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Summary of input data for the 2014 PAU 5A stock assessment

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EXECUTIVE SUMMARY

Fu, D.; McKenzie, A; Naylor, R. (2015). Summary of input data for the 2014 PAU 5A stock assessment.

***New Zealand Fisheries Assessment Report 2015/68.* 88 p.**

This document summarises the data inputs for the 2014 stock assessment of blackfoot paua in PAU 5A. In 2010, the Shellfish Working Group decided that separate assessments be conducted for two subareas of PAU 5A: a southern area including Chalky and the South Coast, and a northern area including Milford, George, Central, and Dusky. The same decision was made for this assessment.

The seven sets of data fitted in the assessment model were: (1) a standardised CPUE series based on CELR data (2) a standardised CPUE series based on PCELR data (3) a standardised research diver survey index (RDSI) (4) a research diver survey proportions-at-lengths series (5) a commercial catch sampling length frequency series (CSLF) (6) tag-recapture length increment data and (7) maturity-at-length data. The CPUE, RDSI, RDLF, and CSLF data were collated for the southern and the northern areas separately, but the same tag-recapture and maturity-at-length data were used for both areas.

Catch history was an input to the model encompassing commercial, recreational, customary, and illegal catch. Three alternative assumptions were made for estimating the commercial catch history for PAU 5A: 18% (lower bound), 40% (base case), and 61% (upper bound) of the catch in Statistical Area 030 was assumed to have been taken from PAU 5A between 1985 and 1996. Assumptions have also been made on the split of the catch between the northern and southern strata for the period when the split proportion cannot be inferred from available data.

A new standardisation was done for the CELR data, based on a derived data set where the fishing duration was likely to be reliable. The standardised CPUE series based on PCELR data was updated to the 2013–14 fishing year. There has been no research diver survey since the last assessment, and therefore the same RDSI and RDLF were used for this assessment. The data from research diver survey were not included in the base case model. Scaled length frequency series from the commercial catch sampling were updated to the 2012–13 fishing year, where the catch samples were stratified by area and numbers at length were scaled up to each landing and then to the stratum catch. There has been no new tag-recapture or maturity-at-length data since the last assessment.

1. INTRODUCTION

This document summarises the data inputs for the 2014 stock assessment of PAU 5A. The work was conducted by NIWA under the Ministry for Primary Industries' contract PAU201401 Objective 1. Two separate documents detail the stock assessment of PAU 5A (Fu 2015a, 2015b). PAU 5A was last assessed in 2010 (Fu & McKenzie 2010a, b) and before that in 2006 (Breen & Kim 2007) and in 2004 (Breen & Kim 2004). 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".

Earlier assessments for PAU 5A (Breen & Kim 2004, 2007) were conducted assuming a homogeneous area covering the whole of PAU 5A. There were concerns about the applicability of the assessment to the entire QMA, although there was general agreement that biomass decline had occurred in the southern region of the stock over recent years. Before 2005–06, fishery-independent surveys were conducted only in the area from Dusky south, which has accounted for about 60% of the catch over the last four years. Recent studies suggested that trends in the changes of abundance may have varied between subareas within PAU 5A (Cordue 2009). A model assuming a homogeneous area is therefore unlikely to reflect the different exploitation histories between subareas or to predict the current status of the stock. Based on differences in exploitation histories and management initiatives, a decision was made in the 2010 assessment to split the QMA into a southern area including Chalky and South Coast, and a northern area, including Milford, George, Central, and Dusky, and to conduct separate assessments for the southern and northern areas (Fu et al. 2010). The same decision was made for this assessment.

This report summarises the model input data for PAU 5A to the 2013–14 fishing year. The data were collated for the southern and the northern areas respectively, including:

1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2014 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 7 assessment (Fu et al. 2012), PAU 5D (Fu et al. 2013), PAU 5B (Fu et al. 2014a), and PAU 3 (Fu et al. 2014b). There has been no research diver survey since the last assessment, and therefore no update were made to the RDSI and RDLF series.

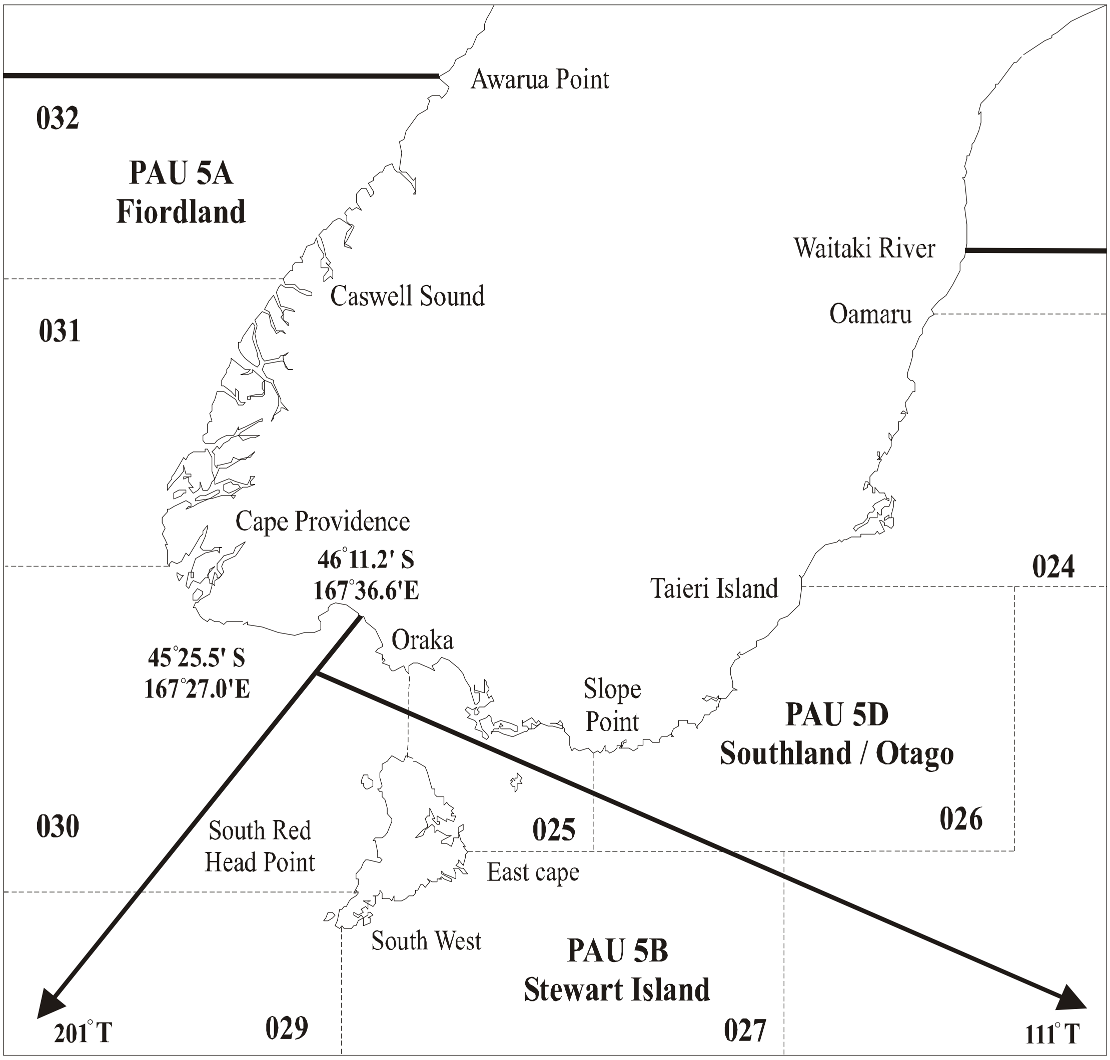


Figure 1: Map showing the QMAs effective from 1 October 1995 (solid dark lines) and the old General Statistical Area boundaries (dashed lines) of PAU 5.

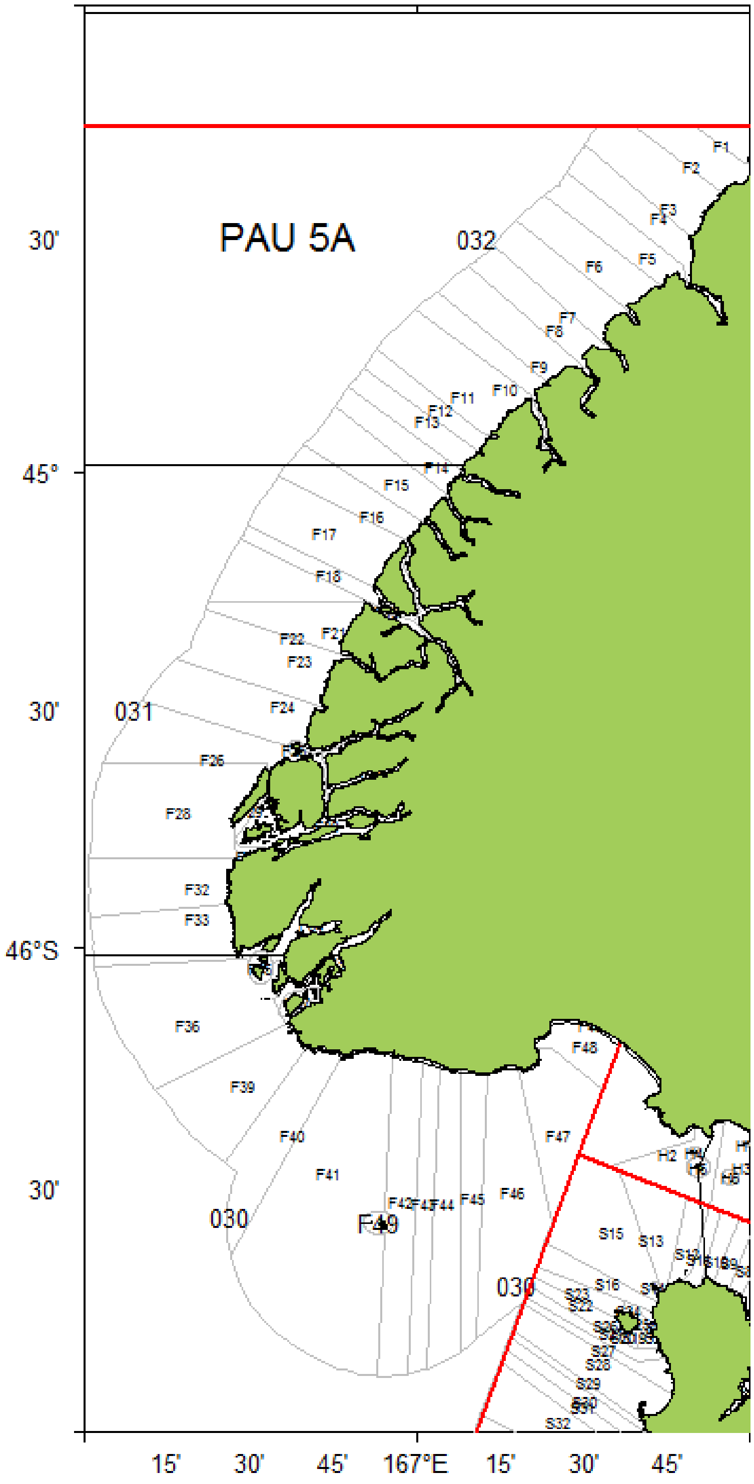


Figure 2: Map showing the location of fine scale Paua Statistical Areas within PAU 5A effective from 1 October 2001.

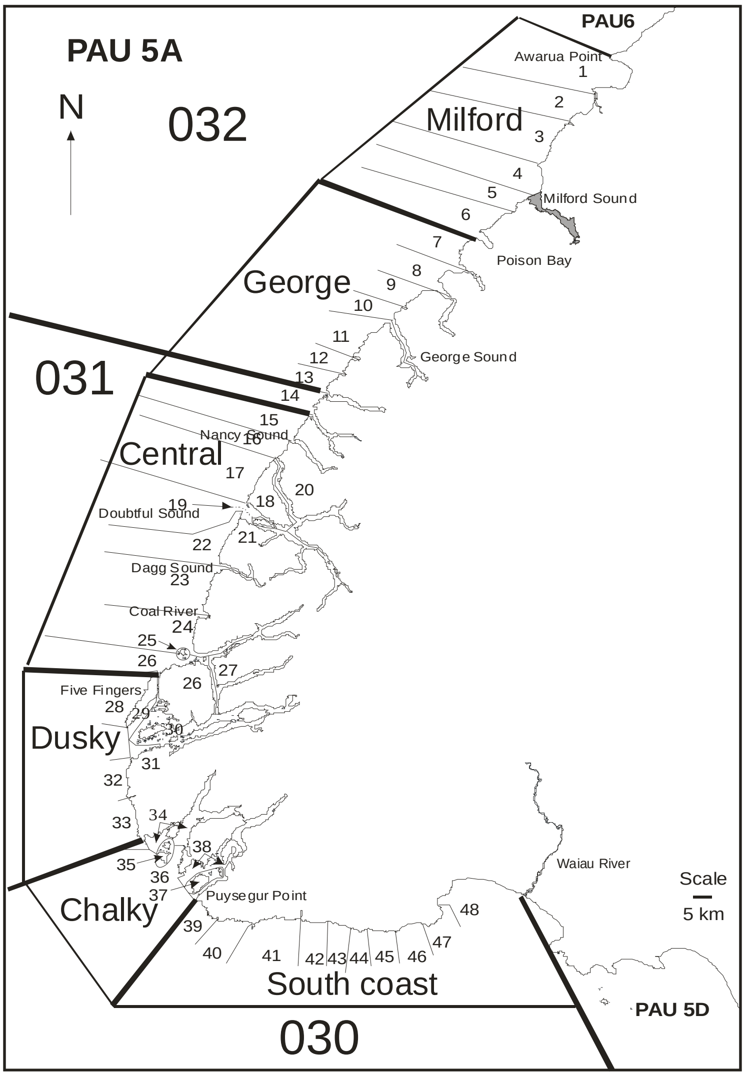


Figure 3: Map of research strata for PAU 5A. Statistical area 049 in shown in Figure 2, but not in this map.

2. DESCRIPTION OF THE FISHERY

PAU 5A includes the coastal areas and islands of Fiordland, from the Waiau River (west of Riverton) to Awarua Point (north of Big Bay). Prior to 1995 PAU 5A 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 145t. 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 finer-spatial scale statistical zones originally developed for the New Zealand Paua Management Company's voluntary logbook (Figure 2). A summary of the spatial resolution of reporting zones and research strata for PAU 5A is given in Tables 2 and 3.

The TACC for PAU 5A has remained at the initial level of 145 t since the 1995–96 fishing year and landings have been close to the TACC since 1998–99. In October 2006, the commercial fishery have undertaken voluntary fishery management measures where they have subdivided the QMA into six voluntary management zones each with its own harvest cap and have undertaken a 30% reduction in catch (30% shelving, Figure 3). The harvest caps are designed to reduce effort in the southern three zones (Dusky, Chalky, and South Coast, Table 4) and to reduce the catch in these areas by 50%. This effectively reduces the allowable catch from 148 983 to 104 290 kg. The shelving has remained unchanged since the 2006–07 fishing year.

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

* FSU data, † QMR/MHR data

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

QMA		Statistical Area		
–30 Sep 1995	Oct 1995–present	–30 Oct 1997	Nov 1997–Sep 2001	Oct 2001–present
PAU 5	PAU 5A	031	A6–A12	P5AF14–P5AF34
		032	A1–A5	P5AF01–P5AF13
		030(part of)	A13–A17	P5AF35–P5AF49

Table 3: Summary of research strata (subareas) and associated Paua Statistical Areas within PAU 5A.

Subarea	Paua Statistical Area
Milford	P5AF01–P5AF06
George	P5AF07–P5AF14
Central	P5AF15–P5AF26
Dusky	P5AF27–P5AF33
Chalky	P5AF34–P5AF38
South	P5AF39–P5AF49

Table 4: Voluntary harvest cap and Minimum harvest size placed on each of the management zones since October 2006.

Management Zones	Milford	George	Central	Dusky	Chalky	South Coast
Harvest Cap (kg)	2 990	30 510	25 770	14 260	9 680	21 070
MHS (mm)	125	127	130	130	130	130

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 the 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 et al. 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 5A. A constant proportion of 23% 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 5A was firstly estimated, where a constant proportion of the annual estimated catch in Statistical Areas 030 was assumed to have been taken from PAU 5A, and that proportion was applied to the QMR/MHR landings in PAU 5 to obtain the catch estimates. In the 2010 assessment for PAU 5A (Fu et al. 2010), alternative assumptions were suggested by the SFWG concerning the proportion of catch in Statistical Area 030 that were taken from PAU 5A, PAU 5B, and PAU 5D between 1983–84 and 1995–96: (1) 18%, 75%, and 7% respectively, (2) 40%, 53%, and 7% respectively, and (3) 61%, 32%, and 7% respectively.. These assumptions have been adopted here to obtain catch estimates for each of the substocks within PAU 5 (Table 5).

The catch histories for the northern and southern areas were obtained by splitting the estimated PAU 5A catch 1974–2014 between the two regions using a proportion determined annually from:

- 1996–2014 estimated catch on the CELR/PCELR by Statistical Areas 030, 031, and 032 within PAU 5A.
- 1984–1995 estimated catch on the FSU/CELR by Statistical Areas 030, 031, and 032, assuming a fixed proportion (18%, 40%, or 61%) of the catch in 030 was taken from PAU 5A.
- 1974–1983 the total estimated catch 1984–1995 by Statistical Areas 030, 031, and 032, assuming a fixed proportion (18%, 40%, or 61%) of the catch in 030 was taken from PAU 5A.

Estimated commercial catch histories for the northern and southern areas in PAU 5A are shown in Figure 4. For the 2014 assessment, the catch history estimated under assumption 2 was used in the base case model run, and the other estimates were used in sensitivity runs.

The estimated catches by fine-scale statistical area from the years of PCELR data are shown in Figure 5. Catches were taken throughout the stock and were widely distributed among subareas, with no signs of apparent serial depletion in the last 11 years (Figure 5), at least at this scale. South coast appeared to be the largest area for the catch, and about 25–35% of the annual catch has been taken from this region since 2002, except in 2008, 2010, and in 2014 (Table 6). George was the second largest area for the catch, accounting for about 20–30% of the total catch in most years, and has become the dominant area over the last two years. Milford was the smallest area in catch, contributing less than 5% of the total catch. However the catch in Milford increased significantly in 2013 and in 2014, as a result of the industry initiative to shift effort to the northern part of PAU 5A.

Table 5: Collated commercial catch histories (kg) for PAU 5A, 5B, and 5D for fishing years 1974–2014 under assumptions 1, 2, and 3 of the proportion of Statistical Area 030 catch to come from PAU 5A.

			Assumption 1 (18%)			Assumption 2 (40%)			Assumption 3 (61%)	
Year	PAU 5	PAU 5A	PAU 5B	PAU 5D	PAU 5A	PAU 5B	PAU 5D	PAU 5A	PAU 5B	PAU 5D
1974	212 670	48 914	110 588	53 168	48 914	110 588	53 168	48 914	110 588	53 168
1975	201 180	46 271	104 614	50 295	46 271	104 614	50 295	46 271	104 614	50 295
1976	160 110	36 825	83 257	40 028	36 825	83 257	40 028	36 825	83 257	40 028
1977	221 400	50 922	115 128	55 350	50 922	115 128	55 350	50 922	115 128	55 350
1978	333 460	76 696	173 399	83 365	76 696	173 399	83 365	76 696	173 399	83 365
1979	349 960	80 491	181 979	87 490	80 491	181 979	87 490	80 491	181 979	87 490
1980	433 100	99 613	225 212	108 275	99 613	225 212	108 275	99 613	225 212	108 275
1981	524 340	120 598	272 657	131 085	120 598	272 657	131 085	120 598	272 657	131 085
1982	346 560	79 709	180 211	86 640	79 709	180 211	86 640	79 709	180 211	86 640
1983	442 980	101 885	230 350	110 745	101 885	230 350	110 745	101 885	230 350	110 745
1984	550 515	107 360	294 704	148 451	146 179	248 276	156 060	183 233	211 222	156 060
1985	352 459	46 409	224 301	81 749	70 894	191 458	90 107	94 266	168 086	90 107
1986	331 697	50 646	215 811	65 240	69 949	188 216	73 532	88 374	169 791	73 532
1987	418 904	25 826	251 501	141 578	36 893	225 028	156 983	47 458	214 464	156 983
1988	458 239	37 310	327 861	93 068	56 492	288 564	113 182	74 803	270 254	113 182
1989	445 978	118 393	231 793	95 791	152 824	191 590	101 563	185 690	158 725	101 563
1990	468 647	74 372	254 105	140 170	106 101	212 681	149 865	136 388	182 394	149 865
1991	510 335	124 440	243 050	142 845	156 661	203 192	150 482	187 417	172 436	150 482
1992	483 037	100 107	254 026	128 904	133 056	212 908	137 073	164 507	181 457	137 073
1993	435 395	50 724	221 898	162 773	81 292	181 583	172 520	110 471	152 404	172 520
1994	440 144	57 733	233 533	148 878	86 016	196 333	157 794	113 015	169 335	157 794
1995	434 708	65 767	231 350	137 591	96 510	192 424	145 774	125 856	163 078	145 774
1996	429 959	138 526	144 661	146 772	138 526	144 661	146 772	138 526	144 661	146 772
1997	433 195	143 848	142 357	146 990	143 848	142 357	146 990	143 848	142 357	146 990
1998	439 279	145 224	145 337	148 718	145 224	145 337	148 718	145 224	145 337	148 718
1999	444 638	147 394	148 547	148 697	147 394	148 547	148 697	147 394	148 547	148 697
2000	409 878	143 913	118 068	147 897	143 913	118 068	147 897	143 913	118 068	147 897
2001	386 949	148 221	89 915	148 813	148 221	89 915	148 813	148 221	89 915	148 813
2002	387 238	148 535	89 963	148 740	148 535	89 963	148 740	148 535	89 963	148 740
2003	350 320	148 764	89 863	111 693	148 764	89 863	111 693	148 764	89 863	111 693
2004	327 008	148 980	90 004	88 024	148 980	90 004	88 024	148 980	90 004	88 024
2005	327 739	148 952	89 970	88 817	148 952	89 970	88 817	148 952	89 970	88 817
2006	328 320	148 922	90 467	88 931	148 922	90 467	88 931	148 922	90 467	88 931
2007	282 163	104 034	89 156	88 973	104 034	89 156	88 973	104 034	89 156	88 973
2008	284 315	105 132	90 205	88 978	105 132	90 205	88 978	105 132	90 205	88 978
2009	283 591	104 823	89 998	88 770	104 823	89 998	88 770	104 823	89 998	88 770
2010	285 420	105 740	90 230	89 450	105 740	90230	89 450	105 740	90 230	89 450
2011	282 770	104 400	89 670	88 700	104 400	89 670	88 700	104 400	89 670	88 700
2012	285 053	106 234	89 589	89 230	106 234	89 589	89 230	106 234	89 589	89 230
2013	284 049	105 560	90 575	87 914	105 560	90 575	87 914	105 560	90 575	87 914
2014	275 731	102 298	88 841	84 592	102 298	88 841	84 592	102 298	88 841	84 592

Table 6: Proportion of estimated catch from PCELR forms for fishing years 2002–2014 in each of the research strata within PAU 5A.

Fishing year	Milford	George	Central	Dusky	Chalky	South	Total (t)
2002	0.03	0.22	0.15	0.12	0.13	0.36	138
2003	0.02	0.11	0.22	0.2	0.11	0.34	141
2004	0.01	0.22	0.10	0.31	0.13	0.24	135
2005	0.02	0.21	0.15	0.23	0.12	0.27	139
2006	0.03	0.19	0.15	0.14	0.18	0.30	146
2007	0.04	0.25	0.23	0.13	0.10	0.25	101
2008	0.03	0.29	0.18	0.17	0.16	0.18	101
2009	0.02	0.26	0.14	0.14	0.12	0.32	100
2010	0.04	0.23	0.23	0.16	0.19	0.14	101
2011	0.07	0.17	0.18	0.22	0.08	0.28	93
2012	0.06	0.26	0.12	0.13	0.13	0.29	98
2013	0.12	0.25	0.07	0.12	0.20	0.23	97
2014	0.21	0.25	0.15	0.02	0.17	0.20	101
Total	0.05	0.22	0.16	0.17	0.14	0.27	1490

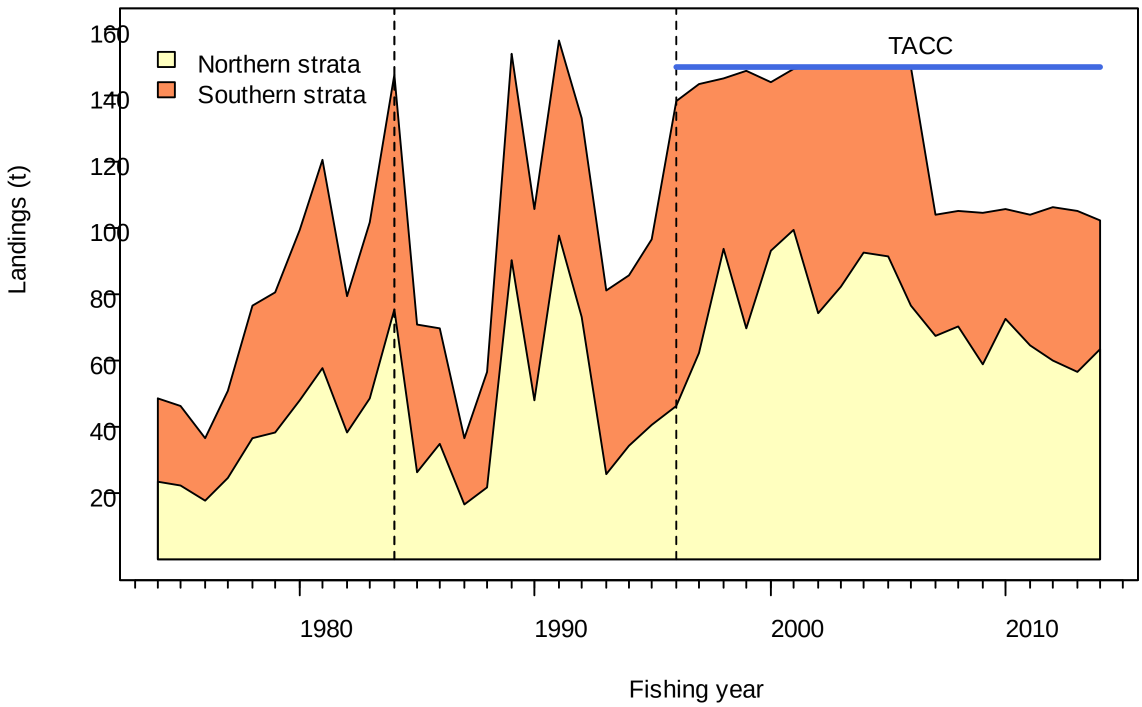


Figure 4: Estimated catch history for the northern and southern strata under assumption 2 (base case), 1974–2014 fishing years.

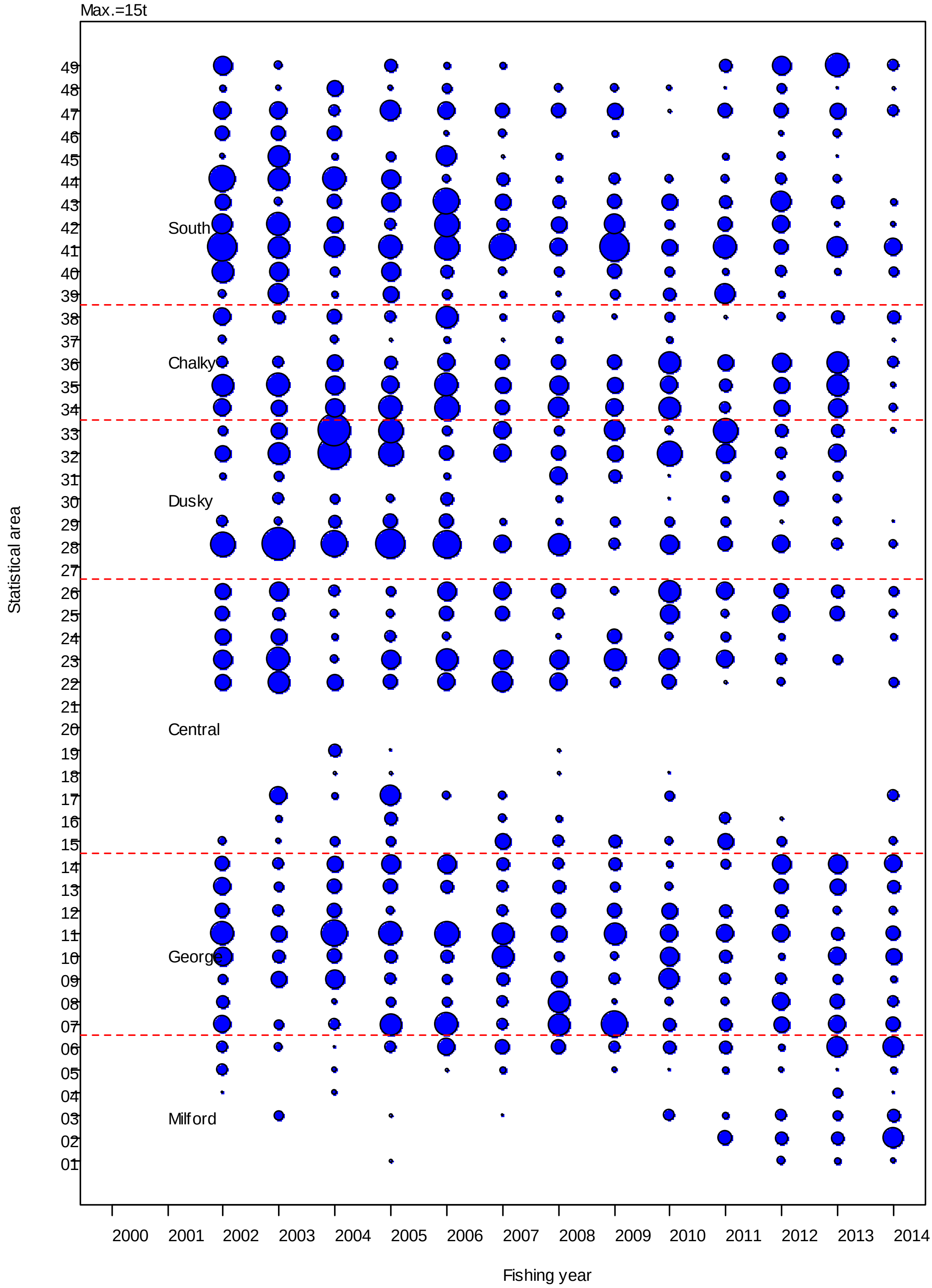


Figure 5: Annual estimated catch by Paua Statistical Area in PAU 5A for fishing years 2002–2014. The size of the circle is proportional to the catch. The red dashed lines delineate where research strata lie (see Figure 3).

3.2 Recreational catch

The 1996 and 1999–2000 National Recreational Fishing Surveys estimated that 37.1 t and 53.2 t were taken respectively from PAU 5 by recreational fisheries but with no substock breakdown. The 2000–01 survey estimated a recreational harvest of 8000 paua from PAU 5A. At an average weight of 357 g, these numbers equate to a recreational harvest of 2.8 t.

The New Zealand Recreational Marine Survey for 2011–12 estimated that about 1480 paua were harvested by recreational fishers in PAU 5A (less than half a ton). For this assessment, the SFWG agreed to assume that the recreational catch rose linearly from 1 t in 1974 to 5 t in 2006, and remained at 5 t between 2007 and 2013.

3.3 Customary catch

There are no published estimates of customary catch. Records of customary non-commercial catch taken under the South Island Regulations show that about 100 to 500 paua were collected each year from 2001–02 to 2012–13 (noting that no information is available in the customary database for PAU 5A for 2003, 2005 or 2007). The customary catch is estimated at less than 1 t as the rununga have a rahui on the issue of customary permits for Fiordland. For the stock assessment model, the SFWG agreed to assume that customary non-commercial catch has been constant at 1 t.

3.4 Illegal catch

There are no estimates of illegal catch for PAU 5A. Illegal catch is not considered to be a major problem because PAU 5A is isolated and exposed to prevailing weather conditions. It is anticipated that any poaching that does occur would happen in the more accessible areas in the southern and northern parts of the QMA. For the purpose of the stock assessment model, the SFWG agreed to assume that illegal catches have been a constant 5 t.

We further assume that 90% of the recreational, customary, and illegal catches in PAU 5A were taken from the southern area, and the rest from the northern area. As in the previous assessment, total catches for 1964 to 1973 were assumed, based on linear interpolation from zero in 1962 to the level of the 1974 catch. The combined total of commercial, recreational, customary, and illegal catch for the southern and northern strata respectively is shown in Figure 6.

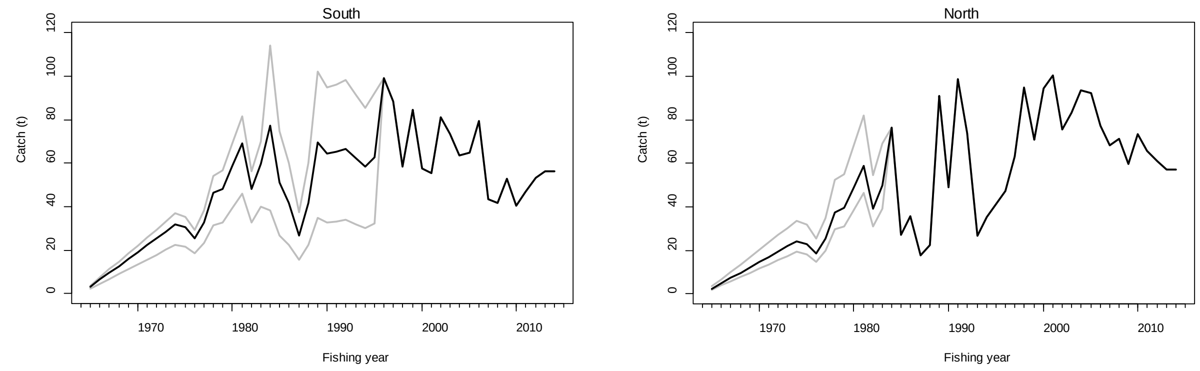


Figure 6: Estimated catch history including commercial, recreational, customary, and illegal catch for the southern and northern strata from 1964 to 2014 under assumption1 (corresponding to a lower catch history for the southern strata, but a higher catch history for the northern strata), the base case (assumption2, black lines), and assumption 3 (corresponding to a higher catch history for the southern strata, but a lower catch history for the northern strata).

4. CPUE STANDARDISATIONS

4.1 Introduction

For both the northern and southern area assessments two separate standardised CPUE series were calculated: (i) one based on CELR data from 1990 to 2001, and (ii) another based on PCELR data from 2002 to 2014. The background analyses, data set used, standardisation method, and results are described in the following sections.

It was decided not to include the FSU data from 1983 to 1988 as there were a low number of records, which covered only a small proportion of the estimated catch.

For the CELR data the fishing duration field is the *total* fishing duration for all divers. However, there is ambiguity as to what is actually recorded for fishing duration, because a mixture of total hours and per diver hours is recorded. To address this, a filtering procedure was used to delineate the records for which fishing duration was recorded as per diver hours. For these records, recorded fishing duration was scaled up by the number of divers to give the total fishing duration. Unlike previous standardisations for PAU 5A, fishing duration was offered as a predictor variable.

4.2 Background analyses for standardisation methodology

Some background analyses were conducted to inform Shellfish Working Group decisions regarding the standardisation data and methodology. In these we examined the utility of the FSU data, serial depletion and data quality for the PCELR data, and changes in fishing duration in the CELR data.

4.2.1 Utility of the FSU data

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.
3. Low coverage of the annual catch.

The PAU 5A FSU catch-effort data covers the period between 1983 and 1988 with a total of 167 records (Table 7). The number of records is low with fewer than 10 records in two of these years. Furthermore, the proportion of the estimated annual catch covered by the FSU data is low (denoted by the white bars in Figure 7). For either of these reasons the FSU data is unsuitable to use in a standardised CPUE analysis.

Table 7: Number of FSU records by fishing year.

Fishing year	1983	1984	1985	1986	1987	1988	Total
Number of records	3	65	37	35	7	20	167

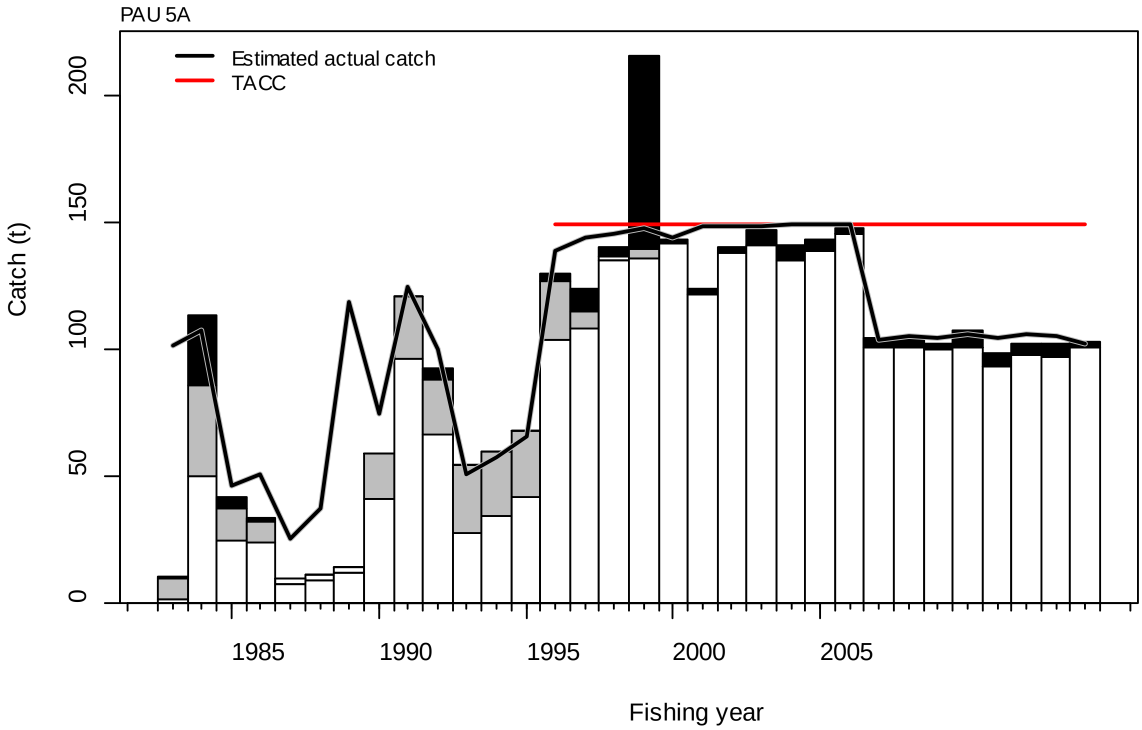


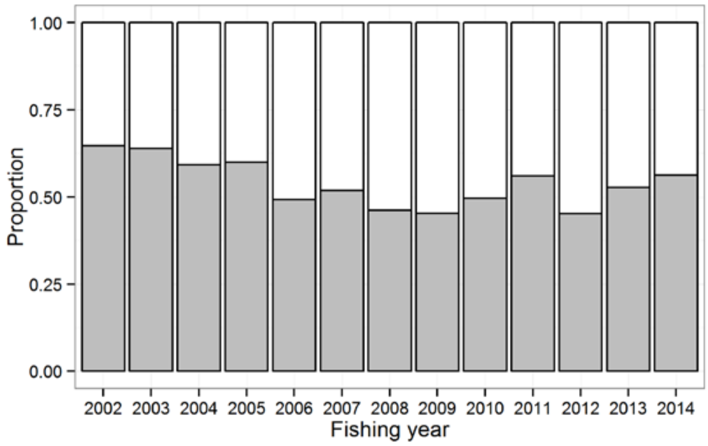
Figure 7: The estimated commercial catch history, TACC, and the FSU/CELR/PCELR catch (vertical bars) for fishing years 1983–2014 for PAU 5A. Black portion of the bar represents estimated catch removed through data grooming; grey represents the estimated catch from records reported to straddling Statistical Area 030 but randomly allocated to PAU 5A (these records were not used in standardisation analyses).

4.2.2 Serial depletion and data quality

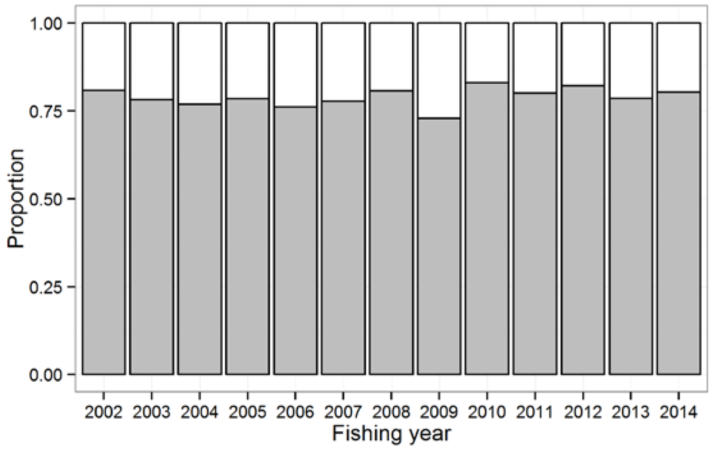
There is little evidence for serial depletion over the past 13 years with no significant changes in the estimated catch distribution over this time period (see Figure 5).

The recorded resolution for the estimated catch and fishing duration for the PCELR data is comparable to other areas and is low. About 50% of the catch is recorded as multiples of 50 kg, and about 75% of recorded fishing durations are multiples of one hour (Figure 8a, b). In about 50% of fishing events the estimated catch was split equally among the divers (Figure 8c).

(a)



(b)



(c)

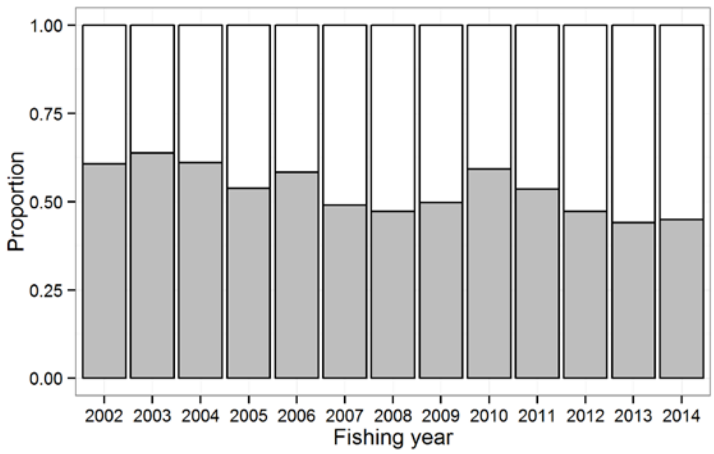


Figure 8: Diagnostic for data resolution on the PCELR forms within PAU 5A: (a) proportion of records that recorded estimated catch in a multiple of 50 kg; (b) proportion of records that recorded hours fished in an exact multiple of 1 hour; (c) proportion of fishing events where recorded estimated catch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

4.2.3 Overview: changes in fishing duration for CELR data

For FSU data the fishing duration field is the daily fishing duration *per* diver (Fisher & Sanders 2011, p. 106 and p. 149). For the CELR data the fishing duration field is 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 in the CELR data, because a mixture of total hours for all divers and per diver hours is recorded, possibly attributable to the transition from the FSU forms.

Because of this ambiguity, fishing duration has not been used in past standardisations as a measure of effort, and the number of divers has been used. However, if the fishing duration changes substantially over time then the number of divers would be a poor measure of effort. To investigate this, a subset of the groomed data set was taken for which the recorded fishing duration was less ambiguous, and this subset was examined to see if fishing duration had changed over time.

4.2.4 Northern area changes in fishing duration

For most trips the number of divers is seven or less (Figure 9). 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 increases, which is what occurs (Figure 10). Another sign of incorrect recording for fishing duration would be a bimodal distribution for the fishing duration when there are two or more divers. There are hints of this when there are two or three divers (Figure 11).

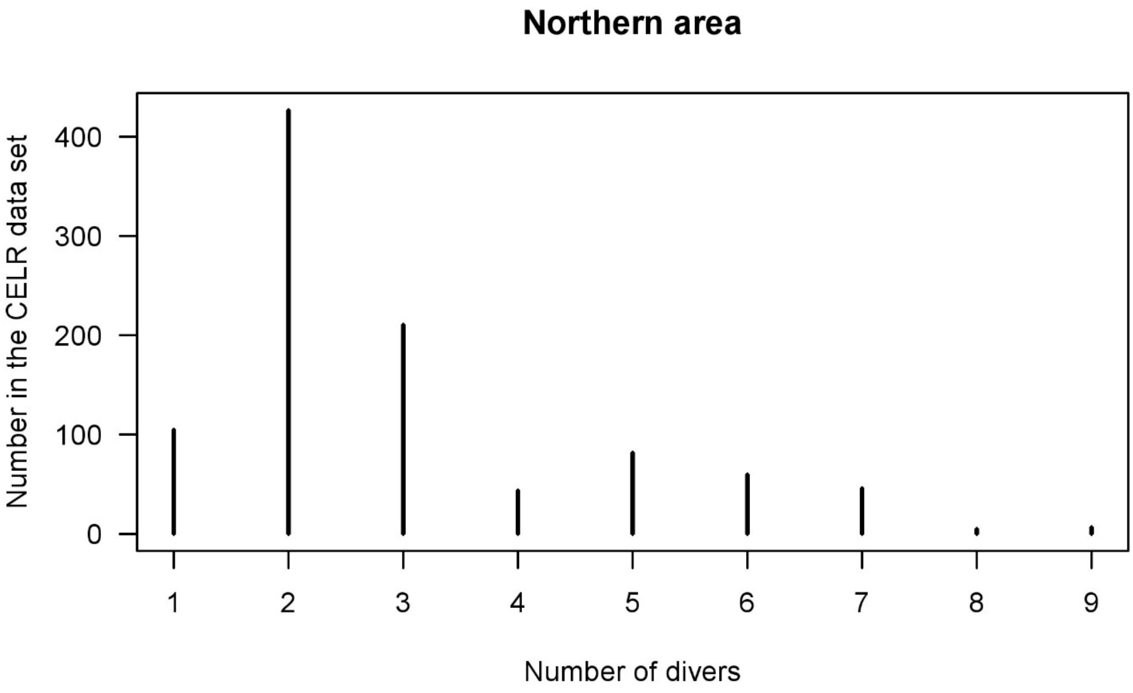


Figure 9: Distribution of the number of divers for a record in the northern CELR dataset.

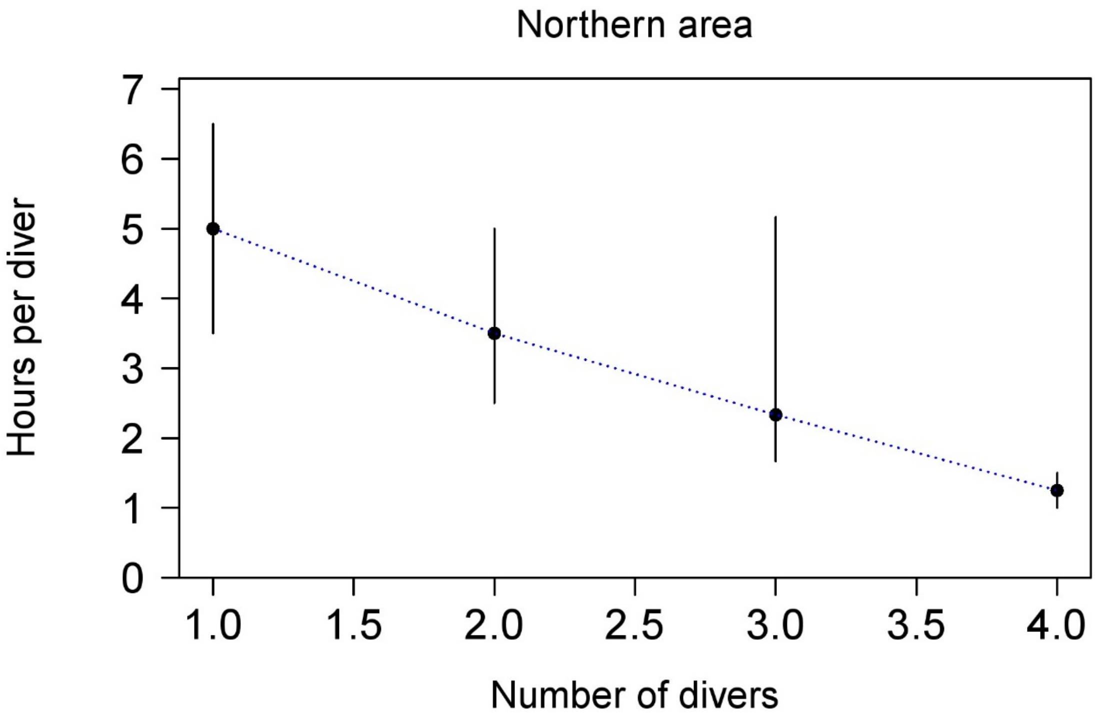


Figure 10: Quantiles by number of divers for the hours per diver in the northern CELR dataset: medians (dot) and lower and upper quartiles (vertical lines). The number of divers is truncated at four or less.

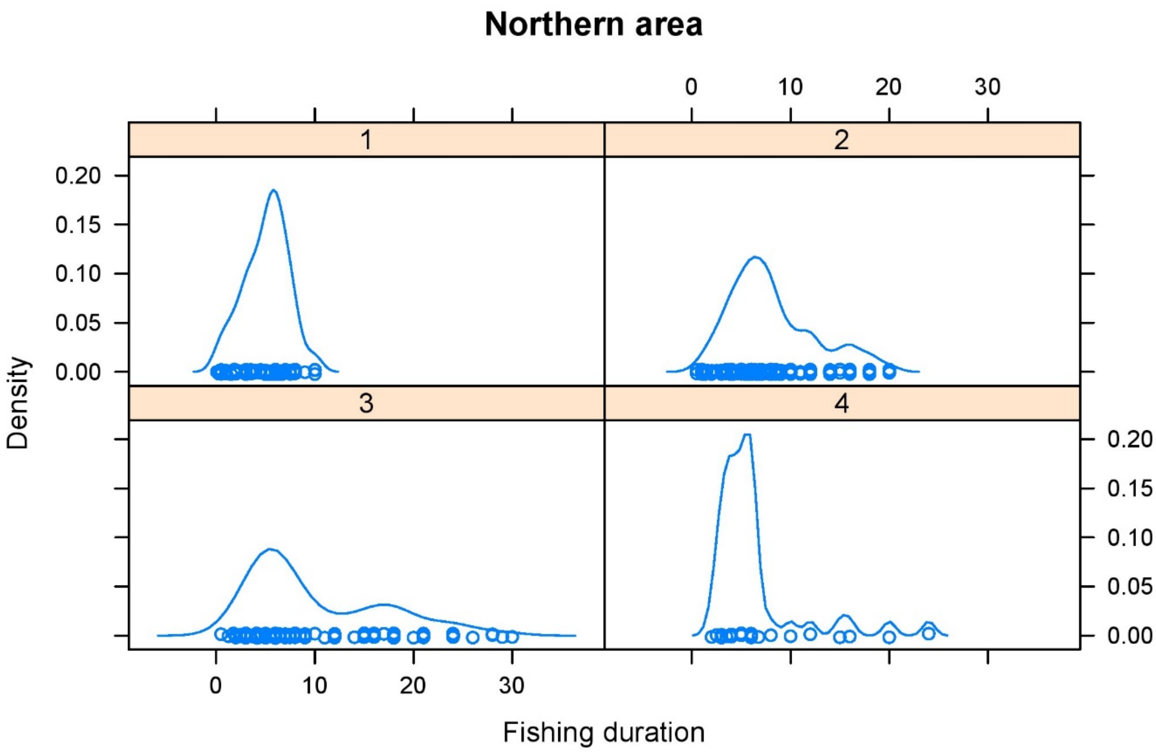


Figure 11: Density and strip plot for the recorded fishing duration in the northern CELR dataset, given the number of divers on a trip (truncated at four or less).

Assuming that there is some ambiguity in what is recorded for the fishing duration a subsetting of the data was undertaken, to obtain a data set with less ambiguity for fishing duration. The initial data set started with was catch-effort records from areas 031 and 032. Before subsetting some grooming of the catch-effort records was undertaken: records were only retained where paua were targeted by diving, and records with missing values for the estimated catch or number of divers were dropped (Table 8). The FIN and date were present for all records. This groomed data set has 987 records (Table 9).

Table 8: Northern area. Number of CELR records removed by fishing year, where the order of grooming is from top to bottom.

Year	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	0	0	0	0
Catch missing	0	0	0	0	0	0	0	0	2	0	0	0	2
Number divers missing	0	0	0	0	0	0	0	0	0	0	2	0	2
Method not diving	1	15	0	3	5	6	16	15	52	5	4	4	126

Following the procedure for PAU 5B the criteria used to subset the data were: (i) only one diver, or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2 (Fu et al. 2014a). Some further grooming was done where records with NA for fishing duration were removed (18 records), and records where fishing duration per diver was greater than 10 hours were removed (4 records). The subsetting retained 41% of the records from 1990–2001 but for many of the years the number of records is low (Table 9). Of the retained records 25% had one diver (Table 10).

Table 9: Northern area. Number of records in the groomed data before and after subsetting.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	87	121	62	26	48	61	40	55	101	148	128	110	987
After	62	58	29	7	21	30	13	22	27	65	38	32	404

Table 10: Northern area. Distribution of the number of divers before and after subsetting.

Number of divers	1	2	3	4	5	6	7	8	9
Before	105	427	211	44	82	60	46	5	7
After	103	194	96	7	1	1	2	0	0

For the subsetted data the recorded duration for each record was divided by the number of divers to calculate the fishing duration per diver (hours per diver). Due to rounding in the fishing duration recorded there is some clumping in the fishing duration per diver (Figure 12). The median and mean fishing duration per diver both change over time (Figures 13–14).

Catch rates (daily kilograms per unit effort) were calculated using: (i) the number of divers, or (ii) total daily diving duration. Comparing the yearly geometric mean of these (i.e. a standardisation with just a year effect) shows that using the diving duration as a measure of effort gives an index that is similar to that using the number of divers (Figure 15).

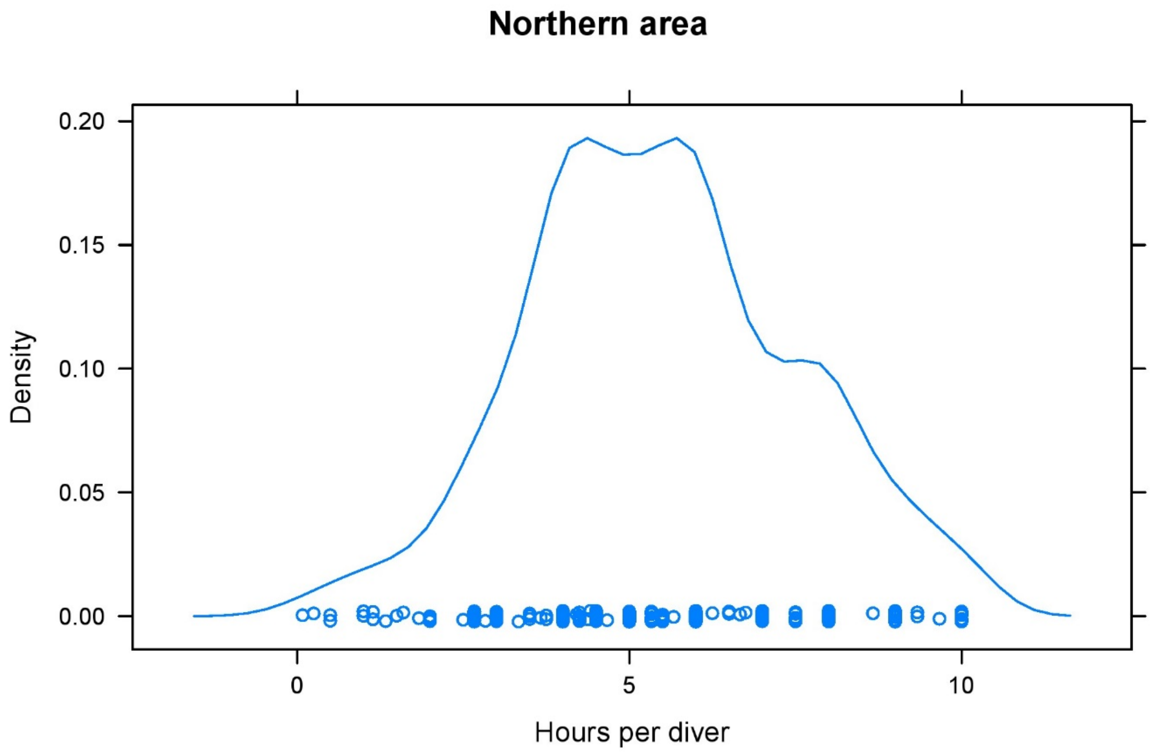


Figure 12: Density and strip plot for the hours per diver in the northern CELR dataset.

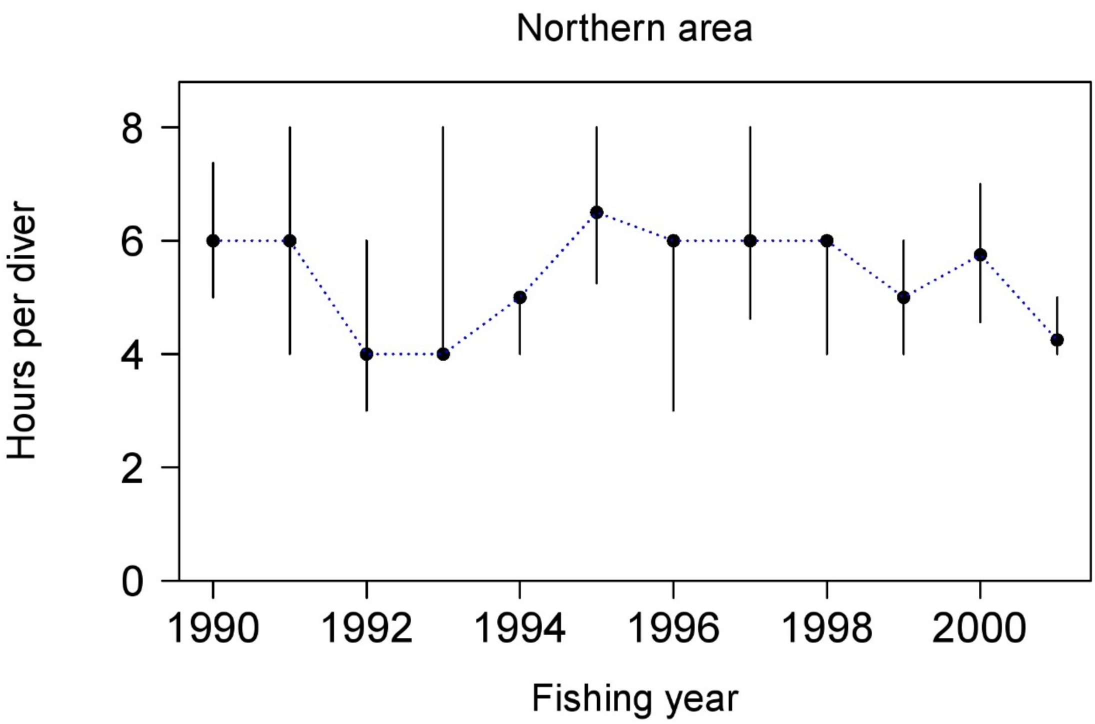


Figure 13: Quantiles by fishing year for the daily fishing duration per diver in the northern CELR dataset: medians (dot) and lower and upper quartiles (vertical lines).

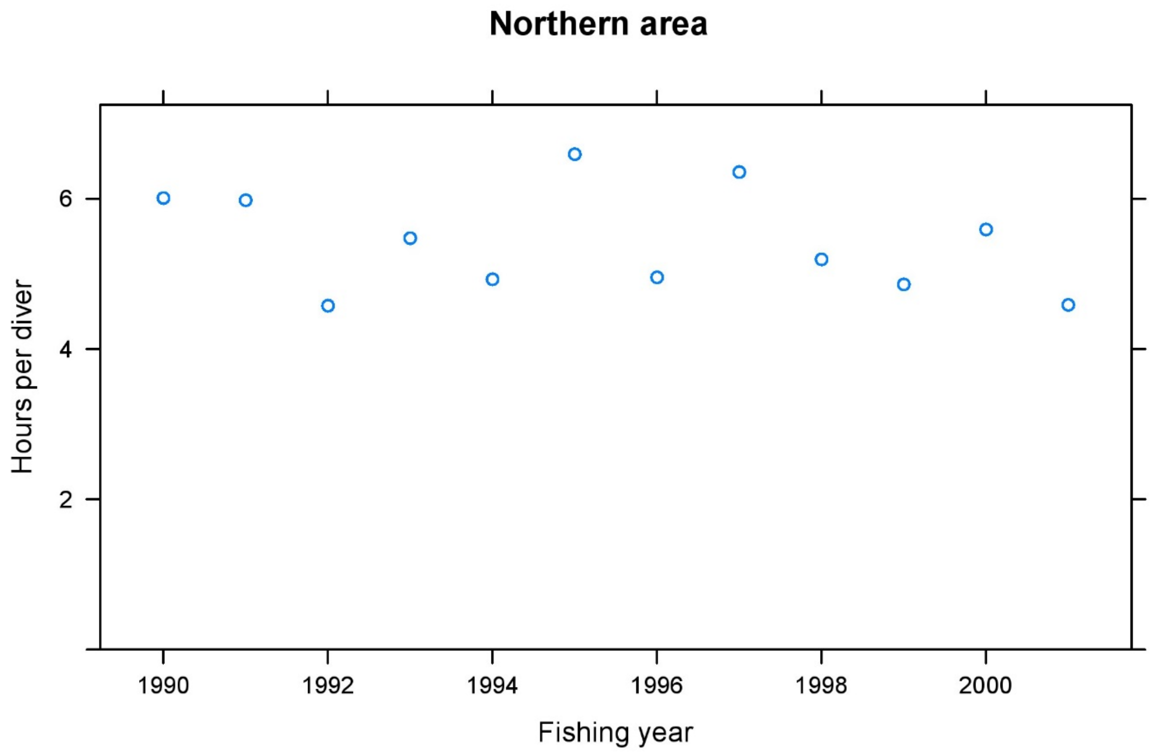


Figure 14: Mean values by fishing year for the daily duration per diver in the northern CELR dataset.

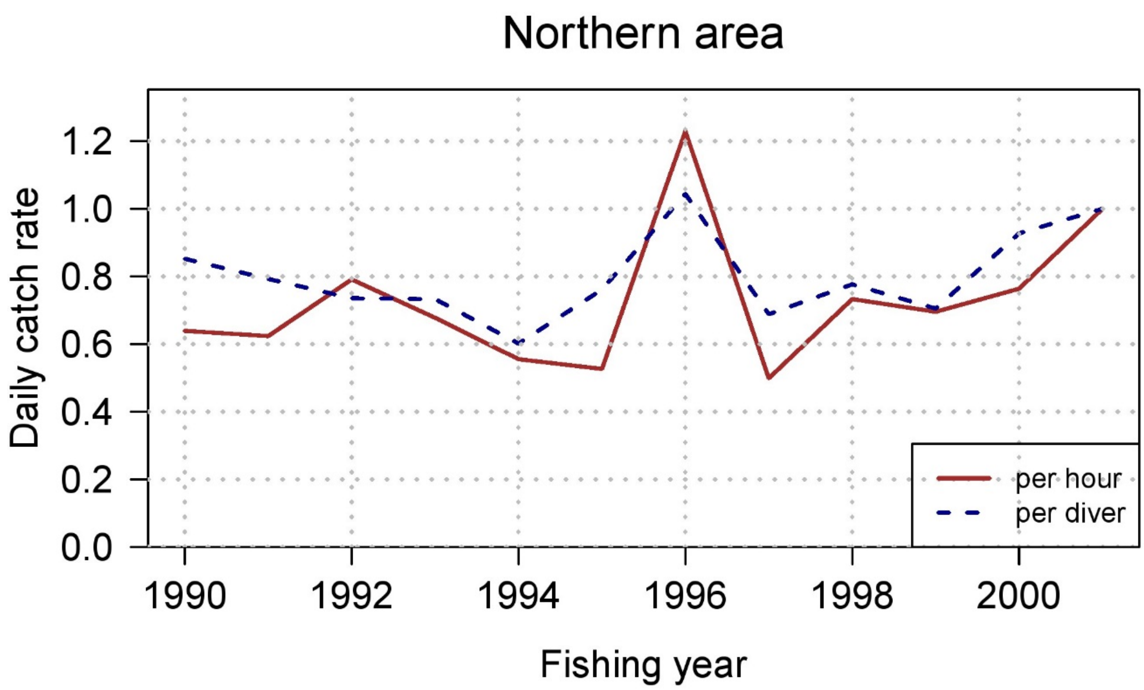


Figure 15: Geometric mean of the daily catch rate by year in the northern CELR dataset. The plots are scaled so that they both have the value one in 2001.

4.2.5 Southern area changes in fishing duration

For most trips the number of divers is four or less (Figure 16). 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 go up, which is what occurs (Figure 17). Another sign of incorrect recording for fishing duration would be a bimodal distribution for the fishing duration when there are two or more divers. There are hints of this when there are two or three divers (Figure 18).

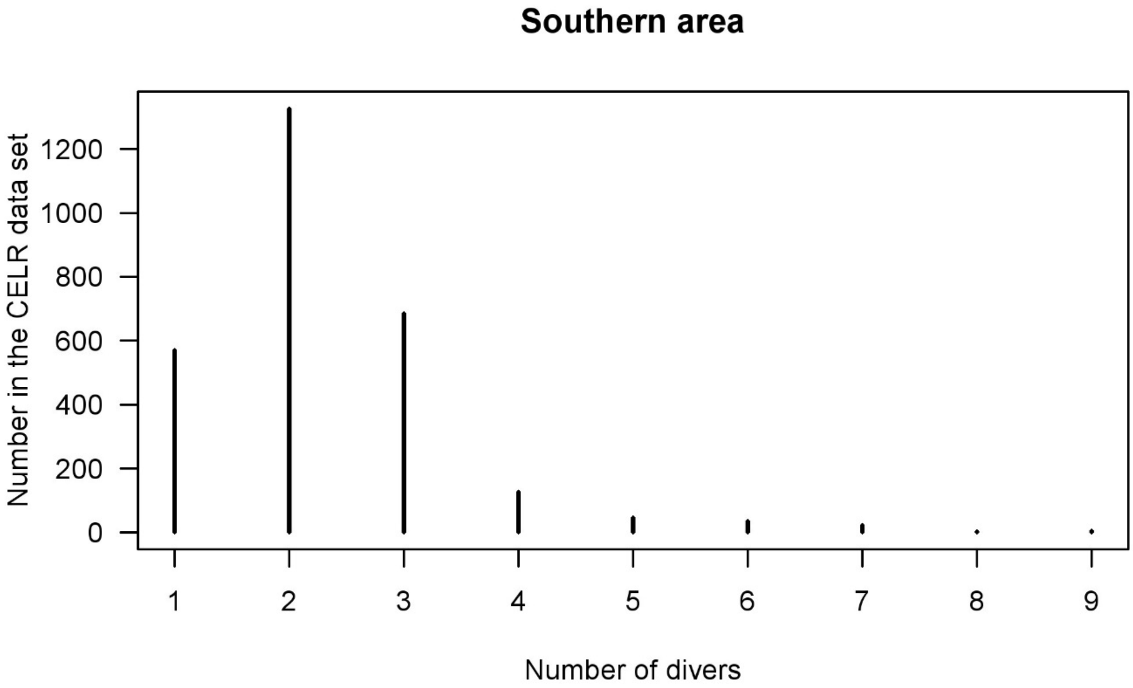


Figure 16: Distribution of the number of divers for a record in the southern CELR dataset.

The initial data set was catch-effort records from area 030. Before subsetting, some grooming of the catch-effort records was done: records were only retained where paua was targeted by diving, and records were removed if values were missing for the estimated catch or the number of divers (Table 11). The FIN and date were present for all records. The groomed data set has 2825 records (Table 12).

Table 11: Southern area. Number of CELR records removed by fishing year, where the order of grooming is from top to bottom.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Not targeting paua	0	0	3	0	0	0	0	0	0	3	0	0	6
Catch missing	0	0	0	0	0	0	0	1	1	1	0	0	3
Number divers missing	0	0	1	0	2	0	4	3	0	0	2	0	12
Method not diving	24	38	57	86	75	82	79	59	35	45	17	16	613

Following the procedure for PAU 5B the criteria used to subset the data were: (i) just one diver, or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2 (Fu et al. 2014a). Some further grooming was done where records with NA for fishing duration were removed (22 records), and records where fishing duration per diver was greater than 10 hours were removed (14 records). The subsetting retained 48% of the records from 1990–2001 (Table 12). Of the retained records 41% had one diver (Table 13).

Table 12: Southern area. Number of records in the groomed data before and after subsetting.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	220	256	255	248	217	262	271	233	213	199	242	209	2825
After	98	119	109	100	94	140	155	108	104	86	140	108	1361

Table 13: Distribution of the number of divers before and after subsetting.

Number of divers	1	2	3	4	5	6	7	8	9
Before	570	1327	686	128	46	36	23	4	5
After	559	445	293	58	5	0	1	0	0

For the subsetted data the recorded duration for each record was divided by the number of divers to calculate the fishing duration per diver (hours per diver). Due to rounding in the fishing duration recorded there is some clumping in the fishing duration per diver (Figure 19). The median and mean fishing duration per diver both change over time (Figures 20–21).

Catch rates (daily kilograms per unit effort) were calculated using: (i) the number of divers, or (ii) total daily diving duration. Comparing the yearly geometric mean of these (i.e. a standardisation with just a year effect) shows that using the diving duration as a measure of effort gives an index that is similar to that using the number of divers (Figure 22).

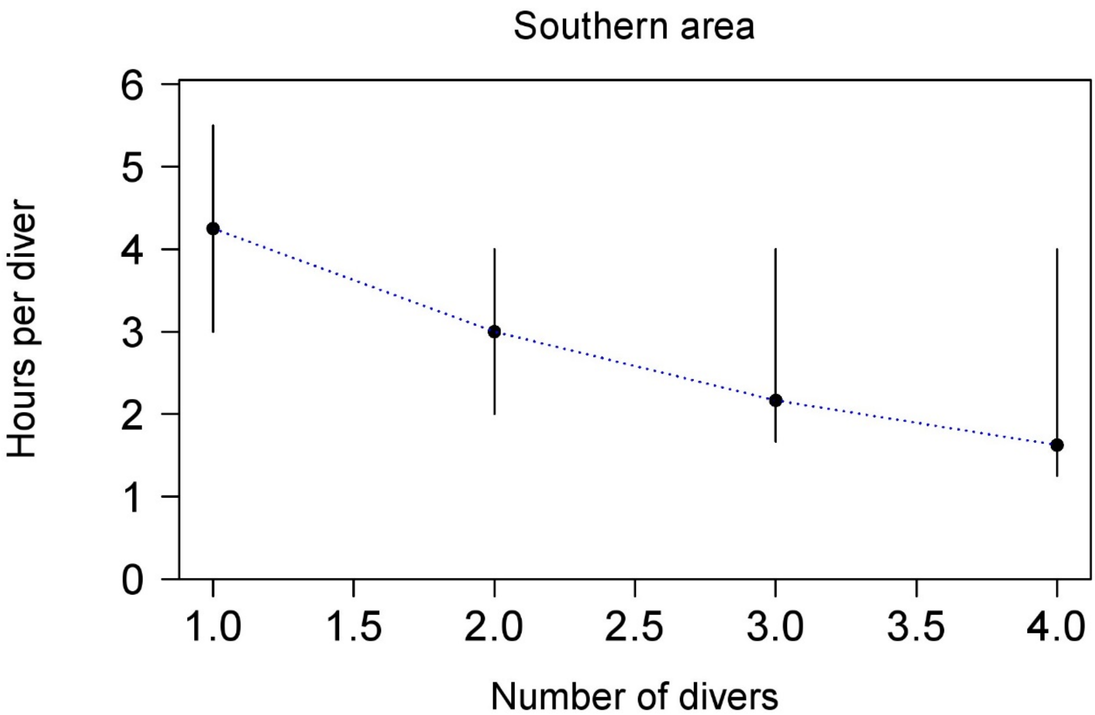


Figure 17: Quantiles by number of divers for the hours per diver in the southern CELR dataset: medians (dot) and lower and upper quartiles (vertical lines). The number of divers is cut-off at four or less.

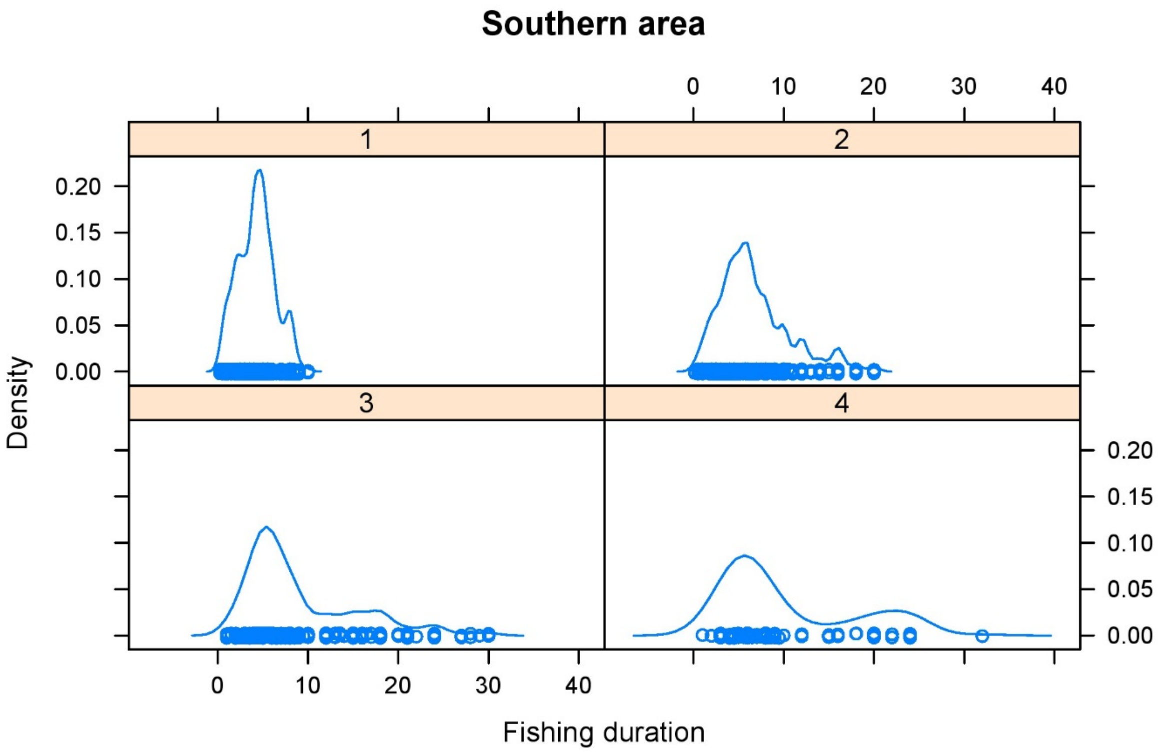


Figure 18: Density and strip plot for the recorded fishing duration in the southern CELR dataset, given the number of divers on a trip (cut-off at four or less).

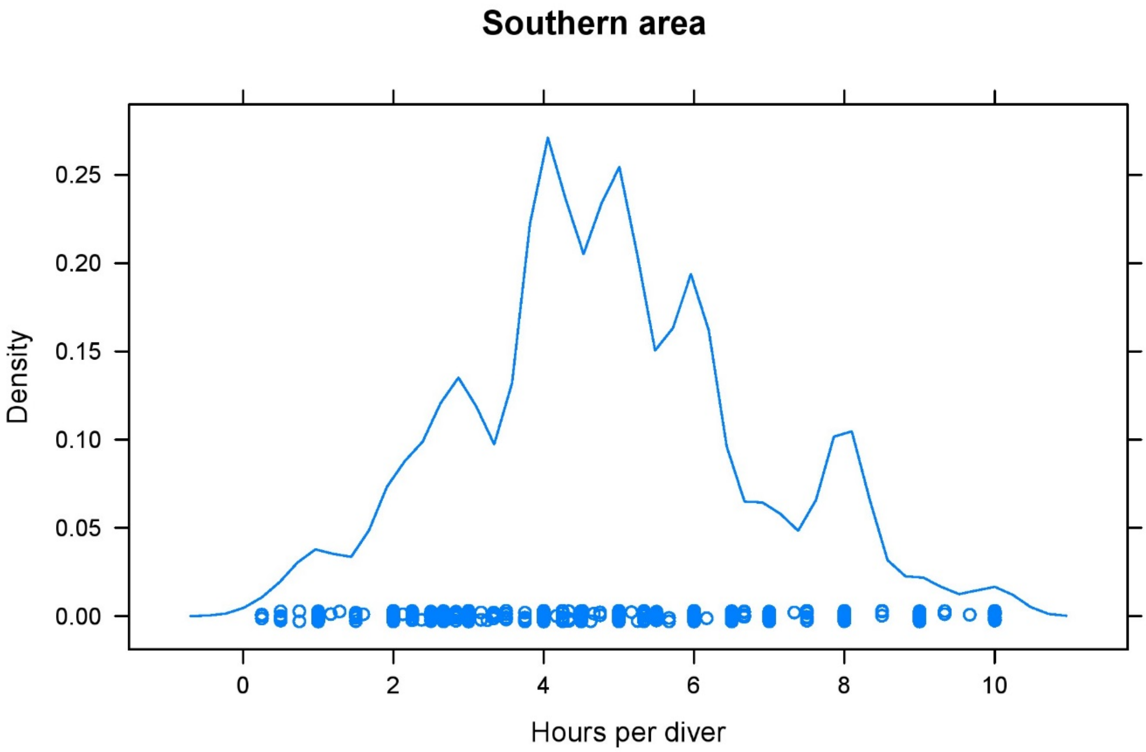


Figure 19: Density and strip plot for the hours per diver in the southern CELR dataset.

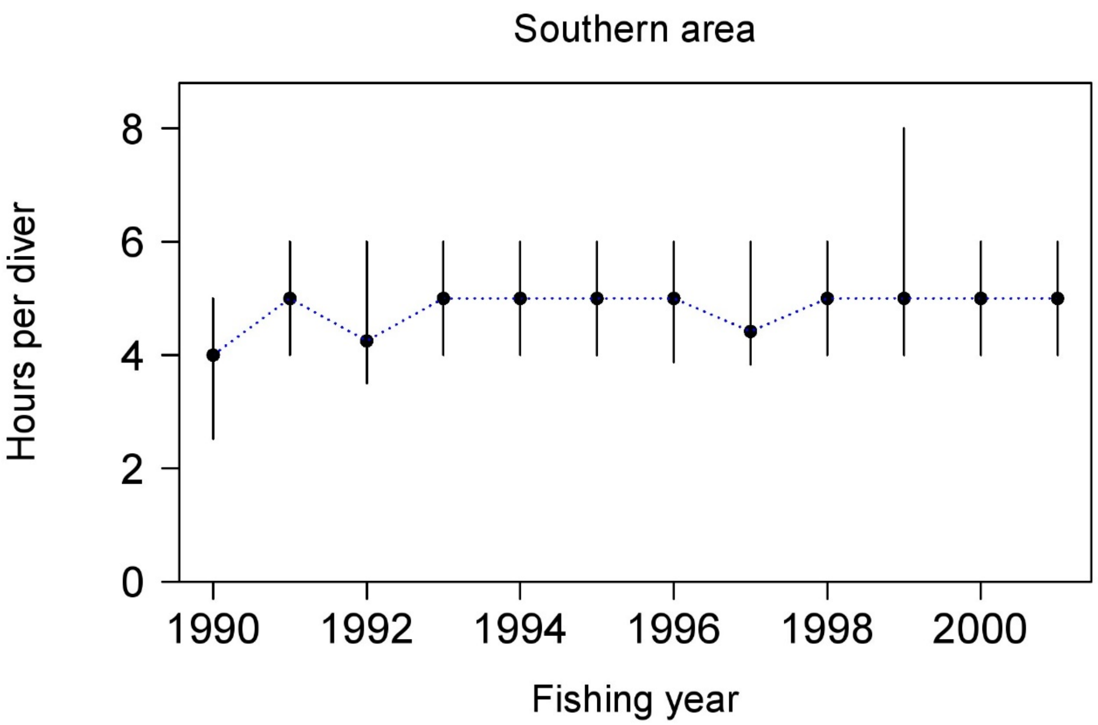


Figure 20: Quantiles by fishing year for the daily fishing duration per diver in the southern CELR dataset: medians (dot) and lower and upper quartiles (vertical lines).

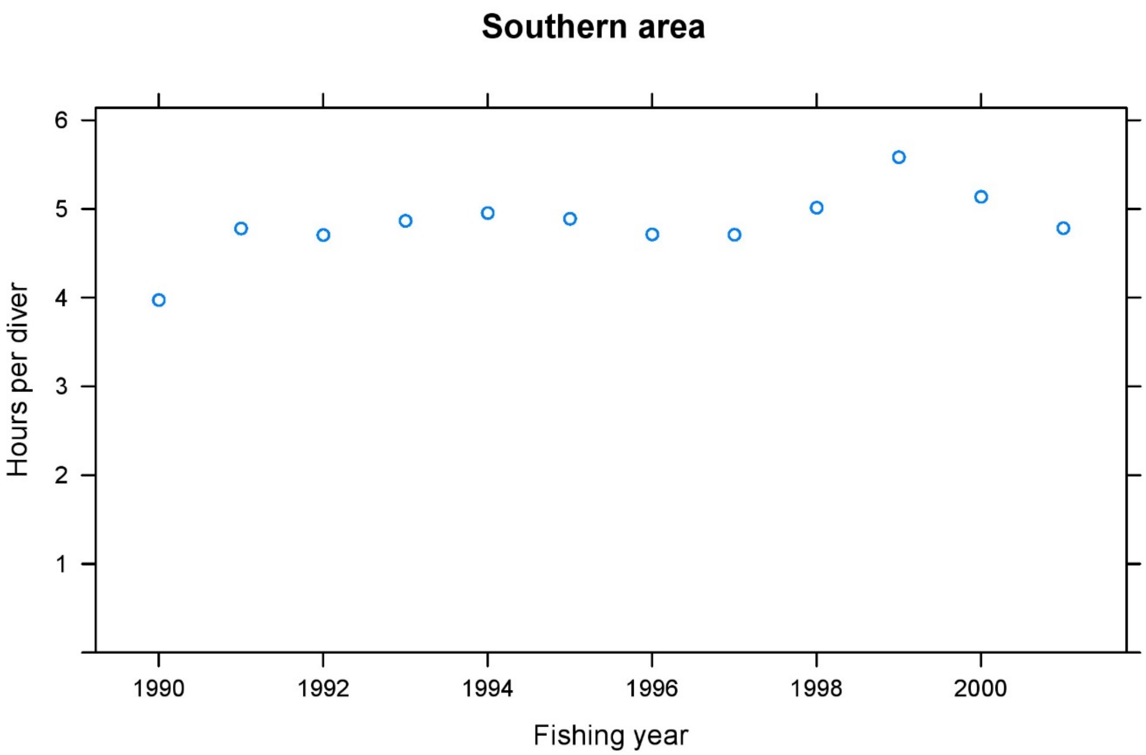


Figure 21: Mean values by fishing year for the daily duration per diver in the southern CELR dataset.

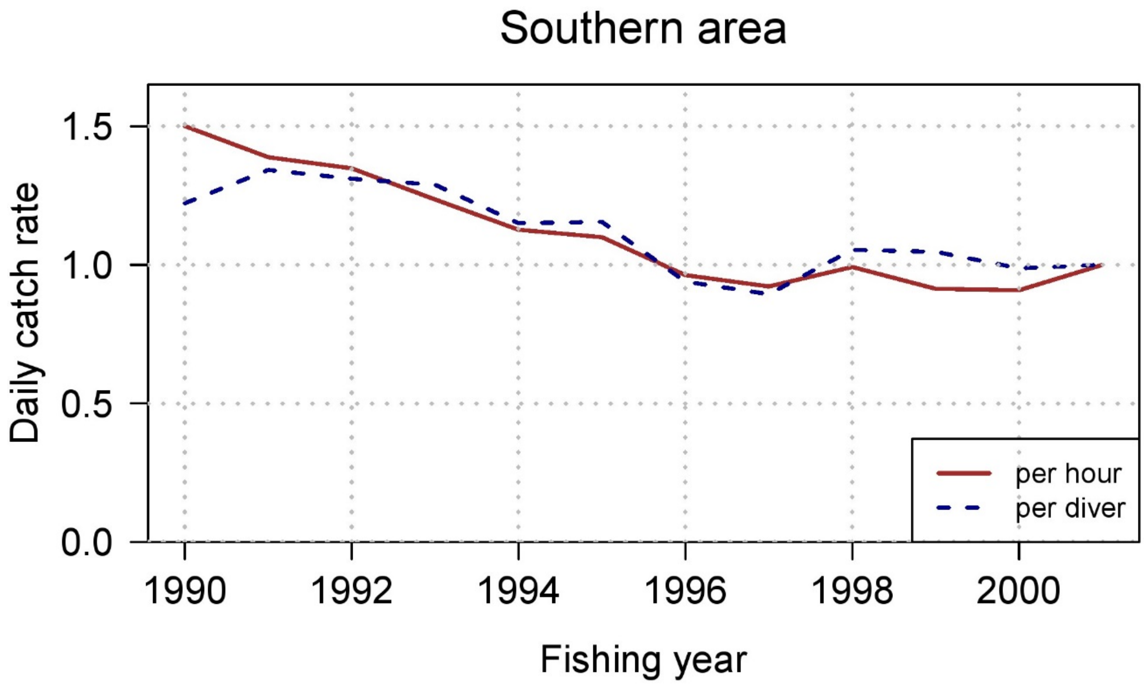


Figure 22: Geometric mean of the daily catch rate by year in the southern CELR dataset. The plots are scaled so that they both have the value one in 2001.

4.3 Standardisation methodology

After consideration of the background analyses, the following decisions were made by the Shellfish Working Group regarding the CPUE standardisations for PAU 5A:

1. To remove FSU data from 1988 and previous years.
2. To use two series for the standardisation, one series based on CELR data up to 2001, the other series based on PCELR data from 2002 onwards.
3. For the southern area CELR standardisation, to use all records that are from the large scale area 030 (i.e. to follow the practice of the previous standardisation). For the northern area CELR standardisation there is no problem with overlapping areas and all records from 031 and 032 are used.
4. For recent CELR standardisations (e.g. PAU 5B) a subset of the groomed data has been used where the recorded fishing duration is less ambiguous: (i) just one diver, or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2. For the PAU 5A dataset it is apparent that most records are recorded as hours *per diver* rather than total hours *for all divers* which should be recorded. Because of this it was decided by the SFWG to use all the data, but scale up the non-subsetted data recorded fishing duration hours taking this into account (i.e to multiply by the number of divers). In the standardisation, both number of divers and duration (as a polynomial) were offered as predictor variables. Unstandardised CPUE should be done comparing catch per hour and catch per diver.

5. To do a sensitivity run for the CELR standardisation where all data are used, except for the filtering, use the criteria (i) just one diver, or (ii) fishing duration ≥ 6 hours and number of divers ≥ 2.

6. Offering Fisher Identification Number (FIN) in standardisation procedures instead of vessel.

7. Not to put in a year:area interaction in the standardisations (to be used in the assessment), but to explore area differences in catch rates by doing separate standardisations where a year:area interaction is forced in at the start. For the PCELR data the natural areas to use for these are the research strata (i.e. Milford, George, Central, Dusky, Chalky, South coast).

The proposed standardisations differs from that done previously (Fu et al. 2010):

- Fishing duration is offered as a predictor in the standardisation (along with the number of divers). Filtering criteria are used to determine which records are likely to have fishing duration recorded correctly, and those for which the fishing duration requires scaling.

- Offering FIN instead of vessel in the standardisation procedure.

4.4 Northern area CELR standardisation (1990–2001)

4.4.1 Initial data set

A set of criteria were used to subset out records for which total hours were most likely recorded: (i) just one diver, or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2 (see Section 4.2.4). For the PAU 5A dataset it is apparent that most records are recorded as hours *per diver* instead of total hours *for all divers* which should be recorded. Because of this it was decided by the Shellfish Working Group to use all the data, but to scale up the non-subsetted data recorded hours taking this into account (i.e. to multiply by the number of divers).

After scaling up fishing duration for non-subsetted data records, some further grooming was done in which records with NA for fishing duration were removed (36 records), and a fishing duration per diver greater than 10 hours was removed (4 records). The subsetting retained 98% of the records from 1990–2001 though in some years the number of records is low (Table 14). Of the retained records 11% had one diver (Table 15).

Table 14: Northern area. Number of records in the dataset before and after grooming.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	87	121	62	26	48	61	40	55	101	148	128	110	987
After	86	119	62	24	48	61	40	55	88	148	124	110	965

Table 15: Northern area. Distribution of the number of divers before and after grooming.

Number of divers	1	2	3	4	5	6	7	8	9
Before	105	427	211	44	82	60	46	5	7
After	103	423	203	44	82	55	43	5	7

Due to rounding in the fishing duration recorded there is some clumping in the fishing duration per diver (Figure 23). The median and mean fishing duration per diver both change over time (Figures 24–25).

Catch rates (daily kilograms per unit effort) were calculated using: (i) the number of divers, or (ii) total daily diving duration. Comparing the yearly geometric mean of these (i.e. a standardisation with just a year effect) shows that using the diving duration as a measure of effort gives an index that is similar to that using the number of divers (Figure 26).

4.4.2 FIN subsetting of data

FIN is used to subset out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 5 records per year for a minimum of 2 years was chosen, this retained 80% of the catch between 1990 and 2001 (Figure 27). Note that while over 80% of the catch is retained, it is less than this for some years (Figures 28–29). The number of days of effort retained after subsetting is 21 or more in every fishing year (Table 16, Figure 30). The number of FIN holder's drops from 62 to 14 under the subsetting criteria.

There is reasonable overlap in effort over time for the FIN holders after subsetting, although there appears to be a split into a pre-1996 and post-1997 groups of FINs (Figures 31–32). Effort by general statistical area and month similarly appears to be split over the same time periods (Figures 33–34).

4.4.1 Standardisation

CPUE was defined as daily catch. Year was forced into the model at the start and other predictor variables offered to the model were FIN, statistical area (031, 032), month, fishing duration (as a cubic polynomial), number of divers, and a month:area interaction. Following previous standardisations, no interaction between fishing year and area was entered into the model, as the stock assessment for PAU 5A north is a single area model. However, a separate standardisation is also done where a year:area interaction is forced in at the start.

The model explained 62% of the variability in CPUE with fishing duration explaining most of this (51%) followed by FIN (3%) (Table 17). The effects appear plausible and the model diagnostics are good (Figures 35–36). There is an apparent increasing effect for the catch taken after a fishing duration of 40 hours, although for the majority of records fishing duration is less than this (Figure 37). The standardised index shows no clear or significant trends (Table 18, Figure 38).

Forcing in a year:area interaction indicates that the indices are different between areas 031 and 032 (Figure 39). However neither area has many records and area 032 has very few for many years, so no conclusions can be drawn from this plot (Table 19).

As a sensitivity analysis to the filtering criteria for the subsetted data set (in which the fishing duration field should be less ambiguous) another standardisation was done in which when the number of divers was ≥2 and the fishing duration had to be ≥ 6 hours (instead of 8 hours). The resulting index is very similar to that where 8 hours was used (Figure 40). For unstandardised indices, there is some difference between using catch per hour versus catch per diver (Figures 41–42).

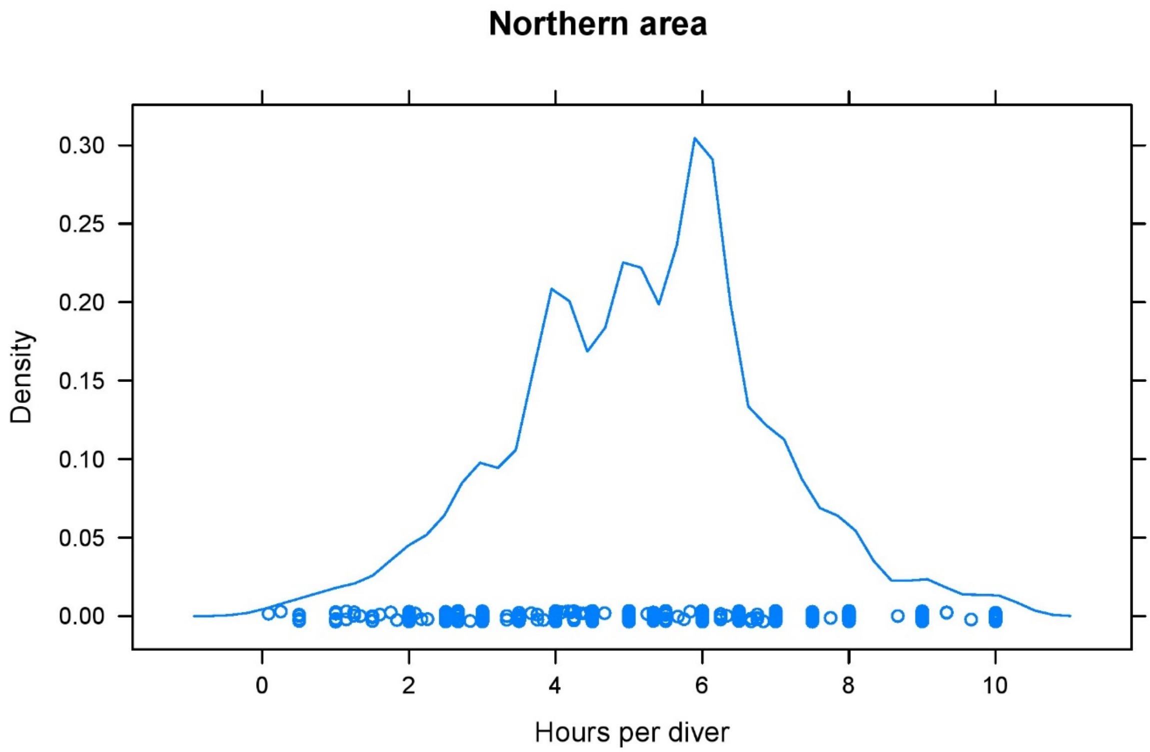


Figure 23: Initial CELR dataset for the northern area. Density and strip plot of hours per diver.

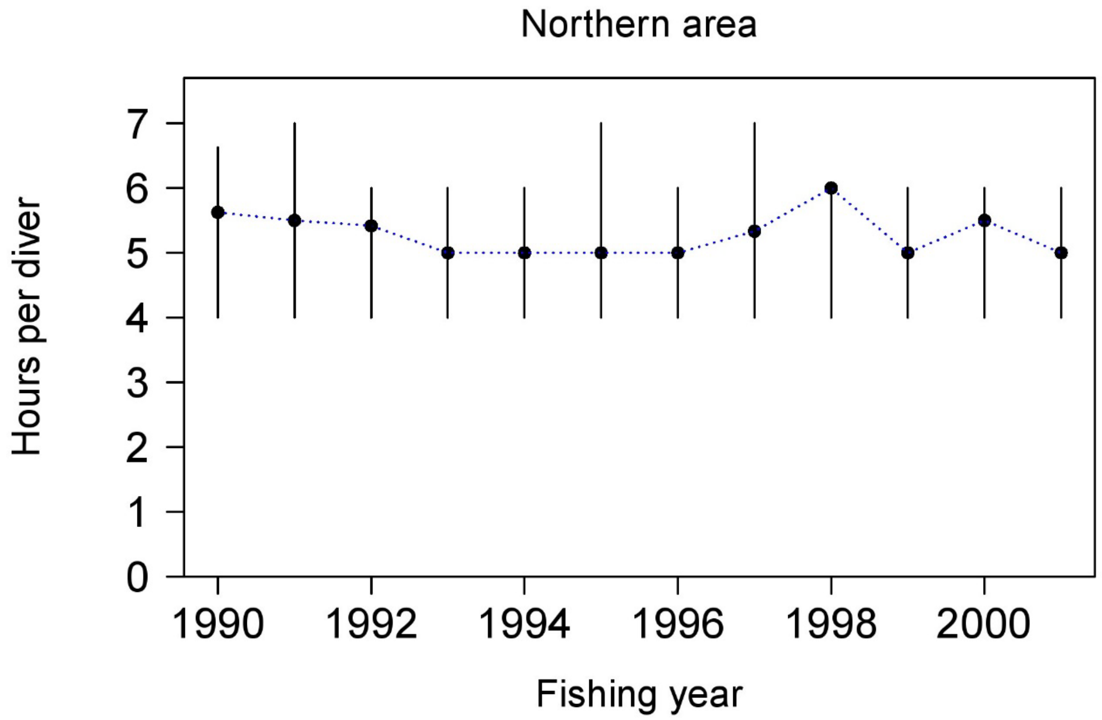


Figure 24: Initial CELR dataset for the northern area. Quantiles by fishing year for the daily fishing duration per diver: medians (dot) and lower and upper quartiles (vertical lines).

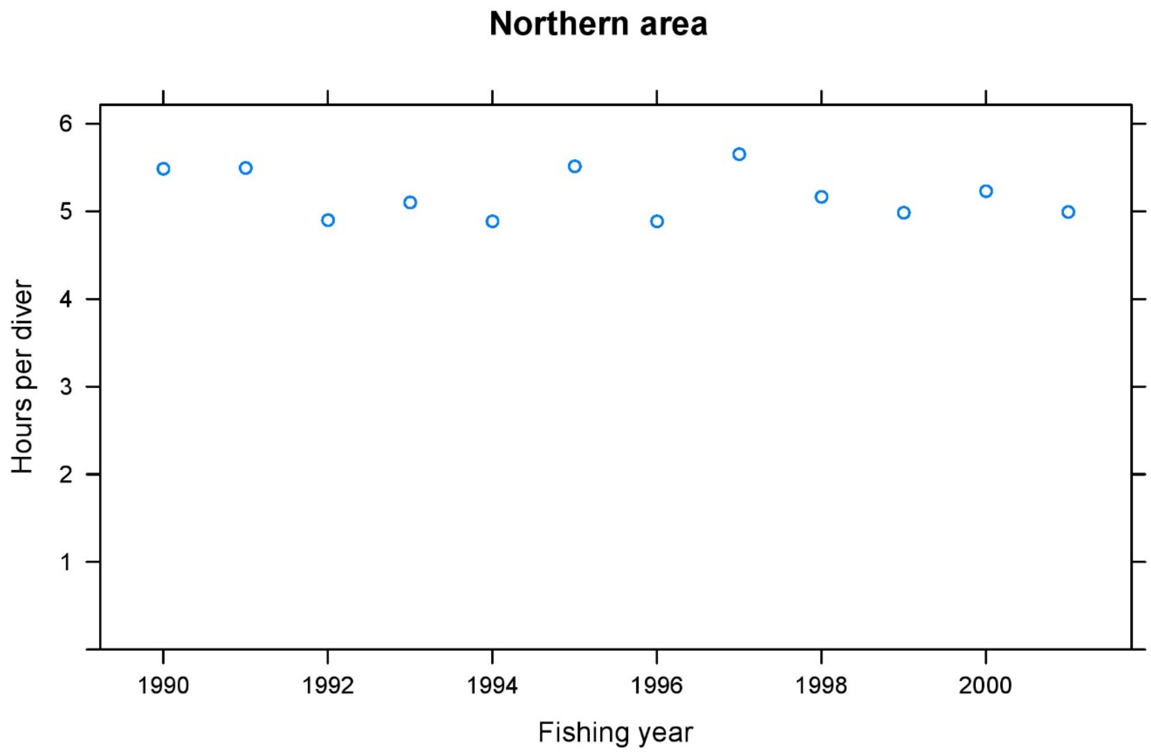


Figure 25: Initial CELR dataset for the northern area. Mean values by fishing year for the daily duration per diver.

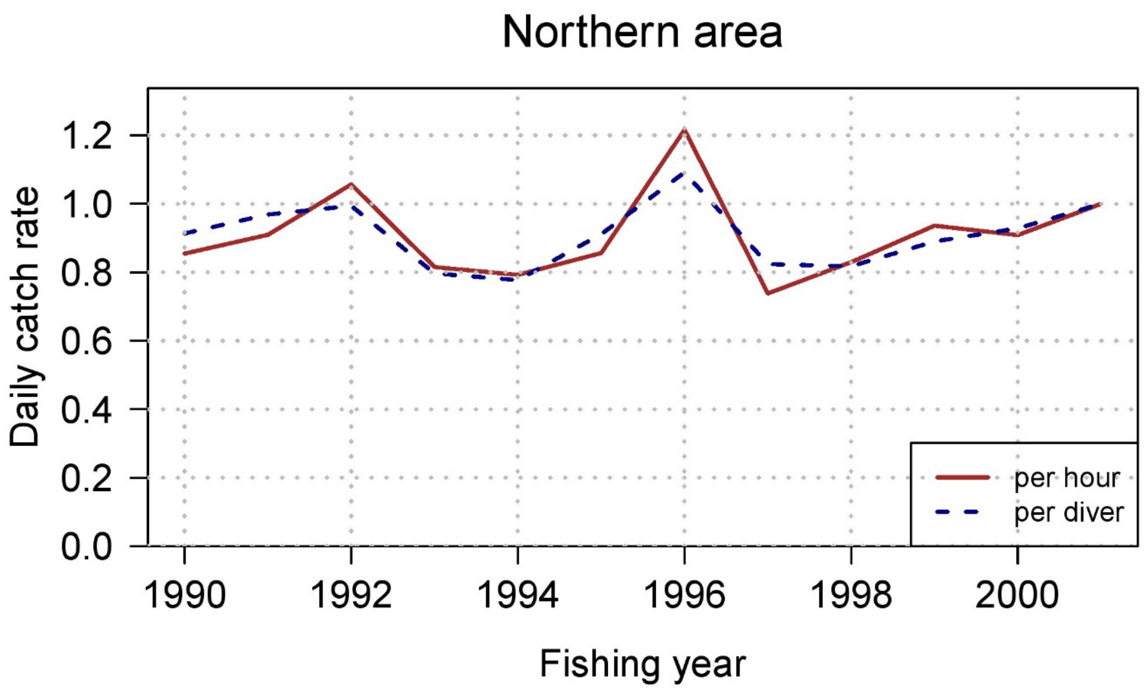


Figure 26: Initial CELR dataset for the northern area. Geometric mean of the daily catch rate by year per hour and per diver. The plots are scaled so that they both have the value one in 2001.

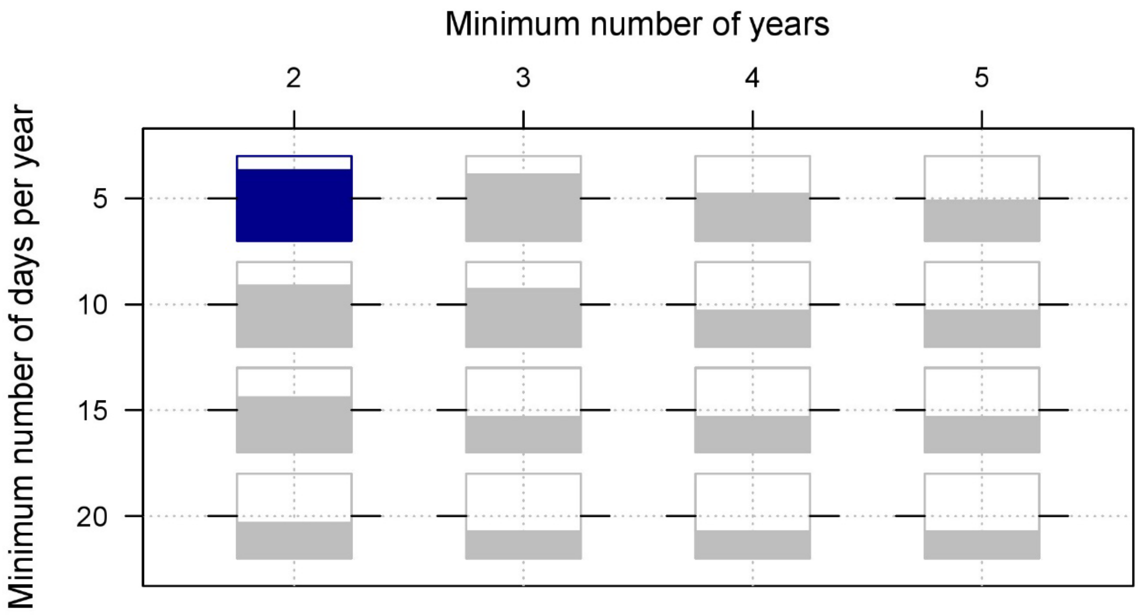


Figure 27: Proportion of the catch taken when subsetting the northern CELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

Table 16: Number of northern CELR records before and after FIN subsetting.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	86	119	62	24	48	61	40	55	88	148	124	110	965
After	71	60	48	21	43	50	25	33	74	122	98	83	728

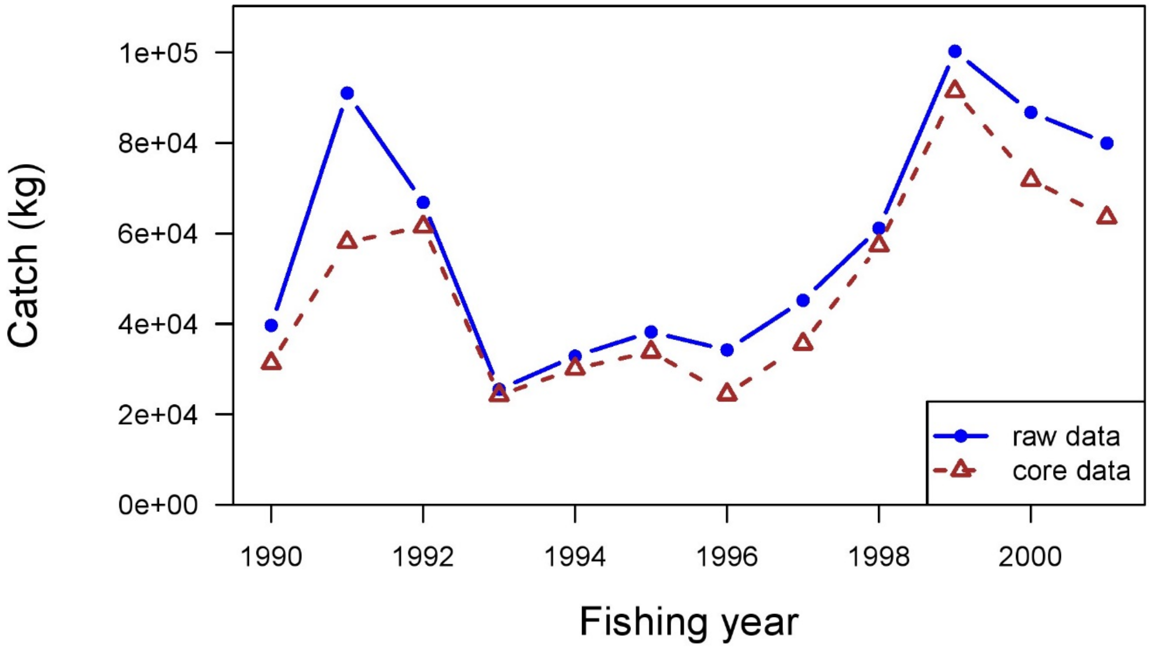


Figure 28: Catch in northern area on CELR forms by fishing year, before FIN subsetting (raw data) and after (core data).

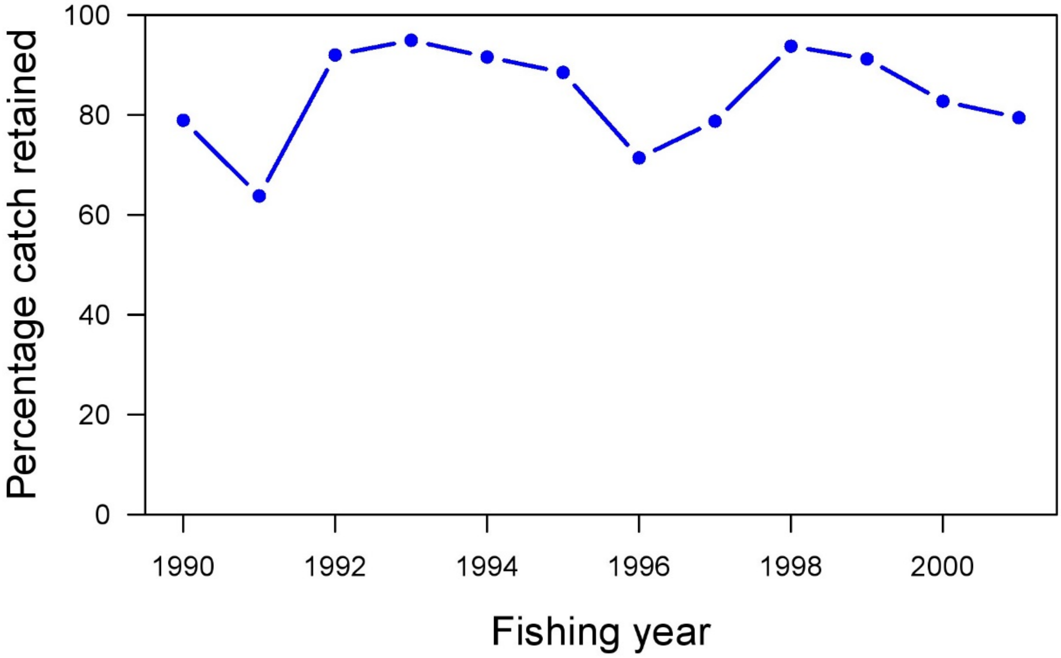


Figure 29: Percentage of the catch retained after FIN subsetting of northern CELR data.

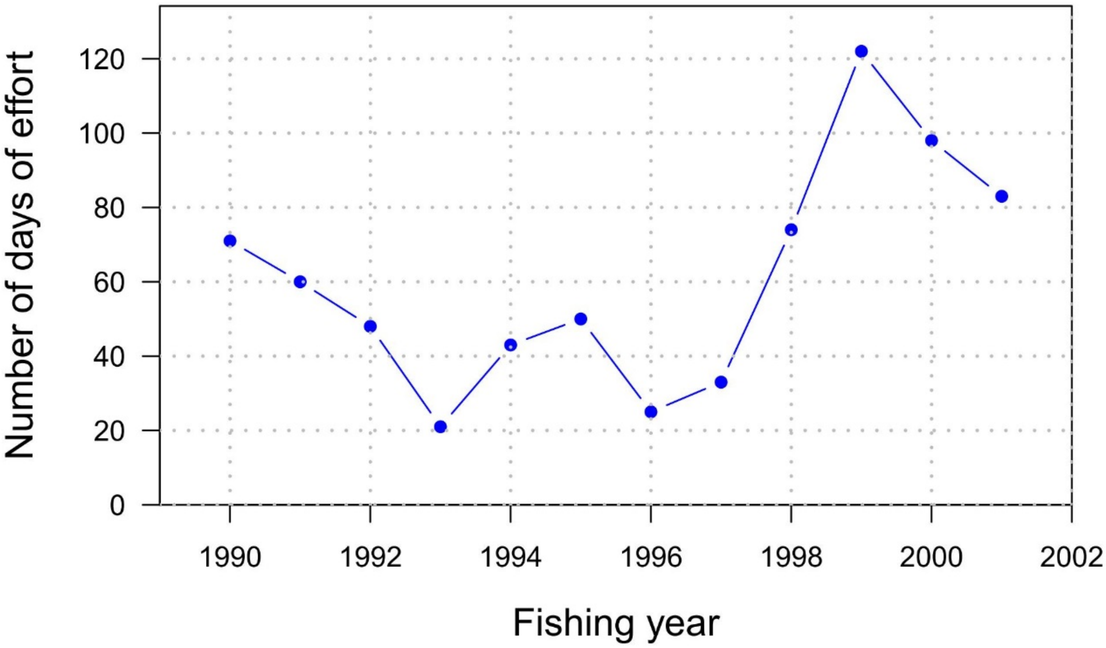


Figure 30: Number of days of effort retained after FIN subsetting of northern CELR data.

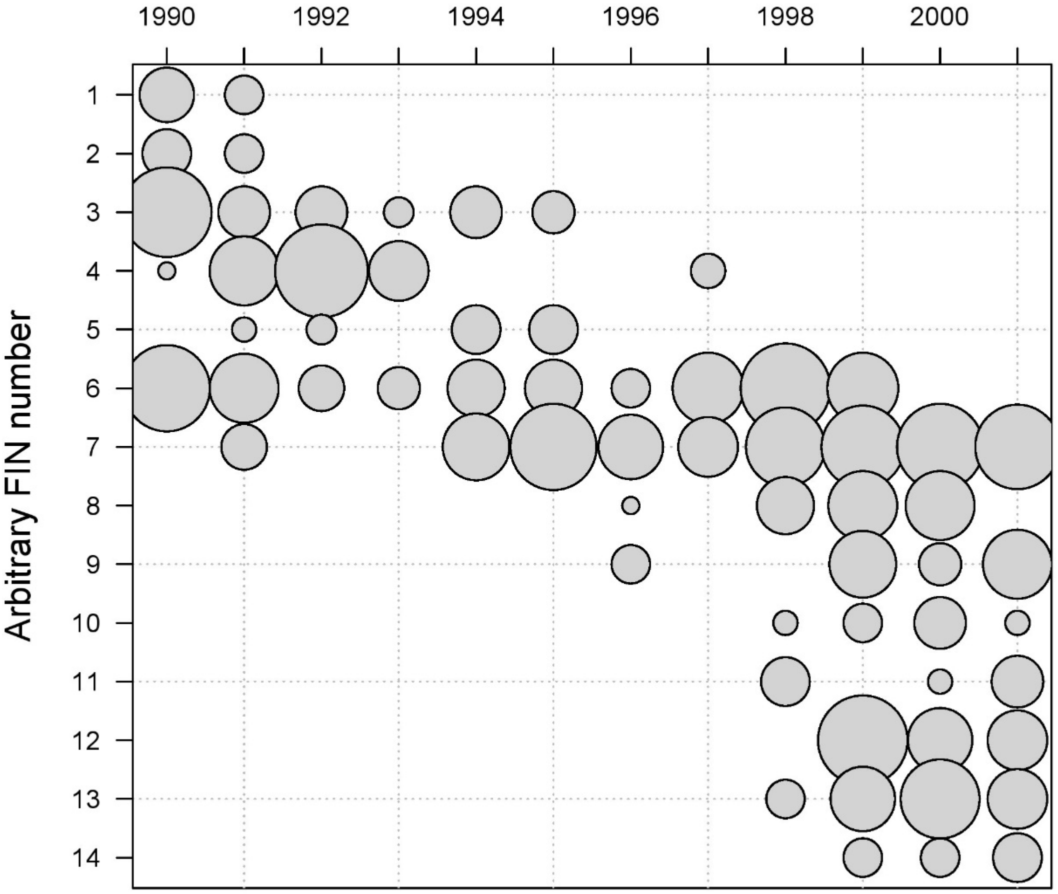


Figure 31: Overlap in days of effort by FIN in northern CELR data. The area of a circle is proportional to the days of effort.

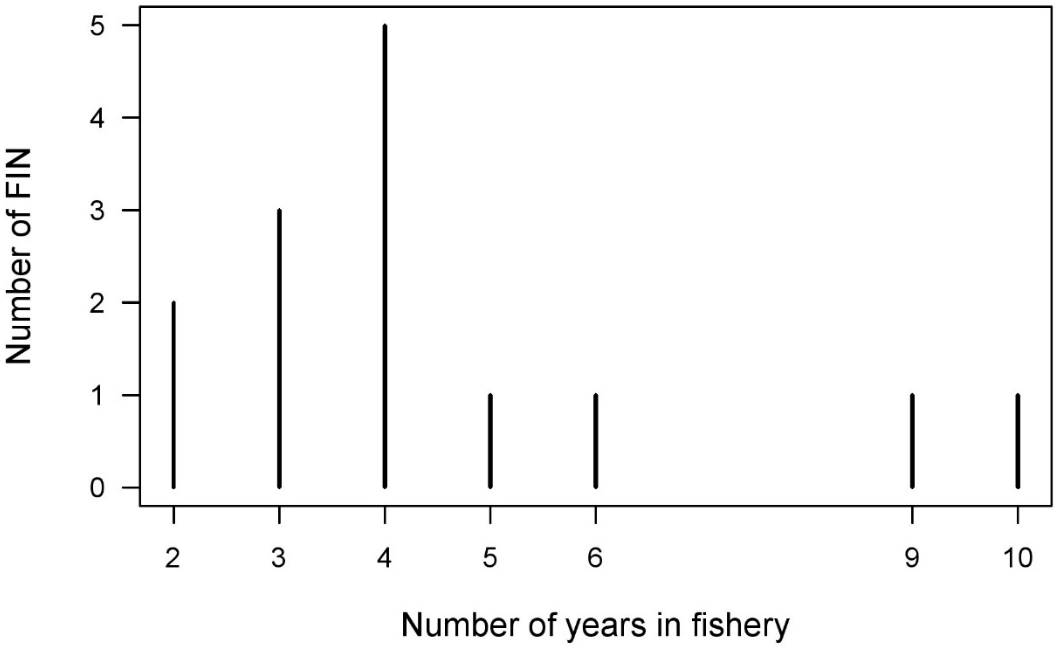


Figure 32: Number of years in the fishery for a FIN holder after subsetting by FIN in northern CELR data.

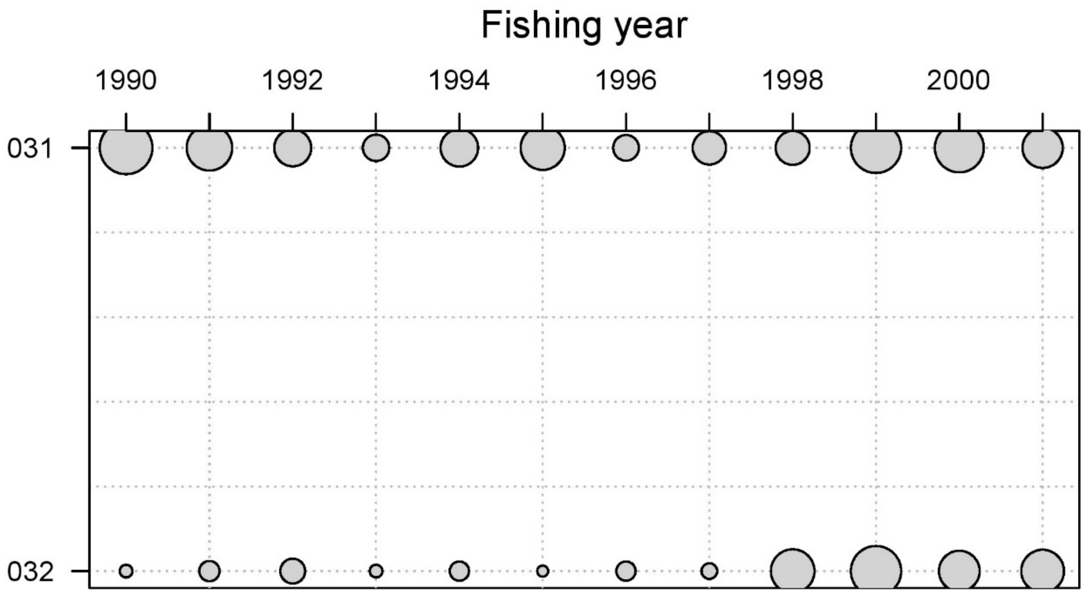


Figure 33: Overlap in days of effort for statistical area by fishing year in northern CELR data.

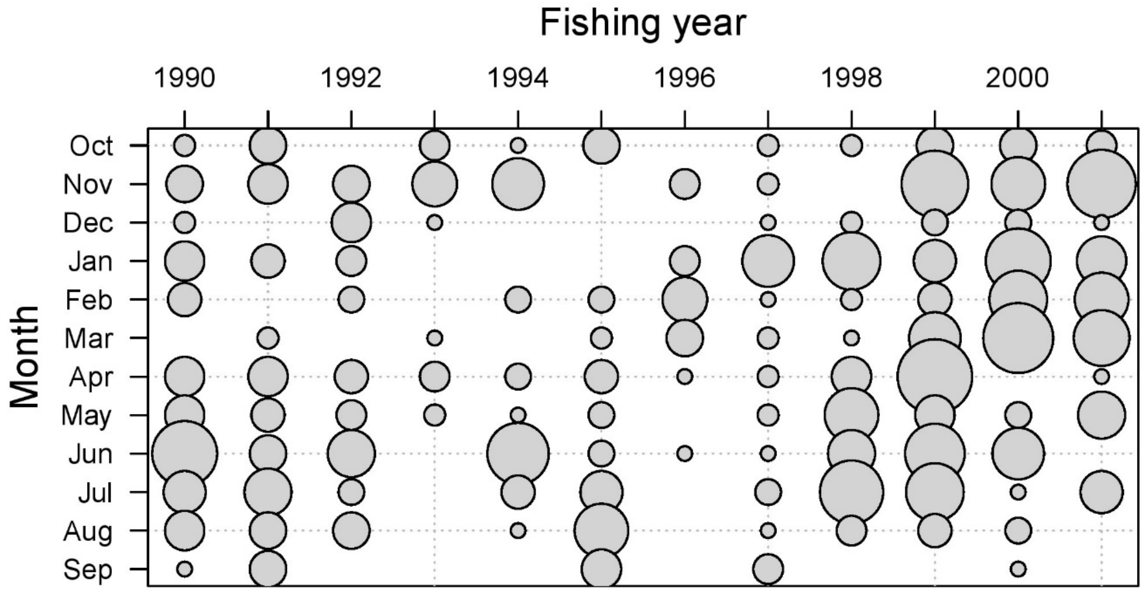


Figure 34: Overlap in days of effort for month by fishing year in northern CELR data.

Table 17: Variables accepted into the northern CELR standardisation model (1% additional deviance explained), 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	11	0.08
Fishing duration	3	0.59
Client key	13	0.62

Table 18: Standardised CELR index for northern area, lower and upper 95% confidence intervals (CIs), and CV.

Year	Index	lower CI	upper CI	CV
1990	0.92	0.69	1.23	0.15
1991	1.01	0.77	1.34	0.14
1992	0.97	0.69	1.38	0.17
1993	0.85	0.54	1.34	0.23
1994	0.89	0.65	1.21	0.16
1995	0.92	0.69	1.24	0.15
1996	1.14	0.77	1.68	0.20
1997	1.22	0.87	1.71	0.17
1998	1.01	0.78	1.29	0.13
1999	1.04	0.82	1.31	0.12
2000	0.98	0.76	1.28	0.13
2001	1.11	0.84	1.46	0.14

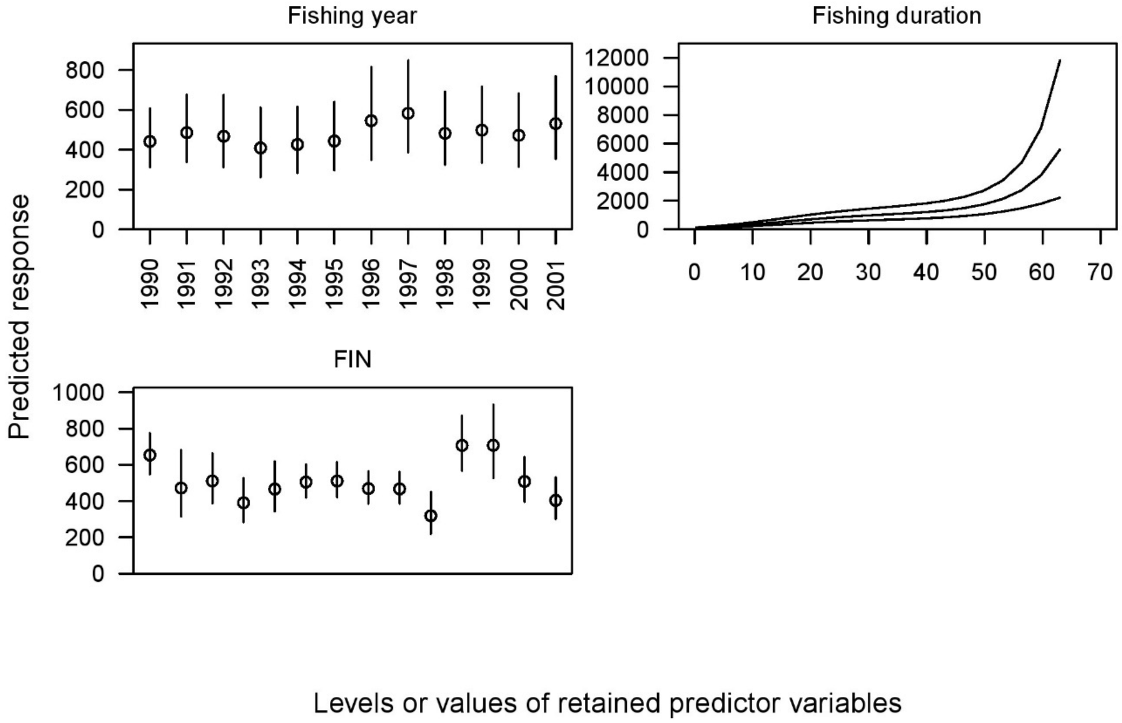


Figure 35: Effects for the northern CELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

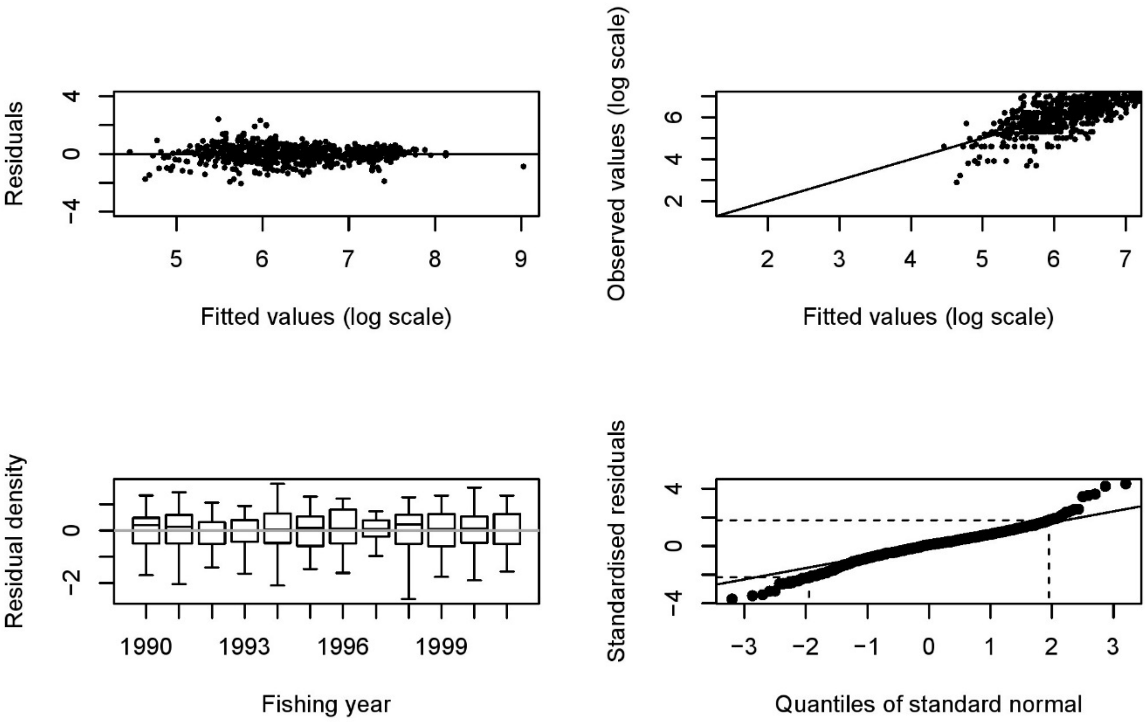


Figure 36: Residuals for the northern CELR standardisation model.

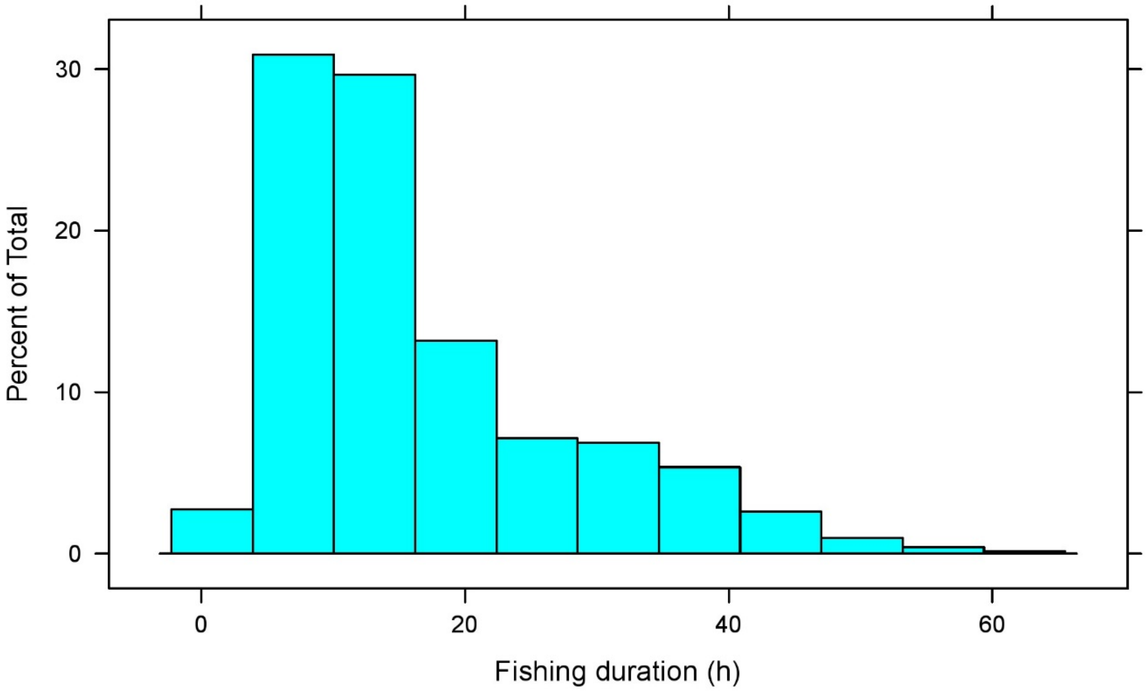


Figure 37: Distribution of fishing duration (h) in the northern CELR data.

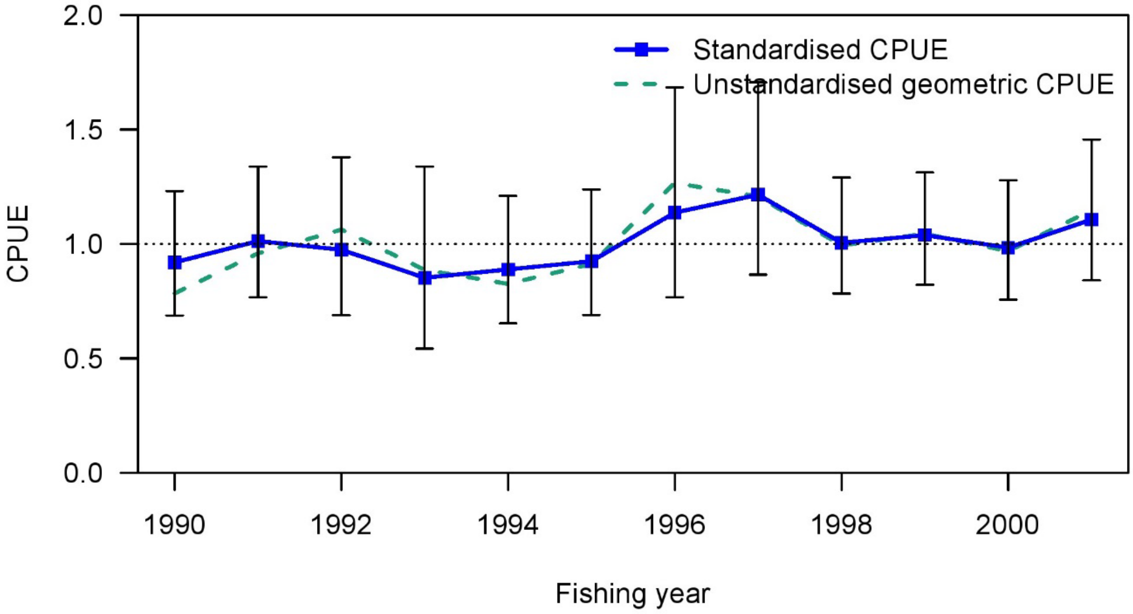


Figure 38: The northern CELR standardised CPUE index with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

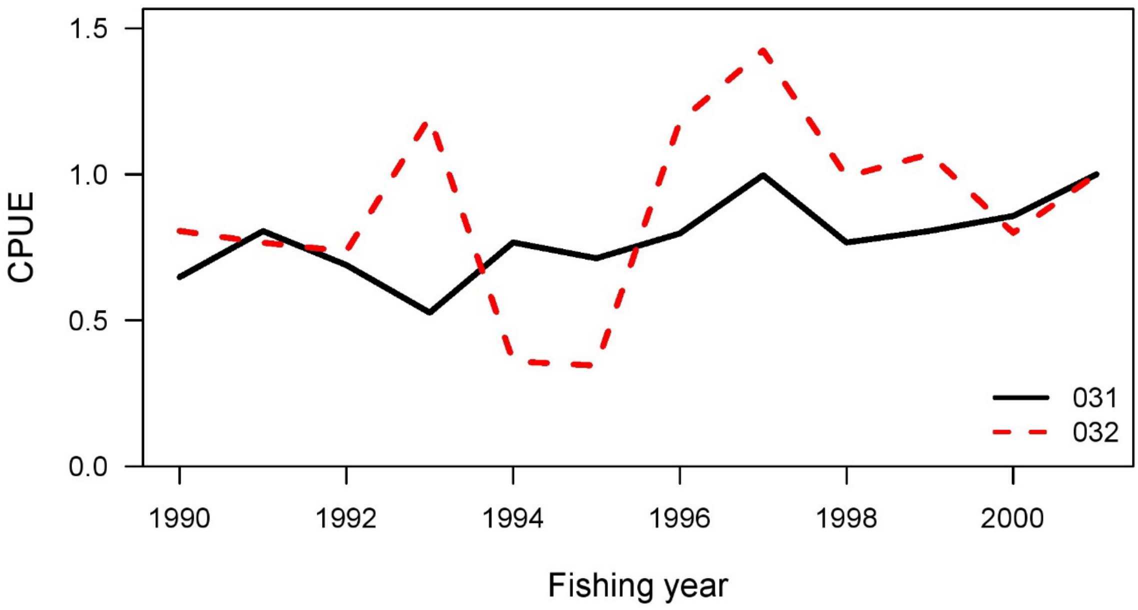


Figure 39: Standardised indices for the northern CELR dataset with a year:area interaction forced into the model. The areas are general statistical areas. The indices are scaled to have the value one in 2001.

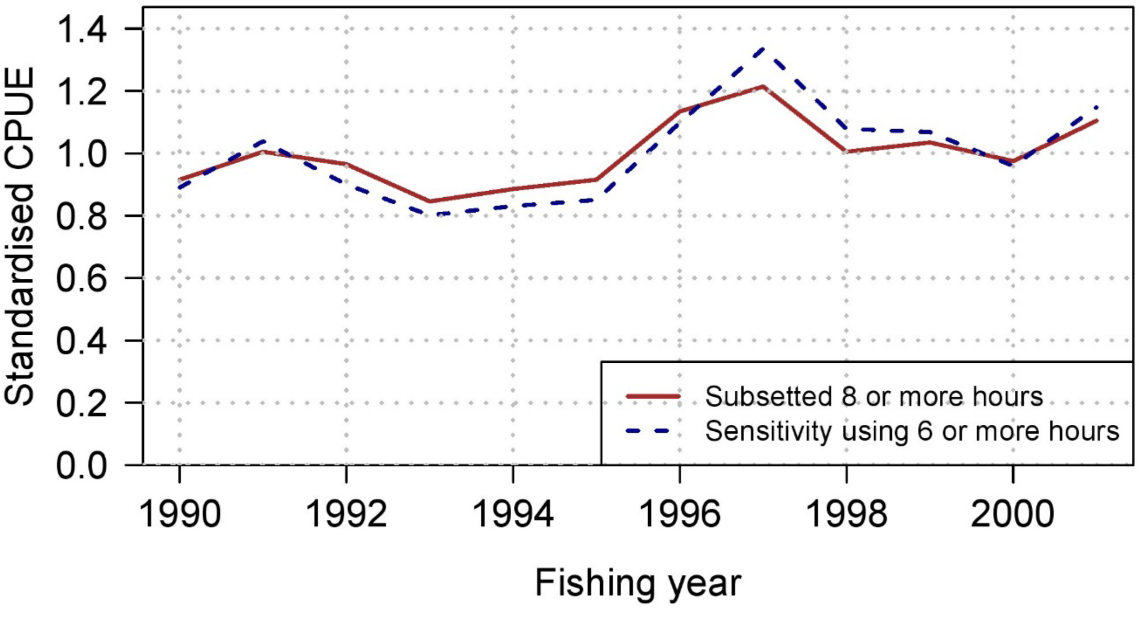


Figure 40: Sensitivity analysis for northern CELR CPUE analysis using a subset of six hours or more duration (for two or more divers).

Table 19: Number of CELR records in the northern area by year and general statistical area.

Year	**031**	**032**
1990	67	4
1991	50	10
1992	33	15
1993	17	4
1994	34	9
1995	47	3
1996	16	9
1997	27	6
1998	28	46
1999	61	61
2000	58	40
2001	39	44

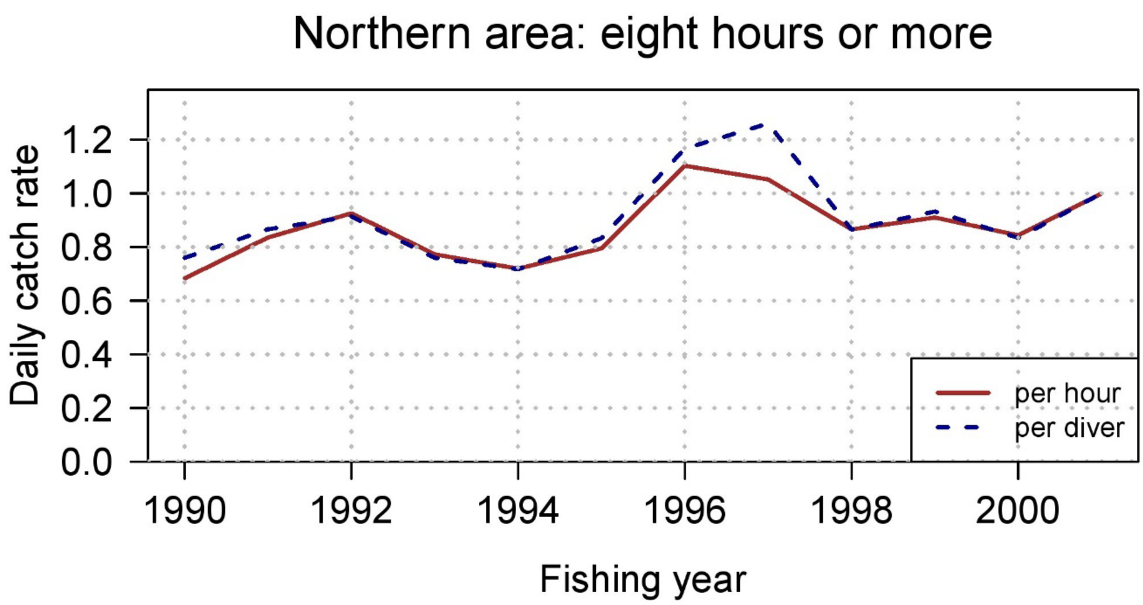


Figure 41: Geometric mean of the daily catch rate in the northern CELR data by year using a fishing duration of eight or more hours for filtering. The plots are scaled so that they both have the value one in 2001.

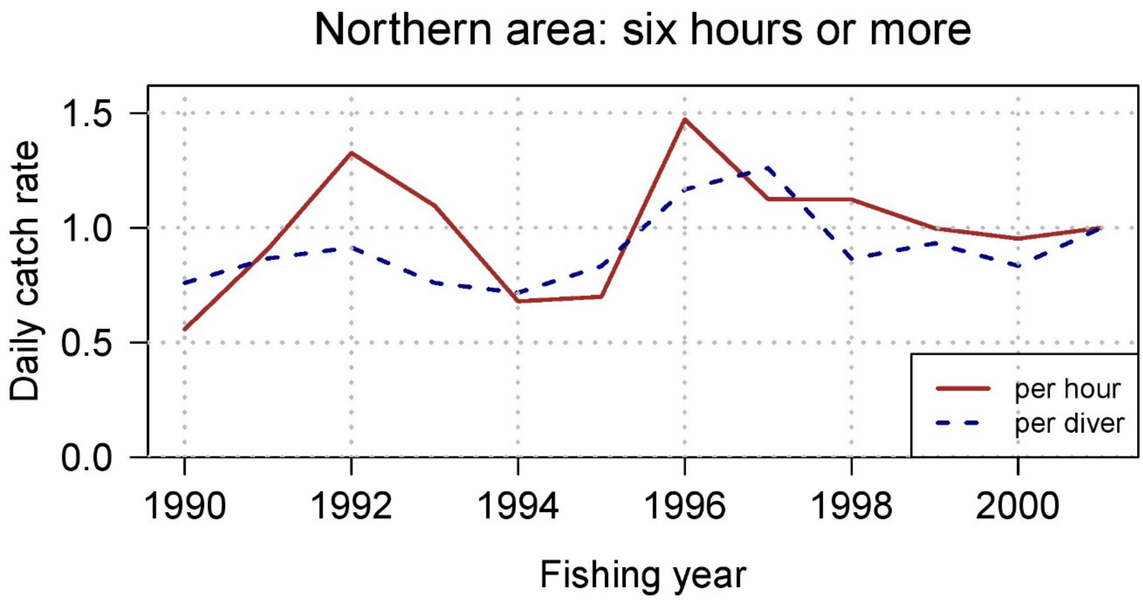


Figure 42: Geometric mean of the daily catch rate by year in the northern CELR data using a fishing duration of six more hours for filtering. The plots are scaled so that they both have the value one in 2001.

4.5 Northern area PCELR standardisation (2002–2014)

4.5.1 Data grooming and subsetting

For the initial data set all records were for paua targeted by diving, and contained FIN, fine scale statistical area, catch weight, fishing duration, and date. One record with no diver key was removed. For the standardisation some further grooming was done: 101 records were removed where no diving condition was recorded (Table 20).

Records were put into 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 were removed (0 records).

FIN was used to subset out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 10 records per year for a minimum of 6 years were selected. This retained 83% of the catch over 2002–2014 (Figures 43–46). The number of FIN holders dropped from 35 to 9 under these criteria. There was good overlap in effort for the FIN holders after subsetting (Figures 47–48). The number of days of records retained after subsetting was 145 or more for every fishing year (Table 21).

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 21). This reduced the number of statistical areas from 30 to 27, and the number of divers from 205 to 51 (37% of divers have only one diving day - this is partly an artefact of the fact that a spelling mistake in the diver's 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 49–52).

Table 20: Number of records removed in the northern PCELR data for which the diving conditions were not recorded.

Year	2002	2003	2004	2005	2007	2008	2009	2010	2011	2012	2013	2014	Total
Number	4	1	5	2	19	4	14	6	18	6	7	15	101

Table 21: Number of records remaining in the northern 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 removed (see Table 20). Year is denoted in short form .e.g. 02 = 2002.

Year	02	03	04	05	06	07	08	09	10	11	12	13	14	Total
Total records	248	259	333	309	327	282	348	211	268	188	241	223	261	3498
FIN subsetting	179	201	296	252	277	248	293	167	224	170	181	145	196	2829
Fine scale stat area>=10 dive days	178	201	293	252	277	248	291	167	224	170	181	138	189	2809
Divers with>=10 dive days	134	192	256	218	244	223	252	134	187	155	154	102	172	2423

4.5.2 Standardisation

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

Except for month, all variables were accepted into the model, which explained 74% of the variability in CPUE (Table 22). Most of the variability was explained by duration (54%) and diver (8%). The effects appear plausible and the diagnostics are good (Figures 53–54). There is an apparent increasing effect for the catch taken after a fishing duration of 10 hours, although for the majority of records fishing duration is less than 10 hours (Figure 55).

The standardised index shows a slow decline from 2002 to 2012 with a slight increase since then (Table 23, Figure 56).

Forcing a year:area interaction into the model, using the research strata as the areas, gives indices that are similar for the different areas (Figure 57). The fluctuating Milford index has a small number of records for many years (Table 24).

Table 22: Variables accepted into the model for the northern PCELR dataset (1% additional deviance explained), and the order in which they were accepted into the model, degrees of freedom (Df), and total variance explained (R-squared)

Predictors	Df	R-squared
Year	12	0.05
Fishing duration	3	0.59
Diver key	50	0.67
Conditions	4	0.71
Statistical area	26	0.74

Table 23: Standardised index for the northern PCELR data set, lower and upper 95% confidence intervals (CI), and CV.

Year	Index	lower CI	Upper CI	CV
2002	1.08	0.90	1.29	0.09
2003	1.16	0.99	1.37	0.08
2004	0.93	0.81	1.07	0.07
2005	1.09	0.94	1.25	0.07
2006	1.08	0.94	1.25	0.07
2007	0.96	0.83	1.10	0.07
2008	0.94	0.82	1.07	0.07
2009	0.95	0.80	1.13	0.09
2010	0.92	0.79	1.07	0.08
2011	1.04	0.88	1.22	0.08
2012	0.90	0.76	1.06	0.08
2013	0.95	0.78	1.17	0.10
2014	1.05	0.87	1.25	0.09

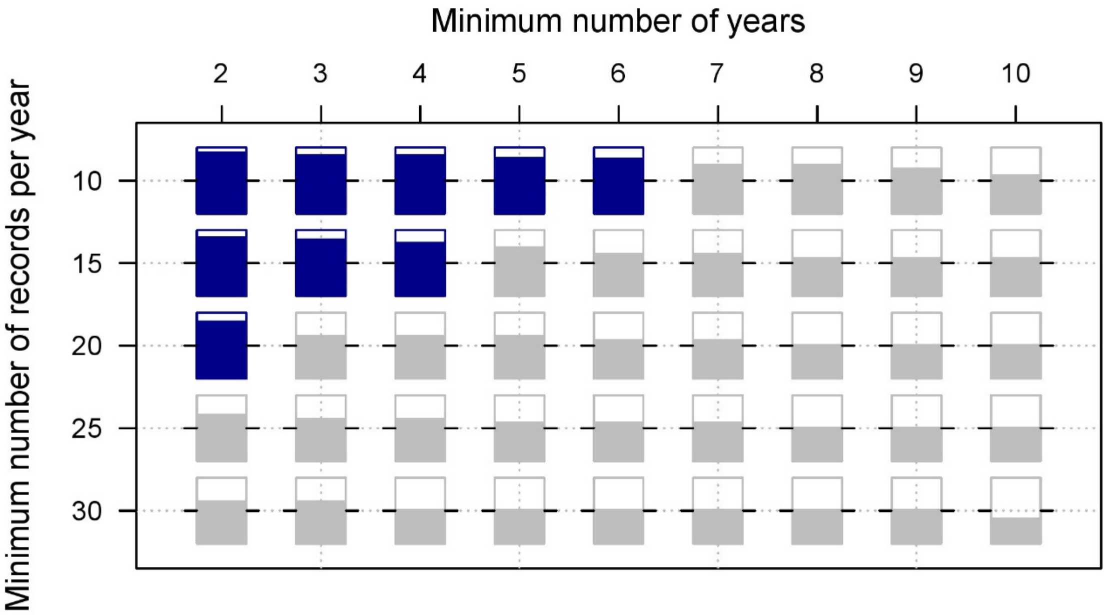


Figure 43: Proportion of the catch taken when subsetting the northern PCELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2014 retained under the criteria, where the horizontal 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.

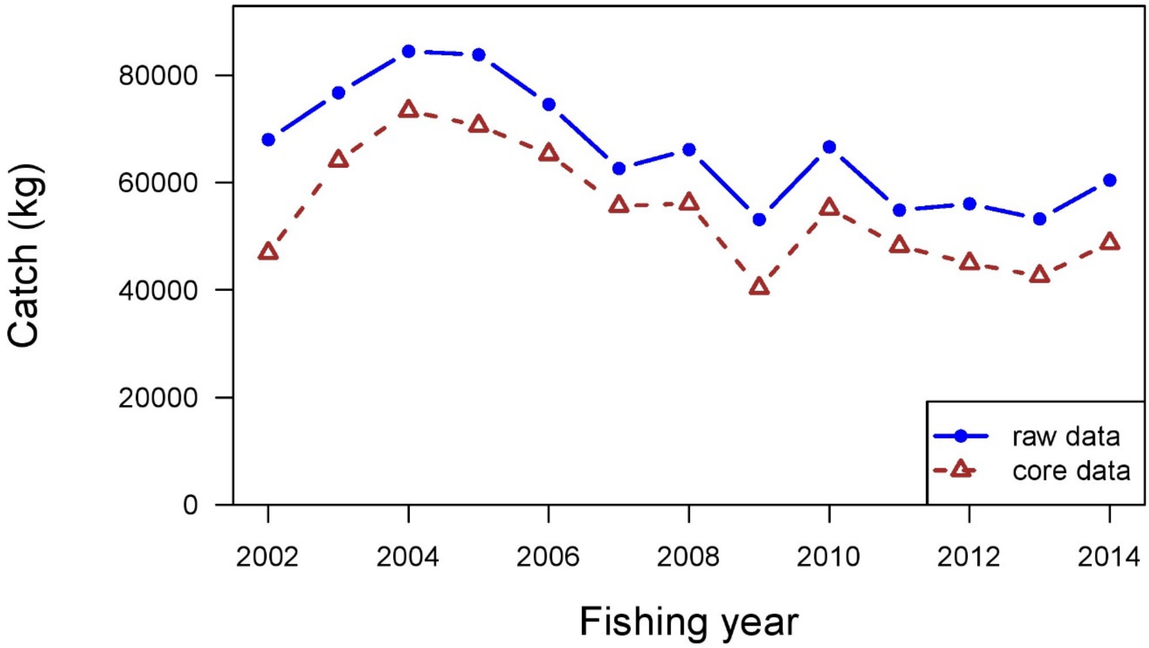


Figure 44: Catch by fishing year from the northern PCELR dataset before FIN subsetting (raw data) and after (core data).

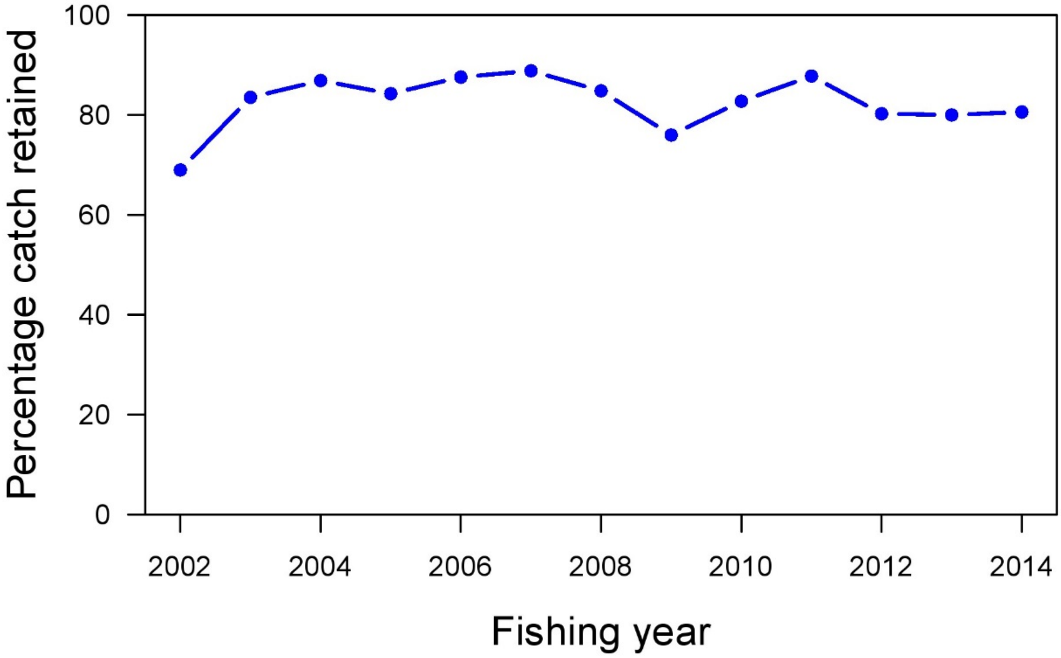


Figure 45: Percentage of the catch retained in the northern PCELR dataset after FIN subsetting.

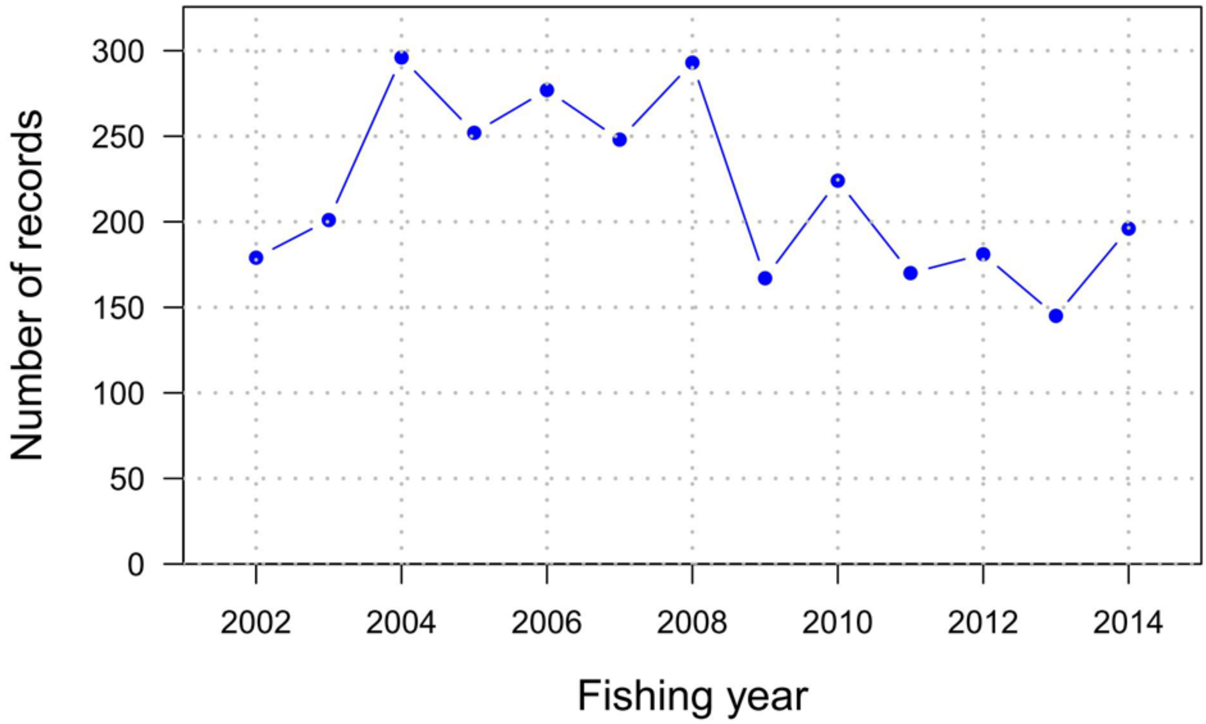


Figure 46: Number of records retained in the northern PCELR dataset after subsetting by FIN.

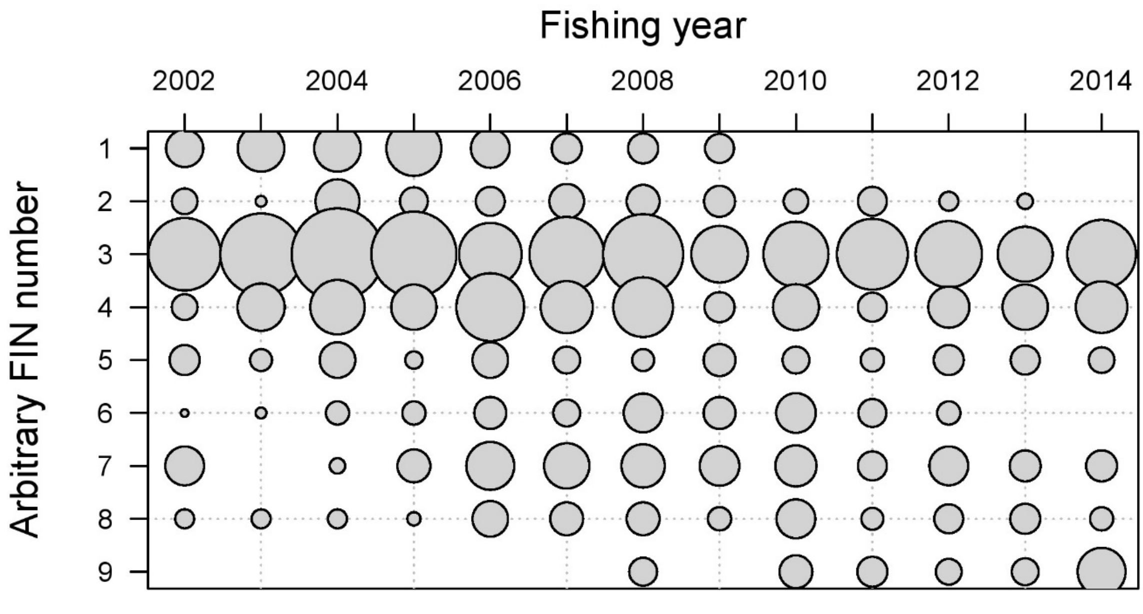


Figure 47: Overlap in number of records in the northern PCELR dataset by FIN after subsetting by FIN. The area of a circle is proportional to the number of records.

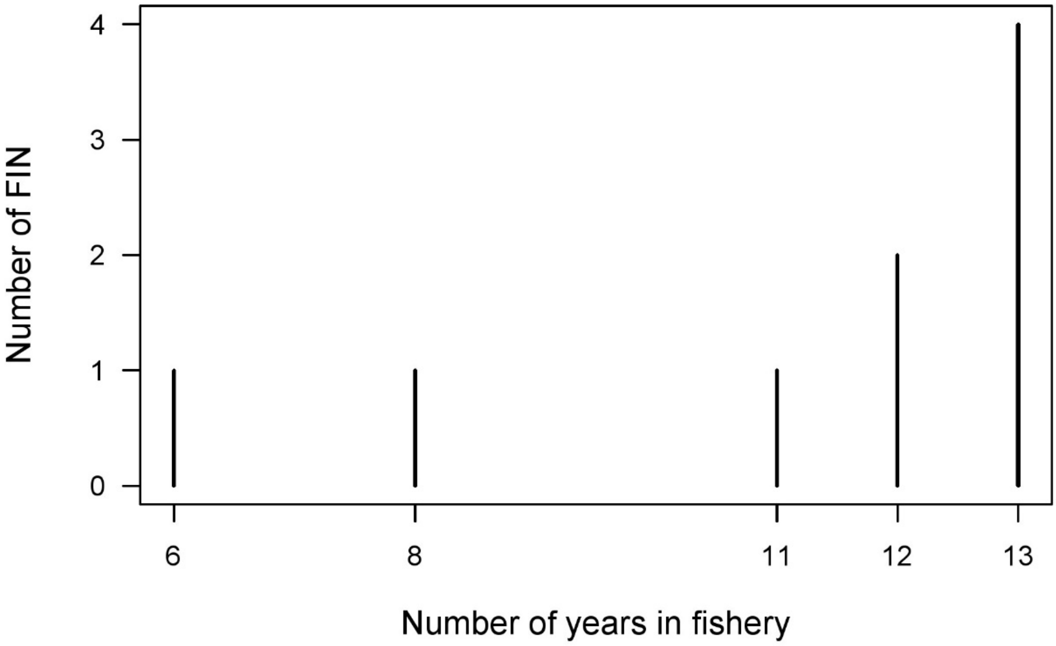


Figure 48: Number of years in the fishery for a FIN holder in the northern PCELR dataset after subsetting by FIN.

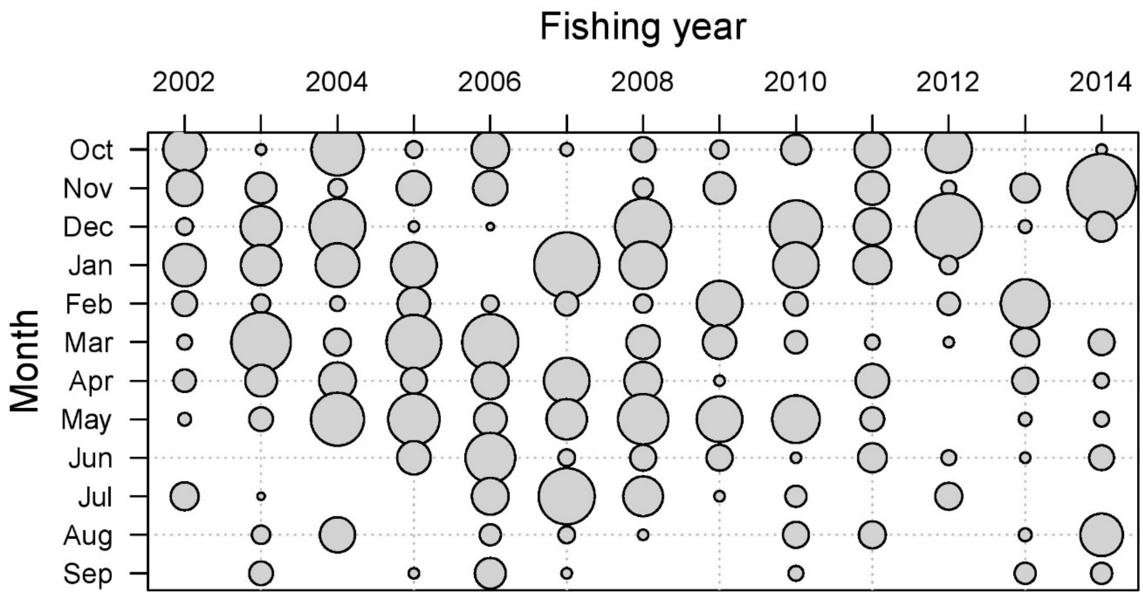


Figure 49: Number of records in the northern PCELR dataset by month and fishing year. The area of a circle is proportional to the number of records.

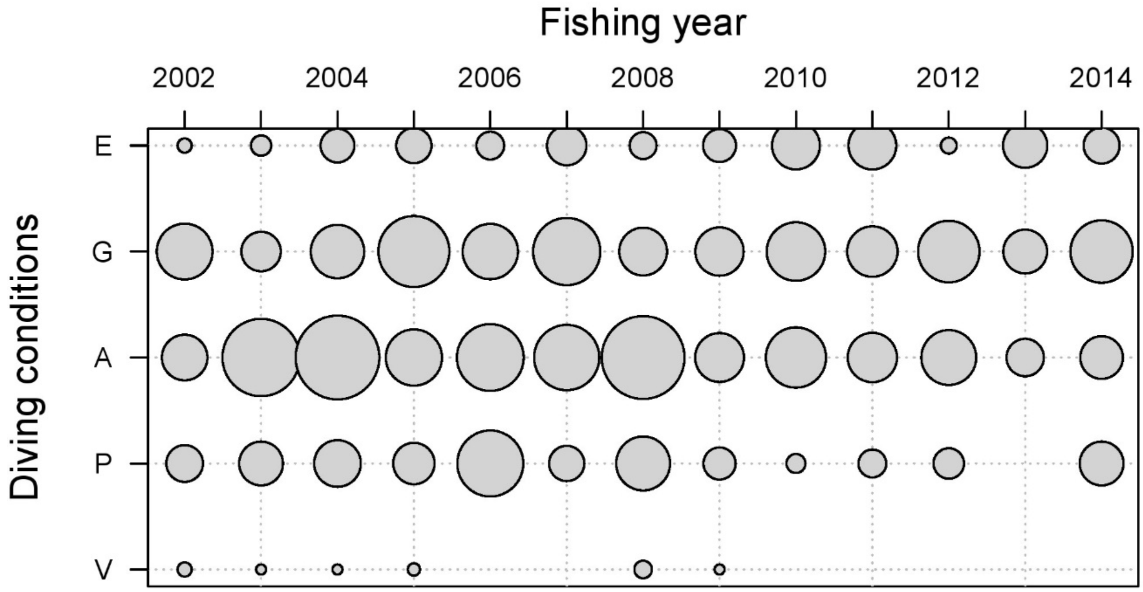


Figure 50: Number of PCELR records in the northern dataset by diving condition (excellent, good, average, poor, very poor) and fishing year. The area of a circle is proportional to the number of records.

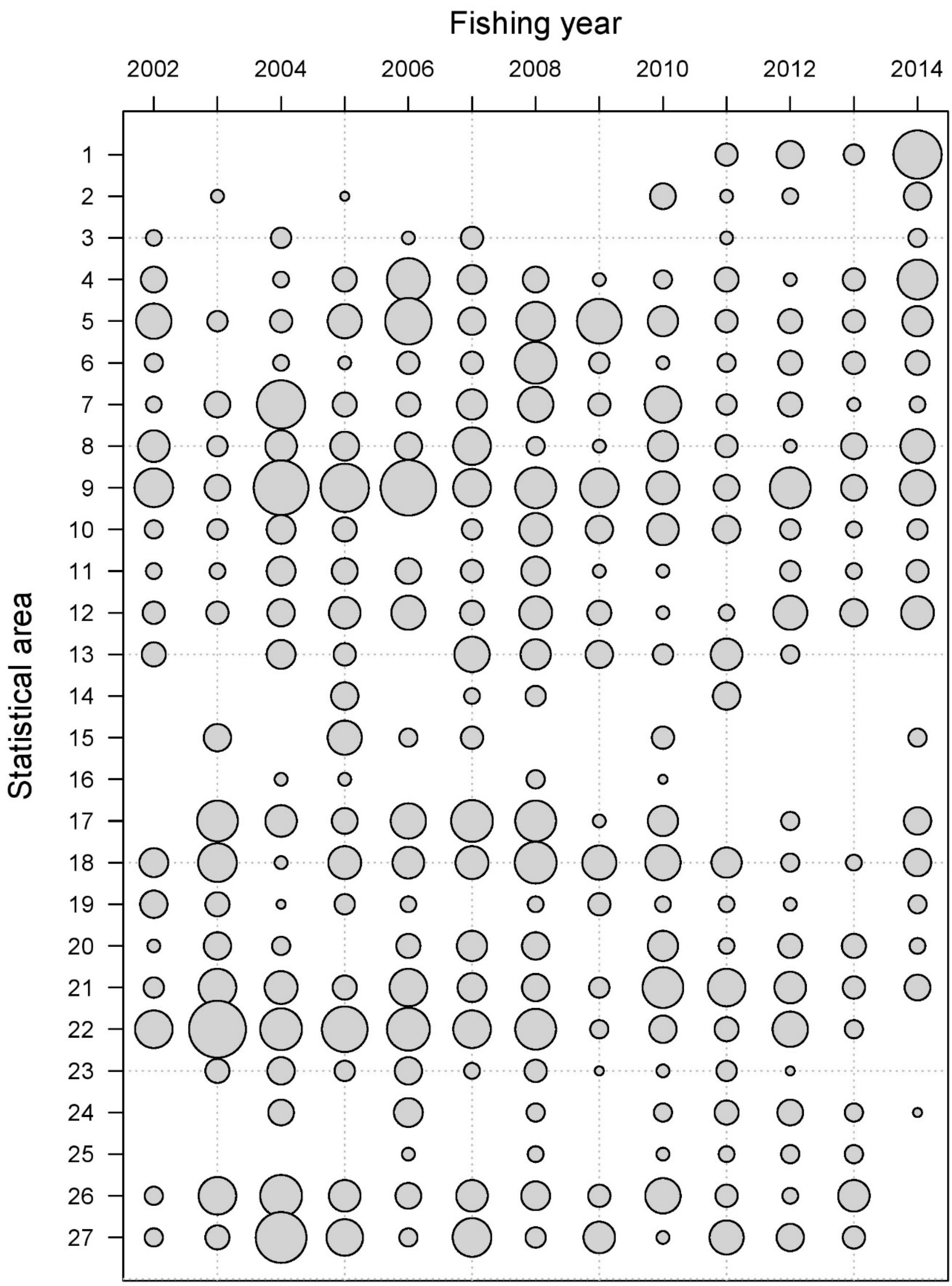


Figure 51: Number of PCELR records in the northern dataset by statistical area and fishing year. The area of a circle is proportional to the number of records. Arbitrary sequential numbers are used for the statistical areas.

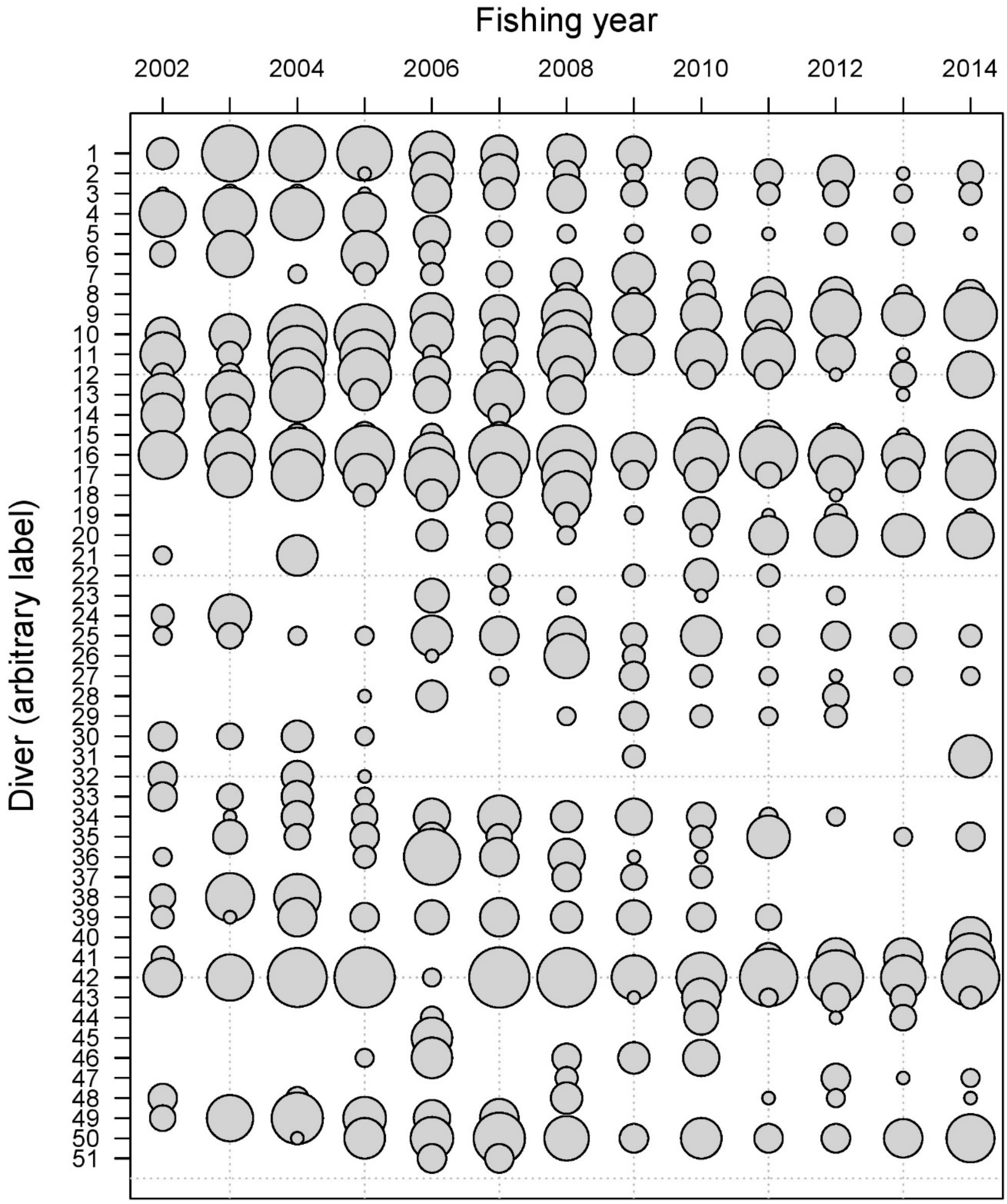


Figure 52: Number of PCELR records in the northern dataset by diver key and fishing year. The area of a circle is proportional to the number of records.

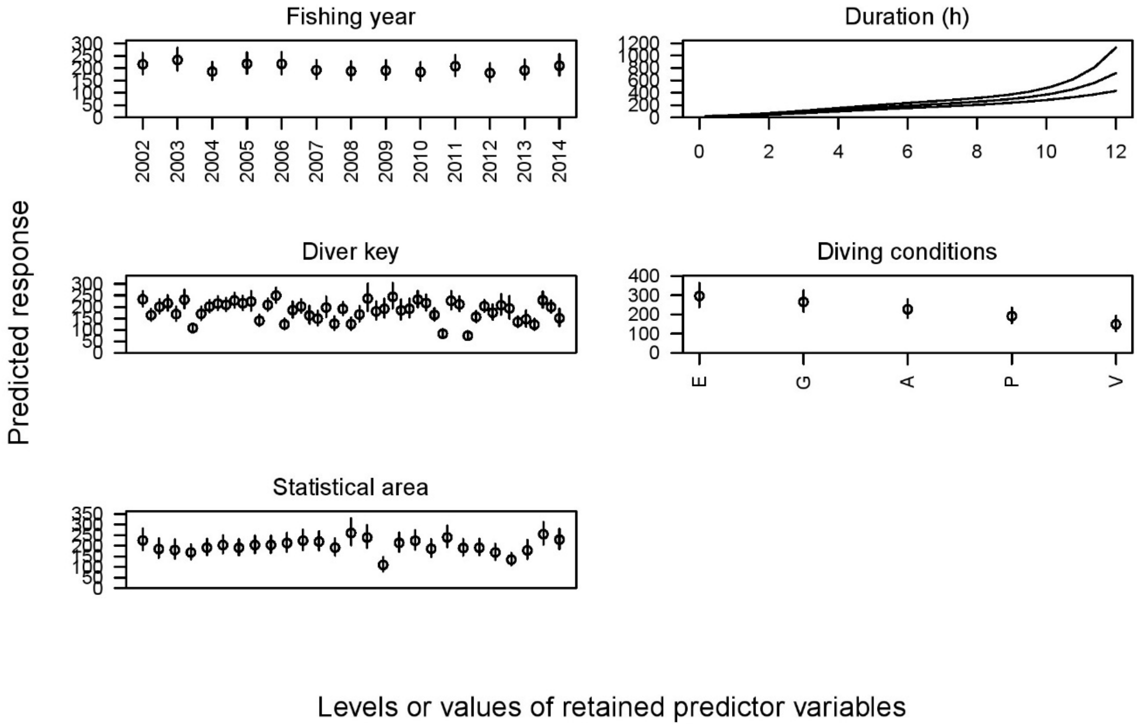


Figure 53: Effects for the northern PCELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

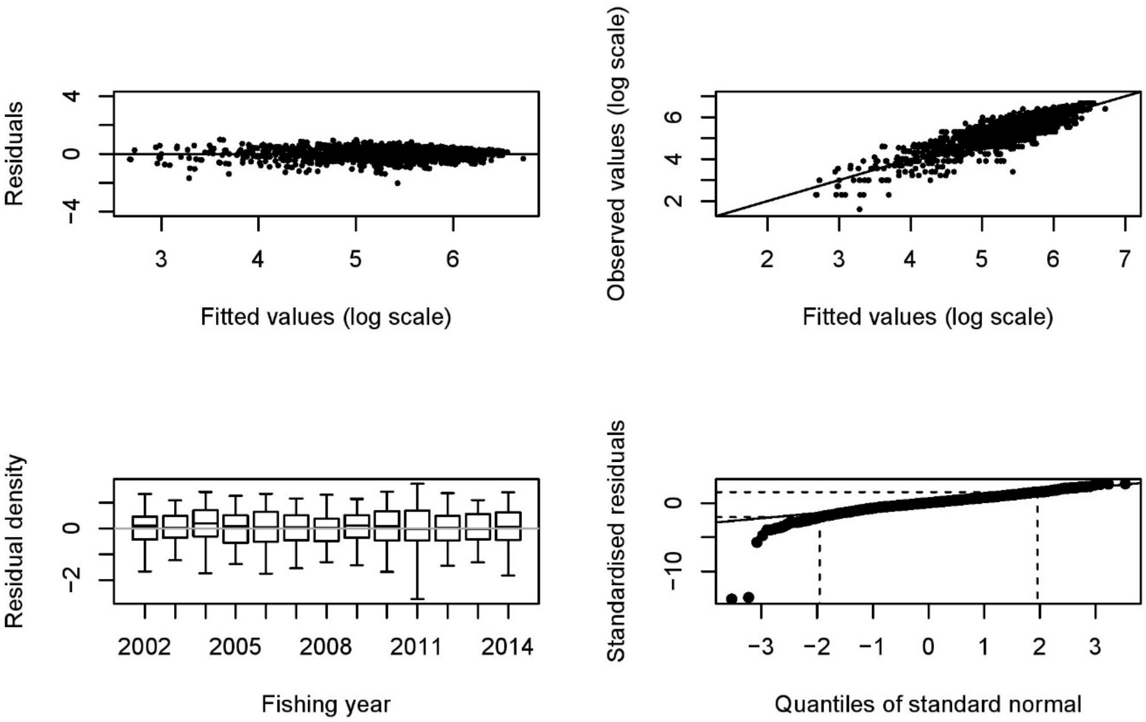


Figure 54: Diagnostic plots for the northern PCELR standardisation model.

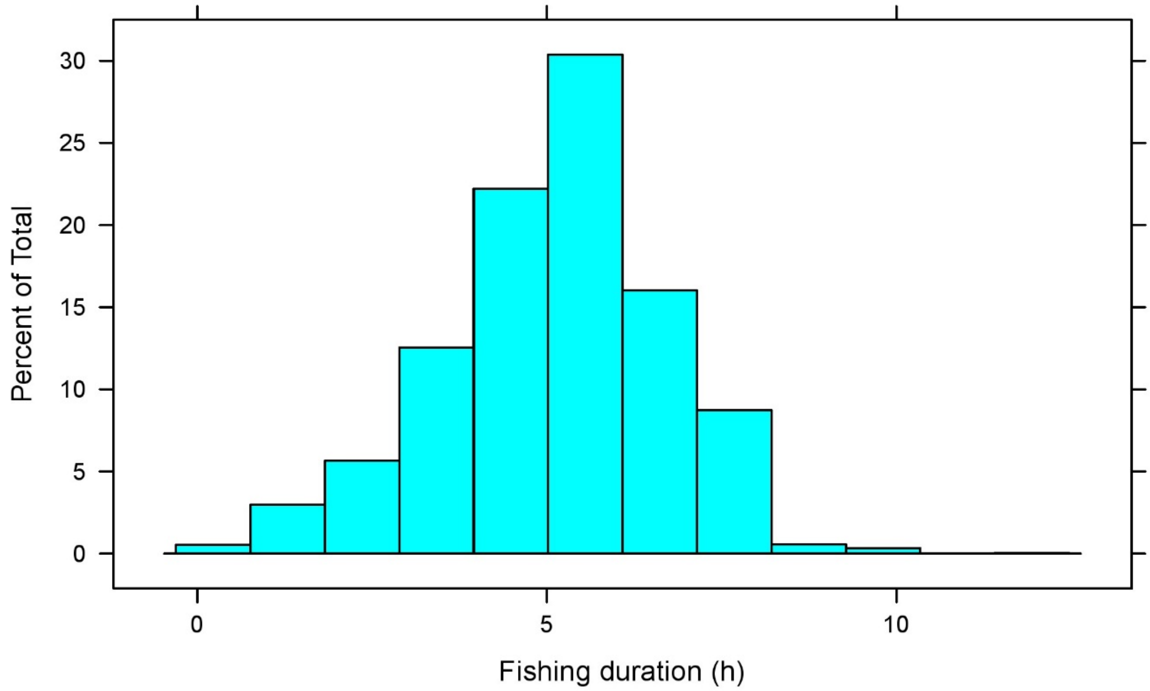


Figure 55: Distribution of fishing duration (h) for the northern PCELR dataset.

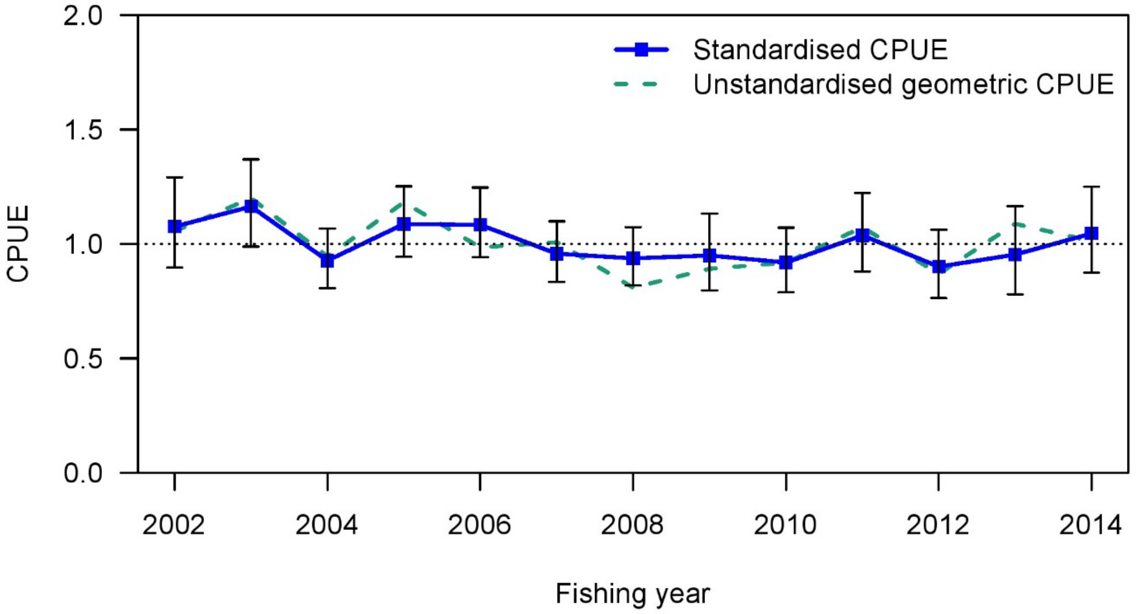


Figure 56: The standardised CPUE index for the northern PCELR dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

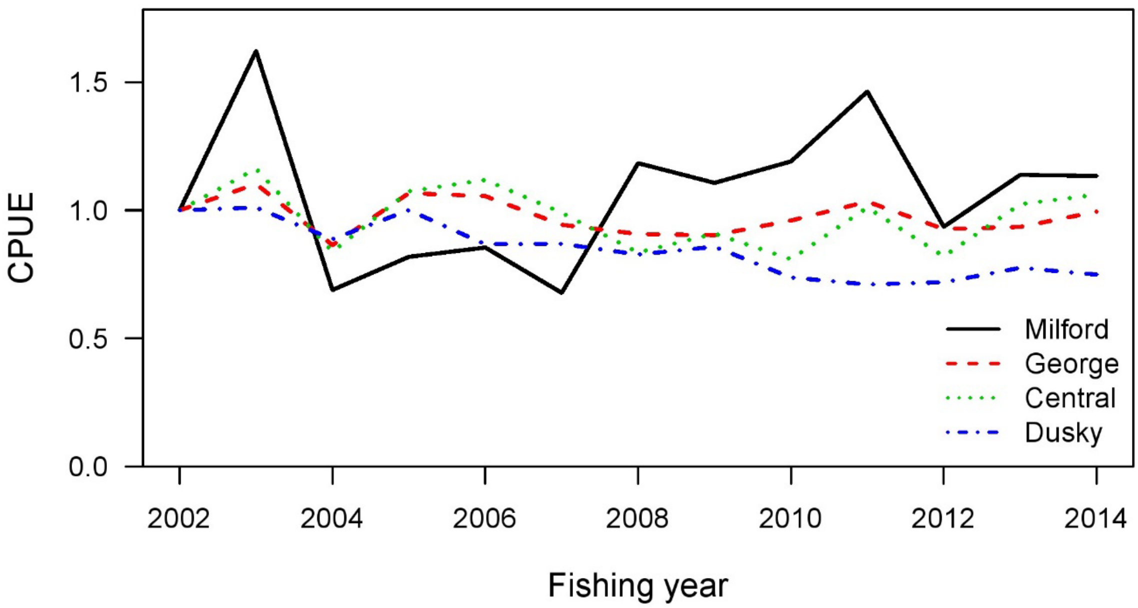


Figure 57: Standardised indices for the northern PCELR dataset with a year:strata interaction forced into the model. The areas are research strata. The indices are scaled to have the value one in 2002.

Table 24: Number of records for the subsetted northern PCELR data by year and research strata.

Year	Milford	George	Central	Dusky
2002	11	65	33	25
2003	2	40	80	70
2004	8	114	44	90
2005	8	88	64	58
2006	24	107	58	55
2007	16	78	79	50
2008	8	114	82	48
2009	2	73	36	23
2010	12	69	72	34
2011	17	41	55	42
2012	14	67	33	40
2013	11	45	16	30
2014	60	74	37	1

4.6 Southern area CELR standardisation (1990–2001)

4.6.1 Initial data set

A set of criteria were used to subset out records for which total hours were most likely recorded: (i) just one diver, or (ii) fishing duration ≥ 8 hours and number of divers ≥ 2 (see Section 4.2.5). For the PAU 5A dataset it is apparent that most records are recorded as hours *per diver* instead of total hours *for all divers* which is what should be recorded. Because of this it was decided by the SFWG to use all data, but to scale up the non-subsetted data recorded hours taking this into account (i.e to multiply by the number of divers).

After scaling up fishing duration for non-subsetted data records, some further grooming was done in which records with NA for fishing duration were removed (38 records), and a fishing duration per diver greater than 10 hours was removed (14 records). The grooming retained 99% of the records from 1990–2001 (Table 25). Of the retained records 20% had one diver (Table 26).

Table 25: Southern area CELR data. Number of records in the dataset before and after grooming.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	220	256	255	248	217	262	271	233	213	199	242	209	2825
After	216	255	253	247	217	260	268	224	209	194	237	209	2789

Table 26: Southern area CELR data. Distribution of the number of divers before and after grooming.

Number of divers	1	2	3	4	5	6	7	8	9
Before	570	1327	686	128	46	36	23	4	5
After	559	1313	679	128	44	36	21	4	5

Due to rounding in the fishing duration recorded there is some clumping in the fishing duration per diver (Figure 58). The median and mean fishing duration per diver both change over time (Figures 59–60).

Catch rates (daily kilograms per unit effort) were calculated using as the units of effort: (i) the number of divers, or (ii) total daily diving duration. Comparing the yearly geometric mean of these (i.e. a standardisation with just a year effect) shows that using the diving duration as a measure of effort gives an index that is similar to that using the number of divers (Figure 61).

4.6.2 FIN subsetting of data

FIN is used to subset out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 5 records per year for a minimum of 3 years was chosen, this retaining 80% of the catch over 1990– 2001 (Figure 62). Note that while over 80% of the catch is retained, it is less than this for some years at the beginning and end of the period (Figures 63–64). The number of days of effort retained after subsetting is 119 or more for every fishing year (Table 27, Figure 65). The number of FIN holders drops from 116 to 25 under the subsetting criteria.

There is good overlap in effort over time for the FIN holders after subsetting (Figures 66–67). There is also a good overlap in time for month (Figure 68).

4.6.1 Standardisation

CPUE was defined as daily catch. Year was forced into the model at the start and other predictor variables offered to the model were FIN, month, fishing duration (as a cubic polynomial), and number of divers.

The model explained 52% of the variability in CPUE with fishing duration explaining most of this (38%) followed by FIN (9%) (Table 28). The effects appear plausible and the model diagnostics are good (Figures 69–70). There is an apparent increasing effect for the catch taken after a fishing duration of 50 hours, although for the majority of records fishing duration is less than this (Figure 71). The standardised index shows a decline until 1997, after which it is approximately constant (Table 29, Figure 72).

As a sensitivity analysis to the filtering criteria for the subsetted data set (in which the fishing duration field should be less ambiguous) another standardisation was done in which when the number of divers was ≥2 the fishing duration had to be ≥ 6 hours (instead of 8 hours). The resulting index is very similar to that when 8 hours is used (Figure 73). For unstandardised indices, there is some difference between using catch per hour versus catch per diver (Figures 74–75).

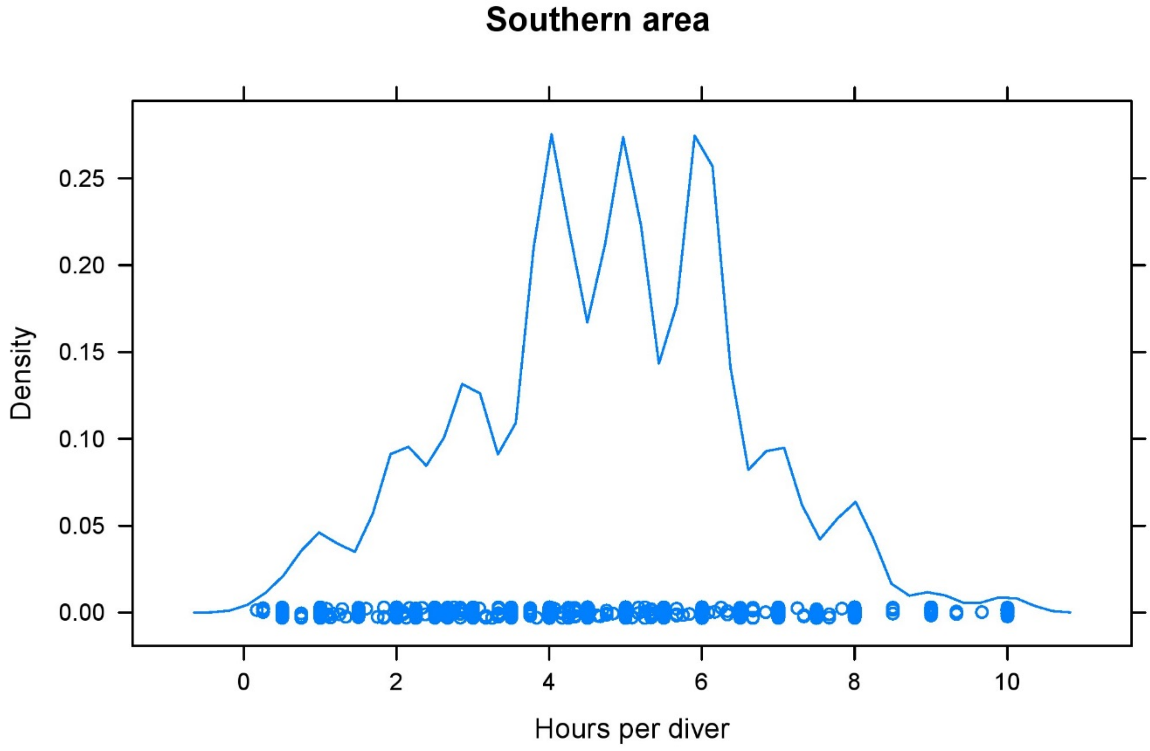


Figure 58: Initial CELR data set for the southern area. Density and strip plot for the hours per diver.

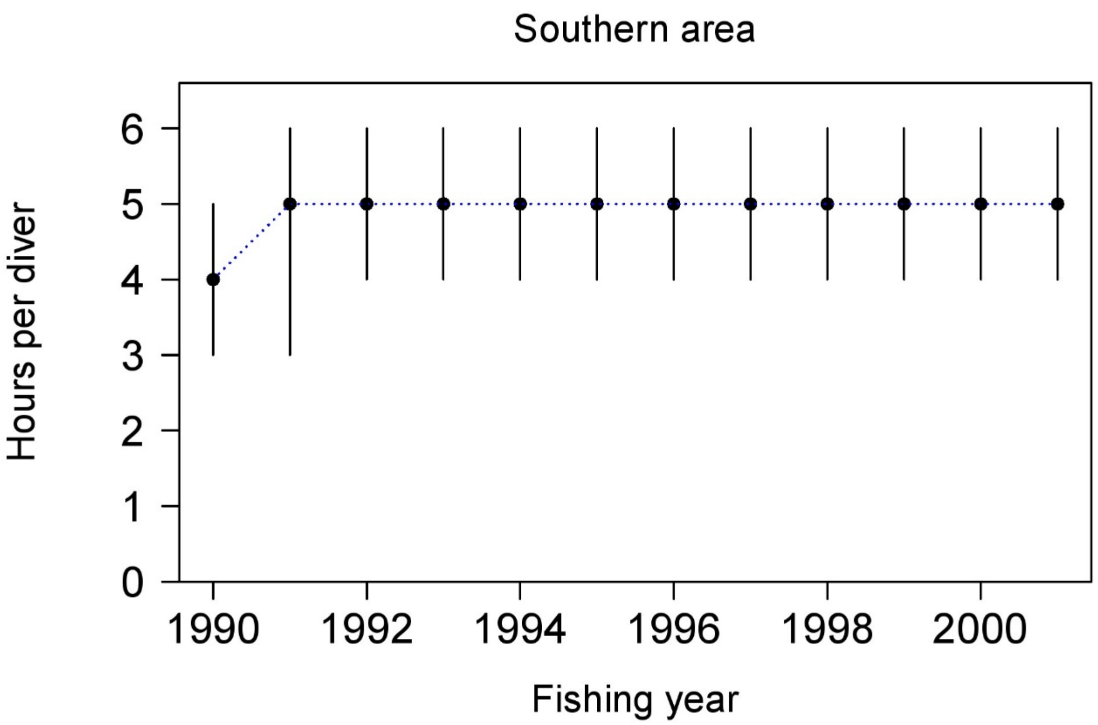


Figure 59: Initial CELR data set for the southern area. Quantiles by fishing year for the daily fishing duration per diver: medians (dot) and lower and upper quartiles (vertical lines).

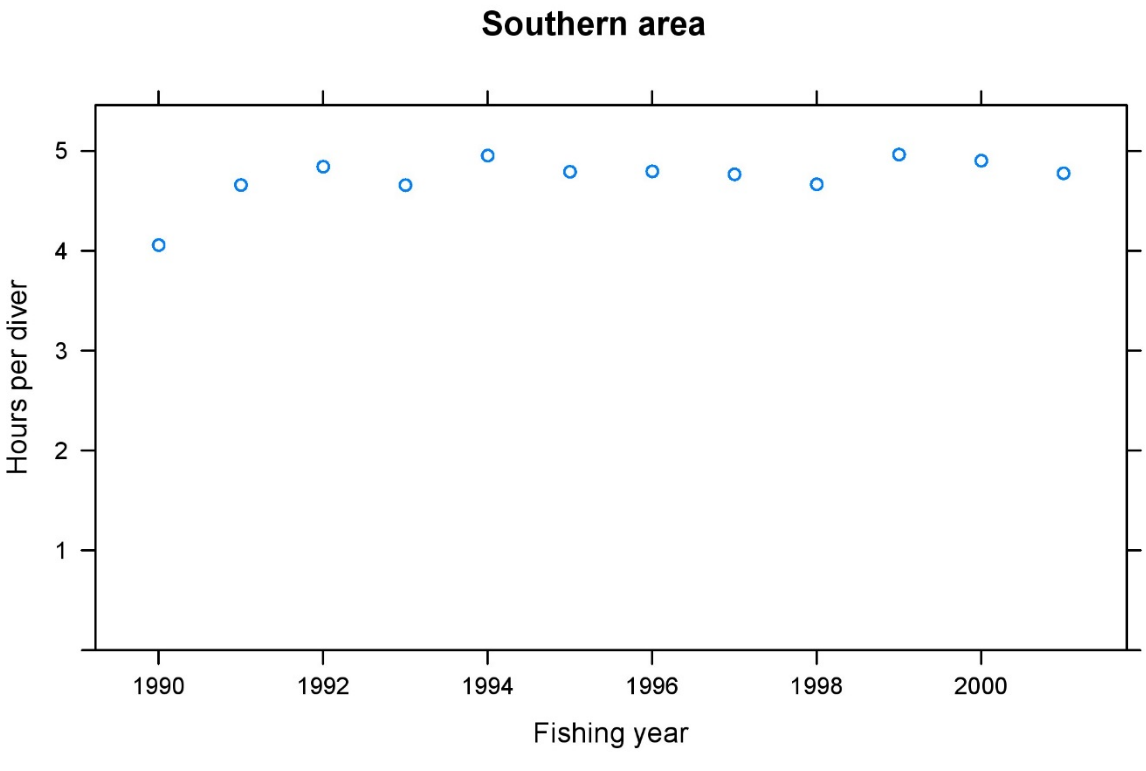


Figure 60: Initial CELR dataset for the southern area. Mean values by fishing year for the daily duration per diver.

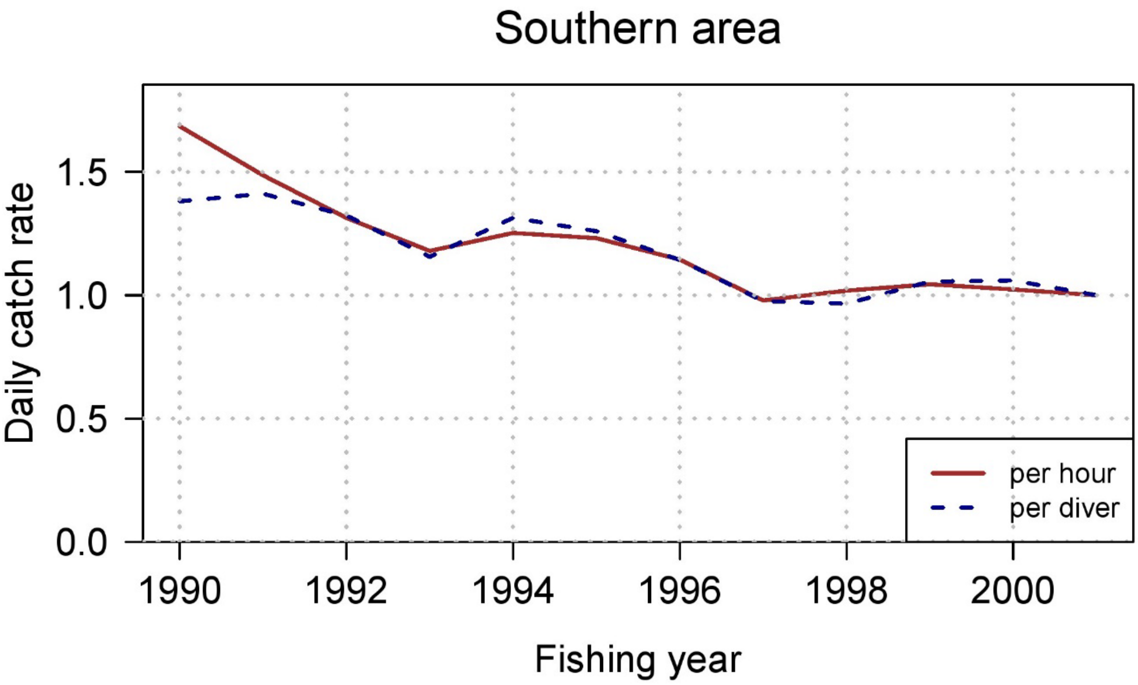


Figure 61: Initial CELR dataset for the southern area. Geometric mean of the daily catch rate by year. The plots are scaled so that they both have the value one in 2001.

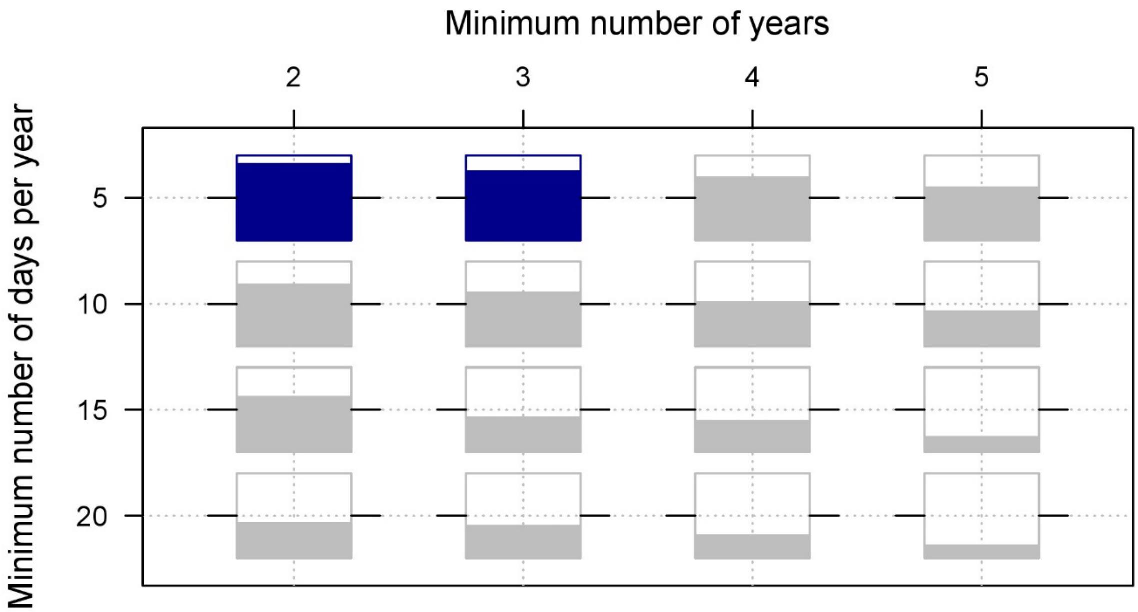


Figure 62: Proportion of the catch taken when subsetting the southern CELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

Table 27: Number of southern CELR records before and after FIN subsetting.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	216	255	253	247	217	260	268	224	209	194	237	209	2789
After	121	153	205	219	173	238	221	206	179	165	134	119	2133

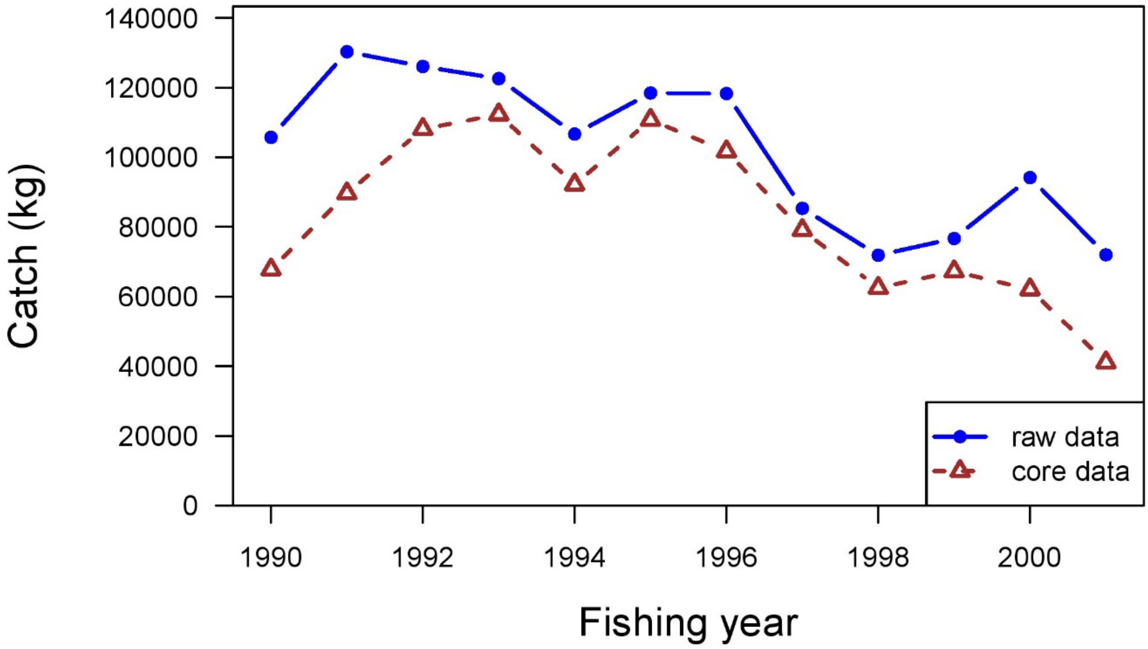


Figure 63: Catch in southern area on CELR forms by fishing year before FIN subsetting (raw data) and after (core data).

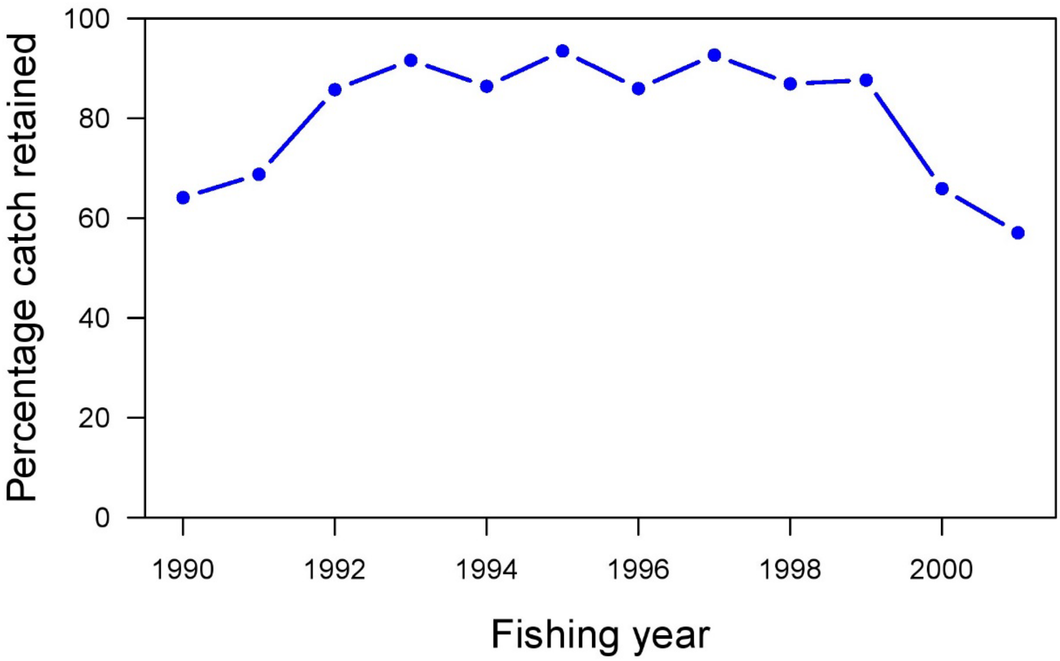


Figure 64: Percentage of the catch retained after FIN subsetting of southern CELR data.

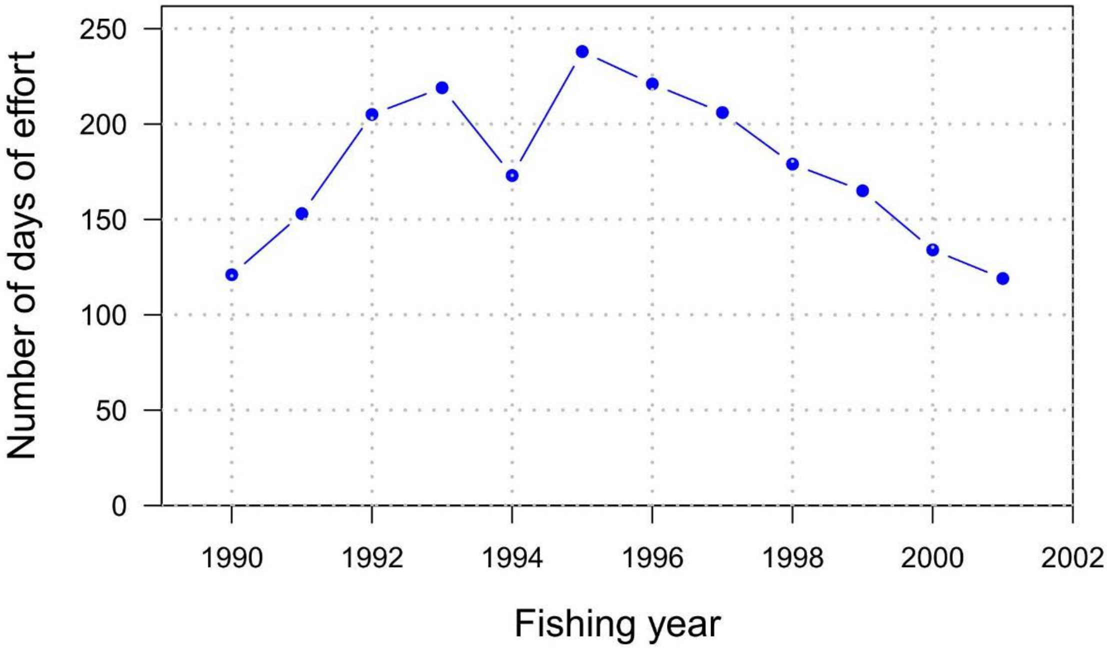


Figure 65: Number of days of effort retained after FIN subsetting of southern CELR data.

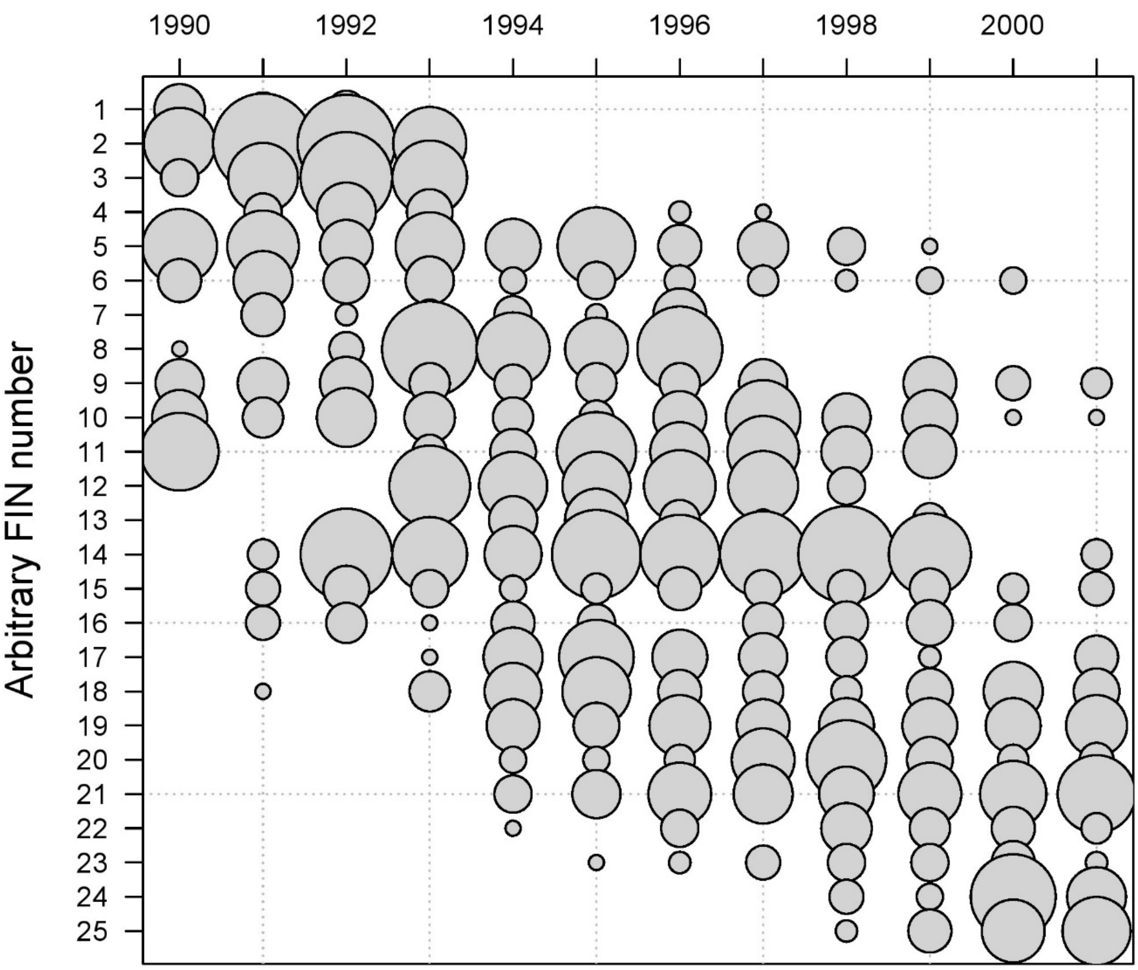


Figure 66: Overlap in days of effort by FIN in southern CELR data. The area of a circle is proportional to the days of effort.

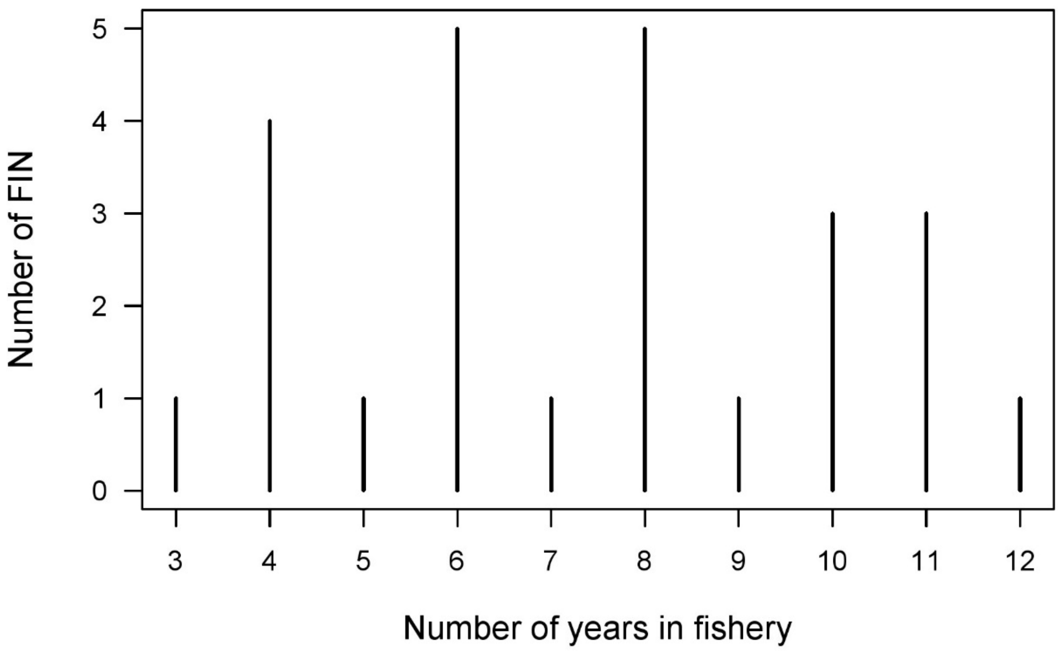


Figure 67: Number of years in the fishery for a FIN holder after subsetting by FIN in southern CELR data.

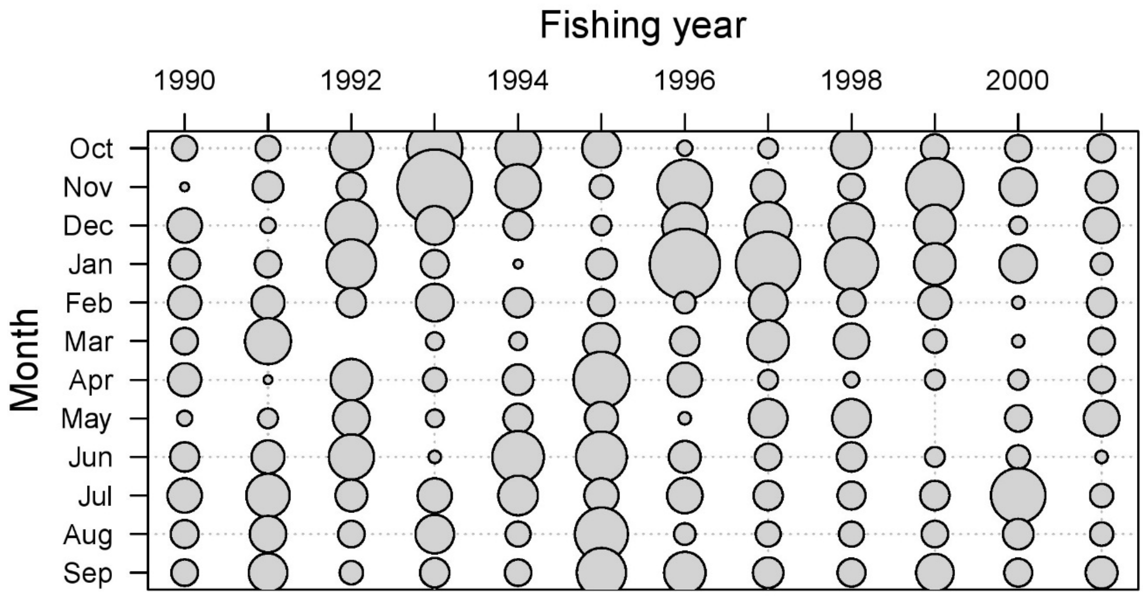


Figure 68: Overlap in days of effort for month by fishing year in southern CELR data.

Table 28: Variables accepted into the southern CELR standardisation model (1% additional deviance explained) and the order in which they were accepted into the model, degree of freedom (Df) and total deviance explained (R-squared).

Predictor	Df	R-squared
Year	11	0.04
Fishing duration	3	0.42
Client key (FIN)	24	0.51
Month	11	0.52

Table 29: Standardised CELR index for southern area, lower and upper 95% confidence intervals (CI), and CV.

Year	Index	lower CI	upper CI	CV
1990	1.58	1.30	1.91	0.10
1991	1.33	1.11	1.59	0.09
1992	1.07	0.92	1.25	0.08
1993	0.99	0.85	1.14	0.07
1994	1.14	0.98	1.33	0.08
1995	1.05	0.91	1.20	0.07
1996	0.92	0.80	1.06	0.07
1997	0.79	0.68	0.91	0.07
1998	0.83	0.71	0.97	0.08
1999	0.81	0.69	0.95	0.08
2000	0.94	0.77	1.14	0.10
2001	0.82	0.67	1.00	0.10

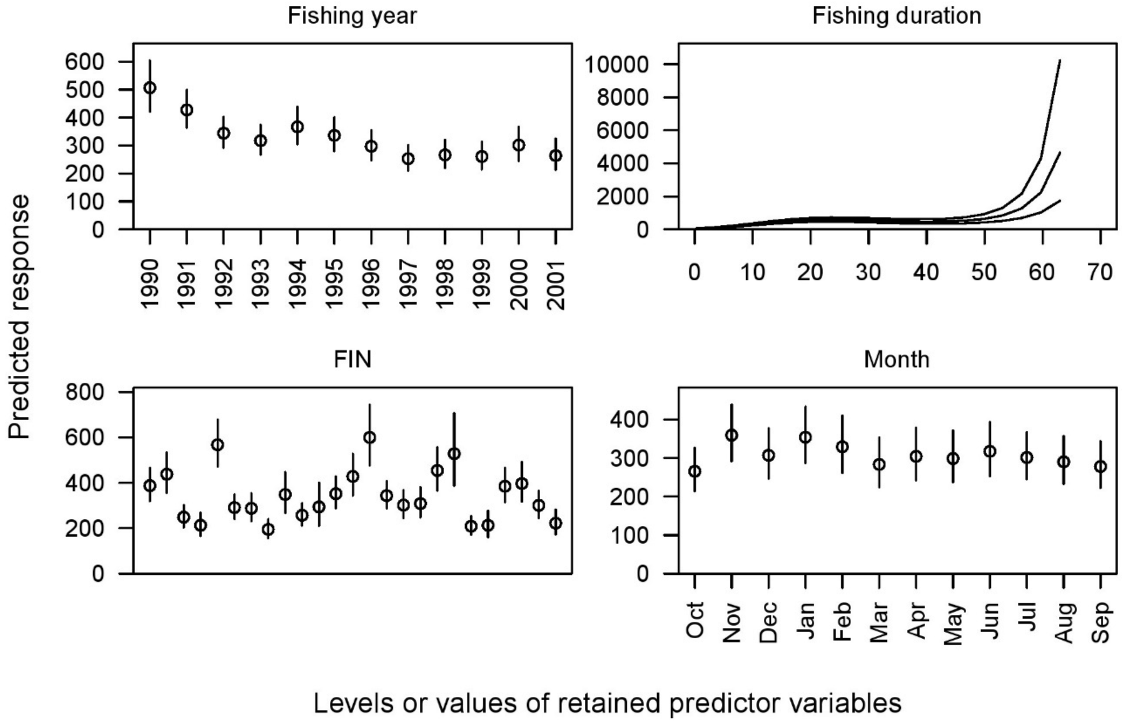


Figure 69: Effects for the southern CELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

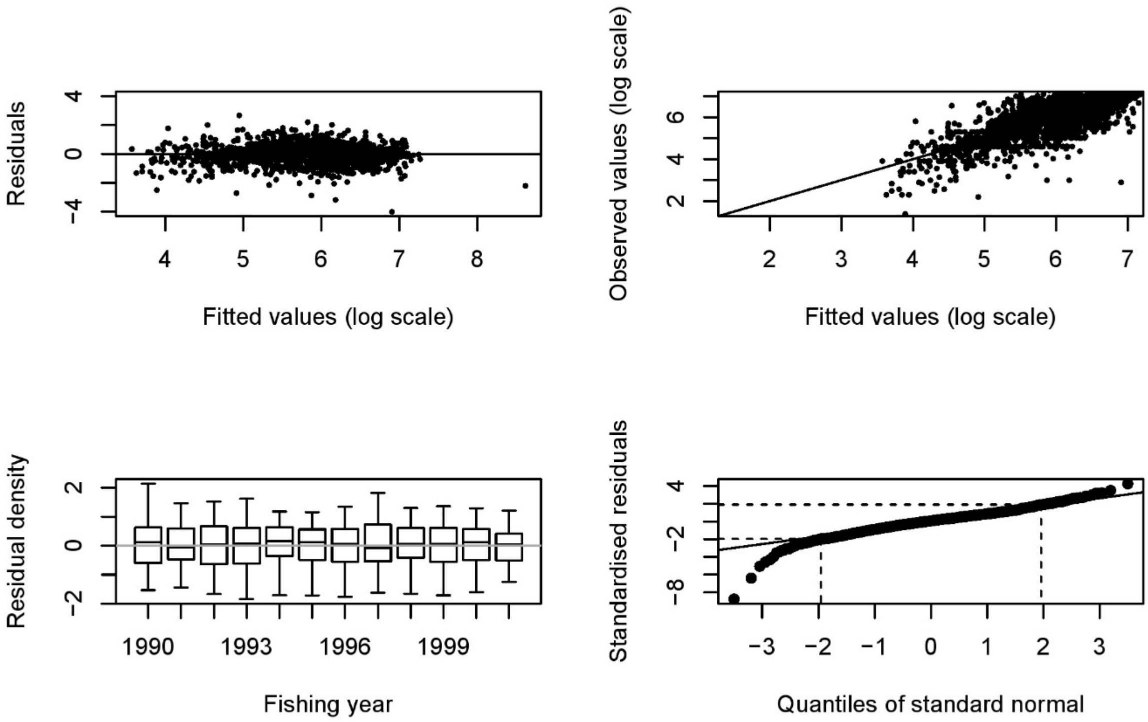


Figure 70: Residuals for the southern CELR standardisation model.

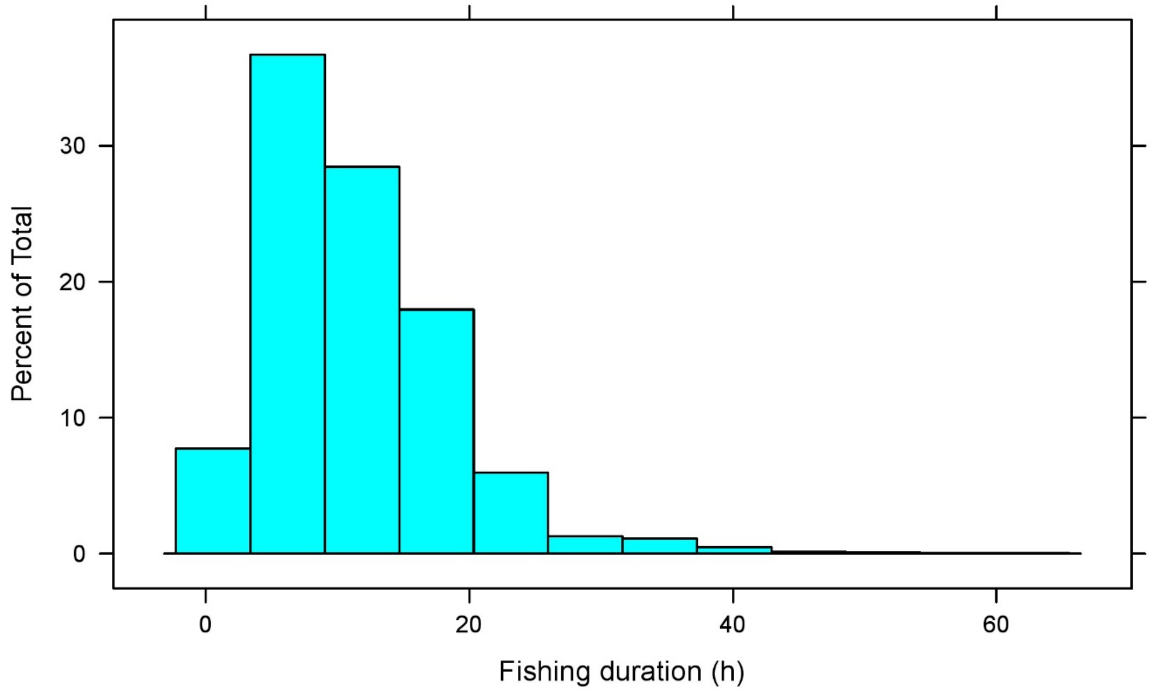


Figure 71: Distribution of fishing duration (h) in the southern CELR dataset.

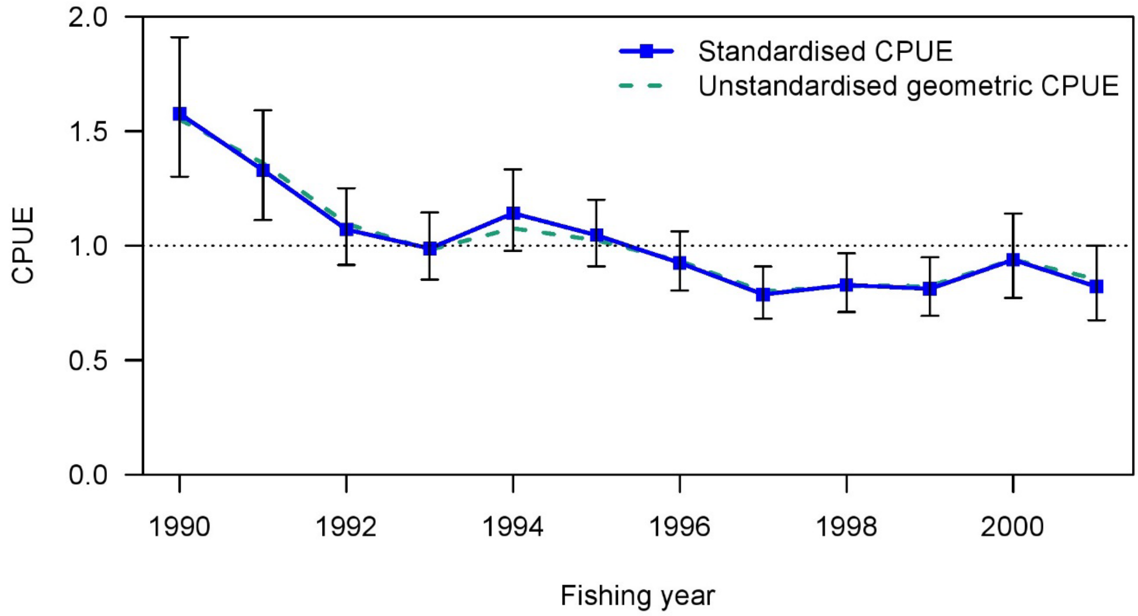


Figure 72: The southern standardised CPUE index with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

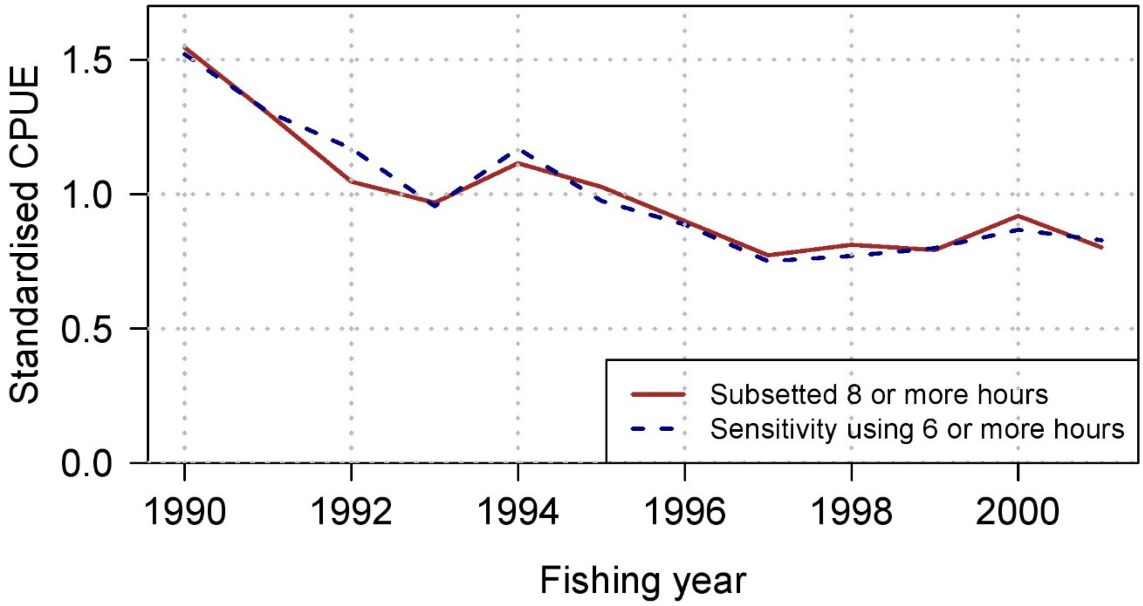


Figure 73: Sensitivity analysis for southern CELR CPUE analysis using a subset of six hours or more (for two or more divers).

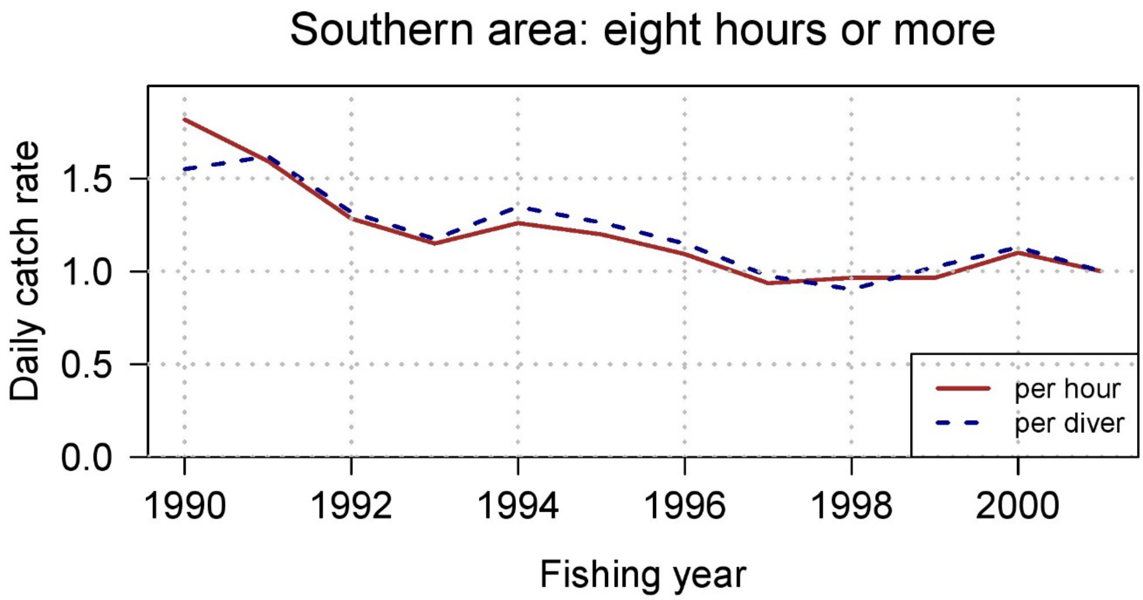


Figure 74: Geometric mean of the daily catch rate in the southern CELR dataset by year using a fishing duration of eight or more hours for filtering. The plots are scaled so that they both have the value one in 2001.

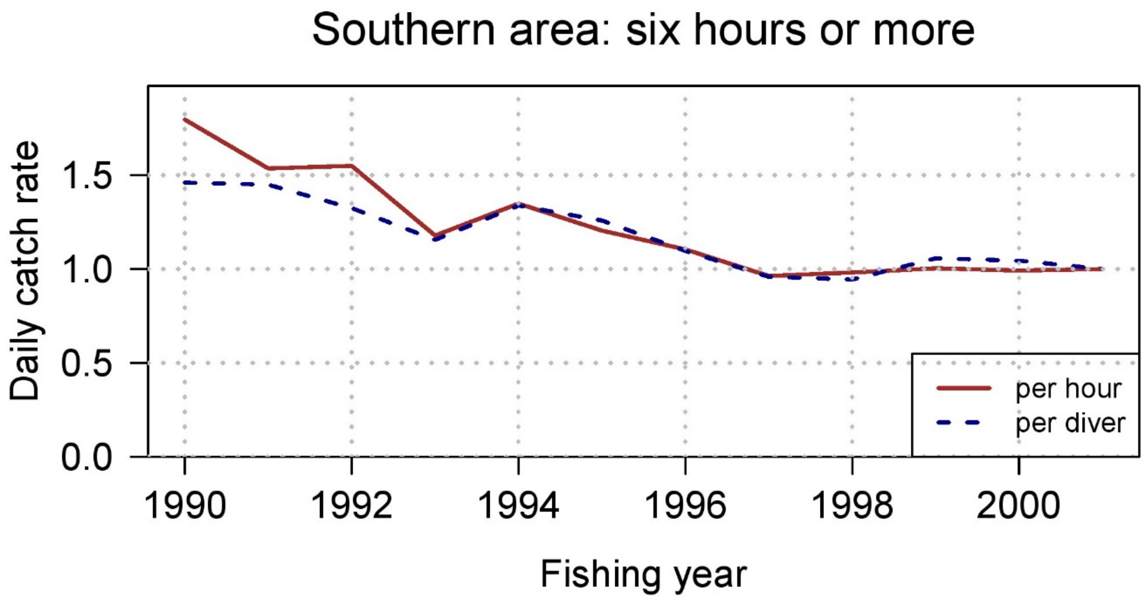


Figure 75: Geometric mean of the daily catch rate by year in the southern CELR data using a fishing duration of six more hours for filtering. The plots are scaled so that they both have the value one in 2001.

4.7 Southern area PCELR standardisation (2002–2014)

4.7.1 Data grooming and subsetting

For the initial data set all records were for paua targeted by diving, and contained FIN, fine scale statistical area, catch weight, fishing duration, and date. Six records with no diver key were removed, and 117 records were removed where no diving condition was recorded (Table 30).

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 were removed (0 records).

FIN was used to subset out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 10 records per year for a minimum of 4 years were selected; this retained 85% of the catch over 2002–2014 (Figures 76–79). The number of FIN holders dropped from 33 to 11 under these criteria. There was good overlap in effort for the FIN holders after subsetting (Figures 80–81). The number of records retained after subsetting was 120 or more for every fishing year (Table 31).

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 31). This left the number of statistical areas unchanged at 16, and the number of divers dropped from 331 to 53 (53% of divers have only one diving day - this is partly an artefact of the fact that a spelling mistake in the diver's 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 82–85).

Table 30: Number of records removed from the southern PCELR dataset for which the diving conditions were not recorded. Fishing year is given in short e.g. 02 = 2002.

Fishing year	02	03	04	05	06	07	08	09	10	11	12	13	14	Total
Number	14	14	16	14	13	5	8	14	4	5	1	3	6	117

Table 31: Number of records remaining by fishing year (02 = 2002 in the southern 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 removed (see Table 30).

Year	02	03	04	05	06	07	08	09	10	11	12	13	14	Total
Total records	277	301	279	275	374	212	201	232	184	135	203	191	158	3022
FIN subsetting	226	273	228	244	327	171	163	216	162	124	161	161	120	2576
Fine scale stat area>=10 dive days	226	273	228	244	327	171	163	216	162	124	161	161	120	2576
Divers with>=10 dive days	151	181	163	212	269	133	137	184	131	106	138	141	85	2031

4.7.2 Standardisation

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

Except for month, all variables were accepted into the model, which explained 85% of the variability in CPUE (Table 32). Most of the variability was explained by duration (73%) and diver (6%). The effects appear plausible and the diagnostics are good (Figures 86–87). There is an apparent increasing effect for the catch taken after a fishing duration of 10 hours, though for the majority of records fishing duration is less than 10 hours (Figure 88).

The standardised index shows a slow decline from 2002 to 2008 with an increase since then (Table 33, Figure 89). The biggest difference between the unstandardised and standardised indices is in 2014, which is attributable to the diver key predictor variable (Figure 90).

Forcing a year:area interaction into the model, using the research strata as the areas, gives similar indices for the different areas (Figure 91). There are a good number of records for both research strata (Table 34).

Table 32: Variables accepted into the model for the southern PCELR dataset (1% additional deviance explained), and the order in which they were accepted into the model, degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R–squared
Fishing year	12	0.04
Fishing duration	3	0.77
Diver key	52	0.83
Diving conditions	4	0.85

Table 33: Standardised index for the southern PCELR data set, lower and upper 95% confidence intervals, and CV.

Year	index	lower CI	upper CI	CV
2002	1.20	1.00	1.43	0.09
2003	1.08	0.92	1.27	0.08
2004	1.04	0.88	1.22	0.08
2005	0.94	0.82	1.09	0.07
2006	0.88	0.77	1.00	0.06
2007	0.86	0.72	1.02	0.09
2008	0.79	0.66	0.94	0.09
2009	1.02	0.87	1.19	0.08
2010	0.90	0.75	1.07	0.09
2011	1.15	0.95	1.39	0.10
2012	0.98	0.83	1.16	0.09
2013	1.14	0.96	1.35	0.09
2014	1.14	0.92	1.41	0.11

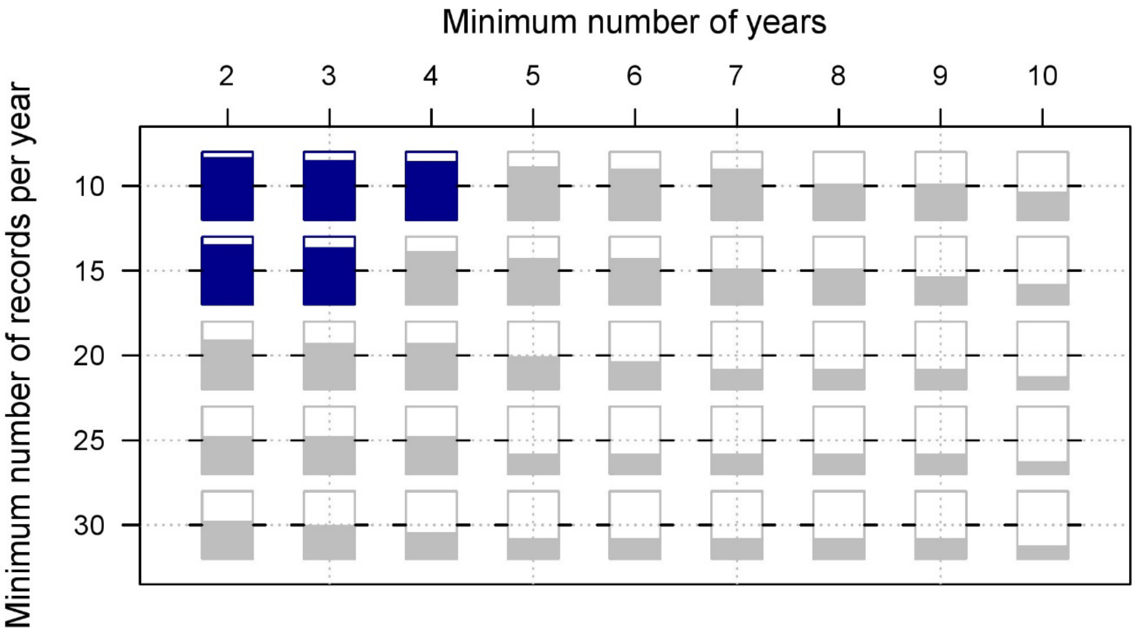


Figure 76: Proportion of the catch taken when subsetting the southern PCELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2014 retained under the criteria, where the horizontal 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.

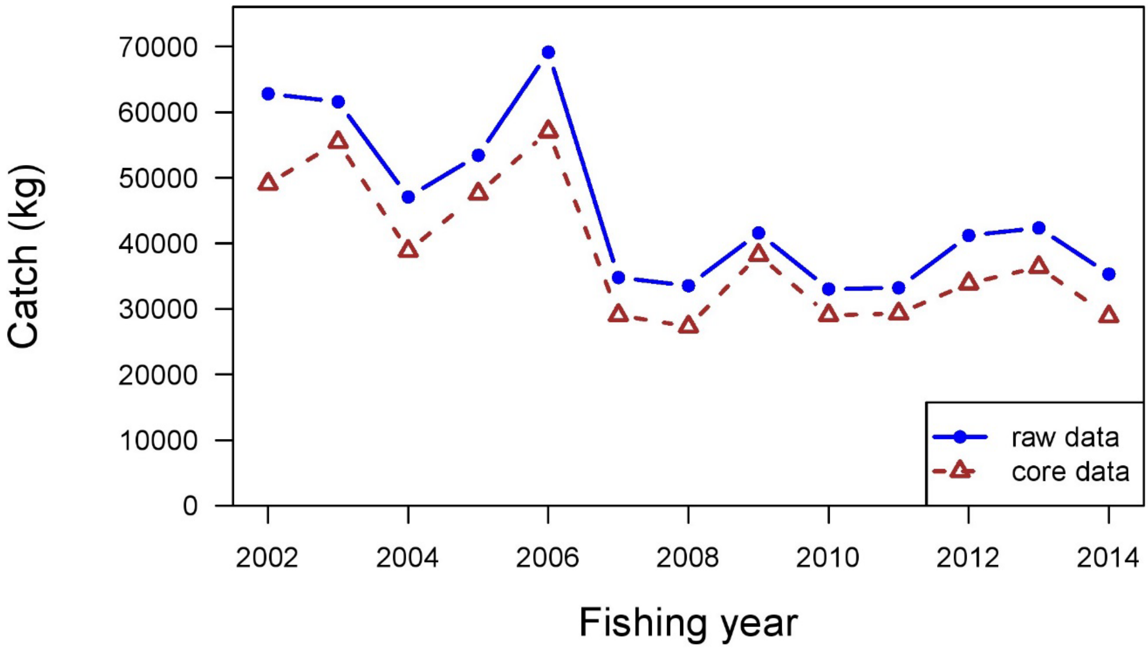


Figure 77: Catch by fishing year from the southern PCELR dataset before FIN subsetting (raw data) and after (core data).

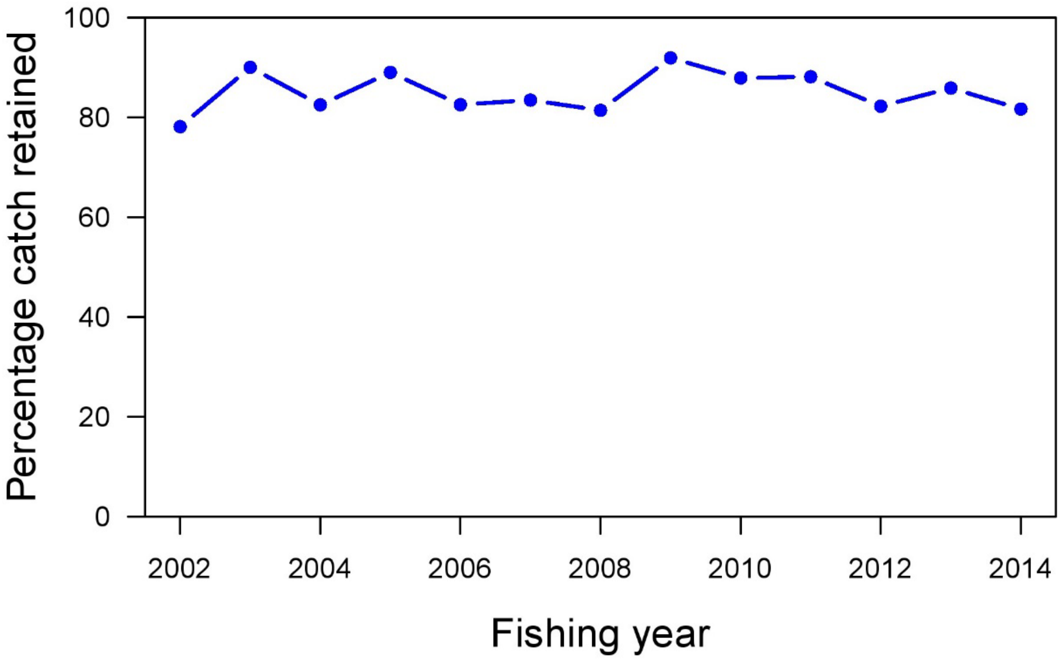


Figure 78: Percentage of the catch retained in the southern PCELR dataset after FIN subsetting.

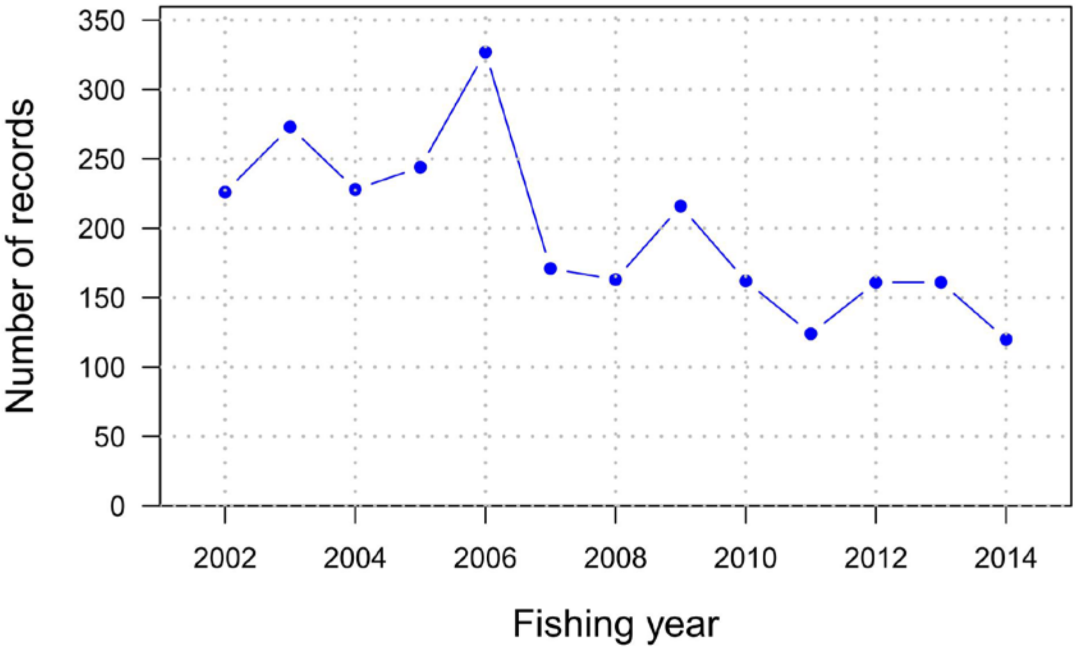


Figure 79: Number of records retained in the southern PCELR dataset after subsetting by FIN.

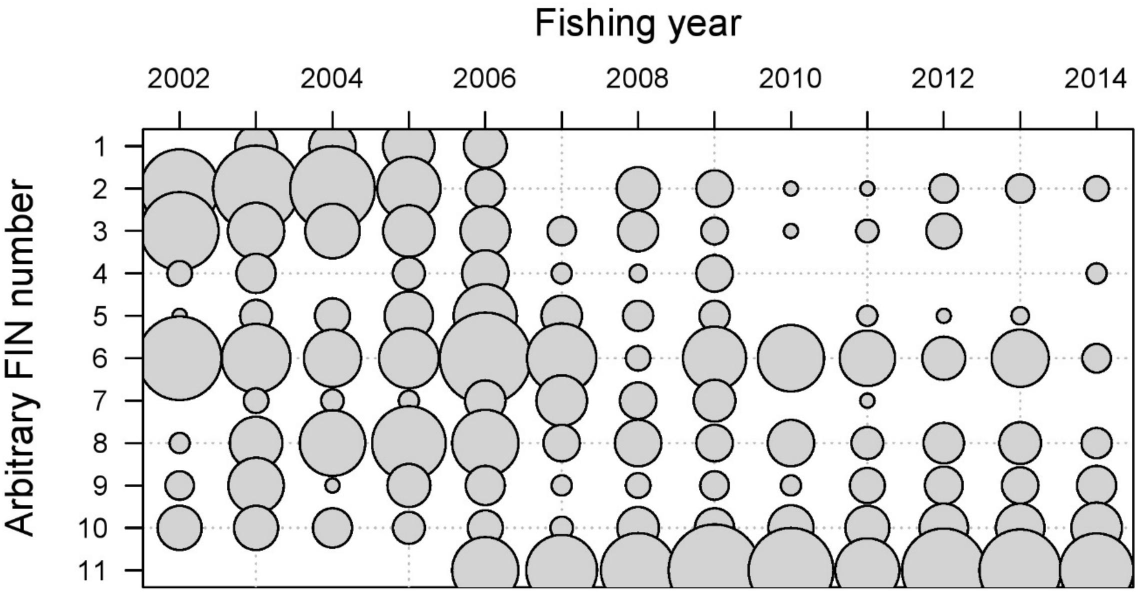


Figure 80: Overlap in number of records in the southern PCELR dataset by FIN after subsetting by FIN. The area of a circle is proportional to the number of records.

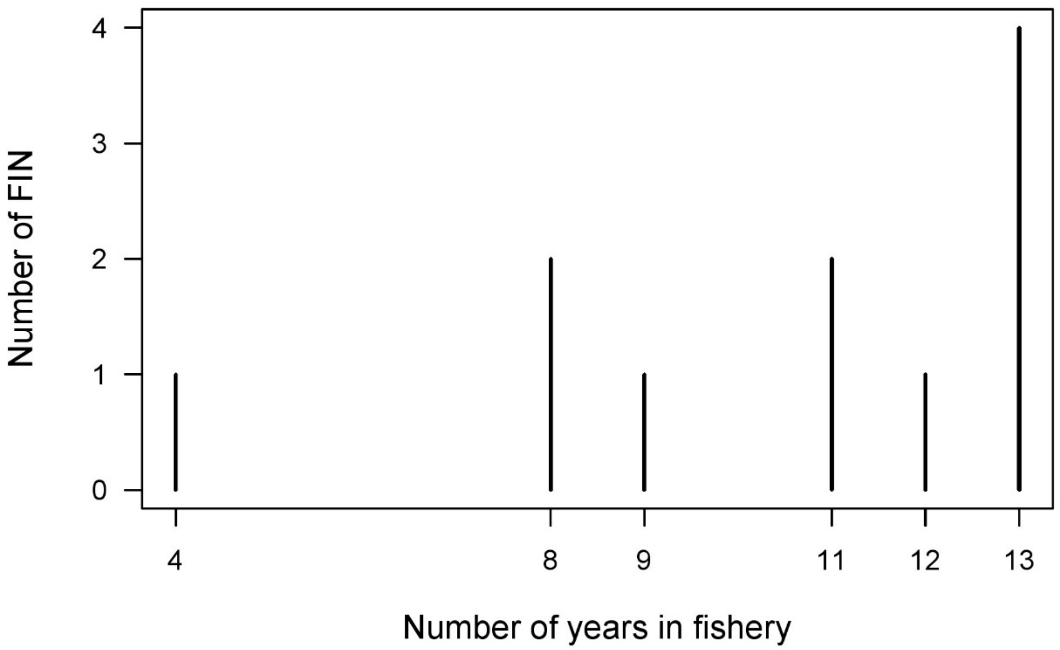


Figure 81: Number of years in the fishery for a FIN holder in the southern PCELR dataset after subsetting by FIN.

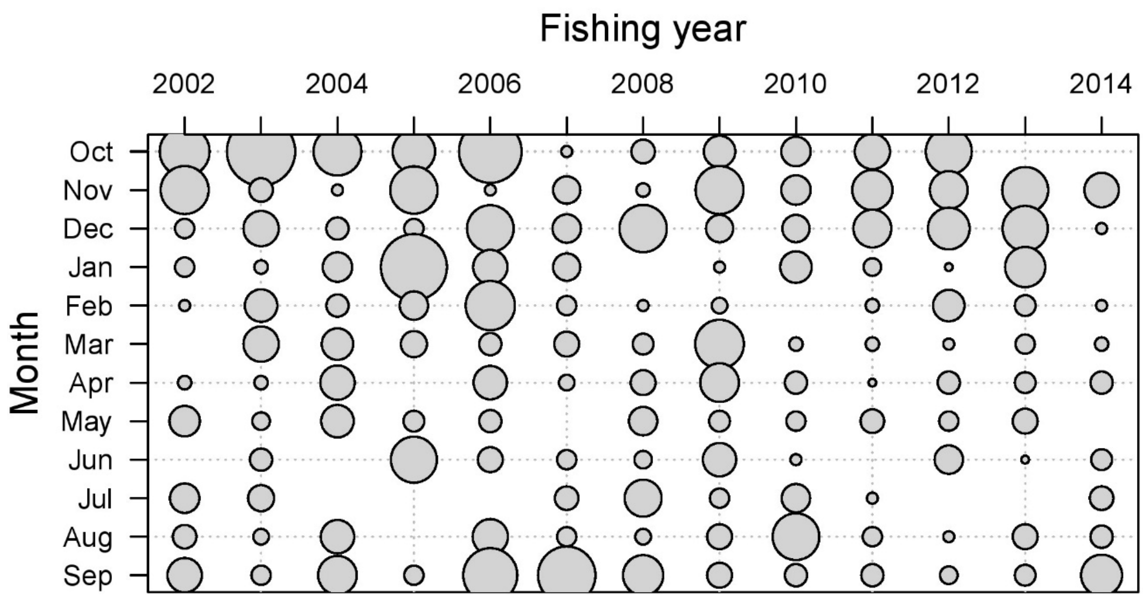


Figure 82: Overlap in number of records in the southern PCELR dataset by month and fishing year. The area of a circle is proportional to the number of records.

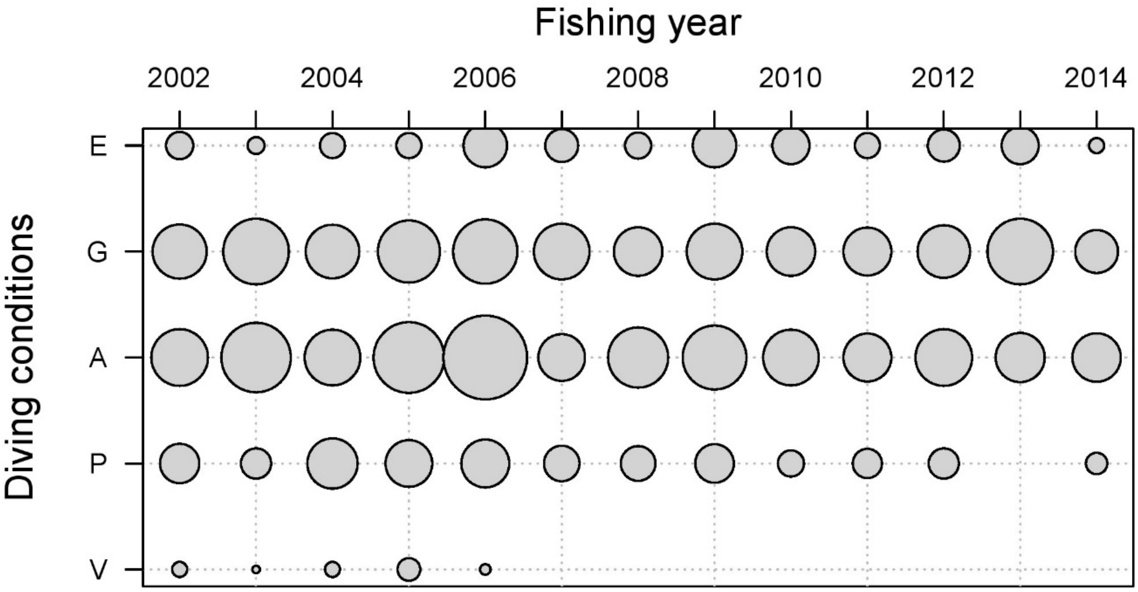


Figure 83: Number of PCELR records in the southern dataset by diving condition (excellent, good, average, poor, very poor) and fishing year. The area of a circle is proportional to the number of records.

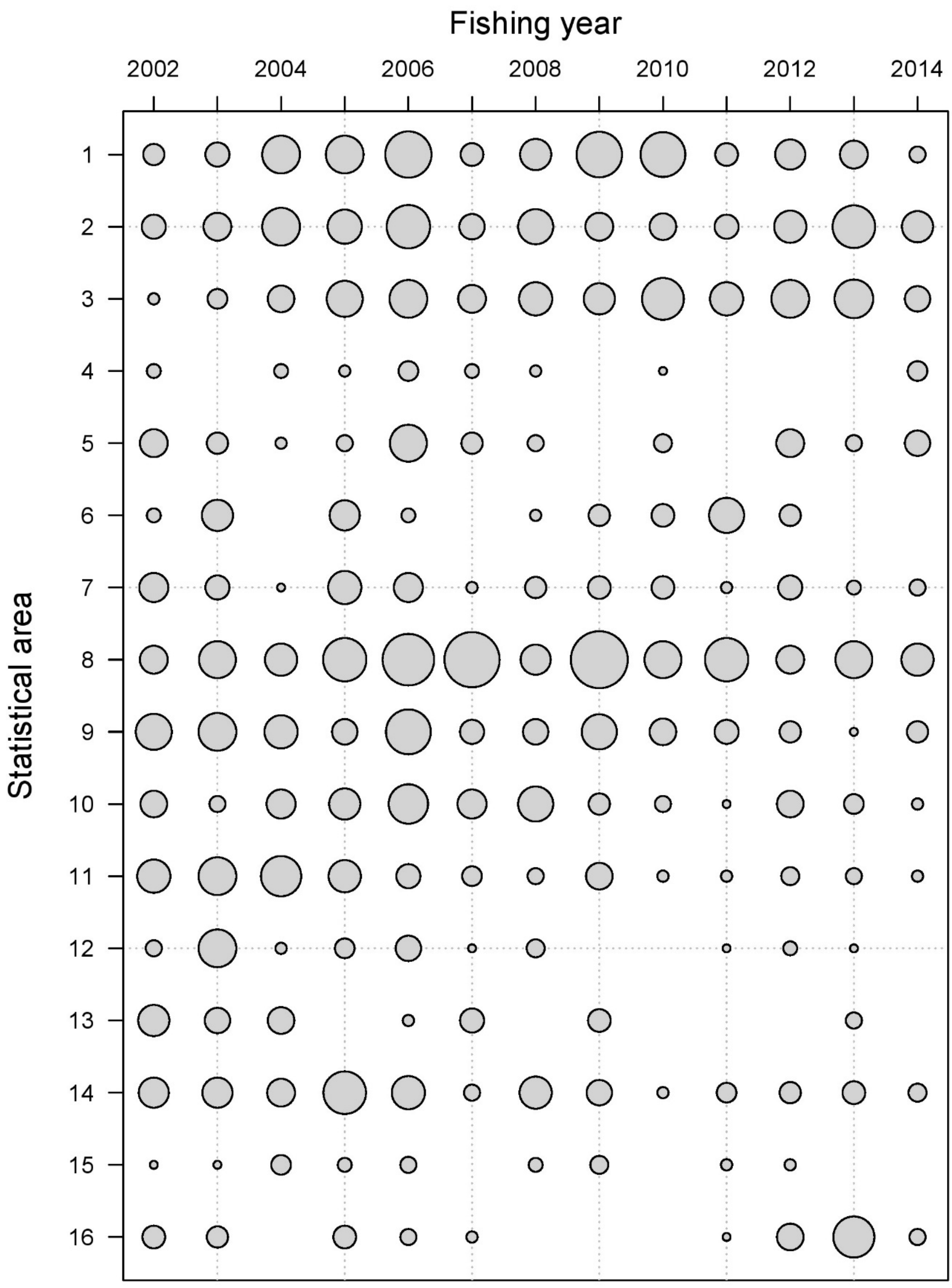


Figure 84: Number of PCELR records in the southern dataset by statistical area and fishing year. The area of a circle is proportional to the number of records. Arbitrary labels are used for the statistical areas.

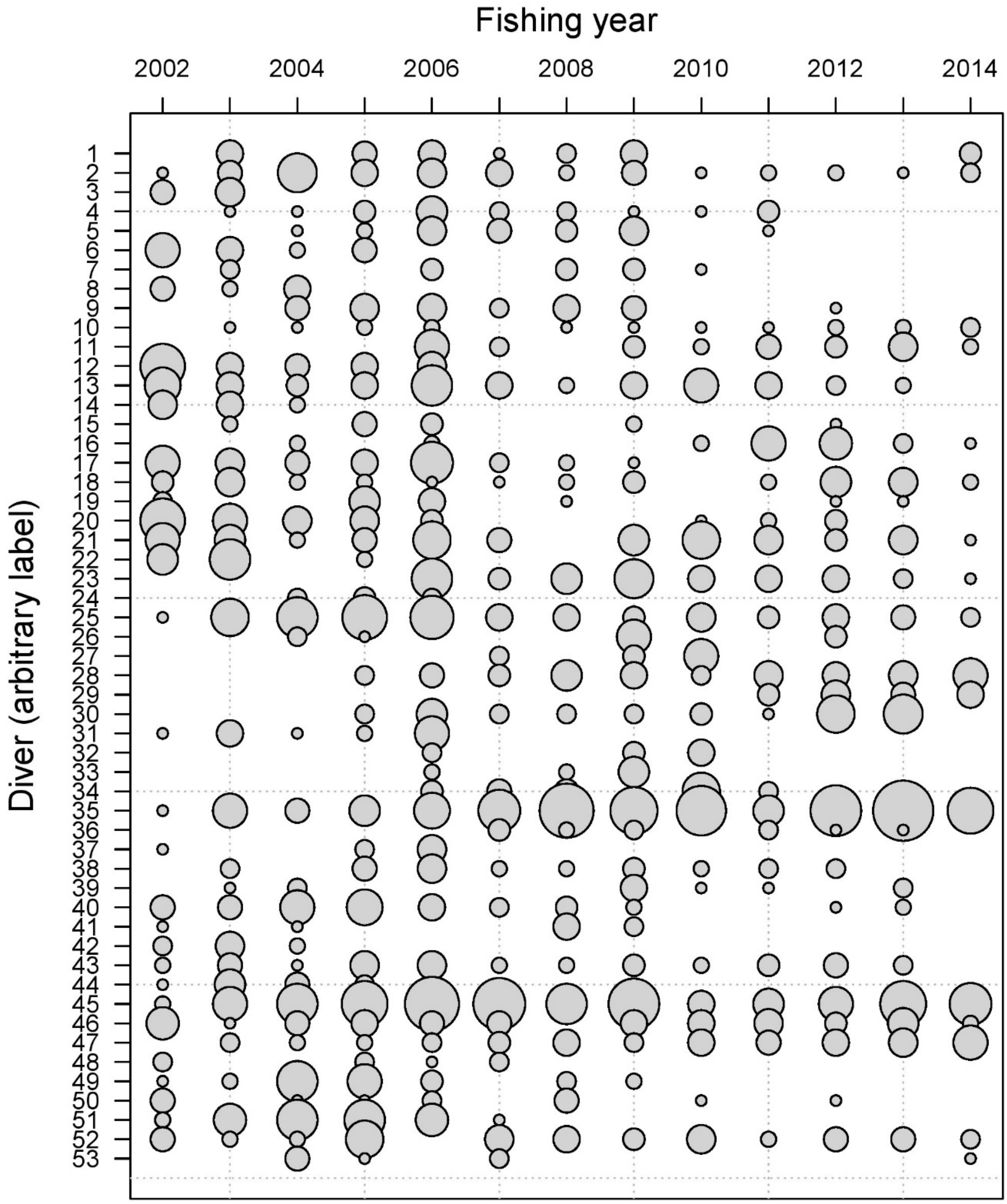


Figure 85: Number of PCELR records in the southern dataset by diver key and fishing year. The area of a circle is proportional to the number of records.

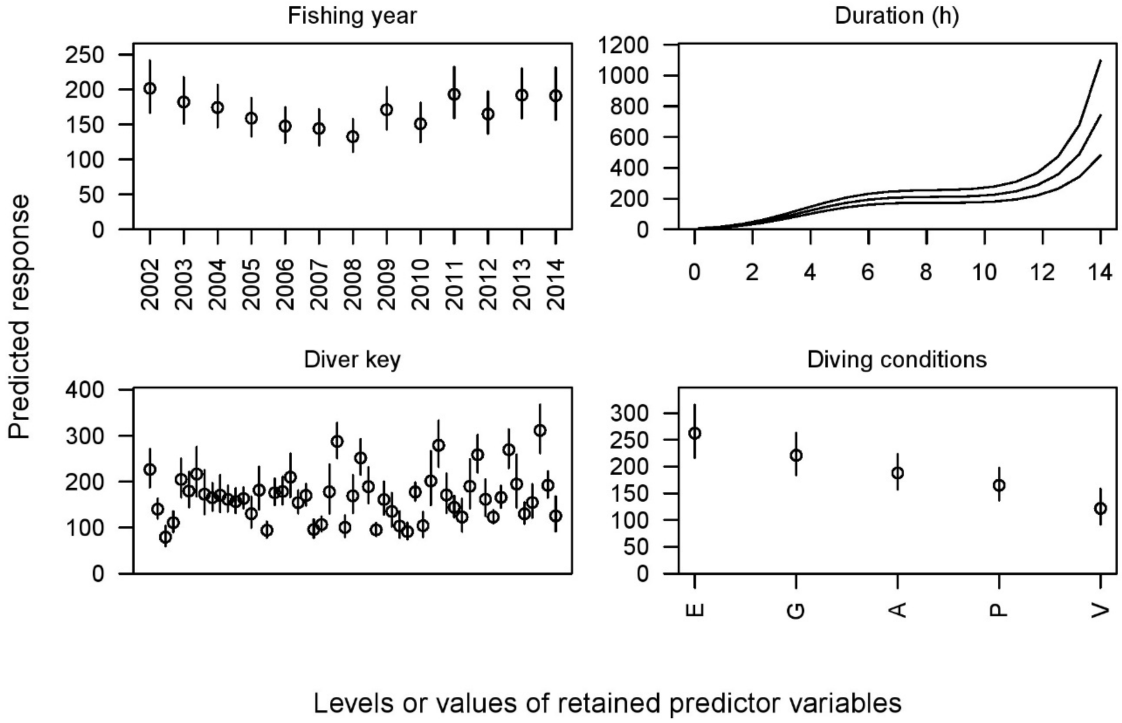


Figure 86: Effects for the southern PCELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

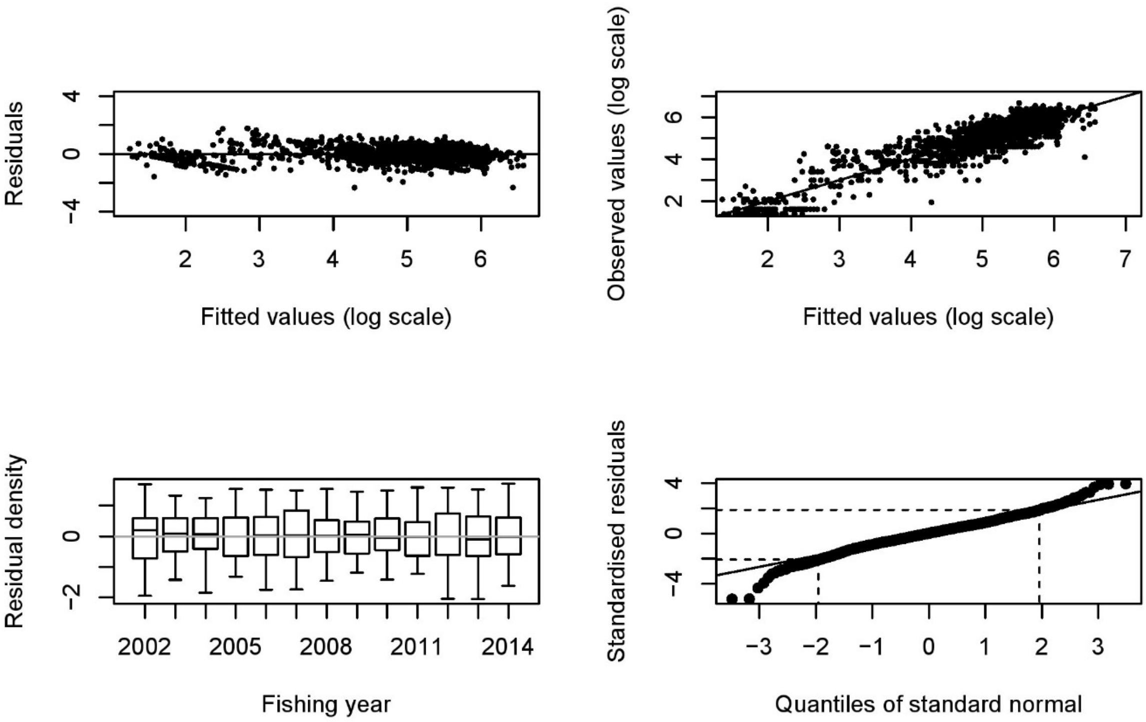


Figure 87: Diagnostic plots for the southern PCELR standardisation model.

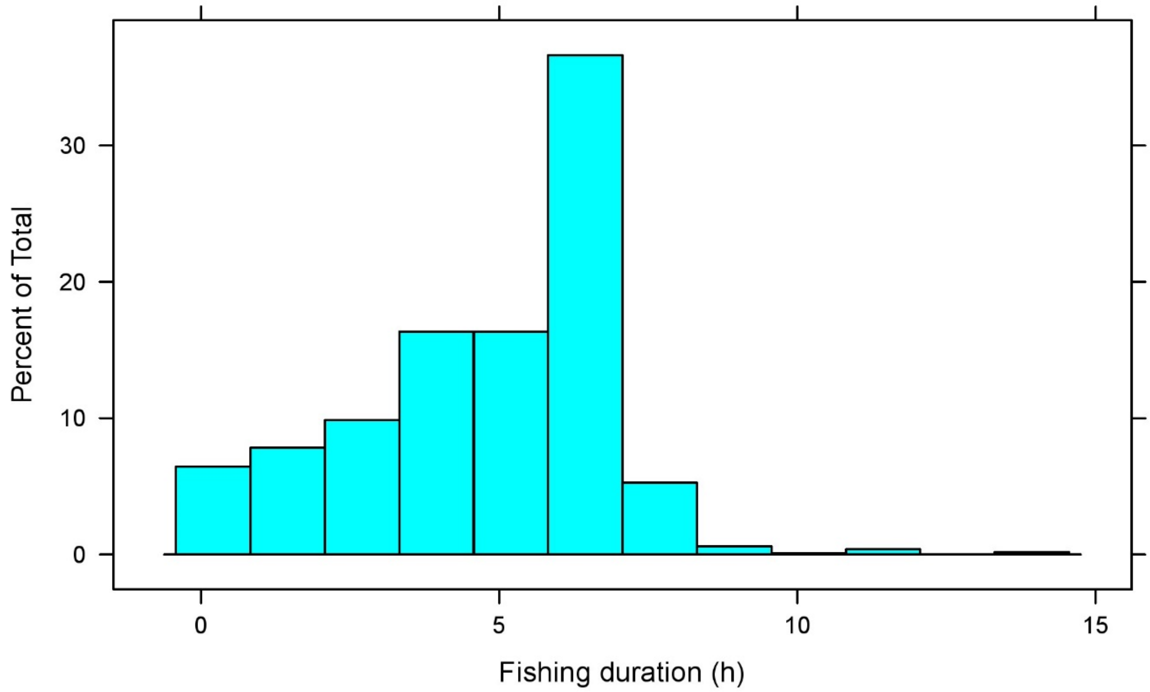


Figure 88: Distribution of fishing duration (h) for the southern PCELR dataset.

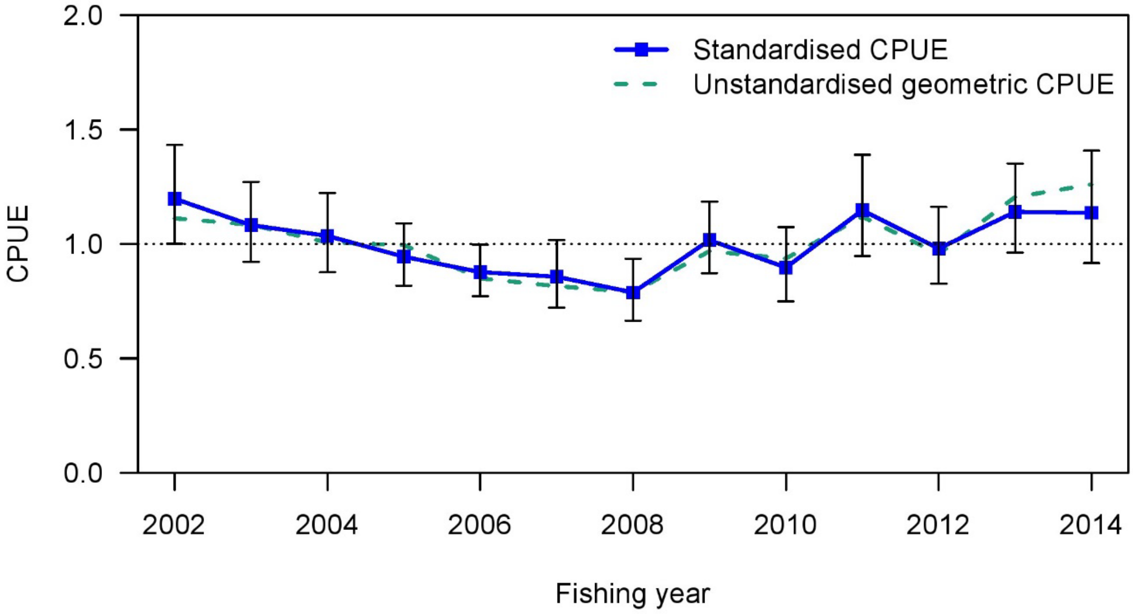


Figure 89: The standardised CPUE index for the southern PCELR dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

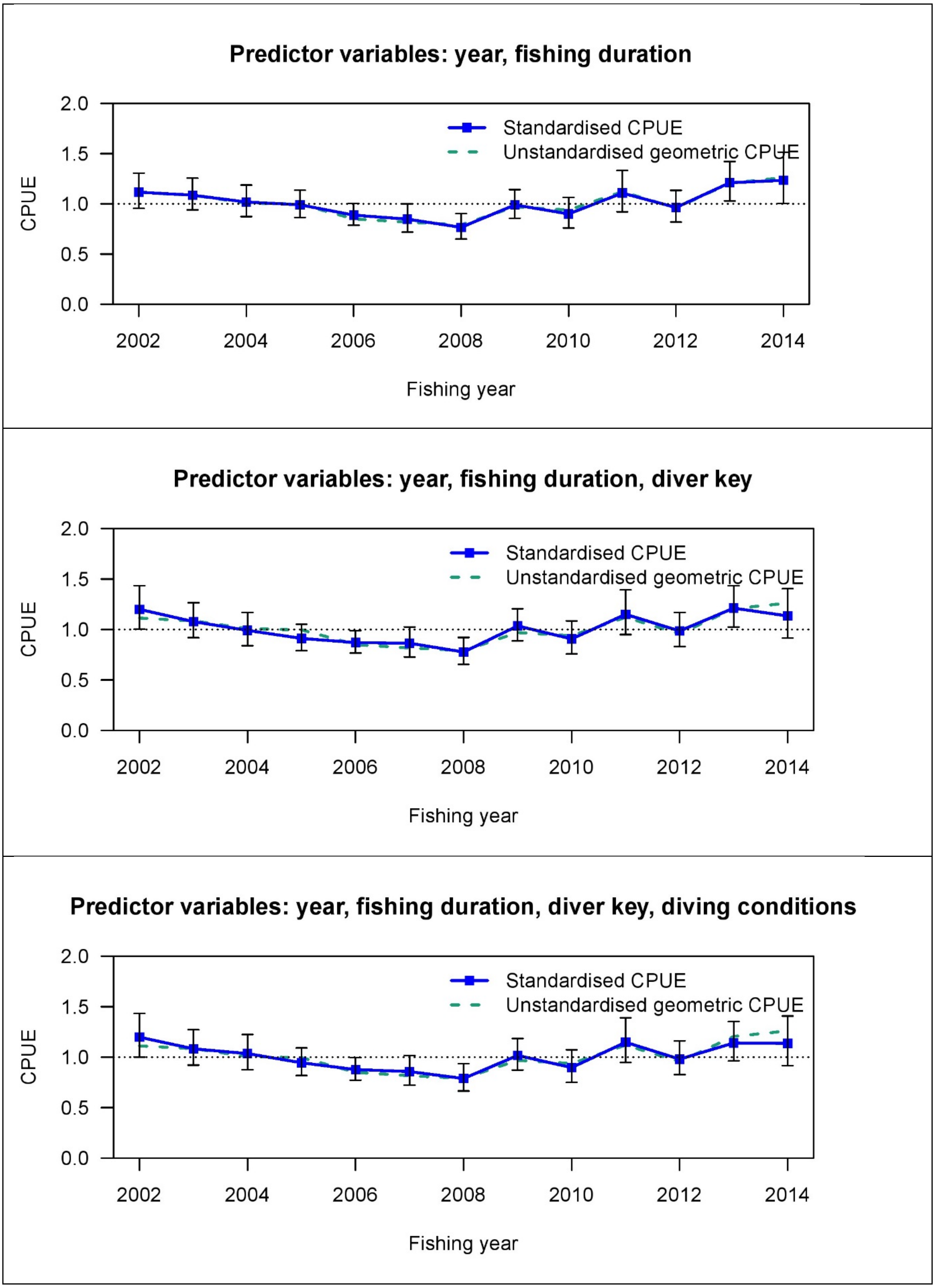


Figure 90: Stepwise addition of predictor variables. The standardised CPUE index for the southern PCELR dataset with 95% confidence interval. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

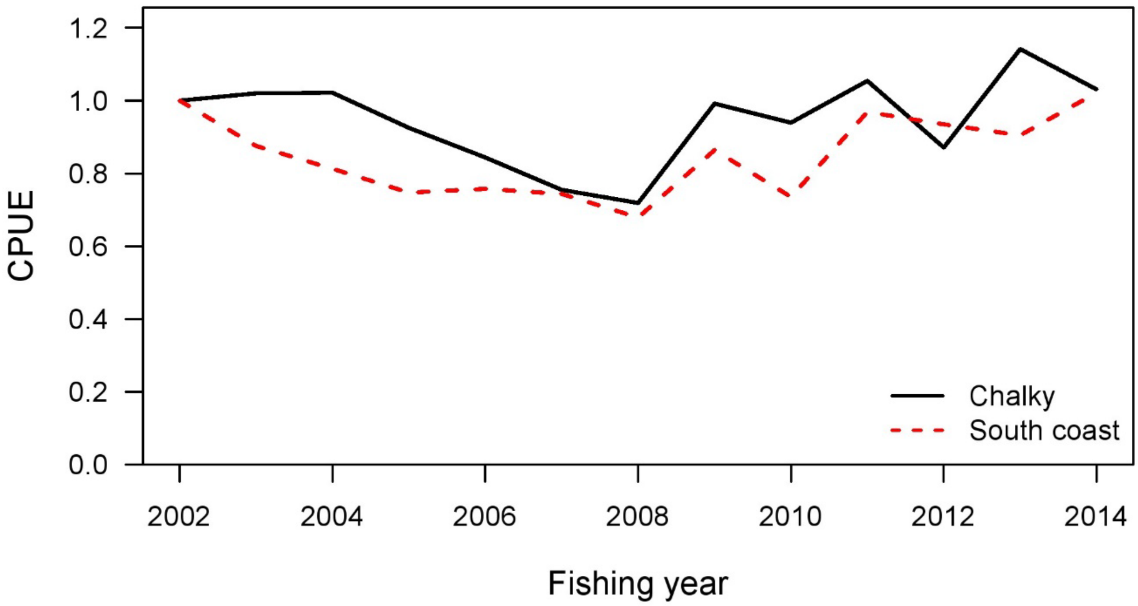


Figure 91: Standardised indices for the southern PCELR dataset with a year:strata interaction forced into the model. The areas are research strata. The indices are scaled to have the value one in 2002.

Table 34: Number of records for the subsetted southern PCELR data by year and research strata.

Year	Chalky	South coast
2002	33	110
2003	34	140
2004	60	103
2005	66	138
2006	111	154
2007	40	91
2008	57	80
2009	59	125
2010	75	56
2011	34	71
2012	64	63
2013	67	48
2014	45	36

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

A new extract of Catch Sampling Length Frequency (CSLF) data was made from the *market* database on 1 August 2014. This totalled 15 472 records containing 66 310 measurements from 1992–94 and 1998–2014. Deducing the statistical area for records prior to 2001–02 required some analysis as a variety of area codes were used.

Only a few landings were sampled each year before 1998 (and no sampling was done between 1995 and 1997). Since 2000, the number of landings sampled each year ranged between 20 and 60, and the number of shells measured generally ranged between 2000 and 8000. A significant proportion of samples mostly between 2000 and 2004 had no area recorded as some operators refused to supply this information (see Table 35). The distribution of sampling effort by stratum is shown in Table 36.Ta. The sampling coverage was reasonably good between 2002 and 2005, with samples generally taken across stratum areas. The sampling was patchy in South Coast and Chalky between 2006 and 2009 and no samples were taken from Milford in this period. A closer examination of catch samples between 2010 and 2013 suggested that the sampling was generally representative of the catch by season and by area but some areas may have been under-sampled in some years (Figure 92). In the 2014 assessment, the SFWG decided to drop the length frequency data from 1992–1994, 1998, 2000, 2001, 2005–2009 in the base case models for both the southern and northern areas (using only the 2002–2005 and 2010-2013 length frequency data).

There appeared to be a temporal and spatial trend in the mean length of the catch samples. The mean lengths of the catch from South coast, Chalky, and Dusky were apparently higher than those from Central, George, and Milford (Figure 93). The temporal and spatial differences in mean length can be partly explained by the increase of the MHS since 2007, as well as the differences in the MHS applied across the regions (see Table 4). There was also large spatial variability in mean length at the level of statistical areas within each stratum (Figure 94).

The scaled length frequency distributions for the southern and northern areas from 2002–2005 and 2010–2014 were calculated. The catch samples were stratified based on the stratum areas. Strata in which there was no sample were combined with adjacent strata (i.e., Milford was combined with George in 2004). The calculation was implemented using NIWA's 'catch-at-age' software (Bull & Dunn 2002). The length frequency distribution 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 distributions for the southern and northern areas are shown in Figure 95. The scaled length frequencies had wider distributions in the southern area than in the northern areas; there were more larger paua (greater than 160 mm) in the catch from the southern area.

Table 35: Number of landings sampled and number of paua measured from the market shed sampling program by General Statistical Area and by fishing year.

	Number of landings sampled					Number of paua measured				
Year	030	031	032	unknown	Total	030	031	032	unknown	Total
1992	3	5	1	0	9	967	3 222	326	0	4 515
1993	2	1	0	0	3	831	331	0	0	1 162
1994	1	0	0	0	1	348	0	0	0	348
1998	1	1	2	0	4	157	121	249	0	527
2000	0	2	0	23	25	0	201	0	3 420	3 621
2001	1	0	2	32	35	120	0	245	4 069	4 434
2002	16	6	9	13	44	1 823	703	1 072	1 532	5 130
2003	27	9	4	14	54	3 278	1 070	482	1 634	6 464
2004	17	15	14	15	61	2 010	1 797	1 813	1 713	7 333
2005	16	7	11	4	38	1 569	714	1 222	477	3 982
2006	10	2	6	3	21	1 126	231	734	349	2 440
2007	10	9	1	0	20	2 018	1 306	166	0	3 490
2008	3	13	6	0	22	431	1 531	586	0	2 548
2009	10	14	1	0	25	540	1 011	102	0	1 653
2010	18	29	16	0	63	1 347	2 459	1 360	0	5 166
2011	7	17	8	0	32	441	1 116	796	0	2 353
2012	13	11	7	0	31	930	879	587	0	2 396
2013	22	9	21	0	52	1 324	670	1 699	0	3 693
2014	19	10	31	0	60	1 469	767	2 819	0	5 055
Total	196	160	140	104	600	20 729	18 129	14 258	13 194	66 310

Table 36: Number of landings sampled from the market shed sampling program by subarea and by fishing year.

	Milford	George	Central	Dusky	Chalky	South	unknown	Total
2002	4	5	3	3	4	12	13	44
2003	1	4	5	3	4	23	14	54
2004	0	15	6	8	5	12	15	61
2005	1	11	2	4	8	8	4	38
2006	0	6	1	1	0	10	3	21
2007	0	3	4	3	7	3	0	20
2008	0	7	9	3	0	3	0	22
2009	0	1	14	0	1	9	0	25
2010	7	10	23	5	13	5	0	63
2011	5	3	8	9	4	3	0	32
2012	2	8	4	4	4	9	0	31
2013	5	18	3	4	8	14	0	52
2014	16	19	6	0	6	13	0	60
Total	41	110	88	47	64	124	49	523

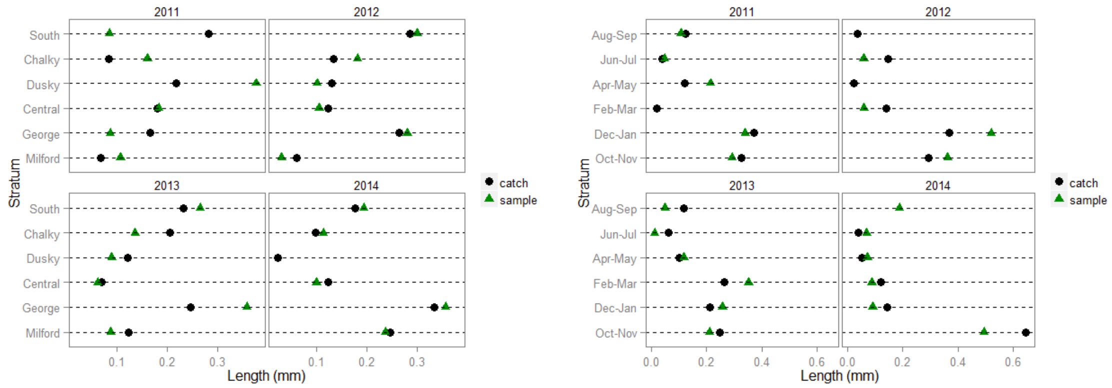


Figure 92: Proportion of total catch and sampled catch by month (left) and by stratum area (right) for the 2011–2014 fishing years.

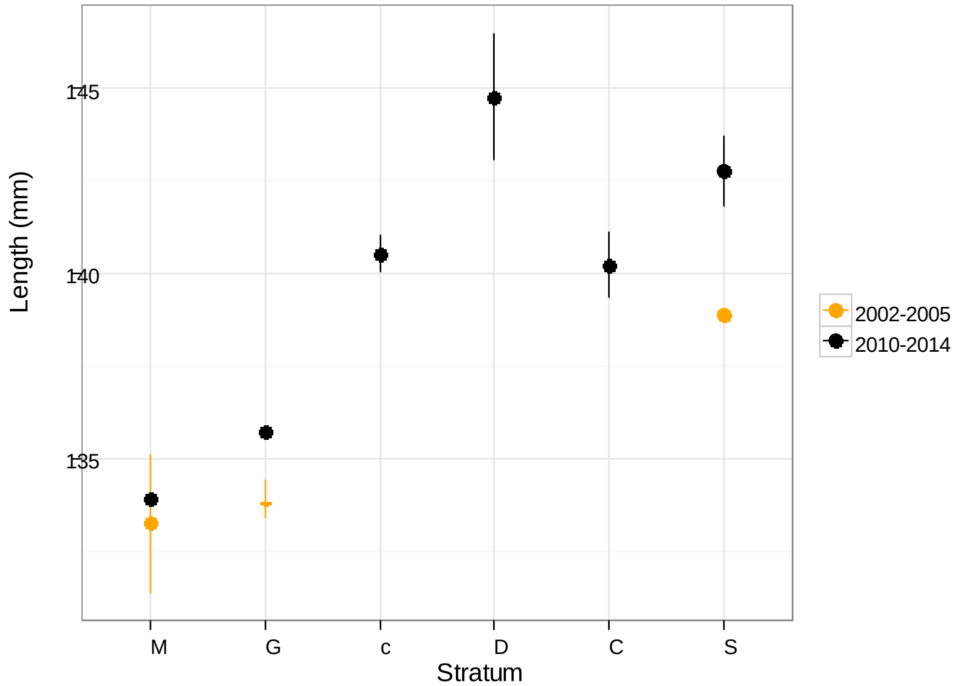


Figure 93: Mean length (dot) with one standard deviation (bar) for measured paua from market shed sampling by sub area and fishing year using data from 2002–2005 and 2010–2014. The standard deviation is calculated from the variance of individual measurements. M, Milford; G, George; c, Central; D, Dusky; C, Chalky; and S, South.

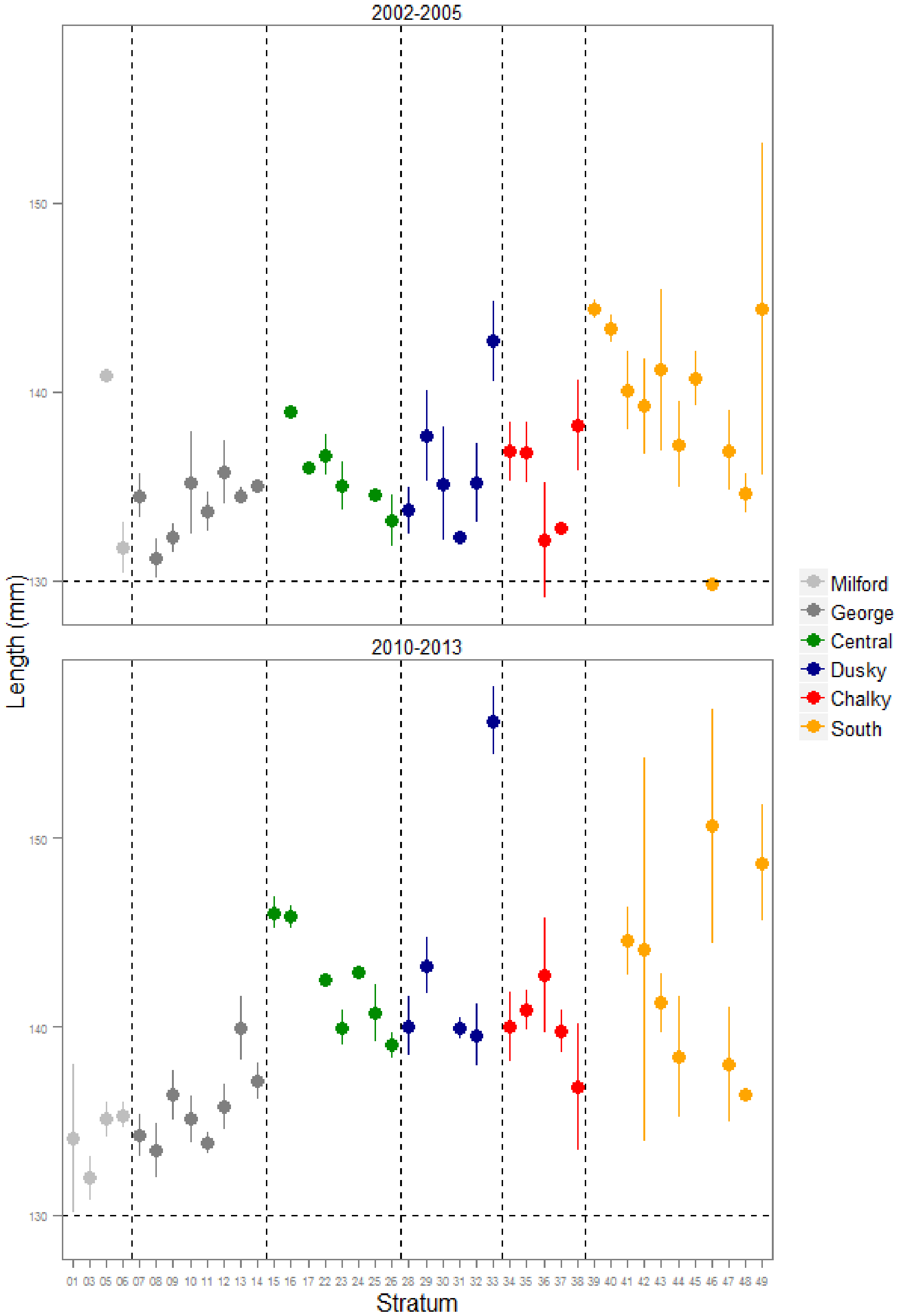


Figure 94: Mean length (dot) with one standard error (bar) of measured paua from market shed sampling by statistical area using data for period 2002–2005 and 2010–2013 The mean is calculated across sampled landings and the standard error is the standard deviation of the mean.

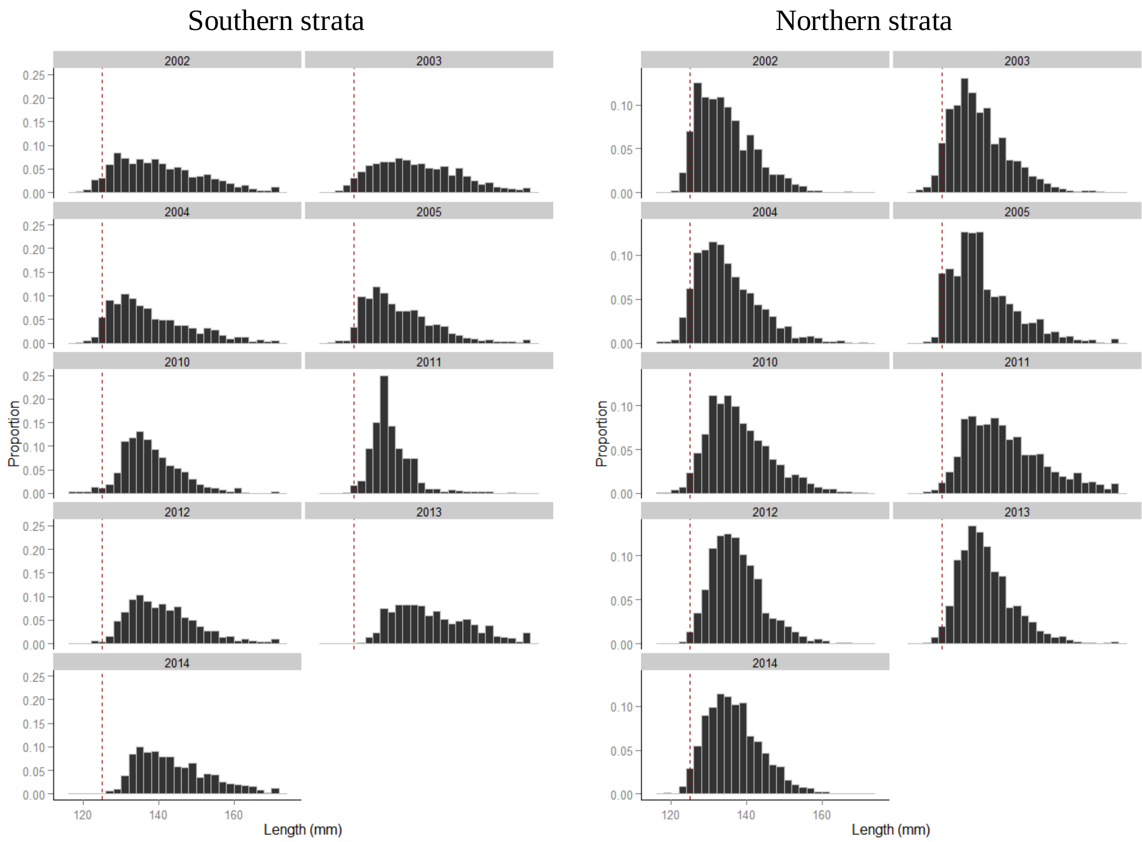


Figure 95: Scaled length frequency distributions for paua from commercial catch sampling for the southern strata (left) and the northern strata (right) in PAU 5A for fishing years 2002–2005, and 2010–2014 The dashed line indicates the MHS of 130 mm.

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 2004, 2007, McKenzie & Smith 2009, Breen & Smith 2008). The previous stock assessment for PAU 5A used the RDSI developed from the survey data up to 2010 (Fu et al. 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 those concerns, in the most recent stock assessments of PAU 5D, PAU 7, PAU 5B (Fu 2014) RDSI and the associated length frequency data (RDLF) were not included in the base case (Fu 2014a). The same decision has been made here: the RDSI and RDLF were excluded from the base case but were included in a sensitivity run. The calculation of the relative abundance indices from the RDSI data was described by Fu et al. (2010).

7. RESEARCH DIVER LENGTH FREQUENCY (RSLF)

The previous stock assessment for PAU 5A used the research diver length frequencies up to 2010 (Fu et al. 2010). There has been no new data since the last assessment. The RDLF data were were excluded from the base case but were included in a sensitivity run.

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Growth data for the New Zealand paua were collected from 30 sites around the New Zealand coast by tag-recapture methods during 2000–02 (Naylor et al. 2006), where growth data for PAU 5A (Naylor & Andrew 2002) were available from three locations – Landing Bay (n=135) , Red Head (n=73), and Poison Bay (n=91). The tag recapture data comprises 299 records, with initial lengths ranging from 81 to 155 mm, time at liberty ranging from 369 to 381 days, and increments ranging from -4 to 28 mm. These data were incorporated into the 2006 assessment to estimate growth.

Naylor & Breen (2008) conducted an isotopic study using 30 paua shells collected from 10 sites in PAU 5A, where the annual temperature cycle as preserved by the $^{18}O/^{16}O$ ratio of the carbonate along the growth axis of the paua shell was used as a year tag or marker, which allowed growth to be estimated for individual shells. A total of 143 sets of individual growth increment data (consecutive growth increments from the same shell were treated as independent observations) were available for the stable isotopic analysis from research strata Chalky (n=33), Dusky (n=39), George (n=25), and South Coast (n=46). The initial lengths ranged from 70 to 129 mm (two records with initial length below 70 mm were excluded), time interval ranged from 275 to 427 days, and increments ranged from -3 to 28 mm.

Chalky and South Coast accounted for 55% of the available growth data (Table 37). Milford was dropped out because this stratum has just one site, and also because the paua at this site seem to be stunted.

Naylor & Breen (2008) analysed the growth increment data using an inverse logistic model and found that the growth curve estimated from the isotopic data was remarkably similar to that from the Chalky Inlet tag recapture data. Therefore the 2010 assessment combined the tag-recapture and the isotopic growth increment data together to estimate the growth within the assessment model. This practice was continued in the 2014 assessment. The combined growth data (without Milford) were used for the assessments of both the southern and northern areas.

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 Δ_{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, σ_{min} is the minimum standard deviation and $\alpha(u_k)^\beta$ is the standard deviation of growth at length L_k (if β is fixed at 1 α will be the coefficient of variation and if β is fixed at 0 α will be the standard deviation).

The assessment model included the 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 linear growth model. Note that this was a separate exercise outside the assessment model, and the estimates were solely based on the tag-recapture data. Those estimates were likely to be different to the growth parameters estimated from the assessment model.

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

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

where y_i is the measured growth increment for the i^{th} paua; μ_i and σ_i are the expected growth (truncated at zero to exclude the possibility of negative growth) and standard deviation respectively; σ_E is the standard deviation of measurement error (assumed to be normally distributed with mean zero); and ϕ and Φ are the standard normal probability density function and cumulative density functions respectively.

Annual growth increment measurements were considered. The linear growth model was fitted to the data for all areas combined (Figure 96). The growth parameters at $L_1 = 75$ mm and $L_2 = 120$ mm were estimated as $g_1 = 24.5$ mm and $g_2 = 6.0$ mm. The parameters for variation in growth were estimated as $\alpha = 1.98, \beta = 0.34$. The measurement error σ_E was assumed to be known as 1 mm.

Table 37: Number of growth-increment pairs by stratum for the tag-recapture and Isotopic growth datasets.

Stratum	Tag-recapture	Isotopic growth	Total	Percent
Milford	135		135	31
George		25	25	6
Central				
Dusky		39	39	9
Chalky	164	33	197	45
South Coast		46	46	10
Total	299	143	442	100%

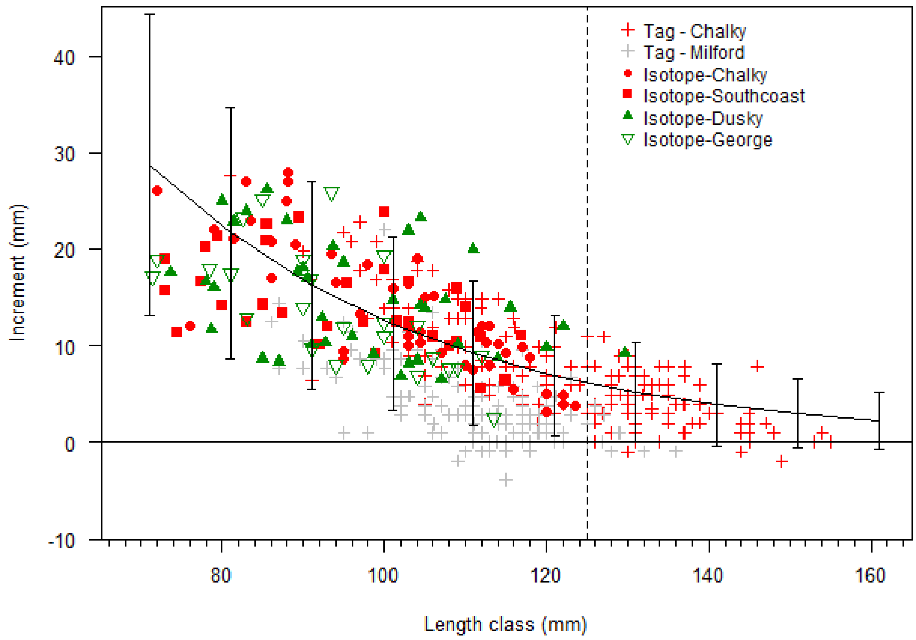


Figure 96: Initial size and mean annual increment from the tag-recapture data (Naylor & Andress 2002), and the isotopic data (Naylor & Breen 2008 within PAU 5A. Lines (and 95% confidence intervals) indicate size-based linear growth curves estimated from these data (excluding Milford). Dashed line indicates the legal size limit (125 mm).

9. MATURITY

Data were collected during February 2006 (Reyn Naylor, NIWA, unpublished data) at sites in the Dusky (n=290), George (n=39), Milford (n=33), and Chalky (n=10) areas, with the bulk of the samples taken from the Dusky area. Three hundred and eighty-five paua of various sizes were sampled visually for sex and maturity. Following Breen & Kim (2007), maturity was determined collectively for both sexes combined, assuming that males and females mature at approximately the same rates with increasing length.

The data ranged from 56 mm to 158 mm. Ten Paua below 70 mm were discarded from the dataset. Samples from George, Milford, and Chalky all exceeded 115 mm and were all mature. The estimated proportion mature, along with exact 95% confidence interval in 5-mm length classes for the Dusky area is shown in Table 38. The sample size is small, but most animals are mature by 110 mm and 50% maturity probably lies between 90 mm and 105 mm. The proportion mature data for all strata combined were fitted with a logistic curve using a binomial likelihood (Figure 97).

Table 38: Number of paua observed, number mature, and proportion mature from the samples collected in the Dusky areas: the bin size is the mid-point.

Bin (mm)	sample size	no. mature	proportion mature	lower limit	upper limit
72.5	7	0	0.000	–	–
77.5	15	1	0.067	0.002	0.319
82.5	30	5	0.167	0.056	0.347
87.5	34	10	0.294	0.151	0.475
92.5	40	26	0.650	0.483	0.794
97.5	32	20	0.625	0.437	0.789
102.5	43	31	0.721	0.563	0.847
107.5	49	48	0.980	0.891	0.999
112.5	38	38	1.000	–	–
117.5	23	23	1.000	–	–
122.5	25	25	1.000	–	–
127.5	11	11	1.000	–	–
132.5	25	25	1.000	–	–

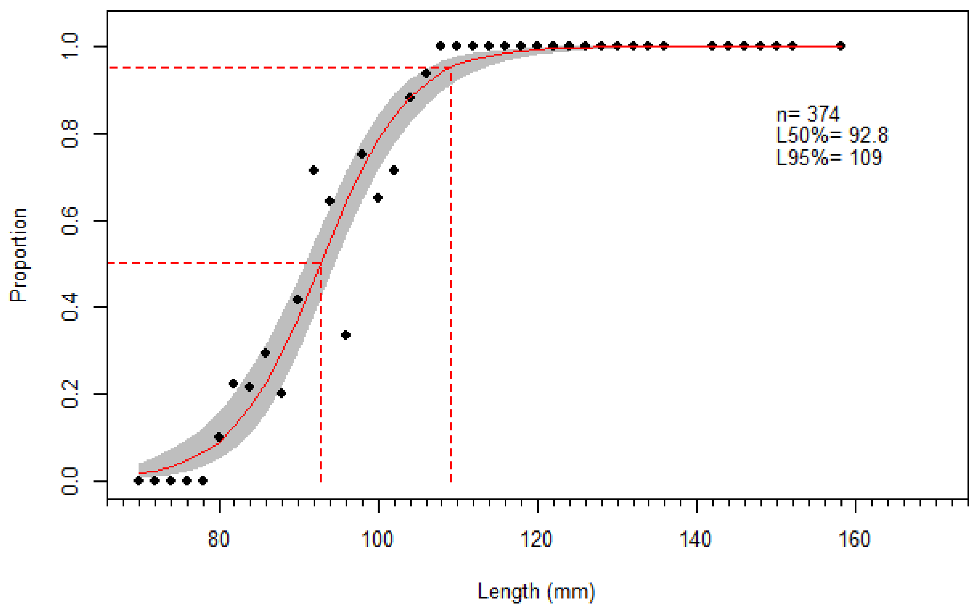


Figure 97: Proportion of maturity at length for PAU 5A. The dots represent the observed proportion mature for each 2 mm length bin. The red line represents a fitted logistic maturity curve. The grey area represents the 95% confidence interval of estimated proportion. The dash lines represent estimated length at 50% and 95% maturity.

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