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Summary of input data for the 2012 PAU 5D stock assessment

New Zealand Fisheries Assessment Report 2013/56

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EXECUTIVE SUMMARY

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This document summarises the data inputs for the 2012 stock assessment of blackfoot paua in PAU 5D. The seven sets of data collated for the assessment model were: (1) a standardised CPUE series based on CELR data (2) a standardised CPUE series based on PCELR data (3) a standardised research diver survey index (RDSI) (4) a research diver survey proportions-at-lengths series (5) a commercial catch sampling length frequency series (6) tag-recapture length increment data and (7) maturity-at-length data. Catch history was an input to the model encompassing commercial, recreational, customary, and illegal catch.

A new standardised CPUE based on CELR data was developed for the 1989–90 to 2000–01 fishing years. The standardised CPUE series based on PCELR data was updated to the 2011–12 fishing year. There were no research diver surveys since the last assessment, but the indices were revised incorporating modifications to the standardisation procedure from recent reviews. The research diver survey covered only the Catlins area which accounted for about 25% of the total catch in PAU 5D. The base case model therefore excluded the research diver survey indices and length frequencies. Scaled length frequency series from the commercial catch sampling were updated to the 2011–12 fishing year, where the catch samples were stratified by area and numbers at length were scaled up to each landing and then to the stratum catch. Tag-recapture length increment data and maturity-at-length data were reanalysed incorporating data available since the last assessment.

1. INTRODUCTION

This document summarises the data inputs for the 2012 stock assessment of PAU 5D. The work was conducted by NIWA under the Ministry for Primary Industries contract PAU200802 Objective 1. A separate document details the stock assessment of PAU 5D (Fu 2013).

PAU 5D was last assessed in 2006 (Breen & Kim 2007) and before that in 2000 (Breen et al. 2000). Data collated for the 2012 assessment were:

1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2012 based on PCELR data.
3. A standardised research diver survey index (RDSI).
4. A research diver survey proportions-at-lengths series (RDLF).
5. A commercial catch sampling length frequency series (CSLF).
6. Tag-recapture length increment data.
7. Maturity-at-length data.

In the previous assessment, a combined standardised CPUE series including both CELR and PCELR data was used. For this assessment, CPUE indices were calculated for the CELR and PCELR data separately, based on methodologies similar to those for the recent PAU 5A assessment (Fu et al. 2010) and PAU 7 assessment (Fu et al. 2012). 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".

2. DESCRIPTION OF THE FISHERY

The PAU 5 Quota Management Area includes the entire southern stock of paua from the Waitaki River mouth on the east coast of the South Island, south around to Awarua Point on the west coast including Stewart Island. The TACC allocation for PAU 5 was 445 t in 1986–87; quota appeals increased this to 492 t by 1991–92. For the 1992–93 fishing year quota holders agreed to a voluntary quota reduction which reduced the TACC to 443 t. In the 1995–96 fishing year, PAU 5 was divided into three substocks: PAU 5A, Fiordland; PAU 5B, Stewart Island; and PAU 5D, Southland/Otago (Figure 1). The TACC was divided equally among the new stocks. It is widely considered that this led to a large redistribution of catch from Stewart Island to Fiordland and the Catlins/Otago coast (Elvy et al. 1997), but the extent to which this happened cannot be determined with certainty because the new stock boundaries are not aligned with the 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 Areas for PAU 5A, PAU 5B, and PAU 5D, respectively. The 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-scale statistical zones developed for the New Zealand Paua Management Company's voluntary logbook (Figure 2). A summary of the spatial resolution of reporting areas for PAU 5D is given in Table 2.

PAU 5D includes the coastal areas from the Waitaki River mouth to the Colac Bay (Figure 3). More than 90% of the commercial catch was historically taken from the Catlins area (McShane 1995, Elvey et al. 1997). The TACC of PAU 5D was set at 148.98 t on 1 October 1995, and was reduced to 114 t on 1 October 2002, and further to 89 t on 1 October 2003. The TACC has remained unchanged since then.

On 1 October 2010 the commercial fishery voluntarily adopted two different minimum harvest sizes of 128 mm and 130 mm specific to statistical areas P5DH38–43 and P5DH01–37 respectively. The minimum legal size of 125 mm remains in statistical areas P5DH 44–47. The commercial fishery have also voluntarily closed 4 specific areas within PAU 5D to commercial harvesting.

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	104 400	148 983	89 673	90,000	88 699	89 000

* FSU data, † QMR/MHR data

2011–12 landings are assumed to be the same as 2010–11 as the data are incomplete.

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

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

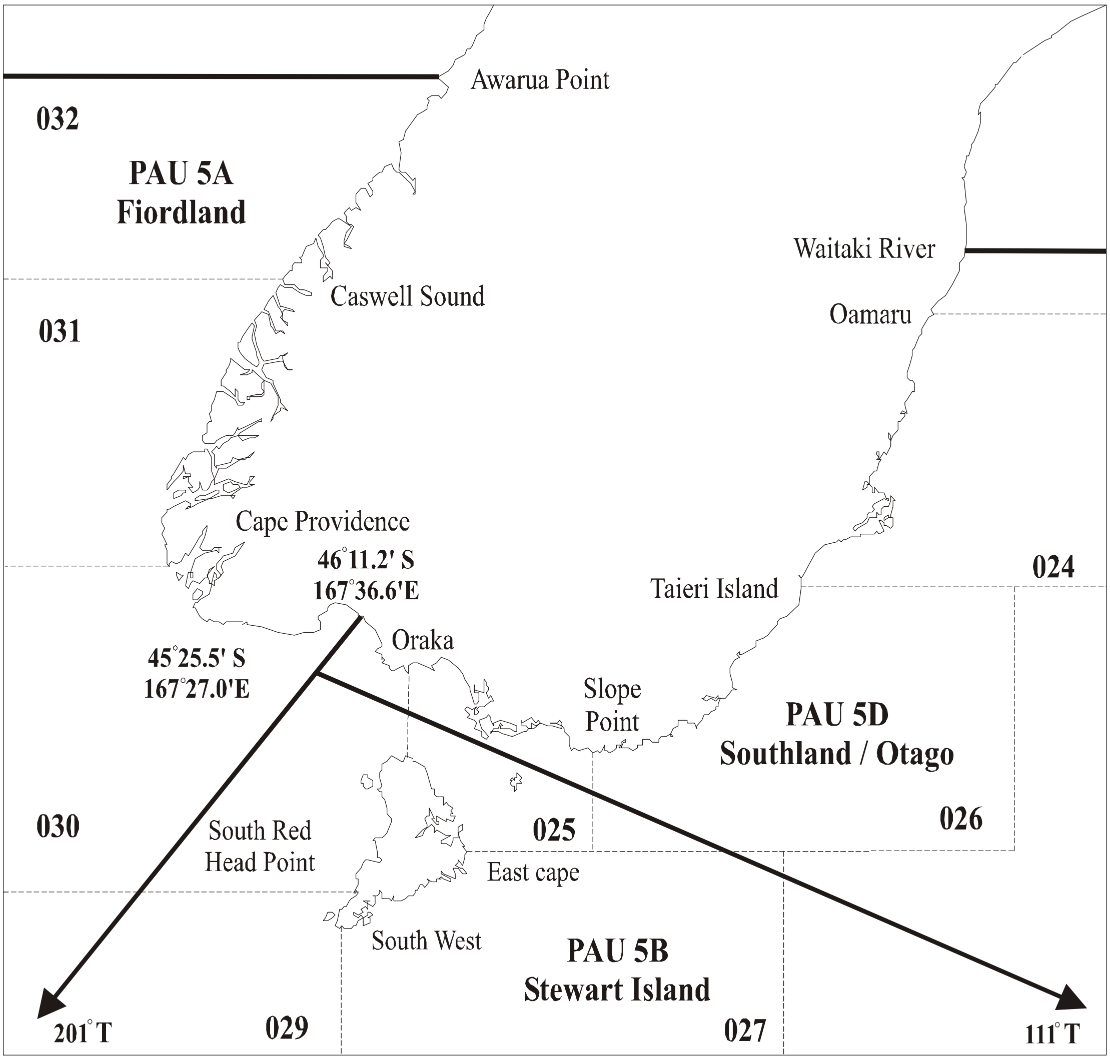


Figure 1: Map showing the new QMAs effective from 1 October 1995 and the old statistical area boundaries (dashed lines) of PAU 5.

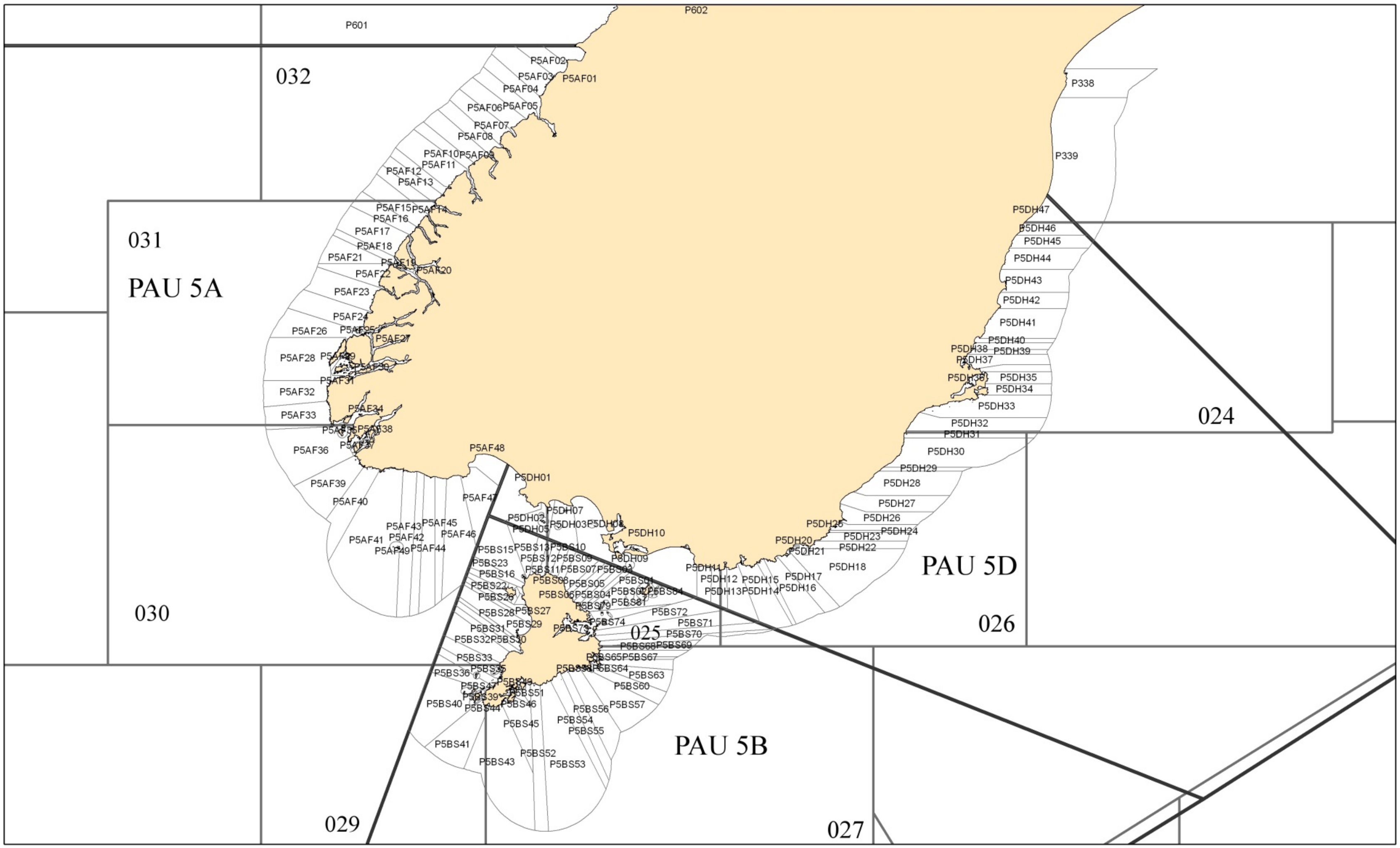


Figure 2: Map showing the location of finer scale statistical areas within PAU 5 effective from 1 October 2001.

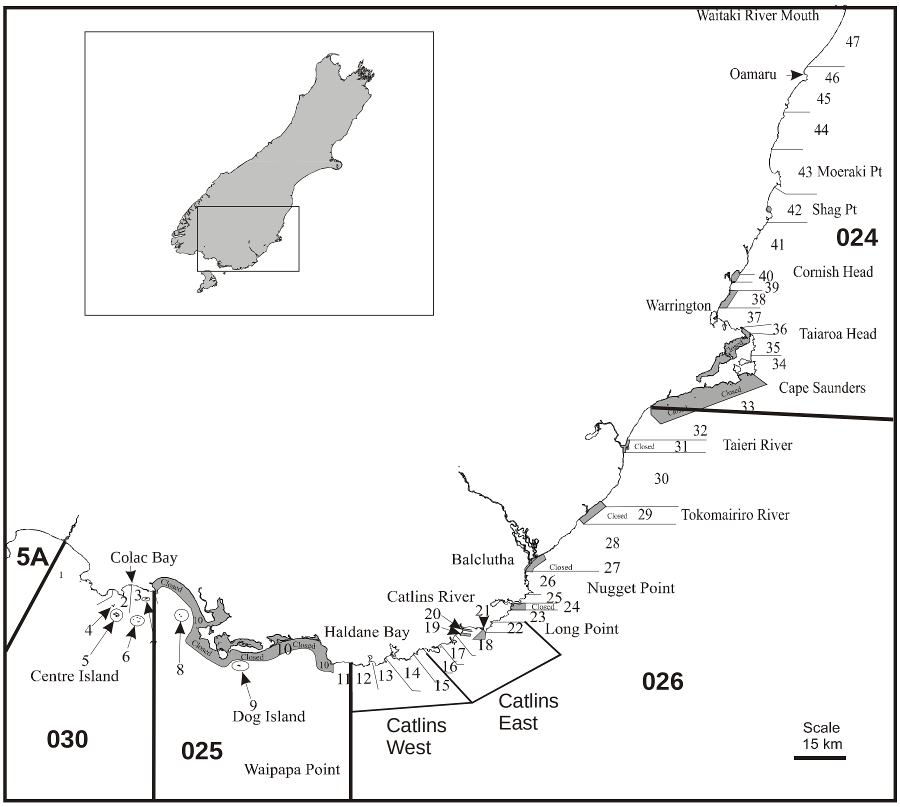


Figure 3: Map of fine-scale statistical areas and research strata for PAU 5D.

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, as some of the statistical areas used to report catch and effort straddle multiple stocks (e.g., Statistical Area 030 straddles PAU 5A, PAU 5B and PAU 5D, see Figure 1). Kendrick & Andrew (2000) described a method for estimating the pre-1995 catches from the substocks within PAU 5. The method was further explained by Breen & Smith (2008a), and was used to assemble the catch history for PAU 5A and PAU 5D in the 2006 stock assessment (Breen & Kim 2007), and for PAU 5B in the 2007 assessment (Breen & Smith 2008b), and for PAU 5A in the 2010 assessment (Fu et al. 2010).

We repeated this procedure to calculate the catch history for PAU 5D. A constant proportion of 25% was applied to the Murray & Akroyd (1984) PAU 5 catch series to obtain catch estimates from 1974 to 1983. From 1983–84 to 1994–95, the annual proportion of catch for PAU 5D was firstly estimated, where 7% and 25% of the annual estimated catch in Statistical Area 030 and 025 respectively was assumed to have been taken from PAU 5D, and that proportion was applied to the QMR/MHR landings in PAU 5 to obtain the catch estimates. In the 2010 assessment for PAU 5A (Fu et al. 2010), alternative assumptions have been suggested by the Shellfish Working Group concerning the proportion of catch in Statistical Area 030 which was taken from PAU 5A, PAU 5B, and PAU 5D between 1983–84 and 1995–96: (1) 18%, 75%, and 7% respectively, (2) 40%, 53%, and 7% respectively, and (3) 61%, 32%, and 7% respectively. These assumptions have been adopted here to obtain catch estimates for each of the substocks within PAU 5 (Table 3). The estimated commercial catches for PAU 5D are the same under the three assumptions. Kendrick & Andrew (2000) also considered an alternative catch split of 67% to 33% between PAU 5B and PAU 5D for Statistical Area 025 from 1983–84 and 1995–96. This alternative catch split was not used because it made only minor changes to the catch estimates. The estimated commercial catch history for PAU 5D is shown in Figure 4.

The estimated catches by finer statistical area from the years of PCELR data are shown in Figure 5. Catches were taken throughout the stock and were widely distributed in the south coast (P5DH01–11), Catlins (P5DH12–22), and the east coast (P5DH23–47). There is very little evidence of serial depletion since 2002. Overall between 2002 and 2012, the east coast accounted for about 50% of the total catch in PAU 5D, with the remainder of the catch approximately equally taken from the south coast and Catlins (Table 4).

Table 3: Collated commercial catch histories (kg) for PAU 5A, 5B, and 5D for fishing years 1974–2012 under the lower bound (assumption 1), base case (assumption 2), and upper bound (assumption 3) assumptions.

		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	282 770	104 400	89 670	88 700	104 400	89 670	88 700	104 400	89 670	88 700

Table 4: Proportion of estimated catch from PCELR forms for fishing years 2002–2012 in each of the area within PAU 5D. South coast, fine statistical areas P5DH01–11; Catlins West, P5DH12–15; Catlins East, P5DH16–22; East coast, , P5DH23–47.

Fishing year	South coast	Catlins West	Catlins East	East coast	Total (t)
2002	0.29	0.12	0.06	0.52	141
2003	0.24	0.16	0.16	0.44	103
2004	0.30	0.12	0.11	0.47	84
2005	0.22	0.19	0.10	0.48	86
2006	0.26	0.13	0.09	0.52	89
2007	0.30	0.10	0.11	0.50	87
2008	0.19	0.11	0.11	0.60	87
2009	0.24	0.19	0.13	0.43	79
2010	0.22	0.20	0.12	0.46	88
2011	0.21	0.14	0.14	0.52	86
2012	0.25	0.10	0.14	0.50	80
Total	0.25	0.14	0.11	0.50	1 013

Figure 4: Estimated commercial catch history for PAU 5D, 1974–2012 fishing years.

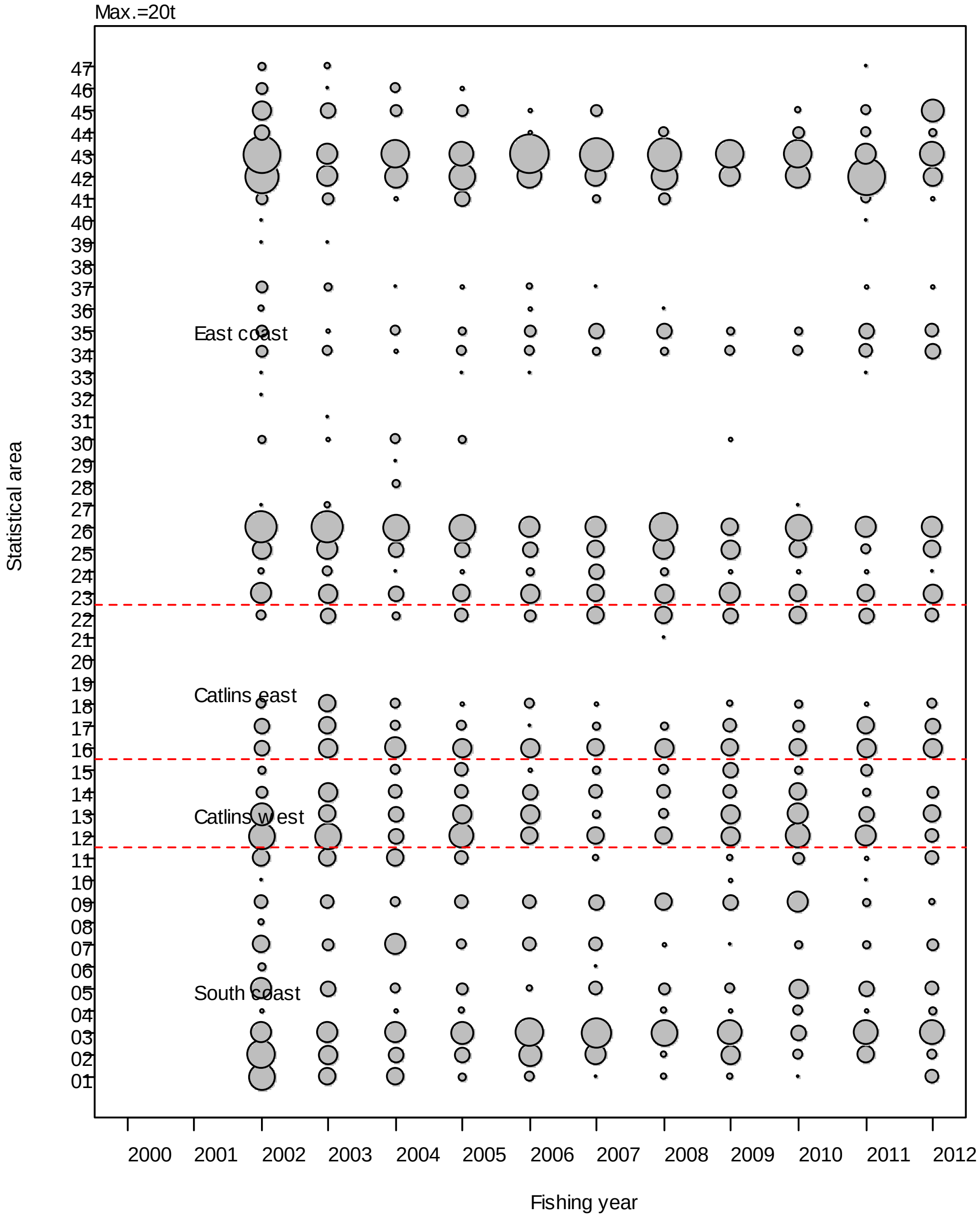


Figure 5: Annual estimated catch by Paua statistical area in PAU 5D for fishing years 2002–2012. The size of the circle is proportional to the catch.

3.2 Recreational catch

The 1996 and 1999–2000 National Recreational Fishing Surveys estimated 37.1 t and 53.2 t were taken respectively from PAU 5 by recreational fisheries but with no substock breakdown. The Marine Recreational Fisheries Technical Working Group considered that some harvest estimates from the 1999–2000 and 2002–01 surveys for some fish stocks were unbelievably high. The Shellfish Working Group examined estimates from national recreational surveys conducted in 1996 and 1999–2001, and following their discussions, the 2006 assessment for PAU 5D assumed that the 1974 recreational catch was 2 t, increasing linearly to 10 t in 2005. For this assessment, the base case assumed that the recreational catch increased linearly from 2t in 1974 to 10 t in 2005, and has remained constant at 10 t between 2006 and 2012; the sensitivity run assumed that the recreational catch increased linearly from 2t in 1974 to 30 t in 2012.

3.3 Customary catch

There are no published estimates of customary catch. For the purpose of the stock assessment model, the SFWG agreed to assume that the customary catch has been constant at 2 t for PAU 5D.

3.4 Illegal catch

Illegal catch was estimated by the Ministry of Fisheries (now Ministry for Primary Industries) to be 20 t. For the purpose of the stock assessment model, the base cased assumed that illegal catches have been constant at 10 t for PAU 5D and the sensitivity run assumed that illegal catches increased linearly from 2 t in 1974 to 30 t in 2012.

4. CPUE STANDARDISATIONS

Two separate standardised CPUE series were calculated: (i) one based on CELR data from 1990 to 2001, and (ii) another on PCELR data from 2002 to 2012. The data set used, methods, and results are described in the following sections. For the CELR data some more detailed analyses were undertaken exploring the impact of potential changes in fishing duration, a predictor variable not used in the standardisation due to ambiguity in how it is recorded.

4.1 Initial data set

Catch effort data reported to the Catch and Effort Landing Return system capturing fishing events that either caught or targeted paua between 1 October 1990 and 30 August 2012 were requested from the Ministry for Primary Industries database "warehou" (extract 8673), including the CELR data until October 2001, and the PCELR data from the 2001–02 fishing year. The FSU data were also extracted from the NIWA-managed database for the period between January 1983 and September 1988 (extract. CL0088), but they were not used for the CPUE standardisation. The data for the 2012 fishing year are incomplete but they captured about 90% of quota and were therefore included in the standardisation. The data were groomed, using methods similar to those described by Kendrick & Andrew (2000) and by Breen & Kim (2007).

Kendrick & Andrew (2000) allocated catch effort records from the straddling statistical areas before 30 September 1995 to the new PAU 5 substocks in proportion to its assumed contribution to the catch. This allows most catch and effort from those areas to be retained in the standardisations but would introduce uncertainties in the process because different CPUE datasets are produced each time the analysis is repeated. In the 2010 assessment of PAU 5A (Fu et al. 2010), the SFWG decided not to include those randomly allocated records in the CPUE standardisations. For PAU 5D, about 7% and 25% of records from Statistical Areas 030 and 025 respectively were randomly allocated to PAU 5D before October 1995. These records generally accounted for only a small proportion of total annual catch and were not included in the standardisations that follow for the 2012 assessment (Figure 6). After the 1995 fishing year, the catch from Statistical Areas 025 and 030 are well determined, and in general, PAU 5D accounted for a small proportion of total catch in 025 and a much smaller proportion in 030 (Figure 7).

For the CELR data the total number of hours for all divers on a vessel should be recorded on a daily basis. Breen & Kim (2007) investigated this and found a linear relationship for up to three divers, but a flattening and decline for more divers (Figure 8). This was interpreted as an ambiguity in what the recorded hours represented in the data, where sometimes total hours had been recorded for all divers, and at other times, hours per diver were recorded (particularly if the number of divers was above three). A similar plot showing the calculated hours per diver for a day, which should remain approximately constant as the number of divers increases, shows a similar pattern (Figure 9). Because of this ambiguity, the number of divers, rather than the duration field, is used in the standardisation as a measure of effort.

The recorded resolution for the estimated catch and fishing duration for the PCELR data is low. About 40% of the catch is recorded as multiples of 50 kg, and about 80% of recorded fishing durations are multiples of one hour (Figure 10). In about 50% of fishing events the estimated catch was split equally amongst the divers (Figure 10).

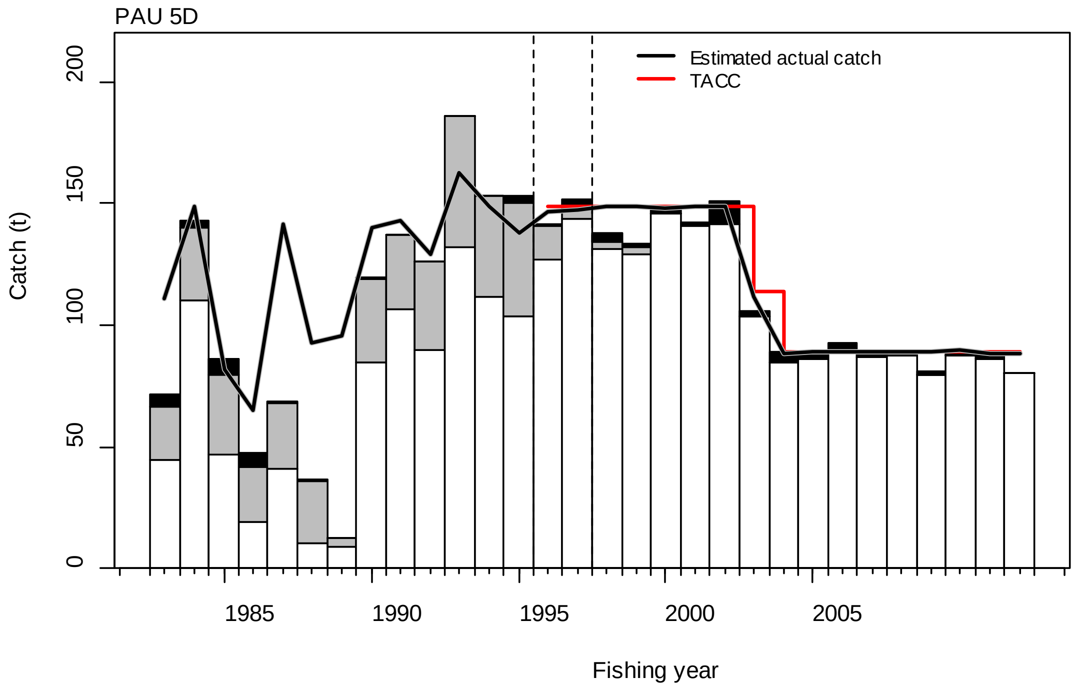


Figure 6: The estimated commercial catch history, TACC, and the FSU/CELR/PCELR catch (vertical bars) for fishing years 1983–2012 for PAU 5D. Black portion of the bar represents estimated catch removed through data grooming; grey represents the estimated catch from records reported to straddling Statistical Areas 025 and 030 but randomly allocated to PAU 5D.

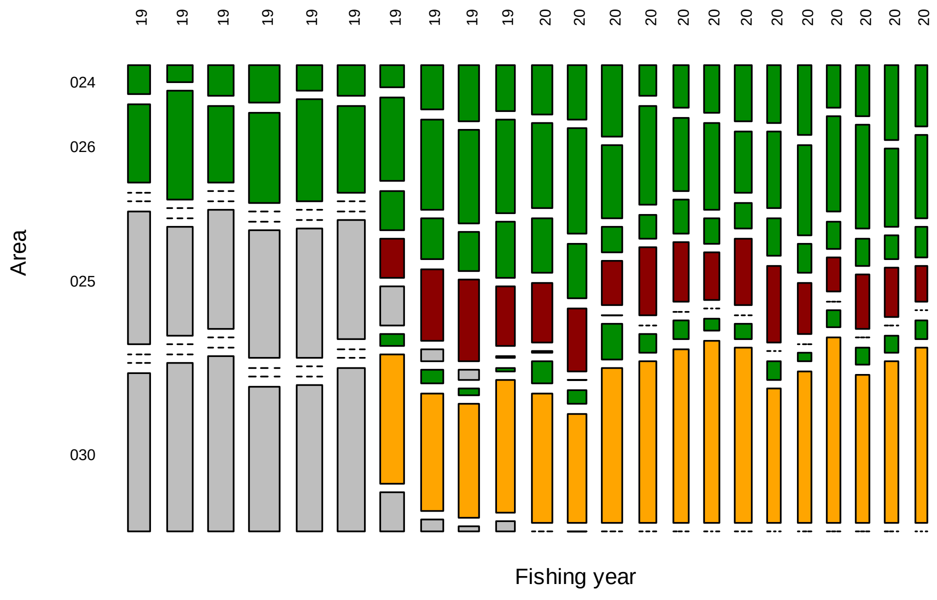


Figure 7: Estimated catch by statistical area and fishing year on the CELRs and PCELRs, 1990–2012. Green represents catch from within PAU 5D; red represents catch from Statistical Area 025 outside PAU 5D; orange represents catch from Statistical Area 030 outside PAU 5D; grey represents catch from areas with substock undetermined. The width of the bar is proportional to the total annual catch.

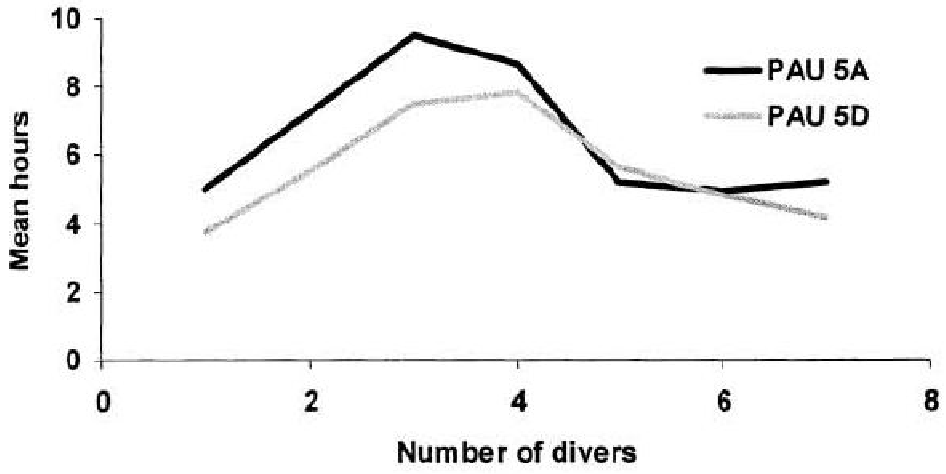


Figure 8: Mean number of hours for records with various numbers of divers in the CELR dataset (reproduced from Breen & Kim 2007, figure 10).

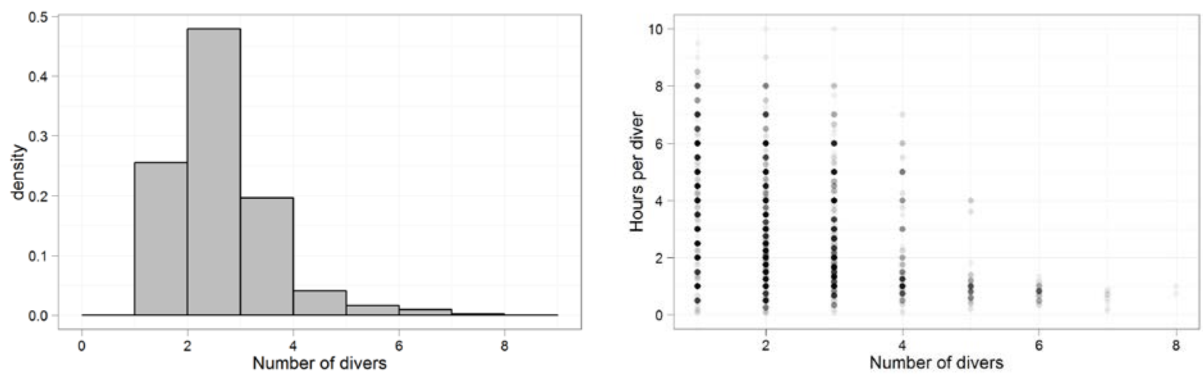
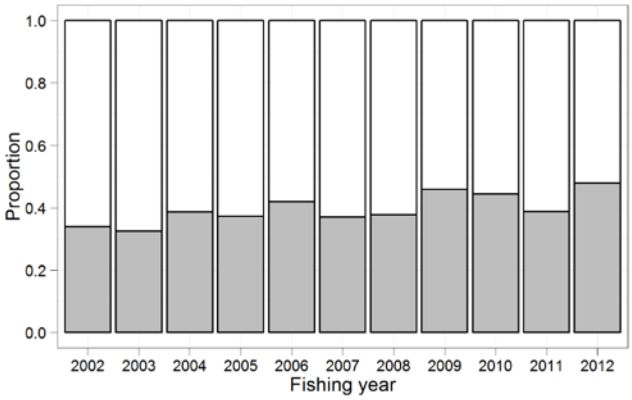
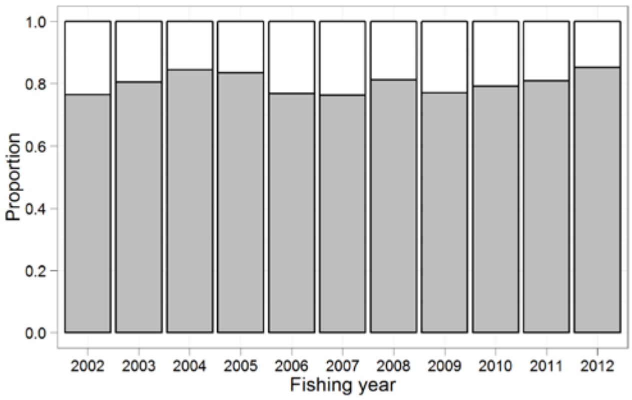


Figure 9: Distribution of the number of divers (left) and the calculated fishing hours per diver (right) on CELR forms within PAU 5D for fishing years 1990–2001 combined.

(a)



(b)



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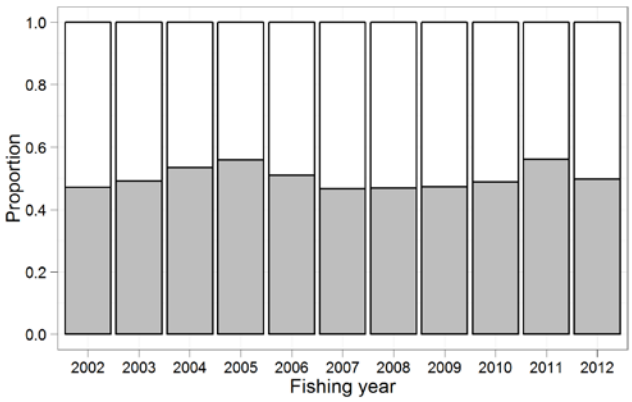

Figure 10: Diagnostic of data resolution on the PCELR forms within PAU 5D: (a) proportion of records that recorded estimated catch in a multiple of 50 kg; (b) proportion of records that recorded hours fished in an exact multiple of 1 hour; (c) proportion of fishing events where recorded estimated catch was equally split among divers.

4.2 Methods

Standardised CPUE indices have been used as relative abundance indices for paua stock assessments (Breen & Kim 2007, Breen & Smith 2008a). The 2006 assessment for PAU 5D used combined FSU, CELR, and PCELR data for the CPUE standardisations, with pre-1996 catch and effort from the straddling statistical area allocated to the substocks using the randomisation procedure described by Kendrick & Andrew (2000). As discussed in the previous section, it was decided by the SFWG not to use randomly allocated catch-effort records in the standardisations.

In more recent paua assessments (Fu et al. 2010, 2012, McKenzie & Smith 2009a, b) CELR and PCELR data were standardised as separate series and FSU data were omitted from the time series following advice by the SFWG. Previous extracts of FSU data have contained incorrect fishing hours, which appear to have been rectified for more recent extracts, but vessels are still missing for a large number of records. For this assessment FSU data was dropped, and the CELR and PCELR datasets were analysed separately to produce two different CPUE series.

For the recent PAU 7 stock assessment Fisher Identification Number (FIN) was used instead of vessel in the standardisation as "the FIN is associated with a permit holder who may employ a suite of grouped vessels, which implies that there could be linkage in the catch rates among vessels operated under a single FIN" (Ministry for Primary Industries, 2012). For the same reason the SFWG agreed to use FIN instead of vessel for the PAU 5D standardisation.

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

(1) NOT to randomly allocate catch-effort records from statistical areas 025 and 030 that overlap with PAU 5D, but are not entirely within it.

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

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

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

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

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

4.3 CELR data standardisation (1990–2001)

The initial data set used to derive the catch history has some preliminary grooming (Figure 6). For the standardisation some further grooming was undertaken: only records where paua was targeted by diving were retained, and records with missing values for the estimated catch or the number of divers were dropped (Table 5). The FIN, general statistical area (024, 025, 026, 030) and date were present for all records.

CPUE was defined as in previous standardisations as catch per diver day (i.e. the estimated daily catch divided by the number of divers). For all records the CPUE was less than the grooming cut-off value of 1000 kg/diver day.

Table 5: Number of records removed.

Fishing 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	1	0	1	2
Catch missing	0	0	0	0	1	0	1	0	2	2	0	0	6
# divers missing	0	0	0	0	0	0	2	1	1	0	1	0	5
Method not diving	10	0	6	53	36	8	27	48	39	45	18	34	324

FIN is used to sub-set out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 10 records per year for a minimum of two years was selected, this retaining 84% of the catch over 1990–2001 (Figure 11). The number of FIN holders dropped from 104 to 27 under these criteria. Note however, that just 58% of the catch is retained in 1990, whereas 80% or more is retained for other years (Figure 12). This lower value of 58% is due to the dropping of a group of FIN holders that are present only in 1990 (Figure 13). There is good temporal overlap in effort by fishing year for the 27 FIN holders after sub-setting (Figures 14–15). The other predictor variables also show good overlap with fishing year (Figures 16–17). The number of days of effort retained after sub-setting is more than 160 for every fishing year (Table 6).

Table 6: Number of records retained before and after FIN sub-setting.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	292	277	340	393	347	323	436	463	476	344	500	434	4625
After	163	231	282	332	290	281	348	408	428	304	436	373	3876

Year was forced into the model at the start and other predictor variables offered to the model were FIN, statistical area (024, 025, 026, 030), month, and a month:area interaction. Following previous standardisations, no interaction of fishing year with area was entered into the model, and for the PAU 5D stock assessment model a single area model was used. Plotting raw catch rates indicates that there is not much difference between the areas after 1995 (Figure 18).

The model explained 26% of the variability in CPUE with FIN (20%) explaining most of this (Table 7). The effects appear plausible and the model diagnostics satisfactory (Figures 19–20). The standardised index fluctuates from 1990 to 1995, then declines until 1998, increases by 40% in 1999, then subsequently declines (Table 8, Figure 21). The standardised index is similar to the unstandardized index with most of the difference being due to the FIN predictor (Figure 22). Forcing a year:area interaction into the standardisation model at the start indicates that there is little difference in CPUE trends between areas after 1995 (Figure 23).

Table 7: Variables accepted into the model (1% additional deviance explained), and the order in which they were accepted into the model.

Predictors	Degrees of freedom	Percentage deviance explained
Fish year	11	0.02
FIN	26	0.22
Month	11	0.26

Table 8: Standardised CELR index, lower and upper 95% confidence intervals, and CV.

Year	Index	Lower CI	Upper CI	CV
1990	1.04	0.88	1.22	0.08
1991	1.19	1.03	1.36	0.07
1992	1.04	0.92	1.17	0.06
1993	1.19	1.06	1.33	0.06
1994	1.06	0.94	1.19	0.06
1995	1.07	0.95	1.21	0.06
1996	0.98	0.88	1.09	0.05
1997	0.90	0.81	0.99	0.05
1998	0.78	0.70	0.86	0.05
1999	1.10	0.98	1.23	0.06
2000	0.93	0.83	1.03	0.05
2001	0.83	0.74	0.93	0.06

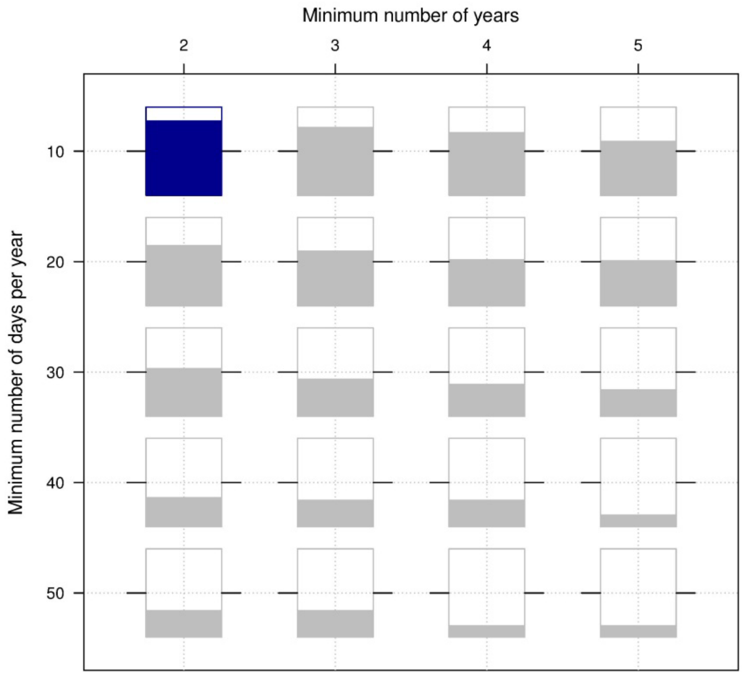

Figure 11: Proportion of the catch taken when sub-setting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

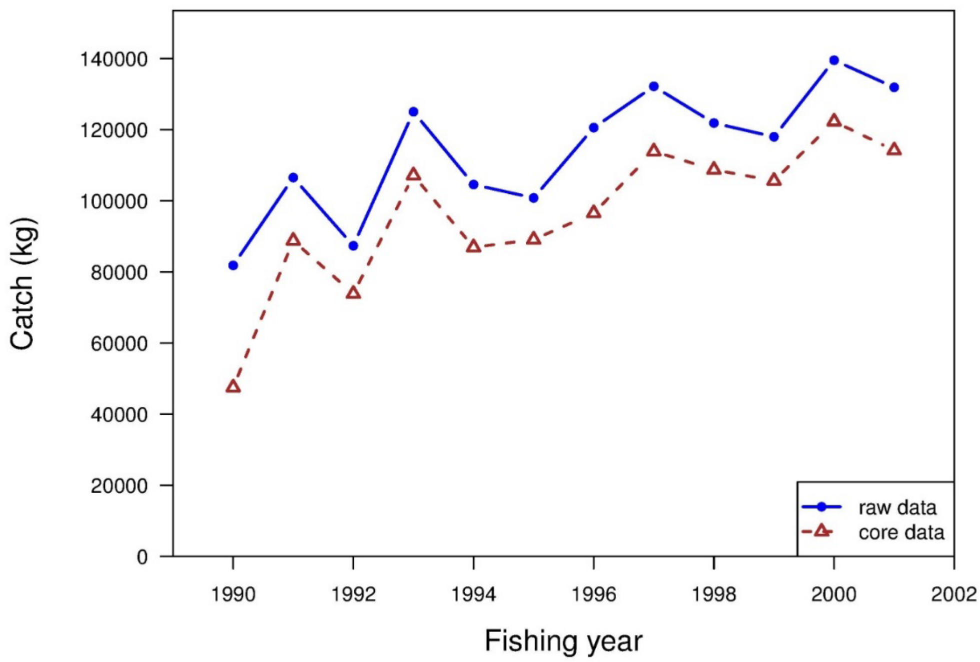

Figure 12: Catch by fishing year before FIN sub-setting (raw data) and after (core data). The sub-setting uses the criteria of a minimum of 10 days per year for a minimum of 2 years.

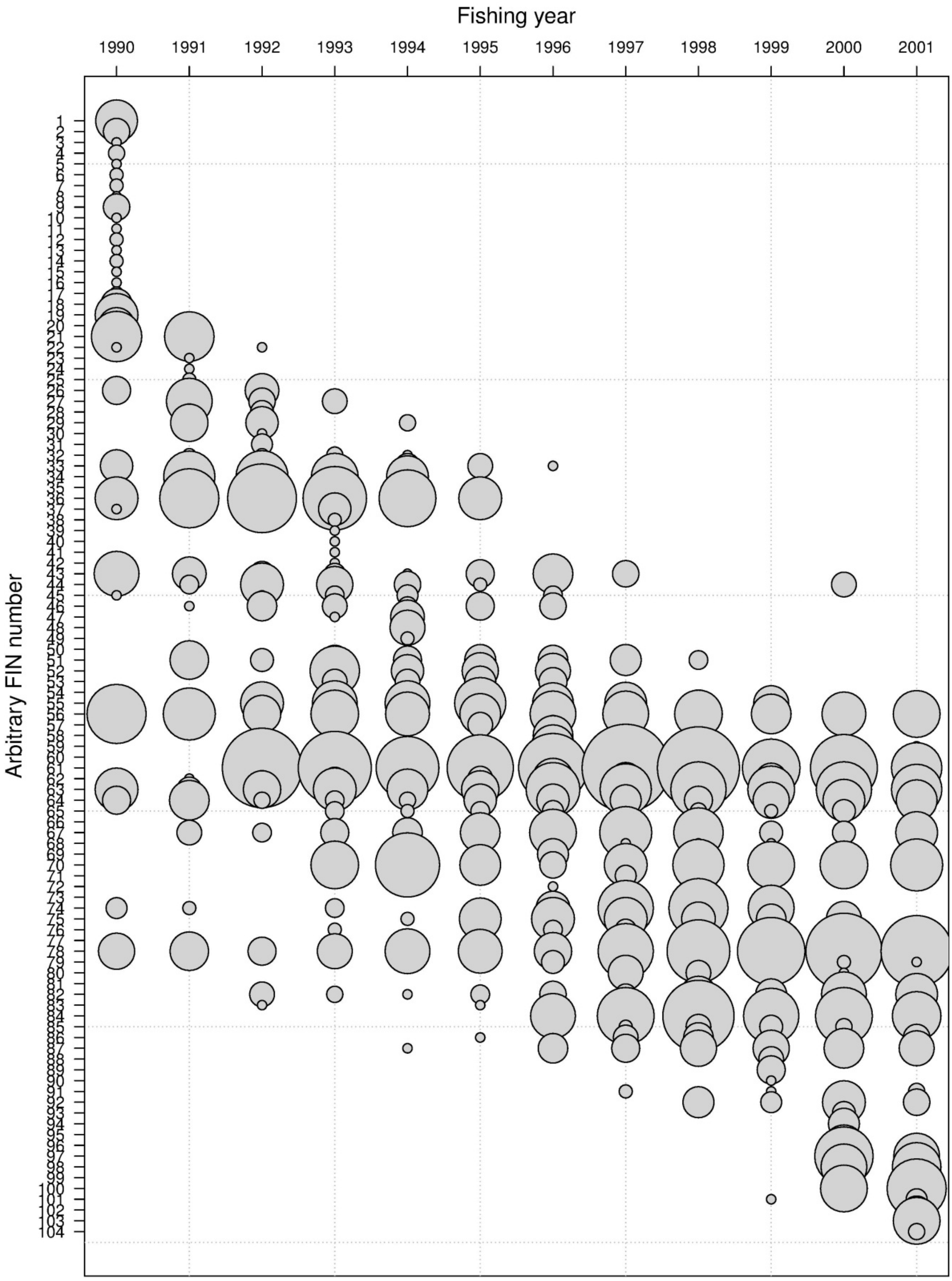

Figure 13: Overlap in days of effort by FIN before sub-setting. The area of a circle is proportional to the days of effort; the largest circle represents 87 days.

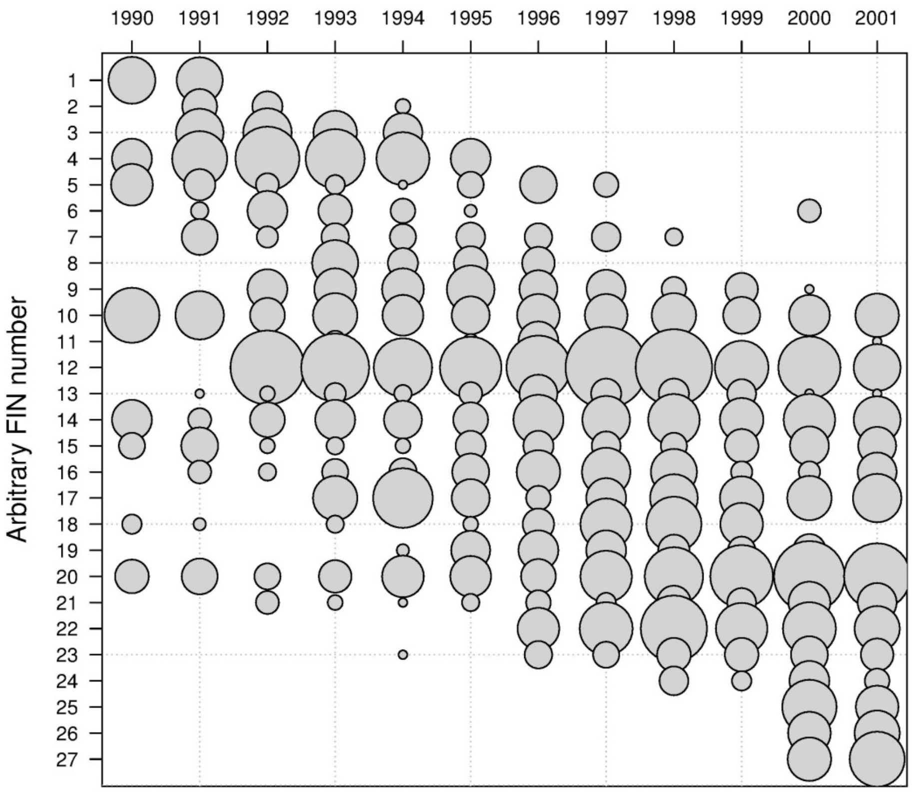

Figure 14: Overlap in days of effort by FIN. The area of a circle is proportional to the days of effort; the largest circle represents 87 days.

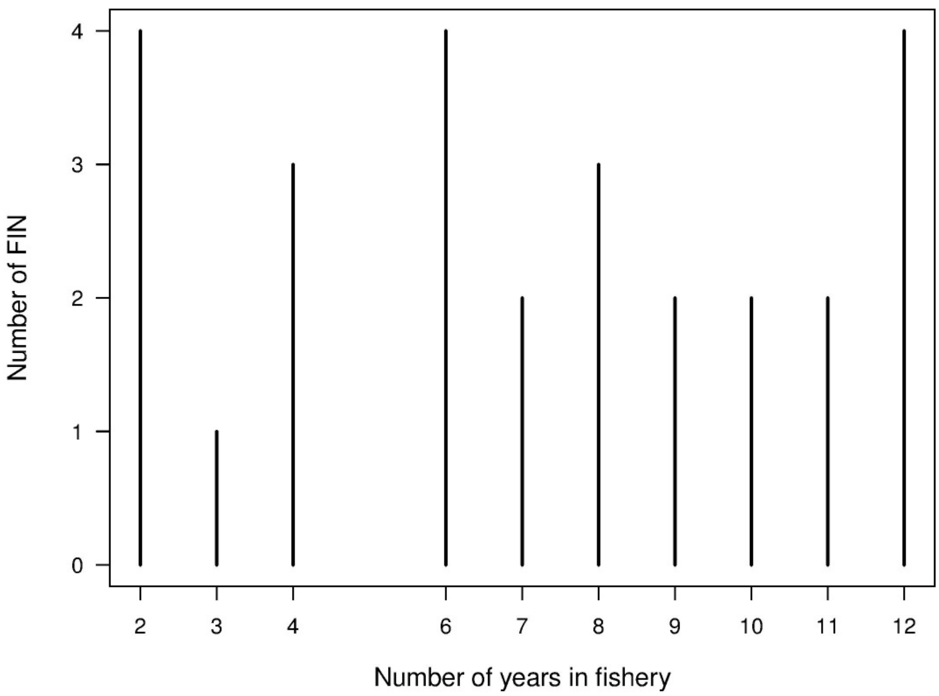

Figure 15: Number of years in the fishery for a FIN holder after sub-setting by FIN.

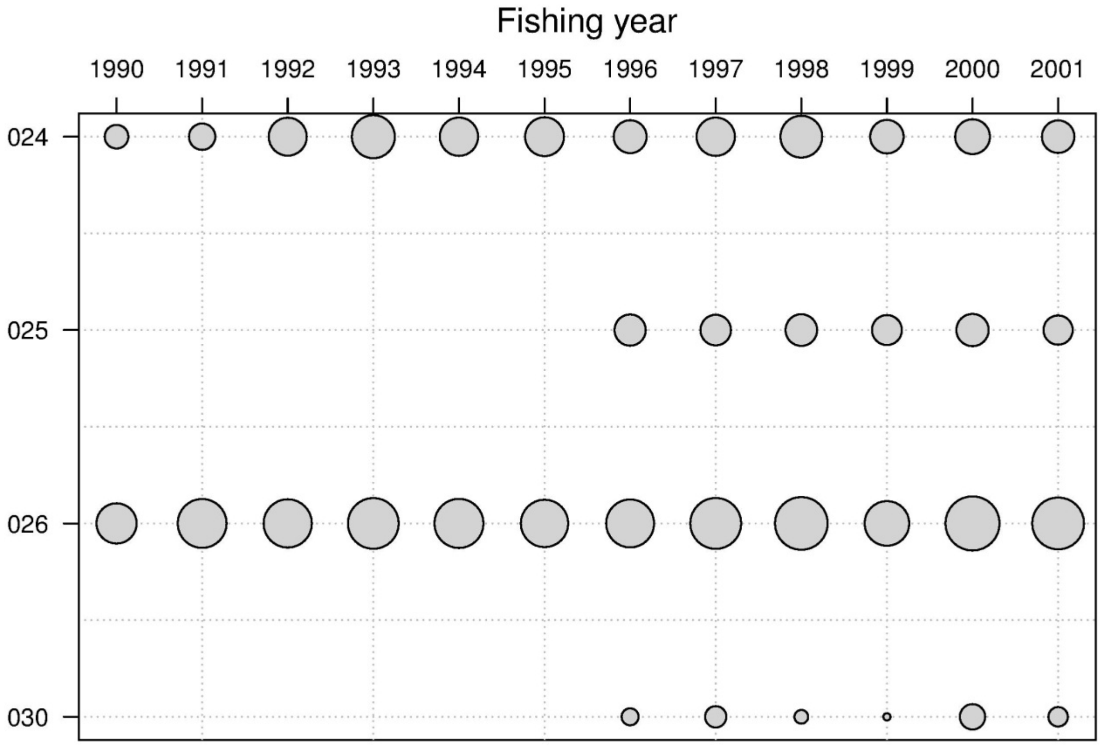

Figure 16: Overlap in days of effort for statistical area by fishing year. The area of a circle is proportional to the days of effort; the largest circle represents 219 days.

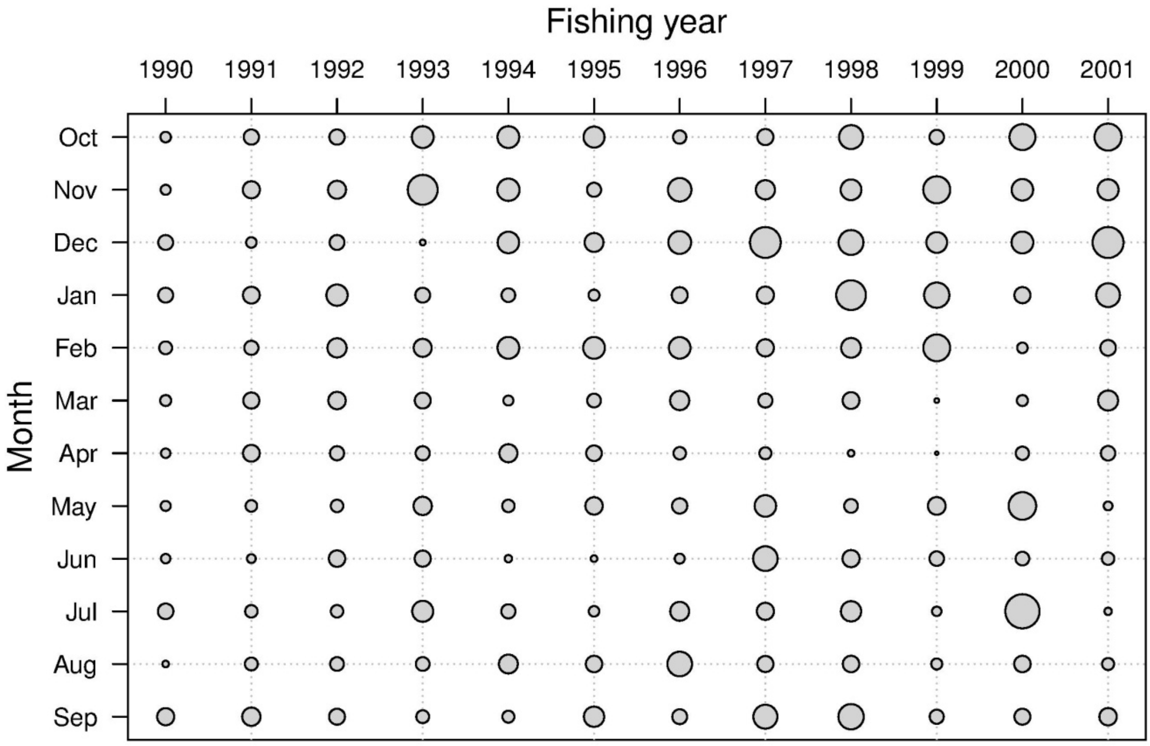

Figure 17: Overlap in days of effort for month by fishing year. The area of a circle is proportional to the days of effort; the largest circle represents 106 days.

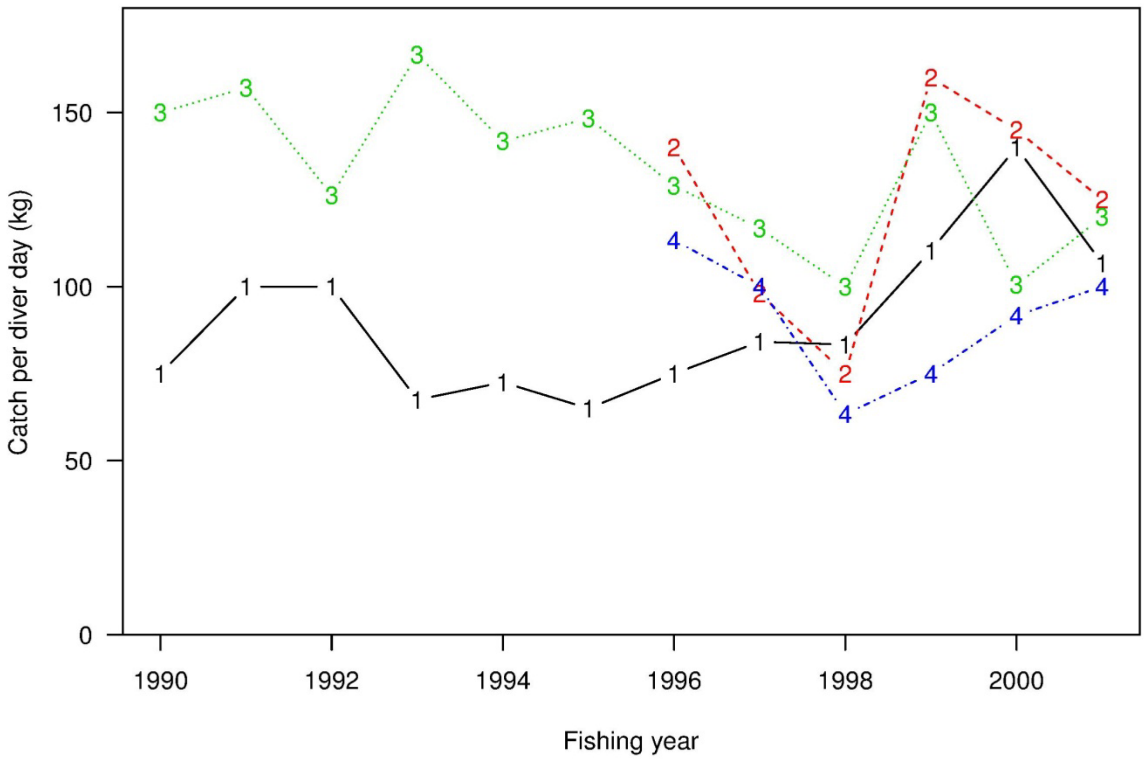

Figure 18: Median values for the groomed CPUE data set by statistical area. The statistical areas 024, 025, 026, 030 are denoted by the plotting symbols 1,2,3,4 respectively. From 1990–2001 the percentage of the catch for the groomed CPUE from the statistical areas is: 024 (24%), 025 (12%), 026 (62%), 030 (3%).

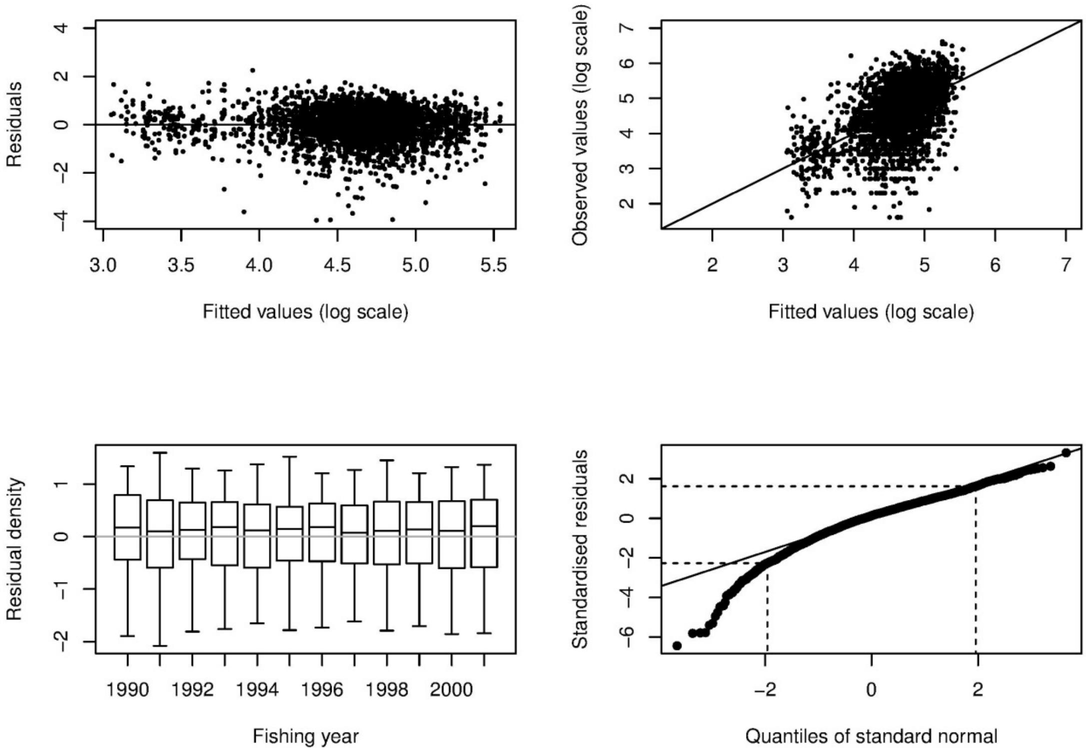

Figure 19: Residuals for the standardisation model.

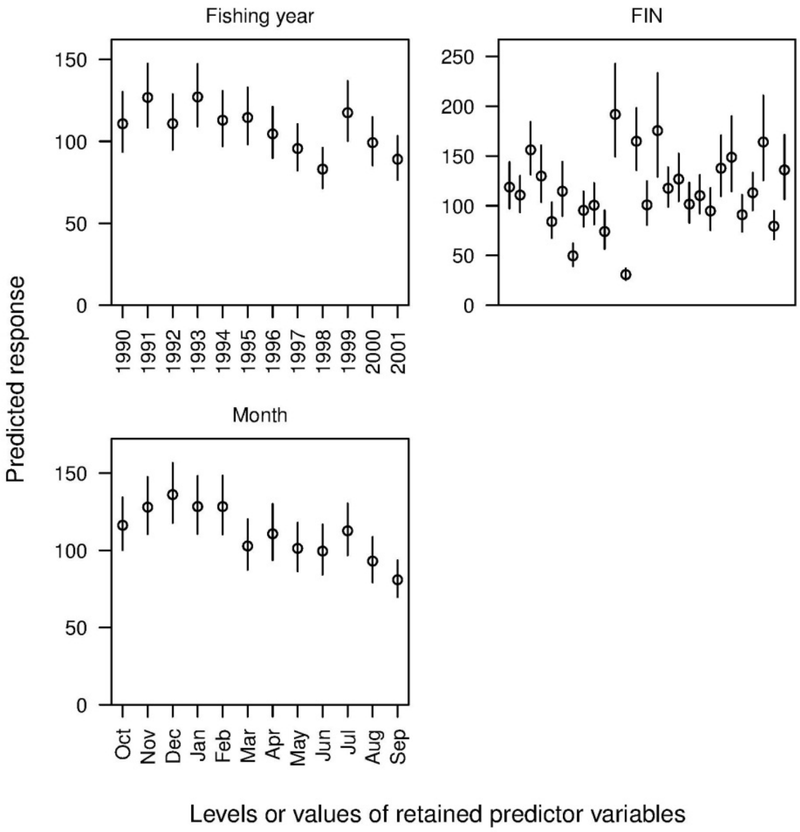

Figure 20: Effects for the standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

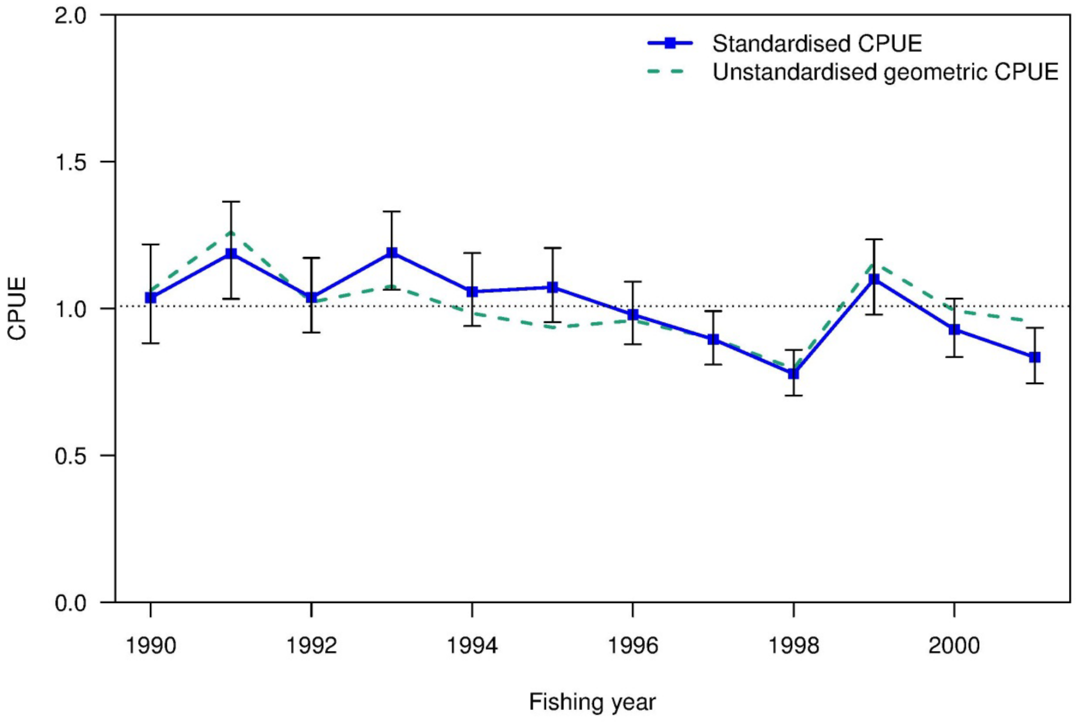

Figure 21: The standardised CPUE index with 95% confidence intervals.

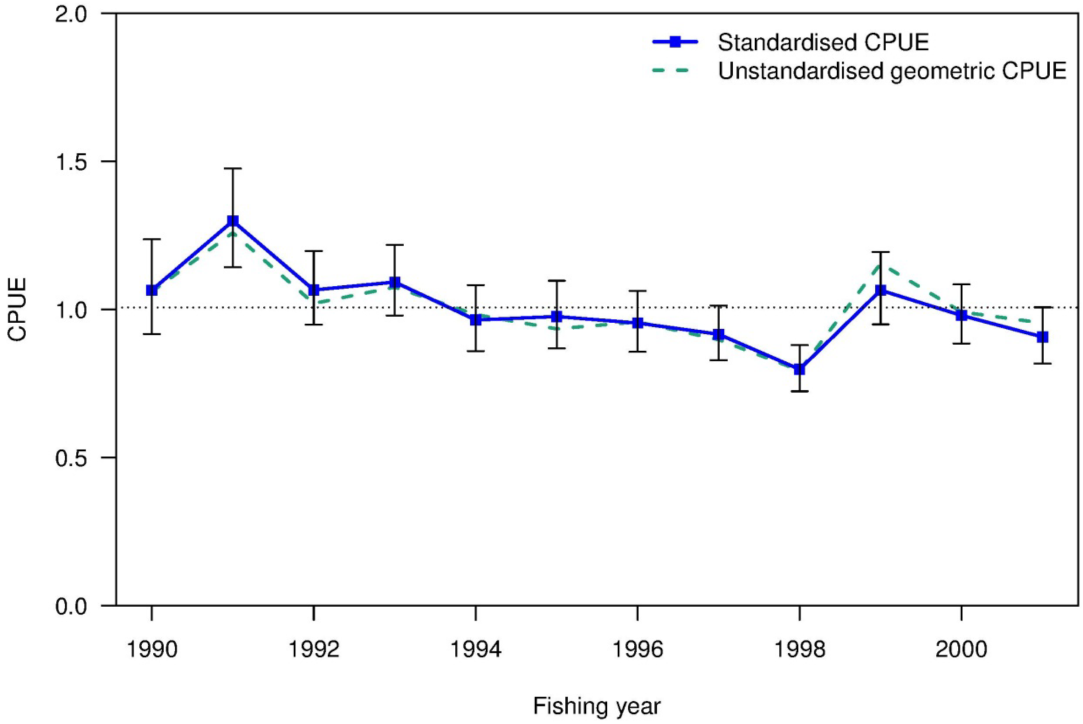

Figure 22: Without FIN offered to the standardisation model. The resulting CPUE index (standardised with the accepted predictors month, area, month:area).

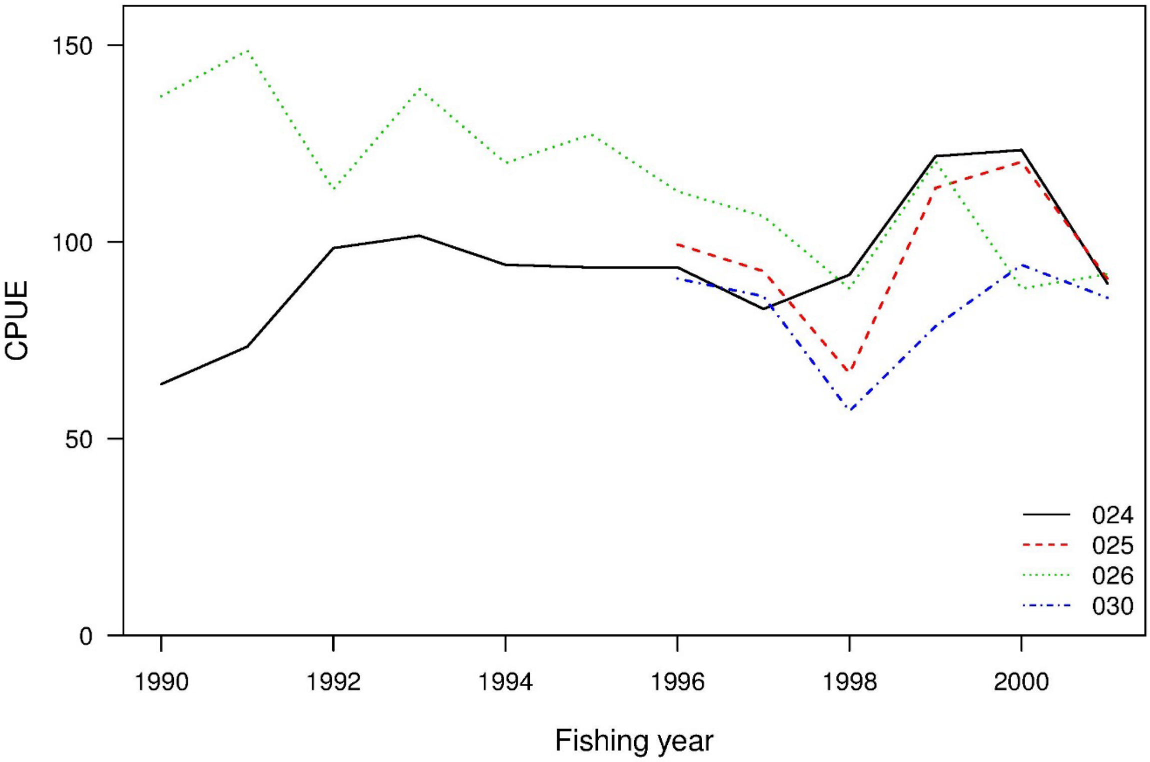

Figure 23: The fishing year:area interaction when this is forced into the standardisation model at the start.

4.4 CELR data: impact of changes in fishing duration

Because of ambiguity in what is recorded for fishing duration it is not used in the standardisation as a measure of effort, instead, the number of divers is used (see Section 4.1). However, if the fishing duration changes substantially over time then the number of divers would be a poor measure of effort. It was suggested by the SFWG that a subset of the CPUE standardisation data set be taken for which the recorded fishing duration was less ambiguous, and that this subset of data could be used to examine whether fishing duration had changed over time.

The criteria suggested for sub-setting was that the number of divers recorded be just one, or that 8 hours or more was recorded for the fishing duration (an unlikely duration for only one diver). To determine the validity of the second criteria (8 hours or more implying more than one diver) an initial sub-set was taken for which dive duration was 8 hours or more, and it was found that 3% of these records had one diver (Table 9). It was decided to drop these records with one diver and more than 8 hours duration as well, and the final criteria used to sub-set the data were: (i) just one diver, or (ii) fishing duration at least 8 hours and the number of divers at least 2. Some further grooming was done in which records with NA for fishing duration were dropped (25 records), and a fishing duration per diver greater than 10 hours dropped (7 records). The sub-setting retained 43% of the records from 1990–2001 (Table 10). 55% of the records had one diver (Table 11).

Table 9: Distribution of the number of divers for records for which the dive duration is 8 hours or more.

Number of divers	1	2	3	4	5	6
Number of records	22	404	289	58	7	1

Table 10: The number of CELR records before and after sub-setting.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	163	231	282	332	290	281	348	408	428	304	436	373	3876
After	58	97	169	191	175	142	178	163	109	114	150	136	1682

Table 11: Distribution of the number of divers after sub-setting.

Number of divers	1	2	3	4	5	6	Total
Number of records	926	402	288	58	7	1	1682

For the sub-setted 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 24). The median fishing duration per diver remains little changed over time (Figure 25), but the mean shows some variation over time (Figure 26).

To explore what impact this change in fishing duration has on the standardisation, another standardisation was done which was the same as the original but with CPUE = daily catch and daily fishing duration offered as a predictor.

Another way of exploring what was recorded on the CELR forms for fishing duration is shown in Figure 28. This seems to show two groups of vessels: one that records the fishing duration for all divers combined, and another that records the total time that the vessel was out fishing. This may offer an avenue for future standardisation: select out only the vessels that record the fishing duration for all divers combined.

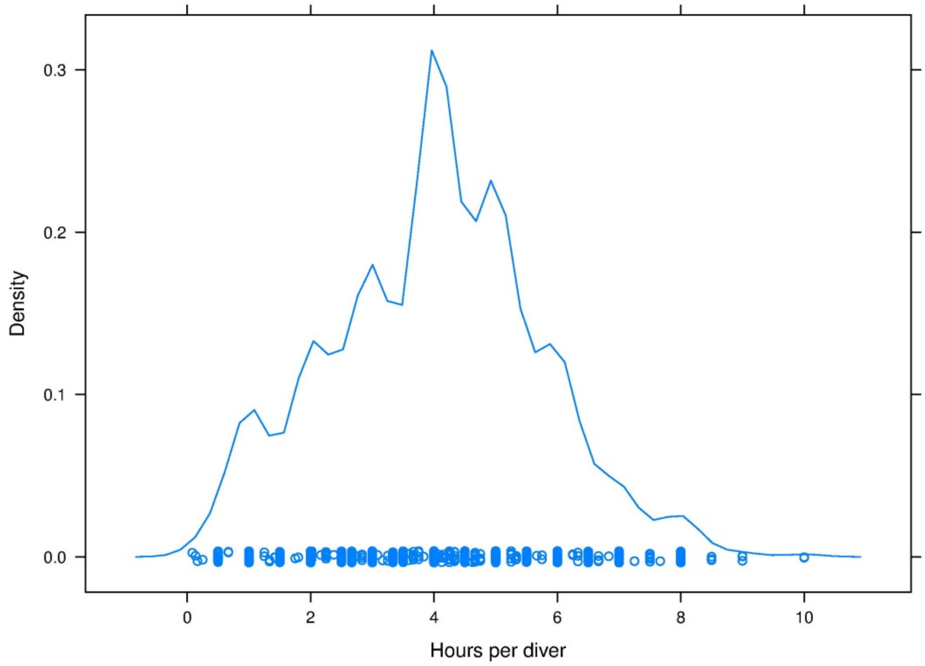

Figure 24: Density and strip plot for the hours per diver.

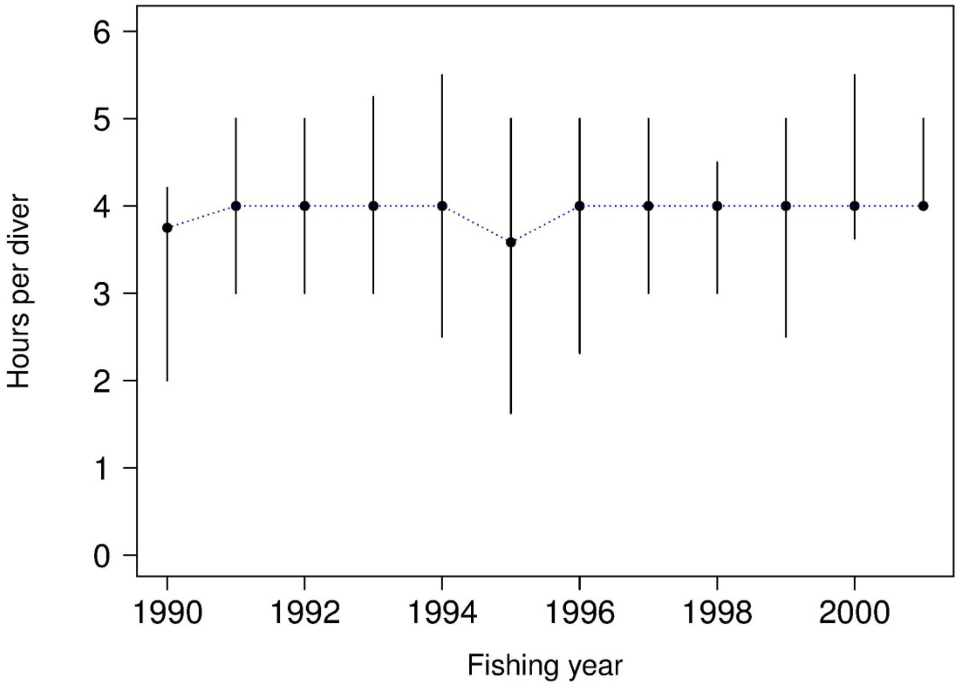

Figure 25: Medians (dot) and lower and upper quartiles (vertical lines) for the fishing duration per diver.

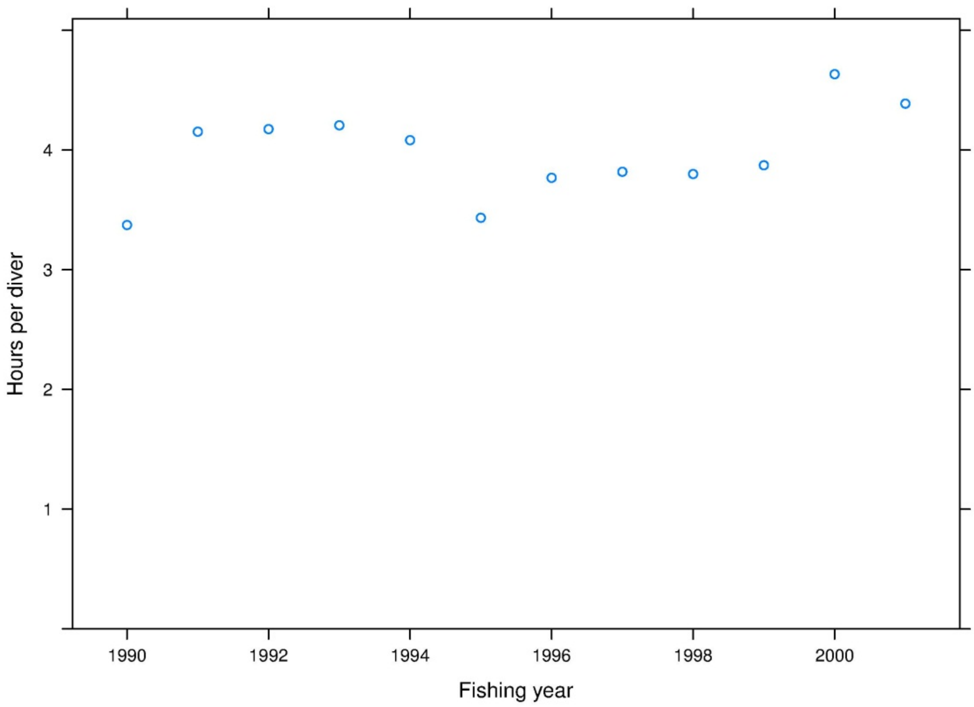

Figure 26: Mean values by fishing year for the fishing duration per diver.

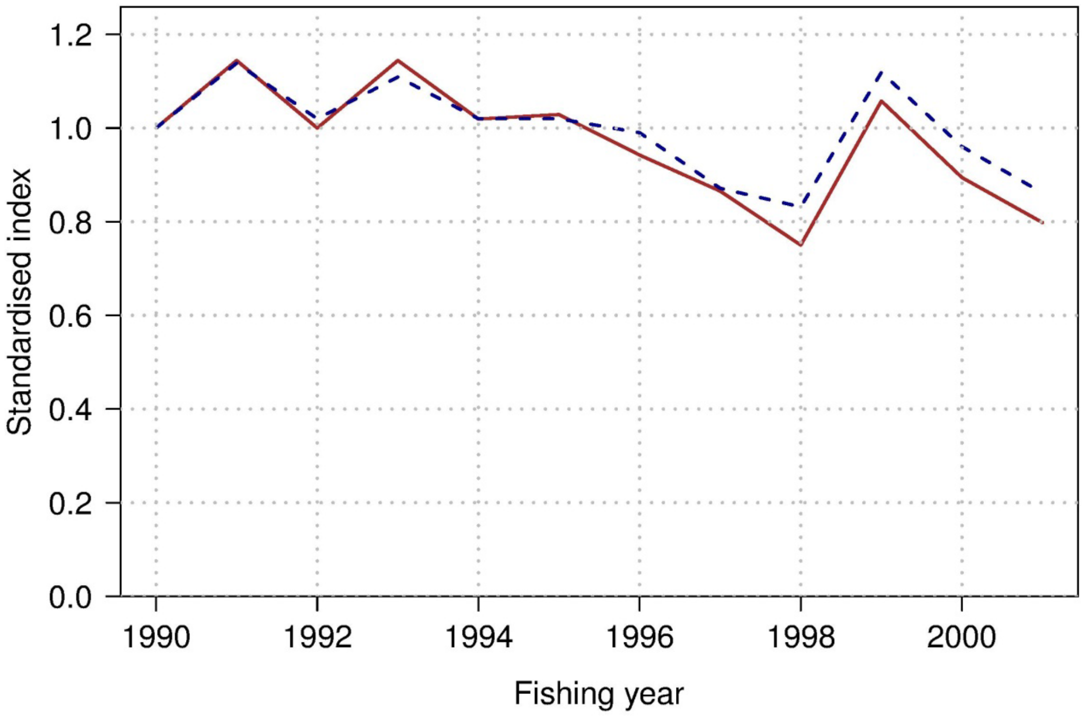

Figure 27: Standardised indices: original (solid red line) and with daily fishing duration as predictor (dashed blue line). The indices are both scaled so as to be one in 1990.

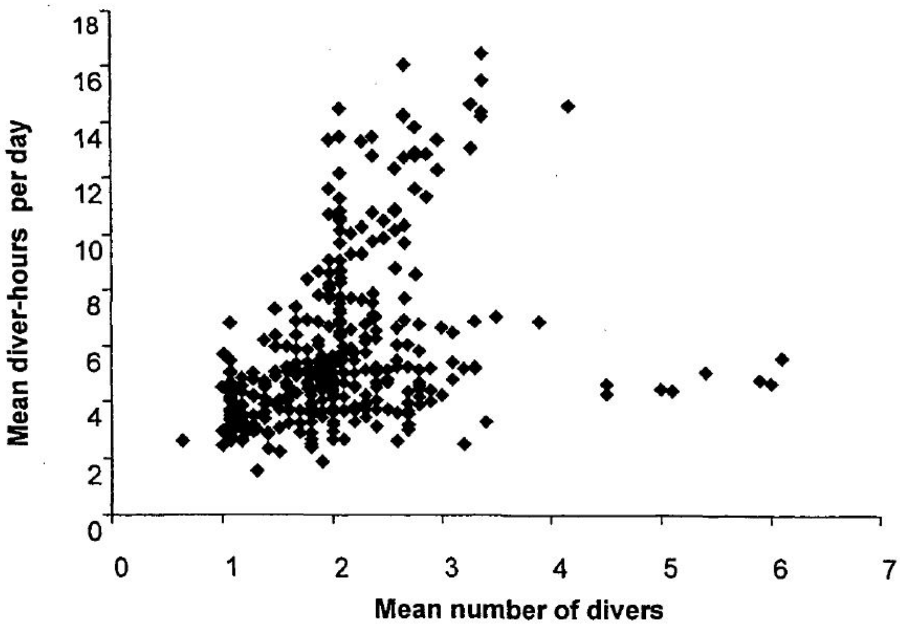

Figure 28: A common error in recording hours of effort was to record the hours that the boat fished for the day, rather than the total diver-hours. Each point plotted is the average for an entire year's fishing by one vessel (vessels recording less than 6 days fishing in a year were excluded). The diver-hours per day (y-axis) is calculated from Diver-hours/ Number of divers. (reproduced from Kendrick & Andrew (2000), figure 3).

4.5 PCELR data standardisation (2002–2011)

The initial data set used to derive the estimated catch history has some preliminary grooming (Figure 6). For the initial data set all records were for paua targeted by diving, and containing FIN, fine scale statistical area, catch weight, fishing duration, diver key, and date. For the standardisation some further grooming was made: records were removed where no diving condition was recorded (Table 12).

Table 12: Number of records removed.

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
No Diving condition	50	28	32	33	14	23	28	19	28	27	19	301

Records were collapsed to daily format for a diver: total catch and dive time over a day for a diver (associated with a specific FIN, diving conditions, and fine scale statistical area). CPUE was defined as the daily catch for a diver with fishing duration offered as a predictor in the model.

FIN was used to sub-set out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years (Figure 29). The criteria of a minimum of 20 records per year for a minimum of three years was selected, this retaining 82% of the catch over 2002–2012 (Figure 30). The number of FIN holders dropped from 37 to 13 under these criteria. The catch retained is lower than the 80% threshold for some years: 2002 (70%), 2003 (74%), 2008 (79%) (Figure 30). There is good overlap in effort for the 13 FIN holders after sub-setting (Figures 31–32). The number of days of records retained after sub-setting is more than 360 for every fishing year (Table 13).

To ensure that there was enough data to estimate fine scale statistical area and diver effects in the standardisation, only those fine scale statistical areas and divers with 10 or more diver days were retained (Table 13). This dropped the number of fine scale statistical areas from 44 to 30, and the number of divers from 474 to 77 (56% of divers had just one dive day).

There is very good temporal overlap for the other predictor variables statistical area, month, dive conditions, and diver (Figures 33–36).

Table 13: Number of records remaining in the data set after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records that didn't contain information needed for the standardisation were removed (Table 12).

Fishing year	2	3	4	5	6	7	8	9	10	11	12	Total
Total records	1181	921	707	640	559	543	513	413	458	419	450	6804
FIN sub-setting	879	738	626	581	505	472	408	352	369	364	393	5687
Fine scale stat area with >=10 dive days	862	729	612	581	504	470	404	350	369	359	393	5633
Divers with >= 10 dives days	701	606	488	521	456	430	352	319	324	335	366	4898

For the standardisation model CPUE (the dependent variable) was modelled as log (daily 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 conditions. Following previous standardisations, no interaction of fishing year with area was entered into the model, and for the PAU 5D stock assessment model a single area model was used.

Except for month, all variables were accepted into the model, which explained 76% of the variability in CPUE (Table 14). Most of the variability was explained by duration (54%) and diver (7%). The effects appear plausible and the diagnostics are satisfactory (Figures 37–38). The standardised index is very similar to the unstandardised index and increases by 58% from 2002 to 2011, then drops by 15% in 2012 (Figure 39, Table 15).

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

Predictors	Degrees of freedom	Percentage deviance explained
Fishing year	10	0.08
Fishing duration	3	0.62
Diver key	76	0.69
Diving conditions	4	0.73
Statistical area	29	0.75
FIN	12	0.76

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

Year	Index	Lower CI	Upper CI	CV
2002	0.81	0.74	0.89	0.05
2003	0.73	0.67	0.80	0.05
2004	0.78	0.71	0.86	0.05
2005	0.90	0.83	0.99	0.04
2006	1.12	1.02	1.23	0.05
2007	1.05	0.95	1.15	0.05
2008	1.03	0.93	1.15	0.05
2009	1.16	1.04	1.29	0.06
2010	1.18	1.06	1.32	0.06
2011	1.31	1.17	1.47	0.06
2012	1.10	0.99	1.23	0.05

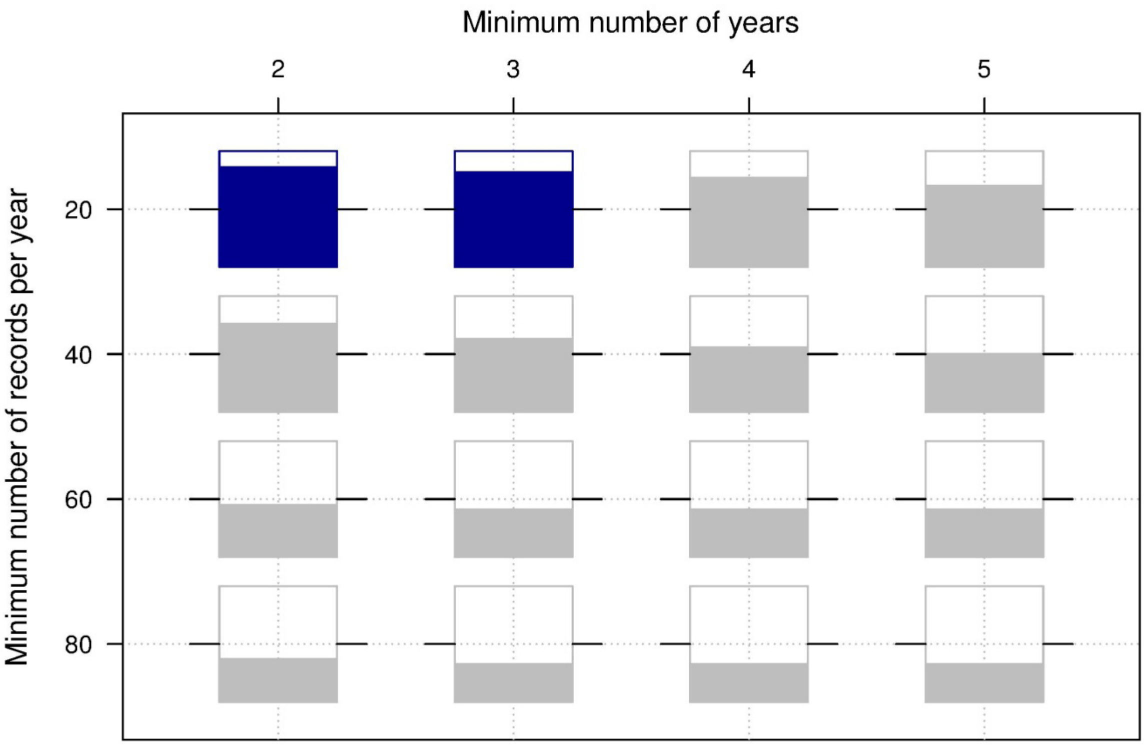

Figure 29: Proportion of the catch taken when sub-setting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2012 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

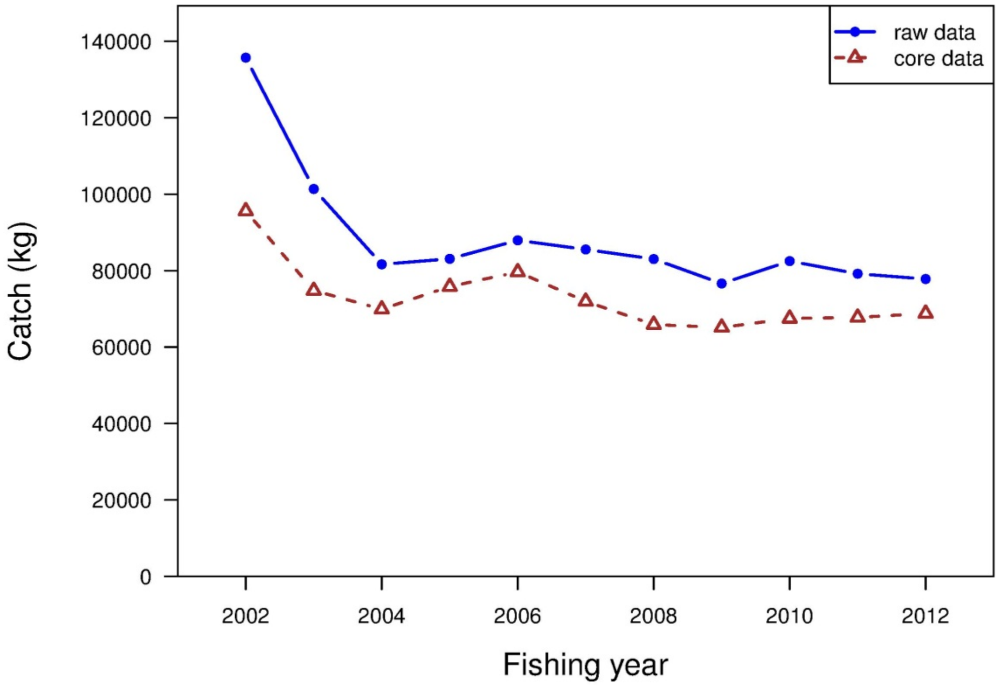

Figure 30: Catch by fishing year before FIN sub-setting (raw data) and after (core data). The sub-setting uses the criteria of a minimum of 20 records per year for a minimum of 3 years.

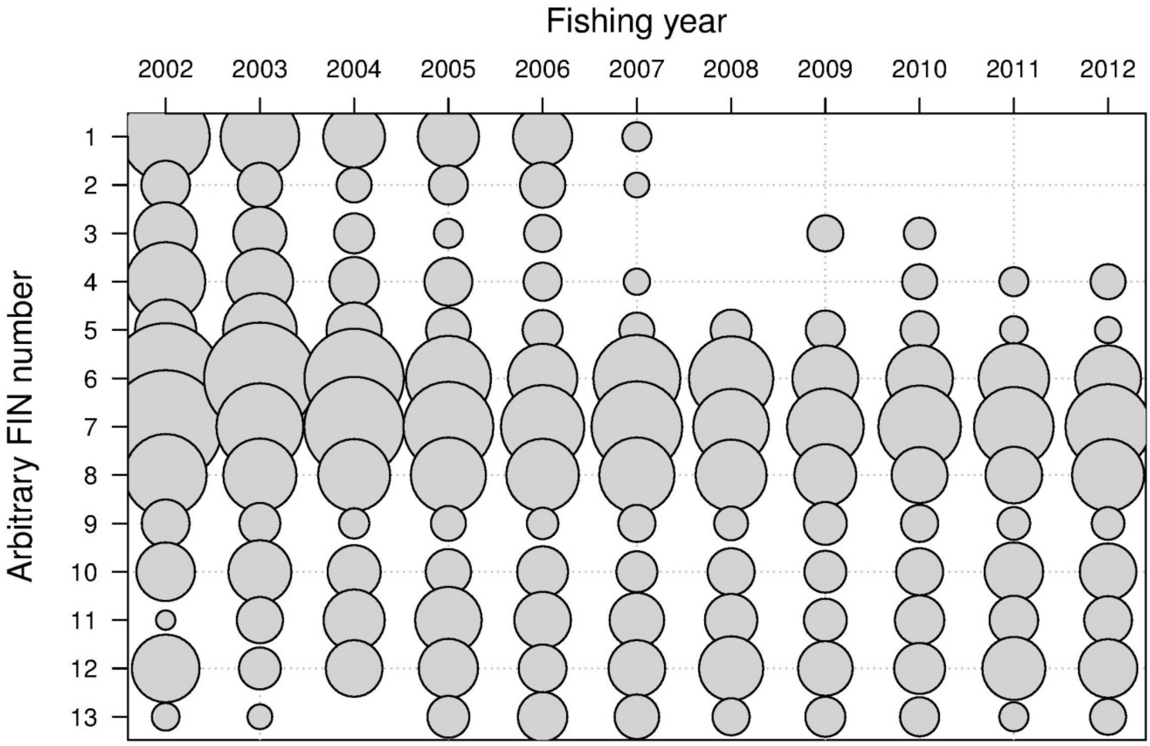

Figure 31: Overlap in number of records by FIN after sub-setting by FIN. The area of a circle is proportional to the days of effort; the largest circle represents 167 records.

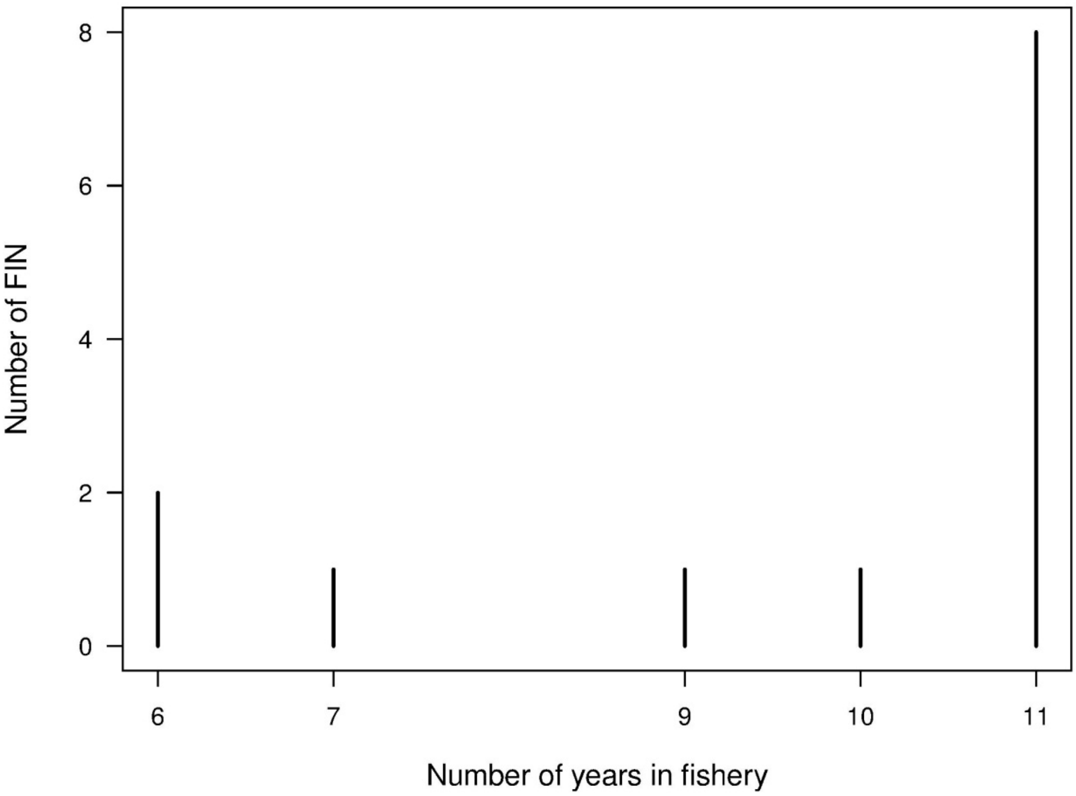

Figure 32: Number of years in the fishery for a FIN holder after sub-setting by FIN.

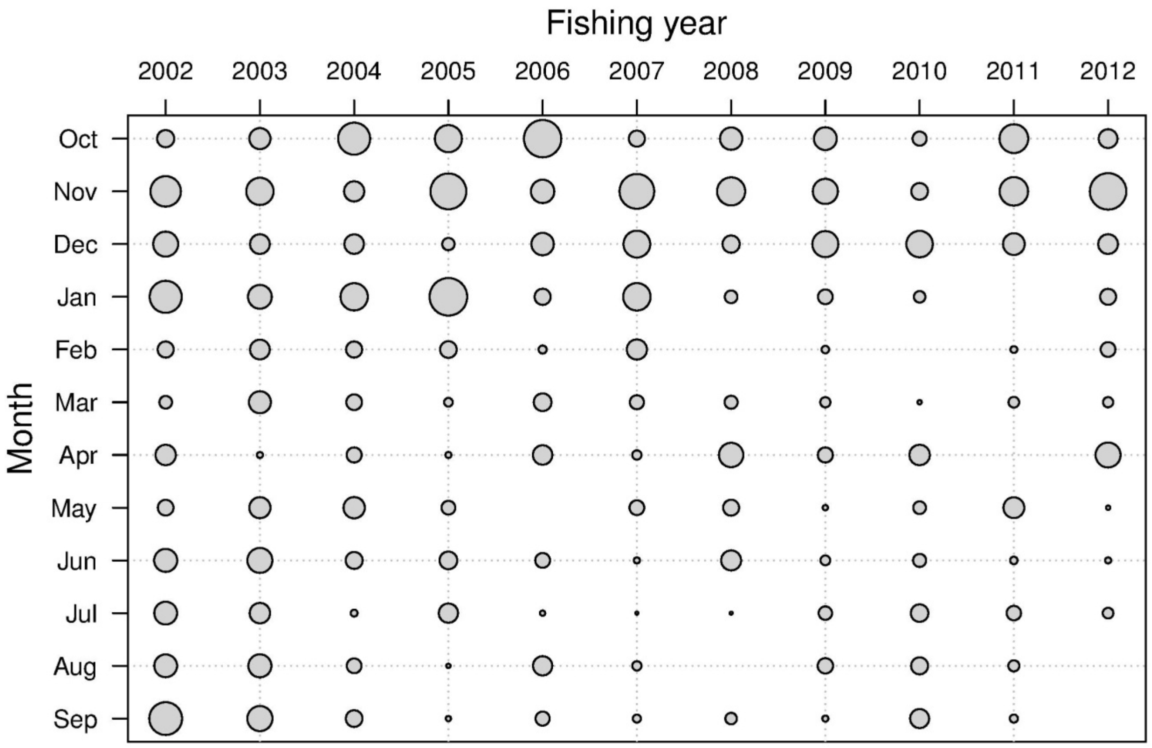

Figure 33: Overlap in number of records for month by fishing year. The area of a circle is proportional to the days of effort; the largest circle represents 150 records.

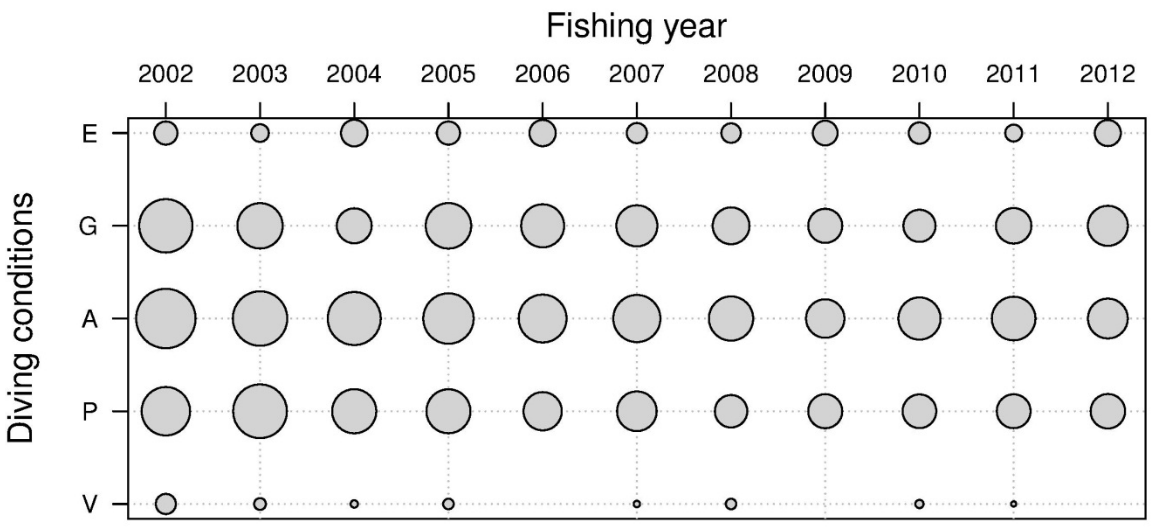

Figure 34: Overlap in number of records for fishing conditions (excellent, good, average, poor, very poor) by fishing year. The area of a circle is proportional to the days of effort; the largest circle represents 256 records.

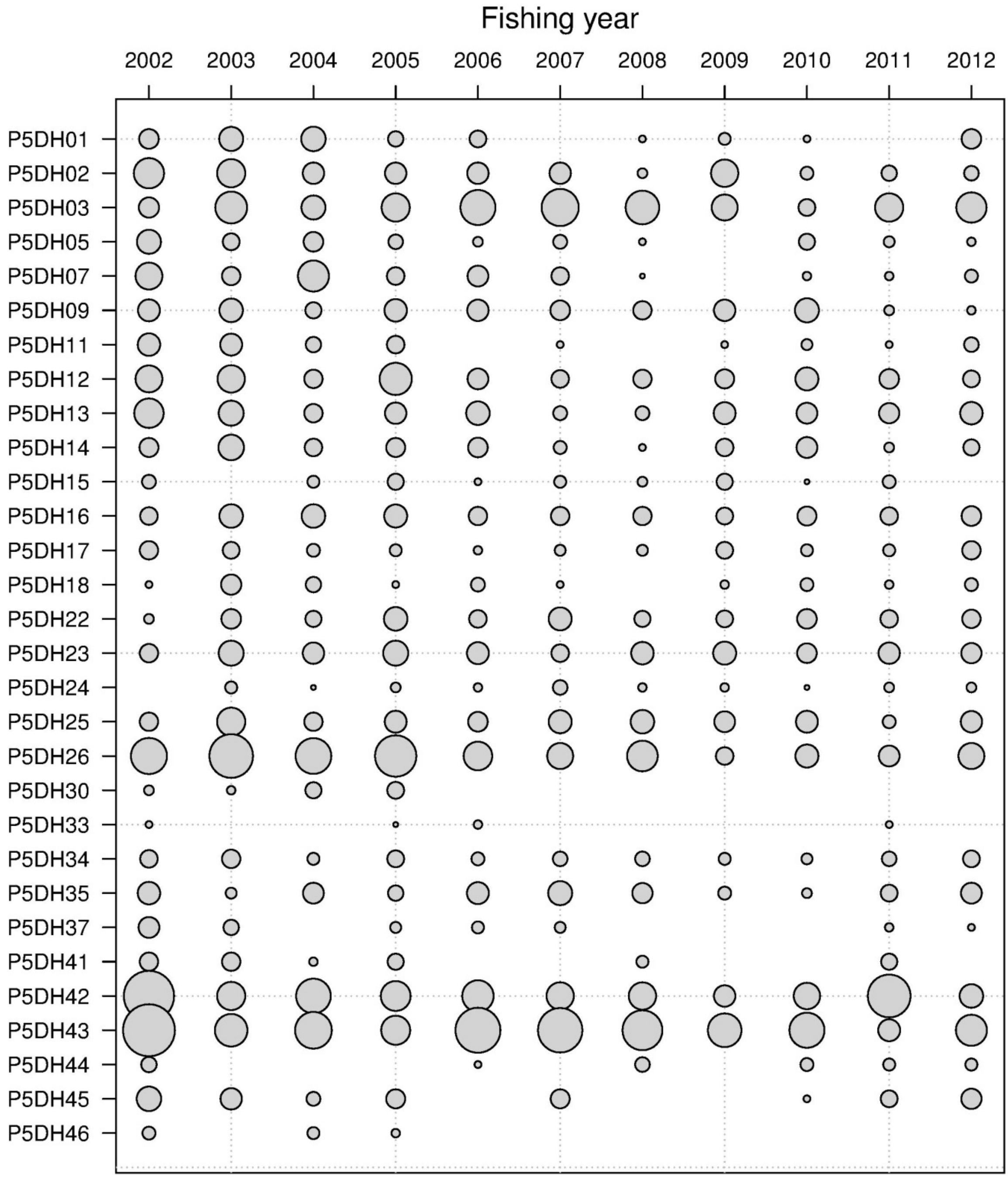

Figure 35: Overlap in number of records for statistical area by fishing year. The area of a circle is proportional to the days of effort; the largest circle represents 112 records.

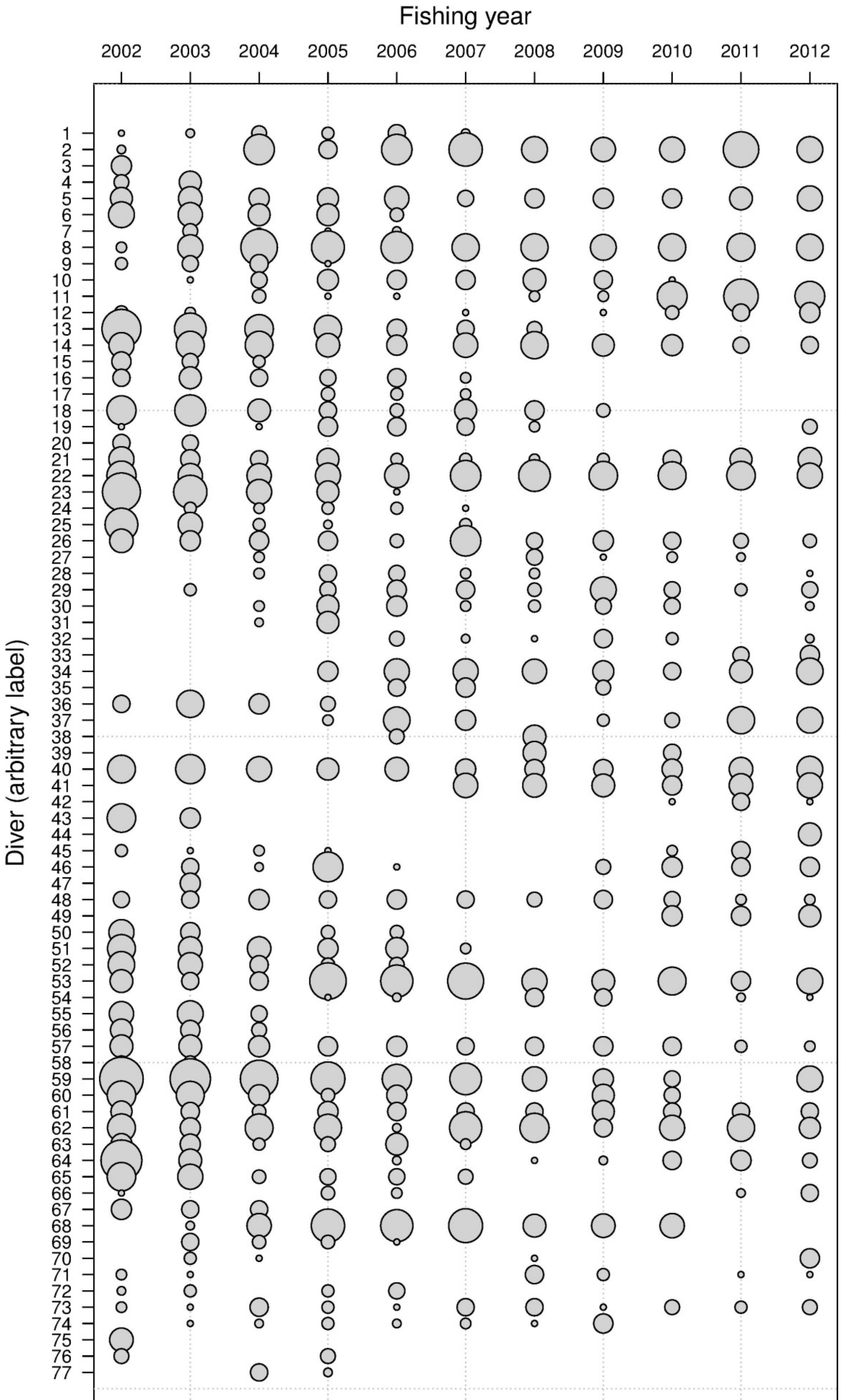

Figure 36: Overlap in number of records for diver key by fishing year. The area of a circle is proportional to the days of effort; the largest circle represents 51 records.

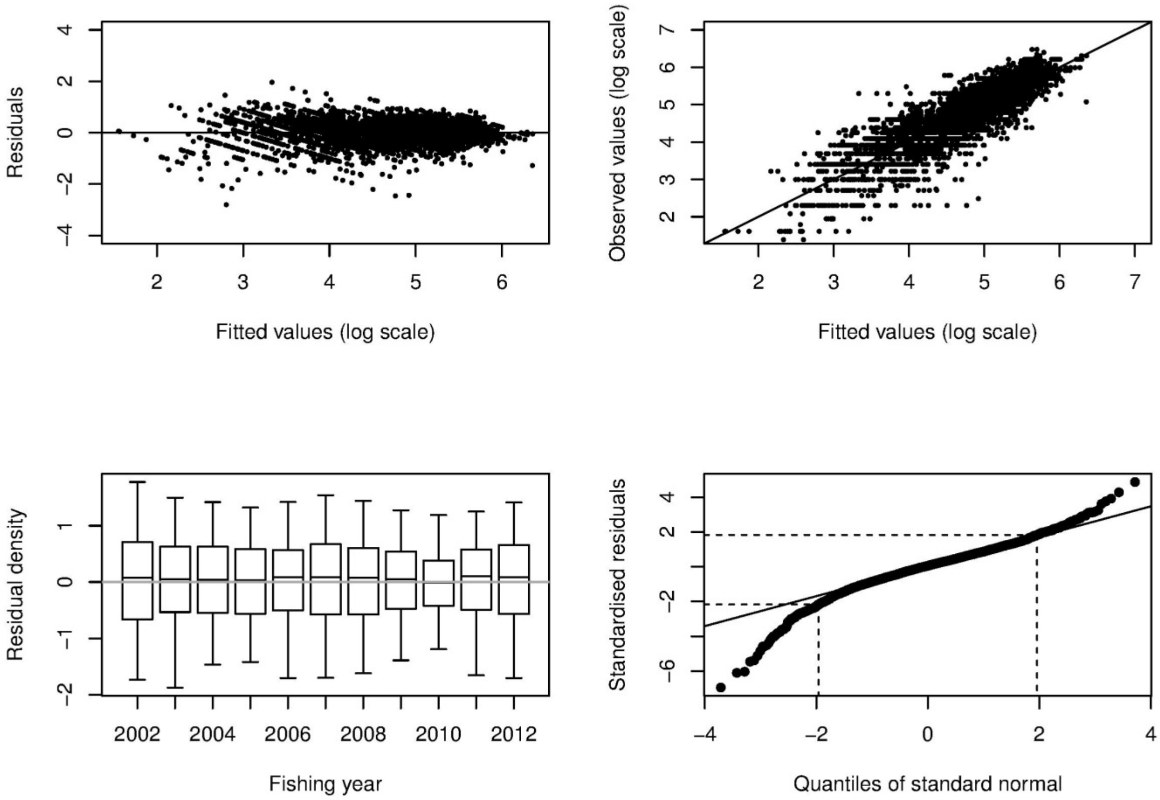

Figure 37: Residuals for the standardisation model.

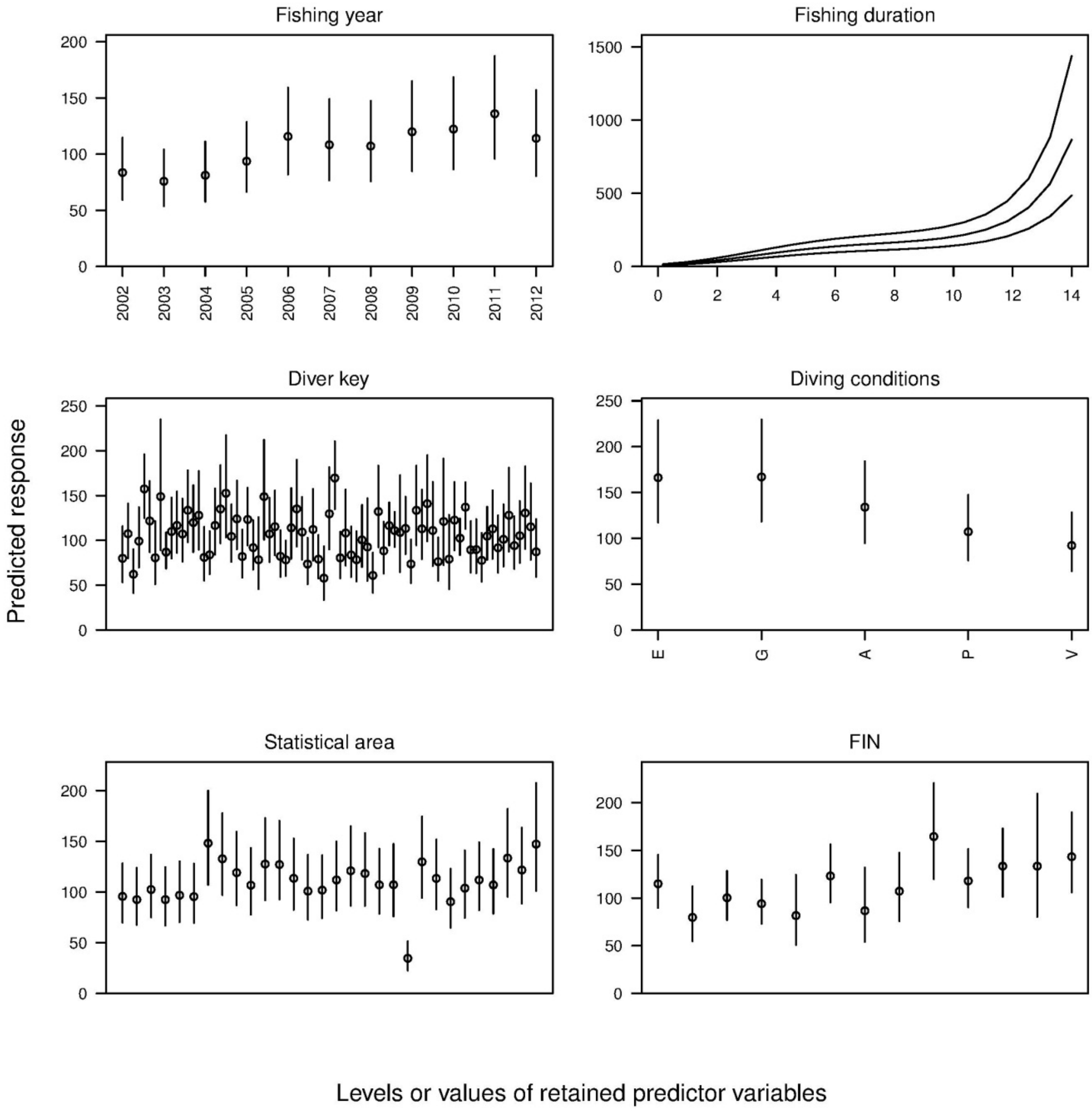

Figure 38: Effects for the standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

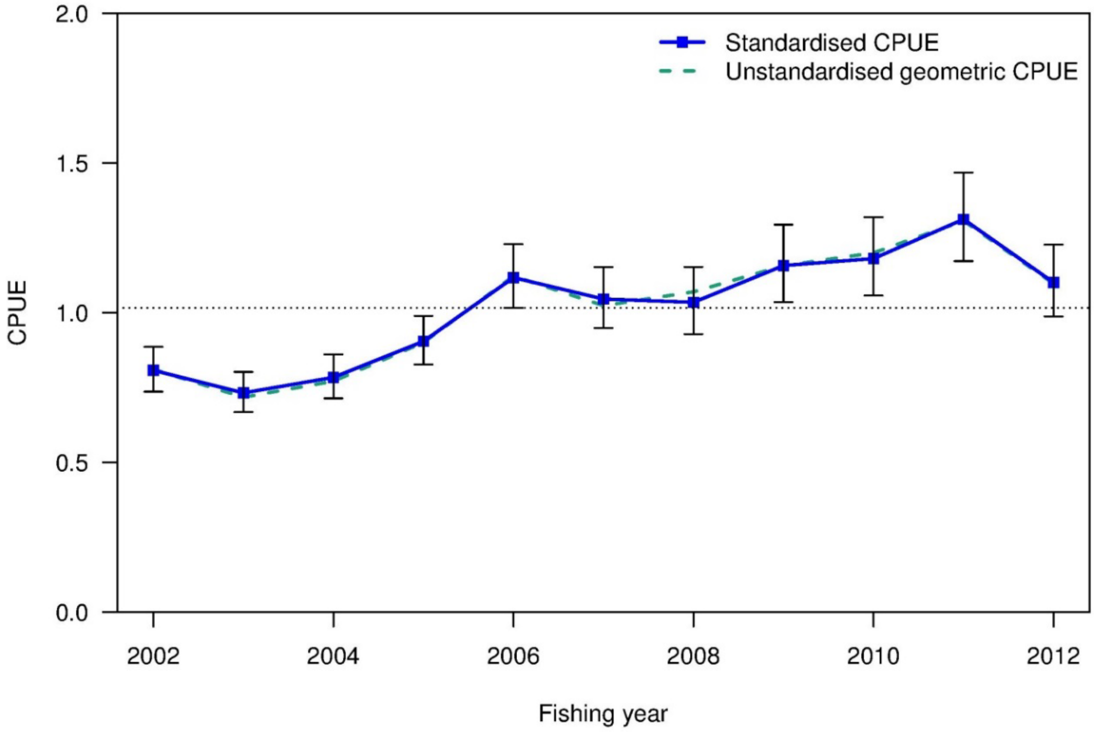

Figure 39**: The standardised CPUE index from PCELR data with 95% confidence intervals.**

5. COMMERCIAL CATCH LENGTH FREQUENCY (CSLF)

The paua catch sampling data comprise measurements of landed paua shells from the commercial catch (paua market sampling). The length frequencies used are of 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. Industry now also measure and record overall length including the spire as well as basal length. Basal length differs from the measurement protocol in the commercial fishery, where the longest overall length is measured. For this reason, a small proportion of the market samples appear to be below the MLS of 125 mm

A new extract of Catch Sampling Length Frequency (CSLF) data was made from the *market* database on 1 September 2012. This totalled 12 505 records containing 64 505 measurements from 1992–94 and 1998–2011. Deducing the statistical area of each record required some analysis as it is not straightforward for much of the dataset.

The number of sampled landings generally ranged from 10 to 60 each year from 1992 to 2012 except in 1999 when there was only one sample (Table 16). Fewer landings were sampled between 2006 and 2008. Typically over 2000 paua were measured each year. About 20% of the samples had no area recorded, mostly between 2000 and 2006, as some operators refused to supply the information (see Table 18). The majority of samples were taken from Statistical Area 026, with fewer samples taken from the southern part of the stock (Statistical Areas 025 or 030). In 1992–1994, 1999, 2000, 2005, 2006, and 2008, neither Statistical Area 025 or 030 was sampled.

Breen & Smith (2007) weighted the length frequency by the ratio of area catch to the mean area catch within each year where data without area information were not added to the weighted length frequency distribution. We adopted a modified approach to calculate the length frequency using NIWA's 'catch-at-age' software (Bull & Dunn 2002). Preliminary analyses suggested that there was no apparent temporal or spatial trend in the distribution of mean length in the commercial length samples. We post-stratified the catch samples using three spatial strata based on statistical areas: 024, 026, and combined 025 and 030. The length frequencies of paua from each landing were scaled up to the landing weight, summed over landings in each stratum, and then scaled up to the total stratum catch to yield length frequencies by stratum and overall. The CV for each length class was computed using a bootstrapping routine: fish length records were resampled within each landing which was resampled with each stratum. For samples where landing weight was unknown the landing weight was assumed to be equal to the sample weight, calculated from the number of fish in the sample and mean fish weight.

Only samples with known areas were included. Data from 1999, 2000, and 2001 were excluded because the number of samples with known areas was too small. Scaled length frequencies for PAU 5D are shown in Figure 40. The Scaled length frequencies suggested wider length distributions in the commercial catch before 1998; there were relatively more small paua in the catch between 2002 and 2005 with the mode of the distribution close to the legal size limit of 125mm. Samples in more recent years contain larger paua with the mode generally greater than 135 mm (Figure 41). The SFWG decided to exclude length frequencies from years in which not all statistical areas were sampled and therefore the length frequencies used in the assessment model are from 1998, 2002–2004, 2007, and 2009–2012.

Table 16: Number of landings sampled and number of paua measured from the market shed sampling program by statistical area and by fishing year.

	Number of landings sampled						Number of paua measured					
Year	030	025	026	024	Unknown	Total	030	025	026	024	Unknown	Total
1992	0	0	10	5	0	15	0	0	3 257	1 549	0	4 806
1993	0	1	10	22	0	33	0	308	2 801	7 300	0	10 409
1994	0	1	9	6	0	16	0	307	3 110	1 875	0	5 292
1998	2	2	6	7	1	18	285	259	803	859	136	2 342
1999	0	0	0	0	1	1	0	0	0	0	187	187
2000	0	0	12	2	18	32	0	0	1 206	218	2 279	3 703
2001	2	1	3	0	38	44	277	122	364	0	4 850	5 613
2002	6	2	28	7	5	48	794	251	3 430	770	659	5 904
2003	7	3	38	3	8	59	914	324	4 355	314	906	6 813
2004	1	8	13	8	6	36	102	819	1 503	853	685	3 962
2005	2	0	7	3	7	19	200	0	741	337	734	2 012
2006	0	0	3	4	4	11	0	0	412	518	499	1 429
2007	3	3	6	6	0	18	374	370	748	568	0	2 060
2008	0	2	7	3	0	12	0	241	848	289	0	1 378
2009	6	3	17	8	0	34	699	294	1 573	704	0	3 270
2010	3	11	23	3	0	40	234	880	2 211	293	0	3 618
2011	3	5	9	7	0	24	168	306	658	575	0	1 707
2012	5	6	9	11	0	31	374	513	735	927	0	2 549
Total	40	48	211	106	88	493	4421	4994	28 882	18 034	10 935	67 266

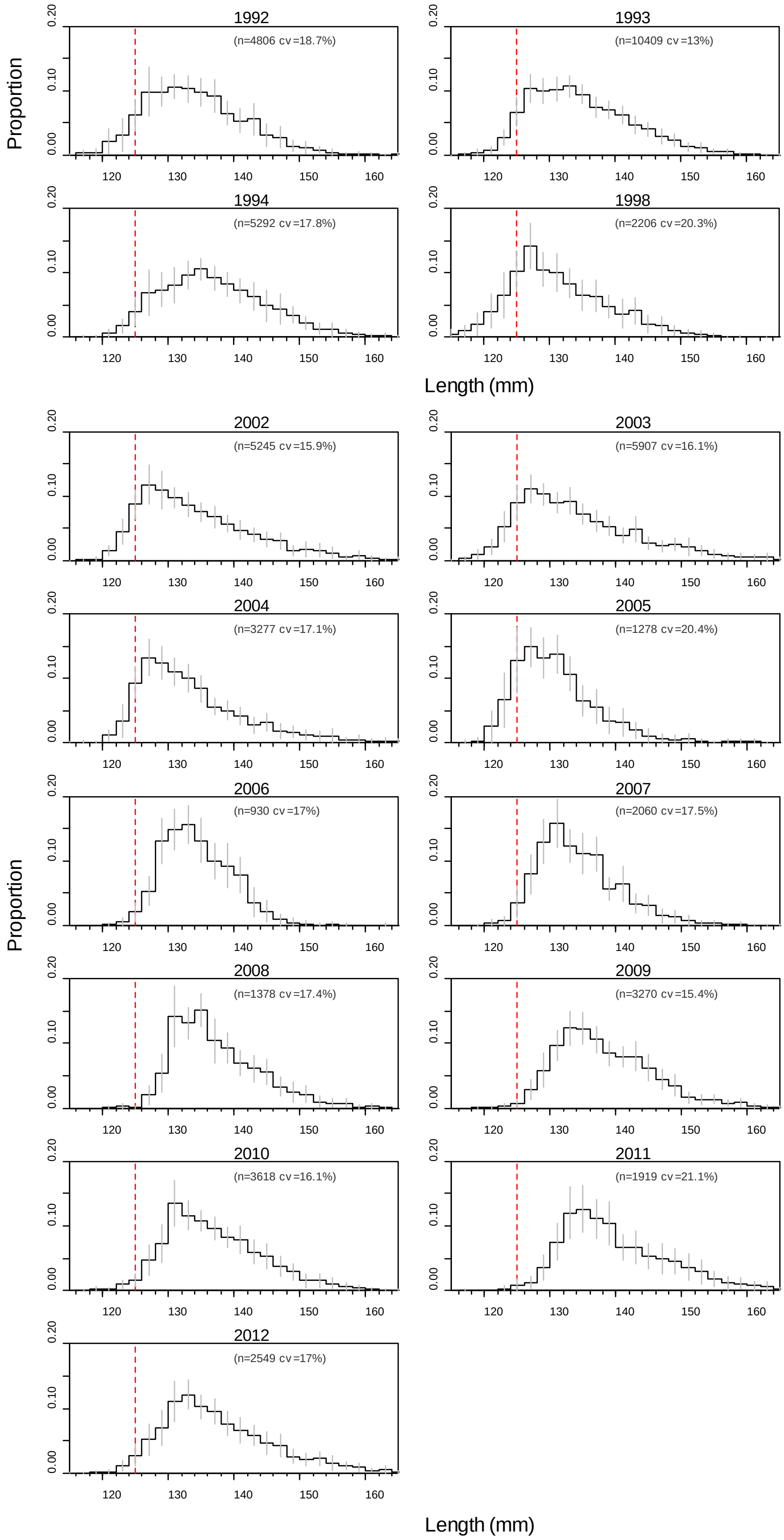

Figure 40: Scaled length frequency from commercial catch sampling in PAU 5D for fishing years 1992–1994, 1998, and 2002–2012. The dashed line indicates the MLS of 125 mm.

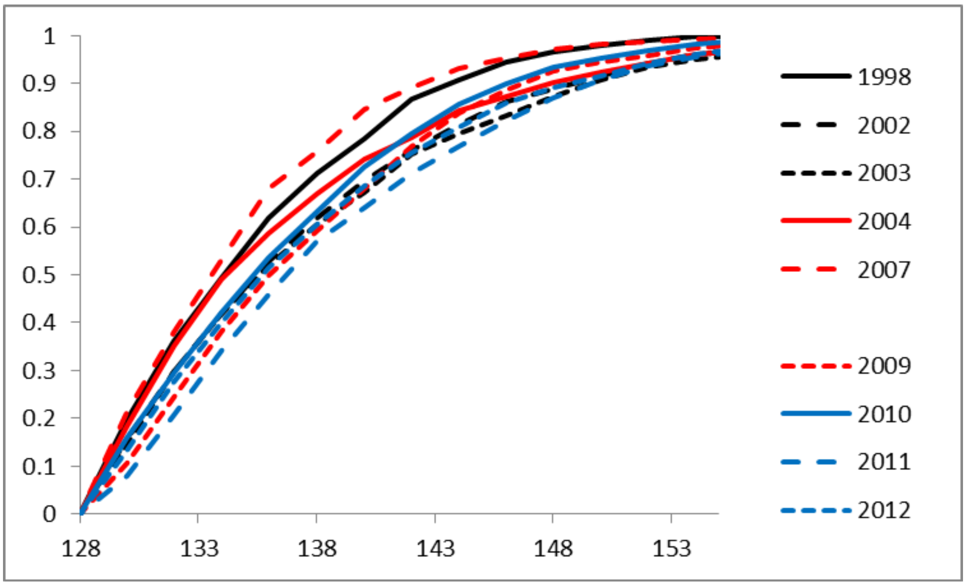

Figure 41: Cumulative distribution of the scaled length frequency in 1998, 2002–2004, 2007, and 2009–2012 from commercial catch sampling in PAU 5D to be used in the assessment model. The dashed line indicates the MLS of 125 mm.

6. RESEARCH DIVER SURVEY INDEX (RDSI)

Research diver surveys based on a timed-swim method as developed by McShane (1994, 1995) and modified by Andrew et al. (2000a) have been conducted to assess the relative abundance of New Zealand paua stocks since 1991 (Andrew et al. 2000b, 2000c, 2002, Naylor & Kim 2004). Relative abundance indices estimated from the survey data (RDSI) have been routinely used in paua stock assessment (Breen & Kim 2003, 2005, Breen & Smith 2008a, 2008b). The previous stock assessment for PAU 5D used the RDSI developed from the survey data up to 2004 (Breen & Kim 2007). There has been no new survey since the last assessment and the same survey data was used for this assessment.

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

The survey follows a stratified-random design (Naylor & Kim 2004). The survey strata in PAU 5D (Catlins East and Catlins West) cover about 25% of the areas producing the recent catches. Each stratum was subdivided into 200 m wide strips, each of which was considered a potential sampling site. Each year sites were randomly selected within strata (chosen sites containing unsuitable habitat were replaced and also permanently discarded from future surveys). Not all strata were surveyed each year and the number of sites sampled within each stratum was chosen to provide mean relative abundance with CVs less than 20% based on the variance estimated from previous surveys.

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

Before 1997 only the patch category was recorded and total counts were inferred from estimates of the mean of the patch category (Table 19). Since 1997 the actual number of paua in patches was recorded. Paua are considered to be in the same patch if they are separated by less than two body lengths. Recent swim data therefore provide integer counts of paua whereas the previous estimates will generally be non-integer.

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

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

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

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

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

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

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

where t is the recorded time to the first paua found (for early surveys an average of the time to first paua from later surveys was used), n_1, n_2 and n_3 are the number of patches in categories 1, 2 and 3 (see Table 19) and 4, 9 and 14 are the estimated times for processing respective patch categories. The search time was included in the standardisation model as an offset term.

To minimise the effects of visibility and differences between divers on estimates of relative abundance, the timed-swim counts were standardised using GLMs (Venables & Ripley 2002). However, a range of standardisation methods has been used in previous studies: Breen & Kim 2005 used a standard linear regression for calculating RSDI for the 2005 PAU 7 assessment and Breen & Kim 2007 used a tweedie model for the 2006 PAU 5A and PAU 5D assessment. More recently a negative binomial model has been used to standardise the RSDI indices (Breen & Smith 2008a, Cordue 2009). Middleton

(2009) examined alternative models fit for PAU 7 RSDI indices and suggested that the negative binomial model provides a better fit than the normal model.

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

The number of paired-swims by stratum is summarised in Table 20. The surveys covered only the Catlins East and Catlins West areas. The mean diver counts for Catlins East and Catlins West showed a similar trend between 1999 and 2004 (Figure 43). Standardised RDSI are shown in Figure 44. Because the Catlins areas accounted for only a small proportion of the total catch in PAU 5D, the SFWG decided that the research diver survey indices would not be included in the base case of the 2012 PAU 5D assessment.

Table 17: Definition of patch type by number of paua and the estimates of mean number per patch for PAU 5D.

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

Table 18: Number of paua research survey paired diver swims in PAU 5D.

Fishing year	Catlins East	Catlins West
1994	10	10
1997	–	10
1999	15	15
2001	2	8
2002	8	7
2004	14	15

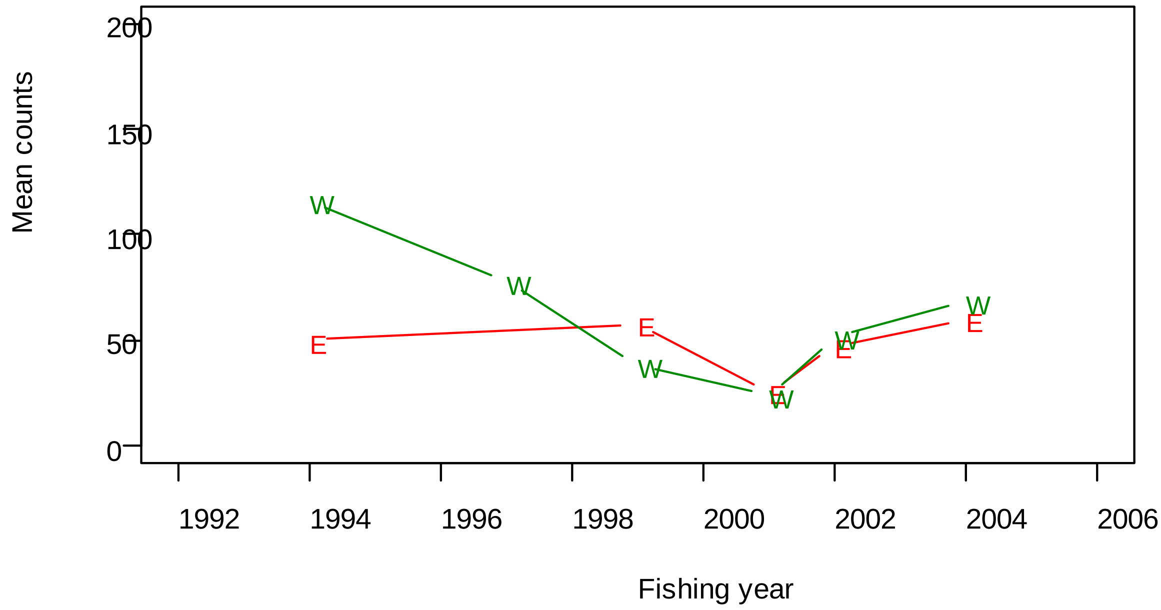

Figure 42: Mean diver counts by research stratum and fishing year for PAU 5D. E, Catlins East; W, Catlins West.

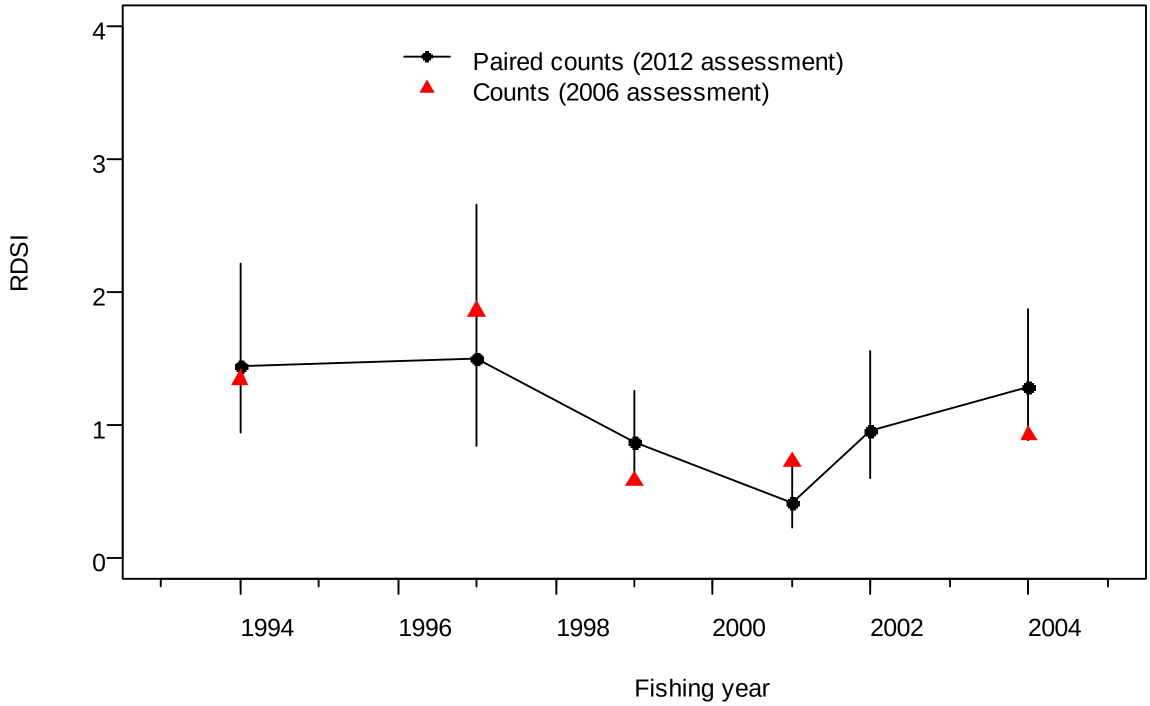

Figure 43: The standardised RDSI from the negative-binomial GLM models fitted to paired diver counts for surveys in PAU 5D. Also plotted are the estimated indices from the 2006 assessment in which individual diver counts were fitted by a tweedie model (see Breen & Kim 2007).

7. RESEARCH DIVER LENGTH FREQUENCY (RSLF)

Paua were sampled to estimate the size composition at each site from the research diver survey where the first four paua encountered from each patch were collected (Table 21). This protocol meant that relatively more paua from small patches were measured than from larger patches; we assume there are no differences in the length composition of paua in patches of different size. Shells were measured to the nearest millimetre with vernier calipers at their longest basal length. Basal length does not include any overhang of the shell spire and in this respect differs from total length (lowest measurement on the anterior-posterior axis) which is used in the commercial fishery to define minimum legal size (125 mm). The data were grouped into 2 mm size classes for presentation with paua longer than 170 mm being pooled into a single size class. A few paua less than 70 mm were excluded from the length frequencies.

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

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

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

We adopted a modified approach to calculate the length frequency by scaling the length frequency from each sample up to the counts in each swim, summed over all counts in each stratum, and then scaled up to the total stratum count to yield length frequencies by stratum and overall (Figure 45). It appears that more larger paua were sampled in early years than in late years for both Catlins East and Catlins West strata. Because the Catlins area accounted for only a small proportion of the total catch in PAU 5D, the SFWG decided that the research diver survey length frequencies would not be included in the base case of the 2012 PAU 5D assessment.

Table 19: Number of paua sampled from the research diver survey by stratum and fishing year.

	Catlins West	Catlins East
1992	930	537
1994	430	604
1997	–	691
1999	694	525
2001	107	289
2002	419	507
2004	709	1167

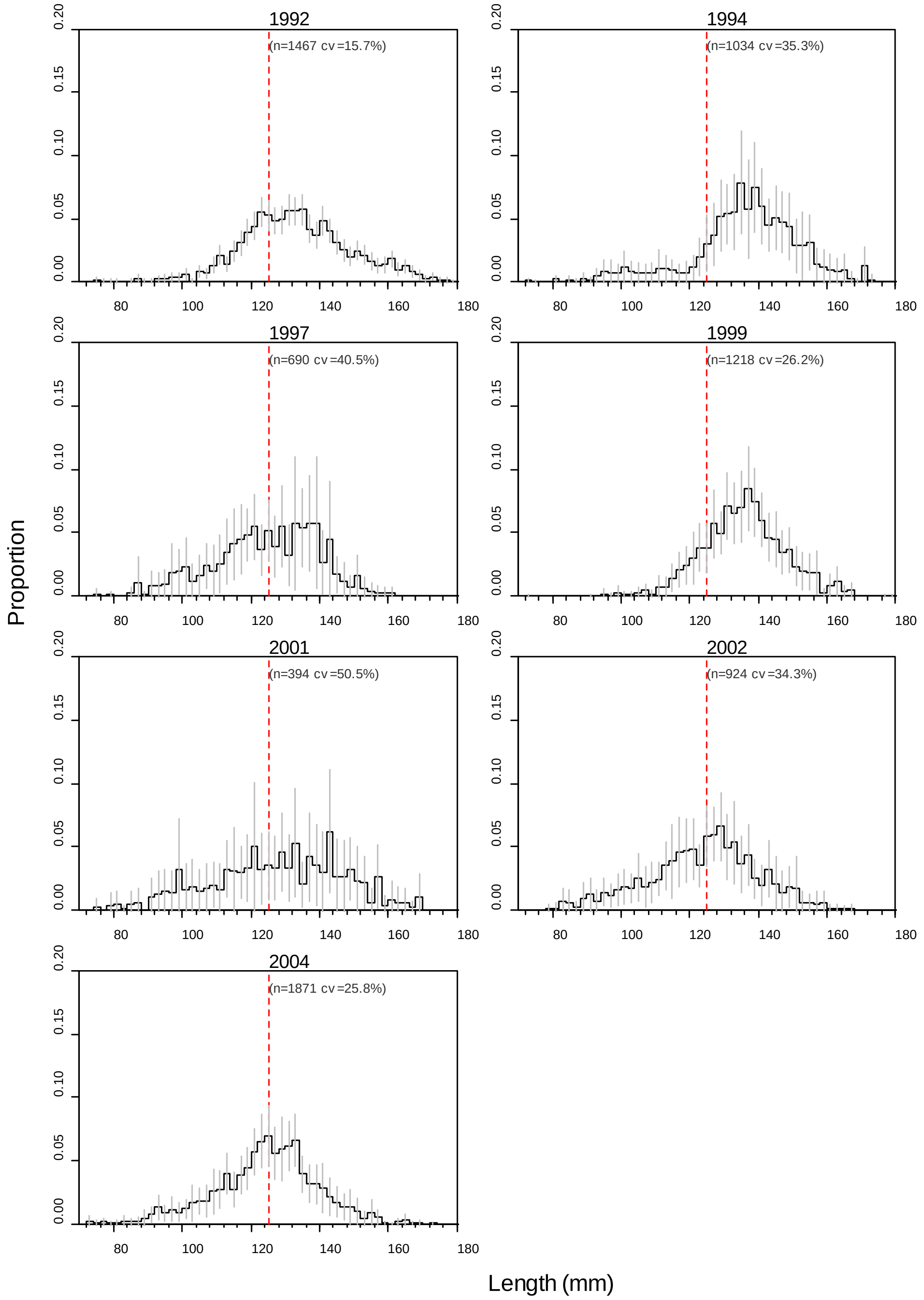

Figure 44: Scaled length frequency from research diver survey sampling in PAU 5Dfor fishing years 1992, 1994, 1997, 1999, 2001, 2002, and 2004. The dashed line indicates the MLS of 125 mm.

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Tag and recapture experiments were conducted at different times and at several sites in PAU 5D (Breen & Kim 2007). Growth data collected from these experiments were available from Catlins west (Boat Harbour n=116), Catlins east (Saddle n=60, Roaring Bay n=9, Papatowai n=20), and East coast (Seal Point n=37). The growth dataset comprises 281 records with initial lengths ranging from 68 to 168 mm, time at liberty ranging from 243 to 473 days and annualised increments ranging from -1 to

28.9 mm. These data were incorporated into the PAU 5D assessment to estimate growth. No new tag recapture data since the last PAU 5D assessment have been collected. We removed 40 records for which paua was tagged at sizes smaller than 70 mm because the model does not represent paua less than 70 mm in length.

The tag-recapture data used in paua assessment models were analysed using a number of length-increment growth models (Fu et al. 2010, 2012). With the linear growth model (Francis 1988) the expected annual growth increment for an individual of initial size L_k is

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

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

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

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

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

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

Variation in growth was normally distributed with $\sigma_k = \max\left(\alpha(u_k)^\beta, \sigma_{\min}\right)$ where u_k is the expected growth at length L_k truncated at zero, $\sigma_{\min}$ is the minimum standard deviation and $\alpha(u_k)^\beta$ is the standard deviation of growth at length L_k (if β is fixed at 1 α will be the coefficient of variance and if β is fixed at 0 α will be the standard deviation). 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 ith 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 46). The growth parameters at $L_1 = 75$ mm and $L_2 = 120$ mm were estimated as $g_1 = 22.5$ mm and $g_2 = 8.6$ mm. The parameters for variation in growth were estimated as $\alpha = 2.33, \beta = 0.26$ and $\sigma_{\min} = 0.85$ mm. The measurement error σ_E was assumed to be known as 1 mm.

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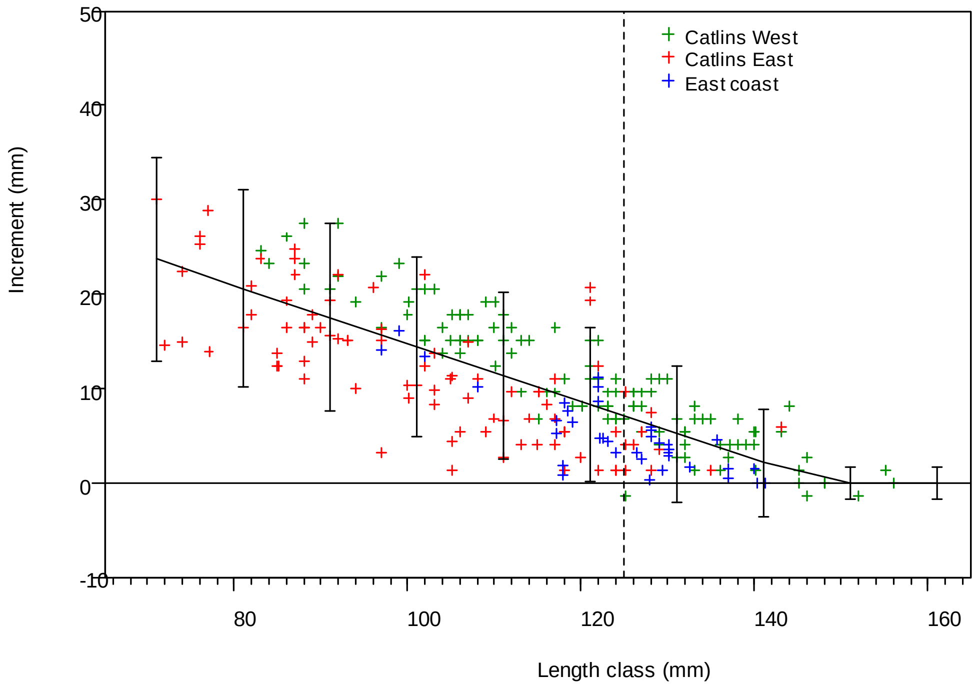

Figure 45: Initial size and mean annual increment from the tag-recapture data within PAU 5D (and 95% confidence intervals) indicate size-based linear growth curves estimated from these data. Dashed line indicates the legal size limit (125 mm).

9. MATURITY

Data had been collected from seven sites in November 1996 (n=66) and one site in March 2001 (n=13) at west Catlins. Paua were examined for maturity and for sex if mature. The sample size was small and data were aggregated for the assessment across all sites and dates. They were collated as the number examined and the number mature in 2-mm length bins (Table 22).

The length of paua examined ranged from 68 to 168 mm but the sample size in each length bin was small (see Table 22). Paua less than 70 mm (n=1) were dropped out of the dataset. The proportion mature data were fitted with a logistic curve using a binomial likelihood (Figure 47). Length at 50% maturity ($L_{50\%}$) was estimated to be about 80.2 mm and Length at 95% maturity ($L_{95\%}$) about 95.9 mm. The estimated length at maturity was very similar to that estimated in the previous assessment (Breen & Kim 2007).

Table 20: : Number of paua observed and proportion mature by 2 mm length class from the samples collected within PAU 5D.

Bin (mm)	Sample size	Number mature	Proportion mature
70	2	0	0.00
72	2	0	0.00
74	3	1	0.33
76	1	0	0.00
78	2	1	0.50
80	2	1	0.50
82	1	1	1.00
84	6	4	0.67
86	5	5	1.00
90	3	3	1.00
92	4	4	1.00
94	11	9	0.82
96	10	9	0.90
98	10	10	1.00
100	1	1	1.00
102	1	1	1.00
132	1	1	1.00
142	1	1	1.00
150	1	1	1.00
154	1	1	1.00
156	4	4	1.00
158	1	1	1.00
162	1	1	1.00
164	1	1	1.00
166	1	1	1.00
168	1	1	1.00

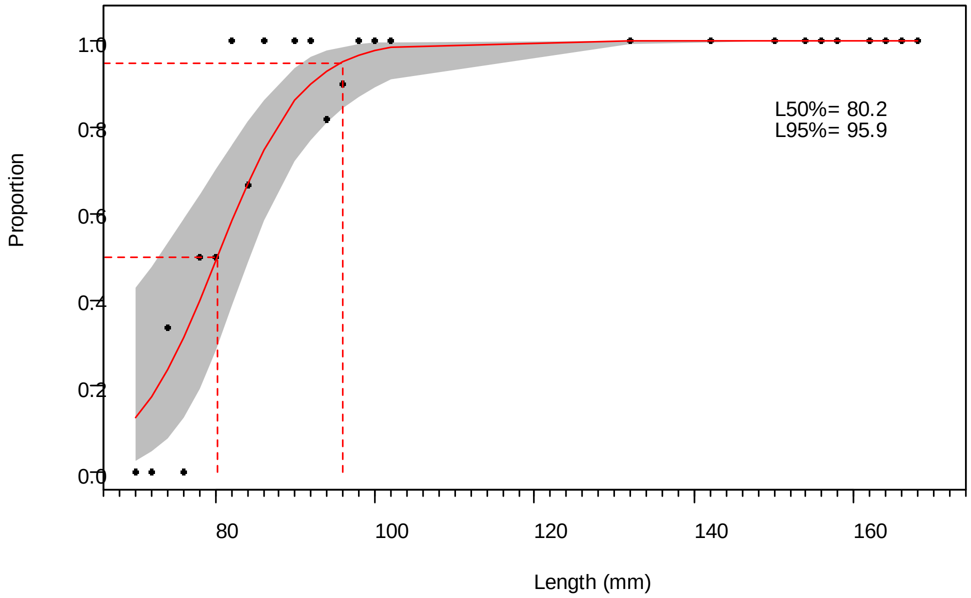

Figure 46: Proportion of maturity at length for PAU 5D. The dots represent the observed proportion mature for each 2 mm length bin. The red line represents a fitted logistic maturity curve. The grey area represents the 95% confidence interval of estimated proportion. The dashed lines represent estimated length at 50% and 95% maturity.

10. ACKNOWLEDGMENTS

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