	-	1.00	1.00	0.00	1.00

H experimental landings
* FSU data

Table 2: Estimated annual harvest of pāua (t) by recreational fishers from telephone-diary surveys*.

Fishstock	PAU 1	PAU 2	PAU 3	PAU 5	PAU 5A	PAU 5B	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

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

1.3 Customary fisheries

There is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices. Limited quantitative information on the level of customary take is available from Fisheries New Zealand (Table 4). These numbers are likely to be an underestimate of customary harvest as only the catch in kilograms and numbers are reported in the table. In addition, many tangata whenua also harvest pāua under their recreational allowance and these are not included in records of customary catch.

1.4 Illegal catch

There is qualitative data to suggest significant illegal, unreported, unregulated (IUU) activity in this fishery. Current quantitative 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 pāua stock assessments, nominal illegal catches are used.

Table 3: Recreational harvest estimates for pāua stocks from the national panel survey in 2011–12 (Wynne-Jones et al 2014) and 2017–18 (Wynne-Jones et al 2019). Mean fish weights were obtained from boat ramp surveys (Hartill & Davey 2015).

Stock	Fishers	Events	Number of pāua	CV	Total weight (t)	CV
2011–12 (national panel survey)						
PAU 1	39	63	43 480		12.16	0.27
PAU 2	158	378	286 182		81.85	0.15
PAU 3	35	67	60 717		16.98	0.31
PAU 5A	2	3	1 487		0.42	0.76
PAU 5B	5	5	2 945		0.82	0.50
PAU 5D	41	84	80 290		22.45	0.30
PAU 7	19	41	50 534		14.13	0.34
PAU total	299	641	525 635		148.82	0.11
2017–18 (national panel survey)						
PAU 1	27	41	27 707	0.34	8.74	0.34
PAU 2	151	367	283 240	0.15	83.22	0.15
PAU 3	21	46	28 140	0.35	8.79	0.35
PAU 5A	3	4	2 419	0.76	0.85	0.76
PAU 5B	10	21	15 361	0.45	9.85	0.45
PAU 5D	48	88	55	0.21	19.28	0.21
PAU 6	E	e	3 076	0.60	0.95	0.61
PAU 7	11	16	10 576	0.36	3.02	0.36
PAU total	274	590	425 661		134.70	

Table 4: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kg) and numbers), since 1998-99. – no data. [Continued next page]

	PAU 1				PAU 2			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	40	40	–	–
1999–00	–	–	–	–	–	–	1 400	820
2000–01	–	–	–	–	–	–	–	–
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	30	30	–	–	–	–
2003–04	–	–	184	146	–	–	4 805	4 685
2004–05	–	–	240	220	–	–	2 780	2 440
2005–06	125	100	40	40	–	–	5 349	4 385
2006–07	705	581	2 175	1 925	–	–	7 088	3 446
2007–08	460	413	2 155	1 618	–	–	11 298	6 164
2008–09	491	191	2 915	2 228	–	–	30 312	24 155
2009–10	184	43	2 825	2 225	–	–	5 505	4 087
2010–11	154	129	5 915	3 952	–	–	20 570	17 062
2011–12	25	8	470	470	243	243	29 759	23 932
2012–13	20	20	1 305	1 193	10	6	51 275	27 653
2013–14	–	–	–	–	–	–	61 486	30 129
2014–15	45	33	700	536	–	–	25 215	16 449
2015–16	50	9	1 425	756	–	–	11 540	6 383
2016–17	–	–	2 190	618	–	–	13 698	6 877
2017–18	15	15	4 612	3 127	–	–	6 960	1 942
2018–19	–	–	1 348	690			8 565	3 189

	PAU 3*				PAU 4			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	300	230	–	–	–	–
2001–02	200	50	6 239	4 832	–	–	–	–
2002–03	–	–	3 422	2 449	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	1 580	1 220	–	–	–	–
2006–07	–	–	5 274	4 561	–	–	–	–

Table 4 [Continued]

	PAU 3*				PAU 4			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
2007–08	–	–	7 515	5 790	–	–	–	–
2008–09	–	–	10 848	8 232	–	–	–	–
2009–10	–	–	8 490	6 467	–	–	635	635
2010–11	–	–	8 360	7 449	–	–	–	–
2011–12	–	–	5 675	4 242	–	–	–	–
2012–13	–	–	15 036	12 874	–	–	–	–
2013–14	–	–	10 259	7 566	–	–	110	110
2014–15	–	–	8 761	7 035	–	–	150	150
2015–16	–	–	14 801	11 808	–	–	320	120
2016–17	–	–	11 374	9 217	–	–	366	366
2017–18	–	–	2 708	1 725	50	50	820	764
2018–19			480	278	330	330		

	PAU 5A				PAU 5B			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	–	–	–	–	50	50
2001–02	–	–	80	70	–	–	610	590
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	–	–	–	–	140	90
2006–07	–	–	–	–	–	–	485	483
2007–08	–	–	100	100	–	–	2 685	2 684
2008–09	–	–	100	100	–	–	3 520	3 444
2009–10	–	–	150	150	–	–	2 680	2 043
2010–11	–	–	150	150	–	–	2 053	1 978
2011–12	–	–	512	462	–	–	495	495
2012–13	–	–	590	527	–	–	1 875	1 828
2013–14	–	–	–	–	–	–	130	130
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	255	50	–	–	2 195	2 003
2016–17	–	–	–	–	–	–	75	75
2017–18	–	–	200	200	–	–	2 245	2 245
2018–19	–	–	–	–			1 405	1 337

	PAU 5D				PAU 6			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	665	417	–	–	–	–
2001–02	–	–	5 530	3 553	–	–	–	–
2002–03	–	–	2 435	1 351	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	1 560	1 560	–	–	–	–
2006–07	–	–	2 845	2 126	–	–	100	100
2007–08	–	–	5 600	5 327	–	–	60	60
2008–09	–	–	6 646	6 094	–	–	–	–
2009–10	–	–	4 840	4 150	–	–	–	–
2010–11	–	–	15 806	15 291	–	–	230	130
2011–12	–	–	7 935	7 835	–	–	–	–
2012–13	–	–	10 254	8 782	–	–	–	–
2013–14	–	–	5 720	5 358	–	–	–	–
2014–15	–	–	–	–	–	–	–	–
2015–16	–	–	15 922	13 110	–	–	50	50
2016–17	–	–	3 676	3 576	–	–	80	80
2017–18	–	–	3 588	3 310	–	–	–	–
2018–19	–	–	950	894				

	PAU 7			
	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–
1999–00	–	–	–	–
2000–01	–	–	–	–
2001–02	–	–	–	–
2002–03	–	–	–	–
2003–04	–	–	–	–
2004–05	–	–	–	–
2005–06	–	–	–	–
2006–07	–	–	–	–

Table 4 [Continued]

	PAU 7			
	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
2007–08	–	–	1 110	808
2008–09	–	–	1 270	1 014
2009–10	–	–	1 085	936
2010–11	–	–	60	31
2011–12	–	–	20	20
2012–13	–	–	–	–
2013–14	–	–	–	–
2014–15	–	–	–	–
2015–16	–	–	–	–
2016–17	–	–	–	–
2017–18	–	–	–	–
2018–19			–	–

*: data before 2010–11 exclude the area between the Hurunui River and the South Shore (just north of Banks Peninsula), as Tangata Tiaki were not appointed there until November 2009.

1.5 Other sources of mortality

Pāua may die from wounds caused by removal desiccation or osmotic and temperature stress if they are brought to the surface. Sub-legal pāua 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 pāua (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 pāua 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 pāua very unlikely (although abrasions and shell damage may occur). Gerring (2003) estimated that in PAU 7, 37% of pāua 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 pāua are kept out of the water for a prolonged period or returned onto sand. To date, the stock assessments developed for pāua have assumed that there is no mortality associated with capture of undersize animals.

2. BIOLOGY

Pāua 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. Pāua are broadcast spawners and spawning is usually annual. Habitat related factors are an important source of variation in the post-settlement survival of pāua. Growth, morphometrics, and recruitment can vary over short distances and may be influenced by factors such as water temperature, wave exposure, habitat structure and the availability of food. Naylor et al (2016) analysed demographic variation in pāua in New Zealand. They concluded that there were large differences in the growth rates and maximum size over a large latitudinal range. Their analysis indicated that water temperature, as indicated by sea surface temperature, was an important determinant of these. Pāua become sexually mature when they are about 70–90 mm long, or 3–5 years old. A summary of generic estimates for biological parameters for pāua is presented in Table 5. Parameters specific to individual pāua QMAs are reported in the specific Working Group reports.

Table 5: Estimates of biological parameters for pāua (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 pāua 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. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the 2020 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the 2018 Aquatic Environment & Biodiversity Annual Review (Ministry for Primary Industries 2019, https://www.mpi.govt.nz/dmsdocument/34854-aquatic-environment-and-biodiversity-annualreview-aebar-2018-a-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment)

4.1 Ecosystem role

Pāua are eaten by a range of predators, and smaller pāua are generally more vulnerable to predation. Smaller pāua are consumed by blue cod (Carbines & Beentjes 2003), snapper (Francis 2003), banded wrasse (Russell 1983), spotties (McCardle 1983), triplefins (McCardle 1983) and octopus (Andrew & Naylor 2003). Large pāua are generally well protected by their strong shells, but are still vulnerable to rock lobsters (McCardle 1983) and the large predatory starfishes *Astrostole scabra* and *Coscinasterias muricata* (Andrew & Naylor 2003). Large pāua 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 pāua.

Pāua 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 pāua abundance and the abundance or distribution of other species, with the exception of kina which, at very high densities, appear to exclude pāua (Andrew et al 2000). Research at D'Urville Island and on Wellington's south coast suggests that there is some negative association between pāua and kina (Andrew & MacDiarmid 1999).

4.2 Fish and invertebrate bycatch

Because pāua are harvested by hand gathering, incidental bycatch is limited to epibiota attached to, or within the shell. The most common epibiont on pāua 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 pāua). Several boring and spiral-shelled polychaete worms are commonly found in and on the shells of pāua. 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 pāua shell (Handley 2004). This species; however, has also been reported to burrow into limestone, or attach its tube to the holdfasts of algae (Read 2004). It is also not uncommon for pāua harvesters to collect predators of pāua (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 pāua caused by predation).

4.3 Incidental catch (seabirds, mammals, and protected fish)

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

4.4 Benthic interactions

The environmental impact of pāua harvesting is likely to be minimal because pāua are selectively hand gathered by free divers. Habitat contact by divers at the time of harvest is limited to the area of pāua foot attachment, and pāua 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.

4.5 Other considerations

4.5.1 Genetic effects

Fishing, and 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 pāua stocks with artificially-reared juveniles has the potential to lead to genetic effects if inappropriate broodstocks are used.

4.5.2 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 pāua 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 pāua 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).

4.5.3 Kaikōura Earthquake

Research was undertaken to investigate the influence of the November 2016 Kaikōura earthquake on pāua stocks in the area of the Kaikōura coastline. The results estimated that the seabed uplift led to a loss of up to 50% of the pre-earthquake fished area across PAU 3 statistical areas. More details can be found in the PAU 3 Working Group report.

4.5.4 Marine heatwave

A baseline report summarising trends in climatic and oceanographic conditions in New Zealand that are of potential relevance for fisheries and marine ecosystem resource management in the New Zealand region has been completed (Hurst et al 2012). There is also an updated chapter on oceanic trends in the Aquatic Environment and Biodiversity Annual Review 2018 (Ministry for Primary Industries 2019). Any effects of recent warmer temperatures (such as the high surface temperatures on the WCSI during the 2016 and 2017 spawning seasons, marine heatwaves and general warming of the Tasman Sea (Sutton & Bowen 2019) on fish distribution, growth, or spawning success have yet to be determined.

Shellfish fisheries have been identified as likely to be vulnerable to ocean acidification (Capson & Guinotte 2014). A recent project that has just reached completion describes the state of knowledge of climate change-associated predictions for components of New Zealand's marine environment that are most relevant to fisheries (Cumming et al in press). Past and future projected changes in coastal and ocean properties, including temperature, salinity, stratification and water masses, circulation, oxygen, ocean productivity, detrital flux, ocean acidification, coastal erosion and sediment loading, wind and waves, are reviewed. Responses to climate change for these coastal and ocean properties are discussed, as well as their likely impact on the fisheries sector, where known.

A range of decision support tools in use overseas were evaluated with respect to their applicability for dissemination of the state of knowledge on climate change and fisheries. Three species, for which there was a relatively large amount of information available were chosen from the main fisheries sectors for further analysis. These were pāua, snapper and hoki (shellfish, inshore, and middle-depths/deepwater fisheries, respectively). Evaluations of each species' sensitivity and exposure to climate change-associated threats, based on currently available published literature and expert opinion, assessed pāua vulnerability to climate change effects as 'low' (Cummings et al. in press).

5. STOCK ASSESSMENT

The dates of the most recent survey or stock assessment for each QMA are listed in Table 6.

Table 6: Recent survey and stock assessment information for each pāua QMA [Continued next page]

QMA	Type of survey or assessment	Date	Comments
PAU 1	No surveys or assessments have been undertaken		
PAU 2	CPUE standardisation using a Bayesian Generalised Linear Mixed Model (GLMM)	2020	Standardised CPUE showed slight oscillation without trend since 2007.
PAU 3	Quantitative assessment using a Bayesian length based model	2013	For the 2013 stock assessment nine model runs were 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. The status of the stock was estimated to be 52% B_0
PAU 4	CPUE Standardisation	2016	In February 2010 the Shellfish Working Group (SFWG) agreed that, due to the lack of data of adequate quality to use in the Bayesian length-based model, a stock assessment for PAU 4 using this model was not appropriate. In 2016 an analysis of the last 14 years of CPUE data was done. This report showed a potential decline in the fishery since the early 2000s, however the poor data quality is causing considerable uncertainty about the real trend in the fishery.
PAU 5A	Quantitative assessment using a Bayesian length based model	2020	The 2020 stock assessment was implemented as a single area model together with a three-area spatial model to corroborate findings from the single area model. The status of the stock was estimated to be 51% B_0. At current levels of catch spawning stock biomass is projected to remain nearly unchanged at 51% B_0 after 3 years, with an equilibrium value of 50% of B_0.
PAU 5B	Quantitative assessment using a Bayesian length based model	2018	The 2018 Plenary accepted this assessment as best scientific information. The status of the stock was estimated to be 47% B_0.

Table 6 [Continued]: Recent survey and stock assessment information for each pāua QMA.

PAU 5D	Quantitative assessment using a Bayesian length based model	2019	The reference case model estimated that the unfished spawning stock biomass (B_0) was about 2029 t (1673–2535 t) and the spawning stock population in 2018 (B_{2018}) was about 40% (25–65%) of B_0. The model projection made for three years assuming current catch levels (which includes commercial catch at and using recruitment re-sampled from the recent model estimates, suggested that the spawning stock abundance will remain at 42% (28–52%) B_0 over the next three years. The projection also indicated that the probability of the spawning stock biomass being above the target (40% B_0) will decrease from about 52% in 2018 to 49% by 2021.
PAU 6	Biomass estimate	1996	This fishery has a TACC of 1 t
PAU 7	Quantitative assessment using a Bayesian length based model	2015	The SFWG agreed that the stock assessment was reliable based on the available data. Currently, spawning stock biomass is estimated to be 18% B_0 and is about as likely as not to be below the soft limit, with fishing intensity very likely to be above the overfishing threshold.
PAU 10	No surveys or assessments have been undertaken		

5.1 Estimates of fishery parameters and abundance

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

In 2014 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 pāua tend to aggregate and, in order to maximise their catch rates, divers move from areas that have been depleted of pāua, 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 pāua 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)) 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 pāua 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 to be uninformative 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.

5.2 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 6). For further information on biomass estimates specific to each pāua QMA refer to the specific Working Group report.

5.3 Yield Estimates and Projections
Yield estimates and projections are estimated as part of the stock assessment process. Both are available for PAU 3, PAU 5A, PAU 5B, PAU 5D and PAU 7. For further information on yield estimates and projections specific to each pāua QMA refer to the specific Working Group report.

5.4 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 and in some QMAs, not catching the full Annual Catch Entitlement (ACE) in a particular fishing year.

6. STATUS OF THE STOCKS

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

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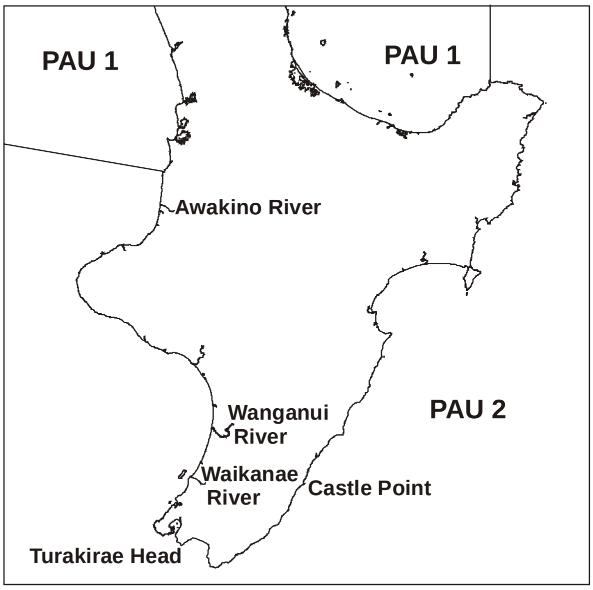
PĀUA (PAU 2) – Wairarapa / Wellington / Taranaki

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

PAU 2 was introduced into the Quota Management System in 1986–87 with a TACC of 100 t. As a result of appeals to the Quota Appeal Authority, the TACC was increased to 121.19 t in 1989 and has remained unchanged to the current fishing year (Table 1). There is no TAC for this QMA: before the Fisheries Act (1996) a TAC was not required. When changes have been made to a TACC after 1996, stocks have been assigned a TAC.

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 2 since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1989	-	-	-	-	100
1989–present	-	-	-	-	121.19

1.1 Commercial fisheries

The fishing year runs from 1 October through to 30 September. Most of the commercial catch comes from the Wairarapa and Wellington South coasts between Castle Point and Turakirae Head. The western area between Turakirae Head and the Waikanae River is closed to commercial fishing.

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

1.2 Recreational fisheries

The most recent recreational fishery survey "The National Panel Survey of Marine Recreational Fishers 2017–18: Harvest Estimates" Wynne-Jones et al (2019), estimated that about 83 t of pāua were harvested by recreational fishers in PAU 2 in 2017–18.

Because pāua around Taranaki are naturally small and never reach the minimum legal size (MLS) of 125 mm, a new MLS of 85 mm was introduced for recreational fishers from 1 October 2009. The new length was on a trial basis for five years and now applies between the Awakino and Wanganui rivers.

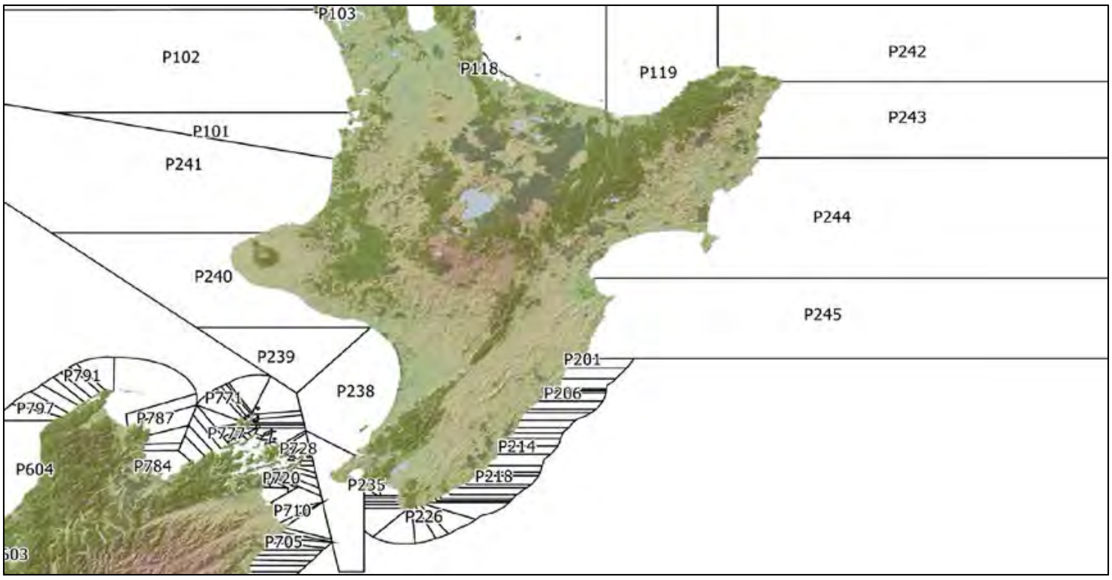


Figure 1: Map of fine scale statistical reporting areas for PAU 2.

Table 2: TACC and reported landings (t) of pāua in PAU 2 from 1983–84 to present.

Year	Landings	TACC
1983–84*	110	–
1984–85*	154	–
1985–86*	92	–
1986–87*	96.2	100
1987–88*	122.11	100
1988–89*	121.5	120.12
1989–90	127.28	121.19
1990–91	125.82	121.19
1991–92	116.66	121.19
1992–93	119.13	121.19
1993–94	125.22	121.19
1994–95	113.28	121.19
1995–96	119.75	121.19
1996–97	118.86	121.19
1997–98	122.41	121.19
1998–99	115.22	121.19
1999–00	122.48	121.19
2000–01	122.92	121.19
2001–02	116.87	121.19
2002–03	121.19	121.19
2003–04	121.06	121.19
2004–05	121.19	121.19
2005–06	121.14	121.19
2006–07	121.20	121.19
2007–08	121.06	121.19
2008–09	121.18	121.19
2009–10	121.13	121.19
2010–11	121.18	121.19
2011–12	120.01	121.19
2012–13	122	121.19
2013–14	120	121.19
2014–15	115	121.19
2015–16	123.74	121.19
2016–17	123.69	121.19
2017–18	113.87	121.19
2018–19	122.89	121.19

* FSU data.

1.3 Customary fisheries

For further information on customary fisheries refer to the introductory PAU Working Group Report.

1.4 Illegal catch

It is widely believed that the level of illegal harvesting is high around Wellington and on the Wairarapa coast. For further information on illegal catch refer to the introductory PAU Working Group Report.

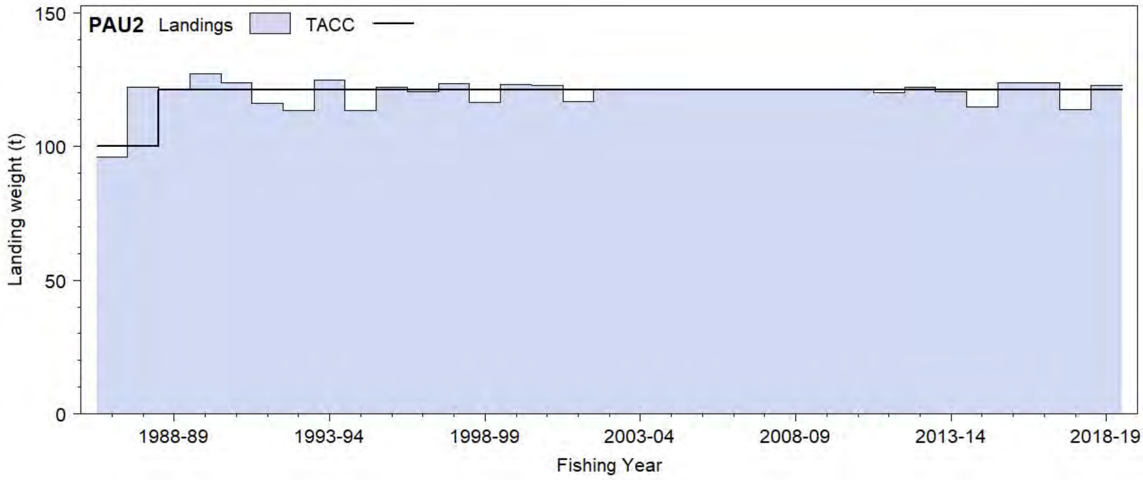


Figure 2: Historical landings and TACC for PAU 2 from 1983–84 to present. QMS data from 1986–present.

1.5 Other sources of mortality

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

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. A summary of published estimates of biological parameters for PAU 2 is presented in Table 3.

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

Area		**Estimate**	**Source**
1. Size at maturity (shell length)			
Wellington	50% mature	71.7 mm	Naylor et al (2006)
Taranaki	50% mature	58.9 mm	Naylor & Andrew (2000)
2. Fecundity = a (length)^b (eggs, shell length in mm)			
Taranaki	a = 43.98	b = 2.07	Naylor & Andrew (2000)
3. Exponential growth parameters (both sexes combined)			
Wellington	g_{50}	30.58 mm	Naylor et al (2006)
	g_{100}	14.8 mm	
Taranaki	G_{25}	18.4 mm	Naylor & Andrew (2000)
	G_{75}	2.8 mm	

3. STOCKS AND AREAS

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

4. RELATIVE ABUNDANCE INDEX

A standardised CPUE index based on commercial catch was constructed covering the 1990 to 2014 fishing years (McKenzie 2015). Two separate indexes were estimated, the first was estimated from CELR data for the fishing years 1989–90 to 2001–02, and the second was estimated from PCELR data for the fishing years 2002–03 to 2013–14. FSU data covering the period from 1983 to 1988 was not used in the standardisation due to problems with this data including: 1) a high proportion of missing values for the vessel field; 2) ambiguity and inaccuracies in what is recorded for the important fishing duration field and 3) low coverage of the annual catch.

There was little evidence of serial depletion over the past 13 years (Figure 3).

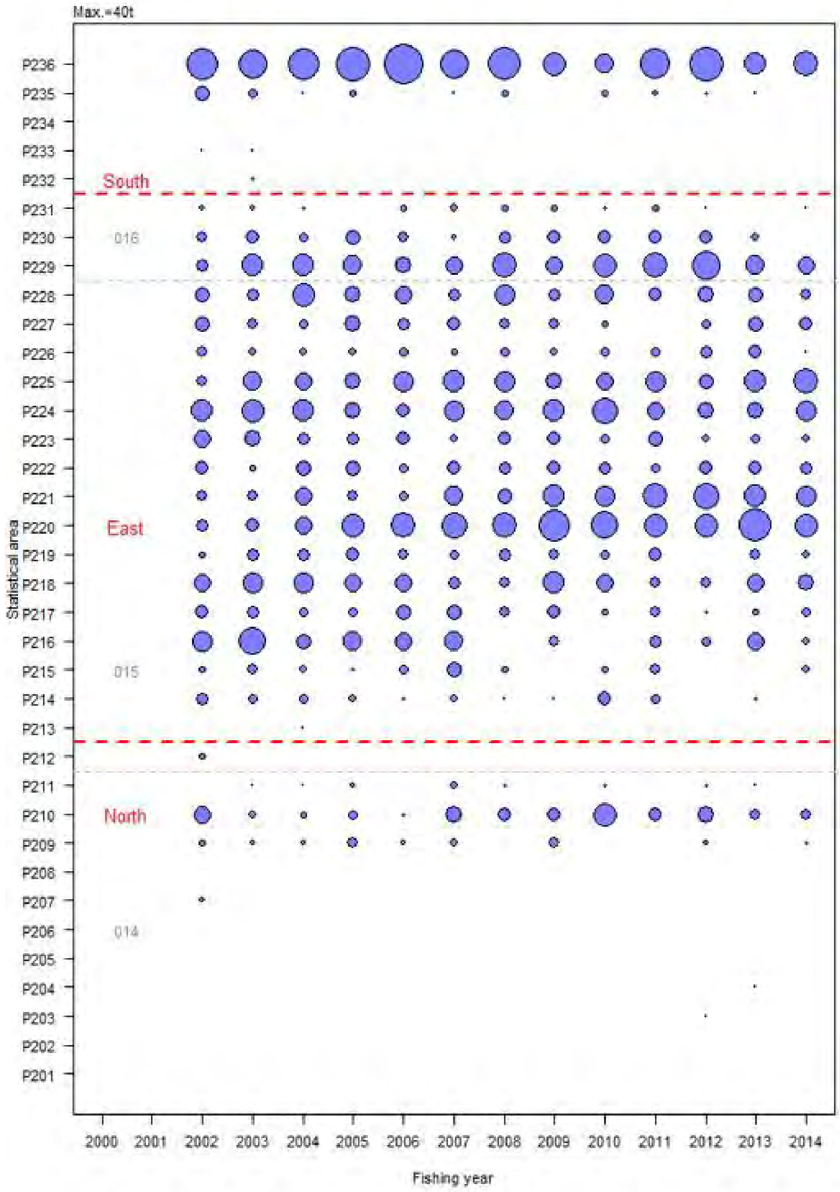


Figure 3: Annual estimated catch by fine-scale statistical area in PAU 2 for fishing years 2002–2014. The size of the circle is proportional to the catch. The red dashed lines delineate different regions.

The CPUE standardisations used the following criteria:

- To restrict the catch-effort records to those from the old Statistical Areas 014, 015, 016 (CELR data) and zones P201–P236 (PCELR data). These areas contain most of the commercial catch.
- For the CELR data standardisation to use a subset of the groomed data for which the recorded duration would be less ambiguous. The criteria to be used to subset the data are: (i) just one diver, or (ii) fishing duration ≥ 6 hours and number of divers ≥ 2. For this subsetted data set, offer both number of divers and duration (as a polynomial) to the model.
- Do a sensitivity CELR data standardisation where the fishing duration cut-off is 4 hours: (i) just one diver, or (ii) fishing duration ≥ 4 hours and number of divers ≥ 2.
- To use Fisher Identification Number (FIN) in standardisation procedures instead of vessel.
- Not to put in a year and area interaction in the standardisations (which would be used in a single area assessment), but to explore area differences in catch rates by doing separate standardisations where a year and area interaction is forced in at the start. For the CELR data the smallest possible area sub-divisions are Statistical Areas 014, 015, and 016. For the PCELR data a close, but more natural division of the areas is South, East, and North (Figure 3), where the large East area can be broken up further based on the strata used for length-frequencies.

4.1 CELR: the standardisation

CPUE was defined as daily catch. Year was forced into the model at the start and other predictor variables offered to the model were FIN, Statistical Area (014, 015, 016), month, fishing duration (as a cubic polynomial), number of divers, and a month:area interaction. Following previous standardisations, no interaction of fishing year with area was entered into the model, however, a separate standardisation is also done where a year:area interaction is forced in at the start.

The model explained 77% of the variability in CPUE with fishing duration (70%) explaining most of this followed by FIN (3%). The effects appear plausible and the model diagnostics were good. The standardised index declines for the first four years, then increases, with a drop in the last year (Table 4, Figure 4).

Table 4: Standardised CELR index, lower and upper 95% confidence intervals, and CV.

Year	index	lower.CI	upper.CI	CV
1990	1.01	0.88	1.17	0.07
1991	0.94	0.81	1.07	0.07
1992	0.89	0.78	1.02	0.07
1993	0.89	0.78	1.01	0.06
1994	0.87	0.76	0.99	0.06
1995	0.91	0.80	1.03	0.06
1996	0.99	0.87	1.12	0.06
1997	0.98	0.86	1.13	0.07
1998	1.08	0.92	1.27	0.08
1999	1.19	1.02	1.39	0.08
2000	1.21	1.03	1.42	0.08
2001	1.13	0.97	1.31	0.08

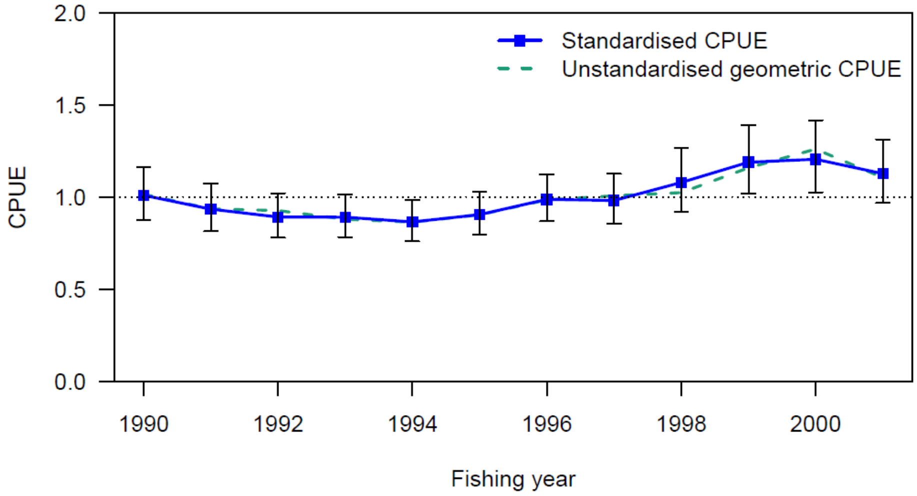


Figure 4: The standardised CPUE index with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

As a sensitivity to the filtering criteria for the subsetted data set (in which the fishing duration field should be less ambiguous), another standardisation was done in which when the number of divers was ≥ 2 then the fishing duration has to be ≥ 4 hours (instead of 6 hours). The resulting index is very similar to that when 6 hours is used (Figure 5).

4.2 PCELR: the standardisation

For the standardisation model CPUE (the dependent variable) was modelled as log of the diver catch with a normal error distribution. Fishing year was forced into the model at the start. Variables offered to the model were month, diver key, FIN, statistical area, duration (third degree polynomial), and diving condition. Following previous standardisations, no interaction of fishing year with area was entered into the model however, a separate standardisation is also done where a year:area interaction is forced in at the start.

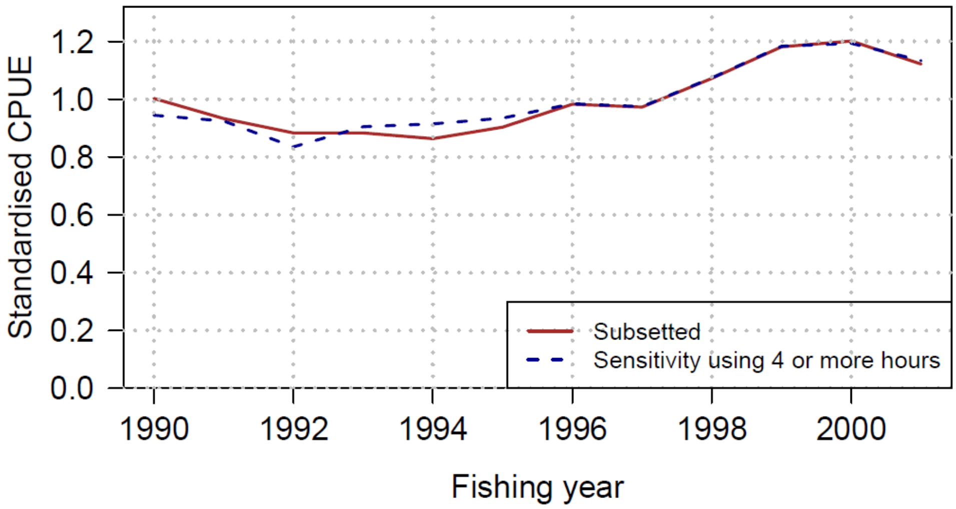


Figure 5: Sensitivity using four hours or more (for two or more divers).

Except for month, all variables were accepted into the model, which explained 73% of the variability in CPUE. Most of the variability was explained by duration (56%) and diver (9%). The effects appear plausible and the diagnostics were good. There is an apparent increasing effect for the catch taken after a fishing duration of 10 hours, although for the majority of records fishing duration is less than 10 hours.

The standardised index shows a slow decline from 2002 to 2012 with a slight increase since then (Table 5, Figure 6). As the standardised index shows little contrast since 2002, and there is little growth data available for PAU 2, stock assessment model estimates of biomass would be highly uncertain and not useful for management purposes. Because of this it was decided by the Shellfish Working Group that a full stock assessment should not be undertaken for PAU 2.

Table 5: Standardised index for the PCELR data set, lower and upper 95% confidence intervals and CV.

Year	index	lower.CI	upper.CI	CV
2002	1.13	0.99	1.28	0.06
2003	1.05	0.94	1.16	0.05
2004	1.05	0.95	1.16	0.05
2005	1.01	0.92	1.11	0.05
2006	1.04	0.94	1.15	0.05
2007	0.95	0.86	1.05	0.05
2008	0.94	0.86	1.04	0.05
2009	0.99	0.89	1.10	0.05
2010	0.97	0.88	1.08	0.05
2011	0.95	0.86	1.05	0.05
2012	0.95	0.86	1.05	0.05
2013	1.01	0.90	1.12	0.05
2014	0.98	0.86	1.11	0.07

It should be noted that a large amount of literature on abalone 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 pāua tend to aggregate and in order to maximise their catch rates divers move from areas that have been depleted of pāua, to areas with higher density. The consequence of this fishing behaviour is that overall abundance is decreasing but CPUE is remaining stable. This may not be such a large problem in PAU 2 because distribution of catch has been consistent for many years and there is little evidence of serial depletion occurring (Figure 3).

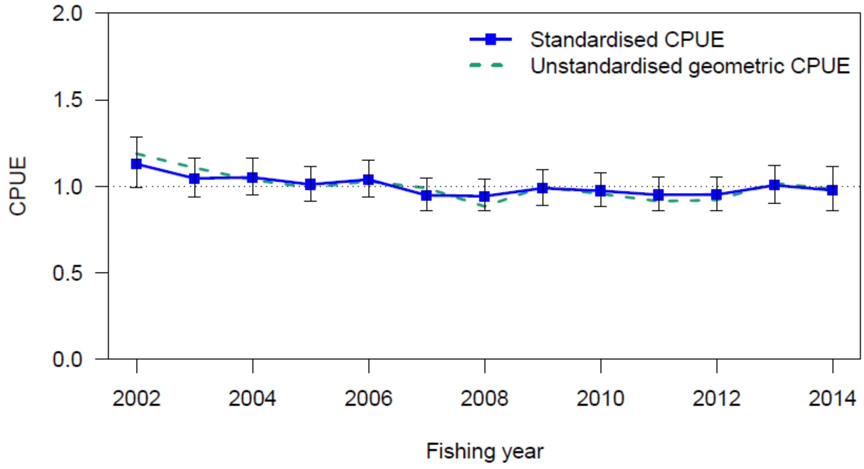


Figure 6: The standardised CPUE index for the PCELR dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

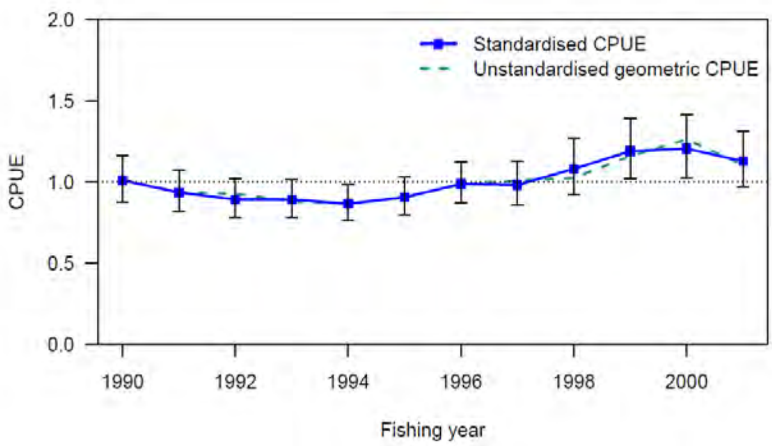
5. STATUS OF THE STOCKS

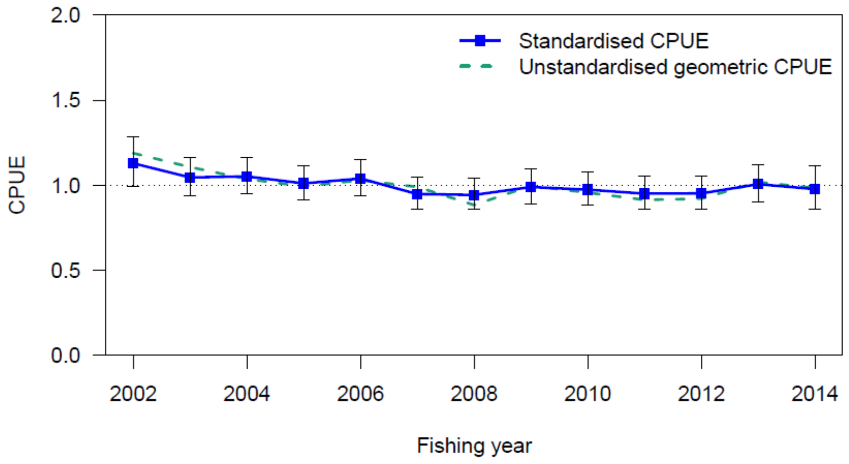
Stock Structure Assumptions

A genetic discontinuity between North Island and South Island pāua populations was found approximately around the area of Cook Strait (Will & Gemmell 2008).

- **PAU 2 -** *Haliotis iris*

Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	Standardised CPUE index
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: -
Status in relation to Target	Unknown
Status in relation to Limits	Unlikely (< 40%) to be below the Soft Limit Unlikely (< 40%) to be below the Hard Limit
Status in relation to Overfishing	Unknown: There are no data for recreational or illegal catch and both are likely to be significant.

Historical Stock Status Trajectory and Current Status

Standardised and unstandardized CPUE index for 1990–2001 with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.



Standardised and unstandardized CPUE index for 2002–2014 using PCELR data, with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	From 1989–90 to 2001–02 the standardized CPUE index oscillates without any obvious trend, and from 2002–03 until 2013–14 the index is flat.
Recent Trend in Fishing Mortality or proxy	-
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	No stock assessment has been undertaken for this stock
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or commence	Unknown

Assessment Methodology		
Assessment Type	-	
Assessment Method	-	
Period of Assessment	Latest assessment: -	Next assessment: -
Overall assessment quality rank	-	
Main data inputs (rank)	-	-
Data not used (rank)	-	-
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments

CPUE is not generally considered to be a reliable indicator of the status of pāua stocks and may not reflect abundance.
A large portion of PAU 2, including the Wellington south coast, is closed to commercial fishing. This means that the CPUE series collected from the commercial catch and effort data are exclusive of this large area and therefore the abundance of pāua in the fishery as a whole will not be captured well by the CPUE index.

Fishery Interactions
-

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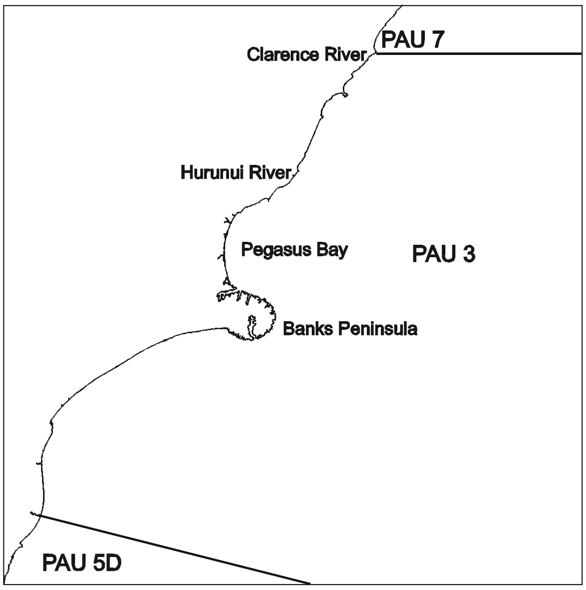
PĀUA (PAU 3) – Canterbury / Kaikōura

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

1.1 Commercial fisheries

PAU 3 was introduced into the Quota Management System on 1 October 1986 with a TACC of 57 t. Before the Fisheries Act (1996) a TAC and allowances for customary, recreational, or other mortality were not required. As a result of appeals to the Quota Appeal Authority, the TACC was increased to 91.62 t in 1995. Following the 2016 Kaikōura earthquake which resulted in the loss of pāua habitat due to coastal uplift, TACC was lowered to 45.8 t, and a TAC was set at 79.3 t with a customary allocation of 15 t, a recreational allocation of 8.5 t, and other sources of mortality were at 10 t (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 3 since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1995	–	–	–	–	57
1995–2017	–	–	–	–	91.62
2017 – present	79.3	15	8.5	10	45.8

Landings have closely followed the TACC since the fishing year 1991–92 (Table 2). The reported landings in 2018–2019 were 44.05 t, with a TACC (t) of 45.8. Catch landings in 2018–19 were 97% of the previous year's landings.

Most of the commercial catch used to come from the northern part of the QMA between the northern end of Pegasus Bay and the Clarence River, and from the southern side of Banks Peninsula.

On 1 October 2001 it became mandatory to report catch and effort on Paua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1). Reported landings for PAU 3 are shown in Table 2 and Figure 2.

Since 2001, a redistribution of fishing effort within PAU 3 has been undertaken by the industry as a response to fears that the more accessible northern part of the fishery was being overfished. A voluntary subdivision was agreed by PauaMAC3 which divided PAU 3 into four management zones (Table 3). A voluntary harvest cap is placed on each management zone and this cap is reviewed annually. Minimum harvest sizes (MHS) are also agreed for each zone in addition to the legislated Minimum Legal Size (MLS). These are also reviewed annually.

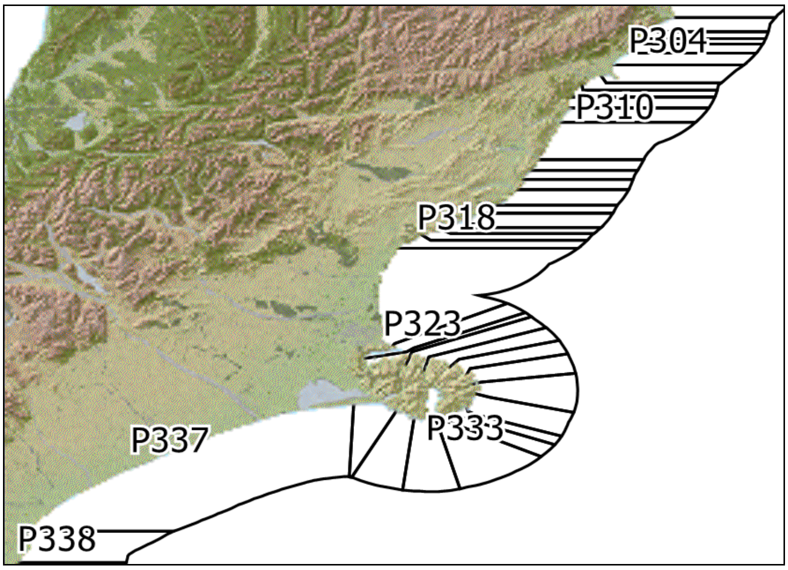


Figure 1: Map of fine scale statistical reporting areas for PAU 3.

Table 2: TACC and reported landings (t) of pāua in PAU 3 from 1983–84 to present. * FSU data.

Year	Landings	TACC
1983–84*	114.00	–
1984–85*	92.00	–
1985–86*	51.00	–
1986–87*	54.02	57.00
1987–88*	62.99	60.49
1988–89*	57.55	66.48
1989–90	73.46	69.43
1990–91	90.68	77.24
1991–92	90.25	91.50
1992–93	94.52	91.50
1993–94	85.09	91.50
1994–95	93.26	91.50
1995–96	92.89	91.62
1996–97	89.65	91.62
1997–98	93.88	91.62
1998–99	92.54	91.62
1999–00	90.30	91.62
2000–01	93.19	91.62
2001–02	89.66	91.62
2002–03	90.92	91.62
2003–04	91.58	91.62
2004–05	91.43	91.62
2005–06	91.60	91.62
2006–07	91.61	91.62
2007–08	91.67	91.62
2008–09	90.84	91.62
2009–10	91.61	91.62
2010–11	90.40	91.62
2011–12	91.14	91.62
2012–13	90.01	91.62
2013-14	90.85	91.62
2014–15	90.44	91.62
2015–16	91.73	91.62
2016–17	66.29	91.62
2017–18	45.59	45.80
2018–19	44.05	45.80

Table 3: Summary of the management zones within PAU 3 as initiated by PāuaMAC3.

Management zone (since 2001)	Area	Statistical area zone
3A	Clarence to Hapuku	P301–P304
3B	Hapuku to Conway	P305–P310
3D	Conway to Waipara	P311–P321
3E	Waipara to Witaki	P322–P329

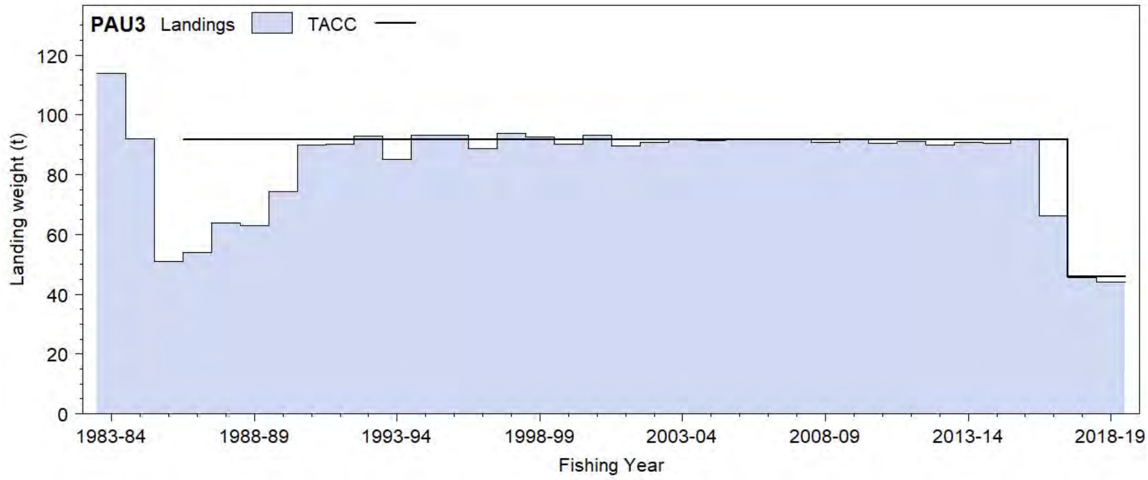


Figure 2: Reported commercial landings and TACC for PAU 3 from 1983–84 to present.

1.2 Recreational fisheries

For further information on recreational fisheries refer to the introductory PAU Working Group Report. The 'National Panel Survey of Marine Recreational Fishers 2017–18: Harvest Estimates' estimated that the recreational harvest for PAU 3 was 8.8 t with a CV of 35%. For the purpose of the 2013 stock assessment, the Shellfish Working Group (SFWG) agreed to assume that the recreational catch rose linearly from 5 t in 1974 to 17 t in 2013.

1.3 Customary fisheries

Estimates of customary catch for PAU 3 are shown in Table 4. These numbers are likely to be an underestimate of customary harvest because only the catch in kilograms and numbers harvested are reported in the table.

Landings before 2010–11 do not include the area between the Hurunui River and the South Shore (just north of Banks Peninsula), because Tangata Tiaki were not appointed there until November 2009. Many tangata whenua also harvest pāua under their recreational allowance and these are not included in records of customary catch.

Table 4: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kilogram) and numbers) of pāua in PAU 3 from 2000–01 to 2018-19. Landings data before 2010–11 exclude the area between the Hurunui River and Pegasus Bay. – no data. [Continued next page]

	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
1998–99	–	–	–	–
1999–00	–	–	–	–
2000–01	–	–	300	230
2001–02	200	50	6 239	4 832
2002–03	–	–	3 422	2 449
2003–04	–	–	–	–
2004–05	–	–	–	–
2005–06	–	–	1 580	1 220
2006–07	–	–	5 274	4 561
2007–08	–	–	7 515	5 790
2008–09	–	–	10 848	8 232
2009–10	–	–	8 490	6 467
2010–11	–	–	8 360	7 449
2011–12	–	–	5 675	4 242
2012–13	–	–	15 036	12 874
2013–14	–	–	10 259	7 566
2014–15	–	–	8 761	7 035

Table 4 [Continued]

	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
2015–16	–	–	14 801	11 808
2016–17	–	–	11 374	9 217
2017–18	–	–	2 708	1 725
2018–19	–	–	480	278

1.4 Illegal catch

For further information on illegal catch refer to the introductory PAU Working Group Report.

For the purpose of the 2013 stock assessment, the SFWG agreed to assume that illegal catches rose linearly from 5 t in 1974 to 15 t in 2000, and remained at 15 t between 2001 and 2013.

1.5 Other sources of mortality

The Working Group agreed that handling mortality would not be included in the model.

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

On 16 November 2016 a 7.8 magnitude earthquake hit the upper east coast of the South Island, causing extensive uplift of about 130 km of coastline by as much as 4 m in some areas. This resulted in the widespread mortality of marine organisms, changes to the structure of intertidal and subtidal rocky reefs, and significant alterations to the structure of nearshore reef communities (Alestra et al. 2019). Ongoing monitoring of these nearshore reef communities has revealed signs of recovery in the low intertidal zones, whereas sub-tidally there has been little recovery in areas that were de-vegetated and previously abundant algal stands appear to have become more sparse and fragmented (Alestra et al. 2020).

The whole northern part of the PAU 3 fishery (Pāua Statistical Areas P301 to P310, Figure 3) was impacted to varying degrees by the earthquake. The earthquake caused the direct mortality of a large number of juvenile and adult pāua that became exposed to the terrestrial environment with no means of being able to return to the water. More indirect mortality is also expected from the earthquake due to an immediate loss of pre-earthquake pāua habitat that now lies above the new post-earthquake high tide mark.

Although the impacts of the seabed uplift on pāua populations around Kaikōura will only become clear in the longer term, work was undertaken to evaluate the area utilised by the pāua fishery that is now above the post-earthquake low tide mark (Neubauer 2017). The results estimated that the seabed uplift led to a loss of up to 50% of the pre-earthquake fished area in the pāua statistical areas P301 to P310. In area 301, the habitat loss was 7 ha, which corresponds to 52% of the fished area. However, this area has contributed relatively little to the commercial catch. In area 302, which has contributed a larger proportion of the PAU 3 commercial catch, the area lost was 43 ha, which corresponds to 43% of the fished area. In other affected areas, the area lost was generally less than 10%. Across PAU 3 statistical areas, a total of 21% of the fished area (24% of catch weight as recorded on PCELR forms), was impacted by uplift (Figure 3).

The immediate loss of area to the fishery, assumed to be good habitat for pāua, is only part of the impact that the seabed uplift associated with the Kaikōura earthquake will have on pāua populations. Juvenile pāua recruit in shallow water, and so the loss of juvenile habitat will have been higher than the loss of adult habitat. This will impact on the number of juvenile pāua growing into the fishery over the coming years. This impact will be more difficult to quantify directly, but may affect pāua populations and fisheries over a span of multiple years.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. A summary of published estimates of biological parameters for PAU 3 is presented in Table 5.

Table 5: Estimates of biological parameters (*H. iris*) in PAU 3.

	Estimate		Source
1. Natural mortality (*M*)			
	0.135 (0.120–0.153)		Median (5–95% range) of posterior distribution for the base case model
2. Weight = a(length)^b (Weight in g, length in mm shell length)			
All	a	b	
	2.99 x 10^{-5}	3.303	Schiel & Breen (1991)
3. Size at maturity (shell length)			
	50% maturity at 82 mm (80–84)		Median (5–95% range) of posterior distribution for the base case model
	95% maturity at 102 mm (96–108)		Median (5–95% range) of posterior distribution for the base case model

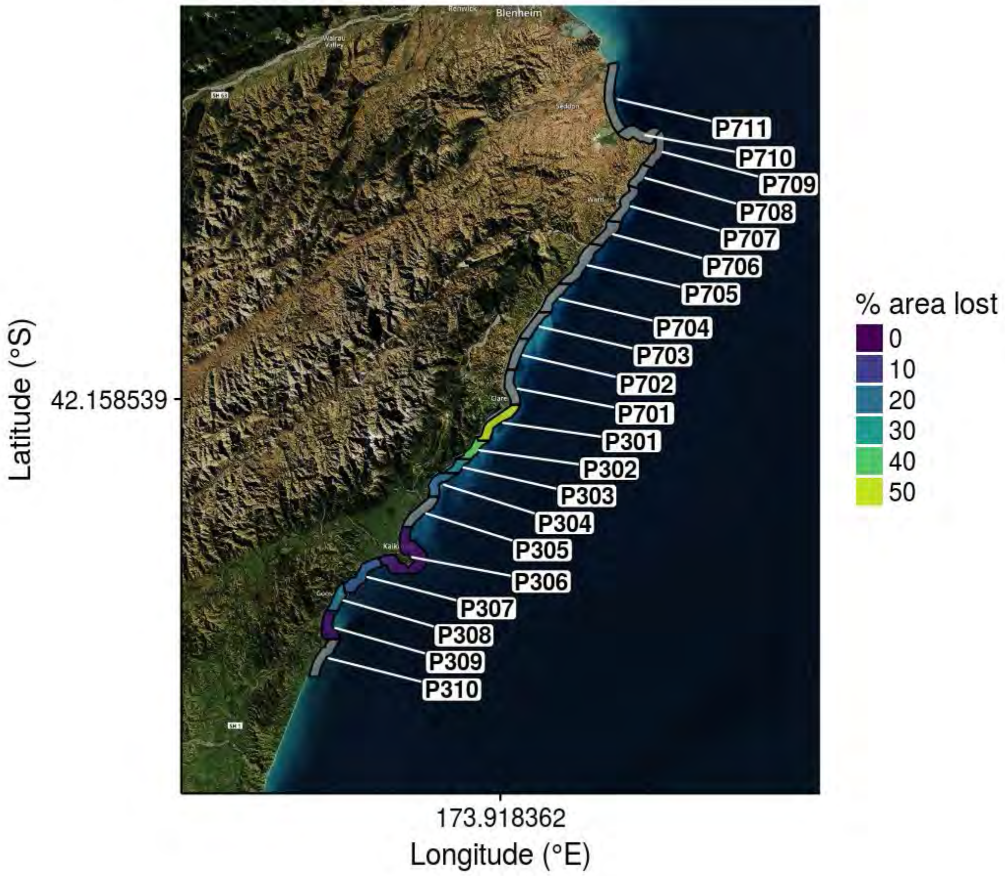


Figure 3: Percent fished area above the post-earthquake low tide mark for statistical areas within the Kaikōura earthquake fishery closure zone. Grey indicates that no post-earthquake elevation data were available.

3. STOCKS AND AREAS

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

4. STOCK ASSESSMENT

The last assessment was conducted in 2014; however, given the potential effects of the earthquake, it is unclear how representative estimates from this assessment are for the current pāua stock.

The stock assessment was implemented using a length-based Bayesian estimation model, with parameter point estimates based on the mode of the joint posterior distribution and uncertainty based on marginal posterior distributions generated from Markov chain Monte Carlo (MCMC) simulations. The most recent stock assessment was conducted in 2014 for the fishing year ended 30 September 2013. The Shellfish WG determined a set of model runs where growth and natural mortality parameter values were fixed. The parameter values were thought to cover the plausible range of productivity assumptions for the stock. Markov chain Monte Carlo (MCMC) simulations were conducted on a model agreed to by the SFWG. This particular model (6.1) estimated M within the model (with a lognormal prior with a mean of 0.1) but fixed the growth parameters at the medium value (g_1=20 mm, g_2=6 mm). On reviewing the results of the MCMC simulations the SFWG chose model 6.1 as the base case. The lack of comprehensive growth and length frequency data for PAU 3 and the lack of contrast in the CPUE series means that uncertainty in the model outputs is higher than preferred.

4.1 Estimates of fishery parameters and abundance indices

Assumed prior distributions for model parameters are summarised in Table 6.

Table 6: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U, uniform; N, normal; LN = lognormal), mean and CV of the prior.

Parameter	Prior	μ	CV	Bounds	
				Lower	Upper
ln($R0$)	U	–	–	5	50
M (Natural mortality)	LN	0.1	0.35	0.01	0.5
Ln(q^I) (catchability coefficient of CPUE)	U	–	–	-30	0
Ln(q^J) (catchability coefficient of PCPUE)	U	–	–	-30	0
L_{50} (Length at 50% maturity)	U	–	–	70	145
L_{95-50}(Length between 50% and 95% maturity)	U	–	–	1	50
D_{50}(Length at 50% selectivity for the commercial catch)	U	–	–	70	145
D_{95-50}(Length between 50% and 95% selectivity the commercial catch)	U	–	–	0.01	50
ϵ (Recruitment deviations)	N	0	0.4	-2.3	2.3

The observational data were:

1. A 1990–2001 standardised CPUE series based on CELR data.
2. A 2002–2012 standardised CPUE series based on PCELR data.
3. A commercial catch sampling length frequency series for 2000, 2002–2012.
4. Maturity at length data.

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2013 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2013. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, with variables entering the model in the order that gave the maximum decrease in the residual deviance. Predictor variables were accepted into the model only if they explained at least 1% of the deviance.

For both the CELR and PCELR data, the Fisher Identification Number (FIN) was used in the standardisations instead of vessel, because the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN.

For the CELR data there is ambiguity in what is recorded for estimated daily fishing duration, and therefore daily fishing duration has not been used in past standardisations as a measure of effort; instead the number of divers has been used. However, there is evidence that the fishing duration for a diver changes over time and, because of this, a subset of the data was selected for which the recorded fishing duration was less ambiguous. The criteria used to subset the data were: (i) just one diver or, (ii) fishing duration ≥ 6 hours and number of divers ≥ 2. This data subset was used for the CELR standardisation, using estimated daily catch and effort measured as either number of divers or fishing duration (both were offered to the standardisation model).

For the PCELR data the unit of catch was diver catch, with effort as diver duration. The diver duration measures the number of hours fished per diver day.

FIN codes were used to select a core group of fishers from the CELR data, with the requirement that there be a minimum of 6 records per year for a minimum of 2 years to qualify for the core fisher group. This retained 84% of the catch over 1990–2001. For the PCELR data the FIN was also used to select a core group of fishers, with the requirement that there be a minimum of 20 records per year for a minimum of 2 years. This retained 84% of the catch over 2002–2013.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN, Statistical Area (018, 020, 022), month, fishing duration (as a cubic polynomial), number of divers, and a month:area interaction. Variables accepted into the model were fishing year, month, FIN, and fishing duration. Following previous standardisations, no interaction of fishing year with area was entered into the model as the stock assessment for PAU 3 is a single area model. However, a separate standardisation is also done where a year:area interaction is forced in. Forcing in a year:area interaction indicates that there are differences in standardised CPUE between the area 018 and the two areas 020 and 022. However, in the years where they differ there are very few records to estimate the year effects for areas 020 and 022.

For the PCELR data, fishing year was forced into the model and variables offered to the model were month, diver key, FIN statistical area, diver duration (third degree polynomial), and diving conditions. All the variables were accepted into the final model.

The standardised CPUE from the CELR data is flat from 1990 to 1994, shows a rise of 20% from 1995 to 1998, then declines for the next three years to 2001 (Figure 4, top). The standardised CPUE from the PCELR data shows a gradual decline of 10% from 2002 to 2013 (Figure 4, bottom).

4.2 Biomass survey and monitoring

Following the 2016 Kaikōura earthquake, a biomass survey was implemented to estimate adult pāua abundance and a monitoring programme was put in place, both in the earthquake-affected area, to inform management decisions relating to the re-opening of the paua fishery (McCowan & Neubauer 2018). To estimate abundance, novel methodologies using GPS dive loggers and underwater electronic calipers were developed. Fixed monitoring points within surveyed areas to monitor discrete pāua populations through time were established.

Pāua were mostly found in aggregations, preferentially in shallow water. This was not just the case for small pāua but also for large individuals (i.e., over 120 mm), although smaller individuals (under 100 mm) showed a strongly decreasing trend with depth. Estimated pāua density was 0.028 pāua per square metre (geometric mean; 95% confidence interval (CI) [0.009; 0.08]). Scaling density estimates to total biomass or abundance was difficult due to the lack of robust estimates of habitat area for pāua. In the absence of a defensible solution, only density was calculated.

Eighty-three discrete monitoring points were established throughout the survey sites. Within the time frames of this project, 30 of these points were re-surveyed. Relatively stable length-frequency distributions were observed between survey times across many monitoring points, although some points showed notable decreases or a complete absence of pāua on re-survey.

4.3 Stock assessment methods

The 2013 PAU 3 stock assessment used the same length-based model as the 2012 PAU 5D assessment (Fu 2013). The model was described by Breen et al (2003). This is the first assessment for PAU 3 using the length based Bayesian model (Fu 2014).

The model structure assumed a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm, in 2 mm bins. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of transition among length classes at each time step. Pāua enter the model following recruitment and are removed by natural mortality and fishing mortality.

The models were run for the years 1965–2013. Catches were collated for 1974–2013 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 at 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 mm and 80 mm. The stock-recruitment relationship is unknown for pāua. A relationship may exist on small geographical scales, but not be apparent when large geographical scales are modelled (Breen et al 2003). However, the Shellfish Working Group agreed to use a Beverton-Holt stock-recruitment relationship with steepness (*h*) of 0.75 for this assessment.

Maturity is not required in the population partition but is necessary for estimating spawning biomass. The model estimated proportions mature from length-at-maturity data. Growth and natural mortalities were also estimated within the model. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and asymptote at 1.

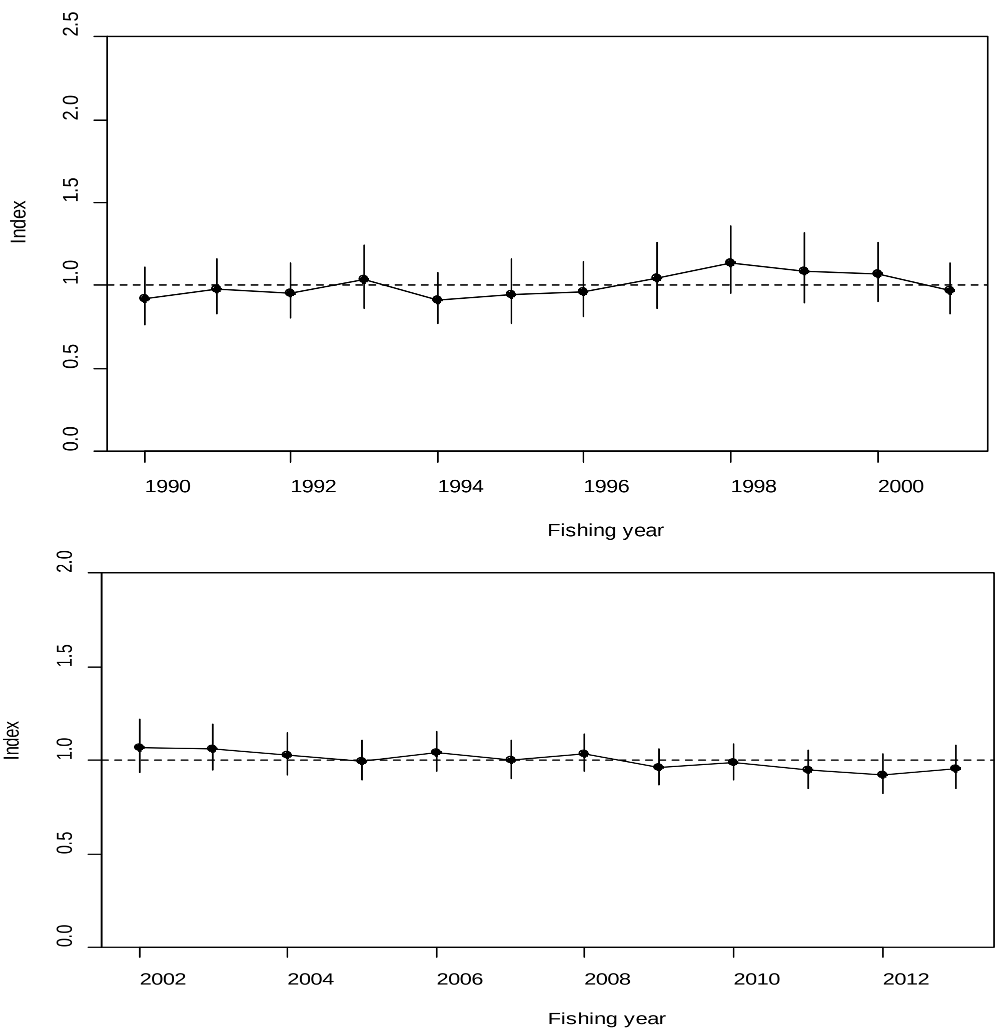


Figure 4: The standardised CPUE indices with 95% confidence intervals for the early CELR/FSU series (top panel) and the recent PCELR series (bottom panel).

The growth data available to the PAU 3 assessment were collected from several sites on Banks Peninsula. Because most of the pāua measured in this experiment were stunted, incorporating these data in the assessment would under-estimate the growth for the whole stock. There were also some growth measurements from an experiment conducted in Cape Campbell (within PAU 7) which is close to the northern boundary of PAU 3, but the sample size is too small to be useful. Therefore the growth parameters were fixed in this assessment.

The growth parameter were fixed at low (g_1=15 mm, g_2=4.5 mm), median (g_1=20 mm, g_2=6 mm), and high (g_1=25 mm, g_2=7.5 mm) values. The median values were based on the estimates of growth using the tag-recapture data from Cape Campbell (Fu 2014). The low and high values were loosely based on the range of growth estimates from assessments of other pāua stocks. For each fixed value of the growth parameters, natural mortality was fixed at three levels, 0.1, 0.15, and 0.2. These values were considered to have covered the plausible range of natural mortality for pāua. In total nine model runs were carried out. The growth and natural mortality parameter values aimed to evaluate the sensitivity of model results to key productivity assumptions and to estimate uncertainty in stock status. Each model run was considered an equally likely scenario. The models were fitted to the data with parameters estimated at the mode of their joint posterior distribution (MPD).

Markov chain Monte Carlo (MCMC) simulations were conducted on a model agreed to by the SFWG to obtain a large set of samples from the joint posterior distribution. This particular model (6.1) estimated M within the model (with a lognormal prior with a mean of 0.1) but fixed the growth parameters at the medium value (g_1=20 mm, g_2=6 mm).

The assessment calculates the following quantities from the posterior distributions: the equilibrium spawning stock biomass with recruitment equal to the average recruitment over the period for which recruitment deviations were estimated (B_0,); and the mid-season spawning and recruited biomass for 2013 (B_{2013} and B^r_{2013}) and for the projection period (B_{proj} and B^r_{proj}).

This assessment also reports the following fishery indictors:

- $B\%B_0$ Current or projected spawning biomass as a percentage of B_0
- $B\%B_{msy}$ Current or projected spawning biomass as a percentage of B_{msy}
- $\Pr(B_{proj} > B_{msy})$ Probability that projected spawning biomass is greater than B_{msy}
- $\Pr(B_{proj} > B_{2013})$ Probability that projected spawning biomass is greater than $B_{current}$
- $B\%B^r_0$ Current or projected recruited biomass as a percentage of B^r_0
- $B\%B^r_{msy}$ Current or projected recruited biomass as a percentage of B^r_{msy}
- $\Pr(B_{proj} > B^r_{msy})$ Probability that projected recruit-sized biomass is greater than B^r_{msy}
- $\Pr(B_{proj} > B^r_{2013})$ Probability that projected recruit-sized biomass is greater than B^r_{2012}
- $\Pr(B_{proj} > 40\%B_0)$ Probability that projected spawning biomass is greater than 40% B_0
- $\Pr(B_{proj} < 20\%B_0)$ Probability that projected spawning biomass is less than 20% B_0
- $\Pr(B_{proj} < 10\%B_0)$ Probability that projected spawning biomass is less than 10% B_0
- $\Pr(U_{proj} > U_{40\%B0})$ Probability that projected exploitation rate is greater than $U_{40\%B0}$

4.4 Stock assessment results

For the nine model runs in which growth and natural mortality were fixed B_0 ranged from 1500 t to 2900 t, and $B_{current}$ ranged from 21% to 66% of B_0 (Table 7). All model runs showed an overall deceasing trend in spawning stock biomass but this trend has become slower in recent years (Figure 5). In general, models with higher values for M and growth had higher estimates of initial and current biomass, and models with lower M and growth had lower estimates of biomass.

Table 7: MPD estimates of B_0, B_{2013}, and U_{2013} for models 3.1–3.3, 4.1–4.3, and 5.1–5.3.

Model	M	g_1	g_2	B_0	B_{2013}	B_{2013}/B_0	U_{2013}
3.1	0.10	25	7.5	2 344	488	0.21	0.32
3.2	0.10	20	6	2 460	672	0.27	0.26
3.3	0.10	15	4.5	2 916	1 231	0.42	0.17
4.1	0.15	25	7.5	1 795	474	0.26	0.39
4.2	0.15	20	6	1 965	718	0.37	0.30
4.3	0.15	15	4.5	2 452	1 262	0.51	0.21
5.1	0.20	25	7.5	1 497	520	0.35	0.40
5.2	0.20	20	6	1 767	848	0.48	0.30
5.3	0.20	15	4.5	2 594	1 708	0.66	0.18

When *M* was fixed at 0.1, the models fitted the CSLF and CPUE data poorly. Model fits improved markedly when *M* was increased to 0.15 or 0.20. The SFWG believed that 0.15 is probably more credible than 0.2 for the natural mortality of pāua. Model fits and likelihood function values did not provide a clear distinction among low, median, or high growth values. Estimates of stock depletion levels were sensitive to the assumed value of the growth parameters.

For model (6.1), the posterior of *M* had a median of 0.14 with a 90% credible interval between 0.12 and 0.15. The posterior distributions of spawning stock biomass showed a gradual declining trend (Figure 6), estimated B_0 was about 2670 t (2470–2960 t) and $B_{current}$ was about 52% (45–60%) of B_0 (Table 8). The SFWG agreed for this model to be adopted as the base case model, but noted that the model underestimates uncertainty in stock biomass and status because of uncertainty in growth.

The estimates of recruitment deviations showed a period of relatively low recruitment between 1980 the 1990, and that recruitment in recent years (after 2002) has been above the long term average. Exploitation rates showed a gradual upward trend since the 2000s, and the estimated exploitation rate in 2013 was about 0.16 (0.09–0.14) (Table 8).

Model projections, assuming current catch levels and using recruitments re-sampled from the recent model estimates, suggested that the spawning stock abundance would slightly decrease to about 51% (41–63) of B_0 over the following three years (Table 9). The projections indicated that the probability of the spawning stock biomass being above the target (40% B_0) over the following three years was close to 100%.

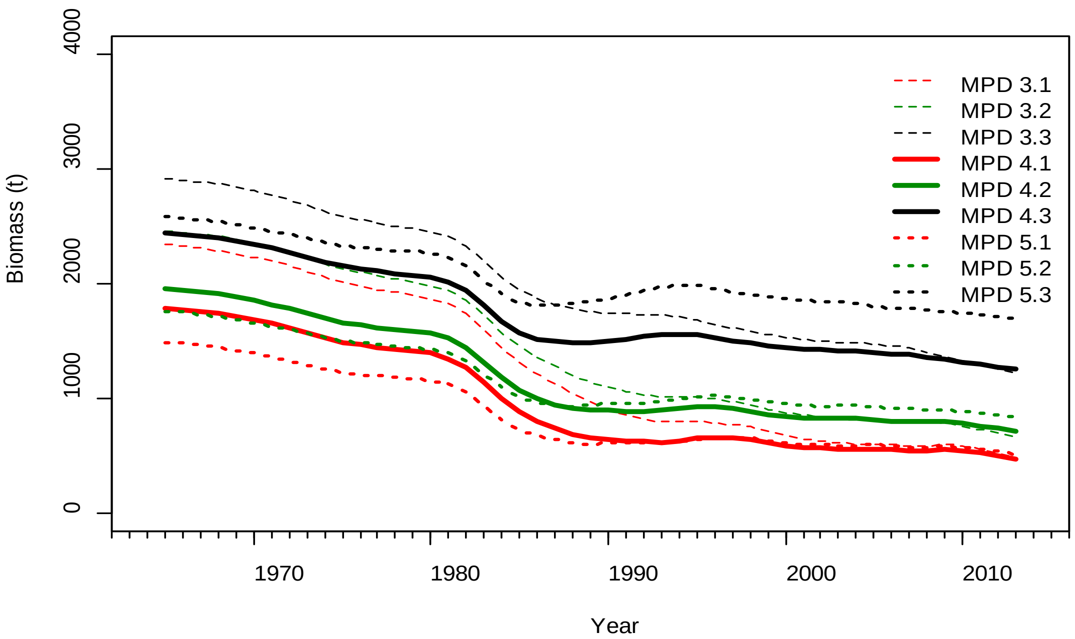


Figure 5: Estimates of spawning stock biomass this page and estimates of spawning stock biomass as a ratio of B_0 (next page) for MPD models 3.1, 3.2, 3.3, 4.1, 4.2, 4.3, 5.1, 5.2, and 5.3. [Continued on next page]

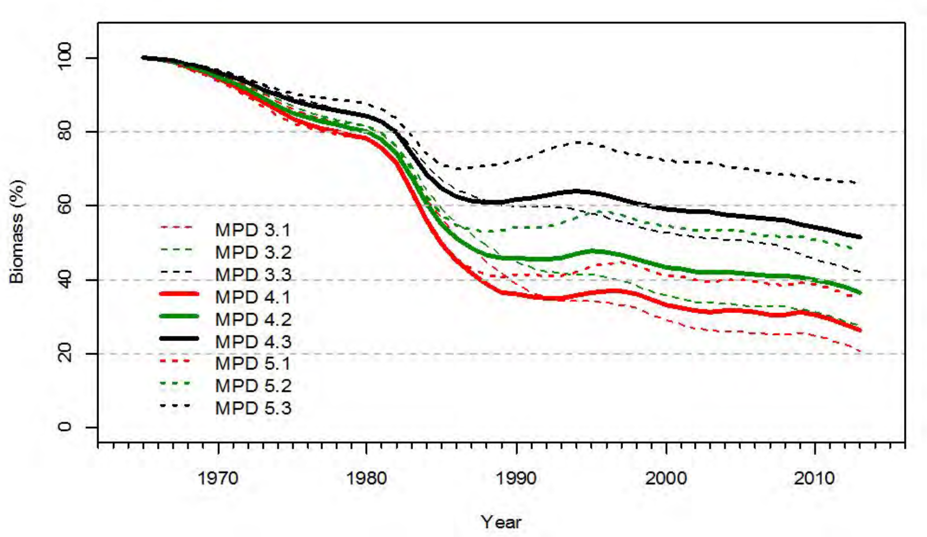


Figure 5 [Continued]: Estimates of spawning stock biomass (previous page) and estimates of spawning stock biomass as a ratio of B_0 (this pagel) for MPD models 3.1, 3.2, 3.3, 4.1, 4.2, 4.3, 5.1, 5.2, and 5.3.

Table 8: Summary of the marginal posterior distributions of key biomass indicators from the MCMC chain from the base case (Model 6.1). The columns show the median, the 5th, and 95th percentiles values observed in the 1000 samples. Biomass is in tonnes.

	5%	Median	95%
B_0	2 470	2 666	2 957
B_{msy}	687	741	834
B_{2013}	1 133	1 390	1 727
B_{2013} %B_0	45	52	60
B_{2013} %B_{msy}	163	187	214
B_{msy} %B_0	27	28	29
rB_0	1 700	1 880	2 100
rB_{msy}	78	126	195
rB_{2013}	502	657	874
rB_{2013}/rB_0	0.28	0.35	0.43
rB_{2013}/rB_{msy}	3.22	5.17	9.32
rB_{msy}/rB_0	0.04	0.07	0.09
MSY	116	131	155
$U_{40\%B0}$	0.39	0.56	0.79
U_{msy}	0.19	0.25	0.34
U_{2013}	0.12	0.16	0.21

Table 9: Summary of current and projected indicators for the base case with future commercial catch set to current TACC: biomass as a percentage of the virgin and current stock status, for spawning stock and recruit-sized biomass. B( ) (current or projected biomass), U( ) (current or projected exploitation rate).

	2013	2014	2015
B_t	1 390 (1 088–1 858)	1 379 (1 067–1 855)	1 371 (1 041–1 847)
% B_0	52 (43.9–62.0)	51.5 (42.9–62.0)	51.3 (41.2–63.1)
% B_{msy}	187 (158–218)	185 (155–220)	184 (149–224)
Pr(>B_{msy})	1.00	1.00	1.00
Pr(>$B_{current}$)	0.35	0.32	0.32
Pr(>40% B_0)	1.00	0.99	0.99
Pr(<20% B_0)	0.00	0.00	0.00
Pr(<10% B_0)	0.00	0.00	0.00
rB_t	657 (481–946)	643 (462–926)	626 (443–915)
% rB_0	34.9 (26.7–45.5)	34.1 (25.2–44.6)	33.2 (24.1–43.9)
% rB_{msy}	517 (295–1 045)	504 (283–1 035)	491 (273–1 019)
Pr(>rB_{msy})	1.00	1.00	1.00
Pr(>$rB_{current}$)	0.12	0.09	0.05
Pr(U_{proj}> $U_{40\% B0}$)	0.03	0.04	0.05

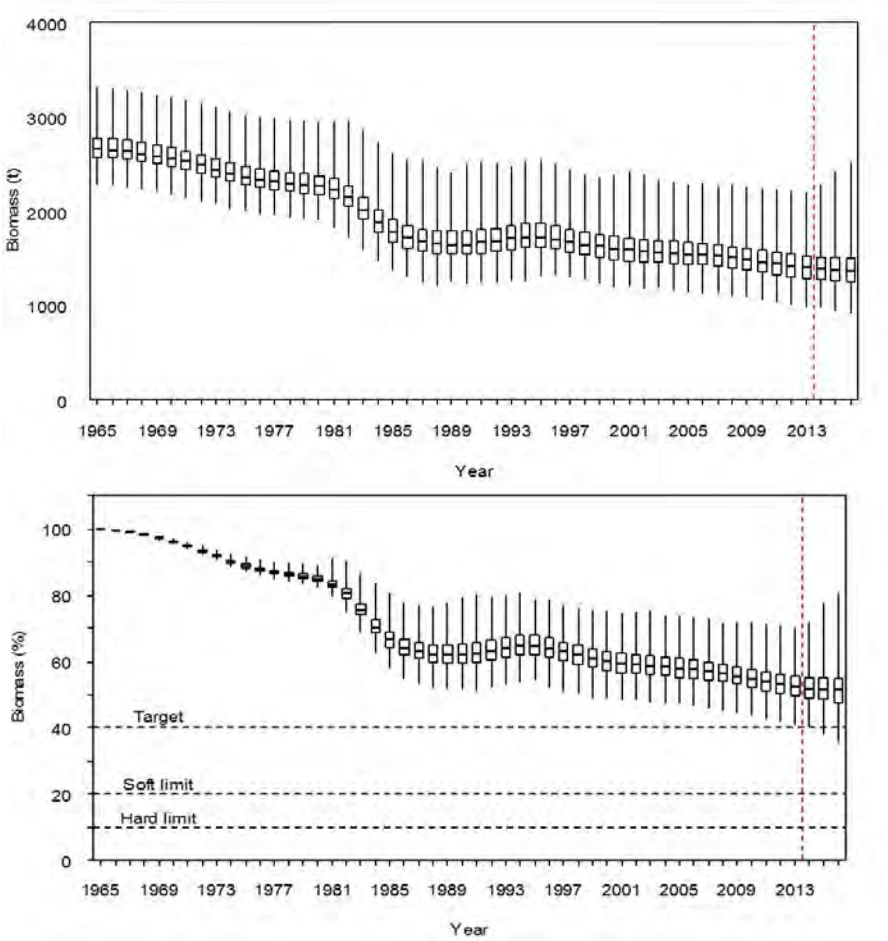


Figure 6: Posterior distributions of spawning stock biomass (top panel) and spawning stock biomass as a percentage of virgin level (bottom panel) from MCMC 6.1 (including projections). The box shows the median of the posterior distribution (horizontal bar), the 25th, and 75th percentiles (box), with the whiskers representing the full range of the distribution.

4.5 Other factors

The assessment used CPUE as an index of abundance. The assumption that CPUE indexes abundance is questionable. The literature on abalone suggests that CPUE is difficult to use in abalone stock assessments because of serial depletion. This can happen when fishers deplete unfished or lightly fished beds and maintain their catch rates by moving to new areas. Thus CPUE stays high while the biomass is decreasing. In PAU 3, both the early and recent CPUE indices have shown a relatively flat trend (the recent CPUE decreased slightly). It is unknown to what extent the CPUE series tracks stock abundance in PAU 3. Information from commercial fishers indicates that the stock is in relatively good shape suggesting that the trend in CPUE series may be credible.

Even if the CPUE indices are credible, they are not very useful in informing estimates of B_0 because they have shown a relatively flat trend. Therefore the catch sampling length frequencies are the most important observations that provide information on the initial size of the stock. The catch sampling coverage in PAU 3 is considered to be reasonably adequate and the CSLF data are likely to have been representative of the stock.

Another source of uncertainty is the catch data. The commercial catch is known with accuracy since 1985, but is probably not well estimated before that. In addition, non-commercial catch estimates are poorly determined. The estimate of illegal catch is uncertain. Anecdotal evidence suggested the recreational catch in PAU 3 is very likely to have increased substantially in recent years and could be much higher than what was assumed in the model. However, the increase in non-commercial catch (if it is true) has not been reflected in the recent CPUE indices, which showed an almost flat trend. One possible reason is that the commercial divers may have fished deeper than recreational fishers and could be fishing different sections of the population. If there is substantial bias in estimates of catches, the model could significantly under-estimate the stock depletion level. Therefore better information on the scale and trend in recreational catch needs to be collated for more accurate assessment of the stock status.

Another source of uncertainty is that fishing may cause spatial contraction of populations (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.

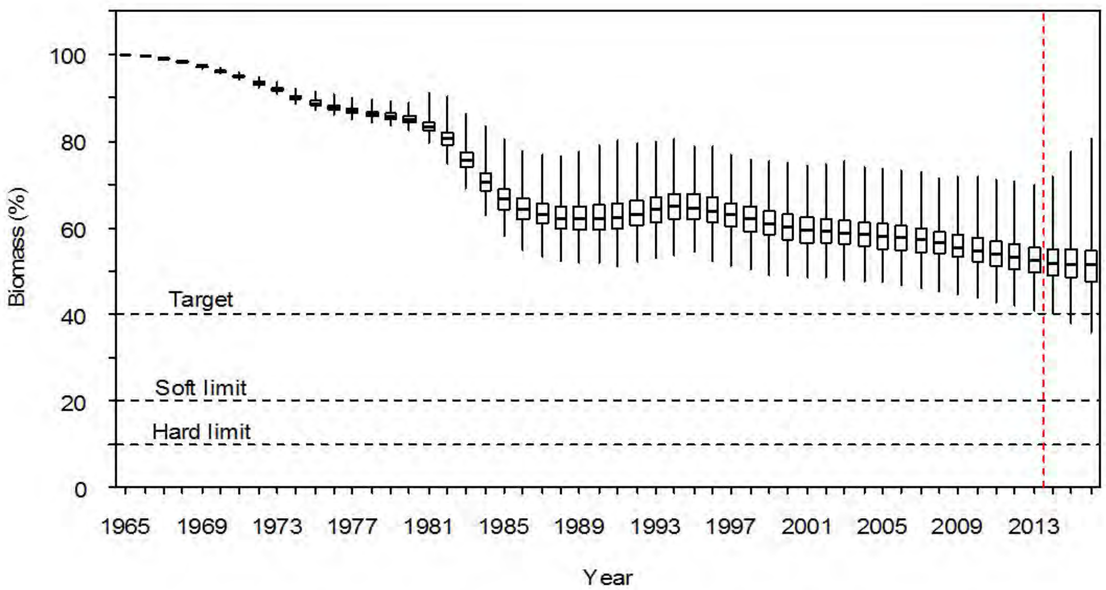
5. STATUS OF THE STOCK

Stock Structure Assumptions
PAU 3 is assumed to be a homogenous stock for purposes of the stock assessment however there is evidence to show this may not be correct (Naylor et al 2006).

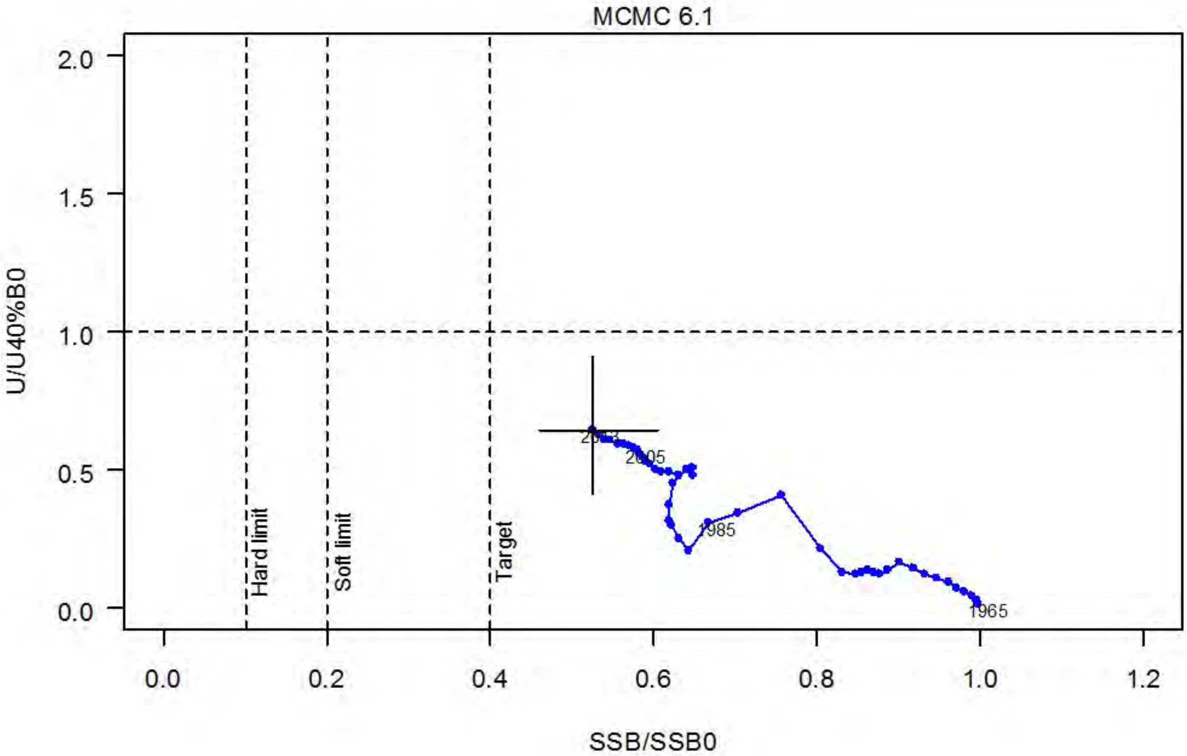
- **PAU 3 - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2014; however, given the potential effects of the earthquake, it is unclear how representative estimates from this assessment are for the current pāua stock
Assessment Runs Presented	MCMC 6.1 base case (M estimated, g_1 fixed at 20 mm and g_2 fixed at 6.0 mm)
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2013} estimated to be 52% B_0 : Very Likely (> 60%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Posterior distributions of spawning stock biomass as a percentage of virgin level from MCMC 6.1 (including projections). 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.



Trajectory of exploitation rate as a ratio U%40B0 and spawning stock biomass as a ratio of B_0 from the start of assessment period 1965 to 2013 for MCMC 6.1 (base case). The vertical lines at 10%, 20%, 40% B_0 represent the hard limit, the soft limit, and the target respectively. U%40B_0 is the exploitation rate at which the spawning stock biomass would stabilise at 40% B_0 over the long term. Each point on trajectory represents the estimated annual stock status: the value on x axis is the mid-season spawning stock biomass (as a ratio of B_0) and the value on the y axis is the corresponding exploitation rate (as a ratio U%40B_0) for that year. The Estimates are based on MCMC median and the 2013 90% CI is shown by the cross line.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Spawning stock biomass has shown an overall deceasing trend but this has become much slower in recent years.
Recent Trend in Fishing Intensity or Proxy	The exploitation rate has shown a gradual upward trend since the 2000s and was about 0.16 (0.09–0.14) in 2013.
Other Abundance Indices	Standardised CPUE remained relatively flat until the early 2000s, and has declined only slightly since then.
Trends in Other Relevant Indicators or Variables	Estimated recruitment was relatively low between 1980 and 1990 but since 2002 has been above the long term average.

Projections and Prognosis	
Stock Projections or Prognosis	The projected spawning stock abundance will slightly decrease over the next three years but will still be remaining above the target
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Results from all model runs suggest it is very unlikely (< 10%) that current catch or TACC will cause a decline below the limits.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	Full quantitative stock assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest: 2014	Next: unknown
Overall assessment quality (rank)	1 – High Quality	

Main data inputs (rank)	- Catch history - CPUE indices early series - CPUE indices later series - Commercial sampling length frequencies - Tag recapture data (to estimate growth) - Maturity at length data	1 – High Quality for commercial catch 2 – Medium or Mixed Quality for recreational catch, which is not believed to be fully representative over the history of the fishery 2 – Medium or Mixed Quality: not believed to proportional to abundance 1 – High Quality 1 – High Quality 2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA 1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	New model	
Major Sources of Uncertainty	- Very little growth data available and growth is not well known. - CPUE may not be a reliable index of abundance. - The model treats the whole of the assessed area of PAU 3 as if it were a single stock with homogeneous biology, habitat and fishing pressures. - Recreational catch in PAU 3 is very likely to have increased substantially in recent years and could be much higher than what was assumed in the model.	

Qualifying Comments:
-The last assessment was conducted in 2014 however, given the potential effects of the earthquake, it is unclear how representative estimates from this assessment are for the current pāua stock. -The lack of comprehensive growth and length frequency data for PAU 3 and the lack of contrast in the CPUE series cause uncertainty in the model outputs. -The SFWG agreed to adopt model 6.1 as the base case model, but noted that the model underestimates uncertainty in stock biomass and stock status because of uncertainty in growth.

Fishery Interactions
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6. FOR FURTHER INFORMATION

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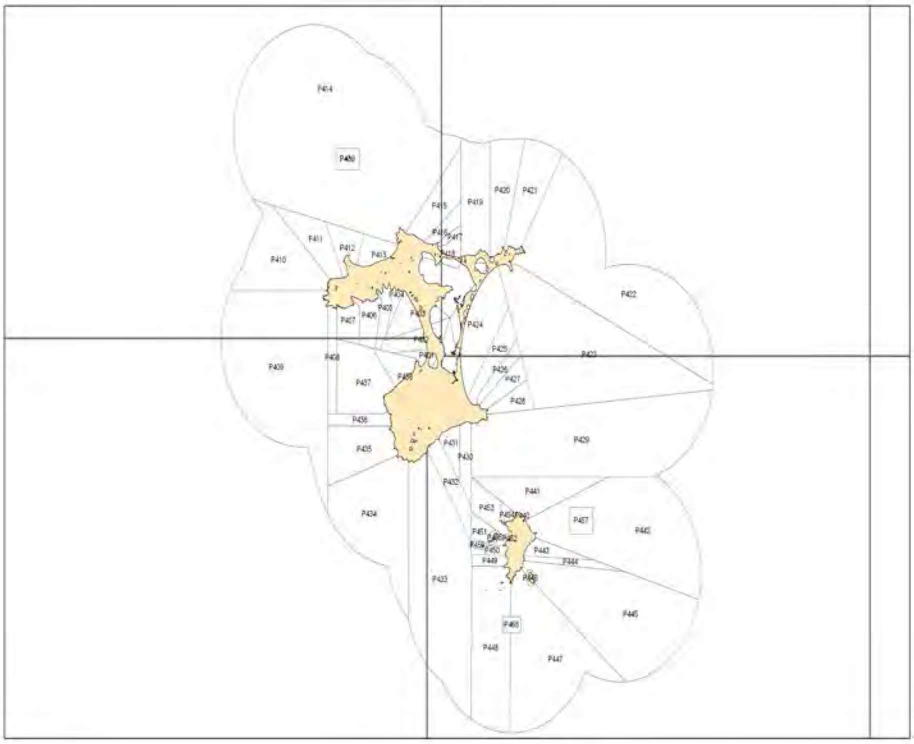
PĀUA (PAU 4) – Chatham Islands

(Haliotis iris)
Pāua



1. FISHERY SUMMARY

PAU 4 was introduced into the Quota Management System (QMS) in 1986–87 with a TACC of 261 t. The TACC was increased to 269 t in 1987–88, 271 t in 1988–89, and 287 in 1989–90. As a result of appeals to the Quota Appeal Authority, the TACC was further increased in 1995–96 to 326 t and has remained unchanged to the current fishing year (Table 1). Before the Fisheries Act (1996) a TAC was not required, and only a TACC was required when PAU 4 entered the QMS.

As a result of a court injunction a review of sustainability measures was undertaken for the 2019–20 fishing year, beginning 1 October 2019. The agreement reached resulted in a TAC, as well as allowances for Māori customary and recreational fishers being set. The TAC was set at 334 t, the TACC at 326.543 t, other mortality at 2 t, customary allowance at 3 t, and the recreational allowance at 3 t.

Because the pāua biomass appears to be declining, the PAU 4 Fishery Plan (approved in 2019 under section 11A of the Fisheries Act 1996) provides a commitment by PAU 4 quota owners to shelve 40% of the PAU 4 ACE.

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 4 since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1987	–	–	–	–	261
1987–1988	–	–	–	–	269
1988–1989	–	–	–	–	271
1989–1995	–	–	–	–	287
1995–2019	–	–	–	–	326
2019 onwards	334	3	3	2	326

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. On 1 October 2001 it became mandatory to report catch and effort on PCELRs using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (see figure above).

At the beginning of the 2009–10 fishing year, reporting of catch in PAU 4 was changed from reporting in greenweight to reporting in meatweight. The TACC is still set in greenweight but fishers are now required to report greenweight catch that is estimated from the meatweight measured by the licensed fish receiver (LFR). The meatweight to greenweight conversion factor is 2.50 (equivalent to 40% meatweight recovery). The change was made to curb the practice of converting meatweight to landed greenweight after shucking to obtain artificially high recovery rates. It was also made to encourage catch spreading by making it commercially viable for fishers to harvest areas where shells are heavily fouled and meatweight recovery is low. Heavy fouling on shells is a problem that occurs in a number of areas around the Chatham Islands. However this reporting requirement was changed back to greenweight at the beginning of the 2017–18 year.

Reported landings have remained below the TACC since 2010–11, averaging 276 t in 2010–11 to 2016–17 before decreasing to 203 t in 2017–18 and 185 t in 2018–19. Landings for PAU 4 are shown in Table 2 and Figure 1.

Table 2: TACC and reported landings (t) of pāua in PAU 4 from 1983–84 to the present.

Year	Landings	TACC
1983–84*	409.00	–
1984–85*	278.00	–
1985–86*	221.00	–
1986–87*	267.37	261.00
1987–88*	279.57	269.08
1988–89*	284.73	270.69
1989–90	287.38	287.25
1990–91	253.61	287.25
1991–92	281.59	287.25
1992–93	266.38	287.25
1993–94	297.76	287.25
1994–95	282.10	287.25
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
2005–06	322.53	326.54
2006–07	322.76	326.54
2007–08	323.98	326.54
2008–09	324.18	326.54
2009–10	323.57	326.54
2010–11	262.15	326.54
2011–12	262.07	326.54
2012–13	263.33	326.54
2013–14	291.98	326.54
2014–15	295.16	326.54
2015–16	294.73	326.54
2016–17	264.63	326.54
2017–18	203.03	326.54
2018–19	185.06	326.54

* FSU data

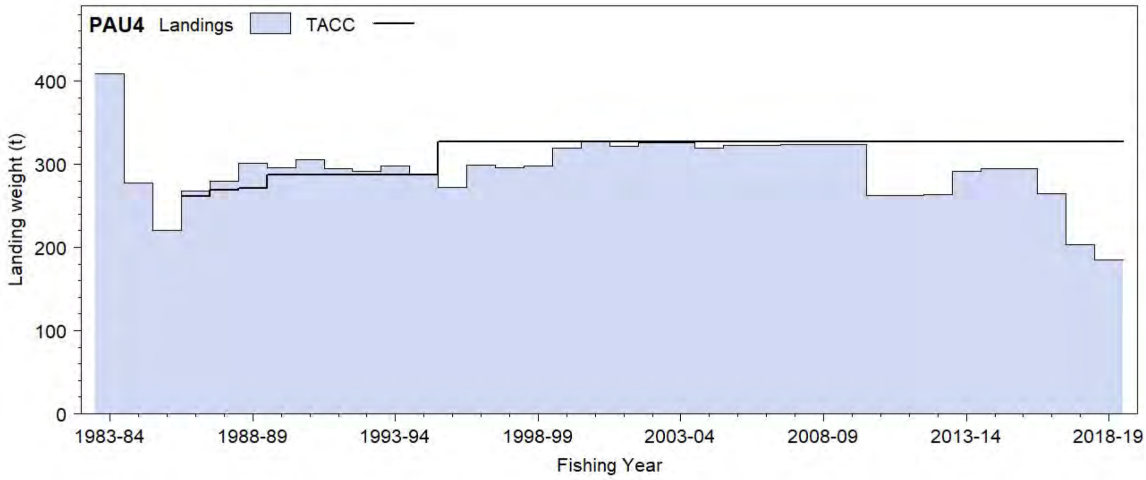


Figure 1: Reported commercial landings and TACC for PAU 4 from 1983–84 to the present.

1.2 Recreational fisheries

There are no estimates of recreational catch for PAU 4. The 1996, 1999–2000, and 2000–01 national marine recreational fishing surveys and the 2011–12 and the 2017–18 national panel surveys did not include PAU 4.

1.3 Customary fisheries

Estimates of customary catch for PAU 4 are shown in Table 3. These numbers are likely to be an underestimate of customary harvest because only the catch in kilograms and numbers are reported in the table.

For the 2004 stock assessment the customary catch was assumed to be zero.

For further information on customary fisheries refer to the introductory PAU Working Group Report.

Table 3: Reported customary landings (number of individuals) of pāua in PAU 4 from 2009–10 to 2018-19. – no data.

	Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**
2009–10	–	–	635	635
2010–11	–	–	–	–
2011–12	–	–	–	–
2012–13	–	–	–	–
2013–14	–	–	110	110
2014–15	–	–	150	150
2015–16	–	–	320	120
2016–17	–	–	366	366
2017–18	50	50	820	764
2018–19	330	330		

1.4 Illegal catch

There are no estimates of illegal catch for PAU 4. For the 2004 stock assessment this catch was assumed to be zero. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality

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

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report.

3. STOCKS AND AREAS

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

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

A standardised CPUE analysis for PAU 4 (Fu 2010) from 1989–90 to 2007–08 was completed in February 2010.

The Shellfish Working Group (SFWG) agreed that, because of extensive misreporting of catch in PAU 4, catch and effort data from the Fisheries Statistical Unit and from the CELR and PCELR forms might be misleading in CPUE analyses and therefore, CPUE cannot be used as an index of abundance in this fishery.

4.2 Stock assessment 2004

The last stock assessment for PAU 4 was completed in 2004 (Breen & Kim 2004). A Bayesian length-based stock assessment model was applied to PAU 4 data to estimate stock status and yield. A reference period from 1991–93 was chosen: this was a period after which exploitation rates increased and then leveled off, and after which biomass declined somewhat and then stabilised. It was not intended as a target. Assessment results suggested that then-current recruited biomass was just above $B_{AV,}$ but with high uncertainty (83% to 125%). and current spawning biomass appeared higher than S_{AV}, (130%), but with cautions related to maturity ogives. Projections suggested that 2007 recruited and spawning biomasses could be above B_{AV}, but this was uncertain.

The SFWG advised that major uncertainties in the assessment required the results to be treated with great caution. The major uncertainties included very sparse research diver survey data, misreported CELR and PCELR data, growth and length frequency data most likely not being representative of the whole population, and the assumption that CPUE was an index of abundance.

In February 2010 the SFWG agreed that, because of 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.

4.3 Biomass estimates

There are no current biomass estimates for PAU 4.

4.4 Yield estimates and projections

There are no estimates of PAU 4.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

H. iris individuals collected from the Chatham Islands were found to be genetically distinct from those collected from costal sites around the North and South Islands (Will & Gemmell 2008).

PAU 4 - *Haliotis iris*

Stock Status	
Year of Most Recent Assessment	2004
Assessment Runs Presented	None
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: U40%B0
Status in relation to Target	Unknown

Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status
In 2010 the SFWG rejected CPUE as an index of abundance, therefore the 2004 stock assessment (Breen & Kim 2004) is no longer considered reliable.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Unknown
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	None
Trends in Other Relevant Indicators or Variables	None

Projections and Prognosis	
Stock Projections or Prognosis	The 2004 stock assessment is no longer considered reliable
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Full Quantitative Stock Assessment, but subsequently rejected	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Last assessment: 2004	Next assessment: No fixed date
Overall assessment quality rank	3 - Low Quality	
Main data inputs (rank)	Catch history CPUE indices Tag recapture growth data Research diver abundance survey data Research diver length frequency data	3 - Low Quality 3 - Low Quality 2- Medium Quality 2- Medium Quality 2- Medium Quality
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	• Potential bias in RDSI • Unreliable reporting of catch and effort data • Assuming CPUE as a reliable index of abundance • Model assumes a homogeneous population • Other model assumptions may be violated	

Qualifying Comments
The 2004 full quantitative stock assessment is no longer considered reliable; *i.e.* the previous assessment has been rejected and there is currently no valid assessment for this stock.

Fishery Interactions
-

6. FOR FURTHER INFORMATION

Breen, P A; Kim, S W (2004) The 2004 stock assessment of paua (*Haliotis iris*) in PAU 4. *New Zealand Fisheries Assessment Report 2004/55.* 79 p.

Fu, D (2010) Summary of catch and effort data and standardised CPUE analyses for paua (Haliotis iris) in PAU 4, 1989–90 to 2007–08. *New Zealand Fiseries Assessment Report 2008/01*. 50 p

Naylor, J R; Andrew, N L; Kim, S W (2003) Fishery independent surveys of the relative abundance, size-structure, and growth of paua (*Haliotis iris*) in PAU 4. *New Zealand Fisheries Assessment Report 2003/08*. 16 p.

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. *New Zealand Journal of Marine and Freshwater Research* 16: 147–161.

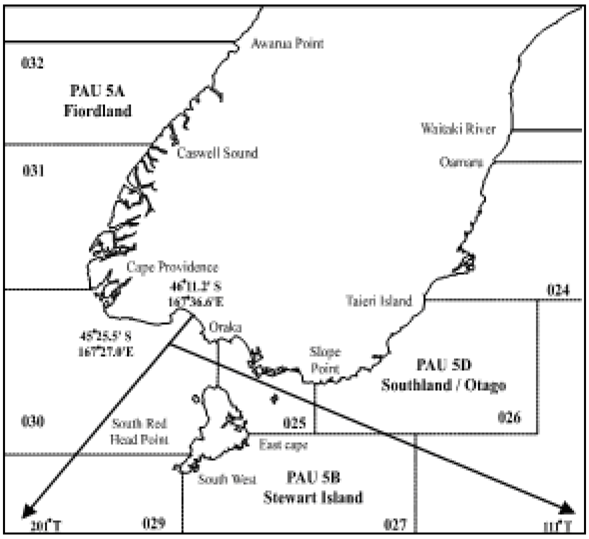
Schiel, D R (1992) The paua (abalone) fishery of New Zealand. *In:* Shepherd, S A; Tegner, M J; Guzman del Proo, S (Eds.), *Abalone of the World: Biology, fisheries, and culture.* Blackwell Scientific, Oxford.

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.

Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. Final Research Report for project GEN2007A. 37 p. (Unpublished report held by Fisheries New Zealand.)

PĀUA (PAU 5A) – Fiordland

(Haliotis iris)
Pāua



1. FISHERY SUMMARY

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

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

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

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

*PAU 5 TACC figures

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September.

On 1 October 2001 it became mandatory to report catch and effort on Pāua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1).

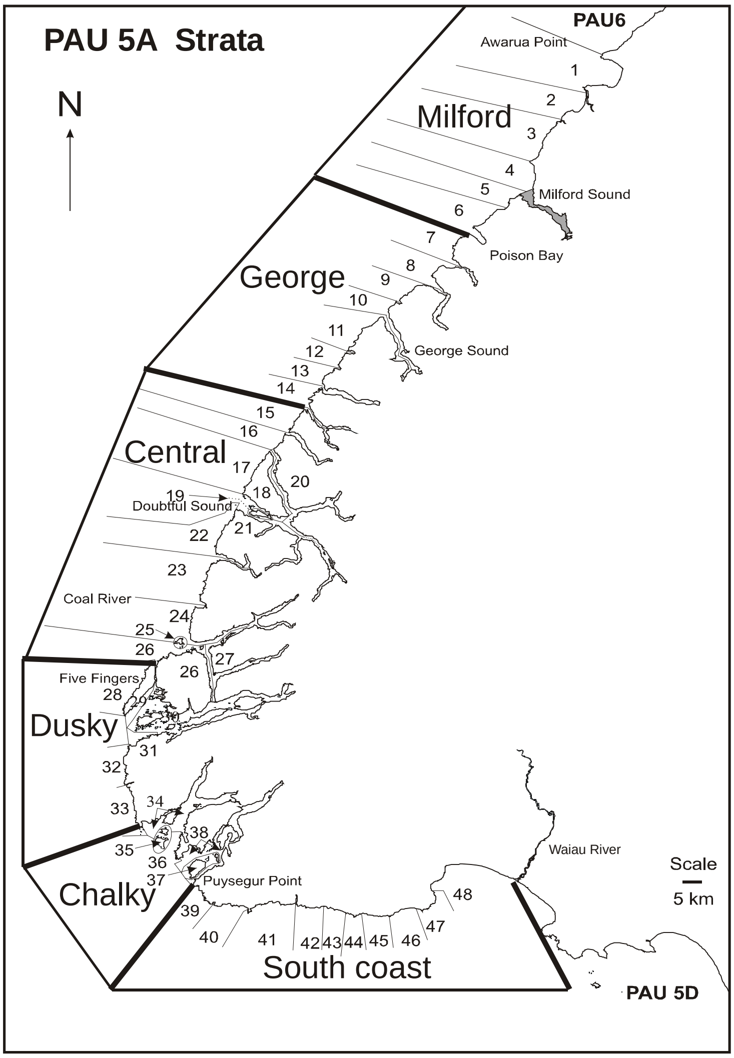


Figure 1: Map of Pāua Statistical Areas, and voluntary management strata in PAU 5A.

PAU 5A landings were close to the TACC from the fishing year 1995–96 to 2005–06, but dropped to an average of 105 t a year from 2006–07 onwards (Table 2 and Figure 2). Landings for PAU 5 prior to 1995–96 are reported in the introductory PAU Working Group Report.

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

Year	Landings	TACC
1995–96	139.53	148.98
1996–97	141.91	148.98
1997–98	145.22	148.98
1998–99	147.36	148.98
1999–00	143.91	148.98
2000–01	147.70	148.98
2001–02	148.53	148.98
2002–03	148.76	148.98
2003–04	148.98	148.98
2004–05	148.95	148.98
2005–06	148.92	148.98
2006–07	104.03	148.98
2007–08	105.13	148.98
2008–09	104.82	148.98
2009–10	105.74	148.98
2010–11	104.40	148.98
2011–12	106.23	148.98
2012–13	105.56	148.98
2013–14	102.30	148.98
2014–15	106.95	148.98
2015–16	106.84	148.98
2016–17	106.50	148.98
2017–18	107.45	148.98
2018–19	99.66	148.98

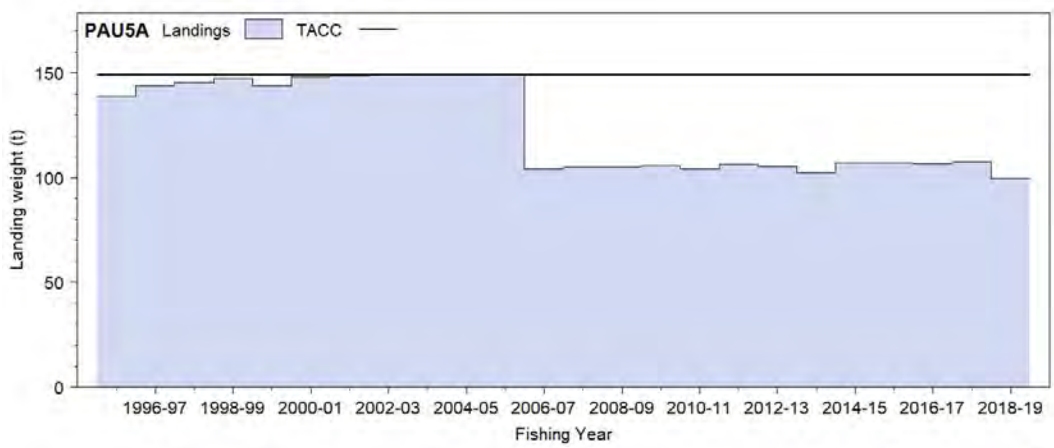


Figure 2: Landings and TACC for PAU 5A from 1995–96 to the present. For historical landings in PAU 5 prior to 1995–96, refer to figure 1 and table 1 in the introductory PAU Working Group Report.

1.2 Recreational fisheries

The National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates Wynne-Jones et al (2014), estimated that about 0.42 t of pāua were harvested by recreational fishers in PAU 5A in 2011–12.

The national panel survey was repeated in 2017–18 (Wynne-Jones et al 2019) and the estimated harvest for PAU 5A was 0.85 t (CV = 0.76). For the purpose of the 2020 stock assessment, the SFWG agreed to assume that the recreational catch rose linearly from 1965 to 1 t in 1974, and has remained at 1 t since 1974.

For further information on recreational fisheries refer to the introductory PAU Working Group Report.

1.3 Customary fisheries

Estimates of customary catch for PAU 5A are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in numbers are reported in the table.

Records of customary non-commercial catch taken under the South Island Regulations show that about 70 pāua were taken in 2001–2002, then nothing until 2007–08. From 2007–08 to 2012–13, 100 to 500 pāua were collected each year. Since then, less pāua have been reported as caught (maximum 200 t in 2017–18).

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported in numbers) of pāua in PAU 5A since 2001–02. – no data.

Fishing year	Approved	Harvested
2001–02	80	70
2002–03	–	–
2003–04	–	–
2004–05	–	–
2005–06	–	–
2006–07	–	–
2007–08	100	100
2008–09	100	100
2009–10	150	150
2010–11	150	150
2011–12	512	462
2012–13	590	527
2013–14	–	–
2014–15	–	–
2015–16	255	50
2016–17	–	–
2017–18	200	200
2018–19	–	–

For the purpose of the 2020 stock assessment model, the SFWG agreed to assume that customary catch has been constant at 1 t.

For further information on customary fisheries refer to the introductory PAU Working Group Report.

1.4 Illegal catch

There is qualitative data to suggest Illegal, unreported, unregulated (IUU) activity in this Fishery. There are no quantitative estimates of illegal catch for PAU 5A. For the purpose of the 2020 stock assessment model, the SFWG agreed to assume that illegal catches have been a constant 5 t.

1.5 Other sources of mortality

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

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. Biological parameters derived using data collected from PAU 5A are summarised in Table 4. Size-at-maturity, natural mortality and annual growth increment parameters were estimated within the assessment model.

Table 4: Estimates of biological parameters (*H. iris*). All estimates are external to the model.

Stock area		Estimate	Source
1. Weight = a (length)^b (weight in kg, shell length in mm)			
PAU 5A	a = 2.99E-08	b = 3.303	Schiel & Breen (1991)
2. Size at maturity (shell length)			
PAU 5A	50% mature	91 mm (89–93)	Median (5–95% range) estimated outside of the assessment
	95% mature	103 mm (101–105)	
3. Estimated annual growth increments (both sexes combined)			
PAU 5A	At 75 mm	16.65 mm (15.96–24.29)	Median (5–95% range) estimated outside of the assessment
	At 120 mm	4.57 mm (3.27–6.40)	

3. STOCKS AND AREAS

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

4. STOCK ASSESSMENT

For 2010 and 2014, the stock assessments for PAU 5A had split PAU 5A into two subareas; the southern area which included the Chalky and South Coast strata, and the northern area which included the Milford, George, Central, and Dusky strata (Figure 1). Separate stock assessments were conducted in each subarea. The division was based on the availability of data, differences in exploitation history and management initiatives. Prior to 2010 the area was assessed as a single area. The 2020 assessment re-evaluated the split of PAU 5A into two subareas, and concluded that the data used for the separate assessments did not adequately reflect the differences in these areas, and the 2020 assessment was therefore run in two configurations: as a single area assessment over all of PAU 5A, and by splitting the area into three areas (statistical areas around Milford Sound (large scale Statistical Area 032) were separated from the previously defined Northern area due to slower growth) and fitting a spatial version of the assessment model (Neubauer 2020a). Initial assessment runs suggested no difference in key estimated quantities between the spatial and single-area models, and the SFWG decided to proceed with the more parsimonious single area model.

4.1 Estimates of fishery parameters and abundance

Parameters estimated in the base case model (for both the southern and northern areas) and their assumed Bayesian priors are summarised in Table 5.

Table 5: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U=uniform; N= normal; LN=lognormal; Beta = beta distribution), mean and CV of the prior.

Parameter	Prior	μ	sd	Bounds Lower	Bounds Upper
ln(*R0*)	LN	13.5	0.5	10	20
D_{50}(Length at 50% selectivity for the commercial catch)	LN	123	0.05	100	145
$D_{95\text{-}50}$(Length between 50% and 95% selectivity the commercial catch)	LN	5	0.5	0.01	50
Steepness (h)	Beta	0.8	0.17	0	1
ϵ (Recruitment deviations)	LN	0	2	0	-

The observational data were:

1. A standardised CPUE series covering 1989–2018 based on combined CELR and PCELR data.
2. A commercial catch sampling length frequency

4.1.1 Relative abundance estimates from standardised CPUE analyses

A combined series of standardised CPUE indices that included FSU (1983–1989), CELR data covering 1990–2001, and PCELR data covering 2002–2019 was used for the 2020 stock assessment (Figure 3). CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among fixed (research strata) and random variables, and between fine-scale reporting (PCELR) and larger scale variables (CELR). The FSU data contained no standardising variables. The variation explained by fine-scale variables (e.g. fine scale statistical areas or divers) in PCELR data was considered unexplained in the CELR and FSU portion of the model and therefore added to observation error.

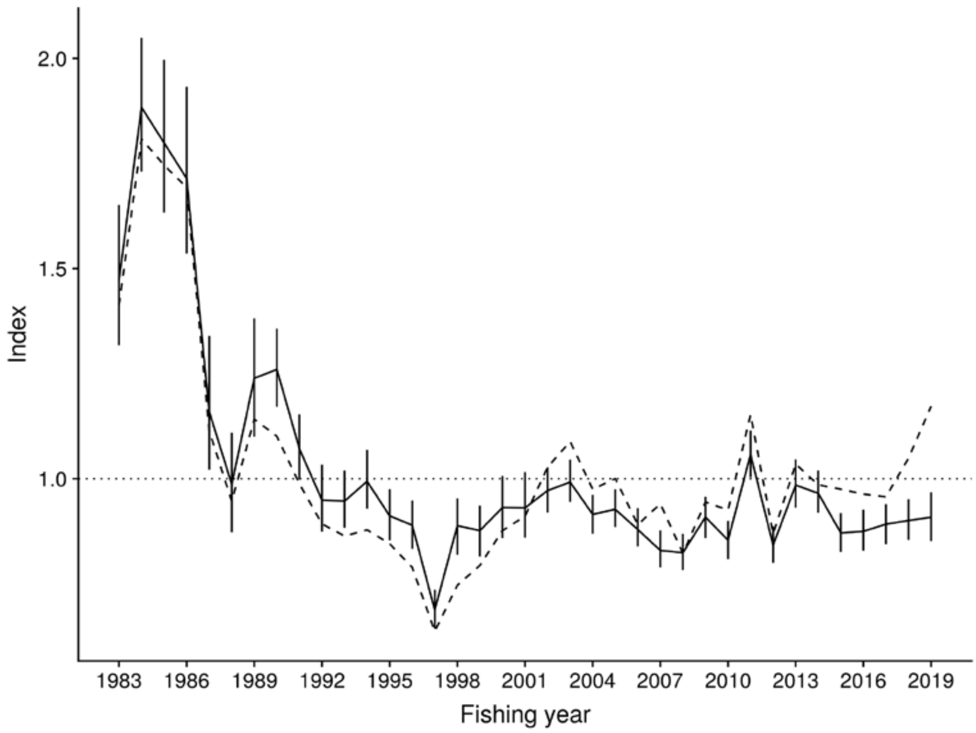


Figure 3: The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardised geometric CPUE (dashed line) for the combined CELR and the PCELR series.

There was ambiguity in the CELR data about what was recorded for estimated daily fishing duration: either incorrectly recorded as hours per diver, or correctly as total hours for all divers. For PAU 5A, fishing duration appeared to have been predominantly recorded as hours per diver. A model-based correction procedure was developed to detect and correct for misreporting, using a mixture model that determines the characteristics of each reporting type by fishing crew and assigns years to correct (reporting for all divers) or incorrect (by diver) reporting regimes with some probability. Only records with greater than 95% certainty of belonging to one or the other reporting type were retained for further analysis.

CPUE was defined as the log of daily catch-per-unit-effort. Variables in the model were fishing year, FIN (Fisher Identification Number), Statistical Area, dive condition, diver ID, and fine-scale statistical area. Variability in CPUE was mostly explained by differences among crews (FINs), with dive conditions also strongly affecting CPUE. The CPUE data showed initially high CPUE in the 1980s, followed by a rapid decline and subsequent increase in the late 1980s. A further decline in the early 1990s was evident, with relatively stable but fluctuating CPUE since 1992. In some circumstances, commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of pāua despite a declining biomass. This occurs because pāua tend to aggregate and divers move among areas to maximise their catch rates. Apparent stability in CPUE should therefore be interpreted with caution. The assumption of CPUE being proportional to biomass was investigated using the assessment model.

4.1.2 Relative abundance estimates from research diver surveys

Relative abundance of pāua in PAU 5A has previously been estimated from research diver surveys conducted in 1996, 2002, 2003, 2006, and 2008–2010. Not every stratum was surveyed in each year, and before 2005–06 surveys were conducted only in the area south of Dusky Sound.

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

4.2 Stock assessment methods

The 2020 stock assessment for PAU 5A used an updated version of the length-based population dynamics model described by Breen et al (2003). The stock was last assessed using data up to the 2014 fishing year (Fu 2015a, b) and the most recent assessment uses data up to the 2018–2019 fishing year (Neubauer 2020b). Although the overall population-dynamics model remained unchanged, the most recent iteration of the PAU 5A stock assessment incorporates changes to the previous methodology (first introduced in the 2019 assessment of Pau 5D; Neubauer & Tremblay-Boyer 2019):

1. The base case model considered the entire area of PAU 5A, rather than conducting separate assessments for the PAU 5A northern and PAU 5A southern areas.
2. CPUE likelihood calculations reverted to predicting CPUE from beginning of year biomass since the previous change to mid-year predictions did not affect the assessment and caused potential for error and an increased computational burden.
3. A Bayesian statistical framework across all data inputs and assessments (MPD runs were not performed; all exploration was performed using full Markov chain Monte Carlo runs).
4. The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB).
5. Catch sampling length-frequency (CSLF) data handling was modified to a model-based estimation of observation error with partitioning between observation and process error for CSLF and CPUE, and use of a multivariate normal model for centred-log-ratio-transformed mean CSLF and observation error.
6. The data weighting procedure was to use a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF.
7. Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.

The model structure assumed a single-sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm in groups of 2 mm, although a spatial version of the assessment model (Neubauer, 2020a) was also tried. For the latter, the model assumed three areas, with the Southern area identical to the previously assessed Southern stock area, and the Northern areas splitting the previous Northern assessment area south of Milford Sound to account for growth differences to the north of Milford Sound.

Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class to change at each time step. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2019. Catches were available for 1974–2019 although catches before 1995 must be estimated from the combined PAU 5 catch, and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step. For the spatial model, it was assumed that 80% of the non-commercial catch was taken from the southern area of PAU 5A, with the remainder being taken from the northern areas.

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. Growth and natural mortalities were estimated within the model from informed prior distributions. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and to reach an asymptote. Dome-shaped selectivity curves were also investigated for the present assessment. The increase in Minimum Harvest Size since 2006 was modelled as a shift in fishing selectivity.

The commercial catch history estimates were made under assumptions about the split of the catch between sub-stocks of PAU 5, and between subareas within PAU 5A. The base case model run assumed that 40% of the catch in Statistical Area 030 was taken from PAU 5A between 1985 and 1996. Estimates made under alternative assumptions (a lower bound of 18% and an upper bound of 61%) were used in sensitivity trials. Commercial catch sampling length-frequency samples before 2002 (1992–1994, 1998, and 2001) were excluded from the base case, because the sample size is low and sampling coverage is dubious. The model was initiated with likelihood weights that were found to lead to subjectively appropriate fits to both CPUE and CSLF inputs in other areas (PAU 5D and PAU 5B) The RDSI and RDLF were excluded from all models, and the CPUE shape parameter was fixed at 1 assuming a linear relationship between CPUE and abundance except for one scenario assuming a hyper-stable CPUE-abundance relationship. The assessment proceeded in three stages (sets):

A first set of model runs explored:

- Including the FSU CPUE index or excluding it.
- Estimating a trend in catchability, and forcing hyper-stable CPUE.
- High and Low Statistical Area 030 catch scenarios prior to 1996.
- Lower recruitment variability.

The trend in catchability was implemented as a linear trend in log-space. Data weight parameters were set to values that produced reasonable fits in other assessments.

A variation of the first set of model runs explored running the same scenarios as described above, but using the spatial model described in Neubauer (2020a) for each of the three large scale reporting strata (Statistical Areas 030, 031, 032). Natural mortality and steepness were shared parameters, whereas recruitment was estimated independently for each region, and total (PAU 5A-wide) unfished recruitment was partitioned into each of the three regions using a composition vector that was estimated within the model using an informed prior based on relative catch levels.

After running the first set of models it was evident that models were using recruitment to adjust the biomass for increases in CPUE after an initial decline in the late 1980s and early 1990s. However, this period of CPUE increase coincides with a period of rapidly increasing efficiency (dive gear, operational aspects, weather forecasts) in all PAU fisheries around the country, which all show some degree of

CPUE increase during this period. The SFWG therefore decided to fix recruitment for the years until CSLF information became available (2000–01), and to instead use variable catchability by i) splitting catchability into reporting epochs (FSU, CELR and PCELR) and ii) estimating increase in catchability for each epoch.

In addition to fixing early recruitment, models using variable selectivity were trialled to account for spatially variable fishing patterns that are likely to drive some of the CPUE variation (rather than variation being recruitment driven): if fishers only fish a subset of available areas in any given year (due to weather or market constraints), variable (and potentially dome-shaped) selectivity would be expected given small scale variation in growth and fishing pressure. Both variable logistic selectivity (variable length at 50% selection), and fixed and variable dome-shaped selectivity (with variable right hand limb of the inverted quadratic curve used for the dome-shaped selectivity) were implemented. Models with variable dome-shaped selectivity did not converge and were therefore excluded.

Lastly, given doubts about accuracy in early FSU reporting, in conjunction with implausible scenarios from excluding FSU data altogether, the working group decided to trial estimating initial depletion in 1984 (and ignoring both catch and CPUE prior to 1984), as well as starting CPUE in 1984 instead of 1983 (reported CPUE was high from 1984, but lower in 1983), but maintaining the catch time-series from 1965. In summary, the second set of models were set up as follows:

- Including the FSU CPUE index, but starting CPUE in 1984, or estimating initial depletion in 1984 (starting catch and CPUE in 1984).
- Estimating a trend in catchability by CPUE reporting period (using separate initial q for FSU, CELR and PCELR).
- Baseline Statistical Area 030 catch scenarios prior to 1996.
- Fixed recruitment prior to CSLF data availability (estimated from three years prior to first year of CSLF data).
- Variable logistic selectivity and dome-shaped selectivity (fixed - variable dome-shape did not converge).

The robustness of models from the first two sets that were judged plausible (Baseline catch with FSU CPUE from 1984, with or without recruitment deviations for pre-CSLF period, with variable selectivity or not) was investigated by varying model weights. Three sets of weights were trialled in addition to weights used in sets 1 & 2: all sets down-weight CPUE by a factor of 2 relative to sets 1 & 2, and either doubled (0.2) or halved (0.05) CSLF weights.

The assessment calculates the following quantities from the marginal posterior distributions of various partitions of the biomass: the equilibrium (unfished) spawning stock biomass (SSB_0) assuming that recruitment is equal to the average recruitment, and the relative spawning and available biomass for 2018 (SSB_{2018} and $B_{2018}^{Avail}\mathrm{B}_{\mathrm{Proj}}^{\mathrm{Avail}}$) and for the projection (*Proj*) period ($\mathrm{SS}B_{Proj}$ and B_{proj}^{Avail}). This assessment also reports the following fishery indictors:

Relative SSB	Estimated spawning stock biomass in the final year relative to unfished spawning stock biomass
Relative B^{Avail}	Estimated available biomass in the final year relative to unfished available stock biomass
P(SSB_{2018} > 40% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 40% of the unfished spawning stock
P(SSB_{2018} > 20% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 20% of the unfished spawning stock (soft limit)
P(SSB_{Proj} > 40% SSB_0)	Probability that projected future spawning stock biomass will be greater than 40% of the unfished spawning stock given assumed future catches
P(SSB_{Proj} > 20% SSB_0)	Probability that projected future spawning stock biomass will be greater than 20% of the unfished spawning stock given assumed future catches
P(B_{Proj} > B_{2018})	Probability that projected future biomass (spawning stock or available biomass) is greater than estimated biomass for the 2018 fishing year given assumed future catches

4.3 Stock assessment results

The initial set of model runs produced three distinct outcomes: models that did not include FSU data suggested very little depletion since the start of the fishery (final stock status above 60% of SSB_0), whereas models with forced hyper-depletion in the CPUE index or estimated increase in catchability lead to higher depletion levels (final stock status near 40% of SSB_0).

The baseline model with FSU data included, as well as scenarios with low or high catch from Statistical Area 030 all produced intermediate status estimates, as did the model with reduced recruitment variability. The latter model stood out as a model that estimated both much faster growth as well as high M (M>0.1; with M<0.1 for all other runs).

Based on these runs the working group decided that model scenarios without FSU data most likely did not adequately capture biomass declines over the initial phase of the fishery, as the estimate of a stock near 75% of un-fished biomass in the early 2000s did not appear compatible with a voluntary 30% shelving of the quota in 2006. Given that models with estimated increase in q produced similar results to those with forced hyper-depletion, the latter were not pursued further.

Spatial model runs were able to partition the initial biomass decline and demographic variability into the three regions. The Northern region (north of Milford) had the lowest depletion level owing to sporadic fishing in the region, which has significantly slower growth than the other regions but a similar share of overall recruitment. Overall, aggregate values from the spatial model were nearly identical to the non-spatial model and the more parsimonious single-area model was therefore preferred by the working group.

All models in the second set of model runs produced similar outcomes, with the exception of the model with variable selectivity, which appeared to over-fit and produce implausible selectivity patterns. Starting CPUE in 1984 (ignoring the low 1983 year) produced very similar results to model runs that include the first year. It was nevertheless excluded from subsequent model runs given concerns about early CPUE reporting. Estimating initial depletion in 1984 invariably led to low estimated initial depletion (i.e., the mode of the posterior distribution for initial depletion near zero). This depletion level was judged implausible by the working group. As models with estimated initial depletion led to similar inferences about stock status and productivity as models with a longer catch time-series, these models were not explored further.

Estimated selectivity in the dome-shaped selectivity model was only slightly domed, with a slight increase in doming after 2006. The (invariable) left-hand limb of the curve was estimated near post-2006 selectivity for models with logistic selectivity. The model with variable logistic selectivity suggested very highly variable selectivity with selection of large individuals in early years to allow the model to fit a steep CPUE decline in the FSU years. However, this pattern was judged implausible by the working group, as it appeared that selectivity was taking the role of other, unknown process error and allowed the model to over-fit.

Models with no time-varying process error (i.e., no yearly variable selectivity or recruitment) prior to availability of CSLF data nevertheless provided reasonable fits to CPUE (which shows some high inter-annual variability).

Changing the weights for CSLF and CPUE data had comparatively little impact on the stock trajectory: Reducing CSLF weights generally led to a lower stock status, but all estimates remained near or above 40% or B_0. A reduction in CSLF weight also led to less extreme variation in estimated selectivity for the variable logistic selectivity model, but the selectivity still suggested selection of large individuals in the early years of the fishery, and a decrease in the fully selected size in more recent years, which is contrary to estimates from a model with a single shift in selectivity in 2006, which suggests a shift in the size-at-50% selection in 2006 in line with an increase in the MHS.

The difference from data weights was altogether small compared with differences introduced by estimating (or not) recruitment for pre-CSLF years. Models that included variable recruitment for all CPUE years as well as trends in q suggested a strong recent increase in q over the PCELR period, and a continued decline of the fishery to below 40% of B_0. However, this recent increase in catchability was judged less likely by the working group, especially since most of the significant innovations in the fishery (better boats, improved wetsuits and fins, and other gear) took place in the CELR period (1990s), and most likely not in the more recent PCELR period.

As a suitable base case, the working group selected a model with:

- CPUE starting in 1984, therefore removing the initial FSU record;
- estimated recruitment from 2001;
- separate catchability for three reporting periods.

The base case suggested a relatively slow but steady downward trend in spawning stock biomass since the 1990s (Figure 4), with a more recent downward trend that was attributed to estimates of recruitment being forced low to compensate for early estimated above-average recruitment (CPUE is slowly increasing most recently). The base case also indicated that the stock is currently above target spawning stock biomass with a high probability, with little to no probability that it is below the soft limit of 0.2 SSB_0. This inference was supported by the agreed sensitivity run, which included an estimated trend in catchability (Figure 4).

Projections from the base case model (Table 5) suggested little movement in spawning stock biomass over the coming years at current catch levels. The tested sensitivity led to lower recent stock status, but with a slight recent increase, providing a better fit to recent CPUE. In addition, projections from this model were slightly more optimistic about future stock trajectory, even at increased catch levels (Table 6).

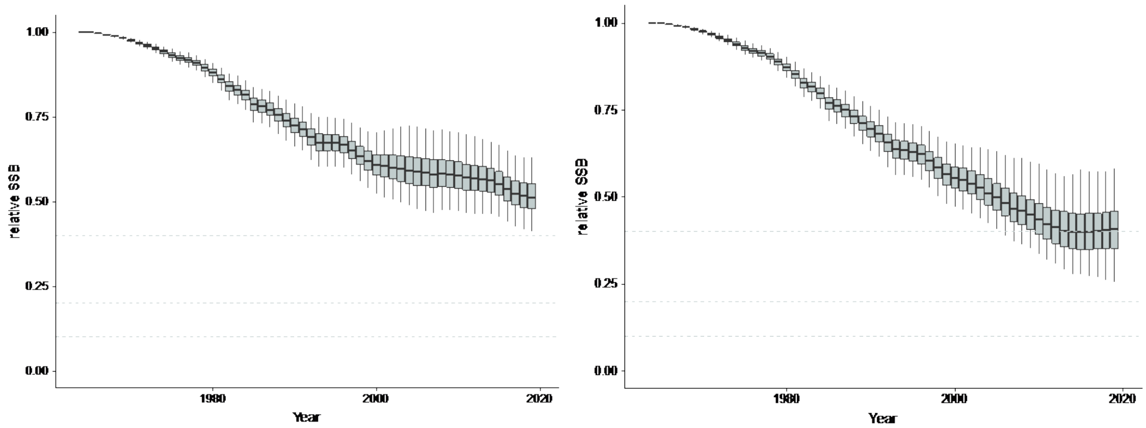


Figure 4: Posterior distributions of spawning stock biomass from the base case model, the sensitivity scenario with increasing catchability. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence range of the distribution.

Table 6: Projections for key fishery indicators from the base case model: probabilities of being above 40% and 20% of unfished spawning biomass (SSB) [P(SSB_{Proj} > 40% SSB_0) and P(SSB_{Proj} > 20% SSB_0)], the probability that SSB in the projection year is above current SSB, the posterior median relative to SSB, the posterior median relative available spawning biomass B_{Proj}^{Avail}, and the probability that the exploitation rate (U) in the projection year is above $U_{40\%\ SSB0}$, the exploitation rate that leads to 40% SSB_0. The total commercial catch (TCC) marked with * corresponds to current commercial catch under 30% shelving of the current TACC (149 t). Other TACC scenarios show 50% shelving (83.4 t), 10% shelving (125.1 t) and fishing at the current TACC. Simulation to equilibrium (assumed to have been reached after 50 projection years) are indicated with Eq. in the year column. [Continued on next page]

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2018})	Median rel. SSB_{Proj}	Median rel. B_{Proj}^{Avail}	P(U > $U_{40\%\ SSB0}$)
83.4	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.98	1	0.39	0.52	0.4	0.58
	2022	0.98	1	0.46	0.52	0.4	0.57
	Eq.	0.85	0.99	0.63	0.59	0.46	0.59
104.3*	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.98	1	0.27	0.51	0.39	0.58
	2022	0.96	1	0.34	0.51	0.39	0.57

Table 6 [Continued]

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2018})	Median rel. SSB_{Proj}	Median rel. B^{Avail}_{Proj}	P(U > $U_{40\% \text{ SSB0}}$)
	Eq.	0.68	0.95	0.43	0.5	0.36	0.51
125.1	2019	0.99	1	0	0.52	0.41	0.6
	2020	0.98	1	0.12	0.52	0.4	0.59
	2021	0.97	1	0.19	0.51	0.39	0.57
	2022	0.95	1	0.25	0.5	0.37	0.56
	Eq.	0.48	0.87	0.24	0.41	0.25	0.42

4.5 Other factors

To run the stock assessment model a number of assumptions must be made, one of these being that CPUE is a reliable index of abundance. The literature on abalone fisheries suggests that this assumption is questionable and that CPUE is difficult to use in abalone stock assessments due to the serial depletion behaviour of fishers along with the aggregating behaviour of abalone. Serial depletion is when fishers consecutively fish-down beds of pāua but maintain their catch rates by moving to new unfished beds; thus CPUE stays high while the overall population biomass is actually decreasing. The aggregating behaviour of pāua results in the timely re-colonisation of areas that have been fished down, as the cryptic pāua that were unavailable at the first fishing event, move to and aggregate within the recently depleted area. Both serial depletion and aggregation behaviour cause CPUE to have a hyperstable relationship with abundance (i.e. abundance is decreasing at a faster rate than CPUE) thus potentially making CPUE a poor proxy for abundance. The strength of the effect that serial depletion and aggregating behaviour have on the relationship between CPUE and abundance in PAU 5A is difficult to determine. However, because fishing has been consistent in for a number of years and effort has been reasonably well spread, it could be assumed that CPUE is not as strongly influenced by these factors, relative to the early CPUE series.

The assumption of CPUE being a reliable index of abundance in PAU 5A can also be upset by exploitation of spatially segregated populations of differing productivity. This can conversely cause non-linearity and hyper-depletion in the CPUE-abundance relationship, making it difficult to accurately track changes in abundance by using changes in CPUE as a proxy.

Another source of uncertainty is the data. The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Major differences may exist between the catches assumed in the model and what was actually taken. Non-commercial catch trends, including illegal catch, are also relatively poorly determined and could be substantially different from what was assumed.

The model treats the whole of the assessed area of PAU 5A as if it were a single stock with homogeneous biology, habitat and fishing pressure. The model assumes homogeneity in recruitment and natural mortality. Heterogeneity in growth can be a problem for this kind of model (Punt 2003). Nevertheless, the spatial-three area model showed nearly identical trends to the single area model, and variation in growth is most likely 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. Nevertheless, length frequency data collected from the commercial catch may not represent the available biomass represented in the model with high precision.

The effect of these factors 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, as spawners must breed close to each other, and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, and the current model does not account for such local processes that may decrease recruitment.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that it may result in some populations becoming relatively unproductive after initial fishing (Gorfine & Dixon 2000). If this happens, the model will overestimate productivity in the population as a whole.

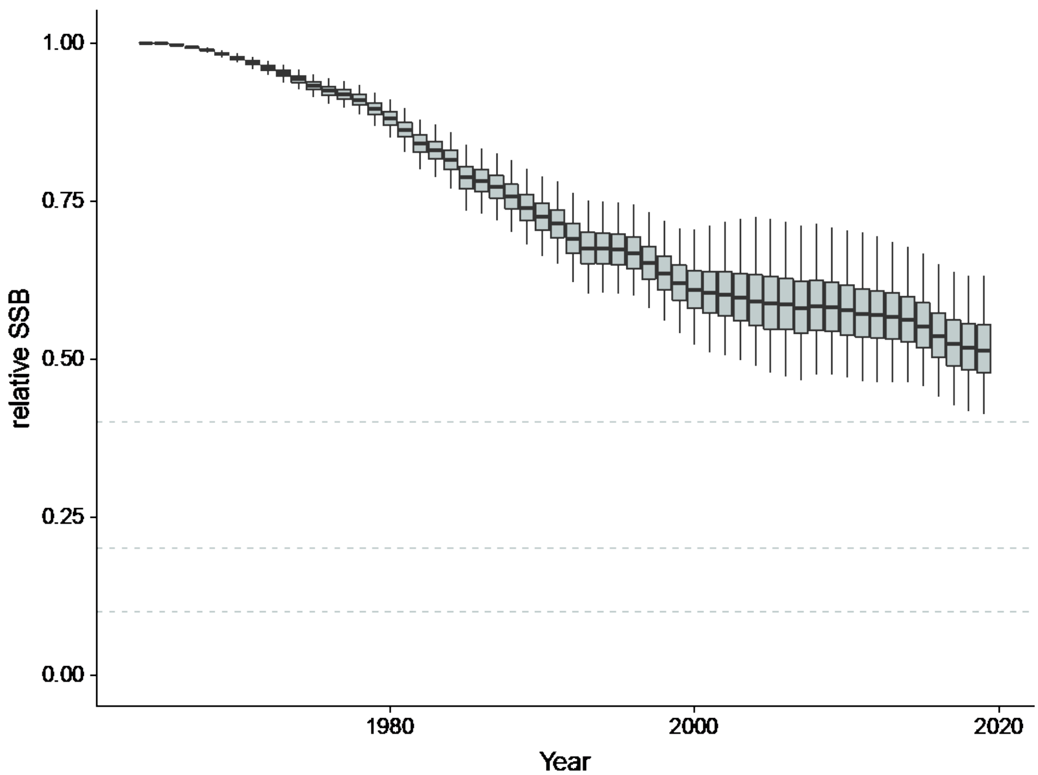
5. STATUS OF THE STOCKS

Stock Structure Assumptions
A genetic discontinuity between North Island and South Island pāua populations was found approximately around the area of Cook Strait (Will & Gemmell 2008).

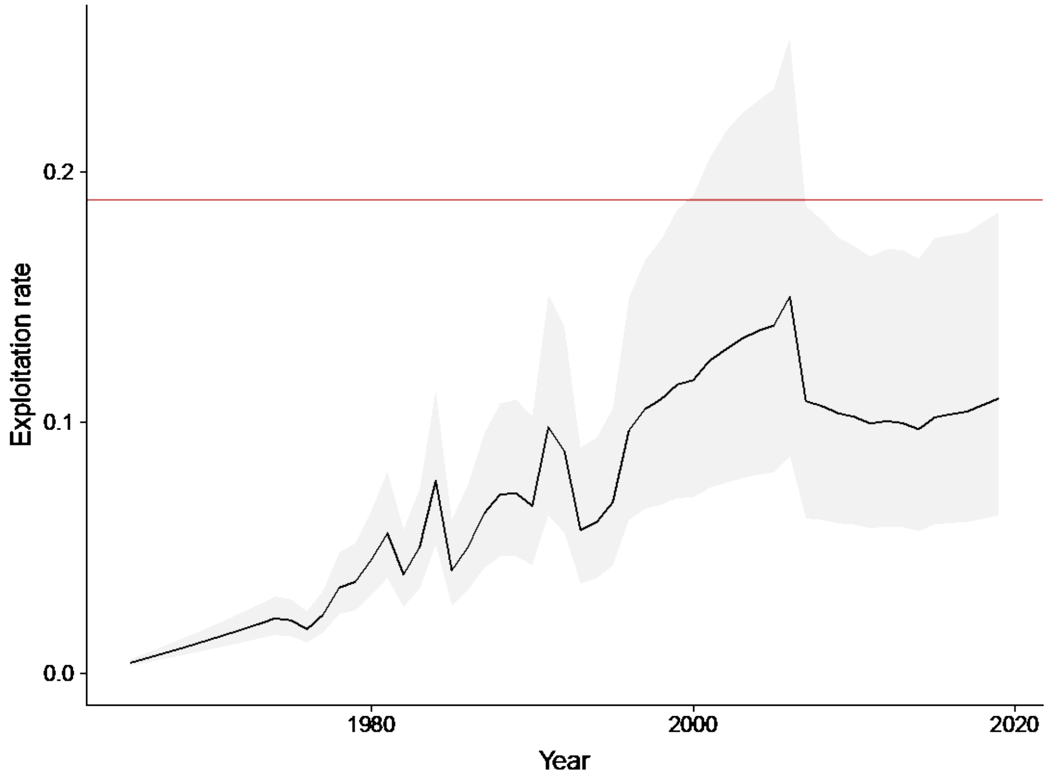
- **PAU 5A -** ***Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	Base case Sensitivity with linearly increasing catchability
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Base case: B_{2019} was estimated at 51% (41–63%) B_0 Sensitivity: B_{2019} was estimated at 40% (26–57%) B_0 For both cases combined, B_{2019} was Likely (> 60%) to be at or above the target
Status in relation to Limits	B_{2019} was Very Unlikely (< 10%) to be below both the soft and hard limits.
Status in relation to Overfishing	The fishing intensity in 2019 was Very Unlikely (< 10%) to be above the overfishing threshold.

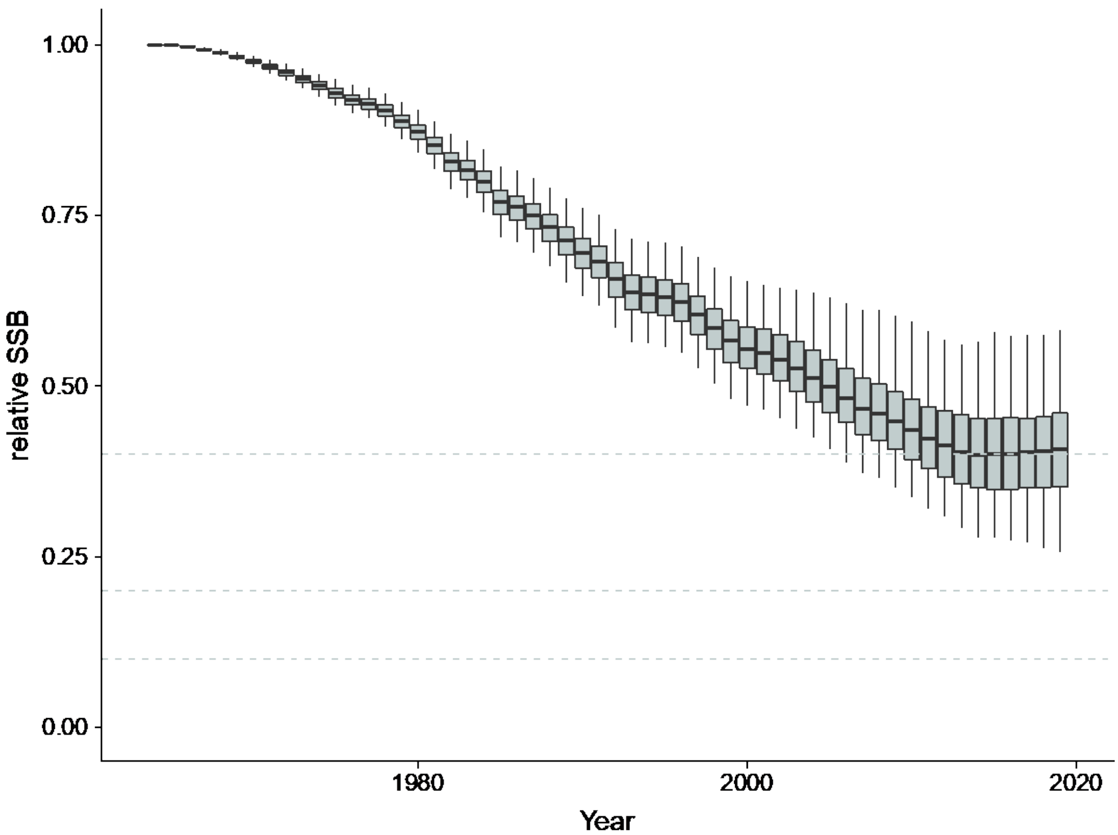
Historical Stock Status Trajectory and Current Status



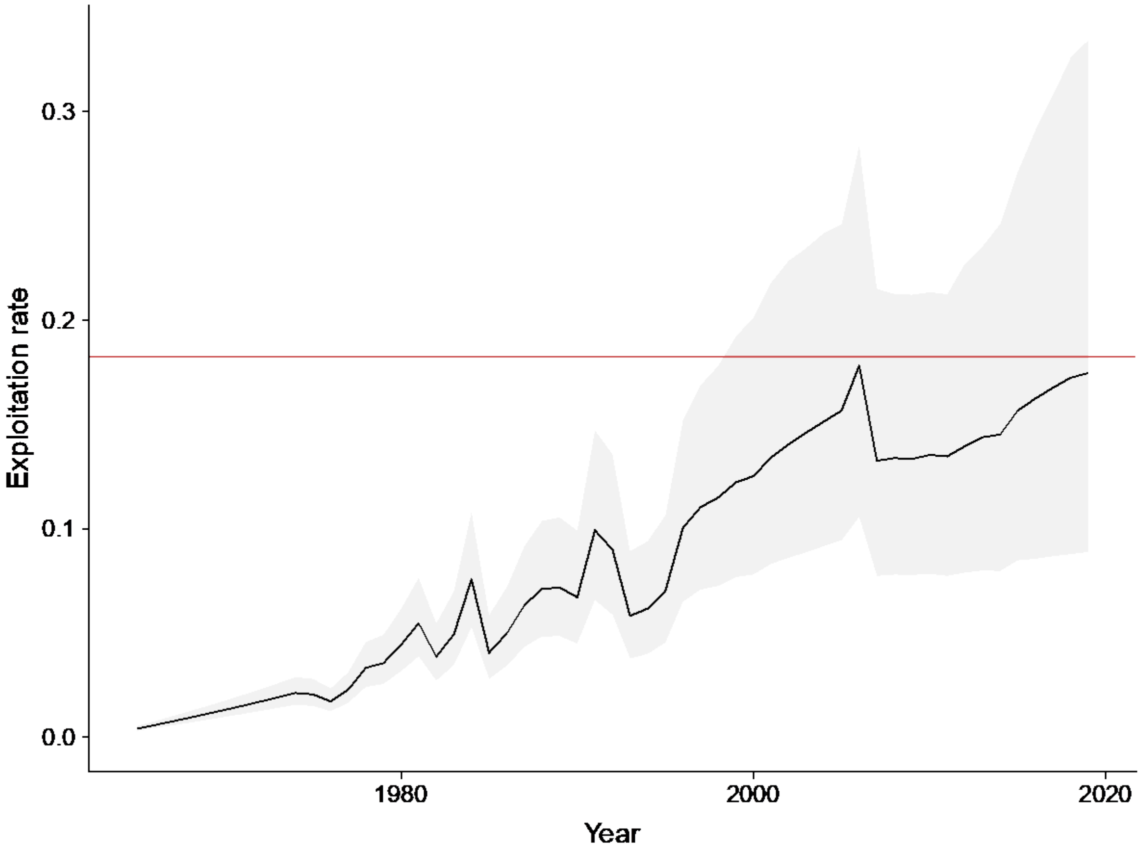
Posterior distributions from the base case model of spawning stock biomass as a percentage of SSB_0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 2.5th and 97.5th percentiles of the distribution. Dashed horizontal lines show target (40% of SSB_0), soft-limit (20% of SSB_0) and hard-limit (10% of SSB_0) reference points.



Posterior distributions from the base case model of exploitation rate (posterior median and 95% confidence interval) relative to the exploitation rate that leads to a relative spawning stock biomass of 40% of *SSB₀*.



Posterior distributions from the main sensitivity (increasing catchability) model of spawning stock biomass as a percentage of SSB_0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 2.5th and 97.5th percentiles of the distribution. Dashed horizontal lines show target (40% of SSB_0) soft-limit (20% of SSB_0) and hard-limit (10% of SSB_0) reference points.



Posterior distributions from the main sensitivity (increasing catchability) of exploitation rate (posterior median and 95% confidence interval) relative to the exploitation rate that leads to a relative spawning stock biomass of 40% of *SSB₀*.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	For the base case, spawning stock biomass declined steeply from the early years up to the early 2000s, with a slow decline since. The more recent trend (since 2015) suggests that biomass remained above 40% SSB_0 but trending slightly downward. The latter conflicts with the CPUE index for the most recent years. The decline in the main sensitivity model is more gradual until about 2015, with a slight increase since 2015 from near 40% SSB_0. The latter trend is more compatible with recent (standardised) CPUE.
Recent Trend in Fishing Intensity or Proxy	For both the base case and the main sensitivity, the exploitation rate reached a peak near 2006, at which point ACE shelving reduced the exploitation rates significantly. For the base case, the exploitation rate remained well below the exploitation rate that leads to a relative spawning stock biomass of 40% SSB_0. In the main sensitivity, the recent exploitation rate has trended upwards in recent years towards the exploitation rate that leads to a relative spawning stock biomass of 40% SSB_0.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At current levels of catch spawning stock biomass is projected to remain nearly unchanged at 51% B_0 after 3 years, with an equilibrium value of 50% B_0. If shelving is reduced to 10%, spawning stock biomass is projected to decline to 50% B_0 over 3 years, and to 41% B_0 in the long term
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%) at current catch levels Unlikely (< 40%) if shelving reduced by 10% About as Likely as Not (40–60%) if shelving reduced by 20%

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Latest assessment: 2020	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch history	1 – High Quality for commercial catch 2 – Mixed or Medium Quality for customary catch 1. No data for recreational or illegal catch
	- CPUE indices early series	2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA
	- CPUE indices later series	1 – High Quality
	- Commercial sampling length frequencies	2 – Medium or Mixed Quality: not believed to be fully representative of the entire QMA
	- Tag recapture data (for growth estimation)	1 – High Quality
	- Maturity at length data	1 – High Quality
Data not used (rank)	- Research Dive Survey Indices - Research Dive Length Frequencies	3 – Low Quality: not believed to index the stock 3 – Low Quality: not believed to be representative of the entire QMA
Changes to Model Structure and Assumptions	- The base case model was implemented as a single area model rather than the separate PAU 5A northern and PAU 5A southern models of previous years. - A three-area spatial model was also developed to corroborate findings from the single area model. - MPD runs were not performed; all exploration was performed using full Markov Chain Monte Carlo runs. - The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB).	

	- A multivariate normal model was used for centred-log-ratio-transformed mean CSLF and observation error. - The data weighting procedure was based on a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF. - Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.
Major Sources of Uncertainty	- CPUE may not be a reliable index of abundance. - Any effect of voluntary increases in MHS may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years.

Qualifying Comments
-

Fishery Interactions
-

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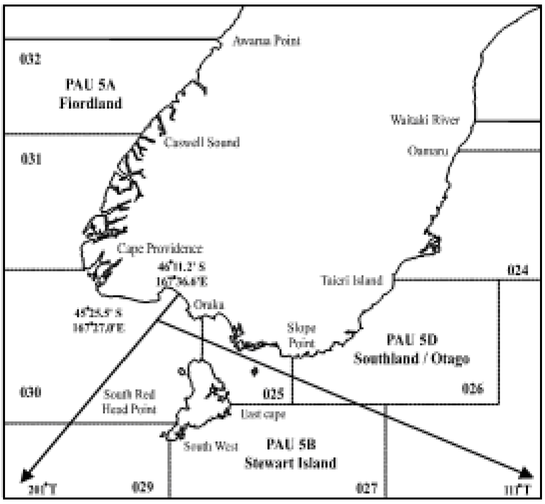
PĀUA (PAU 5B) - Stewart Island

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

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

On 1 October 1999 a TAC of 155.98 t was set for PAU 5B, comprising a TACC of 143.98 t (a 5 t reduction) and customary and recreational allowances of 6 t each. The TAC and TACC were subsequently reduced twice, and TAC was set at 105 t in 2002–2018, with a TACC of 90 t, customary and recreational allowances at 6 t each and an allowance of 3 t for other mortality. In 2018 the TACC was increased to 107 t, and the customary allowance to 7 t, bringing the TAC to 123 t (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 5 and PAU 5B since introduction into the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1991*	-	-	-	-	445
1991–1994*	-	-	-	-	492
1994–1995*	-	-	-	-	442.8
1995–1999	-	-	-	-	148.98
1999–2000	155.9	6	6	-	143.98
2000–2002	124.87	6	6	-	112.187
2002–2018	105	6	6	3	90
2018–Present	123	7	6	3	107

*PAU 5 TACC figures

1.1 Commercial fishery

The fishing year runs from 1 October to 30 September.

Concerns about the status of the stock led to the commercial fishers agreeing to voluntarily reduce their Annual Catch Entitlement (ACE) by 25 t for the 1999/00 fishing year. This shelving continued for the 2000/01and 2001/02 fishing years at a level of 22 t, but was discontinued at the beginning of the 2002/03 fishing year (Table 2).

On 1 October 2001 it became mandatory to report catch and effort on Pāua Catch Effort Landing Returns (PCELRs) using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1).

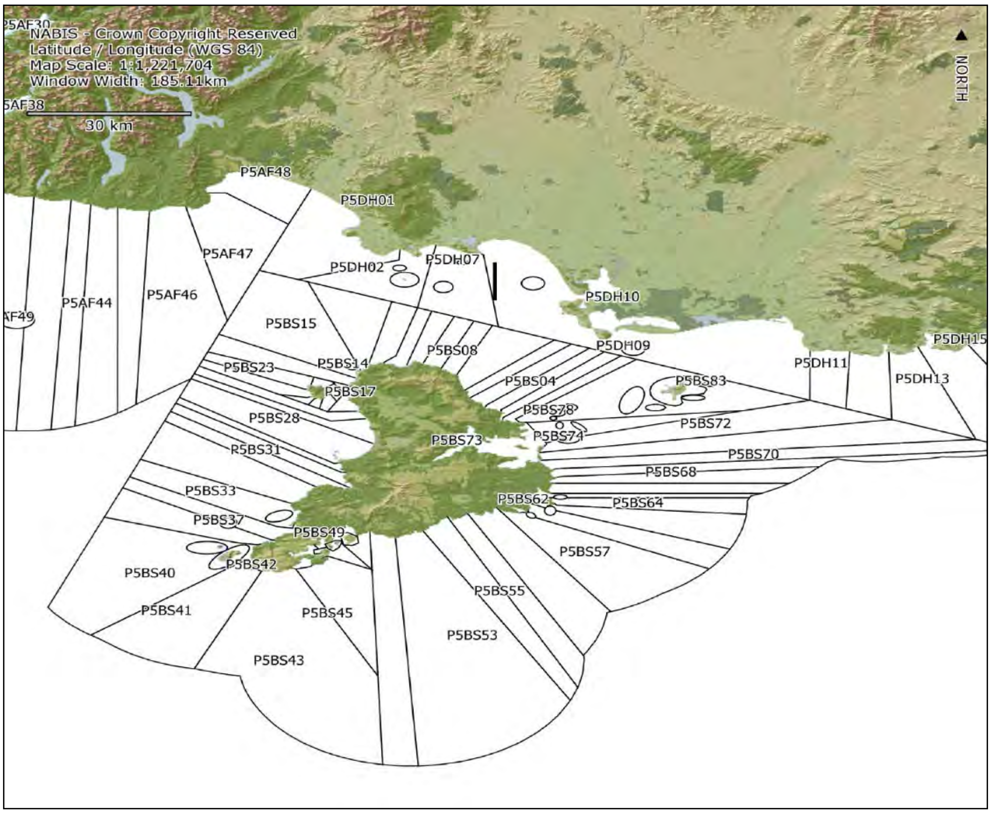


Figure 1: Map of fine scale statistical reporting areas for PAU 5B.

PAU 5B commercial landings have been close to the TACC in most fishing years since 1995, with the exception of the fishing years 1999–00, 2000–01, 2001–02, and 2018–19 when the TACC was not reached (Table 2 and Figure 2). Landings for PAU 5 prior to 1995 are reported in the introductory PAU Working Group Report.

Table 2: TACC and reported commercial landings (t) of pāua in PAU 5B, 1995–96 to present, from QMR and MHR returns. [Continued next page]

Year	Landings	TACC
1995–96	144.66	148.98
1996–97	142.36	148.98
1997–98	145.34	148.98
1998–99	148.55	148.98
1999–00	118.07	143.98
2000–01	89.92	112.19
2001–02	89.96	112.19
2002–03	89.86	90.00
2003–04	90.00	90.00
2004–05	89.97	90.00
2005–06	90.47	90.00
2006–07	89.16	90.00
2007–08	90.21	90.00
2008–09	90.00	90.00
2009–10	90.23	90.00
2010–11	89.67	90.00
2011–12	89.59	90.00
2012–13	90.58	90.00
2013–14	88.84	90.00
2014–15	89.45	90.00
2015–16	88.39	90.00

Table 2 [Continued]

Year	Landings	TACC
2016–17	92.99	90.00
2017–18	89.33	90.00
2018–19	89.03	107.00

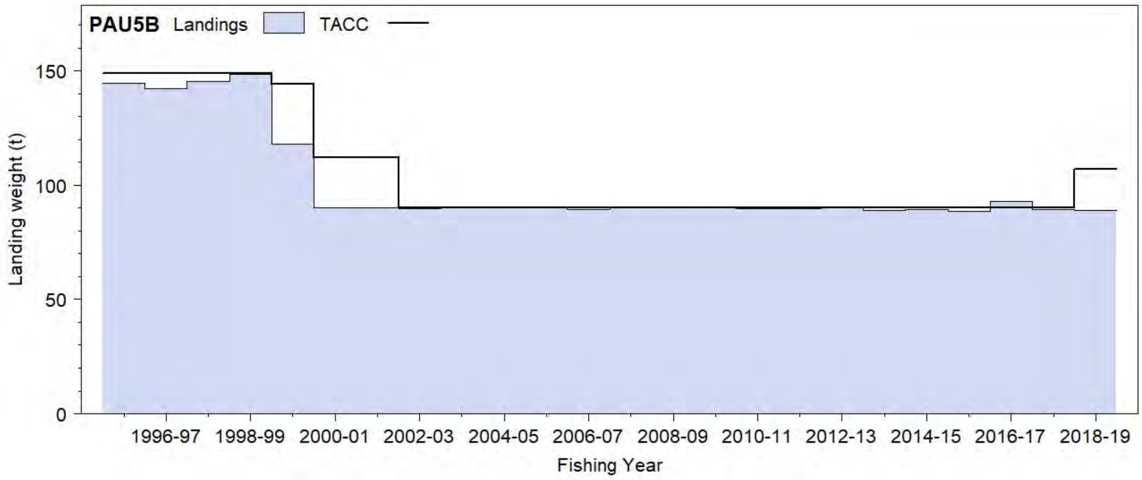


Figure 2: Reported commercial landings and TACC for PAU 5B from 1995–96 to present. For reported commercial landings in PAU 5 before 1995–96 refer to figure 1 and table 1 in the introductory PAU Plenary Report.

1.2 Recreational fisheries

The 'National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates' estimated that the recreational harvest for PAU 5B was 0.82 t with a CV of 50%. For the 2017 assessment model, the SFWG agreed to assume that the recreational catch rose linearly from 1 t in 1974 to 5 t in 2006, and remained at 5 t between 2007 and 2017. The National Panel Survey was repeated in the 2017–18 fishing year (Wynne-Jones et al 2019). The estimated recreational catch for that year was 9.85 tonnes. For further information on recreational fisheries refer to the introductory PAU Plenary Report.

1.3 Customary fisheries

Estimates of customary catch for PAU 5B are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported in numbers) of pāua in PAU 5B between 2000–01 and 2018–19. – no data.

Fishing year	Approved	Harvested
2000–01	50	50
2001–02	610	590
2002–03	–	–
2003–04	–	–
2004–05	–	–
2005–06	140	90
2006–07	485	483
2007–08	2 685	2 684
2008–09	3 520	3 444
2009–10	2 680	2 043
2010–11	2 053	1 978
2011–12	495	495
2012–13	1 875	1 828
2013–14	130	130
2014–15	–	–
2015–16	2 195	2 003
2016–17	75	75
2017–18	2 245	2 245
2018–19	1 405	1 337

For the 2017 assessment model the SFWG agreed to assume that customary catch was equal to 1 t from 1974–2017. Reported customary catch in 2018–19 was 1337 kg.

For further information on customary fisheries refer to the introductory PAU Plenary Report.

1.4 Illegal catch
There is qualitative data to suggest significant illegal, unreported, unregulated (IUU) activity in this Fishery. Illegal catch was estimated by the Ministry of Fisheries to be 15 t, but "Compliance express extreme reservations about the accuracy of this figure." The SFWG agreed to assume for the 2013 assessment that illegal catch was zero before 1986, then rose linearly from 1 t in 1986 to 5 t in 2006, and remained constant at 5 t between 2007 and 2013. For further information on illegal catch refer to the introductory PAU Working Group Report.

1.5 Other sources of mortality
For further information on other sources of mortality refer to the introductory PAU Plenary Report.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Plenary Report. A summary of biological parameters used in the PAU 5B assessment is presented in Table 4.

3. STOCKS AND AREAS

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

Table 4: Estimates of biological parameters (*H. iris*).

		Estimate	Source
1. Natural mortality (*M*)		0.10 (CV 0.10)	Assumed prior probability distribution
2. Weight = a(length)^b (Weight in g, length in mm shell length).			
		All	
	a	b	
	2.99×10^{-5}	3.303	Schiel & Breen (1991)
3. Size at maturity (shell length)			
		50% maturity at 91 mm	Naylor (NIWA unpub. data)
		95% maturity at 133 mm	Naylor (NIWA unpub. data)
4. Growth parameters (both sexes combined)			
	Growth at 75 mm	Growth at 120 mm	Median (5–95% range) of posterior distributions estimated by the assessment model
	26.1 mm (24.8 to 27.2)	6.9 mm (6.5–7.3)	

4. STOCK ASSESSMENT

The stock assessment was done with a length-based Bayesian estimation model, with parameter point estimates based on the mode of the joint posterior distribution and uncertainty estimated from marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The most recent stock assessment was conducted in 2017 for the fishing year ended 30 September 2017. A base case model (0.1) was chosen from the assessment. The SFWG also suggested several sensitivity runs; model 0.4 which assumed an alternate catch history and model 0.6 where a time varying catchability was estimated.

4.1 Estimates of fishery parameters and abundance
Parameters estimated in the assessment model and their Bayesian prior distributions are summarized in Table 5.

Table 5: 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	Phase	Prior	μ	CV	Lower	Upper
$\ln(R_0)$	1	U	–	–	5	50
M (natural mortality)	3	U	–	–	0.01	0.5
g_1(Mean growth at 75 mm)	2	U	–	–	0.01	150
$g2$(Mean growth at 120 mm)	2	U	–	–	0.01	150
g_{50}	2	U	–	–	0.01	150
$g_{50\text{-}95\%}$	2	U	–	–	0.01	150
g_{max}	1	U	–	–	0.01	50
α	2	U	–	–	0.01	10
β	2	U	–	–	0.01	10
Ln(q^I) (catchability coefficient of CPUE)	1	U	–	–	-30	0
Ln(q^I) (catchability coefficient of PCPUE)	1	U	–	–	-30	0
L_{50} (Length at 50% maturity)	1	U	–	–	70	145
$L_{95\text{-}50}$(Length between 50% and 95% maturity)	1	U	–	–	1	50
D_{50}(Length at 50% selectivity for the commercial catch)	2	U	–	–	70	145
$D_{95\text{-}50}$(Length between 50% and 95% selectivity for the commercial catch)	2	U	–	–	0.01	50
D_s	1	U	–	–	0.01	10
ϵ (Recruitment deviations)	1	N	0	0.4	-2.3	2.3

The observational data were:

1. A 1990–2001 standardised CPUE series based on CELR data.
2. A 2002–2017 standardised CPUE series based on PCELR data.
3. A commercial catch sampling length frequency series for 1998, 2002–04, 07, 2009–2012.
4. Tag-recapture length increment data.
5. Maturity at length data

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2017 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2017. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, with variables entering the model in the order that gave the maximum decrease in the residual deviance. Predictor variables were accepted in the model only if they explained at least 1% of the deviance.

For both the CELR and PCELR data, the Fisher Identification Number (FIN) was used in the standardisations instead of vessel, because the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN.

For the CELR data (1990-2001) there is ambiguity in what is recorded for estimated daily fishing duration (total fishing duration for all divers), and it has not been used in past standardisations as a measure of effort; instead the number of divers has been used. However, there is evidence that the fishing duration for a diver changes over time, and because of this criteria were used to identify records for which the recorded fishing duration should predominantly be recorded correctly. The criteria used to subset the data were: (i) just one diver or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2. For the other records the recorded fishing duration was multiplied by the number of diver. The data set consisting of predominantly correct records for the recorded fishing duration, and others with the recorded fishing duration scaled up by the number of divers was used for the CELR standardisation using estimated daily catch and effort as estimated fishing duration.

For the PCELR data (2002–2017) the unit of catch was diver catch, with effort as diver duration.

FIN codes were used to select a core group of fishers from the CELR data, with the requirement that there be a minimum of 7 records per year for a minimum of 2 years to qualify for the core fisher group. This retained 84% of the catch over 1990–2001. For the PCELR data the FIN was also used to select a core group of fishers, with the requirement that there be a minimum of 20 records per year for a minimum of 3 years. This retained 87% of the catch over 2002–2017.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN, Statistical Area (025, 027, 029, 030), month and fishing duration (as a cubic polynomial),. For the PCELR data, fishing year was forced into the model and variables offered to the model were month, diver key, FIN statistical area, diver duration (third degree polynomial), and diving conditions.

The standardised CPUE from the CELR data shows an increase from 1990 to 1991 followed by a steady decline through to 2001 at which point it is 49% of its initial 1990 level (Figure 3-top). The standardised CPUE from the PCELR data shows a 74% increase from 2002 to 2014 then a slight decline from 2014 to 2017. This 13% decline between 2014 and 2017 is not unexpected and is most likely due to the commercial fishers voluntarily increasing the minimum harvest size (Figure 3-bottom).

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua in PAU 5B has also been estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1993 and 2007. The survey strata included Ruggedy, Waituna, Codfish, Pegasus, Lords, and East Cape. These data were included in the assessment although there is concern that the data are not a reliable index of abundance.

Concerns about the ability of the data collected in the independent Research Dive surveys to reflect relative abundance instigated several reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed the reliability of the research diver survey index as an index of abundance and whether the RDSI, when used in the pāua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from pāua stock assessments using the RDSI should be treated with caution however this data was included in the 2017 assessment based on recommendations arising from the pāua stock assessment review workshop (Butterworth et al 2015).

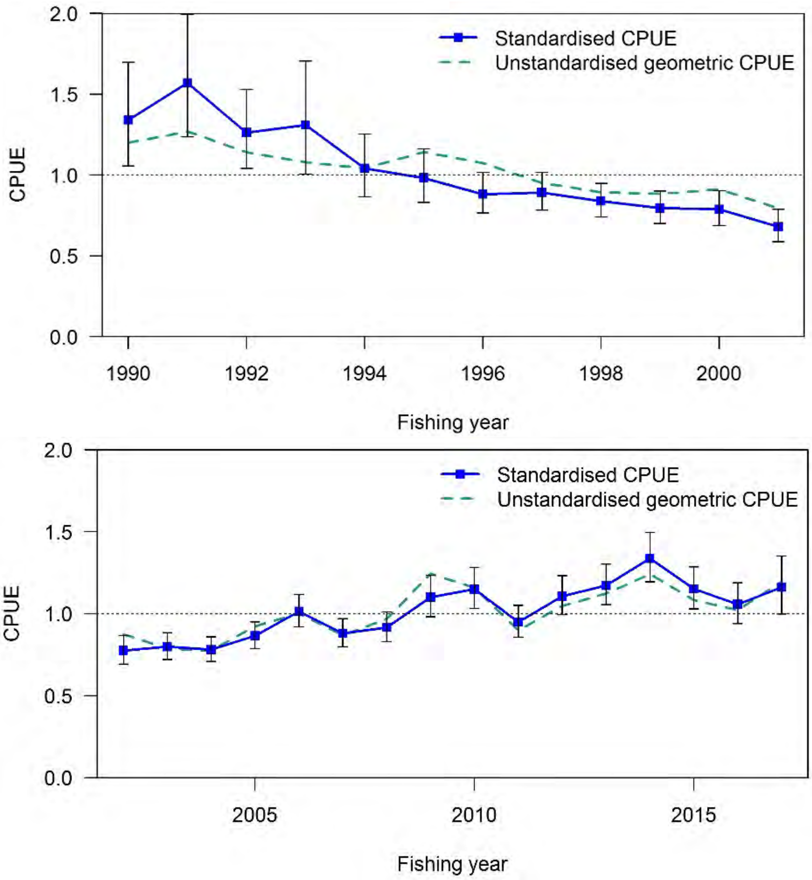


Figure 3: The standardised CPUE indices with 95% confidence intervals for the CELR series covering 1990–2001 (blue line for top-figure). The standardised CPUE indices with 95% confidence intervals for the PCELR series covering 2002–2017 (blue line for bottom-figure). For both indices the unstandardised geometric CPUE is calculated as catch divided by fishing duration.

4.2 Stock assessment methods

The 2017 PAU 5B stock assessment used the same length-based model as the 2017 PAU 5D assessment (Marsh & Fu 2017). The model was described by Breen et al (2003). PAU 5B was last assessed in 2013 (Fu 2014 and Fu et al 2014a).

The model structure assumed a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm in 2 mm bins. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of transitions among length class at each time step. Pāua enter the model following recruitment and are removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2017. Catches were available for 1974–2017 although catches before 1995 must be estimated from the combined PAU 5 catch. Catches 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. No explicit stock-recruitment relationship was modelled in previous assessments; however, the Shellfish Working Group agreed to use a Beverton-Holt stock-recruitment relationship with steepness (h) of 0.75 for this assessment.

Maturity is not required in the population partition but is necessary for estimating spawning biomass. The model estimated proportions mature from length-at-maturity data. Growth and natural mortalities were also estimated within the model. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve and asymptote at 1. The increase in Minimum Harvest Size between 2006 and 2017 was modelled as an annual shift in fishing selectivity.

The assessment was conducted in several steps. First, the model was fitted to the data with parameters estimated at the mode of their joint posterior distribution (MPD). 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 and an agreed set of biological indicators obtained. Model sensitivity was explored by comparing MPD fits made under alternative model assumptions.

The base case incorporated a number of changes since the last assessment of PAU 5B in 2013. First, a more flexible functional form (inverse logistic) was used to describe the variance associated with the mean growth increment at length. Second, the predicted CPUE is now calculated after 50% of the fishing and natural mortality have occurred (previously the CPUE indices were fitted to the vulnerable biomass calculated after 50% of the catch was taken). This is considered to be appropriate if fishing occurs throughout a year (Schnute 1985). The change was recommended by the pāua review workshop held in Wellington in March 2015 (Butterworth et al. 2015). Accordingly, mid-season numbers (and biomass) was calculated after half of the natural mortality and half of the fishing mortality was applied.

The third change was made to the likelihood function, fitting the tag-recapture observations so that weights could be assigned to individual data sets. This also followed the pāua review workshop's recommendation that "the tagging data should be weighted by the relative contribution of average yield from the different areas so that the estimates could better reflect the growth rates from the more productive areas" (Butterworth et al 2015). Two smaller changes were added in this iteration of the assessment model, including: 1) adding a lag between recruitment and spawning for models where the partition was started at > 2 mm; and 2) adding a time varying parameter on the catchability coefficient of the CPUE observations.

The base case model (0.1) and the six sensitivities (0.1all and 0.2–0.6) were considered (Table 6): two separate CPUE series (0.2), excluding research diver observations (0.3), alternative catch history (0.4), modelling the partition at 2 mm (0.5), and estimating a time varying catchability (0.6). MCMCs were carried out for the base case and model runs 0.4 and 0.6.

Table 6: Summary descriptions of base case (0.1) and sensitivity model runs.

Model	Description
0.1	inverse logistic growth model, tag-recapture weighted, CSLF data up to 2016, M prior Uniform, tag data > 70 mm, RDLF and RDSI included, Combined CPUE series, Catch history assumption 3
0.1 all	The same as model 0.1 with CSLF data up to and including the 2017 fishing year.
0.2	Model 0.1 with split CPUE series, one for the CELR and another for the PCELR
0.3	Model 0.1 but with the RDLF and RDSI data excluded
0.4	Model 0.1 but with catch history assumption 1
0.5	Model 0.1 but start modelling at 2 mm instead of 70 mm
0.6	Model 0.1 but with a time varying catchability coefficient, with an estimated drift parameter ~ Uniform(-0.05, 0.05)

The assessment calculated the following quantities from their posterior distributions: the equilibrium spawning stock biomass with recruitment equal to the average recruitment from the period for which recruitment deviation were estimated (B_0,), the mid-season spawning and recruited biomass for 2013 (B_{2013} and $B^r_{proj2013}$) and for the projection period (B_{proj} and B^r_{proj}). This assessment also reported the following fishery indictors:

- $B\%B_0$ Current or projected spawning biomass as a percentage of B_0
- $B\%B_{msy}$ Current or projected spawning biomass as a percentage of B_{msy}
- $\Pr(B_{proj} > B_{msy})$ Probability that projected spawning biomass is greater than B_{msy}
- $\Pr(B_{proj} > B_{2012})$ Probability that projected spawning biomass is greater than $B_{current}$
- $B\%B^r_0$ Current or projected recruited biomass as a percentage of B^r_0
- $B\%B^r_{msy}$ Current or projected recruited biomass as a percentage of B^r_{msy}
- $\Pr(B_{proj} > B^r_{msy})$ Probability that projected recruit-sized biomass is greater than B^r_{msy}
- $\Pr(B_{proj} > B^r_{2012})$ Probability that projected recruit-sized biomass is greater than B^r_{2012}
- $\Pr(B_{proj} > 40\%B_0)$ Probability that projected spawning biomass is greater than 40% B_0
- $\Pr(B_{proj} < 20\%B_0)$ Probability that projected spawning biomass is less than 20% B_0
- $\Pr(B_{proj} < 10\%B_0)$ Probability that projected spawning biomass is less than 10% B_0
- $\Pr(U_{proj} > U_{40\%B0})$ Probability that projected exploitation rate is greater than $U_{40\%B0}$

4.3 Stock assessment results

The base case model (0.1) estimated that the unfished spawning stock biomass (B_0) was about 3948 t (3630–4271 t) (Figure 4), and the spawning stock population in 2017 (B_{2017}) was about 47% (39–58%) of B_0 (Table 7). The base case indicated that spawning biomass increased rapidly after 2002 when the stock was at its lowest level.

Three-year projections (2018–2020) were run for two alternative recruitment assumptions, with the period of recruitment sampled from the past 10 years of estimates and from the past 5 years of estimates (explored due to recent lower-than-average recruitment), and with four different future harvest levels based on changes to the total allowable catch (TACC), with the TACC increasing by 5% (94.5 t), 10% (99 t), 15% (103.5 t) and 20% (108 t) (Tables 8–11). The base case model suggested that the current stock status was very unlikely to fall below the target of 40% B_0. The projections suggested that with an increase of 20% of the current TACC, future biomass was likely to remain constant over the next 3 years. The conclusion was similar across all sensitivity runs.

The MCMC simulation started at the MPD parameter values and the traces show good mixing. MCMC chains starting at either higher or lower parameter values also converged after the initial burn-in phase. The base case model estimated an M of 0.10 with a 90% credible interval between 0.08 and 0.12. The midpoint of the commercial fishery selectivity (pre-2006), where selectivity is 50% of the maximum, was estimated to be about 125 mm and the selectivity ogive was very steep. The model estimated an annual shift of about 1.9 mm in selectivity, with a total increase of about 10 mm between 2006 and 2011.

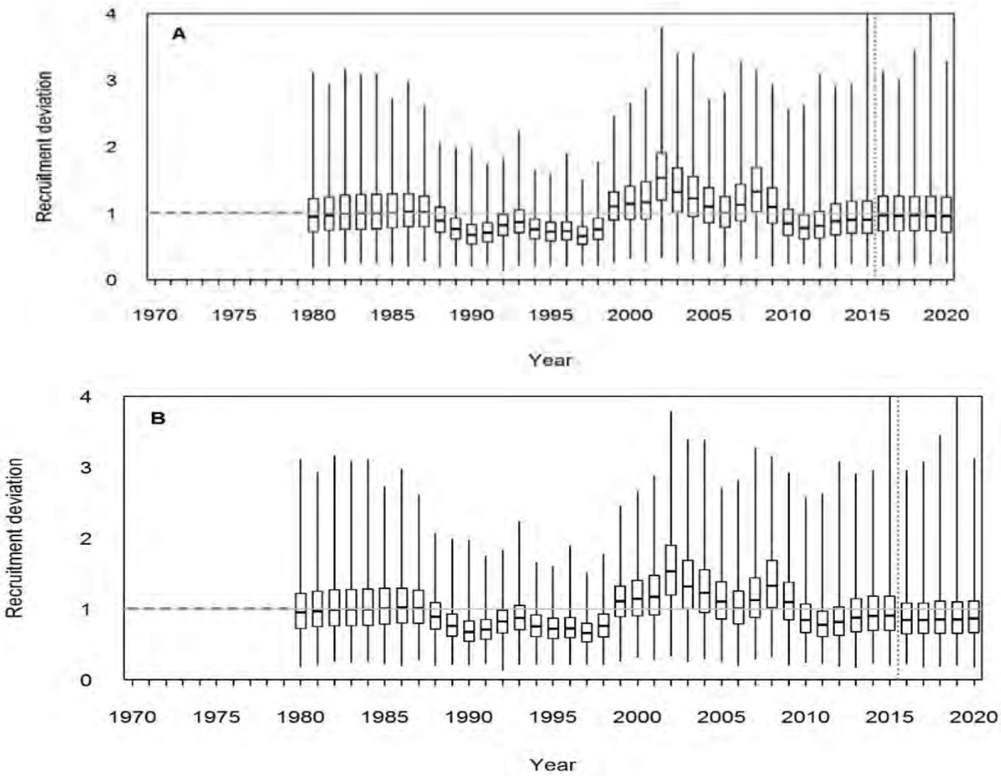


Figure 4: Recruitment deviations around the stock recruitment relationship estimated and forecasted for model 0.1. The red line is the time up to where recruitment deviations were resampled from. The top figure (A) is when we resample from the last 10 years. The bottom figure (B) is when we resample from the last 5 years.

The estimated recruitment deviations showed a period of relatively low recruitment through the 1990s to the early 2000s. From the early 2000s to 2010 recruitment was above the average however, from 2011 until 2015 recruitment has been lower than the long-term average. (Figure 5). Exploitation rates peaked around 2002, but have decreased since then. The base case estimated exploitation rate in 2017 to be about 0.09 (0.07–0.11) (Table 7).

Table 7: Summary of the marginal posterior distributions from the MCMC chain from the base case (Model 0.1), and the sensitivity trials (models 0.4 and 0.6). The columns show the median, the 5th and 95th percentiles values observed in the 1000 samples. Biomass is in tonnes.

	MCMC 0.1	MCMC 0.4	MCMC 0.6
B_0	3948 (3630–4271)	4470 (4112–4841)	3947 (3608–4287)
B_{2017}	1873 (1513–2360)	2144 (1750–2686)	1711 (1223–2410)
$B_{2017}\%B_0$	47 (39–58)	48 (40–59)	44 (32–59)
rB_0	3553 (3221–3876)	4029 (3655–4400)	3569 (3223–3882)
rB_{2017}	1524 (1230–1906)	1755 (1435–2178)	1374 (964–1970)
rB_{2017}/rB_0	0.43 (0.35–0.53)	0.44 (0.36–0.53)	0.39 (0.27–0.54)
$U_{40\%B0}$	16 (13–23)	13 (10–17)	6 (5–9)
U_{msy}	33 (24–53)	33 (24–53)	30 (21–51)
U_{2017}	9 (7–11)	8 (6–9)	10 (7–14)

4.4 Other factors

The assessment used CPUE as an index of abundance. The assumption that CPUE indexes abundance is questionable. The literature on abalone fisheries suggests that CPUE is problematic for stock assessments because of serial depletion. This can happen when fishers deplete unfished or lightly fished beds and maintain their catch rates by moving to new areas. Thus CPUE stays high while the biomass is actually decreasing. For PAU 5B, the model estimate of stock status was strongly driven by the trend in the recent CPUE indices. It is unknown to what extent the CPUE series tracks stock abundance. The SFWG believed that the increasing trend in recent CPUE series are credible, corroborating anecdotal evidence from the commercial divers in PAU 5B that the stock has been in good shape in recent years.

Natural mortality is an important productivity parameter. It is often difficult to estimate *M* reliably within a stock assessment model and the estimate is strongly influenced by the assumed prior. For the pāua assessment, the choice of prior has been based on current belief on the plausible range of the natural mortality for pāua, and therefore it is reasonable to incorporate available evidence to inform the estimation of *M*. The sensitivity of model results to the assumptions on *M* could be assessed through the use of alternative priors.
Another source of uncertainty is the data. The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Major differences may exist between the catches we assume and what was actually 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 be relatively small compared with commercial catch. The estimate of illegal catch in particular is uncertain.

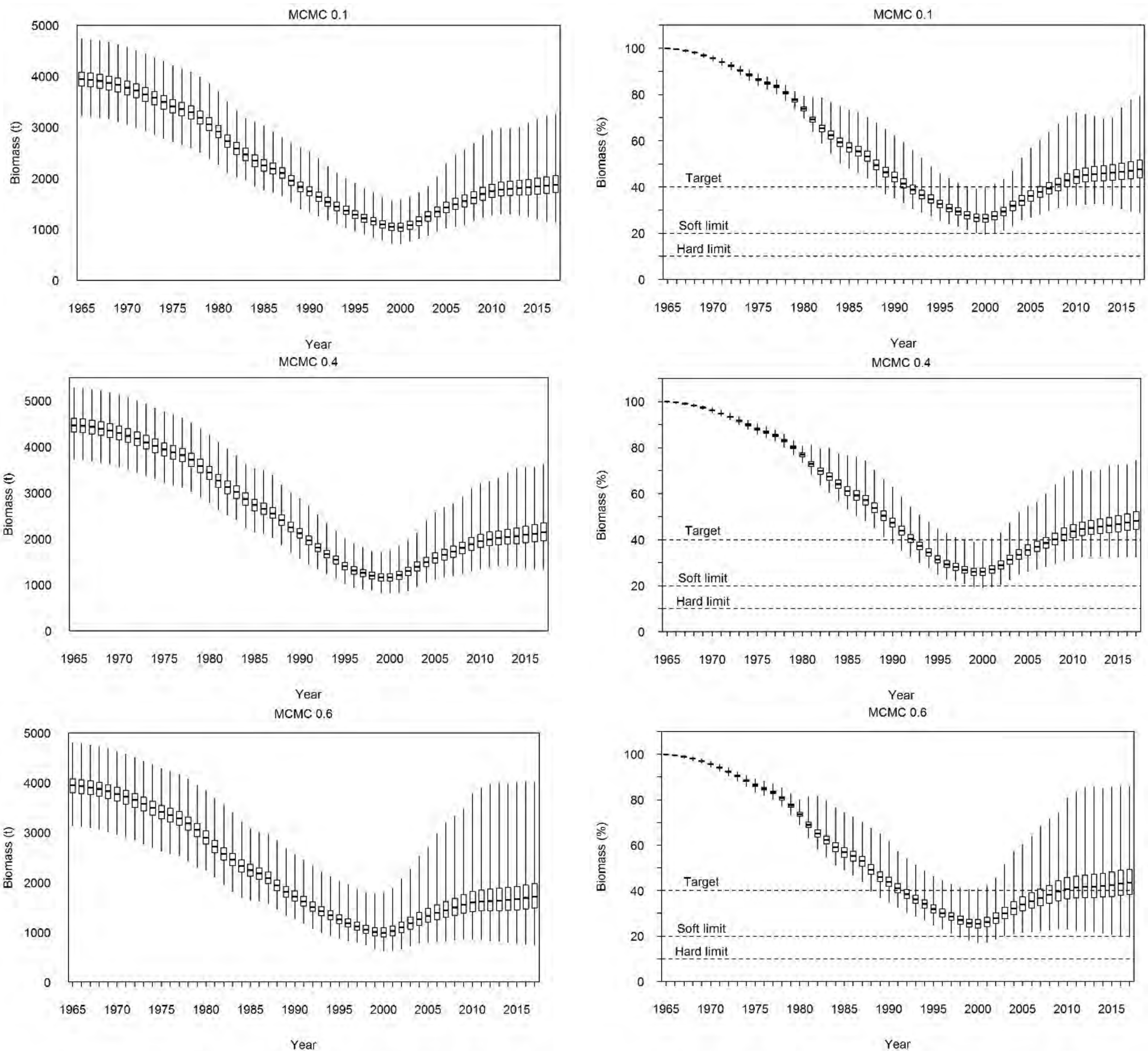


Figure 5: Posterior distributions of spawning stock biomass and spawning stock biomass as a percentage of the unfished level from MCMC for models 0.1, 0.4 and 06. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

Table 8: Projected quantities for the Base model with an assumed 5% TACC increase and recruitment based on the past 10 years.

	2018	**2019**	**2020**
Bt	1898 (1460–2528)	1916 (1451–2594)	1936 (1439–2655)
%*B0*	0.48 (0.38–0.63)	0.49 (0.38–0.64)	0.49 (0.37–0.65)
rBt	1536 (1176–2031)	1550 (1176–2077)	1569 (1177–2124)
%*rB0*	0.43 (0.34–0.56)	0.44 (0.34–0.58)	0.44 (0.34–0.59)
Pr (>*Bcurrent*)	0.65	0.69	0.71
Pr (>40%B_0)	0.93	0.93	0.93
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.61	0.64	0.69
Pr (U>U40% B_0)	0	0	0.01

Table 9: Projected quantities for the Base model with an assumed 20% TACC increase and recruitment based on the past 10 years.

	2018	**2019**	**2020**
Bt	1892 (1453–2521)	1896 (1431–2574)	1904 (1407–2624)
% B_0	0.48 (0.38–0.62)	0.48 (0.37–0.63)	0.48 (0.37–0.64)
rBt	1529 (1169–2024)	1530 (1156–2057)	1537 (1144–2092)
%rB_0	0.43 (0.34–0.56)	0.43 (0.33–0.57)	0.43 (0.33–0.58)
Pr (>*Bcurrent*)	0.58	0.59	0.59
Pr (>40% B_0)	0.93	0.92	0.91
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.53	0.51	0.53
Pr (U>U40% B_0)	0.02	0.02	0.03

Table 10: Projected quantities for the Base model with an assumed 5% TACC increase and recruitment based on the past 5 years.

	2018	**2019**	**2020**
Bt	1876 (1434–2530)	1879 (1406–2571)	1876 (1373–2646)
% B_0	0.48 (0.37–0.62)	0.48 (0.37–0.64)	0.48 (0.36–0.65)
rBt	1536 (1175–2032)	1545 (1167–2073)	1551 (1154–2119)
%rB_0	0.43 (0.34–0.56)	0.44 (0.34–0.58)	0.44 (0.33–0.59)
Pr (>*Bcurrent*)	0.47	0.49	0.48
Pr (>40% B_0)	0.92	0.9	0.88
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.6	0.6	0.59
Pr (U>U40% B_0)	0	0	0.01

Table 11: Projected quantities for the Base model with an assumed 20% TACC increase and recruitment based on the past 5 years.

	2018	**2019**	**2020**
Bt	1869 (1427–2523)	1859 (1386–2551)	1844 (1341–2614)
% B_0	0.47 (0.37–0.62)	0.47 (0.36–0.63)	0.47 (0.35–0.65)
rBt	1529 (1168–2025)	1525 (1147–2053)	1519 (1121–2087)
%rB_0	0.43 (0.34–0.56)	0.43 (0.33–0.57)	0.43 (0.32–0.58)
Pr (>*Bcurrent*)	0.41	0.39	0.37
Pr (>40% B_0)	0.91	0.89	0.85
Pr (<20% B_0)	0	0	0
Pr (<10% B_0)	0	0	0
Pr (>*rBcurrent*)	0.52	0.48	0.44
Pr (U>U40% B_0)	0.02	0.02	0.03

The model treats the whole of the assessed area of PAU 5B as if it were a single stock with homogeneous biology, habitat and fishing pressures. The model assumes homogeneity in recruitment and natural mortality, and assumes that growth has the same mean and variance throughout. 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 of these factors 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 localized depletion of spawners. Spawners must be close to each other to breed and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, so local processes may decrease recruitment, an effect that the current model cannot account for.

Another source of uncertainty is that fishing may cause spatial contraction of populations (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.

4.5 Future research considerations

- Continue to develop fisheries-independent survey methodologies that are representative of the PAU 5B area;
- Further investigate *q*-drift to determine how to quantify it and its implications for assessment outcomes;
- Ensure models are robust to assumptions about, or estimates of, natural mortality and stock-recruitment parameters;
- Review the commercial catch sampling programme in light of the increasing trend of live or frozen-in-shell exports.

5. STATUS OF THE STOCK

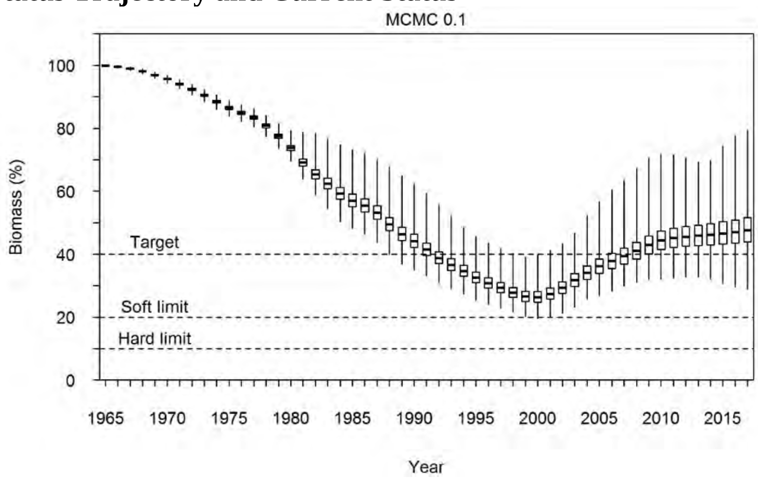
Stock Structure Assumptions

PAU 5B is assumed to be a homogenous stock for purposes of the stock assessment.

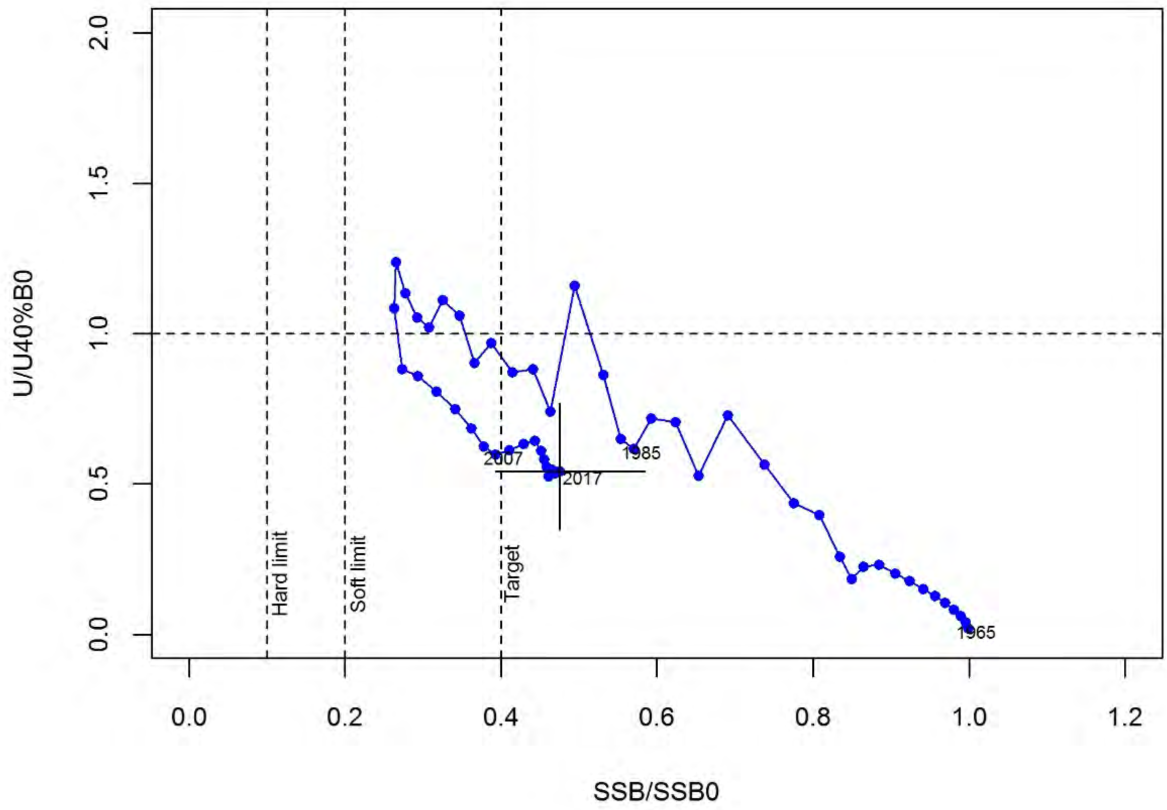
- **PAU 5B - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2018
Assessment Runs Presented	MCMC 0.1 (base case)
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default as per HSS) Hard Limit: 10% B_0 (Default as per HSS) Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2017} was estimated to be 47% B_0 for the base case; Likely (> 60%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft and hard limits
Status in Relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Posterior distributions of spawning stock biomass as a percentage of the unfished level from MCMC 0.1. 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.



Trajectory of exploitation rate as a ratio $U_{40\%B0}$ and spawning stock biomass as a ratio of B_0 from the start of assessment period 1965 to 2017 for MCMC 0.1 (base case). The vertical lines at 10%, 20% and 40% B_0 represent the hard limit, the soft limit, and the target respectively. $U_{40\%B0}$ is the exploitation rate at which the spawning stock biomass would stabilise at 40% B_0 over the long term. Each point on trajectory represents the estimated annual stock status: the value on x axis is the mid-season spawning stock biomass (as a ratio of B_0) and the value on the y axis is the corresponding exploitation rate (as a ratio $U_{40\%B0}$) for that year. The estimates are based on MCMC medians and the 2017 90% CI is shown by the crossed line.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass decreased to its lowest level in 2002 but has increased since then.
Recent Trend in Fishing Intensity or Proxy	Exploitation rate peaked in late 1990s and has since declined.
Other Abundance Indices	Standardised CPUE generally declined until the early 2000s, but has shown an overall increase since then.
Trends in Other Relevant Indicators or Variables	Estimated recruitment was relatively low through the 1990s to the early 2000s, increased from 2002 until 2010 and has since fallen below the long term average.

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch level biomass is expected to remain at or above the target over the next 3 years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Results from all models suggest it is Very Unlikely (< 10%) that current catch or TACC will cause a decline below the limits.
Probability of Current Catch or TACC to cause Overfishing to continue or to commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Full Quantitative Stock Assessment	
Assessment Method	Length-based Bayesian model	
Assessment Dates	Latest: 2018	Next: 2021
Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)	- Catch history - CPUE indices early series - CPUE indices later series - Commercial sampling length frequencies - Tag recapture data (for growth estimation) - Maturity at length data - Research Dive Survey Indices	1 – High Quality for commercial catch 2 – Medium or Mixed Quality for recreational, customary and illegal as catch histories are not believed to be fully representative of the QMA 2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA 1 – High Quality 2 – Medium or Mixed Quality: not believed to be fully representative of the whole QMA 1 – High Quality 1 – High Quality 2 – Medium or Mixed Quality: uncertain whether it indexes the stock
Data not used (rank)	- Research Dive Length Frequencies	2 – Medium or Mixed Quality: not believed to be representative of the entire QMA
Changes to Model Structure and Assumptions	New model	
Major Sources of Uncertainty	- *M* may not be estimated accurately. - CPUE may not be a reliable index of abundance and it is unclear whether catchability has changed over time. - The model treats the whole of the assessed area of PAU 5B as if it were a single stock with homogeneous biology, habitat and fishing pressure. - Any effect of voluntary increases in MHS from 125 mm to 137 mm between 2006 and 2017 may not have been adequately captured by the model, which could therefore be underestimating the spawning biomass in recent years.	

Qualifying Comments:
-

Fishery Interactions
-

6. FOR FURTHER INFORMATION

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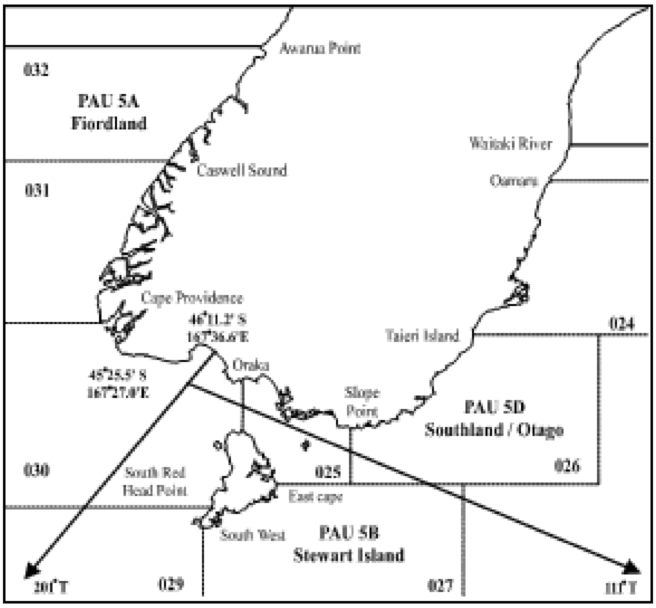
PĀUA (PAU 5D) - Southland / Otago

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

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

On 1 October 2002 a TAC of 159 t was set for PAU 5D, comprising a TACC of 114 t, customary and recreational allowances of 3 t and 22 t respectively, and an allowance of 20 t for other mortality. The TAC and TACC have been changed since then, but customary, recreational and other mortality allowances have remained unchanged (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 5 and PAU 5D since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1991*	-	-	-	-	445
1991–1994*	-	-	-	-	492
1994–1995*	-	-	-	-	442.8
1995–2002	-	-	-	-	148.98
2002–2003	159	3	22	20	114
2003–present	134	3	22	20	89

*PAU 5 TACC figures

1.1 Commercial fishery

The fishing year runs from 1 October to 30 September. On 1 October 2001, it became mandatory to report catch and effort on Paua Catch Effort Landing Return (PCELR) forms using fine-scale reporting areas that had been developed by the New Zealand Pāua Management Company for their voluntary logbook programme (Figure 1). Since 2010, the commercial industry has adopted some voluntary management initiatives which include raising the minimum harvest size for commercial fishers over specific statistical reporting areas. The industry has also voluntarily closed, to commercial harvesting, specific areas that are of high importance to recreational pāua fishers. In recent years commercial fishers have been voluntarily shelving a percentage of their Annual Catch Entitlement (ACE), which is reflected by the annual catch landings falling below the TACC (Figure 2, Table 2).

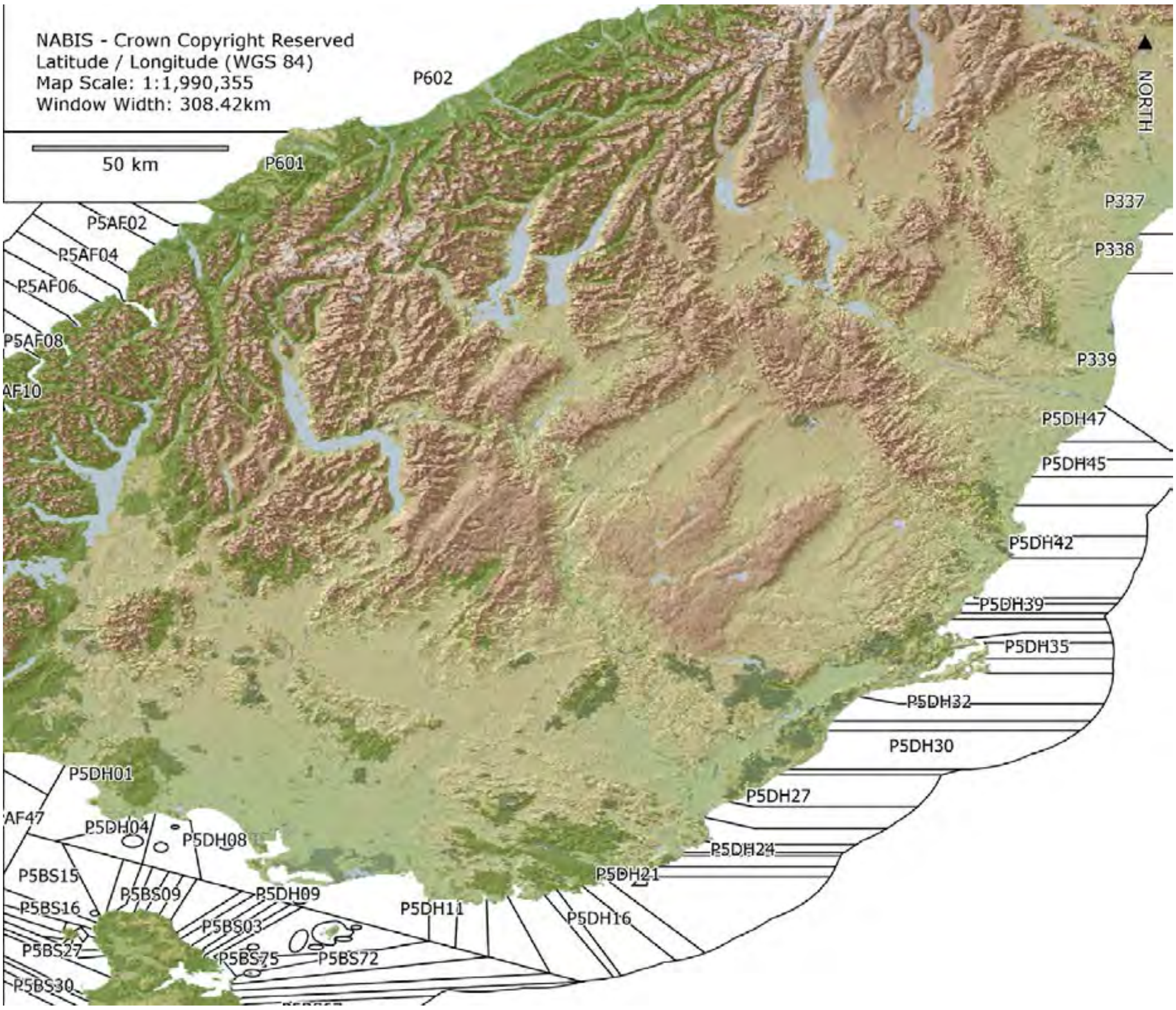


Figure 1: Map of fine scale statistical reporting areas for PAU 5D.

Commercial landings for PAU 5D are shown in Table 2 and Figure 2. Commercial landings for PAU 5 are reported in the introductory PAU Working Group Report.

Table 2: TACC and reported landings (t) of pāua in PAU 5D from 1995–96 to the present. [Continued next page]

Year	Landings	TACC
1995–96	167.42	148.98
1996–97	146.6	148.98
1997–98	146.99	148.98
1998–99	148.78	148.98
1999–00	147.66	148.98
2000–01	149.00	148.98
2001–02	148.74	148.98
2002–03	111.69	114.00
2003–04	88.02	89.00
2004–05	88.82	89.00
2005–06	88.93	89.00
2007–08	88.98	89.00
2006–07	88.97	89.00
2008–09	88.77	89.00
2009–10	89.45	89.00
2010–11	88.70	89.00
2011–12	89.23	89.00
2012–13	87.91	89.00
2013–14	84.59	89.00
2014–15	71.87	89.00

Table 2 [Continued]

Year	Landings	TACC
2015–16	65.95	89.00
2016–17	63.12	89.00
2017–18	62.48	89.00
2018–19	55.55	89.00

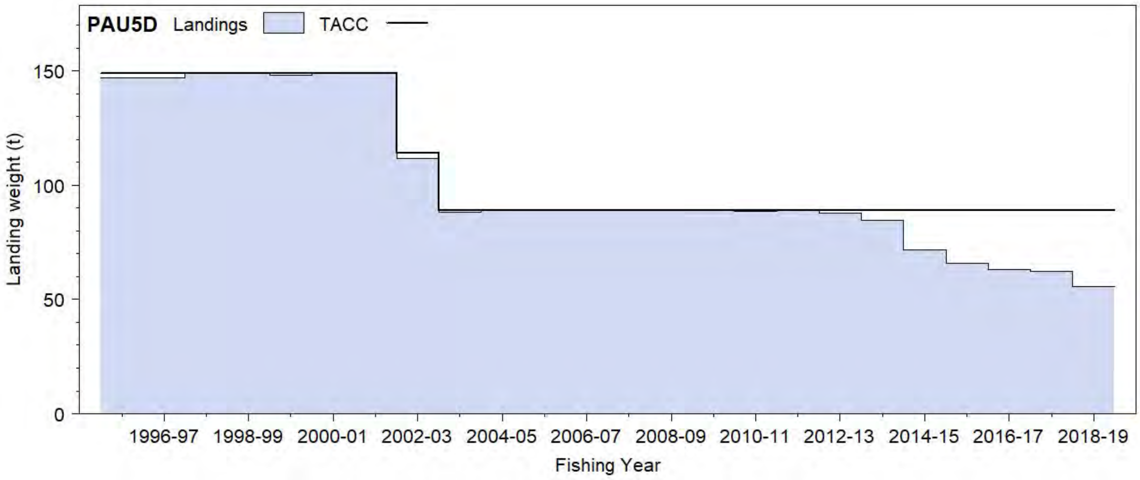


Figure 2: Reported commercial landings and TACC for PAU 5D from 1995–96 to present. For reported commercial landings in PAU 5 prior to 1995–96 refer to Figure 1 and Table 1 of the introductory PAU Working Group Report.

1.2 Recreational fisheries

For the purpose of the stock assessment model, the SFWG agreed to assume that the recreational catch in 1974 was 2 t and that it increased linearly to 10 t by 2005, where it has remained unchanged to date. For further information on recreational fisheries refer to the introductory PAU Working Group Report.

1.3 Customary fisheries

Estimates of customary catch for PAU 5D are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported in numbers) of pāua in PAU 5D between 2000-01 and 2018-19. – no data.

Fishing year	Approved	Harvested
2000–01	665	417
2001–02	5 530	3 553
2002–03	2 435	1 351
2003–04	–	–
2004–05	–	–
2005–06	1 560	1 560
2006–07	2 845	2 126
2007–08	5 600	5 327
2008–09	6 646	6 094
2009–10	4 840	4 150
2010–11	15 806	15 291
2011–12	7 935	7 835
2012–13	10 254	8 782
2013–14	5 720	5 358
2014–15	–	–
2015–16	15 922	13 110
2016–17	3 676	3 576
2017–18	3 588	3 310
2018–19	950	894

For the purpose of the stock assessment model, the SFWG agreed to assume that, for PAU 5D, the customary catch has been constant at 2 t from 1974 to the current stock assessment. The reported customary catch in 2018–19 was 894 kg. 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 model, the SFWG agreed to assume that, for PAU 5D, illegal catches have been constant at 10 t from 1974 to the current stock assessment. For further information on illegal catch refer to the introductory PAU Working Group Report.

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

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Working Group Report. A summary of biological parameters used in the PAU 5D assessment is presented in Table 4.

3. STOCKS AND AREAS

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

Table 4: Estimates of biological parameters (*H. iris*).

		Estimate	Source
1. Natural mortality (M)			
		0.15(0.12-0.19)	Median (5–95% range) of posterior estimated by the base case model
2. Weight = a(length)^b (Weight in g, length in mm shell length)			
All	a	b	
	2.99 x 10^{-5}	3.303	Schiel & Breen (1991)
3. Size at maturity (shell length)			
		50% maturity at 91 mm (89–93)	Median (5–95% range) estimated outside of the assessment
		95% maturity at 103 mm (103–105)	Median (5–95% range) estimated outside of the assessment
4. Estimated annual growth increments (both sexes combined)			
	16.65 (15.96–24.29)	4.57 (3.27–6.40)	

4. STOCK ASSESSMENT

The stock assessment was implemented as a length-based Bayesian estimation model, with uncertainty of model estimates investigated using the marginal posterior distributions generated from Markov chain-Monte Carlo simulations. The most recent stock assessment was conducted for the fishing year ended 30 September 2018. A base case model (0.0 - referred to as the reference model henceforth) was chosen from the assessment. Data weighting had the strongest impact on assessment outcomes, and a range of scenarios with varying weights for CPUE and commercial length-frequency data were explored. QMA specific growth patterns remain highly uncertain due to high spatial variability in growth and relatively low spatial coverage of the tag-recapture programme to estimate pāua growth. This uncertainty translates into uncertainty about stock status and stock trajectories.

4.1 Estimates of fishery parameters and abundance indices
Parameters estimated in the assessment model and their assumed Bayesian priors are summarized in Table 5.

Table 5: A summary of estimated model parameters, lower bound, upper bound, type of prior, (U, uniform; N, normal; LN = lognormal; Beta = beta distribution), mean and CV of the prior.

Parameter	Prior	μ	sd	Bounds Lower	Bounds Upper
ln($R0$)	LN	exp(13.5)	0.5	10	20
D_{50}(Length at 50% selectivity for the commercial catch)	LN	123	0.05	100	145
$D_{95\text{-}50}$(Length between 50% and 95% selectivity the commercial catch)	LN	5	0.5	0.01	50
Steepness (h)	Beta				
ϵ (Recruitment deviations)	LN	0	2	0	-

The observational data were:

1. A standardised CPUE series covering 1989–2018 based on combined CELR and PCELR data.
2. A commercial catch sampling length frequency series for 1991–93, 1997, 1999–2016
3. Tag-recapture length increment data.
4. Maturity at length data

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2019 stock assessment used a combined series of standardised CPUE indices that included both CELR data covering 1990–2001, and PCELR data covering 2002–2018. CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among fixed (research strata) and random variables, and between fine-scale reporting (PCELR) and larger scale variables (CELR). The variation explained by fine-scale variables (e.g. fine scale statistical areas or divers) in PCELR data was considered unexplained in the CELR portion of the model and therefore added to observation error.

For the CELR data, there was ambiguity in what was recorded for estimated daily fishing duration: either incorrectly recorded as hours per diver, or correctly as total hours for all divers. For PAU 5D, fishing duration appeared to have been predominantly recorded as hours per diver. A model-based correction procedure was developed to detect and correct for misreporting, using a mixture model that determines the characteristics of each reporting type by fishing crew and assigns years to correct (reporting for all divers) or incorrect (by diver) reporting regimes with some probability. Only records with greater than 95% certainty of belonging to one or the other reporting type were retained for further analysis.

CPUE was defined as the log of daily catch-per-unit-effort. Variables in the model were fishing year, FIN (Fisher Identification Number), Statistical Area (024, 026), dive condition, diver ID, and fine-scale statistical area. Variability in CPUE was mostly explained by differences among divers and crews (FINs), with dive conditions strongly affecting CPUE. The CPUE data showed a slight decline in the 1990s followed by a strong downturn in CPUE in the early 2000s, followed by a strong recovery of CPUE to levels above those seen in the early 1990s (Figure 3). However, CPUE subsequently declined to below-average levels, where it has remained relatively stationary since 2013. In some circumstances, commercial CPUE may not be proportional to abundance because it is possible to maintain catch rates of pāua despite a declining biomass. This occurs because pāua tend to aggregate and divers move among areas to maximise their catch rates. Apparent stability in CPUE should therefore be interpreted with caution. The assumption of CPUE being proportional to biomass was investigated using the assessment model.

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua in PAU 5D has also been estimated from a number of independent research diver surveys (RDSI) undertaken in various years between 1994 and 2004. The survey strata (Catlins East and Catlins West) cover the areas that produced about 25% of the recent catches in PAU 5D. This data was not included in the assessment because there is concern that the data is not a reliable enough index of abundance and the data is not representative of the entire PAU 5D QMA.

Concerns about the ability of the data collected in the independent Research Dive surveys to reflect relative abundance instigated reviews in 2009 (Cordue 2009) and 2010 (Haist 2010). The reviews assessed the reliability of the research diver survey index as a proxy for abundance and whether the RDSI, when used in the pāua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from pāua stock assessments using the

RDSI should be treated with caution. For a summary of the review's conclusions refer to the introductory PAU Working Group Report.

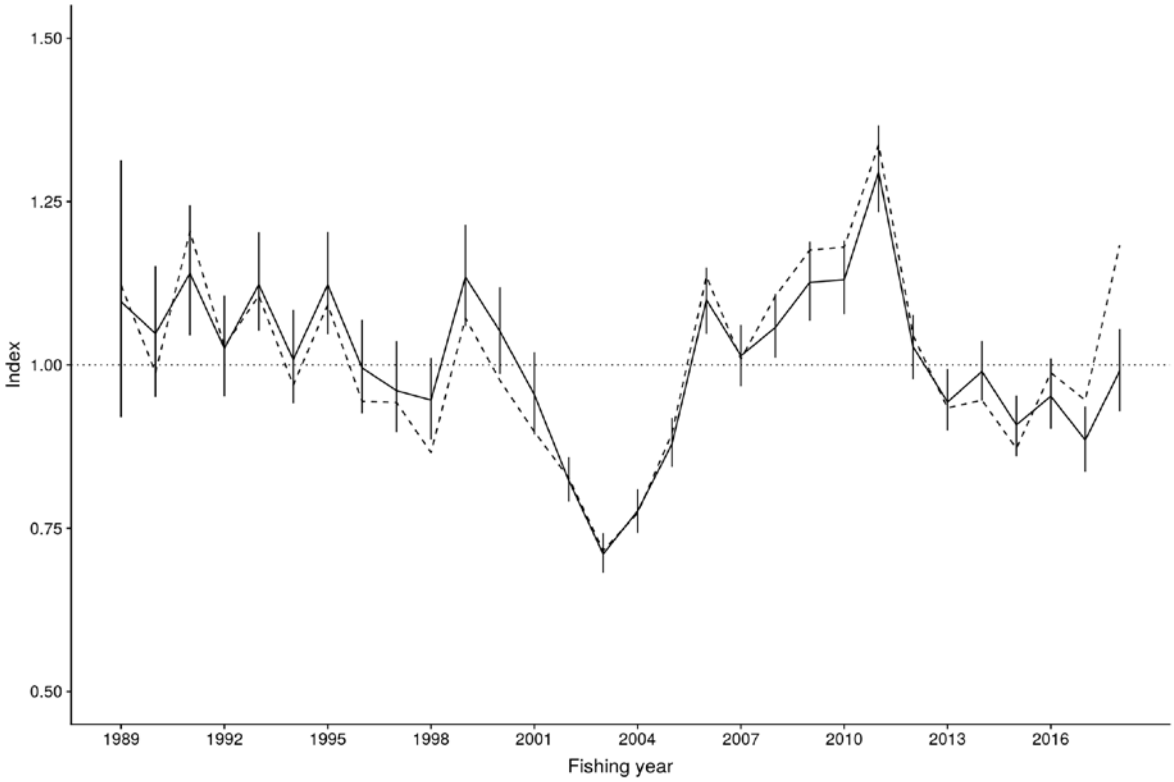


Figure 3: The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardized geometric CPUE (dashed line) for the combined CELR and the PCELR series.

4.2 Stock assessment methods

The 2019 PAU 5D stock assessment used the length-based population dynamics model first described by Breen et al (2003). PAU 5D was last assessed using data up to the 2015–2016 fishing year (Marsh & Fu 2017), and the most recent assessment uses data up to the 2017–2018 fishing year (Neubauer & Tremblay-Boyer 2019). Although the overall population-dynamics model remained unchanged, the most recent iteration of the PAU 5D stock assessment incorporates a number of changes to the previous methodology:

1. CPUE likelihood calculations reverted to predicting CPUE from beginning of year biomass since the previous change to mid-year predictions did not affect the assessment and caused potential for error and an increased computational burden.
2. A Bayesian statistical framework across all data inputs and assessments (MPD runs were not performed; all exploration was performed using full Markov Chain Monte Carlo runs).
3. The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB).
4. Catch sampling length-frequency (CSLF) data handling was modified to a model-based estimation of observation error with partitioning between observation and process error for CSLF and CPUE, and use of a multivariate normal model for centred-log-ratio-transformed mean CSLF and observation error.
5. The data weighting procedure was to use a scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF.
6. Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data were explicitly fitted in the model.

The model structure assumed a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm, in groups of 2 mm. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class changing in each year. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulates the population from 1965 to 2018. Catches were available for 1974–2018 although catches before 1995 must be estimated from the combined PAU 5 catch, and were assumed to increase linearly between 1965 and 1973 from 0 to the 1974 catch level. Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step.

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 pāua. However, the Shellfish Working Group agreed to use a Beverton-Holt stock-recruitment relationship, with steepness (h) estimated for this assessment.

Growth, maturation and natural mortality were also estimated within the model, although no fitting to raw data was performed, and all inputs were provided as priors with mean and observation error. The model estimated the commercial fishing selectivity, which was assumed to follow a logistic curve and to reach an asymptote.

The assessment proceeded iteratively by first replacing the previous growth formulation (i.e. fitting to growth data from PAU 5D only within the model) with an informed prior on mean growth and growth variability. Previous assessments noted that growth collected from a limited number of sites may not represent mean growth and true growth variability across the QMA. It was noted in the current assessment that PAU 5D growth data was almost exclusively from sites with very fast growth, and that alternative assumptions about growth lead to radically different estimates of stock status. To reflect uncertainty about true growth, a prior formulated from a South Island-wide meta-analysis was used in the model.

Providing less information about growth to the model meant that more weight was placed on CPUE and CSLF data, and it was found that data weights were now the most influential uncertainty in the model. Previous methods to weight datasets give more weight to CPUE data by default because CPUE has a more direct link to abundance than CSLF data, and one can argue a lower potential for process error. However, for pāua in particular, CPUE is often seen as a risky index of abundance (see qualifications below). The current assessment therefore does not favour either dataset *a priori*, but rather attempts to explore scenarios where either dataset has high weight relative to the other. To more accurately quantify model fit and information loss from each data source, a new procedure was developed based on the log scoring rule (a scoring rule quantifies the predictive quality of a model). The log score provides a base to weight datasets (i.e. to penalise deviation from any dataset) and to measure information loss from data (e.g. the estimated CPUE and observation error) to model quantities. Models with various divergence penalty configurations for CPUE and CSLF were introduced and the resulting model fit and divergence between model and input were noted until a set of models with satisfactory fits and deviations was found.

The reference model (model 0) excluded the RDSI and RDLF data, fitted the combined CPUE series and the mean CSLF and observation error, estimated process error for CPUE and CSLF, updated growth estimates within the model, and estimated M and steepness within the model. The data weights in this model led to slightly increased information loss from CSLF data relative to CPUE data, with satisfactory fits to both datasets.

The sensitivity trials carried out used lower weight for the CPUE indices and a more restrictive prior for M as opposed to the base-case.

The assessment calculates the following quantities from the marginal posterior distributions of various partitions of the biomass: the equilibrium (unfished) spawning stock biomass (SSB_0) assuming that recruitment is equal to the average recruitment, and the relative spawning and available biomass for

2018 (SSB_{2018} and B^{Avail}_{2018}) and for the projection (*Proj*) period (SSB_{Proj} and B^{Avail}_{proj}. This assessment also reports the following fishery indictors:

Relative *SSB*	Estimated spawning stock biomass in the final year relative to unfished spawning stock biomass
Relative B^{Avail}	Estimated available biomass in the final year relative to unfished available stock biomass
P(SSB_{2018} > 40% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 40% of the unfished spawning stock
P(SSB_{2018} > 20% SSB_0)	Probability that the spawning stock biomass in 2018 was greater than 20% of the unfished spawning stock (soft limit)
P(SSB_{Proj} > 40% SSB_0)	Probability that projected future spawning stock biomass will be greater than 40% of the unfished spawning stock given assumed future catches
P(SSB_{Proj} > 20% SSB_0)	Probability that projected future spawning stock biomass will be greater than 20% of the unfished spawning stock given assumed future catches
P(B_{Proj} > B_{2018})	Probability that projected future biomass (spawning stock or available biomass) is greater than estimated biomass for the 2018 fishing year given assumed future catches

4.3 Stock assessment results

The base case model suggested a relatively flat trend in spawning stock biomass over the past seven years, following a slow downwards trend from 2005 to 2011 (Figure 4). The base case also indicated a high probability that the stock is currently near the target spawning stock biomass (Table 6), with little to no probability that it is below the soft limit of 20% *SSB*. This inference was supported by all sensitivity runs (Table 6). Nevertheless, relative available biomass was markedly lower than the spawning stock biomass, meaning that a considerable part of the spawning biomass was below the minimum harvest size, and is therefore not accessible to the fishery.

Projections suggested relatively stable SSB for scenarios of current catch and 10% or 20% increased or decreased catch (Table 7). For all catch scenarios, available biomass was projected to slowly increase, although this increase is somewhat uncertain (there was a 60% likelihood of an increase in three years over current available biomass at current catch).

Two sensitivity scenarios were agreed as the main sensitivity scenarios that bracketed estimated stock status in the base-case run. The first scenario was the base case with a more restrictive prior for *M* (log-normal SD of 0.1 instead of 0.2) which forced *M* to a lower point in the assessment; it also led to lower recent stock status, all else being equal (Table 6; Figure 4). Nevertheless, this scenario also suggested a recent upturn in the fishery with increasing available biomass, despite a lower stock status estimate. This model run suggested a potentially stronger impact from recent shelving measures than the base case. Projections from this scenario largely agreed with those from the base-case.

Table 6: Model runs for the stock assessment of pāua in management area PAU 5D. Posterior quantities for data fits in terms of the Kullback-Leibler divergence (KLD) for catch-per-unit-effort (CPUE) and catch sampling length frequency (CSLF), stock status (relative spawning stock biomass), relative available biomass and probability of the stock status being above the soft limit (P(SSBproj > 20% SSB0). Numbers are posterior medians, with the 0.025 and 0.975 posterior quantiles in parentheses.

Run	KLD CPUE	KLD CSLF	Stock status	Available	P(SSB_{proj} > 20% SSB_0)
Base	0.67 (0.53;0.82)	0.73 (0.66;0.84)	0.40 (0.25;0.65)	0.25 (0.17;0.39)	1.00
Constrain M	0.68 (0.53;0.92)	0.74 (0.66;0.84)	0.36 (0.24;0.56)	0.23 (0.16;0.35)	1.00
Lower CPUE weight	0.84 (0.70;1.05)	0.73 (0.65;0.83)	0.44 (0.28;0.71)	0.29 (0.19;0.46)	1.00

The second main sensitivity scenario did not up-weight the CPUE and, therefore, only down-weighted CSLF data. This sensitivity scenario resulted in declining recent spawning stock biomass trends (Figure 4), despite resulting in slightly higher estimates for current stock status (Table 6). The declining trend continued for projections in this scenario regardless of the applied catch. For both main sensitivity scenarios, the probability of stock status being at or falling below the soft limit was close to zero over the timeframe of projections.

For a number of reasons (outlined below) reference points based on deterministic MSY or B_{MSY} are not currently used for managing pāua stocks and were therefore not calculated.

There are several reasons why deterministic B_{MSY} is not considered a suitable target for management of the pāua fishery. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge of catch and biology and perfect stock assessments (because current biomass must be known exactly in order to calculate target catch), a constant-exploitation management strategy with annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders), and perfect management implementation of the TACC and catch splits with no under- or over-runs. Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known. Third, deterministic MSY is commonly much higher than realised catch for pāua stocks (e.g. Marsh & Fu 2017) and deterministic B_{MSY} is estimated at biomass levels corresponding to very low available biomass levels. Management based on deterministic MSY-based reference points would likely lead to biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard. Thus, the actual target needs to be above this theoretical deterministic biomass, but the extent to which it needs to be above has not been determined.

In the meantime, an interim target of 40% B_0 is used as a proxy for a more realistic interpretation of B_{MSY}.

Table 7: Projections for key fishery indicators from the base case model: probabilities of being above 40% and 20% of unfished spawning biomass (SSB) [P(SSB_{Proj} > 40% SSB_0) and P(SSB_{Proj} > 20% SSB_0)], the probability that SSB in the projection year is above current SSB, the posterior median relative to SSB, the posterior median relative available spawning biomass B_{Proj}^{Avail}, and the probability that the exploitation rate (U) in the projection year is above $U_{40\%\ SSB0}$, the exploitation rate that leads to 40% SSB_0. The total commercial catch (TCC) marked with * corresponds to current commercial catch under 35% shelving of the current TACC (89 t). Other TACC scenarios show 50% shelving (44.5 t), 20% shelving (71.2 t) and fishing at the current TACC. Simulation to equilibrium (assumed to have been reached after 50 projection years) are indicated with Eq. in the year column.

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2018})	Median rel. SSB_{Proj}	Median rel. B_{Proj}^{Avail}	P(U > $U_{40\%\ SSB0}$)
44.5	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.31
	2020	0.52	1	0.45	0.43	0.5	0.26
	2021	0.53	0.99	0.49	0.44	0.52	0.23
	Eq.	0.63	0.87	0.61	0.52	0.53	0.24
57.85	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.44
	2020	0.5	0.99	0.42	0.42	0.5	0.42
	2021	0.5	0.98	0.44	0.42	0.51	0.4
	Eq.	0.53	0.81	0.52	0.47	0.48	0.4
71.2	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.54
	2020	0.48	0.99	0.39	0.41	0.49	0.53
	2021	0.46	0.96	0.41	0.41	0.5	0.53
	Eq.	0.46	0.75	0.44	0.42	0.42	0.57
89	2018	0.52	1	0	0.41	0.46	0.46
	2019	0.51	1	0.39	0.42	0.48	0.64
	2020	0.45	0.99	0.36	0.4	0.48	0.66
	2021	0.42	0.94	0.37	0.4	0.48	0.68
	Eq.	0.37	0.68	0.34	0.36	0.37	0.73

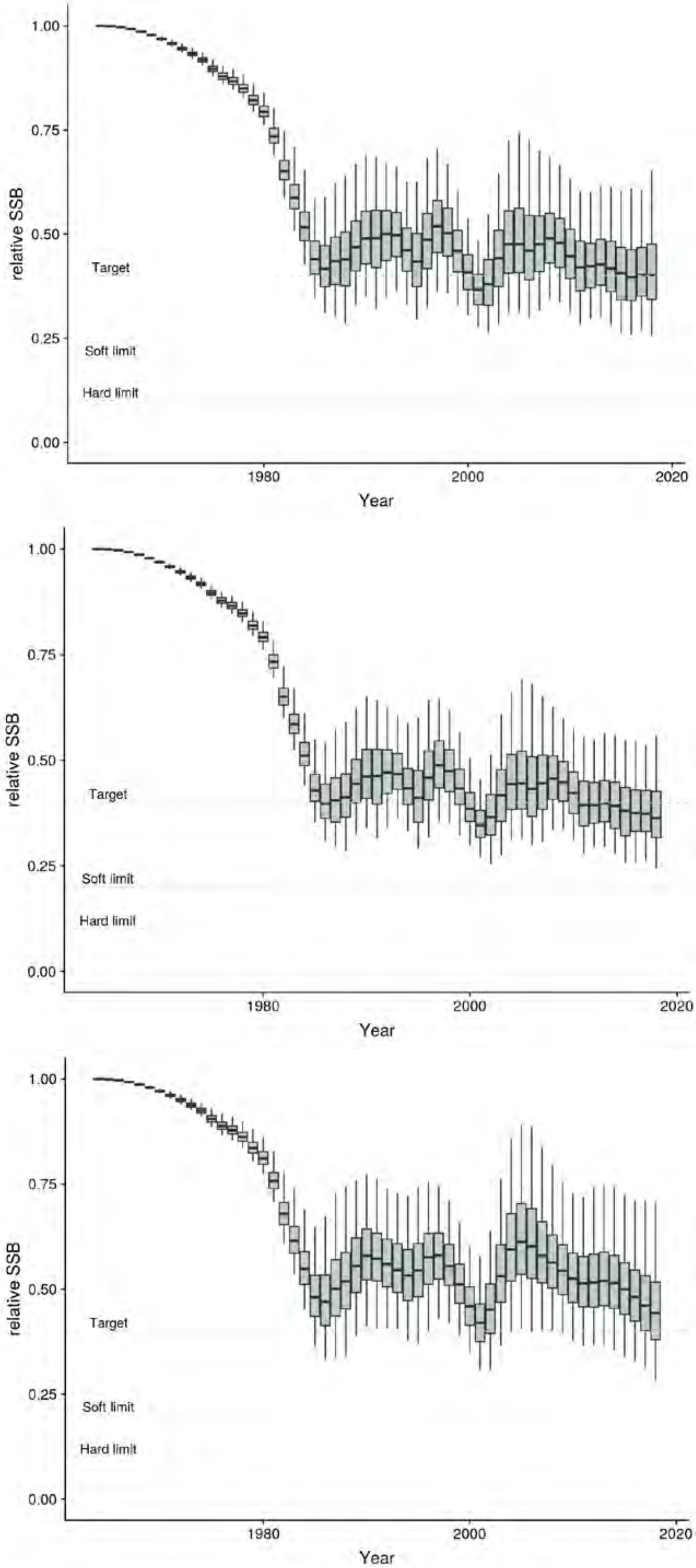


Figure 4: Posterior distributions of spawning stock biomass from the base case model, the sensitivity scenario with a more constrained prior on natural mortality (M), and the sensitivity scenario with lower weight on CPUE. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence range of the distribution.

4.4 Other factors

To run the stock assessment model a number of assumptions must be made, one of these being that CPUE is a reliable index of abundance. The literature on abalone fisheries suggests that this assumption is questionable and that CPUE is difficult to use in abalone stock assessments due to the serial depletion behaviour of fishers along with the aggregating behaviour of abalone. Serial depletion is when fishers consecutively fish-down beds of pāua but maintain their catch rates by moving to new unfished beds; thus CPUE stays high while the overall population biomass is actually decreasing. The aggregating behaviour of pāua results in the timely re-colonisation of areas that have been fished down, as the cryptic pāua, that were unavailable at the first fishing event, move to and aggregate within the recently depleted area. Both serial depletion and aggregation behaviour cause CPUE to have a hyperstable relationship with abundance (i.e. abundance is decreasing at a faster rate than CPUE) thus making CPUE a poor proxy for abundance. The strength of the effect that serial depletion and aggregating behaviour have on the relationship between CPUE and abundance in PAU 5D is difficult to determine. However, because fishing has been consistent in PAU 5D for a number of years and effort has been reasonably well spread, it could be assumed that CPUE is not as strongly influenced by these factors, relative to the early CPUE series.

The assumption of CPUE being a reliable index of abundance in PAU 5D can also be upset by exploitation of spatially segregated populations of differing productivity. This can conversely cause non-linearity and hyper-depletion in the CPUE-abundance relationship, making it difficult to track changes in abundance by using changes in CPUE as a proxy.

Another source of uncertainty is the data. The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Major differences may exist between the catches we assume and what was actually taken. Non-commercial catch estimates, including illegal catch, are also poorly determined and could be substantially different from what was assumed.

The model treats the whole of the assessed area of PAU 5D as if it were a single stock with homogeneous biology, habitat and fishing pressure. The model assumes homogeneity in recruitment and natural mortality.

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. Thus, length frequency data collected from the commercial catch may not represent the available biomass represented in the model with high precision.

The effect of these factors 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, as spawners must breed close to each other, and the dispersal of larvae is unknown and may be limited. Recruitment failure is a common observation in overseas abalone fisheries, so local processes may decrease recruitment, an effect that the current model does not account for.

Another source of uncertainty is that fishing may cause spatial contraction of populations (Shepherd & Partington 1995), or that it may result in some populations becoming 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. FUTURE RESEARCH CONSIDERATIONS

- Revisit PAU 5 catch reconstructions.
- Examine the effects of removing historical catches from areas that are now closed.
- Re-examine the diver surveys and length frequencies to determine their utility.
- Further investigate method for representing potential increases in catchability over time; e.g. a linear trend.

- Consider the need for more tagging in certain areas to fill gaps in growth data; e.g. Colac Bay and Moeraki.
- Further investigate data weighting procedures for pāua stocks. The prior on R_0 previously used in the PAU 5D assessment implied a prior on stock status that may have biased assessments of pāua stock status high. Check this further and determine whether it may also be an issue for other pāua stocks.

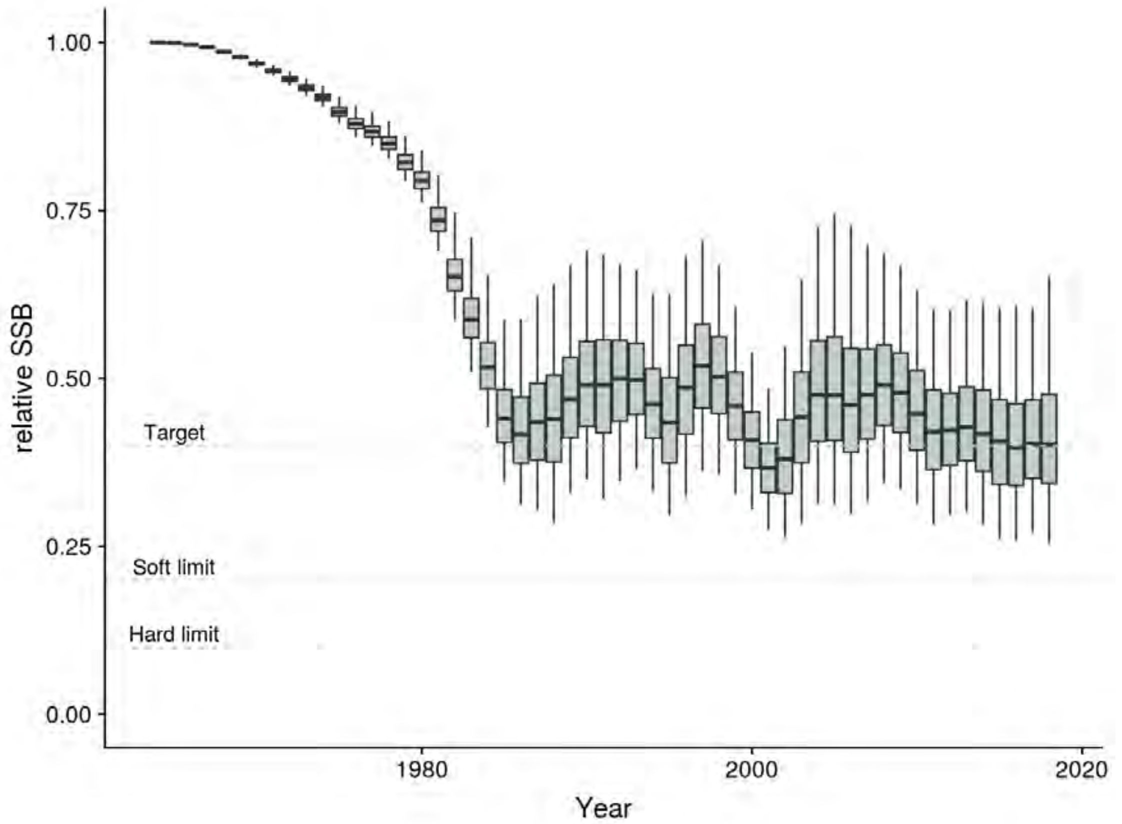
6. STATUS OF THE STOCK

Stock Structure Assumptions
PAU 5D is assumed in the model to be a discrete and homogenous stock

- **PAU 5D - *Haliotis iris***

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	Reference case MCMC
Reference Points	Interim Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	B_{2018} was estimated to be 42% B_0. About as Likely as Not (40–60%) to be at or above the target
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft limit and Very Unlikely (< 10%) to be below the hard limit.
Status in Relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring

Historical Stock Status Trajectory and Current Status



Posterior distributions of spawning stock biomass from the base case model. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence range of the distribution.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass decreased up to about 1984 and has been fluctuating moderately around the target subsequently.
Recent Trend in Fishing Mortality or Proxy	Exploitation rate peaked in 2002 and has since declined.
Other Abundance Indices	Standardised CPUE generally declined until the early 2000s, recovered in the mid-2000s, and gradually decreased to a recent stable but below average level.
Trends in Other Relevant Indicators or Variables	Recruitment appears to pulse in approximately five year intervals, with two larger than average pulses in the mid-1990s and 2000. Increases in pāua areas closed to commercial fishing and voluntary increases in MHS both create buffers to fishing.

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch level biomass is About as Likely as Not (40–60%) to remain at current levels. Under the current TACC, biomass is likely to decline in the short term.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Results from all model assessment runs presented suggest it is Very Unlikely (< 10%) that current levels of catch will cause a decline below the soft or hard limits.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	About as Likely as Not (40–60%) for current catch; Very Likely (> 90%) for current TACC

Assessment Methodology and Evaluation		
Assessment Type	1- Full Quantitative Stock Assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest: 2019	Next: 2022
Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)	- Catch History	2 – Medium or Mixed Quality: not believed to be fully representative of catch in the QMA
	- CPUE Indices early series	2 – Medium or Mixed Quality: not believed to be fully representative of CPUE in the QMA
	- CPUE Indices later series	1– High Quality
	- Commercial sampling length frequencies	1 – High Quality
	- Tag recapture data	2 – Medium or Mixed Quality: not believed to be representative of the whole QMA
	- Maturity at length data	1 – High Quality
Data not used (rank)	- Research Dive survey indices	3 – Low Quality: not believed to be a reliable indicator of abundance in the whole QMA
	- Research Dive length frequencies	3 – Low Quality: not believed to be a reliable indicator of length frequency in the whole QMA
Changes to Model Structure and Assumptions	- Both CPUE series combined to form a single index - Calculations for the CPUE likelihood were reverted to predicting CPUE from beginning of year biomass since the previous change to mid-year predictions did not affect the assessment and caused potential for error and increased computational burden.	

	- A Bayesian statistical framework across all data inputs and assessments (i.e. MPD runs were not performed, all exploration was performed using full Markov Chain Monte Carlo). - The assessment model framework was moved to the Bayesian statistical inference engine Stan (Stan Development Team 2018), including all data input models (the assessment model was previously coded in ADMB). - Changed CSLF data handling to model-based estimation of observation error and partitioning between observation and process error for CSLF and CPUE, with use of a multivariate normal model for centred-log-ratio-transformed mean CSLF and observation error. - Changed data weighting procedure to use scoring rule (log score) and associated divergence measure (Kullbach-Liebler divergence) to measure information loss and goodness of fit for CPUE and CSLF. - Growth and maturation were fit to data across all QMAs outside of the assessment model, and the resulting mean growth and estimate of proportions mature at age were supplied as an informed prior on growth to the model; no growth or maturation data was explicitly fitted in the model.
Major Sources of Uncertainty	- Growth data were limited and may not be representative of growth within the entire QMA. This was mitigated by formulating a weakly informative prior about growth based on meta-analysis for all South Island pāua stocks. - Assuming CPUE is a reliable index of abundance for pāua - Sensitivity of the model to data weighting assumptions - Potential increases in q

Qualifying Comments
Uncertainties in the input data and model structure necessitate caution in the interpretation of the assessed status of the stock. However, the high MHS relative to length-at-maturity (along with closed areas) means that a relatively large proportion of the spawning stock is not available to the fishery and provides a buffer from the effects of fishing for the stock.

Fishery Interactions
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6. FOR FURTHER INFORMATION

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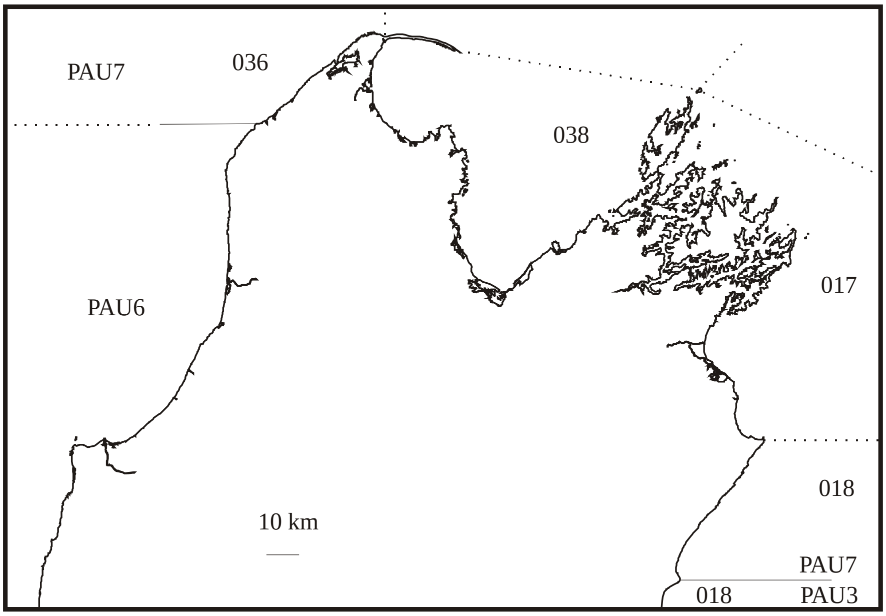
PĀUA (PAU 7) – Marlborough

(Haliotis iris)
Pāua



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. In 2016 the TACC was further reduced to 93.62 t, and the allowance for other mortality was increased to 10 t, setting the TAC to 133.62 (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
1989–01	–	–	–	–	267.48
2001–02	273.73	15	15	3	240.73
2002–16	220.24	15	15	3	187.24
2016–Present	133.62	15	15	10	93.62

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. In 2000–01 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. In the 2012–13 and 2013–14, the industry shelved 20% of the 187.24 t TACC. In 2014–15, PAU 7 stakeholders again agreed to voluntarily shelve 30%. However some only shelved 20% and some shelved 30%; an average of 28% was shelved overall. In October 2016 the TACC was reduced by 50%. Almost immediately following this as a result of the Kaikōura earthquake of November 2016 the southern area of the fishery was closed under emergency provisions, this was later replaced by an official S11 closure. This area historically accounted for approximately 10% of the total PAU 7 catch. From 1 October 2017 the TAC was reduced a further 10%, but this decision was set aside by agreement following a court injunction so the TAC is still set at 133.63 t for PAU7. However, PAU 7 stakeholders have agreed to a 10% shelving which they have maintained to date. The customary and recreational allowances are still set at 15 t.

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

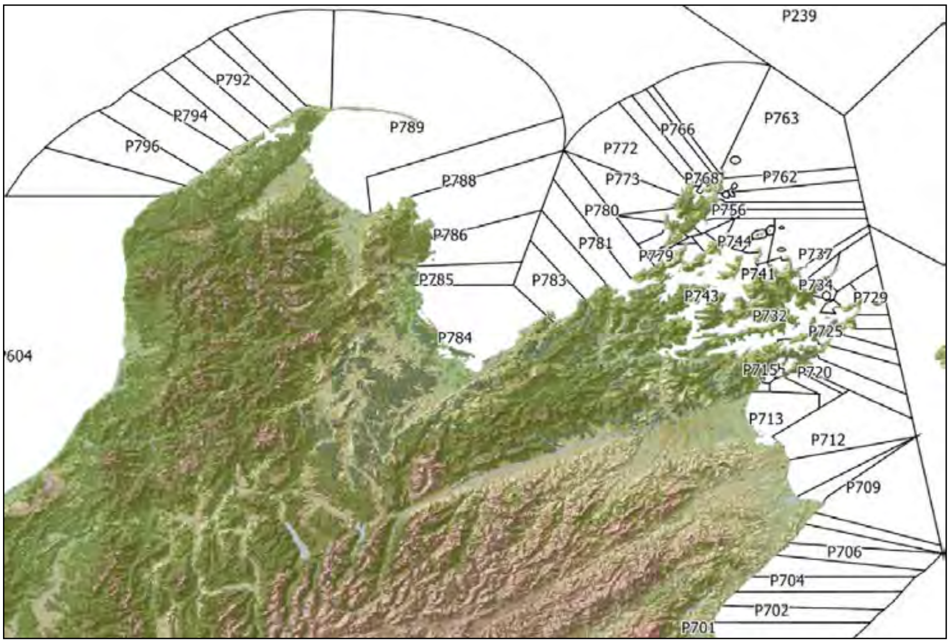


Figure 1: Map of fine scale statistical reporting areas for PAU 7.

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)	Shelving	Year	Landings (t)	TACC (t)	Shelving
1974–75	197 910	-	-	1996–97	267 594	267.48	267.48
1975–76	141 880	-	-	1997–98	266 655	267.48	267.48
1976–77	242 730	-	-	1998–99	265 050	267.48	267.48
1977–78	201 170	-	-	1999–00	264 642	267.48	267.48
1978–79	304 570	-	-	2000–01	215 920	267.48	*213.98
1979–80	223 430	-	-	2001–02	187 152	240.73	240.73
1980–81	490 000	-	-	2002–03	187 222	187.24	187.24
1981–82	370 000	-	-	2003–04	159 551	187.24	*159.15
1982–83	400 000	-	-	2004–05	166 940	187.24	*159.15
1983–84	330 000	-	-	2005–06	183 363	187.24	*159.15
1984–85	230 000	-	-	2006–07	176 052	187.24	*159.15
1985–86	236 090	-	-	2007–08	186 845	187.24	187.24
1986–87	242 180	250		2008–09	186 846	187.24	187.24
1987–88	255 944	250		2009–10	187 022	187.24	187.24
1988–89	246 029	250		2010–11	187 240	187.24	187.24
1989–90	267 052	267.48		2011–12	186 980	187.24	187.24
1990–91	273 253	267.48		2012–13	149 755	187.24	*149.80
1991–92	268 309	267.48	267.48	2013–14	145 523	187.24	*149.80
1992–93	264 802	267.48	267.48	2014–15	133 584	187.24	*134.80
1993–94	255 472	267.48	267.48	2015–16	138 790	187.24	187.24
1994–95	247.108	267.48	267.48	2016–17	93.610	93.620	93.620
1995–96	268 742	267.48	267.48	2017–18	81.880	93.620	*84.26
				2018-19	79.697	93.620	*84.26

* Voluntary shelving

1.2 Recreational fisheries

A nationwide panel survey of over 7000 marine fishers who reported their fishing activity over the fishing year from 1 October 2011 to 30 September 2012 was conducted by The National Research Bureau Ltd in close consultation with Marine Amateur Fishing Working Group (Wynne-Jones et al 2014). The survey is based on an improved survey method developed to address issues and to reduce bias encountered in past surveys. The survey estimated that about 50 534 pāua, or 14.13 t (CV of 34%) were harvested by recreational fishers in PAU 7 for 2011–12. For this assessment, the 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 subsequently. In 2017–18, the National Panel Survey was repeated and the estimated recreational catch was 3.02 t (CV of 36%) (Wynne-Jones et al 2019). For further information on recreational fisheries refer to the introductory PAU Working Group Report.

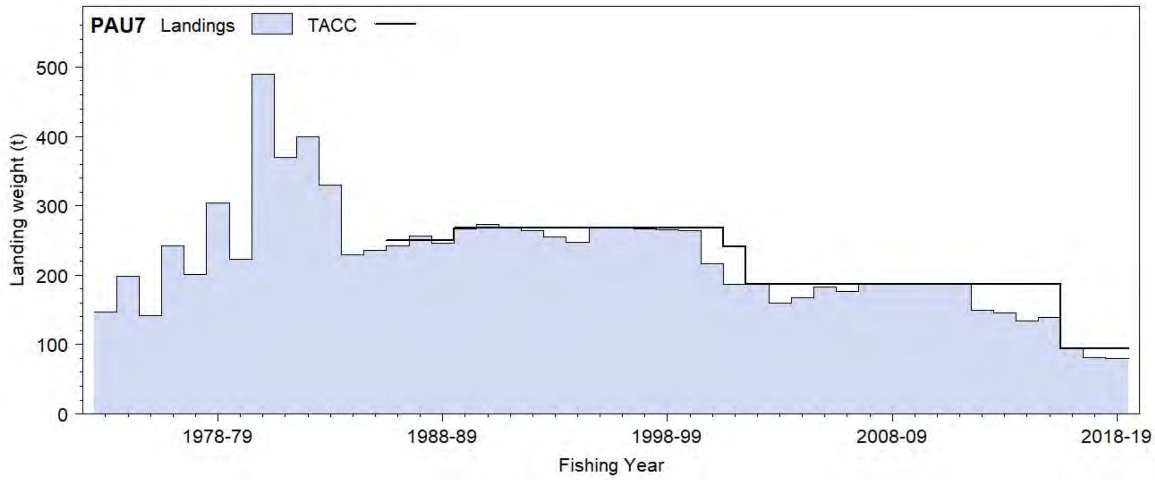


Figure 2: Reported commercial landings and TACC for PAU 7 from 1986–87 to present.

1.3 Customary fisheries

Customary catch was incorporated into the PAU 7 TAC in 2002 as an allowance of 15 t. Estimates of customary catch for PAU 7 are shown in Table 3. These numbers are likely to be an underestimate of customary harvest as only the catch in kilograms and numbers are reported in the table.

Table 3: Fisheries New Zealand records of customary harvest of pāua (reported as weight (kg) and numbers) of pāua in PAU 7 between 2007-08 and 2011-12. No reports since. – no data.

	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
2007–08	–	–	1 110	808
2008–09	–	–	1 270	1 014
2009–10	–	–	1 085	936
2010–11	–	–	60	31
2011–12	–	–	20	20

Records of customary catch taken under the South Island Regulations show that about 20 to 1014 pāua were reported to have been collected each year from 2007–08 to 2011–12, with an average of 449 pieces each year. Those numbers were substantially lower than the annual allowances. There has not been any reports since.

For the 2015 stock assessment, the Working Group agreed to assume that customary catch was 4 t in 1974, increasing linearly to 5 t between 1974 and 2000 and then remaining at 5 t subsequently.

For further information on customary fisheries refer to the introductory PAU Plenary chapter.

1.4 Illegal catch

There are no estimates of illegal catch for PAU 7.

For the 2015 stock assessment, 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 to 2005, then decreasing linearly to 7.5 t in 2008, and then remaining at 7.5 subsequently.

For further information on illegal catch refer to the introductory PAU Plenary chapter.

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 Plenary chapter**.**

On November 16th 2016 a 7.8 magnitude earthquake hit the upper east coast of the South Island, uplifting areas of the coast by as much as 4 m. In the PAU 7 fishery, pāua statistical areas P701 to P710 were impacted to varying degrees by the earthquake. The earthquake caused direct mortality of a large number of juvenile and adult pāua that became exposed to the terrestrial environment with no means of being able to return to the water. More indirect mortality is also expected from the earthquake due to an immediate loss of pre-earthquake pāua habitat that now lies above the new post-earthquake high tide mark.

Impacts of the seabed uplift on pāua populations in PAU 7 will only become clear in the longer term. The immediate loss of area to the fishery, assumed to be good habitat for pāua, is only part of the impact that the seabed uplift associated with the earthquake will have on pāua populations. Juvenile pāua recruit in shallow water, and so the loss of juvenile habitat will have been higher than the loss of adult habitat. This will impact on the number of juvenile pāua growing into the fishery over the coming years. This impact will be difficult to quantify directly, but may affect pāua populations and fisheries over a span of multiple years.

2. BIOLOGY

For further information on pāua biology refer to the introductory PAU Plenary chapter. A summary of biological parameters used in the PAU 7 stock assessment is presented in Table 4.

Table 4: Estimates of biological parameters (*H. iris*).

Fishstock		**Estimate**	**Source**
1. Natural mortality (*M*)			
All		0.02–0.25	Sainsbury (1982)
PAU 7	0.11 (0.10–0.13)	Median (5%–95% CI)	estimated from the base case 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	92 (91.3–92.7) mm	Median (5%–95% CI)	estimated by the assessment model
length at 95% mature - 50% mature	8.7 (9.6–13.4) mm	Median (5%–95% CI)	estimated by the assessment model
4. Exponential growth parameters (both sexes combined)			
l^g_{50}	104 (98.5–107.1) mm	Median (5%–95% CI)	estimated by the assessment model: length of animal at 50% maximum growth increment
$l^g_{95\text{-}50}$	30.9 (25.9–37.4) mm	Median (5%–95% CI)	estimated by the model: length of animal between at 50% and 95% maximum growth increment.
Δ_{max}	30 (26.3–36.1) mm	Median (5%–95% CI)	estimated by the model: maximum growth increment

3. STOCKS AND AREAS

For further information on stocks and areas refer to the introductory PAU Plenary chapter.

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 2015 assessment was restricted to Statistical Areas 017 and 038, which includes approximately 85–95% of the catch over the past 10 years**.**

4.1 Estimates of fishery parameters and abundance indices

Parameters estimated in the assessment model and their assumed Bayesian priors are summarised in Table 5.

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2015 stock assessment used two sets of standardised CPUE indices: one based on CELR data covering 1990–2001, and another based on PCELR data covering 2002–2015. For both series, standardised CPUE analyses were carried out using Generalised Linear Models (GLMs). A stepwise procedure was used to select predictor variables, with variables entering the model in the order that gave the maximum decrease in the residual deviance. Predictor variables were accepted in the model only if they explained at least 1% of the deviance.

For both the CELR and PCELR data, the Fisher Identification Number (FIN) was used in the standardisations instead of vessel, because the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN. FIN codes were used to select a core group of fishers from the CELR data, with the requirement to qualify for the core fisher group that there be a minimum of 15 records per year for a minimum of 3years. For the PCELR data the FIN was also used to select a core group of fishers, with the requirement that there be a minimum of 20 records per year for a minimum of 8 years. For both periods, over 80% of catches were retained.

Table 5: 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	Definition	Phase	Prior	μ	CV	Lower	Upper
$\ln(R0)$	Natural log of base recruitment	1	U	–	–	5	50
M	Instantaneous rate of natural mortality	3	LN	0.1	0.1	0.01	0.5
Δ_{max}	Maximum growth increment	2	U	–	–	1	50
l_{50}^{g}	length at 50% maximum growth	2	U	–	–	0.01	150
l_{95-50}^{g}	length between 50% and 95% maximum growth	2	U	–	–	0.01	150
α	parameter that defines the variance of growth increment	2	U	–	–	0.001	5
β	parameter that defines the variance of growth increment		U	–	–	0.001	5
$Ln(q^I)$	Catchability coefficient of CPUE	1	U	–	–	-30	0
$Ln(q^J)$	Catchability coefficient of PCPUE	1	U	–	–	-30	0
L_{50}	Length at which maturity is 50%	1	U	–	–	70	145
L_{95-50}	Interval between L50 and L95	1	U	–	–	1	50
T_{50}	Length at which Fighting Bay length frequency selectivity is 50%	2	U	–	–	70	125
T_{95-50}	Difference between T50 and T95	2	U	–	–	0.001	50
D_{50}	Length at which commercial diver selectivity is 50%	2	U	–	–	70	145
D_{95-50}	Difference between D_{50} and D_{95}	2	U	–	–	0.01	50
ε	Vector of annual recruitment deviations from 1977 to 2013	1	N	0	0.4	-2.3	2.3
D_s	Change in commercial diver selectivity for one unit of change of MHS	1	U	–	–	0.01	10

The observational data were:

1. A standardised CPUE series covering 1983–2001 based on FSU/CELR data.
2. A standardised CPUE series covering 2002–2015 based on PCELR data.
3. A length frequency dataset from the Fighting Bay fish-down experiment (FBLF).
4. A commercial catch sampling length frequency series (CSLF).
5. Tag-recapture length increment data.
6. Maturity at length data

For the CELR data there is ambiguity in what is recorded for estimated daily fishing duration: either incorrectly recorded as hours *per diver*, or correctly as total hours *for all* divers. For PAU 7, fishing duration appeared to have been predominantly recorded as hours per diver. The standardisation was therefore restricted to records where fishing duration ≤ 10 hours. This subset of data was used for the CELR standardisation using estimated daily catch, and effort as fishing duration.

For the PCELR data the unit of catch was diver catch, with effort as diver duration.

For the CELR data, year was forced into the model and other predictor variables offered to the model were FIN and fishing duration (as a cubic polynomial). For the PCELR data, fishing year was forced into the model and variables offered to the model were month, diver key, FIN statistical area, diver duration (third degree polynomial), and diving conditions.

The standardised CELR index shows a decline from the early 1990s to 2001. The standardised PCELR index shows an increase from 2002 to 2008 with an overall slow decline since then (Figure 3).

4.1.2 Relative abundance estimates from research diver surveys

The relative abundance of pāua 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 pāua stock assessment models, results in model outputs that adequately reflect the status of the stocks. Both reviews suggested that outputs from pāua stock assessments using the RDSI should be treated with caution. For a summary of the conclusions from the reviews refer to the introductory PAU Plenary chapter.

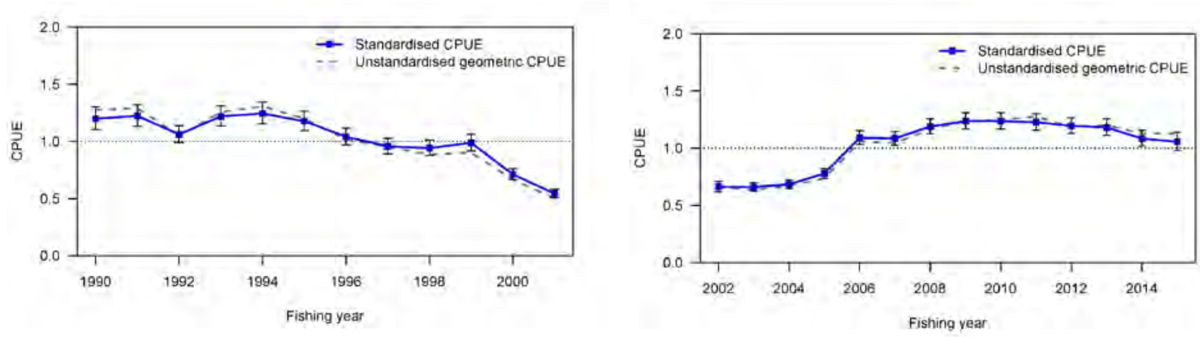


Figure 3: The standardised CPUE indices with 95% confidence intervals for the early CELR series (left) and the recent PCELR series (right).

4.2 Stock assessment methods

The 2015 PAU 7 stock assessment used the length-based model first used in 1999 for PAU 5B (Breen et al 2000) and revised for subsequent assessments in PAU 7 (Breen et al 2001, Breen & Kim 2003, 2005, McKenzie & Smith 2009b, Fu 2012). The model was described in Breen et al (2003). The assessment also addressed a number of recommendations made by the pāua review workshop held in Wellington in March 2015 (Butterworth et al 2015)

The model structure assumes a single sex population residing in a single homogeneous area, with length classes from 70 mm to 170 mm, in groups of 2 mm. Growth is length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class changing at each time step. Pāua 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 over 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 2015. Catches were available for 1974–2015, 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 pāua. 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 the Fighting Bay catch sample 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 Shellfish Working Group for the assessment: The base case model is configured such that (a) predicted CPUE is calculated after half of the natural and fishing mortality has occurred; (b) Francis (2011) method was used to determine the weight of CSLF and CPUE; (c) growth was estimated using the inverse-logistic model; (d) tag-recapture observations from the Staircase were excluded; (e) tag-recapture observations were weighted by the catch in each area; (f) the CPUE shape parameter was fixed at 1 assuming a linear relationship between CPUE and abundance. The base case used a lognormal prior on M, with μ_M= 0.1 and σ_M= 0.1. The choice of CV was arbitrary, but generally chosen to be very informative to prevent obtaining unrealistic estimates. A sensitivity run (MCMC 1.4) used a prior (μ_M = 0.15 and σ_M = 0.25) developed from posterior estimates of M from assessments of PAU 5A and PAU 5B, based on the recommendation from the pāua review workshop (Butterworth et al 2015).

The SFWG also suggested the following sensitivity runs: using a smaller CV of 0.05 (model 1.1), or a larger CV of 0.12 (1.2); estimating the CPUE shape parameter assuming a uniform prior bounded between 0.5 and 1.5 (1.3), or fixing it at the lower (1.3a) and upper value (1.3b) respectively; using an alternative prior when estimating natural mortality; including tag-recapture observations from the Staircase (1.5). The base case and sensitivities are summarised in Table 6.

Table 6: Summary descriptions of base case and sensitivity model runs.

Model	Description
1.0	base case, Francis (2011) weighting, inverse logistic, excluded Staircase growth, growth data weighted
1.1	1.0, CV for CPUE2 = 0.5
1.2	1.0, CV for CPUE2 = 1.2
1.3	1.0, estimated CPUE shape parameter with a uniform prior [0.5,1.5]
1.3a	1.0, CPUE shape parameter = 0.5
1.3b	1.0, CPUE shape parameter = 1.5
1.4	1.0, M estimated with a prior developed using information from PAU 5A and PAU 5B.
1.5	1.0, included Staircase growth

The assessment calculates the following quantities from their posterior distributions: the equilibrium spawning stock biomass assuming that recruitment is equal to the average recruitment from the period for which recruitment deviation were estimated (B_0,), the mid-season spawning and recruited biomass for 2015 (B_{2015} and B^r_{2015}) and for the projection period (B_{proj} and B^r_{proj}). This assessment also reports the following fishery indictors:

$B\%B_0$	Current or projected spawning biomass as a percentage of B_0
$B\%B_{msy}$	Current or projected spawning biomass as a percentage of B_{msy}
$\Pr(B_{proj} > B_{msy})$	Probability that projected spawning biomass is greater than B_{msy}
$\Pr(B_{proj} > B_{2015})$	Probability that projected spawning biomass is greater than $B_{current}$
$B\%B^r_0$	Current or projected recruited biomass as a percentage of B^r_0
$B\%B^r_{msy}$	Current or projected recruited biomass as a percentage of B^r_{msy}
$\Pr(B^r_{proj} > B^r_{msy})$	Probability that projected recruit-sized biomass is greater than B^r_{msy}
$\Pr(B^r_{proj} > B^r_{2015})$	Probability that projected recruit-sized biomass is greater than B^r_{2015}
$\Pr(B_{proj} > 40\%B_0)$	Probability that projected spawning biomass is greater than 40% B_0
$\Pr(B_{proj} < 20\%B_0)$	Probability that projected spawning biomass is less than 20% B_0
$\Pr(B_{proj} < 10\%B_0)$	Probability that projected spawning biomass is less than 10% B_0
$\Pr(U_{proj} > U_{40\%B0})$	Probability that projected exploitation rate is greater than $U_{40\%B0}$

Forward projections (2016–2018) were made for the base case with a number of alternative future catch scenarios. Future recruitment deviations were resampled from model estimates either from 2002–2011 (a period with both high and low recruitment), or from 2010–2011 (a period with low recruitment). The total catch used in the projections was 142 717 kg (28% TACC reduction), 131 515 (35% TACC reduction), 123 514 kg (40% shelving), 107 511 kg (50% shelving) and 91 510 kg (60% TACC), and 27 500 kg (100% TACC reduction).

4.2.1 Stock assessment results

Current estimates from the base case suggested that spawning stock population in 2015 ($B_{current}$) was about 18% (16–21%) of the unfished level (B_0), or 69% (16–21%) of B_{msy} (Figure 4, Table 7). Estimated recent recruitment has been below average (recruitment in 2010 and 2011 was the lowest after 2002). The estimated exploitation rate has declined since 2003, and was further reduced after 2012. The exploitation rate in 2015 was estimated to be 0.46 (0.40–0.52).

The model projection made for three years using recruitment re-sampled from a period with both high and low recruitment (2002–2011), suggested that the spawning stock abundance will increase to 22% (16–29%) of B_0 in 2018 if the future catch remains at the current level (corresponding to a 28% TACC shelving), or 24% (18–31%) of B_0 if the future catch is reduced to 50% of the TACC (Figure 5). The projections using recruitment re-sampled from the recent period with low recruitment (2010–2011), suggested that the spawning stock abundance will only increase to 19% (14–25%) of B_0 in 2018 if the future catch remains at the current level, or 21% (16–27%) of B_0 with a 50% TACC reduction (Figure 6). It was extremely unlikely that the stock status will be above the target (40% B_0) in the short term.

The base case model matched very closely with the early CPUE and predicted CPUE indices were all well within the confidence bounds of the observed values. Predicted CPUE declined more than observed values between 2009 and 2013. However, the overall change in relative abundance between 2002 and 2015 is similar between the predicted and observed values. The standardised residuals show no apparent departure from the model’s assumption of normality. Commercial catch length frequencies were well fitted for most years. The mean length of CSLF has increased since 2003, and has remained reasonably stable since 2007, except in 2014. The average fish size in the catch in recent years has been well below those in the early 1990s. The standardised residuals of the fits to CSLF revealed that in general the model predicted a slightly narrower distribution than what was observed in the catch. This might be because the fishery has been fished down to a low level and the chance of sampling pāua of large sizes has reduced. Estimated logistic selectivity was very close to knife-edge around the MLS, with a small increase in 2015. Fits to growth increment and maturity data appeared adequate. The relative weight assigned to tag-recapture observations from Perano and Rununder was about three times more than those from Northern Faces, and as a result, estimated mean growth was higher than if equal weights were assumed. The Fighting Bay length frequency fitted well, suggesting this length distribution was consistent with the estimated growth rates in the model.

Table 7: Summary of the marginal posterior distributions from the MCMC chain from the base case (1.0) and sensitivities. The columns show the medians and the 5th and 95th percentiles. Biomass is in tonnes.

	MCMC 1.0	MCMC 1.1	MCMC 1.2	MCMC 1.3	MCMC 1.4
B_0	4291 (3980–4584)	4296 (3963–4600)	4296 (3968–4610)	4322 (4011–4632)	3784 (3185–4359)
B_{msy}	1133 (1056–1209)	1133 (1051–1212)	1137 (1053–1216)	1137 (1060–1216)	1019 (913–1153)
$B_{current}$	780 (689–888)	763 (689–855)	786 (683–919)	804 (701–938)	821 (723–937)
$B_{current}/B_0$	0.18 (0.16–0.21)	0.18 (0.15–0.21)	0.18 (0.16–0.22)	0.19 (0.16–0.22)	0.22 (0.17–0.28)
$B_{current}/B_{msy}$	0.69 (0.59–0.81)	0.68 (0.58–0.79)	0.69 (0.59–0.83)	0.71 (0.6–0.85)	0.81 (0.65–0.98)
B_{msy}/B_0	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.26 (0.26–0.27)	0.27 (0.26–0.29)
rB_0	3532 (3185–3842)	3543 (3184–3876)	3538 (3179–3872)	3544 (3210–3876)	3019 (2395–3605)
rB_{msy}	544 (438–638)	546 (443–648)	547 (439–649)	539 (442–643)	414 (279–571)
rBcurrent	300 (260–349)	297 (265–336)	302 (251–364)	314 (265–382)	306 (266–351)
$rB_{current}/rB_0$	0.09 (0.07–0.1)	0.08 (0.07–0.1)	0.09 (0.07–0.11)	0.09 (0.07–0.11)	0.1 (0.08–0.13)
$rB_{current}/rB_{msy}$	0.55 (0.43–0.74)	0.55 (0.43–0.71)	0.55 (0.42–0.76)	0.59 (0.44–0.79)	0.74 (0.51–1.15)
rB_{msy}/rB_0	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.15 (0.14–0.17)	0.14 (0.11–0.16)
MSY	207 (202–214)	207 (201–213)	208 (202–215)	207 (201–214)	217 (206–234)
U_{msy}	0.37 (0.31–0.47)	0.37 (0.3–0.46)	0.37 (0.31–0.47)	0.37 (0.31–0.47)	0.51 (0.35–0.79)
$U_{\%40B0}$	0.19 (0.16–0.23)	0.18 (0.16–0.22)	0.19 (0.16–0.23)	0.19 (0.16–0.22)	0.25 (0.18–0.4)
$U_{current}$	0.46 (0.4–0.52)	0.46 (0.41–0.5)	0.46 (0.38–0.54)	0.44 (0.36–0.51)	0.46 (0.41–0.52)

Table 8: Summary of key indicators for projected biomass in 2018 from the projection for the base case MCMC with 28%, 35%, 40%, 50%, 60%, and 100% TACC reduction. The columns show the medians and the 5th and 95th percentiles. Biomass is in tonnes.

	28% reduction	35% reduction	40% reduction	50% reduction	60% reduction	100% reduction
B_{2018}	943 (711–1227)	971 (739–1255)	990 (759–1274)	1030 (799–1314)	1068 (8381353)	1225 (996–1508)
B_{2018}/B_0	0.22 (0.16–0.29)	0.23 (0.17–0.30)	0.23 (0.17–0.30)	0.24 (0.18–0.31)	0.25 (0.19–0.32)	0.29 (0.23–0.36)
B_{2018}/B_{msy}	0.83 (0.61–1.11)	0.86 (0.64–1.13)	0.88 (0.65–1.15)	0.91 (0.69–1.18)	0.95 (0.72–1.22)	1.08 (0.86–1.36)
Pr (B_{2018}>Bmsy)	0.10	0.14	0.17	0.24	0.3268	0.7546
Pr (B_{2018}>B_{2015})	0.94	0.97	0.98	0.99	0.9972	1
Pr (B_{2018}>40%B0)	0.00	0.00	0.00	0.00	0.0002	0.003
Pr (B_{2018}<20%B0)	0.26	0.19	0.15	0.09	0.05	0.0026
Pr (B_{2018}<10%B0)	0.00	0.00	0.00	0.00	0	0

Changes in stock size in response to fishing pressure over time are shown in Figure 7. This was done by plotting the annual spawning biomass and exploitation rate as a ratio of a reference value from 1965 to 2015. Each point on the trajectory represents the estimated annual stock status: the value on the x axis is the mid-season spawning stock biomass as a ratio of B_0, the value on the y axis is the corresponding exploitation rate as a ratio of $U_{40\%B0}$ for that year. The trajectory started in 1965 when the SSB is close to B_0 and the exploitation rate is close to 0. The model indicated an early phase of the fishery where the exploitation rates were below $U_{40\%B0}$ and the SSBs were above 40% B_0 and a development phase where the exploitation rates increased and the SSBs decreased in relation to the target. The current exploitation rate is about twice of $U_{40\%B0}$ and the current spawning stock biomass is just below 20% B_0.

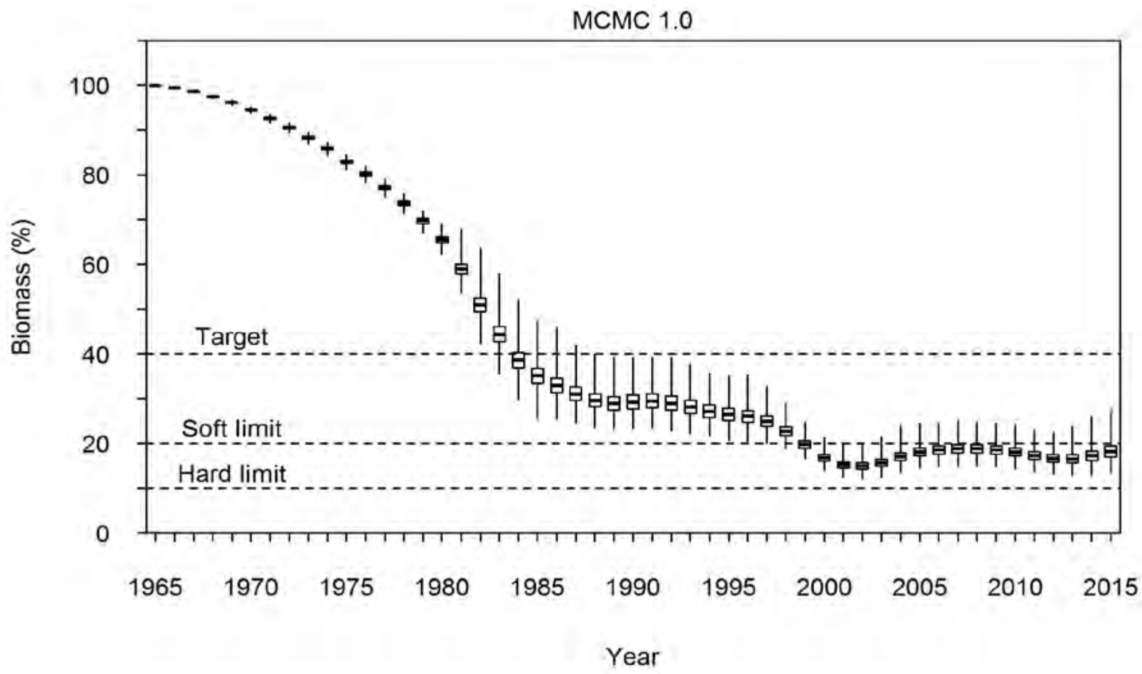


Figure 4: Posterior distribution of spawning stock biomass as a percentage of virgin level from MCMC 1.0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

4.3 Other factors

The stock assessment model assumed homogeneity in recruitment, and 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 pāua fisheries are spatially variable and that apparent growth and maturity in pāua 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 integration across local areas is likely to make model results optimistic.

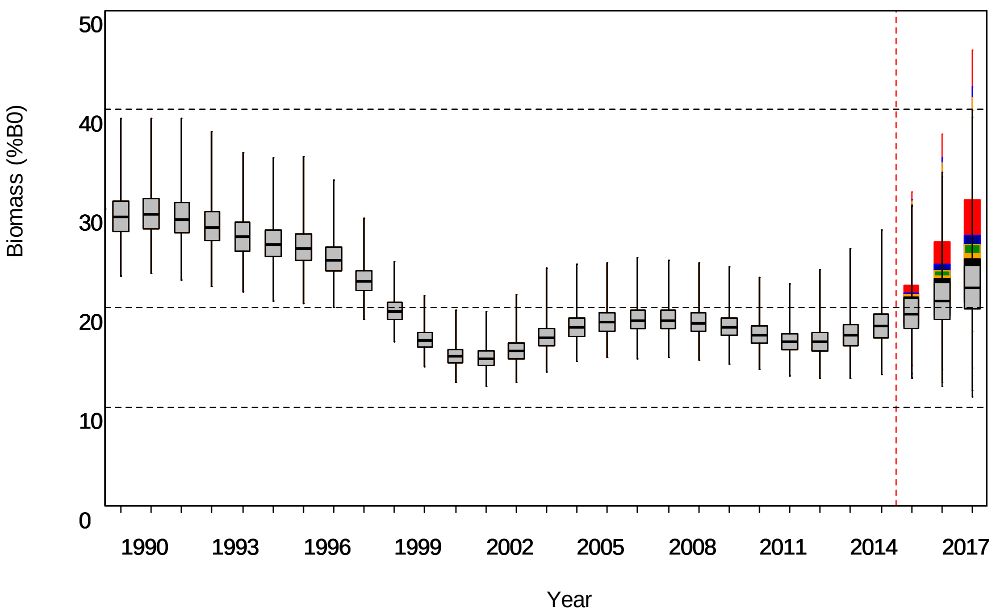


Figure 5: Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2002–2011 under six catch scenarios: 28% TACC reduction (gray), 35% TACC reduction (black), 40% TACC reduction (orange), 50% TACC reduction (green), 60% TACC reduction (blue), and 100% TACC reduction shelving (red). 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.

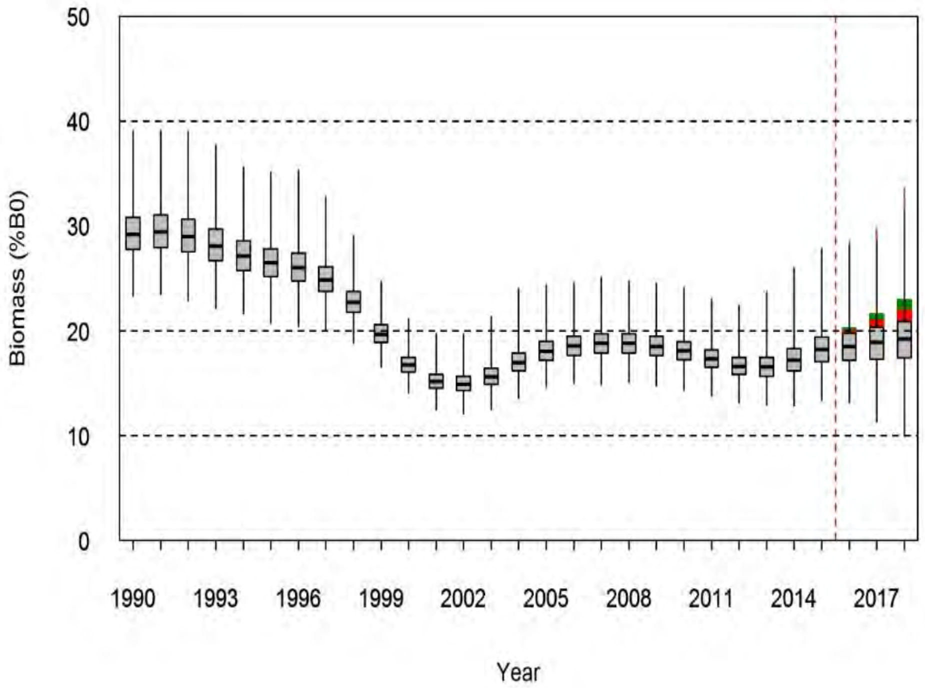


Figure 6: Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2010–2011 under three catch scenarios: 28% TACC reduction (gray), 40% TACC reduction (red), 50% TACC reduction (green), 60%. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

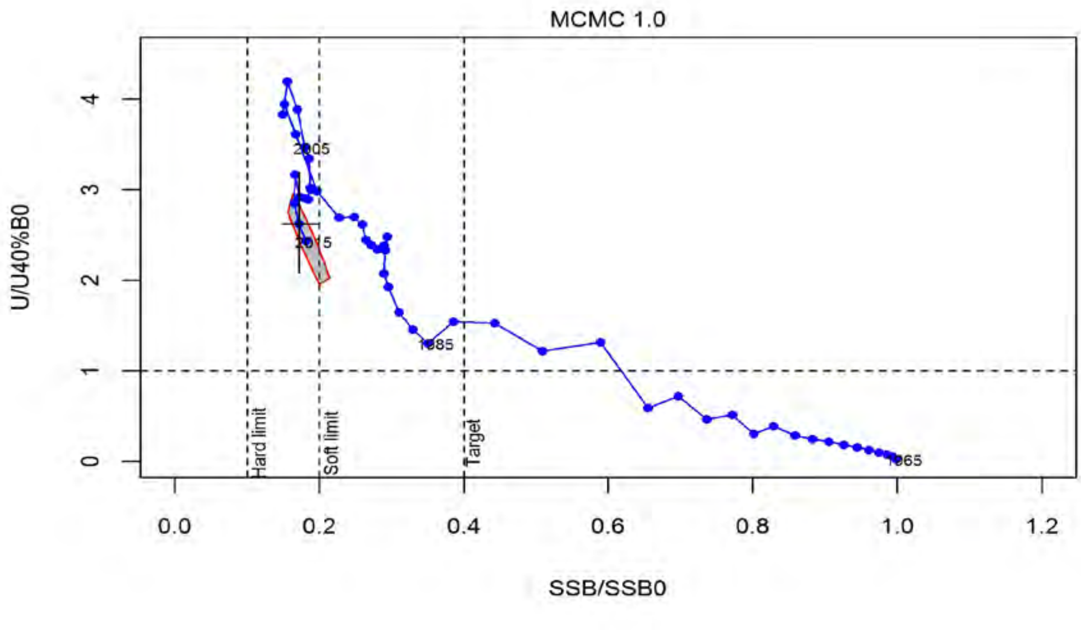


Figure 7: Trajectory of exploitation rate as a ratio of $U_{\%40B0}$ and spawning stock biomass as a ratio of B_0, from the start of assessment period 1965 to 2015 for MCMC 1.0 (base case). The vertical lines at 10%, 20% and 40% B_0 represent the soft limit, the hard limit, and the target. Estimates are based on MCMC median and the 2015 90% marginal CI is shown by the cross line, and joint CI is shown by the grey area.

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.

CPUE provides information on changes in relative abundance. However, CPUE is generally considered to be a poor index of stock abundance for pāua, due to divers' ability to maintain catch rates by moving from area to area despite a decreasing biomass (hyperstability). Breen & Kim (2003) argued that standardised CPUE might be able to relate to the changes of abundance in a fully exploited fishery such as PAU 7, and a large decline in the CPUE is most likely to reflect a decline in the fishery. Analysis of CPUE currently relies on Pāua Catch Effort Landing Return (PCELR) forms, which record daily fishing time and catch per diver on a relatively large spatial scale. These data will likely remain the basis for stock assessments and formal management in the medium term.

Since October 2010, a dive-logger data collection program has been initiated to achieve fine-scale monitoring of pāua fisheries (Neubauer et al 2014, Neubauer & Abraham 2014). The use of the data loggers by pāua divers and ACE holders has been steadily increasing over the last three years. Using fishing data logged at fine spatial and temporal scales can substantially improve effort calculations and the resulting CPUE indices and allow complex metrics such as spatial CPUE to be developed (Neubauer & Abraham 2014). Data from the loggers have been analysed to provide comprehensive descriptions of the spatial extent of the fisheries and insight on relationships between diver behavior, CPUE, and changes in abundance on various spatial and temporal scale (Neubauer et al 2014, Neubauer & Abraham 2014, Neubauer 2015). However the data-loggers can potentially change how the divers operate such that they may become more effective in their fishing operations (the divers become capable of avoiding areas that have been heavily fished or that have relatively low CPUE without them having to go there to discover this), therefore changing the meaning of diver CPUE (Butterworth 2015).

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.

4.4 Future research needs

- Increased tagging to obtain better fine scale growth information.
- Consider including more of the east coast in the assessment, noting that this would need to be considered as a separate fishery due to differences in size limits.
- Examine the possibility of spatial patterns in length and growth.

5. STATUS OF THE STOCKS

Stock Structure Assumptions

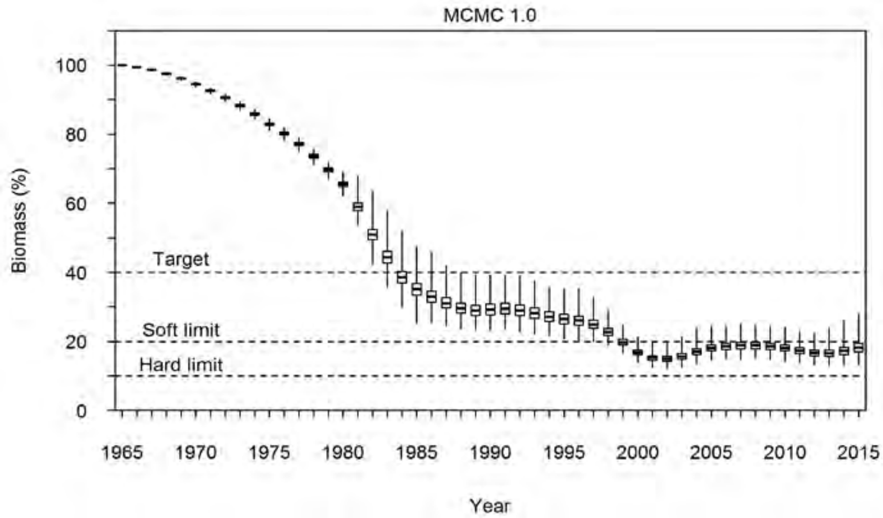
The 2015 assessment was conducted for Statistical Areas 017 and 038 only, but these include most (more than 90%) of the recent catch.

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

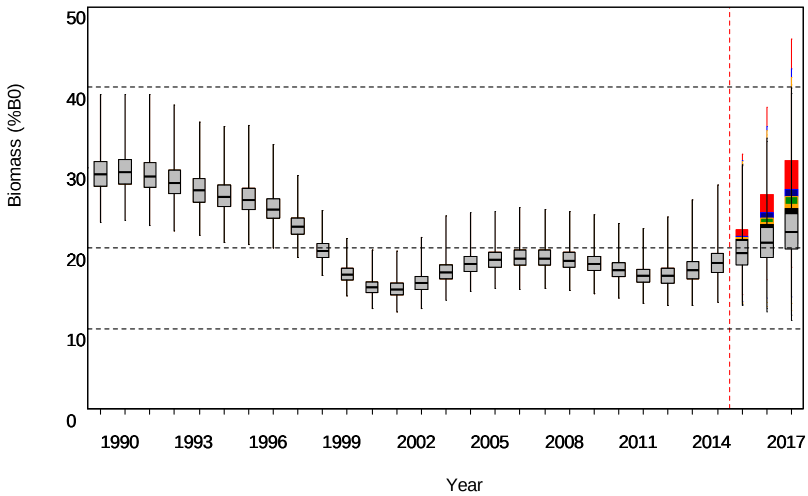
Stock Status	
Year of Most Recent Assessment	2015
Assessment Runs Presented	Base case MCMC
Reference Points	Interim Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%B0}$
Status in relation to Target	Spawning stock biomass was estimated to be 18% B_0 and is Very Unlikely (< 10%) to be at or above the target

Status in relation to Limits	Spawning stock biomass was estimated to be 18% 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
Status in relation to Overfishing	In 2014–15 the fishing intensity was Very Likely (> 90%) to be above the overfishing threshold

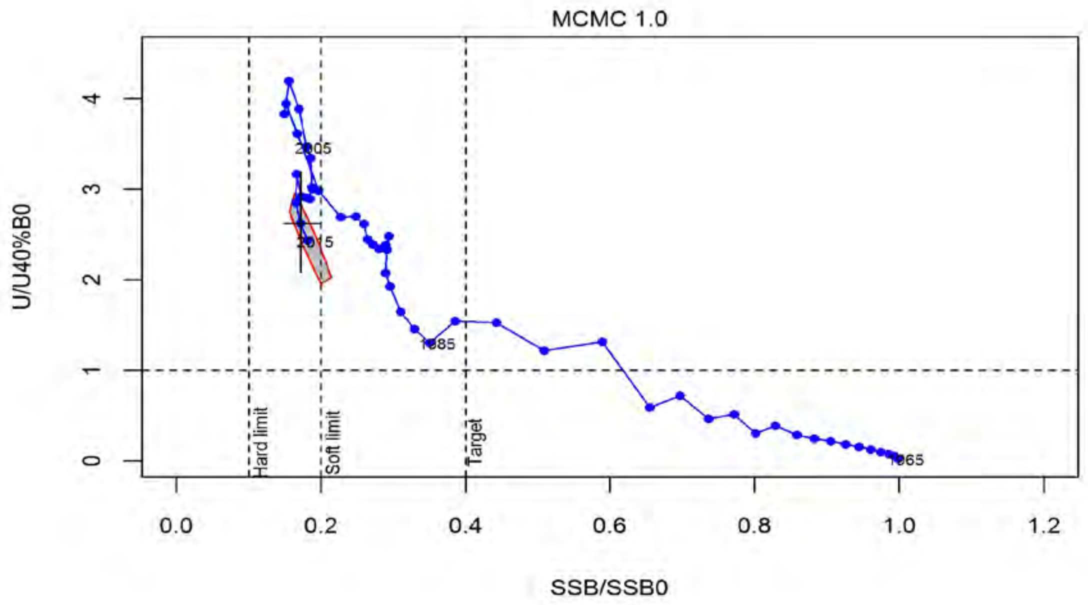
Historical Stock Status Trajectory and Current Status



Posterior distribution 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.



Posterior distributions of projected spawning stock biomass 2016–2018 for the base case (MCMC 1.0) with future recruitment resampled from model estimates 2002–2011 under six catch scenarios: 28% TACC reduction (gray), 35% TACC reduction (black), 40% TACC reduction (orange), 50% TACC reduction (green), 60% TACC reduction (blue), and 100% TACC reduction shelving (red). 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.



Trajectory of exploitation rate as a ratio of $U_{\%40B0}$ and spawning stock biomass as a ratio of B_0, from the start of assessment period 1965 to 2015 for MCMC 1.0 (base case). The vertical lines at 10%, 20% and 40% B_0 represent the soft limit, the hard limit, and the target. Estimates are based on MCMC median and the 2015 90% marginal CI is shown by the cross line, and joint CI is shown by the grey area.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass reached its lowest point in 2002–03. It has since fluctuated at or just below the soft limit.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity peaked in 2003 but has subsequently declined.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-
Projections and Prognosis	
Stock Projections or Prognosis	Three year projections indicate that spawning biomass will increase slightly, to varying degrees, under different levels of catch when future recruitment is resampled from 2002–2011 but it is Very Unlikely (< 10%) to be at or above the target by this time.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: About as Likely as Not (40–60%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Very Likely (> 90%)

Assessment Methodology & Evaluation		
Assessment Type	Full quantitative stock assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2018
Overall assessment quality rank	1 – High Quality	

Qualifying Comments
-

Fishery Interactions
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6. FOR FURTHER INFORMATION

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