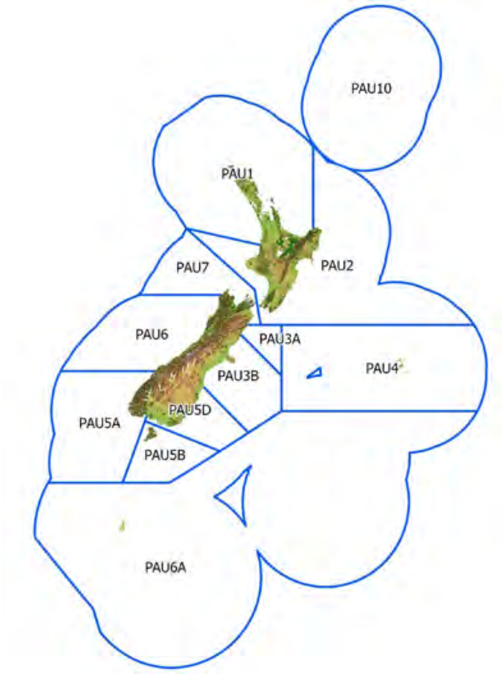
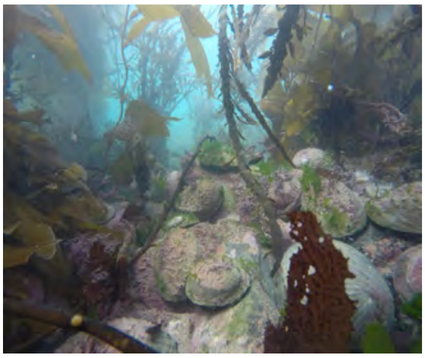
INTRODUCTION – PĀUA (PAU)

(*Haliotis iris, Haliotis australis*)





1. INTRODUCTION

Pāua are important shellfish both commercially and for non-commercial fishers. For assessment purposes, individual reports on the largest commercial fisheries have been produced separately:

1. PAU 2 – Wairarapa / Wellington / Taranaki
2. PAU 3A – Kaikoura
3. PAU 3B – Canterbury
4. PAU 4 – Chatham Islands
5. PAU 5A – Fiordland
6. PAU 5B – Stewart Island
7. PAU 5D – Southland / Otago
8. PAU 7 – Marlborough/Nelson

In 1986–87, pāua stocks were introduced into the Quota Management System (QMS) and mostQuota Management Areas (QMA) have since been managed with a total allowable catch (TAC) that is made up of total allowed commercial catch (TACC), recreational and customary catch, and other sources of mortality (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) for all pāua stocks.

Code	Description	TAC	Customary	Recreational	Other mortality	TACC
PAU 1	Auckland	–	–	–	–	1.93
PAU 2	Wairarapa / Wellington / Taranaki	–	–	–	–	121.19
PAU 3A	Kaikōura	40.5	7.5	5	5	23
PAU 3B	Canterbury	80	15	9	10	46
PAU 4	Chatham Islands	334	3	3	2	326
PAU 5A	Fiordland	–	–	–	–	148.98
PAU 5B	Stewart Island	123	7	6	3	107
PAU 5D	Southland / Otago	134	3	22	20	89
PAU 6	Challenger / Westland	–	–	–	–	1
PAU 7	Marlborough	133.62	15	15	10	93.62
PAU 10	Kermadec	–	–	–	–	1

1.1 Commercial fisheries

The commercial fishery for pāua dates from the mid-1940s. In the early years of this commercial fishery, shell was the main product but the meat was usually sold on the domestic market for paua sausages or for fish and chip market, or used as bait. However, by the late 1950s, both meat and shell were being sold. Since the 1986–87 fishing season, the Quota Management Areas have been managed with an individual transferable quota system with a TAC, allowances for recreational and customary catch, and other sources of mortality and a TACC.

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 of 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 Chatham Islands (PAU 4) and the South Island, Marlborough (PAU 7), Stewart Island (PAU 5B), and Fiordland (PAU 5A). 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*.

Concerns about the status of some stocks, or a desire to increase biomass levels to above B_{MSY}, led to the commercial fishers agreeing to voluntarily reduce their Annual Catch Entitlement (ACE). This management tool is still in place in some QMAs.

Up until the 2002 fishing year, catch was reported by general statistical areas; however, from 2002 onwards, a finer scale system of pāua specific statistical areas was put in place throughout each QMA (refer to the QMA specific Plenary chapters). The historical landings for the main PAU stocks are shown in Figure 1 (between 1986-87 and 1995–96) and Figure 2 (from 1986–87 to present). On 1 October 1995 PAU 5 was divided into three separate QMAs: PAU 5A, PAU 5B, and PAU 5D. On 1 October 2021 PAU 3 was divided into two separate QMAs: PAU 3A and PAU 3B.

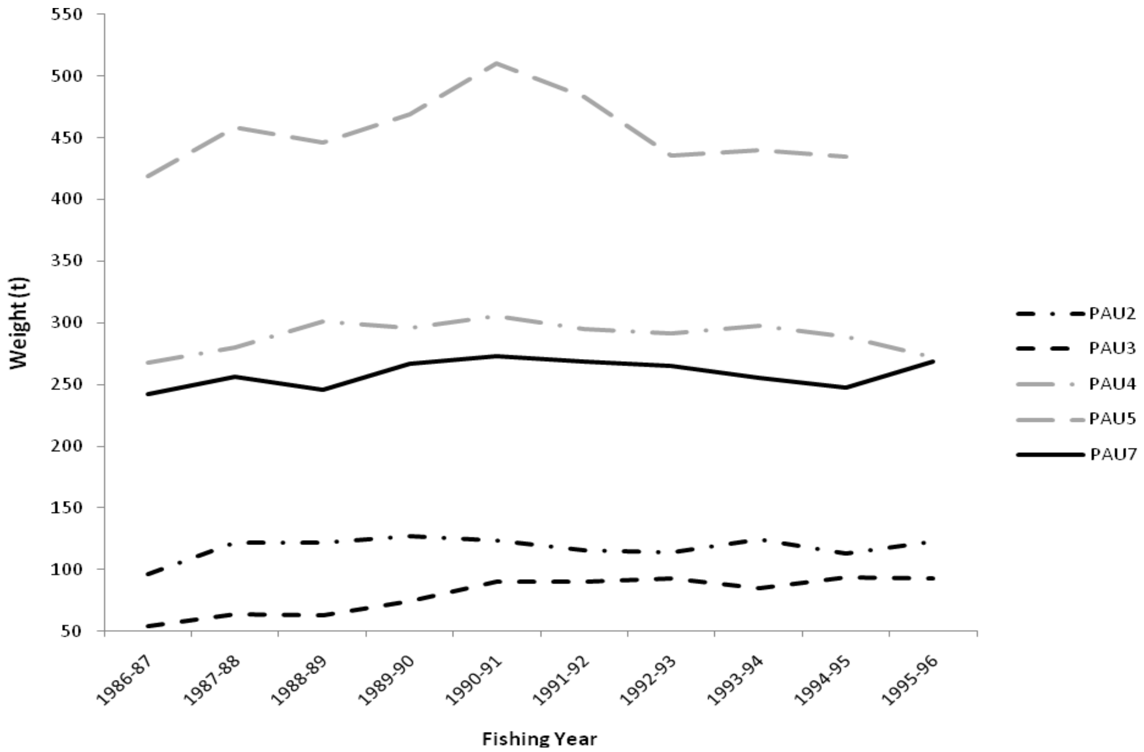


Figure 1: Historical landings for the major pāua QMAs from 1986-87 to 1995–96.

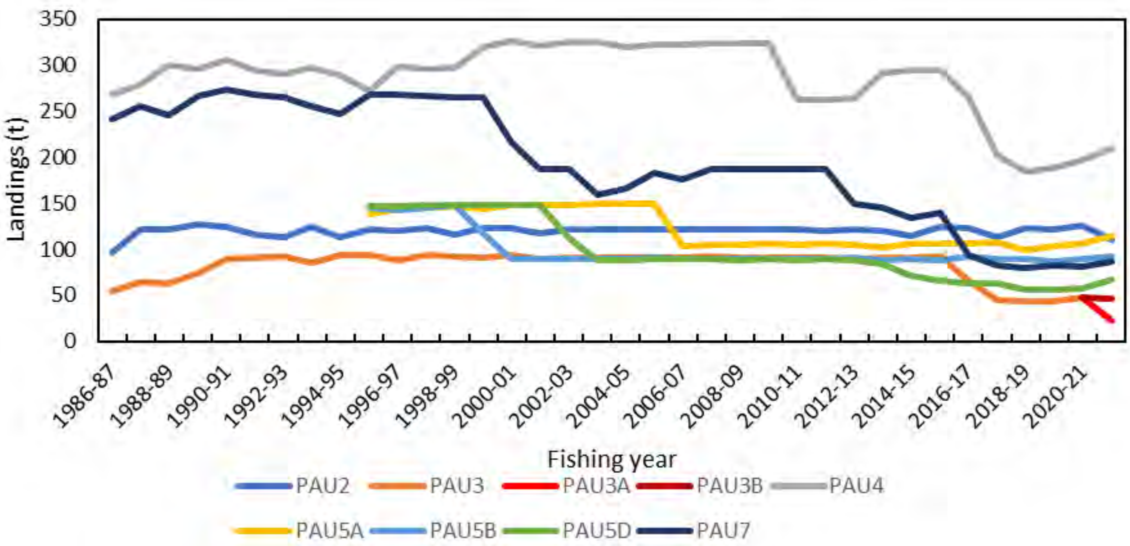


Figure 2: Historical landings for the major pāua QMAs from 1986–87 to present.

Landings for PAU 1, PAU 5 (prior to 1995), PAU 6 and PAU 10 are shown in Table 2. PAU 1 landings have been below the TACC since its introduction to the QMS in 1986–87 with an average of 0.56 t caught per year and with no landings recorded for 2017–18. Landings increased to 1.36 t in 2019–20, close to the TACC of 1.93 t and at a level not seen since 1992–93. In contrast, PAU 6 landings have been close to the TACC since the fishing year 2006–07, except in 2022-23 when there were no landings. For information on landings specific to other pāua QMAs refer to the specific chapters.

Table 2: TACCs and reported landings (t) of pāua by Fishstock from 1983–84 to present. [Continued on next page].

Fishstock	PAU 1		PAU 5		PAU 6		PAU 10	
	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
2019–20	1.36	1.93	–	–	1.00	1.00	0.00	1.00
2020–21	0.64	1.93	–	–	1.00	1.00	0.00	1.00

Table 2 [Continued]

Fishstock	PAU 1		PAU 5		PAU 6		PAU 10	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2021–22	0.93	1.93	–	–	0.99	1.00	0.00	1.00
2022–23	0.42	1.93	–	–	0.00	1.00	0.00	1.00

H experimental landings
* FSU data

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 3.

Table 3: 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.

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 national panel survey was repeated during the 2017–18 and 2022–23 fishing years using very similar methods to produce directly comparable results (Wynne-Jones et al 2019; Heinemann & Gray, in prep). Recreational catch estimates from the three national panel surveys are given in Table 4. Note that national panel survey estimates do not include recreational harvest taken on charter vessel trips or under s111 general approvals. These estimates are very uncertain for some stocks because of the small number of fishers reporting catch, and more precise estimates of recreational harvest are provided by on site approaches (e.g. PAU 3A).

Table 4: Recreational harvest estimates for pāua stocks from the national panel survey in 2011–12 (Wynne-Jones et al 2014), 2017–18 (Wynne-Jones et al 2019) and 2022–23 (Heinemann & Gray in prep). Mean weights from boat ramp surveys (Hartill & Davey 2015, Davey et al 2019; Davey et al in prep). [Continued on next page].

Stock	Fishers	Events	Number of pāua	CV	Total weight (t)	CV
2011–12 (national panel survey)						
PAU 1	39	63	43 480	0.27	12.16	0.27
PAU 2	157	376	285 038	0.15	81.63	0.15
PAU 3	35	67	60 717	0.31	16.98	0.31
PAU 5A	2	3	1 487	0.76	0.42	0.76
PAU 5B	4	4	2 729	0.54	0.76	0.54
PAU 5D	41	84	80 290	0.3	22.45	0.3
PAU 7	19	41	50 534	0.34	14.13	0.34
PAU total	284	638	524 273	0.11	148.54	0.11
2017–18 (national panel survey)						
PAU 1	26	40	26 393	0.35	8.32	0.35
PAU 2	151	365	281 472	0.15	82.7	0.15
PAU 3	21	46	28 140	0.35	8.79	0.35
PAU 5A	2	3	2 293	0.8	0.71	0.81
PAU 5B	10	21	15 361	0.45	4.88	0.45
PAU 5D	48	88	55 141	0.21	19.28	0.21
PAU 6	3	7	3 076	0.6	0.95	0.61
PAU 7	11	16	10 576	0.36	3.02	0.36
PAU total	259	586	422 452	0.11	128.65	0.11

Table 4 [Continued]

Stock	Fishers	Events	Number of pāua	CV	Total weight (t)	CV
2022–23 (national panel survey)						
PAU 1	8	14	28 178	0.87	8.12	0.87
PAU 2	72	143	114 522	0.17	33.01	0.17
PAU 3A	9	12	1 979	0.68	0.57	0.68
PAU 3B	19	23	8 277	0.33	2.39	0.33
PAU 5A	3	5	5 489	0.68	1.58	0.68
PAU 5B	12	26	11 989	0.33	3.46	0.33
PAU 5D	31	62	71 650	0.30	20.65	0.30
PAU 7	9	15	9 908	0.35	2.87	0.35
PAU total	156	300	252 001	0.16	72.66	0.16

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices. Pāua forms an important fishery for customary non-commercial, but the total annual catch is not known.

Māori customary fishers utilise the provisions under both the recreational fishing regulations and the various customary regulations. Many tangata whenua harvest pāua under their recreational allowance and these are not included in records of customary catch. Customary reporting requirements vary around the country. Customary fishing authorisations issued in the South Island and Stewart Island would be under the Fisheries (South Island Customary Fishing) Regulations 1999. Many rohe moana / areas of the coastline in the North Island and Chatham Islands are gazetted under the Fisheries (Kaimoana Customary Fishing) Regulations 1998 which require reporting on authorisations. In the areas not gazetted, customary fishing permits would be issued would be under the Fisheries (Amateur Fishing) Regulations 2013, where there is no requirement to report catch.

The information on Māori customary harvest under the provisions made for customary fishing can be limited (Table 5). These numbers are likely to be an underestimate of customary harvest as only the catch approved and harvested in kilograms and numbers are reported in the table.

Table 5: Fisheries New Zealand records of customary harvest of pāua (approved and reported as weight (kg) and in numbers), since 1998-99. – no data. [Continued on next two pages]

	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	100	100	13 698	6 877
2017–18	15	15	4 632	3 162	–	–	6 960	1 942
2018–19	–	–	1 368	710	–	–	8 585	3 189
2019–20	60	20	120	115	–	–	–	–
2020–21	40	0	375	176	–	–	–	–
2021–22	40	40	–	–	–	–	–	–
2022–23	–	–	–	–	–	–	–	–

	PAU 3*				PAU 3A			
	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	–	–	6 239	4 832	–	–	–	–

Table 5 [Continued]:

	PAU 3*				PAU 3A			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**	**Approved**	**Harvested**	**Approved**	**Harvested**
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	–	–	–	–
2015–16	–	–	14 801	11 808	–	–	–	–
2016–17	–	–	11 374	9 217	–	–	–	–
2017–18	–	–	2 708	1 725	–	–	–	–
2018–19	–	–	480	278	–	–	–	–
2019–20	–	–	30 288	21 527	–	–	–	–
2020–21	–	–	11 462	8 609	–	–	–	–
2021–22	–	–	–	–	–	–	9 228	7 905
2022–23	–	–	–	–	–	–	–	–

	PAU 3B				PAU 4			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	**Approved**	**Harvested**	**Approved**	**Harvested**	**Approved**	**Harvested**	**Approved**	**Harvested**
1998–99	–	–	–	–	–	–	–	–
1999–00	–	–	–	–	–	–	–	–
2000–01	–	–	–	–	–	–	–	–
2001–02	–	–	–	–	–	–	–	–
2002–03	–	–	–	–	–	–	–	–
2003–04	–	–	–	–	–	–	–	–
2004–05	–	–	–	–	–	–	–	–
2005–06	–	–	–	–	–	–	–	–
2006–07	–	–	–	–	–	–	–	–
2007–08	–	–	–	–	–	–	–	–
2008–09	–	–	–	–	–	–	–	–
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	–	–	–	–	53	85	820	764
2018–19	–	–	–	–	330	330	–	–
2019–20	–	–	–	–	–	–	–	–
2020–21	–	–	–	–	–	–	–	–
2021–22	–	–	6 041	4 013	–	–	–	–
2022–23	–	–	2 160	1 086	–	–	–	–

	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

Table 5 [Continued]:

	PAU 5A				PAU 5B			
	Weight (kg)		Numbers		Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested	Approved	Harvested	Approved	Harvested
2019–20	–	–	–	–	–	–	835	815
2020–21	–	–	850	820	–	–	2 645	2 495
2021–22	–	–	–	–	–	–	70	70
2022–23	–	–	–	–	–	–	–	–

	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	–	–	–	–
2019–20	–	–	6 905	6 439	–	–	–	–
2020–21	–	–	10 257	10 030	–	–	–	–
2021–22	–	–	1 730	1 670	–	–	–	–
2022–23	–	–	130	130	–	–	–	–

	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	–	–	–	–
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	–	–	–	–
2019–20	–	–	–	–
2020–21	–	–	–	–
2021–22	–	–	–	–
2022–23	–	–	–	–

* 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.

1.4 Illegal catch

There are 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.

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 undersized 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 undersized animals. The level of mortality for sub-legal pāua caught and returned to sea by amateur fishers is unknown.

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 & Fu (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 6. Parameters specific to individual pāua QMAs are reported in the specific Working Group report chapters.

Table 6: 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 been previously 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 on the North Island and PAU 7 on the South Island.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was updated for the 2021 Fishery Assessment Plenary. A more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021), online at https://www.mpi.govt.nz/dmsdocument/51472-Aquatic-Environment-and-Biodiversity-Annual-Review-AEBAR-2021-A-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment.

4.1 Ecosystem role

McCowan (2019) conducted a review of all relevant literature about the role of pāua in ecosystems and the environmental factors (natural and human-induced) affecting pāua distribution, abundance, and behaviour.

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, except for kina which, at very high densities, appear to exclude pāua (Naylor & Gerring 2001). 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 (Read 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 and, if they do, they will try to anchor on sand where possible). 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 pers. comm.). 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 https://www.mpi.govt.nz/biosecurity/marine-pest-disease-management/fiordland-marine-biosecurity-programme/). There is also in place an Envirosouth-developed code of practice applicable to fishing vessels to prevent unwanted pest transfers.

4.5.3 Kaikōura Earthquake

Research was undertaken to investigate the influence of the November 2016 Kaikōura earthquake on pāua stocks along 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. Annual biomass surveys have showed a recovery of the stock which has led to the reopening of the fishery in 2021–22 for 3 months. More details can be found in the PAU 3A Working Group report chapter.

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 was completed by Hurst et al (2012). There is also an updated chapter on oceanic trends in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021). Any effects of recent warmer temperatures (such as the high surface temperatures off 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 (Cummings et al 2021). 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). An evaluation of the sensitivity and exposure of pāua to climate change-associated threats, based on currently available published literature and expert opinion, assessed pāua vulnerability to climate change effects as ‘very high’ (Cummings et al 2021).

5. STOCK ASSESSMENT

The dates of the most recent survey or stock assessment for each QMA are listed in Table 7.

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 chapter.

In QMAs where quantitative stock assessments have been undertaken, standardised CPUE is 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 because it is possible to maintain high catch rates despite a falling biomass. This occurs because pāua tend to aggregate and, 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 most commercial areas because fishing in these QMAs is consistent across all fishable areas. Further, the single study of CPUE as a proxy of abundance for pāua demonstrated a near linear relationship between CPUE and available biomass, indicating it is a useful tool (Abraham & Neubauer 2015). An exception are the D’Urville Island and Northern Faces areas of PAU 7, where catches have declined substantially, and CPUE now only reflects a few remaining areas. Other areas may be highly depleted but fishery dependent CPUE does not reflect abundance in these areas any longer.

Table 7: Recent survey and stock assessment information for each pāua QMA. [Continued on next page]

QMA	Type of survey or assessment	Date	Comments
PAU 1	No surveys or assessments have been undertaken		
PAU 2	Base case: length-based Bayesian stock assessment	2021	A large proportion of PAU 2, including the Wellington south coast and west of Turakirae, is either a Marine Reserve or voluntarily closed to commercial fishing. This means that the data collected from the commercial fishery are exclusive of this large area and therefore the assessment only applies to the south east component of PAU 2 (Wairarapa), which corresponds to approximately 20% of PAU 2. Lack of contrast in catch, CPUE, and length frequency makes estimation of stock status and biomass trajectories difficult. The 2019–20 year was excluded from the PCELR CPUE series because of concerns about the comparability with previous years due to the effects of COVID-19 on export markets, and ERS reporting issues. This may continue into the future.
PAU 3A	Length based Bayesian integrated assessment	2024	The 2024 PAU 3A stock assessment used the length-based population dynamics model first described by Breen et al. (2003). Although the overall population-dynamics model remained unchanged, the 2024 assessment of the PAU 3A stock used a number of changes from previous models used in PAU 3, including that the 2024 model is spatially explicit. The high CSLF weight (highCSLFw) model without explicit earthquake impacts has been accepted as the base assessment model, noting that recent estimated recruitment was low and likely proxying for earthquake impacts in the model. The estimated stock status for the model was 46% of unfished spawning biomass and very low risk of being below limit reference points, reflecting a large rebuild of biomass post-earthquake from below target levels.
PAU 3B	CPUE Standardisation	2022	A stock assessment for the PAU 3B area was attempted in 2021–22, based on estimates of historical catches, CPUE trends and commercial length frequency data. CPUE trends were found to be stable despite steady increases in catch over the past decades.

Table 7 [Continued]:

QMA	Type of survey or assessment	Date	Comments
PAU 4	Operating model and harvest control rule	2022	From 2020 to 2023, a series of projects aimed to develop an operating model, and test management procedures that could formalise current statistical-area scale industry management initiatives. Operating models were developed as spatial length-based models at the scale of individual pāua statistical areas. Due to a lack of sufficiently reliable time series of catch and CPUE, stock assessment models could not be fitted statistically, but were conditioned on assumed catch times series. Conditioned models suggested a range of outcomes across individual statistical areas; these differences were attributed to conditioning assumptions in the model. While application of control rules led to variable outcomes at the statistical area scale, the spatial variability averaged out on the large scale, leading to highly stable trends at the QMA scale for an implementation window of 5 years, and indicating low risk of further declines under the trialed preliminary harvest control rules
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.
PAU 5D	Quantitative assessment using a Bayesian length-based model	2023	The base case model suggested a recent increase from low levels in spawning stock biomass (*SSB*) over the past seven years, following a slow downwards trend from 2010 to 2015. The base case also indicated that the stock is currently as likely as not to be at the interim target spawning stock biomass of 40% *SSB*, there is little to no probability that it is below the soft limit. 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 increasing *SSB* for scenarios of current catch, with relatively stable stock levels expected with fishing at the current TACC.
PAU 6	Biomass estimate	1996	This fishery has a TACC of 1 t.
PAU 7	Quantitative assessment using a Bayesian length-based model	2022	The SFWG agreed that the stock assessment was reliable for Cook Strait based on the available data. Currently, spawning stock biomass is estimated to be 33% B_0 and is Unlikely to be at or above the target. It is also Very Unlikely to be below the soft and hard limits. Overfishing is About as Likely as Not to be occurring.
PAU 10	No surveys or assessments have been undertaken		

In PAU 4, 5A, 5B, 5D, and 7 the relative abundance of pāua was also estimated from independent research diver surveys (RDS) for a number of years. In PAU 7, seven surveys have been completed over a number of years but only two surveys were conducted in PAU 4. In 2009 and 2010 several reviews were conducted (Cordue 2009, Haist 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, result 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.

For these reasons, RDS data are not used in any recent PAU stock assessments.

5.2 Biomass estimates

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

Biomass has been estimated, as part of the stock assessments, for PAU 2, 5A, 5B, 5D, and 7 (Table 7). Biomass surveys have been conducted in PAU 3A since 2017, following the 2016 Kaikōura earthquakes. For further information on biomass estimates specific to each pāua QMA refer to the specific Working Group report chapter.

5.3 Yield estimates and projections

Yield estimates and projections are estimated as part of the stock assessment process. Both are available for PAU 2, 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 chapter.

5.4 Other factors

In the last few years, the commercial fisheries have been implementing voluntary management actions in the commercial fished QMAs. These management actions include raising the minimum harvest size, subdividing QMAs into smaller management areas, and effort spreading through a system of 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 3A, PAU 3B, PAU 4, PAU 5A, PAU 5B, PAU 5D, and PAU 7 are given in the relevant Working Group report chapters.

7. FOR FURTHER INFORMATION

Abraham, E R; Neubauer, P (2015) Relationship between small-scale catch-per-unit-effort and abundance in New Zealand abalone (pāua, *Haliotis iris*) fisheries. PeerJ PrePrints 3:e1388v2 https://doi.org/10.7287/peerj.preprints.1388v2

Andrew, N L; Breen, P A; Naylor, J R; Kendrick, T H; Gerring, P K (2000a) Stock assessment of paua *Haliotis iris* in PAU 7 in 1998–99. *New Zealand Fisheries Assessment Report 2000/49*.

Andrew, N L; MacDiarmid, A B (1999) Sea urchin fisheries and potential interactions with a kina fishery in Fiordland. *Conservation Advisory Science Notes No. 266*. Department of Conservation, Wellington.

Andrew, N; Naylor, R (2003) Paua. *In*: Andrew, N & Francis, M (Eds)*The Living reef. The ecology of New Zealand's rocky reefs*. Craig Potton Publishing, Nelson, New Zealand.

Andrew, N L; Naylor, J R; Gerring, P; Notman, P R (2000b) Fishery independent surveys of paua (*Haliotis iris*) in PAU 5B and 5D. *New Zealand Fisheries Assessment Report 2000/3*. 21 p.

Andrew, N L; Naylor, J R; Gerring, P (2000c) A modified timed-swim method for paua stock assessment. *New Zealand Fisheries Assessment Report 2000/4*. 23 p.

Andrew, N L; Naylor, J R; Kim, S W (2002) Fishery independent surveys of the relative abundance and size-structure of paua (*Haliotis iris*) in PAU 5B and PAU 5D. *New Zealand Fisheries Assessment Report 2002/41.*

Annala, J H; Sullivan, K J; O'Brien, C; Iball, S (Comps.) (1998) Report from the Fishery Assessment Plenary, May 1998: Stock assessments and yield estimates. 409 p. (Unpublished report held by NIWA library, Wellington.)

Ayling, T; Cox, G J (1982) *Collins' guide to sea fishes of New Zealand*. Collins. Auckland. 343 p.

Boyd, R O; Gowing, L; Reilly, J L (2004) 2000–2001 national marine recreational fishing survey: diary results and harvest estimates. (Unpublished New Zealand Fisheries Assessment Research Report for the Ministry of Fisheries Project REC2000-01 held by Fisheries New Zealand, Wellington.) 92 p.

Boyd, R O; Reilly, J L (2004) 1999/2000 National Marine Recreational Fishing Survey: harvest estimates. (Unpublished New Zealand Fisheries Assessment Research Report for the Ministry of Fisheries Project REC9803 held by Fisheries New Zealand, Wellington.) 28 p.

Bradford, E (1998) Harvest estimates from the 1996 national recreational fishing surveys. New Zealand Fisheries Assessment Research Document 1998/16. 27 p. (Unpublished report held by NIWA library, Wellington.)

Breen, P A; Andrew, N L; Kendrick, T H (2000b) Stock assessment of paua (*Haliotis iris*) in PAU 5B and PAU 5D using a new length-based model. *New Zealand Fisheries Assessment Report 2000/33.*

Breen, P A; Andrew, N L; Kendrick, T H (2000c) The 2000 stock assessment of paua (*Haliotis iris*) in PAU 5B using an improved Bayesian length-based model. *New Zealand Fisheries Assessment Report 2000/48.*

Breen, P A; Andrew, N L; Kim, S W (2001) The 2001 stock assessment of paua *Haliotis iris* in PAU 7. *New Zealand Fisheries Assessment Report 2001/55.*

Breen, P A; Kim, S W (2004) The 2004 stock assessment of paua *Haliotis iris* in PAU 5A. *New Zealand Fisheries Assessment Report 2004/40.*

Breen, P A; Kim, S W (2005) The 2005 stock assessment of paua *Haliotis iris* in PAU 7. *New Zealand Fisheries Assessment Report 2005/47.*

Breen, P A; Kim, S W (2007) The 2006 stock assessment of paua (*Haliotis iris*) stocks PAU 5A (Fiordland) and PAU 5D (Otago). *New Zealand Fisheries Assessment Report 2007/09.*

Breen, P A; Smith, A N (2008a) The 2007 stock assessment of paua (*Haliotis iris*) stock PAU 5B (Stewart Island). *New Zealand Fisheries Assessment Report 2008/05.*

Breen, P A; Smith, A N (2008b) Data used in the 2007 stock assessment for paua (*Haliotis iris)* stock 5B (Stewart Island). *New Zealand Fisheries Assessment Report 2008/06.*

Capson, T L; Guinotte, J (Eds) (2014) Future proofing New Zealand's shellfish aquaculture: monitoring and adaptation to ocean acidification. *New Zealand Aquatic Environment and Biodiversity Report No. 136*. 42 p.

Carbines, G D; Beentjes, M P (2003) Relative abundance of blue cod in Dusky Sound in 2002. New *Zealand Fisheries Assessment Report 2003/37.* 25 p.

Cordue, P L (2009) Analysis of PAU 5A diver survey data and PCELR catch and effort data. SeaFic and PAUMac 5 report. 45 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Cummings, V J; Lundquist, C J; Dunn, M R; Francis, M; Horn, P; Law, C; Pinkerton, M H; Sutton, P; Tracey, D; Hansen, L; Mielbrecht, E (2021) Assessment of potential effects of climate-related changes in coastal and offshore waters on New Zealand's seafood sector. *New Zealand Aquatic Environment and Biodiversity Report No. 261*. 153 p.

Davey, N; Hartill, B; Carter, M (2019) Mean weight estimates for recreational fisheries in 2017–18. *New Zealand Fisheries Assessment Report 2019/35*. 32 p.

Davey, N K; Johnson, K S; Maggs, J Q (in prep.) Mean weight estimates for recreational fisheries in 2022-23.

Francis, R I C C (1990) A maximum likelihood stock reduction method. New Zealand Fisheries Assessment Research Document 1990/4. 8 p. (Unpublished report held by NIWA library, Wellington.)

Francis, M (2003) Snapper. *In*: Andrew, N & Francis, M (Eds), pp. 186–191, *The Living reef. The ecology of New Zealand's rocky reefs*. Craig Potton Publishing, Nelson, New Zealand.

Fisheries New Zealand (2021) Aquatic Environment and Biodiversity Annual Review 2021. Compiled by the Aquatic Environment Team, Fisheries Science and Information, Fisheries New Zealand, Wellington, New Zealand. 779 p.

Gerring, P K (2003) Incidental fishing mortality of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2003/56*. 13 p.

Haist, V (2010) Paua research diver survey: review of data collected and simulation study of survey method. *New Zealand Fisheries Assessment Report 2010/38.*

Hartill, B; Davey, N (2015) Mean weight estimates for recreational fisheries in 2011–12. *New Zealand Fisheries Assessment Report 2015/25*.

Heinemann A; Gray, A. (in prep.) National Panel Survey of Recreational Marine Fishers 2022-23.

Hurst, R J; Renwick, J A; Sutton, P J H; Uddstrom, M J; Kennan, S C; Law, C S; Rickard, G J; Korpela, A; Stewart, C; Evans, J (2012) Climate and ocean trends of potential relevance to fisheries in the New Zealand region. *New Zealand Aquatic Environment and Biodiversity Report No. 90*. 202 p.

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

McCardle, I (1983) Young paua in peril. *Shellfisheries Newsletter 20*.

McCowan, T (2019) Ecosystem approaches to management of pāua fisheries: Review and considerations. https://www.paua.org.nz/_files/ugd/bcdcbd_93a4486463094b64ab28af95d4603938.pdf?index=true

McShane, P E (1992) Paua fishery assessment 1992. New Zealand Fisheries Assessment Research Document 1992/3. 26 p. (Unpublished report held by NIWA library, Wellington.)

McShane, P E (1996) Patch dynamics and effects of exploitation on abalone (*Haliotis iris*) populations. *Fisheries Research 25*: 191–199.

McShane, P E; Mercer, S; Naylor, R (1993) Paua (*Haliotis* spp.) fishery assessment 1993. New Zealand Fisheries Assessment Research Document 1993/6. 22 p. (Unpublished report held by NIWA library, Wellington.)

McShane, P E; Mercer, S F; Naylor, J R; Notman, P R (1994a) Paua fishery assessment 1994. New Zealand Fisheries Assessment Research Document 1994/16. 47 p. (Unpublished report held by NIWA library, Wellington.)

McShane, P E; Mercer, S F; Naylor, J R (1994b) Spatial variation and commercial fishing of New Zealand abalone (*Haliotis iris* and *H. australis*). *New Zealand Journal of Marine and Freshwater Research 28*: 345–355.

McShane, P E; Mercer, S F; Naylor, J R; Notman, P R (1996) Paua (*Haliotis iris*) fishery assessment in PAU 5, 6, and 7. New Zealand Fisheries Assessment Research Document. 1996/11. (Unpublished report held by NIWA library, Wellington.)

McShane, P E; Naylor, J R (1995) Small-scale spatial variation in growth, size at maturity, and yield- and egg-per-recruit relations in the New Zealand abalone *Haliotis iris*. *New Zealand Journal of Marine and Freshwater Research 29*: 603–612.

McShane, P E; Schiel, D R; Mercer, S F; Murray, T (1994c) Morphometric variation in *Haliotis iris* (Mollusca:Gastropoda): analysis of 61 populations. *New Zealand Journal of Marine and Freshwater Research 28*: 357–364.

Miller, K J; Maynard, B T; Mundy, C N (2009) Genetic diversity and gene flow in collapsed and healthy abalone fisheries. *Molecular Ecology 18(2)*: 200–211.

Naylor, J R; Andrew, N L (2000) Determination of growth, size composition, and fecundity of paua at Taranaki and Banks Peninsula. *New Zealand Fisheries Assessment Report 2000/51.*

Naylor, J R; Andrew, N L (2002) Determination of paua growth in PAU 2, 5A, 5B, and 5D. *New Zealand Fisheries Assessment Report 2002/34.*

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.*

Naylor, J R; Andrew, N L; Kim, S W (2006) Demographic variation in the New Zealand abalone *Haliotis iris*. *Marine and Freshwater Research 57*: 215–224.

Naylor, J R; Fu, D (2016). Estimating growth in paua. *New Zealand Fisheries Assessment Report 2016/14*. 76 p.

Naylor, J R; Gerring, P (2001) Interaction between paua and kina. *Water & Atmosphere 9(2)*: 16–17.

Naylor, J R; Kim, S W (2004) Fishery independent surveys of the relative abundance and size-structure of paua *Haliotis iris* in PAU 5D. *New Zealand Fisheries Assessment Report 2004/48*.

Naylor, J R; Notman, P R; Mercer, S F; Gerring, P (1998) Paua (*Haliotis iris*) fishery assessment in PAU 5, 6, and 7. New Zealand Fisheries Assessment Research Document. 1998/05. (Unpublished report held by NIWA library, Wellington.)

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.

Read, G B (compiler) (2004) Guide to New Zealand Shell Polychaetes. https://niwa.co.nz/oceans/resources/marine-identification-guides-and-fact-sheets

Russell, B C (1983) The food and feeding habits of rocky reef fish of north-eastern New Zealand. *New Zealand Journal of Marine and Freshwater Research 17 (2)*: 121–145.

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

Schwarz, A; Taylor, R; Hewitt, J; Phillips, N; Shima, J; Cole, R; Budd, R (2006) Impacts of terrestrial runoff on the biodiversity of rocky reefs. *New Zealand Aquatic Environment and Biodiversity Report No 7*. 109 p.

Sutton, P J H; Bowen, M (2019) Ocean temperature change around New Zealand over the last 36 years. *New Zealand Journal of Marine & Freshwater Research 53(3)*: 305–326. doi: 10.1080/0028830.2018.1562945.

Teirney, L D; Kilner, A R; Millar, R E; Bradford, E; Bell, J D (1997) Estimation of recreational catch from 1991/92 to 1993/94. New Zealand Fisheries Assessment Research Document 1997/15. 43 p. (Unpublished report held by NIWA library, Wellington.)

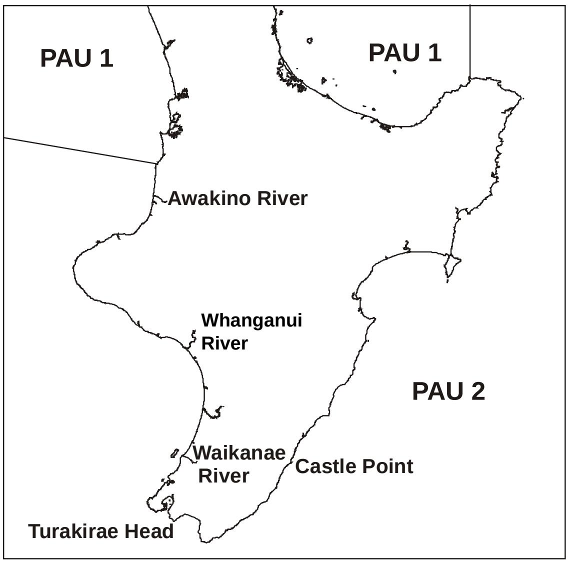
Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. New Zealand Fisheries Research Report. GEN2007A: 37 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

Wynne-Jones,J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67.* 139 p.

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. On 1 October 2023, a TAC of 192.19 t was set with a TACC of 121.19 t, a customary allowance of 12 t, a recreational allowance of 48 t and and an allowance of 11 t for other sources of 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 2 since introduction to the Quota Management System (QMS).

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1989	–	–	–	–	100
1989–2023	–	–	–	–	121.19
2023- present	192.19	12	48	11	121.19

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. Most of the commercial catch comes from the Wairarapa and Wellington South coasts between Castlepoint and Turakirae Head. The western areas between Tirua Point and the Whanganui River, and Turakirae Head and the Waikanae River, and the eastern area between Cape Runaway and Blackhead Lighthouse are 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. Landings have been at or very close to the TACC since 1988–89.

1.2 Recreational fisheries

The most recent recreational fishery survey "The National Panel Survey of Marine Recreational Fishers 2022–23: Harvest Estimates" Heinemann & Gray (in prep), estimated that about 33 t of pāua were harvested by recreational fishers in PAU 2 in 2022–23.

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.

In September 2023, the recreational daily bag limit for pāua in PAU 2 was reduced from 10 yellowfoot pāua and 10 blackfoot pāua per fisher per day to 5 of each species per fisher, per day.

For further information on recreational fisheries refer to the Introduction – Pāua chapter.

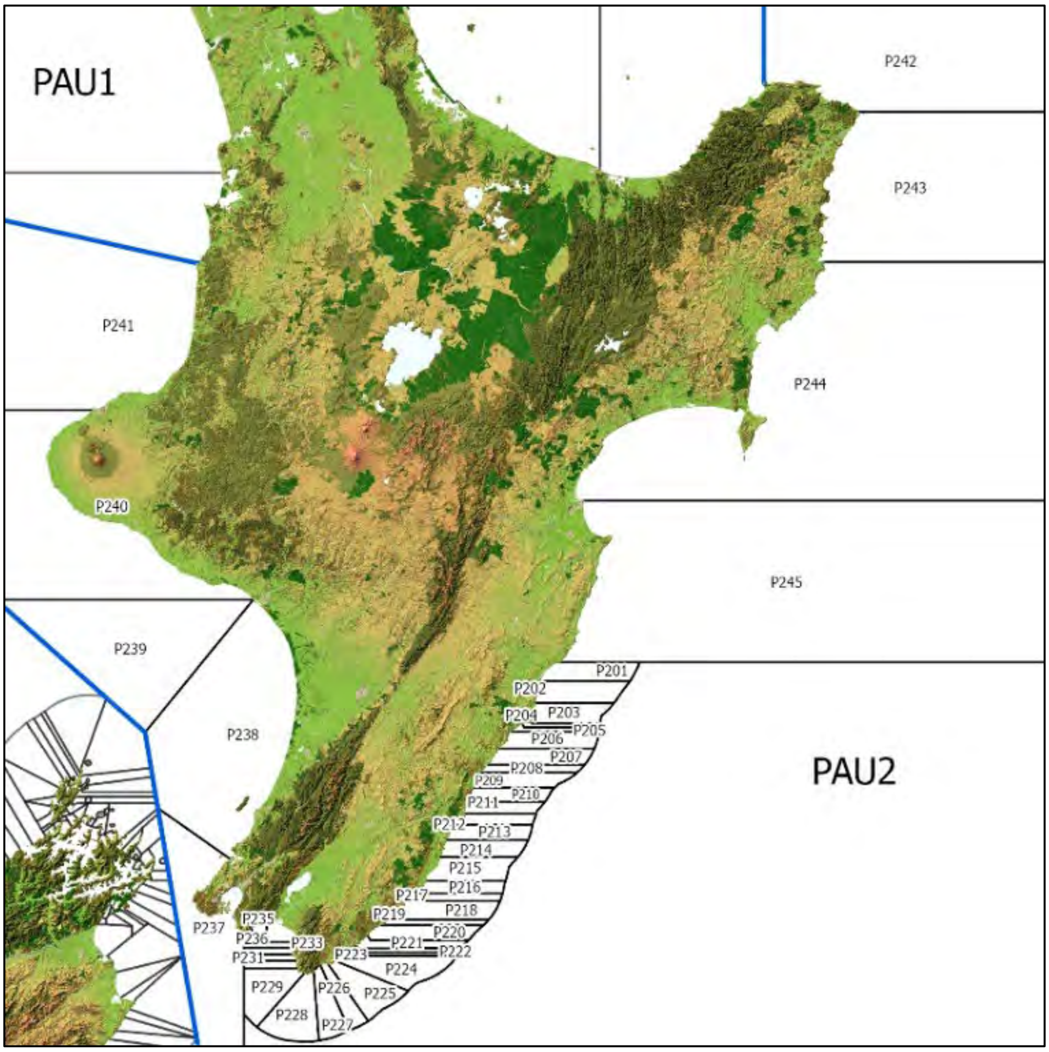


Figure 1: Map of fine-scale statistical reporting areas for PAU 2.

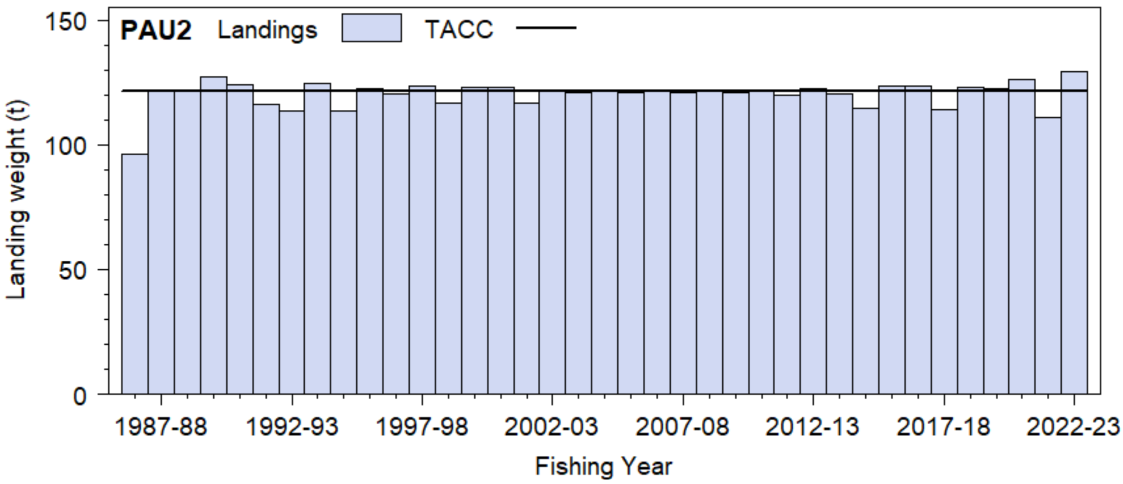


Figure 2: Historical landings and TACC for PAU 2 from 1983–84 to the present. QMS data from 1986 to present.

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

Fishing year	Landings	TACC	Fishing year	Landings	TACC
1983–84*	110	–	2003–04	121.06	121.19
1984–85*	154	–	2004–05	121.19	121.19
1985–86*	92	–	2005–06	121.14	121.19
1986–87*	96.2	100	2006–07	121.20	121.19
1987–88*	122.11	111.33	2007–08	121.06	121.19
1988–89*	121.5	120.12	2008–09	121.18	121.19
1989–90	127.28	121.19	2009–10	121.13	121.19
1990–91	125.82	121.19	2010–11	121.18	121.19
1991–92	116.66	121.19	2011–12	120.01	121.19
1992–93	119.13	121.19	2012–13	122.00	121.19
1993–94	125.22	121.19	2013–14	120.00	121.19
1994–95	113.28	121.19	2014–15	115.00	121.19
1995–96	119.75	121.19	2015–16	123.74	121.19
1996–97	118.86	121.19	2016–17	123.69	121.19
1997–98	122.41	121.19	2017–18	113.87	121.19
1998–99	115.22	121.19	2018–19	122.89	121.19
1999–00	122.48	121.19	2019–20	122.28	121.19
2000–01	122.92	121.19	2020–21	126.26	121.19
2001–02	116.87	121.19	2021–22	110.91	121.19
2002–03	121.19	121.19	2022–23	129.39	121.19

* FSU data.

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

Estimates of customary catch for PAU 2 are given 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. In addition, many tangata whenua also harvest pāua under their recreational allowance and these are not included in records of customary catch.

Table 3: Fisheries New Zealand records of customary harvest of pāua (approved and reported as weight (kg) and in numbers) in PAU 2 since 1998-99 (no reports since 2018-19). – no data.

	Weight (kg)		Numbers	
Fishing year	Approved	Harvested	Approved	Harvested
1998–99	40	40	–	–
1999–00	–	–	1 400	820
2000–01	–	–	–	–
2001–02	–	–	–	–
2002–03	–	–	–	–
2003–04	–	–	4 805	4 685
2004–05	–	–	2 780	2 440
2005–06	–	–	5 349	4 385
2006–07	–	–	7 088	3 446
2007–08	–	–	11 298	6 164
2008–09	–	–	30 312	24 155
2009–10	–	–	5 505	4 087
2010–11	–	–	20 570	17 062
2011–12	243	243	29 759	23 932
2012–13	10	6	51 275	27 653
2013–14	–	–	61 486	30 129
2014–15	–	–	25 215	16 449
2015–16	–	–	11 540	6 383
2016–17	100	100	13 698	6 877
2017–18	–	–	6 960	1 942
2018–19	–	–	8 585	3 189
2019–20	–	–	–	–
2020–21	–	–	–	–
2021–22	–	–	–	–
2022–23	–	–	–	–

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 Introduction – Pāua chapter.

1.5 Other sources of mortality

For further information on other sources of mortality refer to the Introduction – Pāua chapter.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter. A summary of published estimates of biological parameters for PAU 2 is presented in Table 4.

Table 4: 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)
Meta-analysis for fished areas (all QMAs)	50% mature		90.5 mm	Neubauer & Tremblay-Boyer (2019a)
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	
Assessment fit for commercially fished area	G_{75}		14.01 mm (SE 1.36mm)	Neubauer (2022b)
	G_{125}		2.00 mm (SE 0.30 mm)	

3. STOCKS AND AREAS

For further information on stocks and areas refer to the Introduction – Pāua chapter.

4. STOCK ASSESSMENT

In 2020, the Shellfish Fisheries Assessment Working Group evaluated the overall CPUE trend and concluded (given experience with other QMAs) that the data were potentially sufficient to conduct a full length-based stock assessment in line with those run for other QMAs (e.g., Neubauer & Tremblay-Boyer 2019b, Neubauer 2022). However, the Fisheries Assessment Plenary considered the stock assessment results to be insufficiently robust given concerns about the choice of the base-case scenario and sensitivities, and issues with use of the early CPUE data (i.e., FSU and CELR data). Concerns were also raised about the validity of region-wide CPUE and Catch Sampling Length-Frequency (CSLF) trends given the fine-scale stock structure of pāua. An updated model addressing concerns raised in the 2020 plenary was presented to plenary in May 2021, including updated data to the 2020 fishing year.

4.1 Relative abundance estimates from standardised CPUE analyses

A combined series of standardised CPUE indices CELR (1990–2001) data and PCELR (2002–2020) data was considered for the 2021 stock assessment. However, the Plenary concluded that the CELR analysis was unlikely to represent biomass trends and also that the 2019–2020 PCELR data were likely to be inconsistent with earlier years in the series, because of COVID-19 effects on export markets and Electronic Reporting System (ERS) reporting issues, and should therefore be excluded.

There was little evidence in the data for serial depletion at statutory reporting scales; all main areas (i.e., excluding sporadically fished northern areas) were fished consistently throughout the time series (Figure 3).

CPUE standardisation was carried out using Bayesian Generalised Linear Mixed Models (GLMM) which partitioned variation among fixed (research strata) and random variables. CPUE was defined as the log of daily catch within a statistical area. Variables in the model were fishing year, estimated fishing effort, client number, research stratum, dive condition, diver ID (PCELR), and fine-scale statistical area.

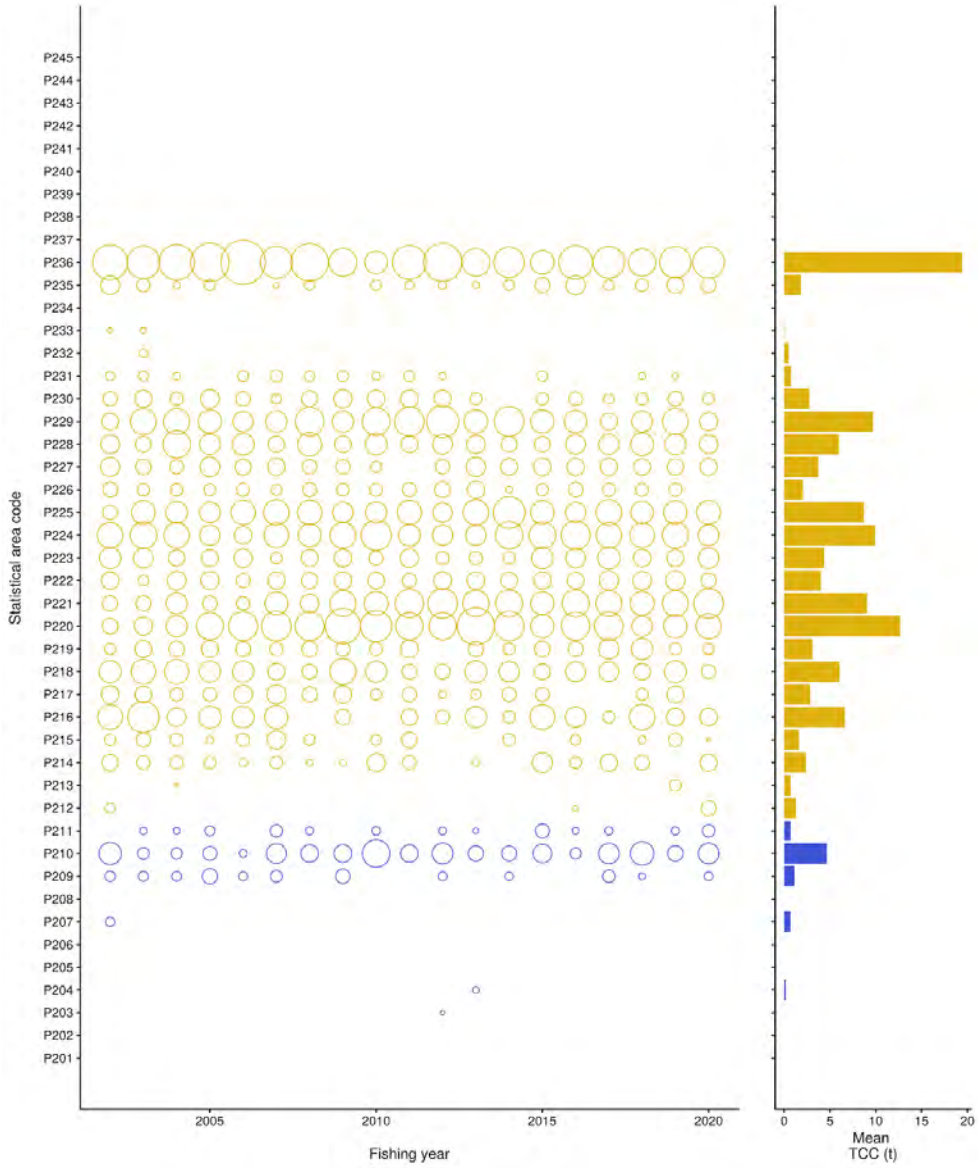


Figure 3: Relative trend in pāua catch (kg) over time by statistical areas in quota management area PAU 2 for the period from 2002 to 2020, with mean commercial catch over the same time period (right-hand side). Statistical areas used for the stock assessment within PAU 2 are colour-coded as gold for Statistical Areas 015 & 016 and blue for the northern Statistical Area 014; the latter area is small and less consistently fished, and was excluded from the stock assessment (but included in CPUE analyses).

Following recommendations from the 2020 plenary, the 2021 CPUE analysis introduced a client experience effect, estimated as a smoothing spline across years that individual clients (usually referring to ACE-holders/boat-owners) had been active in the fishery. The latter was determined across CELR and PCELR data. This effect was found to have a large influence on the CPUE index for CELR data, and the plenary chose not to retain this index because it is unclear to what degree changes in abundance and changes in the fishery at the time are confounded, and in how far the standardisation model can correct for the latter, even in the presence of an experience effect (this effect may itself be confounded with trends in biomass).

For the retained PCELR index, changes over time in ACE-holders present in the fishery had the strongest influence on CPUE (Figure 4). An initial decline was evident from the early part of the PCELR time series, with relatively stable but fluctuating CPUE since 2007 (Figure 5). 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 between areas to maximise their catch rates. The apparent stability in the CPUE should therefore be interpreted with caution.

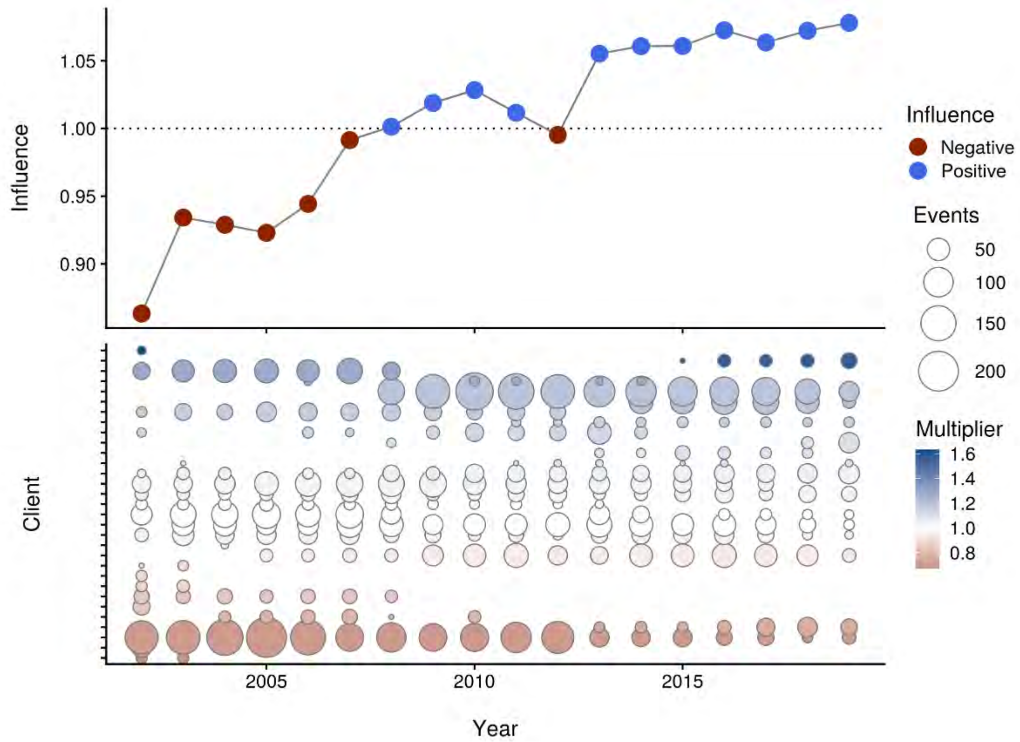


Figure 4: Influence of client number (usually ACE holders) turnover on the PCELR CPUE index through time. A positive influence for any given year suggests that the raw CPUE is inflated because most effort came from clients with higher catch rates in the fishery.

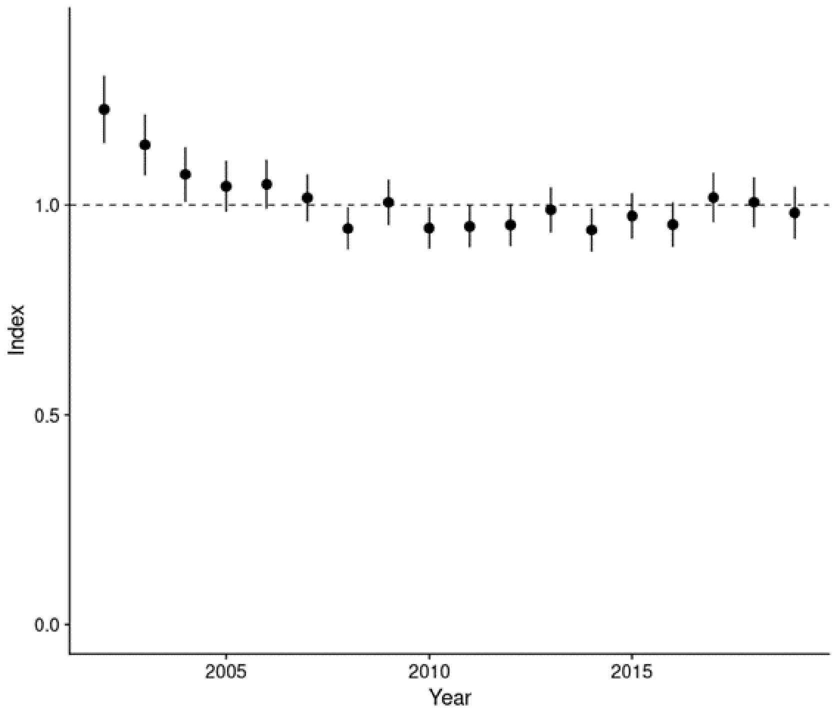


Figure 5: Standardised CPUE index for PCELR data, with posterior mean and standard errors.

4.2 Stock assessment methods

The 2021 stock assessment for PAU 2 used an updated version of the length-based population dynamics model described by Breen et al (2003), catch and commercial length-frequency data up to the 2019–20 fishing year, as well as the above-mentioned CPUE index for fishing years 2002–2019 (Neubauer 2020). Although the overall population dynamics model remained unchanged from Breen et al (2003), the PAU 2 stock assessment incorporates changes to the previous methodology first introduced in the 2018 assessment of PAU 5D (Neubauer & Tremblay-Boyer 2019b). In addition, illegal and recreational catch were, for the first time, split from commercial catch, and illegal catch was modeled as taking pāua in proportion to abundance rather than according to commercial selectivity.

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 2022) was also tried in 2019. The latter provided near identical results to the non-spatial model and was not pursued in 2021.

Growth was length-based, without reference to age, mediated through an estimated growth transition matrix that describes the probability of each length class to change at each time step. A growth prior was formulated from a meta-analysis of pāua growth across fished areas in New Zealand (Neubauer & Tremblay-Boyer 2019a), and the functional form of the resulting growth was encoded in a multivariate normal (Gaussian process) prior on the growth transition matrix. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

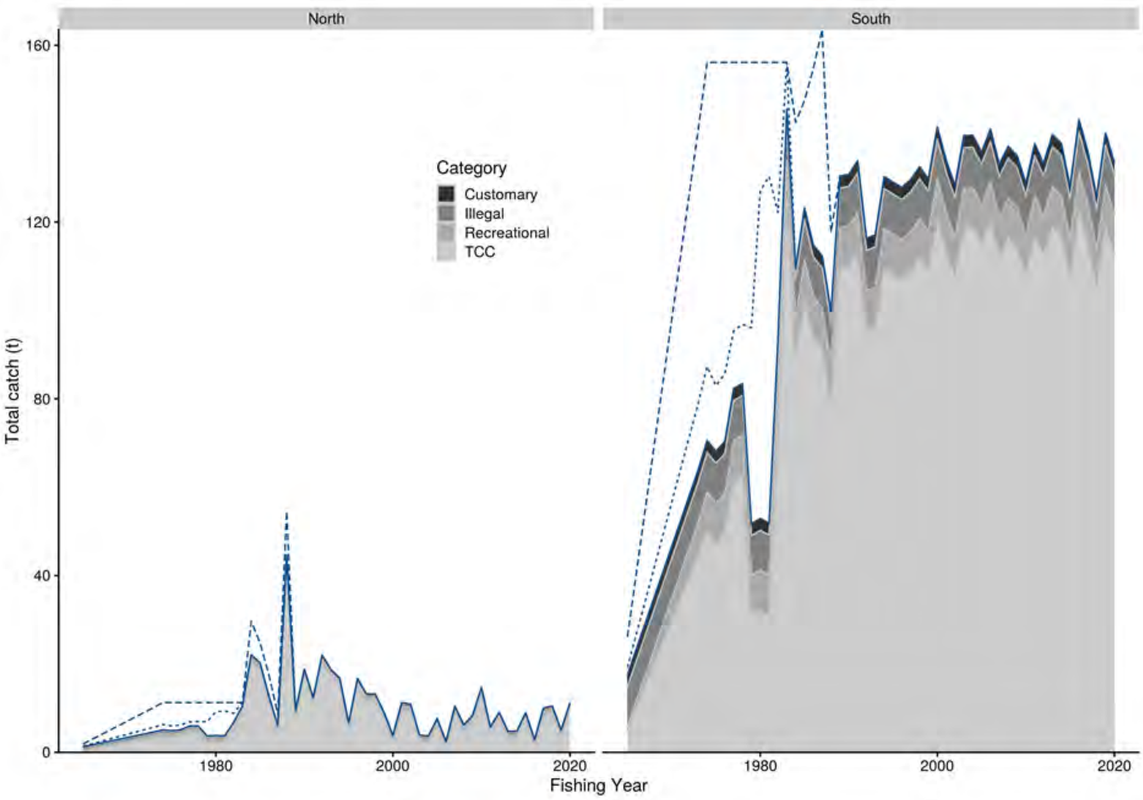


Figure 6: Assumed catch histories for southern (gold circles in Figure 3) and northern (blue circles in Figure 3) statistical areas. Grey shading indicates components of the total catch, with the dotted line showing the base case assumption of total catch, including unreported catches prior to QMS entry of PAU 2, and the dashed line showing a sensitivity with high assumed pre-QMS catches. The reported catches (grey area only) were taken as a second sensitivity.

The model simulates the population from 1965 to 2020. Catches were available for 1974–2020, though catches before 1990 are considered highly uncertain. Interviews with divers at the time suggested that misreporting was prevalent in early years preceding the Quota Management System (i.e., before 1986), and that a considerable amount of catch was unreported at the time. Three different catch levels were tried to account for this uncertainty in the assessment, and catches were assumed to increase linearly from 0 in 1965 to the 1974 catch level (Figure 6). Catches included commercial, recreational, customary, and illegal catch, and all catches occurred within the same time step. Illegal catch was assumed to be constant at 10 t for the commercially fished area (South Wairarapa), whereas recreational catch increased from the start of the fishery to 1974 and remained at 10 t for the remainder of the time series.

Recruitment was assumed to take place at the beginning of the annual cycle, with recruitment deviates estimated from 2000 to 2017, and length-at-recruitment was defined by a uniform distribution with a range between 70 and 80 mm. Natural mortality was fixed at 0.11, with sensitivities at 0.06 and 0.16 bracketing *a priori* assumptions about natural mortality. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve, with increases in recent years due to changes in the minimum harvest size in some areas. Models with variable (random effect) selectivity were also tried, and though they improved fits to commercial length frequency data, they did not markedly change the overall assessment of biomass trends. 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 5, PAU 7), and relative fits for CPUE and CSLF data were examined, based on model fits and residuals.

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 2019 (SSB_{2019} and B^{Avail}_{Proj}) and for the projection ($Proj$) period (SSB_{Proj} and B^{Avail}_{proj}). This assessment also reports the following fishery indicators:

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_{2019} > 40% SSB_0)	Probability that the spawning stock biomass in 2019 was greater than 40% of the unfished spawning stock
P(SSB_{2019} > 20% SSB_0)	Probability that the spawning stock biomass in 2019 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

4.2.1 Estimated parameters

Parameters estimated in the assessment model and their assumed Bayesian priors are summarized in Table 4.

Table 4: A summary of key model parameters, lower bound, upper bound, type of prior, (U, uniform; N, normal; LN = lognormal; Beta = beta distribution), and mean and standard deviation of the prior.

				Bounds	
Parameter	**Prior**	**μ**	**sd**	**Lower**	**Upper**
ln(R_0)	LN	14	10		
ln(q)	LN	-14	100		
M	fixed	0.11		0.06	0.16
Steepness (h)	Beta	0.8	0.17	0	1
Growth	MVN	From Neubauer & Tremblay-Boyer (2019)			
D_{50} (Length at 50% selectivity for recreational and commercial catch before adjustments for commercial minimum harvest size)	LN	125	6.25	100	145
D_{95-50} (Length between 50% and 95% selectivity the commercial catch)	LN	5.6	3	0.01	50
$ln(\epsilon)$ (Recruitment deviations; 2000-2017)	LN	0	0.4		-

The observational data were:

- A standardised CPUE series covering 2002–2019 based on PCELR data.

- Commercial catch sampling length frequency from 2006 to 2020
- Catches were assumed known at three levels

4.3 Stock assessment results

The base model with *M*=0.11 and estimated growth gave a relatively good fit to CPUE and CSLF data, although the first year of PCELR CPUE was not fitted well by this model or any sensitivities. This lack of fit is due to constraints on recruitment deviations that were estimated from 2000, given LF data are available in sufficient numbers since 2006. Since recruitment into the model occurs between 70 and 80 mm (assumed to be 3 year olds), these individuals would only appear in the commercial data as about 6 year olds, and recruitment would likely need to be freed up back to 1996 to fit these points. Fits to recent CSLF data (2019, 2020) were also slightly worse than for other years, potentially due to changes in markets and resulting selectivity. Model sensitivities with low *M* (0.06) fitted CSLF data poorly, and estimated very slow growth, indicating that this assumption is not consistent with data and assumptions about growth in fished areas.

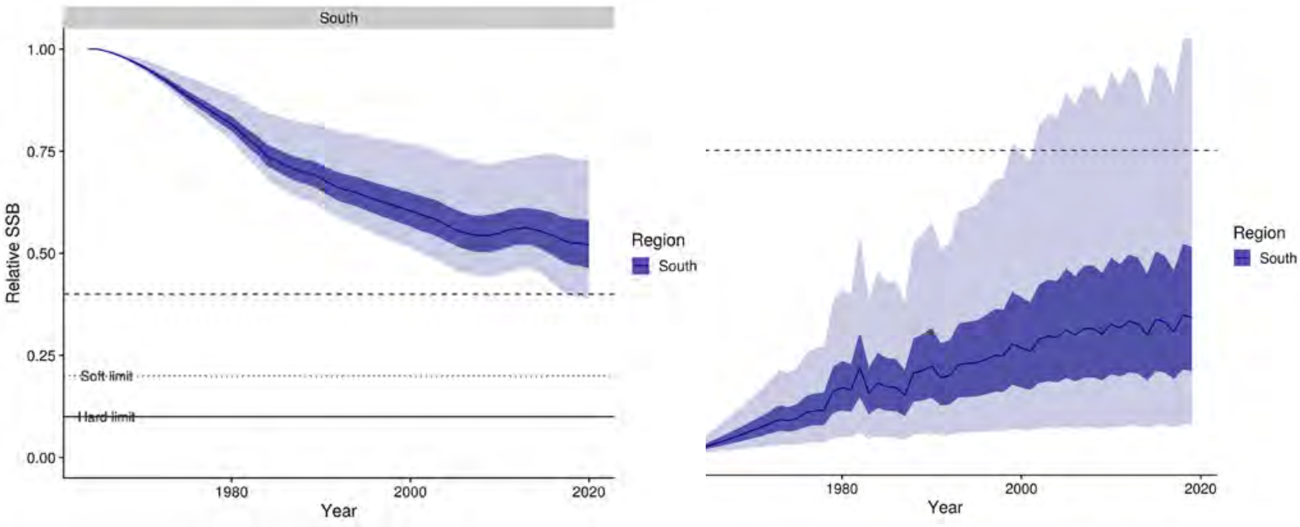


Figure 7: Posterior distributions of relative spawning stock biomass (*SSB*, left panel) and trends in relative commercial exploitation rate (right panel) in the base case model. Exploitation rate (*U*) is relative to the exploitation rate that would result in a stock depletion to 40% of unfished spawning biomass (U_{40}). The dark purple line shows the median of the posterior distribution, the 25th and 75th percentiles are shown as dark ribbons, with light ribbons representing the 95% confidence range of the distribution.

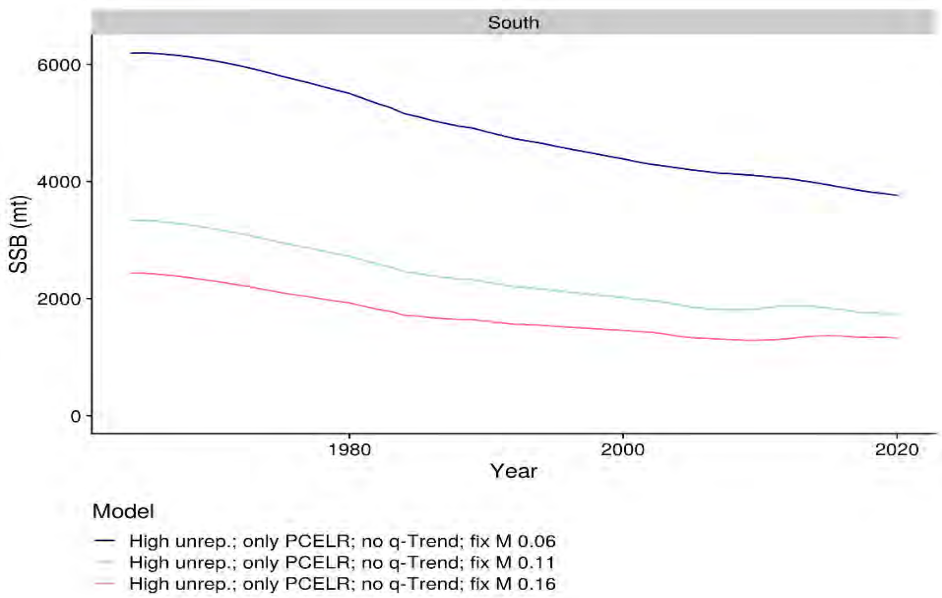


Figure 8: Posterior median of spawning stock biomass (*SSB*; left panel) from model with different levels of natural mortality.

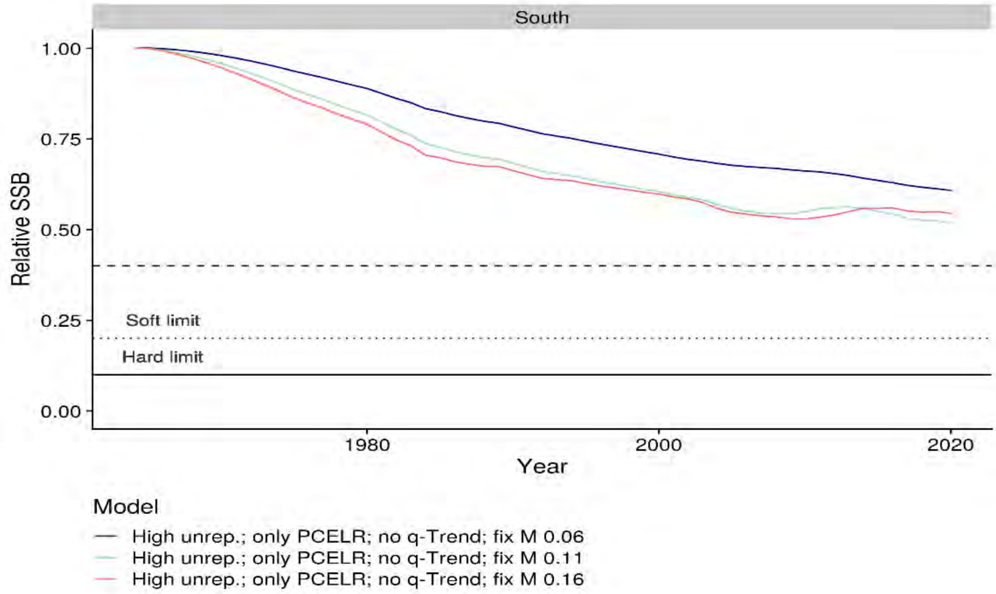


Figure 9: Posterior median of relative spawning stock biomass (SSB; left panel) from model with different levels of natural mortality.

Table 5: 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 mean relative to *SSB*, the posterior mean 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 (TACC at 121 t). Other projection scenarios show 20% catch reduction to 97 t and a 20% TACC increase (145 t).

TACC (t)	Year	P(SSB_{Proj} > 40% SSB_0)	P(SSB_{Proj} > 20% SSB_0)	P(SSB_{Proj} > SSB_{2020})	Median rel. SSB_{Proj}	Median rel. B_{Proj}^{Avail}	P(U > $U_{40\%\ SSB0}$)
97	2021	0.96	1	0.04	0.53	0.37	0.04
	2022	0.96	1	0.27	0.53	0.37	0.04
	2023	0.96	1	0.44	0.54	0.38	0.04
	2024	0.96	1	0.54	0.54	0.38	0.03
	2025	0.96	1	0.57	0.55	0.39	0.03
121	2021	0.96	1	0.04	0.53	0.37	0.08
	2022	0.95	1	0.13	0.53	0.37	0.08
	2023	0.94	1	0.22	0.53	0.36	0.09
	2024	0.93	1	0.28	0.53	0.36	0.09
	2025	0.92	1	0.32	0.53	0.36	0.09
145	2021	0.96	1	0.04	0.53	0.37	0.14
	2022	0.94	1	0.05	0.52	0.36	0.16
	2023	0.92	1	0.11	0.52	0.35	0.19
	2024	0.89	1	0.14	0.51	0.34	0.21
	2025	0.86	1	0.15	0.5	0.33	0.23

The base model estimated a steady reduction in spawning biomass from the beginning of the fishing history (assumed to be 1965) to the mid-2000s (Figure 7), with a relatively steady biomass since, reflecting the relatively stable CPUE (Figure 5) and catch (Figure 6) since then. The model estimates that the stock stabilised near 50% of the unfished spawning biomass, with a relatively stable recent exploitation rate (Figure 8).

Alternative models investigated uncertainty in *M*. These models differed in the estimated growth, with the low-*M* model estimating very slow growth to fit commercial length frequency data. As a consequence, the model estimates much higher biomass than at higher *M* to sustain observed catches at stable CPUE. Despite these differences, all models suggest that current stock status is above the target of 40% of unfished biomass. Projections for the base case model suggest unchanged biomass at current exploitation levels (121 t of commercial catch, Table 5).

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 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 2 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 2 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 1990. The model assumes that catches were higher than those reported for the early period of the fishery (1980s) to account for large discrepancy between export and reported catch by QMA. 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 very poorly determined and could be substantially different from what was assumed.

The model treats the whole of the assessed area of PAU 2 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 trialed in 2019 showed near identical trends to the single area model, and variation in growth is likely addressed to some extent by having a stochastic growth transition matrix; 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 imprecise at a local scale. For instance, if some local stocks are fished very hard and others not fished, recruitment failure can result because of the depletion of spawners, because spawners must breed close to each other, and 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.

4.5 Future research considerations

The Plenary considered that the stock assessment model was promising, but that it needed extra work before it could be accepted. Accordingly, the following research considerations are split into those that should be implemented using existing data, and those related to longer term considerations (most of which are also applicable to other PAU stocks).

<u>Short term</u>

- Investigation of alternative non-informative priors in CPUE analysis

- Explore changes in fisher catachability over time (including changing fisher experience, new technology, increasing professionalism) across all PAU fisheries
- Describe effective scaling, and how it's used to estimate size composition of removals (relevant for all PAU assessments). Explore the potential of incorporating seasonal effects into the standardisation model for length compositions.
- More tagging is needed in a larger number of representative strata/areas to estimate growth.
- It is unclear whether a single area model (and an aggregate CPUE index) can adequately represent biomass trends for the many sub-populations in PAU stocks. Spatial use trends and variability in biomass trends can induce both positive and negative bias in CPUE, and more sophisticated models may be needed to counter these biases (e.g., spatio-temporal models, Neubauer 2017). Similarly, finer-scale assessment models should be considered to account for potentially different trends within small-scale populations components, although this is difficult when there are inadequate data to support spatial assessments.
- Re-investigation of value of fishery-independent data (timed swim surveys) for PAU, with view to develop series for PAU 2. This might include sub legal population surveys/sampling.
- Explore sensitivity to alternative growth assumptions and growth rates.
- Investigate implications of non-stationary selectivity

Longer term

- It is unclear to what degree large scale aggregate statistics of commercial length frequency distributions represent changes in the overall length composition of the fishery. Although standardisation of CSLF was carried out for the attempted stock assessment, systematic deviations from stock assessment model expectations point to potential problems with the use of aggregate CSLF data.
- Paua growth is known to be temperature dependent. With warming and increasing heat waves linked to global warming, pāua fisheries could see reductions in long-term productivity linked with direct (physiological) and indirect (bottom-up) changes in the environment. The extent of these changes and potential fishery interactions should be investigated.

5. STATUS OF THE STOCKS

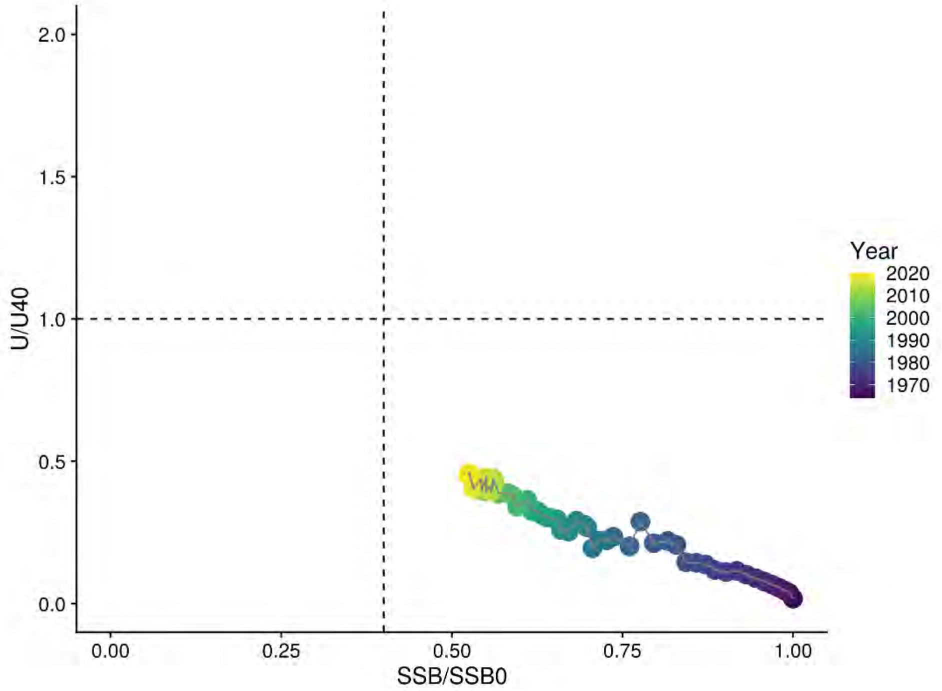
Stock Structure Assumptions

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

The PAU 2 assessment described here applies to the south east component of the region (Wairarapa coast), encompassed by the region between pāua statistical reporting areas P212–P236.

- **PAU 2 - Wairarapa**

Stock Status		
Most Recent Assessment Plenary Publication Year	2021	
Catch in most recent year of assessment	Year: 2019–20	Catch: 129 t
Assessment Runs Presented	Base case: length-based Bayesian stock assessment	
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	Likely (> 60%) to be at or above	
Status in relation to Limits	B_{2020} is 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 medians of relative stock status (spawning stock biomass (*SSB*) depletion level relative to unfished biomass (SSB_0)) and exploitation rate (*U*), relative to the exploitation rate that would result in a stock depletion to 40% of unfished biomass (U_{40}).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Spawning stock biomass has fluctuated without a long-term trend since the early 2000s.
Recent Trend in Fishing Mortality or proxy	Fluctuating without trend
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Commercial length frequency data (CSLF) have shown stable length frequency distributions since the early 2000s, with slight increases in recent CSLF lengths possibly due to market demands and catch-spreading arrangements.

Projections and Prognosis	
Stock Projections or Prognosis	At current catch levels and given the recent trend, the stock would continue to fluctuate without trend.
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 commence	Very Unlikely (< 10%)

Assessment Methodology		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Bayesian length-based stock assessment	
Period of Assessment	Latest assessment: 2021	Next assessment: 2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE indices PCELR series	1 – High Quality

	- Commercial sampling length frequencies	1 – High Quality
Data not used (rank)	CELR CPUE series FSU CPUE series	3 – Low Quality: variable catchability and changes in technology 3 – Low Quality: poor recording
Changes to Model Structure and Assumptions	This represents the first accepted assessment model for PAU 2	
Major Sources of Uncertainty	Growth is known to vary spatially over small scales, and it is unclear how representative the available samples are of the PAU 2 fishery area. Recruitment: length composition data available to the stock assessment provide little information about relative year class strengths. The assessment model is sensitive to natural mortality, which is poorly quantified. Early catch history: Pre QMS pāua exports exceeded catches reported to FMAs, and it is unclear which areas these catches came from. Selectivity in the commercial fishery has varied spatially and over time as voluntarily agreed Minimum Harvest Size (MHS) has changed. Different MHSs have been applied to different statistical areas within the assessed area in the same year.	

Qualifying Comments
A large proportion of PAU 2, including the Wellington south coast and west of Turakirae, is either a marine reserve or voluntarily closed to commercial fishing. This means that the data collected from the commercial fishery are exclusive of this large area and therefore the assessment only applies to the south east component of PAU 2 (Wairarapa). Lack of contrast in catch, CPUE, and length frequency makes estimation of stock status and biomass trajectories difficult. The 2019–20 year was excluded from the PCELR CPUE series owing to concerns about the comparability with previous years due to the effects of COVID-19 on export markets, and ERS reporting issues. This may continue into the future.

Fishery Interactions
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6. FOR FURTHER INFORMATION

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

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.

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

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

Fu, D (2014) 2014 PAU 2 stock assessment – Model input. SFWG 14-76. (Unpublished report held by Fisheries New Zealand.)

Fu, D; McKenzie, A; Naylor, R (2014a) Summary of input data for the 2013 PAU 3 stock assessment. *New Zealand Fisheries Assessment Report 2014/42*.

Fu, D; McKenzie, A; Naylor. R (2014b) Summary of input data for the 2013 PAU 5B stock assessment. *New Zealand Fisheries Assessment Report 2014/43.*

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

Heinemann A; Gray, A. (in prep.) National Panel Survey of Recreational Marine Fishers 2022-23.

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

McKenzie, A (2015) Standardised CPUE analyses for paua (*Haliotis iris*) in PAU 2, 1989–90 to 2013–14 (Draft New Zealand Fisheries Assessment Report held by Fisheries New Zealand.)

McKenzie, A; Naylor, J R; Smith, N H (2009) Characterisation of PAU 2 and PAU 3. Final Research Report. 58 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Naylor, J R; Andrew, N L (2000) Determination of growth, size composition, and fecundity of paua at Taranaki and Banks Peninsula. *New Zealand Fisheries Assessment Report 2000/51*.

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.

Naylor, J R; Andrew, N L; Kim, S W (2006) Demographic variation in the New Zealand abalone *Haliotis iris. Marine and Freshwater Research 57*: 215–224.

Neubauer, P (2017) Spatial bias in pāua (*Haliotis iris*) catch-per-unit-effort. *New Zealand Fisheries Assessment Report 2017/57*. 33 p.

Neubauer, P (2022) The 2021 stock assessment of pāua (H*aliotis iris*) for PAU 2. *New Zealand Fisheries Assessment Report 2022/35*. 108p

Neubauer, P (2020) Development and application of a spatial stock assessment model for pāua (*Haliotis iris*). *New Zealand Fisheries Assessment Report 2020/30*. 42 p.

Neubauer, P (2022a) The 2020 stock assessment of paua (*Haliotis iris)* for PAU 5A. *New Zealand Fisheries Assessment Report 2022/33 103*p.

Neubauer, P (2022b) The 2021 stock assessment of pāua (H*aliotis iris*) for PAU 2. *New Zealand Fisheries Assessment Report 2022/35 108p.*

Neubauer, P; Tremblay-Boyer, L (2019) The 2018 stock assessment of pāua (Haliotis iris) for PAU 5D. *New Zealand Fisheries Assessment Report 2019/39*. 58 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, New Zealand.) 165 p.

Punt, A E (2003) The performance of a size-structured stock assessment method in the face of spatial heterogeneity in growth. *Fisheries Research 65(1)*: 391–409.

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.

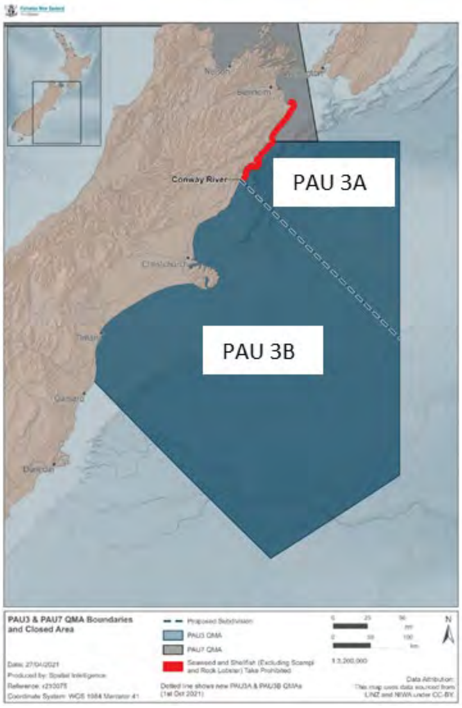
Schiel, D R; Breen, P A (1991) Population structure, ageing and fishing mortality of the New Zealand abalone *Haliotis iris*. *Fishery Bulletin 89*: 681–691.

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

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24.* 104 p.

PĀUA (PAU 3A) – Kaikōura

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

Prior to October 2021, PAU 3A was part of the PAU 3 QMA. The PAU 3 fishery was introduced into the QMS on 1 October 1986 with a TACC of 57 t and later increased to 91.62 t in 1995 as a result of appeals to the Quota Appeal Authority (Table 1).

The coastline between the Clarence River and Conway River was closed to commercial and recreational pāua fishing to protect the surviving pāua populations and associated habitats (see coastline in red in Figure above) due to a significant loss of pāua habitat resulting from coastal uplift following the 2016 Kaikōura earthquakes. In addition, the TACC for PAU 3 was lowered to 45.8 t, and the TAC was set at 79.3 t with a customary allowance of 15 t, a recreational allowance of 8.5 t, and other sources of mortality were at 10 t (Table 1). The closure of the Kaikōura coastline to fishing caused fishing effort to move onto the unaffected open Canterbury coastline (now PAU 3B).

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 and PAU 3A since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1995*	–	–	–	–	57.0
1995–2017*	–	–	–	–	91.62
2017–2021*	79.3	15	8.5	10	45.8
2021–present	40.5	7.5	5	5	23.0

*PAU 3 figures

On 1 October 2021, the PAU 3 QMA was subdivided into two smaller QMAs—PAU 3A (Kaikōura) and PAU 3B (Canterbury)—in response to the changed nature of the fishery (see Figure above). At that time, a new TAC, TACC, and allowances were set to reflect the QMA subdivision, pre-earthquake catch levels, and the need to adopt a precautionary approach to enable the fishery to rebuild to continue while providing for utilisation opportunities.

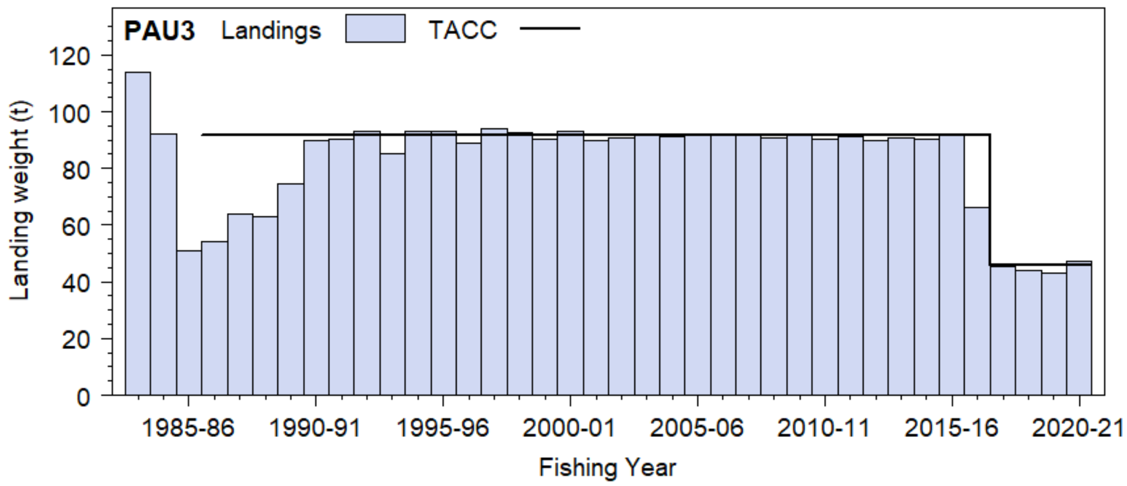
In response to a rebuilding of pāua biomass, the commercial and recreational fisheries were initially reopened for a limited three-month period in December 2021. The commercial fishery was later reopened on a permanent basis in January 2023, as well as a further two-month recreational season between April and June 2023.

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September.

Commercial fishers in PAU 3A gather pāua by hand while freediving. The commercial sector accounted for most of the harvest in the previous PAU 3 fishery. Prior to the 2016 earthquakes, commercial catches predominantly came from the northern part of the QMA, now PAU 3A, between the northern end of Pegasus Bay and the Clarence River, and from the southern side of Banks Peninsula. Annual commercial catches were generally evenly distributed between these two fishing areas with about 45 tonnes (50% of the 91.6 tonne TACC) being caught in each area.

Reported landings for PAU 3 are shown in Figure 1 and Table 2 between 1983–84 and 2020–21. Landings in PAU 3 closely followed the TACC between the fishing year 1991–92 and the 2016 earthquake closure. Following the 2016 earthquake, the coastline from Clarence Point in the north to the Conway River in the south was closed to all commercial (and recreational) pāua fishing. This caused all commercial catches to be taken entirely from the open unaffected Canterbury areas, mainly the southern side of Banks Peninsula but also from the Motunau and Gore Bay areas. The reported landings in 2020–21 totalled 47.10 t, with a TACC of 45.8 t, all of which came from areas unaffected by the earthquake, which remained open to commercial fishing. These areas now make up the PAU 3B QMA.



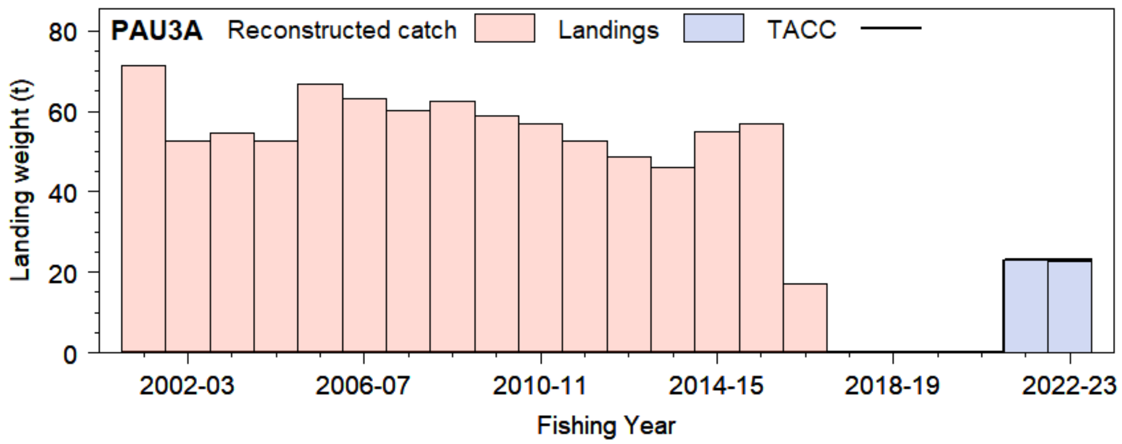


Figure 1: Reported commercial landings and TACC for PAU 3 (top) from 1983–84 to 2020–21 (last year before the QMA subdivision) and PAU 3A (bottom) from 2001–02 to 2022–23. The PAU 3A reconstructed landings between 2001–02 and 2020–21 correspond to the PAU 3 estimated catch for Pāua Statistical Areas P301 to P310 which correspond to the PAU 3A QMA created in 2021–22. No catch from 2017–18 to 2020–21 reflects the fishery closure following the 2016 Kaikōura earthquake.

Table 2: TACC and reported landings (t) of pāua in PAU 3 between 1983–84 and 2020–21 and in PAU 3A from 2022–23. The PAU 3A reconstructed landings between 2001–02 and 2020–21 correspond to the PAU 3 estimated catch for Pāua Statistical Areas P301 to P310 which correspond to the PAU 3A QMA created in 2021–22.

	PAU 3		PAU 3A		
Year	Landings	TACC	Reconstructed estimated catch	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	71.36		
2002–03	90.92	91.62	52.47		
2003–04	91.58	91.62	54.64		
2004–05	91.43	91.62	52.50		
2005–06	91.60	91.62	66.66		
2006–07	91.61	91.62	63.27		
2007–08	91.67	91.62	60.34		
2008–09	90.84	91.62	62.38		
2009–10	91.61	91.62	59.01		
2010–11	90.40	91.62	56.93		
2011–12	91.14	91.62	52.78		
2012–13	90.01	91.62	48.54		
2013-14	90.85	91.62	46.03		
2014–15	90.44	91.62	55.08		
2015–16	91.73	91.62	56.90		
2016–17	66.29	91.62	17.03		
2017–18	45.59	45.80	0		
2018–19	44.05	45.80	0		
2019–20	43.09	45.80	0		
2020–21	47.10	45.80	0		
2021–22†				22.96	23.00
2022–23				22.71	23.00

* FSU data.
† The 2021–22 season was 1 December 2021 to 28 February 2022.

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 2). The PAU 3A QMA effective since 1 October 2021 corresponds to the Pāua Statistical Areas P301 to P310.

Table 2 shows the reconstructed estimated catch equivalent to PAU 3A from the estimated PAU 3 catch between 2001–02 and 2020–21. Table 2 also shows the reported landings for PAU 3A since 2021–22, noting the fishing season for 2021–22 was only 3 months (1 December 2021 to 28 February 2022).

Since 2001, a redistribution of fishing effort within PAU 3 was 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 PāuaMAC3 which divided PAU 3 into four management zones. A voluntary harvest cap was placed on each management zone and this cap was reviewed annually. Minimum harvest sizes (MHS) were also agreed each year for each zone in addition to the legislated minimum legal size (MLS). These management initiatives were officially in place until 2020–21.

In 2021, the Minister for Oceans and Fisheries approved a Fisheries Plan for the PAU 3 fishery under s11A of the Fisheries Act 1996 to better manage commercial harvest activity across the wider fishery. This Plan prescribes an 'adaptive rebuild' approach in response to the Kaikōura earthquakes using a number of tools including catch spreading arrangements, harvest control rules, a larger minimum harvest size, and fine scale catch reporting and monitoring. The Plan includes new voluntary management areas (Table 3). On the basis of survey information (see section 4.1), the fishery was reopened in December 2021 with a commercial total allowable catch (TACC) of 23 t, a figure that was thought of as precautionary (catch prior to the earthquake was regularly in excess of 50 t).

Following the biomass survey of the adult pāua population conducted in 2021-22 as well as a survey of the recreational catch during that short 2021/22 fishing season, the Minister approved the permanent reopening of the PAU 3A commercial fishery from 5 January 2023.

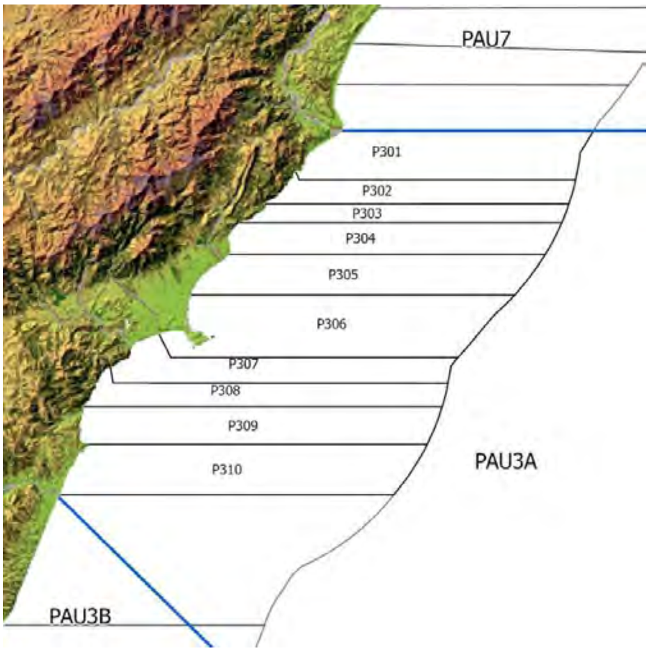


Figure 2: Map of fine scale Pāua Statistical Areas for PAU 3.

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

Management zone (since 2021)	Area	Pāua Statistical Area zone
3A1	Paparoa	P301–P302
3A2	Rakautara	P303–P304
3A3	Omihi	P307–P308
3A4	Oaro	P309–P310

1.2 Recreational fisheries

For further information on recreational fisheries refer to the Introduction – Pāua chapter. 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% (Wynne-Jones et al 2019). For 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.

Following initial high levels of mortality related to the earthquake, local pāua abundance recovered significantly, and the pāua fishery was re-opened on 1 December 2021, until 1 March 2022. The significant local interest in the fishery and high numbers of easily accessible pāua were considered likely to lead to a very active recreational fishery, once reopened. Therefore, a recreational harvest estimation survey (Holdsworth 2021) using a roving access design was implemented over the December to March fishing period. The survey estimated a recreational take of 42 tonnes (CV 17.5%) over the three-month open season (Holdsworth 2022). Pre- and post-fishery surveys indicated significant removal of legal sized pāua in the most popular recreational fishing sites during the fishery, but high densities of sub-legal sized pāua remained (Gerrity & Schiel 2023).

After reviewing the results of the recreational catch survey and the biomass survey of the adult pāua population conducted in 2021–22, the Minister agreed to reopen the recreational fishery between 15 April 2023 and 15 June 2023 with a daily limit of 3 pāua per person. A subsequent survey during the open season estimated a total take of 11.66 (CV: 0.25) by recreational fishers in the area (Holdsworth et al 2023).

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

Estimates of customary catch for PAU 3 until 2020–21 are shown in Table 4. These numbers are likely to be an underestimate of customary harvest because only the catch approved and harvested in 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.

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.

Estimates of customary take before the 2016 earthquakes ranged from about 7 to 13 tonnes. Customary take then initially declined, given the immediate loss of significant pāua abundance along the Kaikōura coastline, but increased in 2019–20 in response to feeding the local communities during the Covid-19 event. Information is not available at the PAU 3A level up to 2020–21 and customary estimates since 2021–22 for PAU 3A are given in Table 5.

Table 4: Fisheries New Zealand records of customary harvest of pāua (approved and reported in numbers) in PAU 3 between 2000–01 and 2020-21. Landings data before 2010–11 exclude the area between the Hurunui River and Pegasus Bay. – no data.

	Numbers			Numbers	
Fishing year	Approved	Harvested	Fishing year	Approved	Harvested
2000–01	300	230	2011–12	5 675	4 242
2001–02	6 239	4 832	2012–13	15 036	12 874
2002–03	3 422	2 449	2013–14	10 259	7 566
2003–04	–	–	2014–15	8 761	7 035
2004–05	–	–	2015–16	14 801	11 808
2005–06	1 580	1 220	2016–17	11 374	9 217
2006–07	5 274	4 561	2017–18	2 708	1 725
2007–08	7 515	5 790	2018–19	480	278
2008–09	10 848	8 232	2019–20	30 288	21 527
2009–10	8 490	6 467	2020–21	4 960	3 242
2010–11	8 360	7 449			

Table 5: Fisheries New Zealand records of customary harvest of pāua (approved and reported in numbers) in PAU 3A since 2021–22. – no data.

Fishing	Numbers	
year	Approved	Harvested
2021–22	3 639	3 058
2022–23	–	–

1.4 Illegal catch

For further information on illegal catch refer to the Introduction – Pāua chapter.

For the purpose of the 2013 stock assessment and recent operational models (Neubauer & Kim 2023), 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 Introduction – Pāua chapter.

On 16 November 2016 a 7.8 magnitude earthquake hit the upper east coast of the South Island, causing extensive uplift of about 110 km of coastline by as much as 6 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 sparser and more fragmented (Alestra et al 2020).

The whole northern part of the PAU 3 fishery (Pāua Statistical Areas P301 to P310, now PAU 3A, 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 suggested 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 P301, the habitat loss was 7 ha, which corresponds to 52% of the fished area. However, this area contributed relatively little to the commercial catch. In area P302, 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. Recent surveys have indicated large scale recovery of pāua populations in the affected areas (McCowan & Neubauer 2021, 2022, 2023).

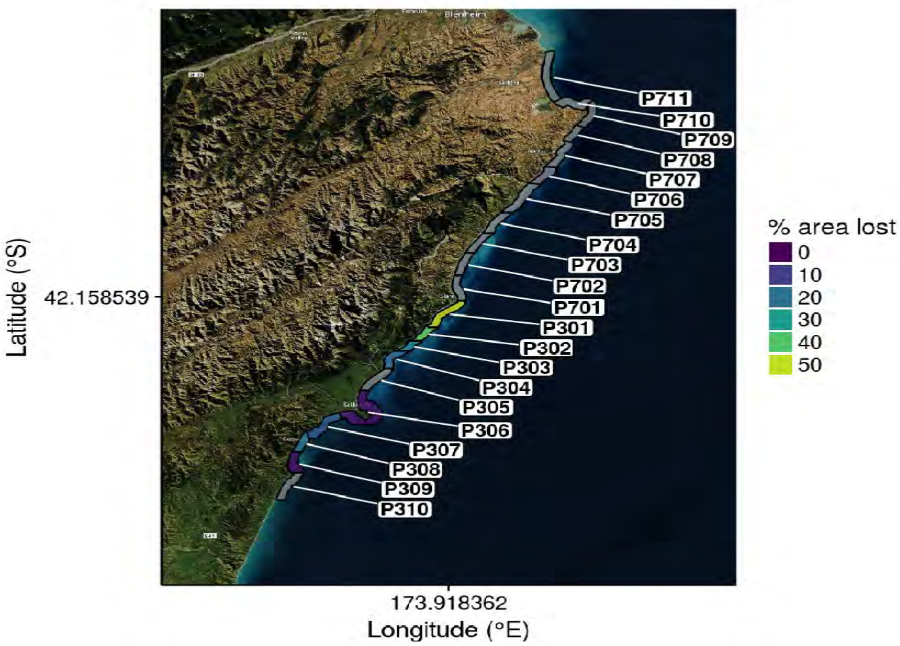


Figure 3: Percent fished area above the post-earthquake low tide mark for statistical areas within the Kaikōura earthquake fishery closure zone. Grey indicates that no post-earthquake elevation data were available.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter. A summary of published estimates of biological parameters for PAU 3 is presented in Table 6. Note that these values are from the most recent stock assessment covering the whole of PAU 3 and may therefore not be appropriate for PAU 3A. No area-specific, representative biological data are available for PAU 3A.

Table 6: Estimates of biological parameters (*H. iris*) in PAU 3.

		Estimate	Source
1. Natural mortality (M)			
		0.13 (0.120–0.14)	Median (5–95% range) of posterior distribution for the base case model
2. Weight = $a(\text{length})^b$ (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 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

3. STOCKS AND AREAS

For further information on stocks and areas refer to the Introduction – Pāua chapter.

4. STOCK ASSESSMENT

Since 2018, the recovery of the PAU 3A fishery area has been monitored with biomass surveys. The fishery reopened in 2021–22. Since 2021, models have been under development to assess and simulate the PAU 3A fishery, and an assessment has been accepted in 2024.

4.1 Biomass survey and monitoring

Following the 2016 Kaikōura earthquake, a biomass survey was implemented to estimate and monitor pāua abundance and recruitment in the earthquake-affected area, to inform management decisions relating to the re-opening of the pāua fishery (McCowan & Neubauer 2018, 2021, 2022, 2023). To estimate abundance, novel methodologies using GPS dive loggers and underwater electronic callipers were developed. Thirty-five sites were initially surveyed to obtain baseline estimates of site- and fishery-level abundance and length-frequency.

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. Initially estimated pāua density was 0.028 pāua per square metre (geometric mean; 95% confidence interval (CI) [0.009; 0.08]) across the earthquake-affected fishery closure. 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. After the first two years, the project was extended for another three years until mid-2023.

As of March of 2024, six further rounds of surveys of the 35 initially surveyed sites have been undertaken to monitor pāua abundance and recruitment trends (Figure 4), although not all sites could be surveyed in each round due to adverse weather conditions. Surveys in 2021–22 were split into pre- and post-season surveys in an attempt to assess impacts of fishing after re-opening the fishery. The post-season survey, however, encountered difficult survey conditions, and only some sites in PAU 3A could be surveyed. As a result, apparent declines in abundance in the post-season survey are likely to be confounded by the dive conditions and non-random subset of sites that were re-surveyed. As a result, these results are unlikely to provide a reliable index of abundance (McCowan & Neubauer

2023); these results are therefore excluded from survey indices used in models to evaluate management procedures.

The number of measurements per unit effort (MPUE) was initially used as a proxy for pāua density to overcome issues with missing data from GPS dive units (originally used to delimit area to estimate density) and to enable the use of significantly larger data sets of measurements and counts of pāua at each site. An assessment of the appropriateness of MPUE, as well as biomass per unit of survey effort (BPUE, number of measurements multiplied by the weights inferred from the length frequency distribution of measured pāua), showed that both correlated well (R^2=0.86) with density. Therefore, BPUE has since been used as the main index of changes in pāua abundance.

An overall increase in pāua abundance was observed at a QMA-wide level in both QMAs over the seven survey periods (Figure 4). Increased abundance was generally more pronounced in PAU 7 than in PAU 3. In PAU 3, abundance trended slightly downwards in the second survey period, which was likely to be due to the consistently poor survey conditions during the period, as well as a potential bias towards sampling sites with lower rates of increase due to weather conditions. Since the reopening of the fishery, the survey index has declined slightly.

There was high variability in abundance trends across sites. This variability was in part related to variability in the amount of uplift at each site, because sites with a larger increase in abundance were those with less uplift (Figure 5). Variability in abundance trends across sites could also be linked to habitat-related factors and pre-earthquake abundance. Comparison of length frequency profiles across the four survey periods showed reasonably stable profiles in larger size classes (125–160 mm, Figure 6), with an increase in the number of individuals in the 80–100 mm size range in both QMAs, which is likely to be indicative of post-earthquake recruitment. Recruitment signals were variable between sites due to differences in available recruitment habitat and variability in uplift.

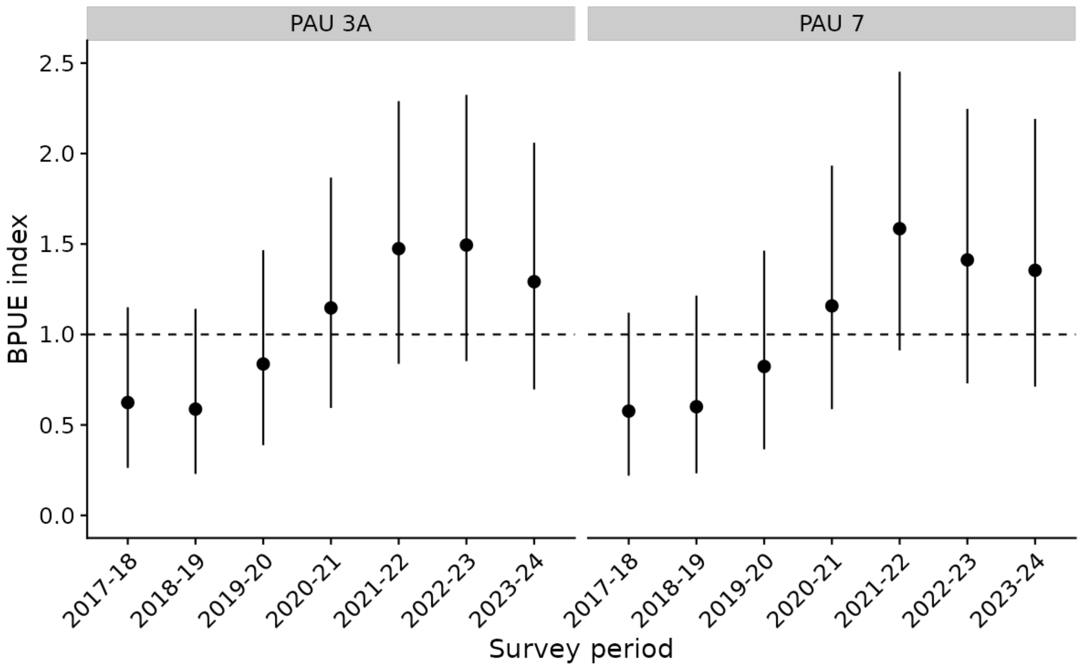


Figure 4: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for QMAs PAU 3 and PAU 7 from the BPUE model after accounting for confounding variables.

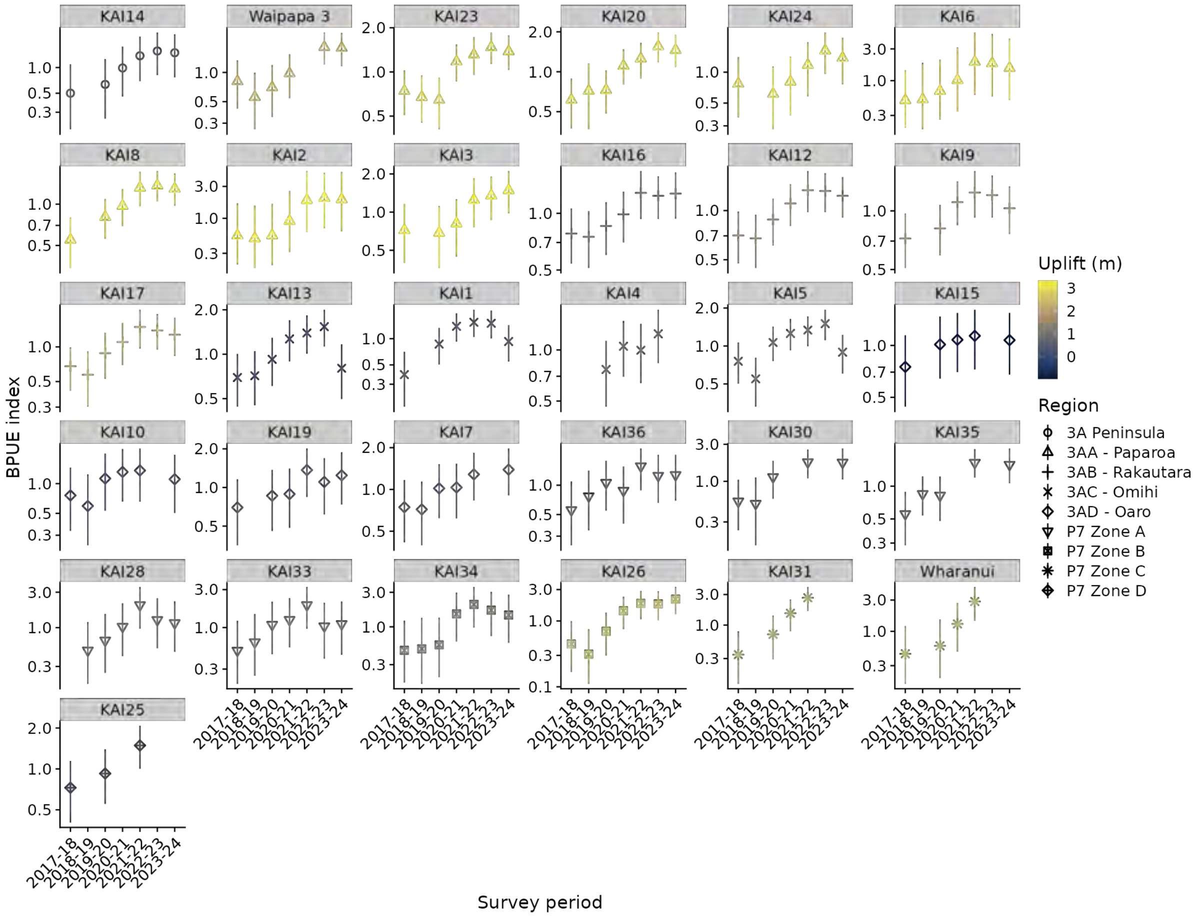


Figure 5: Marginal trend (relative to a geometric mean of 1 at each site) in biomass per unit effort (BPUE) across survey years for all sites, plotted across industry management zones ("Region") in QMAs PAU 3A and PAU 7 from the BPUE model after accounting for confounding variables.

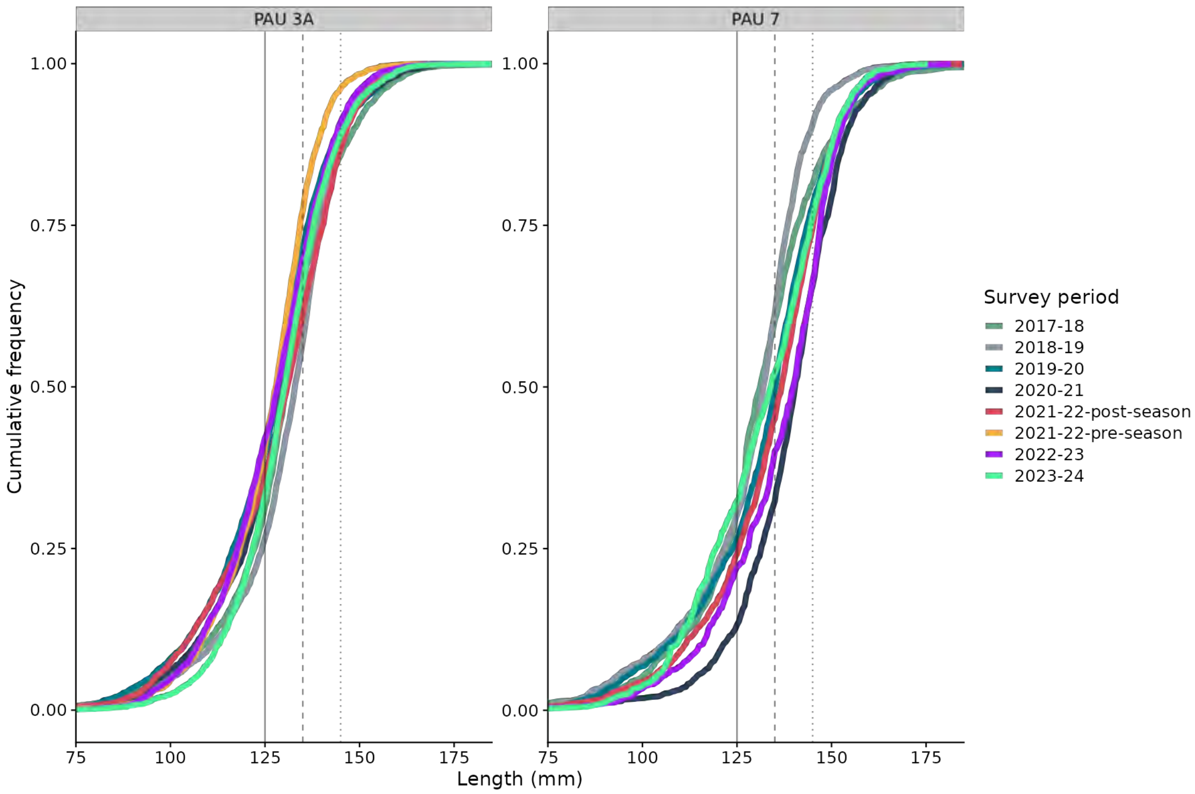


Figure 6: Cumulative length-frequency profiles for all pāua measured over four survey periods in PAU 3 and PAU 7. Vertical lines show the legal size of 125 mm (MLS; solid line), 135 mm (dashed line), and 145 mm (dotted line).

4.2 Stock assessment model

Prior to the earthquake, the PAU 3 quota management area was assessed on the basis of a length-based statistical stock assessment (Fu 2014). The stock was thought to be in healthy condition, although large uncertainties about stock status remained due to insufficient biological information that can inform understanding of local stock productivity. Two projects conducted since 2021 attempted to develop assessment models and test management options for PAU 3A as the fishery rebuilds. The work focused on key uncertainties that remained for management of the fishery long term: modelling of earthquake impacts and recovery, and the development of estimates of recreational catch over time.

The most recent model, developed in 2024, was accepted as a stock assessment and to evaluate management procedures. The model was spatially explicit across four main sub-areas (A – Paparoa, B – Rakautara, C – Omihi, and D - Oaro), based on length-based assessment models used in other areas, and tested a range of simple assumptions about plausible earthquake impacts. The model excluded areas around the Kaikoura peninsula (Pāua Statistical Areas P305 and P306), which are not currently commercially fished. It was fitted to commercial CPUE as well as length compositions from commercial shed sampling and (post-earthquake) onboard sampling of catch compositions. Survey data were integrated into the model by fitting to the survey index for each of the four sub-areas and to survey length frequencies summarised across survey sites falling within each of the four sub-areas.

Commercial catch is only known with certainty since 2002 (Table 2). Catch prior to 2002 was reconstructed based on the catch proportions coming from PAU 3A statistical areas in the first four years of PCELR reporting (2002–2006). For catch between 1974 and 1984, catch was taken from Murray & Ackroyd (1984) with the same catch proportions applied. Recreational catch is poorly known prior to the earthquake, and alternative recreational catch scenarios were explored, either fixing recreational catch at 24 t, or applying a ramp from 12 t to 24 t. Alternative models were run with an assumed catch at 12 t. For these models, catch proportions estimated from effort in recent recreational surveys were applied to all recreational catch. Illegal catch was assumed to be high in the 1990s and early 2000s, with high compliance effort leading to lower illegal catch in recent years. Although customary catch reporting has been highly variable, it was assumed to be steady at 5 t in the assessment. The model was initiated at the equilibrium biomass with no catch in 1964, with all catches ramping up linearly to 1974. The assumed catch history for all sub-areas is shown in Figure 7.

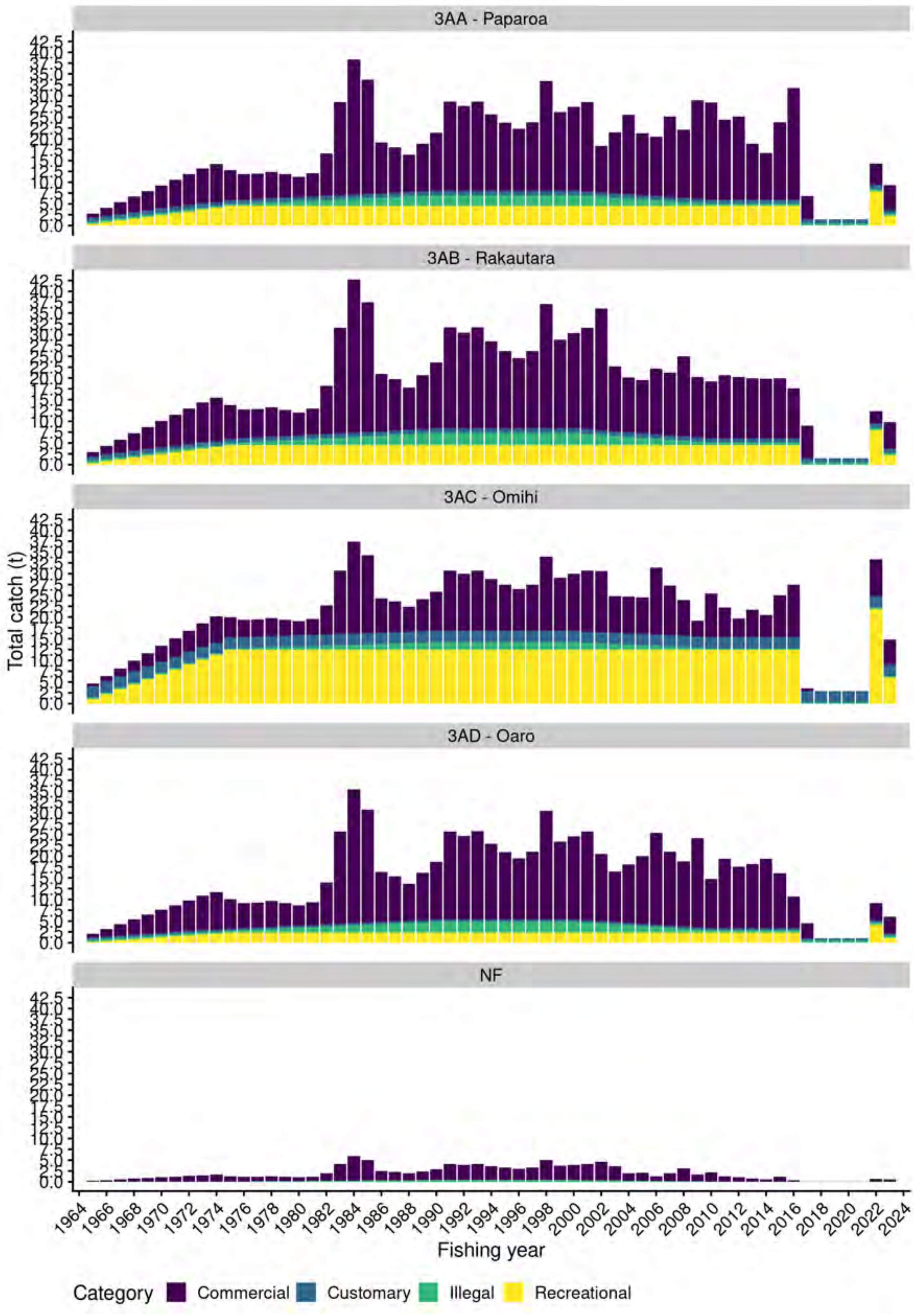


Figure 7: Assumed catch history for the base model for PAU 3A, by sub-areas. NF represents the area around the Kaikoura peninsula that is not currently commercially fished, and was not part of the stock assessment.

4.2.1 Relative abundance estimates from standardised CPUE analyses

The 2024 stock assessment used a combined series of PCELR data covering 2002–2016, and ERS data from 2022–2023. These data were combined in a single index. The 2017 fishing year, which includes some data prior to the earthquake in that fishing year, was included in the estimation of the CPUE index, but was not used in the stock assessment.

CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among sub-areas within QMAs, and statistical areas within sub-areas, while accounting for effects of ACE-holders and individual divers. CELR data prior to 2002 cannot be attributed to PAU 3A because General Statistical Area 018 straddles PAU 7, PAU 3A and PAU 3B, and therefore these data were not used.

CPUE was defined as the log of daily catch, standardized for effort defined as time per statistical area and day (formulated as a cubic spline within the model). Other variables in the model were fishing year, FIN (Fisher Identification Number), sub-areas, diver ID, and fine-scale statistical area, as well as the interaction between sub-areas and year to derive an index by area. Variability in CPUE was mostly explained by differences among ACE-holders and individual divers (Figure 8). CPUE prior to the earthquake showed little directional trend, but post-earthquake CPUE was substantially higher, mirroring signs of biomass recovery seen in the surveys (Figure 9). In all regions, recent CPUE was above the highest CPUE in the time-series seen prior to the earthquake.

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, with divers searching larger areas. 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.

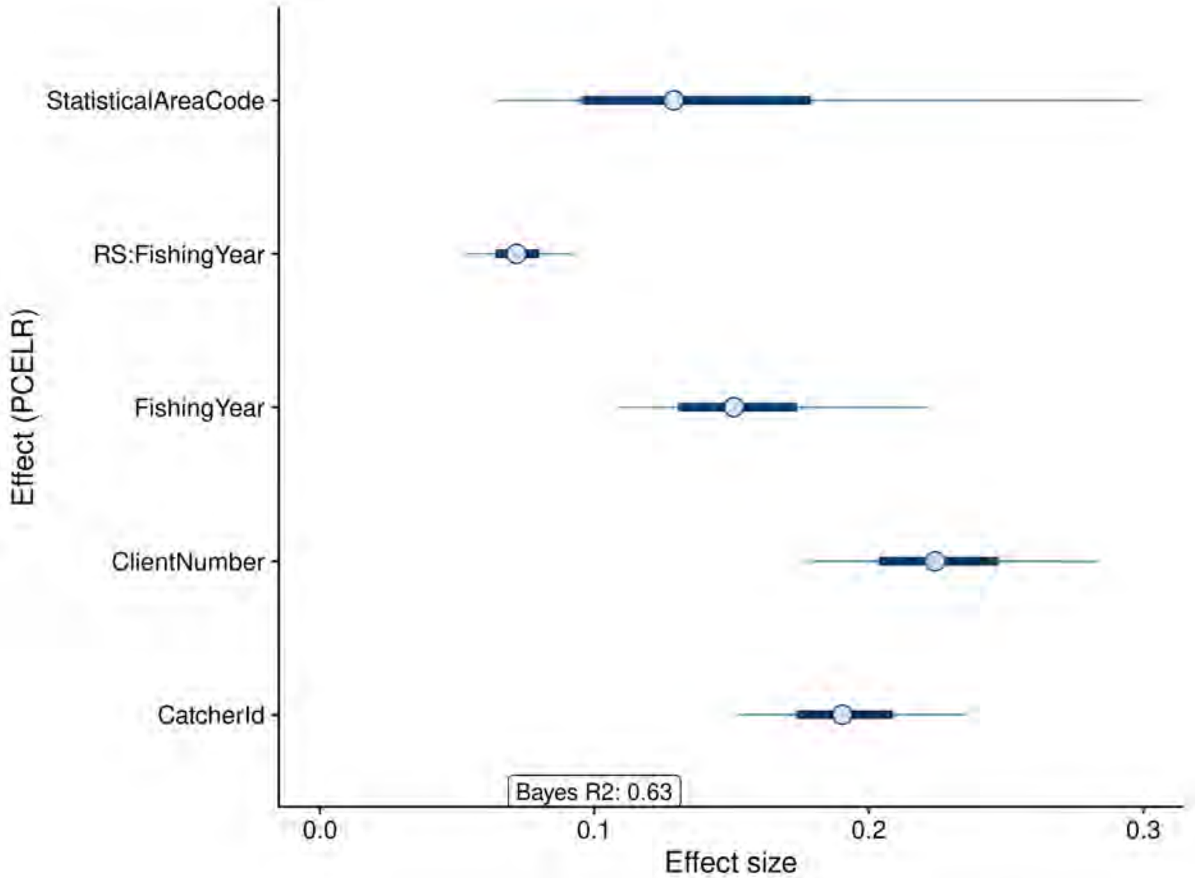


Figure 8: Effect size for the CPUE index standardisation model used for the base-case stock assessment model. RS: management zone (research stratum), CatcherID: diver number.

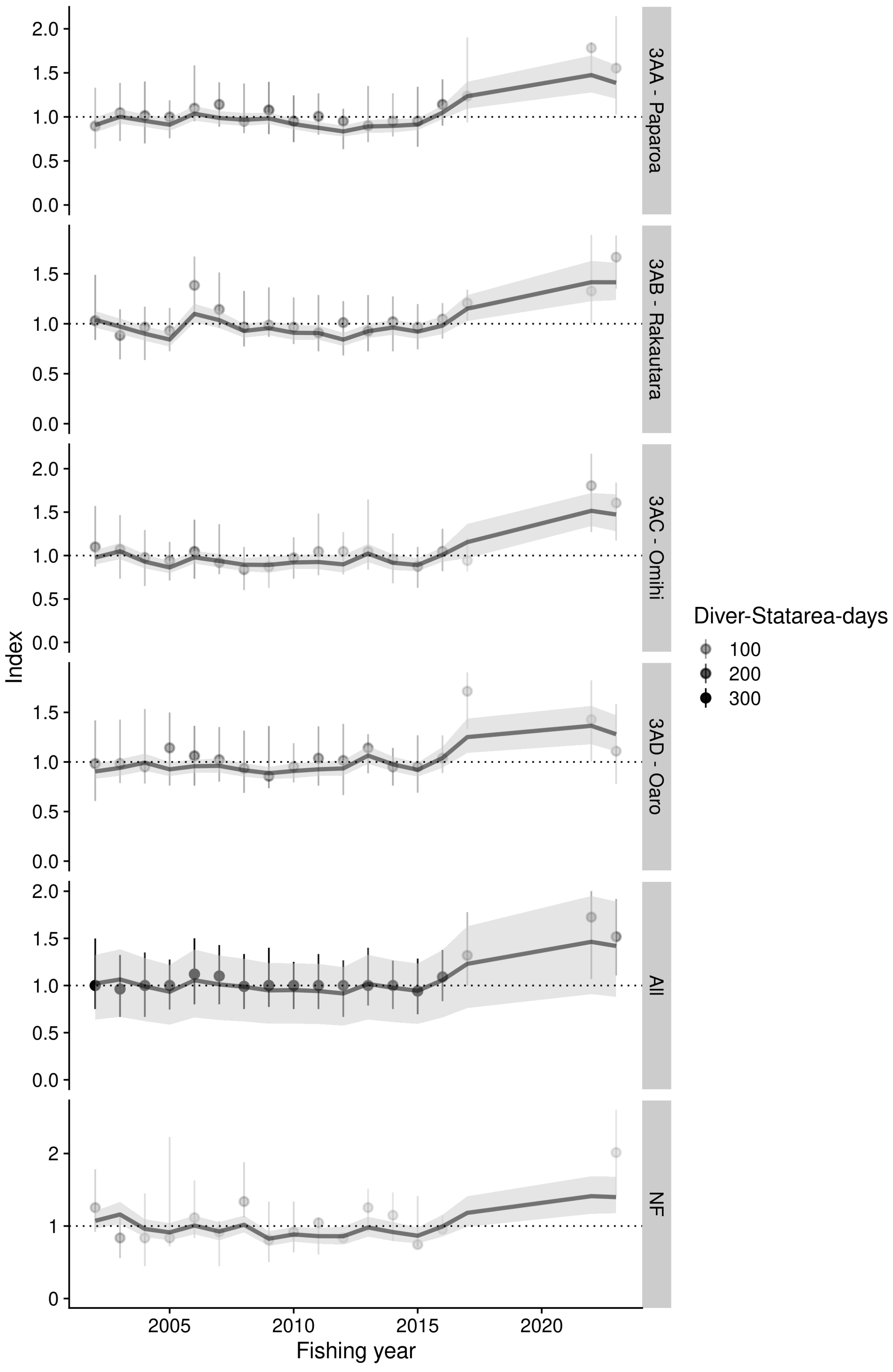


Figure 9: Standardised CPUE indices with 95% confidence intervals (solid line and ribbon) and unstandardized geometric CPUE and variability (points and inter-quartile error bars) for the combined PCELR and ERS time-series used in the base-case assessment model. Series presented by sub-area, NF represents the area around the Kaikoura peninsula that is not currently commercially fished, and was not part of the stock assessment.

4.2.2 Stock assessment methods

The 2024 PAU 3A stock assessment used the length-based population dynamics model first described by Breen et al (2003). Although the overall population-dynamics model remained unchanged, the 2024 assessment of the PAU 3A stock incorporated a number of changes from the previous models used in PAU 3.

1. Catch sampling length-frequency (CSLF) data were standardised using an improved model (Neubauer & Kim 2023) to better estimate uncertainty in removals.
2. Selectivity was allowed to vary in time, along an estimated offset parameterised by the mean minimum harvest size for each year. Due to changes in the spatial extent of the fishery among years, and variable harvest sizes, selectivity cannot be assumed to be constant.
3. The model was spatially explicit.

The model simulated the population from 1965 to 2023. The model structure assumed a single sex population within each area (defined as management zones for spatial models), with length classes from 70 mm to 170 mm, in bins of 2 mm. Growth was length-based, without reference to age, mediated through a growth transition matrix that describes the probability of each length class changing in each year. The transition matrix was estimated in the model from a meta-analysis derived informative prior and length compositions. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality, as well as enforced earthquake assumptions.

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; the assessment used a Beverton-Holt stock-recruitment relationship, with steepness (h) fixed at 0.7 for the 2024 stock assessment.

Growth, maturation and natural mortality were estimated within the model, although no fitting to raw data was performed, and all inputs were provided as priors with mean and uncertainty. The model estimated the commercial fishing selectivity, which was assumed to follow a logistic curve and to reach an asymptote. The selectivity was estimated as varying in time, with a random effect describing deviations from an estimated offset parameterised by the mean minimum harvest size in the QMA for each year. Survey selectivity was also estimated, with vague priors centered around the age of emergence for pāua. Catchability was parameterised as a nuisance parameter with a flat prior. All other parameters were given either informative (M, growth) or vaguely informative priors, and likelihood profiles were constructed to inspect for potentially unintended consequences of priors on stock size. Parameters estimated in the assessment model and their assumed Bayesian priors are summarised in Table 7.

Table 7: A summary of estimated model parameters and type of prior, (N, normal; LN = lognormal; MVN = multivariate normal, MA = prior derived from meta-analysis), mean and standard deviation of the prior.

Parameter	Prior	μ	SD	CV
Unfished recruitment [ln($R0$)]	N	12		2
D_{50} (Length at 50% selectivity for the commercial catch)	LN	125		1
$D_{95\text{-}50}$ (Length between 50% and 95% selectivity the commercial catch)	LN	5		1
SD of time varying selectivity	LN	1		1
Survey L_{50} (Length at 50% selectivity for the survey)	LN	90		0.2
Survey $L_{95\text{-}50}$ (Length between 50% and 95% survey selectivity)	LN	2		1
Natural mortality (M)	LN	0.12		0.2
Recruitment deviations [ln(ϵ)]	N	0	0.4	
Growth transition matrix	MVN	MA	MA	

The observational data were:

1. A standardised CPUE series covering 2002–2023 (with a break from 2017–2021 when the fishery was closed) based on combined PCELR and ERS data.
2. A commercial catch sampling length frequency series for 2002–2023 (with a break from 2017–2021 when the fishery was closed)
3. Survey length frequencies (2018–2023)
4. Survey index (2018–2023)

Assumptions about earthquake impacts were tested using the model and evaluated on the basis of fits to survey and commercial data. While the Plenary acknowledged that this does not provide a strong basis for definitively modeling earthquake impacts, it provides a way to discard assumptions that are incompatible with observations to date. Models used either i) no earthquake impact (hypothesizing that models can deal with earthquake impacts by estimating low recruitment deviates), ii) a high but exponentially declining earthquake mortality (scaled by the level of uplift observed in each management area), or iii) an exponentially declining temporary reduction in recruitment (also scaled by the amount of coastline uplift).

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 2023 (SSB_{2023} and B_{2023}^{Avail}). This assessment also reports the following fishery indicators:

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_{2023} > 40% SSB_0)	Probability that the spawning stock biomass in 2023 was greater than 40% of the unfished spawning stock
P(SSB_{2023} > 20% SSB_0)	Probability that the spawning stock biomass in 2023 was greater than 20% of the unfished spawning stock (soft limit)

4.2.3 Model results

Although most models could fit increases in post-earthquake survey indices (Figure 10), assumptions about lower recruitment from the earthquake (assumption iii) did not fit with the observed levels of increase in the most impacted sub-area (A - Paparoa). This assumption was therefore not retained further when evaluating model sensitivities. The weight placed on length compositions was influential for the estimated stock trajectory and stock status (especially in sub-area B - Rakautara; Figure 11), as were assumptions about natural mortality and earthquake mortality (especially in sub-area A - Paparoa).

The Plenary accepted the high CSLF weight (highCSLFw) model without explicit earthquake impacts as the base assessment model, noting that recent estimated recruitment was low and likely proxying for earthquake impacts in the model. The base model provided good fits to survey data (Figure 10) and reasonable fits to CPUE trends and could fit CSLF data reasonably well (Figure 12), reflecting commercial selectivity for large pāua since the earthquake. It estimated a natural mortality of 0.13 (95% CI: 0.12–0.14), with relatively fast growth (compared with the meta-analysis derived prior mean, estimated from other QMAs).

The estimated stock status for the model was 46% [95% CI: 41–51%] of unfished spawning biomass and very low risk of being below limit reference points (0% estimated; Figure 13), reflecting a large rebuild of biomass post-earthquake from below target levels. Other model sensitivities showed a similar status, with estimates ranging from 0.36 to 0.51 (Figure 11), and similarly low risk, with earthquake mortality assumptions leading to the lowest status estimates of stock status in sub-area A (Paparoa).

Estimates of relatively low pre-earthquake biomass relative to current levels were largely driven by commercial catch compositions that were dominated by small individuals (relative to sizes seen post-earthquake) in years prior to the earthquake, especially in Rakautara (Figures 11, 12). The estimated commercial exploitation rate was relatively high in this area, whereas in Omihi, the recreational exploitation rate was as high as the commercial one, meaning that the combined exploitation rate was estimated to be relatively high pre-earthquake as well (Figure 14). Post-earthquake exploitation rates were low by comparison to pre-earthquake years in all areas except Omihi, where the bulk of the recreational harvest was estimated to have occurred post-reopening.

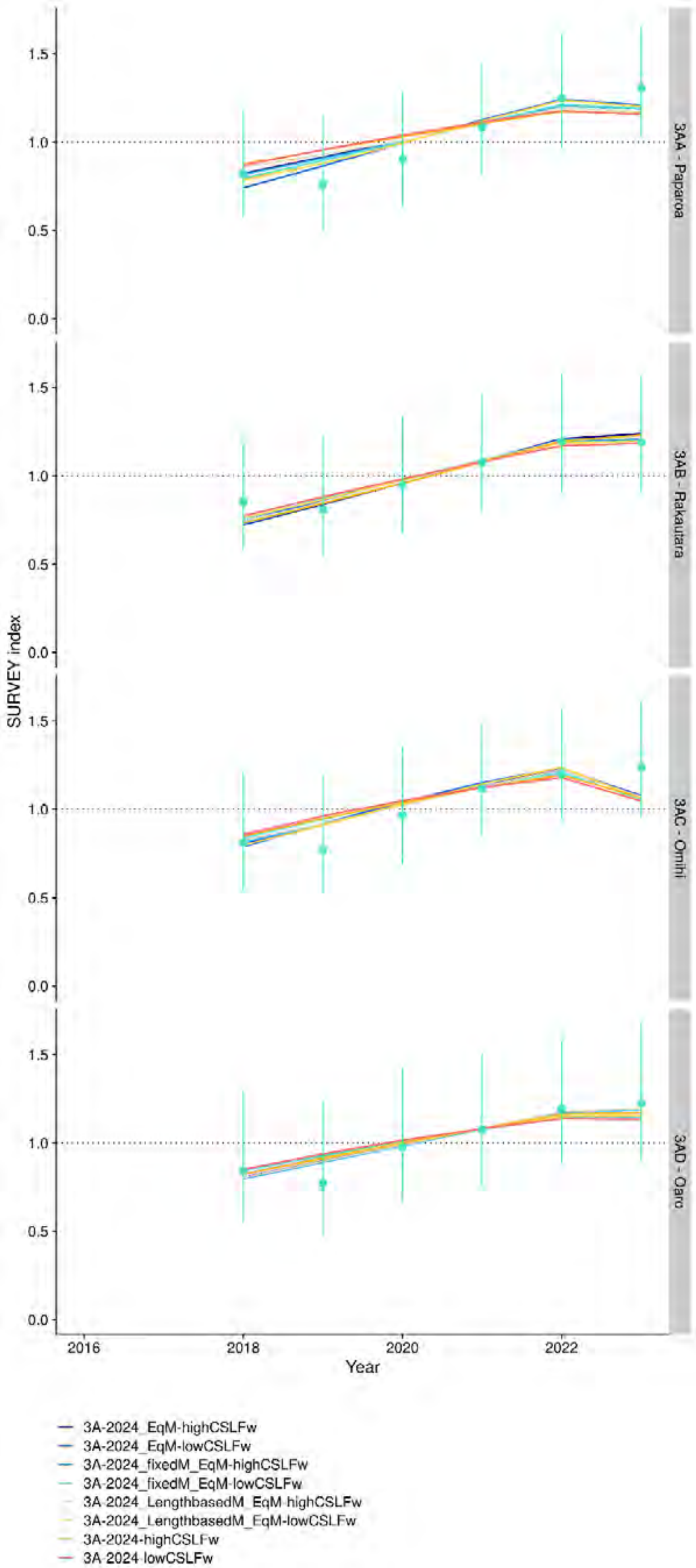


Figure 10: Estimated fit to survey indices generated from post-earthquake surveys for pāua in four management zones in the PAU 3A fishery, comparing plausible operating models with different assumptions about model weights for commercial length frequencies CSLFw [high vs low weight]; natural mortality [fixed at 0.12, length-based (estimated) or length-invariant (estimated)]; and explicit earthquake mortality (EqM).

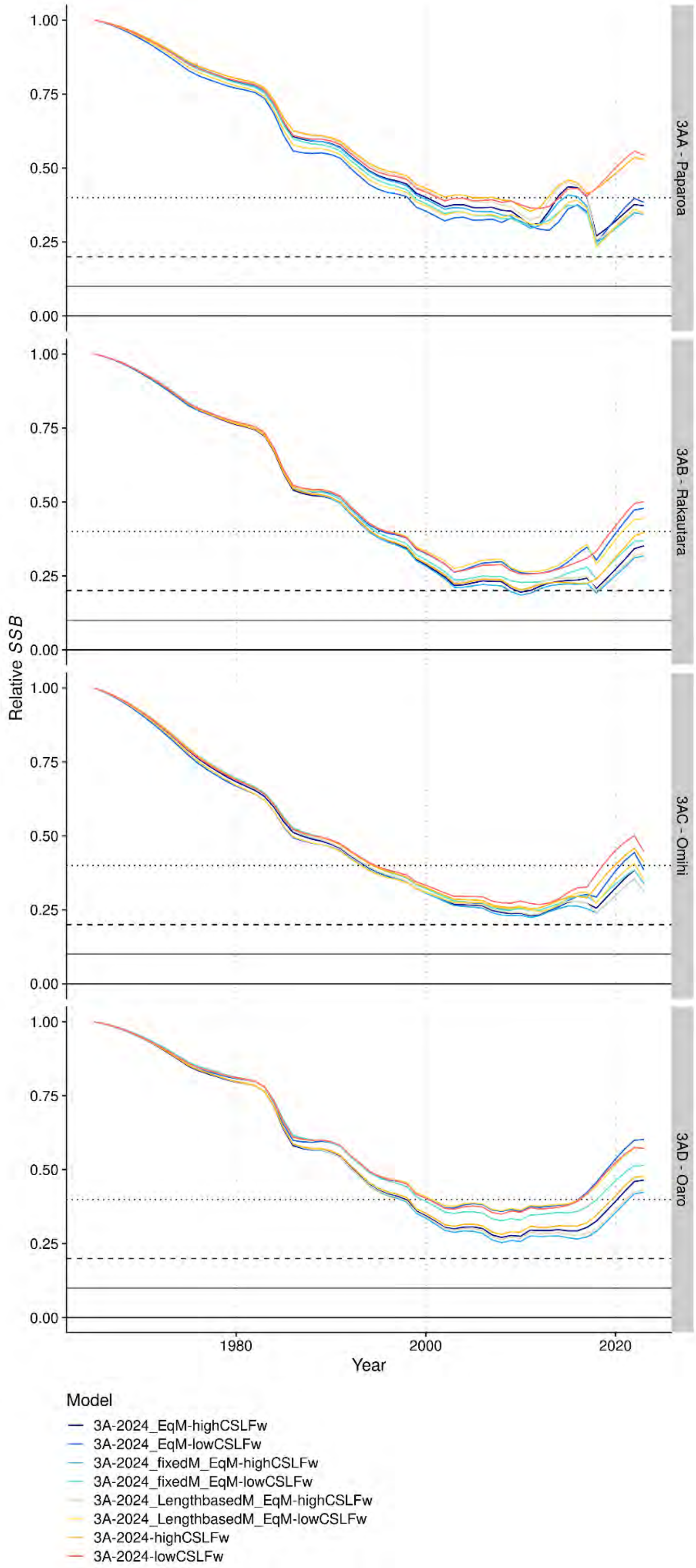


Figure 11: Estimated relative spawning stock biomass (SSB) trend for pāua in four management zones in the PAU 3A fishery, comparing plausible operating models with different assumptions about model weights for commercial length frequencies CSLFw [high vs low weight; natural mortality [fixed at 0.12, length-based (estimated) or length-invariant (estimated)]; and explicit earthquake mortality (EqM).

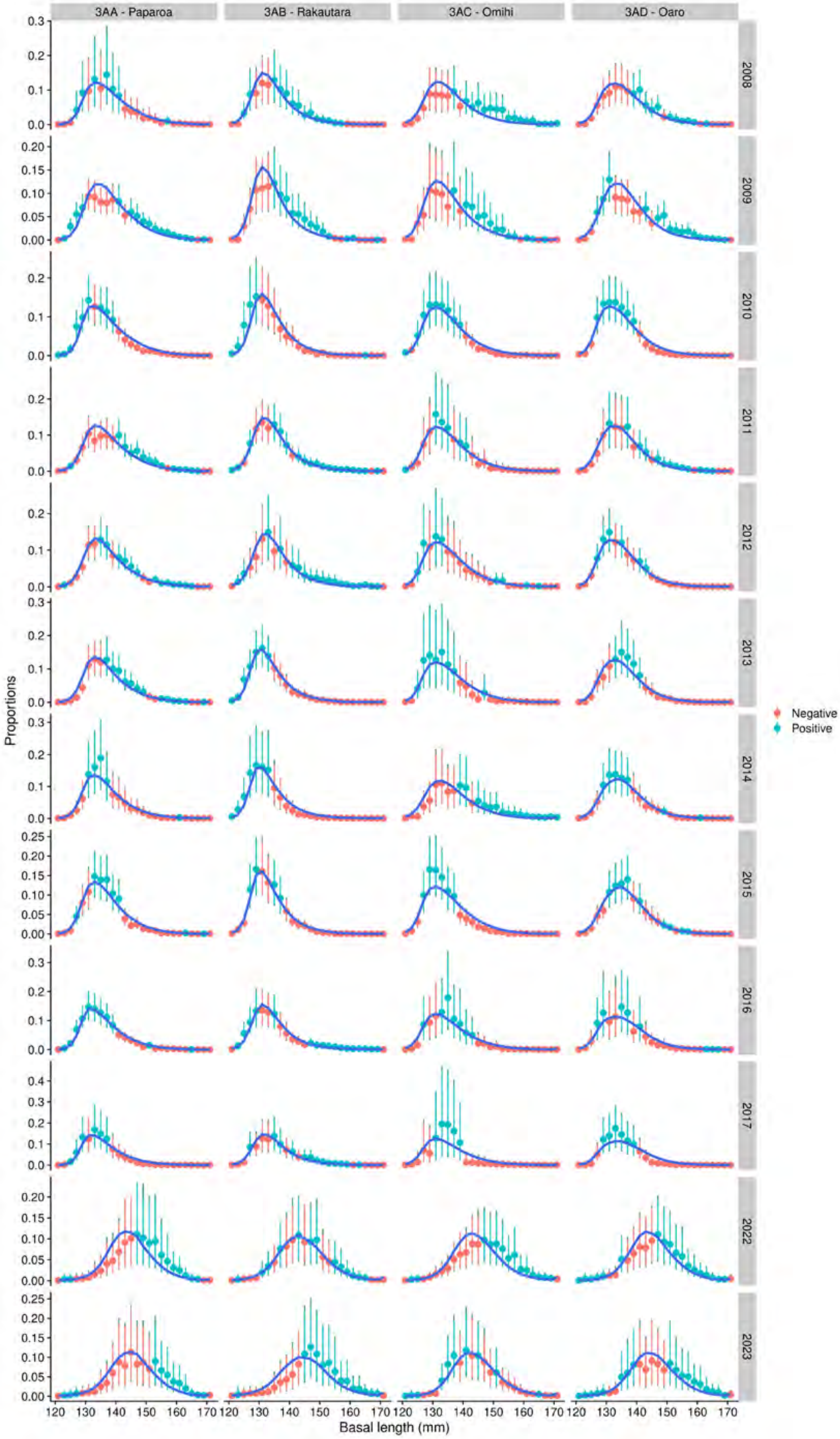


Figure 12: Estimated length composition (blue line) and corresponding model inputs (points and uncertainty by length bin) for the base model for the 2024 PAU 3A stock assessment. Residuals are marked as positive (blue) and negative (red).

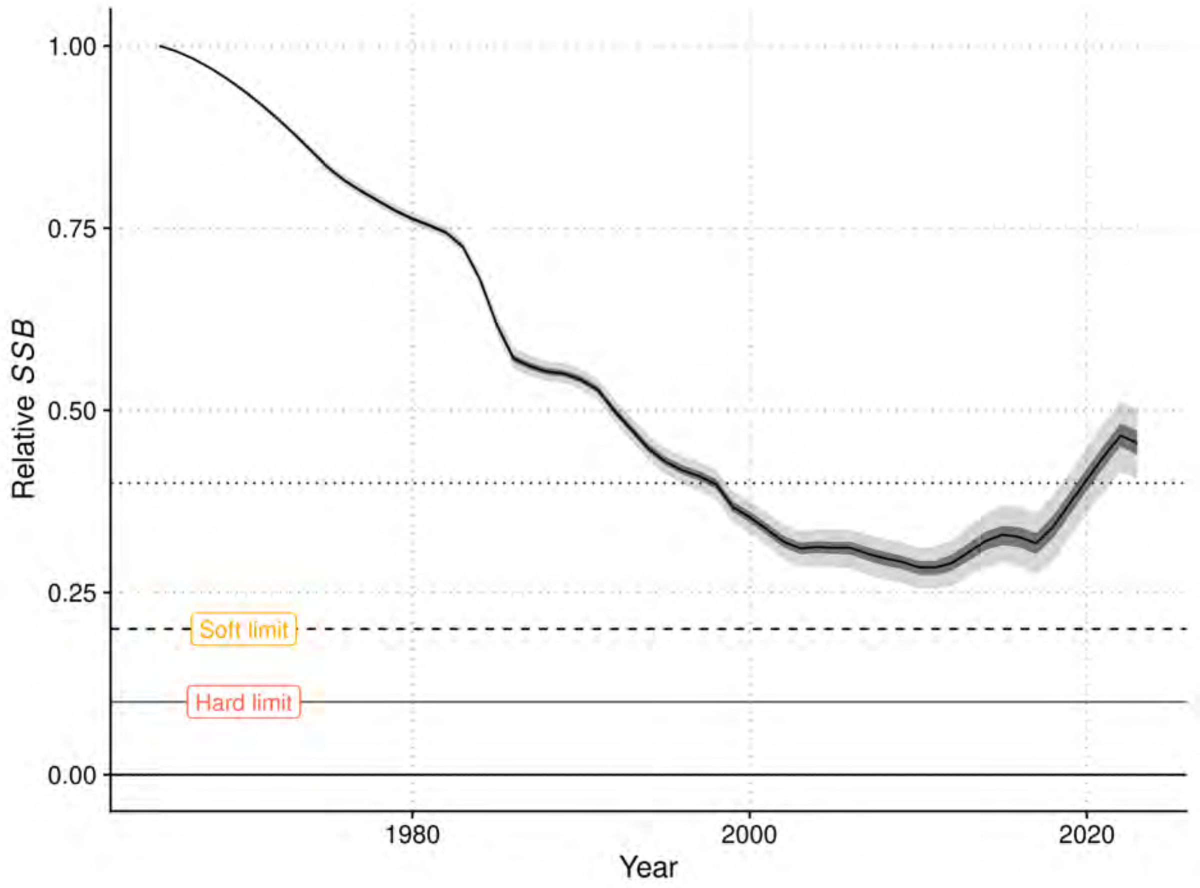


Figure 13: Estimated stock trajectory for relative spawning biomass (relative to unfished spawning biomass). Shown are the posterior median (black line), and interquartile (dark shade) and 95% confidence bounds (light shade).

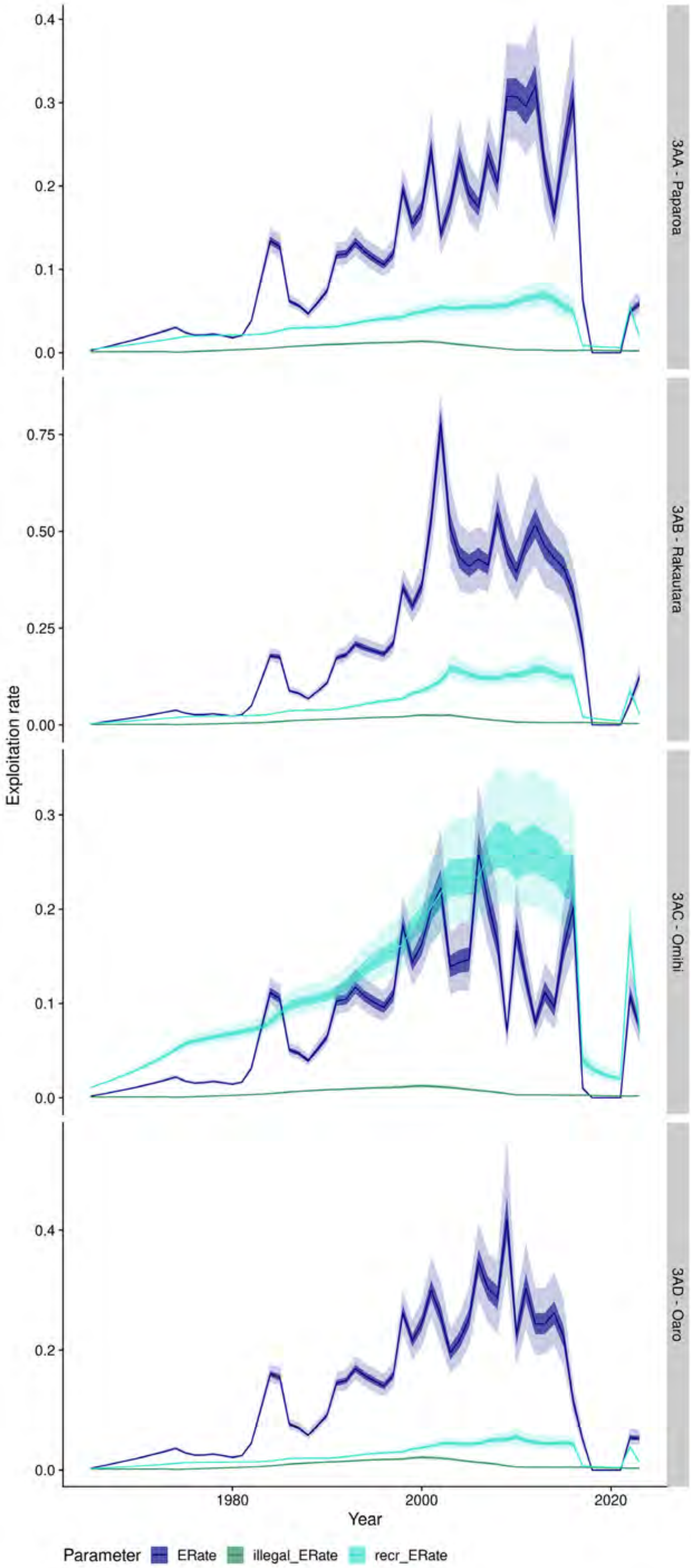


Figure 14: Estimated exploitation rate for commercial (ERate), illegal (illegal_ERate) and recreational+customary (recr_ERate) fishery components assumed in the model.

4.3 Evaluation of management procedures for PAU 3A

New management procedures were developed in 2024 on the basis of length-based estimators of spawning potential ratio (SPR; Hordyk et al 2016) and CPUE. These rules set a spawning potential target and use CPUE or survey indices to indicate the "direction of travel", adjusting catch to drive biomass towards the target SPR (Figure 15). The SPR can be estimated from commercial or survey data. The combination of SPR and indices was aimed at offsetting the relatively slow response of SPR to changes in exploitation and recruitment. The target SPR was set at 50% to reflect a precautionary target for pāua.

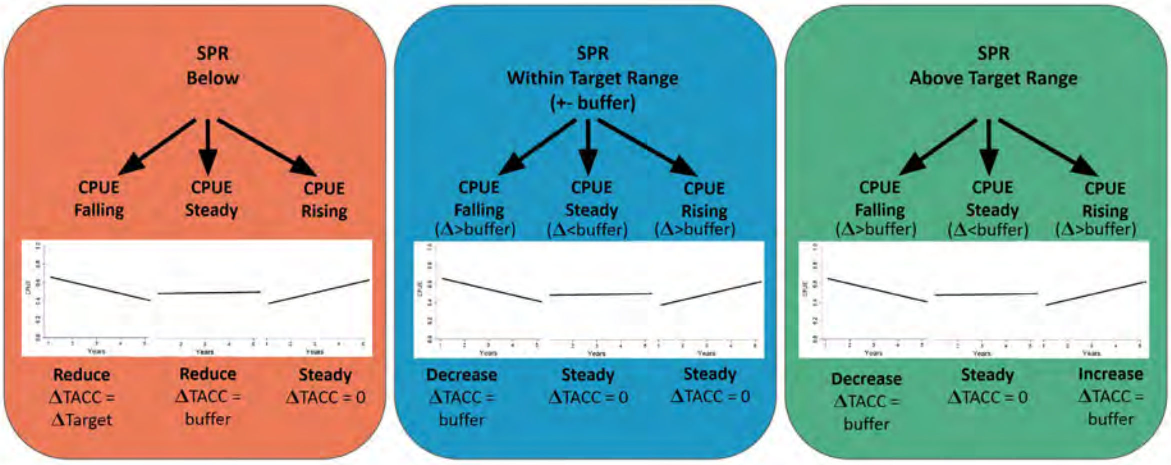


Figure 15: SPR control rule for pāua in PAU 3A. The spawning potential ratio target is set and TACCs are adjusted to steer CPUE in the direction of the target SPR.

Control rules were tested against a range of models and with a range of "base settings", including starting commercial and recreational catch levels, as well as minimum legal sizes for pāua harvest. All models used for testing suggested substantial recovery post-earthquake of pāua biomass, however, the models did so under different productivity assumptions and with different estimated stock status levels. These models were used to test the robustness of starting settings and subsequent management under the length-based SPR management procedure under different productivity and status assumptions.

Performance of the control rules in terms of catch and risk was only minimally influenced by the rule settings over the short-medium term, but catch trends were strongly influenced by initial TACC settings. The largest differences in medium to long-term outcomes were seen under alternative model assumptions, with lower initial stock status leading to lower average stock status and catch (Figure 16). However, no combination of models, initial management settings and control rules led to overfishing risk, largely due to the high minimum commercial harvest size which protects nearly 20% of the spawning biomass by virtue of making a large proportion of spawning biomass inaccessible to commercial fisheries. Although recreational and customary fisheries can still access smaller fish under settings of unchanged legal harvest sizes, the assumed levels of catch combined with a responsive commercial fishery catch do not appear to lead to risk in the medium or long-term.

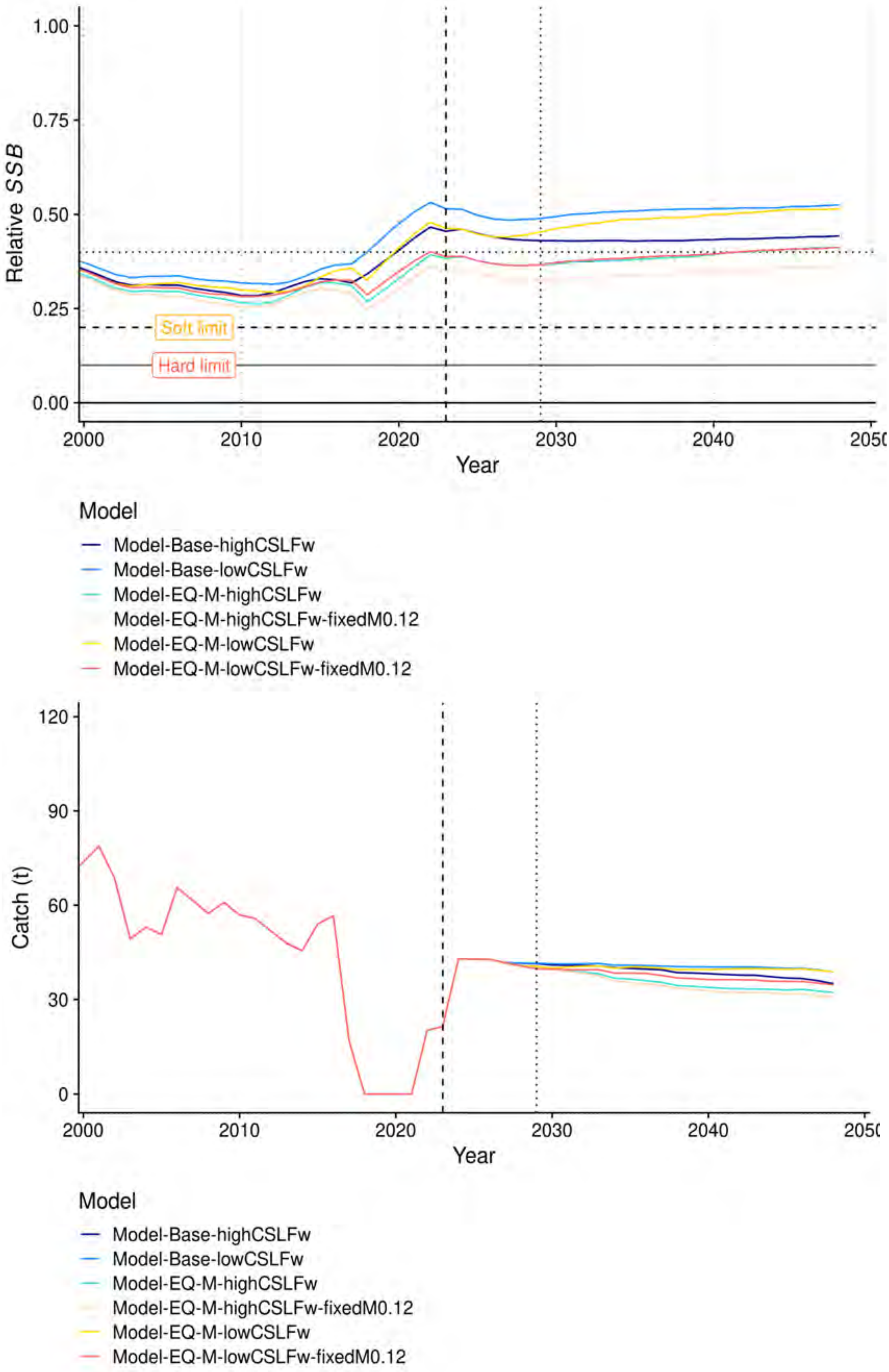


Figure 16: Simulated total catch (top) and relative spawning stock biomass (*SSB*; bottom) trends for pāua, comparing operating models with different assumptions about model weights for commercial length frequencies CSLFw [high vs low weight]; natural mortality [fixed at 0.12 or estimated]; and explicit earthquake mortality (EqM). Management was applied according to the tested control rules for each management zone in quota management area PAU 3A. The dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, the dotted vertical line shows the tested limit of validity (3 years) of the tested rule. The last projection year is 2041.

Future research considerations

Recreational harvest
Regular estimates of recreational harvest are required to evaluate the effects of this important component of the fishery.

Surveys
Evaluate alternative survey designs to increase effort in each subarea on a rotational basis to improve precision.

CPUE
In CPUE models investigate fisher specific relationships with catch per hour.

Stock assessment
Exploration of the sensitivity to pre 2002 harvests, and potentially starting the model in 2002.
Exploration of approaches to the timing of the survey within the model year the assessment model.
Use strata specific (rather than global) in the length frequency regression analysis.

Harvest control rule
Evaluating HCR with different historical harvest (including different levels of recreational harvest).
Investigate the implications of autocorrelation in CPUE abundance indices.
Investigate available data on earthquake impact to identify potential alternative hypotheses.

5. STATUS OF THE STOCKS

● PAU 3A – Kaikōura region

Stock Status		
Most Recent Assessment Plenary Publication Year	2024	
Catch in most recent year of assessment	Year: 2022–23	Catch: 22.71 t
Assessment Runs Presented	One base run (High CSLFw)	
Reference Points	Default 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_{2023} was estimated to be 46% B_0; About as Likely as Not (40–60%) at or above the target	
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below the Soft Limit Hard Limit: Very Unlikely (< 10%) to be below the Hard Limit	
Status in relation to Overfishing	Unknown	

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Recent trends in the survey index provide evidence of a substantial recovery of biomass since the 2016 earthquake.
Recent Trend in Fishing Intensity or Proxy	Little trend since the fishery was reopened in December 2021.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Slight increase in abundance under current (2023) catch settings

Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) at current catch settings Hard Limit: Very Unlikely (< 10%) at current catch settings
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Length based Bayesian integrated assessment in STAN	
Assessment Dates	Latest assessment Plenary publication year: 2024	Next: 2029
Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)	- Catch history	1 – High Quality; catch history prior to 2002 requires an assumption of a catch split between adjacent QMAs. Pre 2016 recreational harvest highly uncertain
	- CPUE (PCELR & ERS)	1 – High Quality
	- Commercial length samples	1 – High Quality
	- Survey biomass index	1 – High Quality
	- Survey length samples	2 – Medium or mixed Quality: low sample sizes in some strata / years
Data not used (rank)	Recreational length samples	2 – Medium or mixed Quality: short time series, post earthquake only, that might not represent recreational selectivity
Changes to Model Structure and Assumptions	No previous assessment for PAU 3A. Previously assessed as PAU 3.	
Major Sources of Uncertainty	Impact of earthquake on medium term stock productivity Pre earthquake recreational harvest	

Qualifying Comments:
Recreational harvest currently exceeds recreational allowance.

Fishery Interactions
-

6. FOR FURTHER INFORMATION

Alestra, T; Gerrity, S; Dunmore, R A; Marsden, I; Pirker, J; Schiel, D R (2019) Rocky reef impacts of the Kaikōura earthquake: quantification and monitoring of nearshore habitats and communities. *New Zealand Aquatic Environment and Biodiversity Report No. 212*. 120 p.

Alestra, T; Gerrity, S; Dunmore, R A; Schiel, D R (2020) Rocky reef impacts of the Kaikōura earthquake: extended monitoring of nearshore habitats and communities – Year 1 results. *New Zealand Fisheries Assessment Report 2019/01*. 40 p.

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

Fu, D (2013) The 2012 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2013/57*.

Fu, D (2014) The 2013 stock assessment of paua (*Haliotis iris*) for PAU 3. *New Zealand Fisheries Assessment Report 2014/44*.

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

Gerrity, S T; Schiel, D R (2023) Recreational fishing effects on wadeable pāua populations along the Kaikōura coast, 2021–22. *New Zealand Fisheries Assessment Report 2023/01*. 27 p.

Gorfine, H K; Dixon, C D (2000) A behavioural rather than resource-focused approach may be needed to ensure sustainability of quota managed abalone fisheries. *Journal of Shellfish Research 19*: 515–516.

Holdsworth, J C (2021) Pāua amateur harvest survey design for the Kaikōura Marine Area. *New Zealand Fisheries Assessment Report 2021/63.* 13 p.

Holdsworth, J (2022) Harvest estimates from land-based amateur fishers—Kaikōura Marine Area to Marfells Beach. *New Zealand Fisheries Assessment Report 2022/40*. 27 p.

Holdsworth, J C; Curtis, S; Neubauer, P (2023) Pāua harvest estimates by land-based amateur fishers—Kaikōura Marine Area in 2023. *New Zealand Fisheries Assessment Report 2023/62.* 21 p.

Hordyk, A R; Ono, K, Prince, J D, Walters, C J (2016) A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: application to spawning potential ratios for data-poor stocks. *Canadian Journal of Fisheries and Aquatic Sciences, 73*(12), 1787–1799.

Kim, S W (2004) CPUE analysis of fine-scale logbook data for PAU 3. Ministry of Fisheries Research Report PAU 2001/01 Obj. 7. (Unpublished report held by Fisheries New Zealand, Wellington.)

McCowan, T; Neubauer, P (2018) Paua biomass estimates and population monitoring in areas affected by the November 2016 Kaikoura earthquake. *New Zealand Fisheries Assessment Report 2018/54*. 24 p.

McCowan, T; Neubauer, P (2021) Pāua abundance trends and population monitoring in areas affected by the November 2016 Kaikōura earthquake. *New Zealand Fisheries Assessment Report 2021/26*. 23 p.

McCowan, T A; Neubauer, P (2022) Pāua abundance trends and population monitoring in areas affected by the November 2016 Kaikōura earthquake, December 2021 update. *New Zealand Fisheries Assessment Report 2022/15.* 20 p.

McCowan, T A; Neubauer, P (2023) Pāua population monitoring in areas affected by the November 2016 Kaikōura earthquake, February 2023 update. *New Zealand Fisheries Assessment Report 2023/26.* 19 p.

McKenzie, A; Naylor, J R; Smith, N H (2009) Characterisation of PAU 2 and PAU 3. Final Research Report. 58 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Murray, T; Ackroyd, J (1984) The New Zealand paua fishery. An update and review of biological considerations to be reconciled with management goals. Internal Report No. 5. Fisheries Research Division. 25 p.

Naylor, J R; Andrew, N L (2000) Determination of growth, size composition, and fecundity of paua at Taranaki and Banks Peninsula. *New Zealand Fisheries Assessment Report 2000/51*. 25 p.

Naylor, J R; Andrew, N L; Kim, S W (2006) Demographic variation in the New Zealand abalone *Haliotis iris. Marine and Freshwater Research 57*: 215–224.

Neubauer, P (2017) Area lost to the paua fishery from the November 2016 Kaikoura earthquake, 7 p. (Unpublished report held by Fisheries New Zealand.)

Neubauer, P; Kim, K (2023) Operating model and management procedure evaluation for pāua (*Haliotis iris*) fisheries in PAU 3A. *New Zealand Fishery Assessment Report 2023/28*. 109 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.

Poore, G C B (1972) Ecology of New Zealand abalones, *Haliotis* species (Mollusca: Gastropoda). 3. Growth. *New Zealand Journal of Marine and Freshwater Research 6*: 534–59.

Poore, G C B (1973) Ecology of New Zealand abalones, *Haliotis* species (Mollusca: Gastropoda). 4. Reproduction. *New Zealand Journal of Marine and Freshwater Research 7* (*1&2)*: 67–84.

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.

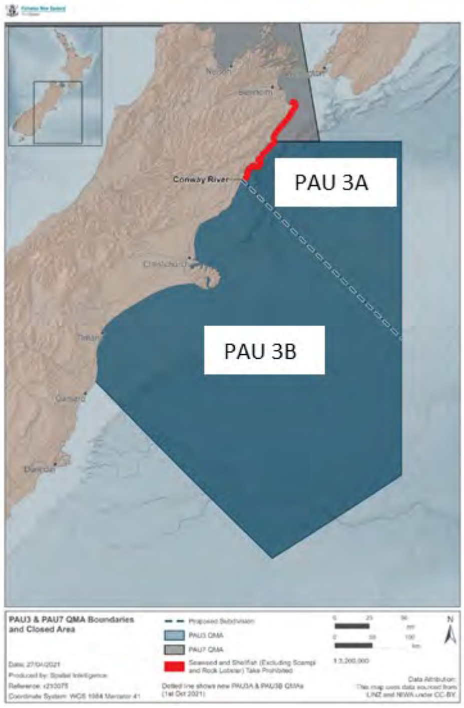
Shepherd, S A; Partington, D (1995) Studies on Southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. *Marine and Freshwater Research 46*: 669–680.

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

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24.* 104 p.

PĀUA (PAU 3B) - Canterbury

(*Haliotis iris*)
Pāua



1. FISHERY SUMMARY

Prior to October 2021, PAU 3B was part of the PAU 3 QMA, which was introduced into the QMS on 1 October 1986 with a TACC of 57 t and later increased to 91.62 t in 1995 as a result of appeals to the Quota Appeal Authority (Table 1).

The coastline between the Clarence River and Conway River was closed to commercial and recreational pāua fishing to protect the surviving pāua populations and associated habitats (see coastline in red in figure above) due to a significant loss of pāua habitat resulting from coastal uplift following the 2016 Kaikōura earthquakes. In addition, the TACC was lowered to 45.8 t, and a TAC was set at 79.3 t with a customary allowance of 15 t, a recreational allowance of 8.5 t, and other sources of mortality were at 10 t (Table 1). The closure of the Kaikōura coastline to fishing caused fishing effort to move onto the remaining open Canterbury coastline, which was unaffected by the earthquake, south of statistical area P310 (now PAU 3B).

On 1 October 2021, the PAU 3 QMA was subdivided into two smaller QMAs—PAU 3A (Kaikōura) and PAU 3B (Canterbury)— in response to the changed nature of the fishery (see figure above). At that time, a new TAC, TACC, and allowances were set to reflect the QMA subdivision, pre-earthquake catch levels, and the need to adopt a precautionary approach to enable the PAU 3A fishery rebuild to continue while providing for utilisation opportunities.

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 and PAU 3B since introduction to the QMS.

Year	TAC	Customary	Recreational	Other mortality	TACC
1986–1995*	–	–	–	–	57.0
1995–2017*	–	–	–	–	91.62
2017–2021*	79.3	15	8.5	10	45.8
2021–present	80	15	9	10	46

*PAU 3 figures

1.1 Commercial fisheries

The fishing year runs from 1 October to 30 September. Commercial fishers gather pāua by hand while freediving.

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 shows these fine scale statistical reporting areas with a focus on PAU 3B which became effective on 1 October 2021 and which corresponds to the fine-scale reporting statistical areas 311 to 339.

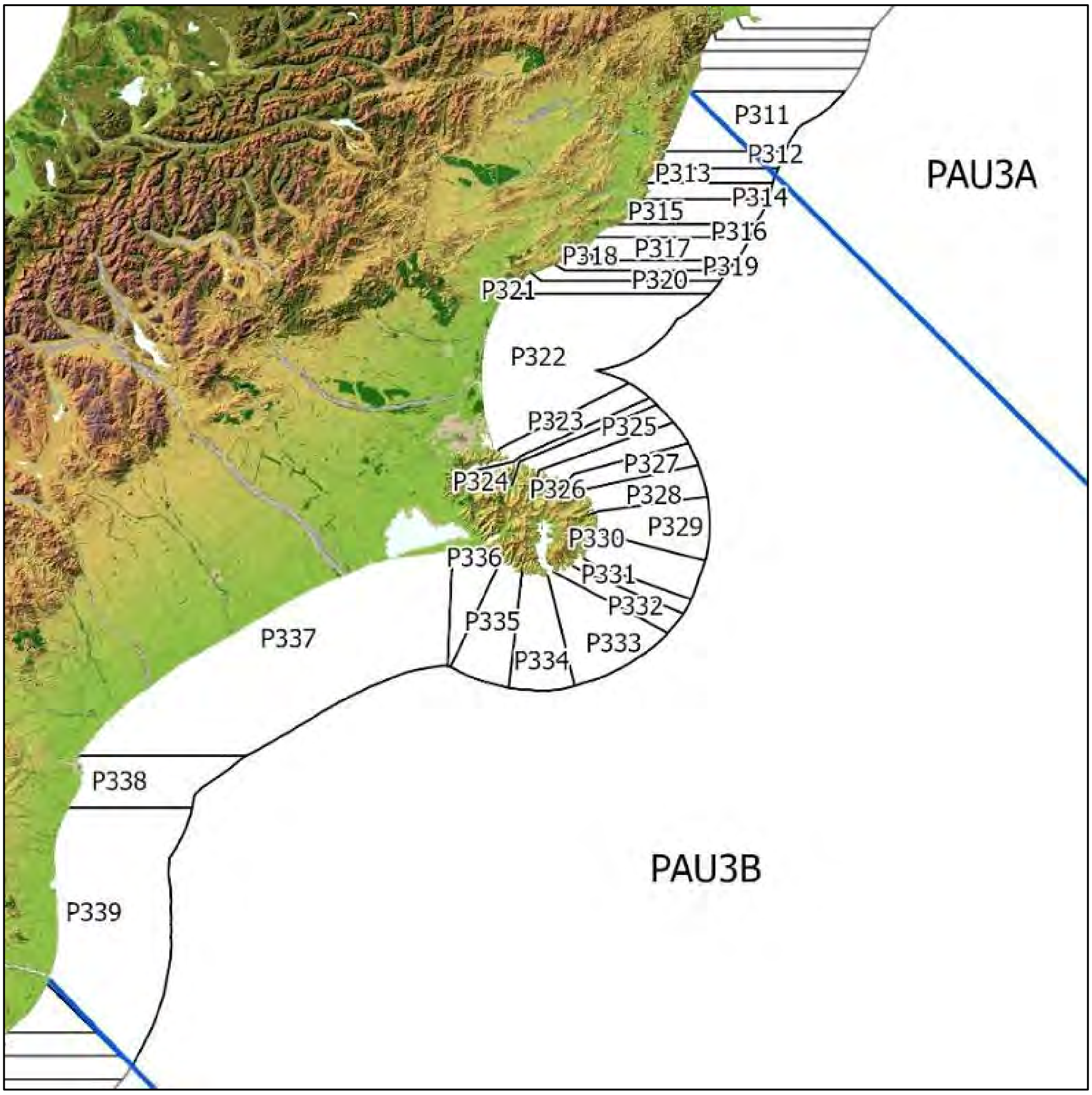


Figure 1: Map of fine scale statistical reporting areas for PAU 3.

Reported landings for PAU 3 are shown in Figure 2 and Table 2 between 1983–84 and 2020–21. Landings in PAU 3 have closely followed the TACC since the fishing year 1991–92. The commercial sector accounts for most of the harvest in the previous PAU 3 fishery.

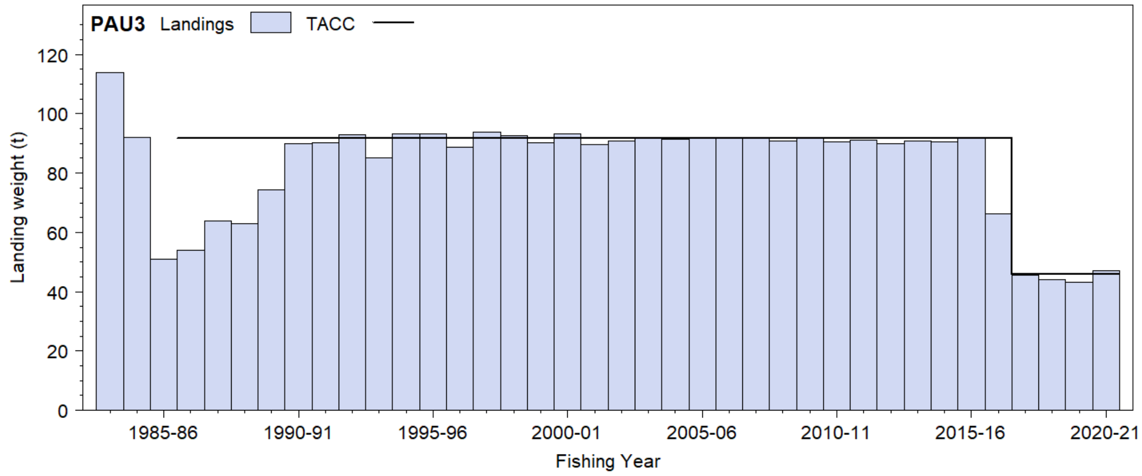
Prior to the 2016 earthquakes, commercial catches predominantly came from the Kaikōura coastline (now PAU 3A) and Motunau/Banks Peninsula. Annual commercial catches were generally evenly distributed between these two fishing areas with about 45 tonnes (50% of the 91.6 tonne TACC) being caught in each area.

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 PāuaMAC3 which divided PAU 3 into four management zones.

A voluntary harvest cap was placed on each management zone and this cap was reviewed annually. Minimum harvest sizes (MHS) were also agreed each year for each zone in addition to the legislated minimum legal size (MLS). These management initiatives were officially in place until 2020–21.

Following the 2016 earthquakes, the coastline from Clarence Point in the north to the Conway River in the south was closed to all commercial (and recreational) fishing. This caused all commercial catches to be taken entirely from the open unaffected Canterbury areas, mainly the southern side of Banks Peninsula.

Table 2 also shows the reconstructed estimated catch equivalent to PAU 3B from the estimated PAU 3 catch between 2001–02 and 2020–21 and the reported landings for PAU 3B since 2021–22. The reported PAU 3B landings in 2021–22 totalled 46.56 t, with a TACC (t) of 46 t.



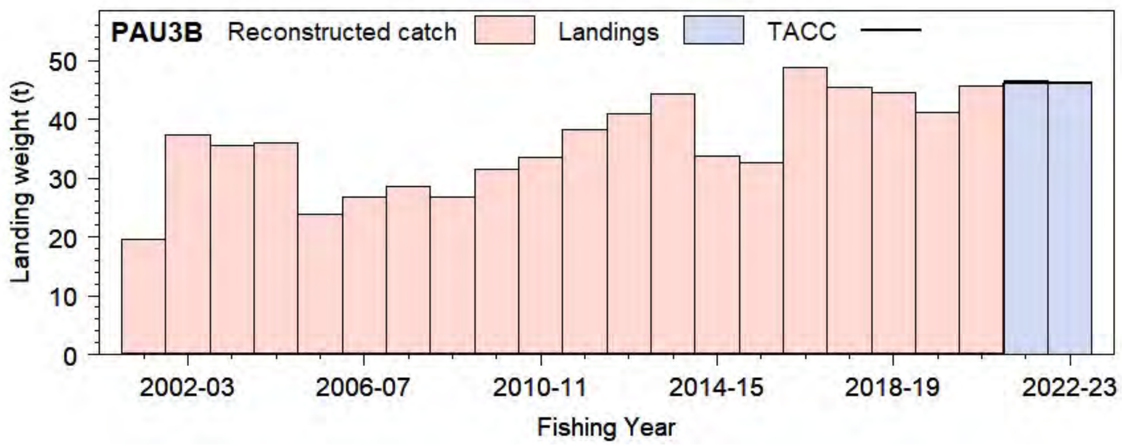


Figure 2: Reported commercial landings and TACC for PAU 3 (top) from 1983–84 to 2020–21 (last year before the QMA subdivision) and PAU 3B (bottom). The PAU 3B reconstructed landings between 2001-02 and 2020–21 correspond to the PAU 3 estimated catch for statistical areas 311 to 339 which correspond to PAU 3B QMA created in 2021–22.

In 2021, the Minister for Ocean and Fisheries approved a Fisheries Plan for the PAU fishery under s11A of the Fisheries Act 1996 to better manage commercial harvest activity across the wider fishery. This Plan prescribes using an 'adaptive rebuild' approach in response to the Kaikōura earthquakes using a number of tools including catch spreading arrangements, harvest control rules, larger minimum harvest size, and fine scale catch reporting and monitoring. The Plan includes new voluntary management areas (Table 3).

Table 2: TACC and reported landings (t) of pāua in PAU 3 between 1983–84 and 2020–21 and in PAU 3B from 2021–22. The PAU 3B reconstructed landings between 2001-02 and 2020-21 correspond to the PAU 3 estimated catch for statistical areas 311 to 339 which correspond to PAU 3B QMA created in 2021–22.

	PAU 3		PAU 3B		
Year	**Landings**	**TACC**	**Reconstructed estimated catch**	**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	19.67	–	–
2002–03	90.92	91.62	37.29	–	–
2003–04	91.58	91.62	35.47	–	–
2004–05	91.43	91.62	36.01	–	–
2005–06	91.60	91.62	23.80	–	–
2006–07	91.61	91.62	26.72	–	–
2007–08	91.67	91.62	28.50	–	–
2008–09	90.84	91.62	26.73	–	–
2009–10	91.61	91.62	31.50	–	–
2010–11	90.40	91.62	33.59	–	–
2011–12	91.14	91.62	38.15	–	–
2012–13	90.01	91.62	40.99	–	–
2013–14	90.85	91.62	44.19	–	–
2014–15	90.44	91.62	33.73	–	–
2015–16	91.73	91.62	32.66	–	–
2016–17	66.29	91.62	48.76	–	–
2017–18	45.59	45.80	45.49	–	–
2018–19	44.05	45.80	44.46	–	–
2019–20	43.09	45.80	41.20	–	–
2020–21	47.10	45.80	45.54	–	–
2021–22	–	–	–	46.56	46.00
2022–23				46.02	46.00

* FSU data.

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

Management zone (since 2021)	Area	Statistical area zone
3B1	Conway River to Motunau Island	P311–P317
3B2	Motunau Island	P318
3B3	Motunau Island to Hickory Bay	P319–P329
3B4	Hickory Bay to Te Oka Bay	P330–P335
3B5	Te Oka Bay to Waitaki River	P336-P339

1.2 Recreational fisheries

For further information on recreational fisheries refer to the Introduction – Pāua chapter. The 'National Panel Survey of Marine Recreational Fishers 2022–23: Harvest Estimates' estimated that the recreational harvest for PAU 3B was 2.4 t with a CV of 33% (Heinemann & Gray, in prep). Previous National Panel Survey estimates from the PAU 3B area are 6.7 t (CV 56%) and 8.8 t (CV 36%) in 2011–12 and 2017–18 (Wynne-Jones et al 2014; 2019).

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

Estimates of customary catch for PAU 3 until 2020–21 are shown in Table 4. These numbers are likely to be an underestimate of customary harvest because only the catch approved and harvested in 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.

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.

Estimates of customary take before the 2016 earthquakes ranged from about 7 to 13 tonnes. Customary take then initially declined given the immediate loss of significant pāua abundance along the Kaikōura coastline, but increased in 2019–20 in response to feeding the local communities during the Covid-19 event. Information is not available at the PAU 3B level up to 2020–21 and customary estimates since 2021–22 for PAU 3B are shown in Table 5.

Table 4: Fisheries New Zealand records of customary harvest of pāua (approved and reported in numbers) in PAU 3 between 2000–01 and 2020–21. Landings data before 2010–11 exclude the area between the Hurunui River and Pegasus Bay. – no data.

	Numbers			Numbers	
Fishing year	**Approved**	**Harvested**	**Fishing year**	**Approved**	**Harvested**
2000–01	300	230	2011–12	5 675	4 242
2001–02	6 239	4 832	2012–13	15 036	12 874
2002–03	3 422	2 449	2013–14	10 259	7 566
2003–04	–	–	2014–15	8 761	7 035
2004–05	–	–	2015–16	14 801	11 808
2005–06	1 580	1 220	2016–17	11 374	9 217
2006–07	5 274	4 561	2017–18	2 708	1 725
2007–08	7 515	5 790	2018–19	480	278
2008–09	10 848	8 232	2019–20	30 288	21 527
2009–10	8 490	6 467	2020–21	11 462	8 609
2010–11	8 360	7 449			

Table 5: Fisheries New Zealand records of customary harvest of pāua (approved and reported in numbers) in PAU 3B since 2021–22. – no data.

Fishing		**Numbers**
year	**Approved**	**Harvested**
2021–22	6 041	4 013
2022–23	2 160	1 086

1.4 Illegal catch

For further information on illegal catch refer to the Introduction – Pāua chapter.

Within the 2021 stock assessment process (no accepted assessment was produced), the SFWG agreed to assume that illegal catches rose linearly from 1 t in 1974 to 10 t in 1990 and remained at 10 t between 1990 and 2000. A subsequent decline in illegal fishing from 10 t in 2000 to 2 t by 2010 was assumed due to perceived advances in fisheries enforcement.

1.5 Other sources of mortality

For further information on other sources of mortality refer to the Introduction – Pāua chapter.

On 16 November 2016 a 7.8 magnitude earthquake hit the upper east coast of the South Island, causing extensive uplift of about 110 km of coastline by as much as 6 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).

The whole northern part of the PAU 3 fishery (Pāua Statistical Areas P301 to P310, now PAU 3A) was impacted to varying degrees by the earthquake; however, the area now included within PAU 3B was largely unaffected. 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.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter. A summary of published estimates of biological parameters for PAU 3 is presented in Table 6. Note, that these values are from the most recent stock assessment covering the whole of PAU 3 and may therefore not be appropriate for PAU 3B. No area-specific, representative biological data are available for PAU 3B.

Table 6: 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	
	2.99×10^{-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

3. STOCKS AND AREAS

For further information on stocks and areas refer to the Introduction – Pāua chapter.

4. STOCK ASSESSMENT

A stock assessment for the PAU 3B area was attempted in 2021–22, based on estimates of historical catches, CPUE trends, and commercial length frequency data. CPUE trends were found to be stable despite steady increases in catch over the past decades. For this reason, all stock assessment models that were attempted estimated an exceedingly high biomass that was judged to be implausible by the Fisheries New Zealand Shellfish Working Group. In the absence of an acceptable assessment model, the Shellfish Working Group explored comparative analyses of absolute CPUE in PAU 3B in comparison with areas of assessed stock status. These analyses were used to gain a qualitative understanding of current biomass level and exploitation rate in the fishery.

4.1 Relative abundance estimates from standardised CPUE analyses

PCELR and ERS data from 2002 to 2021 were used to derive a standardised, fishery-dependent index of abundance, initially for use within a stock assessment model, and subsequently to estimate median current absolute CPUE. Data prior to 2002 (CELR, FSU reporting) were not used in the assessment process; as for other recent assessments, changes to the composition of the fleet and gear during the 1990s, combined with inconsistent reporting, mean that the trends in CPUE from CELR data are questionable and likely hyper-stable to an unknown degree in most PAU QMAs.

CPUE standardisation was carried out using Bayesian Generalised Linear Mixed Models (GLMM) which partitioned variation among fixed (research strata) and random variables. CPUE was defined as the log of daily catch. Variables in the model were fishing year, estimated fishing effort, client number, research stratum, diver ID (PCELR). Previous standardisation models for PCELR data routinely used small scale statistical areas as a standardising variable. For the present assessment, this variable was not available with sufficient precision for recent (ERS) data, where it is inferred from position data, and was therefore omitted. Nevertheless, follow-up work on the quality of ERS data for pāua CPUE suggested limited effects of spatial reporting and the inclusion, or not, of statistical areas in the standardisation made little difference to resulting indices before 2021 (Neubauer & Kim 2023).

Standardised CPUE in all areas suggested increases in recent years, after nearly two decades of stable CPUE (Figure 3), with the most notable increase in zone B2 - Motunau Island and highly variable trends in raw CPUE in other areas. While other zones (B3, B4) also showed increases in raw CPUE in 2020 and 2021, these increases were largely compensated by the standardisation model. Median absolute CPUE (> 50 kg/h) was found to be substantially higher than in all assessed PAU QMAs (< 50 kg/h), suggesting that current PAU densities in PAU 3B are high relative to other QMAs. The latter may be linked to relatively low catches across the PAU 3B area prior to the 2016 Kaikōura earthquake, when most of the commercial catch was located in areas P301–P310, which now make up the PAU 3A QMA.

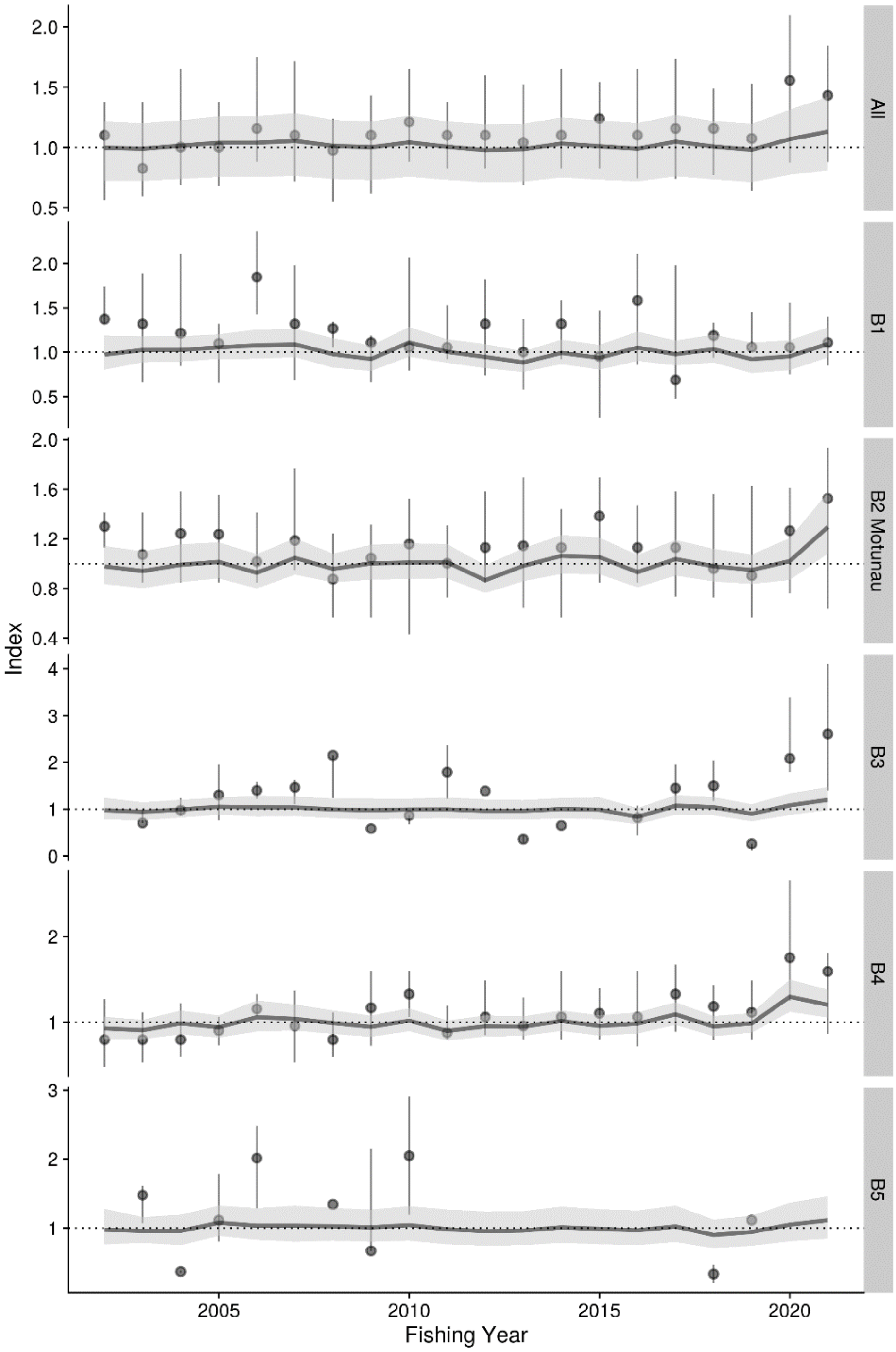


Figure 3: Raw CPUE (points are median with inter-quartile interval indicated by vertical intervals) and standardised CPUE index (line) with 95% confidence interval (shaded ribbon) by industry management zone (B1–B5) and overall (All). Shading of points indicates the relative amount of data available for standardisation.

4.2 Operating model and testing management procedures

With the establishment of PAU 3B, there has been increased interest in understanding the stock status of the area and in developing management measures that can maintain the fishery at target levels. Between 2020 and 2022, a project aimed to develop models to understand stock status and to test potential management procedures in PAU 3B.

The project compiled catch, catch-per-unit-effort (CPUE), and length frequency information to inform models for stock in PAU 3B. Catch and CPUE information is only known with some certainty since the early 2000s and the establishment of fine-scale pāua statistical areas, which allow partitioning of PAU 3 catches and catch and effort data into PAU 3A and PAU 3B components. Assumptions about spatial catch splits needed to be made to reconstruct catches prior to 2002. Nevertheless, early catches were likely relatively low because the area was less targeted by commercial fisheries than the northern area of PAU 3. The CPUE has remained relatively constant throughout the 2000s, with a small increase in recent years (see section 4.1).

An initial attempt to fit stock assessment models was unsuccessful based on the flat or increasing CPUE, which occurred in the context of increasing catch over time. In the absence of a robust stock assessment model, the use of CPUE (kg/h) relative to CPUE in other areas was explored as an indirect measure of potential stock status or exploitation rate. This approach suggested a relatively low exploitation rate and high stock status.

To test potential harvest control rules, we used empirical estimates of stock status to condition operating models using depletion-based stock reduction analysis. The operating models produced a range of outcomes depending on productivity assumptions and conditioning constraints and were used to test the suitability of control rules to maintain target catch rates.

4.3 Other factors

Another source of uncertainty are the catch data. The commercial catch is known with accuracy since 1985 but is probably not well estimated before that. Furthermore, the recent split of PAU 3 into PAU 3A and PAU 3B following the Kaikōura earthquake and subsequent fishery closure did not match the early (CELR) reporting areas, leading to substantial uncertainties about catch prior to 2002, when PCELR and fine-scale reporting was introduced. In addition, non-commercial catch estimates are poorly determined. Therefore, better information on the scale and trend in recreational catch needs to be collated for more accurate assessment of the stock status.

5. STATUS OF THE STOCKS

- **PAU 3B - Canterbury**

Stock Status		
Most Recent Assessment Plenary Publication Year	2022, not successful given conflicting signals in catch and CPUE trends	
Catch in most recent year of assessment	Year: 2020–21	Catch: 46 t
Assessment Runs Presented	-	
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	Unknown, but likely relatively high given that CPUE levels are well above most other mainland QMAs	
Status in relation to Limits	Unknown	
Status in relation to Overfishing	Unknown	

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has been stable or increasing in all management zones, despite increasing catches.
Recent Trend in Fishing Intensity or Proxy	Steady increase in catch over the past decades, but high and stable CPUE suggests low overall exploitation rates.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	None accepted	
Assessment Method	N/A	
Assessment Dates	Latest assessment Plenary publication year: 2021	Next: unknown
Overall assessment quality (rank)	N/A	
Main data inputs (rank)	- Catch history - CPUE indices early series - CPUE indices later series (since 2002) - Commercial sampling length frequencies	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
	- Tag recapture data (to estimate growth) - Maturity at length data	2 – Medium or Mixed Quality: no area specific data, inferred from meta-analysis of New Zealand-wide data 1 – Medium or Mixed Quality: no area specific data, inferred from meta-analysis of New Zealand-wide data
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	No accepted stock assessment model	
Major Sources of Uncertainty	- Catch levels and trends uncertain prior to 2002 - CPUE may not be a reliable index of abundance at low exploitation rates - Very little growth data available and growth not well known	

Qualifying Comments:
-

Fishery Interactions
-

6. FOR FURTHER INFORMATION

Alestra, T; Gerrity, S; Dunmore, R A; Marsden, I; Pirker, J; Schiel, D R (2019) Rocky reef impacts of the Kaikōura earthquake: quantification and monitoring of nearshore habitats and communities. *New Zealand Aquatic Environment and Biodiversity Report No. 212*. 120 p.

Alestra, T; Gerrity, S; Dunmore, R A; Schiel, D R (2020) Rocky reef impacts of the Kaikōura earthquake: extended monitoring of nearshore habitats and communities – Year 1 results. *New Zealand Fisheries Assessment Report 2019/01*. 40 p.

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

Fu, D (2013) The 2012 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2013/57.*

Fu, D (2014) The 2013 stock assessment of paua (Haliotis iris) for PAU 3. *New Zealand Fisheries Assessment Report 2014/44*.

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

Gorfine, H K; Dixon, C D (2000) A behavioural rather than resource-focused approach may be needed to ensure sustainability of quota managed abalone fisheries. *Journal of Shellfish Research 19*: 515–516.

Heinemann A; Gray, A. (in prep.) National Panel Survey of Recreational Marine Fishers 2022-23.

Kim, S W (2004) CPUE analysis of fine-scale logbook data for PAU 3. Ministry of Fisheries Research Report PAU 2001/01 Obj. 7. (Unpublished report held by Fisheries New Zealand, Wellington.)

McCowan, T; Neubauer, P (2018) Paua biomass estimates and population monitoring in areas affected by the November 2016 Kaikoura earthquake. *New Zealand Fisheries Assessment Report 2018/54*. 24 p.

McCowan, T; Neubauer, P (2021) Pāua abundance trends and population monitoring in areas affected by the November 2016 Kaikōura earthquake. *New Zealand Fisheries Assessment Report 2021/26*. 23 p.

McCowan, T A; Neubauer, P (2022) Pāua abundance trends and population monitoring in areas affected by the November 2016 Kaikōura earthquake, December 2021 update. *New Zealand Fisheries Assessment Report 2022/15.* 20 p.

McCowan, T A; Neubauer, P (2023). Pāua population monitoring in areas affected by the November 2016 Kaikōura earthquake, February 2023 update. *New Zealand Fisheries Assessment Report 2023/26*. 19 p.

McKenzie, A; Naylor, J R; Smith, N H (2009) Characterisation of PAU 2 and PAU 3. Final Research Report. 58 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Naylor, J R; Andrew, N L (2000) Determination of growth, size composition, and fecundity of paua at Taranaki and Banks Peninsula. *New Zealand Fisheries Assessment Report 2000/51*. 25 p.

Naylor, J R; Andrew, N L; Kim, S W (2006) Demographic variation in the New Zealand abalone *Haliotis iris. Marine and Freshwater Research 57*: 215–224.

Neubauer, P (2017) Area lost to the paua fishery from the November 2016 Kaikoura earthquake, 7 p. (Unpublished report held by Fisheries New Zealand.)

Neubauer, P; Kim, K (2023) Developing an operating model and testing management procedures for pāua (*Haliotis iris*) fisheries in PAU 3B. *New Zealand Fisheries Assessment Report 2023/27*. 65 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.

Poore, G C B (1972) Ecology of New Zealand abalones, *Haliotis* species (Mollusca: Gastropoda). 3. Growth. *New Zealand Journal of Marine and Freshwater Research 6*: 534–559.

Poore, G C B (1973) Ecology of New Zealand abalones, *Haliotis* species (Mollusca: Gastropoda). 4. Reproduction. *New Zealand Journal of Marine and Freshwater Research 7 (1&2)*: 67–84.

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.

Shepherd, S A; Partington, D (1995) Studies on Southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. *Marine and Freshwater Research 46*: 669–680.

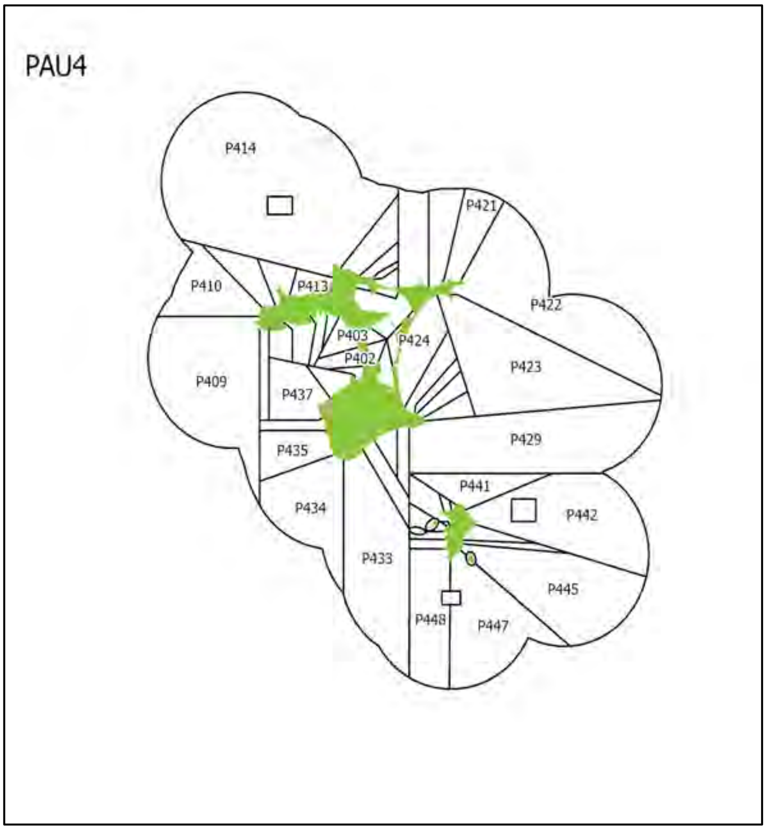
Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. (Unpublished report GEN2007A held by Fisheries New Zealand, Wellington). 37 p.

Wynne-Jones,J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67.* 139 p.

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

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 appeared 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 was still set in greenweight but fishers were required to report greenweight catch that is estimated from the meatweight measured by the licensed fish receiver (LFR). The meatweight to greenweight conversion factor was 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. This meatweight reporting requirement was changed back to greenweight at the beginning of the 2017–18 year. This was due to issues with the accurate meatweight being recorded and delays in weighting the meat which meant that the conversion back to greenweight was not accurate due to blood and moisture loss being variable across the different processors and landing fishing receivers (LFRs).

Reported landings have remained below the TACC since 2010–11, averaging 276 t in 2010–11 to 2016–17 before decreasing to an average of 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	Year	Landings	TACC
1983–84*	409.00	–	2003–04	325.85	326.54
1984–85*	278.00	–	2004–05	319.24	326.54
1985–86*	221.00	–	2005–06	322.53	326.54
1986–87*	267.37	261.00	2006–07	322.76	326.54
1987–88*	279.57	269.08	2007–08	323.98	326.54
1988–89*	284.73	270.69	2008–09	324.18	326.54
1989–90	287.38	287.25	2009–10	323.57	326.54
1990–91	253.61	287.25	2010–11	262.15	326.54
1991–92	281.59	287.25	2011–12	262.07	326.54
1992–93	266.38	287.25	2012–13	263.33	326.54
1993–94	297.76	287.25	2013–14	291.98	326.54
1994–95	282.10	287.25	2014–15	295.16	326.54
1995–96	220.17	326.54	2015–16	294.73	326.54
1996–97	251.71	326.54	2016–17	264.63	326.54
1997–98	301.69	326.54	2017–18	203.03	326.54
1998–99	281.76	326.54	2018–19	185.06	326.54
1999–00	321.56	326.54	2019–20	188.47	326.54
2000–01	326.89	326.54	2020–21	196.65	326.54
2001–02	321.64	326.54	2021–22	209.10	326.54
2002–03	325.62	326.54	2022–23	202.04	326.54

* FSU data

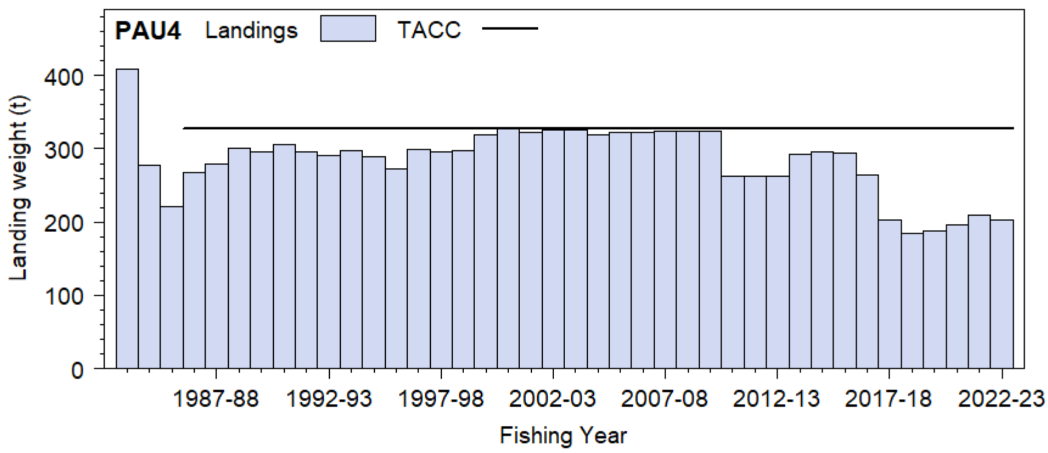


Figure 1: Reported commercial landings and TACC for PAU 4 from 1983–84 to the present.

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. There are 14 areas around the Chatham Islands which are closed to commercial fishing and act as recreational/customary only fishing areas. It is assumed that a significant portion of recreational catch is taken from these areas.

1.3 Customary fisheries
Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

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 approved and harvested 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.

Table 3: Fisheries New Zealand records of customary harvest of pāua (approved and reported as weight (kg) and in numbers) of pāua in PAU 4 from 2009–10 to present. – 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	53	85	820	764
2018–19	330	330	–	–
2019–20	–	–	–	–
2020–21	–	–	–	–
2021–22	–	–	–	–
2022–23	–	–	–	–

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

For further information on customary fisheries refer to the Introduction – Pāua chapter.

1.4 Illegal catch
There are no estimates of illegal catch for PAU 4. For the 2004 stock assessment and 2023 operational models for harvest control rule evaluations this catch was assumed to be zero. For further information on illegal catch refer to the Introduction – Pāua chapter.

1.5 Other sources of mortality
For further information on other sources of mortality refer to the Introduction – Pāua chapter.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter.

3. STOCKS AND AREAS

For further information on stocks and areas refer to the Introduction – Pāua chapter.

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.

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 Operating model development and harvest control rule evaluation

From 2020 to 2023, a series of projects aimed to develop an operating model and to test management procedures that could formalise current statistical area-scale industry management initiatives (Neubauer & Kim 2023). Operating models were developed as spatial length-based models at the scale of individual pāua statistical areas. Due to a lack of sufficiently reliable time series of catch and CPUE, stock assessment models could not be fitted statistically but were conditioned on assumed catch time series. Conditioning assumed a distribution of plausible current stock status levels and simulated a range of stock trajectories that are consistent with assumed status.

Status assumptions were initially derived from a meta-analysis of stock status against catch-per-unit-effort in QMAs with accepted stock assessments. Results from this analysis suggested very high status and did not reflect industry concerns that have led to shelving of annual catch entitlements over the past decade. More conservative assumptions about stock status were therefore used to condition models, with conditioning scaled spatially from an analysis of recent spatial CPUE, which was judged more reliable than past CPUE trends based on CELR or PCELR data.

Control rules for management procedures were developed from a template applied in other pāua fisheries and centred on a target catch-rate given by fishers and catches as specified in the 2022 PAU 4 annual operating plan for each statistical area. Rules were then scaled according to assumed differences in available biomass between statistical areas derived from spatial CPUE (Figure 2). These rules were used as a preliminary set of rules to test the potential of formalising current industry management practice which considers catch as a function of perceived status at the statistical area level.

Conditioned models suggested a range of outcomes across individual statistical areas; these differences were attributed to conditioning assumptions in the model. While application of control rules led to variable outcomes at the statistical area-scale, the spatial variability averaged out on the large scale, leading to highly stable trends at the QMA scale for an implementation window of 5 years (Figure 3) and indicating low risk of further declines under the trialled preliminary harvest control rules.

4.4 Biomass estimates

There are no current biomass estimates for PAU 4.

4.5 Yield estimates and projections

There are no estimates of PAU 4.

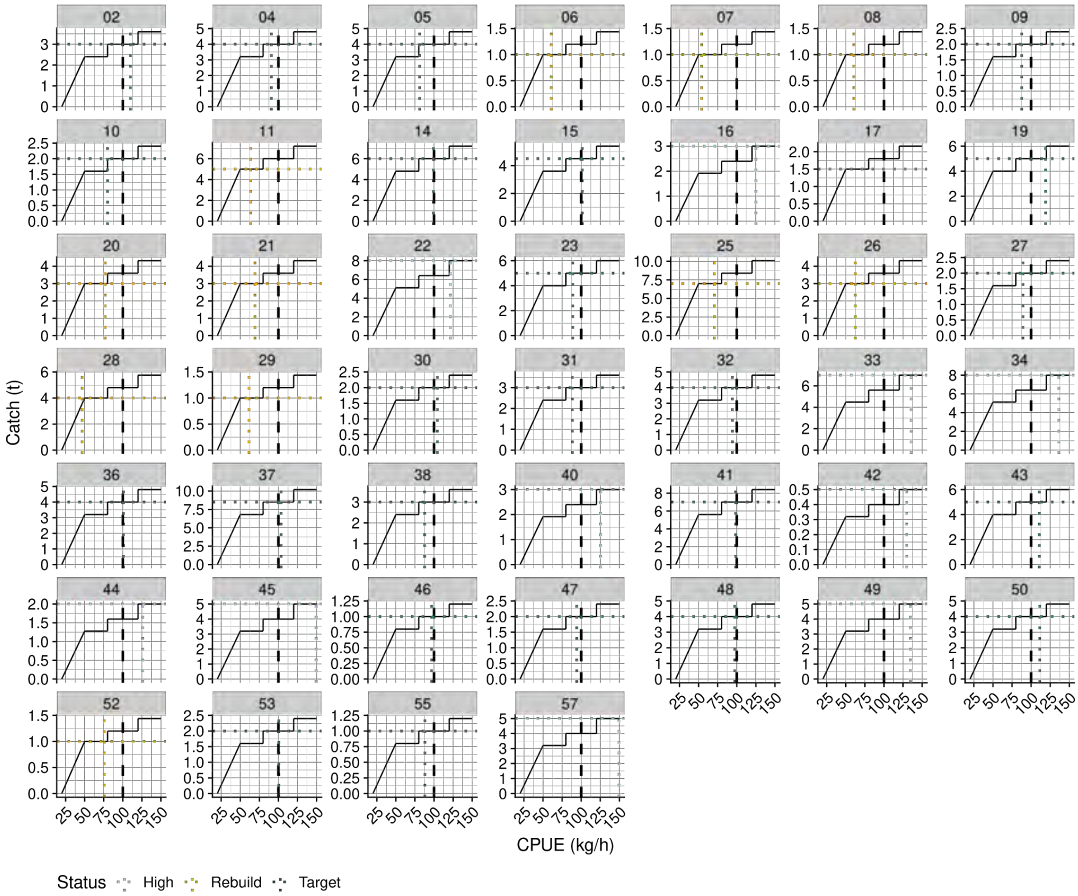


Figure 2: Preliminary harvest control rules for PAU 4 (by statistical area): total commercial catch (TCC) as a function of catch-per-unit-effort (CPUE). Target CPUE is shown as the dashed vertical line, recent CPUE and corresponding control rule catch are shown in coloured dotted lines, corresponding to estimates of areas being below ('Rebuild'), at ('Target'), or above target ('High').

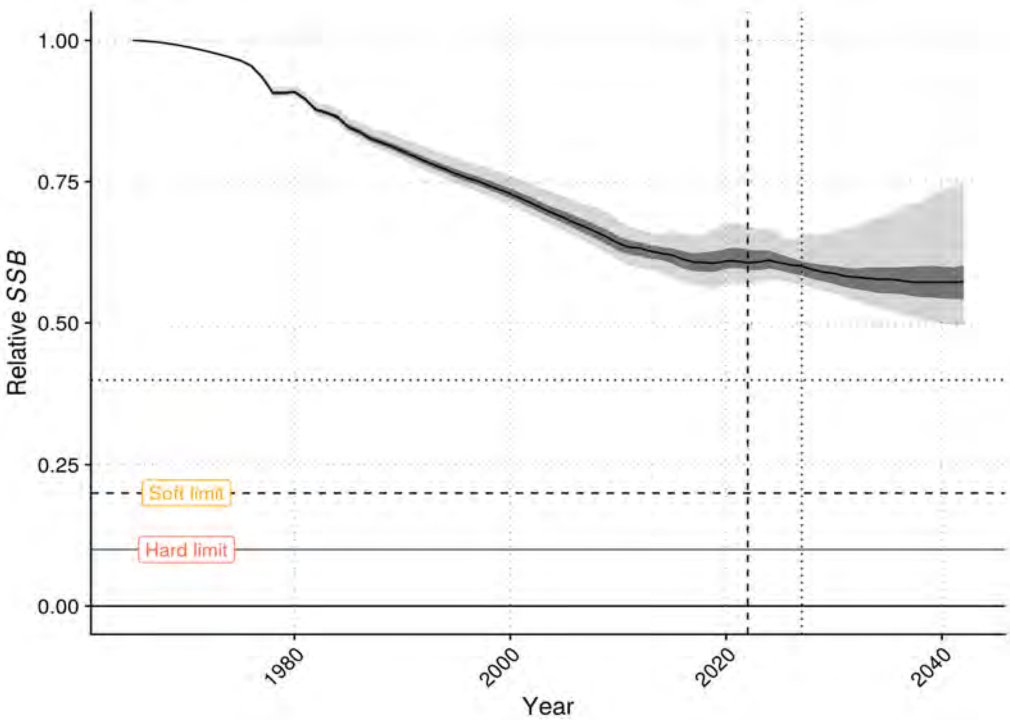


Figure 3: Projected relative spawning stock biomass (*SSB*) under base conditioning and biological assumptions in the PAU 4 operating model. The dashed vertical line shows the beginning of simulated trends based on the assessed harvest control rule, the dotted vertical line shows the tested limit of validity (5 years) of the tested rule. The last projection year is 2041.

5. STATUS OF THE STOCKS

Stock Structure Assumptions
Haliotis 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 - Chatham Islands

Due to concerns over reported catch and effort, no formal integrated stock assessment of the resource has been successful for several years, and the status of the fishery continues to be unknown. However, an operating model was developed in 2022, and management procedures were tested to attempt to formalise current statistical-area scale industry management initiatives.

Operating models were developed as spatial length-based models at the scale of individual pāua statistical areas. Due to a lack of sufficiently reliable time-series of catch and CPUE, stock assessment models could not be fitted statistically, but were conditioned on assumed catch times series. Conditioning assumed a distribution of plausible current stock status levels and simulated a range of stock trajectories that are consistent with assumed status.

Status assumptions were initially derived from a meta-analysis of stock status against catch-per-unit-effort in QMAs with accepted stock assessments. Results from this analysis suggested very good status and did not reflect industry concerns that have led to shelving of annual catch entitlements over the past decade. More conservative assumptions about stock status were therefore used to condition models, with conditioning scaled spatially from an analysis of recent spatial CPUE, which was judged more reliable than past CPUE trends based on CELR or PCELR data.

The model suggested potential declines in statistical areas with low CPUE and low past catch. However, due to their low biomass, these areas contribute relatively little to the QMA-wide trends. Despite a range of outcomes and variable trends at small spatial scales, trends at the QMA scale were relatively stable and suggested an overall stable fishery with low risk of further declines under the trialled harvest control rules.

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 Fisheries 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.

Neubauer, P; Kim, K (2023) Developing an operating model and testing management procedures for pāua (*Haliotis iris*) fisheries in PAU 4. *New Zealand Fisheries Assessment Report 2023/29.* 50 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.

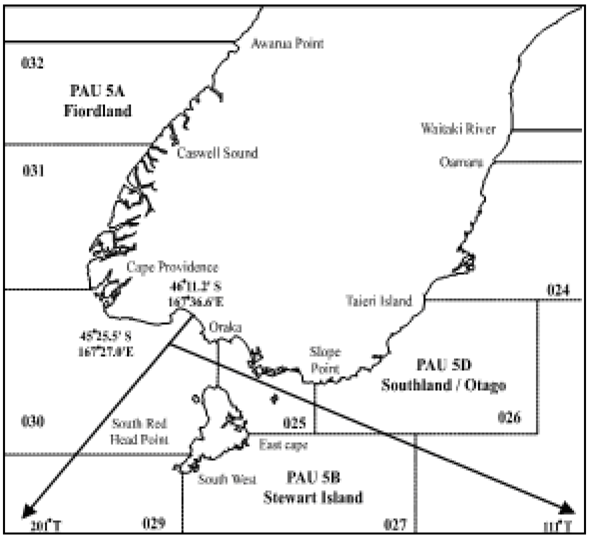
Schiel, D R (1992) The paua (abalone) fishery of New Zealand. *In:* Shepherd, S A; Tegner, M J; Guzman del Proo, S (Eds.), *Abalone of the World: Biology, fisheries, and culture.* Blackwell Scientific, Oxford.

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).

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 Introduction – Pāua chapter.

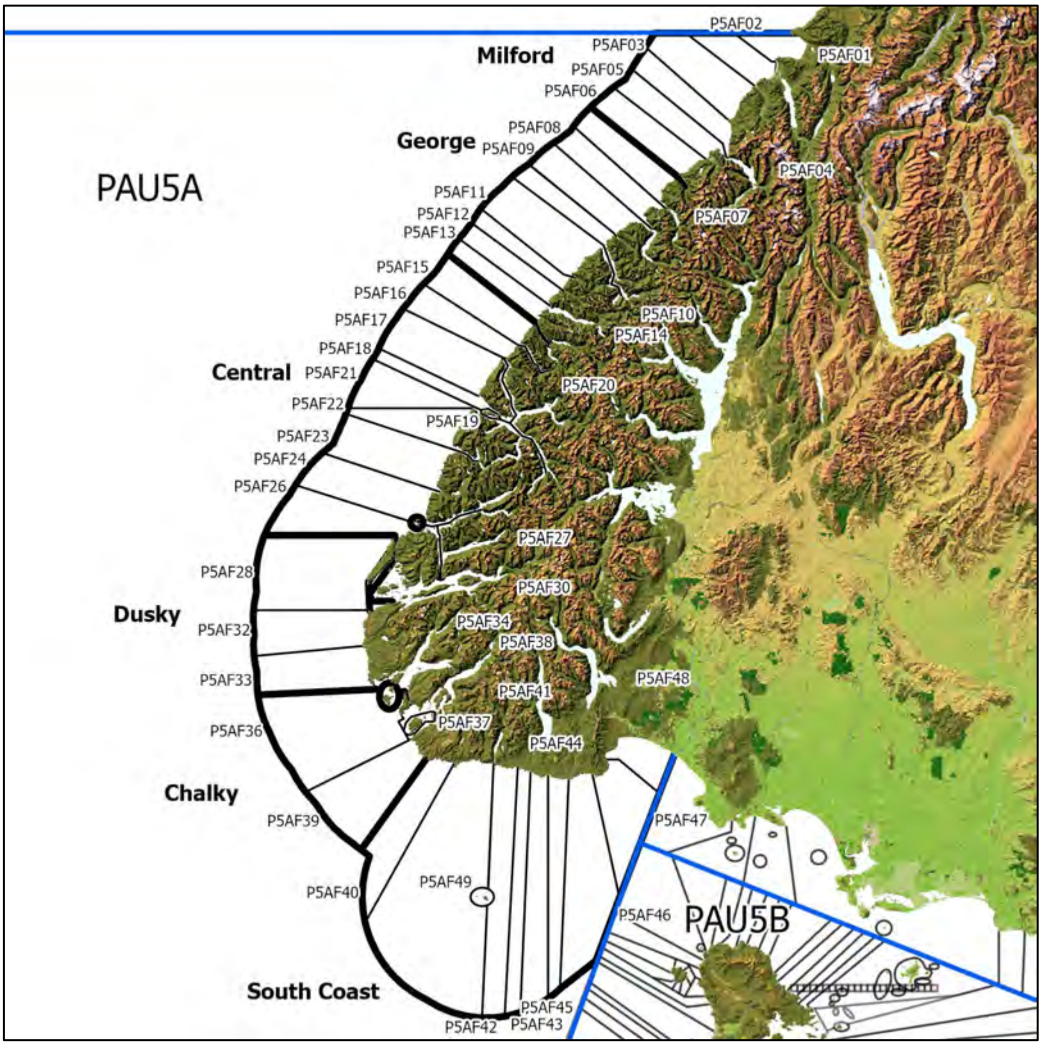


Figure 1: Map of Pāua Statistical Areas, and voluntary management strata in PAU 5A.

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

Year	Landings	TACC	Year	Landings	TACC
1995–96	139.53	148.98	2009–10	105.74	148.98
1996–97	141.91	148.98	2010–11	104.40	148.98
1997–98	145.22	148.98	2011–12	106.23	148.98
1998–99	147.36	148.98	2012–13	105.56	148.98
1999–00	143.91	148.98	2013–14	102.30	148.98
2000–01	147.70	148.98	2014–15	106.95	148.98
2001–02	148.53	148.98	2015–16	106.84	148.98
2002–03	148.76	148.98	2016–17	106.50	148.98
2003–04	148.98	148.98	2017–18	107.45	148.98
2004–05	148.95	148.98	2018–19	99.66	148.98
2005–06	148.92	148.98	2019–20	103.03	148.98
2006–07	104.03	148.98	2020–21	106.02	148.98
2007–08	105.13	148.98	2021–22	114.88	148.98
2008–09	104.82	148.98	2022–23	111.51	148.98

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 (CV 0.76) 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 0.71 t (CV 0.81). 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.

The most recent national panel survey harvest estimate for PAU 5A is 1.58 t (CV 0.68) for 2022–23 (Heinemann & Gray in prep).

For further information on recreational fisheries refer to the Introduction – Pāua chapter.

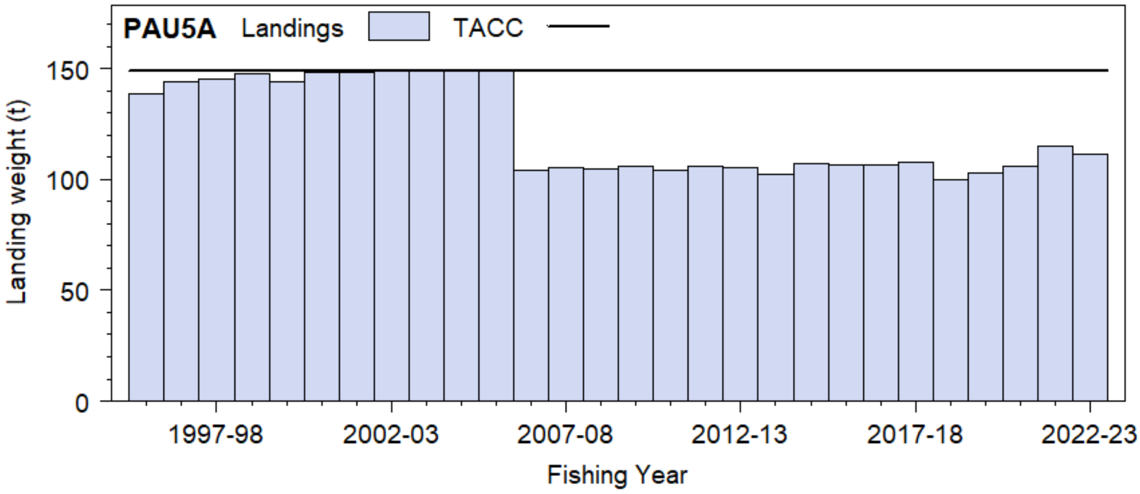


Figure 2: Landings and TACC for PAU 5A from 1995–96 to the present. For historical landings in PAU 5 prior to 1995–96, refer to figure 1 and table 1 in the Introduction – Pāua chapter.

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

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 approved and harvested in numbers is 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.

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

	Numbers	
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	–	–
2019–20	–	–
2020–21	850	820
2021–22	–	–
2022–23	–	–

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).

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 Introduction – Pāua chapter.

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 Introduction – Pāua chapter.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter. 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 Introduction – Pāua chapter.

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 2020). 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	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.

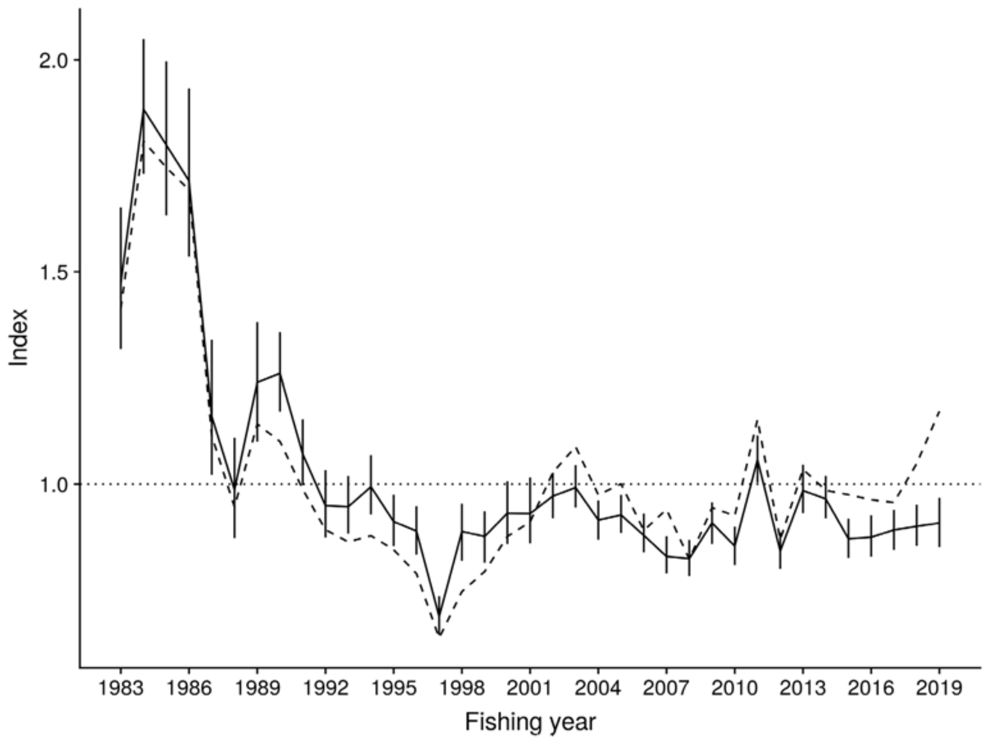


Figure 3: The standardised CPUE indices with 95% confidence intervals (solid line and vertical error bars) and unstandardised geometric CPUE (dashed line) for the combined CELR and the PCELR series.

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 Introduction – Pāua chapter.

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 2022). 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 2020) 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 (2020) 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 (SSB_{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).

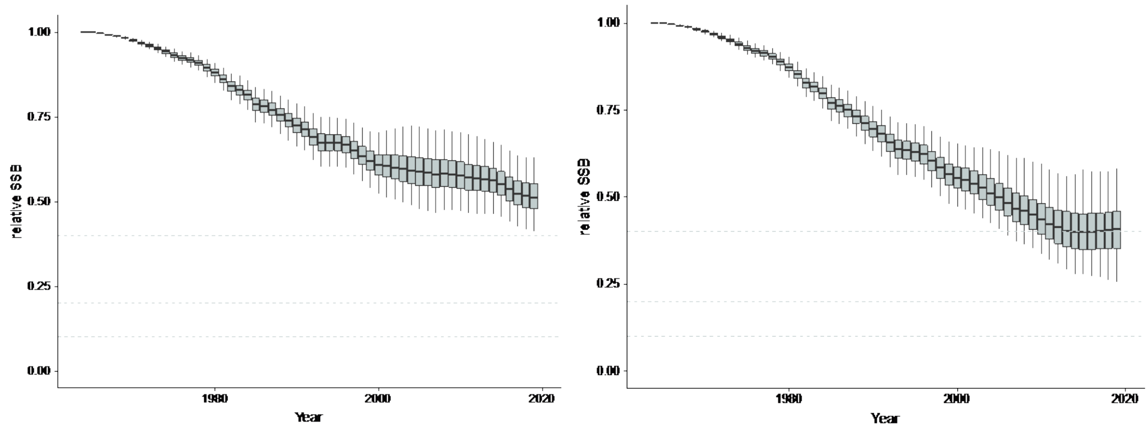


Figure 4: Posterior distributions of spawning stock biomass from the base case model, the sensitivity scenario with increasing catchability. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 95% confidence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

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
	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

4.4 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 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

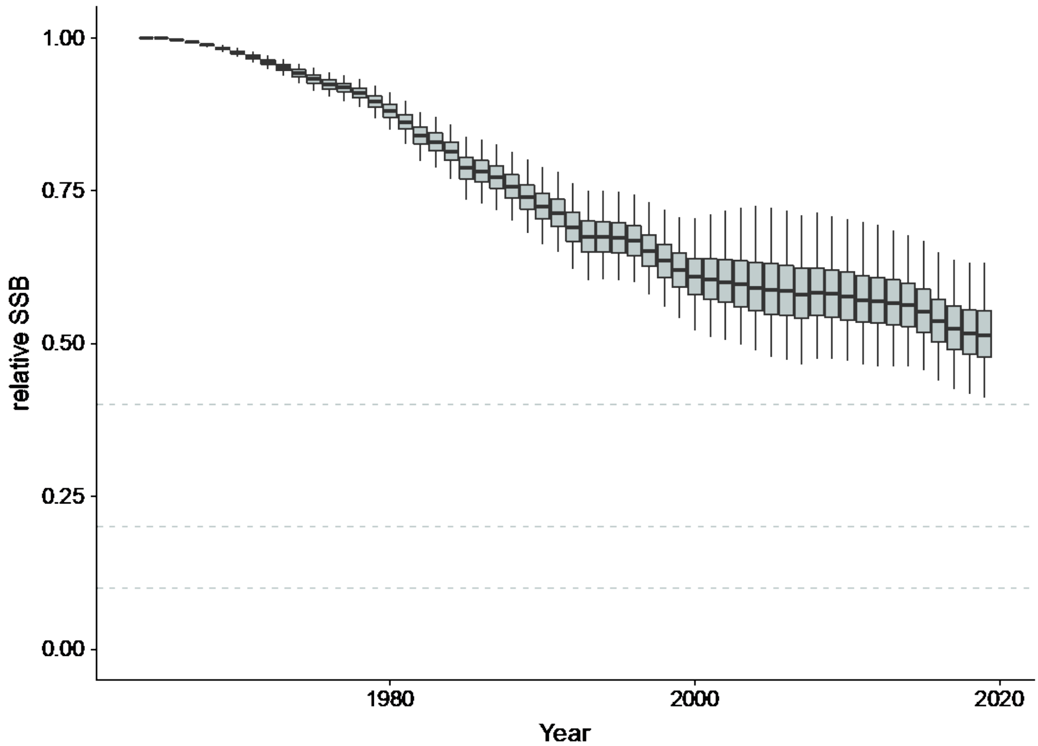
Stock Structure Assumptions
A genetic discontinuity between North Island and South Island pāua populations was found approximately around the area of Cook Strait (Will & Gemmell 2008).

- **PAU 5A - Fiordland**

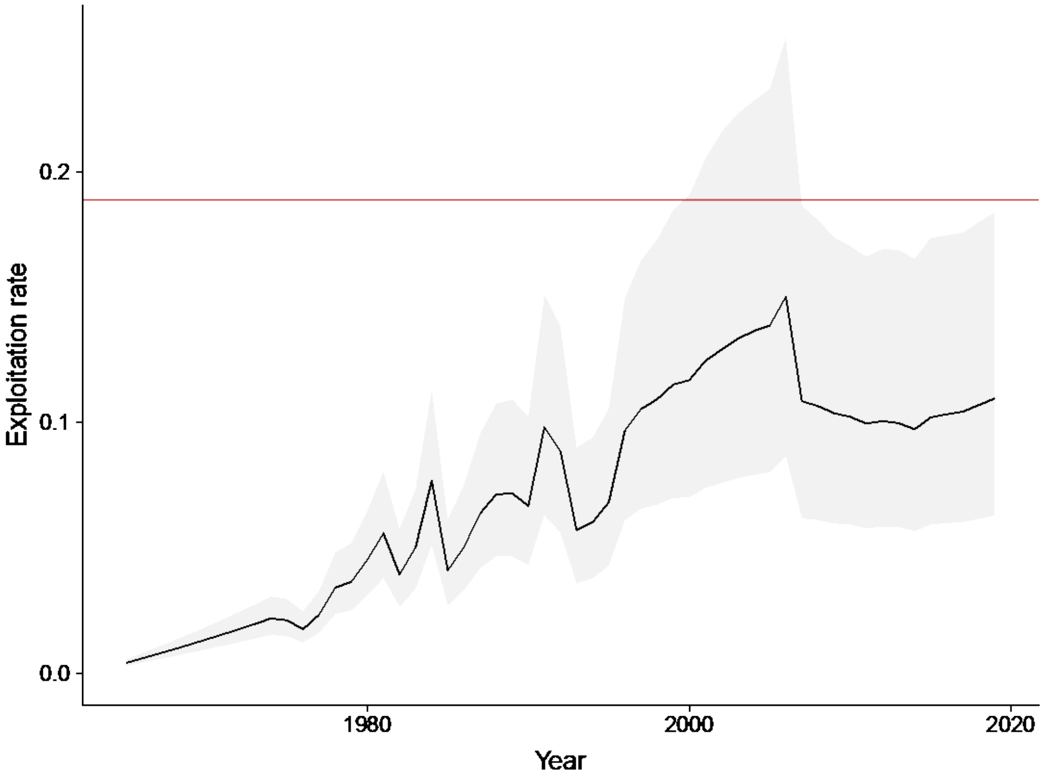
Stock Status		
Most Recent Assessment Plenary Publication Year	2020	
Catch in most recent year of assessment	Year: 2018–19	Catch: 100 t
Assessment Runs Presented	Base case Sensitivity with linearly increasing catchability	
Reference Points	Target: 40% B_0 (Default as per HSS) Soft Limit: 20% B_0 (Default 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.

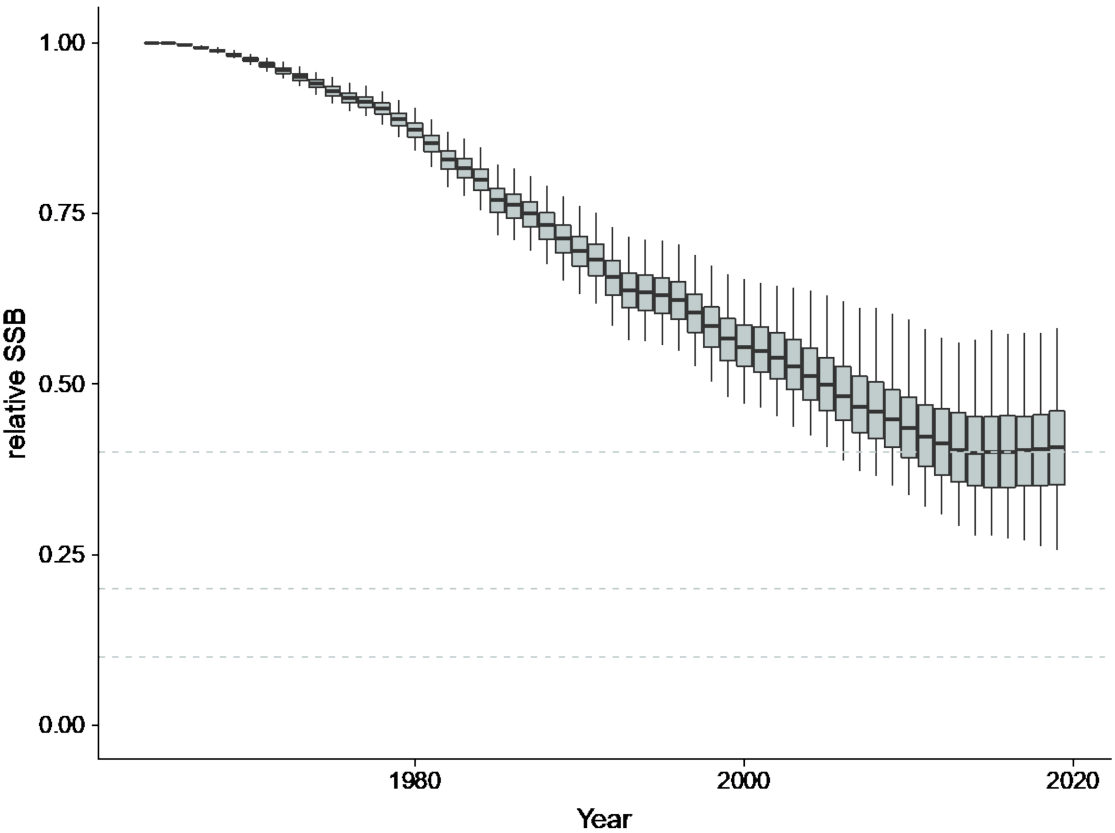
Historical Stock Status Trajectory and Current Status



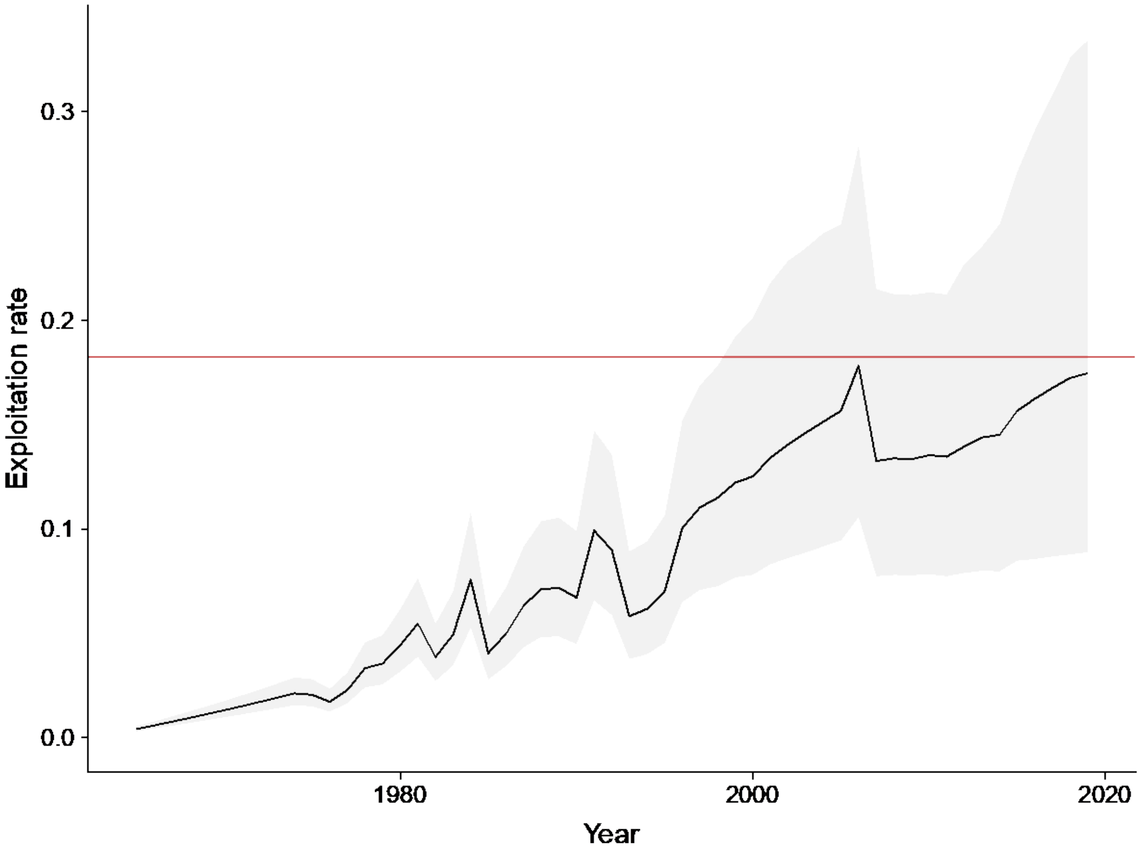
Posterior distributions from the base case model of spawning stock biomass as a percentage of SSB_0. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the 2.5th and 97.5th percentiles of the distribution. Dashed 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 SSB_0.



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 Plenary publication year: 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	3 – Low Quality: not believed to index the stock
	- Research Dive Length Frequencies	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
-

6. FOR FURTHER INFORMATION

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

Andrew, N L; Naylor, J R; Kim, S W (2002) Fishery independent surveys of the relative abundance and size structure of paua (*Haliotis iris*) in PAU 5B and 5D. *New Zealand Fisheries Assessment Report 2002/41*. 41 p.

Breen, P A; Andrew, N L; Kendrick, T H (2000) The 2000 stock assessment of paua (*Haliotis iris*) in PAU 5B using an improved Bayesian length-based model. *New Zealand Fisheries Assessment Report 2000/48*. 36 p.

Breen, P A; Kim, S W (2004) The 2004 stock assessment of paua (*Haliotis iris*) in PAU 5A. *New Zealand Fisheries Assessment Report 2004/40*. 86 p.

Breen, P A; Kim, S W (2005) The 2005 stock assessment of paua *(Haliotis iris)* in PAU *7*. New *Zealand Fisheries Assessment Report 2005/47*. 114 p.

Breen, P A; Kim, S W (2007) The 2006 stock assessment of paua (*Haliotis iris*) stocks PAU 5A (Fiordland) and PAU 5D (Otago). *New Zealand Fisheries Assessment Report 2007/09*. 164 p.

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

Breen, P A; Smith, A N H (2008) Data used in the 2007 assessment for paua (*Haliotis iris*) stock PAU 5B (Stewart Island). *New Zealand Fisheries Assessment Report 2008/6*. 45 p.

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

Cordue, P L (2009) Analysis of PAU 5A diver survey data and PCELR catch and effort data. SeaFic and PAUMac 5 report. 45 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Francis, R I C C (2011) Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68*: 1124–1138.

Fu, D (2013) The 2012 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2013/57*.

Fu, D (2014) The 2013 stock assessment of paua (*Haliotis iris*) for PAU 5B. *New Zealand Fisheries Assessment Report 2014/45*.

Fu, D (2015a) The 2014 stock assessment of paua (*Haliotis iris*) for Chalky and South Coast in PAU 5A. *New Zealand Fisheries Assessment Report 2015/64*.

Fu, D (2015b) The 2014 stock assessment of paua (*Haliotis iris*) for Milford, George, Central, and Dusky in PAU 5A. *New Zealand Fisheries Assessment Report 2015/65*.

Fu, D; McKenzie, A (2010a) The 2010 stock assessment of paua (*Haliotis iris*) for Chalky and South Coast in PAU 5A. *New Zealand Fisheries Assessment Report 2010/36*.

Fu, D; McKenzie, A (2010b) The 2010 stock assessment of paua (*Haliotis iris*) for Milford, George, Central, and Dusky in PAU 5A. *New Zealand Fisheries Assessment Report 2010/46*.

Fu, D; McKenzie, A; Naylor, R (2010) Summary of input data for the 2010 PAU 5A stock assessment. *New Zealand Fisheries Assessment Report 2010/35*.

Fu, D; McKenzie, A; Naylor, R (2015) Summary of input data for the 2014 PAU 5A stock assessment. *New Zealand Fisheries Assessment Report 2015/68*.

Heinemann A; Gray, A. (in prep.) National Panel Survey of Recreational Marine Fishers 2022-23.

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

Haist, V (2010) Paua research diver survey: review of data collected and simulation study of survey method. *New Zealand Fisheries Assessment Report 2010/38*.

Hart, A M (2005) Review of paua research surveys. Final Research Report to the Ministry of Fisheries for project SAP2005-02. 20 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

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

McKenzie, A; Smith, A N H (2009) The 2008 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2009/34*. 84 p.

Naylor, J R; Andrew, N L (2002) Determination of paua growth in PAU 2, 5A, 5B, and 5D. *New Zealand Fisheries Assessment Report 2002/34*.

Naylor, J R; Breen, P A (2008) Fine-scale growth in paua populations. (Unpublished Final Research Report for Ministry of Fisheries Project PAU2006/04 held by Fisheries New Zealand, Wellington.) 33 p.

Neubauer, P (2020) Development and application of a spatial stock assessment model for paua (*Haliotis iris*). *New Zealand Fisheries Assessment Report 2020/30*. 42 p.

Neubauer, P (2022) The 2020 stock assessment of pāua (*Haliotis iris*) for PAU 5A. *New Zealand Fishery Assessment Report 2022/33*. 103 p.

Neubauer, P; Tremblay-Boyer, L (2019) The 2018 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2019/39*. 58 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.

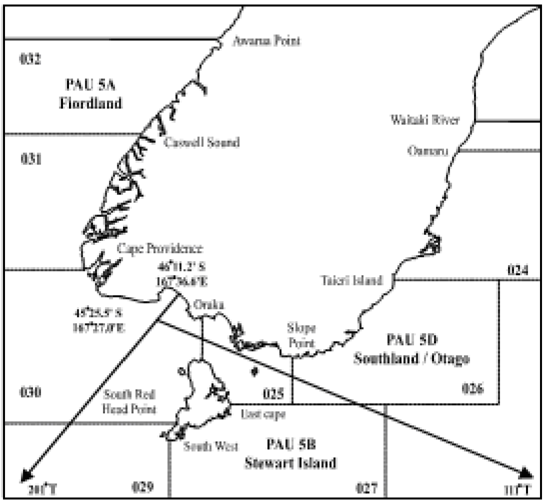
Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. New Zealand Final Research Report for project GEN2007A: 37 p. (Unpublished report held by Fisheries New Zealand, Wellington).

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

Wynne-Jones,J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report* 2014/67.

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 PAU5B TACC was increased to 107 t, and the customary allowance to 7 t, bringing the TAC to 123 t. Prior to the increase being triggered however an injunction was filed by parties concerned about the possible impact on s.28N rights in the fishery. Subsequently, in 2022, the 28N Rights in question were extinguished and the injunction withdrawn, which allowed the TAC increase to proceed at the start of the October 2022 season (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. † The decision to increase the PAU5B TACC and customary allowance on 1 October 2018 was not implemented due to a High Court issued interim order. That order was discharged on 30 September 2022 and the increase actioned on 1 October 2022.

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).

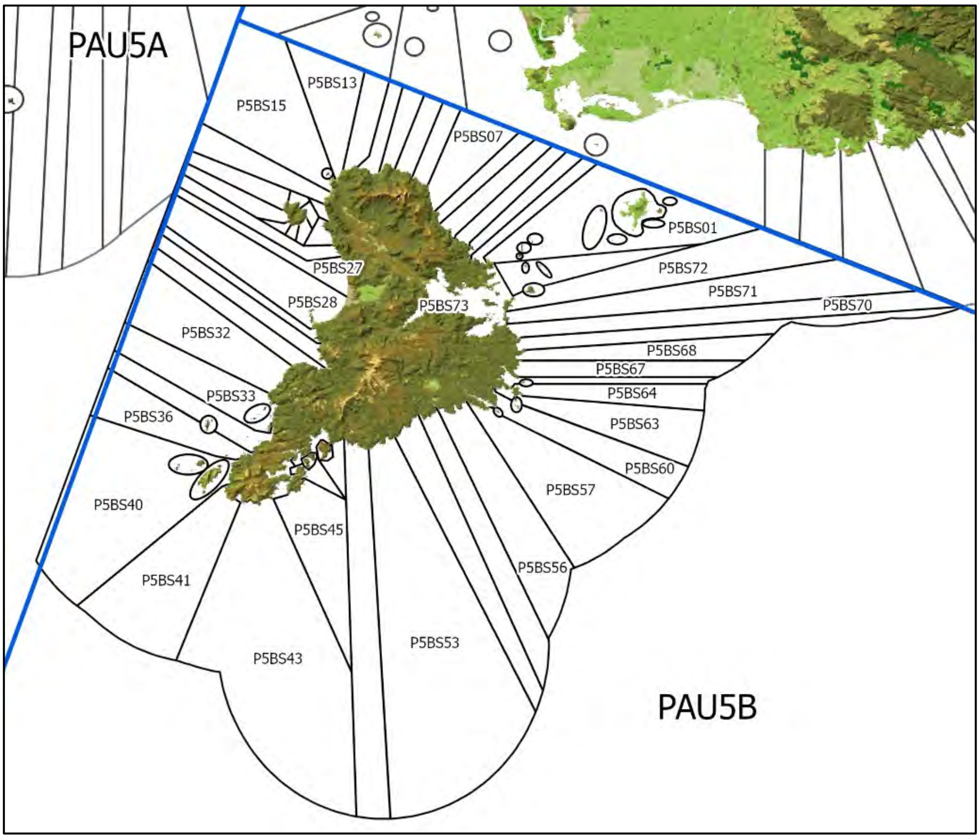


Figure 1: Map of fine scale statistical reporting areas for PAU 5B.

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

Year	Landings	TACC	Year	Landings	TACC
1995–96	144.66	148.98	2009–10	90.23	90.00
1996–97	142.36	148.98	2010–11	89.67	90.00
1997–98	145.34	148.98	2011–12	89.59	90.00
1998–99	148.55	148.98	2012–13	90.58	90.00
1999–00	118.07	143.98	2013–14	88.84	90.00
2000–01	89.92	112.19	2014–15	89.45	90.00
2001–02	89.96	112.19	2015–16	88.39	90.00
2002–03	89.86	90.00	2016–17	92.99	90.00
2003–04	90.00	90.00	2017–18	89.33	90.00
2004–05	89.97	90.00	2018–19	89.03	90.00
2005–06	90.47	90.00	2019–20	87.19	107.00
2006–07	89.16	90.00	2020–21	89.60	107.00
2007–08	90.21	90.00	2021–22	92.97	107.00
2008–09	90.00	90.00	2022–23	105.06	107.00

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, and 2001–02, when the TACC was not reached (Table 2 and Figure 2). Landings for PAU 5 prior to 1995 are reported in the Introduction – Pāua chapter.

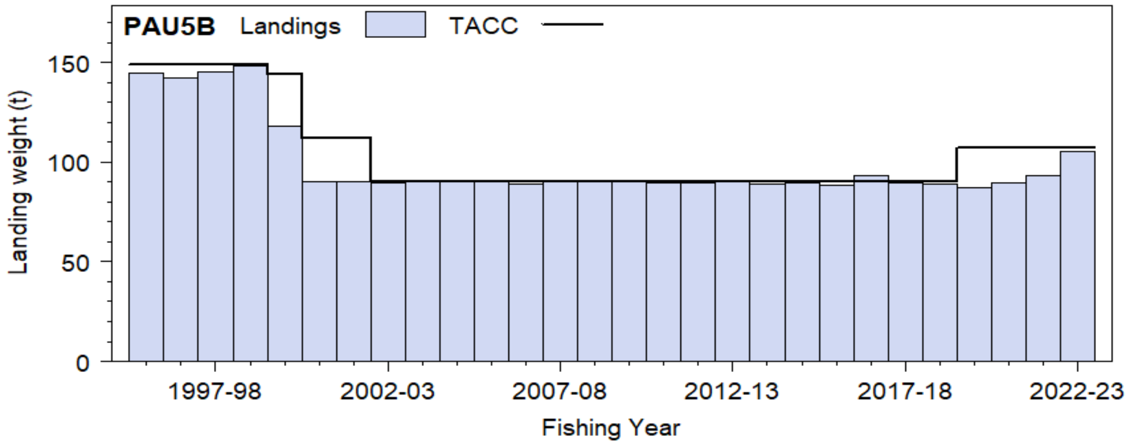


Figure 2: Reported commercial landings and TACC for PAU 5B from 1995–96 to present. For reported commercial landings in PAU 5 before 1995–96 refer to figure 1 and table 1 in the Introduction – Pāua chapter.

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 0.76 t with a CV of 54%. 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 4.88 tonnes (CV 0.45). The most recent national panel survey harvest estimate for PAU 5B is 3.46 t (CV 0.33) for 2022–23 (Heinemann & Gray in prep). For further information on recreational fisheries refer to the Introduction – Pāua chapter.

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

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 approved and harvested in numbers is 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.

For the 2017 assessment model the SFWG agreed to assume that customary catch was equal to 1 t from 1974–2017.

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 Introduction – Pāua chapter.

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

	Numbers	
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
2019–20	835	815
2020–21	2 645	2495
2021–22	70	70
2022–23	–	–

1.5 Other sources of mortality
For further information on other sources of mortality refer to the Introduction – Pāua chapter.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter. 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 Introduction – Pāua chapter.

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 x 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.

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.

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^J) (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

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 divers. 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).

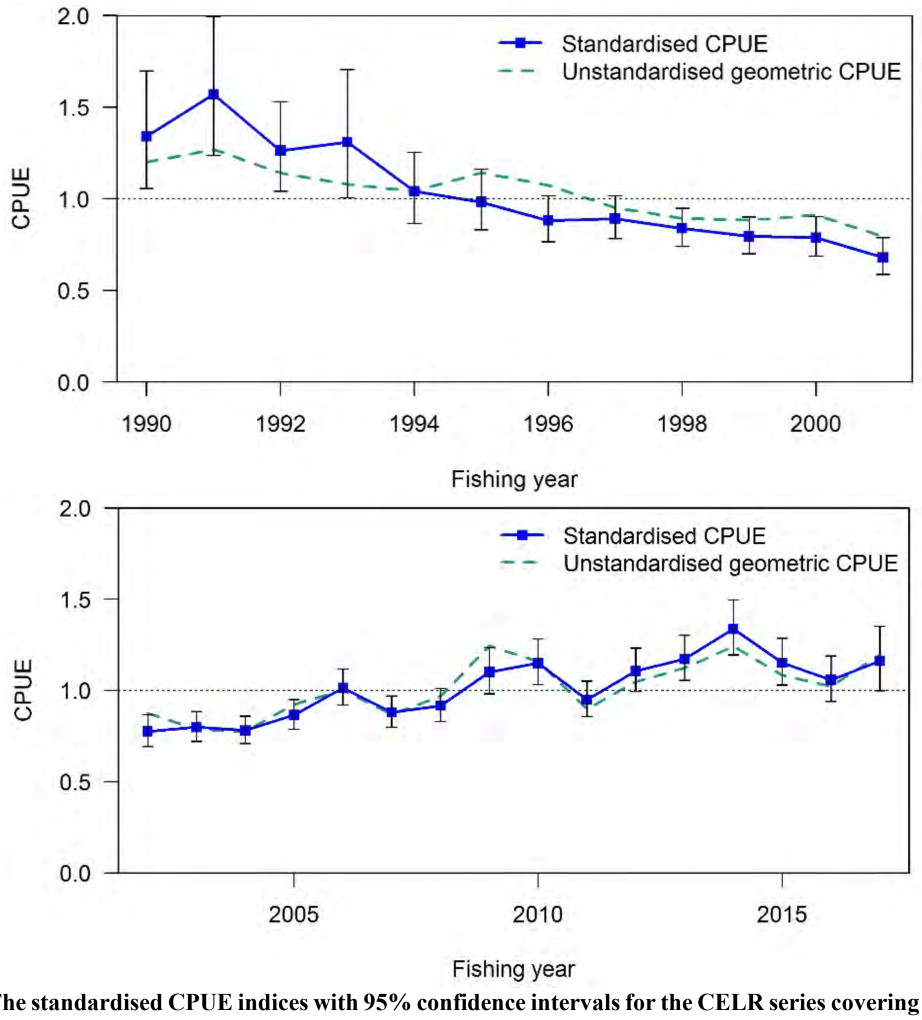


Figure 3: The standardised CPUE indices with 95% confidence intervals for the CELR series covering 1990–2001 (blue line for top-figure). The standardised CPUE indices with 95% confidence intervals for the PCELR series covering 2002–2017 (blue line for bottom-figure). For both indices the unstandardised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

4.1.2 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).

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 $B_{current}$
- $B\%B_0^r$ Current or projected recruited biomass as a percentage of B_0^r
- $B\%B_{msy}^r$ Current or projected recruited biomass as a percentage of B_{msy}^r
- $\Pr(B_{proj} > B_{msy}^r)$ Probability that projected recruit-sized biomass is greater than B_{msy}^r
- $\Pr(B_{proj} > B_{2012}^r)$ Probability that projected recruit-sized biomass is greater than B_{2012}^r
- $\Pr(B_{proj} > 40\%B_0)$ 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.

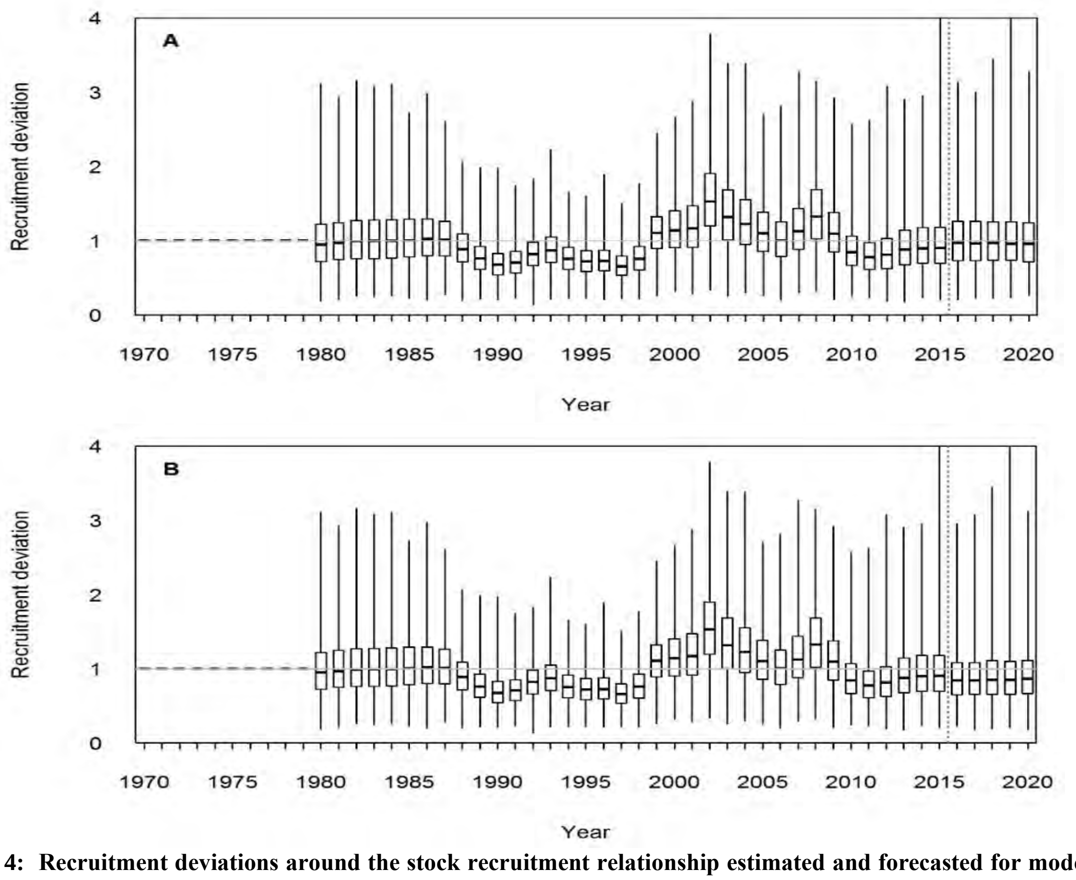


Figure 4: Recruitment deviations around the stock recruitment relationship estimated and forecasted for model 0.1. The red line is the time up to where recruitment deviations were resampled from. The top figure (A) is when we resample from the last 10 years. The bottom figure (B) is when we resample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

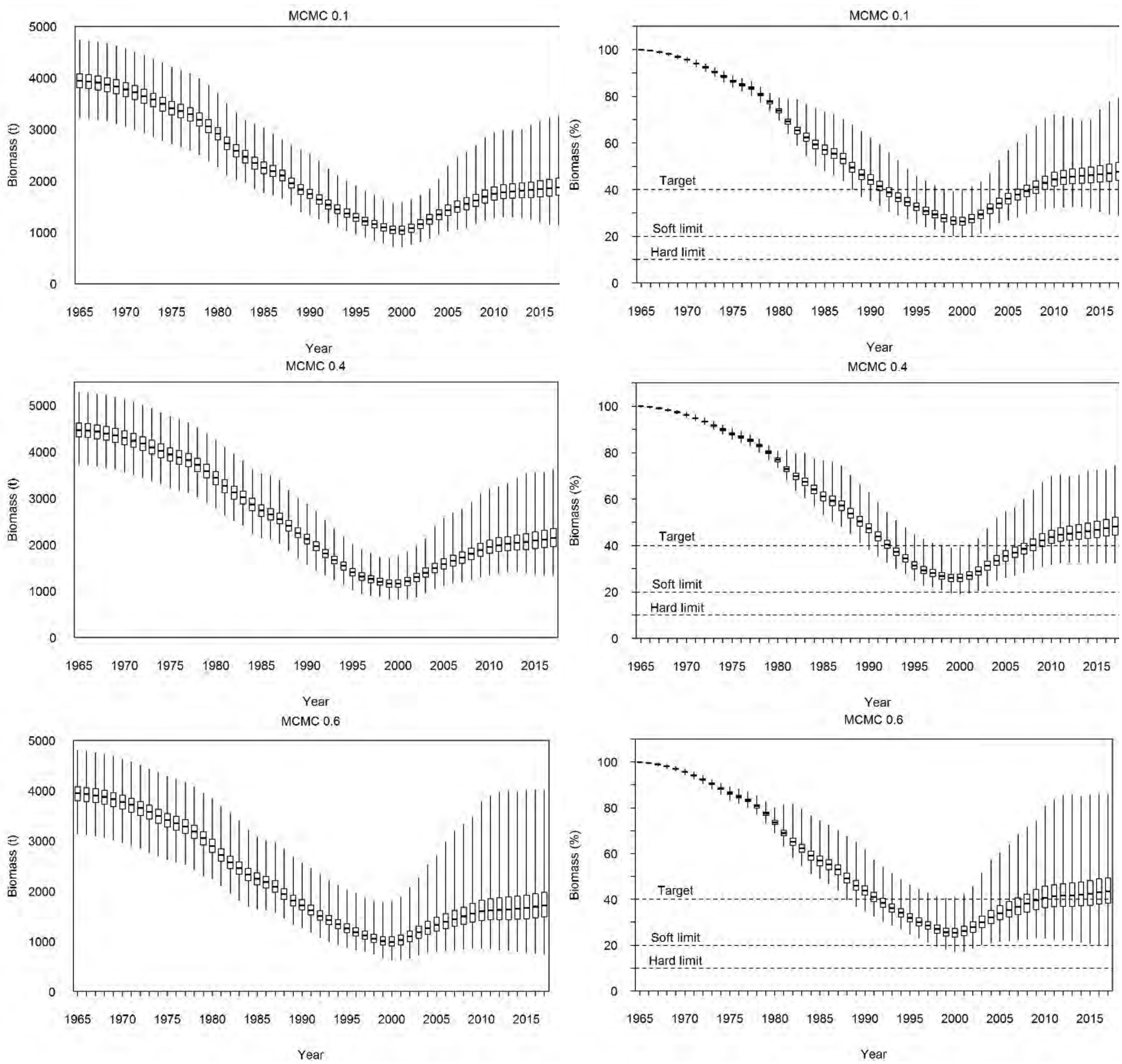


Figure 5: Posterior distributions of spawning stock biomass and spawning stock biomass as a percentage of the unfished level from MCMC for models 0.1, 0.4 and 06. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing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

Table 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.

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. [Continued on next page]

	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

Table 10 [Continued]:

	2018	2019	2020
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

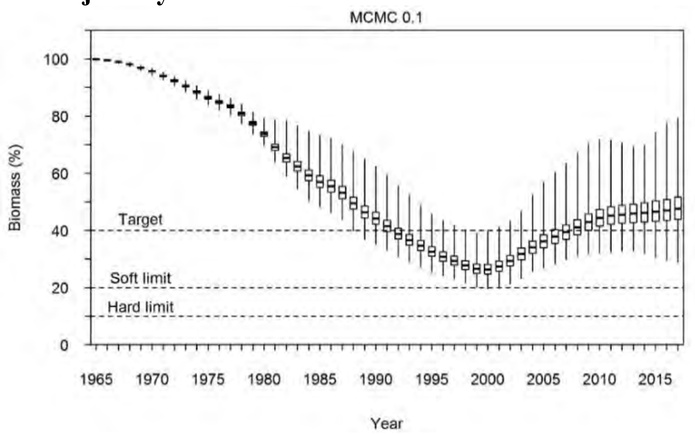
Stock Structure Assumptions

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

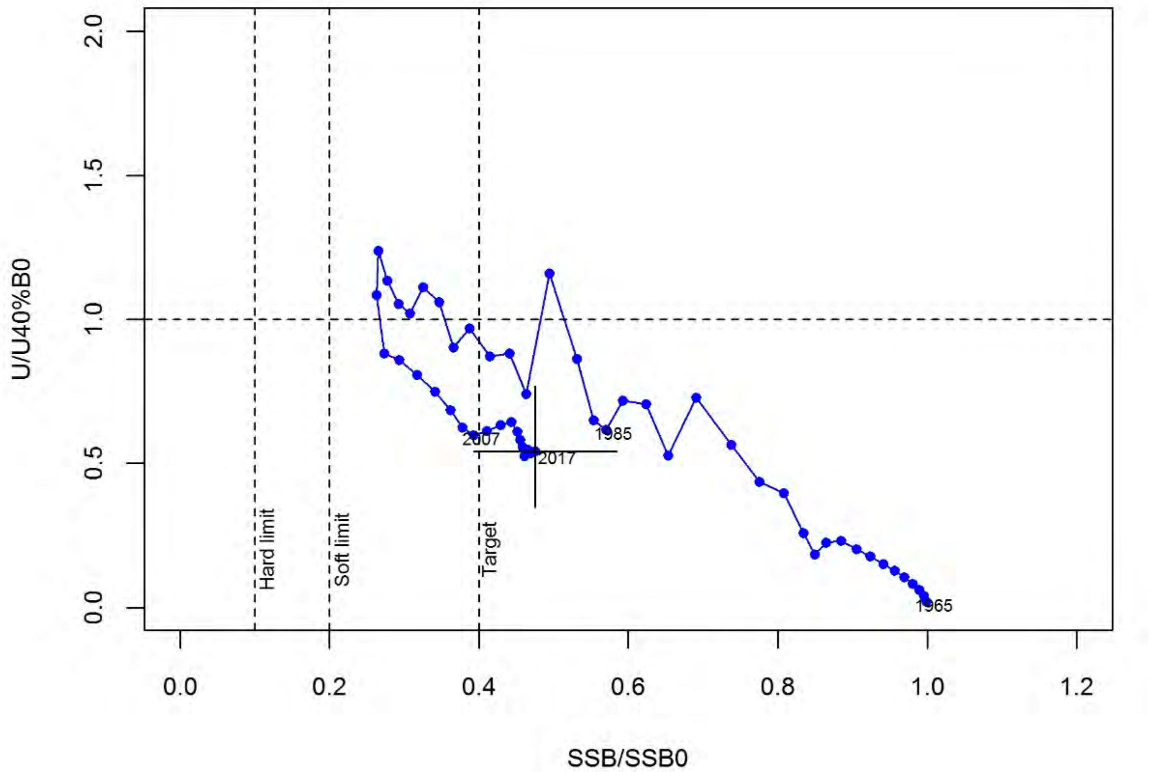
- **PAU 5B - Stewart Island**

Stock Status		
Most Recent Assessment Plenary Publication	2018	
Catch in most recent year of assessment	Year: 2016–17	Catch: 93 t
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	Level 1 - Full Quantitative Stock Assessment
Assessment Method	Length-based Bayesian model

Assessment Dates	Latest assessment Plenary publication year: 2018	Next: 2021
Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)	- Catch history	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
	- CPUE indices early series	2 – Medium or Mixed Quality: not believed to be fully representative of the whole 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 whole QMA
	- Tag recapture data (for growth estimation)	1 – High Quality
	- Maturity at length data	1 – High Quality
	- Research Dive Survey Indices	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

Andrew, N L; Naylor, J R; Gerring, P (2000a) A modified timed-swim method for paua stock assessment. *New Zealand Fisheries Assessment Report 2000/4*. 23 p.

Andrew, N L; Naylor, J R; Gerring, P; Notman, P R (2000b) Fishery independent surveys of paua (*Haliotis iris*) in PAU 5B and 5D. *New Zealand Fisheries Assessment Report 2000/3*. 21 p.

Andrew, N L; Naylor, J R; Kim, S W; Doonan, I J (2002) Fishery independent surveys of the relative abundance and size-structure of paua (*Haliotis iris*) in PAU 5B and PAU 5D. *New Zealand Fisheries Assessment Report 2002/41*. 25 p.

Bradford, E (1998) Harvest estimates from the 1996 national recreational fishing surveys. New Zealand Fisheries Assessment Research Document. 1998/16. 27 p. (Unpublished document held by NIWA library, Wellington.)

Breen, P A; Andrew, N L; Kendrick, T H (2000a) Stock assessment of paua (*Haliotis iris*) in PAU 5B and PAU 5D using a new length-based model. *New Zealand Fisheries Assessment Report 2000/33*. 37 p.

Breen, P A; Andrew, N L; Kendrick, T H (2000b) The 2000 stock assessment of paua (*Haliotis iris*) in PAU 5B using an improved Bayesian length-based model. *New Zealand Fisheries Assessment Report 2000/48*. 36 p.

Breen, P A; Andrew, N L; Kim, S W (2001) The 2001 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2001/55*. 53 p.

Breen, P A; Kim, S W (2005) The 2005 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2005/47*. 114 p.

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

Breen, P A; Smith, A N H (2008) The 2007 assessment for paua (*Haliotis iris)* stock PAU 5B (Stewart Island). *New Zealand Fisheries Assessment Report 2008/05*. 64 p.

Butterworth, D; Haddon, M; Haist, V; Helidoniotis, F (2015) Report on the New Zealand Paua stock assessment model; 2015. *New Zealand Fisheries Science Review 2015/4*. 31 p.

Cordue, P L (2009) Analysis of PAU 5A diver survey data and PCELR catch and effort data. SeaFic and PAUMac 5. (Unpublished report held by Fisheries New Zealand, Wellington.) 45 p.

Fu, D (2013) The 2012 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2013/57.*

Fu, D (2014) The 2013 stock assessment of paua (*Haliotis iris*) for PAU 5B. *New Zealand Fisheries Assessment Report 2014/45*. 51 p.

Fu, D; McKenzie, A; Naylor, R (2014) Summary of input data for the 2013 PAU 5B stock assessment. *New Zealand Fisheries Assessment Report 2014/43*. 61 p.

Gerring, P K (2003) Incidental fishing mortality of paua (*Haliotis iris*) in the PAU 7 commercial fishery. *New Zealand Fisheries Assessment Report 2003/56*.

Gorfine, H K; Dixon, C D (2000) A behavioural rather than resource-focused approach may be needed to ensure sustainability of quota managed abalone fisheries. *Journal of Shellfish Research 19*: 515–516.

Haist, V (2010) Paua research diver surveys: review of data collected and simulation study of survey method. *New Zealand Fisheries Assessment Report 2010/38*. 54 p.

Heinemann A; Gray, A. (in prep.) National Panel Survey of Recreational Marine Fishers 2022-23.

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

Marsh, C; Fu, D (2017) The 2016 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2017/33*.

Punt, A E (2003) The performance of a size-structured stock assessment method in the face of spatial heterogeneity in growth. *Fisheries Research 65*: 391–409.

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.

Schnute, J (1985) A General Theory for Analysis of Catch and Effort Data. *Canadian Journal of Fisheries and Aquatic Sciences, 42(3)*: 414–429.

Shepherd, S A; Partington, D (1995) Studies on Southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. *Marine and Freshwater Research 46*: 669–680.

Teirney, L D; Kilner, A R; Millar, R E; Bradford, E; Bell, J D (1997) Estimation of recreational catch from 1991/92 to 1993/94. New Zealand Fisheries Assessment Research Document 1997/15. 43 p. (Unpublished report held by NIWA library, Wellington.)

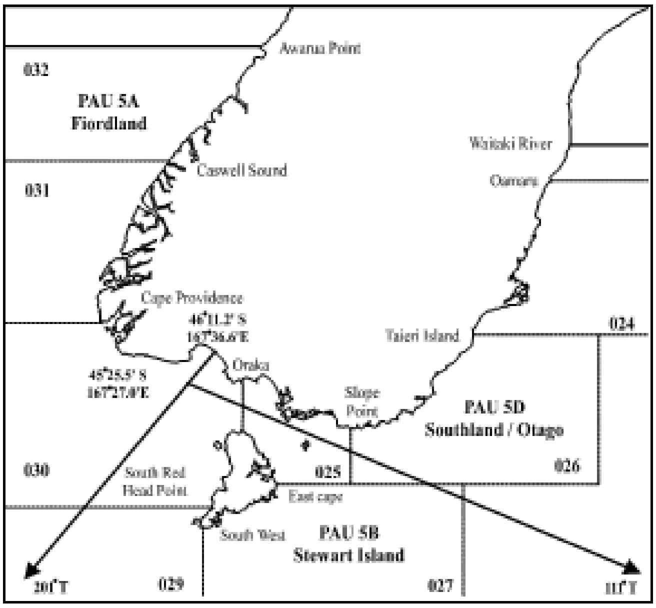
Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. New Zealand Fisheries Research Report. GEN2007A: 37 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

Wynne-Jones, J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 p.

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 allowance	Recreational allowance	Other sources of 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 Pāua 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) These voluntary measures are now implemented under the PAU 5 Fisheries Plan approved under section 11A of the Fisheries Act by the Minister for Oceans and Fisheries.

Commercial landings for PAU 5D are shown in Table 2 and Figure 2. Landings matched the TACC until 2012–13, and then declined to an average of 65 t since 2013–14.

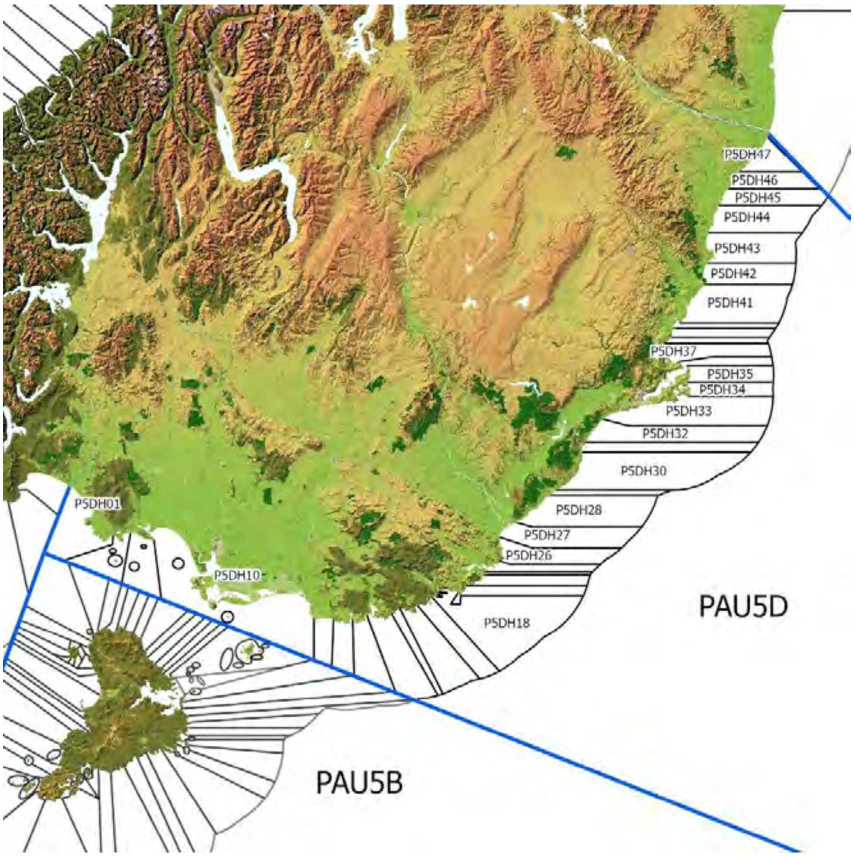


Figure 1: Map of fine scale statistical reporting areas for PAU 5D.

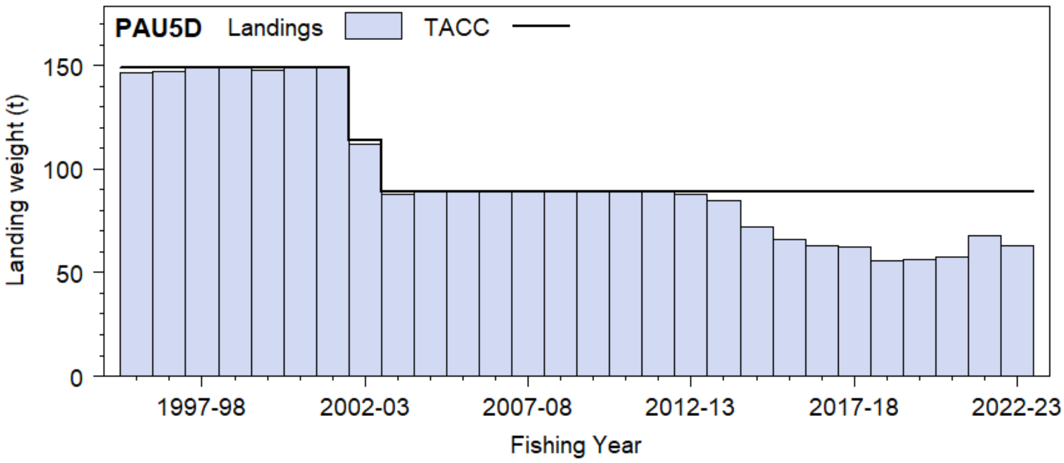


Figure 2: Reported commercial landings and TACC for PAU 5D from 1995–96 to present. For reported commercial landings in PAU 5 prior to 1995–96 refer to figure 1 and table 1 of the Introduction – Pāua chapter.

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

Year	Landings	TACC	Year	Landings	TACC
1995–96	167.42	148.98	2009–10	89.45	89.00
1996–97	146.6	148.98	2010–11	88.70	89.00
1997–98	146.99	148.98	2011–12	89.23	89.00
1998–99	148.78	148.98	2012–13	87.91	89.00
1999–00	147.66	148.98	2013–14	84.59	89.00
2000–01	149.00	148.98	2014–15	71.87	89.00
2001–02	148.74	148.98	2015–16	65.95	89.00
2002–03	111.69	114.00	2016–17	63.12	89.00
2003–04	88.02	89.00	2017–18	62.48	89.00
2004–05	88.82	89.00	2018–19	55.55	89.00
2005–06	88.93	89.00	2019–20	56.55	89.00
2007–08	88.98	89.00	2020–21	57.78	89.00
2006–07	88.97	89.00	2021–22	67.57	89.00
2008–09	88.77	89.00	2022–23	62.76	89.00

1.2 Recreational fisheries

The ‘National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates’ estimated that the recreational harvest for PAU 5D was 80 290 pāua and of 22.45 t with a CV of 30% (Wynne-Jones et al 2014). 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 19.28 tonnes with a CV of 21%.

For the purpose of the 2023 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. The estimate used within the assessment was lower than estimates from the National Panel Survey as only a portion of recreational activity overlaps with commercial fisheries.

The most recent national panel survey harvest estimate for PAU 5D is 20.65 t (CV 0.30) for 2022–23 (Heinemann & Gray in prep). For further information on recreational fisheries refer to the Introduction – Pāua chapter.

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices. For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

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 approved and harvested in numbers is 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.

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

	Numbers	
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
2019–20	6 905	6 439
2020–21	10 257	10 030
2021–22	1 730	1 670
2022–23	130	130

For the purpose of the 2023 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.

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 Introduction – Pāua chapter.

1.5 Other sources of mortality
For further information on other sources of mortality refer to the Introduction – Pāua chapter. Other sources of mortality are considered to be negligible, except in the case of occasional environmentally induced local freshwater inundation events.

2. BIOLOGY

For further information on pāua biology refer to the Introduction – Pāua chapter. 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 Introduction – Pāua chapter.

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

		Estimate		Source
1. Natural mortality (*M*)				
		0.11 (0.09-0.14)		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*	
	2.99×10^{-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)				
		Growth at 75 mm 25.70 (21.79–30.26)		Median (5–95% range) of posterior estimated by the base case model
		Growth at 125 mm 5.61 (4.35–7.28)		Median (5–95% range) of posterior estimated by the base case model

4. STOCK ASSESSMENT

The stock assessment was implemented as a length-based Bayesian estimation model representing the commercially fished area of PAU 5D, 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 2022. A base case model was chosen from the assessment. Spatial models were initially trialled for the area but were highly sensitive to assumptions due to data deficiencies in the southern region and were therefore not pursued further (models with reasonable parameter estimates were very close to single area models). Compared with previous analyses, the most recent stock assessment estimated lower stock status, due largely to the dropping of CELR CPUE. Estimates of growth were higher than in previous assessment, although 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 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
$\ln(R_0)$	LN	exp(13.5)	3
D_{50} (Length at 50% selectivity for the commercial catch)	LN	log(123)	0.05
$D_{95\text{-}50}$ (Length between 50% and 95% selectivity the commercial catch)	LN	log(5)	0.5
Steepness (h)	Fixed	0.75	
Recruitment deviations (ϵ)	LN	0	0.4

The observational data were:

1. A standardised CPUE series covering 2002–2022 based on combined PCELR and ERS data.
2. A commercial catch sampling length frequency series for 2002–2022.
3. Tag-recapture length increment data.
4. Maturity at length data.

4.1.1 Relative abundance estimates from standardised CPUE analyses

The 2022 stock assessment used a combined series of PCELR data covering 2002–2019, and ERS data from 2019 to 2022. These data were combined, but due to concerns with ERS data reporting in the area (see Neubauer 2023), a number of sensitivities were run:

- ERS and PCELR data were treated as a single time series,
- ERS reported data were subsetted to clients for which reporting showed no substantial difference from PCELR reporting, as measured by the likelihood of differences between the reporting periods exceeding 0.5, or 0.05, leading to two sensitivity runs as detailed by Neubauer (2023),
- fishing duration was dropped from the analysis, such that CPUE was analysed as catch-per-day in a given statistical area.

CPUE standardisation was carried out using a Bayesian Generalised Linear Mixed Model (GLMM) which partitioned variation among management zones within QMAs, and statistical areas within management zones, while accounting for effects of ACE-holders and individual divers. Unlike previous assessments for PAU 5D, CELR data prior to 2002 were considered unreliable and unlikely to reflect abundance trends, in accordance with recent assessments in PAU 7 and PAU 2. Gear improvements and fisher turnover in the fishery during the late 1980s to the late 1990s likely caused substantial hyper-stability in CELR CPUE indices for pāua. In addition, spatial reporting during CELR years was at the scale of CELR statistical areas, which do not line up with QMA boundaries. As a result, large amounts of CELR catch-per-unit effort data cannot be used for CPUE analyses at the QMA scale because the data cannot be unambiguously attributed to a single QMA.

CPUE was defined as the log of daily catch-per-unit-effort. Variables in the model were fishing year, FIN (Fisher Identification Number), management zone, diver ID, and fine-scale statistical area. Sensitivities for the CPUE data showed little variation from the base model (Figure 3), apart from model runs removing fishing duration from the analysis. The latter was taken as a sensitivity analysis for stock assessment runs.

Variability in CPUE was mostly explained by differences among divers (Figure 4). CPUE trends showed some similarity among management zones, which showed an increasing trend from 2002 to about 2011. However, CPUE subsequently declined to below-average levels, with a low point between 2015 and 2017, and substantial subsequent increases since 2017 (Figure 5). In nearly all models and regions, recent CPUE was near or above the highest CPUE in the time series.

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, with divers searching larger areas. 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.

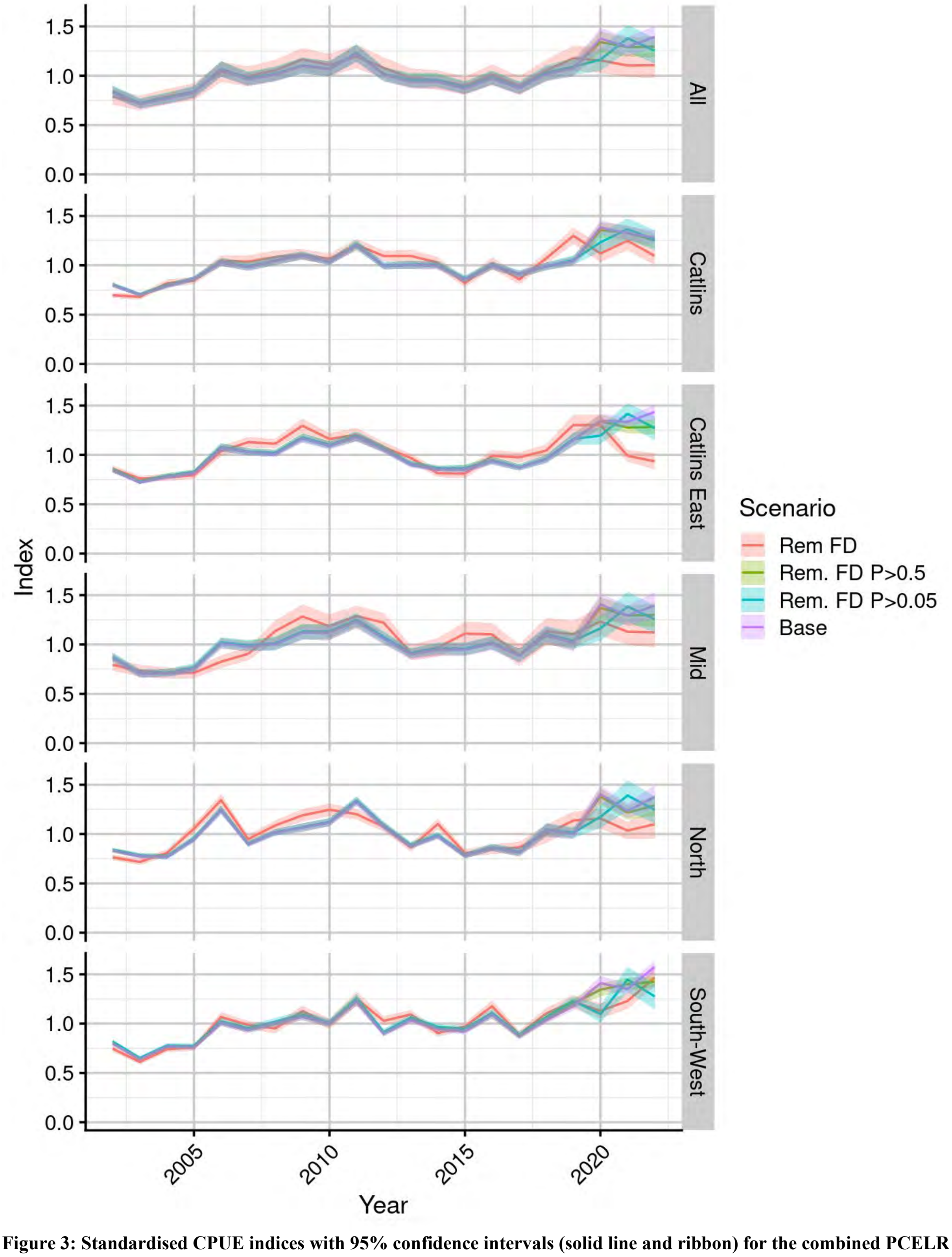


Figure 3: Standardised CPUE indices with 95% confidence intervals (solid line and ribbon) for the combined PCELR and ERS time series. Base uses all available CPUE data (after grooming procedures were applied), REM FD removed fishing duration from the analysis, and REM FD P>0.5 and P>0.05 removed clients unless reporting was as likely as not (0.5) and highly likely (0.05) to have remained the same.

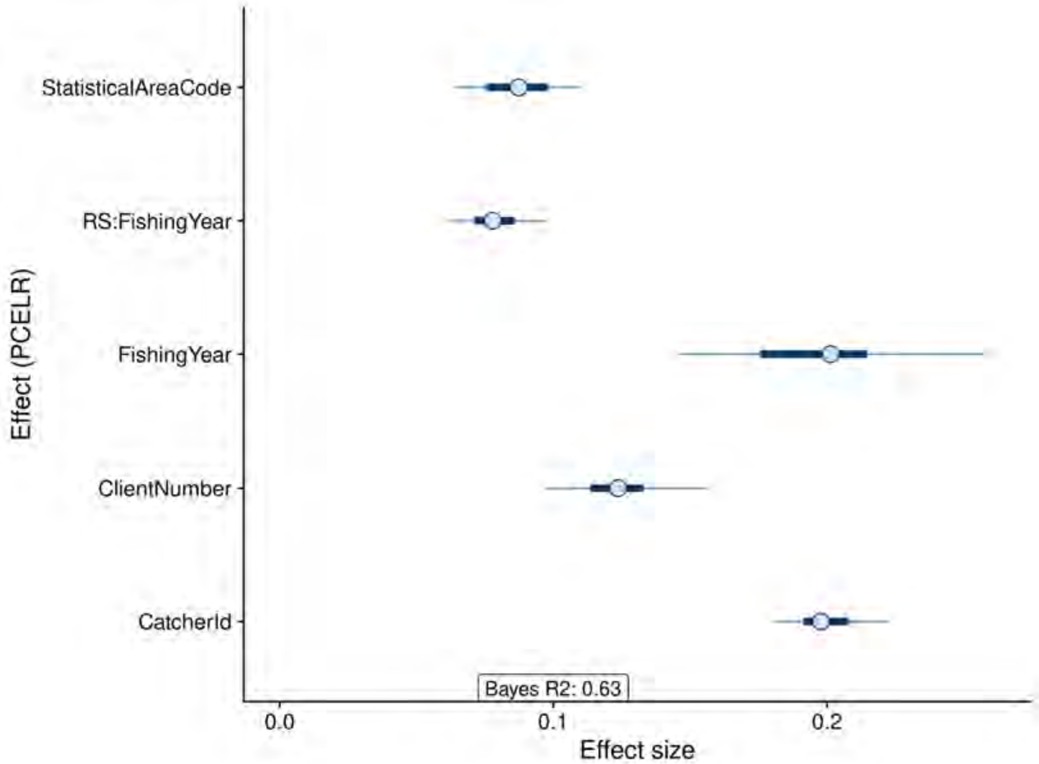


Figure 4: Effect size for the CPUE index standardisation model used for the base-case stock assessment model. RS: management zone (research stratum), CatcherID: diver number.

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 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. These data were not included in the assessment because there is concern that the data are not a reliable enough index of abundance and the data are 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 (RDSI) 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 Introduction – Pāua chapter.

4.2 Stock assessment methods

The 2023 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 2017–18 fishing year (Neubauer & Tremblay-Boyer 2019), and the most recent assessment uses data up to the 2021–22 fishing year. 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. CELR data were dropped from the analysis, in order to avoid potential confounding from efficiency creep in the fishery in the 1990s.
2. Length-frequency data were standardised using an improved model (Neubauer et al in prep) to better estimate uncertainty in estimated removals.
3. Selectivity was allowed to vary in time, along an estimated offset parameterised by the mean minimum harvest size in the QMA for each year. Due to changes in the spatial extent of the fishery among years, and variable harvest sizes, selectivity cannot be assumed to be stationary.
4. Both spatial and single-area models were trialled, but spatial models were highly sensitive to assumptions due to a lack of length-frequency data from southern areas, and only single area models were therefore retained.

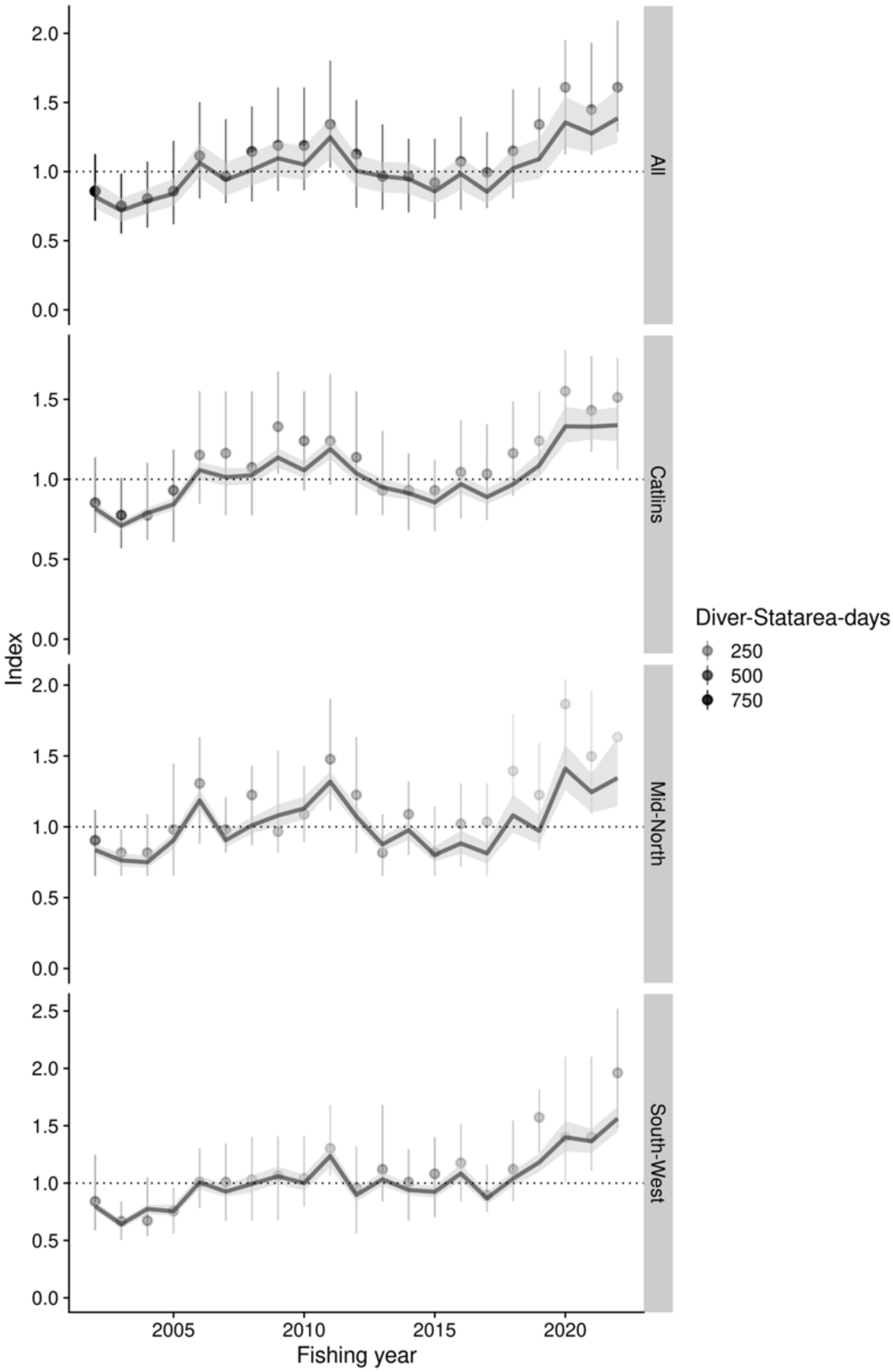


Figure 5: Standardised CPUE indices with 95% confidence intervals (solid line and ribbon) and unstandardised geometric CPUE and variability (points and error bars) for the combined PCELR and ERS time series used in the base-case assessment model.

The model structure assumed a single sex population within each area (defined as management zones for spatial models, and the whole QMA for single-area models), with length classes from 70 mm to 170 mm, in groups of 2 mm. Growth was 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 simulated the population from 1965 to 2022. Catches were available for 1974–2022, 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) fixed at 0.75 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 selectivity was estimated as varying in time, with a random effect describing deviations from an estimated offset parameterised by the mean minimum harvest size in the QMA for each year.

The assessment initially attempted to fit both spatial and non-spatial models. However, length-composition data from the Southern area of the QMA is sparse until recently, and models were found to be highly sensitive to assumptions and inputs, with models often estimating unrealistically high stock status (low depletion levels). The single area models did not share this sensitivity and were therefore retained. Single area models were used to explore sensitivity to natural mortality (fitted in the base case), selectivity assumptions and CPUE scenarios, as well as hyper-stability scenarios.

The reference model (model 0) excluded the RDSI and Research Diver Length Frequency data, fitted the combined CPUE series for PCELR and ERS data (excluding CELR data) and the mean Catch Sampling Length Frequency (CSLF) and observation error, estimated process error for CPUE and CSLF, updated growth estimates within the model, and estimated *M* within the model. The data weights in this model led to satisfactory fits to both datasets.

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 2022 (SSB_{2022} and $B_{2022}^{Avail} B_{Proj}^{Avail}$) and for the projection (*Proj*) period (SSB_{Proj} and B_{proj}^{Avail}. This assessment also reports the following fishery indicators:

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_{2022} > 40% SSB_0)	Probability that the spawning stock biomass in 2022 was greater than 40% of the unfished spawning stock
P(SSB_{2022} > 20% SSB_0)	Probability that the spawning stock biomass in 2022 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_{2022})	Probability that projected future biomass (spawning stock or available biomass) is greater than estimated biomass for the 2022 fishing year given assumed future catches

4.3 Stock assessment results

The base case model suggested a recent increase from low levels in spawning stock biomass over the past seven years, following a slow downwards trend from 2010 to 2015 (Figure 6). The base case also indicated that although the stock is currently as likely as not at the interim target spawning stock biomass of 40% *SSB* (Table 6), there is little to no probability that it is below the soft limit of 20% *SSB*. 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.

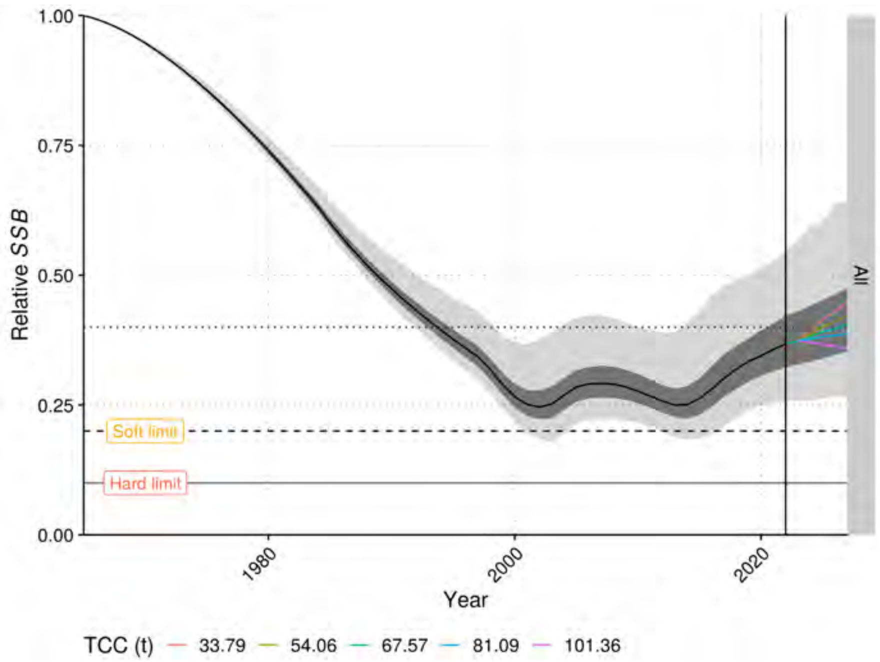


Figure 6: Posterior distributions of spawning stock biomass from the base case model. The black line shows the median of the posterior distribution; the 25th and 75th percentiles are indicated by the dark grey band, with the light grey representing the 95% confidence range of the posterior distribution. Coloured lines for projections relate to alternative future catch levels indicated in the legend.

Table 6: Model sensitivity runs for the stock assessment of pāua in management area PAU 5D. Stock status (posterior mean relative spawning stock biomass), relative available biomass and probability of the stock status being above the soft limit (P(SSB_{proj} > 20% SSB_0). Numbers are posterior medians.

Sensitivity	Stock status	Available	P(SSB_{proj} > 20% SSB_0)
Base	0.38	0.28	1.00
M=0.1	0.33	0.24	1.00
M=0.16	0.66	0.46	1.00
No time-varying selectivity	0.34	0.26	1.00
CPUE without fishing duration	0.39	0.28	1.00

High shelving rates up to > 35% and increased minimum harvest sizes for many areas in PAU 5D since 2015 have led to a strong reduction in exploitation rate (Figure 7), which is currently below U_{40}. It is likely that this reduction in catch has led to the current increase in biomass from previously low levels near the soft limit of 20% *SSB*.

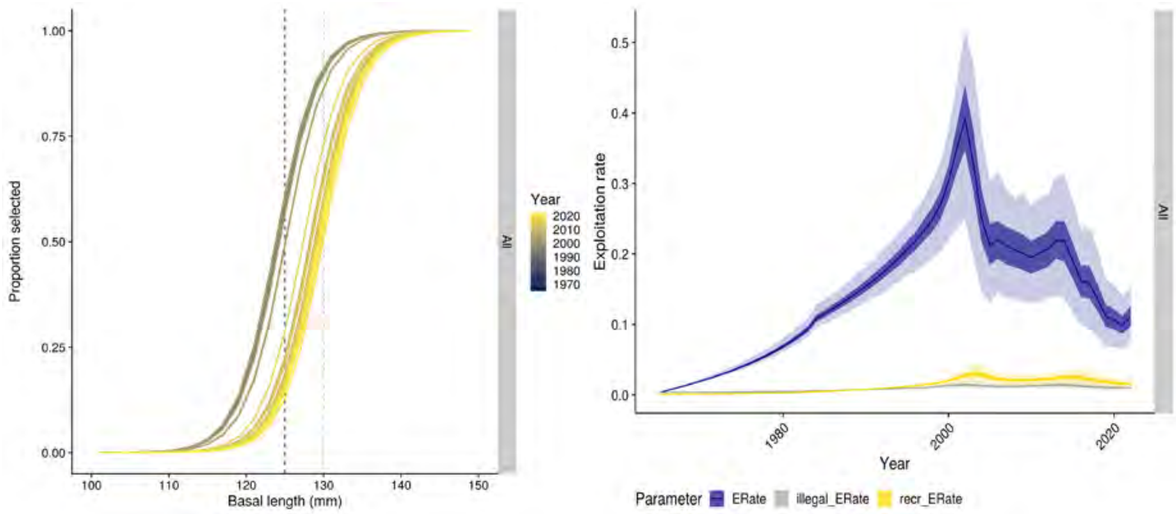


Figure 7: Estimated selectivity by year (left) and exploitation rate (right) for commercial (ERate), illegal (illegal_ERate), and recreational fishery components assumed in the model. Vertical dashed and dotted lines show the minimum legal size and 130 mm as a reference.

Projections suggested increasing *SSB* for scenarios of current catch and 20% increased or decreased catch (Table 7); however, the estimated equilibrium biomass at 89 t (i.e., the current TACC) appears close to 40% *SSB* whereas at current catch (67.5 t), *SSB* is projected to increase further and is projected to be more likely than not to be above target by 2026, with a long-term likelihood of exceeding target harvest rates (U_{40}) of 8%, compared to a risk of exceeding target harvest rates near 60% for projections at the TACC (89 t).

Sensitivities were set up to investigate the robustness of the model to key assumptions about CPUE and time-varying selectivity, as well as specific values of *M*. For CPUE, an alternative CPUE time series derived from CPUE without fishing duration (no-FD) was used to fit the model but resulted in only very minor deviation from the base case model, with slightly lower stock status estimated. Models without time-varying selectivity and fixed *M* at 0.1 gave a similar result, whereas a model with high *M* at 0.16 produced a far more optimistic estimate of stock status across the time series.

For a number of reasons, reference points based on deterministic *MSY* or B_{MSY} are not currently used for managing pāua stocks and were therefore not calculated. B_{MSY} is not considered a suitable target for management of the pāua fishery. 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 25% shelving of the current TACC (89 t). Other scenarios show projections at the current TACC and 20% decreased catch relative to current catch. Simulations 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_{2022})	Median rel. SSB_{Proj}	Median rel. B_{Proj}^{Avail}	P(U > $U_{40\%\ SSB0}$)
54	2023	0.37	1.00	0.67	0.38	0.28	0.13
	2024	0.47	1.00	0.90	0.40	0.30	0.11
	2025	0.56	1.00	0.94	0.42	0.32	0.10
	2026	0.65	1.00	0.96	0.44	0.33	0.09
	2027	0.73	1.00	0.98	0.46	0.35	0.09
	Eq.	1.00	1.00	1.00	0.79	0.69	0.03
67.5*	2023	0.37	1.00	0.67	0.38	0.28	0.31
	2024	0.43	1.00	0.80	0.40	0.29	0.29
	2025	0.50	1.00	0.85	0.41	0.30	0.28
	2026	0.55	1.00	0.88	0.42	0.31	0.27
	2027	0.61	1.00	0.90	0.44	0.32	0.24
	Eq.	0.99	1.00	1.00	0.68	0.58	0.08
89	2023	0.33	1.00	0.66	0.38	0.28	0.63
	2024	0.35	1.00	0.58	0.38	0.27	0.63
	2025	0.37	0.99	0.57	0.38	0.27	0.62
	2026	0.38	0.99	0.57	0.38	0.27	0.62
	2027	0.38	0.99	0.57	0.38	0.27	0.61
	Eq.	0.62	0.91	0.70	0.44	0.33	0.51

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. Recent empirical data (Abraham & Neubauer 2015, McCowan & Neubauer 2021) provide some evidence of linear relationships between CPUE and abundance, albeit at spatial scales that are smaller than that of the overall fishery.

The commercial catch is unknown before 1974 and is estimated with uncertainty before 1995. Differences may exist between assumed catches 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. Sensitivities to alternative catch histories are considered.

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.

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.

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.

4.5 Testing management procedures

Management procedures have been operating in the PAU 5D fishery since 2016. A harvest control rule developed with commercial fisheries stakeholders was tested at the time using the available stock assessment model as an operating model. The control rule was updated in the context of the 2023 stock assessment for PAU 5D to introduce further safeguards (a lag year on increases, allowing increases in catch only if two successive increases in CPUE are observed), and allowing a maximum of 5% increase in catch per year.

Testing of the control rule included testing against a range of sensitivities used in the stock assessment process (levels of natural mortality), as well as scenarios of poor recruitment. The control rule was able to maintain steady exploitation rates, and maintained the stock at or above the interim target by applying catch that was fluctuating between current catch levels and the TACC. The control rule was highly likely to maintain biomass above limit reference points.

5. FUTURE RESEARCH CONSIDERATIONS

- Consider sensitivity analyses with alternative catch histories.
- Improve estimates of growth. Expand collection of tagging and environmental data to investigate drivers of growth.
- Further investigate data weighting procedures for pāua stocks. Replace use of likelihood multipliers using observational errors to set initial data weights.
- Re-examine the historical diver surveys and length frequencies to determine their utility.
- Collect additional data to update the length-weight relationship.
- Explore alternative selectivity parameterisation, considering non symmetrical ogives and allowing both L_{50} and a_{95} to vary over time.

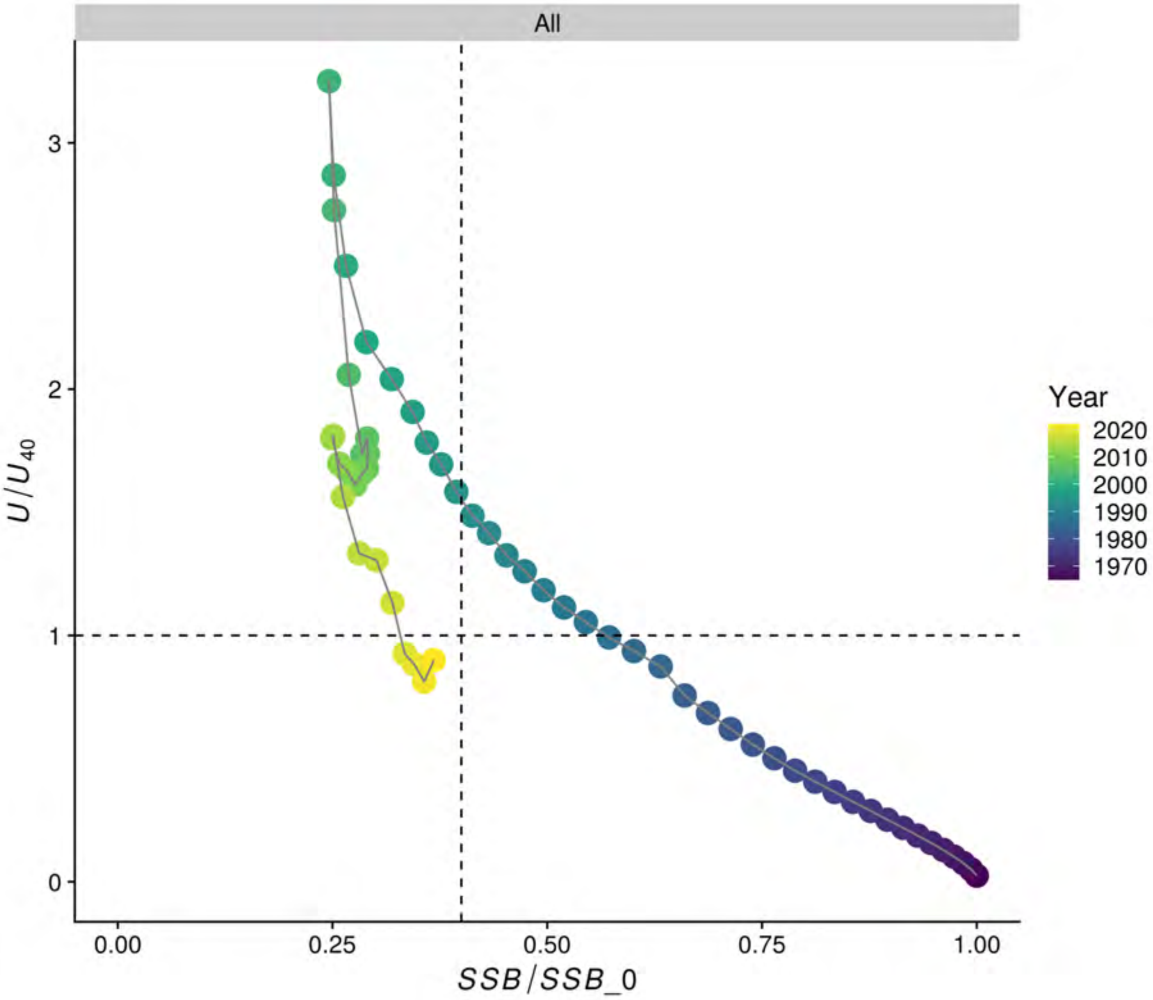
6. STATUS OF THE STOCK

Stock Structure Assumptions
PAU 5D is assumed in the model to be a discrete and homogenous stock within the area of PAU 5D that is commercially fished.

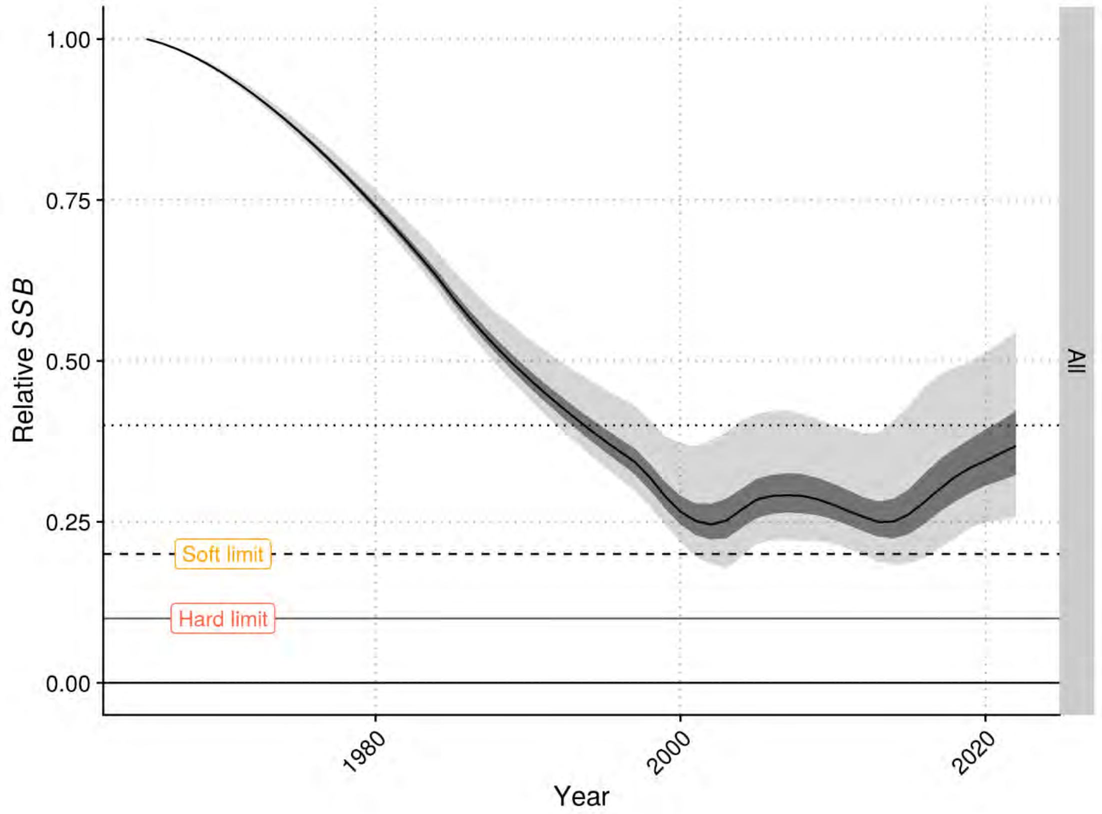
PAU 5D - Southland / Otago

Stock Status		
Year of Most Recent Assessment	2023	
Catch in most recent year of assessment	Year: 2021–22	Catch: 68 t
Assessment Runs Presented	Base case MCMC	
Reference Points	Interim Target: 40% SSB_0 Soft Limit: 20% SSB_0 Hard Limit: 10% SSB_0 Overfishing threshold: $U_{40\%SSB0}$	
Status in relation to Target	SSB_{2022} was estimated to be 38% SSB_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 both the soft and hard limits	
Status in Relation to Overfishing	Overfishing is About as Likely as Not (40–60%) to be occurring	

Historical Stock Status Trajectory and Current Status



Plot of *SSB* relative to unfished spawning biomass (*SSB_0*), and exploitation rate (*U*) relative to exploitation rate at 40% of *SSB_0*.



Posterior distributions of spawning stock biomass from the base case model. The line shows the median of the posterior distribution; the 25th and 75th percentiles are indicated by the dark grey, and the light grey represents the 95% confidence range of the distribution.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass decreased up to about 2015 and has been increasing recently towards the interim target reference point.
Recent Trend in Fishing Mortality or Proxy	Exploitation rate peaked in 2002 and has since declined.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At the current catch level, biomass is About as Likely as Not (40–60%) to rebuild above the interim target reference biomass. At the current TACC, biomass is About as Likely as Not (40–60%) to remain at the interim target 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 Unlikely (< 40%) that current levels of catch or the TACC will cause a decline below the soft or hard limits.
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (<40%) for current catch; About as Likely as Not (40–60%) for current TACC.

Assessment Methodology and Evaluation		
Assessment Type	1 - Full Quantitative Stock Assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest assessment Plenary publication year: 2023	Next: 2028

Overall assessment quality (rank)	1 – High Quality	
Main data inputs (rank)	- Catch History - CPUE Indices PCELR & ERS series - Commercial sampling length frequencies - Tag recapture data - Maturity at length data	2 – Medium or Mixed Quality: not believed to be fully representative of catch in the QMA 1 – High Quality 2 – Medium or Mixed Quality: not believed to be representative of the whole fishery 2 – Medium or Mixed Quality: not believed to be representative of the whole QMA 1 – High Quality
Data not used (rank)	- Research Dive survey indices - Research Dive length frequencies CPUE (CELR series years)	3 – Low Quality: not believed to be a reliable indicator of abundance in the whole QMA 3 – Low Quality: not believed to be a reliable indicator of length frequency in the whole QMA 3 – Low Quality: not believed to be fully representative of CPUE in the QMA
Changes to Model Structure and Assumptions	- CELR data were dropped from the analysis, to avoid potential confounding from efficiency creep in the fishery in the 1990s. - Length frequency data were standardised using an improved model to better estimate uncertainty in estimated removals. - Selectivity was allowed to vary over time through an estimated offset to L_{50} parameterised by the fishery minimum harvest size.	
Major Sources of Uncertainty	- Growth estimates were informed by a weakly informed prior - Influence of changes in reporting due to ERS on CPUE indices may have a small effect on stock status determinations.	

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 minimum harvest size 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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7. FOR FURTHER INFORMATION

Abraham, E R; Neubauer, P (2015). Relationship between small-scale catch-per-unit-effort and abundance in New Zealand abalone (pāua, *Haliotis iris*) fisheries. PeerJ PrePrints No. e1733.

Andrew, N L; Kim, S W; Naylor, J R; Gerring, P; Notman, P R (2002) Fishery independent surveys of paua (*Haliotis iris*) in PAU 5B and PAU 5D. *New Zealand Fisheries Assessment Report 2002/3*. 21 p.

Andrew, N L; Naylor, J R; Gerring, P (2000a) A modified timed-swim method for paua stock assessment. *New Zealand Fisheries Assessment Report 2000/4*. 23 p.

Andrew, N L; Naylor, J R; Gerring, P; Notman, P R (2000b) Fishery independent surveys of paua (*Haliotis iris*) in PAU 5B and 5D. *New Zealand Fisheries Assessment Report 2000/3*. 21 p.

Breen, P A; Andrew, N L; Kendrick, T H (2000a) Stock assessment of paua (*Haliotis iris*) in PAU 5B and PAU 5D using a new length-based model. *New Zealand Fisheries Assessment Report 2000/33*. 37 p.

Breen, P A; Andrew, N L; Kendrick, T H (2000b) The 2000 stock assessment of paua (*Haliotis iris*) in PAU 5B using an improved Bayesian length-based model. *New Zealand Fisheries Assessment Report 2000/48*. 36 p.

Breen, P A; Kim, S W (2005) The 2005 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2005/47*. 114 p.

Breen, P A; Kim, S W (2007) The 2006 stock assessment of paua (*Haliotis iris*) stocks PAU 5A (Fiordland) and PAU 5D (Otago). *New Zealand Fisheries Assessment Report 2007/09*. 164 p.

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

Butterworth, D; Haddon, M; Haist, V; Helidoniotis, F (2015) Report on the New Zealand Paua stock assessment model; 2015. *New Zealand Fisheries Science Review 2015/4*. 31 p.

Cordue, P L (2009) Analysis of PAU 5A diver survey data and PCELR catch and effort data. SeaFic and PAUMac 5 report. 45 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Elvy, D; Grindley, R; Teirney, L (1997) Management Plan for Paua 5. Otago Southland Paua Management Working Group Report. 57 p. (Unpublished document held by Fisheries New Zealand, Dunedin.)

Francis, R I C C (2011) Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68*: 1124–1138.

Fu, D (2013) The 2012 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2013/57*. 51 p.

Fu, D (2016) The 2015 stock assessment of paua (*Haliotis iris*) for PAU 7. *New Zealand Fisheries Assessment Report 2016/35*. 52 p.

Fu, D; McKenzie, A; Naylor, J R (2012) Summary of input data for the 2011 PAU 7 stock assessment. *New Zealand Fisheries Assessment Report 2012/26*. 46 p.

Fu, D; McKenzie, A; Naylor, R (2013) Summary of input data for the 2012 PAU 5D stock assessment. *New Zealand Fisheries Assessment Report 2013/56*. 51 p.

Gerring, P K (2003) Incidental fishing mortality of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2003/56*. 13 p.

Gorfine, H K; Dixon, C D (2000) A behavioural rather than resource-focused approach may be needed to ensure sustainability of quota managed abalone fisheries. *Journal of Shellfish Research 19*: 515–516.

Haist, V (2010) Paua research diver surveys: review of data collected and simulation study of survey method. *New Zealand Fisheries Assessment Report 2010/38*. 54 p.

Heinemann A; Gray, A. (in prep.) National Panel Survey of Recreational Marine Fishers 2022-23.

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

Marsh, C; Fu, D (2017) The 2016 stock assessment of paua (*Haliotis iris*) for PAU 5D. *New Zealand Fisheries Assessment Report 2017/33*.

McCowan, T; Neubauer, P (2021) Pāua abundance trends and population monitoring in areas affected by the November 2016 Kaikōura earthquake. *New Zealand Fisheries Assessment Report 2021/26*. 23 p.

McShane, P E; Naylor, J R (1995) Small-scale spatial variation in growth, size at maturity, and yield- and egg-per-recruit relations in the New Zealand abalone (*Haliotis iris*). *New Zealand Journal of Marine and Freshwater Research 29*: 603–612.

Neubauer, P; Tremblay-Boyer, L (2019) The 2018 stock assessment of paua (*Haliotis iris*) for PAU 5 D. *New Zealand Fisheries Assessment Report 2019/39*. 62 p.

Neubauer, P (2023) Quantifying effects of reporting changes for pāua (*Haliotis iris*) catch-per-unit-effort. *New Zealand Fisheries Assessment Report 2023/18*. 19 p.

Neubauer, P; Kim, K; A'mar, T (in prep) The 2023 stock assessment of paua (*Haliotis iris*) for PAU 5D. Draft New Zealand Fisheries Assessment Report.

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

Punt, A E (2003) The performance of a size-structured stock assessment method in the face of spatial heterogeneity in growth. *Fisheries Research 65*: 391–409.

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 (1989) Paua fishery assessment 1989. New Zealand Fishery Assessment Research Document 1989/9. 20 p. (Unpublished document held by NIWA library, Wellington.)

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.

Stan Development Team (2018) RStan: the R interface to Stan. R package version 2.17.3. Retrieved from http://mc-stan.org/.

Shepherd, S A; Partington, D (1995) Studies on Southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. *Marine and Freshwater Research 46*: 669–680.

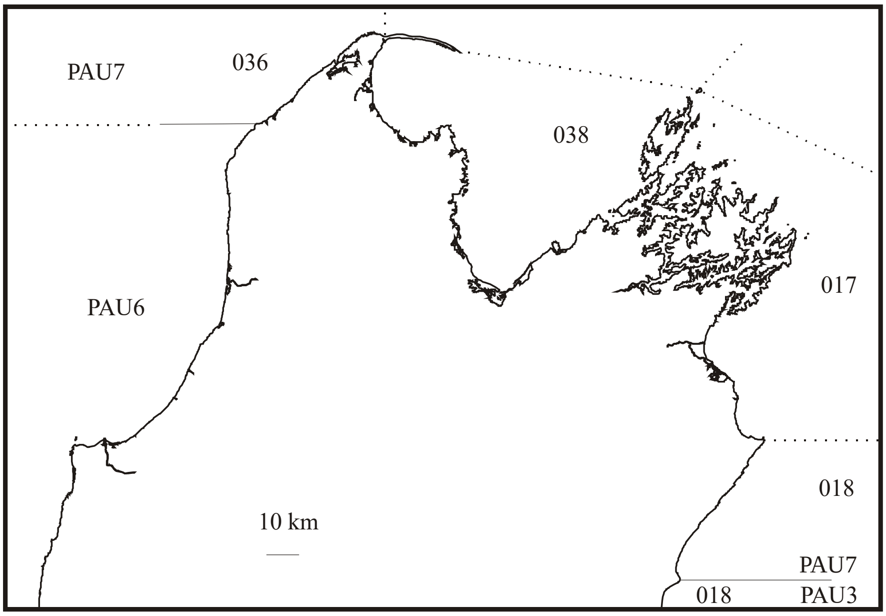
Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. New Zealand Fisheries Research Report. GEN2007A. 37 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

Wynne-Jones, J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 p.

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 was 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 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 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 PAU 7. However, PAU 7 stakeholders agreed to a 10% shelving, and annual landings were on average 81.5 t since 2017–18. The customary and recreational allowances are still set at 15 t. The east coast fishery re-opened on 1 December 2021 and was subsequently fished according to pre-agreed geographical zone limits.

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. The early catches from Schiel (1992) were not considered for the base case in the 2022 stock assessment (Neubauer 2023). Reporting switched to electronic reporting in 2019–20, with no explicit reporting of statistical areas, which were inferred from fishing locations until their explicit re-introduction in 2021–22.

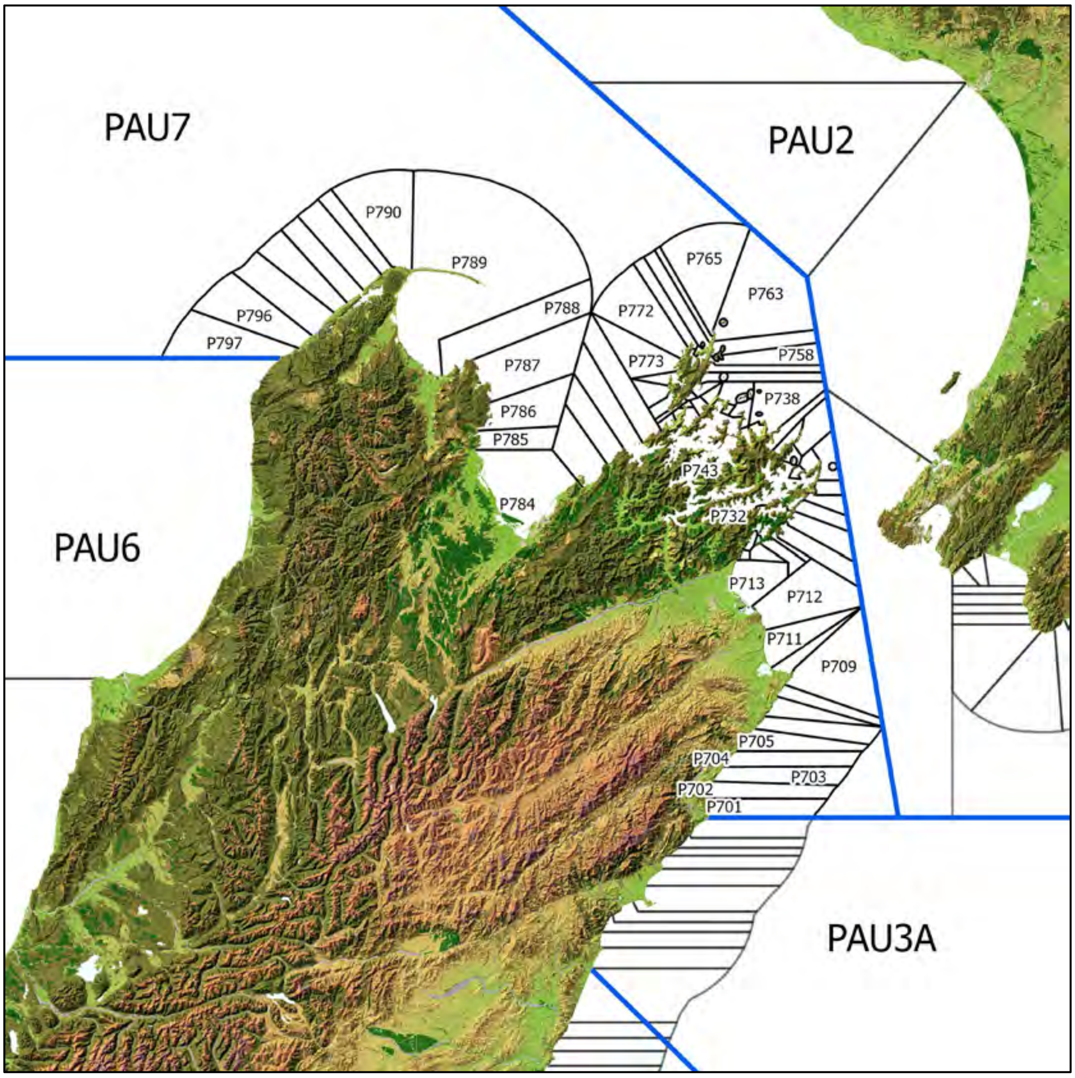


Figure 1: Map of fine scale statistical reporting areas for PAU 7.

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 was based on an improved survey method developed to address issues and to reduce bias encountered in past surveys. The survey estimated that 14.13 t (CV of 34%), were harvested by recreational fishers in PAU 7 for 2011–12. 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). The most recent national panel survey harvest estimate for PAU 7 is 2.87 t (CV 0.35) for 2022–23 (Heinemann & Gray in prep).

For further information on recreational fisheries refer to the Introduction – Pāua chapter.

For the 2021 stock 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 until 2008, with a subsequent decline to 2 t by 2018.

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. Catches from 1980–81 to 1986–85 appear to be from Schiel (1992).

Year	Landings (t)	TACC (t)	Shelving	Year	Landings (t)	TACC (t)	Shelving
1974–75	197.910	–	–	1999–00	264.642	267.48	267.48
1975–76	141.880	–	–	2000–01	215.920	267.48	*213.98
1976–77	242.730	–	–	2001–02	187.152	240.73	240.73
1977–78	201.170	–	–	2002–03	187.222	187.24	187.24
1978–79	304.570	–	–	2003–04	159.551	187.24	*159.15
1979–80	223.430	–	–	2004–05	166.940	187.24	*159.15
1980–81	490.000	–	–	2005–06	183.363	187.24	*159.15
1981–82	370.000	–	–	2006–07	176.052	187.24	*159.15
1982–83	400.000	–	–	2007–08	186.845	187.24	187.24
1983–84	330.000	–	–	2008–09	186.846	187.24	187.24
1984–85	230.000	–	–	2009–10	187.022	187.24	187.24
1985–86	236.090	–	–	2010–11	187.240	187.24	187.24
1986–87	242.180	250	–	2011–12	186.980	187.24	187.24
1987–88	255.944	250	–	2012–13	149.755	187.24	*149.80
1988–89	246.029	250	–	2013–14	145.523	187.24	*149.80
1989–90	267.052	267.48	–	2014–15	133.584	187.24	*134.80
1990–91	273.253	267.48	–	2015–16	138.790	187.24	187.24
1991–92	268.309	267.48	267.48	2016–17	93.610	93.620	93.620
1992–93	264.802	267.48	267.48	2017–18	81.880	93.620	*84.26
1993–94	255.472	267.48	267.48	2018–19	79.697	93.620	*84.26
1994–95	247.108	267.48	267.48	2019–20	81.983	93.620	*84.26
1995–96	268.742	267.48	267.48	2020–21	81.338	93.620	*84.26
1996–97	267.594	267.48	267.48	2021–22	87.787	93.620	*87.00
1997–98	266.655	267.48	267.48	2022–23	76.540	93.620	*85.39
1998–99	265.050	267.48	267.48				

* Voluntary shelving

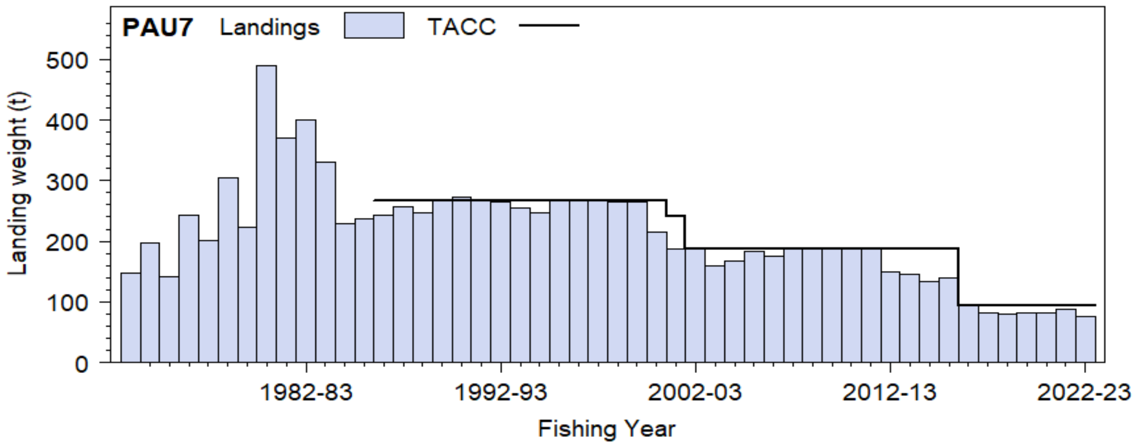


Figure 2: Reported commercial landings and TACC for PAU 7 from 1986–87 to present.

1.3 Customary fisheries

Pāua is a taonga species and as such there is an important customary use of pāua by Maori for food, and the shells have been used extensively for decorations and fishing devices.

For information on customary catch regulations and reporting refer to the Introduction – Pāua chapter.

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 because only the catch in numbers approved and harvested 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.

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

	Numbers	
Fishing year	**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 have not been any reports since.

For the 2021 stock assessment, the Working Group agreed to assume that customary catch was 1 t in 1974, increasing linearly to 2 t between 1974 and 2000 and then remaining at 2 t until 2015, with recent catches around 1 t.

1.4 Illegal catch
There are no estimates of illegal catch for PAU 7.

For the 2021 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 2.5 t in 2015, and remaining at 2.5 subsequently.

For further information on illegal catch refer to the Introduction – Pāua chapter.

1.5 Other sources of mortality
For further information on other sources of mortality refer to the Introduction – Pāua chapter.

On 16 November 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 occurred 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. Recent surveys, however, have indicated large scale recovery of pāua populations in the affected areas (McCowan & Neubauer 2021, 2022).

2. BIOLOGY

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

3. STOCKS AND AREAS

For further information on stocks and areas refer to the Introduction – Pāua chapter.

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

Fishstock		Estimate	Source
1. Natural mortality (M)			
All		0.02–0.25	Sainsbury (1982)
PAU 7		0.12	Fixed in the base case assessment model based on estimates of M in other areas
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)			
Meta-analysis for fished areas (all QMAs)	50% mature	90.5 mm	Neubauer & Tremblay-Boyer (2019a)
4. Growth-increment estimates (both sexes combined)			
Assessment fit for main commercially fished area (Cook Strait)	G_{75}	17.38 mm (SE 1.44 mm)	Neubauer (2023)
	G_{125}	2.71 mm (SE 0.36 mm)	

4. STOCK ASSESSMENT

The stock assessment is 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. In contrast to previous assessments, which assumed a single population across Statistical Areas 017 and 038, the most recent stock assessment split the area into finer scale units that align more closely with industry management units (Figure 3), due to strong differences in catch trends among these regions (Figure 4). In particular, D'Urville Island and Northern Faces statistical areas accounted for approximately 40 t of catch through the early 2000s, with subsequent declines in catch to very low levels in recent years. By contrast, statistical areas in Cook Strait have continuously yielded between 70 and 150 t per year since the early 2000s. This area constitutes over 80% of the fishery in recent years.

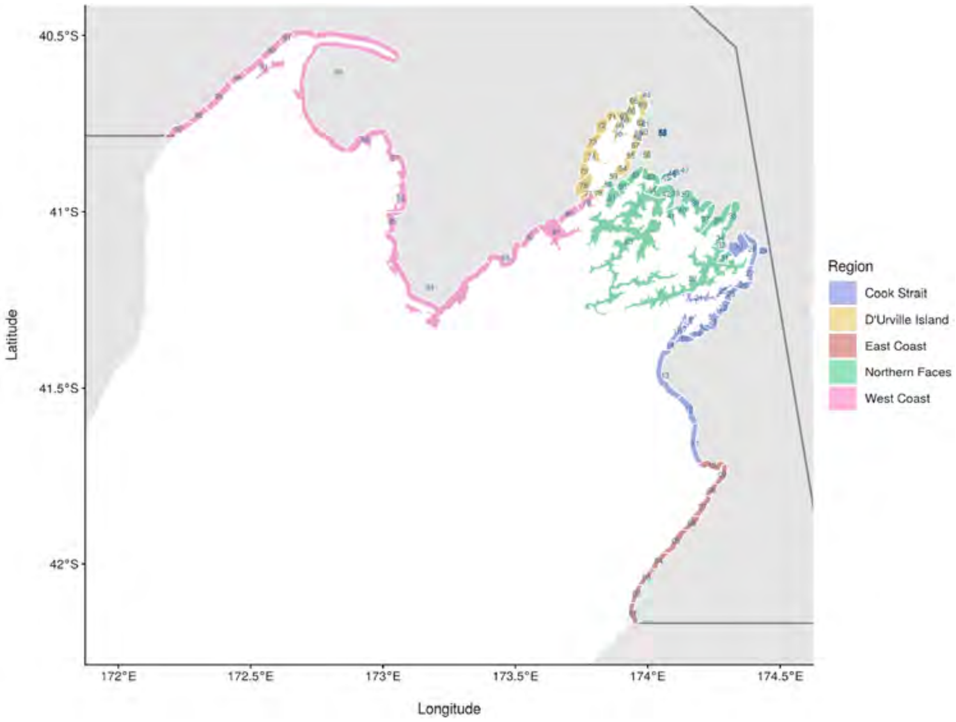


Figure 3: Region definition used in the stock assessment; the stock assessment was run for Cook Strait, Northern Faces, and D'Urville Island only. The East Coast area was closed following the 2016 Kaikōura earthquake; the West Coast is only sporadically fished with relatively small proportions of catch coming from the area.

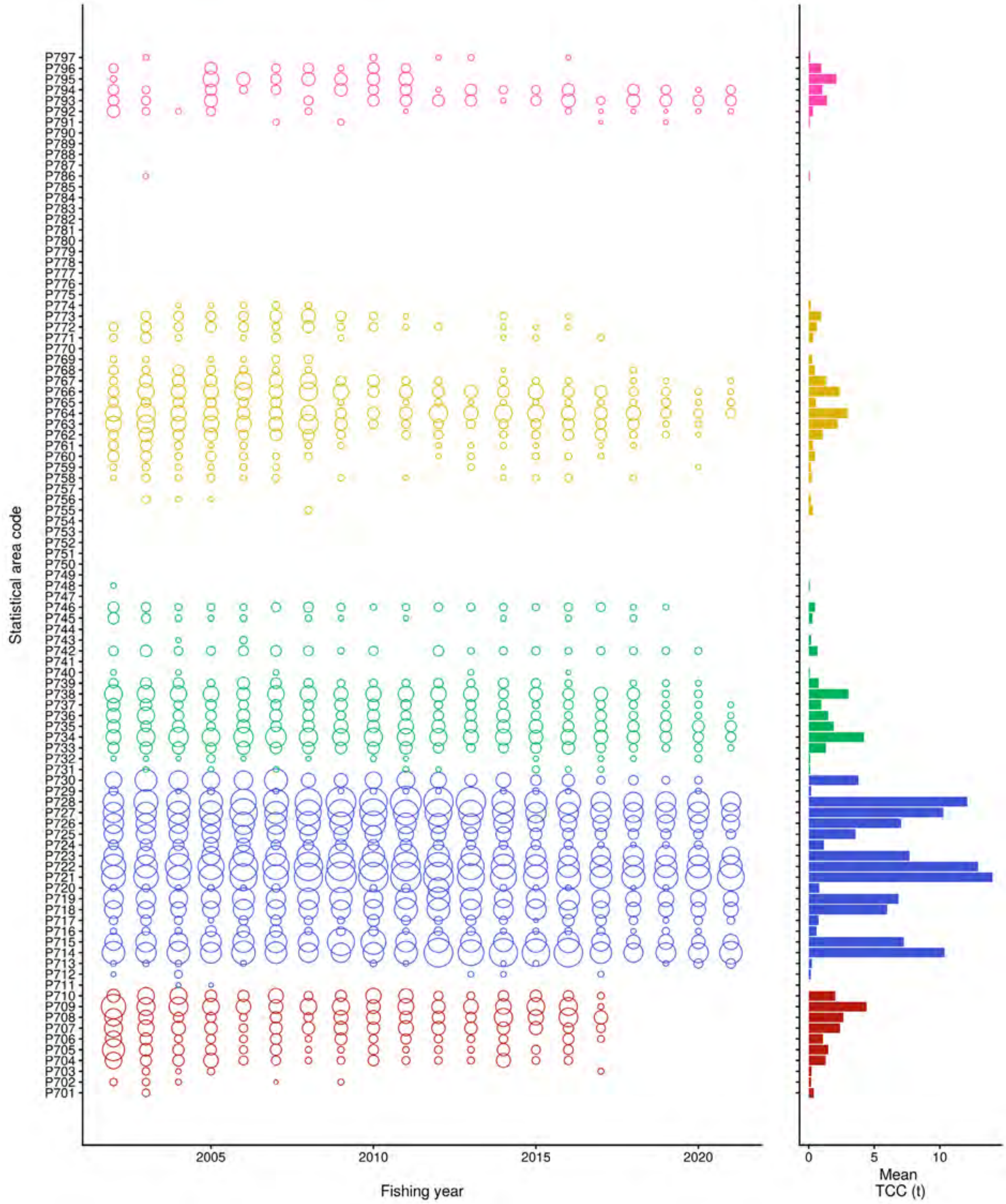


Figure 4: Trend in pāua catch (kg) over time by statistical areas in quota management area PAU 7 for the period from 2002 to 2021, with mean commercial catch over the same time period (right-hand side). Statistical reporting areas used for the stock assessment within PAU 7 are colour coded blue (Cook Strait); other areas were excluded from the stock assessment given limited recent catch (but included in catch per unit effort (CPUE) analyses).

4.1 Estimates of abundance indices

4.1.1 Relative abundance estimates from standardised CPUE analyses

PCELR and ERS data from 2002 were used to derive a standardised, fishery-dependent index of abundance. Previously used CELR data were not used in the present assessment; as for other recent assessments, changes to the composition of the fleet and gear during the 1990s, combined with inconsistent reporting, mean that the trends in CPUE from CELR data are questionable, and likely hyper-stable to an unknown degree.

CPUE standardisation was carried out using Bayesian Generalised Linear Mixed Models (GLMM) which partitioned variation among fixed (research strata) and random variables. CPUE was defined as the log of daily catch. Variables in the model were fishing year, estimated fishing effort, client number, research stratum, and diver ID (PCELR). Previous standardisation models for PCELR data routinely used small scale statistical areas as a standardising variable. For the present assessment, this variable was not available with sufficient precision for recent (ERS) data, where it is inferred from position data, and was therefore omitted. Nevertheless, follow-up work on the quality of ERS data for pāua CPUE suggested limited effects of spatial reporting and the inclusion, or not, of statistical areas in the standardisation made little difference to resulting indices for Cook Strait. Indices for other subareas were sensitive to the inclusion of statistical area.

Standardised CPUE in all areas suggested increases in recent years (Figure 5), with most notable increase in Cook Strait, and highly variable trends in raw CPUE in other areas. Although initial models were attempted for D'Urville Island and Northern Faces, the Shellfish Working Group decided that, due to recent reductions and spatial concentration of catch in these areas to a limited number of statistical areas, CPUE may not be representative of these areas as a whole anymore.

For Cook Strait, standardisation acted to reduce the rate of recent increases relative to raw CPUE alone. Client (ACE-holder) and diver ID had the strongest standardising effects for recent CPUE (Figure 6), due to concentration of ACE in the hands of a smaller number of efficient fishing operations in recent years. Nevertheless, recent increases in standardised CPUE are of the order of 50% since the TACC was reduced in 2016–17.

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 Introduction – Pāua chapter.

4.1.3 Biomass survey and monitoring for earthquake affected areas

Following the 2016 Kaikōura earthquake, a biomass survey was implemented to estimate and monitor pāua abundance and recruitment in the earthquake-affected areas of PAU 7 and PAU 3 (now PAU 3A), to inform management decisions relating to the re-opening of the pāua fishery (McCowan & Neubauer 2018, 2022). To estimate abundance, novel methodologies using GPS dive loggers and underwater electronic callipers were developed. Thirty-five sites were initially surveyed to obtain baseline estimates of site- and fishery-level abundance and length frequency (LF).

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. Initially, estimated pāua density was 0.028 pāua per square metre (geometric mean; 95% confidence interval (CI) [0.009; 0.08]) across the earthquake-affected fishery closure. 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. After the first two years, the project has been extended for another three years until mid-2023. As of March 2022, four further rounds of surveys of the 35 initially surveyed sites have been undertaken to monitor pāua abundance and recruitment trends.

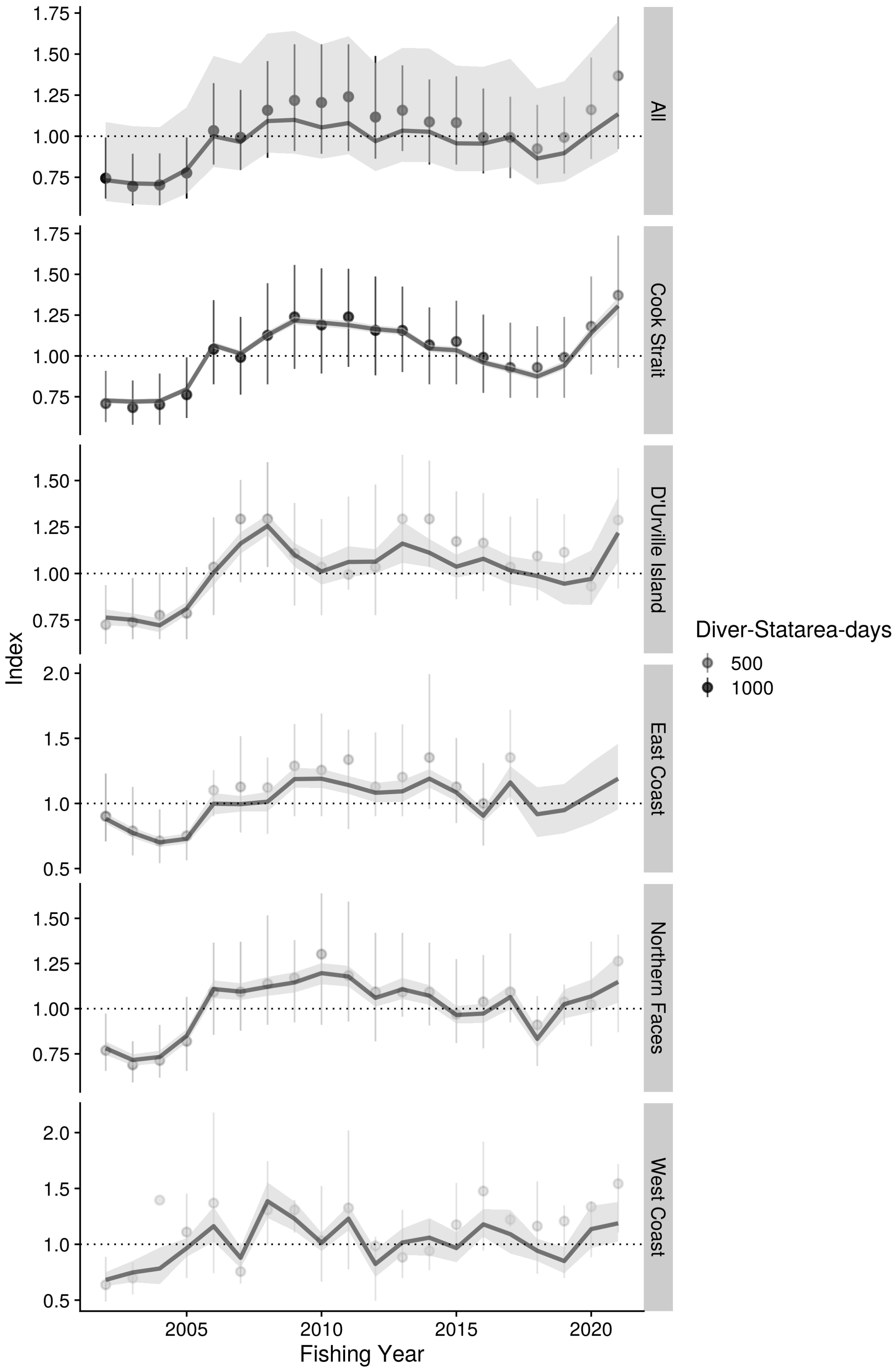


Figure 5: Raw CPUE (points are median with inter-quartile interval indicated by vertical intervals) and standardised CPUE index (line) with 95% confidence interval (shaded ribbon). Shading of points indicates the relative amount of data available for standardisation, showing low available data for D'Urville Island and Northern Faces in recent years.

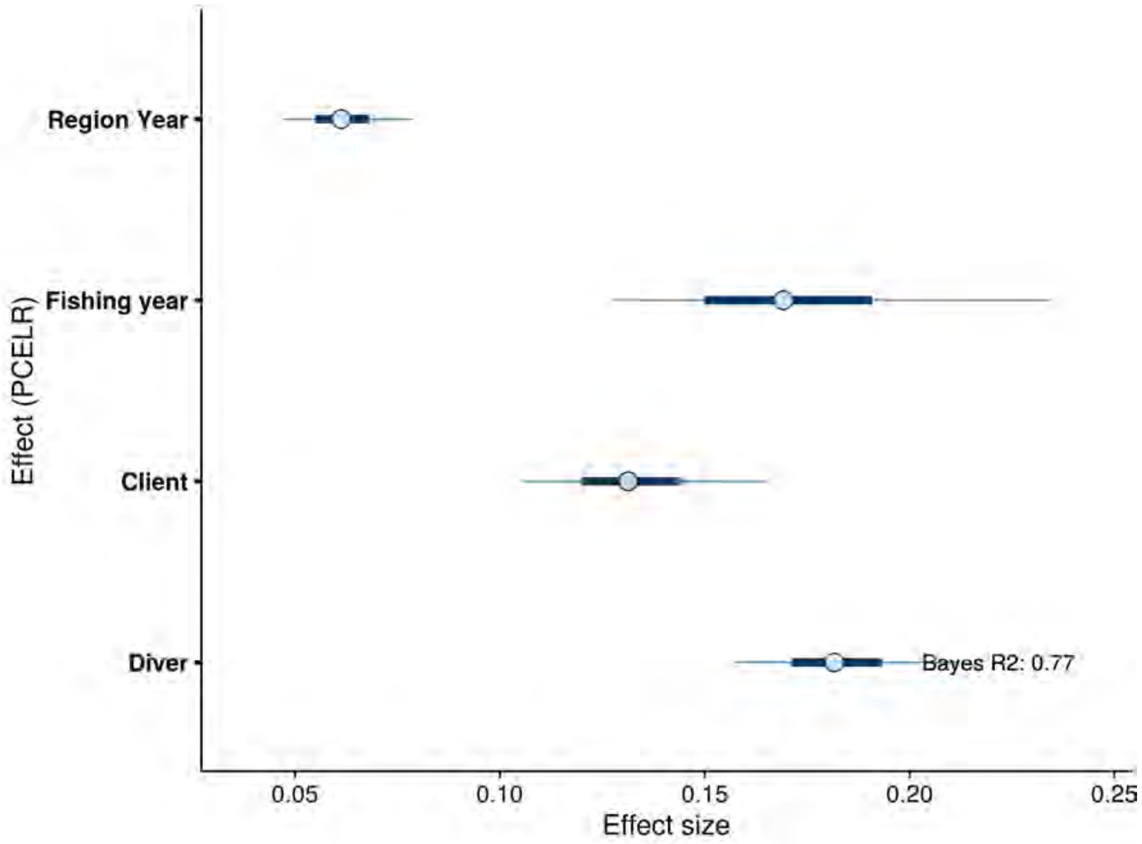


Figure 6: Relative importance (in terms of proportion of variance explained) of standardising variables in the GLMM used to standardise PAU 7 CPUE.

Initially an assessment was made of the appropriateness of using the number of measurements per unit effort (MPUE) as a proxy for pāua density to overcome issues with missing data from GPS dive units (originally used to delimit area to estimate density) and to enable the use of significantly larger data sets of measurements and counts of pāua at each site. The measurements per unit effort, as well as biomass per unit of survey effort (BPUE; number of measurements multiplied by the length frequency distribution of measured pāua), correlated well (R^2=0.86) with density. Therefore, MPUE and BPUE were used as indices of changes in pāua density.

An overall increase in pāua abundance was observed at a QMA-wide level in both QMAs over the four survey periods (Figure 7). Increased abundance was generally more pronounced in PAU 7 than in PAU 3. In PAU 3, abundance trended slightly downwards in the second survey period, which was likely due to the consistently poor survey conditions during the period, as well as a potential bias towards sampling sites with lower rates of increase due to weather conditions. There was high variability in abundance trends across sites. This variability was in part related to variability in the amount of uplift at each site, because sites with a larger increase in abundance were those with less uplift (Figure 8). Variability in abundance trends across sites could also be linked to habitat related factors and pre-earthquake abundance. Comparison of length frequency profiles across the four survey periods showed reasonably stable profiles in larger size classes (125–160 mm; Figure 9, with an increase in the number of individuals in the 80–100 mm size range in both QMAs, which is likely to be indicative of post-earthquake recruitment. Recruitment signals were variable between sites due to differences in available recruitment habitat and variability in uplift.

4.2 Stock assessment methods

The 2021 stock assessment for PAU 7 used an updated version of the length-based population dynamics model described by Breen et al (2003), and the most recent assessment uses catch and commercial length frequency data up to the 2019–20 fishing year, as well as the above-mentioned CPUE index for years 2002–2021. Although the overall population-dynamics model remained unchanged from Breen et al (2003), the PAU 7 stock assessment incorporates changes to the previous methodology first introduced in the 2018 assessment of PAU 5D (Neubauer & Tremblay-Boyer 2019b). In addition, illegal and recreational catch were, for the first time, split from commercial catch, and illegal catch was modelled as taking pāua in proportion to abundance rather than according to commercial selectivity. Although commercial minimum harvest size (MHS) increased in recent years, recreational catch retained a logistic selectivity centred on the minimum legal size (MLS).

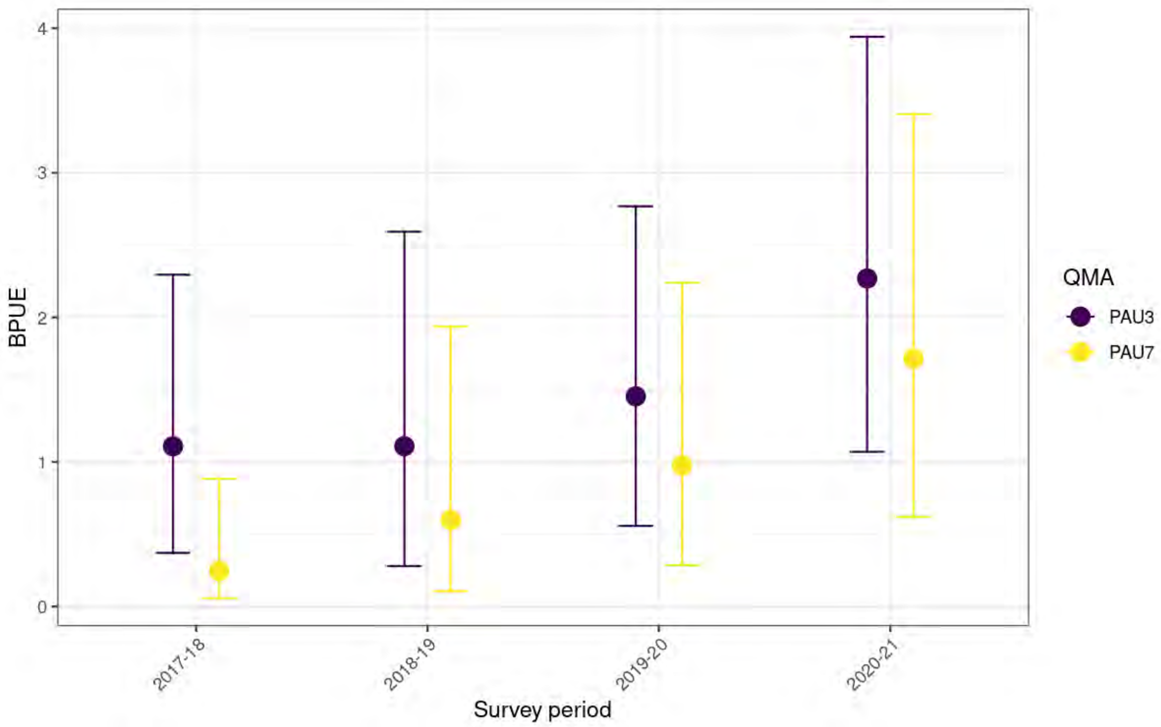


Figure 7: Marginal trend (relative to a geometric mean of 1) in biomass per unit effort (BPUE) across survey years for QMAs PAU 3 and PAU 7 from the BPUE model after accounting for confounding variables.

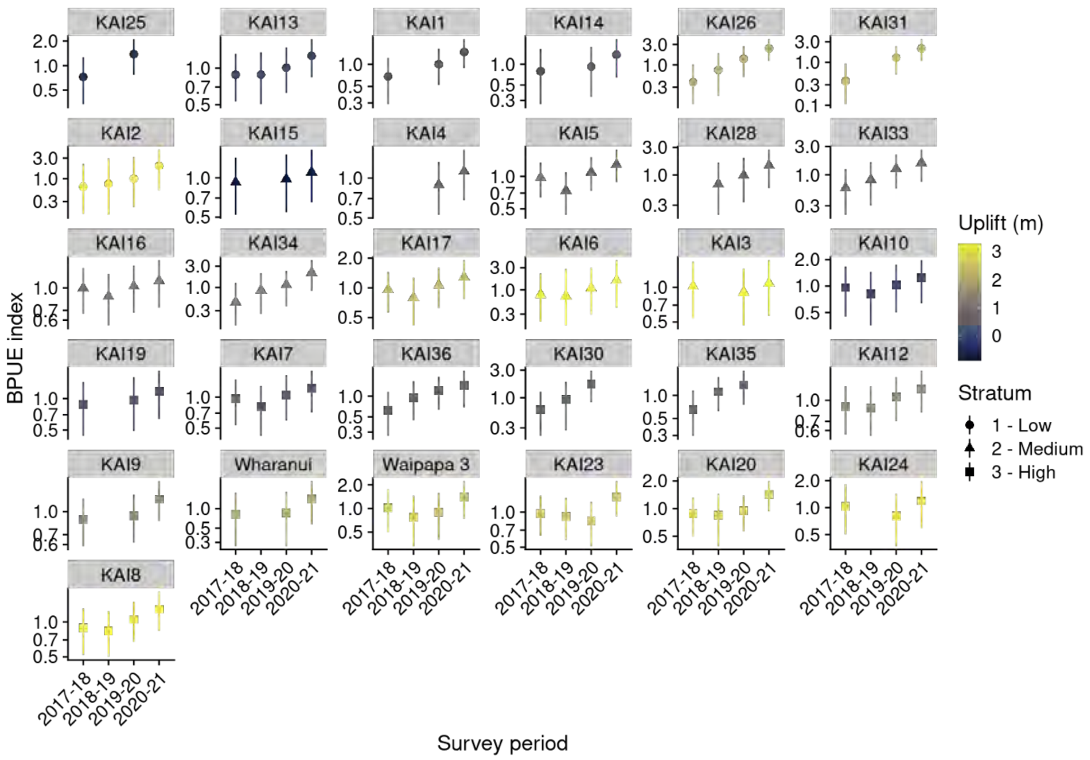


Figure 8: Marginal trend (relative to a geometric mean of 1 at each site) in biomass per unit effort (BPUE) across survey years for QMAs PAU 3 and PAU 7 from the BPUE model after accounting for confounding variables.

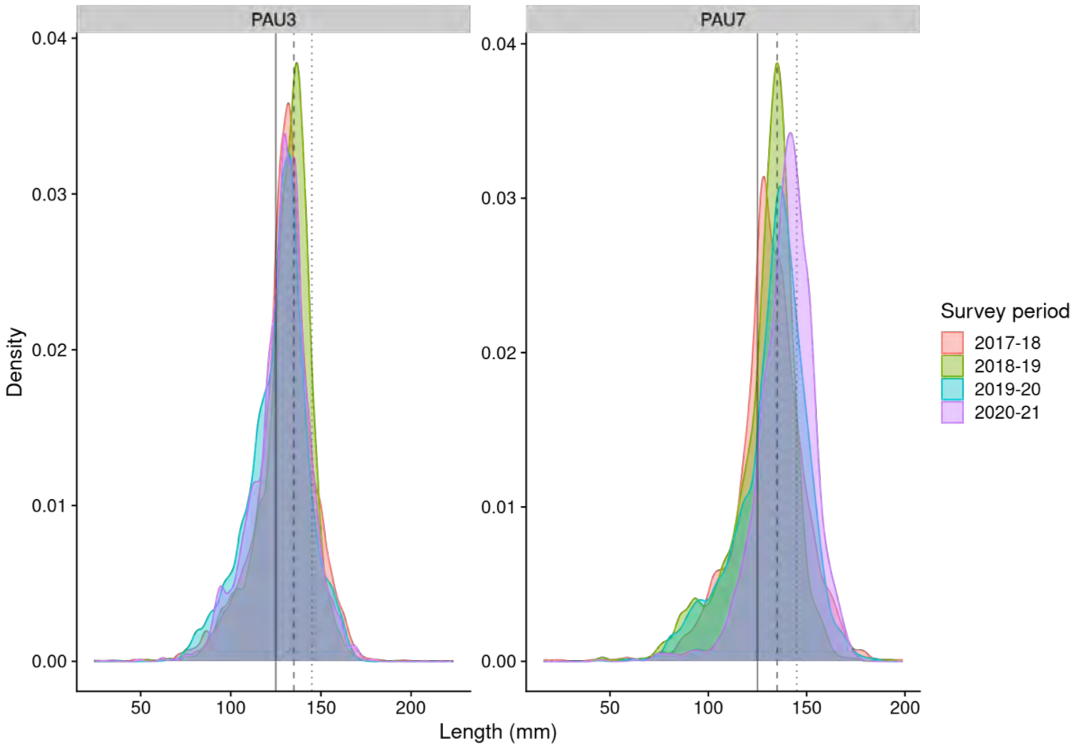


Figure 9: Length frequency profiles (as relative densities) for all pāua measured over four survey periods in PAU 3 and PAU 7. Vertical lines show the legal size of 125 mm (MLS; solid line), 135 mm (dashed line), and 140 mm (dotted line).

Due to substantial reductions in catch without evident effects on CPUE in D'Urville Island and Northern Faces, these areas were split from the Cook Strait area in initial assessment runs, which were performed using a spatial assessment model. In addition, the earthquake-affected area on the east coast of PAU 7 was excluded from the assessment, with surveys used to monitor rebuilding of the fishery in that area. Only the model for Cook Strait was accepted by the working group as a reasonable model for the current PAU 7 fishery. This model was subsequently run as a single area assessment. 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 was length-based, without reference to age, mediated through an estimated growth transition matrix that describes the probability of each length class to change at each time step. A growth prior was formulated from a meta-analysis of pāua growth across fished areas in New Zealand (Neubauer & Tremblay-Boyer 2019a), and the functional form of the resulting growth was encoded in a multivariate normal (Gaussian process) prior on the growth transition matrix. Pāua entered the partition following recruitment and were removed by natural mortality and fishing mortality.

The model simulated the population from 1965 to 2021. Catches were available for 1974–2021 at a broad spatial scale, although catches before the 1990s are considered highly uncertain. Catches were assumed to increase linearly from 0 in 1965 to the 1974 catch level (Figure 10). Detailed spatial reporting of catches is only available since 2002, when PCELR forms introduced recording of estimated catch for fine-scale statistical areas. Catches prior to 2002 were partitioned into regions using average catch splits for the first 4 years of PCELR data only (2002–2006), to avoid undue influences from reductions in catch from areas other than Cook Strait. Two different catch levels were initially tried to account for overall catch uncertainty in the assessment (Figure 10). 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, with recruitment deviates estimated from 1984 to 2017, and length at recruitment was defined by a uniform distribution with a range between 70 and 80 mm. Natural mortality in the base model was fixed at 0.12. The model estimated the commercial fishing selectivity, assumed to follow a logistic curve, with increases in recent years due to changes in the minimum harvest size in some areas. 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 5, PAU 7), and relative fits for CPUE and CSLF data were examined based on model fits and residuals.

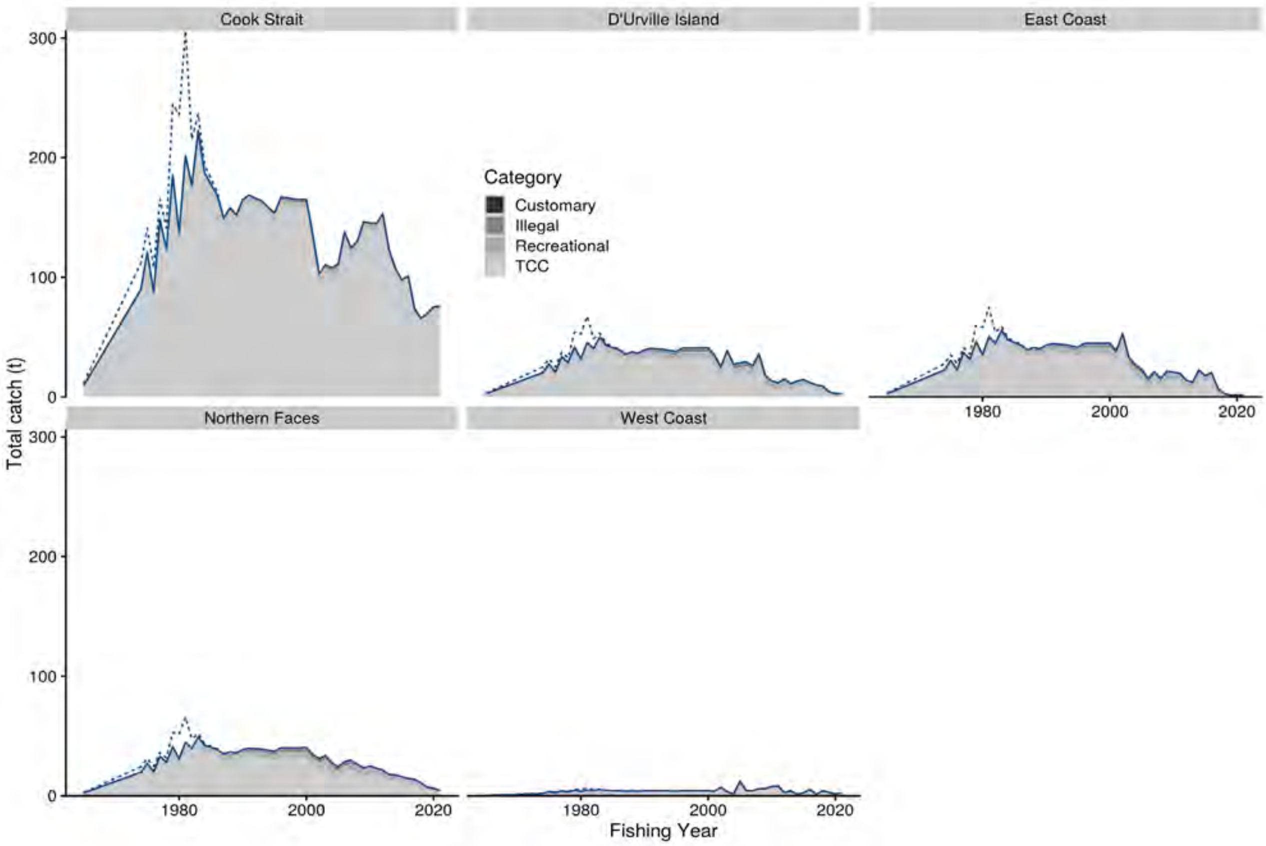


Figure 10: Assumed catch histories for industry management areas within PAU 7. Grey shading indicates components of the total catch, with the solid lines showing the base-case assumption of total catch (commercial, recreational, and illegal), including unreported catches prior to QMS entry of PAU 7, and the dashed line showing a sensitivity with high assumed pre-QMS catches.

The assessment calculated 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 2021 (SSB_{2021} and) and for the projection (*Proj*) period (SSB_{Proj} and B^{Avail}_{proj}). This assessment also reported the following fishery indicators:

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_{2021} > 40% SSB_0)	Probability that the spawning stock biomass in 2021 was greater than 40% of the unfished spawning stock
P(SSB_{2021} < 20% SSB_0)	Probability that the spawning stock biomass in 2021 was less 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 less 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

4.2.1 Estimated parameters

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

Table 5: A summary of key model parameters, lower bound, upper bound, type of prior, (U, uniform; N, normal; LN = lognormal; Beta = beta distribution), mean and standard deviation of the prior. Bounds for fixed parameters represent model sensitivities.

Parameter	Prior	μ	sd	Bounds	
				Lower	Upper
ln(*R0*)	LN	13.5	10		
M	fixed	0.12		0.08	0.16
Steepness (h)	Beta(1,1) on (0.2;1)	0.6	0.23	0	1
Growth	MVN		From Neubauer & Tremblay-Boyer 2019b		
D_{50} (Length at 50% selectivity for recreational and commercial catch before adjustments for commercial minimum harvest size)	LN	125	6.25	100	145
$D_{95\text{-}50}$ (Length between 50% and 95% selectivity the commercial catch)	LN	5.6	3	0.01	50
$ln(\epsilon)$ (Recruitment deviations; 1985–2017)	LN	0	0.4		-

The observational data were:

- A standardised CPUE series covering 2002–2021 based on PCELR and ERS data.
- Commercial catch sampling length frequency from 1990 to 2020.
- Catches were assumed to be known without error, although a catch penalty was applied in the model.

4.3 Stock assessment results

The base model with *M*=0.12 estimated a steady reduction in spawning biomass from the beginning of the fishing history (assumed to be 1965) to the early 2000s (Figure 11), with a subsequent increase in biomass driven by trends in CPUE (see Figure 5) after considerable (40%) reductions in catch between 2001 and 2004 (Figure 10). The recovery largely stalled, and the stock started to decline again after a 15% shelving was lifted in 2007–08 (Figure 11). Although subsequent shelving from 2012–13 to 2014–15 reduced fishing pressure somewhat, these reductions did not lead to the desired increases in biomass. Current harvest rates, following the 50% TACC reduction in 2016–17, have approached target levels, and have led to a recent rebuild of the biomass to levels approaching target biomass levels.

The base model with *M*=0.12 and estimated growth gave a relatively good fit to CPUE and CSLF data. Although CPUE responded to reductions in catch in the early 2000s, leading to a strong subsequent increase in biomass, this initial increase in CPUE was partly explained by recruitment in the model. The latter suggests that the assumed productivity was not enough to explain the level of increase in CPUE in the early 2000s. By contrast, recent recruitment estimates were only slightly above average, suggesting that more recent increases were in line with assumed (and estimated) levels of productivity.

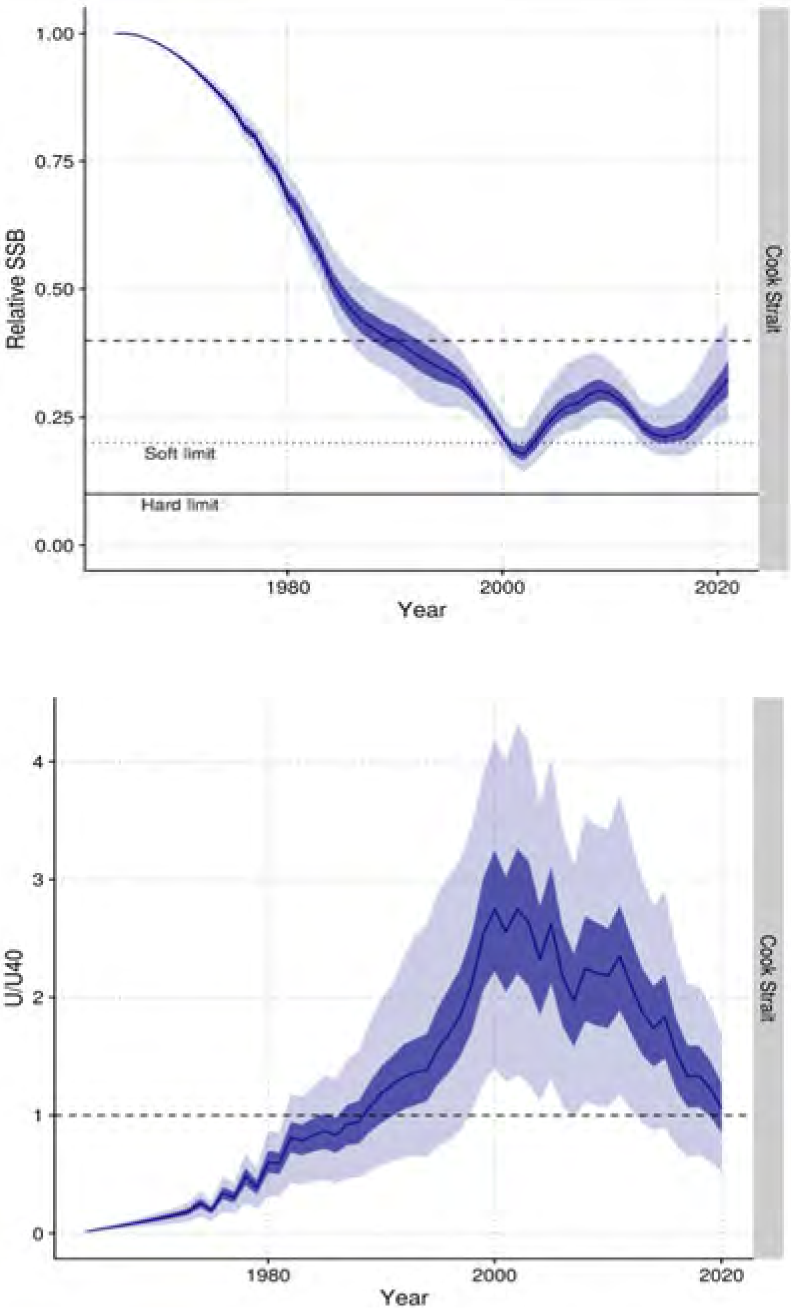


Figure 11: Posterior distributions of relative spawning stock biomass (*SSB*, top panel) and trends in relative commercial exploitation rate (bottom panel) in the base case model for Cook Strait in PAU 7. Exploitation rate (*U*) is relative to the exploitation rate that would result in a stock depletion to 40% of unfished spawning biomass (U_{40}). The dark purple line shows the median of the posterior distribution, the 25th and 75th percentiles are shown as dark ribbons, with light ribbons representing the 95% confidence range of the distribution.

Alternative models investigated uncertainty in *M*, early (pre-PCELR) catch levels, steepness, and data weights. All models estimated very similar trends in biomass, with slightly different outcomes in terms of recent stock status; low *M* and high early catch scenarios had the lowest estimates of recent biomass with 27% and 31% of unfished spawning biomass in 2021. Despite these differences, all models suggested recent increases in biomass, with relatively rapid expected rebuilding under the base model (by 2026, Table 6).

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 mean relative to *SSB*, the posterior mean relative available spawning biomass B^{Avail}_{Proj}, 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 (TACC at 74.6 t). Other projection scenarios show 20% catch reduction to 56 t and a 20% TACC increase (89.5 t). Simulation to equilibrium (assumed to have been reached after 50 projection years) are indicated with Eq. in the year column.

Region	$TCC(t)$	$Year$	$P(SSB_y > 0.4 \cdot SSB_0)$	$P(SSB_y < 0.2 \cdot SSB_0)$	$P(SSB_y > SSB_{cur})$	SSB_y	B_y^{avail}	$P(H_y > H_{0.4 \cdot SSB})$
Cook Strait	60	2021	0.09	0	1.00	0.33	0.12	0.51
Cook Strait	60	2022	0.26	0	0.92	0.36	0.14	0.10
Cook Strait	60	2023	0.40	0	0.96	0.38	0.17	0.03
Cook Strait	60	2024	0.49	0	0.97	0.40	0.20	0.01
Cook Strait	60	2025	0.56	0	0.98	0.42	0.23	0.01
Cook Strait	60	2026	0.62	0	0.98	0.43	0.25	0.01
Cook Strait	60	Eq.	0.98	0	1.00	0.58	0.45	0.00
Cook Strait	75	2021	0.09	0	1.00	0.33	0.12	0.51
Cook Strait	75	2022	0.26	0	0.92	0.36	0.14	0.32
Cook Strait	75	2023	0.37	0	0.93	0.38	0.17	0.19
Cook Strait	75	2024	0.43	0	0.93	0.39	0.19	0.13
Cook Strait	75	2025	0.48	0	0.94	0.40	0.21	0.10
Cook Strait	75	2026	0.52	0	0.94	0.41	0.23	0.08
Cook Strait	75	Eq.	0.85	0	0.98	0.51	0.36	0.01
Cook Strait	90	2021	0.09	0	1.00	0.33	0.12	0.51
Cook Strait	90	2022	0.26	0	0.92	0.36	0.14	0.54
Cook Strait	90	2023	0.34	0	0.87	0.37	0.16	0.41
Cook Strait	90	2024	0.39	0	0.85	0.38	0.18	0.33
Cook Strait	90	2025	0.40	0	0.84	0.39	0.19	0.28
Cook Strait	90	2026	0.43	0.01	0.85	0.39	0.20	0.25
Cook Strait	90	Eq.	0.55	0.03	0.81	0.42	0.26	0.18

4.3.1 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.

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 and may have been experienced in D'Urville and Northern Faces.

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 the ability of divers 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 and ERS, which record daily fishing time and catch per diver on a relatively small spatial scale. These data will likely remain the basis for stock assessments and formal management in the medium term.

Between October 2010 and 2018, a dive-logger data collection program was operated by the commercial industry to achieve fine-scale monitoring of pāua fisheries (Neubauer et al 2014, Neubauer & Abraham 2014). 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 behaviour, CPUE, and changes in abundance on various spatial and temporal scale (Neubauer et al 2014, Neubauer & Abraham 2014). However, the data-loggers, and recent changes to fine-scale electronic statutory reporting, 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 et al 2015, Neubauer 2017).

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.

Areas outside Cook Strait are now poorly monitored by CPUE. The declines in CPUE in areas that are fished (D'Urville and Northern Faces) and contribute to CPUE therefore may substantially under-estimate the true extent of declines in these areas. While anecdotal evidence suggests that environmental factors have played a primary role in these declines, no firm conclusion can be reached about the relative contributions of environmental changes and fishing impacts on declines of pāua populations in the areas. Although these areas now only contribute very little to the commercial fishery, it is unclear whether these areas can be expected to recover, and in the absence of CPUE to monitor abundance there is currently a lack of information that can inform about local trends in these areas.

4.4 Future research considerations

- Monitoring of biomass in areas where CPUE does not provide an index of biomass (D'Urville Island and Northern Faces).
- Continued monitoring of growth and maturation to understand effects of changing environment, particularly with respect to SST. This might also be achieved by meta-analysis across stocks and could include consideration of SST effects on CPUE across stocks. Consider including more of the east coast in the assessment, noting that this would need to be considered as a separate fishery due to recent earthquake impacts and new management settings.
- Estimate recreational harvest using approaches linked to stock size.
- Explore use of smaller time steps within the assessment model to improve fits to LF data.

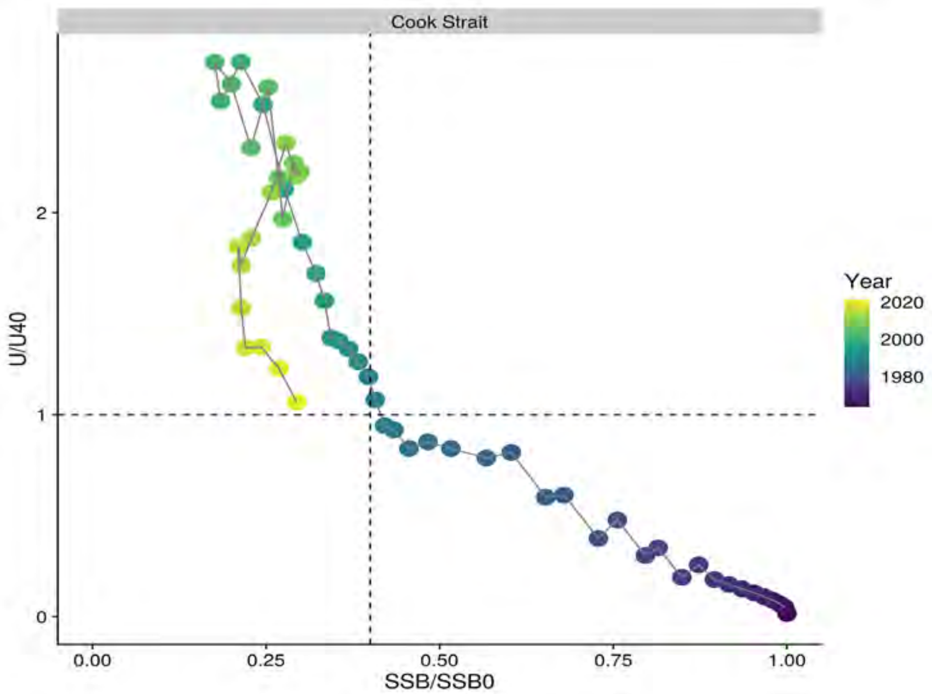
5. STATUS OF THE STOCKS

Stock Structure Assumptions
The 2022 assessment was conducted for Cook Strait (pāua statistical areas 711–730), but these include most (more than 90%) of the recent catch.

- **PAU 7- Marlborough**

Stock Status		
Most Recent Assessment Plenary Publication	2022	
Catch in most recent year of assessment	Year: 2020–21	Catch: -
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 33% B_0 and is Unlikely (< 40%) 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	About as Likely as Not (40–60%) that overfishing is occurring	

Historical Stock Status Trajectory and Current Status

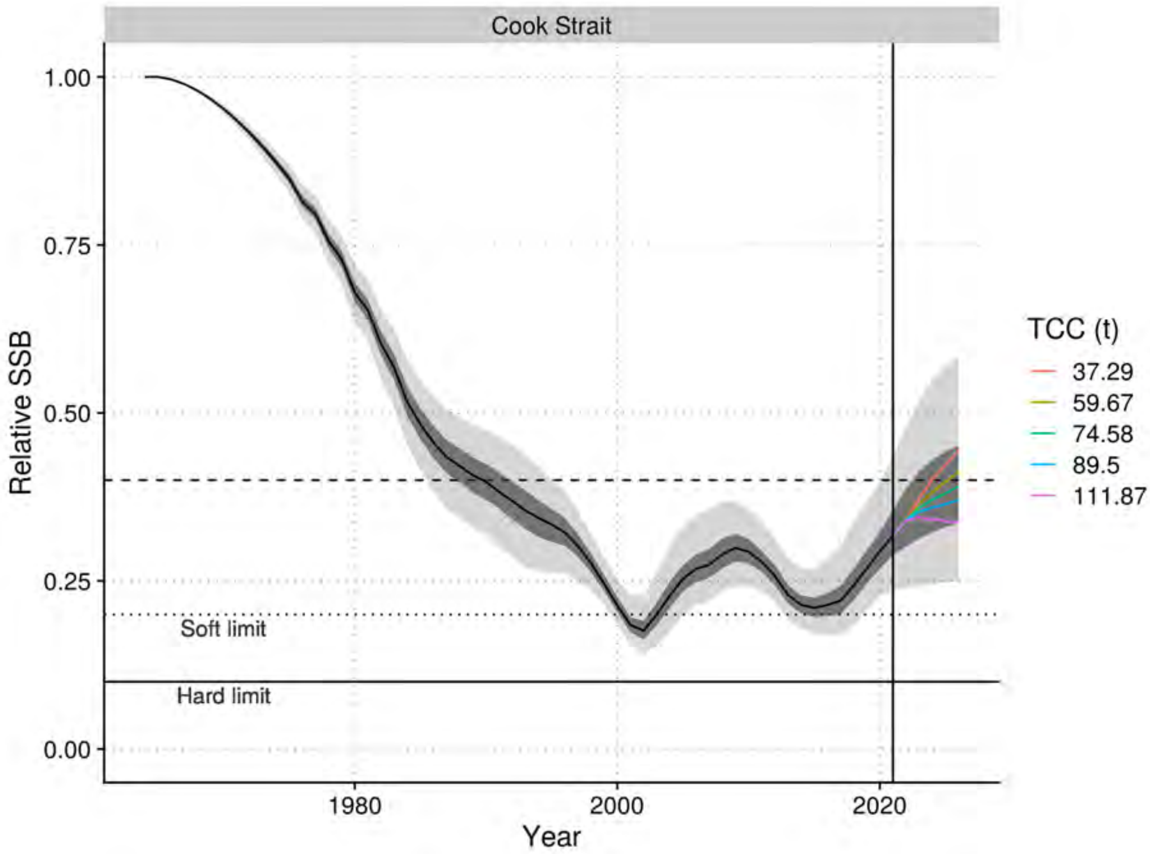


Posterior medians of relative stock status (spawning stock biomass (*SSB*) depletion level relative to unfished biomass (SSB_0)) and exploitation rate (*U*), relative to the exploitation rate that would result in a stock depletion to 40% of unfished biomass (U_{40}).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The stock has rebuilt substantially towards the target biomass level since 2017.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity peaked in the early 2000s but has subsequently declined steadily.

Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis



Stock trajectory and projected stock biomass (2022–2026), colours show median trajectories for current catch, (green) and 20% (50%) increase (decrease) from current catch. Uncertainty intervals show inter-quartile and 95% confidence from the base-case MCMC under observed catch (current catch for projected biomass).

Stock Projections or Prognosis	Five-year projections suggest that, at current catch levels, the biomass will be rebuilt to target levels by 2026.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Unlikely (< 40%)

Assessment Methodology & Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Length based Bayesian model	
Assessment Dates	Latest assessment Plenary publication year: 2022	Next assessment: 2027
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE indices PCELR & ERS series	1 – High Quality
	- Commercial sampling length frequencies	1 – High Quality

	Growth estimate priors	2 – Medium or mixed quality: fine scale spatial (and potentially temporal) variation in growth rates
Data not used (rank)	CELR CPUE series	3 – Low Quality: variable catchability and changes in technology
	FSU CPUE series	3 – Low Quality: poor recording
Changes to Model Structure and Assumptions	- Assessment area reduced to Cook Strait only, due to poor representation of other areas in fishery-dependent data in recent years - Changed growth to use a prior derived from meta-analysis, model does not explicitly fit to PAU 7 growth data (deemed poorly representative of spatial growth variation) - Fixed *M* in base case (estimated *M* from this model is consistent with previous estimate and current fixed value) - Length frequency likelihood logistic normal, rather than multinomial	
Major Sources of Uncertainty	- Recruitment: length composition data available to the stock assessment provide little information about relative year class strengths - Assessment model is sensitive to natural mortality, which is poorly quantified - Early catch history: Pre QMS pāua exports exceeded catches reported to FMAs, and it is unclear which areas these catches came from	

Qualifying Comments
-This assessment covers only the Cook Strait component of the catch. The stock appears to be depleted in D'Urville and Northern Faces. - The East Coast portion of the QMA was closed to fishing following the Kaikōura earthquake in 2016, and subsequent surveys suggest an appreciable increase.

Fishery Interactions
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6. FOR FURTHER INFORMATION

Andrew, N L; Breen, P A; Kendrick, T H; Naylor, J R (2000) Stock assessment of PAU 7 for 1998–99. *New Zealand Fisheries Assessment Report 2000/48*. 22 p.

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

Breen, P A; Andrew, N L; Kendrick, T H (2000) Stock assessment of paua (*Haliotis iris*) in PAU 5B and PAU 5D using a new length-based model. *New Zealand Fisheries Assessment Report 2000/33*. 37 p.

Breen, P A; Kim, S W (2003) The 2003 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fishery Assessment Report 2003/41*. 119 p.

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

Breen, P A; Kim, S W (2005) The stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2005/47*. 114 p.

Butterworth, D; Haddon, M; Haist, V; Helidoniotis, F (2015) Report on the New Zealand Paua stock assessment model; 2015. *New Zealand Fisheries Science Review 2015/4*. 31 p.

Cordue, P L (2009) Analysis of PAU 5A diver survey data and PCELR catch and effort data. SeaFic and PAUMac 5 report. 45 p. (Unpublished report held by Fisheries New Zealand, Wellington.)

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

Francis, R I C C (2011) Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68(6)*: 1124–1138.
Fu, D (2012) The 2011 stock assessment of paua (*Haliotis iris*) for PAU 7. *New Zealand Fisheries Assessment Report 2012/27*. 57 p.
Fu, D; McKenzie, A; Naylor, R (2012) Summary of input data for the PAU 7 stock assessment for the 2010–11. *New Zealand Fisheries Assessment Report 2012/26*.
Gerring, P; Andrew, N L; Naylor, J R (2003) Incidental fishing mortality of paua (*Haliotis iris*) in the PAU 7 commercial fishery. *New Zealand Fisheries Assessment Report 2003/56*. 13 p.
Gorfine, H K; Dixon, C D (2000) A behavioural rather than resource-focused approach may be needed to ensure sustainability of quota managed abalone fisheries. *Journal of Shellfish Research 19*: 515–516.
Haist, V (2010) Paua research diver surveys: review of data collected and simulation study of survey method. *New Zealand Fisheries Assessment Report 2010/38*. 54 p.
McCowan, T; Neubauer, P (2018) Paua biomass estimates and population monitoring in areas affected by the November 2016 Kaikoura earthquake. *New Zealand Fisheries Assessment Report 2018/54*. 24 p.
McCowan, T; Neubauer, P (2021) Pāua abundance trends and population monitoring in areas affected by the November 2016 Kaikōura earthquake. *New Zealand Fisheries Assessment Report 2021/26*. 23 p.
McCowan, T A; Neubauer, P (2022) Pāua abundance trends and population monitoring in areas affected by the November 2016 Kaikōura earthquake, December 2021 update. *New Zealand Fisheries Assessment Report 2022/15*. 20 p.
McKenzie, A (2004) Alternative CPUE standardisation for PAU 7. NIWA Client Report WLG2004-74. 18 p.
McKenzie, A (2010) CPUE standardisation for PAU 7 in 2010. NIWA Client Report, WLG2010-29. 12 p.
McKenzie, A; Smith, A N H (2009a) Data inputs for the PAU 7 stock assessment in 2008. *New Zealand Fisheries Assessment Report 2009/33*. 34 p.
McKenzie, A; Smith, A N H (2009b) The 2008 stock assessment of paua (*Haliotis iris*) in PAU 7. *New Zealand Fisheries Assessment Report 2009/34*. 86 p.
McShane, P E; Naylor, J R (1995) Small-scale spatial variation in growth, size at maturity, and yield- and egg-per-recruit relations in the New Zealand abalone *Haliotis iris*. *New Zealand Journal of Marine and Freshwater Research 29*: 603–612.
Neubauer, P.; Abraham, E. (2014). Using GPS logger data to monitor change in the PAU7 pāua (*Haliotis iris*) fishery. *New Zealand Fisheries Assessment Report 2014/31*. 18 p.
Neubauer, P; Abraham, E; Knox, C; Richard, Y (2014) Assessing the performance of pāua (*Haliotis iris*) fisheries using GPS logger data. Final Research Report for Ministry for Primary Industries project PAU2011-03 (Unpublished report held by Fisheries New Zealand, Wellington.)
Neubauer, P. (2017) Spatial bias in pāua (*Haliotis iris*) catch-per-unit-effort. *New Zealand Fisheries Assessment Report 2017/57*. 33 p.
Nuebauer, P. (2023) The 2022 stock assessment of pāua (Haliotis iris) for PAU 7. *New Zealand Fisheries Assessment Report 2023/17*. 46 p.
Neubauer, P; Tremblay-Boyer, L (2019a) Input data for the 2018 stock assessment of pāua (Haliotis iris) for PAU 5D. *New Zealand Fisheries Assessment Report 2019/38*. 44 p.
Neubauer, P; Tremblay-Boyer, L (2019b) The 2018 stock assessment of pāua (Haliotis iris) for PAU 5D. *New Zealand Fisheries Assessment Report 2019/39*. 58 p.
Neubauer, P (2023) The 2022 stock assessment of pāua (*Haliotis iris*) for PAU 7. *New Zealand Fisheries Assessment Report 2023/17*. 46 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.
Punt, A E (2003) The performance of a size-structured stock assessment method in the face of spatial heterogeneity in growth. *Fisheries Research 65*: 391–409.
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 (1989) Paua fishery assessment 1989. New Zealand Fishery Assessment Research Document 1989/9: 20 p. (Unpublished document held by NIWA library, Wellington.)
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.
Shepherd, S A; Partington, D (1995) Studies on Southern Australian abalone (genus *Haliotis*). XVI. Recruitment, habitat and stock relations. *Marine and Freshwater Research 46*: 669–680.
Will, M C; Gemmell, N J (2008) Genetic Population Structure of Black Foot paua. (Unpublished report for GEN2007A, held by Fisheries New Zealand, Wellington.) 37 p.
Wynne-Jones, J; Gray, A; Heinemann, A; Hill, L; Walton, L (2019) National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.
Wynne-Jones, J; Gray, A; Hill, L; Heinemann, A (2014) National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 p.