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Summary of input data for the 2016 PAU 5D stock assessment

New Zealand Fisheries Assessment Report 2017/32

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EXECUTIVE SUMMARY

Fu, D.; McKenzie, A.; Marsh C. (2017). Summary of input data for the 2016 PAU 5D stock assessment.

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This document summarises the data inputs for the 2016 stock assessment of blackfoot paua in PAU 5D. The seven sets of data available for 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 (RDLF) (5) a commercial catch sampling length frequency series (CSLF) (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.

A new standardisation was done for the CELR data using fishing duration as the measure of effort, and the standardised CPUE series based on PCELR data was updated to the 2015–16 fishing year. There has been no research diver survey since the last assessment, and therefore the same RDSI and RDLF were available for this assessment as in the last assessment. The data from research diver surveys were not included in the base case model, only in sensitivity runs. Scaled length frequency series from the commercial catch sampling were updated to the 2015–16 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. There have been no new tag-recapture data but maturity-at-length data were reanalysed incorporating data available since the last assessment.

1. INTRODUCTION

This document summarises the data inputs for the 2016 stock assessment of PAU 5D. The work was conducted by NIWA under the Ministry for Primary Industries' contract PAU201601 Objective 1. A separate document details the stock assessment of PAU 5D (Marsh & Fu 2017). PAU 5D was last assessed in 2012 (Fu 2013, Fu et al. 2013), before that in 2006 (Breen & Kim 2007) and before that in 2000 (Breen et al. 2000). 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".

This report summarises the model input data available for PAU 5D to the 2015–16 fishing year.

1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2016 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.

Standardised CPUE indices were calculated for the CELR and PCELR data separately, based on methodologies similar to those for the recent PAU 5B (Fu et al. 2014), PAU 5A (Fu et al. 2015), and PAU 7 (Fu et al. 2016) assessments. There has been no research diver survey since the last assessment, and therefore no updates were made to the RDSI and RDLF series.

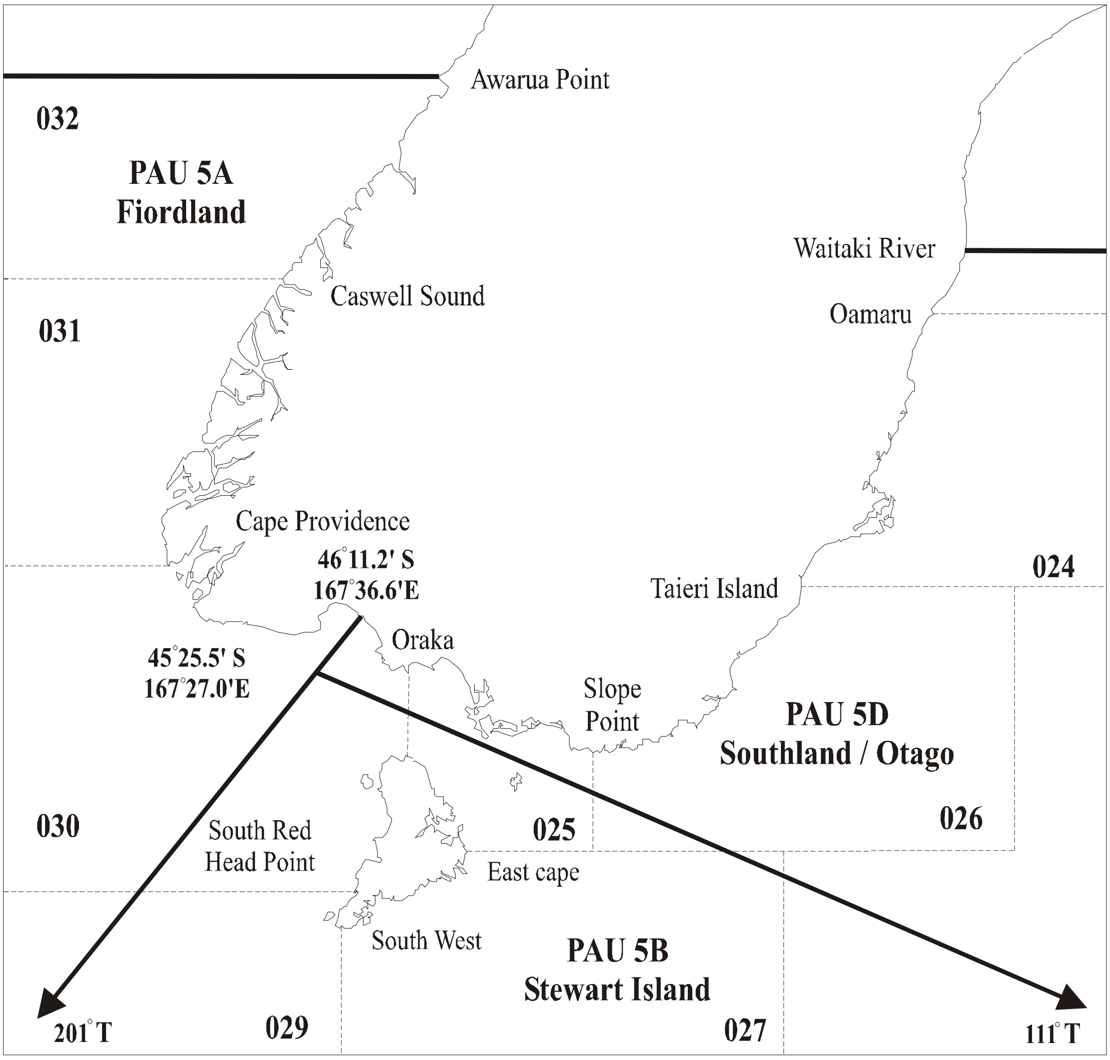


Figure 1: Map showing the new QMAs effective from 1 October 1995 and the old statistical area boundaries (dashed lines) of PAU 5.

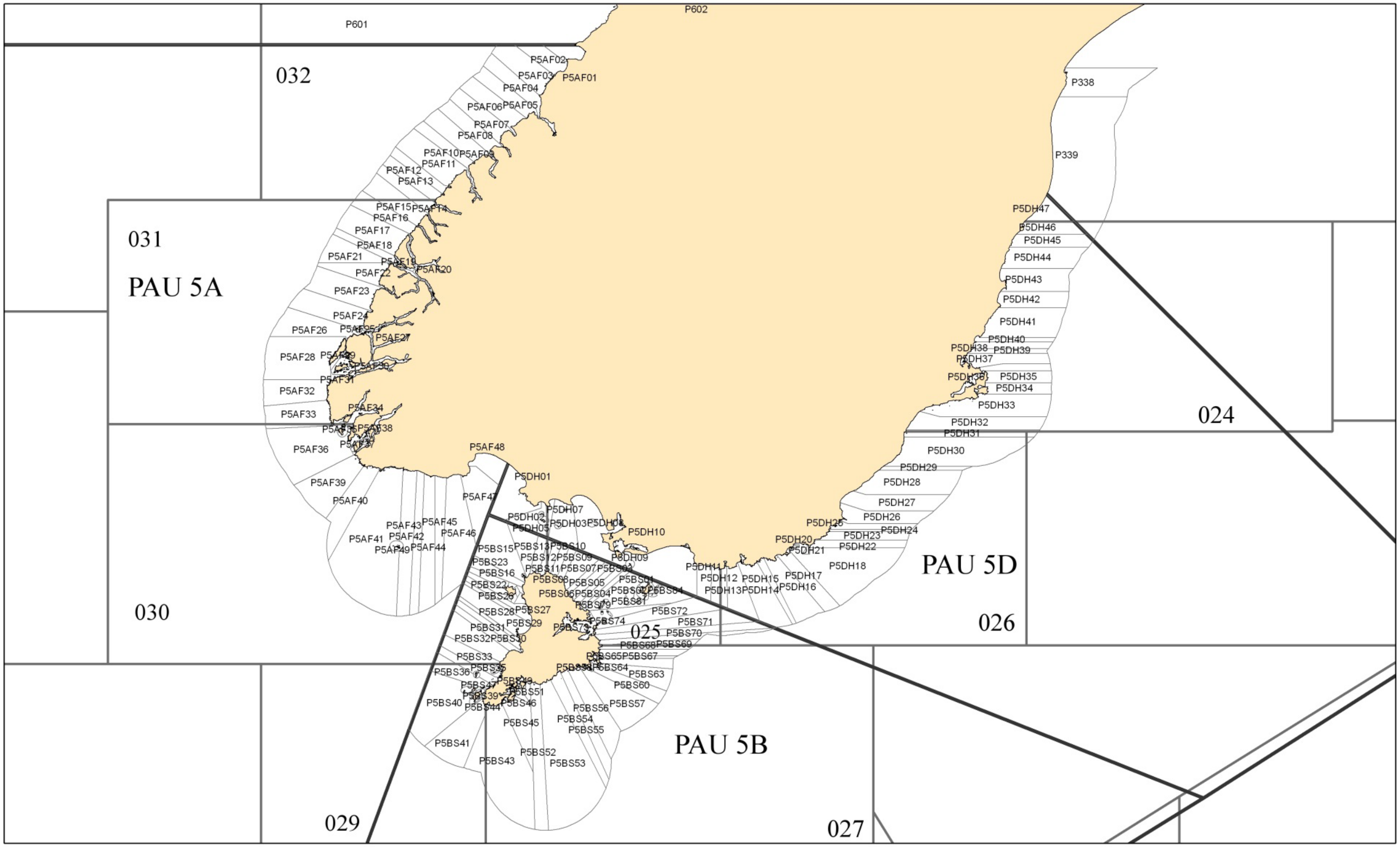


Figure 2: Map showing the location of fine-scale statistical areas within PAU 5 effective from 1 October 2001.

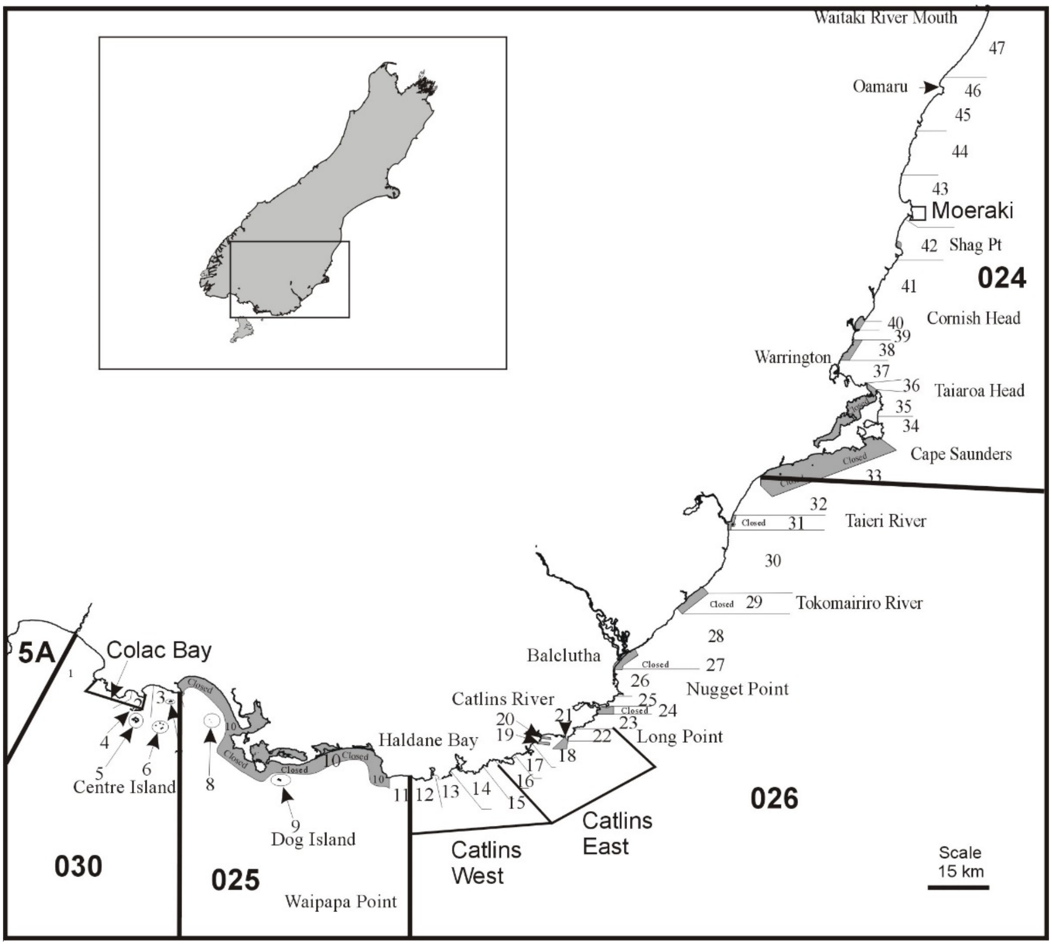


Figure 3: Map of fine-scale statistical areas and research strata for PAU 5D. Regulated closed areas are shown in grey.

2. DESCRIPTION OF THE FISHERY

PAU 5D includes the coastal areas of the Otago and Southland coast (Figure 1). Prior to 1995 PAU 5D was part of the larger PAU 5 QMA, which was introduced into the QMS in 1986 with a TACC of 445 t, and included the entire southern stock of paua from the Waitaki River mouth on the east coast of the South Island, around to Awarua Point on the west coast including Stewart Island.

The TACC for PAU 5 was increased to 492 t in the 1991–92 fishing year making PAU 5 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 separate QMAs; PAU 5A, Fiordland; PAU 5B, Stewart Island; and PAU 5D, Southland/Otago (Figure 1). The TACC was divided equally among the new stocks giving each of the new QMAs a TACC of 145 t. 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.

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 fine-scale spatial scale of 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 for PAU 5D and subareas used in this report are given in Tables 2 and 3.

The quota management area of PAU 5D runs from the Waiau River (west of Riverton) to the Waitaki river mouth (north of Oamaru) and includes Centre Island and Dog Island in Foveaux Strait (Figure 3). More than 90% of the commercial catch was historically taken from the Catlins area (McShane 1995, Elvy et al. 1997). The TACC of PAU 5D was set at 148.98 t on 1 October 1995, and was reduced to 114 t on 1 October 2002, and further to 89 t on 1 October 2003. The TACC has remained unchanged since then.

In recent years the commercial paua fishery has implemented a number of voluntary management actions within most QMAs (Ministry for Primary Industries 2014). Agreement to these actions has been formalised in each QMA through the development of an Annual Operational Plan (AOP) that is agreed to and signed by all Quota and ACE holders within the fishery. The plan explains the voluntary management actions that will be undertaken for the fishing year. On 1 October 2010 the commercial fishery voluntarily adopted two different minimum harvest sizes of 130 mm and 128 m specific to Statistical Areas P5DH02–37 and P5DH38–43 respectively. The minimum legal size of 125 mm remains in all other statistical areas. From the 2013–14 fishing year the MHS was increased to 132 mm for P5DH02–37 and P5DH42–43. The minimum legal size of 125 mm remains in Statistical Areas P5DH44–47. In addition, there are also several regulated closed areas (see Figure 3). The commercial fishery in PAU 5D also has four areas voluntarily closed to commercial harvesting (for details see the 2015 AOP).

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
2013–14†	N/A	N/A	102 298	148 983	88 841	90 000	84 592	89 000
2014–15†	N/A	N/A	106 950	148 983	89 450	90 000	71 870	89 000
2015–16†	N/A	N/A	78 316	148 983	61 780	90 000	54 624	89 000

* FSU data, † QMR/MHR data

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

QMA		Statistical areas		
–Sep 1995	Oct 1995–present	1983–Oct 1997	Nov 1997–Sep 2001	Oct 2001–
PAU 5	PAU 5D	024	D7–D11	P5DH32–P5DH47
		026	D4–D6	P5DH13–P5DH31
		025 (part of)	D2–D3	P5DH03 & P5DH06–P5DH12
		030 (part of)	D1	P5DH01–P5DH02 & P5DH04–P5DH05

Table 3: Summary of subareas used in the analyses and associated Paua Statistical Areas within PAU 5D. Historically, the Catlins area was further divided into Catlins west (P5DH11 – P5DH15) and Catlins East (P5DH16 – P5DH21).

Subarea	Paua Statistical Area
South	P5DH01 – P5DH10
Catlins	P5DH11 – P5DH21
East	P5DH22 – P5DH26
Middle	P5DH27 – P5DH40
North	P5DH41 – P5DH47

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 the PAU 5A assessment in 2006 (Breen & Kim 2007) and 2010 (Fu & McKenzie 2010); for the PAU 5B assessment in 2007 (Breen & Smith 2008b) and 2013 (Fu 2014); 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 5D. A constant proportion of 25% 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 5D was firstly estimated, where 7% and 25% of the annual estimated catch in Statistical Area 030 and 025 respectively was assumed to have been taken from PAU 5D, 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 Shellfish Working Group concerning the proportion of catch in Statistical Area 030 which was 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). The estimated commercial catches for PAU 5D are the same under the three assumptions. Kendrick & Andrew (2000) also considered an alternative catch split of 67% to 33% between PAU 5B and PAU 5D for Statistical Area 025 from 1983–84 and 1995–96. This alternative catch split was not used because it made only minor changes to the catch estimates. The fishery in PAU 5D was estimated to be below 40% of virgin biomass in the most recent assessment (Fu 2013), and fishers decided to shelve 20% of the current TACC of 89 t in 2014–15 and 30% in 2015–16. For this assessment we assume that the 2016 commercial catch was 70% of the TACC.

Table 4: Collated commercial catch histories (kg) for PAU 5A, 5B, and 5D for fishing years 1974–2016 under assumptions 1, 2, and 3 of the proportion of Statistical Area 030 catch to come from PAU 5A. The estimated commercial catches for PAU 5D are the same under all assumptions.

			Assumption 1 (18%)		Assumption 2 (40%)		Assumption 3 (61%)	
Year	PAU 5	PAU 5D	PAU 5A	PAU 5B	PAU 5A	PAU 5B	PAU 5A	PAU 5B
1974	212 670	53 168	48 914	110 588	48 914	110 588	48 914	110 588
1975	201 180	50 295	46 271	104 614	46 271	104 614	46 271	104 614
1976	160 110	40 028	36 825	83 257	36 825	83 257	36 825	83 257
1977	221 400	55 350	50 922	115 128	50 922	115 128	50 922	115 128
1978	333 460	83 365	76 696	173 399	76 696	173 399	76 696	173 399
1979	349 960	87 490	80 491	181 979	80 491	181 979	80 491	181 979
1980	433 100	108 275	99 613	225 212	99 613	225 212	99 613	225 212
1981	524 340	131 085	120 598	272 657	120 598	272 657	120 598	272 657
1982	346 560	86 640	79 709	180 211	79 709	180 211	79 709	180 211
1983	442 980	110 745	101 885	230 350	101 885	230 350	101 885	230 350
1984	550 515	148 451	107 360	294 704	146 179	255 885	183 233	218 831
1985	352 459	81 749	46 409	224 301	70 894	199 816	94 266	176 444
1986	331 697	65 240	50 646	215 811	69 949	196 508	88 374	178 083
1987	418 904	141 578	25 826	251 501	36 893	240 433	47 458	229 869
1988	458 239	93 068	37 310	327 861	56 492	308 679	74 803	290 369
1989	445 978	95 791	118 393	231 793	152 824	197 362	185 690	164 497
1990	468 647	140 170	74 372	254 105	106 101	222 376	136 388	192 089
1991	510 335	142 845	124 440	243 050	156 661	210 829	187 417	180 073
1992	483 037	128 904	100 107	254 026	133 056	221 077	164 507	189 626
1993	435 395	162 773	50 724	221 898	81 292	191 330	110 471	162 151
1994	440 144	148 878	57 733	233 533	86 016	205 249	113 015	178 251
1995	434 708	137 591	65 767	231 350	96 510	200 607	125 856	171 261
1996	429 959	146 772	138 526	144 661	138 526	144 661	138 526	144 661
1997	433 195	146 990	143 848	142 357	143 848	142 357	143 848	142 357
1998	439 279	148 718	145 224	145 337	145 224	145 337	145 224	145 337
1999	444 638	148 697	147 394	148 547	147 394	148 547	147 394	148 547
2000	409 878	147 897	143 913	118 068	143 913	118 068	143 913	118 068
2001	386 949	148 813	148 221	89 915	148 221	89 915	148 221	89 915
2002	387 238	148 740	148 535	89 963	148 535	89 963	148 535	89 963
2003	350 320	111 693	148 764	89 863	148 764	89 863	148 764	89 863
2004	327 008	88 024	148 980	90 004	148 980	90 004	148 980	90 004
2005	327 739	88 817	148 952	89 970	148 952	89 970	148 952	89 970
2006	328 320	88 931	148 922	90 467	148 922	90 467	148 922	90 467
2007	282 163	88 973	104 034	89 156	104 034	89 156	104 034	89 156
2008	284 315	88 978	105 132	90 205	105 132	90 205	105 132	90 205
2009	283 591	88 770	104 823	89 998	104 823	89 998	104 823	89 998
2010	285 420	89 450	105 740	90 230	105 740	90 230	105 740	90 230
2011	282 770	88 700	104 400	89 670	104 400	89 670	104 400	89 670
2012	285 053	89 230	106 234	89 589	106 234	89 589	106 234	89 589
2013	284 049	87 914	105 560	90 575	105 560	90 575	105 560	90 575
2014	275 731	84 592	102 298	88 841	102 298	88 841	102 298	88 841
2015	268 270	71 870	106 950	89 450	106 950	89 450	106 950	89 450
2016	194 720	54 624	78 316	61 780	78 316	61 780	78 316	61 780

3.2 Recreational catch

The 1996 and 1999–2000 National Recreational Fishing Surveys estimated that 37.1 t and 53.2 t were taken from PAU 5 by recreational fisheries, but with no substock breakdown. However the Marine Recreational Fisheries Technical Working Group considered that some harvest estimates from the 1999–2000 and 2002–01 surveys for some fish stocks were unbelievably high.

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, a specialist in large-scale social surveys, in close consultation with the 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 about 80 290 paua, or 22.45 t (CV of 30%) were harvested by recreational fishers in PAU 5D in 2011–12. However, it was suggested that much of the catch was likely to have been taken in areas closed to commercial fishing. For the base case in the assessment, the SFWG agreed to assume that recreational catch was 2 t in 1974 and that it increased linearly to 10 t in 2005 and then remained at 10 t subsequently for the base case. As a sensitivity analysis, it was assumed that recreational catch increased linearly from zero in 1974 to 10 t by the mid-1990s then linearly increased to 20 t by 2012 where it remained until 2016.

3.3 Customary catch

Customary catch was incorporated into the PAU 5D TAC in 2002 as an allowance of 3 t. There are no published estimates of customary catch. Records of customary non-commercial catch taken under the South Island Regulations show that about 300 kg to 4500 kg of paua (Table 5) were reported to have been collected each year from 1998 to 2016 (assuming an average weight of 0.28 kg), with a marked increase after 2008. Overall the reported annual catch was under the annual allowances, with an average of 2 t per year between 2008 and 2016. The reported customary catch is substantially lower than the commercial harvest. For the purpose of the stock assessment model, the SFWG agreed to assume that the customary catch has been constant at 2 t for PAU 5D.

Table 5: Reported annual customary catch (in numbers) for PAU 5D under Te Runanga o Ngai Tahu. Weight (kg) is derived assuming an average weight of 0.28 kg.

Year	Quantity (number)	Weight (kg)
1998	1 119	313
1999	1 907	534
2000	3 127	876
2001	2 634	738
2002	2 747	769
2003	3 645	1 021
2004	3 161	885
2005	3 128	876
2006	2 240	627
2007	2 486	696
2008	5 442	1 524
2009	5 489	1 537
2010	9 834	2 754
2011	16 043	4 492
2012	3 459	969
2013	6 172	1 728
2014	5 358	1 500
2016	5 293	1 482

3.4 Illegal catch

There are no official published estimates of illegal catch. Some believe that annual illegal harvest in New Zealand is 200 to 300 t, about 20–30% of the commercial harvest (Chapman-Smith & Gasteiger 2015). For the purpose of the stock assessment model, the SFWG agreed to assume that illegal catches have been constant at 10 t for PAU 5D.

Estimated commercial catch history including commercial, customary, recreational, and illegal catch for the 1974–2016 fishing years is shown in Figure 4.

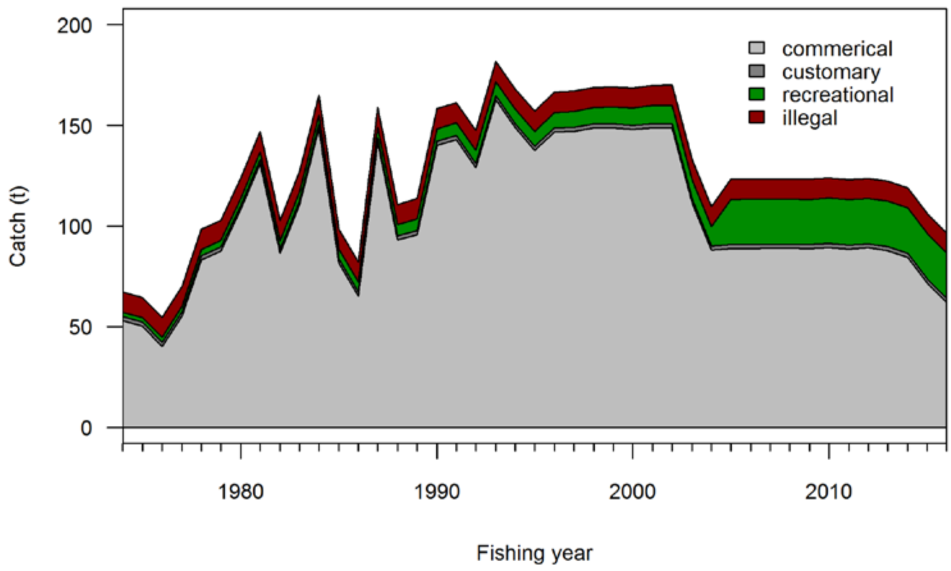


Figure 4: Estimated catch history including commercial, customary, recreational, and illegal catch 1974–2016 in PAU 5D.

4. CPUE STANDARDISATIONS

Three separate standardised CPUE series were calculated: (i) based on CELR data from 1990 to 2001, (ii) on PCELR data from 2002 to 2016, and (iii) using combined data from 1990 to 2016. The data set used, methods, and results are described in the following sections. For the CELR data some more detailed analyses were undertaken exploring the impact of potential changes in fishing duration, a predictor variable used for standardisations reported here, but not in the previous standardisations.

4.1 Initial data set

Catch effort data reported to the Catch and Effort Landing Return system capturing fishing events that either caught or targeted paua between 1 October 1990 and 30 June 2016 were requested from the Ministry for Primary Industries database “warehou” (extract 10697), including the CELR data until October 2001, and the PCELR data from the 2001–02 fishing year. The FSU data were also extracted from the NIWA-managed database for the period between January 1983 and September 1988 (extract. CL0088), but they were not used for the CPUE standardisation. The data for the 2016 fishing year are incomplete but they captured about 60% of quota and were therefore included in the standardisation. The data were groomed, using methods similar to those described 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 its assumed contribution to the catch. This allows most catch and effort from those areas to be retained in the standardisations but would introduce uncertainties in the process because different CPUE datasets are produced each time the analysis is repeated. In the 2010 assessment of PAU 5A (Fu et al. 2010), the SFWG decided not to include those randomly allocated records in the CPUE standardisations. For PAU 5D, about 7% and 25% of records from Statistical Areas 030 and 025 respectively were randomly allocated to PAU 5D before October 1995. These records generally accounted for only a small proportion of total annual catch and were not included in the standardisations that follow for the 2012 assessment (Figure 5). After the 1995 fishing year, the catch from Statistical Areas 025 and 030 are well determined, and in general, PAU 5D accounted for a small proportion of total catch in 025 and a much smaller proportion in 030 (Figure 5).

The estimated catches by fine-scale statistical areas from the years of PCELR data are shown in Figure 6. Catches were taken throughout the stock and were widely distributed in the South (P5DH01–10), Catlins (P5DH11–18), East (P5DH22–26), and North (P5DH41–47). There is very little evidence of serial depletion at the level of these fine-scale statistical areas since 2002. Overall between 2002 and 2012, the East, Middle, and Northern areas accounted for about 50% of the total catch in PAU 5D, with the remainder of the catch approximately equally taken from the south coast and Catlins (Table 6).

For the CELR data the total number of hours for all divers on a vessel should be recorded on a daily basis. Breen & Kim (2007) investigated this and found a linear relationship for up to three divers, but a flattening and decline for more divers (Figure 7). This was interpreted as an ambiguity in what the recorded hours represented in the data, where sometimes total hours had 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 7). More detailed analysis shows that most of the fishing duration records for PAU 5D are actually incorrectly recorded as hours per diver (see ahead in Section 4.7.1).

The recorded resolution for the estimated catch and fishing duration for the PCELR data is low. About 40% of the catch is recorded as multiples of 50 kg, and about 80% of recorded fishing durations are multiples of one hour (Figure 8). In about 50% of fishing events the estimated catch was split equally amongst the divers (Figure 8). But there appears to be no trend over time.

Table 6: Proportion of estimated catch from PCELR forms for fishing years 2002–2016 in each of the sub-areas (see Table 3) within PAU 5D.

Fishing year	South	Catlins	East	Middle	North	Total (t)
2002	0.27	0.20	0.17	0.05	0.3	141
2003	0.2	0.33	0.28	0.03	0.16	103
2004	0.26	0.27	0.19	0.05	0.24	84
2005	0.19	0.29	0.22	0.04	0.25	86
2006	0.26	0.20	0.18	0.05	0.31	89
2007	0.29	0.16	0.24	0.05	0.25	87
2008	0.19	0.18	0.29	0.05	0.31	87
2009	0.24	0.29	0.23	0.03	0.21	79
2010	0.2	0.29	0.25	0.03	0.23	88
2011	0.2	0.24	0.17	0.07	0.32	86
2012	0.22	0.23	0.23	0.07	0.25	88
2013	0.39	0.17	0.22	0.05	0.17	85
2014	0.3	0.22	0.19	0.04	0.26	81
2015	0.44	0.19	0.14	0.05	0.19	70
2016	0.34	0.22	0.22	0.03	0.2	49
Total	0.26	0.23	0.21	0.05	0.25	1306

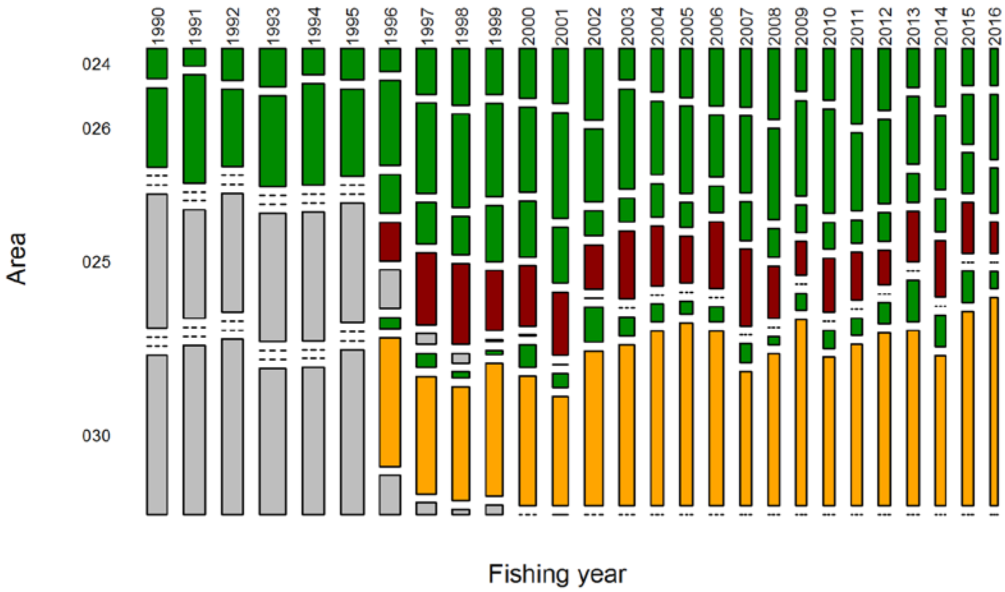


Figure 5: Proportion of reported catch by statistical area and fishing year on the CELRs and PCELRs, 1990–2016. Green represents catch from within PAU 5D; red represents catch from Statistical Area 025 outside PAU 5D; orange represents catch from Statistical Area 030 outside PAU 5D; grey represents catch from areas with substock undetermined. The width of the bar is proportional to the total annual catch.

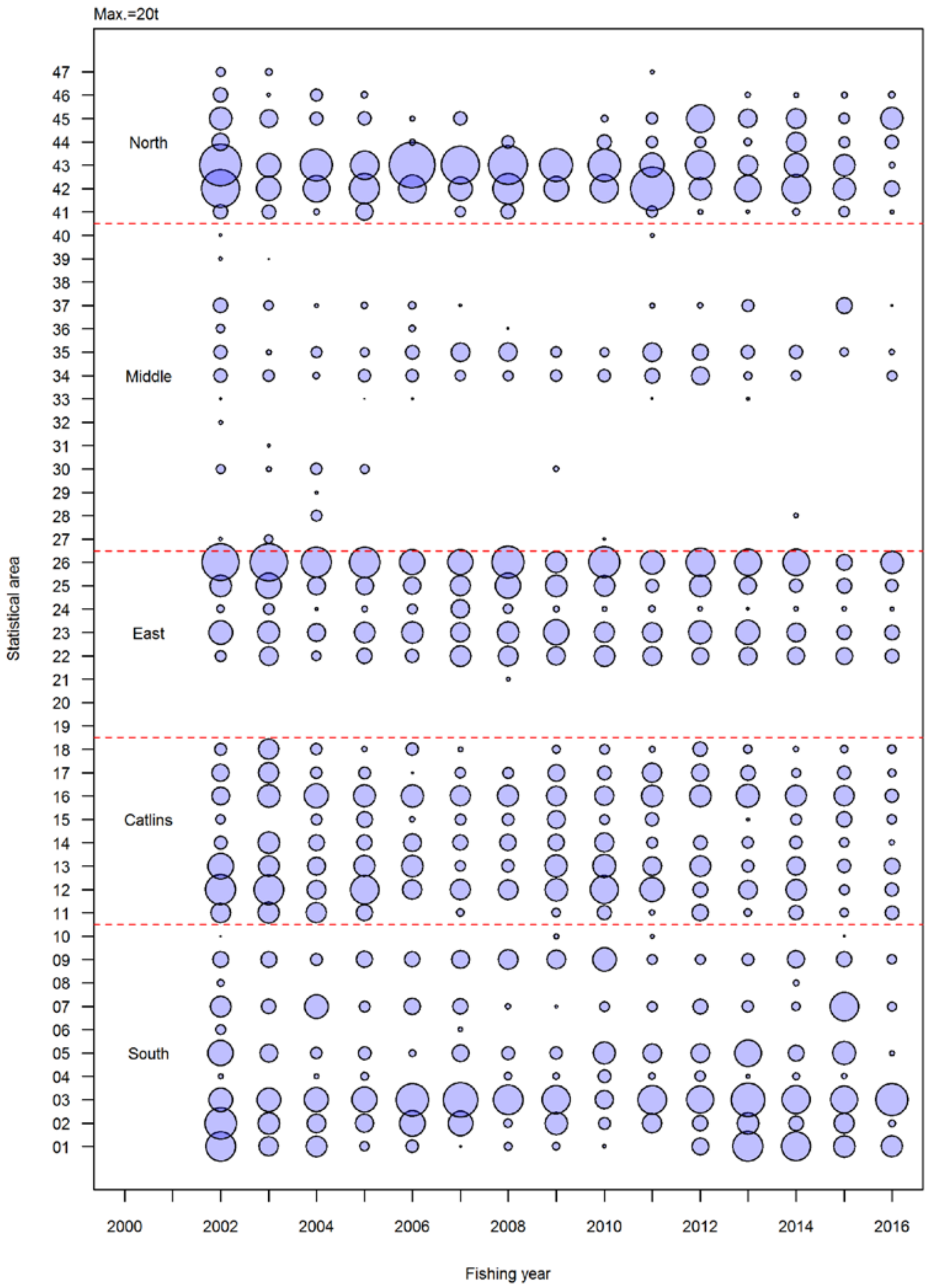


Figure 6: Annual estimated catch by Paua Statistical Area in PAU 5D for fishing years 2002–2016. The size of the circle is proportional to the catch.

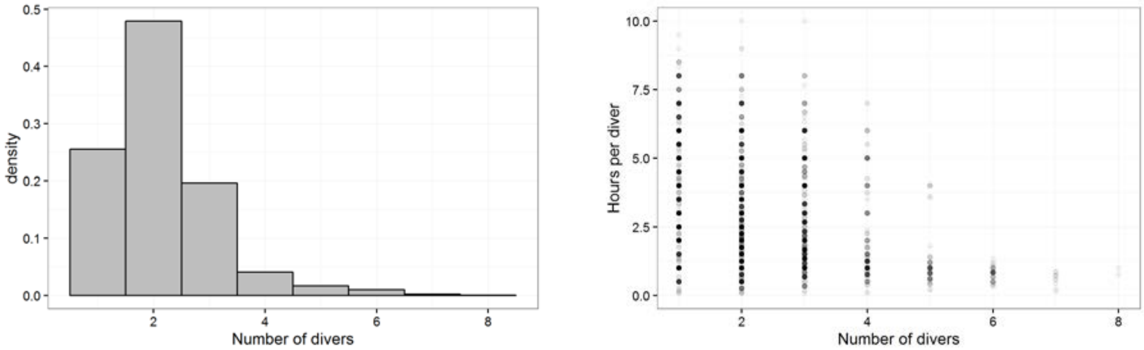
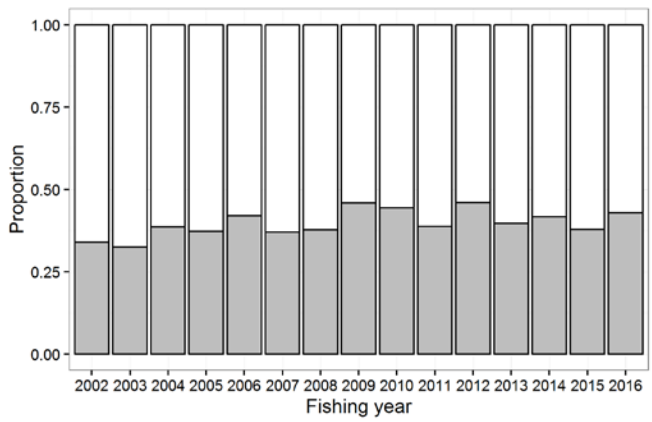
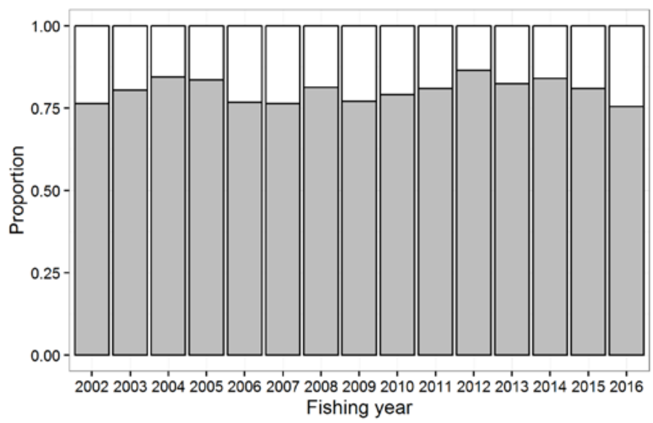


Figure 7: Distribution of the number of divers (left) and the calculated fishing hours per diver (right) on CELR forms within PAU 5D for fishing years 1990–2001 combined.

(a)



(b)



(c)

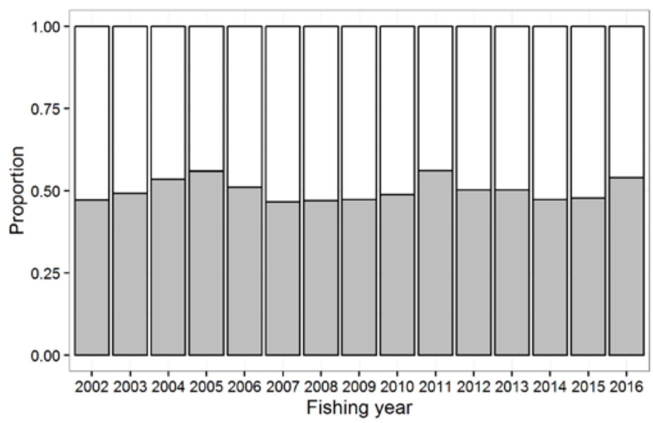


Figure 8: Diagnostic of data resolution on the PCELR forms within PAU 5D: (a) proportion of records that recorded estimated catch in a multiple of 50 kg; (b) proportion of records that recorded hours fished in an exact multiple of 1 hour; (c) proportion of fishing events where recorded estimated catch was equally split among divers.

4.2 Overview

Previous PAU 5D standardisations have included the Fisheries Statistics Unit (FSU) data which covers the fishing year period from 1983–1988. Because of problems with the FSU data the Shellfish Working Group decided not to use it in CPUE standardisations (see Section 4.5 below).

Data used in the standardisation included Catch Effort Landing Returns (CELR) covering 1990–2001, and Paua Catch Effort Landing Returns (PCELR) covering 2002–2016. It was decided by the Shellfish Working Group that duration (which changed over time), was a better measure of effort than the number of divers, and three standardisations were done:

1. CELR data (1990–2001)

2. PCELR data (2002–2016)

3. Combined CELR and PCELR data (1990–2016)

For the assessment base case, the CELR and PCELR indices were used, with the combined CELR and PCELR data index as a sensitivity run.

Before doing the three standardisations we first:

a) summarise previous standardisations;
b) outline CPUE standardisation recommendations from a review of paua stock assessments;
c) look at the usefulness of the FSU data; and
d) investigate serial depletion and data quality in the PCELR data.

4.3 Previous standardisations for PAU 5D

CPUE standardisations for PAU 5D were last done for the 2012 assessment (Fu et al. 2013). Four decisions made by the working group for the standardisations were:

1. Not to randomly allocate catch-effort records from Statistical Areas 025 and 030 which overlap with PAU 5D, 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 from 1990 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 the CELR data covering 1990 to 2001 the unit of effort was diver-day (so CPUE was daily catch divided by the number of divers for the day). A subset of data for which the fishing duration was less ambiguous was used to investigate changes in fishing duration over time (there was some change) and an alternative standardised CPUE.

For the PCELR data covering 2002 onward fishing duration was offered and accepted by the standardisation model.

Recent CELR data standardisations differ from the last standardisation for PAU 5D in that the fishing duration field is used (Fu et al. 2015; Fu et al. 2016). In these standardisations the data were filtered to give a data set for which the recorded duration was less ambiguous. Both recorded duration and number of divers were offered to the standardisations (instead of using only the number of divers as the measure of effort). For the current standardisation, the Shellfish Working Group decided, after investigation of the fishing duration field data, to offer only fishing duration to the standardisation.

4.4 Recommendations from the paua stock assessment model review

In March 2015 an expert panel reviewed the New Zealand paua stock assessment models and associated data collection programmes (Butterworth et al. 2015). Recommendation twenty one from the review concerned paua CPUE standardisations (see Appendix A for details). In summary, it states that as assessments are more likely to be sensitive to CPUE indices than other data, alternative CPUE series should be developed to test in model sensitivity runs. Recent paua CPUE standardisations have used two indices based on different data sources: FSU/CELR and PCELR. Possible alternative CPUE series suggested were:

- Combining all data to give a single index.
- For CELR data, standardising by diver day instead of diver hours (in recent standardisations both have been offered to the standardisation model, but only diver hours has been selected).

Furthermore, it was felt that if a CELR data subset was required for which fishing duration was thought to be reliably recorded, this subset should only use records for which there was one diver associated with a vessel. It was felt that any other subsetting would introduce bias into the catch rates.

With regard to the PAU 5D assessment and these recommendations, it was decided by the Shellfish Working Group to use a combined CELR/PCELR index covering 1990–2016 as a sensitivity run in the assessment. For the CELR data it was clear that most records had fishing duration consistently and reliably recorded, albeit incorrectly, so there was no need to subset the data (see below in Section 4.7.1).

4.5 Usefulness of FSU data

The FSU catch-effort data covers the period 1983 to 1988 for a total of 969 records (Table 7). Records are removed that are missing fields required for standardisations (Table 8). The vessel key is not recorded for many records in 1983–1984. Grooming retains 69% of the records over all years (Table 9).

Table 7: Number of FSU records by fishing year before any grooming.

Fishing year	1983	1984	1985	1986	1987	1988
Number of records	254	485	121	40	54	15

Table 8: Number of FSU records removed 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	100	96	0	0	0	0	196
Duration missing	10	16	2	6	4	0	38
Number divers missing	0	0	0	0	0	0	0
Method not diving	25	17	28	0	0	0	70

Table 9: Number of FSU records left before and after grooming.

Fishing year	1983	1984	1985	1986	1987	1988	Total
Before	254	485	121	40	54	15	969
After	119	356	91	34	50	15	665
Percent remaining	47	73	75	85	93	100	69

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

1. A high proportion of missing values for the vessel field.
2. Ambiguity and inaccuracies in what is recorded for the important fishing duration field, and
3. Low coverage of the annual catch.

As already noted, the vessel key is not recorded for many records in 1983–1984 (Table 8). For FSU data the fishing duration field is the daily fishing duration per diver (Fisher & Sanders 2011, p. 106 and p. 149). In earlier analyses problems were found with this field in that values were recorded that were ten times the likely values (Kendrick & Andrew 2000). But these appear to have mostly been fixed with the majority of values less than 10 hours duration, although the correction process is undocumented (Figure 9).

Records with duration greater than 10 hours account for 1% of the groomed data, and always have more than one diver, and are in 1986–1987. Dropping these records and plotting the fishing duration indicates that it increases over time (Figures 10–11). Consequently, the raw CPUE using fishing duration as the measure of effort is flatter than if day is the measure of effort (Figure 12).

The proportion of estimated annual catch covered by the FSU data, while reasonable for the three years 1983–85 declines rapidly after that (denoted by the white bars in Figure 13). The concern is that if this data were used in a standardisation that the catch rates could be biased in some way, if the characteristics of the fishery changed between 1983–85 and the subsequent period. In the data there is a group of vessels that operated from 1983–85, but is less apparent after then, which coincides with when fishing duration was less (Figure 14).

In summary, the problems with the FSU data are that: (i) vessel key is missing for many records, (ii) the fishing duration field appears to have been corrected, but the correction process is undocumented, and (iii) the coverage of the catch is very low from 1986–1988. For these reasons it was recommended that the FSU data not be used in the standardisations, as was done after review by the Shellfish Working Group.

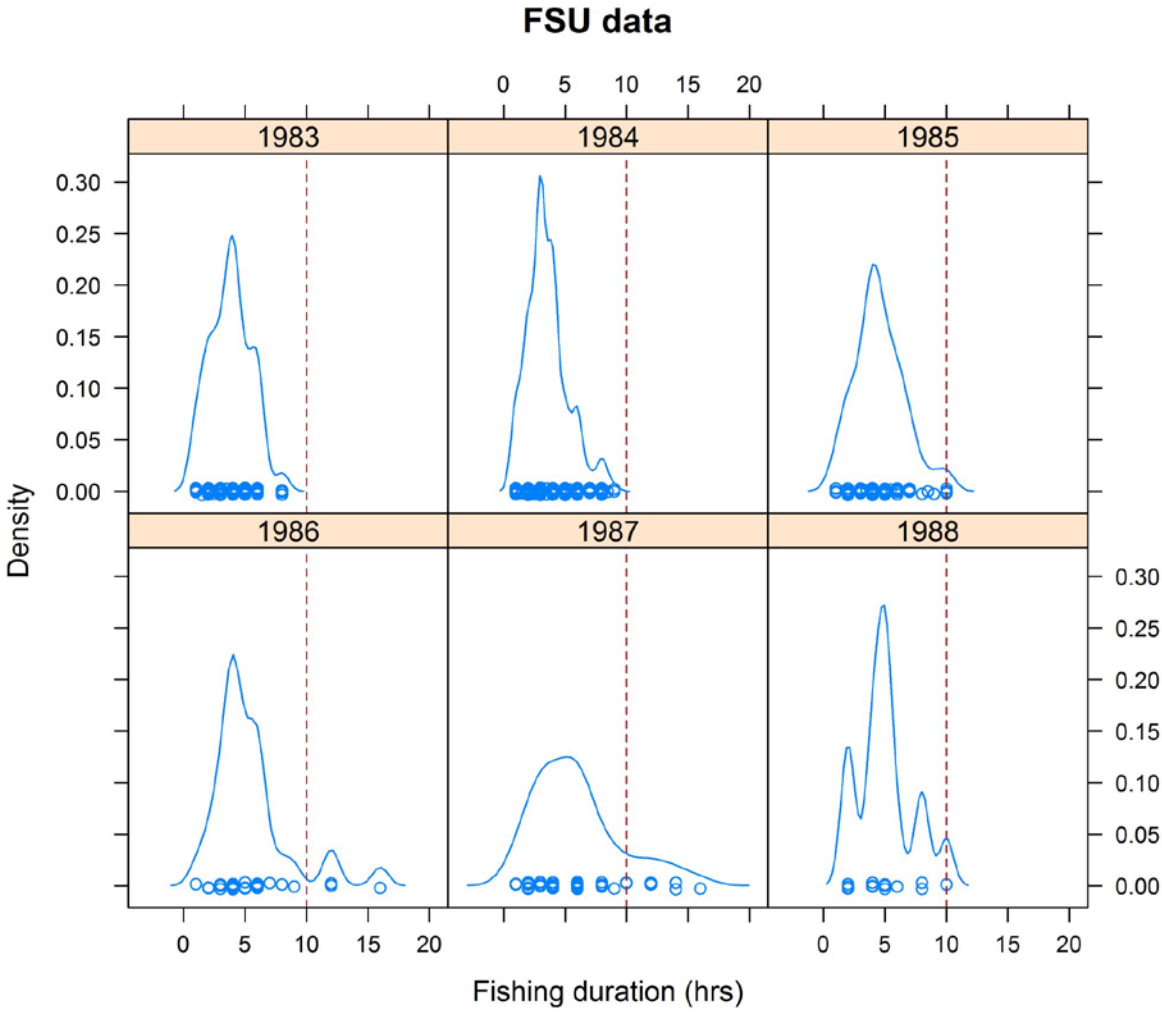


Figure 9: Density and strip plot for hours per diver. The vertical dashed reference line is at a fishing duration of 10 hours. The groomed data is used.

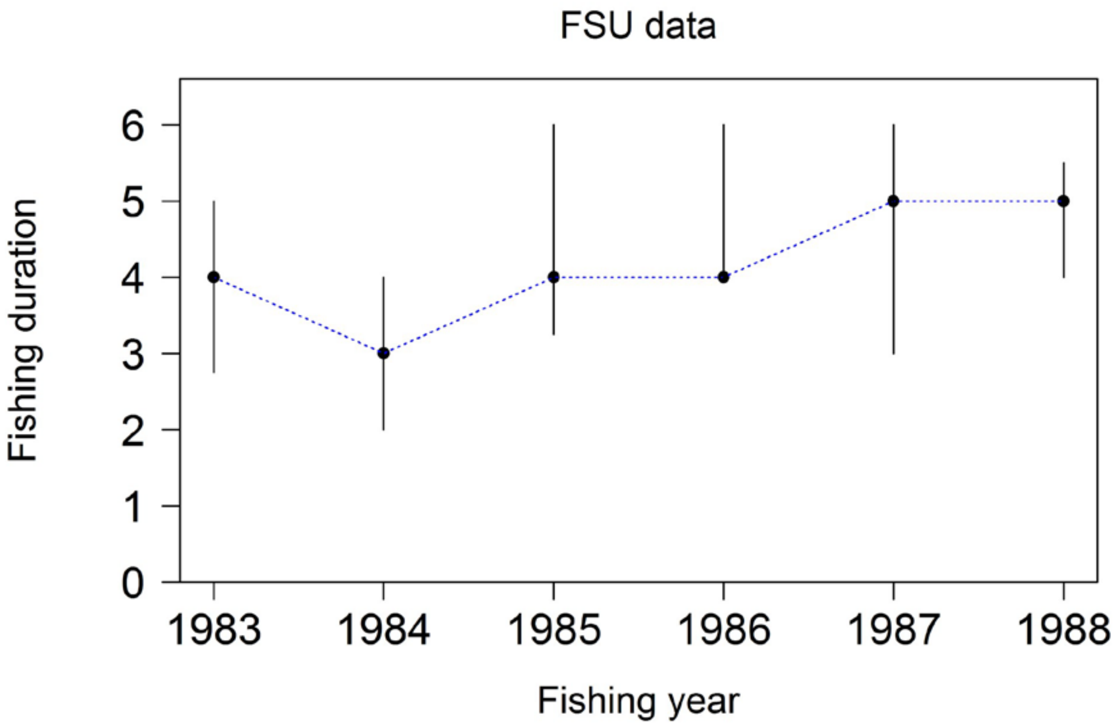


Figure 10: Quantiles by fishing year for the recorded daily fishing duration: medians (dot) and lower and upper quartiles (vertical lines). Records with a fishing duration greater than 10 hours are dropped.

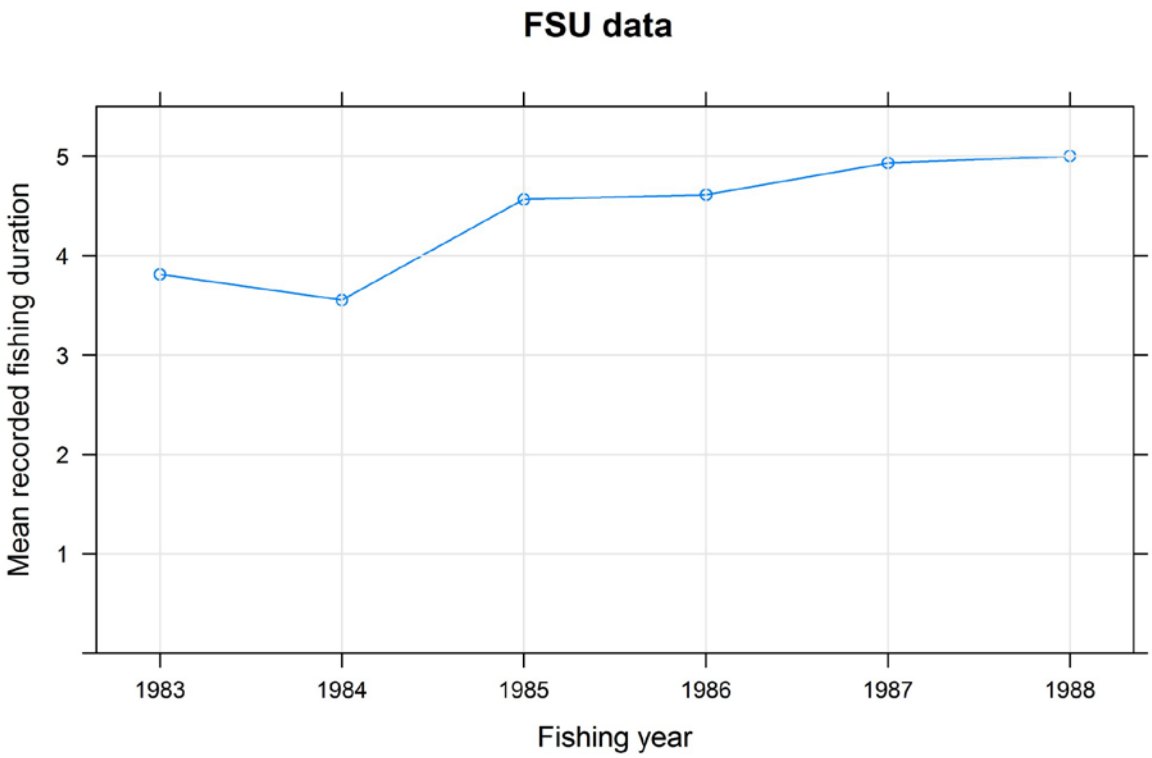


Figure 11: Mean values by fishing year for the daily fishing duration. Records with a fishing duration greater than 10 hours are dropped.

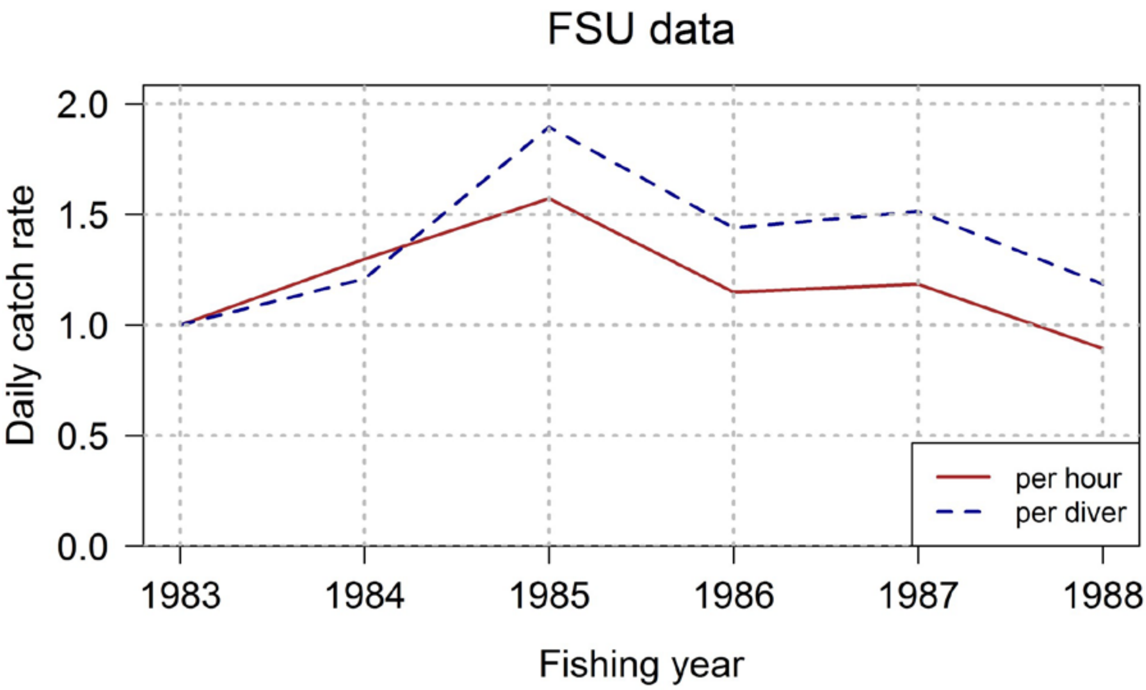


Figure 12: Geometric mean of the daily catch rate by year. The plots are scaled so that they both have the value one in 1983. Daily duration is calculated as the recorded fishing duration multiplied by the number of divers. Records with a fishing duration greater than 10 hours are dropped.

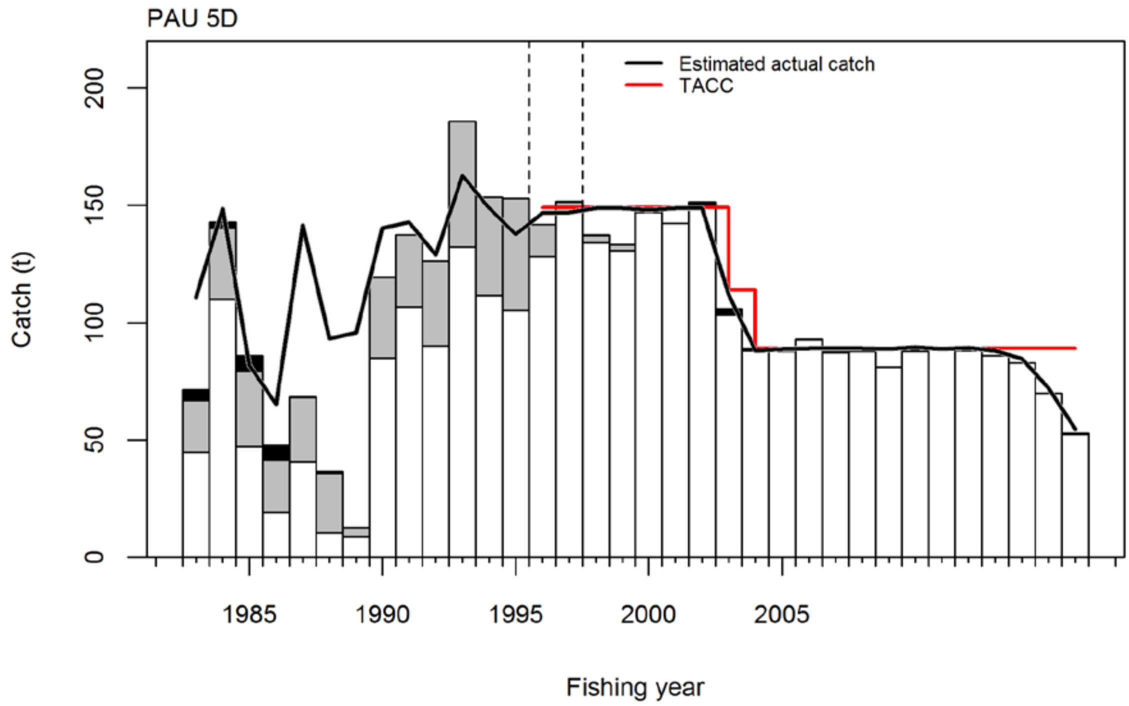


Figure 13: The estimated commercial catch history, TACC, and the FSU/CELR/PCELR catch (vertical bars) for fishing years 1983–2016 for PAU 5D. The black portion of the bar represents estimated catch removed through data grooming; grey represents the estimated catch from records reported to straddling Statistical Areas 025 and 030 but randomly allocated to PAU 5D.

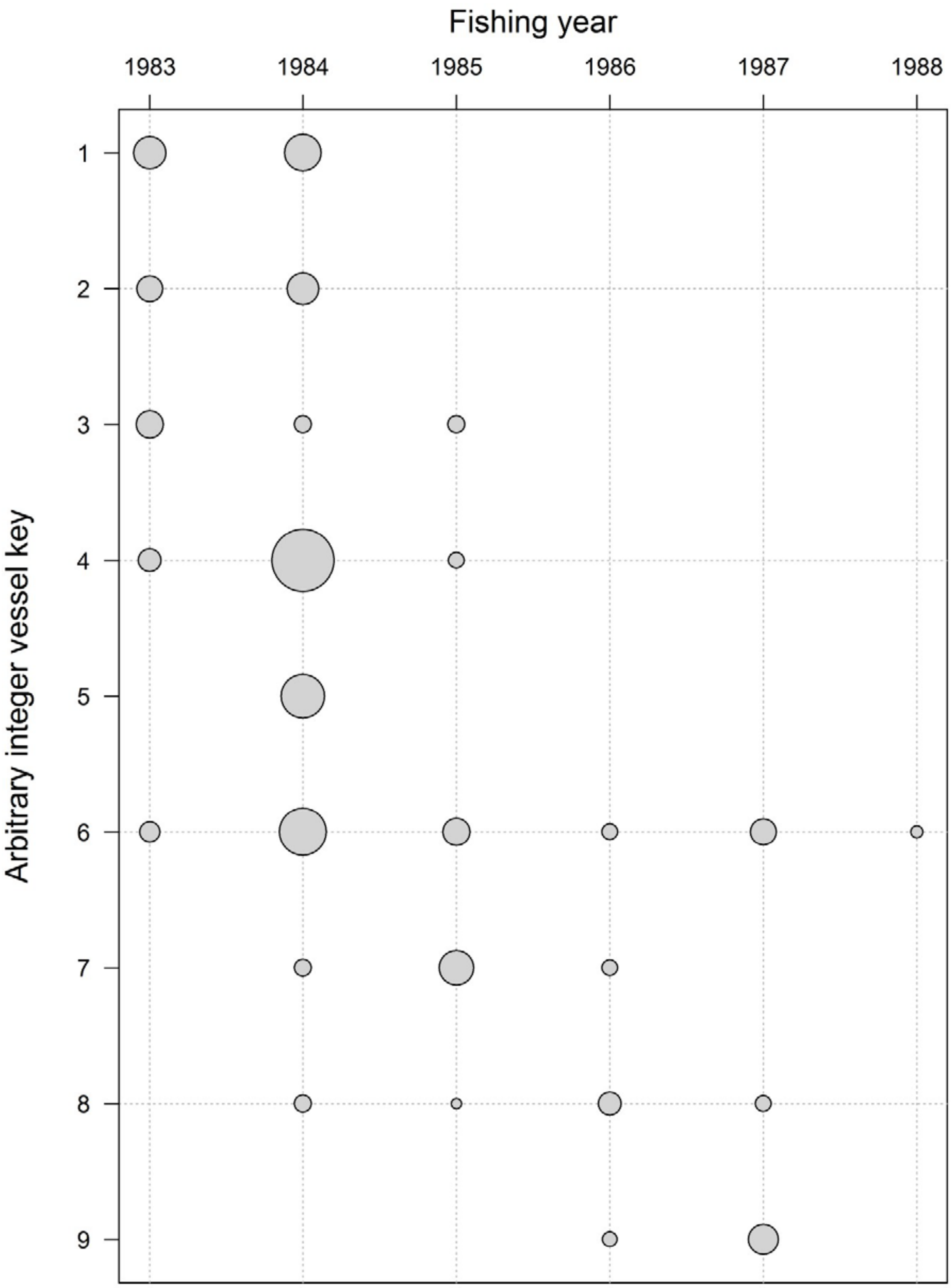


Figure 14: Number of records in the FSU dataset by vessel and fishing year, plotting only the vessels with at least 30 records. An arbitrary integer is used for the vessel key.

4.6 Serial depletion and data quality

There is little evidence for serial depletion over the past 15 years with no significant changes in the estimated catch distribution over this time period (Figure 15).

The recorded resolution for the estimated catch and fishing duration for the PCELR data is comparable to other areas and is low. About 40% of the catch is recorded as multiples of 50 kg, and about 75% of recorded fishing durations are multiples of one hour (Figure 16a,b). In about 50% of fishing events the estimated catch was split equally among the divers (Figure 16c).

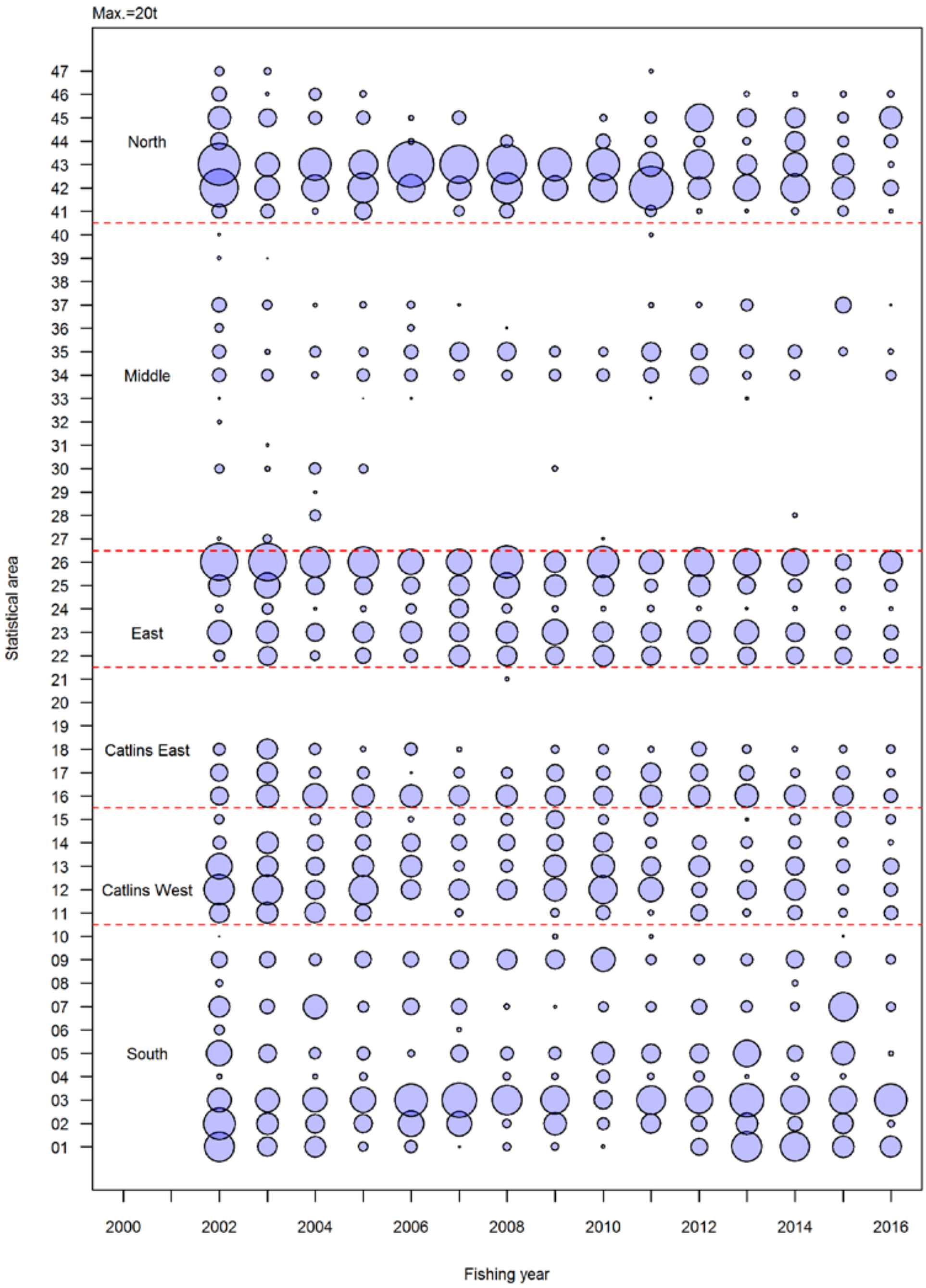


Figure 15: Annual estimated catch by Paua Statistical Area in PAU 5D for fishing years 2002–2016. The size of the circle is proportional to the catch.

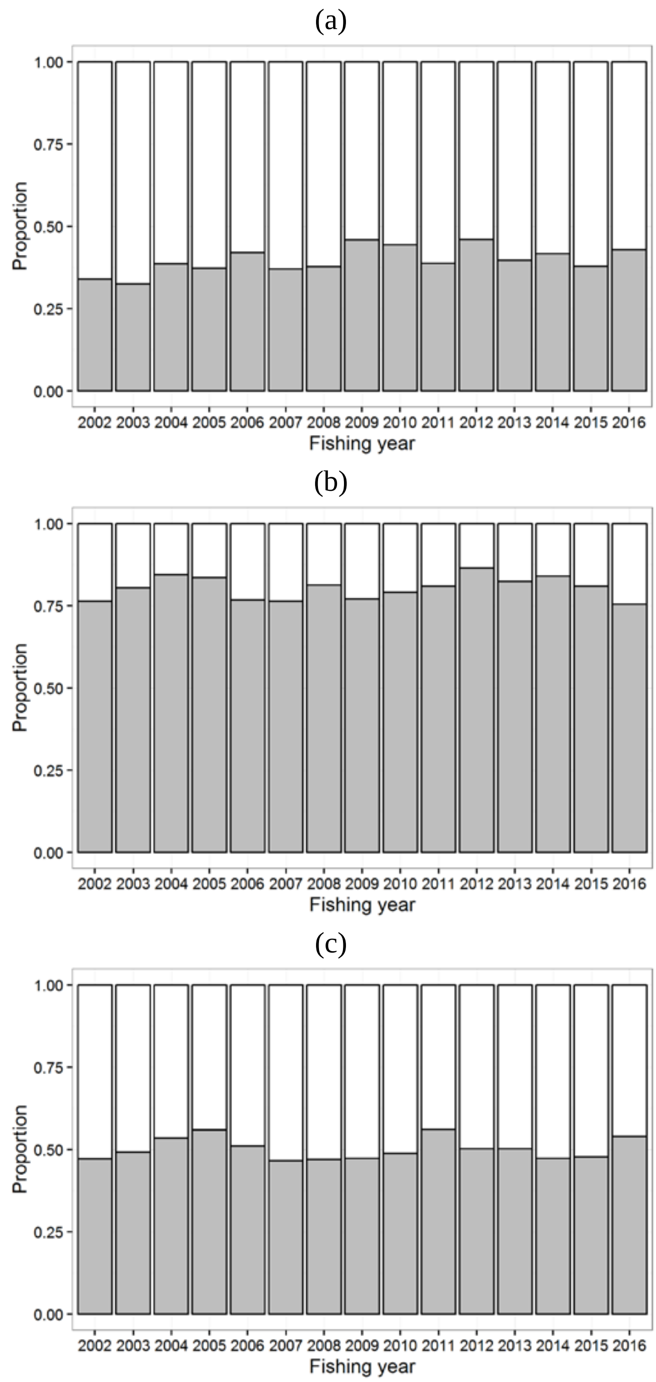


Figure 16: Diagnostic of data resolution on the PCELR forms within PAU 5D: (a) proportion of records that recorded estimated catch in a multiple of 50 kg; (b) proportion of records that recorded hours fished in an exact multiple of 1 hour; (c) proportion of fishing events where recorded estimated catch was equally split among divers.

4.7 CELR data (1990–2001)

4.7.1 The CELR data

The initial data set consisted of all CELR catch-effort records from PAU 5D. The Fisher Identification Number (FIN) and date were present for all records.

Some grooming of the catch-effort records was undertaken: records were only retained where paua was targeted by diving, and records with missing values for the estimated catch or number of divers were dropped (Table 10). This groomed data set has 4625 records (Table 11), and most records have fewer than four divers (Table 12).

For FSU data the fishing duration field is the daily fishing duration per diver (Fisher & Sanders 2011, p. 106 and p. 149). However, for the CELR data the fishing duration field contains the total fishing duration for all divers. It has been noted in some past analyses that there is ambiguity as to what is actually recorded for fishing duration for the CELR data, because a mixture of total hours and per diver hours is put down, possibly attributable to the transition from the FSU forms.

For most trips the number of divers is four or less (Figure 17). One possible sign that fishing duration is incorrectly recorded as per diver, would be a decrease in the hours per diver as the number of divers goes up. The hours per diver drops by 30% going from one to two divers (Figure 18). Another sign of incorrect recording for fishing duration would be a bimodal distribution for the fishing duration when there are two or more divers. What is seen is a prominent mode for which the position is unchanged as the number of divers goes up (Figure 19).

There is some ambiguity, but it looks as if for most records the fishing duration is recorded as hours per diver. To explore how the raw CPUE varies time over it is assumed that fishing duration is recorded as hours per diver, and records with a fishing duration greater than 10 are dropped (10% of the records). From 1990–2001 the hours per diver increases (Figures 20–21). A raw CPUE based on using duration as the measure of effort gives a decline slightly less than 30% from 1990–2001 (Figure 22).

One of the recommendations of the review, in order to reduce ambiguity in fishing duration, is to restrict records to just those with one diver. However, this restriction would result in the number of records in each year becoming very low, and the number would reduce by about another 75% when FIN subsetting for the standardisation was done (Table 13). Comparing the raw CPUE using one diver or all divers gives a comparable trend, despite the difference in the number of records (Figure 23).

Table 10: Number of CELR records removed by fishing year, where the order of grooming is from top to bottom.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Not targeting paua	0	0	0	0	0	0	0	0	0	1	0	1	2
Catch missing	0	0	0	0	1	0	1	0	2	2	0	0	6
Number divers missing	0	0	0	0	0	0	2	1	1	0	1	0	5
Method not diving	10	0	6	53	36	8	27	48	39	45	18	34	324

Table 11: Number of CELR records after grooming. Year 1990 is denoted "90" and 2001 as "01".

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
Number of records	292	277	340	393	347	323	436	463	476	344	500	434	4625

Table 12: Distribution of the number of divers in the CELR dataset after grooming.

Number of divers	1	2	3	4	5	6	7	8
Number of records	1170	2180	938	197	80	48	10	2

Table 13: Number of records in the CELR dataset after restricting to records with one diver. Year 1990 is denoted "90" and 2001 as "01".

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
Number of records	90	76	132	117	127	83	130	109	64	72	95	64	1159

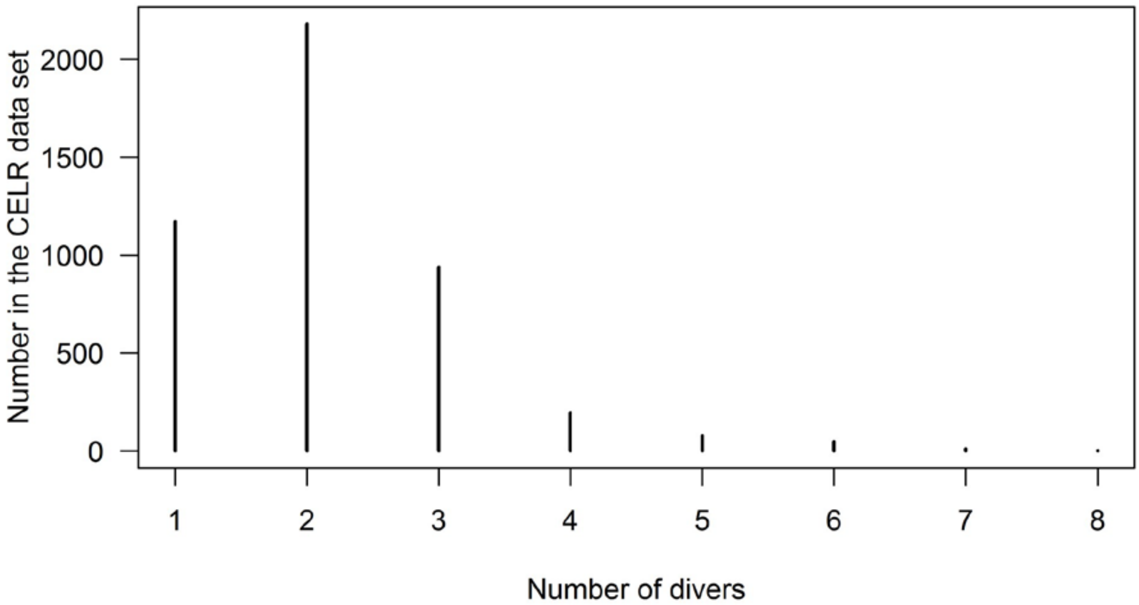


Figure 17: Distribution of the number of divers per record.

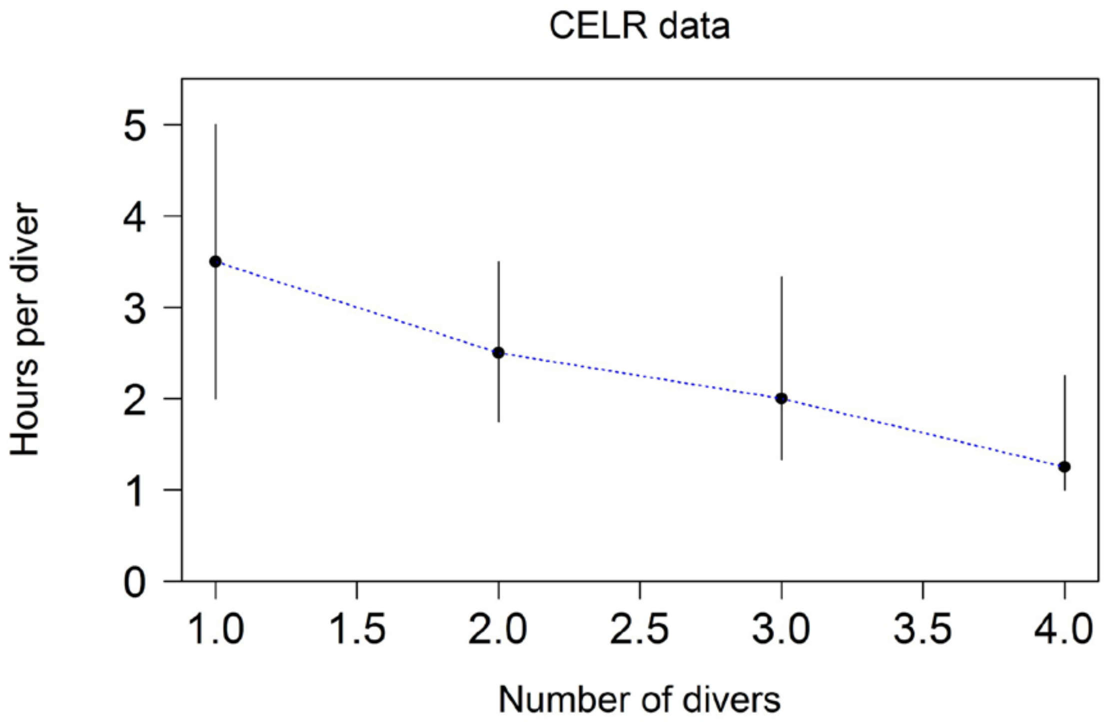


Figure 18: Quantiles by number of divers for the hours per diver: medians (dot) and lower and upper quartiles (vertical lines). The number of divers is restricted to four or less.

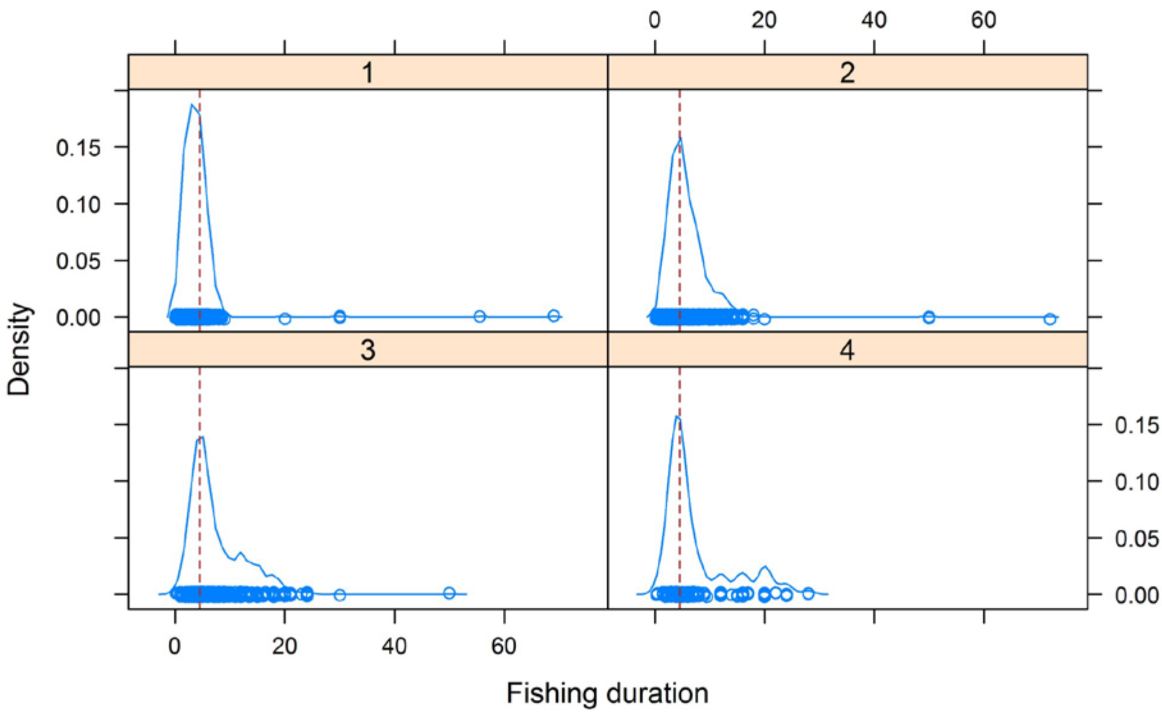


Figure 19: Density and strip plot for the recorded fishing duration in the CELR dataset, given the number of divers on a trip (restricted to four or less). The vertical dashed reference line is at a fishing duration of 4.5 hours.

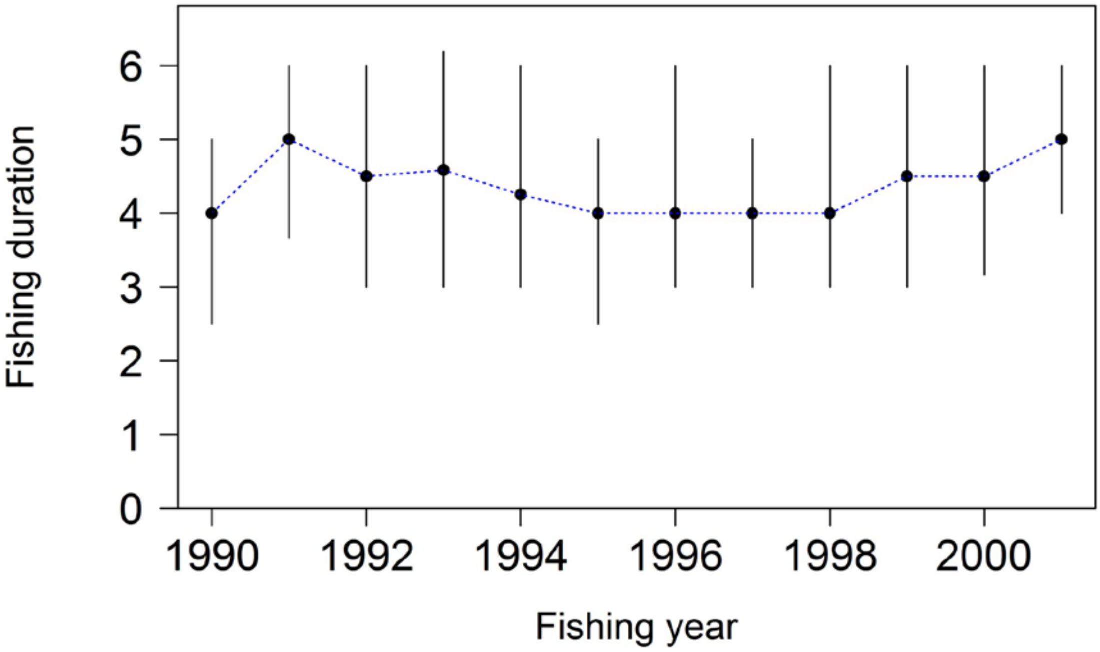


Figure 20: Quantiles by fishing year for the recorded daily fishing duration in the CELR dataset: medians (dot) and lower and upper quartiles (vertical lines). Records with a fishing duration greater than 10 hours are dropped.

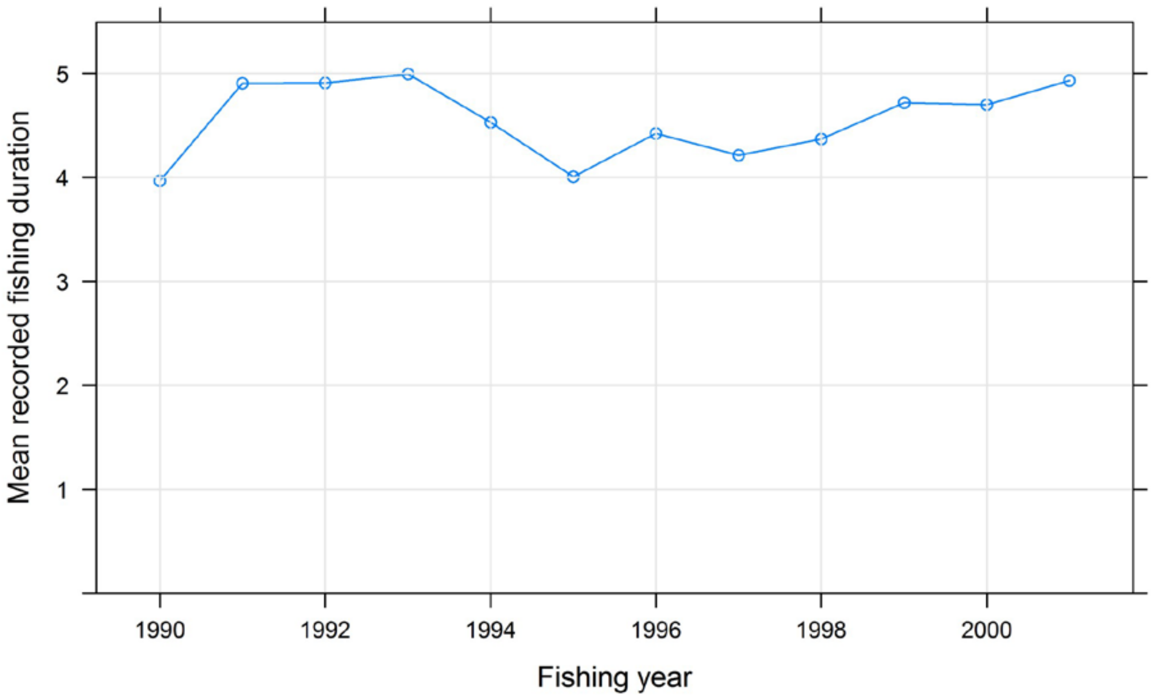


Figure 21: Mean values by fishing year for the daily fishing duration in the CELR dataset. Records with a fishing duration greater than 10 hours are dropped.

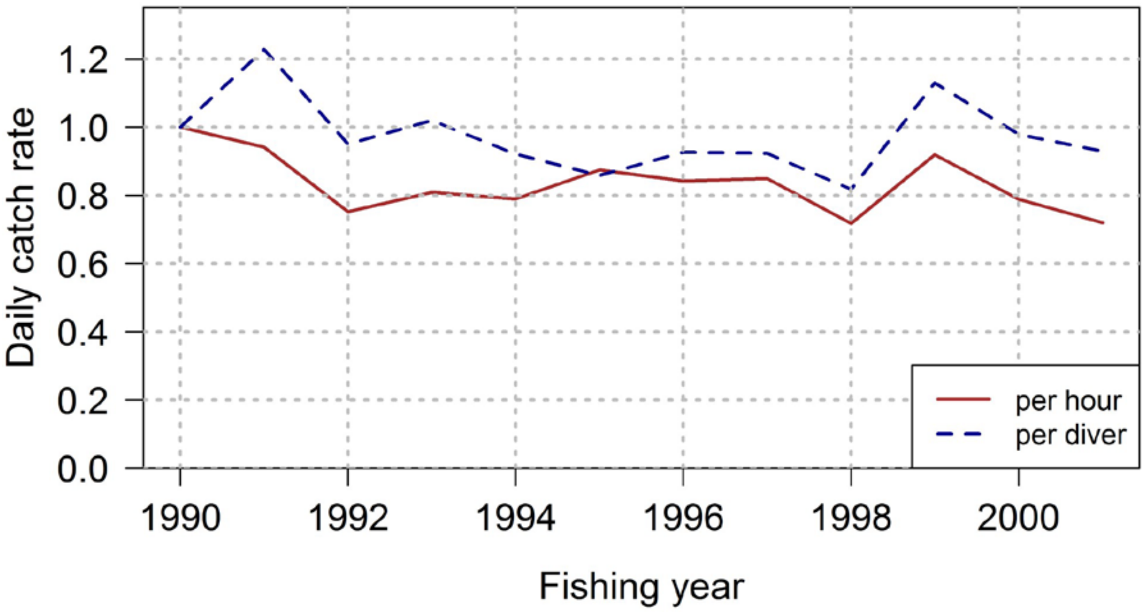


Figure 22: Geometric mean of the daily catch rate by year (CELR), using as the measure of effort either the number of divers for the day (per diver) or the daily fishing duration (per hour). The plots are scaled so that they both have the value one in 1990. Daily duration is calculated as the recorded fishing duration multiplied by the number of divers. Records with a fishing duration greater than 10 hours are dropped.

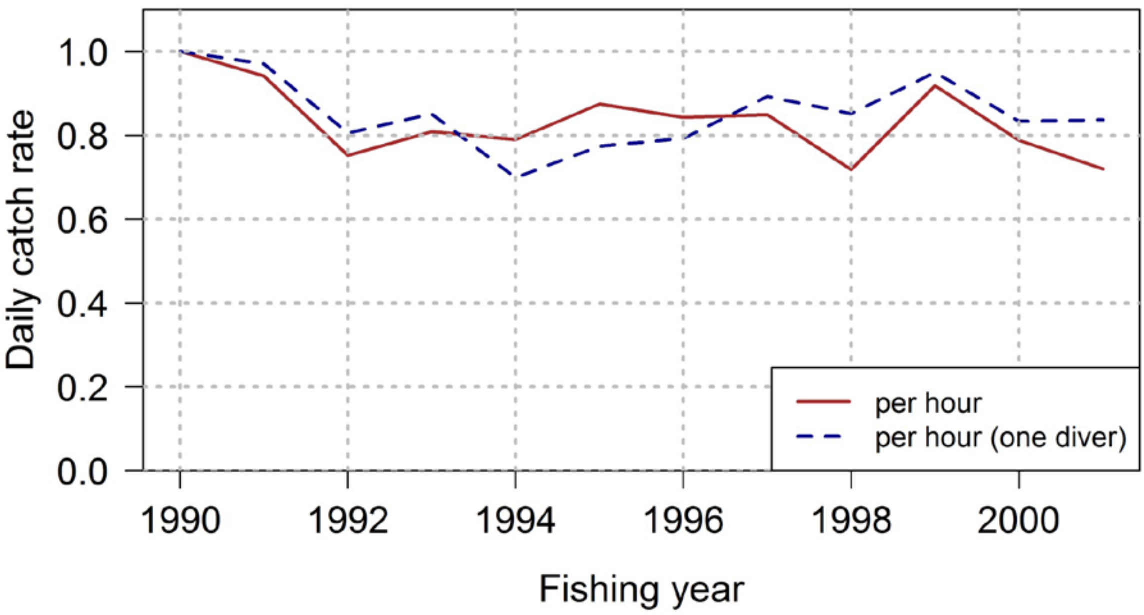


Figure 23: Geometric mean of the daily catch rate by year (CELR), using as the measure of effort the fishing effort duration. The daily catch rate for all divers ("per hour") is compared with the daily catch rate when there is only one diver ("per hour (one diver)"). The plots are scaled so that they both have the value one in 1990. Daily duration is calculated as the recorded fishing duration multiplied by the number of divers. Records with a fishing duration greater than 10 hours are dropped.

4.7.2 Standardised CELR

The initial data set used for the standardised CPUE consists of the CELR records remaining after removing records for which the recorded fishing duration (interpreted as hours per diver) is greater than 10 hours.

Fisher Identification Number is used to identify a core group of permit holders in the fishery, with the requirement that there be a minimum number of records per year for a permit holder, for a minimum number of years. The criteria of a minimum of 5 records per year for a minimum of 4 years was chosen, which retains a subset including 82% of the catch over the period 1990–2001 (Figure 24). While 82% of the catch is retained overall, slightly less than this is retained in some years (Figures 25–26). The number of days of effort retained after subsetting is 132 or more for every fishing year (Table 14, Figure 27). The number of FIN holders drops from 103 to 24 under the subsetting criteria.

There is good overlap in effort over time for the permit holders after subsetting (Figures 28–29). Similarly for overlap in time for area and month (Figures 30–31).

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, and total fishing duration (as a cubic polynomial). Total fishing duration is the recorded fishing duration multiplied by the number of divers for a record (recall that fishing duration is incorrectly recorded as the diving duration per diver).

The model explained 69% of the variability in CPUE with fishing duration (53%) explaining most of the variability followed by FIN (13%) (Table 15). The effects appear plausible and the model diagnostics good (Figures 32–33). There is an apparent increasing effect for the catch taken above a fishing duration of 50 hours, though for the majority of records fishing duration is less than 20 hours (Figure 34). The standardised index shows an irregular decline (Table 16, Figure 35).

Most of the catch for the CPUE data is from area 026 followed by 024, with more recorded in 025 from 1996 onwards (Table 17). There are insufficient records to do a reliable standardisation with a year:area interaction forced into the model, so instead raw CPUE is calculated for each area. This shows that 024 and 026 have a different trend in CPUE up to 1995, but indices for the area show similar patterns after this (Figure 36).

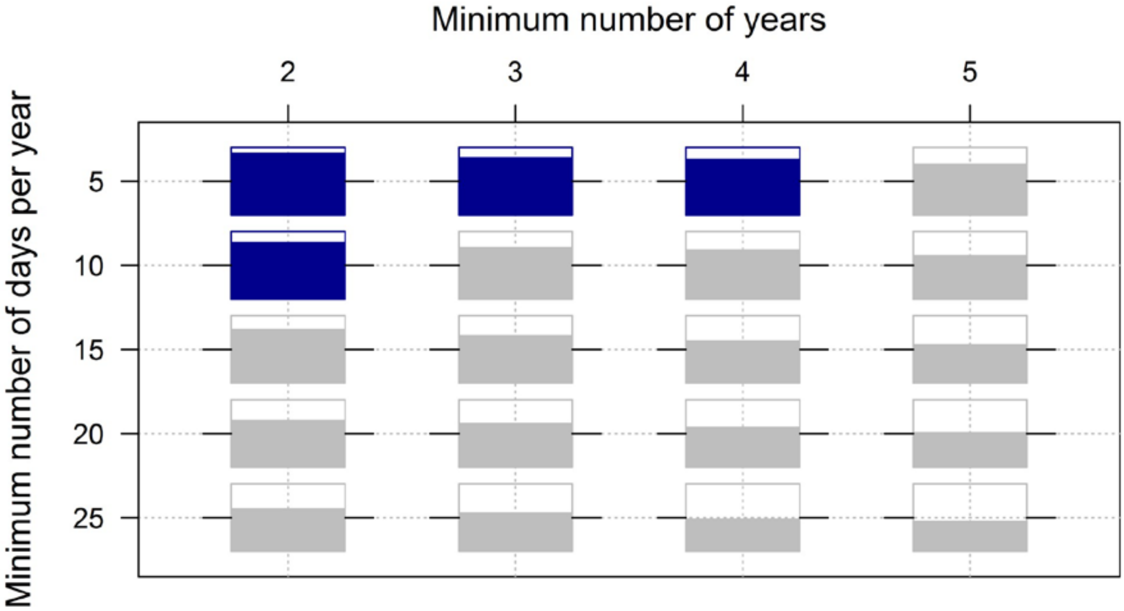


Figure 24: Proportion of the catch taken when subsetting the CELR dataset by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

Table 14: Number of records in the CELR dataset before and after FIN subsetting. Year 1990 is denoted "90" and 2001 as "01".

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
Before	274	265	311	356	308	270	381	399	437	322	447	391	4161
After	132	184	259	312	266	252	298	335	396	286	341	269	3330

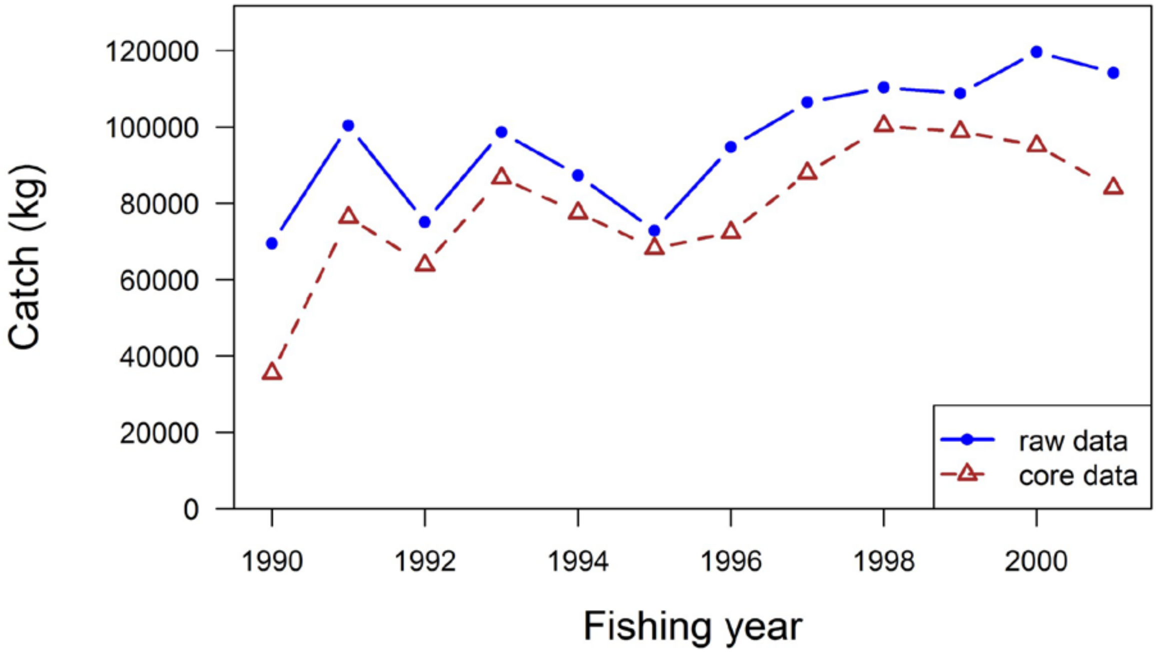


Figure 25: Catch by fishing year (CELR dataset) before FIN subsetting (raw data) and after (core data).

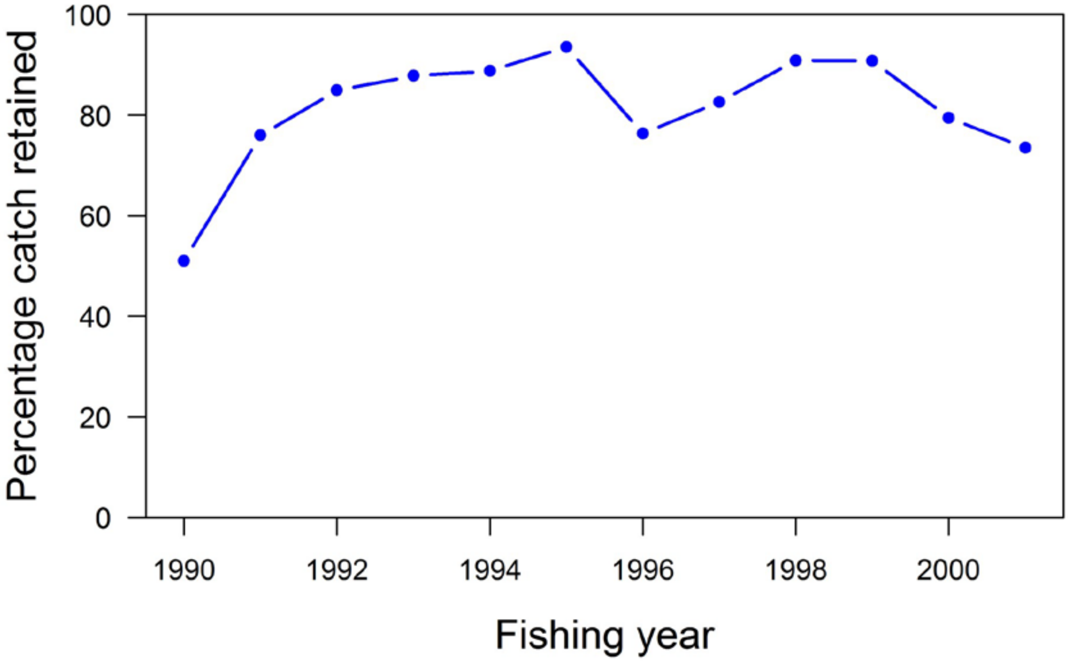


Figure 26: Percentage of the catch in the CELR dataset retained after FIN subsetting.

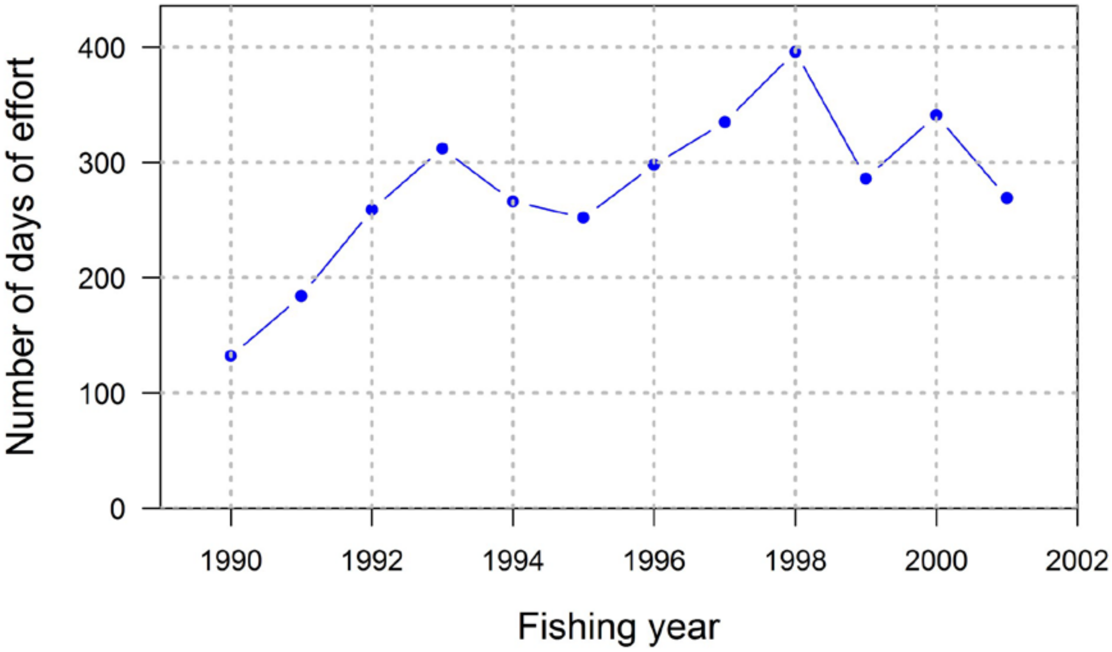


Figure 27: Number of days of effort in the CELR dataset retained after FIN subsetting.

Table 15: Variables accepted into the CELR standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fishing year	11	0.02
total fishing duration	3	0.55
client key	23	0.68
month	11	0.69

Table 16: Standardised CELR index, lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
1990	0.94	0.79	1.11	0.09
1991	1.17	1.01	1.36	0.08
1992	1.04	0.91	1.18	0.06
1993	1.11	0.99	1.25	0.06
1994	1.10	0.97	1.24	0.06
1995	1.11	0.98	1.25	0.06
1996	0.99	0.88	1.11	0.06
1997	0.92	0.83	1.03	0.06
1998	0.86	0.77	0.95	0.05
1999	1.07	0.95	1.20	0.06
2000	0.94	0.84	1.05	0.06
2001	0.83	0.74	0.94	0.06

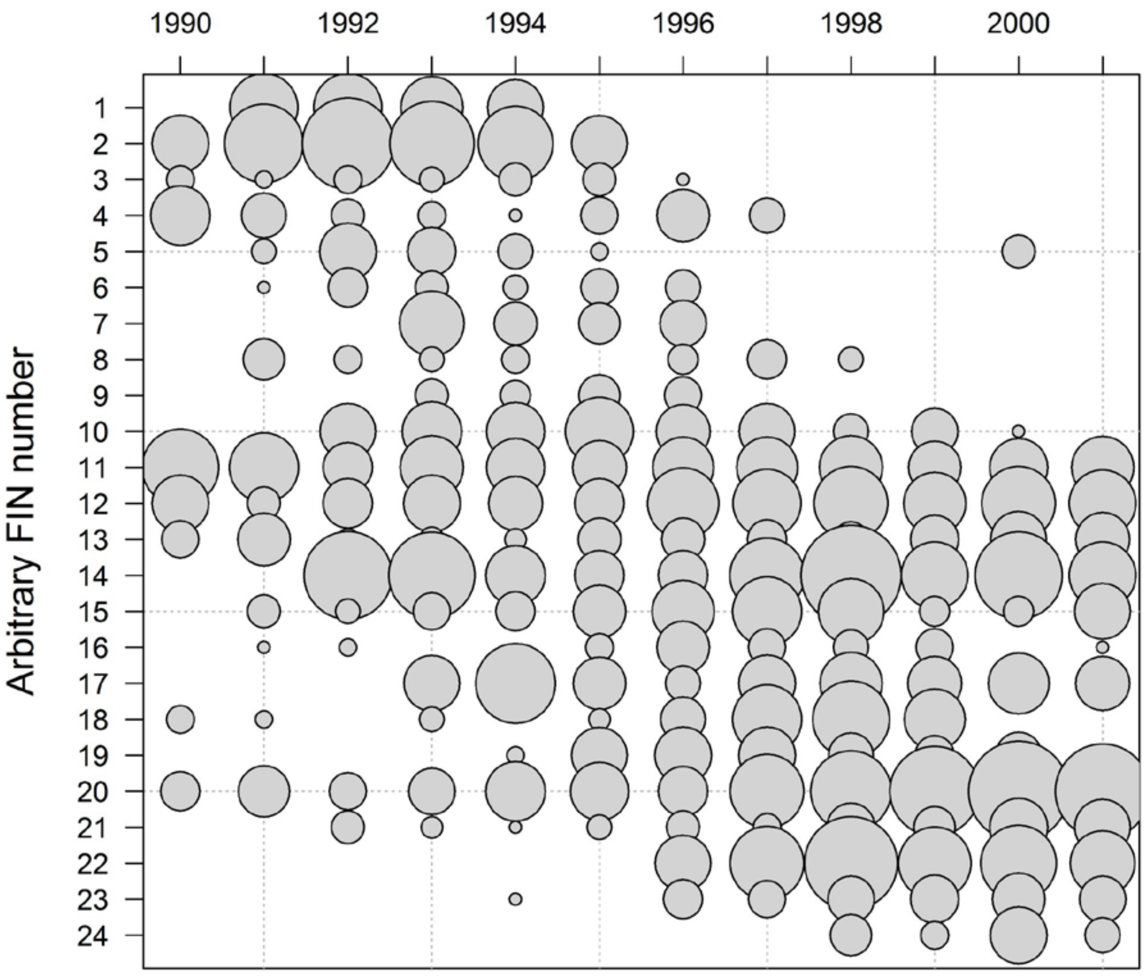


Figure 28: Days of effort in the CELR dataset by FIN and fishing year. The area of a circle is proportional to the days of effort.

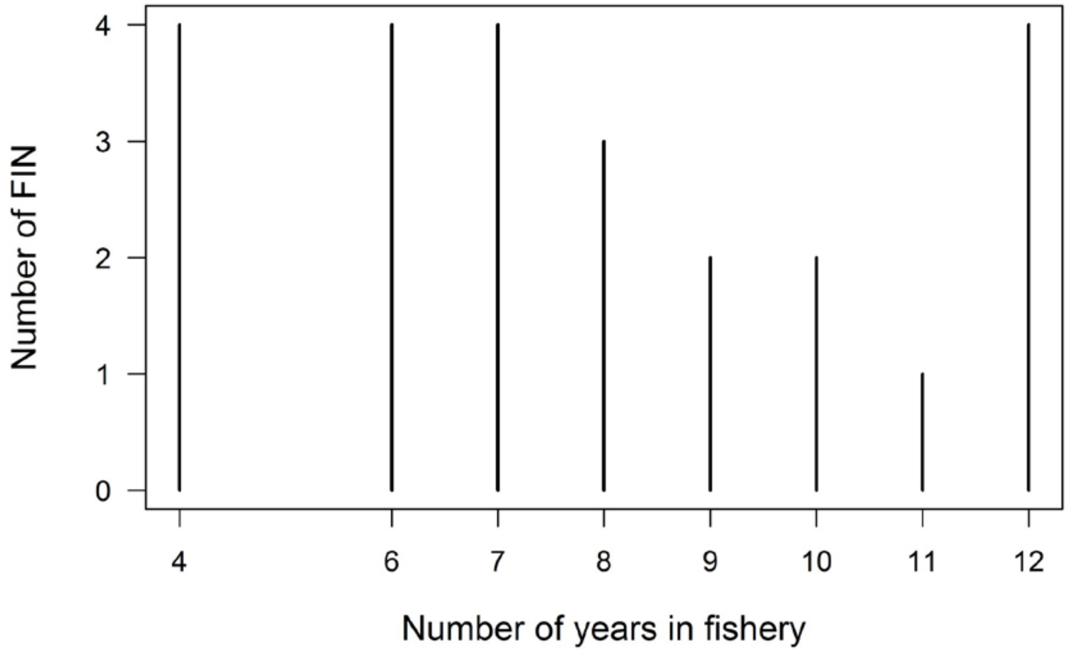


Figure 29: Number of years in the fishery for a permit holder in the CELR dataset after subsetting by FIN.

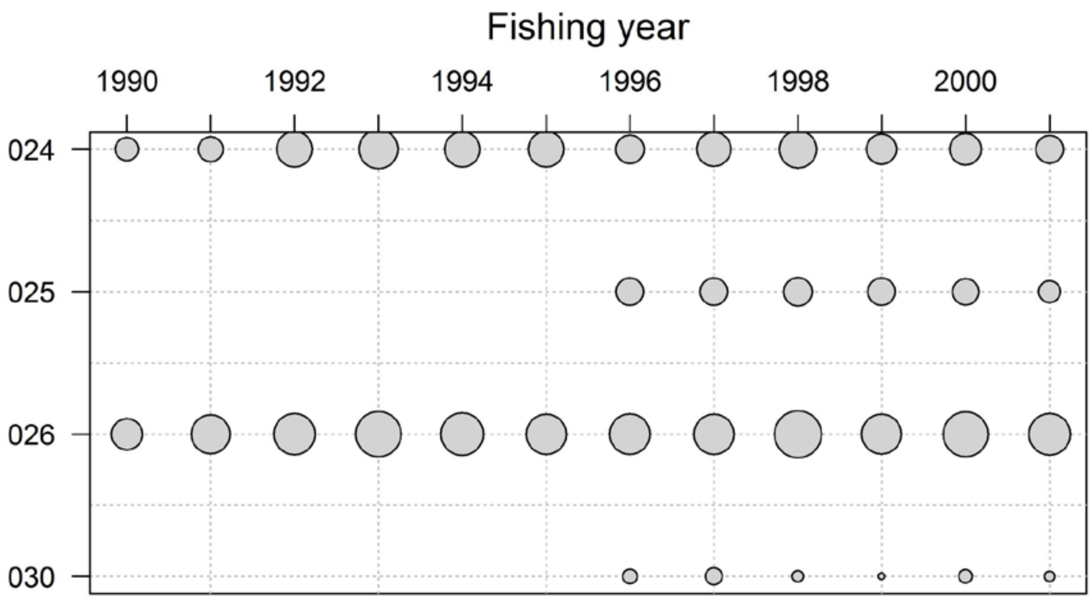


Figure 30: Days of effort in the CELR dataset by area and fishing year.

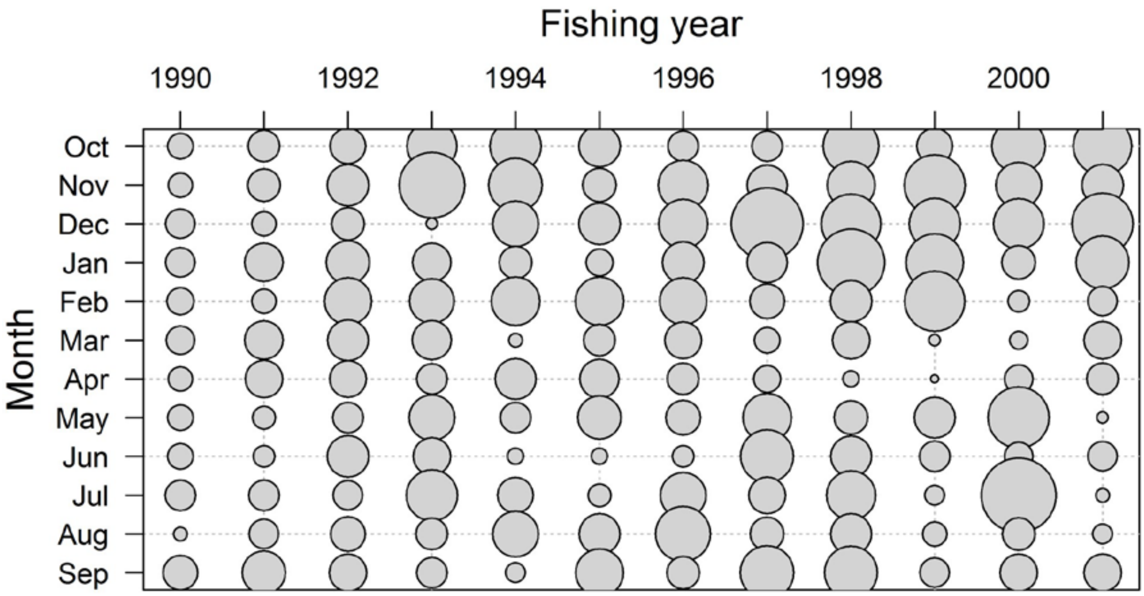


Figure 31: Days of effort in the CELR dataset by month and fishing year.

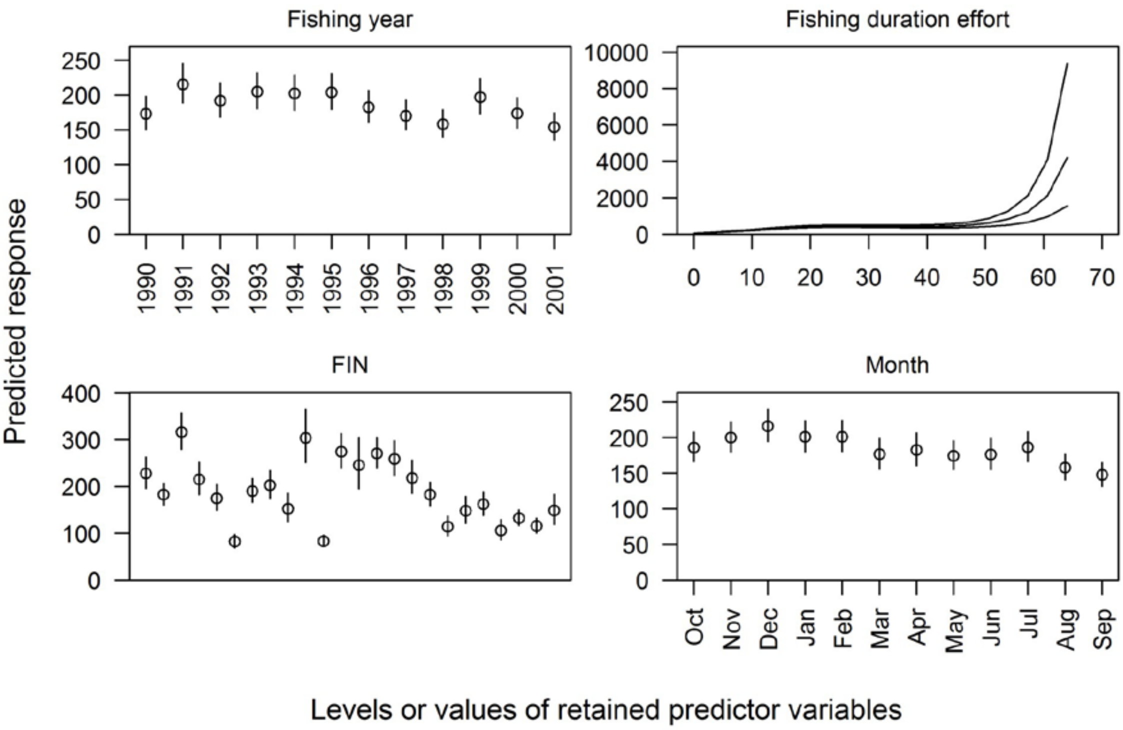


Figure 32: Effects catch rates from the CELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

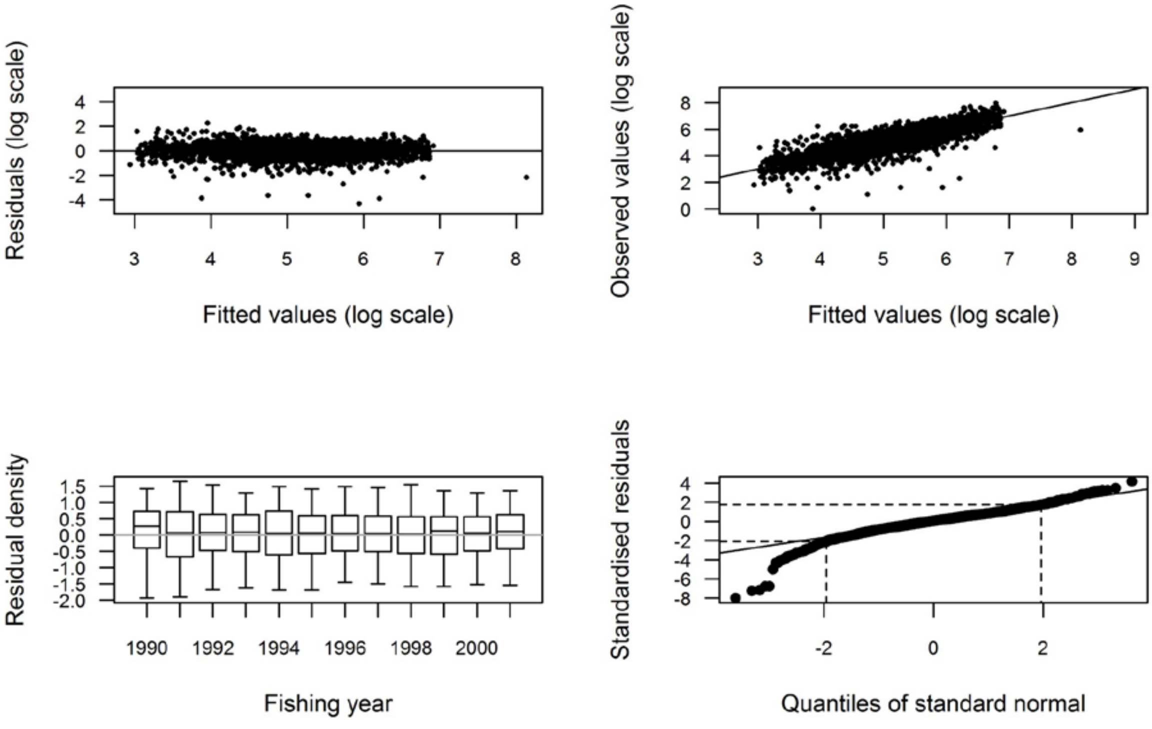


Figure 33: Residuals from the standardisation model for the CELR dataset.

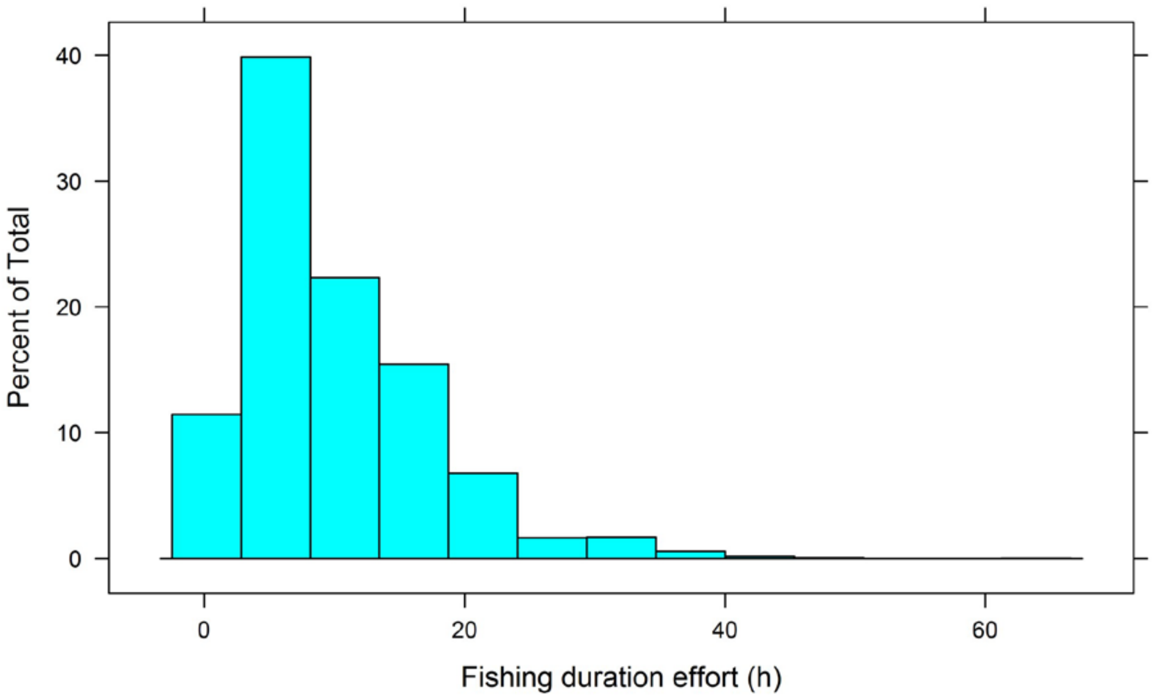


Figure 34: Distribution of fishing duration effort (h) in the CELR dataset.

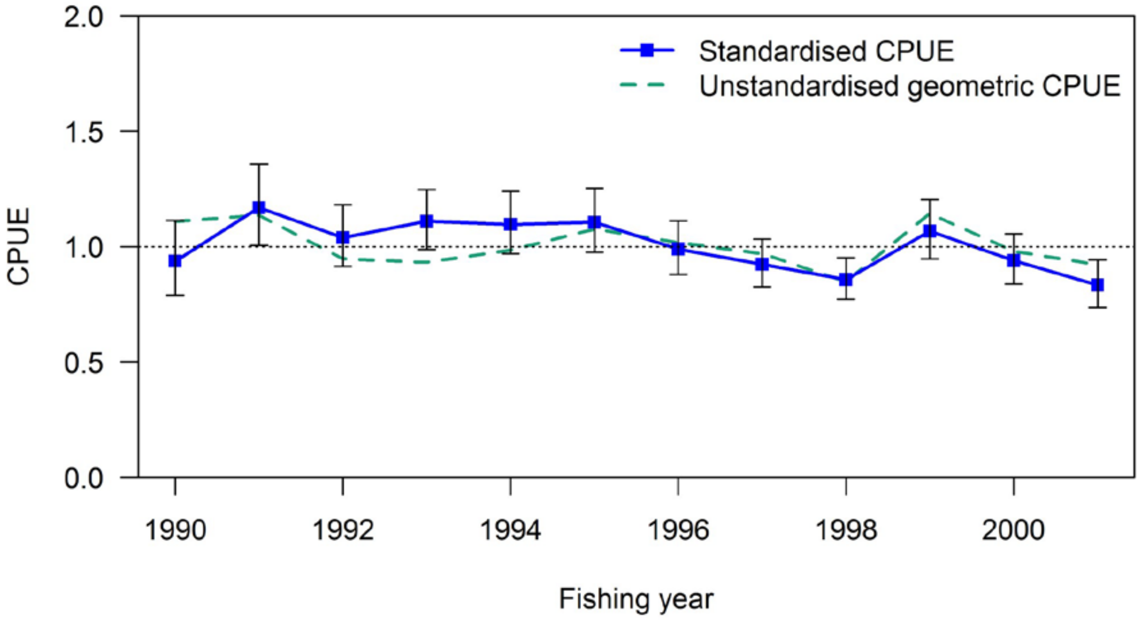


Figure 35: The standardised CPUE index with 95% confidence intervals for the CELR dataset. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

Table 17: Percentage of catch by Statistical Area for each year (for CELR data).

	024	025	026	030
1990	22	0	78	0
1991	14	0	86	0
1992	37	0	63	0
1993	33	0	67	0
1994	24	0	76	0
1995	38	0	62	0
1996	15	28	50	8
1997	30	20	44	6
1998	32	14	52	2
1999	25	27	47	1
2000	32	22	43	3
2001	27	22	48	2

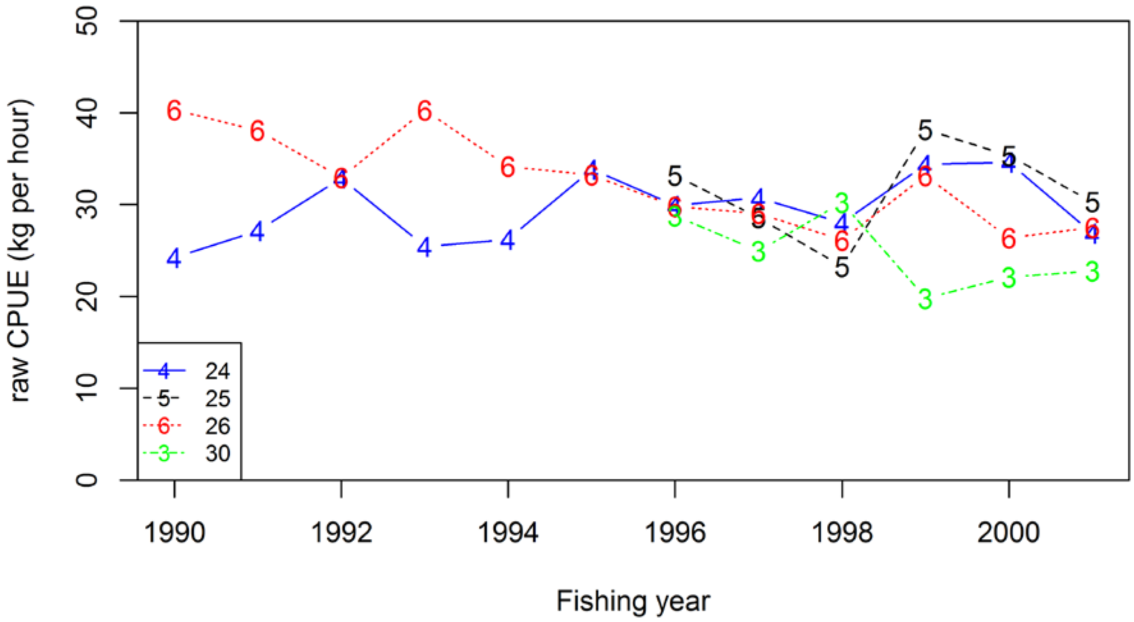


Figure 36: Standardised indices for the CELR dataset with a year:area interaction forced into the model.

4.8 PCELR data (2002–2016)

4.8.1 Data grooming and subsetting

The initial data set consisted of all records in which paua was targeted by diving. All records contained entries for FIN, fine scale statistical area, catch weight, fishing duration, and date. Records were removed which had no diver key (14 records). Some further grooming was done: 392 records were removed where no diving condition was recorded (Table 18).

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 statistical area). CPUE was defined as the catch for a diver with fishing duration offered as a predictor in the model. Records with a CPUE greater than 200 kg/h would have been removed, but there were none.

Fisher Identification Number was used to identify a core group of permit holders, with the requirement that there be a minimum number of records per year for a permit holder, for a minimum number of years. The criteria of a minimum of 20 records per year for a minimum of 4 years was chosen, this retained 84% of the catch over the period 2002–2016 (Figures 37–39). The number of FIN holders dropped from 42 to 15 under these criteria. There was good overlap in effort for the FIN holders after subsetting (Figures 40–41). The number of records retained after subsetting was 253 or more for every fishing year (Table 19, Figure 42).

To ensure that there was enough data to estimate statistical area and diver effects in the standardisation, only those statistical areas and divers with 10 or more diver days were retained (Table 19). This reduced the number of statistical areas from 44 to 33, and the number of divers from 591 to 91 (57% of divers have only one diving day - this is partly an artefact 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 43–46).

Table 18: Number of records removed from PCELR dataset by fishing year where diving condition was not recorded (12 = 2012).

Fishing year	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
No diving condition	50	28	32	33	14	23	28	19	28	27	21	37	27	16	9	392

Table 19: Number of records remaining by fishing year (12 = 2012) in the PCELR dataset after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records without information needed for the standardisation were also removed (see the table above).

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Total records	1174	921	707	640	559	543	513	413	458	419	506	542	535	506	313	8749
FIN subsetting	858	719	619	588	492	485	416	338	367	371	470	489	491	371	253	7327
Fine scale stat area ≥10 dive days	844	712	618	588	491	483	412	336	367	368	470	489	488	369	253	7288
Divers with ≥10 dive days	689	588	483	521	441	444	361	308	322	345	438	434	441	315	204	6334

4.8.2 Standardised PCELR

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, 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 5D is a single area model. However, a separate standardisation is also done where a year:area interaction is forced in at the start (using five sub-areas).

Except for FIN, all variables were accepted into the model, which explained 74% of the variability in CPUE (Table 20). Most of the variability was explained by duration (55%) and diver (7%). The effects appear plausible and the diagnostics are good (Figures 47–48). There is an apparent increasing effect for the catch taken above a fishing duration of 10 hours, although for the majority of records fishing duration is less than 10 hours (Figure 49).

The standardised index shows an increase from 2002 to 2011, then a decline after this (Table 21, Figure 50). There is little difference between the unstandardised and standardised CPUE, with most of the difference attributable to the fishing duration predictor (Figure 51).

Five sub-areas for PAU 5D are given in Table 21, each of which has a good number of records, except the sub-area denoted “Middle” (Table 22). Forcing a year:area interaction into the model gives similar indices for the different sub areas (Figure 52).

Table 20: Variables accepted into the model for the PCELR dataset (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fishing year	14	0.06
fishing duration	3	0.61
diver key	90	0.68
condition	4	0.72
statistical area	32	0.74

Table 21: Standardised index for the PCELR data set, lower and upper 95% confidence intervals, and CVs.

year	index	lower CI	upper CI	CV
2002	0.84	0.77	0.92	0.05
2003	0.76	0.69	0.83	0.05
2004	0.78	0.71	0.86	0.05
2005	0.90	0.82	0.99	0.05
2006	1.12	1.02	1.24	0.05
2007	1.04	0.94	1.14	0.05
2008	1.04	0.94	1.16	0.05
2009	1.15	1.02	1.28	0.06
2010	1.20	1.07	1.34	0.06
2011	1.33	1.19	1.48	0.05
2012	1.08	0.97	1.19	0.05
2013	0.97	0.88	1.07	0.05
2014	1.00	0.91	1.11	0.05
2015	0.95	0.85	1.07	0.06
2016	1.01	0.88	1.15	0.07

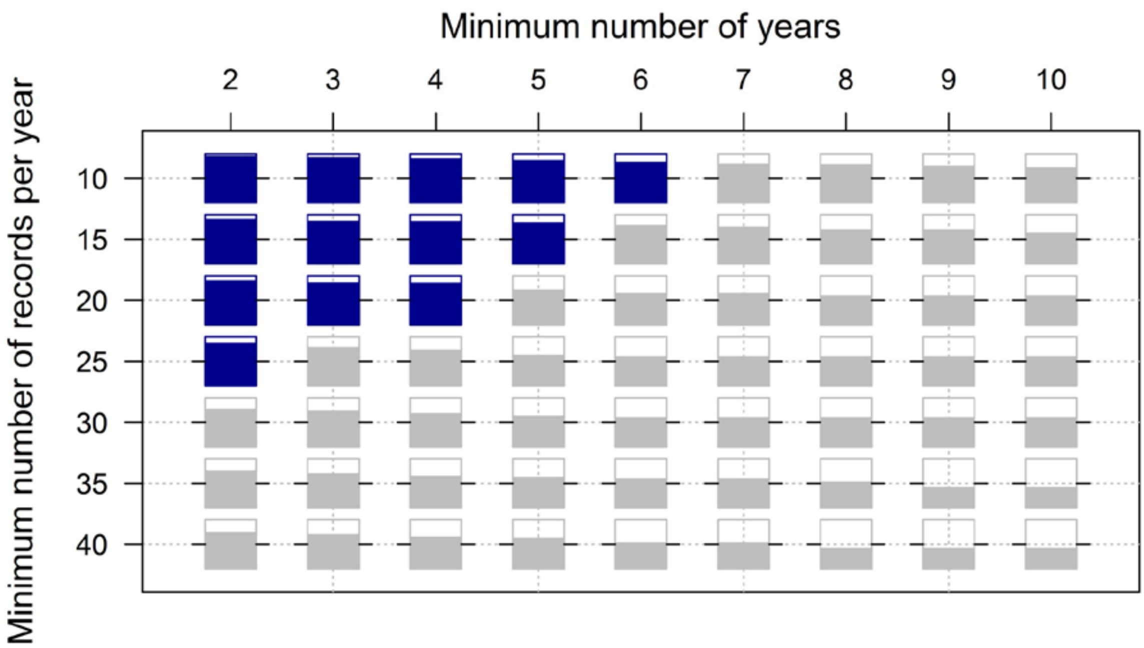


Figure 37: Proportion of the catch taken when subsetting the PCELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2015 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

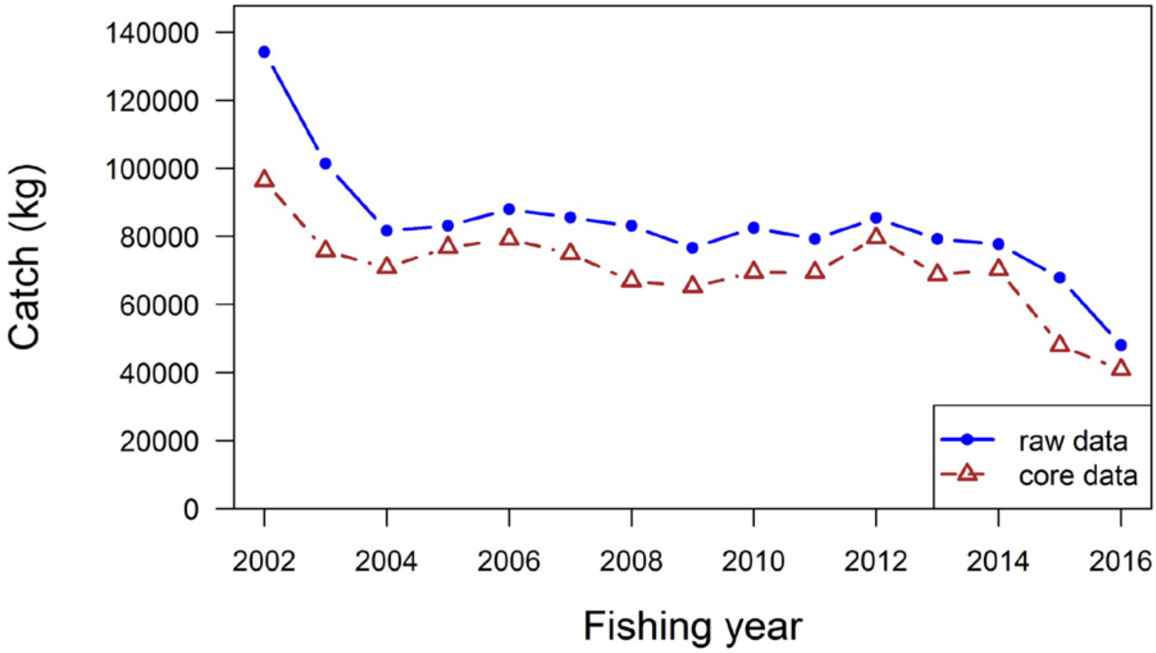


Figure 38: Catch by fishing year from the PCELR dataset before FIN subsetting (raw data) and after (core data).

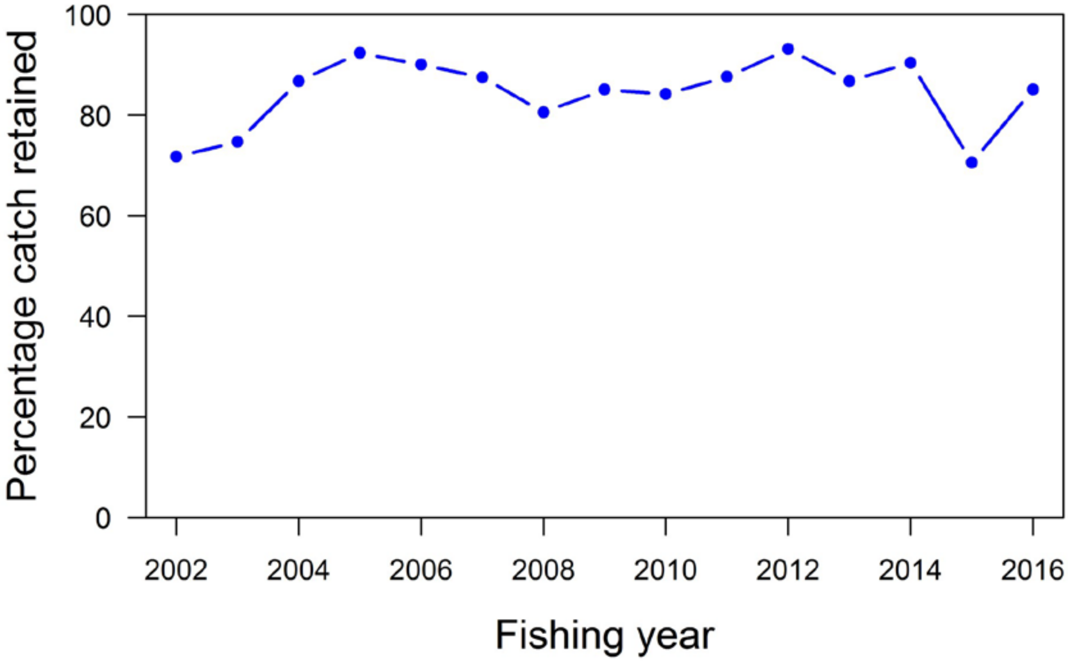


Figure 39: Percentage of the catch from the PCELR dataset retained after FIN subsetting.

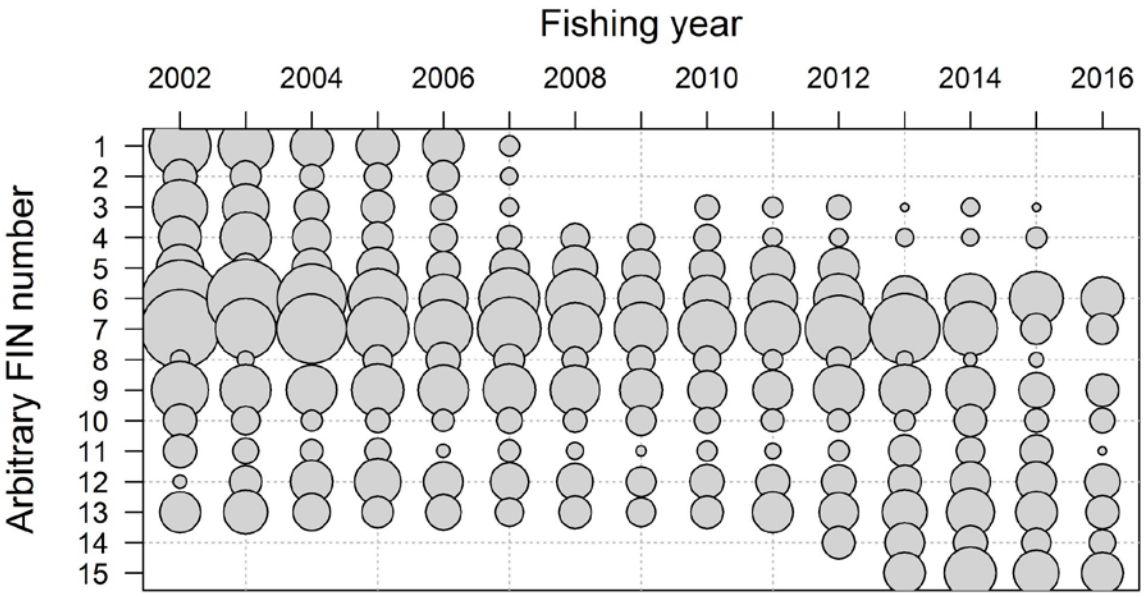


Figure 40: Number of records in the PCELR dataset by FIN and fishing year after subsetting by FIN. The area of a circle is proportional to the number of records.

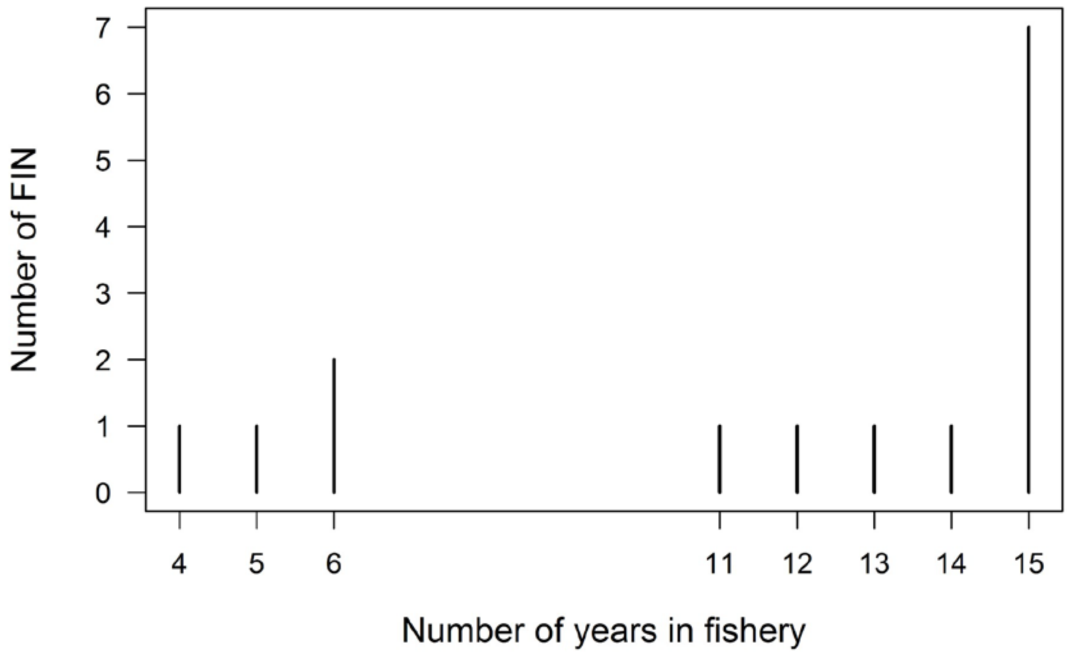


Figure 41: Number of years in the fishery for a FIN holder after subsetting by FIN, from the PCELR dataset.

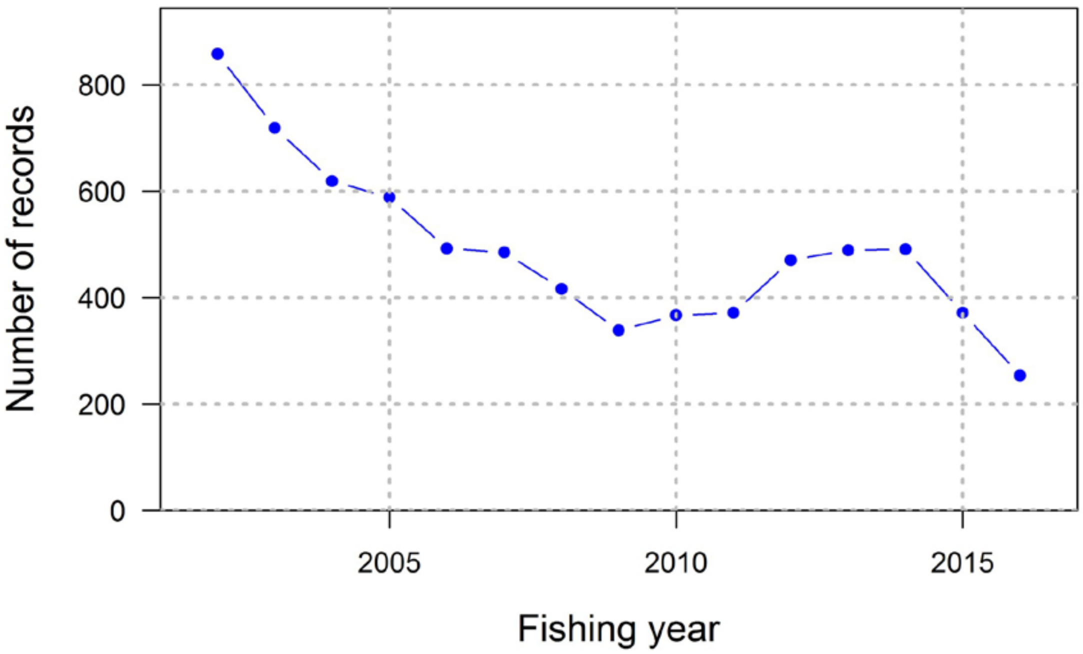


Figure 42: Number of records in the PCELR dataset retained after subsetting by FIN.

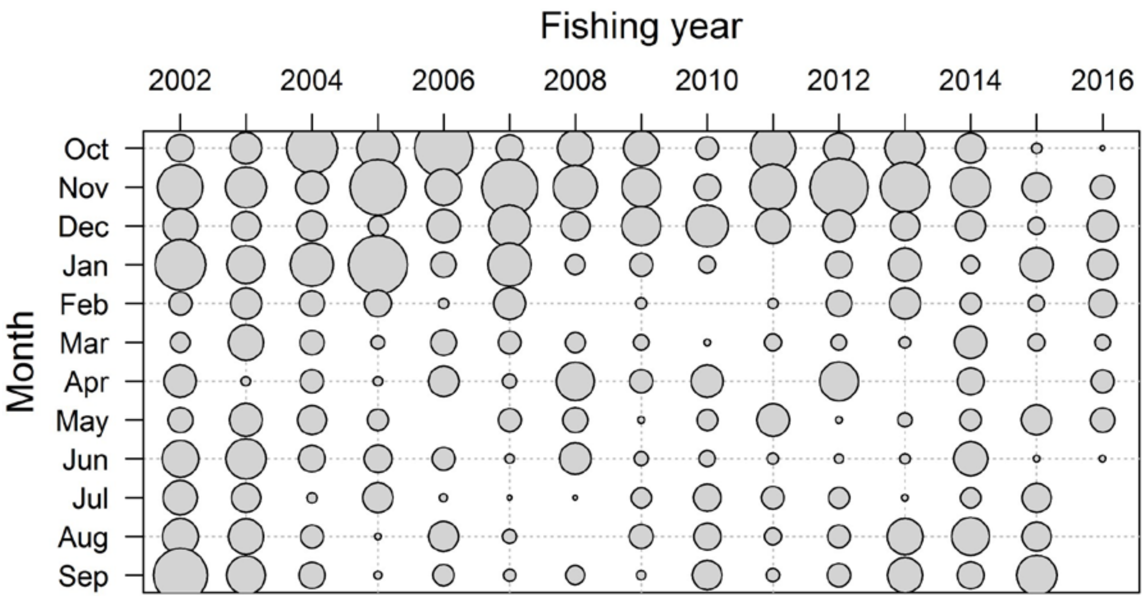


Figure 43: Number of records in the PCELR dataset by month and fishing year. The area of a circle is proportional to the number of records.

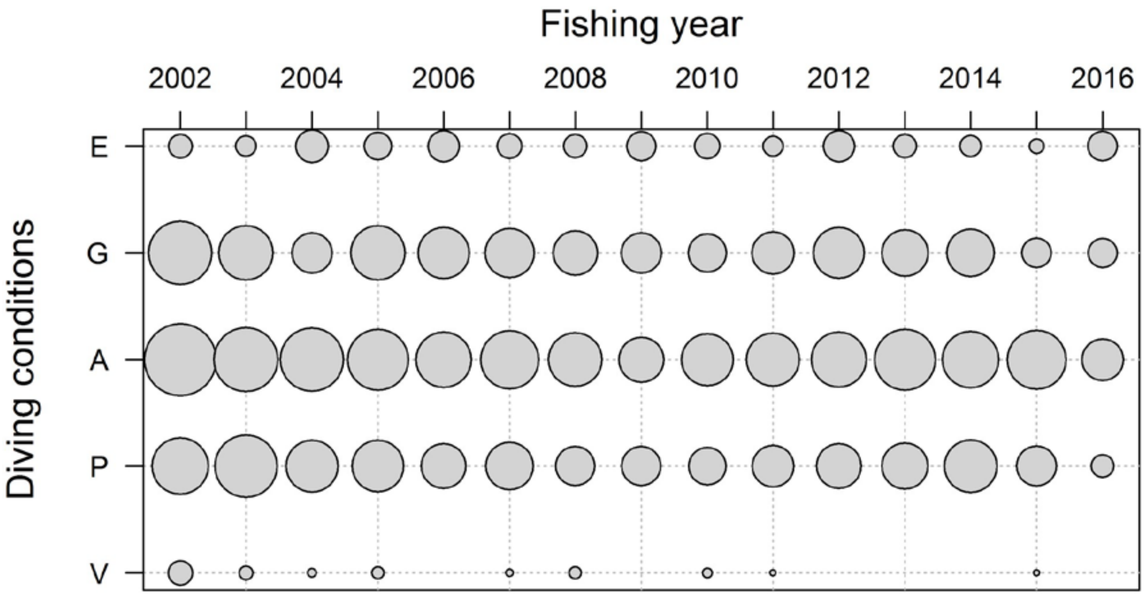


Figure 44: Number of records in the PCELR dataset by diving condition (excellent, good, average, poor, very poor) and fishing year. The area of a circle is proportional to the number of records.

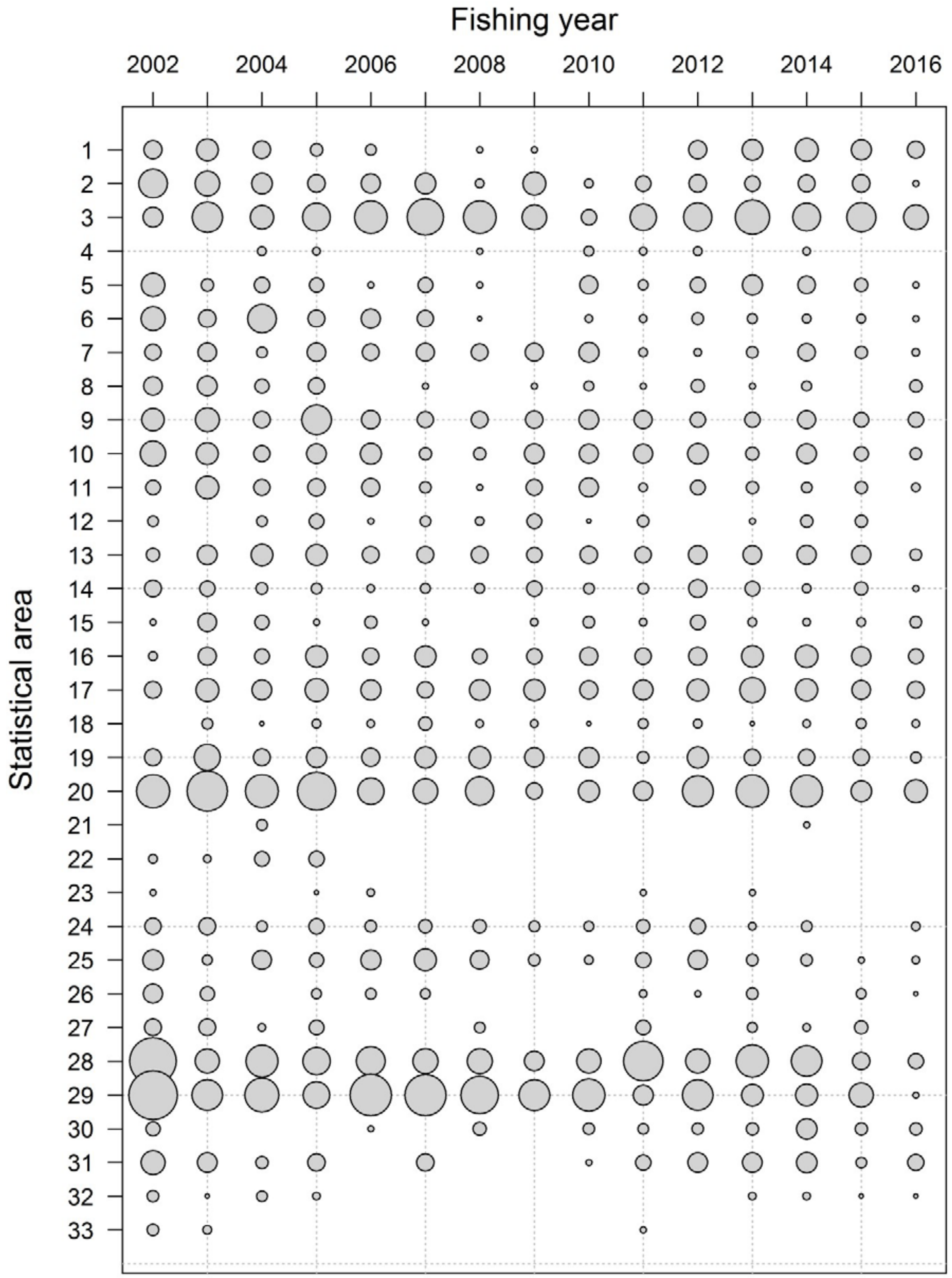


Figure 45: Number of records in the PCELR dataset by statistical area and fishing year. The area of a circle is proportional to the number of records. Arbitrary labels are used for the statistical areas.

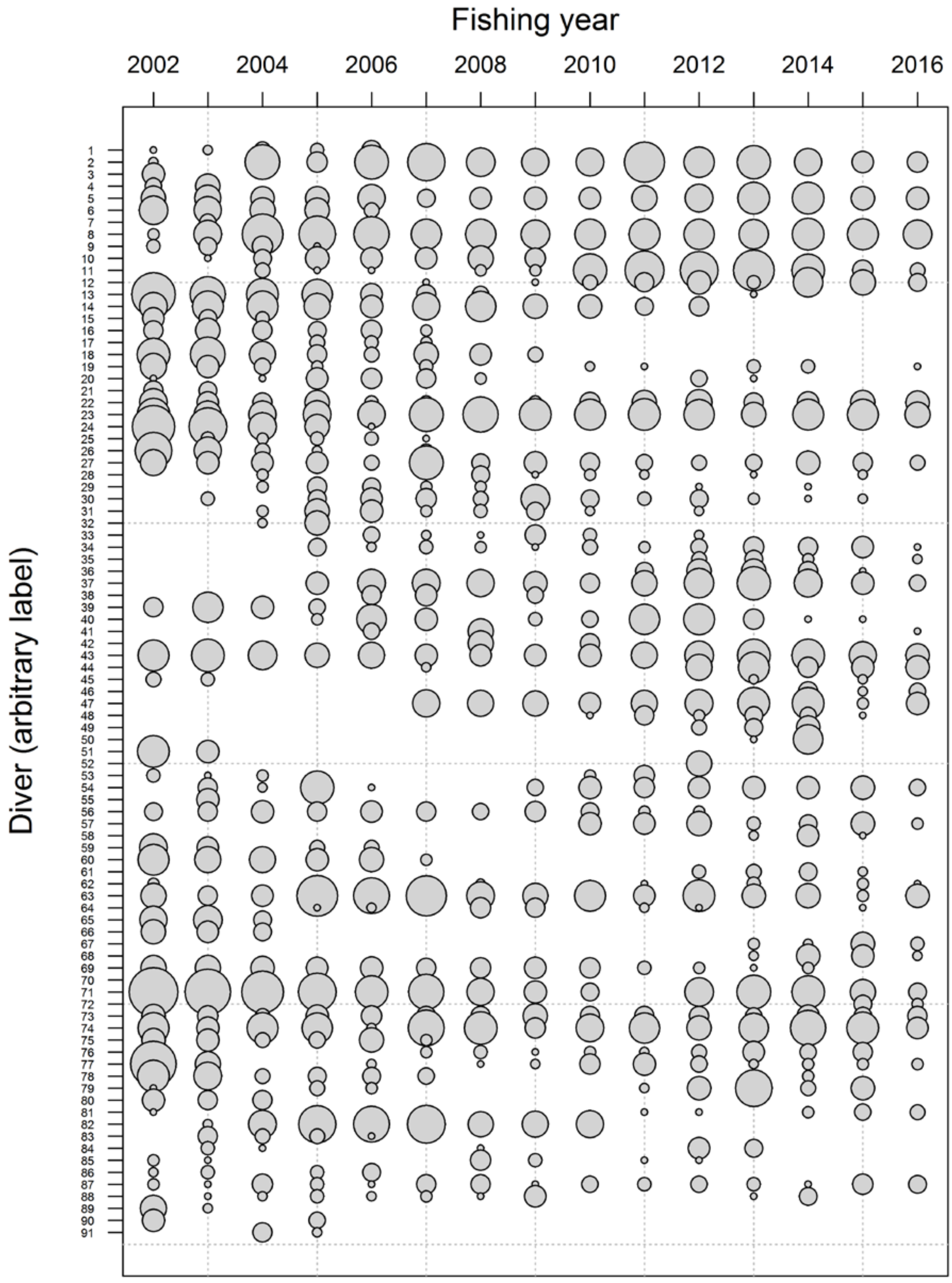


Figure 46: Number of records in the PCELR dataset by diver key and fishing year. The area of a circle is proportional to the number of records.

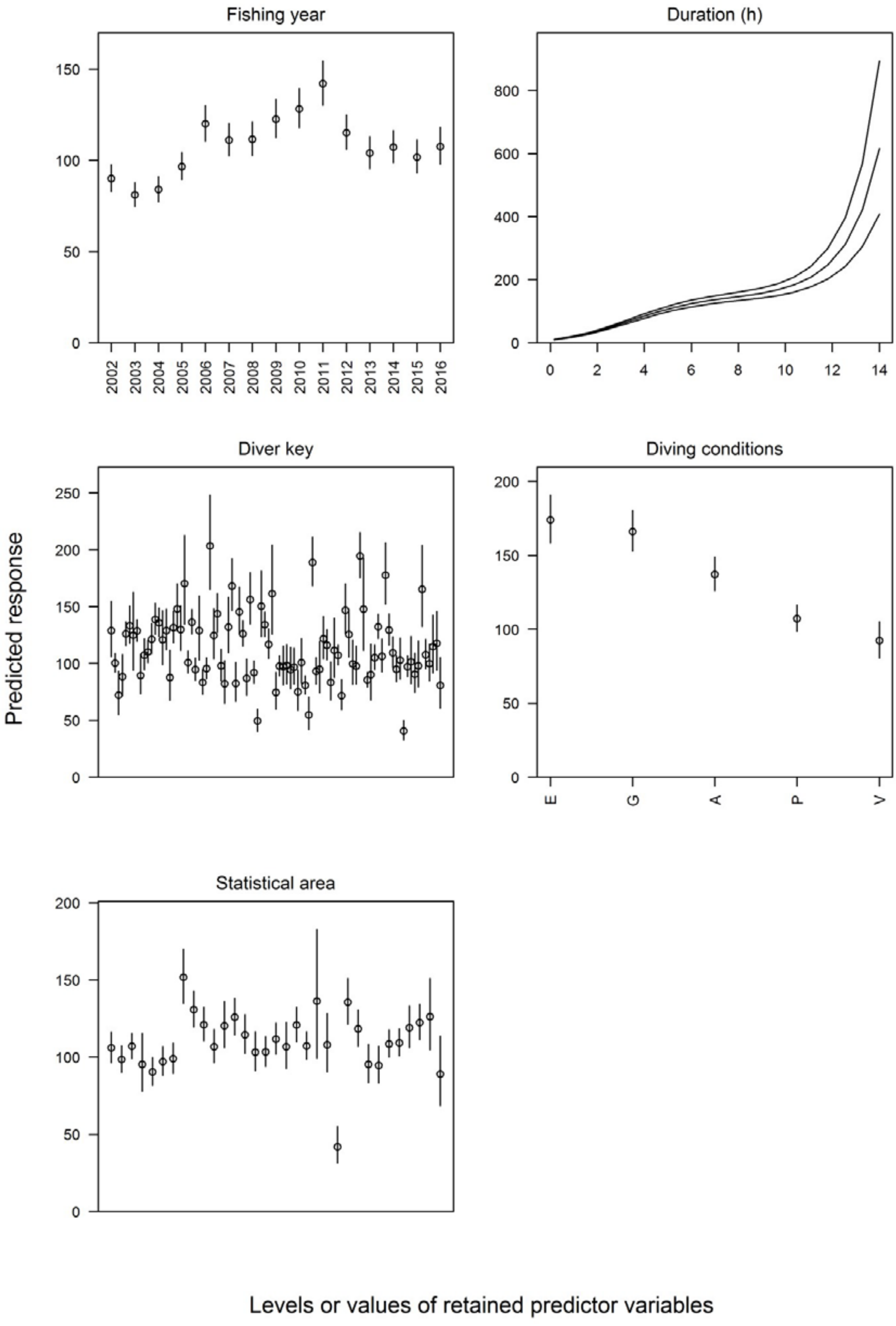


Figure 47: Effects catch rates from the PCELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

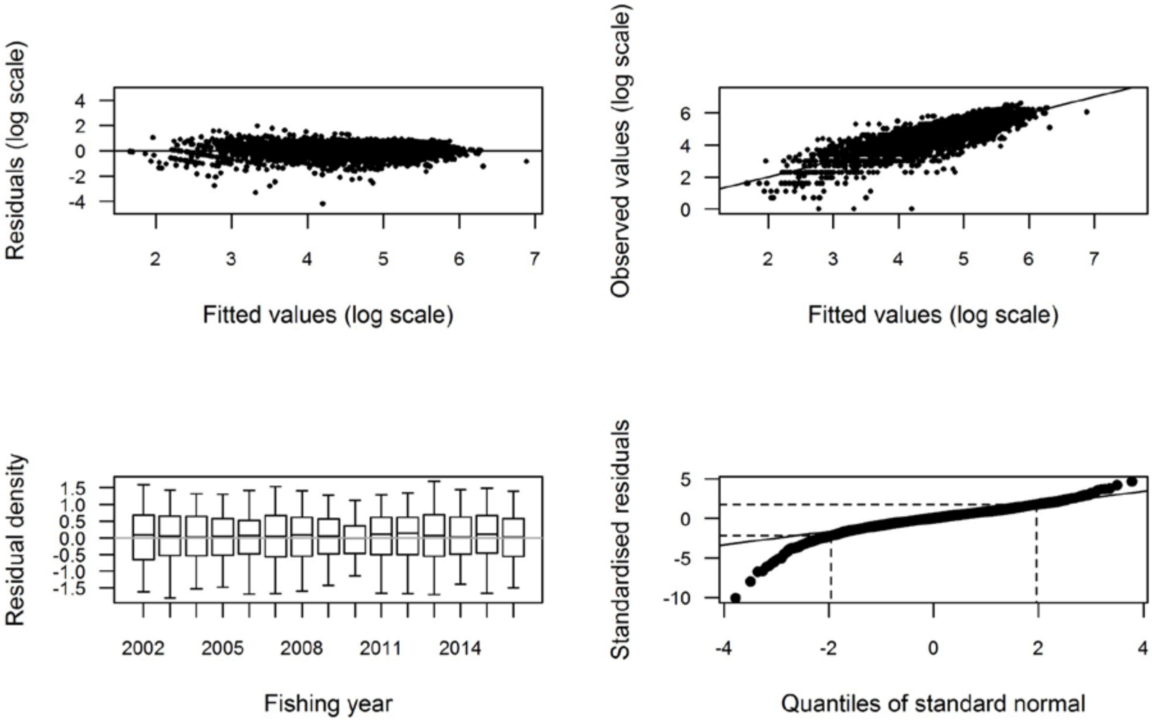


Figure 48: Diagnostic plots for the PCELR standardisation model.

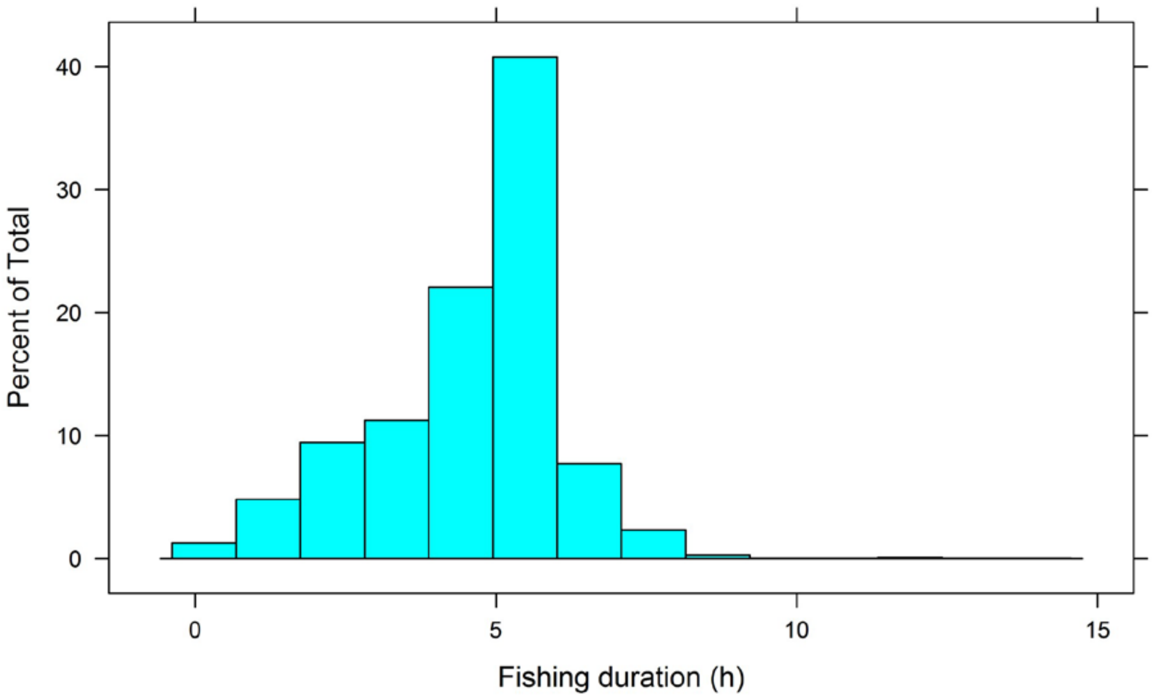


Figure 49: Distribution of fishing duration (h) for the PCELR dataset.

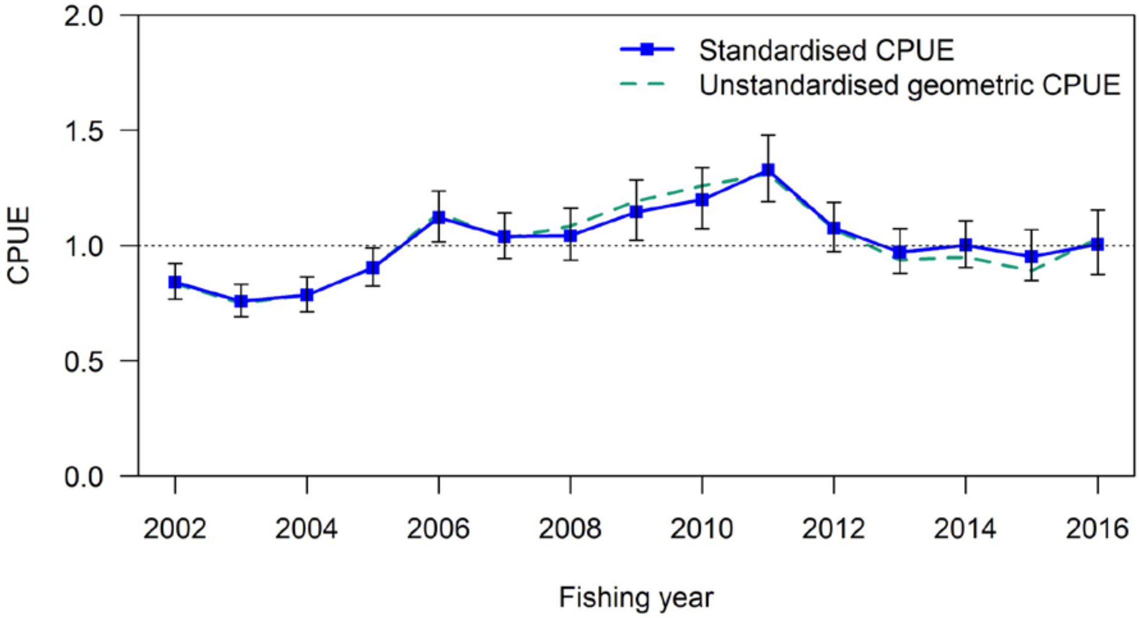


Figure 50: The standardised CPUE index for the PCELR dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

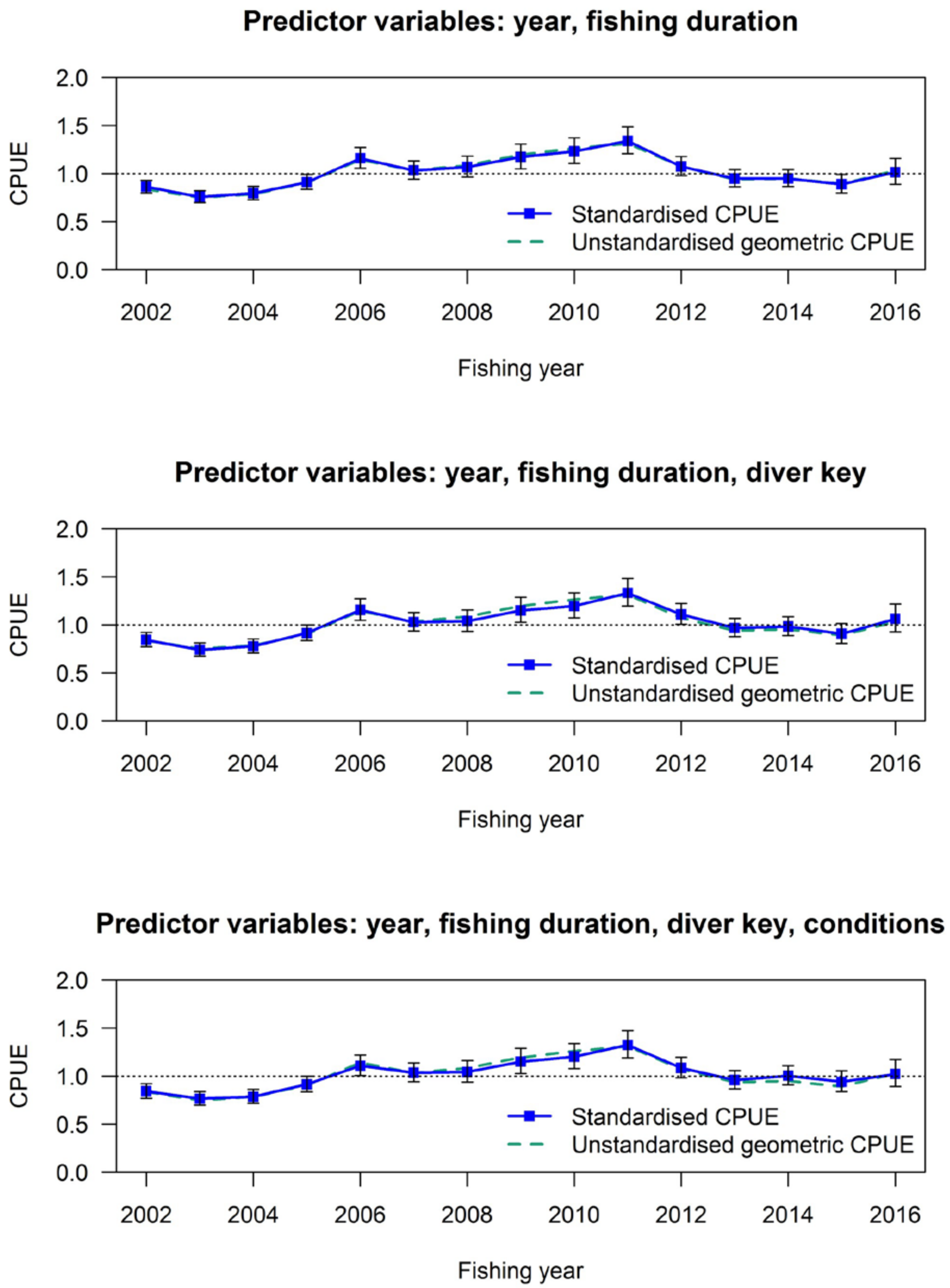


Figure 51: Stepwise addition of predictor variables. The standardised CPUE index for the PCELR dataset with 95% confidence interval. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

Table 22: Paua Statistical Areas associated with sub-areas used for modelling.

	Statistical Area
North	P5DH41–P5DH47
Middle	P5DH27–P5DH40
East	P5DH22–P5DH26
Catlins (East & West)	P5DH11–P5DH21
South	P5DH01–P5DH10

Table 23: Number of records in the PCELR dataset by year and sub area.

	North	Middle	East	Catlins (East & West)	South
2002	286	58	86	116	143
2003	113	32	160	145	138
2004	123	41	98	96	125
2005	101	40	144	131	105
2006	127	36	86	82	110
2007	128	38	96	57	125
2008	114	26	97	47	77
2009	66	13	68	87	74
2010	89	9	75	89	60
2011	127	26	62	69	61
2012	101	32	112	97	96
2013	109	19	119	65	122
2014	118	15	114	79	115
2015	68	7	74	68	98
2016	36	8	60	47	53

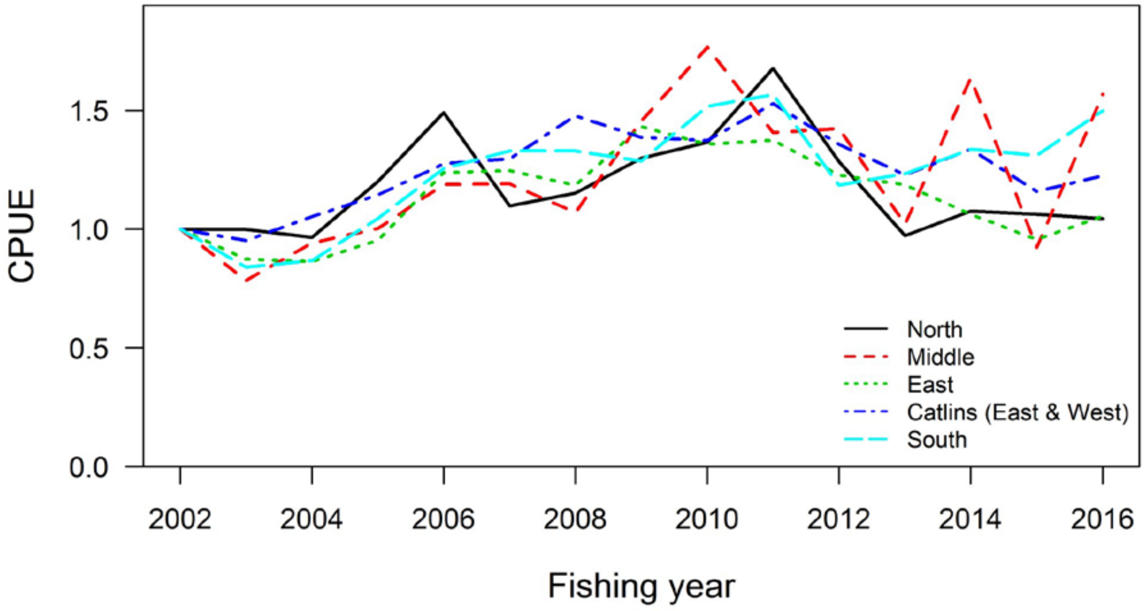


Figure 52: Standardised indices for the PCELR dataset with a year:area interaction forced into the model. The areas are sub-areas. The indices are scaled to have the value one in 2002.

4.9 Combined data (1990–2016)

4.9.1 The combined data set

For the years 1990–2001 the same data set is used as for the CELR standardisations. For the PCELR data the catch and fishing effort (both duration and number of divers) are collapsed down to a daily total for a given date, vessel, and large scale area (024, 025, 026, or 030). The collapsed PCELR data is then combined with the CELR data to give a data set covering the period 1990–2016. All records with a fishing duration per diver greater than 10 hours are dropped (as is done for the CELR data) with the number of records remaining shown in Table 23 in the “Before” column.

For the combined data set the daily hours per diver decreases from 1990 to 1995, then decreases until 2001, afterwards dropping then slowly increasing (Figures 53–54).

A raw CPUE analysis based on either total daily duration or number of divers as the measure of effort shows an irregular decline from 1990–2001 then an increase to 2011, followed by a decline with an increase in 2016 (Figures 55–56).

Table 24: Number of records in the combined dataset before and after FIN subsetting.

Year	Before	After
1990	274	104
1991	265	152
1992	311	209
1993	356	270
1994	308	235
1995	270	209
1996	381	238
1997	399	308
1998	437	384
1999	322	277
2000	447	367
2001	391	330
2002	537	449
2003	435	363
2004	315	276
2005	281	250
2006	241	208
2007	231	191
2008	200	163
2009	179	146
2010	204	172
2011	198	178
2012	207	181
2013	221	192
2014	223	196
2015	211	152
2016	147	128
Total	7991	6328

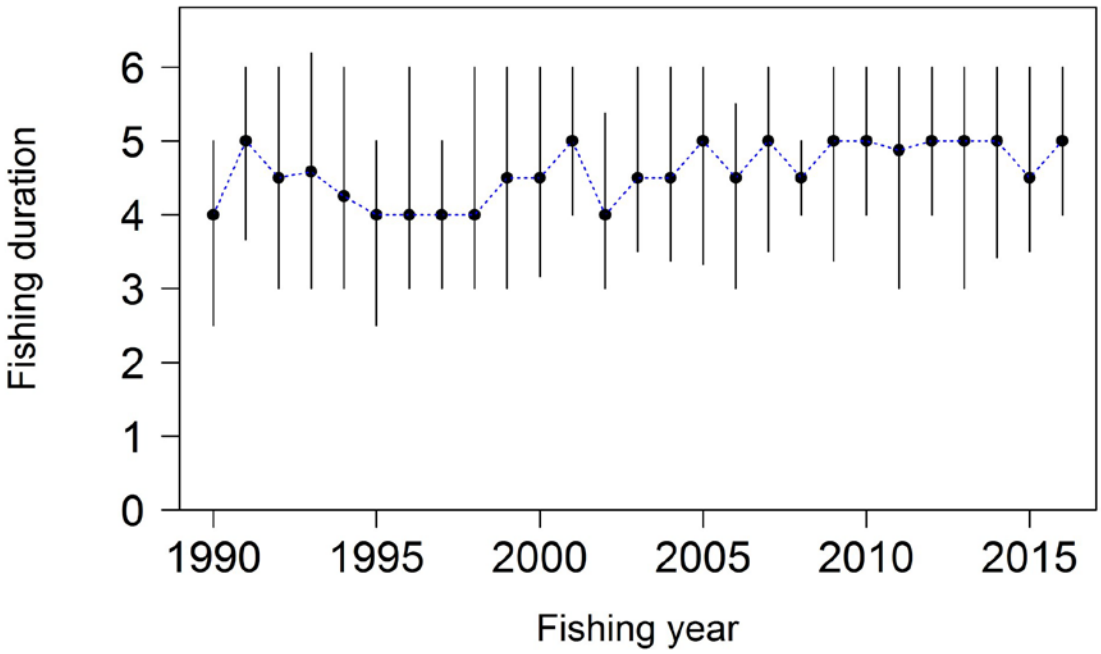


Figure 53: Quantiles by fishing year in the combined dataset for the daily fishing hours per diver: medians (dot) and lower and upper quartiles (vertical lines). Records with a value greater than 10 hours are dropped.

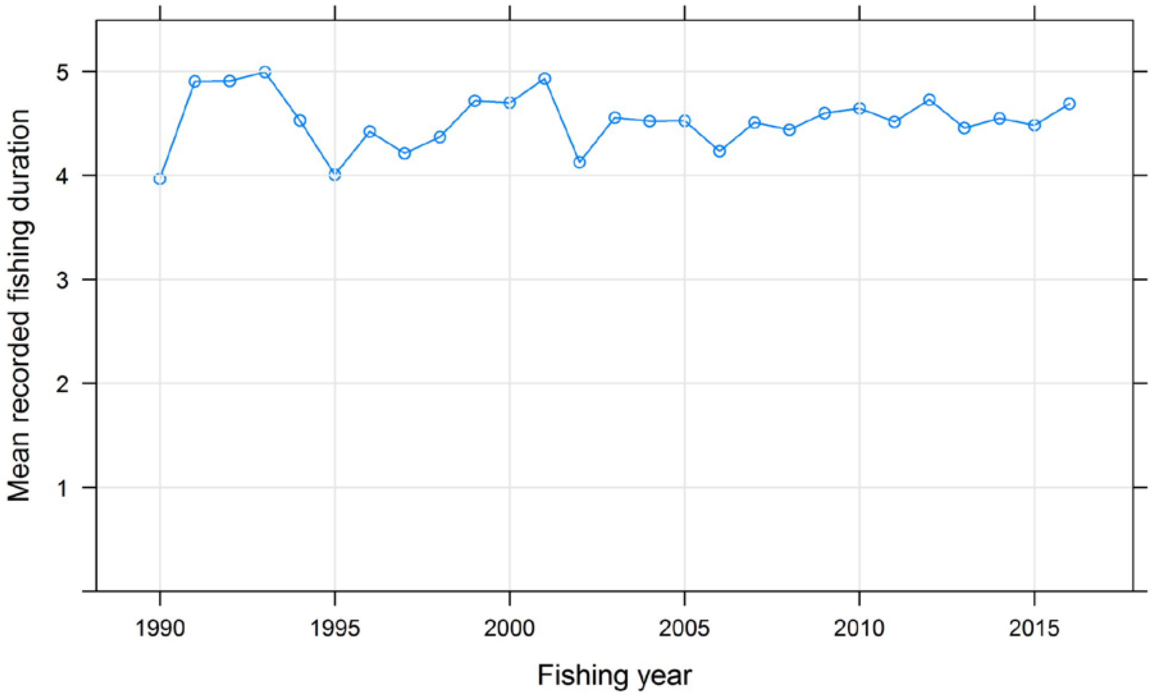


Figure 54: Mean values by fishing year in the combined dataset for daily hours per diver. Records with a value greater than 10 hours are dropped.

Figure 55: Geometric mean of the daily catch rate by year in the combined dataset, where the plots are scaled so that they both have the value one in 1990. Records with a fishing duration per diver greater than 10 hours are dropped.

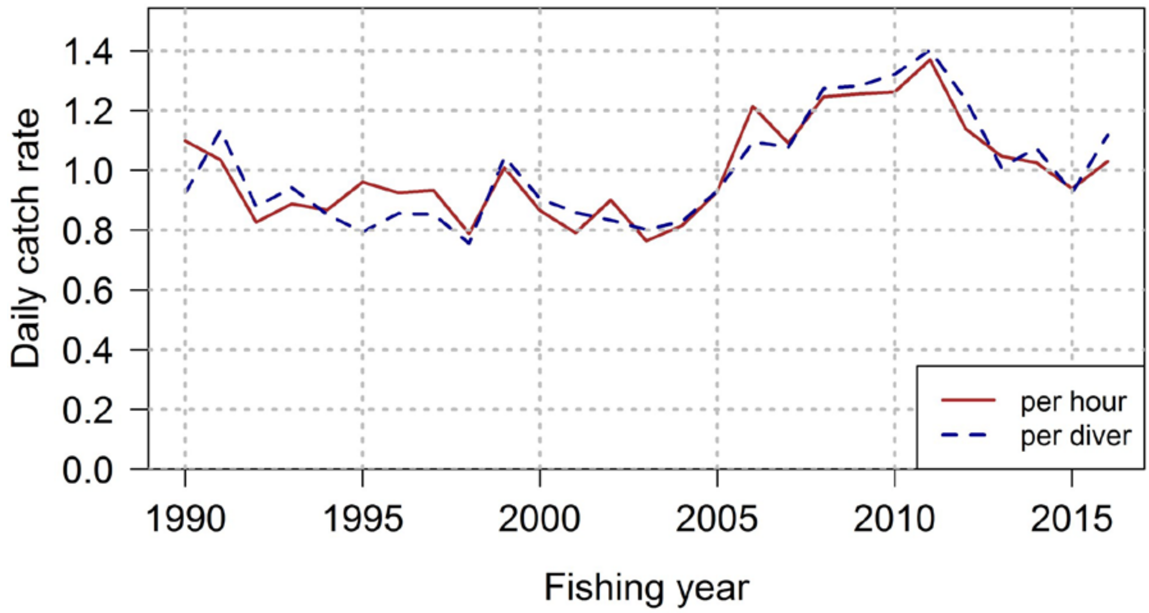


Figure 56: As in Figure 55, except that the plots are scaled so that they both have a mean value of one.

4.9.2 Standardised CPUE for the combined dataset

Fisher Identification Number is used to identify a core group of permit holders, with the requirement that there be a minimum number of records per year for a permit holder (FIN), for a minimum number of years. The criteria of a minimum of 10 records per year for a minimum of 4 years was chosen, this retains 80% of the catch over 1990–2016 (Figure 57). While 80% of the catch is retained overall, it is less than this for some years although always more than 40% (Figures 58–59). Number of days of effort retained after subsetting is 104 or more for every fishing year (see Table 23, Figure 60). The number of FIN holders drops from 122 to 25 under the subsetting criteria.

There is good overlap in effort over time for the permit holders after subsetting (Figures 61–63). Similarly for overlap in time for month (Figure 64).

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, month, and fishing duration (as a cubic polynomial).

The model explained 69% of the variability in CPUE with fishing duration (56%) explaining most of this followed by FIN (7%) (Table 24). The effects appear plausible and the model diagnostics good (Figures 65–66). There is an apparent increasing effect for the catch taken above a fishing duration of 50 hours, although for the majority of records fishing duration is less than this (Figure 67). The standardised index shows a decline from 1990–2001, followed by an increase until 2009, after which it declines (Table 25, Figure 68).

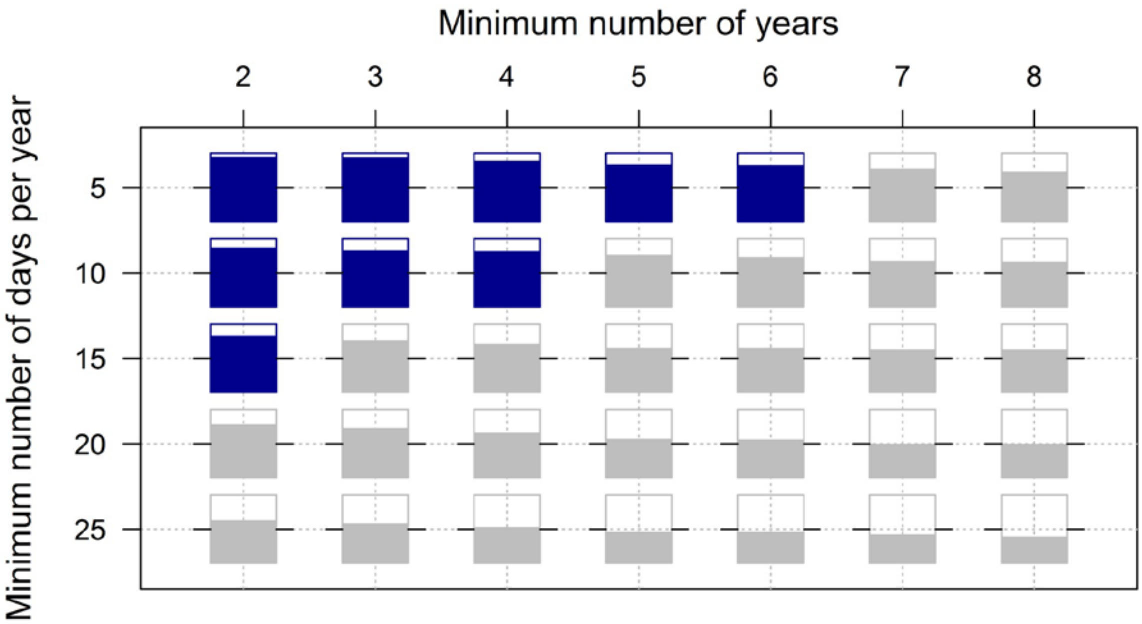


Figure 57: Proportion of the catch taken when subsetting the combined dataset by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2016 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

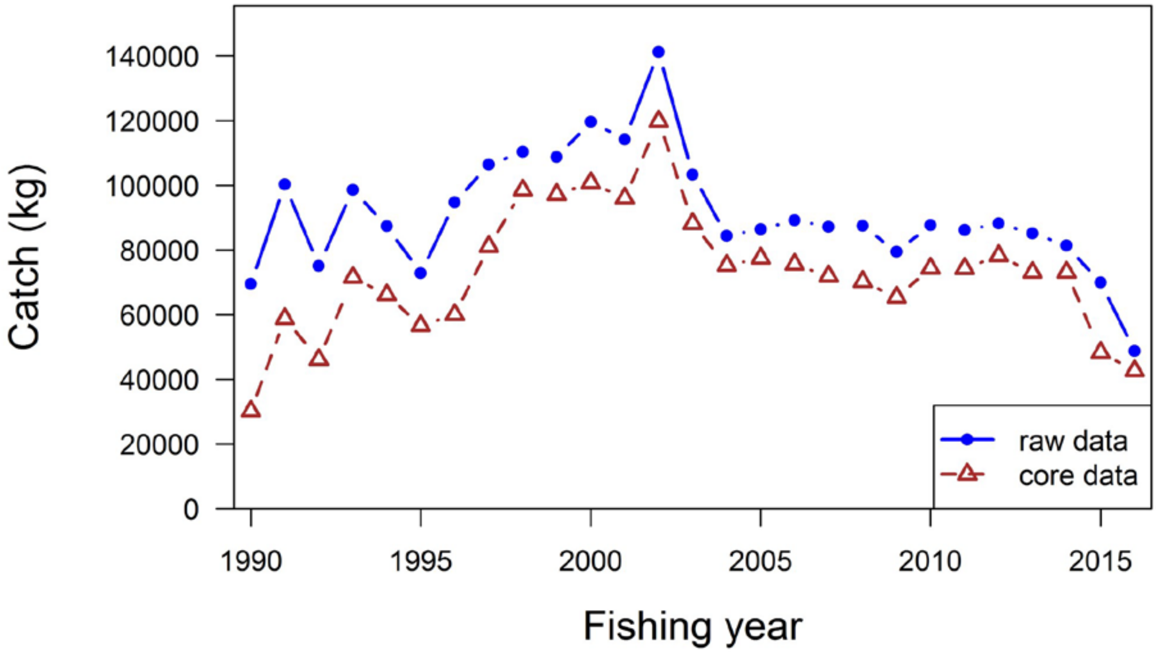


Figure 58: Catch by fishing year in the combined dataset before FIN subsetting (raw data) and after (core data).

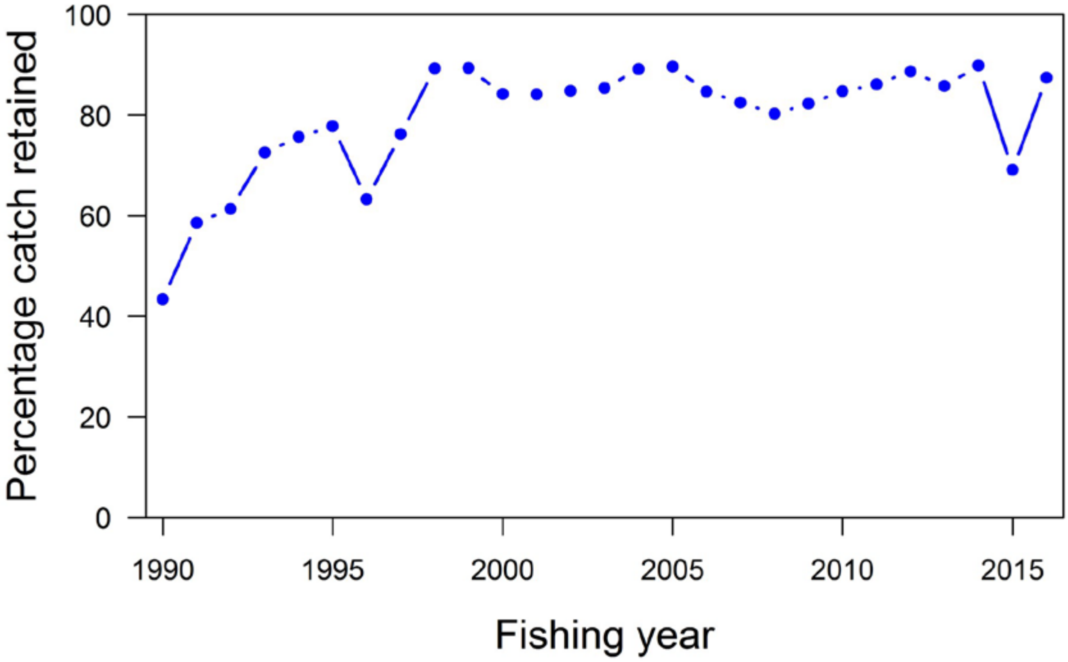


Figure 59: Percentage of the catch retained in the combined dataset after FIN subsetting.

Table 25: Variables accepted into the standardisation model for the combined dataset (at least 1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish year	26	0.06
Fishing duration	3	0.62
client key	24	0.69

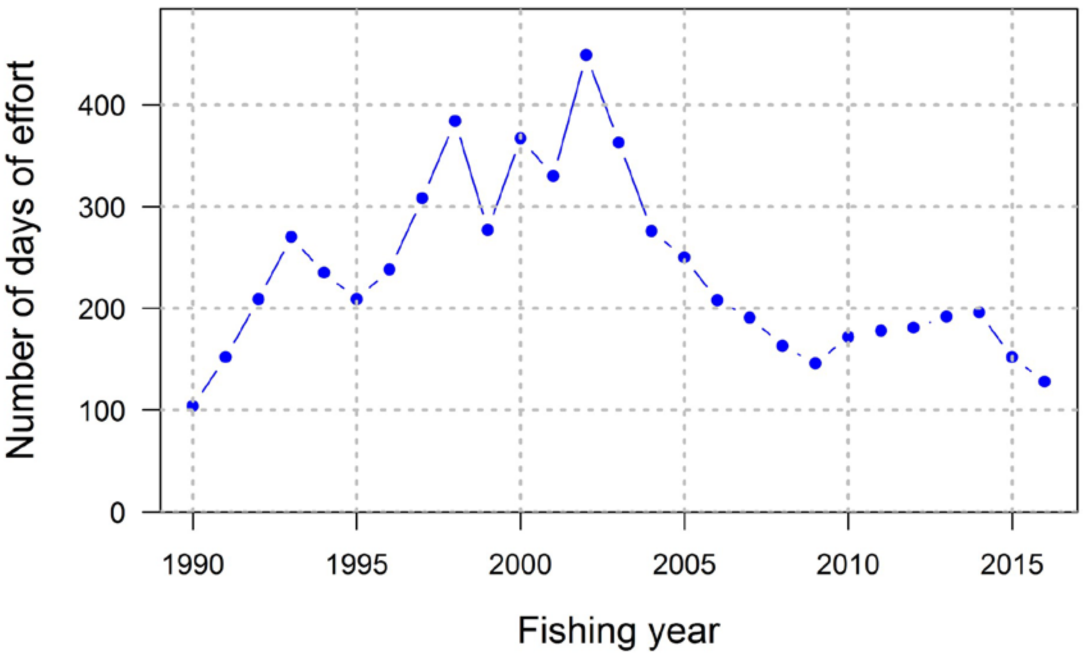


Figure 60: Number of days of effort retained in the combined dataset after FIN subsetting.

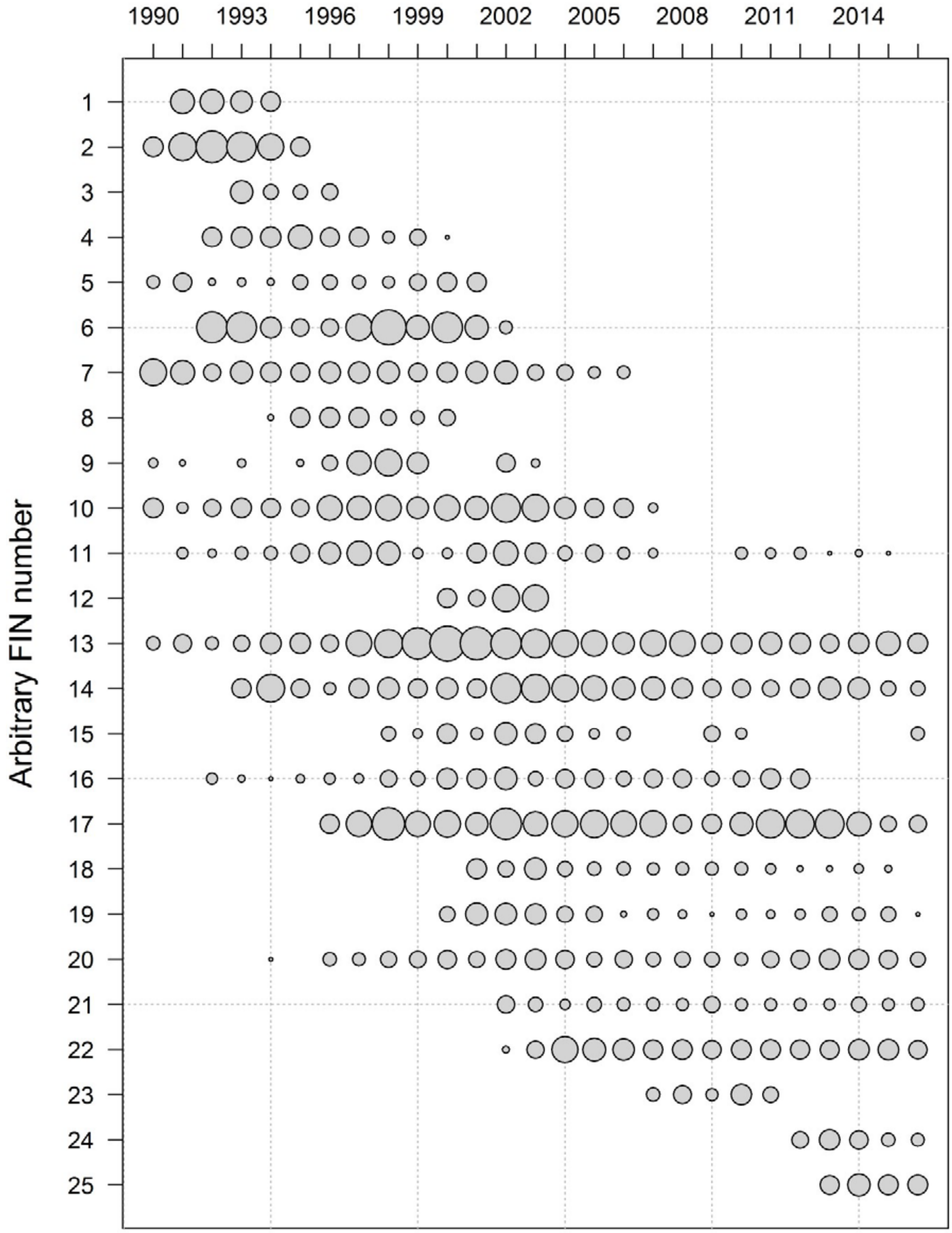


Figure 61: Days of effort in the combined dataset by FIN and fishing year. The area of a circle is proportional to the days of effort.

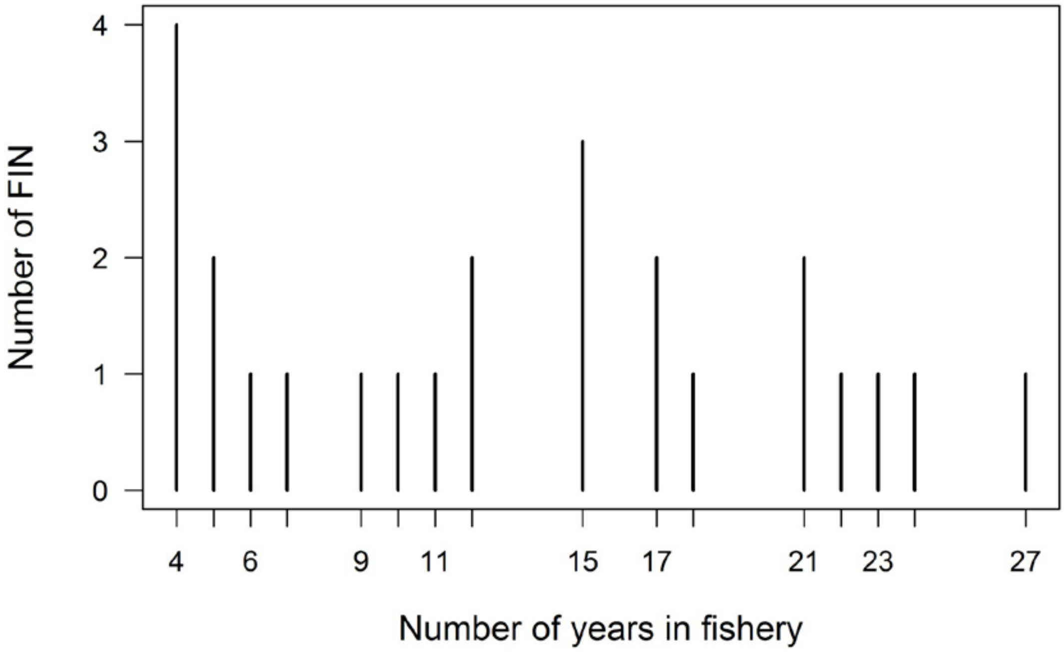


Figure 62: Number of years in the fishery in the combined dataset for a FIN holder after subsetting by FIN.

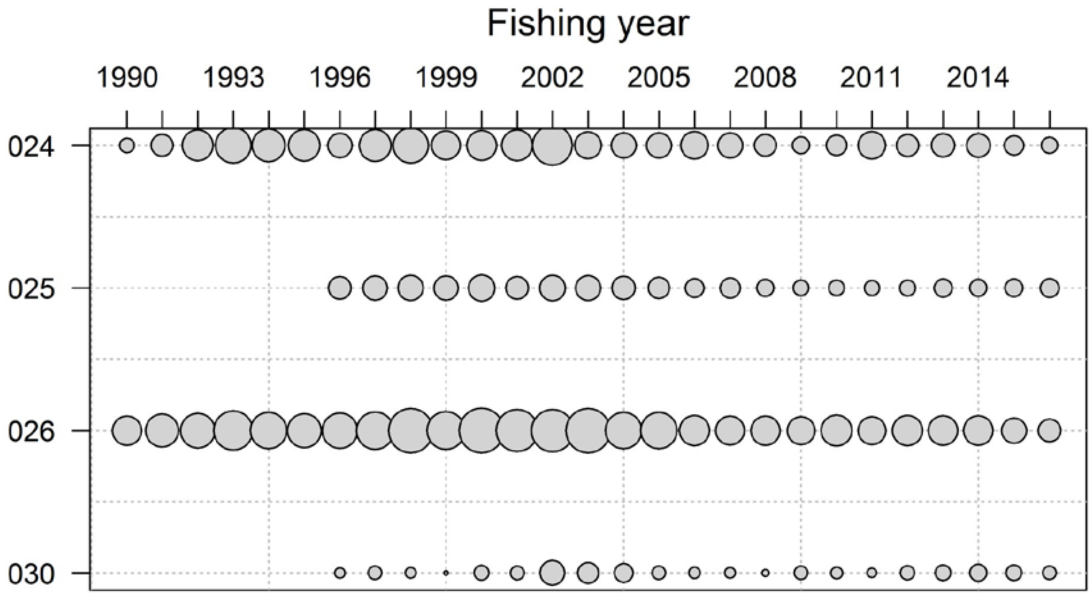


Figure 63: Days of effort in the combined dataset by area and fishing year.

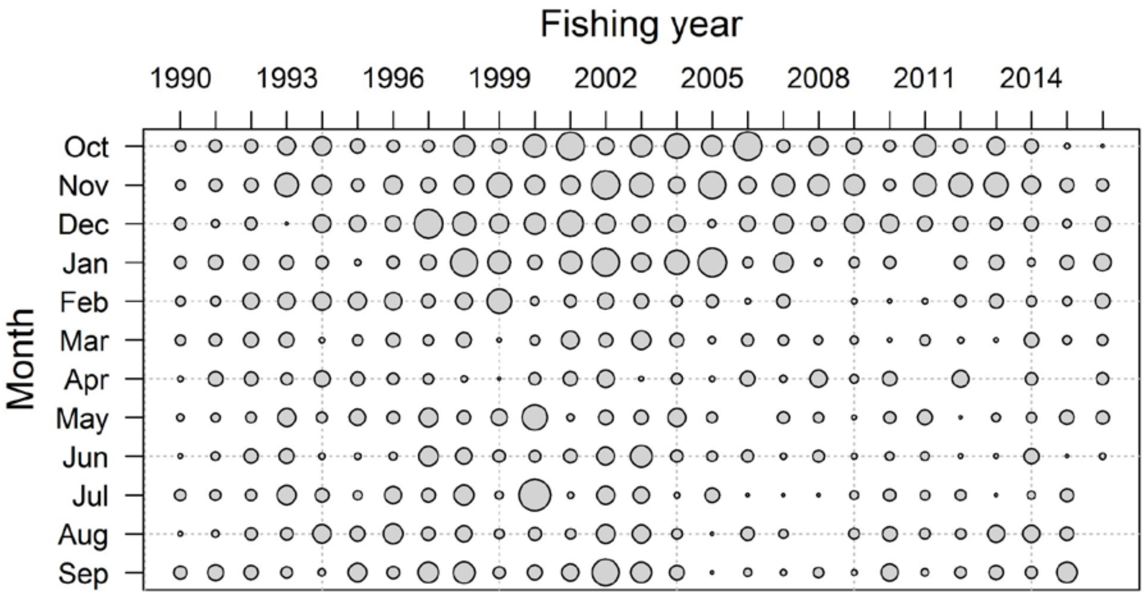


Figure 64: Days of effort in the combined dataset by month and fishing year.

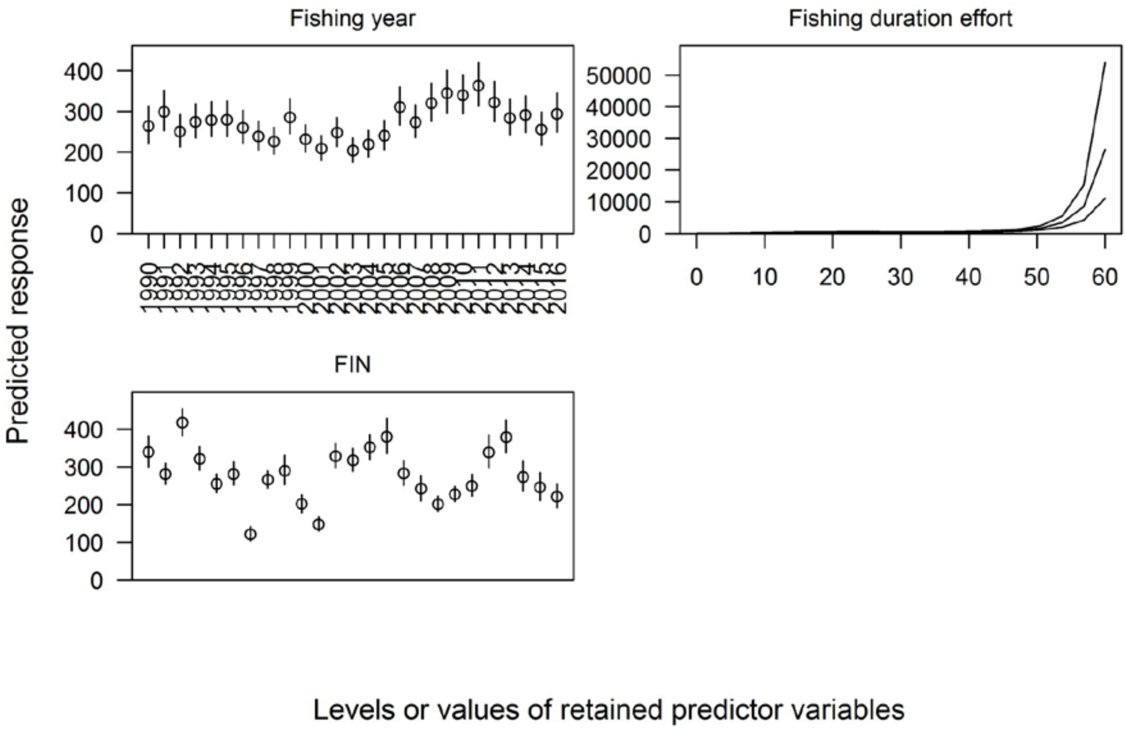


Figure 65: Effects catch rates from the standardisation model for the combined dataset. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

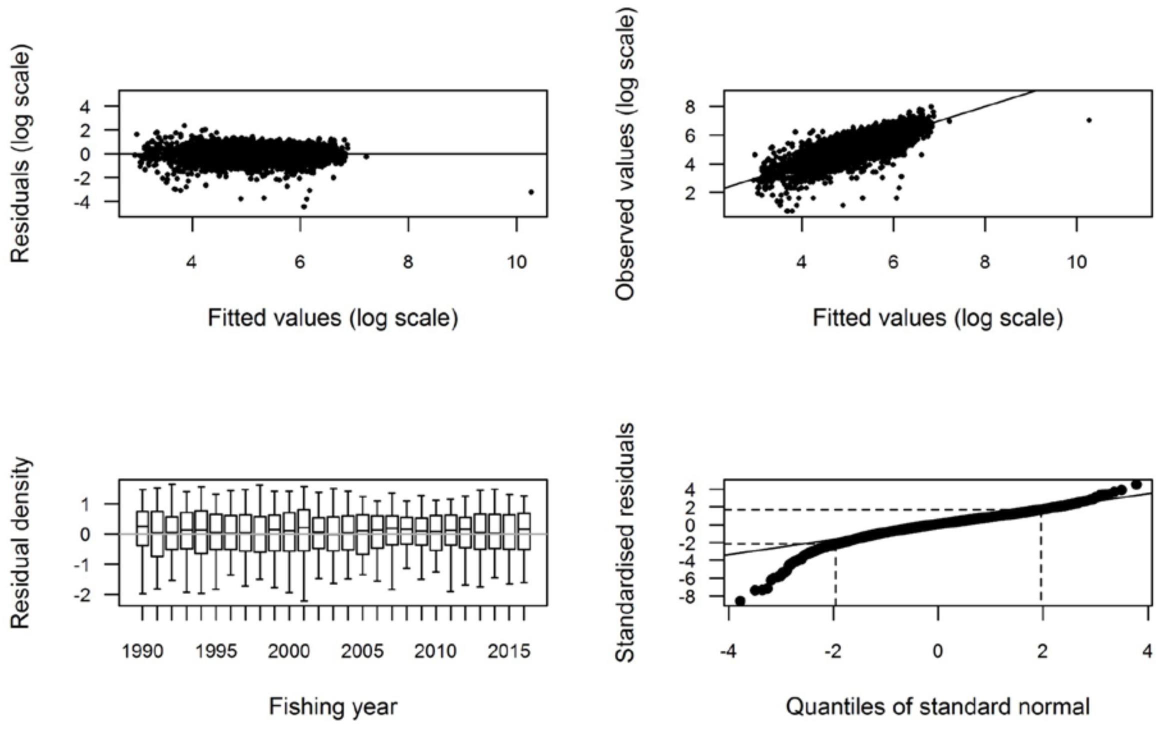


Figure 66: Residuals from the standardisation model for the combined dataset.

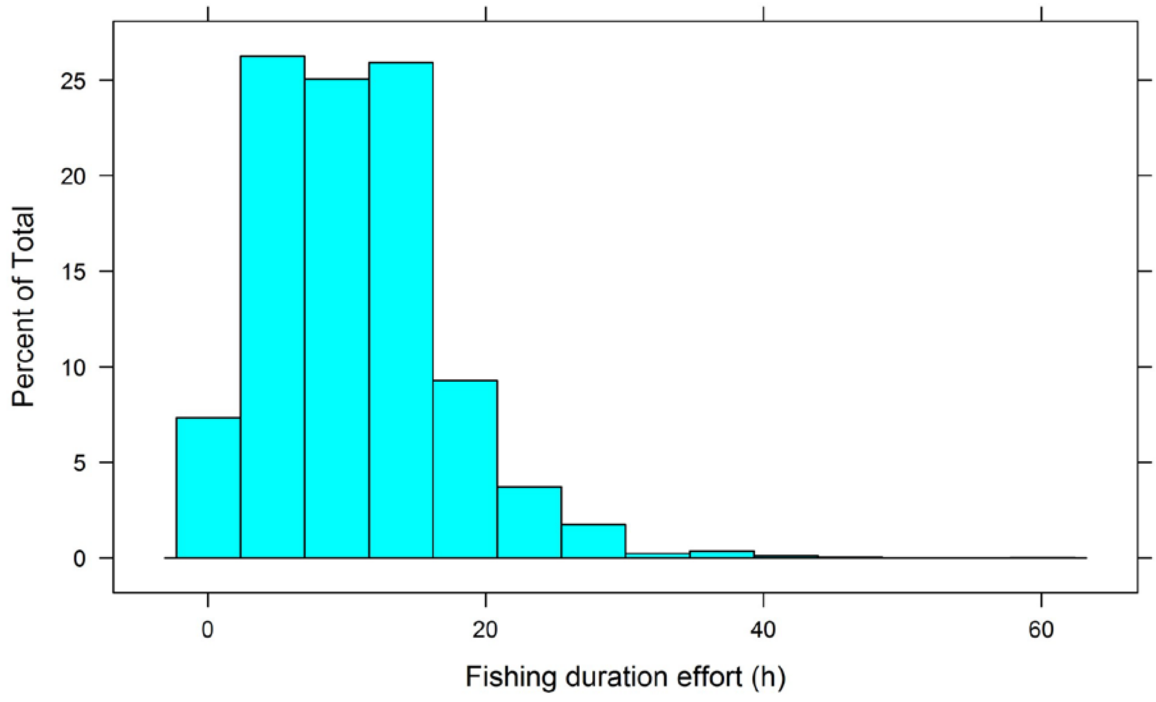


Figure 67: Distribution of fishing duration effort (h) in the combined dataset.

Table 26: Standardised CPUE index for the combined dataset, lower and upper 95% confidence intervals, and CVs.

year	index	lower CI	upper CI	CV
1990	0.97	0.80	1.19	0.10
1991	1.10	0.93	1.31	0.09
1992	0.92	0.79	1.07	0.08
1993	1.01	0.89	1.15	0.07
1994	1.03	0.90	1.18	0.07
1995	1.03	0.89	1.19	0.07
1996	0.96	0.84	1.10	0.07
1997	0.88	0.78	0.99	0.06
1998	0.83	0.75	0.93	0.05
1999	1.05	0.93	1.19	0.06
2000	0.85	0.77	0.95	0.05
2001	0.77	0.69	0.86	0.06
2002	0.91	0.83	1.01	0.05
2003	0.75	0.67	0.84	0.05
2004	0.81	0.71	0.91	0.06
2005	0.89	0.78	1.00	0.06
2006	1.15	1.00	1.31	0.07
2007	1.01	0.87	1.17	0.07
2008	1.18	1.01	1.38	0.08
2009	1.27	1.08	1.50	0.08
2010	1.25	1.07	1.46	0.08
2011	1.34	1.15	1.56	0.08
2012	1.19	1.02	1.38	0.07
2013	1.05	0.90	1.21	0.07
2014	1.07	0.93	1.24	0.07
2015	0.94	0.80	1.11	0.08
2016	1.09	0.91	1.30	0.09

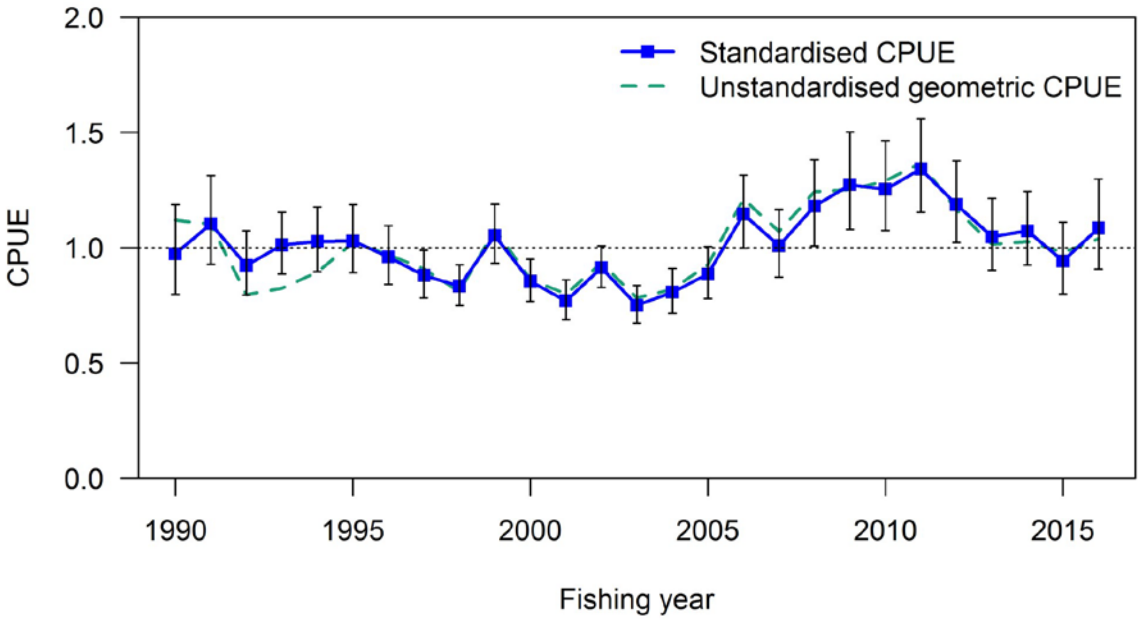


Figure 68: The standardised CPUE index for the combined dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

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 measurement used was 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. Note that basal length differs from the measurement method used in the commercial fishery which is the longest overall length measured (not restricted to basal). For this reason, a small proportion of the market samples appear to be below the MLS of 125 mm. Since 2006–07, the paua catch sampling data have been collected by the Paua Industry Council and they measure and record overall length including the spire as well as basal length.

A new extract of Catch Sampling Length Frequency (CSLF) data was made from the *market* database on 1 August 2016. This totalled 17 196 records containing 80 327 measurements from 1990–94 and 1998–2015. Deducing the statistical area for records prior to 2001–02 required some analysis as a variety of area codes were used. Statistical area information was obtained for 86% of records using a variety of fields in the data and lookup tables provided from previous assessments (Table 26). One record was removed as lengths greater than 200 mm were reported. The majority of samples were taken from Statistical Area 026 (Catlins and East), with fewer samples taken from the southern part of the stock (Statistical Areas 025 and 030). In 1992–1994, 1999, 2000, 2005, 2006, and 2008, Statistical Areas 025 and 030 were not sampled at all. In general, between 10 and 60 landings were sampled each year. There appears to be an increase in sampling effort since 2013, particularly in Statistical Areas 025 and 030. But overall the volume of samples in recent years is still considerably lower than in other QMAs such as PAU 3 and PAU 7 (Haist 2014). The sampling coverage from 2012 to 2015 was reasonably representative of the commercial catch in the fishery with respect to season (Figure 69-left) and area (Figure 69-right), although there tends to be relatively more samples in October-November when the fishing season started. There also tend to be relatively more samples in the South compared to the North.

Spatial and temporal variations in length distributions were examined by comparing the mean length in the sampled landings across statistical areas for 2002–2005, 2006–2010, and 2011–2015 (Figure 70). There appears to be no discernible trend in mean length overall and in general the mean length has been similar across fine statistical zones although there were considerable variations. However, there appears to be an increase in mean length eastward within “South” and “Catlin east”, possibly a reflection of differences in growth at fine spatial scales. The mean length in catch samples has increased over time (across the three periods). The increase of mean length in 2006–2010 is consistent with the increased catch rates during this period, probably as a result of improved stock status in responding to the TACC reduction in the early 2000s, and also as a result of the implementation in the increase of minimum harvest size across the main fishery areas in PAU 5D since 2005–06.

Only samples with known areas were included. Data from 1999, 2000, and 2001 were excluded because there was a large number of samples with areas unknown. The scaled length frequency distributions for PAU 5D from 1992–1994, 1998 and 2002–2015 were calculated. The calculation was implemented using NIWA’s ‘catch-at-age’ software (Bull & Dunn 2002). Between 1992 and 2001, the catch samples were stratified using the general Statistical Areas; wheras between 2002 and 2013 the stratification was based on the sub-areas (see Table 3). The length frequency distributions 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 frequency distributions 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. Scaled length frequency distribution for the southern and northern areas are shown in Figure 71.

Table 27: Number of landings sampled and number of paua measured from the market shed sampling program by statistical area and by fishing year. * indicates area unknown.

	Number of landings sampled						Number of paua measured					
Year	030	025	026	024	*	Total	030	025	026	024	*	Total
1992	0	0	10	5	0	15	0	0	3 257	1 549	0	4 806
1993	0	1	10	22	0	33	0	308	2 801	7 300	0	10 409
1994	0	1	9	6	0	16	0	307	3 110	1 875	0	5 292
1998	2	2	6	7	1	18	285	259	803	859	136	2 342
1999	0	0	0	0	1	1	0	0	0	0	187	187
2000	0	0	12	2	18	32	0	0	1 206	218	2 279	3 703
2001	2	1	3	0	38	44	277	122	364	0	4 850	5 613
2002	6	2	28	7	5	48	794	251	3 430	770	659	5 904
2003	7	3	38	3	8	59	914	324	4 355	314	906	6 813
2004	1	8	13	8	6	36	102	819	1 503	853	685	3 962
2005	2	0	7	3	7	19	200	0	741	337	734	2 012
2006	0	0	3	4	4	11	0	0	412	518	499	1 429
2007	3	3	6	6	0	18	374	370	748	568	0	2 060
2008	0	2	7	3	0	12	0	241	848	289	0	1 378
2009	6	3	17	8	0	34	699	294	1 573	704	0	3 270
2010	3	11	23	3	0	40	234	880	2 211	293	0	3 618
2011	3	5	9	7	0	24	168	306	658	575	0	1 707
2012	5	6	9	11	0	31	374	513	735	927	0	2 549
2013	8	11	25	12	0	56	739	801	1 701	880	0	4 121
2014	21	9	24	7	0	61	1 828	763	2 017	646	0	5 254
2015	15	16	11	12	0	54	1 155	1 069	796	878	0	3 898
Total	84	84	270	136	88	662	8 143	7 627	33 269	20 353	10 935	80 327

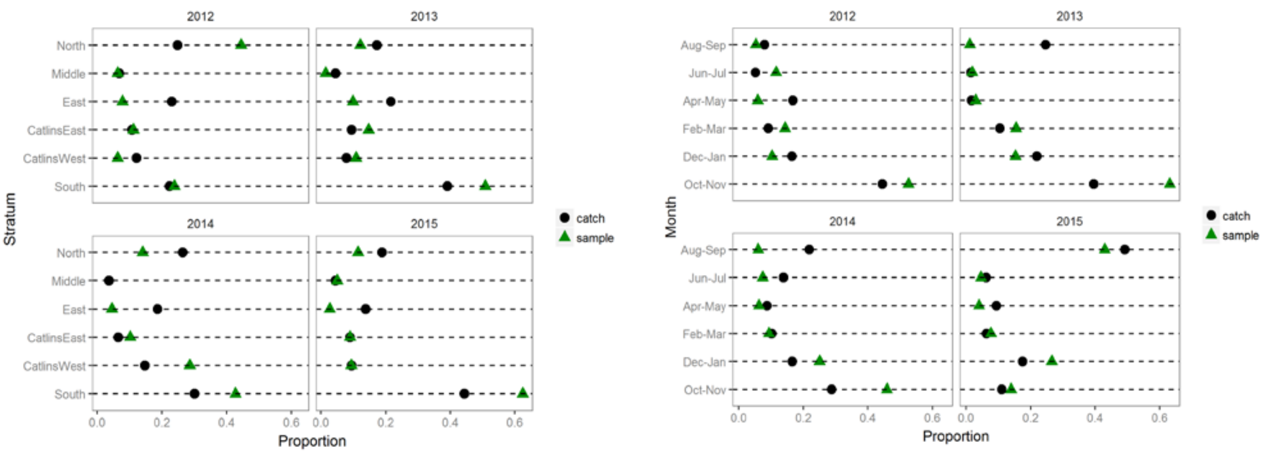


Figure 69: Proportion of total catch and sampled catch by subarea (left) and by month (right) for the 2008–2015 fishing years.

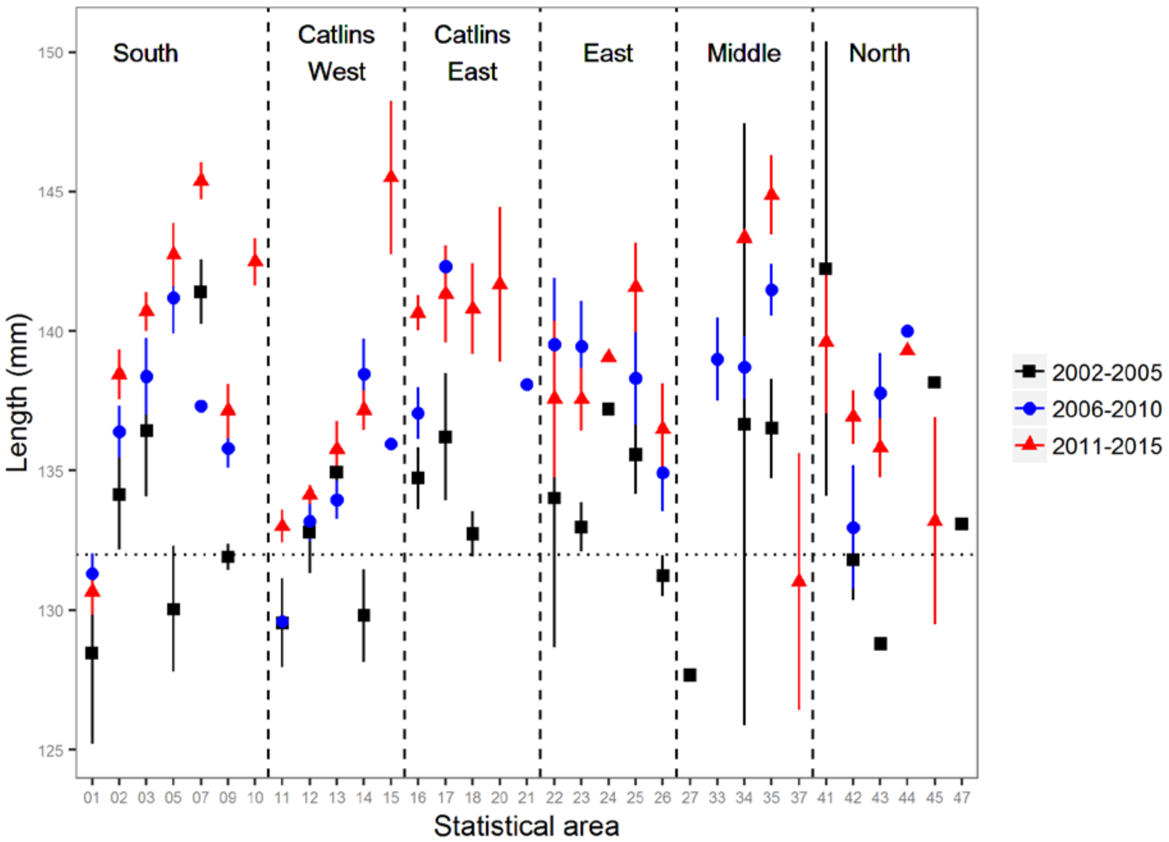


Figure 70: Mean length (dot) with one standard error (bar) of measured paua from market shed sampling by statistical area calculated for periods 2002–2005, 2006–2010, and 2011–2015. The mean is calculated across sampled landings and the standard error is the standard deviation of the mean.

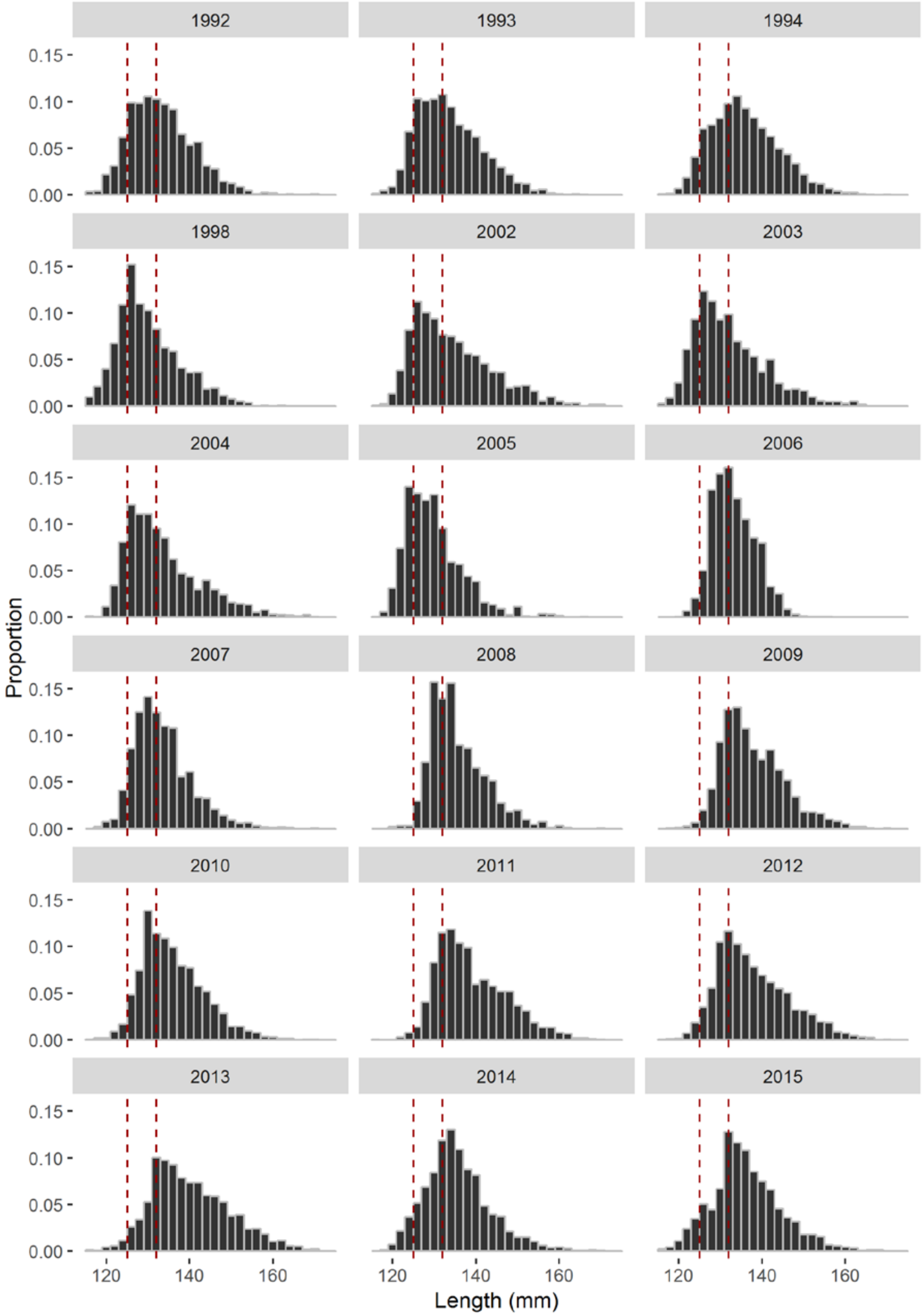


Figure 71: Scaled length frequency distributions for paua from commercial catch sampling for PAU 5D for fishing years 1992–1994, 1998, and 2002–2015 The dashed lines indicate the minimum legal size limit of 125 mm and the minimum harvest size of 132 mm implemented more recently.

6. RESEARCH DIVER SURVEY INDEX (RDSI)

Research diver surveys based on a timed-swim method 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 & Kim, 2007, McKenzie & Smith 2009, Breen & Smith 2008b). The previous stock assessment for PAU 5A used the RDSI developed from the survey data up to 2010 (Fu & McKenzie 2010). There has been no new survey since the last 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.

Given these concerns, in the most recent stock assessments of PAU 5D (Fu 2013), PAU 7 (Fu 2016), PAU 5B (Fu 2014) RDSI and the associated length frequency data (RDLF) were not included in the base case. The same decision has been made here: the RDSI and RDLF were excluded from the base case but the RDLF were included as a sensitivity analysis. The calculation of the relative abundance indices from the RDSI data were described by Fu et al. 2010.

7. RESEARCH DIVER LENGTH FREQUENCY (RSLF)

The RDLF data are unchanged from the previous assessment but were excluded from the base case,

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Tag and recapture experiments were conducted at different times and at several sites in PAU 5D (Breen & Kim 2007). Growth data collected from these experiments were available from Catlins west (Boat Harbour n=116), Catlins east (Saddle n=61, Papatowai n=24), and East coast (Roaring Bay n=43, Seal Point n=37). The growth dataset comprises 281 records with initial lengths ranging from 43 to 168 mm, time at liberty ranging from 243 to 473 days and annualised increments ranging from -1 to 28.9 mm. These data were incorporated into the PAU 5D assessment to estimate growth. No new tag recapture data have been collected since the last PAU 5D assessment.

The growth-increment 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 assuming fixed at 1 mm 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 growth-increment 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 inverse-logistic 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 ø and Φ are the standard normal probability density function and cumulative density functions respectively. The measurement error σ_E was assumed to be known as 1 mm.

Annual growth increment measurements were considered. The inverse-logistic model was fitted to the data for all areas combined (Figure 72). The growth parameters were estimated to be $\Delta_{\max}$=20.2 mm, $l_{50}^g = 114.6$ mm $l_{95}^g = 152.0$ mm. The parameters for variation in growth were estimated as α=1.46 β=0.44 mm. The inverse-logistic model was also fitted to the data where paua tagged at sizes smaller than 70 mm were removed (n=40) because the assessment model does not represent paua less than 70 mm in length. This appears to have little effect on estimates of either growth parameters or variance components.

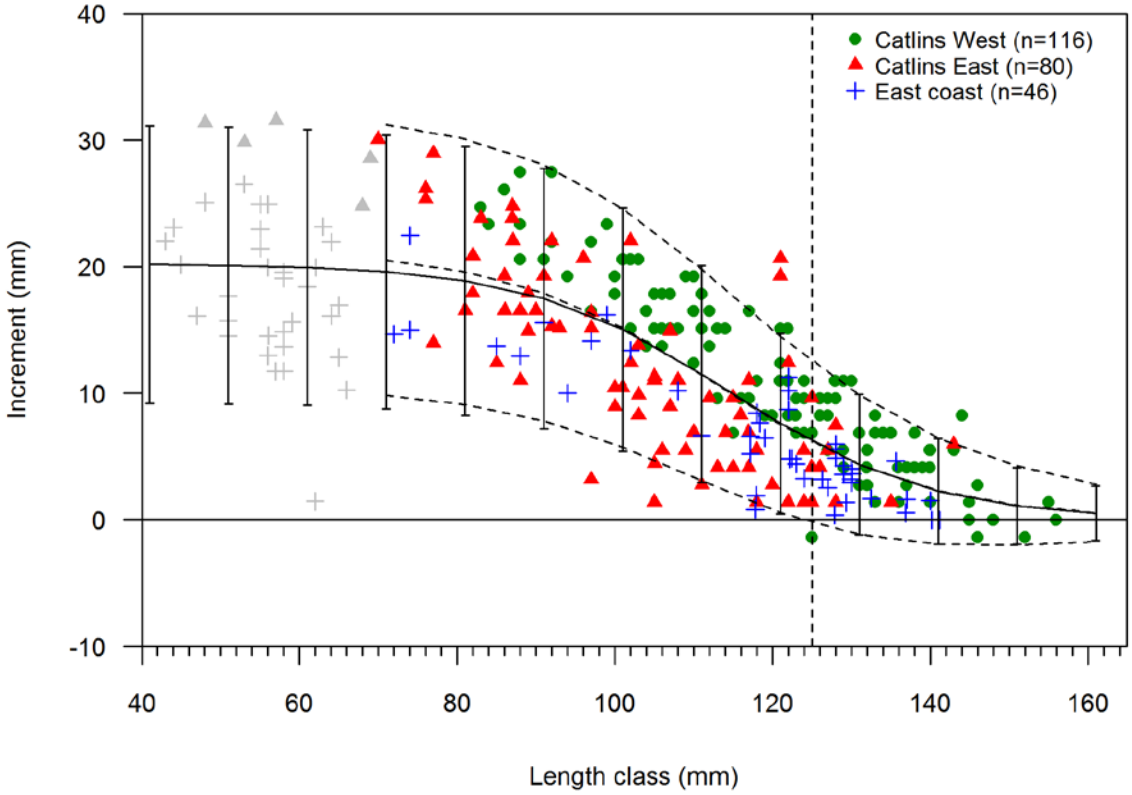


Figure 72: Initial size and mean annual increment from the tag-recapture data within PAU 5D fitted with an inverse logistic growth curve (and 95% confidence intervals). Solid lines are estimates from the model fitted to all the data; dashed lines are from the model fitted to all data with initial size ≤70mm being excluded (grey symbols) Vertical dashed line indicates the legal size limit (125 mm).

9. MATURITY

Previous length at maturity data were collected in November 1996 (n=66) and in March 2001 (n=13). These samples were collected from the Catlins west research stratum from a total of eight sites, one in fine scale Paua Statistical Area H11, three from H13 and four from H14. New samples were collected from Catlins west in 2016, one from fine scale Paua Statistical Area H12 in May (n= 103) and one from fine scale Paua Statistical Area H14 in August (n=142).

The length of paua examined ranged from 58 mm to 168 mm. The proportion mature data were fitted with a logistic curve using a binomial likelihood for the early and recent samples separately (2001 data was combined with 1996 due to the small sample sizes), as well as for all the data combined (Figure 73). Length at 50% maturity ($L_{50\%}$) was estimated to be 80.2 mm and Length at 95% maturity ($L_{95\%}$) about 95.9 mm, for data collected in 1996. Length at 50% maturity was estimated to be higher for samples collected in 2016, with $L_{50\%}$ estimated to be 86 mm, and $L_{95\%}$ estimated to be 98.7. Further analysis of the 2016 samples shows that samples from fine scale Paua Statistical Area H12 had a much higher length at 50% maturity, which was estimated to be about 93 mm. These differences suggested considerable spatial variability of the lengths-at-maturity. For the combined data $L_{50\%}$ was estimated to be 84.5 mm and $L_{95\%}$ about 98.3 mm.

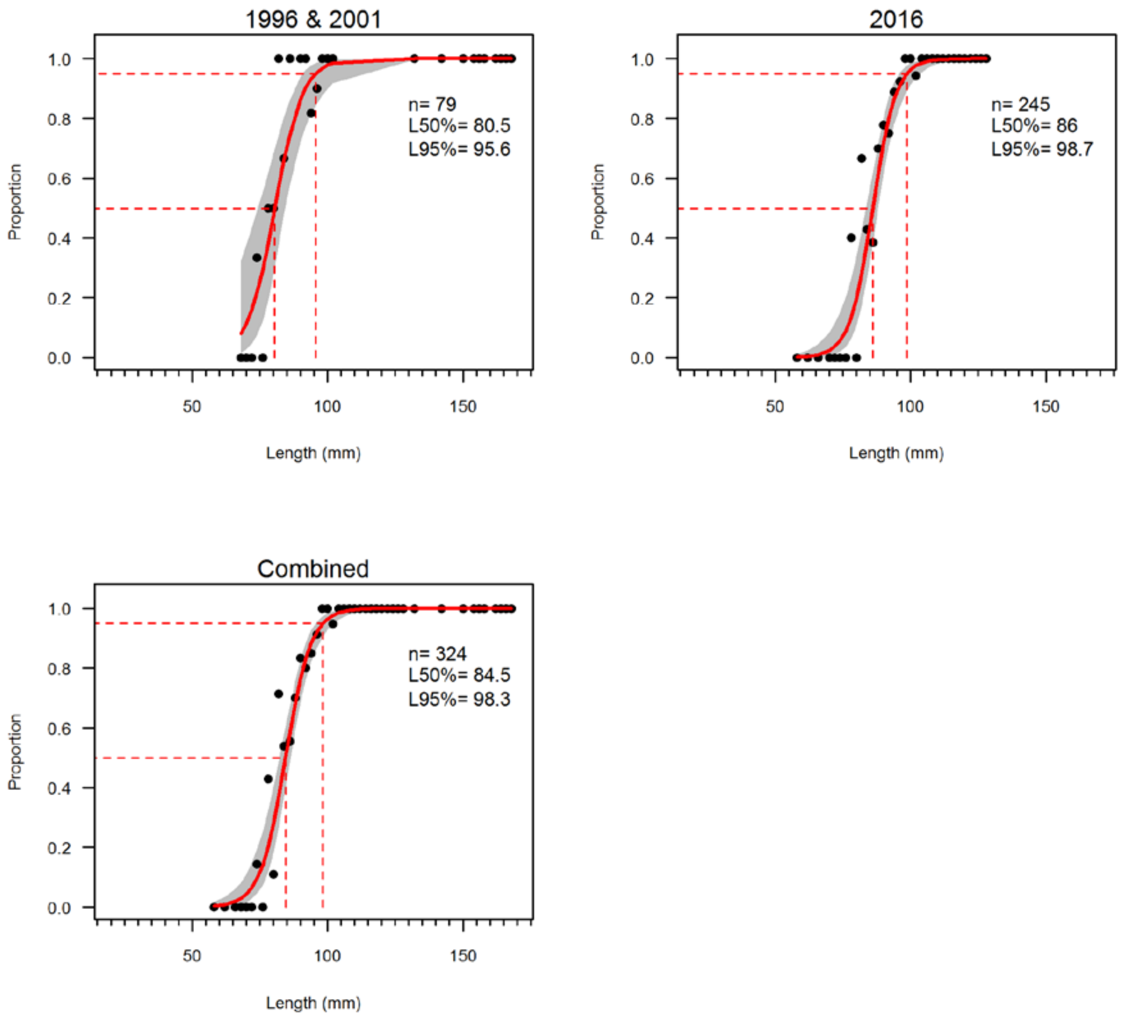


Figure 73: Proportion of maturity at length for PAU 5D. The dots represent the observed proportion mature for each 2 mm length bin. The red line represents a fitted logistic maturity curve. The grey area represents the 95% confidence interval of estimated proportion. The dashed lines represent estimated length at 50% and 95% maturity.

10. ACKNOWLEDGMENTS

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APPENDIX A

In March 2015 an expert panel reviewed the New Zealand paua stock assessment models and associated data collection programmes (Butterworth et al. 2015). Recommendation twenty one from the review concerned paua CPUE standardisations and states the following:

"Robustness to the CPUE standardisation assumptions should be fully investigated by developing alternative CPUE series to test in model sensitivity runs. Alternative series potentially include: PCELR data collapsed to the CELR format to form a single CPUE series; standardising CELR data by diver day instead of by diver hour; and for PAU 5B, including data from all Statistical Area 25 and 30 observations into the CELR standardisation. Unless there is clearly no effect of the alternative standardisation approach, the alternative CPUE series should be fitted in the assessment model as sensitivities".

Rationale: *The CPUE indices have a large effect on model estimates of abundance, in particular the recent trends in abundance. As such, model sensitivity to alternative CPUE indices will likely show more variability in the estimates of recent trends than other sensitivity runs*.

For the PAU 5B CELR standardisation, virtually all of the Area 25 and 30 catch-effort data for 1990 1995 are excluded from the standardisation because these areas are partially outside of PAU 5B. Given that Area 25/30 represents over half of the PAU 5B catch, if CPUE trends in these areas differ from those of Areas 27/28, the standardised CPUE will not reflect abundance trends. An approach to check for this would be to conduct a CELR standardisation that includes all Area 25 and Area 30 catch-effort records (approximately 75% of the catch from these areas is attributed to PAU 5B).

The selection of data records for the CELR standardisation (using diver hours as the fishing duration measure) may introduce bias. Records are selected where the number of divers is 1, or the number of divers is 2 or greater and the number of hours fished is 8 or greater. The data for single divers often have median dive times of about 4 hours, which suggests that many records with legitimate dive times (i.e. 2 divers and less than 8 hours fished) would be eliminated. This is a problem, in terms of bias, only if catch rates for short duration days differ from long duration days. The only way to ensure unbiased data to evaluate if dive hours per day has changed over time, or if there is correlation between catch rates and fishing hours/day, is to restrict the data set to records that represent a single diver. Any other process will retain some erroneous records and remove some correct records.