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Summary of input data for the 2013 PAU 5B stock assessment

New Zealand Fisheries Assessment Report 2014/43

D. Fu
A. McKenzie
R. Naylor

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EXECUTIVE SUMMARY

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.**

This document summarises the data inputs for the 2013 stock assessment of blackfoot paua in PAU 5B. The seven sets of data fitted in the assessment model were: (1) a standardised CPUE series based on CELR data (2) a standardised CPUE series based on PCELR data (3) a standardised research diver survey index (RDSI) (4) a research diver survey proportions-at-lengths series (5) a commercial catch sampling length frequency series (6) tag-recapture length increment data and (7) maturity-at-length data. Catch history was an input to the model encompassing commercial, recreational, customary, and illegal catch.

The standardised CPUE series based on PCELR data was updated to the 2012–13 fishing year. There has been no research diver survey since the last assessment, but the indices were revised incorporating modifications on the standardisation procedure suggested by recent reviews. Scaled length frequency series from the commercial catch sampling were updated to the 2012–13 fishing year, where the catch samples were stratified by area and numbers at length were scaled up to each landing and then to the stratum catch. Tag-recapture length increment data and maturity-at-length data were reanalysed incorporating data available since the last assessment.

1. INTRODUCTION

This document summarises the data inputs for the 2013 stock assessment of PAU 5B. The work was conducted by NIWA under the Ministry for Primary Industries contract PAU201304 Objective 1. A separate document details the stock assessment of PAU 5B (Fu 2014).

PAU 5B was last assessed in 2007 (Breen & Smith 2008b) and before that in 2000 (Breen et al. 2000). Data used in the 2013 assessment were:

1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2013 based on PCELR data.
3. A standardised research diver survey index (RDSI).
4. A research diver survey proportions-at-lengths series (RDLF).
5. A commercial catch sampling length frequency series (CSLF).
6. Tag-recapture length increment data.
7. Maturity-at-length data.

In the previous assessment, a combined standardised CPUE series including both CELR and PCELR data was used. For this assessment, CPUE indices were calculated for the CELR and PCELR data separately, based on methodologies similar to those for the recent PAU 5A assessment (Fu et al. 2010), PAU 7 assessment (Fu et al. 2012), and PAU 5D (Fu et al. 2013). The fishing year for paua is from 1 October to 30 September and in this document we refer to fishing year by the second year that it covers; thus we call the 1997–98 fishing year “1998”.

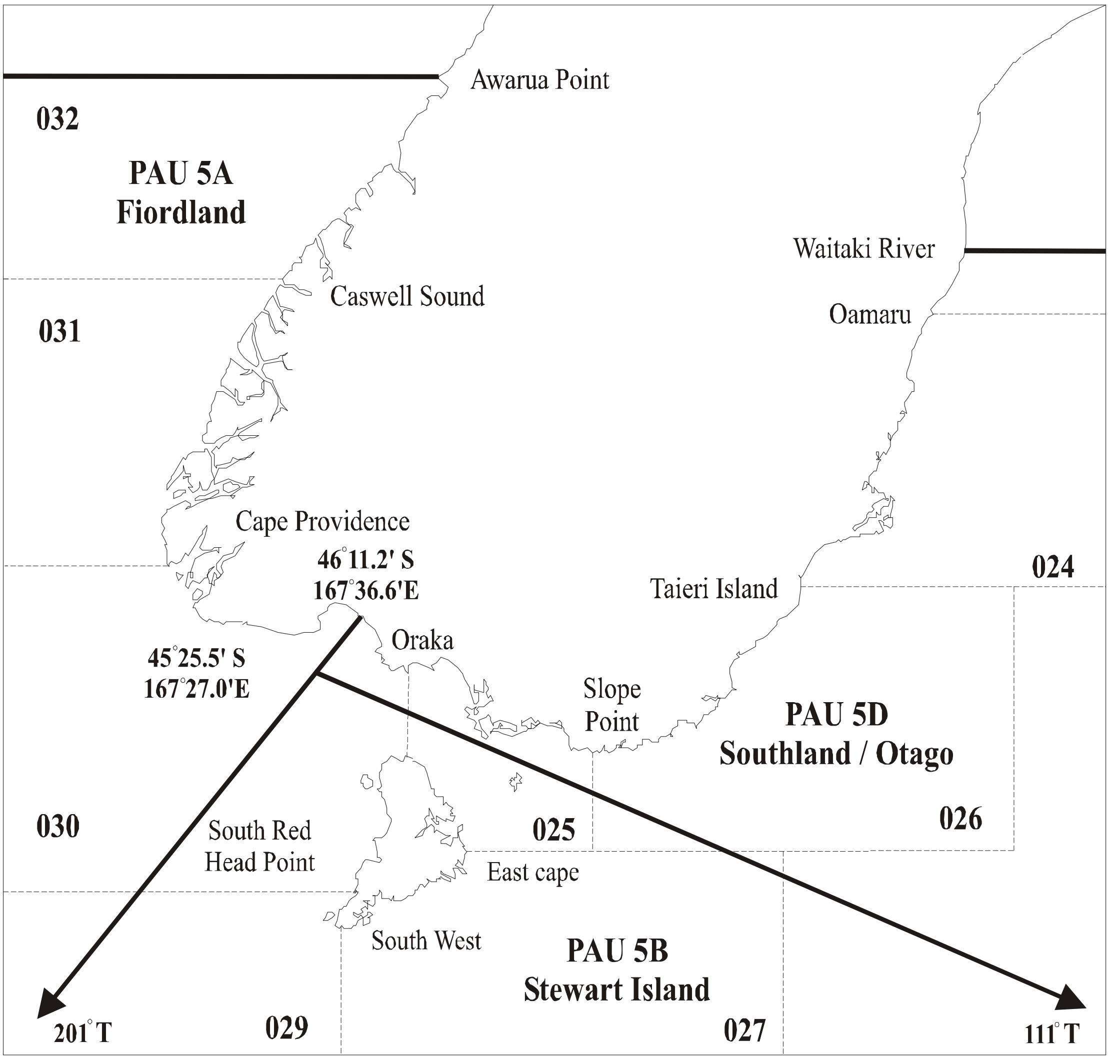


Figure 1: Map showing the QMAs effective from 1 October 1995 (solid dark lines) and the old General Statistical Area boundaries (dashed lines) of PAU 5.

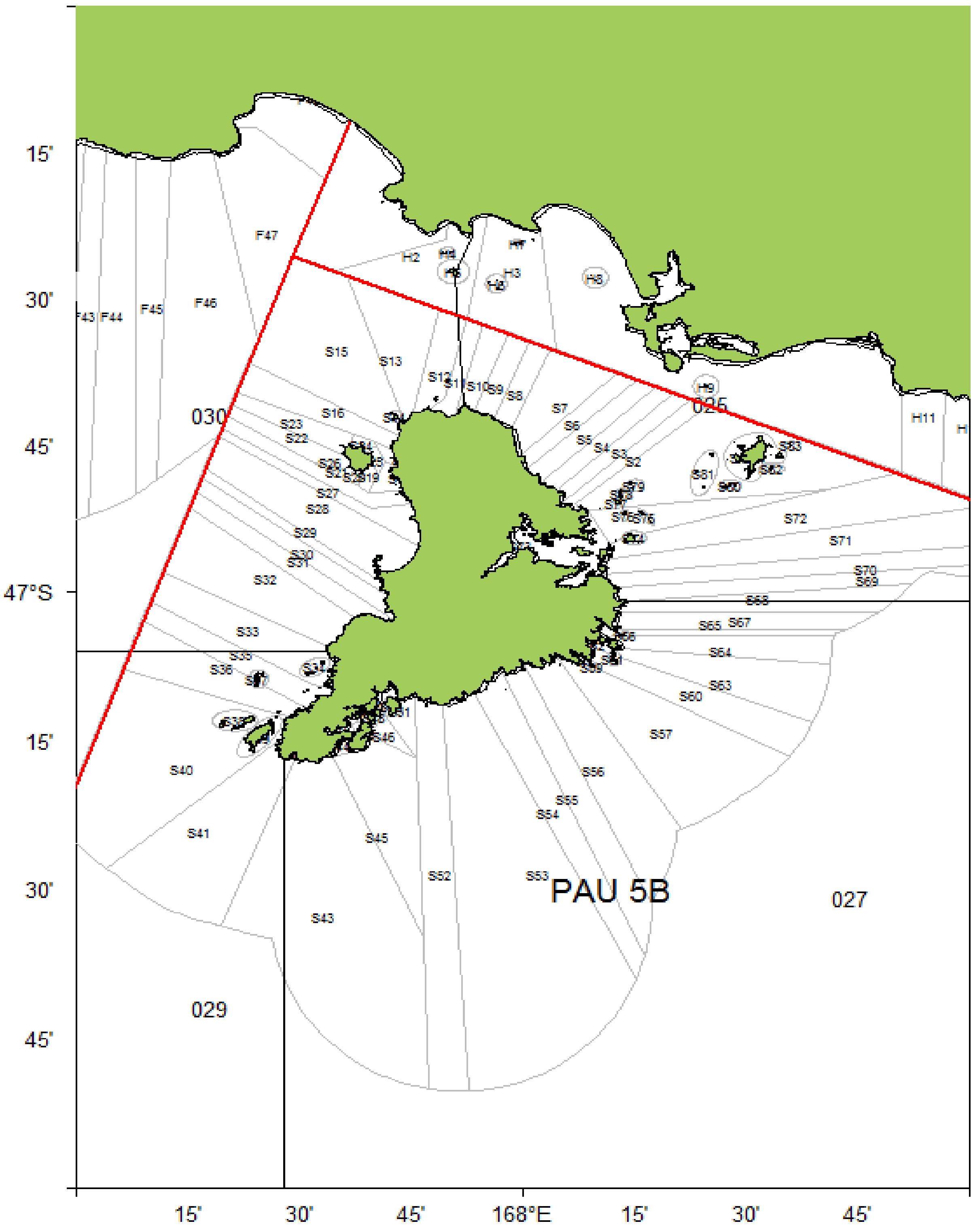


Figure 2: Map showing the location of fine scale Paua Statistical Areas within PAU 5B effective from 1 October 2001.

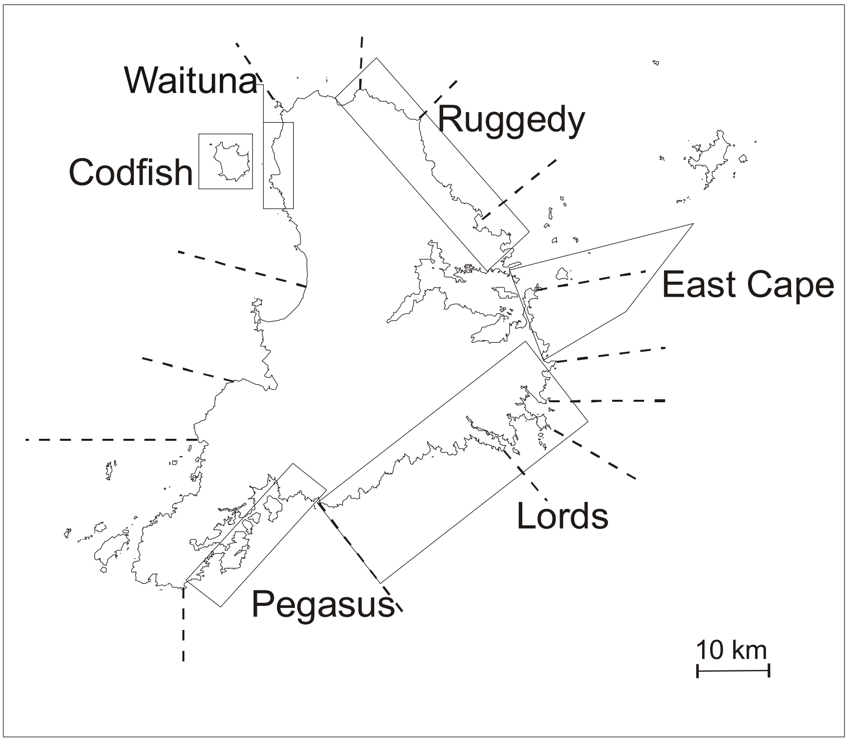


Figure 3: Map of research strata for PAU 5B.

2. DESCRIPTION OF THE FISHERY

The PAU 5 Quota Management Area includes the entire southern stock of paua from the Waitaki River mouth on the east coast of the South Island, south around to Awarua Point on the west coast including Stewart Island. The TACC allocation for PAU 5 was 445 t in 1986–87; quota appeals increased this to 492 t by 1991–92. For the 1992–93 fishing year quota holders agreed to a voluntary quota reduction which reduced the TACC to 443 t. In the 1995–96 fishing year, PAU 5 was divided into three substocks: PAU 5A, Fiordland; PAU 5B, Stewart Island; and PAU 5D, Southland/Otago (Figure 1). The TACC was divided equally among the new stocks. It is widely considered that this led to a large redistribution of catch from Stewart Island to Fiordland and the Catlins/Otago coast (Elvy et al. 1997), but the extent to which this happened cannot be determined with certainty because the new stock boundaries are not aligned with the old statistical areas used to report catch and effort. The reported landings (QMR/MHR) and TACC for the old PAU 5 and the subdivided stocks are shown in Table 1.

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. Concerns of over-exploitation led to a series of management interventions to reduce the TACC and commercial catch. On 1 October, 1999, the industry agreed to shelve 25 t of quota in addition to the 5 t TACC reduction, resulting in an effective commercial catch limit of about 112 t. This shelving continued into 2000 at a level of about 22 t. In 2002, shelving was discontinued, and the TACC was set at 90 t, about 60% of the catch level in the 1995–96 fishing year. On 1 October 2010 the commercial fishery voluntarily adopted a minimum harvest size of 135 mm for all statistical areas throughout PAU 5B.

Landings in PAU 5 were reported to the single management stock (PAU 5) before 1 October 1995, and then to the three separate substocks PAU 5A, PAU 5B, and PAU 5D (although a number of fishers continued to use the code PAU 5). Estimated catch on the CELR forms was reported on the scale of the General Statistical Areas until 1 November 1997, when these areas were further subdivided into 17, 16, and 11 Paua Statistical Reporting Areas for PAU 5A, PAU 5B, and PAU 5D, respectively. The spatial scale of reporting was further reduced from 1 October 2001, when the specific PCELR forms were adopted and it became mandatory to report catch and effort on the finer-spatial scale statistical zones originally developed for the New Zealand Paua Management Company's voluntary logbook (Figure 2). A summary of the spatial resolution of reporting zones and research strata for PAU 5B is given in Tables 2–3.

Table 1: TACCs and reported landings (kg) of paua for PAU 5 and substocks PAU 5A, PAU 5B, and PAU 5D. PAU 5 was subdivided into PAU 5A, PAU 5B, and PAU 5D on 1 October 1995 and reported landings for these Fishstocks are given separately from 1995–96.

	PAU 5		PAU 5A		PAU 5B		PAU 5D	
Fishstock	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	550 515	–	N/A	N/A	N/A	N/A	N/A	N/A
1984–85*	352 459	–	N/A	N/A	N/A	N/A	N/A	N/A
1985–86†	331 697	–	N/A	N/A	N/A	N/A	N/A	N/A
1986–87†	418 904	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1987–88†	458 239	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1988–89†	445 978	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1989–90†	468 647	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1990–91†	510 335	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1991–92†	483 037	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1992–93†	435 395	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1993–94†	440 144	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1994–95†	434 708	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1995–96†	N/A	N/A	138 526	148 983	144 661	148 984	146 772	148 983
1996–97†	N/A	N/A	143 848	148 983	142 357	148 984	146 990	148 983
1997–98†	N/A	N/A	145 224	148 983	145 337	148 984	148 718	148 983
1998–99†	N/A	N/A	147 394	148 983	148 547	148 984	148 697	148 983
1999–00†	N/A	N/A	143 913	148 983	118 068	143 984	147 897	148 983
2000–01†	N/A	N/A	148 221	148 983	89 915	112 187	148 813	148 983
2001–02†	N/A	N/A	148 535	148 983	89 963	112 187	148 740	148 983
2002–03†	N/A	N/A	148 764	148 983	89 863	90 000	111 693	114 000
2003–04†	N/A	N/A	148 980	148 983	90 004	90 000	88 024	89 000
2004–05†	N/A	N/A	148 952	148 983	89 970	90 000	88 817	89 000
2005–06†	N/A	N/A	148 922	148 983	90 467	90 000	88 931	89 000
2006–07†	N/A	N/A	104 034	148 983	89 156	90 000	88 973	89 000
2007–08†	N/A	N/A	105 132	148 983	90 205	90 000	88 978	89 000
2008–09†	N/A	N/A	104 823	148 983	89 998	90 000	88 770	89 000
2009–10†	N/A	N/A	105 741	148 983	90 227	90 000	89 453	89 000
2010–11†	N/A	N/A	104 400	148 983	89 673	90 000	88 699	89 000
2011–12†	N/A	N/A	106 234	148 983	89 589	90 000	89 230	89 000
2012–13	N/A	N/A	106 115	148 983	88 609	90 000	85 137	89 000

* FSU data, † QMR/MHR data

Table 2: Summary of spatial and temporal resolution of catch effort data available for PAU 5B.

QMA		Statistical Reporting Areas		
1986/87–1994/95	Oct 1995–present	1986/87–30 Oct 1997	Nov 1997–Sep 2001	Oct 2001–present
PAU5	PAU 5B	27	B6–B10	P5BS43–P5BS68
		28	N/A	
		29	B5	P5BS33–P5BS42
		025(part of)	B11–B15	P5BS01–P5BS10
				P5BS69–P5BS84
		030 (part of)	B1–B4 B16	P5BS11–P5BS32

Table 3: Summary of research strata (subareas) and associated Paua Statistical Areas within PAU 5B. West and Ruapuke are areas not covered by research strata (see Figure 3). Statistical Areas P5BS11–P5BS14 are not covered by any research strata but are assumed to be Waituna in this report.

Subarea	Paua Statistical Area
Ruggedy	P5BS01–P5BS10
Waituna	P5BS11–P5BS18
Codfish	P5BS19–P5BS25
West	P5BS26–P5BS42
Pegasus	P5BS43–P5BS52
Lords	P5BS53–P5BS68
EastCape	P5BS69–P5BS72
Ruapuke	P5BS76–P5BS84

3. CATCH HISTORY

3.1 Commercial catch

The subdivision of the PAU 5 stock and changes in the spatial scale of reporting harvest led to complications in the allocation of catch statistics to the new QMAs. The historical catch series for the substocks within PAU 5 before 1995 cannot be determined with certainty, because some of the statistical areas used to report catch and effort straddle multiple stocks (e.g., Statistical Area 030 straddles PAU 5A, PAU 5B and PAU 5D, see Figure 1). Kendrick & Andrew (2000) described a method for estimating the pre-1995 catches from the substocks within PAU 5. The method was further explained by Breen & Smith (2008a), and was used to assemble the catch history for PAU 5A assessment in 2006 (Breen & Kim 2007) and 2010 (Fu et al. 2010), for the PAU 5B assessment in 2007 (Breen & Smith 2008b), and for the PAU 5D assessment in 2006 (Breen & Kim 2007) and 2012 (Fu et al. 2013).

We repeated this procedure to calculate the catch history for PAU 5B. A constant proportion of 52% was applied to the Murray & Akroyd (1984) PAU 5 catch series to obtain catch estimates from 1974 to 1983. From 1983–84 to 1994–95, the annual proportion of catch for PAU 5B was firstly estimated, where 75% of the annual estimated catch in Statistical Areas 030 and 025 was assumed to have been taken from PAU 5B, and that proportion was applied to the QMR/MHR landings in PAU 5 to obtain the catch estimates. In the 2010 assessment for PAU 5A (Fu et al. 2010), alternative assumptions were suggested by the SFWG concerning the proportion of catch in Statistical Area 030 that were taken from PAU 5A, PAU 5B, and PAU 5D between 1983–84 and 1995–96: (1) 18%, 75%, and 7% respectively, (2) 40%, 53%, and 7% respectively, and (3) 61%, 32%, and 7% respectively. These assumptions have been adopted here to obtain catch estimates for each of the substocks within PAU 5

(Table 4). Kendrick & Andrew (2000) also considered an alternative catch split of 67% to 33% between PAU 5B and PAU 5D for Statistical Area 025 between 1983–84 and 1995–96. This assumption was not used here because the difference it made to the catch estimates was insignificant.

Estimated commercial catch histories for PAU 5B are shown in Figure 4. The estimated catches by Paua Statistical Area from the years of PCELR data are shown in Figure 5. Catches were taken throughout the stock and were widely distributed among subareas, with no signs of serial depletion in the last 11 years (see Figure 5), at least at this scale. West and Ruggedy were the two largest areas for the catch, accounting for over 40% of the total catch in PAU 5B between 2002 and 2013 (Table 5).

Table 4: Collated commercial catch histories (kg) for PAU 5A, 5B, and 5D for fishing years 1974–2013 under assumptions 1, 2, and 3.

		Assumption 1 (18%)			Assumption 2 (40%)			Assumption 3 (61%)		
Year	PAU 5	PAU 5A	PAU 5B	PAU 5D	PAU 5A	PAU 5B	PAU 5D	PAU 5A	PAU 5B	PAU 5D
1974	212 670	48 914	110 588	53 168	48 914	110 588	53 168	48 914	110 588	53 168
1975	201 180	46 271	104 614	50 295	46 271	104 614	50 295	46 271	104 614	50 295
1976	160 110	36 825	83 257	40 028	36 825	83 257	40 028	36 825	83 257	40 028
1977	221 400	50 922	115 128	55 350	50 922	115 128	55 350	50 922	115 128	55 350
1978	333 460	76 696	173 399	83 365	76 696	173 399	83 365	76 696	173 399	83 365
1979	349 960	80 491	181 979	87 490	80 491	181 979	87 490	80 491	181 979	87 490
1980	433 100	99 613	225 212	108 275	99 613	225 212	108 275	99 613	225 212	108 275
1981	524 340	120 598	272 657	131 085	120 598	272 657	131 085	120 598	272 657	131 085
1982	346 560	79 709	180 211	86 640	79 709	180 211	86 640	79 709	180 211	86 640
1983	442 980	101 885	230 350	110 745	101 885	230 350	110 745	101 885	230 350	110 745
1984	550 515	107 360	294 704	148 451	146 179	248 276	156 060	183 233	211 222	156 060
1985	352 459	46 409	224 301	81 749	70 894	191 458	90 107	94 266	168 086	90 107
1986	331 697	50 646	215 811	65 240	69 949	188 216	73 532	88 374	169 791	73 532
1987	418 904	25 826	251 501	141 578	36 893	225 028	156 983	47 458	214 464	156 983
1988	458 239	37 310	327 861	93 068	56 492	288 564	113 182	74 803	270 254	113 182
1989	445 978	118 393	231 793	95 791	152 824	191 590	101 563	185 690	158 725	101 563
1990	468 647	74 372	254 105	140 170	106 101	212 681	149 865	136 388	182 394	149 865
1991	510 335	124 440	243 050	142 845	156 661	203 192	150 482	187 417	172 436	150 482
1992	483 037	100 107	254 026	128 904	133 056	212 908	137 073	164 507	181 457	137 073
1993	435 395	50 724	221 898	162 773	81 292	181 583	172 520	110 471	152 404	172 520
1994	440 144	57 733	233 533	148 878	86 016	196 333	157 794	113 015	169 335	157 794
1995	434 708	65 767	231 350	137 591	96 510	192 424	145 774	125 856	163 078	145 774
1996	429 959	138 526	144 661	146 772	138 526	144 661	146 772	138 526	144 661	146 772
1997	433 195	143 848	142 357	146 990	143 848	142 357	146 990	143 848	142 357	146 990
1998	439 279	145 224	145 337	148 718	145 224	145 337	148 718	145 224	145 337	148 718
1999	444 638	147 394	148 547	148 697	147 394	148 547	148 697	147 394	148 547	148 697
2000	409 878	143 913	118 068	147 897	143 913	118 068	147 897	143 913	118 068	147 897
2001	386 949	148 221	89 915	148 813	148 221	89 915	148 813	148 221	89 915	148 813
2002	387 238	148 535	89 963	148 740	148 535	89 963	148 740	148 535	89 963	148 740
2003	350 320	148 764	89 863	111 693	148 764	89 863	111 693	148 764	89 863	111 693
2004	327 008	148 980	90 004	88 024	148 980	90 004	88 024	148 980	90 004	88 024
2005	327 739	148 952	89 970	88 817	148 952	89 970	88 817	148 952	89 970	88 817
2006	328 320	148 922	90 467	88 931	148 922	90 467	88 931	148 922	90 467	88 931
2007	282 163	104 034	89 156	88 973	104 034	89 156	88 973	104 034	89 156	88 973
2008	284 315	105 132	90 205	88 978	105 132	90 205	88 978	105 132	90 205	88 978
2009	283 591	104 823	89 998	88 770	104 823	89 998	88 770	104 823	89 998	88 770
2010	285 420	105 740	90 230	89 450	105 740	90230	89 450	105 740	90 230	89 450
2011	282 770	104 400	89 670	88 700	104 400	89 670	88 700	104 400	89 670	88 700
2012	285 053	106 234	89 589	89 230	106 234	89 589	89 230	106 234	89 589	89 230
2013	285 053	106 234	89 589	89 230	106 234	89 589	89 230	106 234	89 589	89 230

Table 5: Proportion of estimated catch from PCELR forms for fishing years 2002–2013in each of the research strata within PAU 5B.

	Ruggedy	Waituna	Codfish	West	Pegasus	Lords	EastCape	Ruapuke	Total
2002	0.22	0.12	0.10	0.29	0.05	0.12	0.04	0.06	95
2003	0.33	0.11	0.11	0.13	0.07	0.15	0.04	0.07	98
2004	0.21	0.11	0.09	0.27	0.05	0.15	0.04	0.09	91
2005	0.15	0.13	0.14	0.23	0.08	0.15	0.02	0.10	88
2006	0.27	0.09	0.11	0.11	0.08	0.18	0.04	0.12	87
2007	0.18	0.07	0.09	0.18	0.05	0.20	0.04	0.18	87
2008	0.10	0.12	0.08	0.25	0.09	0.20	0.03	0.14	88
2009	0.09	0.10	0.13	0.31	0.09	0.20	0.02	0.07	83
2010	0.16	0.06	0.06	0.38	0.08	0.13	0.04	0.08	84
2011	0.15	0.11	0.10	0.28	0.12	0.12	0.07	0.05	83
2012	0.12	0.17	0.14	0.24	0.09	0.18	0.03	0.04	81
2013	0.20	0.14	0.21	0.27	0.03	0.09	0.05	0.03	60
Total	0.18	0.11	0.11	0.24	0.07	0.16	0.04	0.09	1025

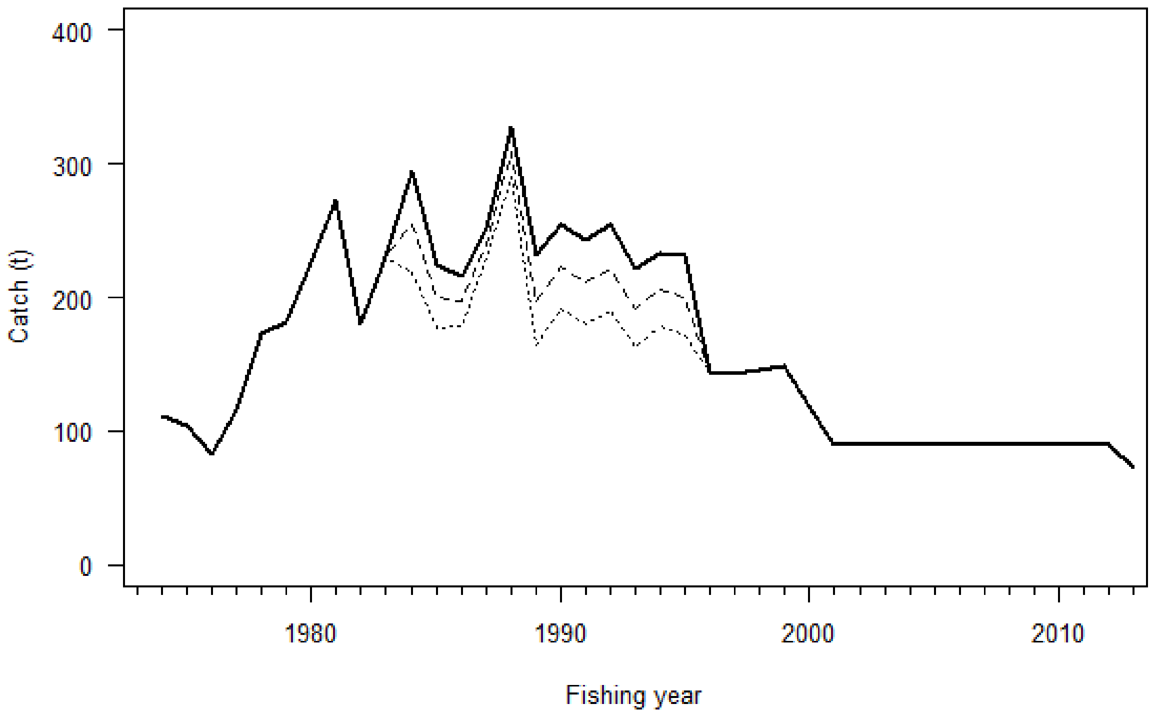


Figure 4: Estimated commercial catch history for PAU 5B under assumptions 1, 2, and 3, 1974–2013 fishing years. Assumption 1 produced the highest estimates and assumption 3 produced the lowest estimates.

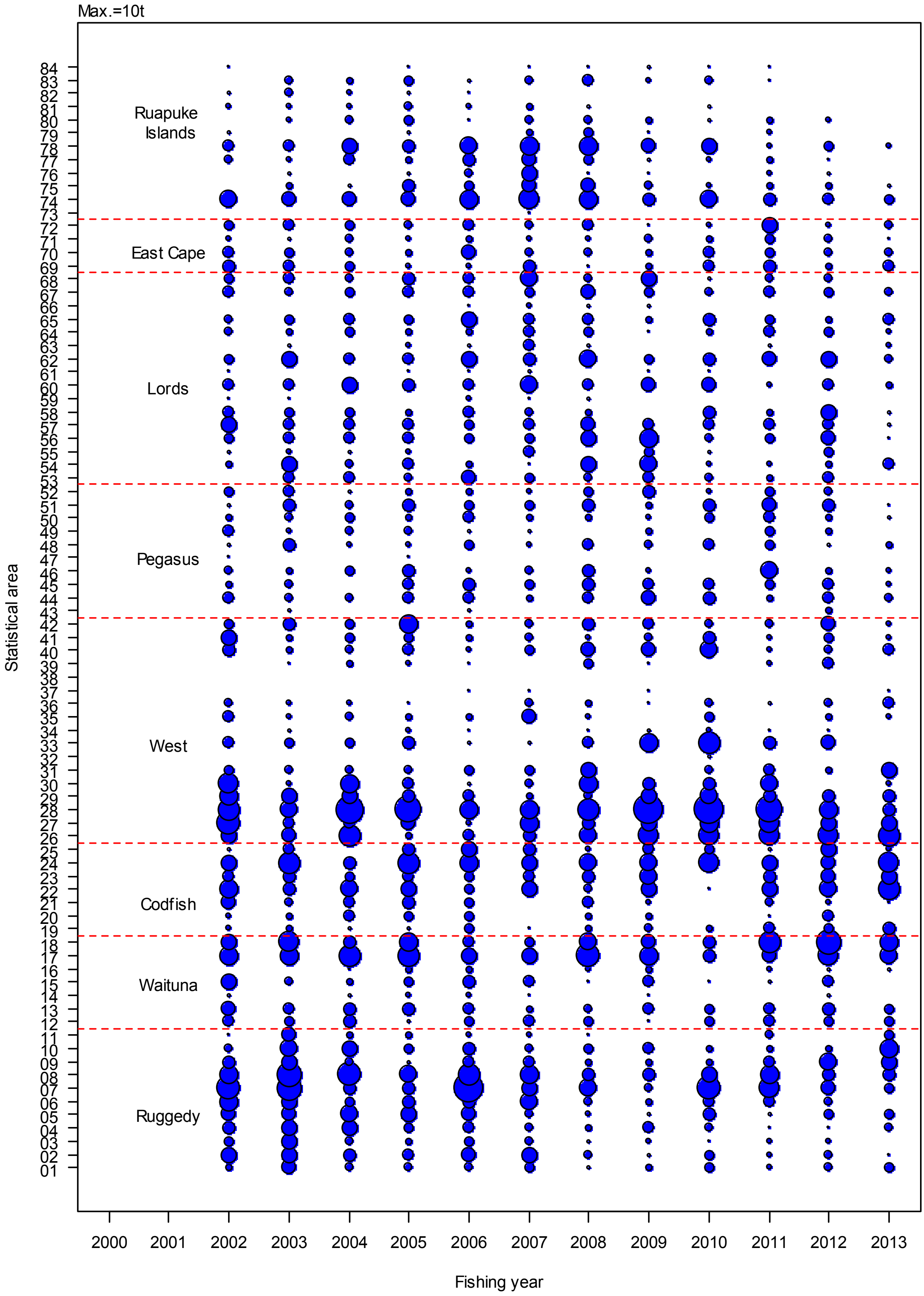


Figure 5: Annual estimated catch by Paua Statistical Area in PAU 5B for fishing years 2002–2013. The size of the circle is proportional to the catch. The red dashed lines delineate where research strata lie (see Figure 3).

3.2 Recreational catch

The 1996 and 1999–2000 National Recreational Fishing Surveys estimated that 37.1 t and 53.2 t respectively were taken from PAU 5 by recreational fisheries but with no substock breakdown. The Marine Recreational Fisheries Technical Working Group considered that some harvest estimates from the 1999–2000 and 2001–02 surveys for some fish stocks were unbelievably high. The Shellfish Fisheries Working Group (SFWG) examined estimates from national recreational surveys conducted in 1996 and 1999–2001, and following their discussions, the 2007 assessment for PAU 5B assumed that the 1974 recreational catch was 1 t, increasing linearly to 5 t in 2006. The New Zealand Recreational Marine Survey for 2011–12 estimated that the recreational harvest for PAU 5B was 0.82 t with a CV of 50%. For this assessment, 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 2013.

3.3 Customary catch

There are no published estimates of customary catch. For the purpose of the stock assessment model, the SFWG agreed to assume that the customary catch has been constant at 1 t for PAU 5B.

3.4 Illegal catch

Illegal catch was estimated by the Ministry of Fisheries to be 15 t (Breen & Smith 2008a), but "Compliance express extreme reservations about the accuracy of this figure." For this assessment, the SFWG agreed to assume 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.

4. CPUE STANDARDISATIONS

Two separate standardised CPUE series were calculated: (i) one based on CELR data from 1990 to 2001, and (ii) another based on PCELR data from 2002 to 2013. The data set used, methods, and results are described in the following sections.

It was decided, following previous paua CPUE standardisations, to drop the FSU data from 1983 to 1989 inclusive. Subsequent to this decision the utility of this data was investigated in more detail, and it appeared to have some use, although potential problems still remain, and it was decided by the SFWG not to use it for the current set of standardisations (Section 4.1).

For the CELR data standardisation a subset of the groomed data was used for which the recorded duration would be less ambiguous, and duration was offered to the standardisations, in contrast to previous standardisations for PAU 5B (Section 4.3).

4.1 Utility of the FSU data

The FSU data were extracted from the NIWA-managed database (newly established) for the period between January 1983 and September 1988 (extract. CL0088), but they were not used for the CPUE standardisation.

Problems uncovered in the past with the FSU data for paua have included:

1. low coverage of the annual catch,
2. a high proportion of missing values for the vessel field, and

3. ambiguity and inaccuracies in what is recorded for the important fishing duration field.

The FSU catch-effort data attributable to PAU 5B as a proportion of the estimated annual catch is comparable to the CELR data from 1990 to 1995 (denoted by the white in Figure 6), although it does have a declining pattern between 1983 and 1989. The number of records was 699 with more than 80 records in each fishing year (Table 6).

Most of the records have a vessel key and grooming leaves most of the records (Tables 7–8). For the FSU data used in the previous assessment (Breen & Smith 2008a) fewer records had vessel keys. These appear to have been corrected in the new FSU database, and vessel keys have been assigned to most records (David Fisher, NIWA, pers. comm.)

For the FSU data the fishing duration field is the daily fishing duration *per* diver (see p. 106 and p. 149 of Fisher & Saunders 2011). In earlier analyses (Breen & Smith 2008a) problems were found with this field in that values were recorded that were 10 times the likely values (Kendrick & Andrew 2000). This problem appeared to be only associated the old FSU database. In the new FSU database most values are now clustered around 5 hours duration (Figure 7).

For the CELR data the fishing duration field is the *total* fishing duration for all divers. There is ambiguity in what is actually recorded for the CELR data because a mixture of *total* and *per* is put down, possibly attributable to the transition from the FSU forms. For the FSU data, there are mostly one or two divers on a boat and the recorded fishing duration is about the same for either, indicating *per* diver duration is recorded in both cases (Table 9, Figure 8). The fishing duration increases when three divers are on a boat (6% of the records), though the significance of this is unclear. For the CELR data standardisation there is a process of subsetting the data to get a set that is considered reliable for the recorded fishing duration (Section4.3). But for the FSU data this subsetting process probably isn't needed because the fishing duration seems to be reliably recorded, although a fishing duration greater than 10 hours seems spurious (one of the criteria used for subsetting the CELR data).

In summary, for the FSU data nearly all the records have the vessel keys; what is recorded in the fishing duration field is unambiguous; there are a good number of records per year and the coverage of the catch although modest, is comparable with the CELR data coverage from 1990 to 1995. So it appears that the FSU data would be useable in a CPUE standardisation.

However, of particular concern is the declining pattern in the FSU catch (the white bars in Figure 6) which may bias the catch rates. Dropping the records with a duration greater than 10 hours, a raw CPUE is calculated as total daily catch divided by total daily hours (Figure 9). This is relatively constant until 1986 then drops substantially in 1987. This corresponds to the drop in the catch on the FSU records yet the overall estimated actual catch for PAU 5B remains high and is increasing (Figure 6). The same pattern in the catch rate is seen in standardised indices calculated in various other ways in the past (Figure 10).

A difficulty in integrating the FSU data into the CELR standardisation is the lack of a FIN in the data (used in the CELR standardisation instead of vessel), although this is not necessarily an insurmountable problem because FINs are likely to be able to be assigned back to the data. If that could be done, or if it were simply decided to use vessel in the standardisation, then a single index incorporating the FSU and CELR data could be calculated where the effort variable of fishing duration could be used instead of diver-days.

Table 6: Number of records in the FSU dataset by fishing year.

Fishing year	1983	1984	1985	1986	1987	1988
Number of records	143	181	99	99	90	87

Table 7: Number of records removed by grooming from the FSU dataset by fishing year, where the order of grooming is from top to bottom.

	1983	1984	1985	1986	1987	1988	Total
Not targeting paua	0	0	0	0	0	0	0
Catch missing	0	0	0	0	0	0	0
Vessel keys missing	12	0	0	0	0	0	12
Duration missing	1	3	16	2	2	1	25
Number divers missing	0	0	0	0	0	0	0
Method not diving	0	0	0	0	0	0	0

Table 8: Number of records in the FSU dataset left after grooming.

Fishing year	1983	1984	1985	1986	1987	1988	Total
Number of records	130	178	83	97	88	86	662

Table 9: Number of records in the FSU dataset by number of divers on a vessel.

Number of divers	1	2	3	4	5
Number of records	381	219	39	22	1

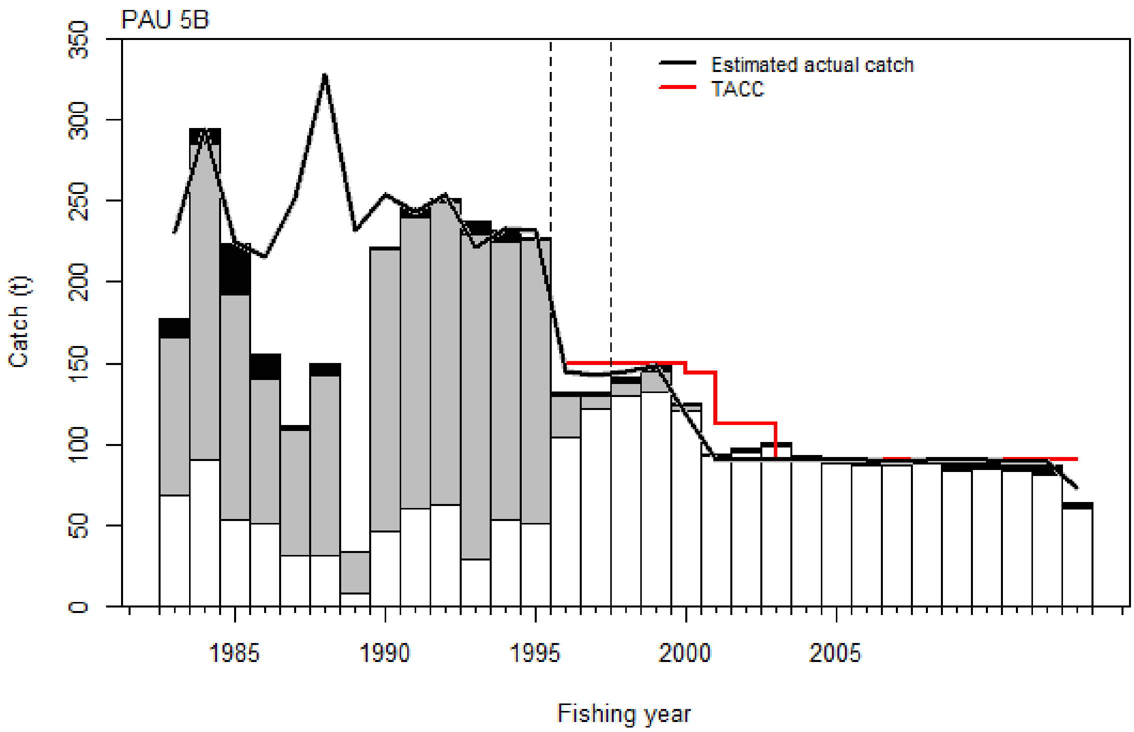


Figure 6: The estimated commercial catch history, TACC, and the FSU/CELR/PCELR catch (vertical bars) for fishing years 1983–2013for PAU 5B. Black portion of the bar represents estimated catch removed through data grooming; grey represents the estimated catch from records reported to straddling Statistical Areas 025 and 030 but randomly allocated to PAU 5B.

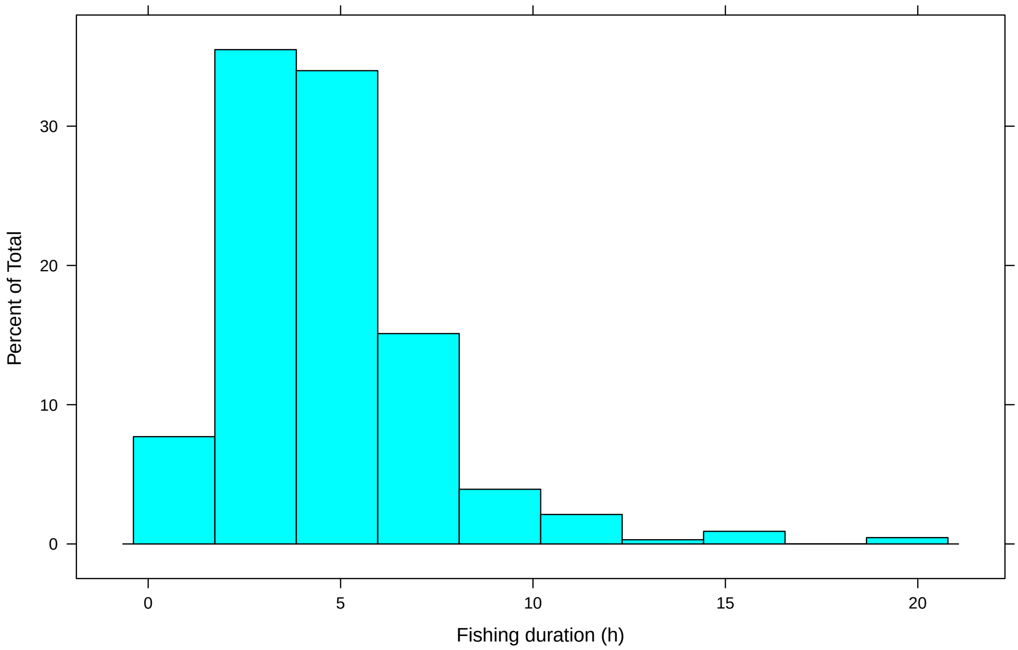


Figure 7: Distribution of fishing duration for the FSU data.

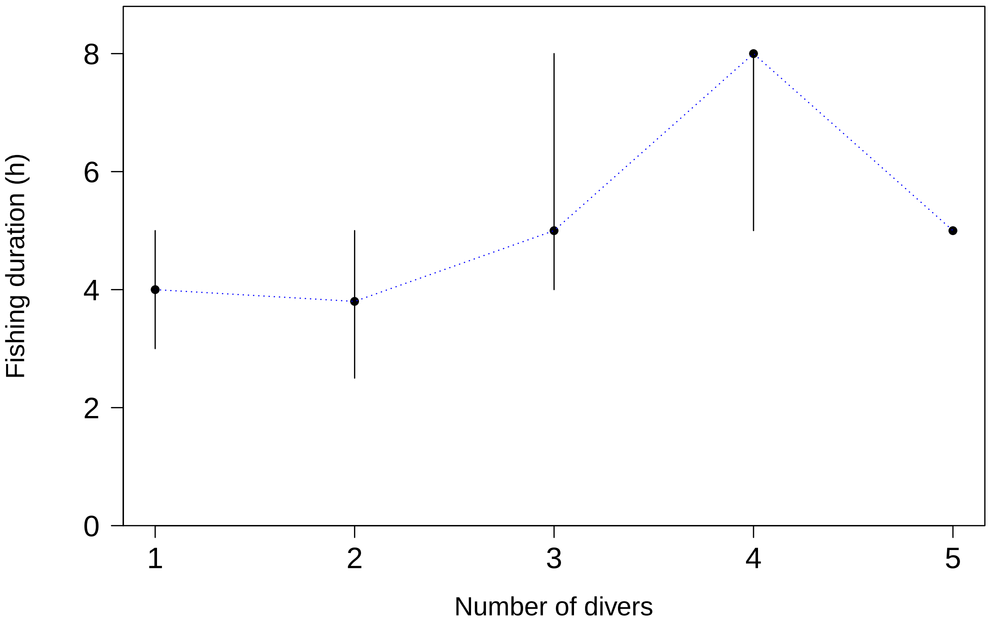


Figure 8: Distribution of fishing duration in the FSU dataset by the number of divers on a boat. The dot shows the median value and vertical lines extend to the lower and upper quartiles.

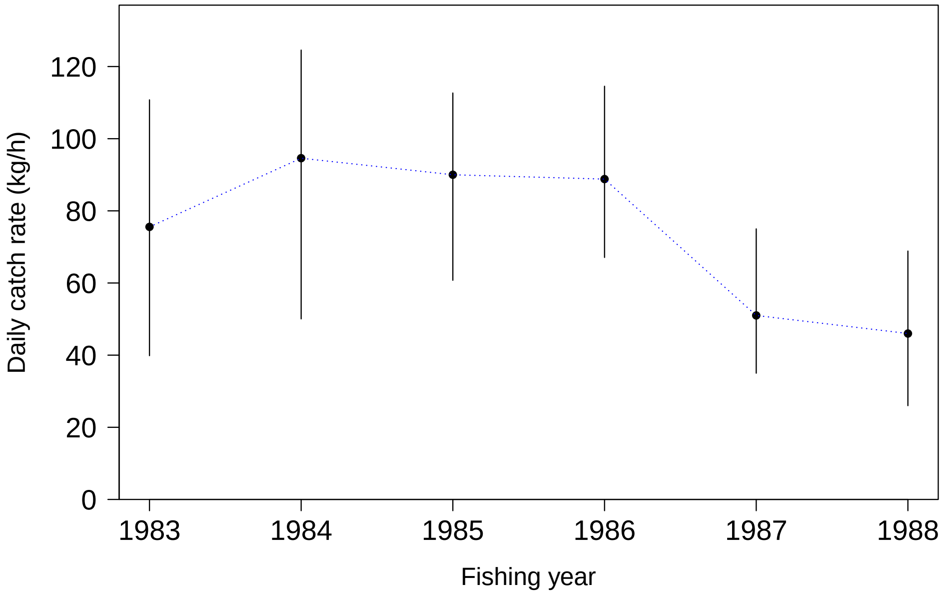


Figure 9: The raw daily catch rate (kg/h) for the FSU data. Dots show median value and the vertical lines extend to lower and upper quartiles.

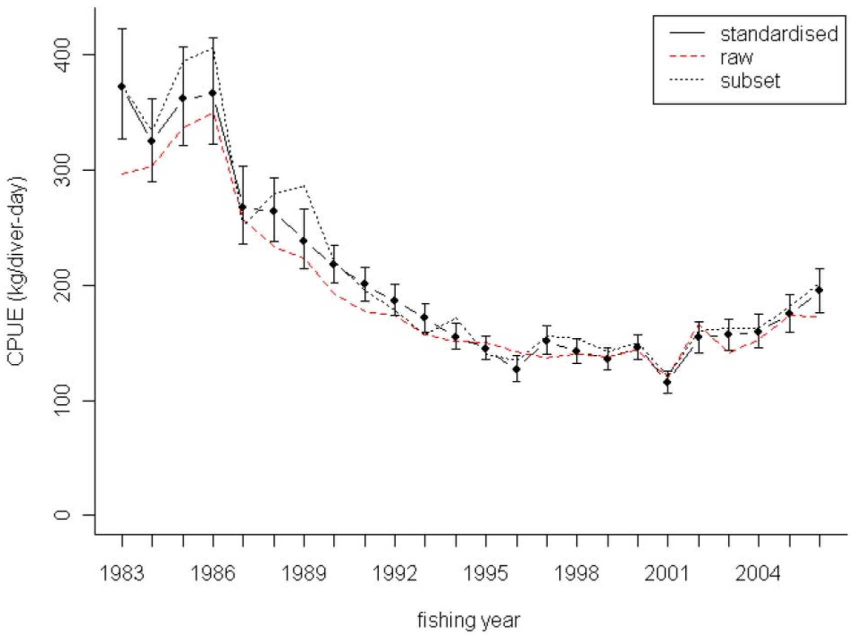


Figure 10: Standardised and raw CPUE, with an additional line representing the standardised CPUE recalculated with a data subset in which all the records from areas 025 and 030, randomly allocated to PAU 5B by Kendrick & Andrew (2000), were removed (figure and caption reproduced from Ministry for Primary Industries (2013)).

4.2 Initial data set for the CELR/PCELR data standardisations

Catch effort data reported to the Catch Effort system capturing fishing events that either caught or targeted paua between 1 October 1990 and 30 August 2013 were requested from the Ministry for Primary Industries database "warehou" (extract 9066), including the CELR data before October 2001 and the PCELR data from the 2001–02 fishing year onwards. The data were groomed, using methods similar to those used by Kendrick & Andrew (2000) and Breen & Kim (2007).

Kendrick & Andrew (2000) allocated catch effort records from the straddling statistical areas before 30 September 1995 to the new PAU 5 substocks in proportion to their assumed contribution to the catch. This allowed most catch and effort from those areas to be retained in the standardisations but would introduce uncertainties in the process because different CPUE datasets were produced each time the analysis was repeated. In the 2010 assessment of PAU 5A (Fu et al. 2010) and the 2012 assessment of PAU 5D (Fu et al. 2013) the SFWG decided not to include those randomly allocated records in the CPUE standardisations. About 75% of records from Statistical Area 030 and 025 were randomly allocated to PAU 5B before October 1995 and they accounted for a large proportion of total annual catch (see Figure 6, Figure 11). After the 1995 fishing year, the catch from Statistical Areas 025 and 030 were well determined. Randomly allocated records were not included in the standardisation catch-effort records.

For the CELR data, what should be recorded on a daily basis is the total number of hours for all divers on a vessel. Breen & Kim (2007) investigated this and found a linear relationship for up to three divers, but a flattening and decline for more divers (Figure 12). This was interpreted as an ambiguity in what the recorded hours represented in the data, where sometimes total hours been recorded for all divers, and at other times hours per diver were recorded (particularly if the number of divers was above three). A similar plot showing the calculated hours per diver for a day, which should remain approximately constant as the number of divers increases, shows a similar pattern (Figure 13). Because of this ambiguity, a subset of the data is used where what is recorded for fishing duration is less ambiguous (Section 4.3).

The recorded resolution for the estimated catch and fishing duration for the PCELR data was comparable to other areas and is low. About 40% of the catch was recorded as multiples of 50 kg, and about 70% of recorded fishing durations were multiples of one hour (Figure 14 a, b). In about 35% of fishing events the estimated catch was split equally among the divers (Figure 14c).

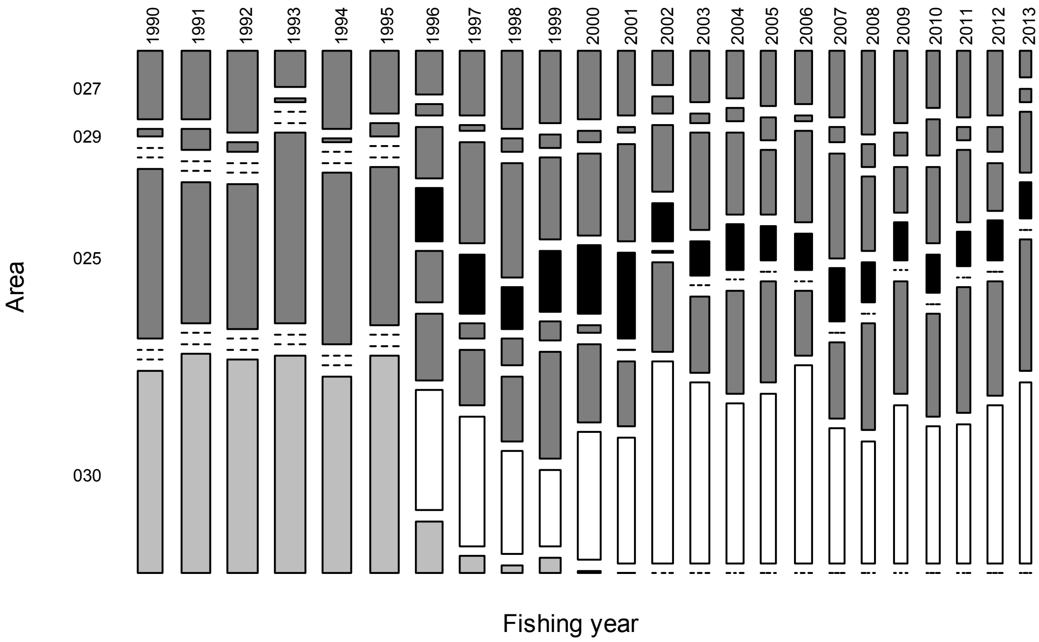


Figure 11: Estimated catch by statistical area and fishing year on CELRs and PCELRs, 1990–2013. Dark grey represents catch from within PAU 5B; black represents catch from Statistical Area 025 outside PAU 5B; white represents catch from Statistical Area 030 outside PAU 5B; light grey represents catch from areas with substock undetermined. The width of the bar is proportional to the total annual catch.

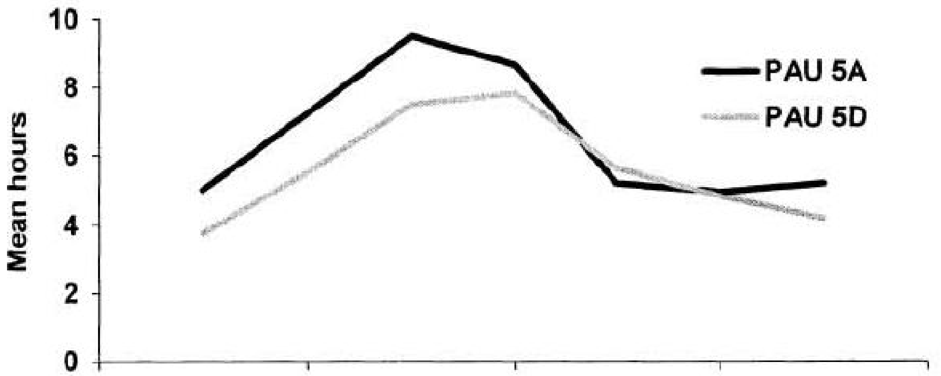


Figure 12: Mean number of hours for records with various numbers of divers in the CELR dataset (reproduced from Breen & Kim 2007, figure 10).

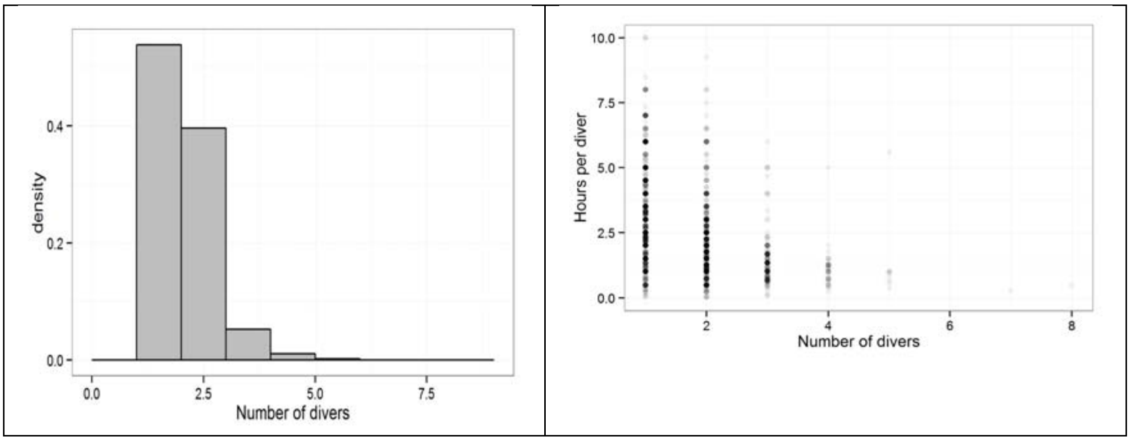
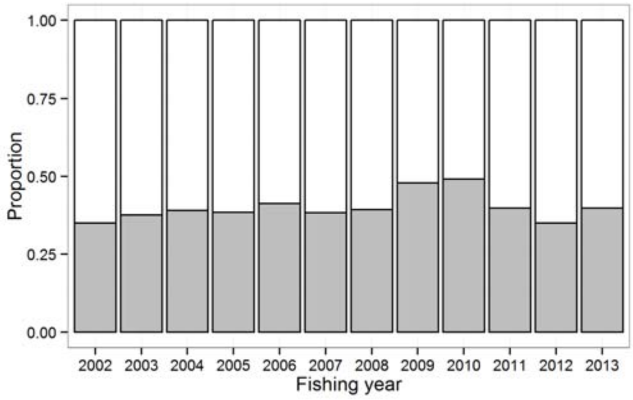
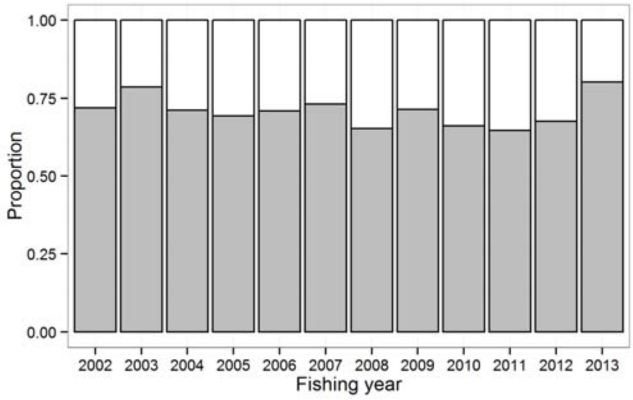


Figure 13: Distribution of the number of divers (left) and the calculated fishing hours per diver (right) on CELR forms within PAU 5B for fishing years 1990–2001 combined.

(a)



(b)



(c)

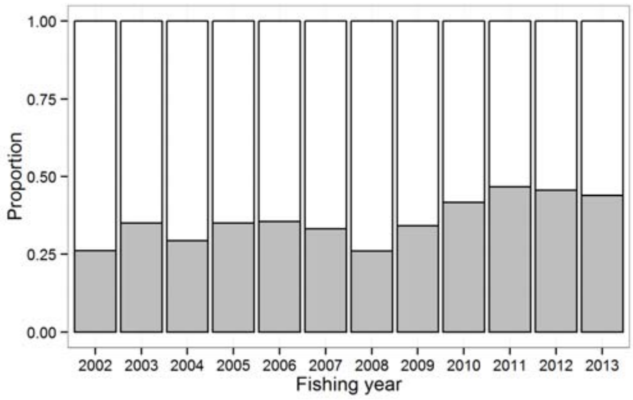


Figure 14: Diagnostic of data resolution on the PCELR forms within PAU 5B: (a) proportion of records that recorded estimated catch in a multiple of 50 kg; (b) proportion of records that recorded hours fished in an exact multiple of 1 hour; (c) proportion of fishing events where recorded estimated catch was equally split among divers.

4.3 Changes in fishing duration for the CELR data

Because of ambiguity in what is recorded for fishing duration it has not been used in past standardisation as a measure of effort, instead the number of divers has been used (Breen & Smith 2008a, Fu et al. 2010, 2012). However, if the fishing duration changes substantially over time then the number of divers would be a poor measure of effort. To investigate this, a subset of the groomed data set was taken for which the recorded fishing duration was less ambiguous, and this subset was examined to see whether fishing duration had changed over time.

The initial dataset was catch-effort records from PAU 5B (no random allocation of records). Before subsetting some grooming of the catch-effort records was undertaken: only records where paua was targeted by diving were retained, and records were dropped if they had missing values for the estimated catch or the number of divers (Table 10). The FIN, General Statistical Area (025, 027, 029, 030) and date were present for all records. This groomed data set has 3086 records (Table 11).

Table 10: Number of records dropped during grooming from the CELR dataset.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Not targeting paua	0	2	2	0	0	0	1	1	3	6	1	0	16
Catch missing	0	0	0	0	0	0	0	0	0	1	0	0	1
# divers missing	0	1	0	0	0	0	5	3	1	5	1	0	16
Method not diving	27	48	62	40	44	48	102	146	112	177	70	61	937

Following the procedure for PAU 5D the criteria used to subset the data were: (i) just one diver, or (ii) fishing duration at least eight hours and at least two divers (Fu et al. 2013). Some further grooming was done in which records with NA for fishing duration were dropped (33 records), and a fishing duration per diver of greater than 10 hours was also dropped (7 records). The subsetting retained 60% of the records from 1990–2001 (Table 11). Of the retained records 65% had one diver (Table 12).

Table 11: Number of records in the groomed CELR data set before and after subsetting.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	128	129	165	73	144	179	289	360	409	374	437	399	3086
After	99	79	106	49	77	111	172	184	220	240	264	250	1851

Table 12: Distribution of the number of divers in the CELR dataset before and after subsetting.

Number of divers	1	2	3	4	5	6	7	8	9
Before	1211	1351	387	63	22	31	14	5	2
After	1203	421	214	12	1	0	0	0	0

For the subsetted data the recorded duration for each record was divided by the number of divers to calculate the fishing duration per diver (hours per diver). Due to rounding in the fishing duration recorded there is some clumping in the fishing duration per diver (Figure 15). The median and mean fishing duration per diver both show an increase from about 1995 (Figures 16–17).

Catch rates (daily kilograms per unit effort) were calculated using as the units of effort: (i) the number of divers, or (ii) total daily diving duration. Comparing the yearly geometric mean of these (i.e. a standardisation with just a year effect) shows that using the diving duration as a measure of effort gives an index that is similar to using the number of divers (Figure 18).

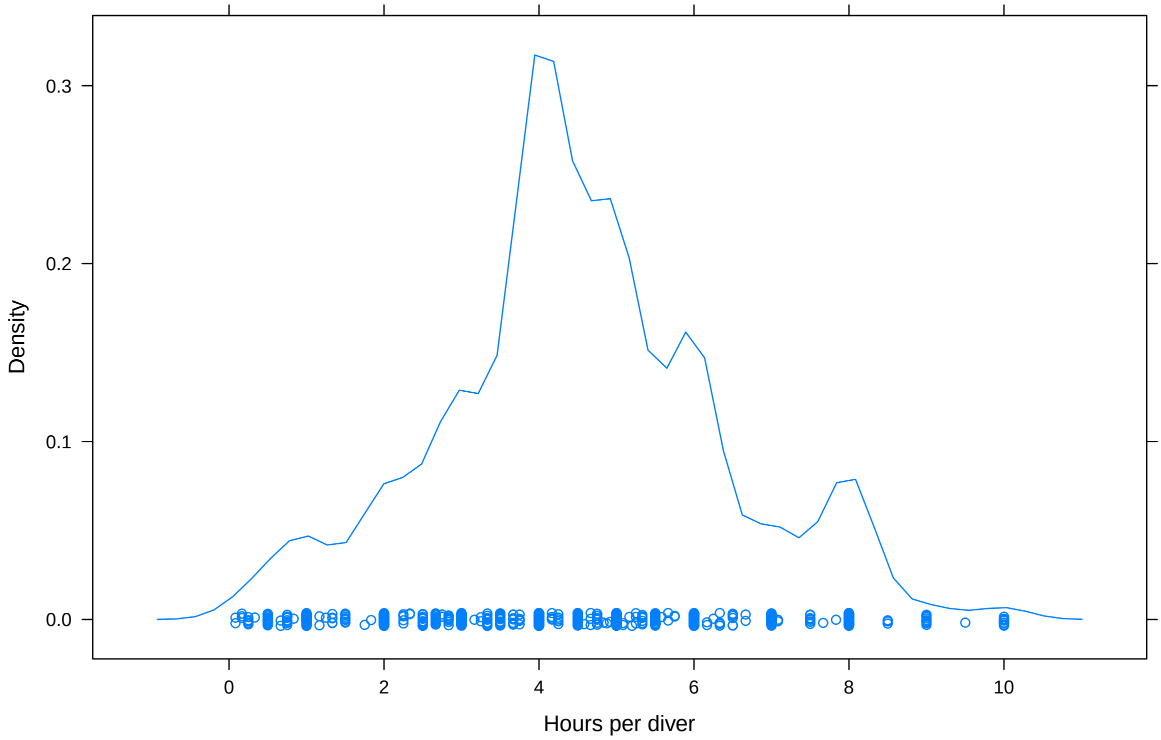


Figure 15: Density and strip plot for the hours per diver from the CELR dataset.

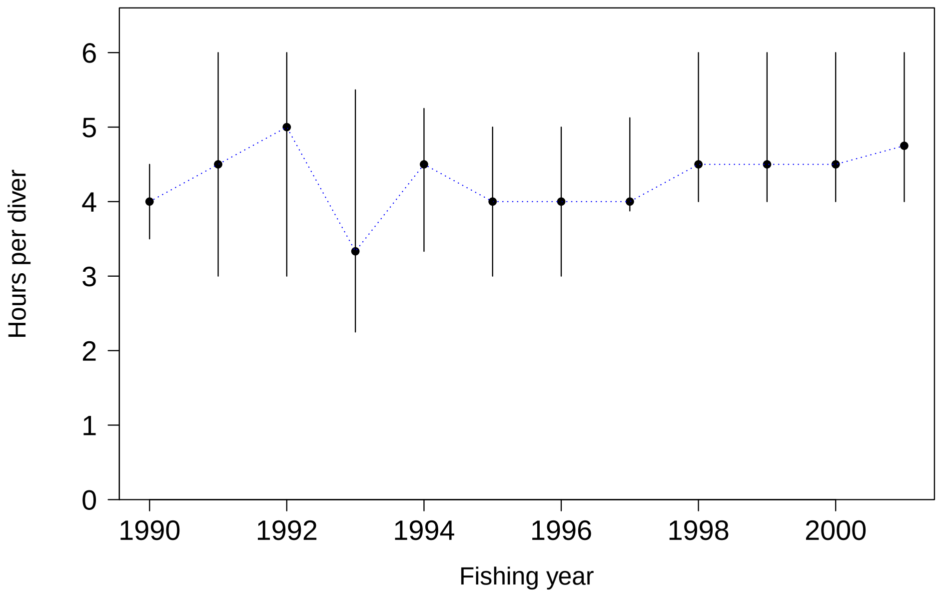


Figure 16: Quantiles by fishing year for the daily fishing duration per diver from the CELR dataset: medians (dot) and lower and upper quartiles (vertical lines).

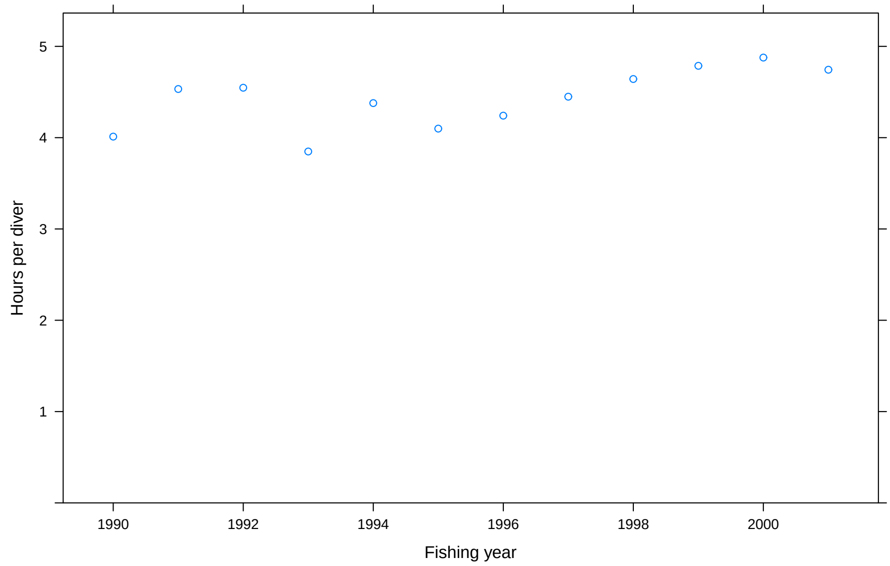


Figure 17: Mean values by fishing year for the daily fishing duration per diver in the CELR dataset.

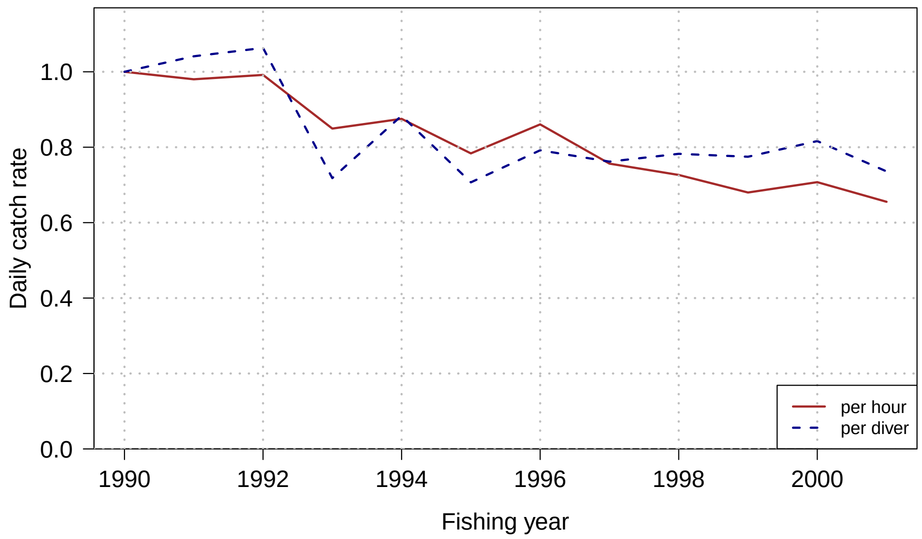


Figure 18: Geometric mean of the daily catch rate by year in the CELR dataset. The plots are scaled so that both have the value one in 1990.

4.4 Methods

Standardised CPUE indices have been used as relative abundance indices for paua stock assessments (Breen & Kim 2007, Breen & Smith 2008a). The 2007 assessment for PAU 5B used combined FSU, CELR, and PCELR data for the CPUE standardisations, with pre-1996 catch and effort from the straddling statistical area allocated to the substocks using the randomisation procedure used by Kendrick & Andrew (2000). As discussed in section 4.2, it was decided by the SFWG not to use randomly allocated catch-effort records in the standardisations.

In more recent paua assessments (Fu et al. 2010, 2012, 2013) CELR and PCELR data were standardised as separate series and FSU data were omitted from the time series following advice by the SFWG (see Section 4.1). For this assessment FSU data were dropped, and the CELR and PCELR datasets were analysed separately to produce two different CPUE series.

For the recent PAU 7 and PAU 5D stock assessments Fisher Identification Number (FIN) was used instead of vessel in the standardisation 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"* (Ministry for Primary Industries 2013, p. 811). For the same reason the SFWG agreed to use FIN instead of vessel for the PAU 5B standardisation.

In summary, four decisions were made by the Shellfish Working Group regarding the CPUE standardisations for PAU 5B:

(1) For the CELR standardisation: NOT to randomly allocate catch-effort records from statistical areas 025 and 030 that overlap with PAU 5B but are not entirely within it.

(2) To drop FSU data from 1989 and previous years.

(3) To use two series for the standardisation, one series one based on CELR data up to 2001, the other from 2002 onwards using the more fine scale PCELR data.

(4) To use Fisher Identification Number (FIN) in standardisation procedures instead of vessel.

For all series standardised catch per unit effort (CPUE) analyses were carried out using Generalised Linear Models (GLMs), based on the procedure explained by Vignaux (1994), as modified by Francis (2001). The aim behind this analysis is to remove the effect of changes in fishing patterns and conditions (e.g., where and when fishing was done) on the catch rate, leaving a component that is presumed to be proportional to the biomass of fish present.

Catch rate (the dependent variable) was modelled as log(catch rate) with a normal error distribution. Fishing year was forced into the model at the start. A step forward procedure was used to select other predictor variables, and they were entered into the model in the order which gave the maximum decrease in the residual deviance. Predictor variables were accepted into the model only if they explained at least 1% of the deviance.

4.5 CELR standardisation (1990–2001)

Because of ambiguity in what is recorded for fishing duration it has not been used as a measure of effort in past standardisations, instead the number of divers has been used. However, there is evidence that the fishing duration for a diver changes over time, and because of this a subset of the groomed data set was taken in which the recorded fishing duration was less ambiguous (Section 4.3).

FIN was then used to subset out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of five records per year for a minimum of two years were chosen, this retained 80% of the catch from 1990–2001 (Figure 19). Using these criteria, over 80% of the catch was retained for most years, except for 1990 and 1991 in which less than 60% of the catch was retained (Figures 20–21). The number of days of effort retained after subsetting is 40 or more for every fishing year (Table 13). The number of FIN holders drops from 67 to 19 under the subsetting criteria.

There is good overlap in effort over time for the FIN holders after subsetting (Figures 22–23). Similarly, there is good overlap for General Statistical Area and month (Figures 24–25).

Table 13: Number of records from the CELR dataset retained before and after FIN subsetting.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	99	79	106	49	77	111	172	184	220	240	264	250	1851
After	67	56	77	43	66	92	139	167	202	223	206	210	1548

CPUE was defined as daily catch. Year was forced into the model at the start and other predictor variables offered to the model were FIN, Statistical Area (024, 025, 026, 030), month, fishing duration (as a cubic polynomial), number of divers, and a month:area interaction. Following previous standardisations, no interaction of fishing year with area was entered into the model, because the stock assessment for PAU 5B is a single area model. However, a separate standardisation is also done where a year:area interaction is forced in at the start.

The model explained 68% of the variability in CPUE with fishing duration explaining most of this (55%) followed by FIN (9%), (Table 14). The effects appear plausible and the model diagnostics good (Figures 26–27). There is a plateauing effect for the catch taken after a fishing duration of 10 hours, although for the majority of records fishing duration is less than this (Figure 28). The standardised index fluctuates – it has a bump in 1991, but is relatively flat for the first four years, then declines to 40–50% of its initial level (Table 15, Figure 29).

The standardised index differs from an unstandardised index (where CPUE is daily catch divided by daily fishing duration) in that the decline over time is steeper (Figure 29). Most of this difference is due to the FIN predictor variable (Figure 30). As a sensitivity to the effect of using the subsetted data set (in which the fishing duration field is less ambiguous) another standardisation was done using the full data set with a CPUE of daily catch divided by the daily number of divers. The decline in this index is similar to that using the subsetted data set (Figure 31).

Forcing in a year:area interaction indicates that there are differences in standardised CPUE between areas 027 and 029 (Figure 32). However, there are very few records to estimate the area 029 year effects with eight of the years having fewer than 10 records (Table 16).

Table 14: Variables accepted into the CELR standardisation model (1% additional deviance explained), and the order in which they were accepted into the model.

Predictors	Degrees of freedom	Percentage deviance explained
Fishing year	11	0.01
Fishing duration	3	0.56
FIN	18	0.65
Area	3	0.68

Table 15: Standardised CELR index, lower and upper 95% confidence intervals, and CV.

Year	Index	lower CI	upper CI	CV
1990	1.34	1.01	1.78	0.14
1991	1.70	1.25	2.32	0.16
1992	1.45	1.12	1.87	0.13
1993	1.40	1.02	1.92	0.16
1994	1.03	0.80	1.33	0.13
1995	0.96	0.77	1.19	0.11
1996	0.89	0.74	1.07	0.09
1997	0.86	0.72	1.03	0.09
1998	0.81	0.69	0.96	0.08
1999	0.77	0.65	0.90	0.08
2000	0.69	0.58	0.83	0.09
2001	0.66	0.54	0.80	0.10

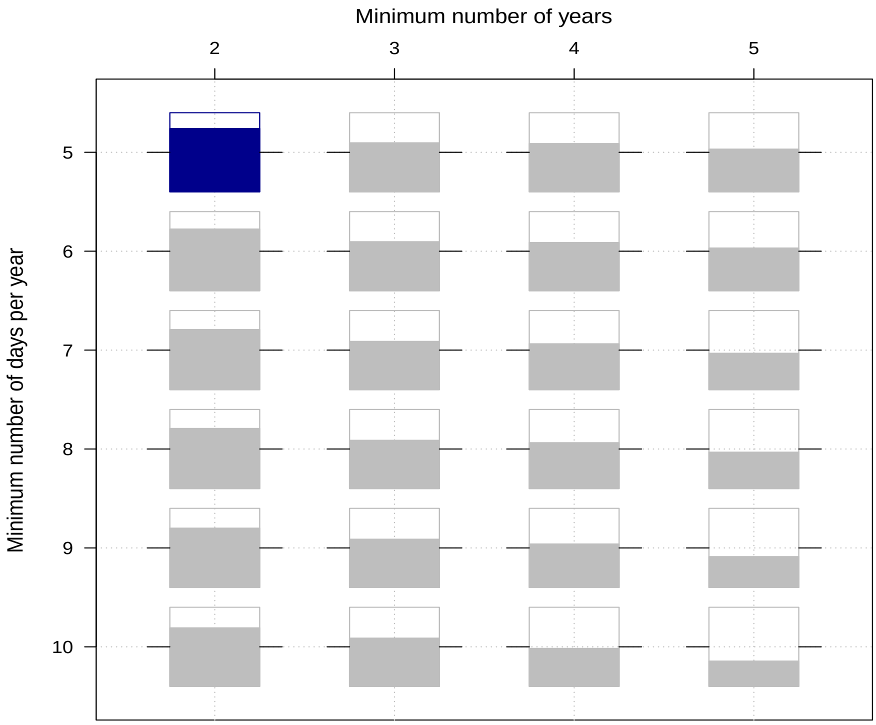


Figure 19: Proportion of the catch taken when subsetting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey

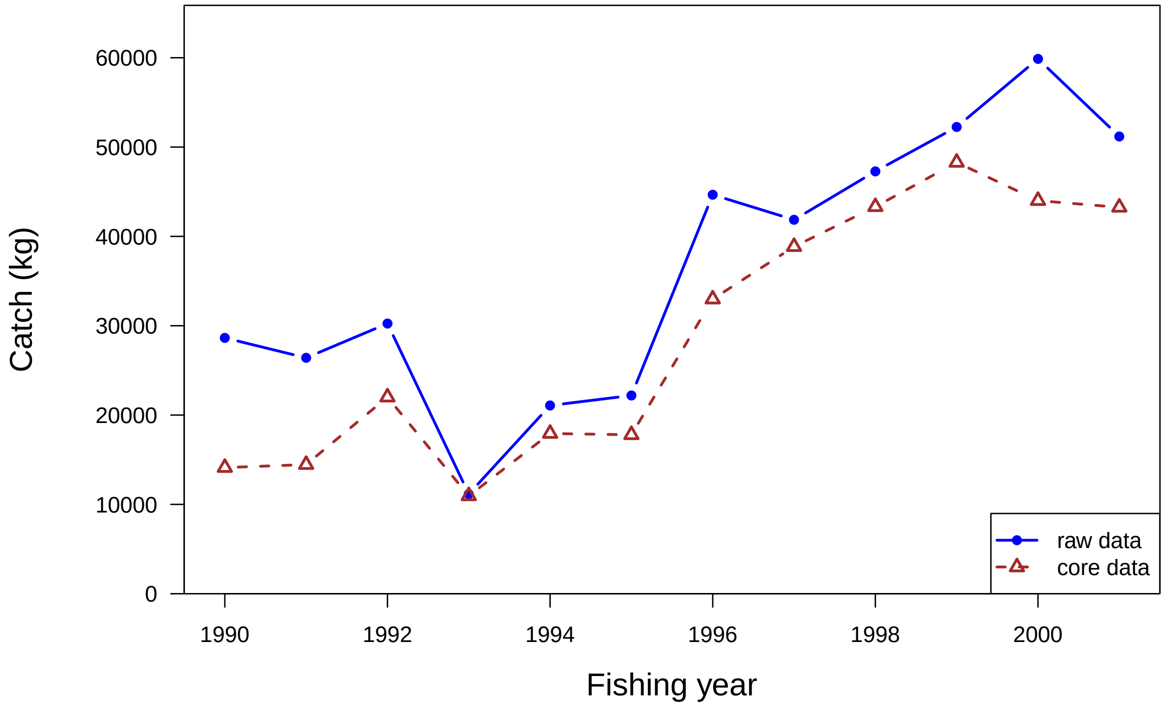


Figure 20: Catch by fishing year from the CELR dataset before FIN subsetting (raw data) and after (core data). The subsetting uses the criteria of a minimum of five days per year for a minimum of two years.

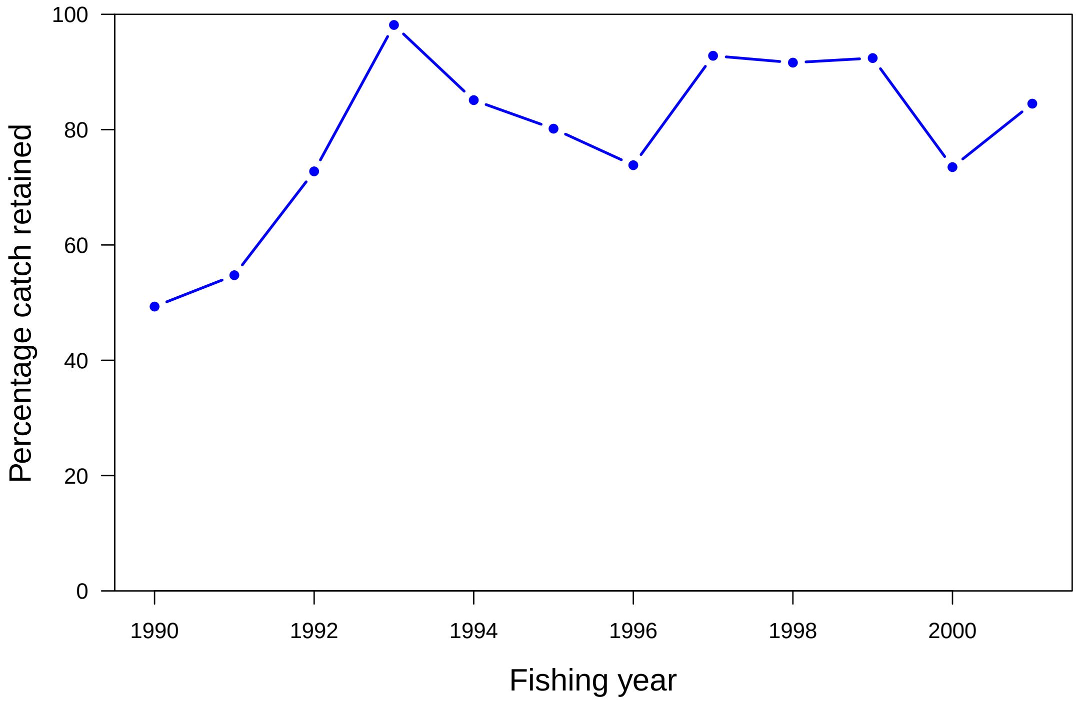


Figure 21: Percentage of the catch retained in the CELR dataset after FIN subsetting using the criteria of a minimum of five days per year for a minimum of two years.

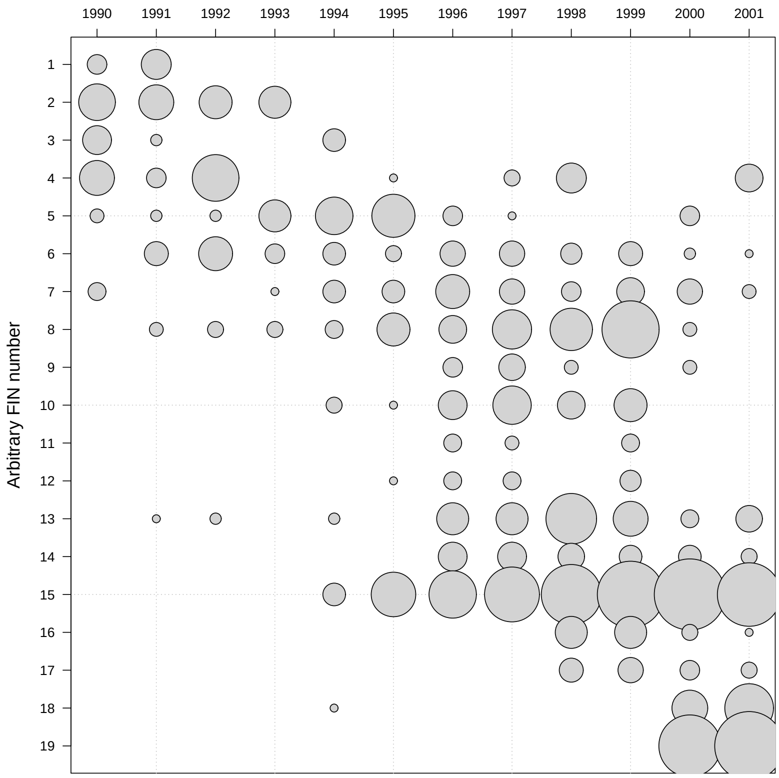


Figure 22: Overlap in days of effort in the CELR dataset by FIN. The area of a circle is proportional to the number of days of effort; the largest circle represents 79 days.

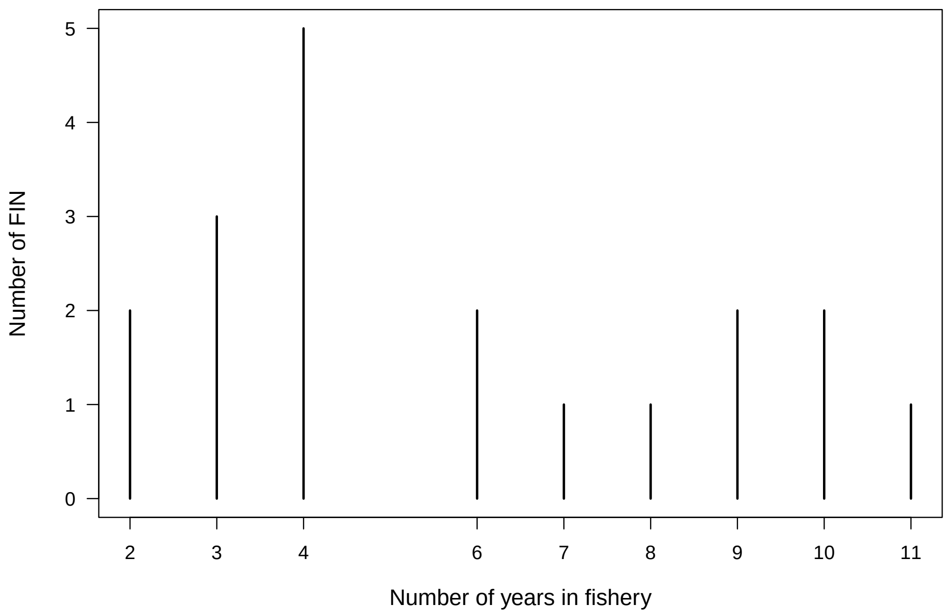


Figure 23: Histogram of the number of years in the fishery for each FIN holder after sub-setting by FIN.

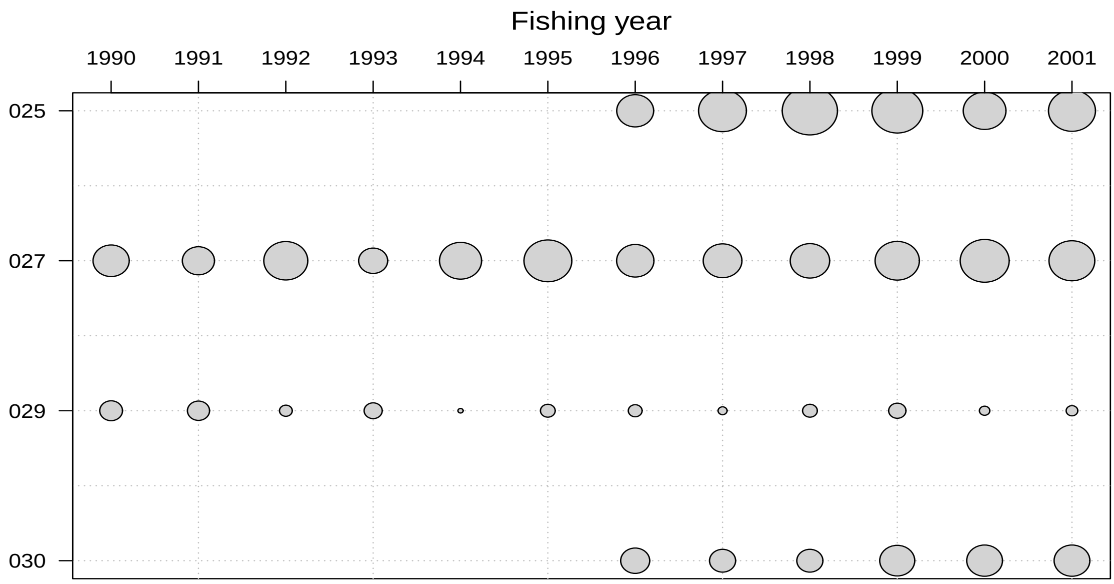


Figure 24: Number of days of effort in the CELR dataset by Statistical Area and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 112 days.

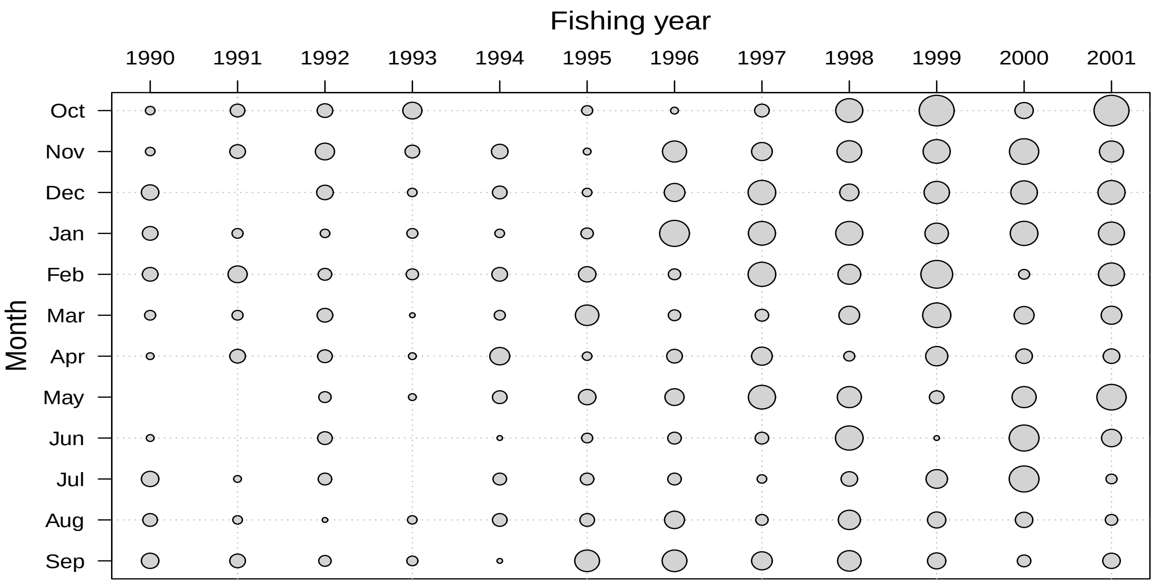


Figure 25: Number of days of effort in the CELR dataset by month and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 40 days.

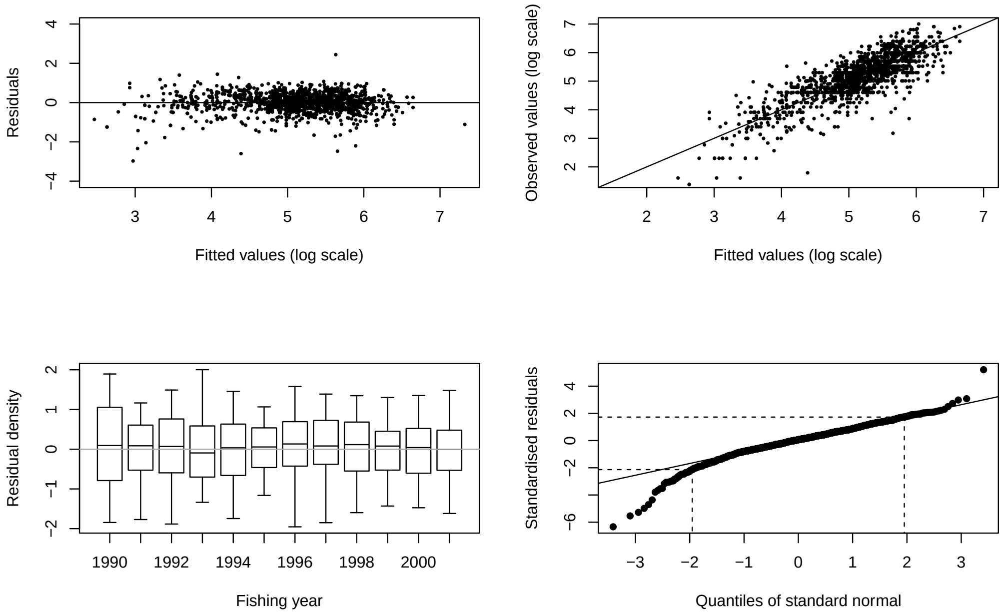


Figure 26: Diagnostic plots for the CELR standardisation model.

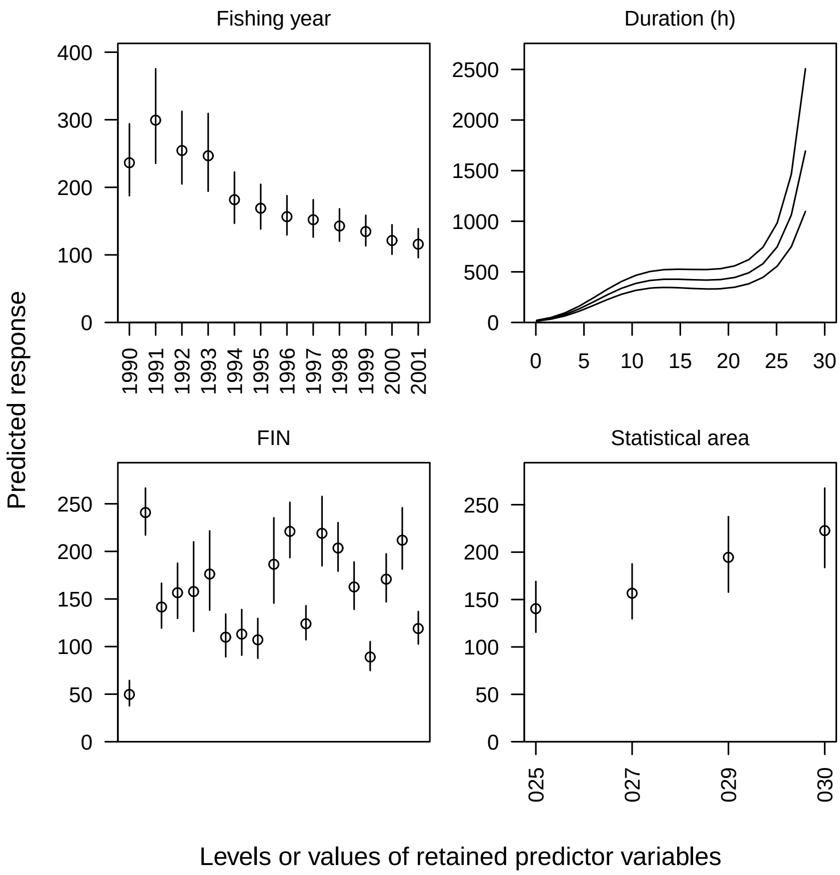


Figure 27: Effects for the CELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

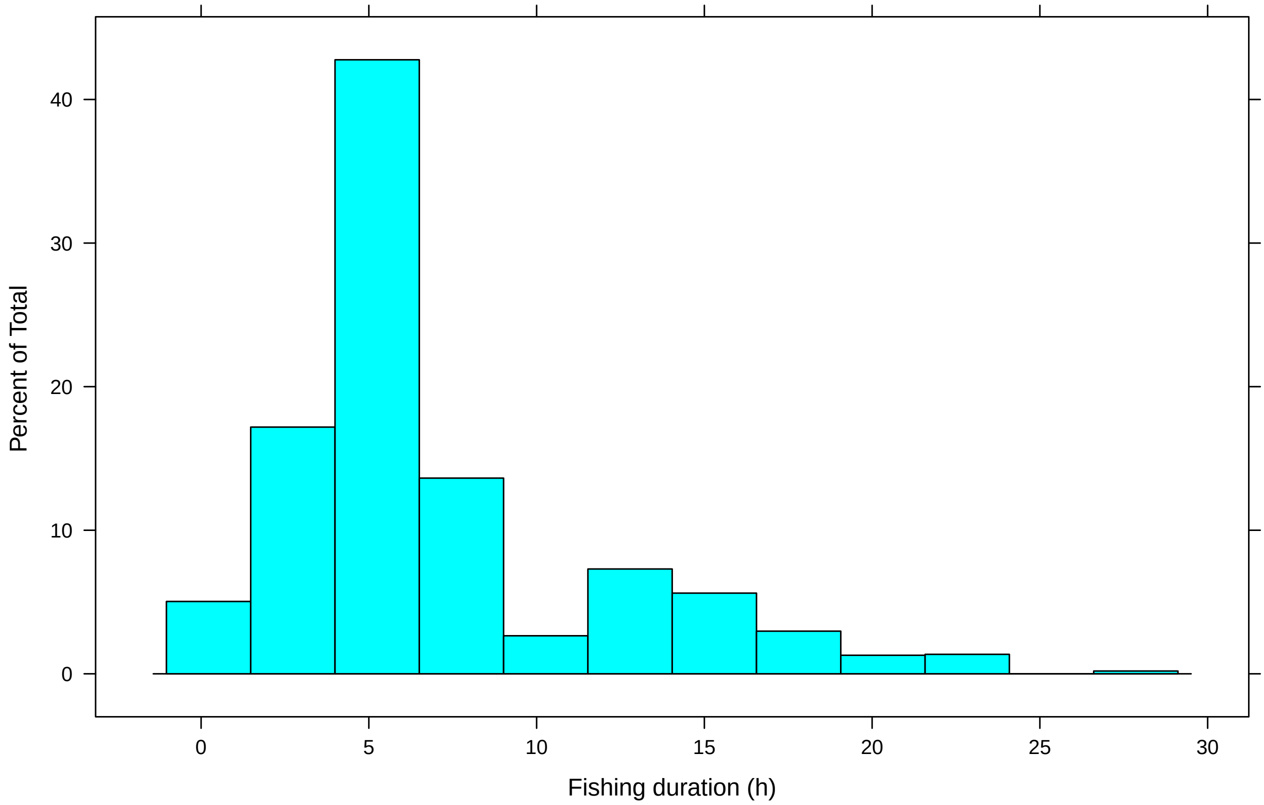


Figure 28: Distribution of fishing duration in the CELR dataset.

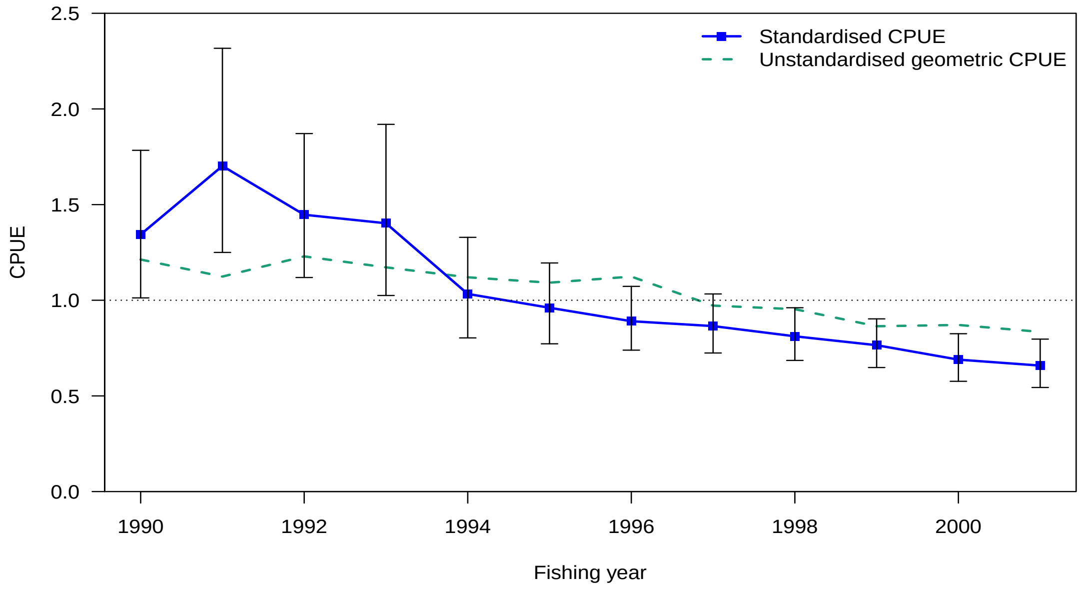


Figure 29: The standardised CPUE index for the CELR dataset with 95% confidence intervals. The "unstandardised geometric CPUE" is calculated as daily catch divided by daily fishing duration.

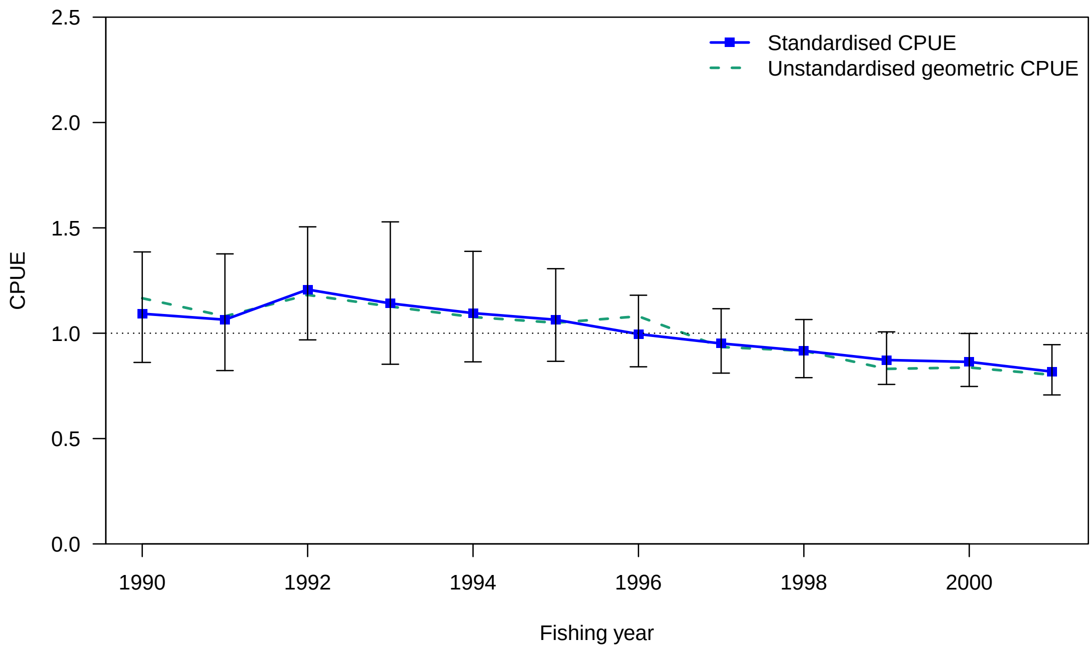


Figure 30: The standardised CPUE index for the CELR dataset without FIN in the final standardisation model. The "unstandardised geometric CPUE" is calculated as daily catch divided by daily fishing duration.

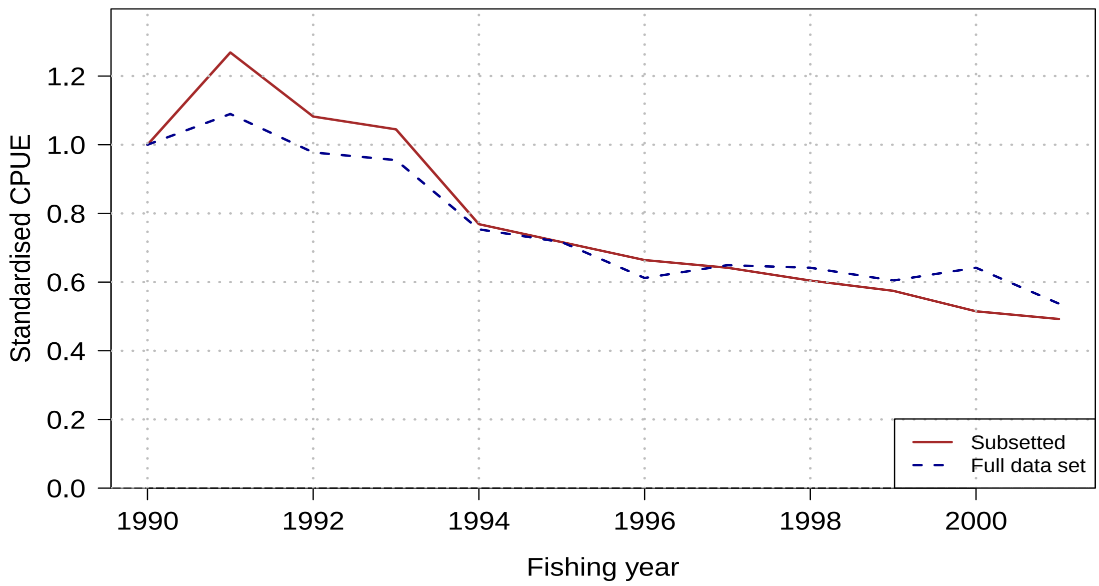


Figure 31: Comparing standardised indices calculated using the full CELR dataset and the subsetted dataset (to give a dataset for which the fishing duration field is less ambiguous). Both standardised indices are scaled so as to have the value one in 1990.

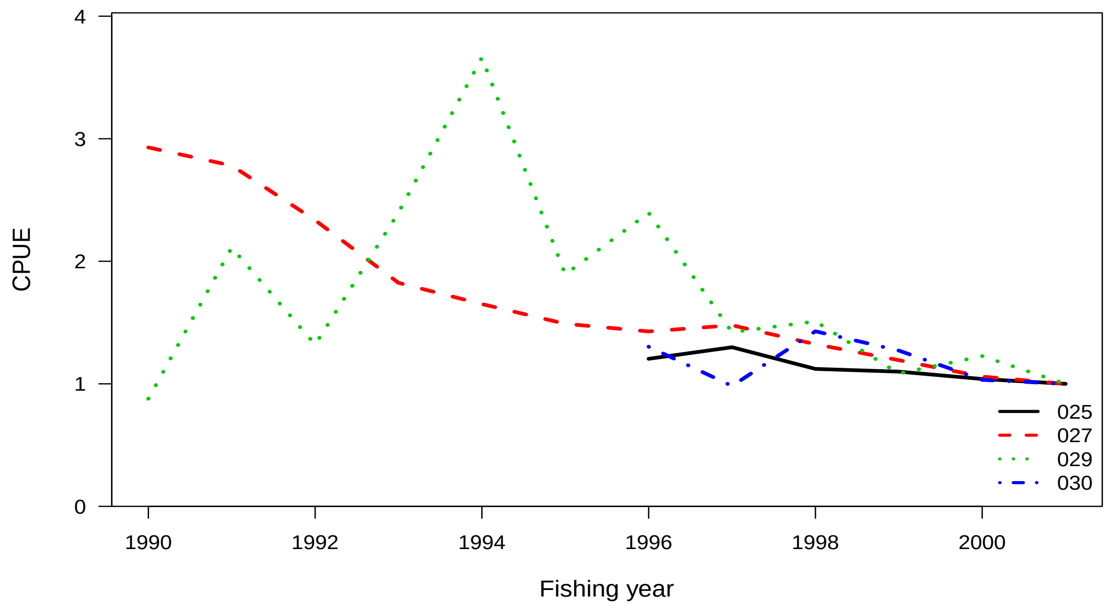


Figure 32: Standardised indices of the CELR dataset using the subsetted data with a year:area interaction forced into the model. The indices are scaled so as to have the value one in 2001.

Table 16: Number of records for the subsetted CELR data by year and area.

	Statistical Area			
Fishing year	025	027	029	030
1990	0	48	19	0
1991	0	38	18	0
1992	0	71	6	0
1993	0	31	12	0
1994	0	65	1	0
1995	0	84	8	0
1996	50	51	7	31
1997	84	55	3	25
1998	112	57	8	25
1999	95	72	11	45
2000	67	88	4	47
2001	81	77	5	47

4.6 PCELR data (2002–2013)

The initial PCELR dataset contained all records in which paua were targeted by diving, and contained FIN, fine scale Paua Statistical Area, catch weight, fishing duration, diver key, and date. For the standardisation some further grooming was made: records were removed where no diving condition was recorded (Table 17). Also six records were removed from 2002 where the diver key was not recorded.

Table 17: Number of catch effort records removed during grooming of the PCELR dataset.

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
No Diving condition	50	65	11	5	18	42	33	23	12	10	20	12	301

Records were put in a “daily” format: total catch and dive time over a day for a diver (associated with a specific FIN, diving condition, and Paua Statistical Area). CPUE was defined as the catch for a diver with fishing duration offered as a predictor in the model.

FIN was used to sub-set out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 20 records per year for a minimum of three years were selected; this retained 89% of the catch over 2002–2013(Figures 33–34). The number of FIN holders dropped from 37 to 19 under these criteria. There was good overlap in effort for the 19 FIN holders after subsetting (Figures 35–36). The number of days of records retained after subsetting was more than 400 for every fishing year (Table 18).

To ensure that there was enough data to estimate statistical area and diver effects in the standardisation, only those Paua Statistical Areas and divers with 10 or more diver days were retained (Table 18). This dropped the number of statistical areas from 83 to 75, and the number of divers from 398 to 78 (51% of divers have only one diving day and note that this is just an artifact of the fact that a spelling mistake in the divers name looks like a completely new diver).

There is very good temporal overlap for the other predictor variables statistical area, month, dive conditions, and diver (Figures 37–40).

Table 18: Number of records remaining in the PCELR dataset after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records that didn't contain information needed for the standardisation were removed (Table 17).

Fishing year	02	03	04	05	06	07	08	09	10	11	12	13	Total
Total records	549	662	664	582	586	590	566	425	452	570	486	315	6447
FIN subsetting	473	583	622	536	515	501	500	391	393	487	420	283	5704
Paua Statistical Area with >=10 dive days	470	582	622	535	508	492	497	389	389	487	418	282	5671
Divers with >= 10 dive days	410	512	564	495	469	437	425	325	346	422	379	256	5040

For the standardisation model CPUE (the dependent variable) was modelled as log(diver catch) with a normal error distribution. Fishing year was forced into the model at the start. Variables offered to the model were month, diver key, FIN, Paua Statistical Area, duration (third degree polynomial), and diving condition. Following previous standardisations, no interaction of fishing year with area was entered into the model, because the stock assessment for PAU 5B is a single area model. However, a separate standardisation is also drone where a year:area interaction is forced in at the start (using the research strata as the areas).

Except for month and diving conditions, all variables were accepted into the model, which explained 82% of the variability in CPUE (Table 19). Most of the variability was explained by duration (65%) and diver (9%). The effects appear plausible and the diagnostics are good (Figures 41–42). There is evidence that catch plateaus somewhat with fishing duration (Figure 42), and there is a reasonable amount of data to fit this relationship up to about 10 hours fishing duration (Figure 43).

The standardised index shows an increase of about 30% from 2002 to 2011 (Table 20, Figure 44). Very little of the difference between the standardised index and the unstandardised index (using CPUE as catch divided by fishing duration) is due to modelling the relationship between catch and fishing duration as a third-degree polynomial (Figure 45), with much of the change due to the diver key (Figure 46).

Forcing a year:area into the model, using the research strata as the areas, gives indices that are similar for the different areas (Figure 47).

Table 19: Variables accepted into the standardisation model for the PCELR dataset (1% additional deviance explained) and the order in which they were accepted into the model.

Predictors	Degrees of freedom	Percentage deviance explained
Fishing year	11	0.02
Fishing duration	3	0.67
Diver key	77	0.76
Statistical area	74	0.81
FIN	17	0.82

Table 20: Standardised index for the PCELR dataset, lower and upper 95% confidence intervals, and CV.

Year	Index	lower CI	upper CI	CV
2002	0.80	0.71	0.89	0.06
2003	0.81	0.73	0.91	0.05
2004	0.80	0.72	0.88	0.05
2005	0.87	0.79	0.97	0.05
2006	1.04	0.94	1.15	0.05
2007	0.94	0.85	1.04	0.05
2008	1.00	0.90	1.11	0.05
2009	1.18	1.05	1.33	0.06
2010	1.22	1.08	1.37	0.06
2011	1.03	0.92	1.15	0.06
2012	1.18	1.05	1.33	0.06
2013	1.28	1.12	1.45	0.07

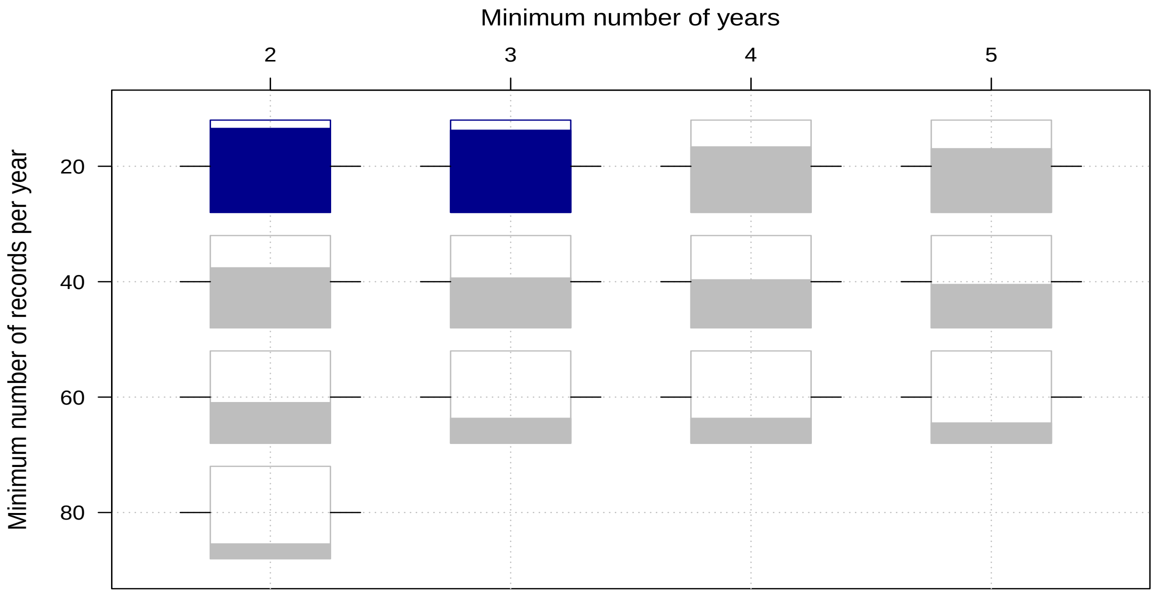


Figure 33: Proportion of the catch taken when subsetting the PCELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2013retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

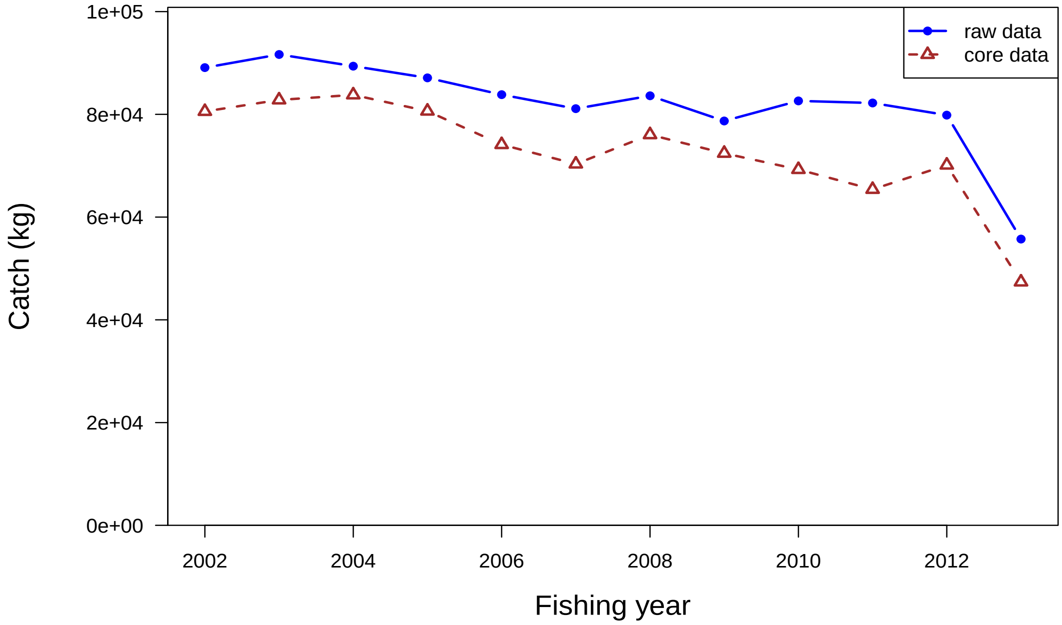


Figure 34: Catch by fishing year from the PCELR dataset before FIN subsetting (raw data) and after (core data). The subsetting uses the criteria of a minimum of 20 records per year for a minimum of three years.

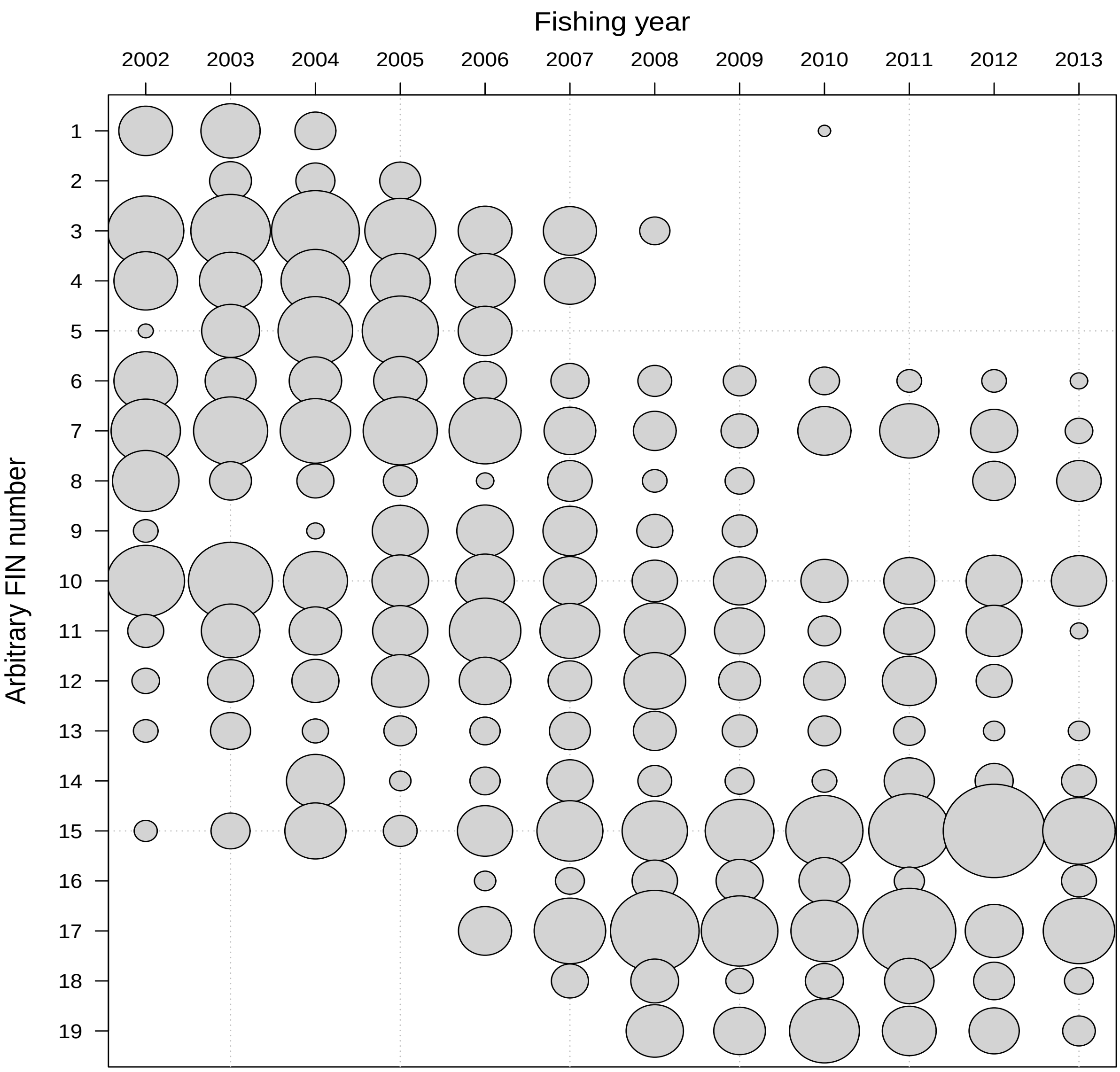


Figure 35: Overlap in number of records in the PCELR dataset by FIN after subsetting by FIN. The area of a circle is proportional to the number of days of effort; the largest circle represents 136 records.

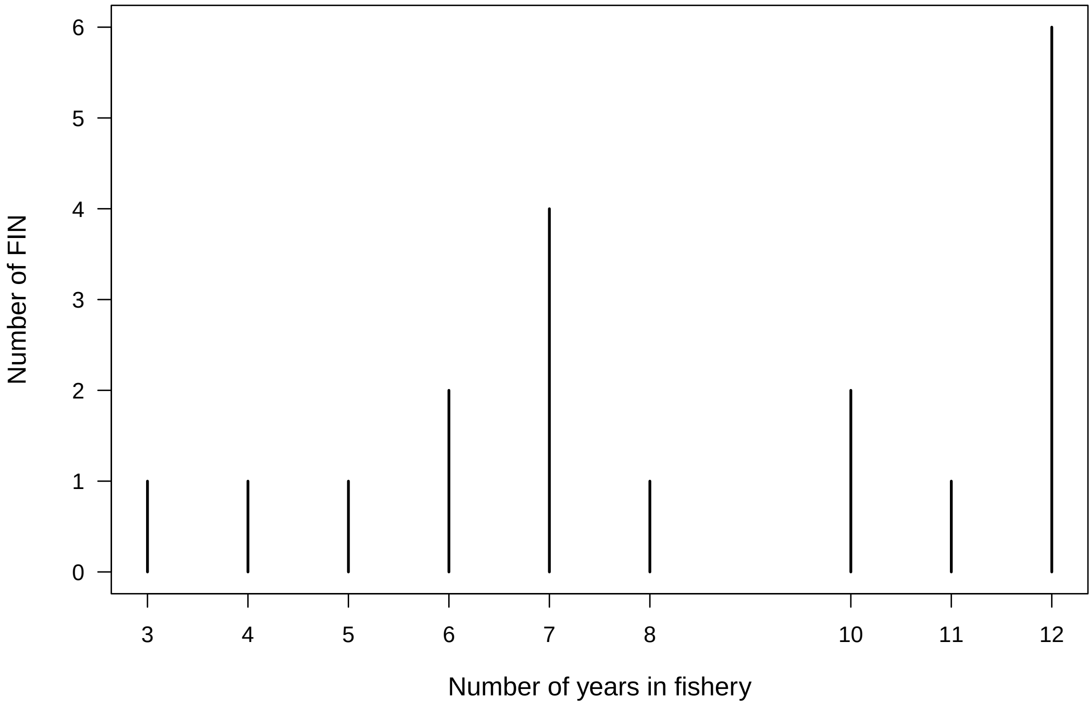


Figure 36: Histogram of the number of years in the fishery for each FIN holder in the PCELR dataset after subsetting by FIN.

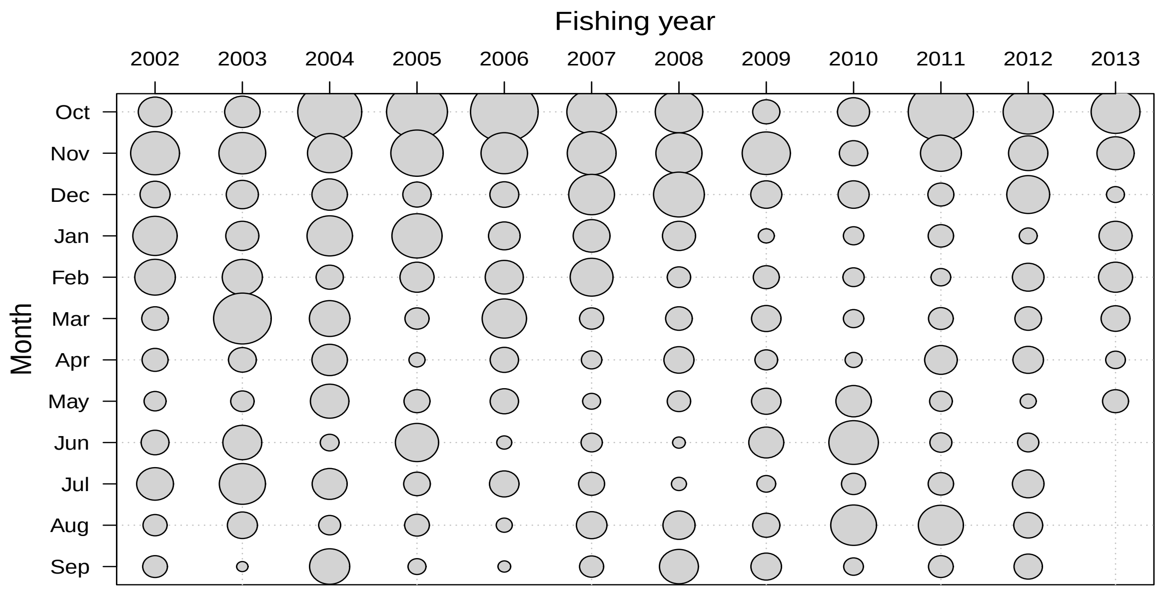


Figure 37: Number of PCELR records by month and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 142 records.

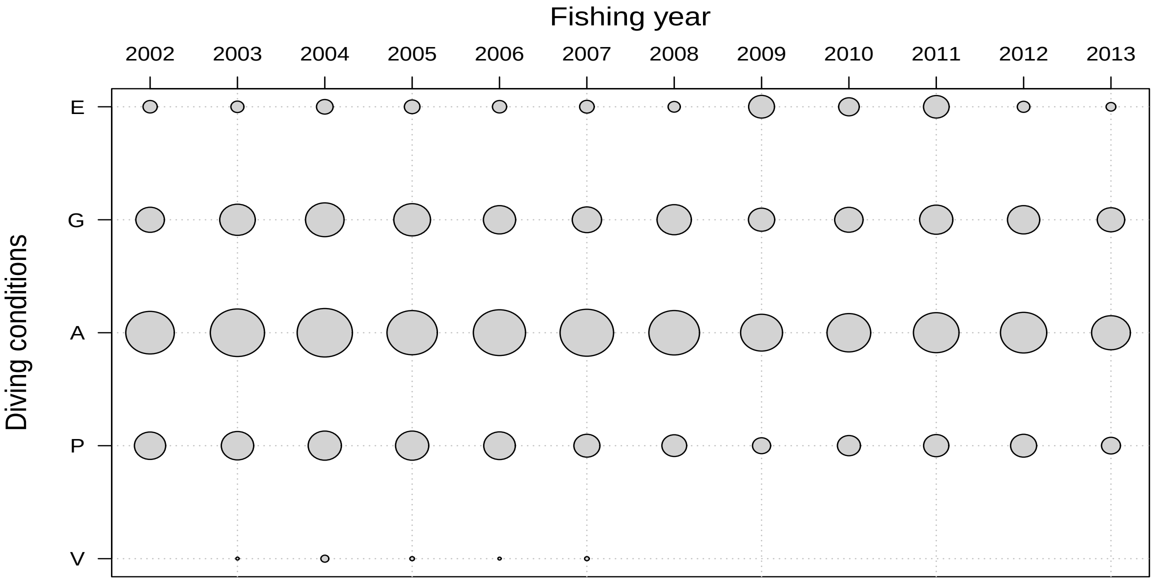


Figure 38: Number of PCELR records by diving condition (excellent, good, average, poor, very poor) and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 288 records.

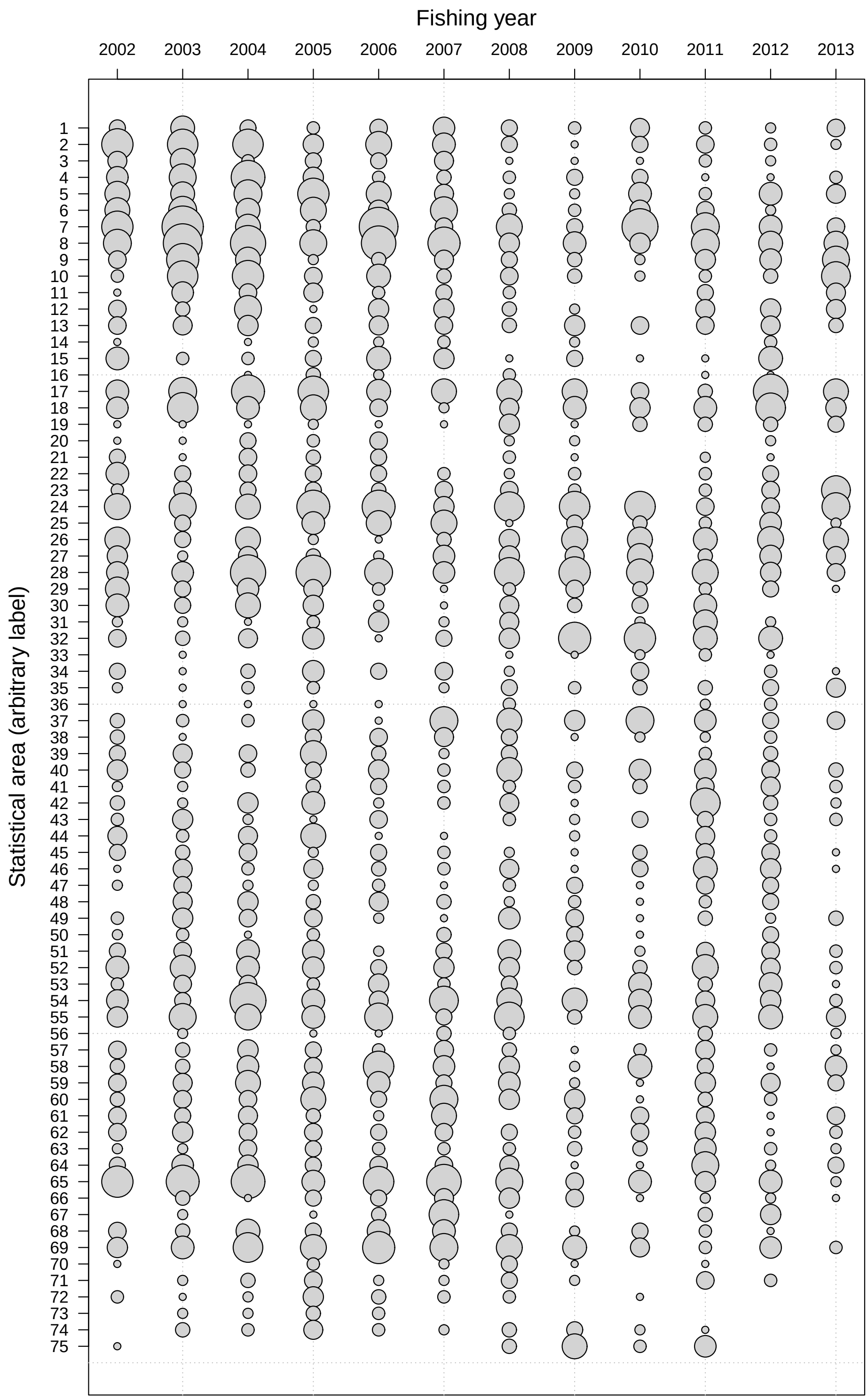


Figure 39: Number of PCELR records by statistical area and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 33 records.

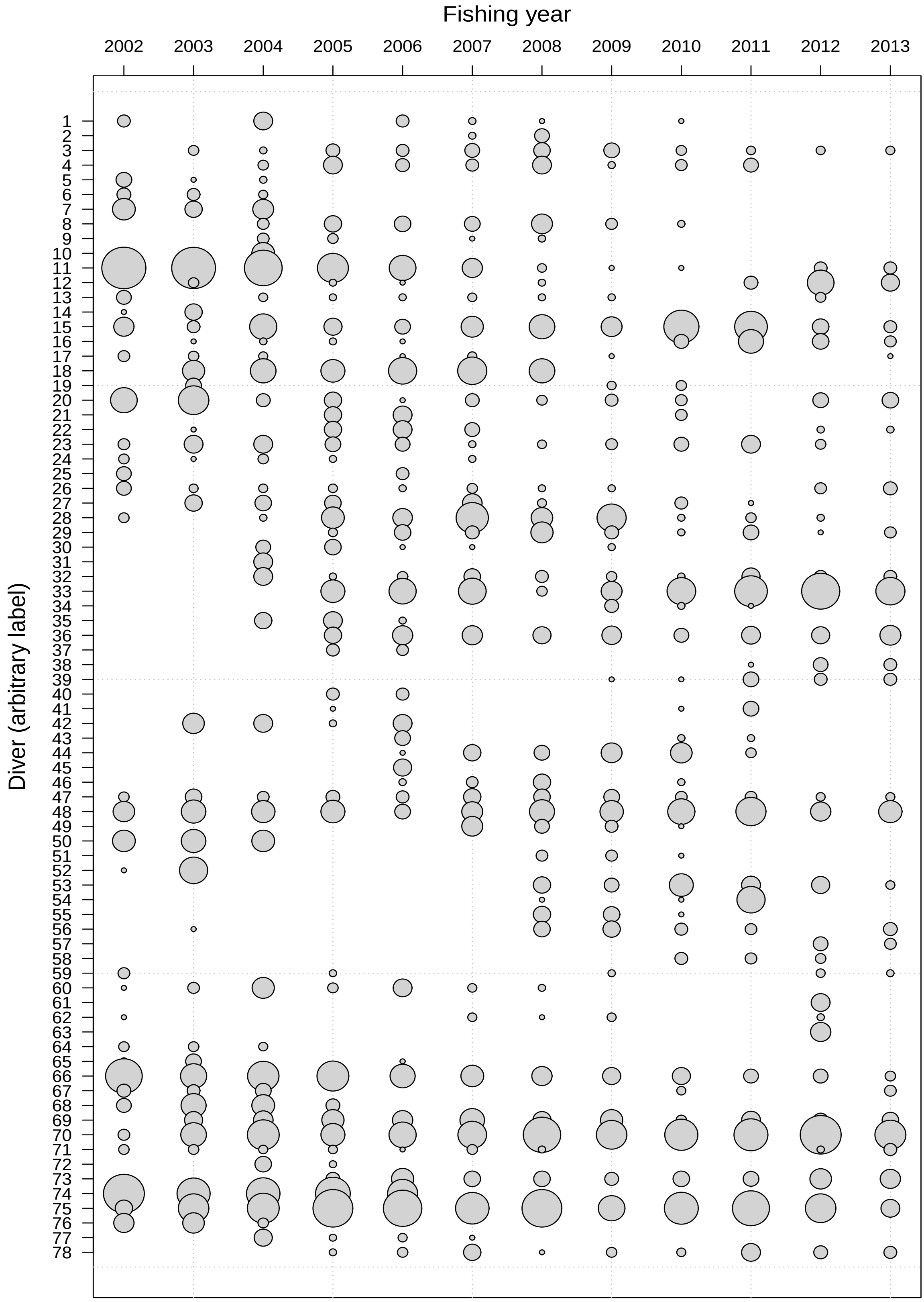


Figure 40: Number of PCELR records by diver key and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 71 records.

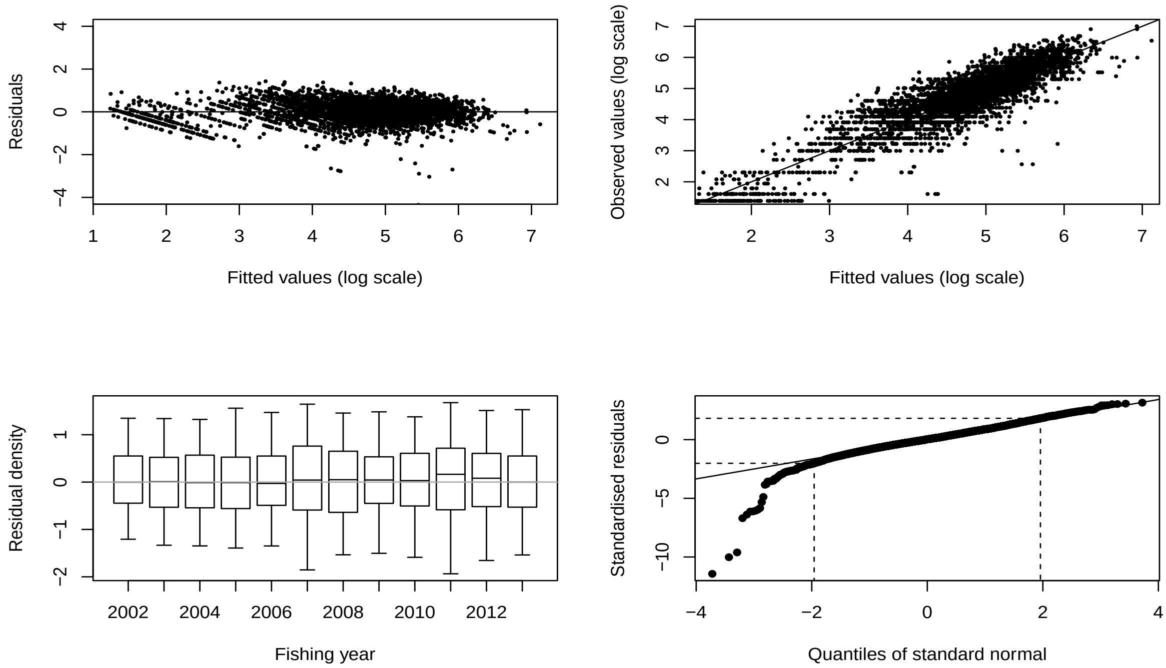


Figure 41: Diagnostic plots for the PCELR standardisation model.

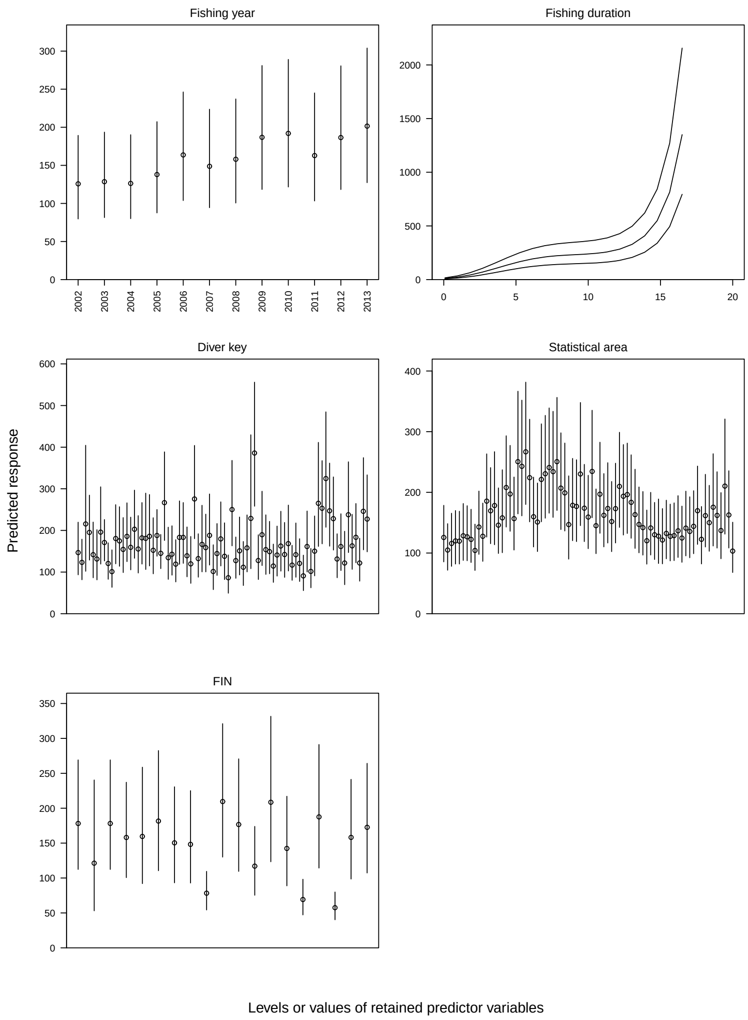


Figure 42: Effects for the PCELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

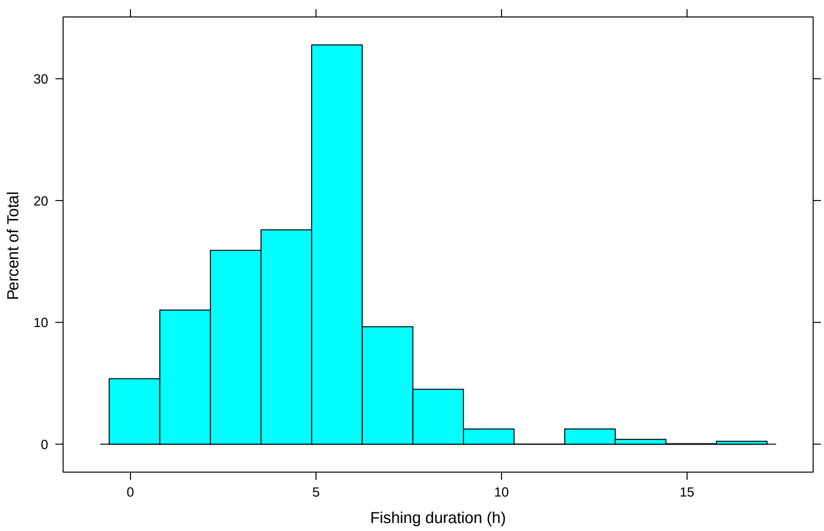


Figure 43: Distribution of fishing duration in the PCELR dataset.

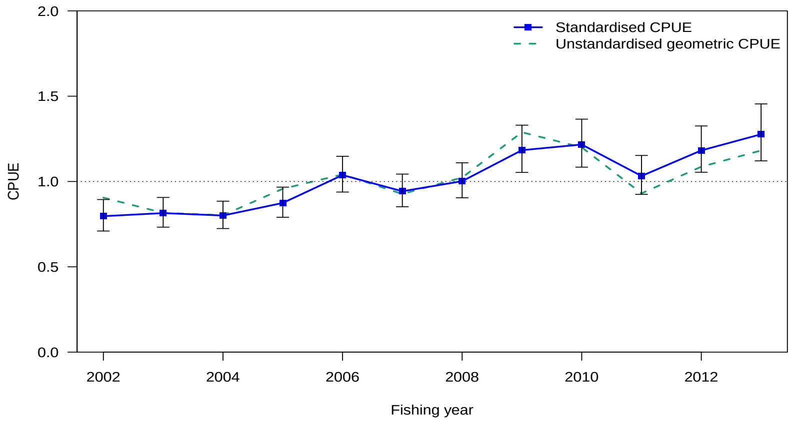


Figure 44: The standardised CPUE index for the PCELR dataset with 95% confidence intervals. The "unstandardised geometric CPUE" is calculated as catch divided by fishing duration.

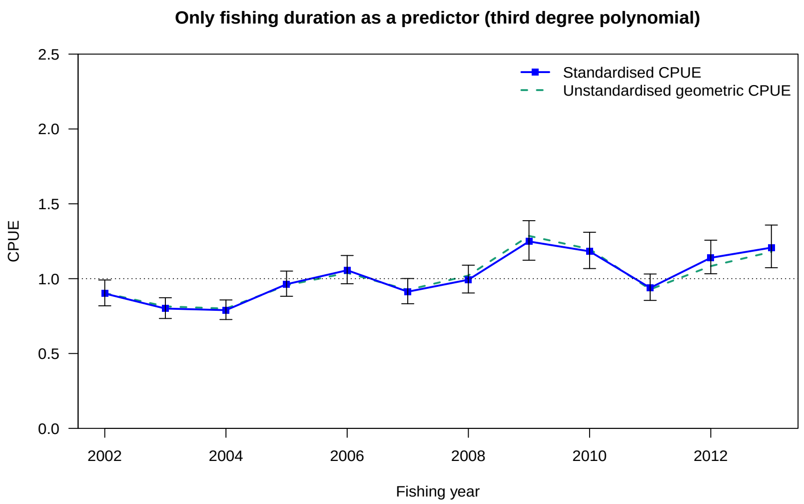


Figure 45: Standardised indices for the PCELR dataset with just the fishing duration predictor variable.

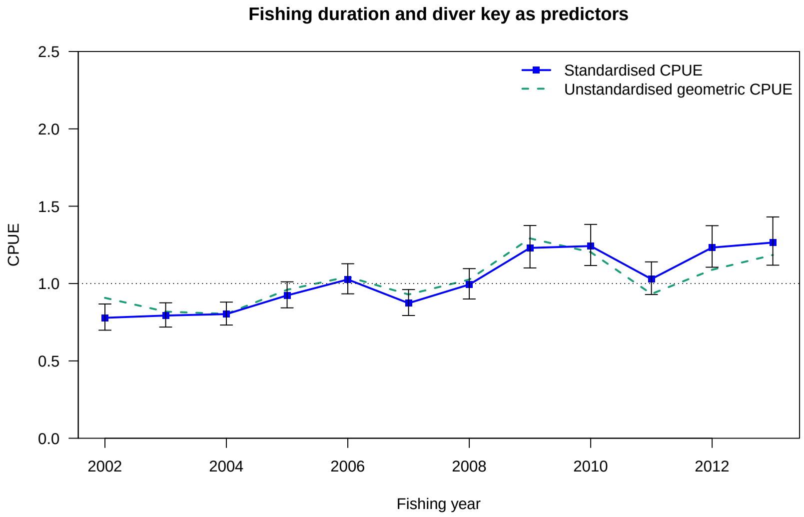


Figure 46: Standardised indices for the PCELR dataset with just fishing duration and diver key as predictor variables.

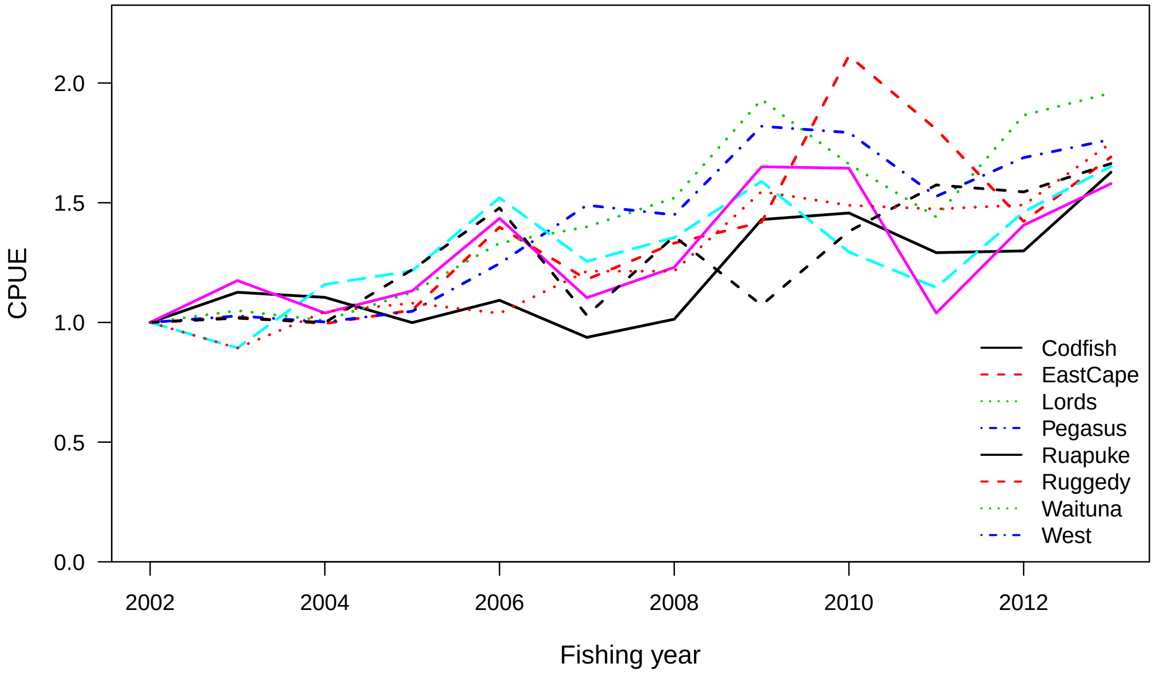


Figure 47: Standardised indices for the PCELR dataset with a year:strata interaction forced into the model. The areas are research strata.

5. COMMERCIAL CATCH LENGTH FREQUENCY (CSLF)

The paua catch sampling data comprise measurements of paua shells landed from the commercial catch (paua market sampling). Prior to 2006–07, the data were collected by NIWA and the length frequencies used were the basal length of the paua shell. This is the longest measurement along the anterior-posterior axis of the shell lip (as defined by the limit of the shell nacre when viewed with the shell upside down). It does not include the spire if it overhangs the base of the shell, or any encrusting organisms. Since 2006–07, the data have been collected by the Paua Industry Council and the industry now also measure and record overall length including the spire as well as basal length. Note that basal length differs from the measurement method used in the commercial fishery, in which the longest overall length is measured. For this reason, a small proportion of the market samples appear to be below the MLS of 125 mm

A new extract of Catch Sampling Length Frequency (CSLF) data was made from the *market* database on 1 September 2013. This totalled 49 982 records containing 125 682 measurements from 1992–94 and 1998–2013. Deducing the statistical area of for records prior to 2001–02 required some analysis as a variety of area codes were used.

The number of catch landings sampled per year ranged from 30 to 90 from 1992 to 2013 except in 1998 when there were only 9 samples taken (Table 21). Typically, over 4000 paua were measured each year. Between 2000 and 2006, about 20% of samples had no area recorded, because some operators refused to supply the information (see Table 21). Since 2002, most subareas have been consistently sampled and sampling coverage was reasonably adequate, although West appears to have small sample sizes for most years relative to its catch level (Table 22).

There appeared to be a temporal trend in the catch samples. The mean length of measured paua has increased since 2007 in most areas (Figure 48). This is because the voluntary minimum harvest size

(MHS) has been increased by a total of 10 mm over a 5-year period in PAU 5B (it was increased to 127 mm in 2007, 131 mm in 2009, 133 mm in 2010, and 135 mm in 2011). There were also spatial variations in the mean length between subareas: paua sampled from Ruggedy were smaller than those sampled from Waituna and Pegasus. This spatial contrast was evident for both the early years from 2002 to 2006 and the recent years from 2007 to 2013 (Figure 49).

Breen & Smith (2008a) weighted the length frequency by the ratio of area catch to the mean area catch within each year. Data without area information were not added to the weighted length frequency distribution. We adopted a modified approach to calculate the length frequency using NIWA's 'catch-at-age' software (Bull & Dunn 2002). Between 1992 and 2001, the catch samples were stratified using three spatial strata based on the General Statistical Areas: 025, 030, and 027/029. Between 2002 and 2013 the stratification was based on the research strata (see Table 22). Strata in which there was no sample were combined with adjacent strata (i.e., Ruggedy was combined with Waituna in 2002 and 2005, Pegasus was combined with West in 2005, 2008 and 2009; East Cape was combined with Ruapuke in 2003 and 2007). The length frequencies of paua from each landing were scaled up to the landing weight, summed over landings in each stratum, and then scaled up to the total stratum catch to yield length frequencies by stratum and overall. The CV for each length class was computed using a bootstrapping routine: fish length records were resampled within each landing which was resampled within each stratum. For samples where landing weight was unknown the landing weight was assumed to be equal to the sample weight, calculated from the number of fish in the sample and mean fish weight.

Only samples with known areas were included. Scaled length frequencies for PAU 5B are shown in Figure 50. The scaled length frequencies had wider distributions before 1998; there were more smaller paua in the catch between 2003 and 2006 with the mode of the distribution close to 125 mm. Samples in more recent years contain larger paua with the mode generally greater than 135 mm, evidently as a result of the increase in MHS.

Table 21: Number of landings sampled and number of paua measured from the market shed sampling program by General Statistical Area and by fishing year.

	Number of landings sampled						Number of paua sampled					
Year	030	025	027	029	Unknown	Total	030	025	027	029	Unknown	Total
1992	13	34	7	0	1	55	4528	11654	2287	0	346	18815
1993	17	27	1	0	0	45	5828	9337	335	0	0	15500
1994	13	22	9	0	0	44	4253	6663	3790	0	0	14706
1998	3	3	3	0	0	9	515	379	160	0	0	1054
1999	9	17	16	1	1	44	944	1770	1725	102	115	4656
2000	5	9	12	0	4	30	503	1044	1263	0	405	3215
2001	7	10	4	0	11	32	875	1332	500	0	1438	4145
2002	12	4	16	1	4	37	1465	439	1756	109	424	4193
2003	10	11	11	0	9	41	1122	1230	1236	0	1009	4597
2004	20	22	16	0	14	72	2132	2325	1666	0	1502	7625
2005	5	14	9	1	16	45	520	1459	917	106	1654	4656
2006	4	12	10	0	14	40	406	1222	1004	0	1400	4032
2007	5	16	4	2	0	27	640	2180	487	230	0	3537
2008	12	18	7	0	0	37	1586	1957	641	0	0	4184
2009	26	11	11	1	0	49	2748	1200	964	104	0	5016
2010	22	29	19	1	0	71	2064	2770	1935	86	0	6855
2011	25	36	18	0	0	79	1865	2752	1212	0	0	5829
2012	22	22	20	1	0	65	1789	1895	1726	62	0	5472
2013	31	42	13	2	0	88	2380	3560	1185	206	0	7331
Total	261	359	206	10	75	911	36163	55168	24789	1005	8557	125682

Table 22: Number of landings sampled from the market shed sampling program by subarea and by fishing year

	Ruggedy	Waituna	Codfish	West	Pegasus	Lords	EastCape	Ruapuke	Unknown
2002	0	4	2	7	7	9	1	3	4
2003	7	4	3	2	2	9	0	5	9
2004	18	4	8	7	2	14	1	4	14
2005	5	0	3	3	0	9	2	7	16
2006	5	2	1	1	1	9	3	4	14
2007	10	2	1	3	1	3	0	7	0
2008	9	8	2	1	0	7	3	7	0
2009	4	9	2	16	0	11	3	4	0
2010	17	4	5	14	1	18	6	6	0
2011	20	14	2	7	3	15	8	10	0
2012	14	14	3	5	4	16	2	7	0
2013	36	10	6	14	7	6	6	3	0

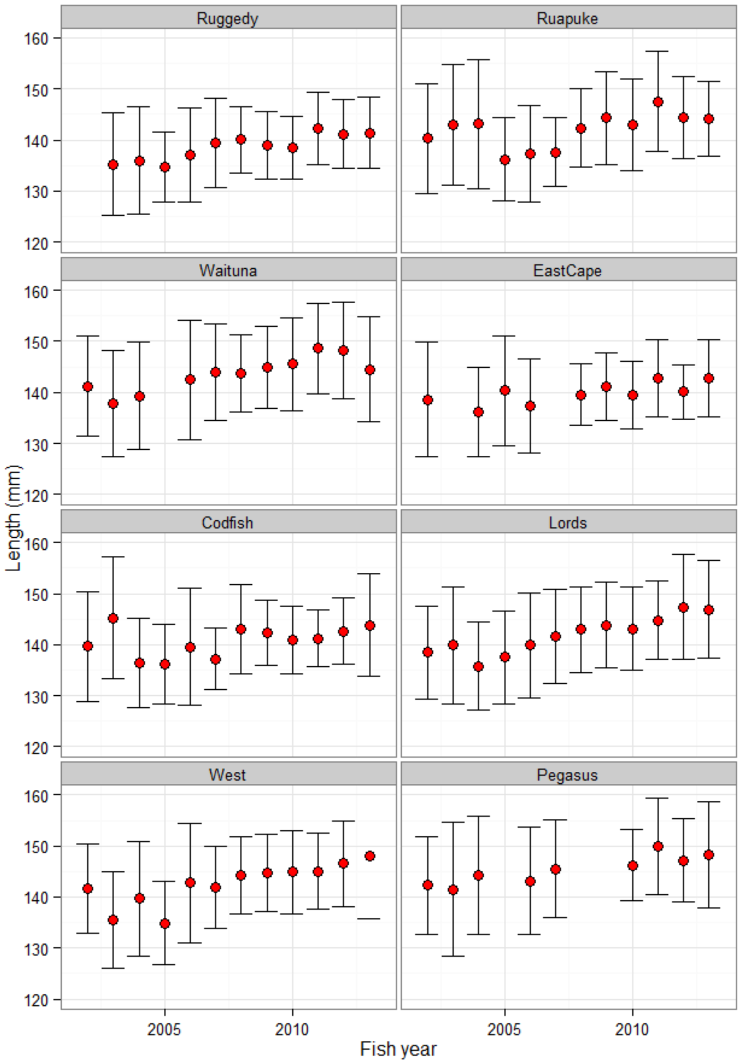


Figure 48: Mean length (dot) with one standard deviation (bar) for measured paua from market shed sampling by sub area and fishing year using data from 2002 to 2013. The standard deviation is calculated from the variance of individual measurements.

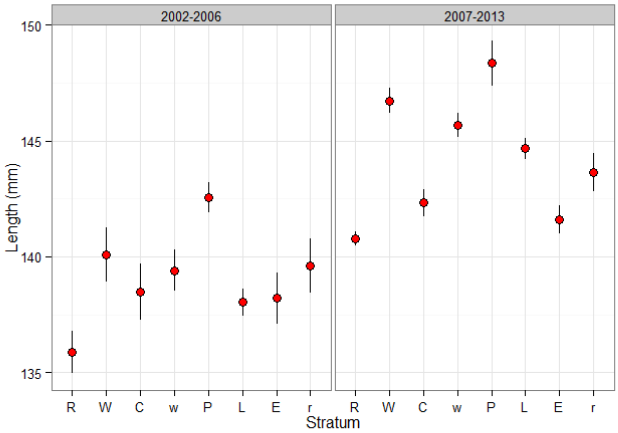


Figure 49: Mean length (dot) with one standard error (bar) of measured paua from market shed sampling by sub area using data for period 2002– 2006 and for 2007– 2013 The mean is calculated across sampled landings and the standard error is the standard deviation of the mean.

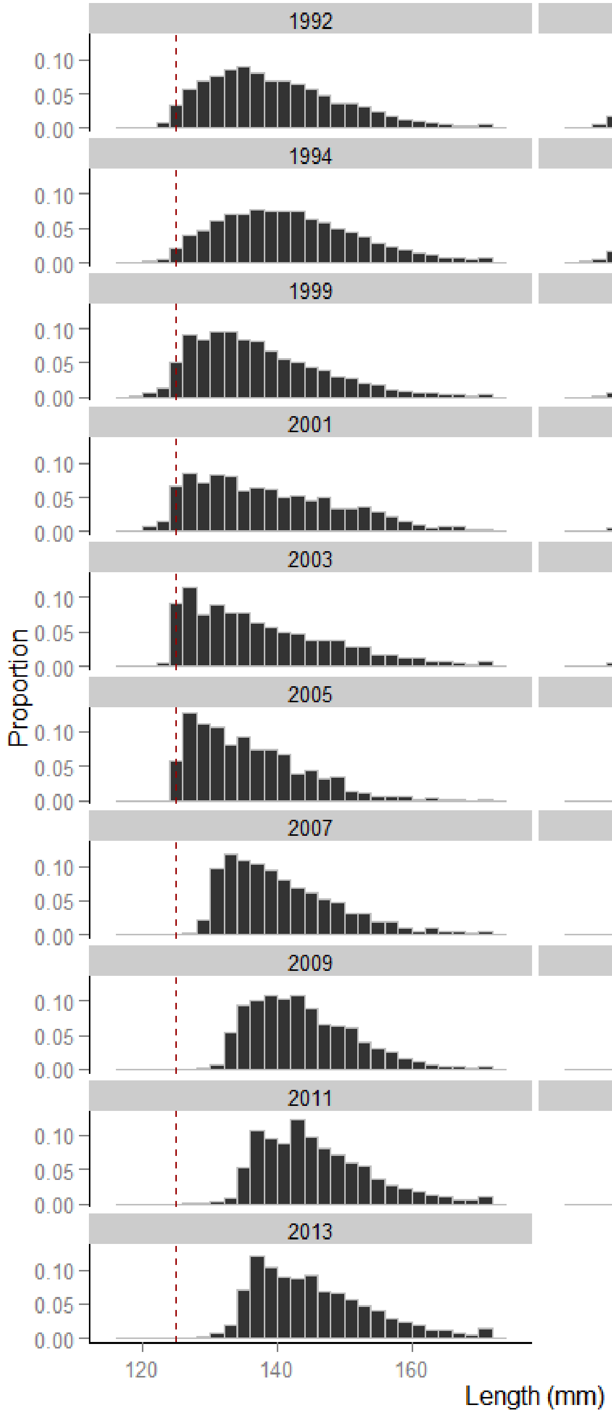


Figure 50: Scaled length frequency distributions for paua from commercial catch sampling in PAU 5B for fishing years 1992–1994, 1998, and 2002–2013 The dashed line indicates the MLS of 125 mm.

6. RESEARCH DIVER SURVEY INDEX (RDSI)

Research diver surveys based on a timed-swim method as developed by McShane (1994, 1995) and modified by Andrew et al. (2000a) have been conducted to assess the relative abundance of New Zealand paua stocks since 1991 (Andrew et al. 2000b, 2000c, 2002, Naylor & Kim 2004). Relative abundance indices estimated from the survey data (RDSI) have been routinely used in paua stock assessment (Breen & Smith 2008a, 2008b). The previous stock assessment for PAU 5B used the RDSI developed from the survey data up to 2007 (Breen & Smith 2008a). There has been no new survey since last assessment and the same survey data was used for this assessment.

Concerns over the survey methodology and its usefulness in providing relative abundance indices led to a number of reviews. Andrew et al. (2002) recommended slight modifications which have been adopted and were subsequently reviewed by Hart (2005). Cordue (2009) conducted simulation studies and concluded that the diver-survey based on the timed swim approach is fundamentally flawed and is inadequate for providing relative abundance indices. More recently, Haist (2010) has suggested that the existing RDSI data are likely to be more useful at stratum level.

We present a reanalysis of the RDSI below and the reanalysis has adopted a number of recommendations from Haist (2010) and Cordue (2009). However, given the concerns over the usefulness of the RDSI as relative abundance indices, the WG suggested that the RDSI not be included in the base case model and only used in a sensitivity analysis.

The survey follows a stratified-random design (Naylor & Kim 2004). The survey strata in PAU 5B are shown in Figure 3. Each stratum was subdivided into 200 m wide strips, each of which was considered a potential sampling site. Each year sites were randomly selected within strata (chosen sites containing unsuitable habitat were replaced and also permanently discarded from future surveys). Not all strata were surveyed each year and the number of sites sampled within each stratum was chosen to provide mean relative abundance with CV less than 20% based on the variance estimated from previous surveys.

At each site, two 10 minute searches were conducted by divers using surface-supplied air. The areas searched were not overlapping and were constrained to be within 100 m of the vessel. The survey area covered suitable paua habitat in shallow water extending to a depth of 10 m to the shore. The diver counts from each paired swim were combined to give an estimate of the paua count at the single site.

Before 1997 only the patch category was recorded and total counts were inferred from estimates of the mean of the patch category (Table 23). Since 1997 the actual number of paua in patches was recorded. Paua are considered to be in the same patch if they are separated by less than two body lengths. Recent swim data therefore provide integer counts of paua whereas the previous estimates will generally be non-integer.

In earlier survey years the 10 minute swim began when the first paua was encountered (the clock was stopped when large paua patches were encountered). In later years the clock was started as soon as the diver was on suitable reef and two "clocks" were used. The first clock ran for 10 minutes from when the diver first encountered the reef and the second clock ran for 10 minutes from when the first paua was encountered.

In previous analyses of the survey data the paua counts from the total swim were used. For this assessment the paua counts were standardised to the first 10 minutes of swim (Haist 2010). For the early surveys where the first 10 minutes counts were not recorded, the total paua counts were adjusted using the ratio between 10-minute counts and the total counts derived using available data from surveys from all QMAs.

In previous assessments the estimates of the mean number of paua per time-swim were adjusted to account for differences in searching time. Searching time is influenced by the time required to process each patch (collect paua and record data) which was estimated by McShane et al. (1996) to be 7.8 seconds per patch. Based on this estimate the scaled count was estimated to be:

$$N' = 600N/(600-7.8n)$$

where N' is the scaled count N is the raw count and n is the number of patches encountered.

The RDSI data were calculated adopting a number of amendments based on suggestions by Haist (2010). Firstly, only patches with fewer than 20 paua per patch were considered as divers stop their clock when the patch size looks larger than 20. Secondly, the processing time was adjusted for the time taken to observe the patches which included the 10 minutes swim plus the time to find the first paua. The search time is therefore estimated to be:

$$\frac{600 + t - n_1 * 4 - n_2 * 9 - n_3 * 14}{600 + t}$$

where t is the recorded time to the first paua found (for early surveys an average of the time to first paua from later surveys was used), n_1, n_2 and n_3 are the number of patches in categories 1, 2 and 3 (see Table 23) and 4, 9 and 14 are the estimated times for processing respective patch categories. The search time was included in the standardisation model as an offset term.

To minimise the effects of visibility and differences between divers on estimates of relative abundance, the timed-swim counts were standardised using GLMs. However, a range of standardisation methods has been used in previous studies: Breen & Kim 2005 used a standard linear regression for calculating RSDI for the 2005 PAU 7 assessment and Breen & Kim 2007 used a tweedie model for the 2006 PAU 5A and PAU 5D assessment. More recently a negative binomial model has been used to standardise the RSDI indices (Breen & Smith 2008a, Cordue 2009). Middleton (2009) examined alternative model fits for PAU 7 RSDI indices and suggested that the negative binomial model provides a better fit than the normal model.

We standardised the unscaled counts with a negative-binomial log-link function as described by Breen & Smith (2008a) with the search time entering the model as an offset term. Non-integer counts arising from the earlier estimation by patch size were rounded to the nearest integer.

The number of paired-swims by stratum is summarised in Table 24. The mean diver counts for most areas showed a similar trend up to 1998 (Figure 51). Between 1998 and 2007 the three strata in the east (Pegasus, Lords, and East Cape) showed an opposite trend to the three strata in the west (Ruggedy, Codfish, and Waituna). The Standardised RDSI for all areas combined are shown in Figure 52. The combined indices were more influenced by the trend in the three east strata, which had more samples than the west strata.

Table 23: Definition of patch type by number of paua and the estimates of mean number per patch for PAU 5.

Patch type	Patch size	Old estimates	New Estimates
1	1–4	1.6	1.7
2	5–10	6.9	7
3	11–20	14.4	14.3
4	21–40	27.4	27.8
5	41–80	51.5	48.9
6	>80	129.9	128.5

Table 24: Number of paua research survey paired diver swims in PAU 5B by fishing year.

Fishing year	Ruggedy	Waituna	Codfish	Pegasus	Lords	East Cape
1993	–	9	5	–	–	–
1994	–	9	11	8	6	9
1995	4	7	–	3	4	4
1996	17	–	4	–	5	10
1998	18	7	7	20	20	18
2001	15	15	7	15	16	15
2007	15	2	6	11	12	13

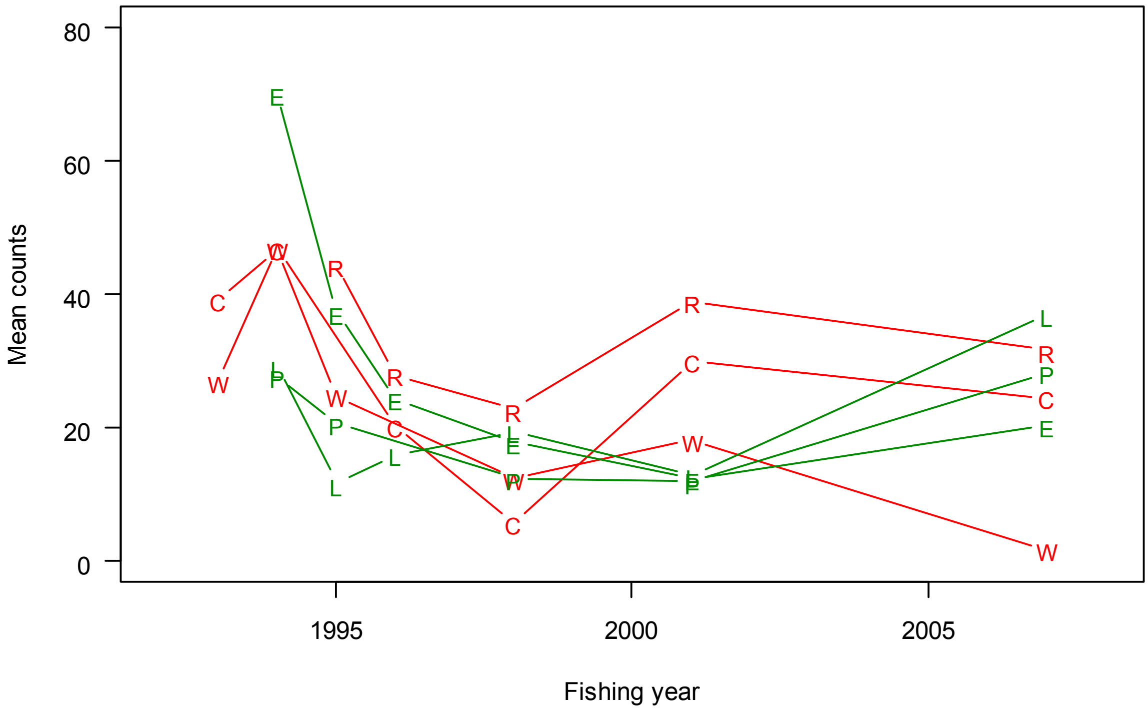


Figure 51: Mean diver counts by research stratum and fishing year for PAU 5B. R, Ruggedy; W, Waituna; C, Codfish; P, Pegasus; L, Lords; E, East Cape.

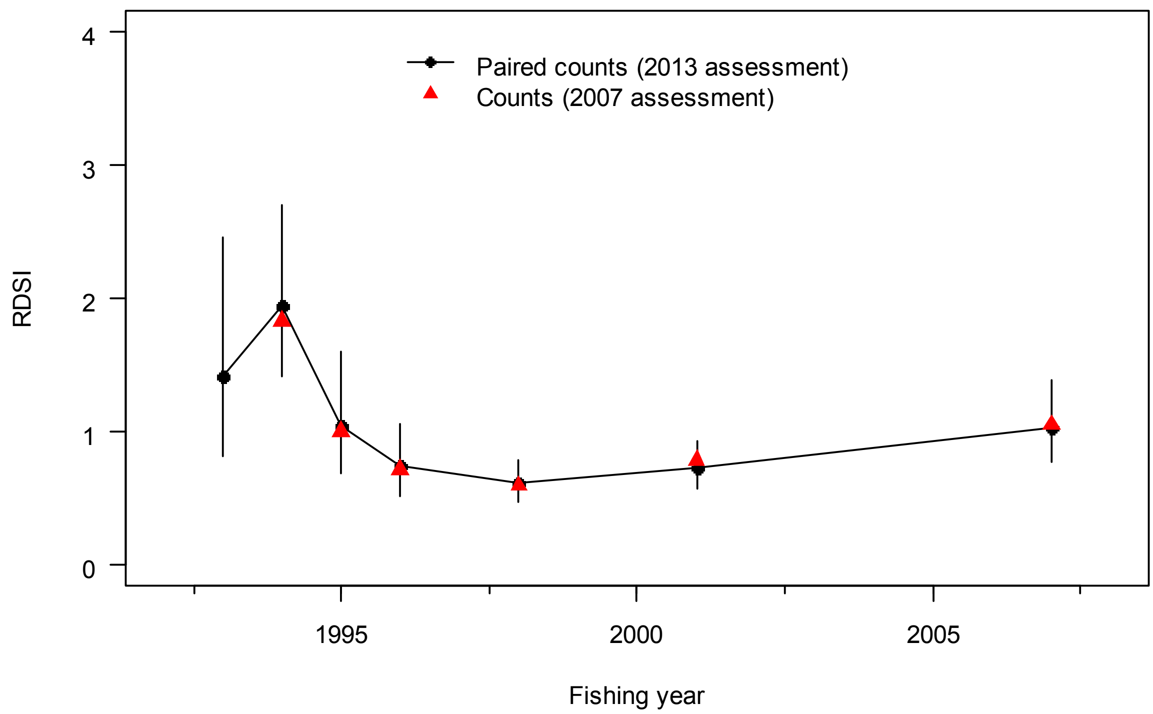


Figure 52: The standardised RDSI from the negative-binomial GLM models fitted to paired diver counts for surveys in PAU 5B. Also plotted are the estimated indices from the 2007 assessment in which individual diver counts were fitted by a tweedie model (see Breen & Smith 2008a).

7. RESEARCH DIVER LENGTH FREQUENCY (RSLF)

Paua from the research diver survey were sampled to estimate the size composition at each site. The first four paua encountered from each patch were collected (Table 25). This protocol meant that relatively more paua from small patches were measured than from larger patches; we assume that there are no differences in the length composition of paua in patches of different size. Shells were measured to the nearest millimetre with vernier calipers at their longest basal length. Basal length does not include any overhang of the shell spire and in this respect differs from total length (lowest measurement on the anterior-posterior axis) which is used in the commercial fishery to define minimum legal size (125 mm). The data were grouped into 2 mm size classes for presentation with paua longer than 170 mm being pooled into a single size class. A few paua less than 70 mm were excluded from the length frequencies.

In previous assessments the RSLF was estimated by weighting the length frequency from each swim by the paua counts for that swim:

$$L_{s,j,y} = L'_{s,j,y} \frac{IS_{j,y}}{\sum_j IS_{j,y} / n_y}$$

where $L'_{s,j,y}$ is the raw frequency at size s from the j^{th} sample in year y $IS_{j,y}$ is the paua counts of the j^{th} sample in year y and n_y is the number of swims in year y.

We adopted a modified approach to calculate the length frequency by scaling the length frequency from each sample up to the counts in each swim, summed over all counts in each stratum, and then scaled up to the total stratum count to yield length frequencies by stratum and overall (Figure 53). In the early years (1982–1991) when timed-swim counts were not available, the unscaled length frequencies were used. The RDLF data were not included in the base case of the assessment model and were only used as a sensitivity.

Table 25: Number of paua sampled from the research diver survey by stratum and fishing year.

	Ruggedy	Waituna	Codfish	West	Pegasus	Lords	East Cape
1982							93
1983	825						
1984	1155						
1989	3659	1703		1495			289
1991		161	142	316		52	190
1993		434	469				193
1994		334	372	107	230	230	420
1995	179	107	83	960	49	73	476
1996	1809					117	173
1998	649	99	61	301	298	355	374
2001	1010	469	267		309	302	352
2007	646	8	154		394	347	333

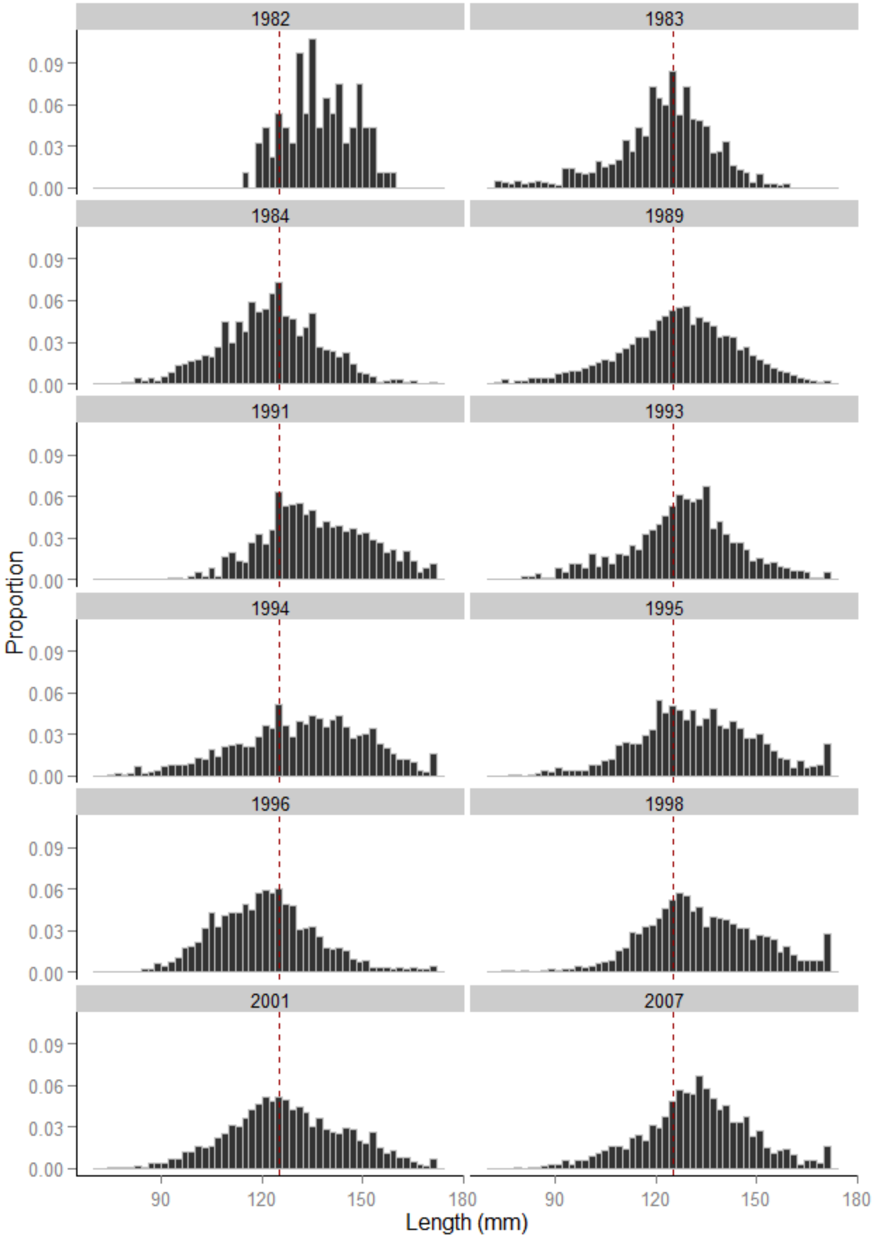


Figure 53: Scaled length frequency from research diver survey sampling in PAU 5B. The dashed line indicates the MLS of 125 mm.

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Tag and recapture experiments were conducted at different times and at several sites in PAU 5B (Breen & Kim 2008a). Growth data collected from these experiments were available from East Cape (n=116), Lords (n=52), Ruggedy (n=78), and Waituna (n=132). The growth dataset comprises 333 records with initial lengths ranging from 22 to 143 mm, time at liberty ranging from 214 to 364 days and annualised increments ranging from -2 to 54 mm. These data were incorporated into the PAU 5B assessment to estimate growth. No new tag recapture data since the last PAU 5B assessment have been collected. We removed 30 records for which paua were tagged at sizes smaller than 70 mm because the model does not represent paua less than 70 mm in length.

The tag-recapture data used in paua assessment models were analysed using a number of length-increment growth models. With the linear growth model (Francis 1988) the expected annual growth increment for an individual of initial size L_k is

(1) $$u_k = g_1 + (g_2 - g_1)(l_k - L_1)/(L_2 - L_1)$$

where g_1 and g_2 are the mean annual growth increments for paua with arbitrary lengths L_1 and L_2. With the exponential growth model:

(2) $$u_k = g_1 (g_2 / g_1)^{(l_k - L_1)/(L_2 - L_1)}$$

where u_k is the expected increment for a paua of initial size L_k; and g_1 and g_2 are the mean annual growth increments for paua with arbitrary lengths L_1 and L_2. With the inverse logistic model (Haddon et al. 2008) the expected annual growth increment for a paua of initial size L_k is:

(3) $$u_k = \frac{\Delta_{\max}}{\left(1 + \exp\left(\ln(19)\left(\left(l_k - l_{50}^g\right)/\left(l_{95}^g - l_{50}^g\right)\right)\right)\right)}$$

where $\Delta_{\max}$ is the maximum growth increment l_{50}^g is the length at which the annual increment is half the maximum and l_{95}^g is the length at which the annual increment is 5% of the maximum.

Variation in growth was normally distributed with $\sigma_k = \max\left(\alpha(u_k)^\beta, \sigma_{\min}\right)$ where u_k is the expected growth at length L_k truncated at zero, $\sigma_{\min}$ is the minimum standard deviation and $\alpha(u_k)^\beta$ is the standard deviation of growth at length L_k (if β is fixed at 1 α will be the coefficient of variation and if β is fixed at 0 α will be the standard deviation).

The assessment model included the tag-recapture data as an observational dataset and estimated the growth parameters within the model. Therefore the estimated growth parameters were also dependent upon other observations included within the model (e.g. commercial length frequency data). Below we present a simple analysis of the tag-recapture data using the linear growth model. Note that this was a separate exercise outside the assessment model, and the estimates were solely based on the tag-recapture data. Those estimates were likely to be different to the growth parameters estimated from the assessment model.

The parameters were estimated using maximum likelihood as defined in Dunn (2007):

$$L_i(\mu_i, \sigma_i, \sigma_E) = \frac{1}{\sigma_E}\phi\left(\frac{y_i}{\sigma_E}\right)\Phi\left(-\frac{\mu_i}{\sigma_i}\right) + \frac{1}{\sqrt{\sigma_i^2 + \sigma_E^2}}\phi\left(\frac{y_i - \mu_i}{\sqrt{\sigma_i^2 + \sigma_E^2}}\right)\Phi\left(\frac{\sigma_i^2 y_i + \sigma_E^2 \mu_i}{\sqrt{\sigma_i^2 \sigma_E^2 \left(\sigma_i^2 + \sigma_E^2\right)}}\right)$$

where y_i is the measured growth increment for the i^{th} paua; μ_i and σ_i are the expected growth (truncated at zero to exclude the possibility of negative growth) and standard deviation respectively;

σ_E is the standard deviation of measurement error (assumed to be normally distributed with mean zero); and ϕ and Φ are the standard normal probability density function and cumulative density functions respectively.

Annual growth increment measurements were considered. The linear growth model was fitted to the data for all areas combined (Figure 54). The growth parameters at $L_1 = 75$ mm and $L_2 = 120$ mm were estimated as $g_1 = 24.5$ mm and $g_2 = 6.0$ mm. The parameters for variation in growth were estimated as $\alpha = 1.98, \beta = 0.34$. The measurement error σ_E was assumed to be known as 1 mm.

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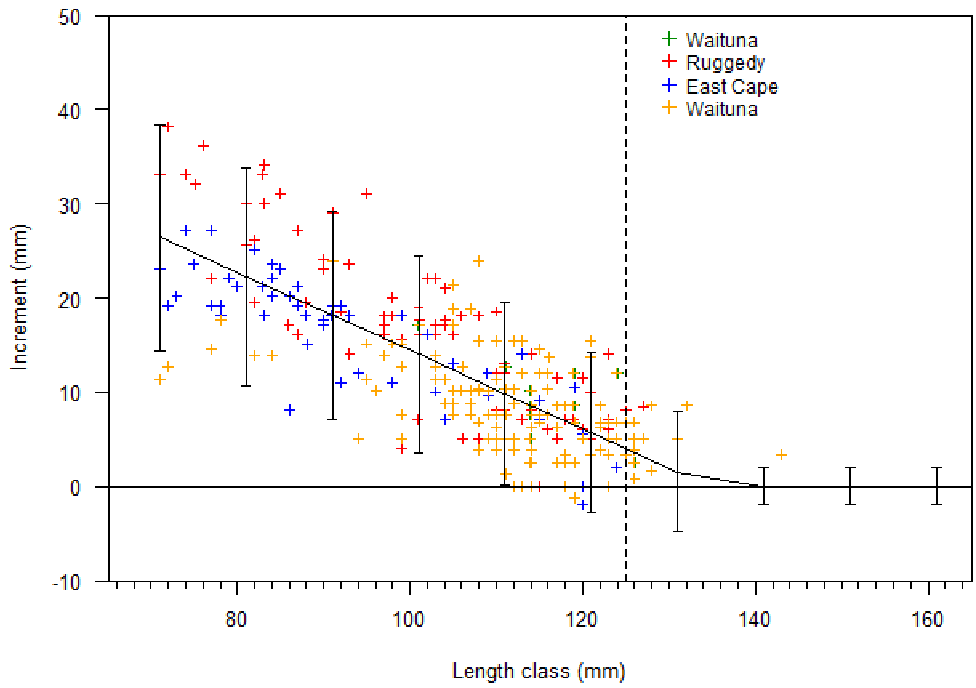

Figure 54: Initial size and mean annual increment from the tag-recapture data within PAU 5B (and 95% confidence intervals) indicate size-based linear growth curves estimated from these data. Dashed line indicates the legal size limit (125 mm).

9. MATURITY

Maturity data was collected in February 2007 from four sites in Codfish (n=24), one site in Lord (n=2), two sites in Pegasus (n=19), and seven sites in Ruggedy. Data were also collected in February 1995 from nine sites and in November 2006 from one site in East Cape (n=82), and in June 2004 from five sites in Waituna. Paua were examined for maturity and for sex if mature. The sample size was small and data were aggregated for the assessment across all sites and dates. They were collated as the number examined and the number mature in 2-mm length bins.

The length of paua examined ranged from 56 to 126 mm. Paua less than 70 mm (n=4) were dropped out of the dataset. The proportion mature data were fitted with a logistic curve using a binomial likelihood for sub areas (a few adjacent strata were combined due to small sample size) as well as for all areas (Figure 55). Length at 50% maturity (L50%) was estimated to be about 91 mm for Ruggedy, 96 mm for East Cape, Lords and Pegasus, and 78 mm for Waituna and Codfish. Length at 50% maturity was estimated to be about 91 mm for all areas combined.

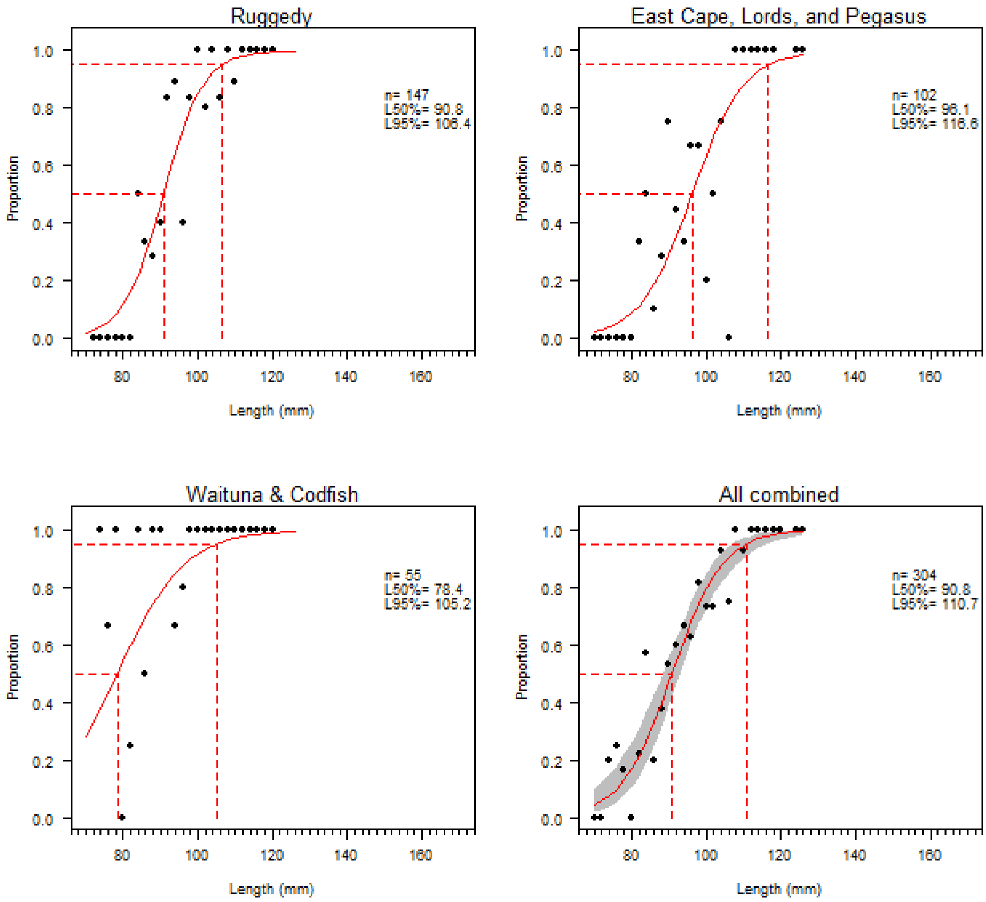

Figure 55: Proportion of maturity at length for PAU 5B. The dots represent the observed proportion mature for each 2 mm length bin. The red line represents a fitted logistic maturity curve. The grey area represents the 95% confidence interval of estimated proportion. The dash lines represent estimated length at 50% and 95% maturity.

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