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Summary of input data for the 2015 PAU 7 stock assessment

New Zealand Fisheries Assessment Report 2016/38

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EXECUTIVE SUMMARY

Fu, D.; McKenzie, A; Naylor, R. (2016). Summary of input data for the 2015 PAU 7 stock assessment.

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This document summarises the data inputs for the 2015 stock assessment of blackfoot paua in PAU 7 (upper South Island). The six sets of data fitted in the assessment model were: (1) a standardised CPUE series based on the early CELR data, (2) a standardised CPUE series based on recent PCELR data, (3) commercial catch sampling length frequency series (CSLF), (4) tag-recapture length increment data, (5) maturity-at-length data (6) length frequency data from the Fighting Bay fish-down experiment. The assessment covers only Statistical Areas 017 and 038 where the catch was predominantly taken.

A new standardisation was done for the CELR data, where fishing duration was used as the measure of effort. The standardised CPUE series based on PCELR data was updated to the 2014–15 fishing year. Scaled length frequency series from the commercial catch sampling were updated to the 2014–15 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. Maturity data were updated to include samples collected since the last assessment. The Fighting Bay length frequency distribution was assumed to represent the length distribution from an equilibrium unfished population. There have been no research diver surveys since the last assessment and the research diver survey data were not used in this assessment because there is concern that the data are not a reliable index of abundance.

1. INTRODUCTION

This document summarises the data inputs for the 2015 stock assessment of PAU7. The work was conducted by NIWA under the Ministry for Primary Industries' contract PAU2015-01 Objective 1. A separate document details the stock assessment of PAU 7 (Fu 2016). PAU 7 was assessed in 2011 (Fu 2012, Fu et al. 2012), 2008 (McKenzie & Smith 2009a, 2009b) and before that in 2005 (Breen & Kim 2005), in 2003 (Breen & Kim 2003), and in 2001 (Breen et al. 2001). 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".

The PAU 7 area covers the upper part of the South Island and is delineated by the fine scale Paua Statistical Areas P701 to P797 (Figure 1). Reporting catch by these fine scale statistical areas has been effective since the 2001–02 fishing year. (Figure 1). Prior to this time, from 1995 to 2001, catch was reported by the larger scale Statistical Areas 017, 018, 036, 037, 038, and 039, all of which have coastline that is completely or partially contained within PAU 7. Previous stock assessments for PAU 7 have only included data from Statistical Areas 017 and 038. Not only does the majority of the catch come from these two larger scale Statistical Areas but data from research diver surveys and commercial length frequency measurements only exist for these two areas (Breen et al. 2001, Breen & Kim 2003, 2005, and McKenzie & Smith 2009a, 2009b). Because most of the catch is still taken from these two areas, the 2015 stock assessment followed the approach of previous years and focused only on Statistical Areas 017 and 038.

This report summarises the model input data for PAU 7 to the 2014–15 fishing year. The data included:

1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2015 based on PCELR data.
3. A length frequency distribution from the Fighting Bay fish-down experiment (FBLF).
4. A commercial catch sampling length frequency series (CSLF).
5. Tag-recapture length increment data.
6. 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 assessments: PAU 5D (Fu et al. 2013), PAU 5B (Fu et al. 2014a), PAU 3 (Fu et al. 2014b), and PAU 5A (Fu et al. 2015). There have been no research diver surveys since the last assessment, and therefore no updates were made to the RDSI and RDLF series. The research diver survey data were not used in this assessment because there is concern that the data are not a reliable index of abundance. The research diver length frequencies were not used because they may not be representative of the population.

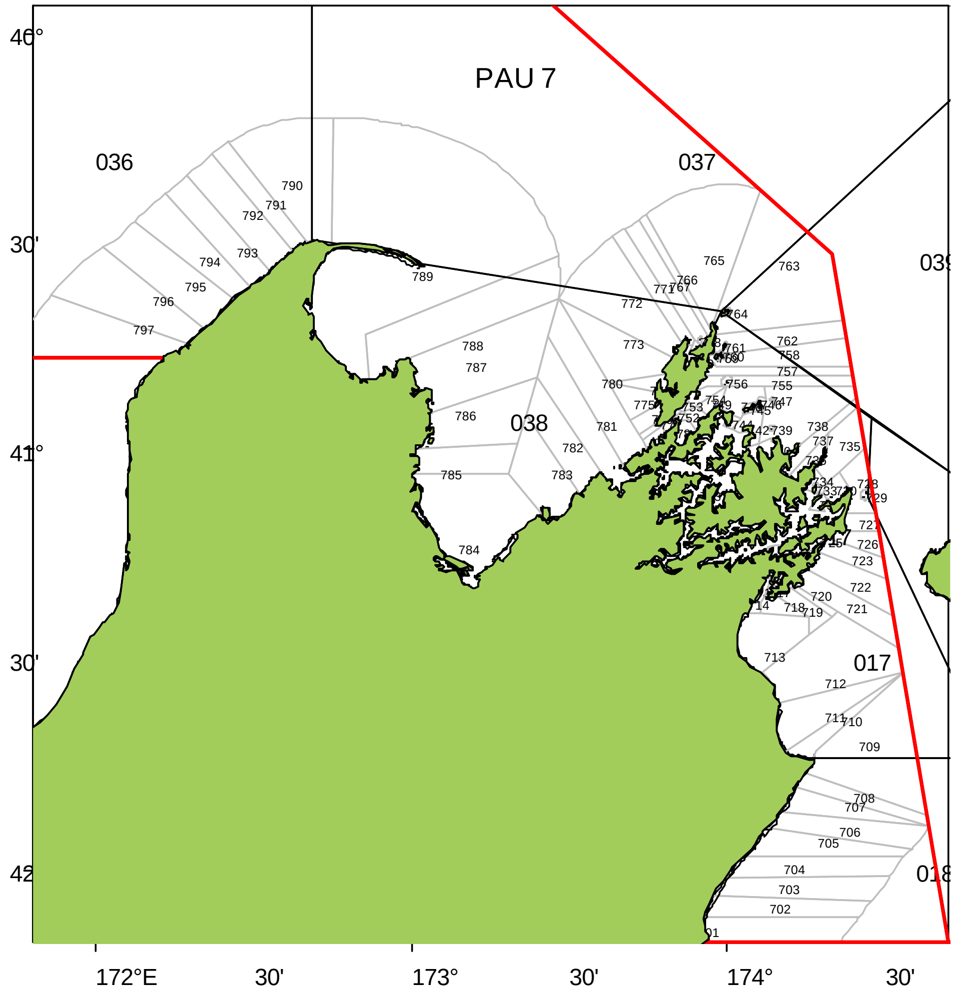


Figure 1: Map showing PAU 7 QMAs effective from 1 October 1995 (solid red lines), the old General Statistical Area boundaries (black lines) and the new Paua Statistical Areas (grey lines) effective from 1 October 2001.

2. DESCRIPTION OF THE FISHERY

PAU 7 was introduced into the Quota Management System in 1986–87 with a TACC of 250 t which increased to 267.48 t as a result of the appeal process. In 2001–02 the TACC was reduced to 240.73 t and in 2002–03 was further reduced to 187.24 t. In the 2003–04 fishing year, industry voluntarily shelved 15% of their Annual Catch Entitlement (ACE) and due to a continuing low CPUE they chose to shelve 20% and 22% of their ACE in the 2012–13 and 2013–14 fishing years respectively. This voluntary agreement not to catch the full TACC was in response to the 2011 stock assessment (Fu 2012) that estimated the status of the PAU 7 stocks to be at 20%B_0 and indicated the rate of rebuild of the fishery to be slow. In 2014–15, PAU 7 stakeholders again agreed to voluntarily shelve 28% (Jeremy Cooper pers. comm.)

In recent years the commercial paua industry has implemented a number of voluntary management actions within most QMAs. Agreement to these actions has been formalised in each QMA through the development of individual Annual Operational Plans (AOP) that are agreed to by all PauaMac (Paua Management Company) members. The plans explain the voluntary management actions that will be undertaken in each particular QMA for the upcoming fishing year. While there is a Minimum Legal Size (MLS) of 125 mm for paua, PauaMac7 members have agreed to implement an alternative Minimum Harvest Size (MHS) in parts of their fishery to better reflect biological parameters and spatial needs (PAUMAC7 2015). Between 2011–12 and 2014–15, the MHS was 130 mm on the West Coast (Kahurangi Point to Cape Farewell) and East Coast (Wairau River to Clarence River) and 127 mm in Ocean Bay and Robin Hood Bay (Fu 2012). The MHS for the rest of PAU 7 was 125 mm between 2011–12 and 2014–15. The effect of the change of Minimum Harvest Size on the stock assessment was ignored in the previous assessment (Fu 2012) because the west and east coast areas are outside of the assessment area and the combined catch of Ocean Bay and Robin Hood Bay is very small. For 2014–15 the MHS between Cape Koamaru to Wairau River has been increased to 126 mm. Because this is the main fishery area, the increase in the MHS needs to be incorporated in the current stock assessment model.

Estimated catch was reported on the scale of the general statistical areas using the CELR forms (Catch Effort and Landing Return) until 30 September 2001. The scale of reporting was reduced from 1 October 2001 when the PCELR forms (Paua Catch Effort and Landing Return) were adopted and it became mandatory to report catch and effort on the finer-scale statistical zones that had originally been developed for the New Zealand Paua Management Company’s voluntary logbook programme (see Figure 1).

3. CATCH HISTORY

3.1 Commercial catch

The catch history for 1974–83 was estimated by Murray & Akroyd (1984) and for 1984–88 by Schiel (1989). Murray & Akroyd (1984) found that landings before 1974 were unreliable. Schiel (1992) revisited the estimates for 1981–85 but the effect of these changes (affecting mostly the 1981 and 1982 catches) was explored by Andrew et al. (2000a) and found to be small. We used the estimates from Murray & Akroyd (1984) for the catch history for 1974–1980, and those by Schiel (1992) for 1981–1985. The 1986 catch appears suspiciously low and as in previous years the average of 1985 and 1987 catches is used (Table 1). We further assumed that these catches all come from Statistical Areas 017 and 038. However, there was evidence suggesting that large quantities of paua were taken from the west coast in the early years, but the extent cannot be quantified.

Catches from 1987 onwards were captured on QMR forms and reported in Plenary documents (e.g. Ministry for Primary Industries 2014). Data for 1987–2015 were supplied by the Ministry for Primary Industries (data log 10138). For 1987–2015 the catch history was calculated following the methodology of the 2008 assessment (McKenzie & Smith 2009a). In order to confine the stock assessment to Statistical Area 017 and 038 the percentage of the catch that came from these two areas was estimated using the estimated catches from the catch effort data. For 1987 to 1988, this is based on FSU data. For 1989 to 2001, this is based on CELR data, and from 2002 to 2015 is based on PCELR data. These percentages were then used to estimate the total catch from areas 017 and 038 by multiplying each year's catch from Monthly Harvest Returns (MHR) by the percentages. Following McKenzie & Smith (2009a) P764 was included in Statistical Area 017 when in fact it lies within area 039 (Figure 1).

There are some differences in these percentages for the period 1987–2002 compared to those made by Breen & Kim (2005), which were used in the 2011 assessment (Figure 2). For example, in 2000 and 2001, the estimated proportion of catch out of areas 017 and 038 was 85% and 91%, respectively, much higher than the estimates made by Breen & Kim 2005 (75% and 65% respectively).

The catch between 1981 and 1983 appears to be considerably higher than the years before and immediately after. Schiel (1992) suggested that there were considerable fluctuations in landings before the ITQ system was established as a result of many influences including prices, employment opportunities, and distance to market. The method for estimating the catch between 1981 and 1985 is not well documented in Schiel (1992) therefore we are not able to replicate those estimates. As a sensitivity analysis alternative estimates for this period are considered, using those by Murray & Akroyd (1984) for 1981–1983 (330 861, 289 271, and 364 597 kg, respectively), and from FSU data for 1984 and 1985 (377 825 and 269 021 kg, respectively). The estimates by Schiel (1992) for 1981 and 1983 were much higher than the estimates by Murray & Akroyd (1984), and for 1984 and 1985 were lower than the FSU catch.

The percentage of the catch that came from Statistical Areas 017 and 038 is given in Table 2. It is clear that 017 is the dominant statistical area. The proportion of catch increased over time in 017 through the 1990s to the early 2000s. In 2012 about 95% of the commercial catch was taken from 017. Overall (1990–2015) about 86% of the total commercial catch was taken from 017. The catch has been declining in 038 (mostly D'Urville Island), partly as a result of continued "greening" problems (when the paua are processed). The catch in 038 fluctuated between 10 t and 20 t between 2001 and 2008, and has decreased to below 5 t between 2009 and 2013.

The estimated catches by fine scale statistical area from the years of PCELR data are shown in Figure 3. The areas where the highest consistent catches were taken are Fighting Bay South, Tory South, Tory, and Tory North, which are all on the east coast of the Marlborough Sounds. Since 2004, about 60–80% of the annual catch was taken from these areas (Table 3).

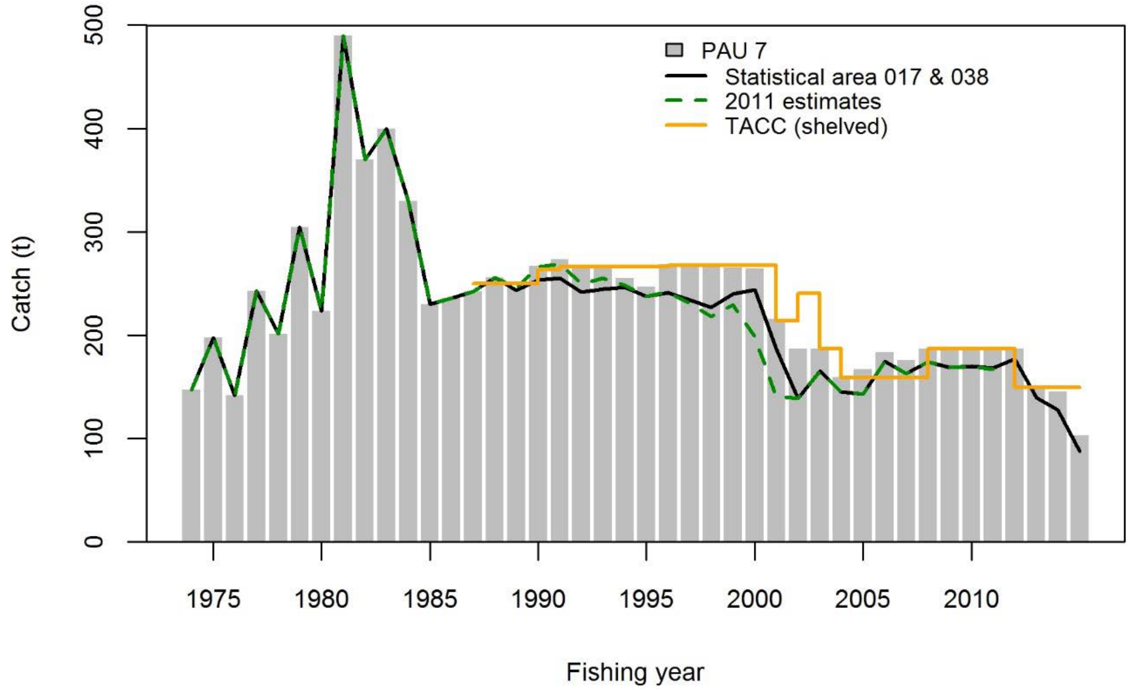


Figure 2: Estimated commercial catch history for PAU 7, for General Statistical Areas 017 and 038 only, and TACC (after shelving). Estimated commercial catch history from the 2011 (Fu 2012) assessment is shown as the green dashed line.

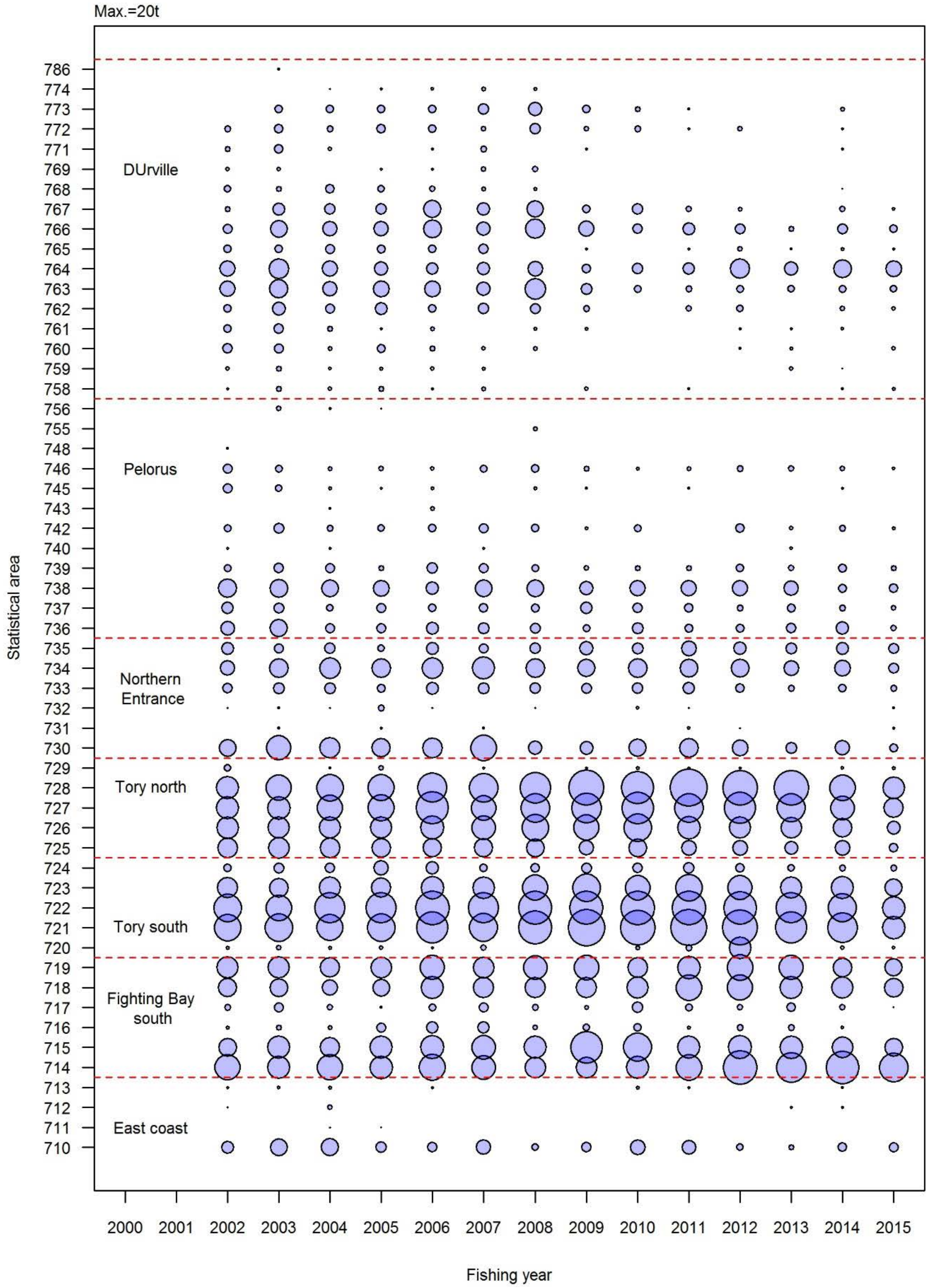


Figure 3: Annual estimated catch by Paua Statistical Area in PAU 7 for fishing years 2002–2015. The area of the circle is proportional to the catch.

3.2 Recreational catch

The 1996 National Marine Recreational Fishing Survey estimated that 23 000 paua were taken annually in PAU 7. The 1999–2000 and 2000–2001 national surveys estimated 15.8 t and 7.7 t respectively. The Marine Recreational Fisheries Technical Working Group (RFTWG) considered the harvest estimates from the national surveys and concluded that the estimates from the 1996 survey are unreliable due to a methodological error. The RFTWG also concluded that some harvest estimates from the 1999–2000 and 2000–2001 surveys for some fish stocks were unbelievably high.

A nationwide panel survey of over 7000 marine fishers who reported their fishing activity over the fishing year from 1 October 2011 to 30 September 2012 was conducted by The National Research Bureau Ltd, an organisation specialising in large-scale social surveys, in close consultation with the Marine Amateur Fishing Working Group (Wynne-Jones et al. 2014). The survey is based on an improved survey methodology developed to address issues and to reduce bias encountered in past surveys. The survey estimated that about 50 534 paua, or 14.13 t (CV of 34%) were harvested by recreational fishers in PAU 7 for 2011–12. For this assessment, the SFWG agreed to assume that recreational catch was 5 t in 1974 and that it increased linearly to 15 t in 2000 and then remained at 15 t subsequently.

3.3 Customary catch

Customary catch was incorporated into the PAU 7 TAC in 2002 as an allowance of 15 t. There are no published estimates of customary catch. Records of customary catch taken under the South Island Regulations show that about 200 to 5500 paua were reported to have been collected each year from 2001–02 to 2014–15, with an average of 1700 pieces each year (or 0.68 t). Those numbers were substantially lower than the annual allowances. About 70% of the reported customary catch was taken from Port Underwood, Queen Charlotte Sound, and Tory Channel.

The Working Group agreed to assume that customary catch was 4 t in 1974, increasing linearly to 5 t between 1974 and 2000 and then remaining at 5 t subsequently (see Table 1)

3.4 Illegal catch

There are no estimates of illegal catch for PAU 7. The Working Group agreed to assume that illegal catch was 1 t in 1974 and that it increased linearly to 15 t between 1974 and 2000, remaining at 15 t from 2000 to 2005, then decreasing linearly to 7.5 t in 2008, and remaining at 7.5 subsequently (see Table 1).

Table 1: Catch data used in the 2015 stock assessment. The table shows the sources of the data by fishing year. The "All PAU 7" catch (kilograms) is calculated from the QMR or MHR. "CELR/QMR" is the ratio of the (P)CELR catches to the reported catches. The proportion of the estimated catch from General Statistical Areas 017 and 038 is used to calculate the commercial catch in areas 017 and 038. The illegal, recreational, and customary catch are added to estimate the total catch in areas 017 and 038. This is compared to the effective catch limit after shelving. The 2015 catch is assumed to be the shelved TACC (with 28% shelving).

Source	Year	All PAU 7	CELR/ QMR	017 and 038	Comm. 017 and 038	Illegal	Rec.	Cust.	Total 017 and 038	Limit after Shelving
Murray &	1974	147 440		100.0	147 440	1 000	5 000	4 000	157 440	
Akroyd	1975	197 910		100.0	197 910	1 538	5 385	4 231	208 872	
1984	1976	141 880		100.0	141 880	2 077	5 769	4 462	153 803	
	1977	242 730		100.0	242 730	2 615	6 154	4 692	255 615	
	1978	201 170		100.0	201 170	3 154	6 538	4 923	215 016	
	1979	304 570		100.0	304 570	3 692	6 923	5 154	319 378	
	1980	223 430		100.0	223 430	4 231	7 308	5 385	239 199	
Schiel	1981	490 000		100.0	490 000	4 769	7 692	5 615	506 731	
1992	1982	370 000		100.0	370 000	5 308	8 077	5 846	387 692	
	1983	400 000	52.4	100.0	400 000	5 846	8 462	6 077	418 654	
	1984	330 000	82.9	100.0	330 000	6 385	8 846	6 308	349 615	
	1985	230 000	75.3	100.0	230 000	6 923	9 231	6 538	250 577	
From data	1986	236 090	38.0	100.0	236 090	7 462	9 615	6 769	257 628	
extract	1987	242 180	0.5	100.0	242 180	8 000	10 000	4 500	264 680	250
log10138	1988	255 944	0.3	100.0	255 944	8 538	10 385	4 538	279 406	250
	1989	246 029	12.7	98.9	243 273	9 077	10 769	4 577	267 696	250
	1990	267 052	87.1	95.0	253595	9 615	11 154	4 615	278 980	263.53
	1991	273 253	89.7	93.4	268 782	10 154	11 538	4 654	281 546	266.24
	1992	268 309	97.3	90.2	249 789	10 692	11 923	4 692	269 353	266.17
	1993	264 802	94.0	92.4	255 045	11 231	12 308	4 731	272 871	266.17
	1994	255 472	101.2	96.6	248 285	11 769	12 692	4 769	275 892	266.17
	1995	247 108	104.1	96.3	237 571	12 308	13 077	4 808	268 089	266.17
	1996	268 742	91.8	89.7	242 057	12 846	13 462	4 846	272 200	267.48
	1997	267 594	93.4	87.5	230 570	13 385	13 846	4 885	266 354	267.48
	1998	265 933	93.7	85.4	218 479	13 923	14 231	4 923	260 197	267.48
	1999	265 050	94.4	90.5	229 198	14 462	14 615	4 962	273 912	267.48
	2000	264 642	96.0	92.2	198 419	15 000	15 000	5 000	278 920	267.48
	2001	215 920	95.1	86.6	140 731	14 062	15 000	5 000	221 061	*213.98
	2002	187 152	98.7	74.3	139 112	13 125	15 000	5 000	172 237	240.73
	2003	187 222	98.4	88.2	165 102	12 188	15 000	5 000	197 290	187.24
	2004	159 551	99.0	91.2	145 502	11 250	15 000	5 000	176 753	159.15
	2005	166 940	99.0	85.6	142 826	10 312	15 000	5 000	173 138	159.15
	2006	183 363	101.0	95.3	174 728	9 375	15 000	5 000	204 103	159.15
	2007	176 052	98.5	92.6	162 970	8 438	15 000	5 000	191 428	159.15
	2008	186 845	98.1	93.3	174 366	7 500	15 000	5 000	201 865	187.24
	2009	186 846	98.3	90.5	169 136	7 500	15 000	5 000	196 636	187.24

Table 1. Cont.

Source	Year	All PAU 7	CELR/ QMR	017 and 038	Comm. 017 and 038	Illegal	Rec.	Cust.	Total 017 and 038	Limit after Shelving
	2010	187 022	97.3	90.8	169 809	7 500	15 000	5 000	197 309	187.24
	2011	186 770	98.5	90.1	168 250	7 500	15 000	5 000	195 750	187.24
	2012	186 980	100.0	94.6	176 881	7 500	15 000	5 000	204 381	187.24
	2013	149 755	101.1	93	139 266	7 500	15 000	5 000	166 766	149.79
	2014	145 523	100.2	87.9	127 911	7 500	15 000	5 000	155 411	149.79
	2015	134 812	94.2	85.46	115 217	7 500	15 000	5 000	142 717	134.81

Table 2: Proportion of estimated catch for PAU 7 by statistical area and fishing year from catch effort landing return and paua-specific catch effort landing returns (introduced in 2002). For Statistical Area 018, only catches reported to PAU 7 are included. Total estimated catches are in kilograms.

	018	017	038	036	Total
1990	0.05	0.81	0.14	0.00	227 290
1991	0.06	0.84	0.10	0.01	243 908
1992	0.04	0.79	0.11	0.06	259 670
1993	0.05	0.8	0.13	0.02	247 840
1994	0.03	0.88	0.08	0.00	257 648
1995	0.02	0.87	0.09	0.02	254 355
1996	0.03	0.78	0.12	0.07	240 933
1997	0.06	0.76	0.11	0.07	241 560
1998	0.14	0.81	0.04	0.01	229 471
1999	0.06	0.80	0.09	0.04	222 203
2000	0.06	0.87	0.05	0.03	233 201
2001	0.07	0.79	0.08	0.06	194 376
2002	0.22	0.72	0.03	0.03	181 457
2003	0.11	0.82	0.06	0.01	180 800
2004	0.09	0.85	0.06	0.00	157 668
2005	0.08	0.80	0.06	0.06	165 068
2006	0.03	0.88	0.07	0.02	183 839
2007	0.06	0.87	0.06	0.02	173 342
2008	0.04	0.85	0.09	0.02	182 212
2009	0.07	0.87	0.03	0.02	183 497
2010	0.06	0.88	0.02	0.04	181 753
2011	0.06	0.88	0.02	0.04	183 533
2012	0.05	0.94	0.01	0.00	184 602
2013	0.05	0.93	0.00	0.02	148 474
2014	0.12	0.86	0.02	0.00	144 464
2015	0.13	0.84	0.01	0.02	96 812
Total	0.07	0.84	0.07	0.03	5 199 976

Table 3: Proportion of estimated commercial catch for PAU 7 by subarea and fishing year from paua-specific PCELR forms (introduced in 2002). Total estimated catches are in kilograms. See Appendix A for definition of the subareas.

	East coast	Fighting Bay South	Tory south	Tory north	Northern Entrance	Pelorus	D'Urville	West coast	Total
2002	0.24	0.16	0.17	0.14	0.07	0.08	0.09	0.03	180 042
2003	0.14	0.16	0.16	0.15	0.10	0.09	0.16	0.01	180 800
2004	0.12	0.17	0.21	0.19	0.11	0.06	0.12	0.00	157 593
2005	0.09	0.17	0.21	0.18	0.08	0.05	0.12	0.06	165 068
2006	0.04	0.21	0.23	0.21	0.10	0.05	0.12	0.02	183 839
2007	0.08	0.20	0.21	0.19	0.12	0.06	0.11	0.02	173 342
2008	0.05	0.17	0.25	0.22	0.07	0.06	0.15	0.02	182 212
2009	0.08	0.21	0.27	0.24	0.06	0.04	0.06	0.02	183 497
2010	0.08	0.20	0.26	0.25	0.08	0.05	0.04	0.04	181 746
2011	0.08	0.20	0.27	0.23	0.09	0.04	0.03	0.04	183 533
2012	0.05	0.25	0.29	0.22	0.07	0.04	0.06	0.00	184 582
2013	0.05	0.27	0.25	0.26	0.05	0.05	0.03	0.02	148 474
2014	0.13	0.25	0.24	0.18	0.07	0.04	0.06	0.00	144 464
2015	0.14	0.29	0.22	0.17	0.05	0.03	0.06	0.02	96 812
Total	0.10	0.20	0.23	0.20	0.08	0.05	0.09	0.02	2 346 005

4. CPUE STANDARDISATIONS

4.1 Introduction

Previous PAU 7 standardisations have included the Fisheries Statistics Unit (FSU) data which covers the fishing year period from 1983–1988. Because of problems with the FSU data the Shellfish Working Group decided not to use it in CPUE standardisations (see Section 4.4 below).

Data used in the standardisation included Catch Effort Landing Returns (CELR) covering 1990–2001, and Paua Catch Effort Landing Returns (PCELR) covering 2002–2015. The Shellfish Working Group decided that five standardisations should be done:

1. CELR data using duration as the measure of effort
2. CELR data using number of divers as the measure of effort
3. PCELR data update using duration as the measure of effort
4. Combined CELR and PCELR data using duration as the measure of effort
5. Combined CELR and PCELR data using number of divers as the measure of effort.

It was decided by the Shellfish Working Group that duration (which changed over time), was a better measure of effort compared to the number of divers, and in the stock assessment three of these standardised indices were used (1, 3, and 5). For the base case, two indices were used: (a) CELR data using duration as the measure of effort, and (b) PCELR data using duration as the measure of effort. A sensitivity analysis was done (against the base case) using combined CELR and PCELR data with duration as the measure of effort.

Before doing the five standardisations we first:

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

4.2 Previous standardisations for PAU 7

CPUE standardisations for PAU 7 were last done for the 2011 assessment (Fu et al. 2012). The stock assessment was restricted to the large scale General Statistical Areas 017 and 038, as was the data for the standardisations. Two standardised indices were used in the assessment (Figures 4–5):

1. Using FSU/CELR data covering 1983–2001. This was the same index used for the 2005 and 2008 assessments (Breen & Kim 2005; McKenzie & Smith 2009b). The unit of catch used was total estimated daily catch for a vessel, and for effort the number of divers on a vessel for a day. Vessels were restricted to those that fished the top 75% of catch in any given year.

2. An updated index using PCELR data covering 2002–2011. The unit of catch used was the daily catch by a diver (associated with a specific vessel, diving conditions, and fine scale statistical area). Effort was the diving duration associated with the catch. The Fisher Identification Number (the identification number of every individual ACE holder, FIN) was used to identify a core data

subset with the criterion of a minimum number of records per year for a minimum number of years for each FIN. FIN was offered instead of vessel as a predictor variable. Only fine scale statistical areas and divers with 10 or more diver days were retained.

Recent CELR data standardisations differ from the FSU/CELR standardisation last done for PAU 7 in that:

- Following the procedure for other PCELR data standardisations, FIN is used instead of vessel to identify a core subset of records (instead of retaining the vessels in each year that fished the top 75% of the catch).
- The data is filtered to give a subset for which the recorded duration is unambiguous. Both recorded duration and number of divers are offered to the standardisation (instead of using only the number of divers as the measure of effort).

The previous PAU 7 standardisation for the PCELR data (Fu et al. 2012) followed the same procedure used for recent paua assessments (Fu et al. 2014a, Fu et al. 2015).

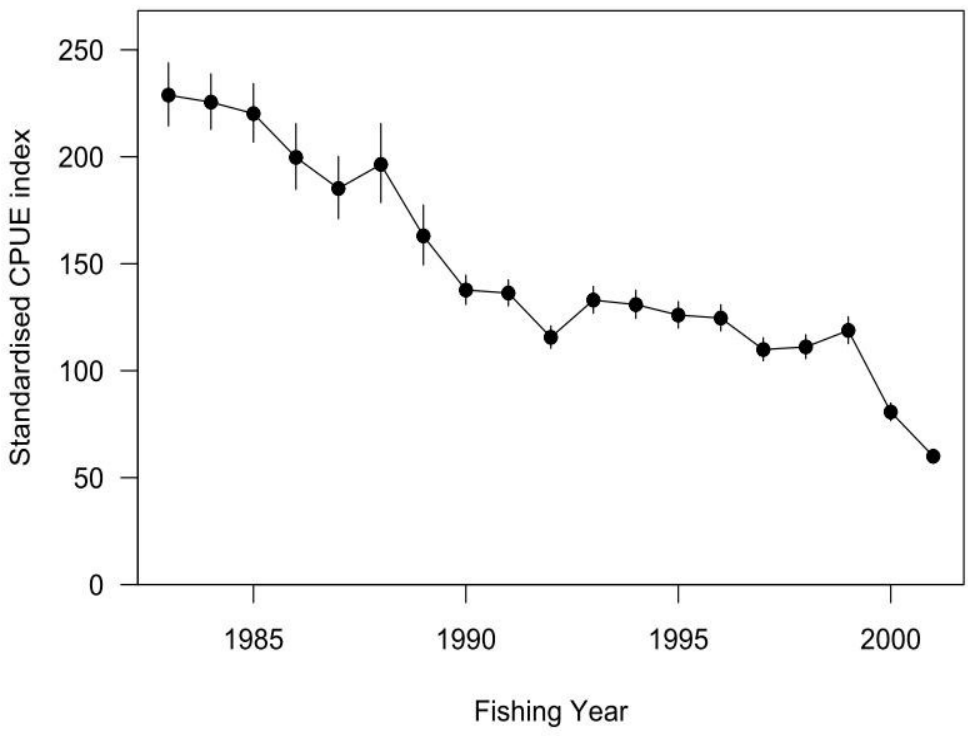


Figure 4: Standardised CPUE (kg/diver day) for areas 017 and 038 combined, taken from FSU/CELR data, and used in the 2011 PAU 7 stock assessment.

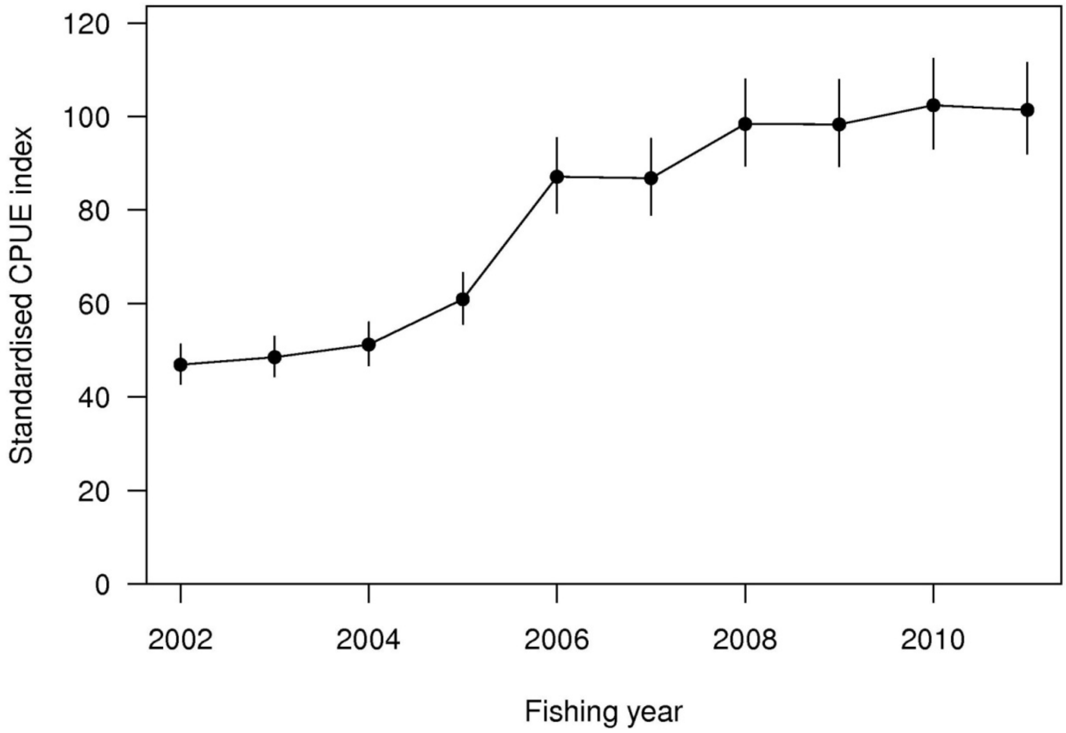


Figure 5: Standardised CPUE (kg/hr) with 95% confidence intervals used in the 2011 PAU 7 stock assessment. Taken from PCELR data.

4.3 Recommendations from the paua stock assessment model review

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

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

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

With regard to the PAU 7 assessment and these recommendations, it was decided by the Shellfish Working Group to use a combined CELR/PCELR index covering 1990–2015 as a sensitivity run in the assessment. For the CELR data it was clear that most records had fishing duration consistently and reliably recorded, albeit incorrectly, so there was no need to subset the data (see below in Section 4.6.1).

4.4 Usefulness of FSU data

The FSU catch-effort data for areas 017 and 038 covers the period 1983 to 1988 with a total of 3340 records (Table 4). Records are removed that are missing fields that are required for standardisation (Table 5). Duration is not recorded for many records between 1986 and 1988 (inclusive). Grooming retains 80% of the records over all years (Table 6).

Table 4: Number of FSU records by fishing year before any grooming.

Fishing year	1983	1984	1985	1986	1987	1988
Number of records	788	955	599	327	423	248

Table 5: Number of FSU records removed during grooming, by fishing year, where the order of grooming is from top to bottom.

	1983	1984	1985	1986	1987	1988	Total
Not targeting paua	0	0	0	0	0	0	0
Catch missing	0	0	0	0	0	0	0
Vessel keys missing	134	1	16	0	0	0	151
Duration missing	30	16	70	68	184	69	437
Number divers missing	0	0	0	0	0	0	0
Method not diving	40	39	0	0	0	8	87

Table 6: Number of FSU records left before and after grooming.

Fishing year	1983	1984	1985	1986	1987	1988	Total
Before	788	955	599	327	423	248	3340
After	584	899	513	259	239	171	2665
Percent remaining	74	94	86	79	57	69	80

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

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

Most of the records have a vessel key associated with them, with the majority of the records without a vessel key being from 1983 (see Table 6).

For FSU data the fishing duration field is the daily fishing duration *per* diver (Fisher & Sanders 2011, p. 106 and p. 149). In earlier analyses problems were found with this field in that values were recorded that were ten times the likely values (Andrew & Kendrick 2000). But these appear to have mostly been fixed with the majority of values now less than 10 hours duration (Figure 6).

Records with duration greater than 10 hours account for 5% of the groomed data, have one diver 58% of the time, and are scattered across the fishing years. Dropping these records and plotting the fishing duration indicates that it drops over time (Figures 7–8).

The proportion of estimated annual catch covered by the FSU data, while good for the three years from 1983 to 1985 declines rapidly after that (denoted by the white bars in Figure 9). The concern if this data were used in a standardisation is that the catch rates could be biased in some way, depending on the characteristics of the fishery from 1983–85 compared to the subsequent period. In the data there are groups of vessels that operated from 1983–85, but are less apparent after then, which coincides with the period when fishing duration was less (Figure 10).

In summary, while the FSU data has vessel keys for most records, the proportion of the annual catch covered by them declines rapidly after 1985 which coincides with an apparent change in the vessel fleet. The fishing duration field used to contain recorded values that were 10 times the likely values, which appear to have been corrected, although there is no documentation for this correction process. Because of the problems with the FSU data the Shellfish Working Group decided not to use it in the CPUE standardisations.

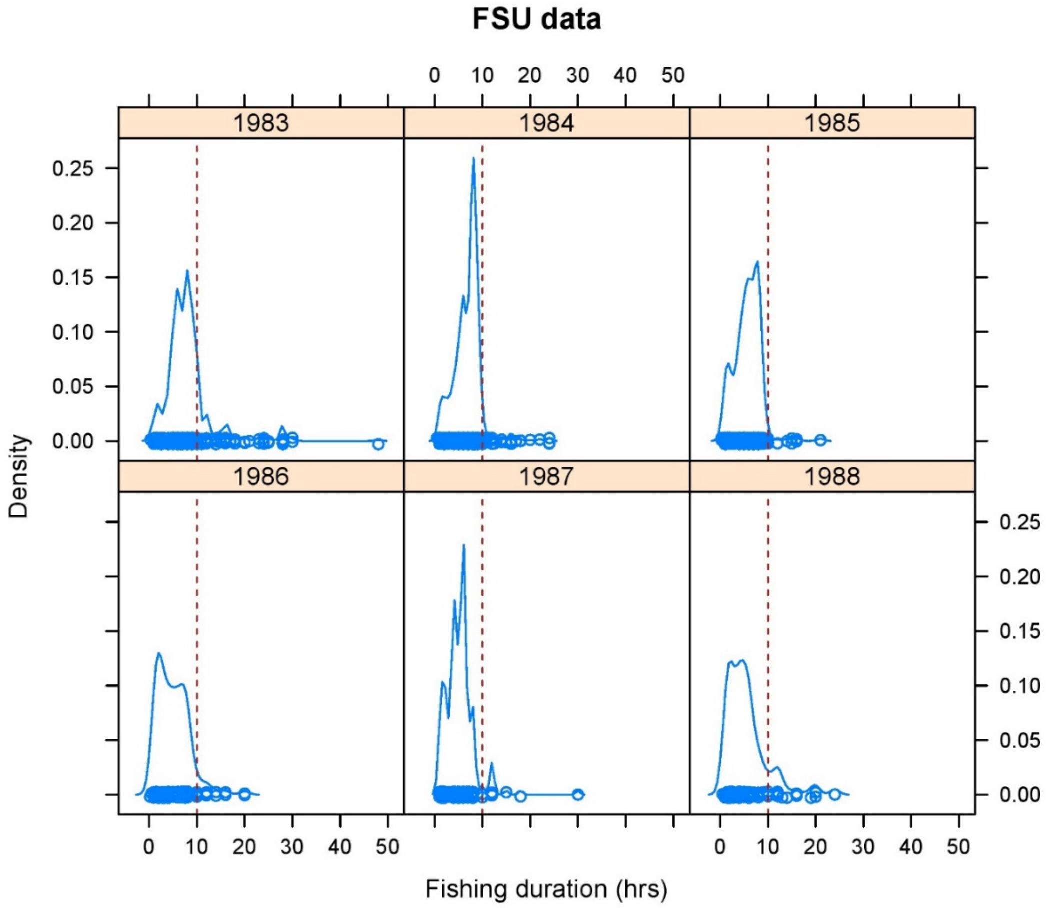


Figure 6: Density and strip plot for hours per diver. The vertical dashed reference line is at a fishing duration of 10 hours. The groomed data is used.

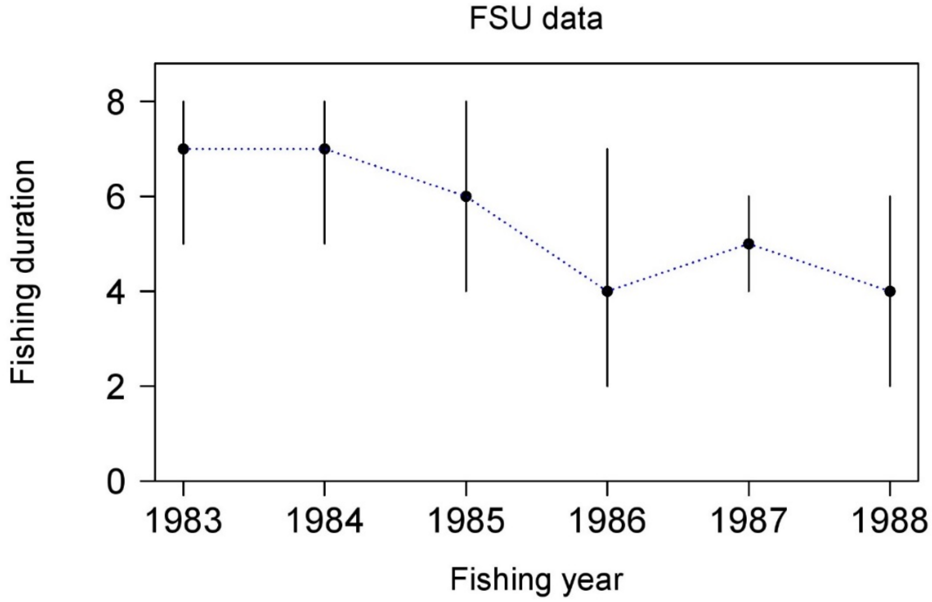


Figure 7: Quantiles by fishing year for the recorded daily fishing duration in FSU data: medians (dot) and lower and upper quartiles (vertical lines). Records with a fishing duration greater than 10 hours are dropped.

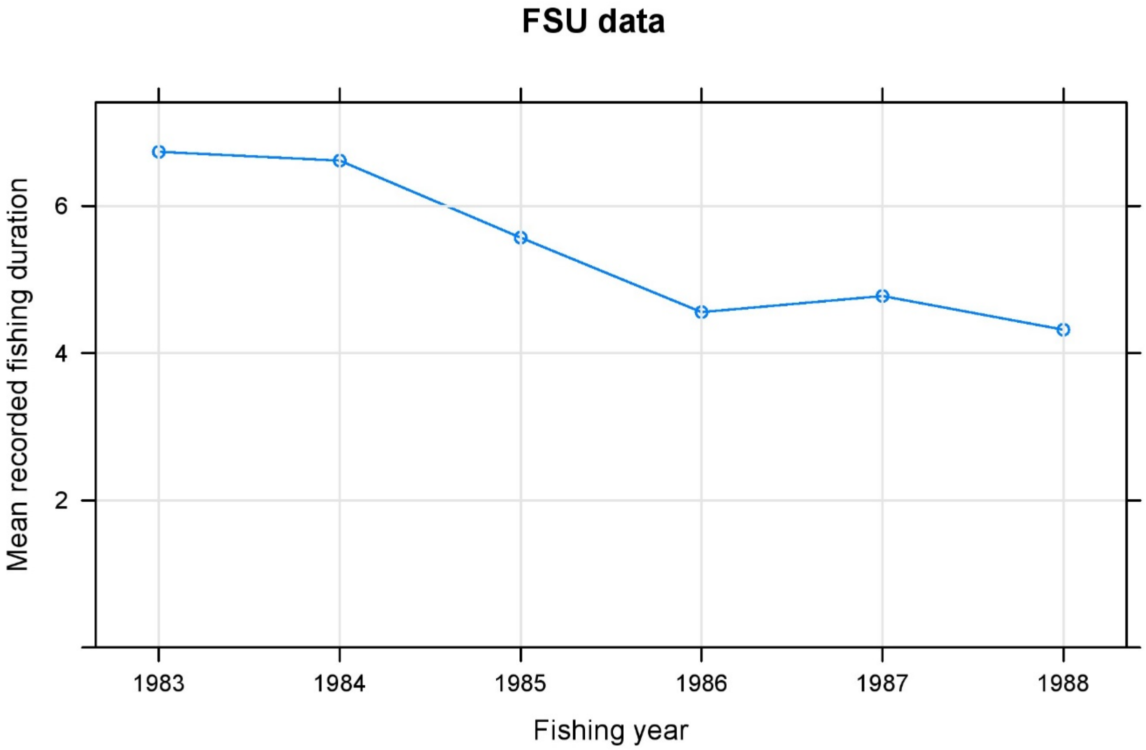


Figure 8: Mean values by fishing year for the daily fishing duration in FSU data. Records with a fishing duration greater than 10 hours are dropped.

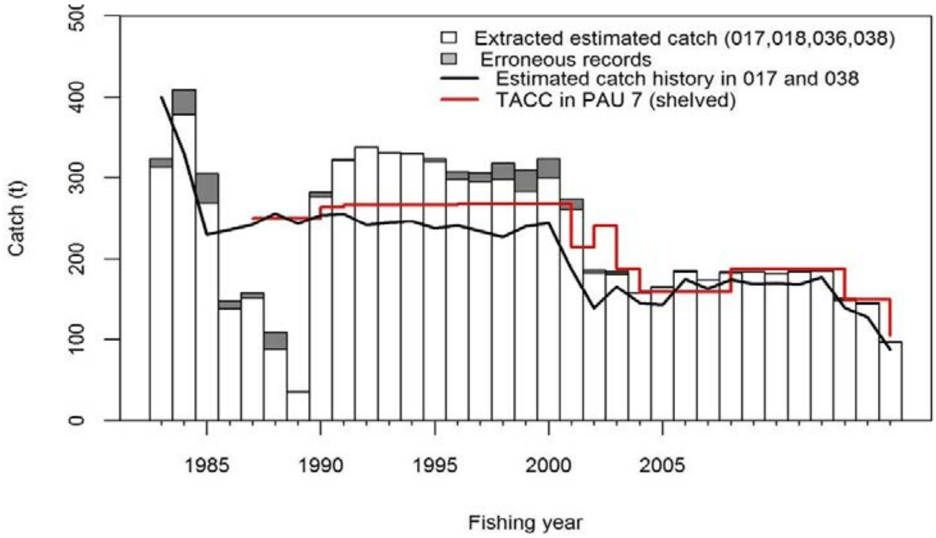


Figure 9: The estimated commercial catch history, TACC, and the FSU/CELR/PCELR catch (vertical bars) for fishing years 1983–2015 for PAU 7. The black portion of the bar represents estimated catch removed through data grooming.

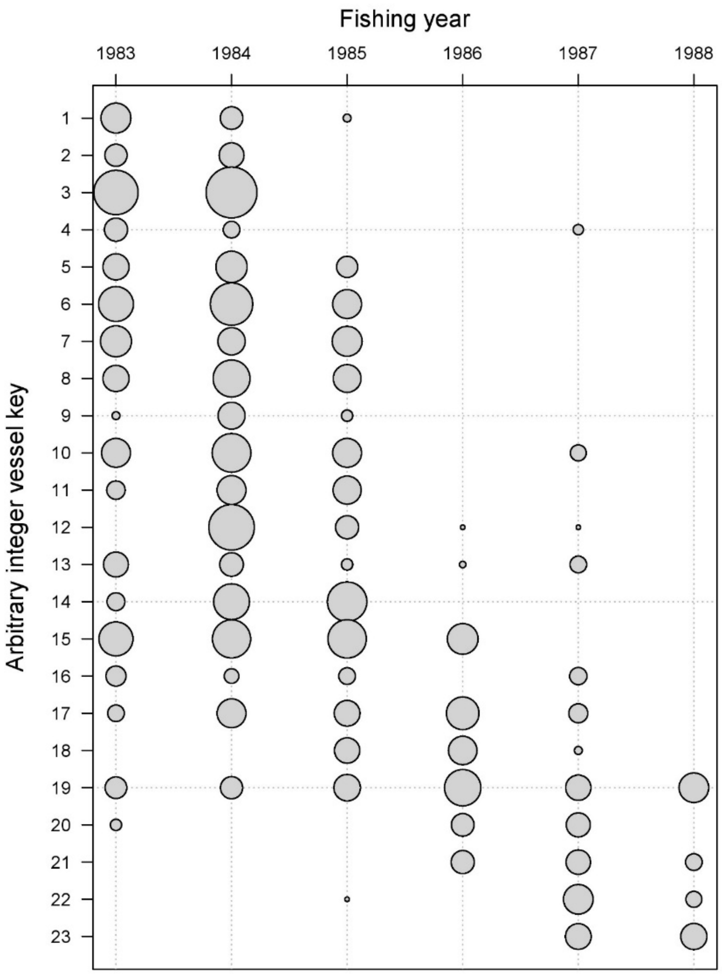


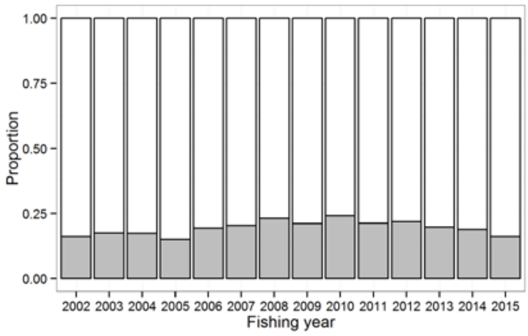
Figure 10: Number of records by vessel and fishing year, plotting only vessels with at least 30 records. An arbitrary integer is used for vessel key.

4.5 Serial depletion and data quality

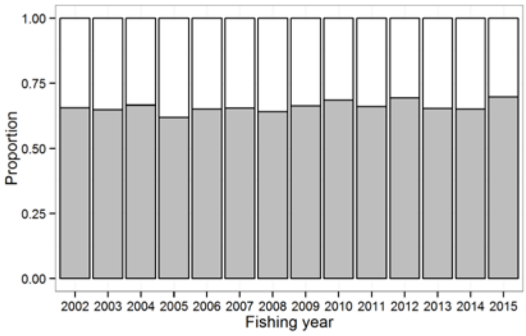
There is little evidence for serial depletion over the past 14 years with no significant changes in the estimated catch distribution over this time period (Figure 3).

The recorded resolution for the estimated catch and fishing duration for the PCELR data is comparable to other areas and is low. About 20% of the catch is recorded as multiples of 50 kg, and about 70% of recorded fishing durations are multiples of one hour (Figure 11a,b). In about 20% of fishing events the estimated catch was split equally among the divers (Figure 11c).

(a)



(b)



(c)

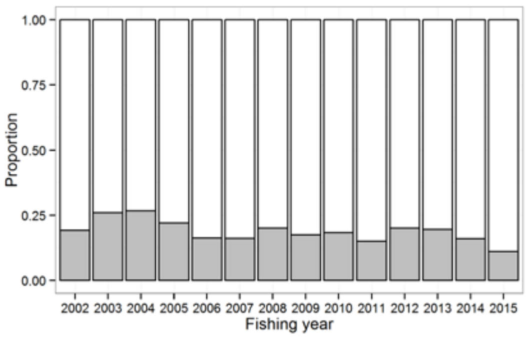


Figure 11: Diagnostic of data resolution on the PCELR forms within PAU 7: (a) proportion of records that recorded estimated catch in a multiple of 50 kg; (b) proportion of records that recorded hours fished in an exact multiple of 1 hour; (c) proportion of records in which the catch was equally split amongst divers.

4.6 CELR data (1990–2001)

4.6.1 The CELR data

The initial data set was catch-effort records from areas 017 and 038. Some grooming of the catch-effort records was undertaken: records were only retained where paua was targeted by diving, and records were dropped with missing values for the estimated catch or number of divers (Table 7). The FIN and date were present for all records. This groomed data set has 13 229 records (Table 8).

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 and per diver hours is put down, possibly attributable to the transition from the FSU forms.

For most trips the number of divers is four or less (Figure 12). 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. For example, where the hours per diver drops by 50% going from one to two divers (Figure 13). Another sign of incorrect recording for fishing duration would be a bimodal distribution for the fishing duration when there are two or more divers, but what is seen is single mode distributions with some higher values (Figure 14).

There is some ambiguity, but it looks as if for most records the fishing duration is recorded as hours per diver. To explore how the raw CPUE varies over time it is assumed that fishing duration is recorded as hours per diver, and records with a fishing duration greater than 10 are dropped (6% of the records). From 1990–2001 the number of hours per diver increases (Figures 15–16). A raw CPUE based on using either duration or number of divers as the measure of effort gives a decline of about 40% from 1990–2001 (Figure 17).

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

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Not targeting paua	0	0	0	3	0	0	0	1	1	0	0	0	5
Catch missing	0	0	0	0	0	0	6	5	1	0	0	0	12
Number divers missing	0	0	0	0	0	0	1	10	6	9	15	1	42
Method not diving	0	5	38	59	87	61	58	48	15	11	57	99	538

Table 8: Number of CELR records after grooming.

Fishing year	90	91	92	93	94	95	96	97	98	99	2000	2001	Total
After	1047	1121	1256	919	945	986	974	1067	983	962	1388	1581	13229

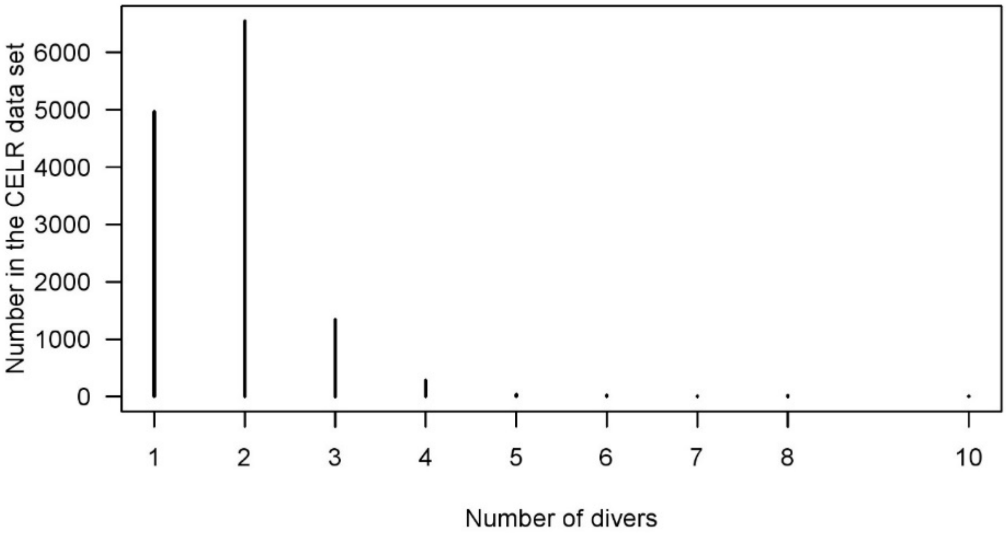


Figure 12: Distribution of the number of divers for a record in the CELR dataset.

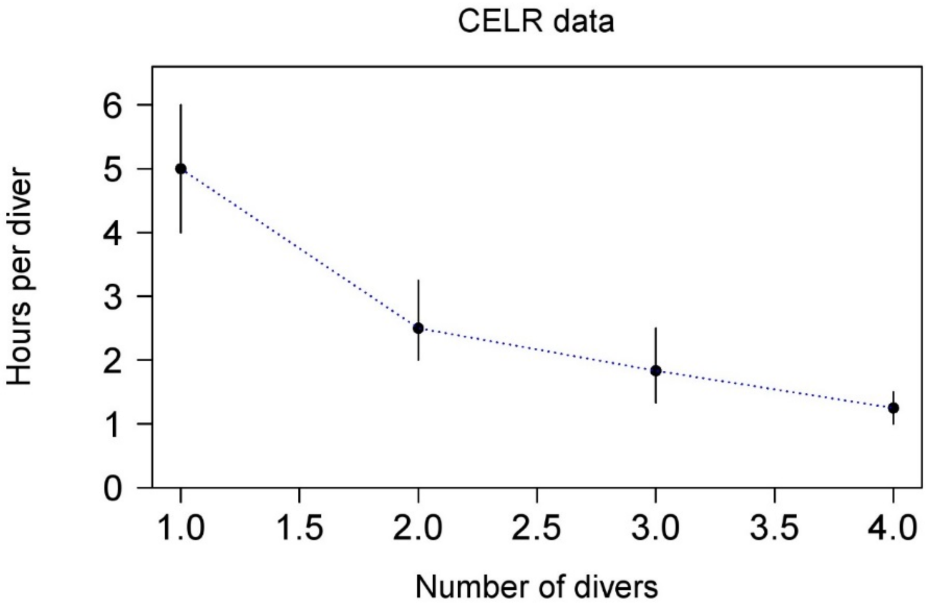


Figure 13: Quantiles by number of divers for the hours per diver in the CELR dataset: medians (dot) and lower and upper quartiles (vertical lines). The number of divers is restricted to four or less.

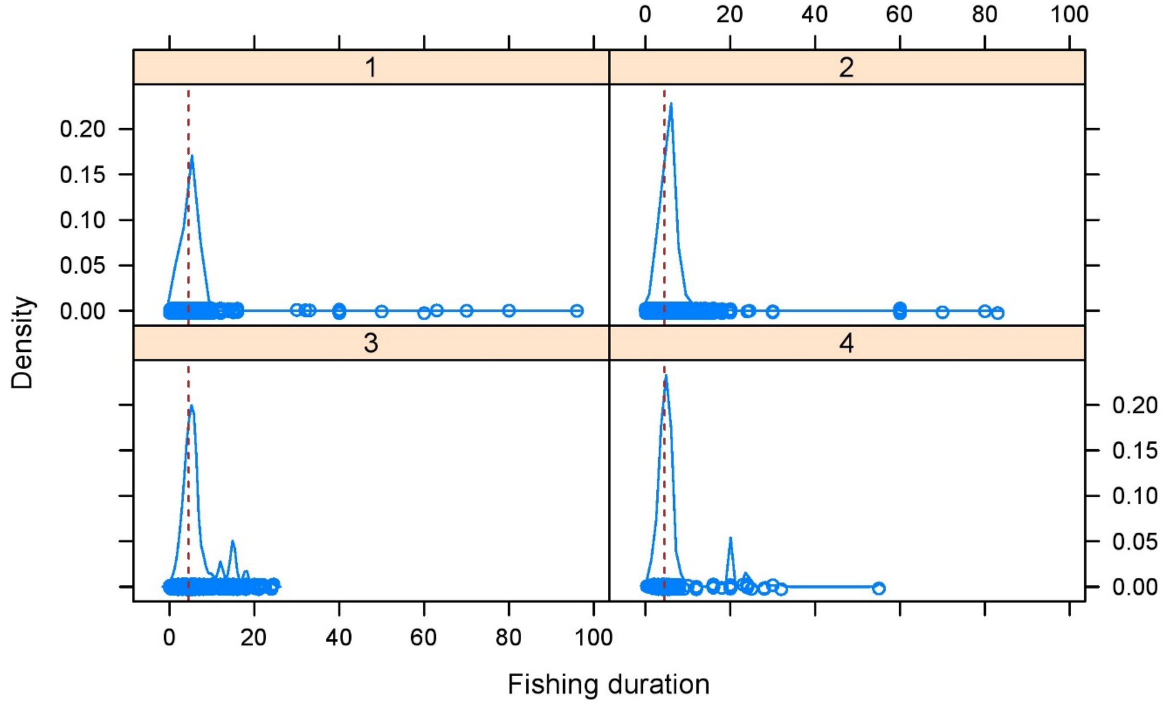


Figure 14: Density and strip plot for the recorded fishing duration in the CELR dataset, given the number of divers on a trip (restricted to four or less). The vertical dashed reference line is at a fishing duration of 4.5 hours.

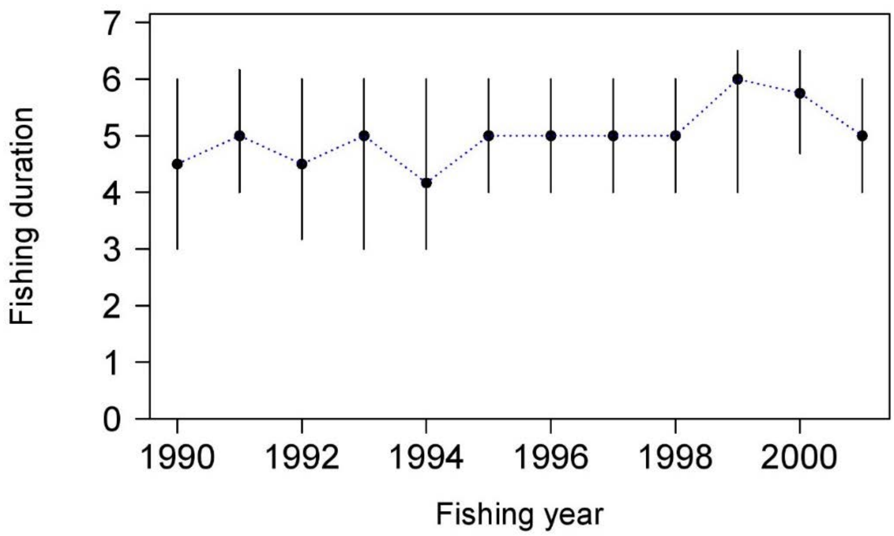


Figure 15: Quantiles by fishing year for the recorded daily fishing duration in the CELR dataset: medians (dot) and lower and upper quartiles (vertical lines). Records with a fishing duration greater than 10 hours are dropped.

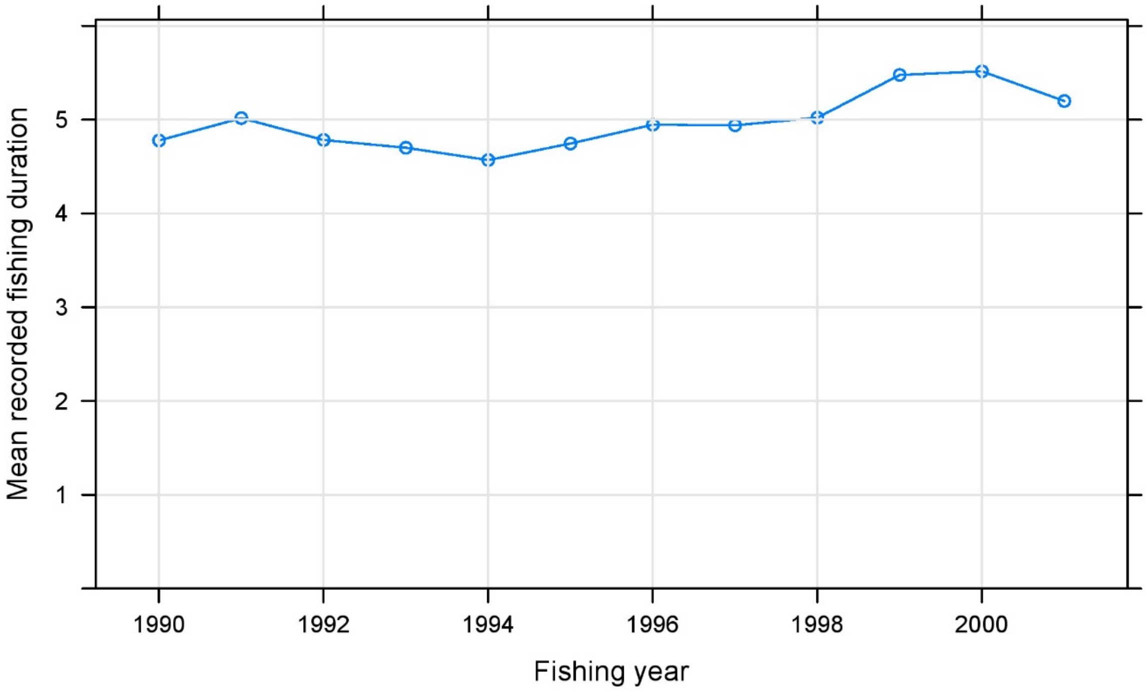


Figure 16: Mean values by fishing year for the daily fishing duration in the CELR dataset. Records with a fishing duration greater than 10 hours are dropped.

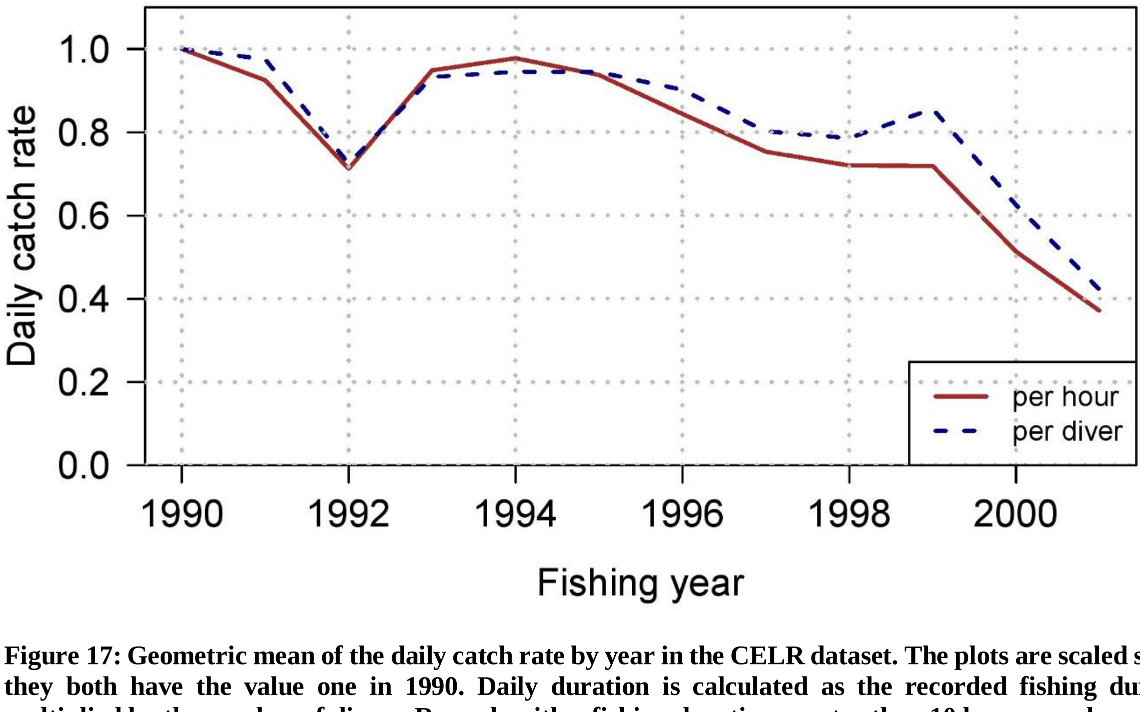


Figure 17: Geometric mean of the daily catch rate by year in the CELR dataset. The plots are scaled so that they both have the value one in 1990. Daily duration is calculated as the recorded fishing duration multiplied by the number of divers. Records with a fishing duration greater than 10 hours are dropped.

4.6.2 Standardised CELR using total fishing duration as effort

The data set started with was groomed, and records for a diver with a fishing duration of greater than 10 hours were removed (see Section 4.6.1).

FIN was used to identify a core subset 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 15 records per year for a minimum of 3 years was chosen, this retained 81% of the catch over 1990–2001 (Figure 18). While 81% of the catch is retained overall, this amount varies slightly between years (Figures 19–20). Over all years the number of days of effort retained after subsetting is 633 or more (Table 9, Figure 21). After subsetting; the number of FIN holders drops from 156 to 51, there is good overlap in effort over time for the FIN holders (Figures 22–23) and the overlap of days of effort by month is also good (Figure 24).

CPUE was defined as catch per day (with daily total fishing duration offered to the model as a predictor) Year was forced into the model at the start and other predictor variables offered to the model were FIN, month, and total fishing duration (as a cubic polynomial). Total fishing duration is the recorded fishing duration multiplied by the number of divers for a record.

The model explained 64% of the variability in CPUE with fishing duration (41%) explaining most of this followed by FIN (14%) (Table 10). The effects appear plausible and the model diagnostics good (Figures 25–26). 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 27). The standardised index shows a decline until 1997, after which it is approximately constant (Table 11, Figure 28).

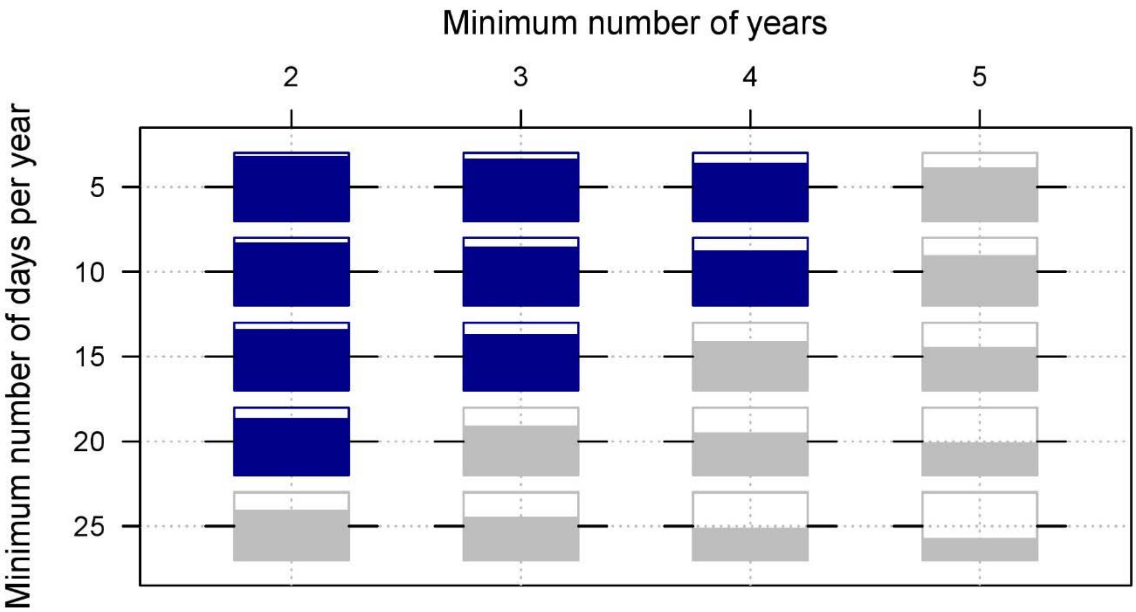


Figure 18: Proportion of the catch taken (in the CELR dataset) when subsetting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

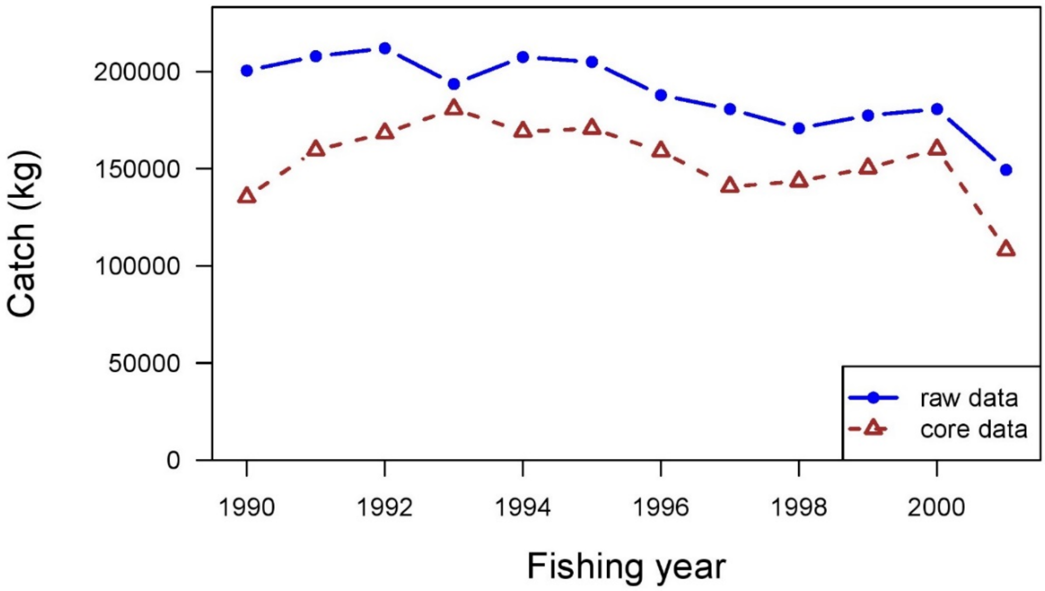


Figure 19: Catch by fishing year (CELR dataset) before FIN subsetting (raw data) and after (core data).

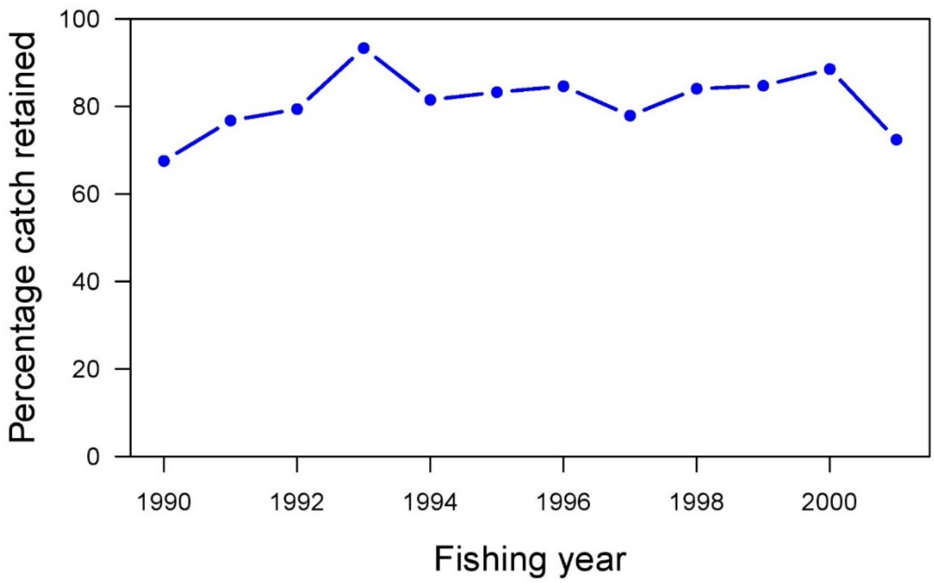


Figure 20: Percentage of the catch retained (CELR dataset) after FIN subsetting.

Table 9: Number of records in CELR dataset before and after FIN subsetting.

Fishing year	90	91	92	93	94	95	96	97	98	99	2000	2001	Total
Before	1012	1062	1217	871	887	921	910	998	909	905	1244	1514	12450
After	633	747	882	780	670	748	776	775	769	767	1067	1001	9615

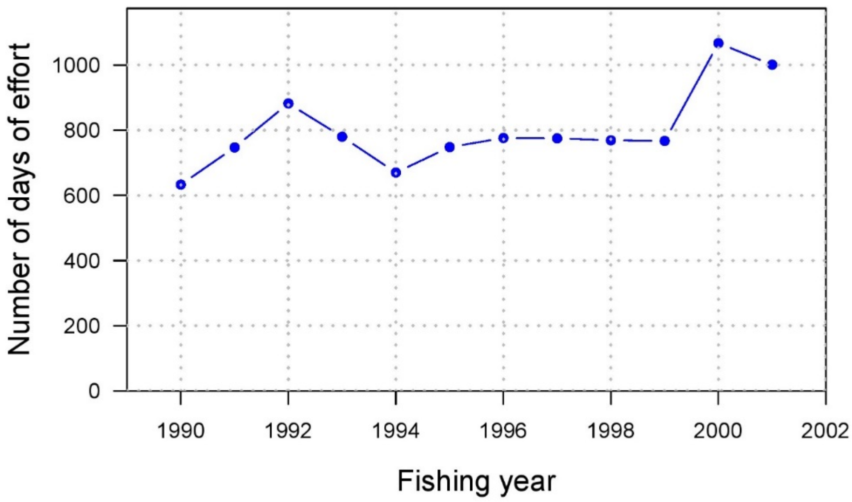


Figure 21: Number of days of effort retained (CELR dataset) after FIN subsetting.

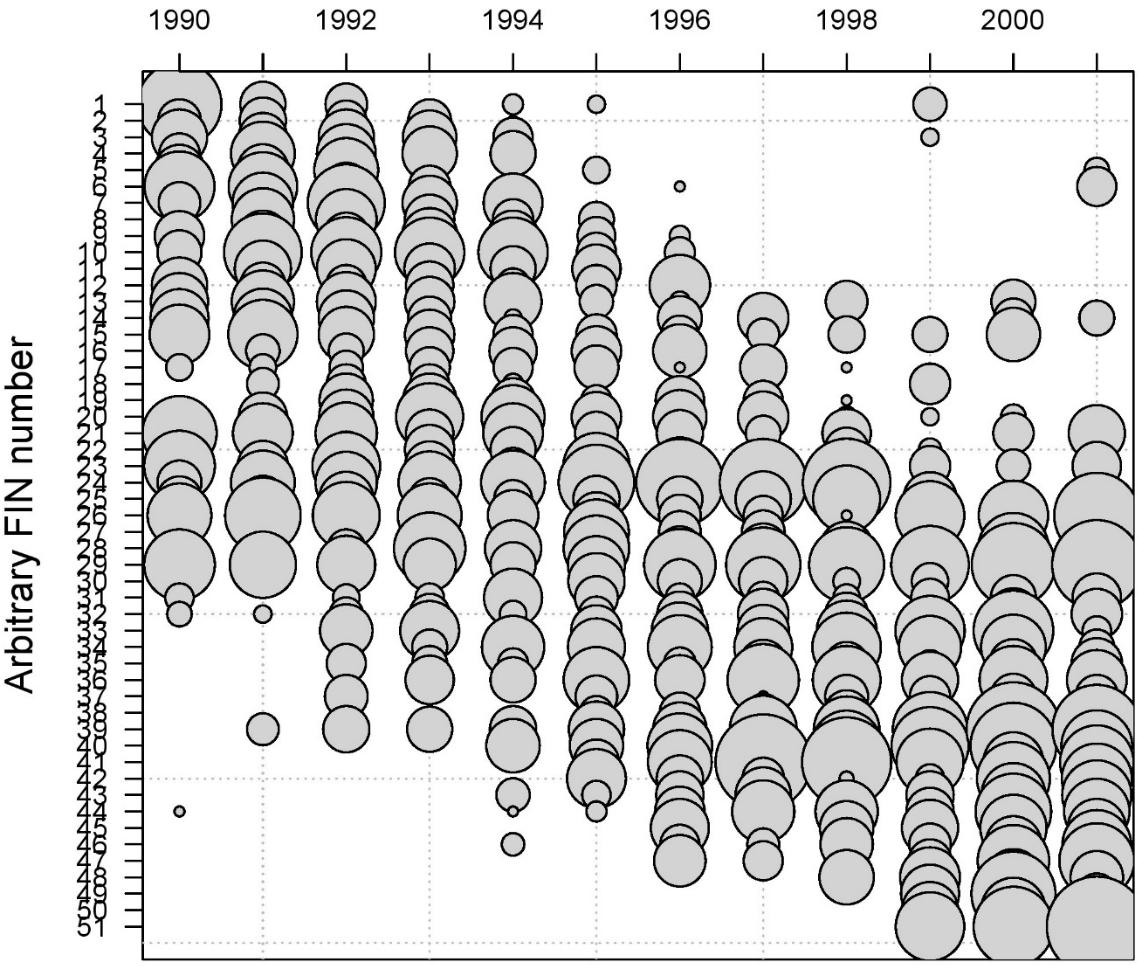


Figure 22: Overlap in days of effort (CELR dataset) by FIN. The area of a circle is proportional to the days of effort.

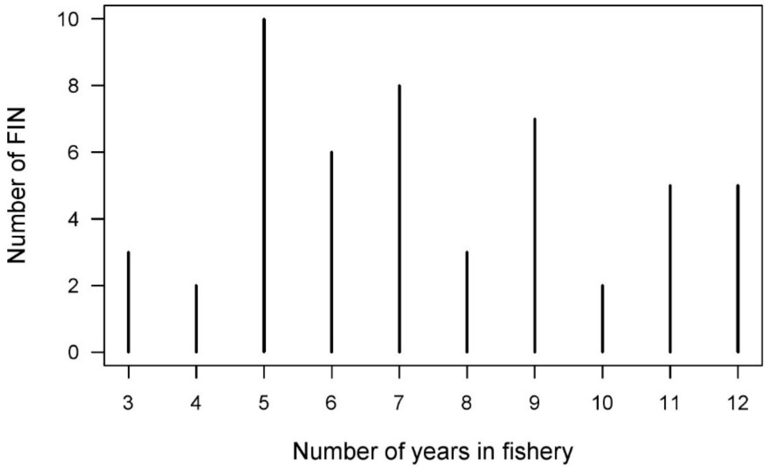


Figure 23: Number of years in the fishery (CELR dataset) for a FIN holder after subsetting by FIN.

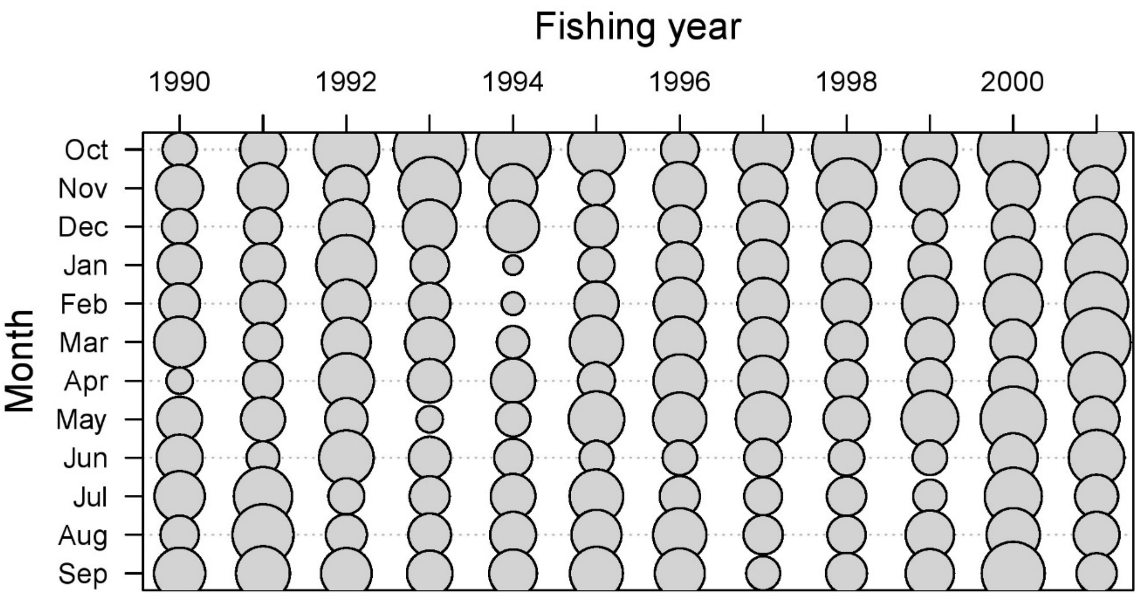


Figure 24: Overlap in days of effort for month by fishing year in the CELR dataset.

Table 10: Variables accepted into the 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
Fishing year	11	0.09
Fishing duration	3	0.50
FIN	50	0.64

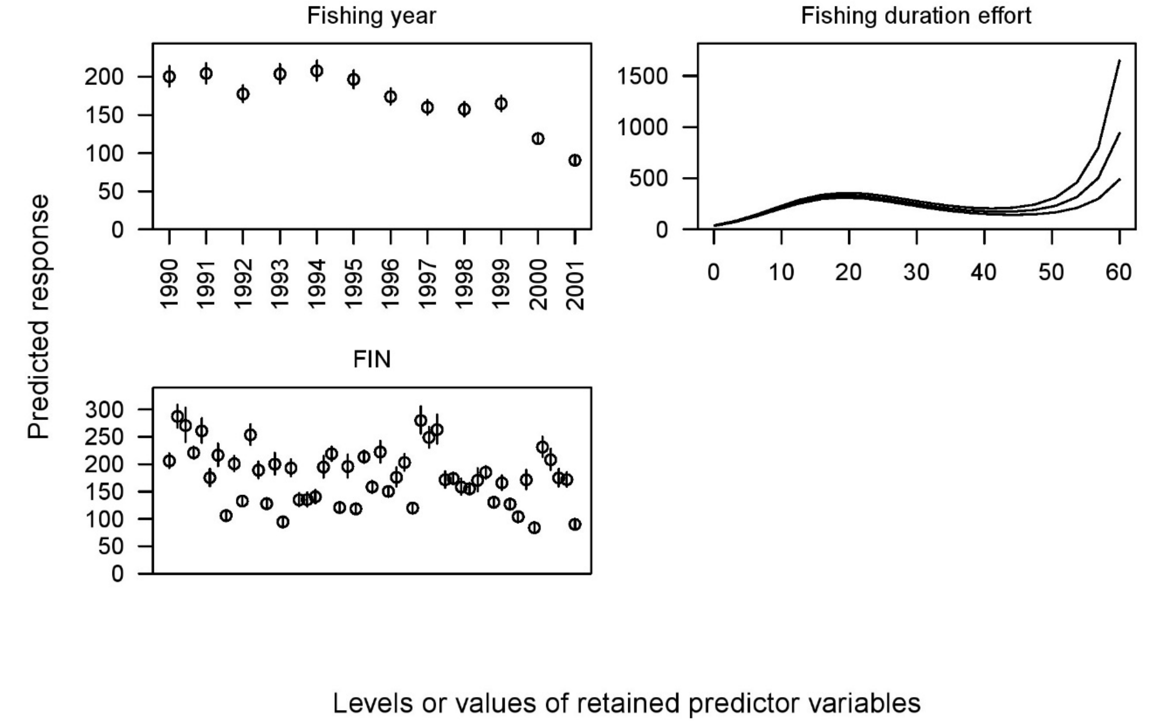


Figure 25: Effects for the CELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

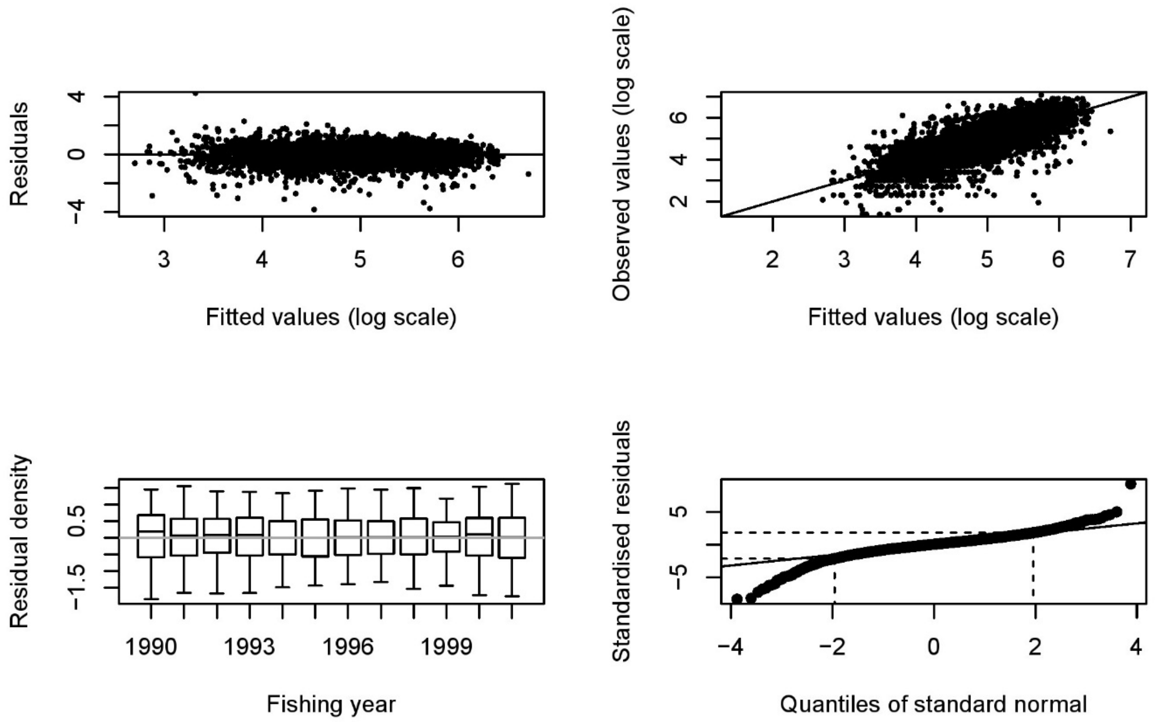


Figure 26: Residuals for the CELR standardisation model.

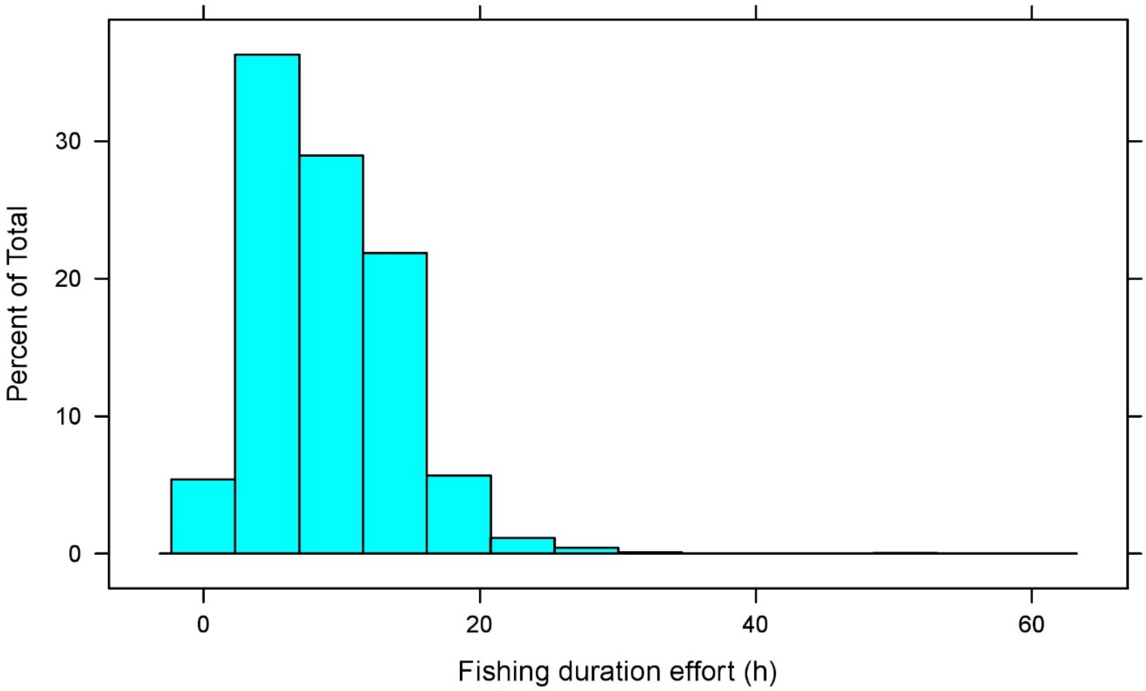


Figure 27: Distribution of fishing duration effort (h) in the CELR dataset.

Table 11: Standardised CELR index, lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
1990	1.20	1.10	1.30	0.04
1991	1.22	1.13	1.32	0.04
1992	1.06	0.99	1.14	0.03
1993	1.22	1.13	1.31	0.04
1994	1.24	1.15	1.34	0.04
1995	1.18	1.09	1.27	0.04
1996	1.04	0.97	1.12	0.04
1997	0.96	0.89	1.03	0.04
1998	0.94	0.88	1.01	0.04
1999	0.99	0.92	1.06	0.04
2000	0.71	0.67	0.76	0.03
2001	0.54	0.51	0.58	0.03

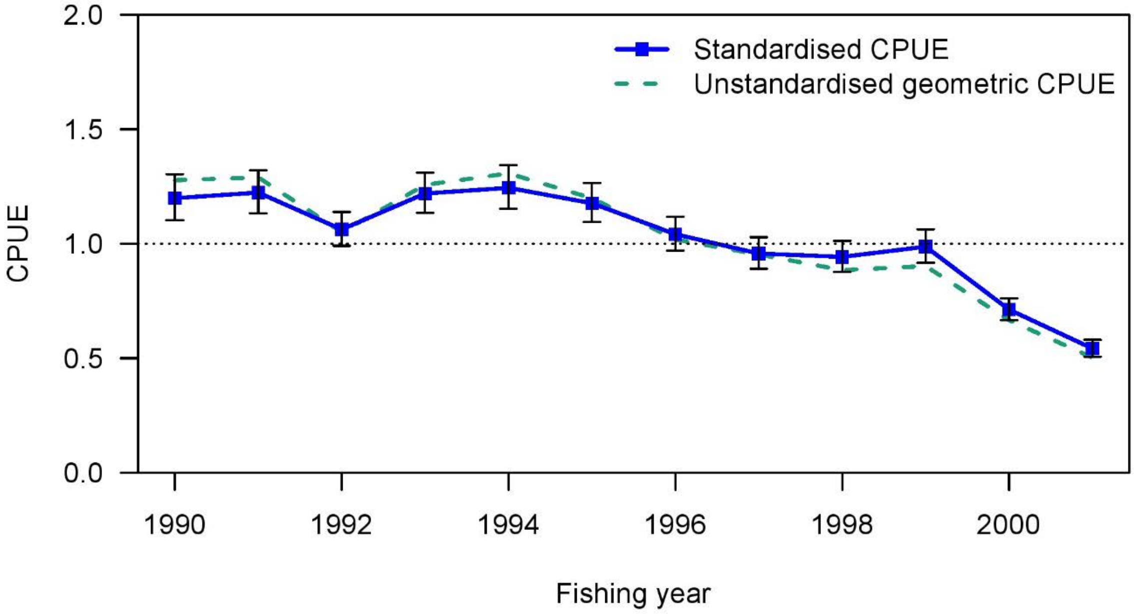


Figure 28: The standardised CPUE index from the CELR dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

4.6.3 Standardised CELR using number of divers as effort

After data grooming (see Section 4.6.1), FIN was used to identify a core subset 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 15 records per year for a minimum of 3 years was chosen, this retained 82% of the catch over 1990–2001 (Figure 29). While 82% of the catch is retained overall, it is slightly less than this for some years (Figures 30–31). Over all years the number of days of effort retained after subsetting is 654 or more (Table 12, Figure 32). After subsetting; the number of FIN holders drops from 157 to 5. There is good overlap in effort over time for the FIN holders (Figures 33–34) and the overlap in time for month is good (Figure 35).

CPUE was defined as catch per day (with the number of divers offered to the model as a predictor variable). Year was forced into the model at the start and other predictor variables offered to the model were FIN, month, and number of divers.

The model explained 40% of the variability in CPUE with FIN (21%) explaining most of this followed by the number of divers (10%) (Table 13). The effects appear plausible and the model diagnostics good (Figures 36–37). The standardised index shows a decline until 1997, after which it is approximately constant (Table 14, Figure 38).

4.6.4 Comparing CELR standardisations using different measures of effort

The indices using different measures of effort show similar patterns, with the standardised index using fishing duration as the measure of effort showing more of a decline from 1990 to 2001 (Figures 39–40).

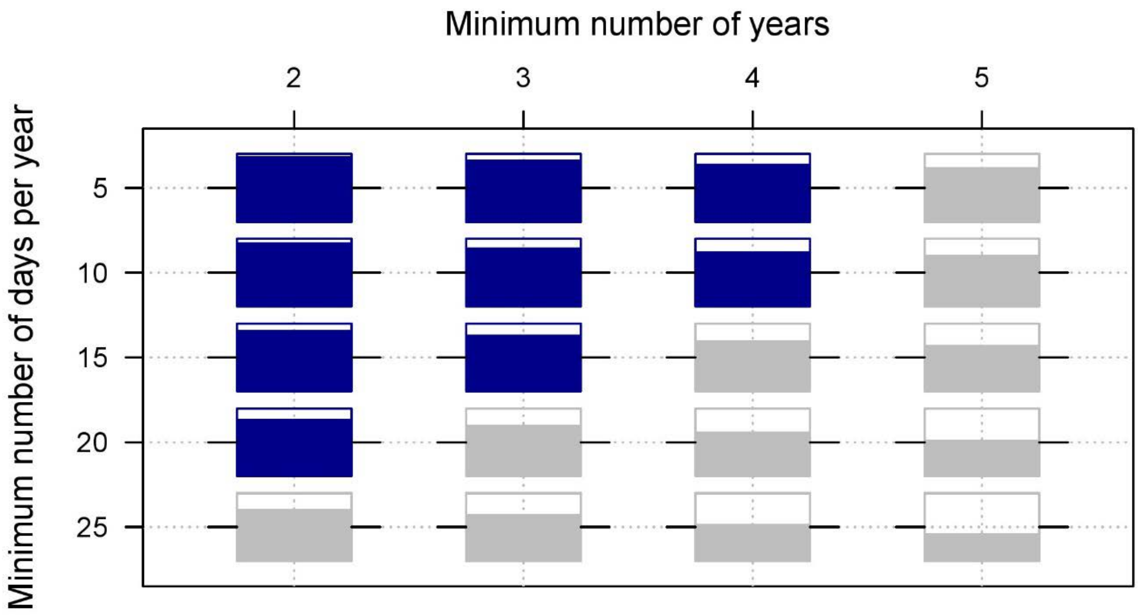


Figure 29: Proportion of the catch taken when subsetting the CELR dataset (using number of divers) data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, 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.

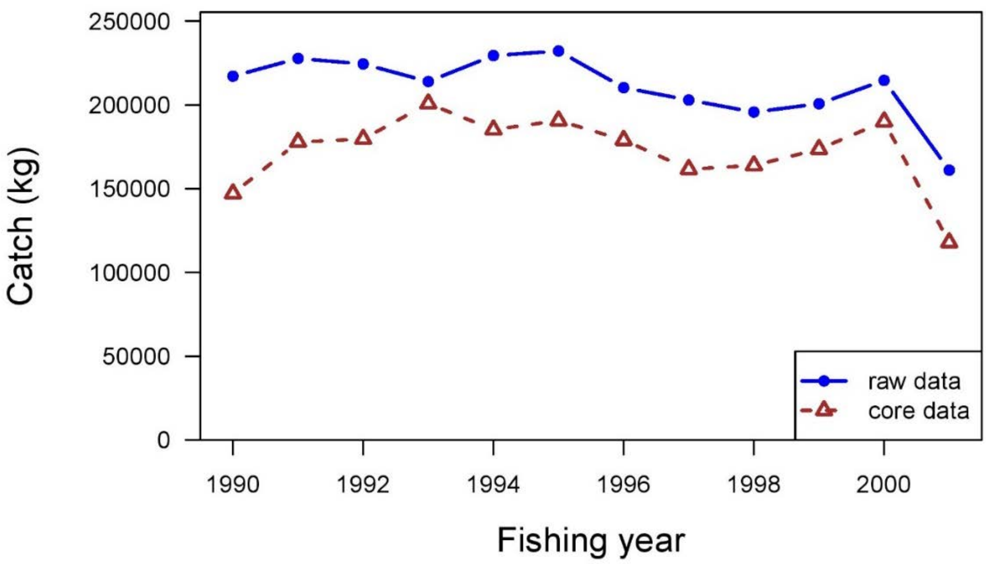


Figure 30: Catch by fishing year in the CELR dataset (using number of divers) before FIN subsetting (raw data) and after (core data).

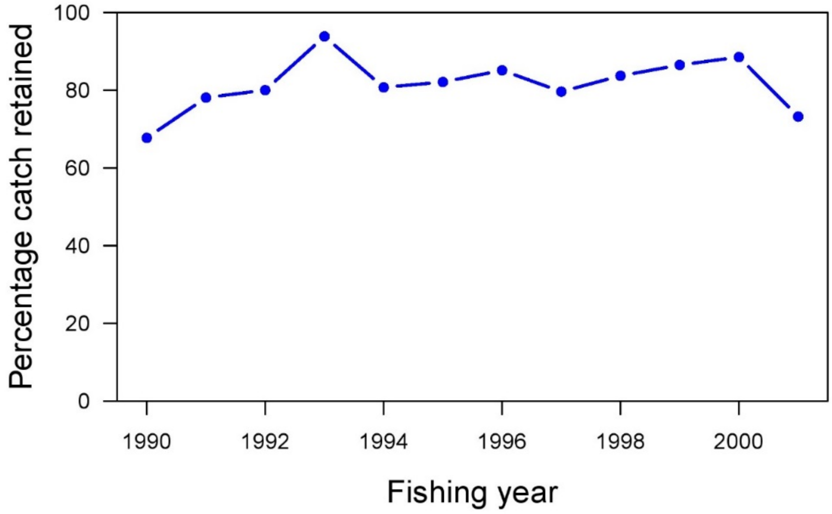


Figure 31: Percentage of the catch in the CELR dataset (using number of divers) retained after FIN subsetting.

Table 12: Number of records in CELR dataset (using number of divers) before and after FIN subsetting.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	1047	1121	1256	919	945	986	974	1067	983	962	1388	1581	13229
After	654	797	912	827	713	797	835	837	824	824	1186	1058	10264

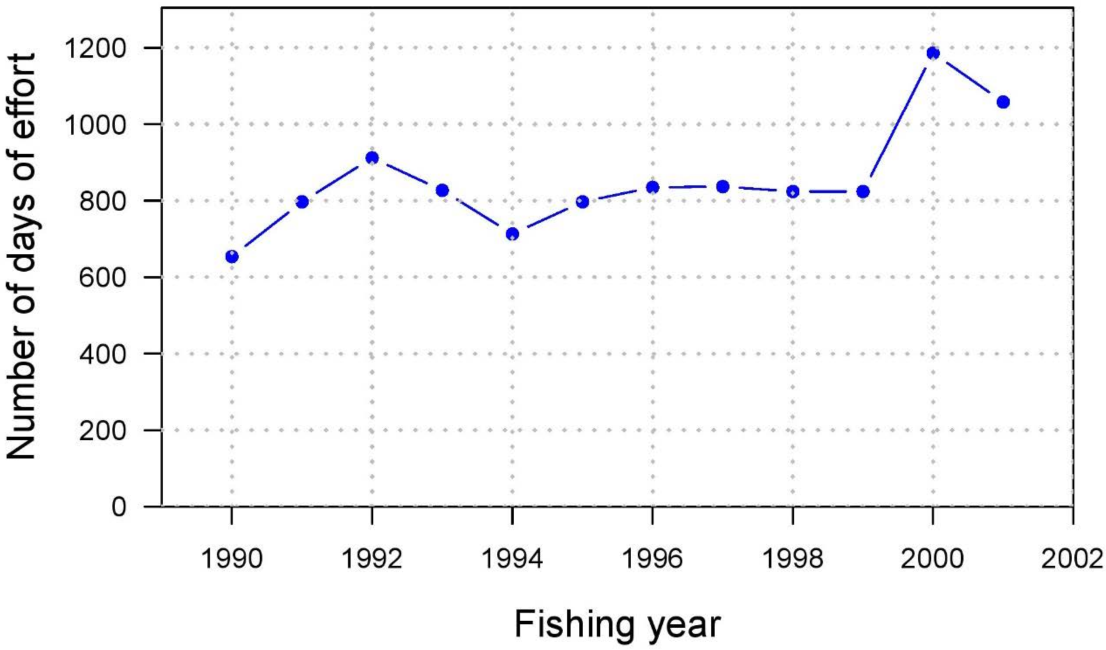


Figure 32: Number of days of effort in the CELR dataset (using number of divers) retained after FIN subsetting.

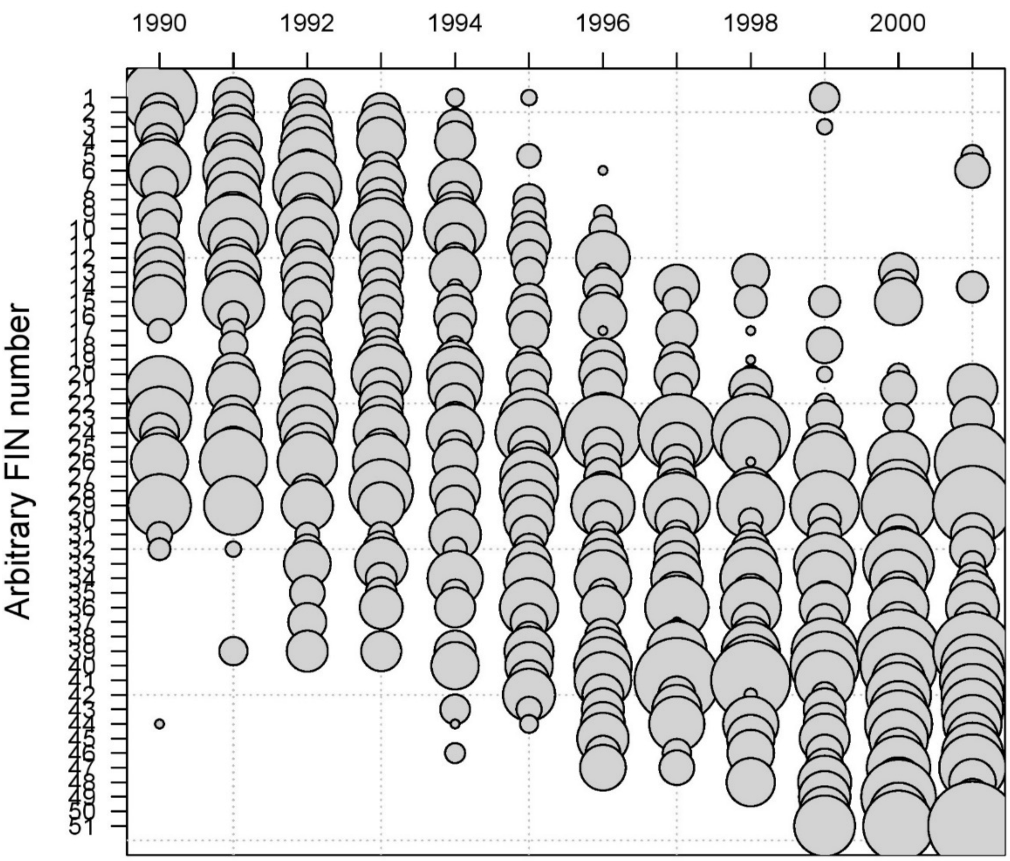


Figure 33: Overlap in days of effort in the CELR dataset (using number of divers) by FIN. The area of a circle is proportional to the days of effort.

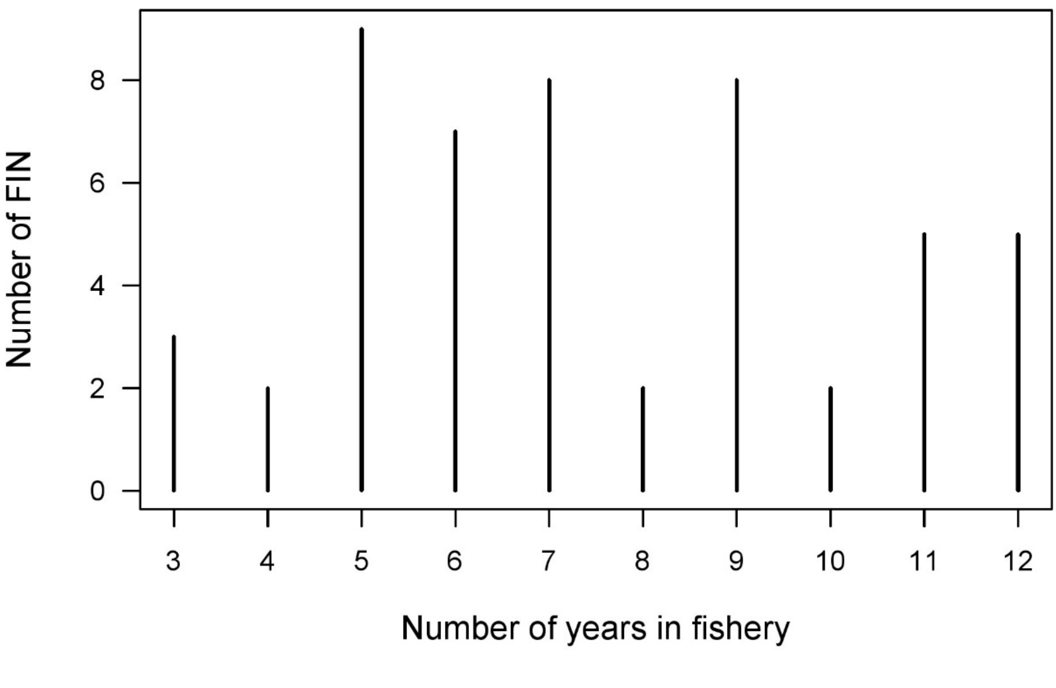


Figure 34: Number of years in the fishery for a FIN holder in the CELR dataset (using number of divers) after subsetting by FIN.

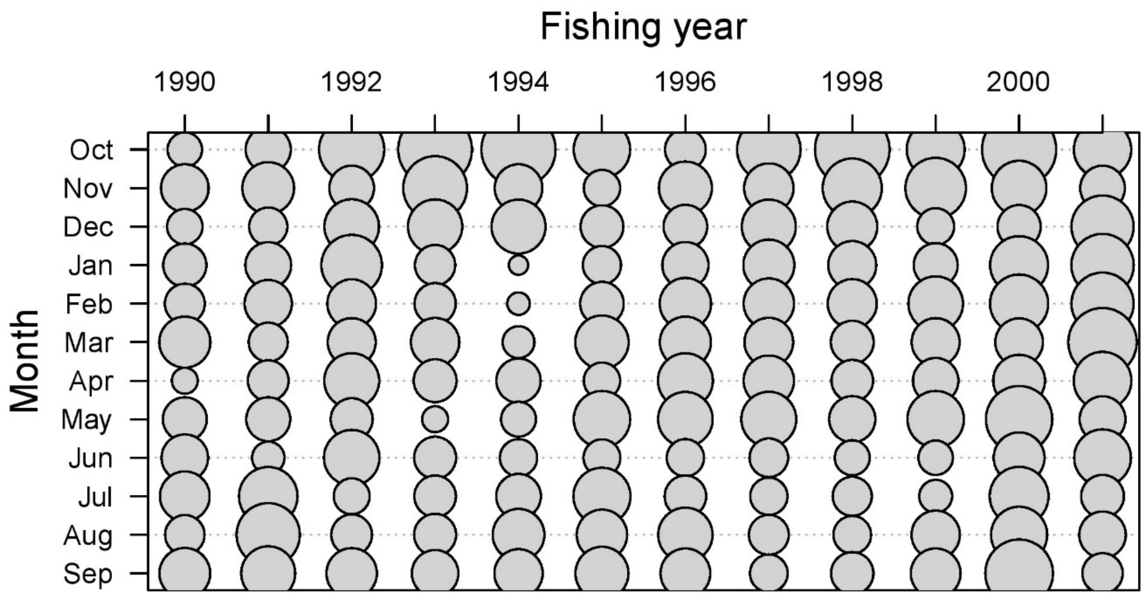


Figure 35: Overlap in days of effort in the CELR dataset (using number of divers) for month by fishing year.

Table 13: Variables accepted into the CELR (using number of divers) 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
Fishing year	11	0.09
FIN	50	0.30
Number of divers	1	0.40

Table 14: Standardised CELR (using number of divers) index, lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
1990	1.08	1.00	1.17	0.04
1991	1.20	1.11	1.29	0.04
1992	1.02	0.95	1.09	0.03
1993	1.17	1.10	1.26	0.03
1994	1.20	1.11	1.29	0.04
1995	1.14	1.07	1.23	0.04
1996	1.06	0.99	1.13	0.03
1997	0.98	0.91	1.05	0.03
1998	0.97	0.91	1.04	0.03
1999	1.11	1.03	1.19	0.04
2000	0.77	0.72	0.82	0.03
2001	0.55	0.52	0.59	0.03

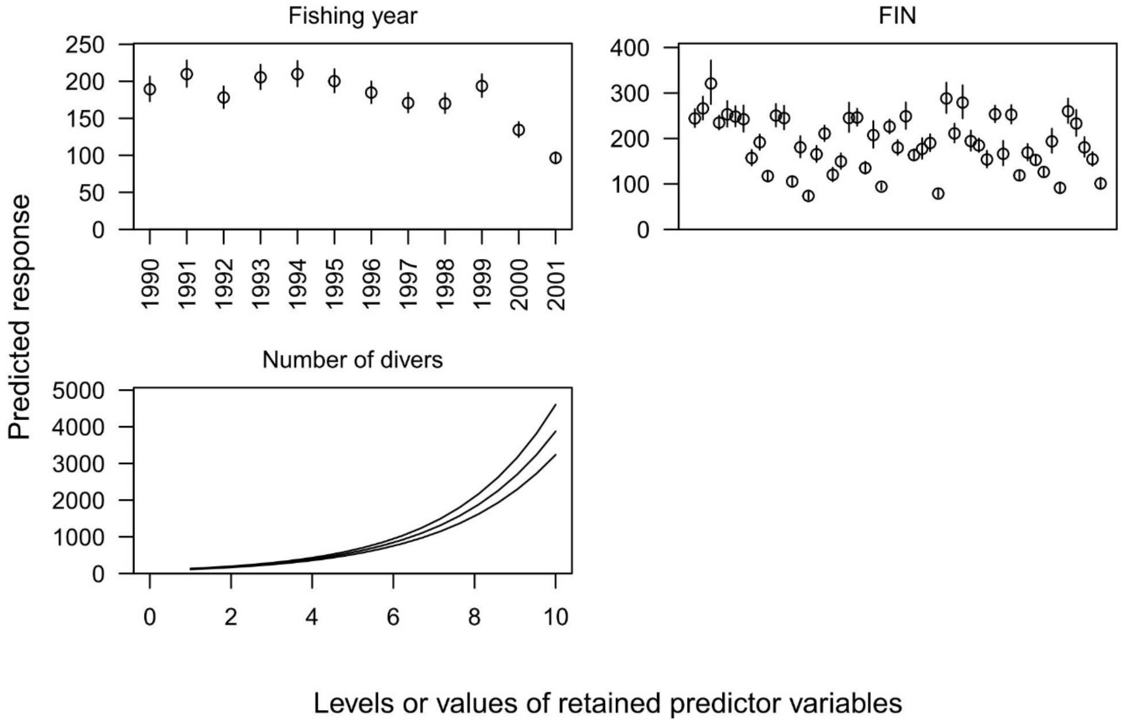


Figure 36: Effects for the CELR (using number of divers) standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

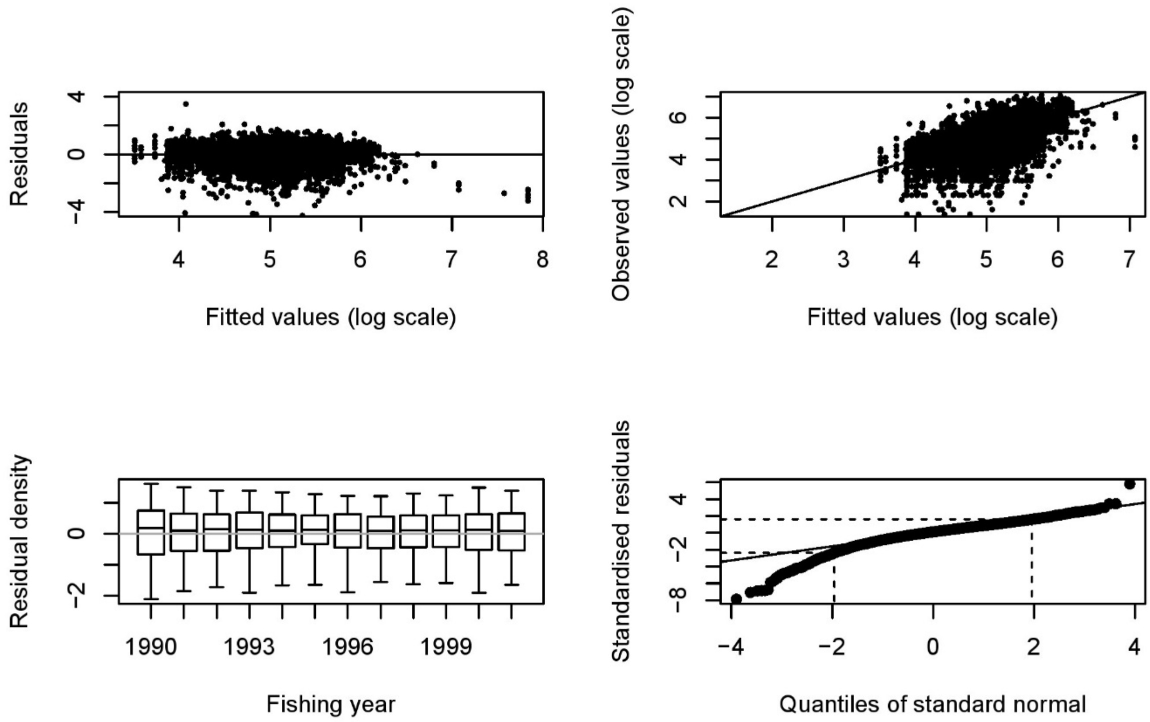


Figure 37: Residuals for the standardisation model for CELR data using number of divers.

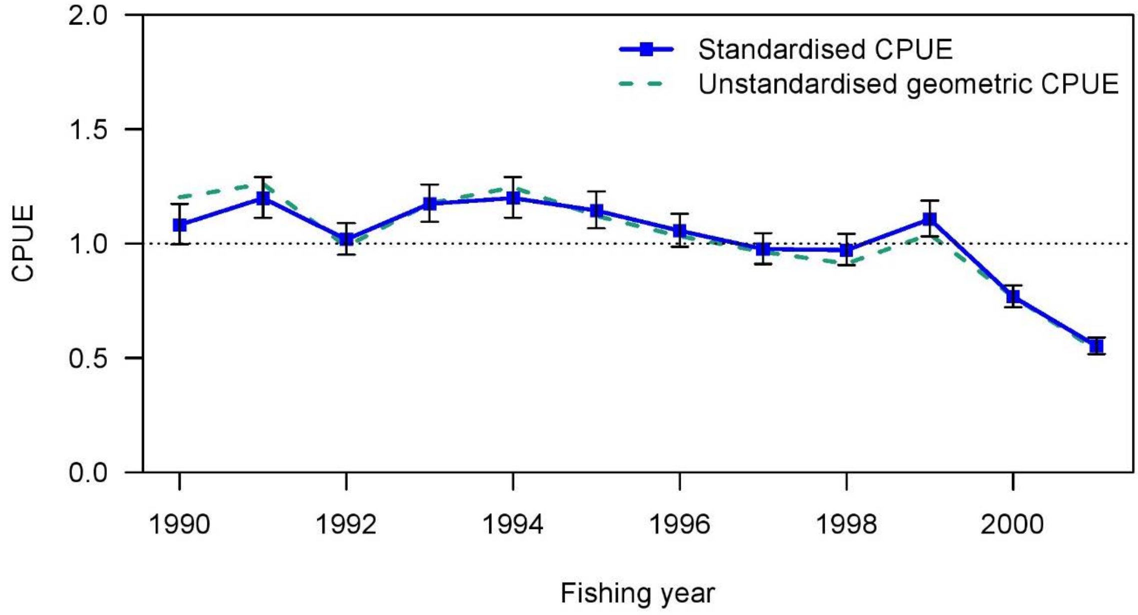


Figure 38: The standardised CPUE index (using number of divers) with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by the number of divers.

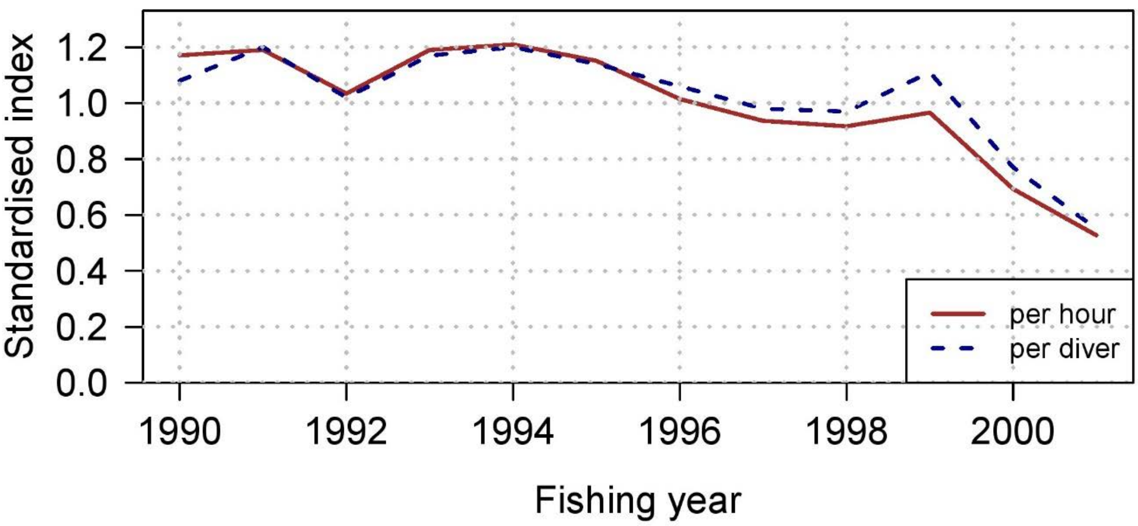


Figure 39: Comparing the standardised indices from CELR data using different measures of effort. Both indices are scaled to have a mean value of one.

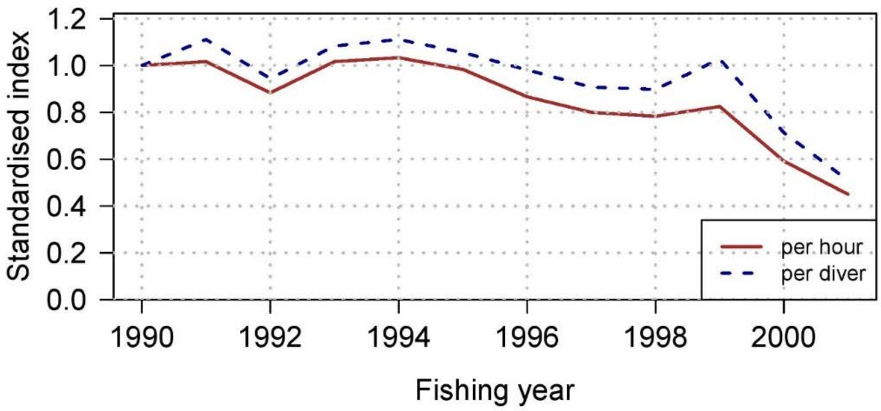


Figure 40: Comparing the standardised indices from CELR data using different measures of effort. Both indices are scaled to have the value one in 1990.

4.7 PCELR data (2002–2015)

4.7.1 Data grooming and subsetting

The initial data set records were for paua targeted by diving, all of which contained entries for FIN, fine scale statistical area, catch weight, fishing duration, and date. Records from the Fighting Bay fishing down experiment in P720 were removed (15 records) as were some records with no diver key (5 records). Some further grooming was done: 698 records were removed where no diving condition was recorded (Table 15).

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 20 records per year for a minimum of 8 years were selected; this retained 82% of the catch over 2002–2015 (Figures 41–43). The number of FIN holders dropped from 75 to 21 under these criteria. There was good overlap in effort for the FIN holders after subsetting (Figures 44–45). The number of records retained after subsetting was 732 or more for each individual fishing year (Table 16, Figure 46).

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 16). This dropped the number of statistical areas from 54 to 43, and the number of divers from 468 to 107 (49% of divers have only one diving day - this is partly an artefact of the fact that a spelling mistake in the divers name looks like a completely new diver). There is very good temporal overlap for the other predictor variables statistical area, month, dive conditions, and diver (Figures 47–50).

Table 15: Number of records in the PCELR dataset removed by fishing year (02 = 2002).

Fishing year	02	03	04	05	06	07	08	09	10	11	12	13	14	15	Total
No diving condition	86	51	68	67	51	61	32	32	37	38	51	28	63	33	698

Table 16: Number of records remaining by fishing year (02 = 2002) in the PCELR dataset after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records without information needed for the standardisation were removed (see the table above).

	02	03	04	05	06	07	08	09	10	11	12	13	14	15	Total
Total records	2169	2692	2328	2060	1727	1600	1443	1371	1379	1389	1531	1310	1276	883	23158
FIN subsetting	1060	1509	1395	1524	1422	1460	1353	1243	1205	1291	1340	1133	1091	732	17758
Fine scale stat. area≥10 dive days	1056	1504	1391	1521	1417	1451	1347	1243	1205	1288	1340	1131	1089	731	17714
Divers with≥10 dive days	990	1429	1329	1454	1356	1410	1323	1220	1130	1222	1307	1094	1051	699	17014

4.7.2 Standardisation

For the standardisation model CPUE (the dependent variable) was modelled as log(diver catch) with a normal error distribution. Fishing year was forced into the model at the start. Variables offered to the model were month, diver key (identification code for each individual diver), FIN, statistical area, duration (third degree polynomial), and diving condition. Following previous standardisations, no interaction of fishing year with area was entered into the model, because the stock assessment for PAU 7 is a single area model. However, a separate standardisation is also done where a year:area interaction is forced in at the start (using seven sub-areas).

Except for FIN, all variables were accepted into the model, which explained 80% of the variability in CPUE (Table 17). Most of the variability was explained by duration (52%) and diver (10%). The effects appear plausible and the diagnostics are good (Figures 51–52). 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 53).

The standardised index shows an increasing CPUE from 2002 to 2009 and a decline from 2010 to 2015 (Table 18, Figure 54). The biggest difference between the unstandardised and standardised indices is in 2015, which is attributable to the diver and area predictor variables (Figure 55).

Seven sub areas for PAU 7 are given in Table 19, for each of which there are a good number of records (Table 6). Forcing a year:area interaction into the model gives similar indices for the different sub areas (Figure 56).

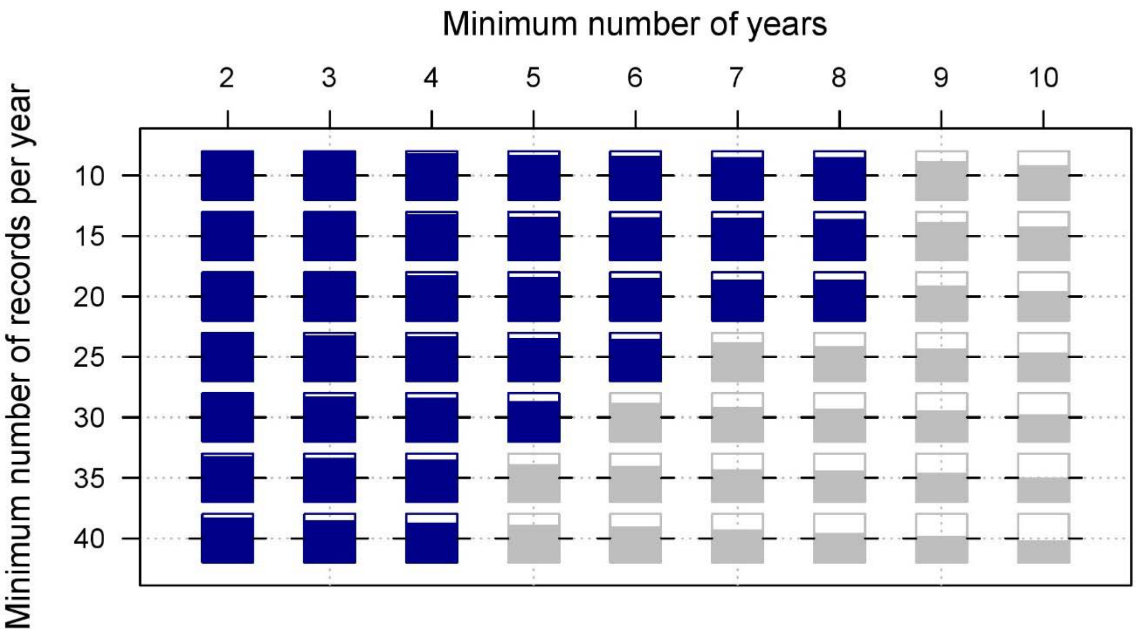


Figure 41: Proportion of the catch taken when subsetting the PCELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2015 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

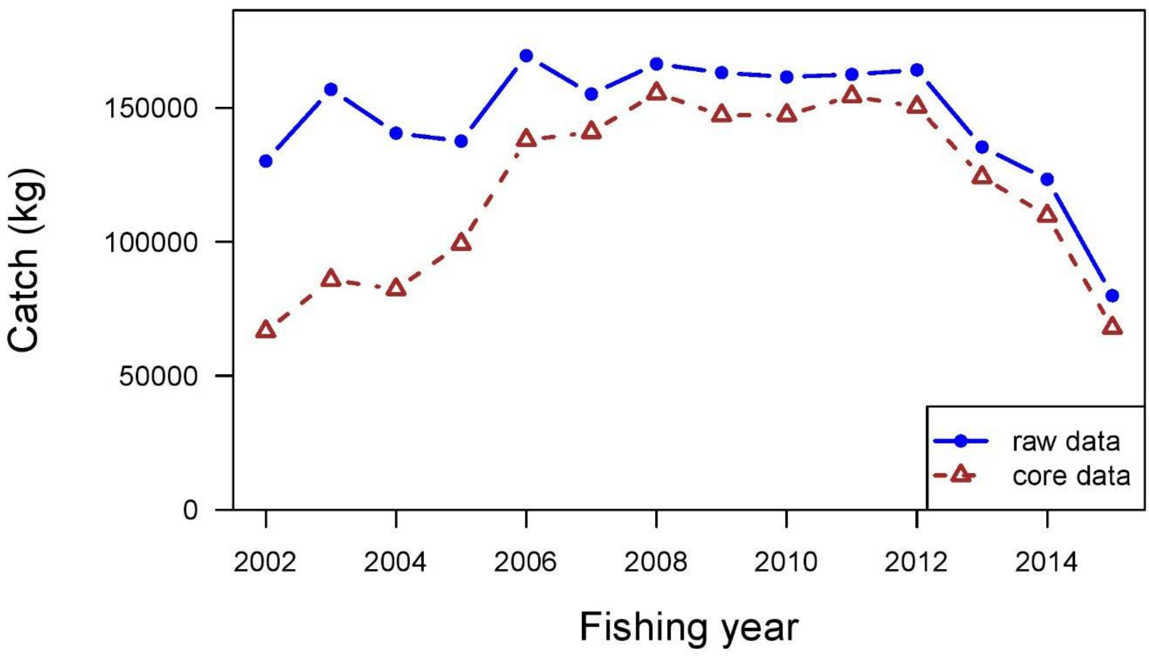


Figure 42: Catch by fishing year from the PCELR dataset before FIN subsetting (raw data) and after (core data).

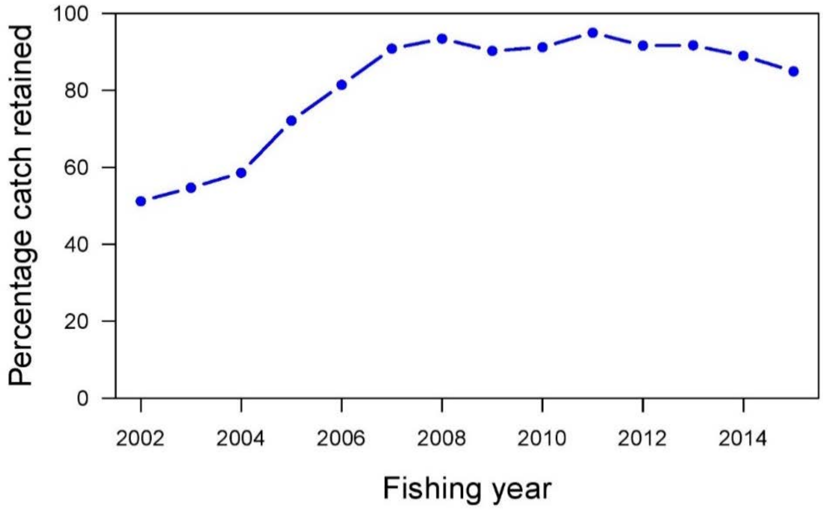


Figure 43: Percentage of the catch retained in the PCELR dataset after FIN subsetting.

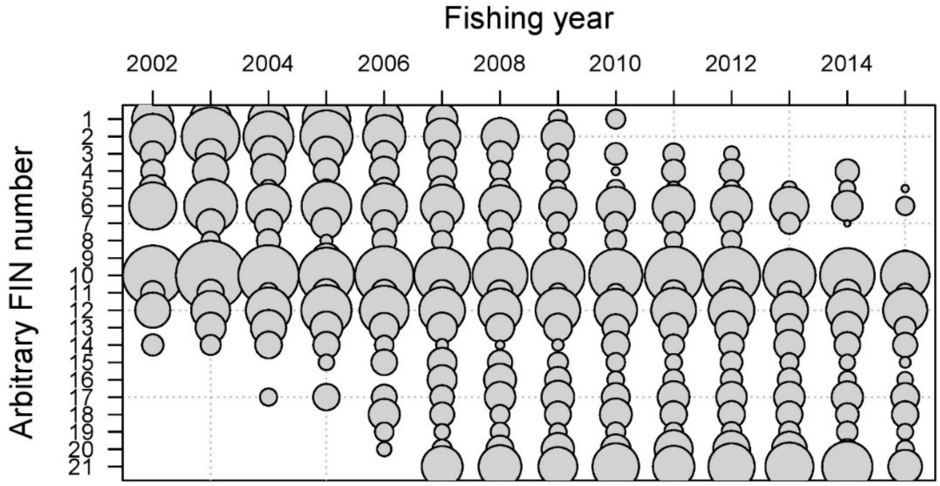


Figure 44: Overlap in number of records in the PCELR dataset by FIN after subsetting by FIN. The area of a circle is proportional to the number of records.

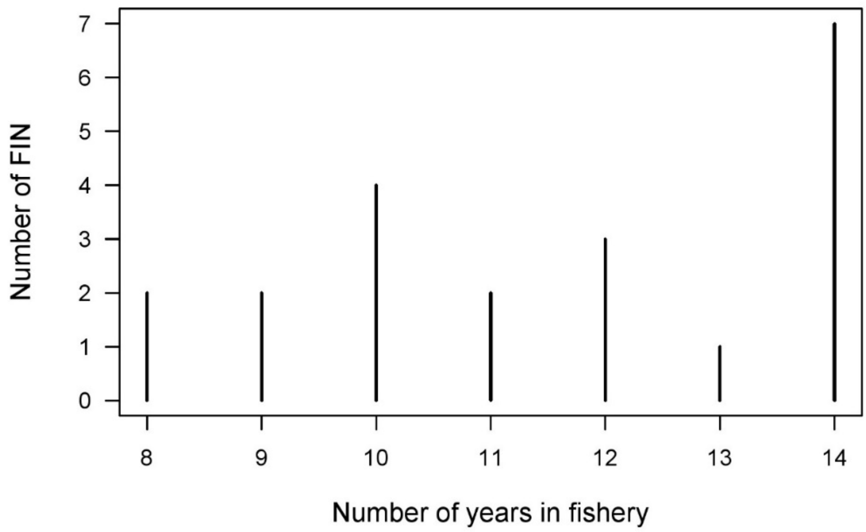


Figure 45: Number of years in the fishery for a FIN holder in the PCELR dataset after subsetting by FIN.

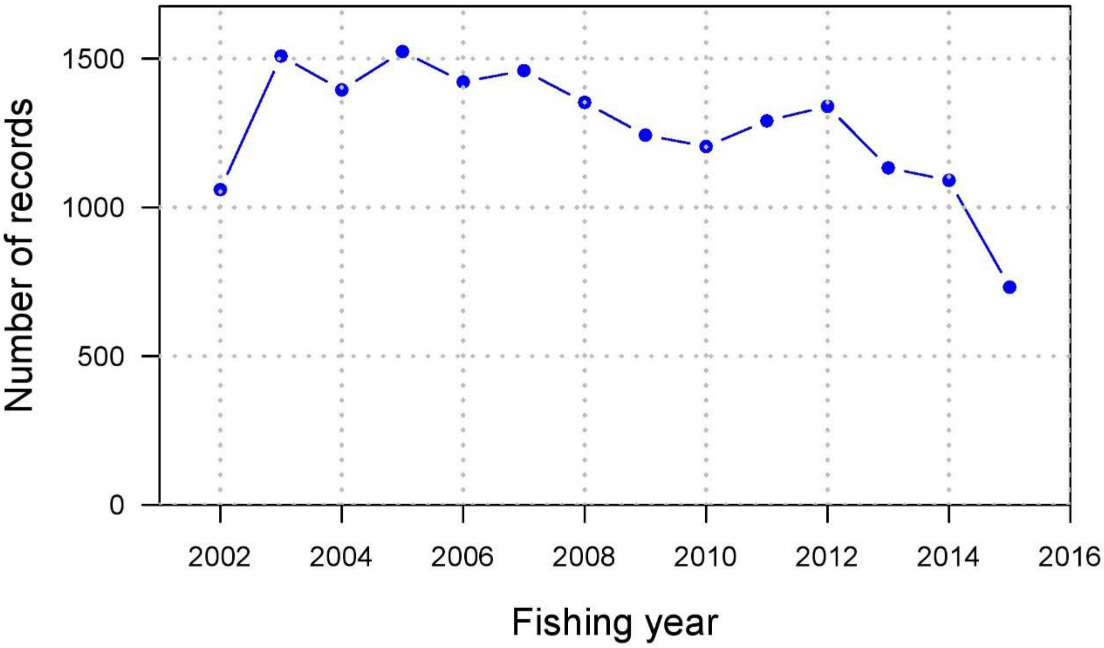


Figure 46: Number of records retained in the PCELR dataset after subsetting by FIN.

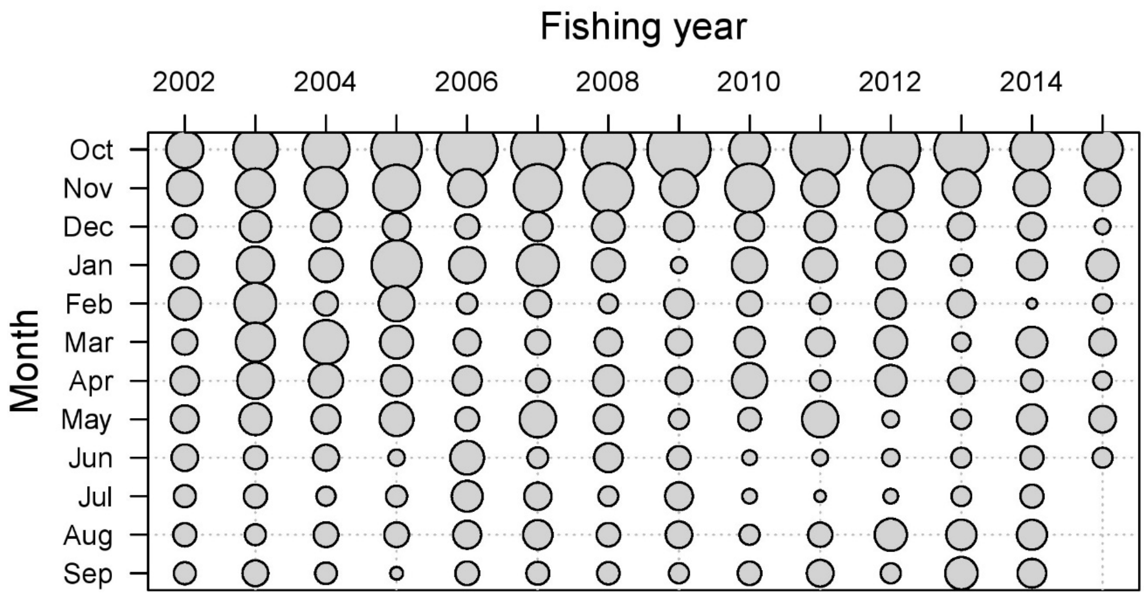


Figure 47: Overlap in number of PCELR records by month and fishing year. The area of a circle is proportional to the number of records.

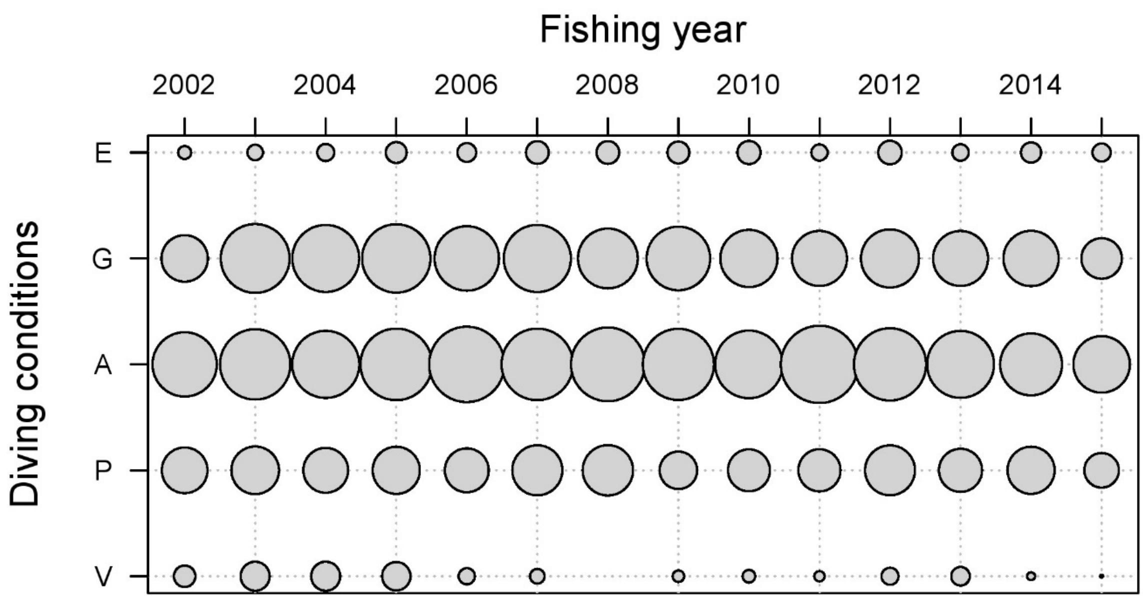


Figure 48: Number of PCELR records by diving condition (excellent, good, average, poor, very poor) and fishing year. The area of a circle is proportional to the number of records.

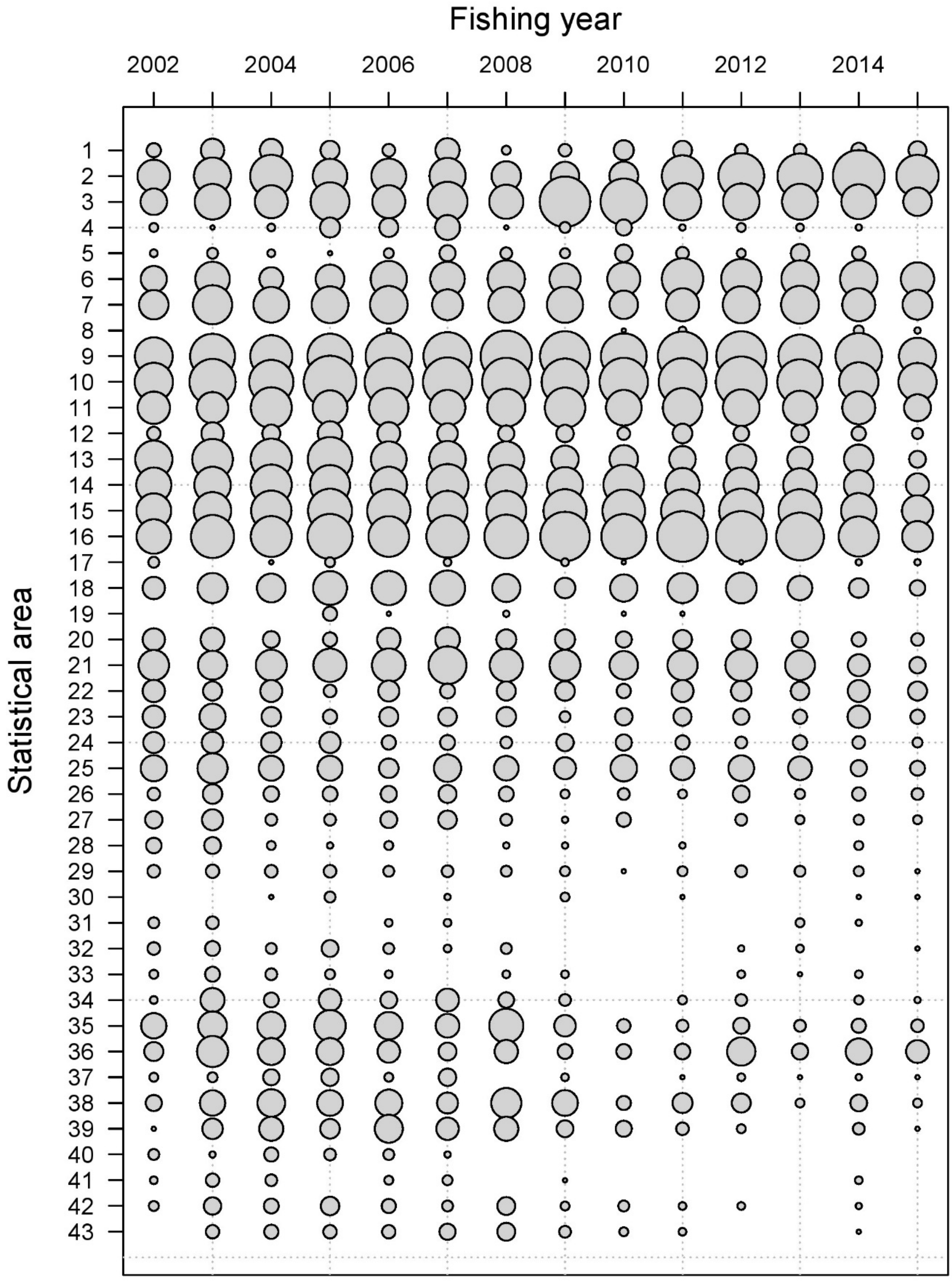


Figure 49: Number of PCELR records by statistical area and fishing year. The area of a circle is proportional to the number of records. Arbitrary labels are used for the statistical areas.

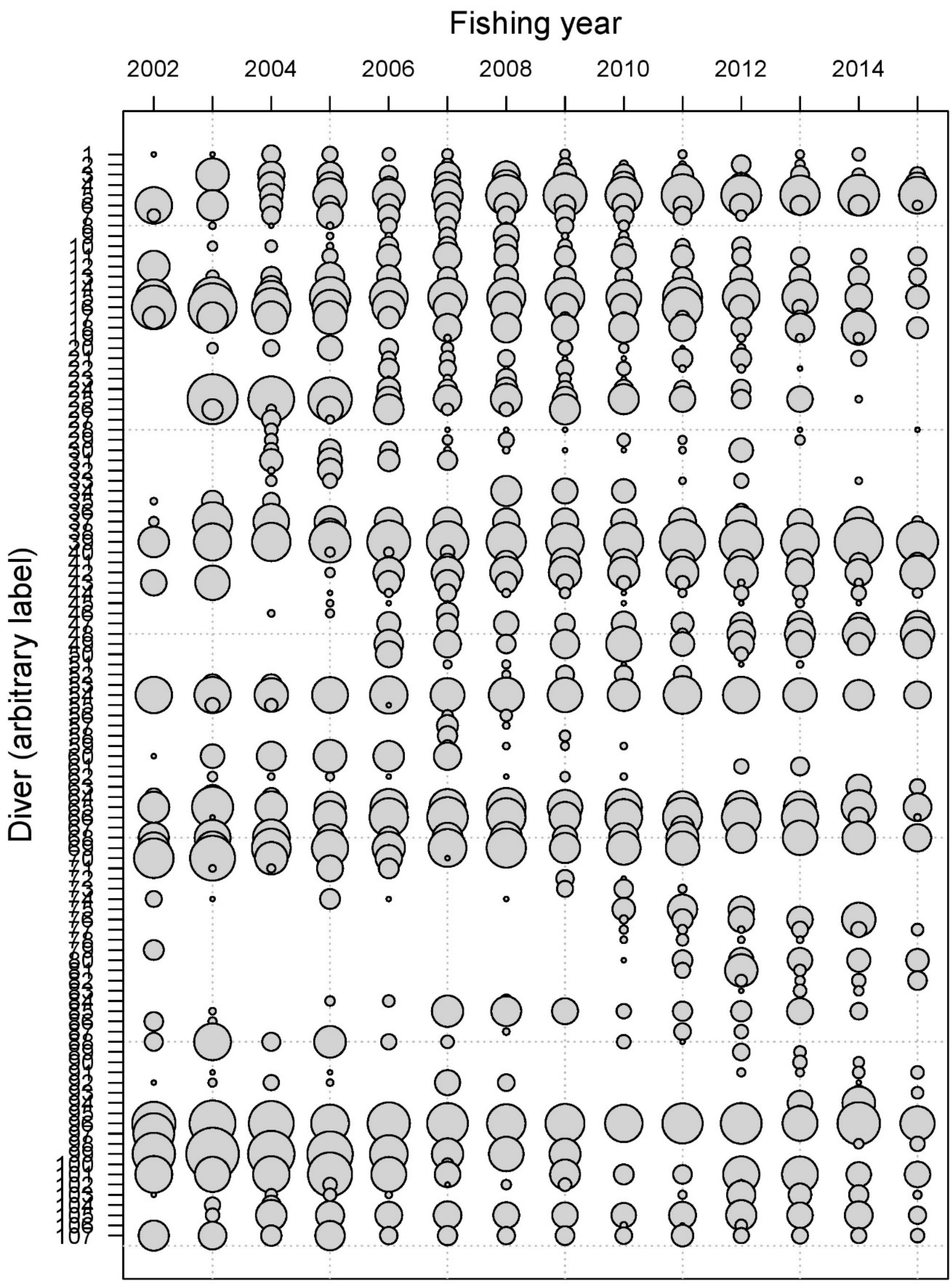


Figure 50: Number of PCELR records by diver key and fishing year. The area of a circle is proportional to the number of records.

Table 17: Variables accepted into the model for the PCELR dataset (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
fishing year	13	0.15
fishing duration	3	0.67
diverkey	106	0.77
stats area code	42	0.79
month	11	0.80

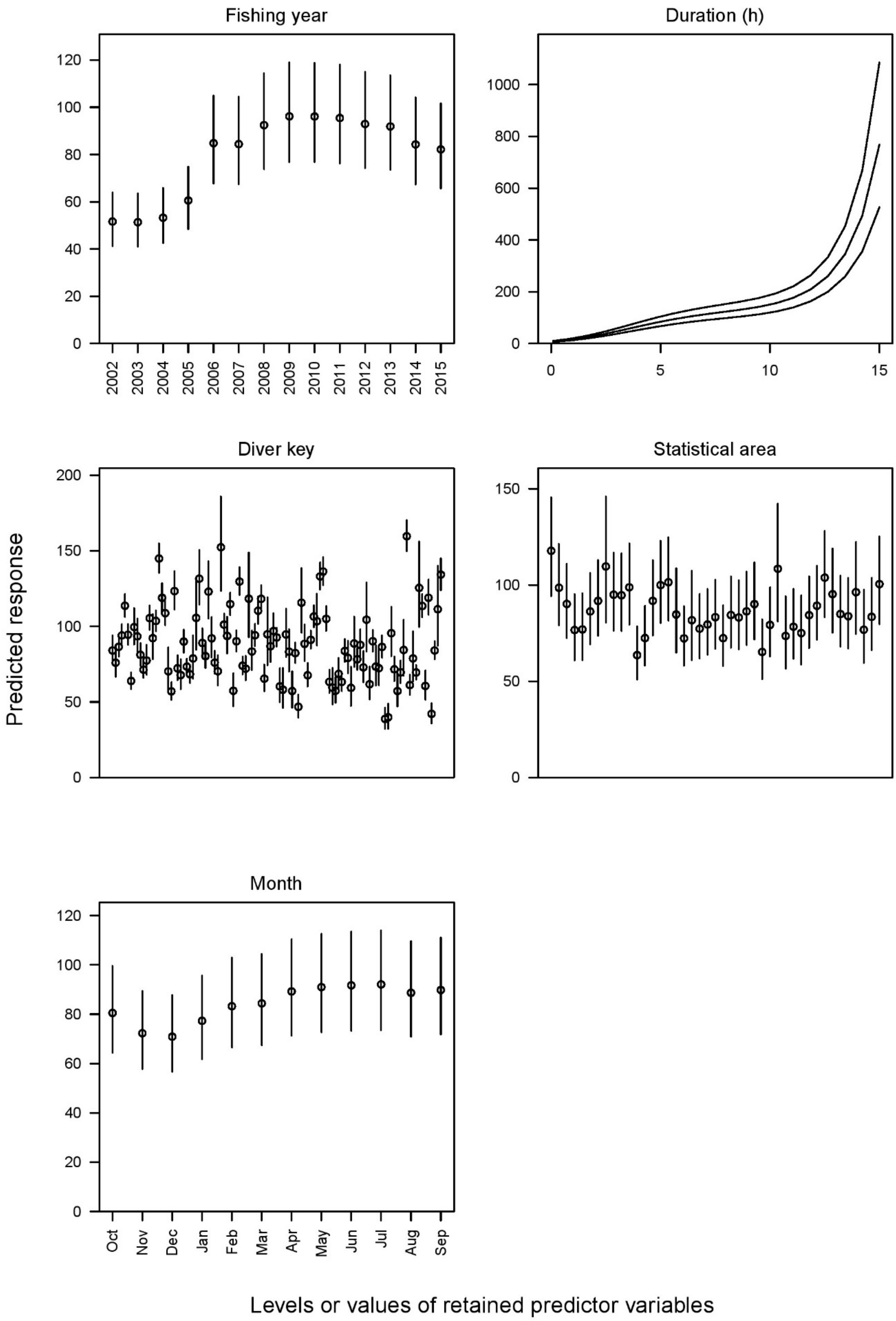


Figure 51: Effects for the PCELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

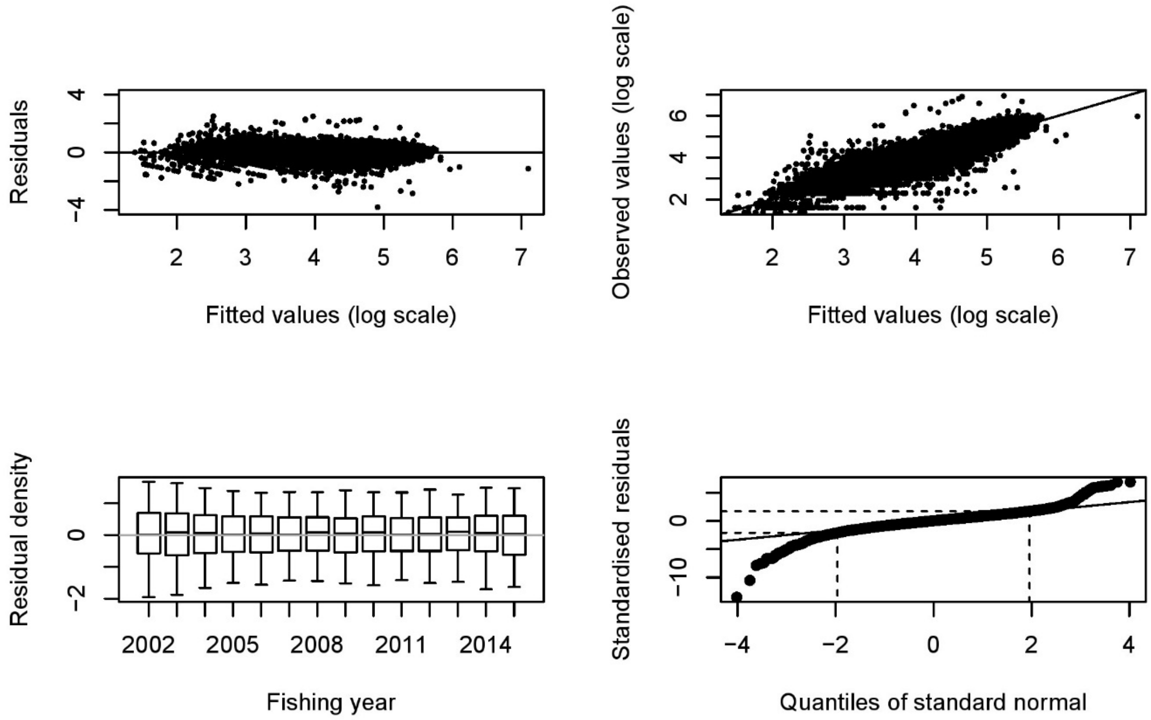


Figure 52: Diagnostic plots for the PCELR standardisation model.

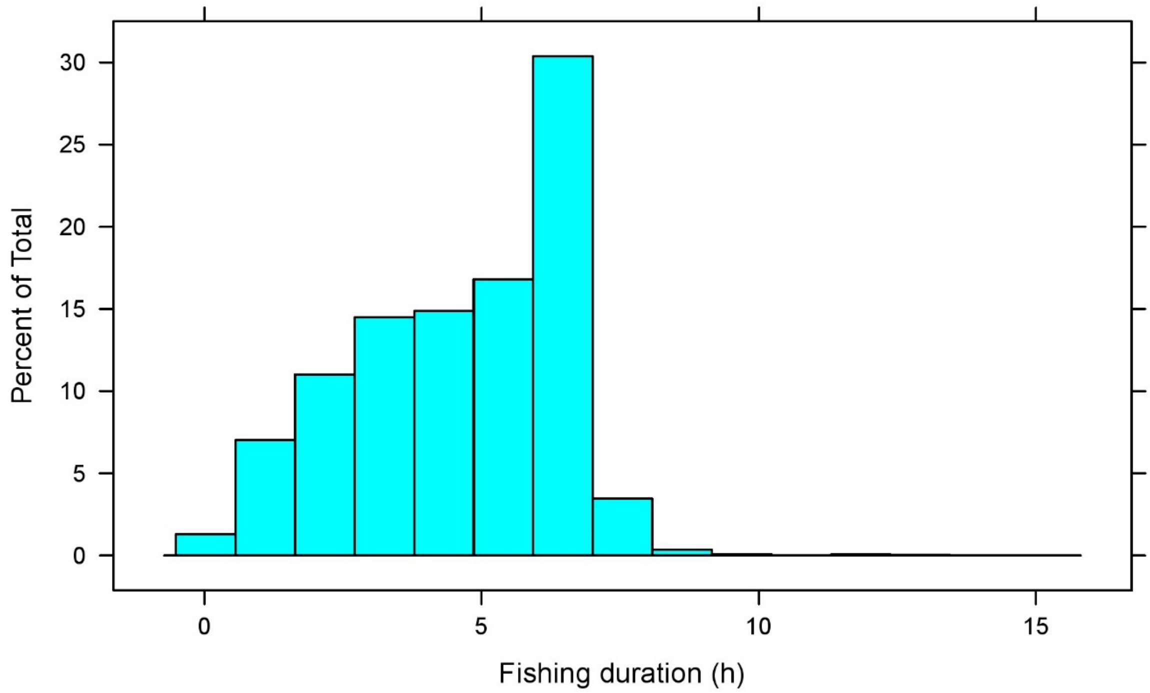


Figure 53: Distribution of fishing duration (h) for the PCELR dataset.

Table 18: Standardised index for the PCELR data set, lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
2002	0.66	0.62	0.71	0.03
2003	0.66	0.62	0.70	0.03
2004	0.68	0.65	0.72	0.03
2005	0.78	0.74	0.82	0.03
2006	1.09	1.03	1.15	0.03
2007	1.09	1.03	1.15	0.03
2008	1.19	1.12	1.26	0.03
2009	1.24	1.17	1.31	0.03
2010	1.24	1.16	1.31	0.03
2011	1.23	1.16	1.30	0.03
2012	1.20	1.13	1.26	0.03
2013	1.18	1.11	1.26	0.03
2014	1.08	1.02	1.15	0.03
2015	1.06	0.98	1.14	0.04

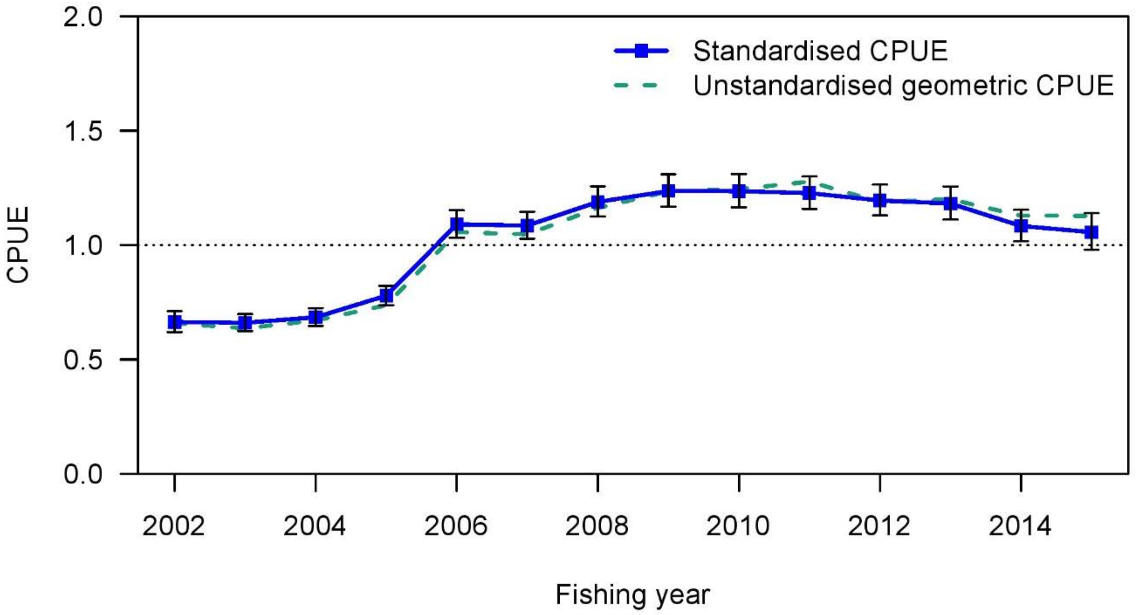


Figure 54: The standardised CPUE index for the PCELR dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

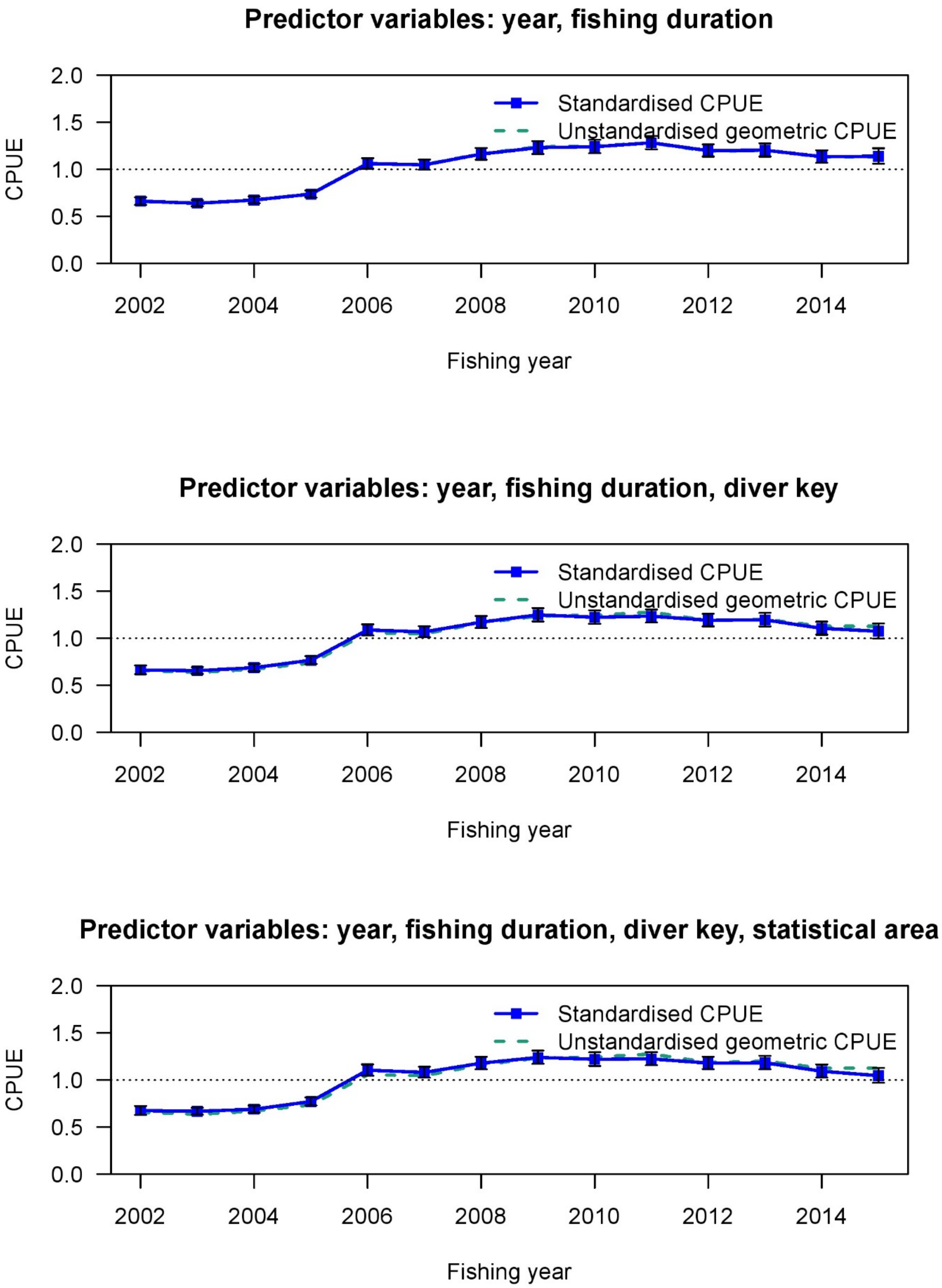


Figure 55: Stepwise addition of predictor variables. The standardised CPUE index for the PCELR dataset with 95% confidence interval. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

Table 19: Paua Statistical Areas associated with the sub areas.

	Paua Statistical Area
East Coast	P701–P713
Fighting Bay South	P714–P719
Tory South	P720–P724
Tory North	P725–P729
Northern Entrance	P730–P735
Pelorus	P736–P756
D'Urville	P757–P774
West Coast	P790–P797

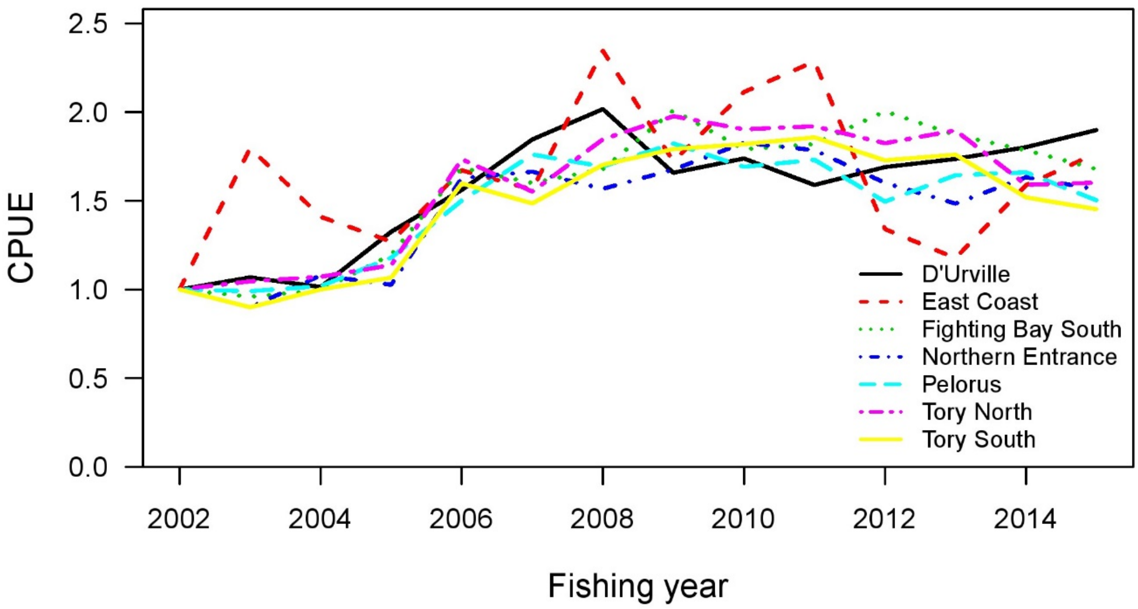


Figure 56: Standardised indices for the PCELR dataset with a year:area interaction forced into the model. The areas are sub-areas. The indices are scaled to have value one in 2002.

4.8 Combined data (1990–2015)

4.8.1 The combined data set

For the years 1990–2001 the same initial data set is used as in the CELR standardisations. For the PCELR data the catch and fishing effort (both duration and number of divers) are collapsed down to a daily total for a given date, vessel, and large scale area (017 or 018). The collapsed PCELR data is then combined with the CELR data to give a dataset covering 1990–2015. When using the daily number of divers as the measure of effort then all data is used. If fishing duration is used as the measure of effort then records with a fishing duration per diver greater than 10 hours are dropped (as is done for the CELR data).

For the combined data set the daily hours per diver increases from 1990 to 2000, then decreases until 2004, afterwards remaining fairly stable (Figures 57–58). A raw CPUE based on either total daily duration or number of divers as the measure of effort shows a decline from 1990–2001 then an increase to 2009, followed by a decline (Figure 59).

4.8.2 Standardisation using total fishing duration as effort

FIN is used to identify a core subset 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 15 records per year for a minimum of 5 years was chosen, this retaining 81% of the catch over 1990–2015 (Figure 60). While 81% of the catch is retained overall, it is slightly less than this for some years (Figures 61–62). Number of days of effort retained after subsetting is 361 or more for every fishing year (Table 20, Figure 63). The number of FIN holders drops from 188 to 55 under the subsetting criteria.

There is good overlap in effort over time for the FIN holders after subsetting (Figures 64–65). Similarly overlap in time for month is good (Figure 66).

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

The model explained 68% of the variability in CPUE with fishing duration (48%) explaining most of this followed by FIN (9%) (Table 21). The effects appear plausible and the model diagnostics good (Figures 67–68). There is an apparent increasing effect for the catch taken after a fishing duration of 50 hours, though for the majority of records fishing duration is less than this (Figure 69). The standardised index shows a decline from 1990–2001, followed by an increase until 2009, after which it declines (Table 22, Figure 70).

4.8.3 Standardisation using the number of divers as effort

FIN is used to identify a core subset 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 15 records per year for a minimum of 5 years was chosen, this retained 81% of the catch over 1990–2015 (Figure 71). While 81% of the catch is retained overall, it is slightly less than this for some years (Figures 72–73). The number of days of effort retained after subsetting is 361 or more for each individual fishing year (Table 23, Figure 74). After subsetting; the number of FIN holders drops from 189 to 55.

There is good overlap in effort over time for the FIN holders (Figures 75–76) and overlap in time for month is also good (Figure 77).

The model explained 41% of the variability in CPUE with fishing duration (9%) explaining most of this followed by FIN (21%) (Table 24). The effects appear plausible and the model diagnostics good (Figures 78–79). The standardised index shows a decline until 1997, after which it is approximately constant (Table 25, Figure 80).

4.8.1 Comparing standardisations using different measures of effort

The indices using different measures of effort show similar patterns, with the standardised index using fishing duration as the measure of effort showing slightly more decline from 1990 to 2015 (Figures 81–82).

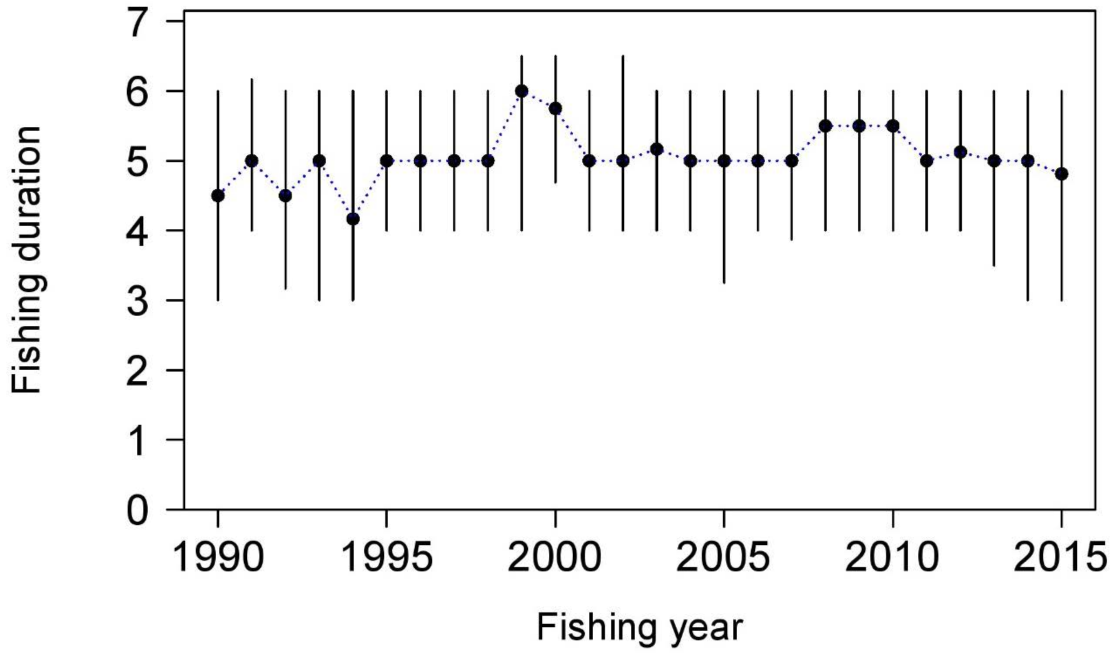


Figure 57: Quantiles by fishing year for daily fishing hours per diver in the CELR/PCELR dataset: medians (dot) and lower and upper quartiles (vertical lines). Records with a value greater than 10 hours are dropped.

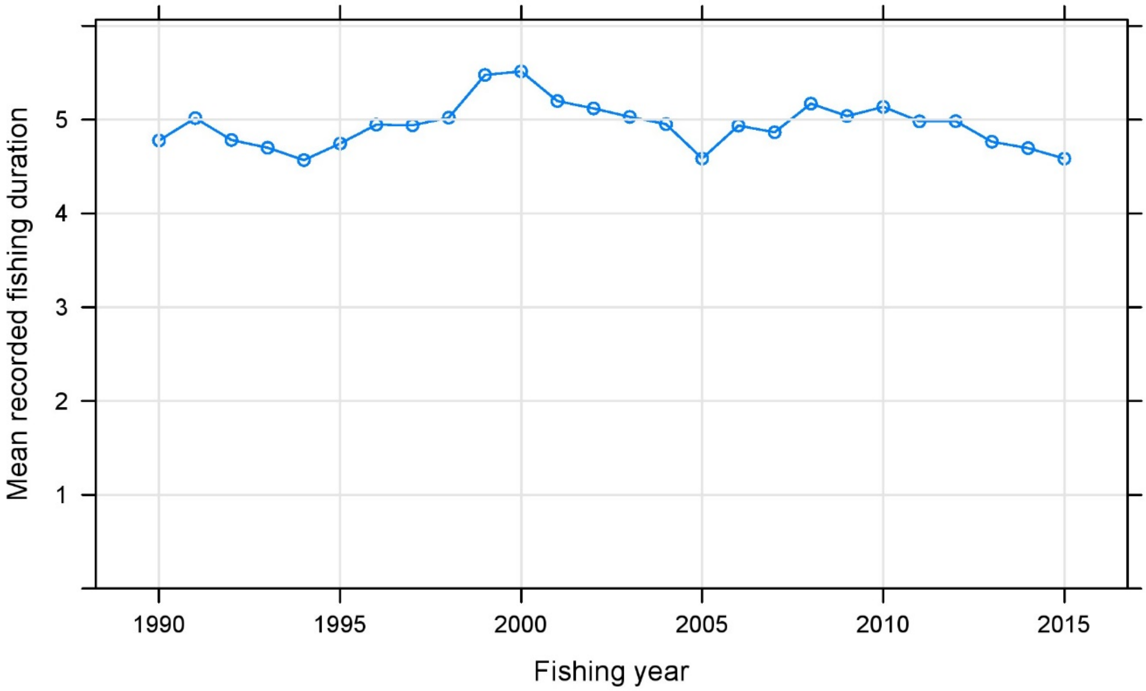


Figure 58: Mean values by fishing year for the daily hours per diver in the CELR/PCELR dataset. Records with a value greater than 10 hours are dropped.

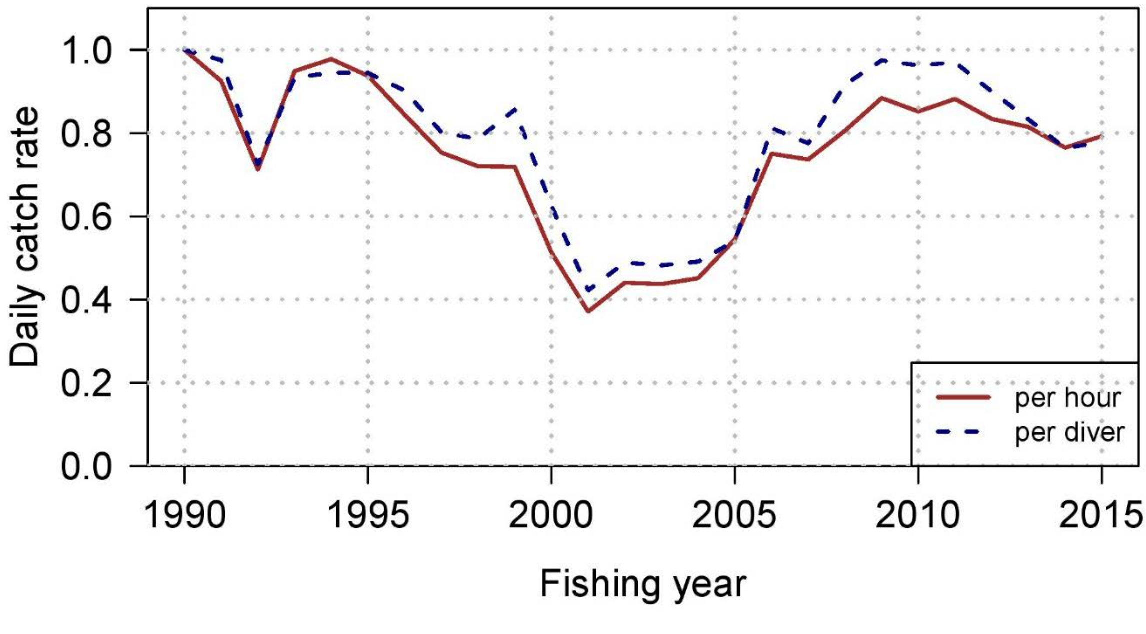


Figure 59: Geometric mean of the daily catch rate by year in the CELR/PCELR dataset. The plots are scaled so that they both have the value one in 1990. Records with a fishing duration per diver greater than 10 hours are dropped.

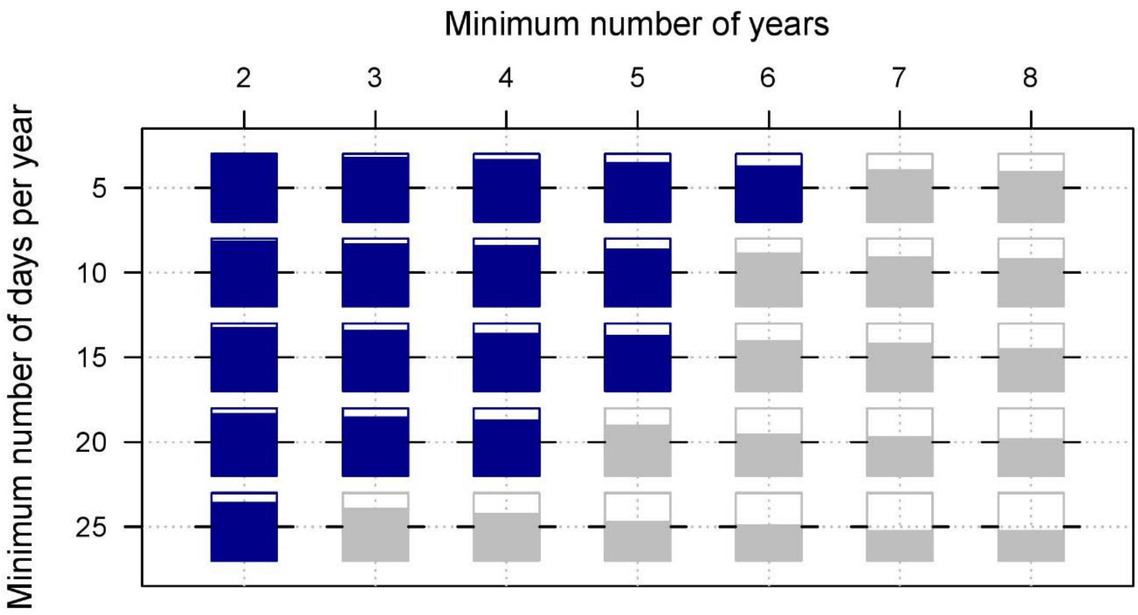


Figure 60: Proportion of the catch taken in the CELR/PCELR dataset (using total fishing duration) when subsetting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2015 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

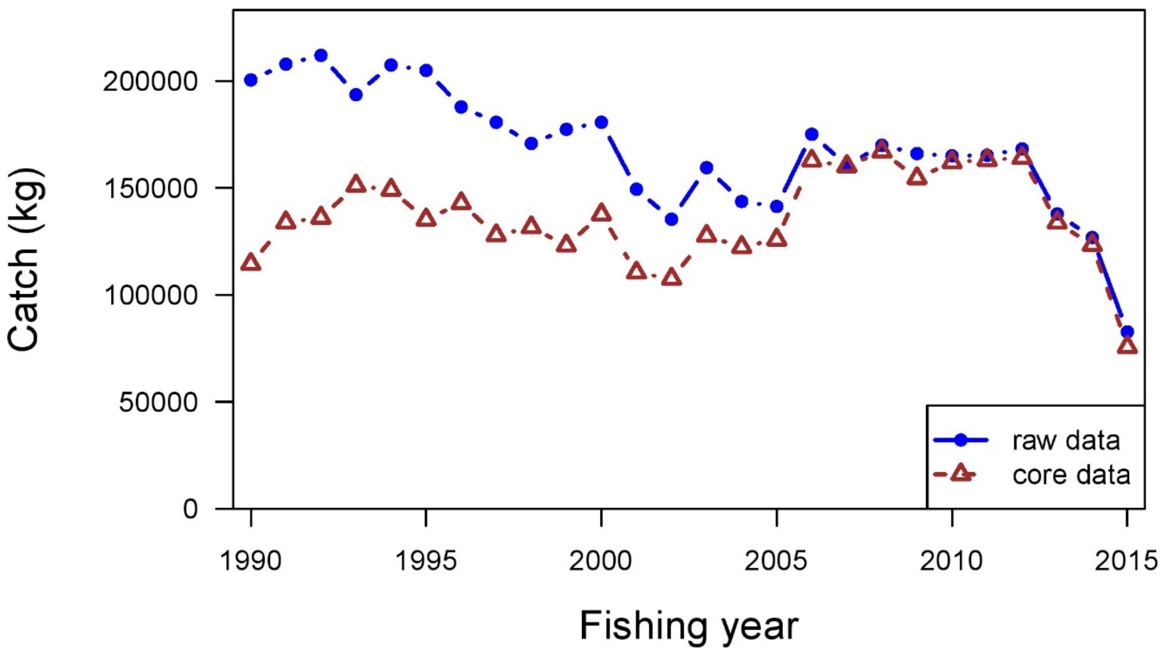


Figure 61: Catch by fishing year in the CELR/PCELR dataset (using total fishing duration) before FIN subsetting (raw data) and after (core data).

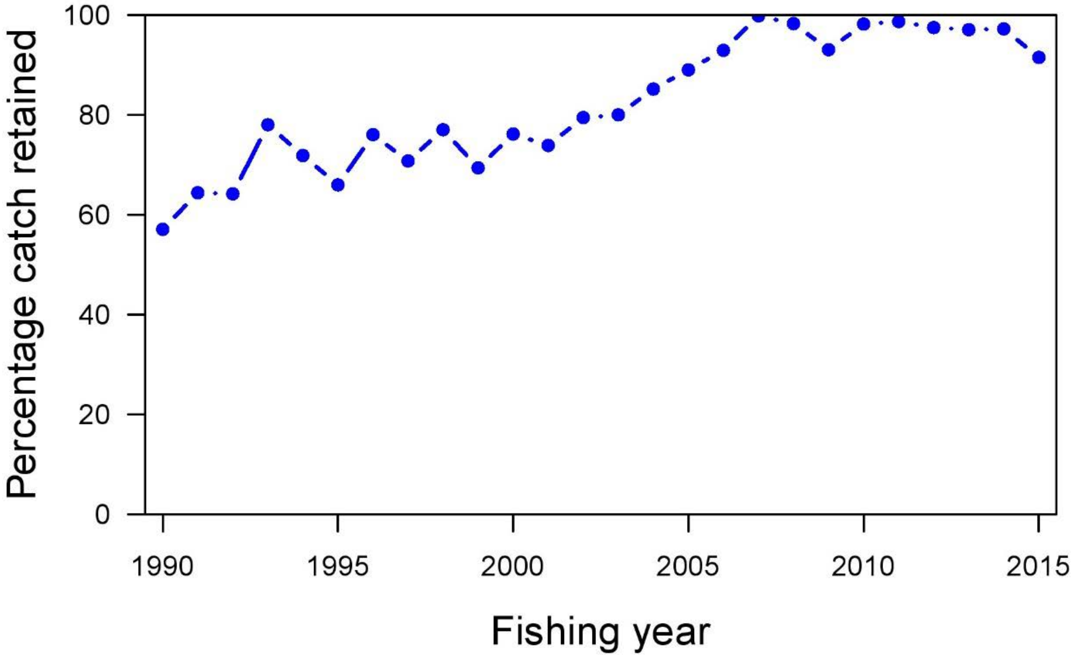


Figure 62: Percentage of the catch in the CELR/PCELR dataset (using total fishing duration) retained after FIN subsetting.

Table 20: Number of records in the CELR/PCELR dataset (using total fishing duration) before and after FIN subsetting.

Fishing year	Before	After
1990	1012	532
1991	1062	637
1992	1217	738
1993	871	682
1994	887	614
1995	921	606
1996	910	718
1997	998	713
1998	909	715
1999	905	618
2000	1 244	970
2001	1 514	1053
2002	1 100	837
2003	1 295	978
2004	1 101	915
2005	943	800
2006	798	725
2007	754	746
2008	703	680
2009	669	637
2010	692	664
2011	666	656
2012	701	676
2013	611	578
2014	589	565
2015	401	361
Total	23 473	18 414

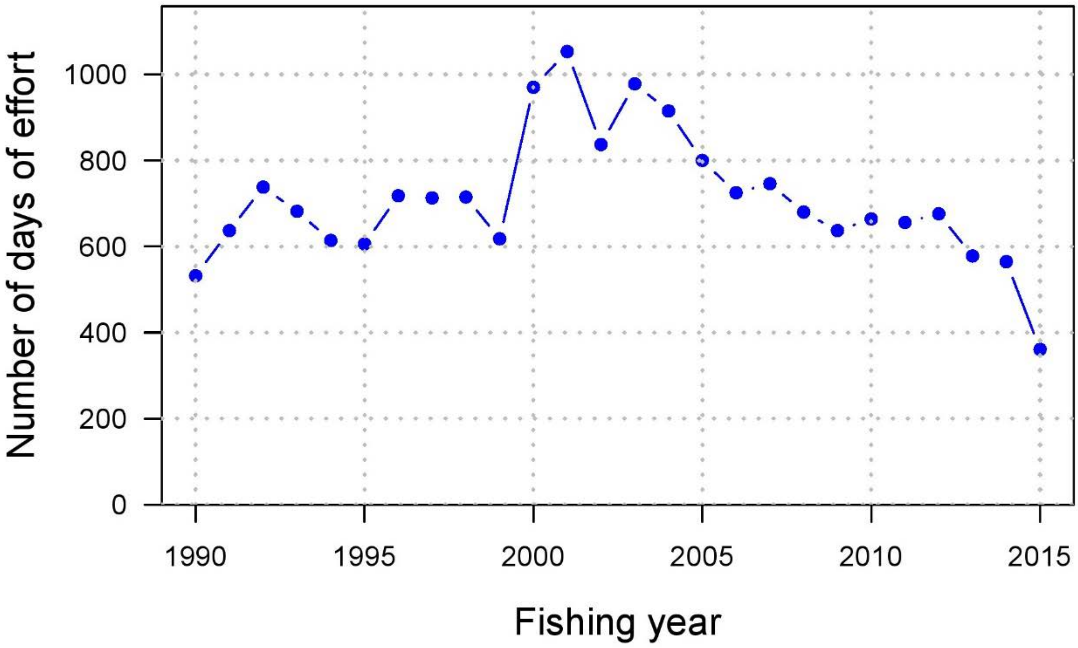


Figure 63: Number of days of effort in the CELR/PCELR dataset (using total fishing duration) retained after FIN subsetting.

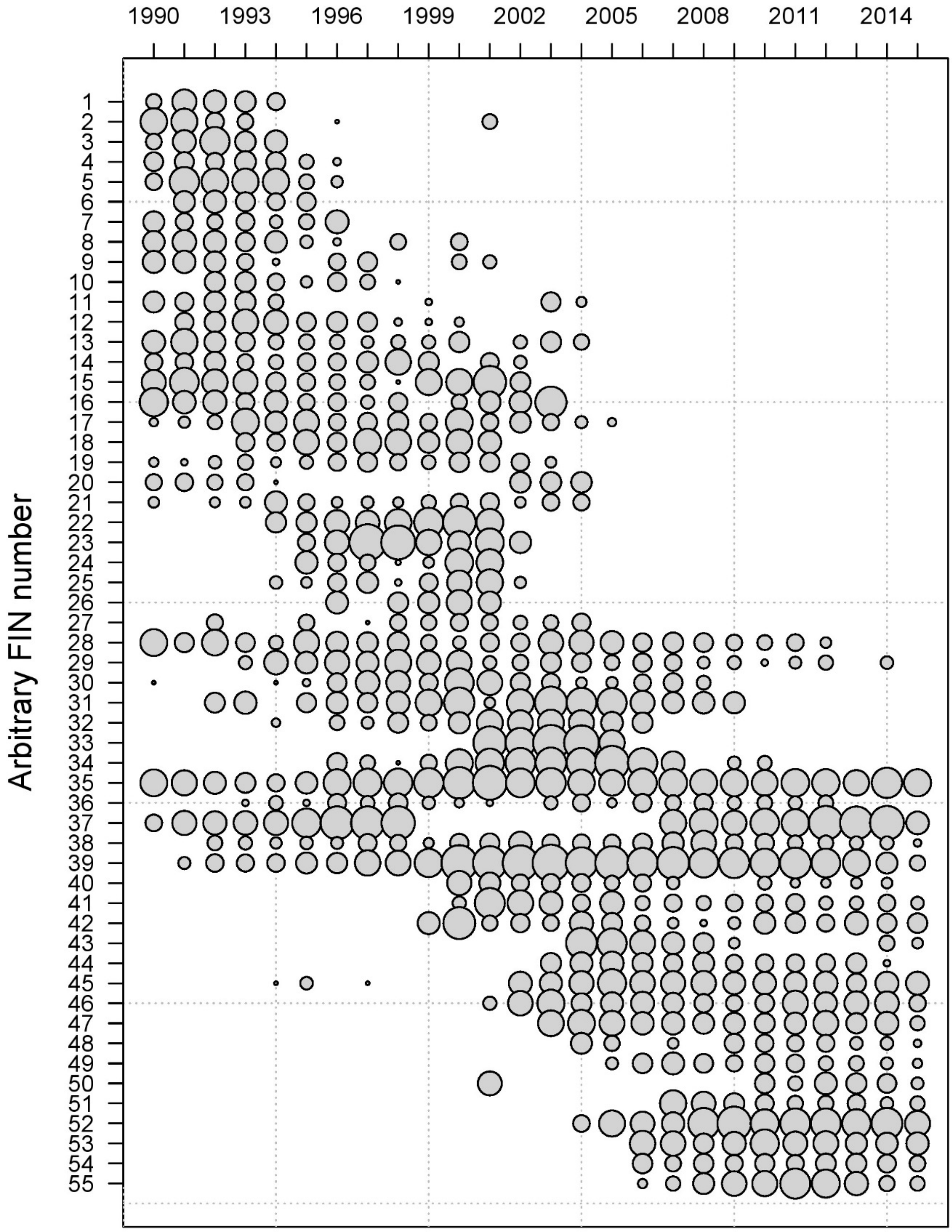


Figure 64: Overlap in days of effort by FIN in the CELR/PCELR dataset (using total fishing duration). The area of a circle is proportional to the days of effort.

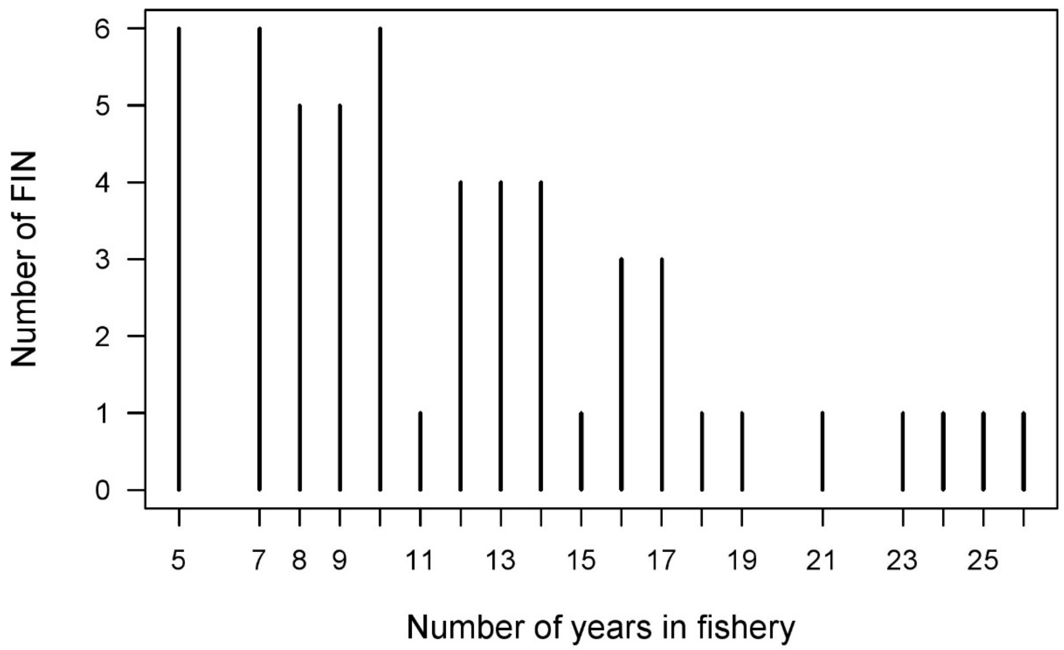


Figure 65: Number of years in the fishery for a FIN holder in the CELR/PCELR dataset (using total fishing duration) after subsetting by FIN.

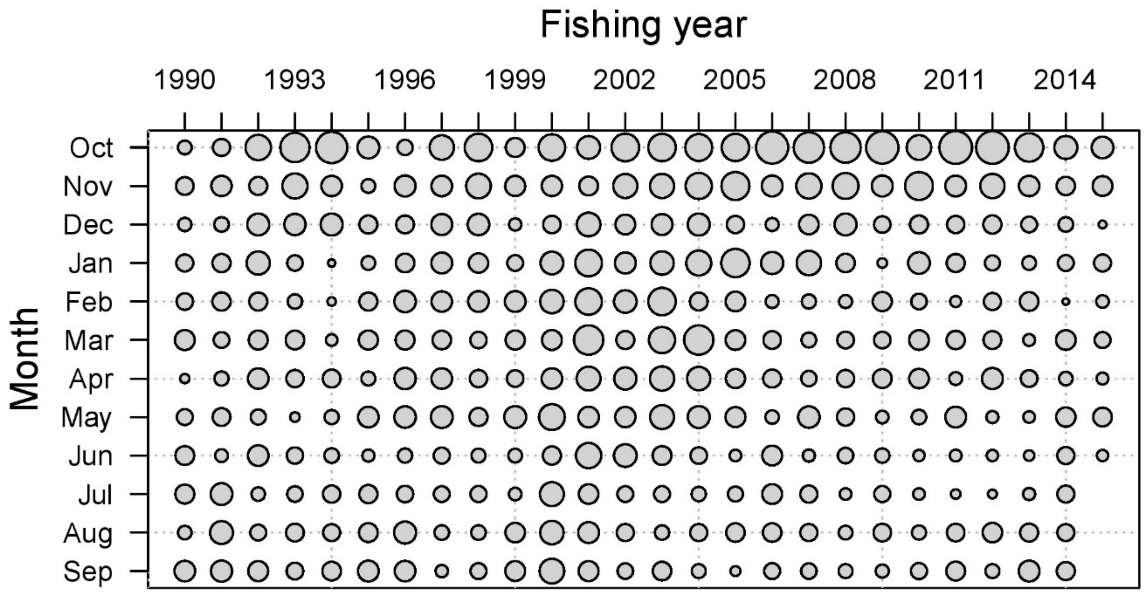


Figure 66: Overlap in days of effort for month by fishing year in the CELR/PCELR dataset (using total fishing duration).

Table 21: Variables accepted into the CELR/PCELR 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	25	0.11
fishing duration	3	0.59
FIN	54	0.68

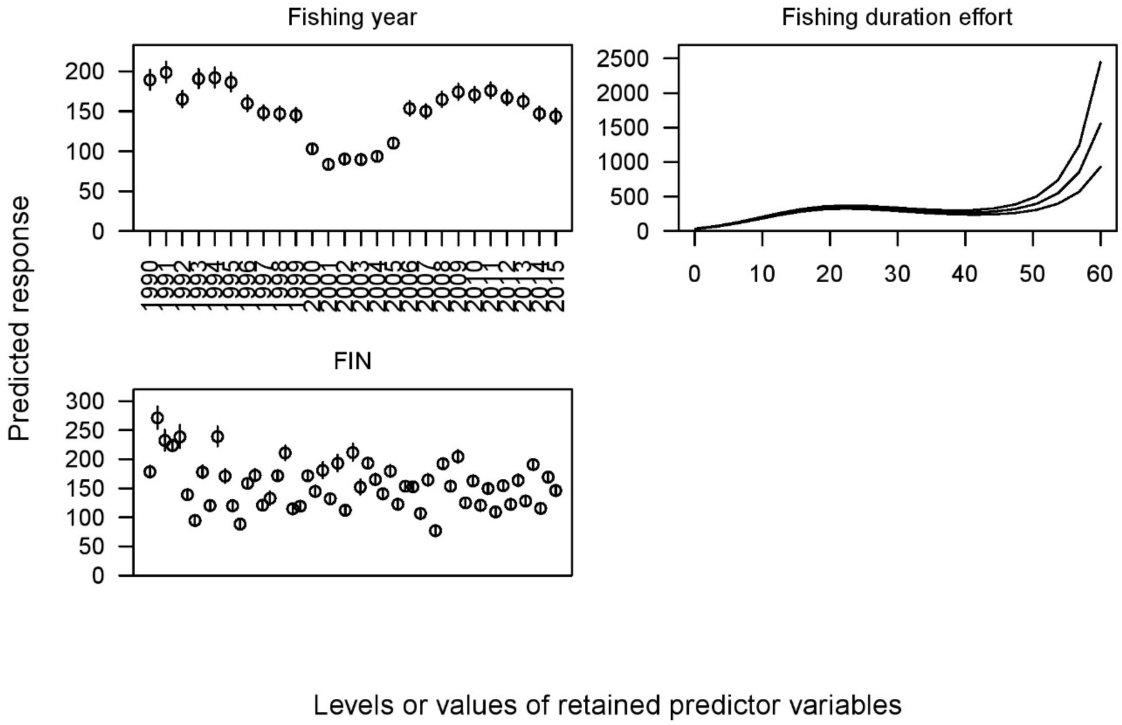


Figure 67: Effects for the combined standardisation model in the CELR/PCELR dataset (using total fishing duration). Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

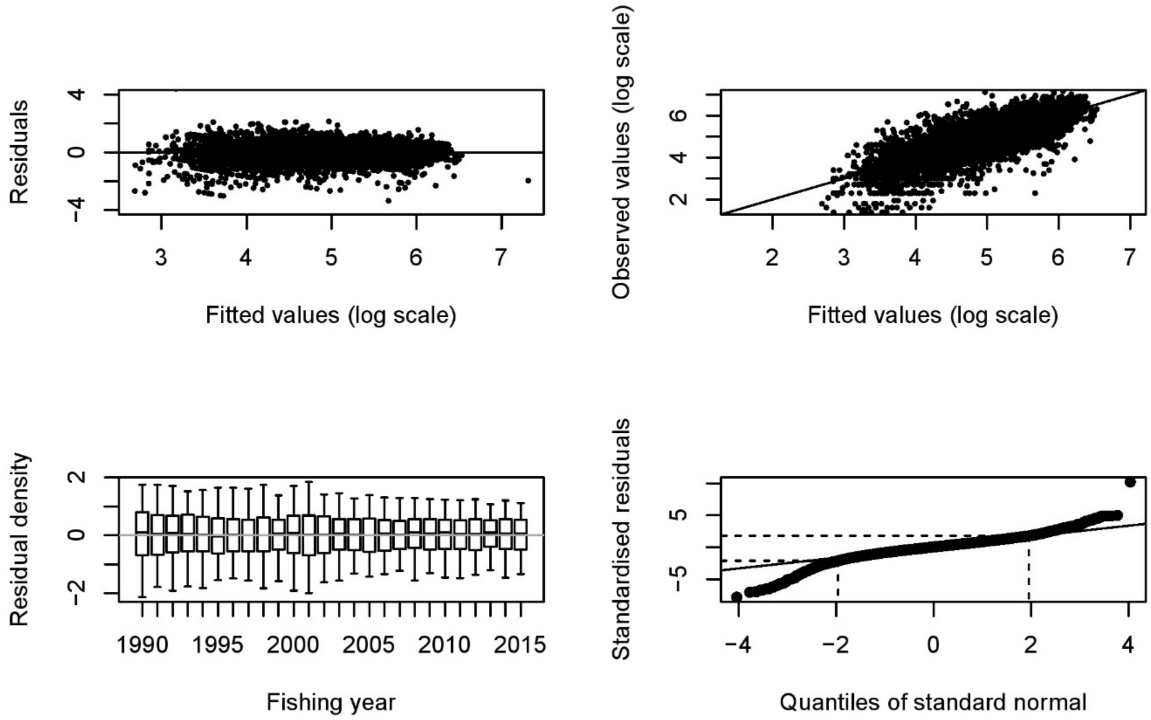


Figure 68: Residuals for the standardisation model for the CELR/PCELR dataset (using total fishing duration).

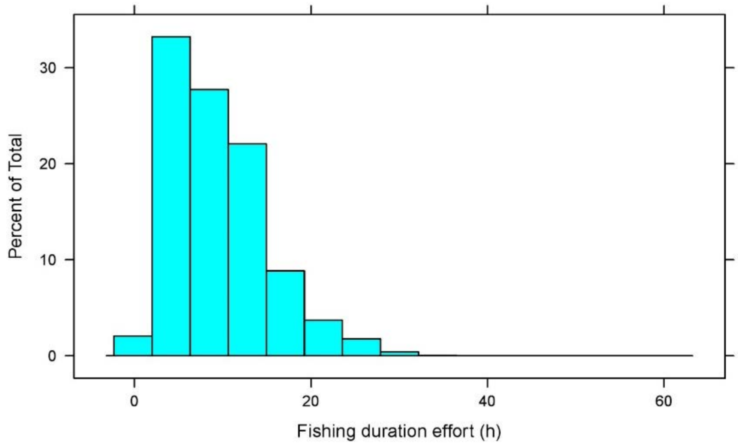


Figure 69: Distribution of fishing duration effort (h) in the CELR/PCELR dataset (using total fishing duration).

Table 22: Standardised index for the combined CELR/PCELR dataset (using total fishing duration), lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
1990	1.30	1.18	1.43	0.05
1991	1.36	1.25	1.49	0.04
1992	1.13	1.05	1.23	0.04
1993	1.31	1.21	1.42	0.04
1994	1.32	1.21	1.44	0.04
1995	1.28	1.18	1.39	0.04
1996	1.10	1.02	1.19	0.04
1997	1.02	0.94	1.10	0.04
1998	1.01	0.93	1.09	0.04
1999	1.00	0.92	1.08	0.04
2000	0.71	0.66	0.76	0.03
2001	0.57	0.54	0.61	0.03
2002	0.62	0.58	0.67	0.04
2003	0.62	0.58	0.66	0.03
2004	0.64	0.60	0.69	0.03
2005	0.76	0.70	0.81	0.04
2006	1.05	0.98	1.14	0.04
2007	1.03	0.96	1.11	0.04
2008	1.13	1.05	1.22	0.04
2009	1.20	1.10	1.30	0.04
2010	1.17	1.08	1.27	0.04
2011	1.21	1.12	1.31	0.04
2012	1.15	1.06	1.24	0.04
2013	1.12	1.03	1.21	0.04
2014	1.01	0.93	1.10	0.04
2015	0.99	0.89	1.10	0.05

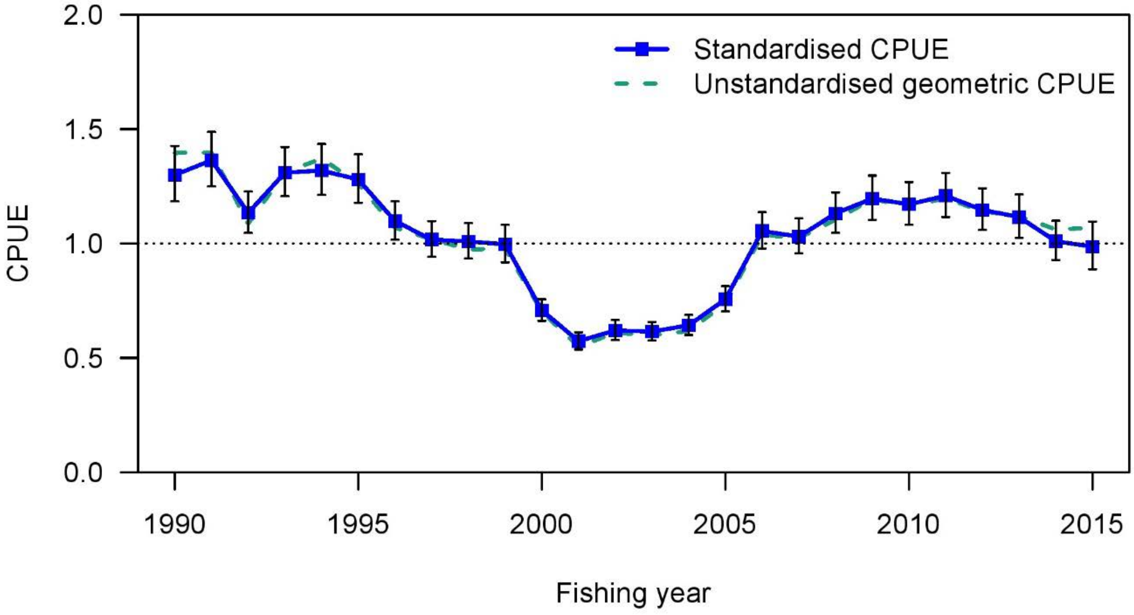


Figure 70: The standardised CPUE index in the CELR/PCELR dataset (using total fishing duration) with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

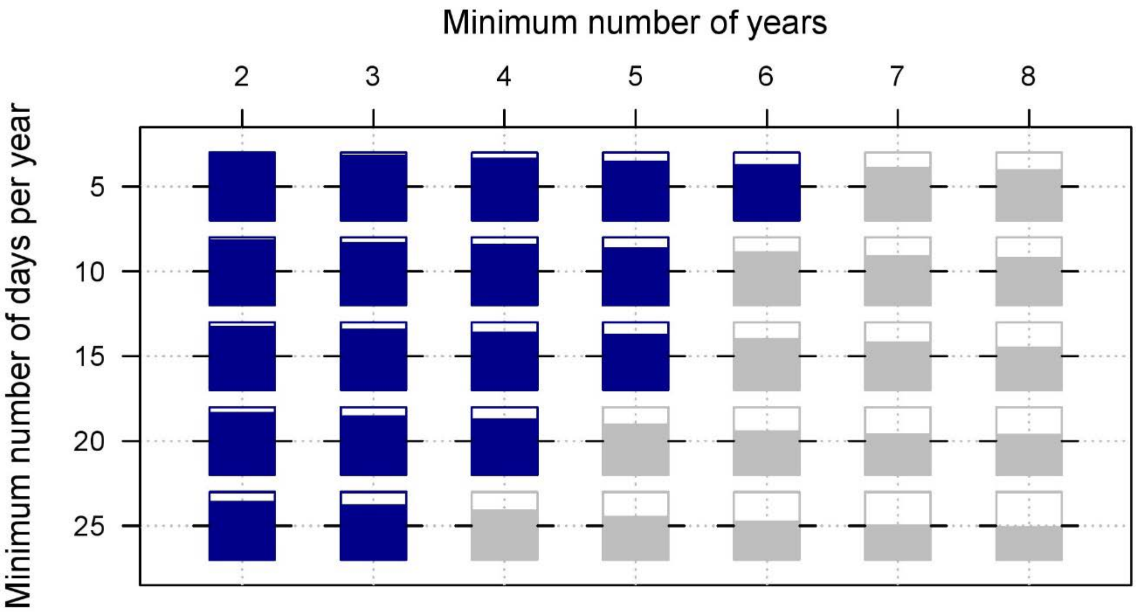


Figure 71: Proportion of the catch taken in the CELR/PCELR dataset (using number of divers) when subsetting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2015 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

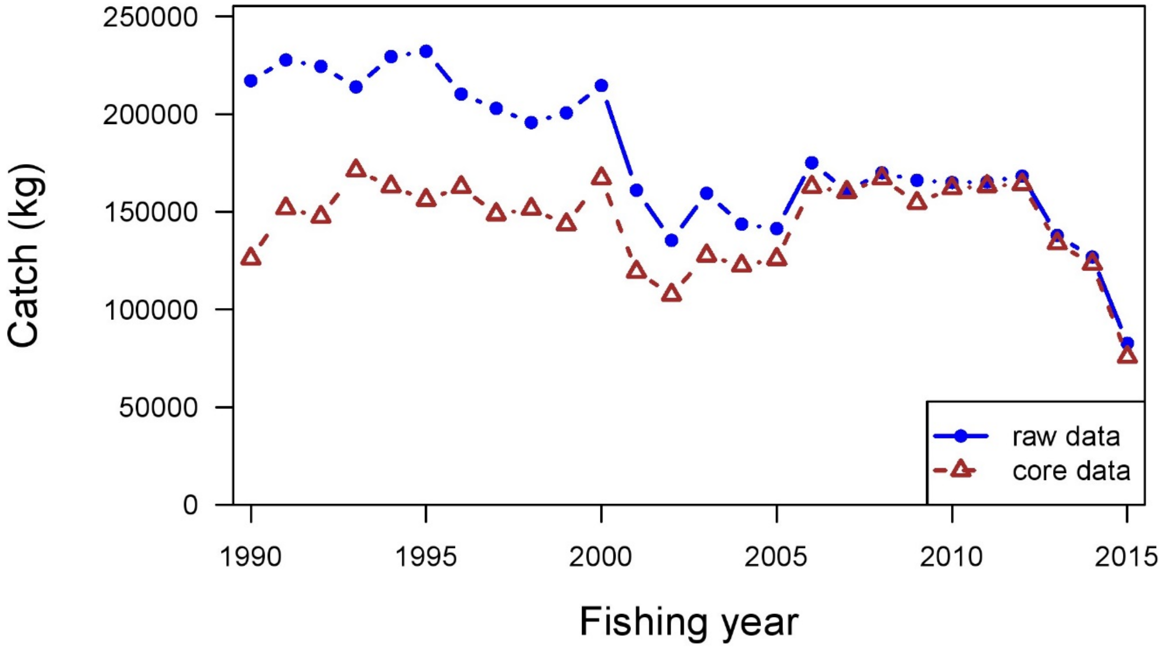


Figure 72: Catch by fishing year in the CELR/PCELR dataset (using number of divers) before FIN subsetting (raw data) and after (core data).

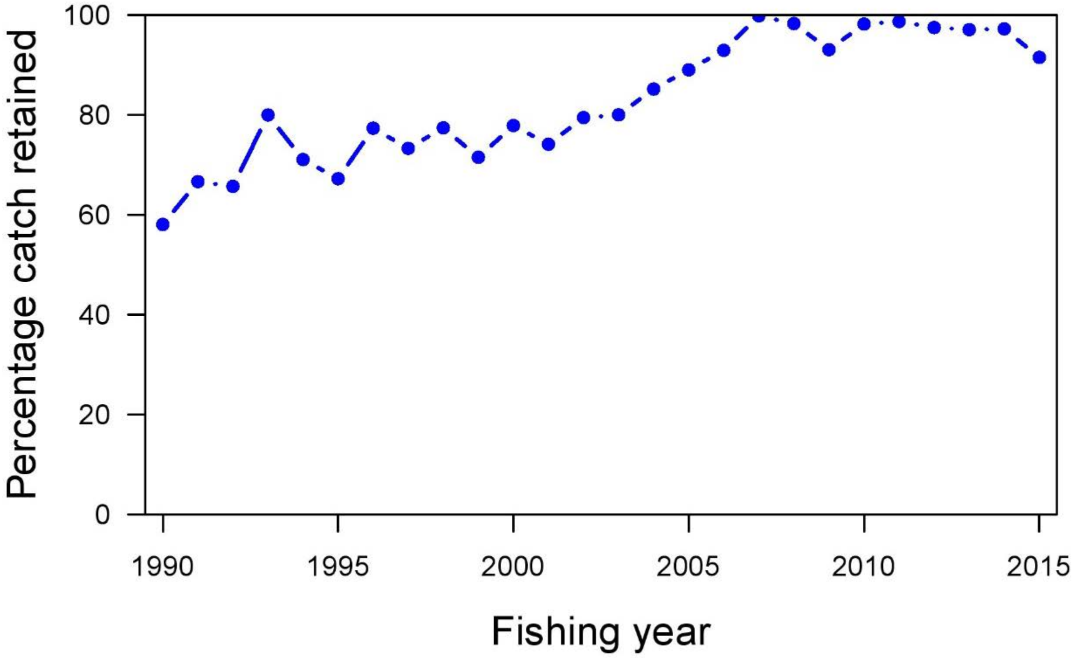


Figure 73: Percentage of the catch in the CELR/PCELR dataset (using number of divers) retained after FIN subsetting.

Table 23: Number of records in the CELR/PCELR dataset (using number of divers) before and after FIN subsetting.

Year	Before	After
1990	1 047	553
1991	1 121	685
1992	1 256	768
1993	919	729
1994	945	646
1995	986	656
1996	974	776
1997	1 067	775
1998	983	769
1999	962	670
2000	1 388	1 088
2001	1 581	1 102
2002	1 100	837
2003	1 295	978
2004	1 101	915
2005	943	800
2006	798	725
2007	754	746
2008	703	680
2009	669	637
2010	692	664
2011	666	656
2012	701	676
2013	611	578
2014	589	565
2015	401	361
Total	24 252	19 035

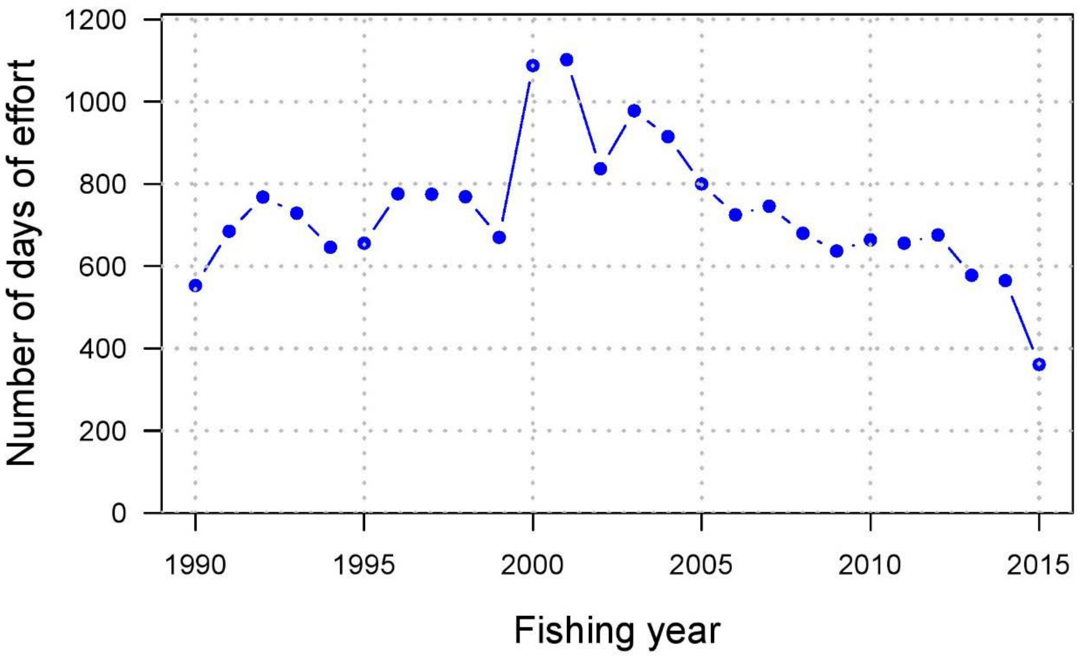


Figure 74: Number of days of effort in the CELR/PCELR dataset (using number of divers) retained after FIN subsetting.

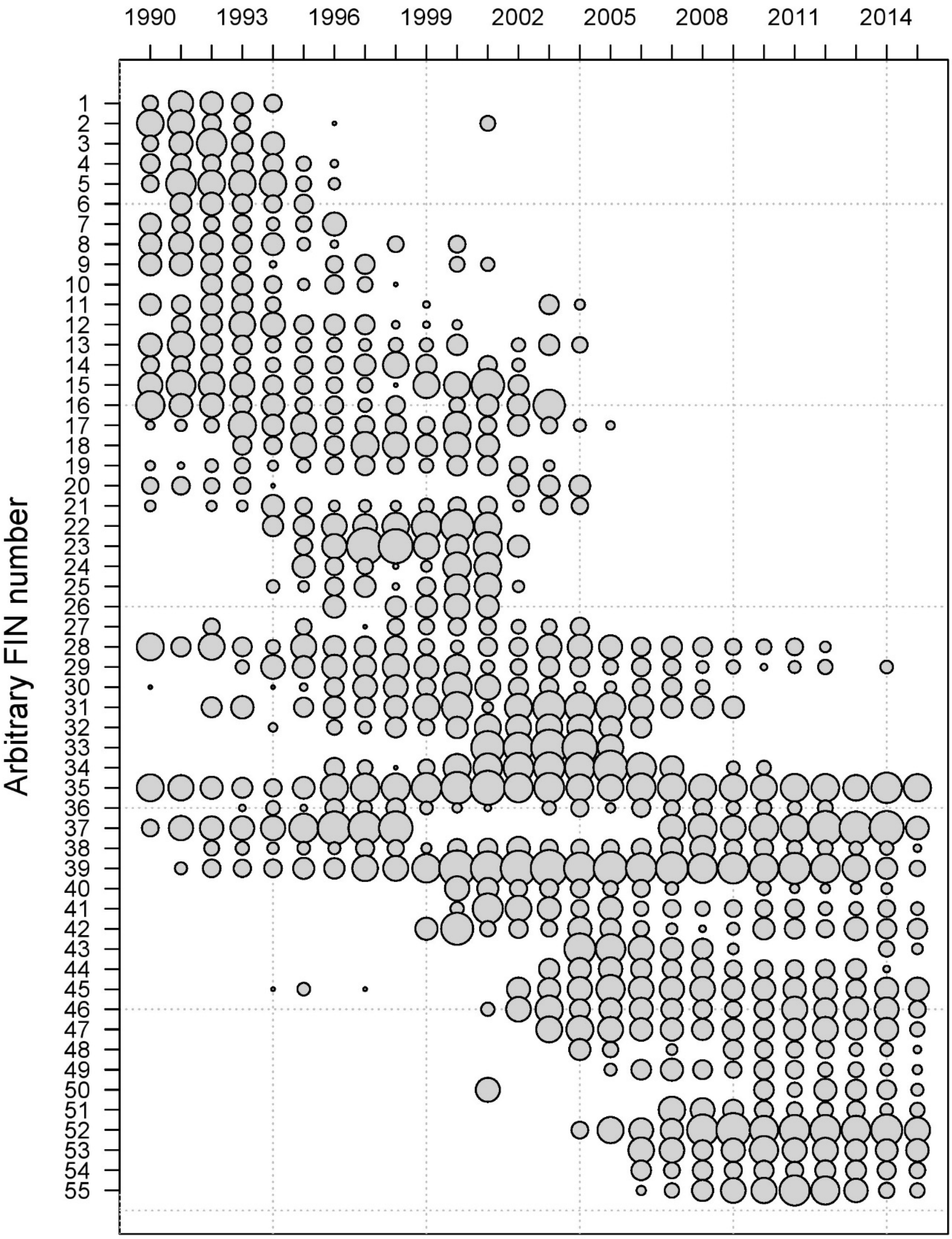


Figure 75: Overlap in days of effort in the CELR/PCELR dataset (using number of divers) by FIN. The area of a circle is proportional to the days of effort.

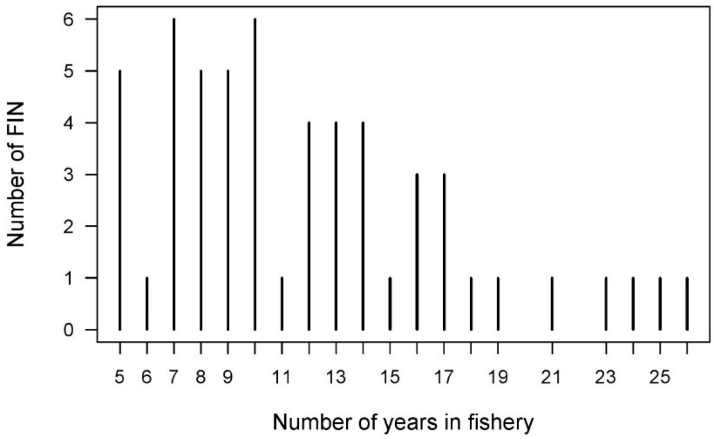


Figure 76: Number of years in the fishery in the CELR/PCELR dataset (using number of divers) for a FIN holder after subsetting by FIN.

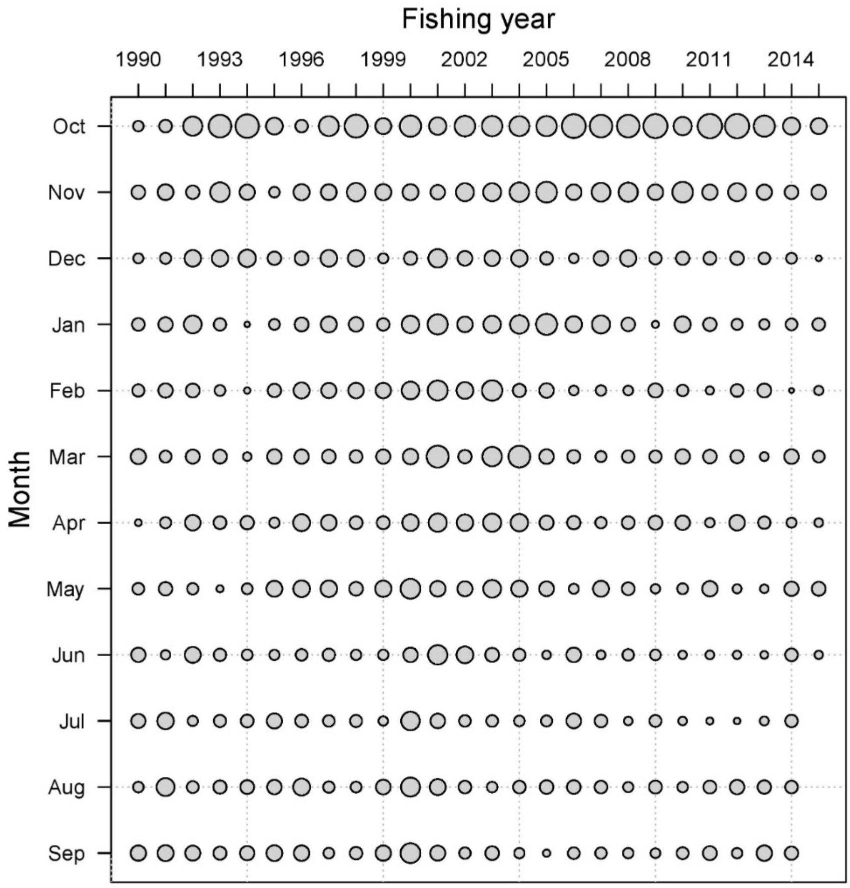


Figure 77: Overlap in days of effort for month by fishing year in the CELR/PCELR dataset (using number of divers).

Table 24: Variables accepted into the CELR/PCELR dataset (using number of divers) 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	25	0.11
client key (FIN)	54	0.31
number of divers	1	0.41

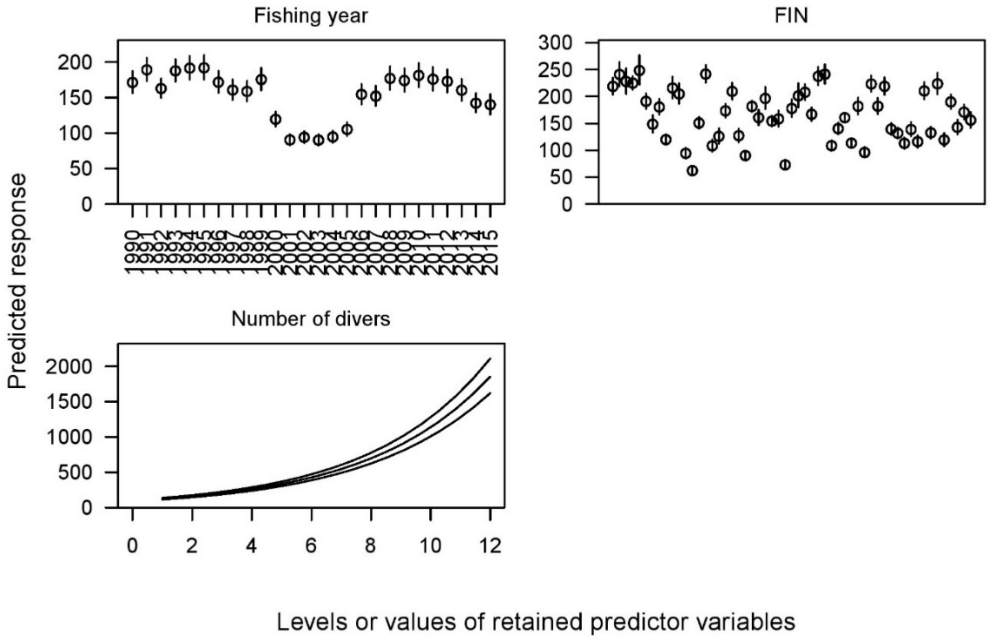


Figure 78: Effects for the standardisation model for the CELR/PCELR dataset (using number of divers). Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

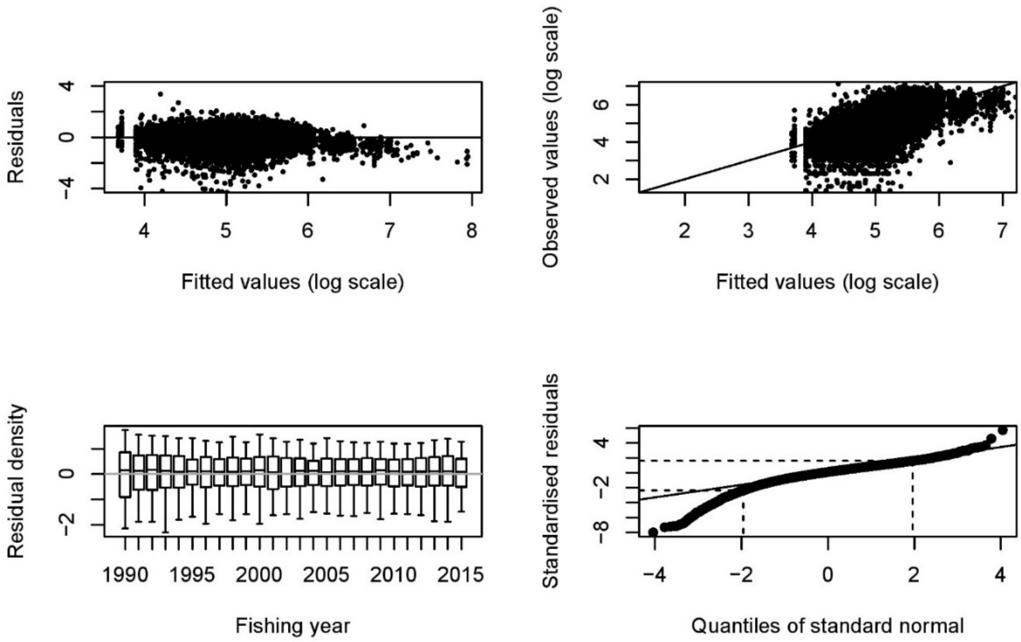


Figure 79: Residuals for the standardisation model for the CELR/PCELR dataset (using number of divers).

Table 25: Standardised index for combined CELR/PCELR data (using number of divers), lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
1990	1.15	1.05	1.26	0.05
1991	1.27	1.17	1.38	0.04
1992	1.09	1.01	1.18	0.04
1993	1.26	1.16	1.36	0.04
1994	1.28	1.18	1.39	0.04
1995	1.29	1.19	1.39	0.04
1996	1.15	1.07	1.24	0.04
1997	1.08	1.00	1.16	0.04
1998	1.06	0.99	1.15	0.04
1999	1.18	1.09	1.27	0.04
2000	0.80	0.75	0.85	0.03
2001	0.61	0.57	0.65	0.03
2002	0.63	0.59	0.68	0.04
2003	0.60	0.57	0.65	0.03
2004	0.63	0.59	0.68	0.03
2005	0.71	0.66	0.76	0.04
2006	1.04	0.96	1.12	0.04
2007	1.02	0.95	1.10	0.04
2008	1.19	1.10	1.28	0.04
2009	1.17	1.08	1.27	0.04
2010	1.22	1.12	1.32	0.04
2011	1.18	1.09	1.28	0.04
2012	1.16	1.07	1.25	0.04
2013	1.08	0.99	1.17	0.04
2014	0.95	0.88	1.04	0.04
2015	0.94	0.85	1.04	0.05

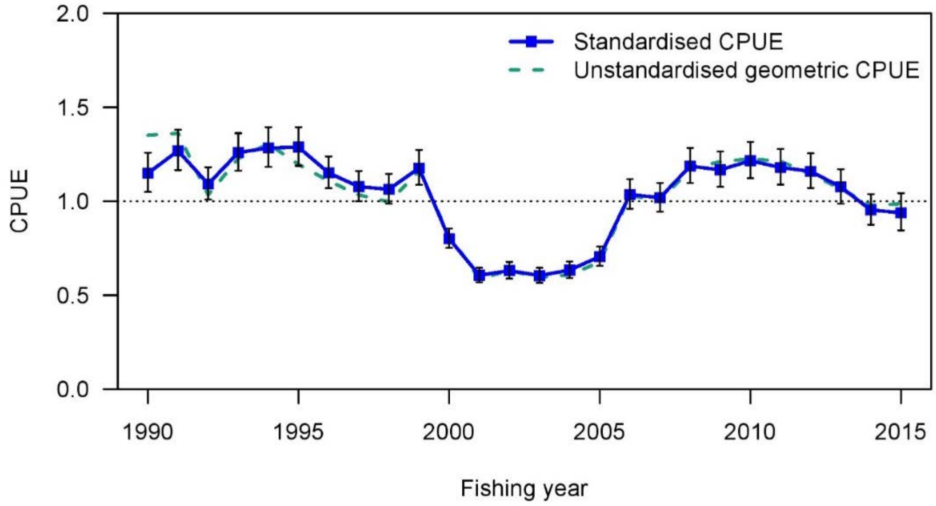


Figure 80: The standardised CPUE index in the CELR/PCELR dataset (using number of divers) with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by the number of divers.

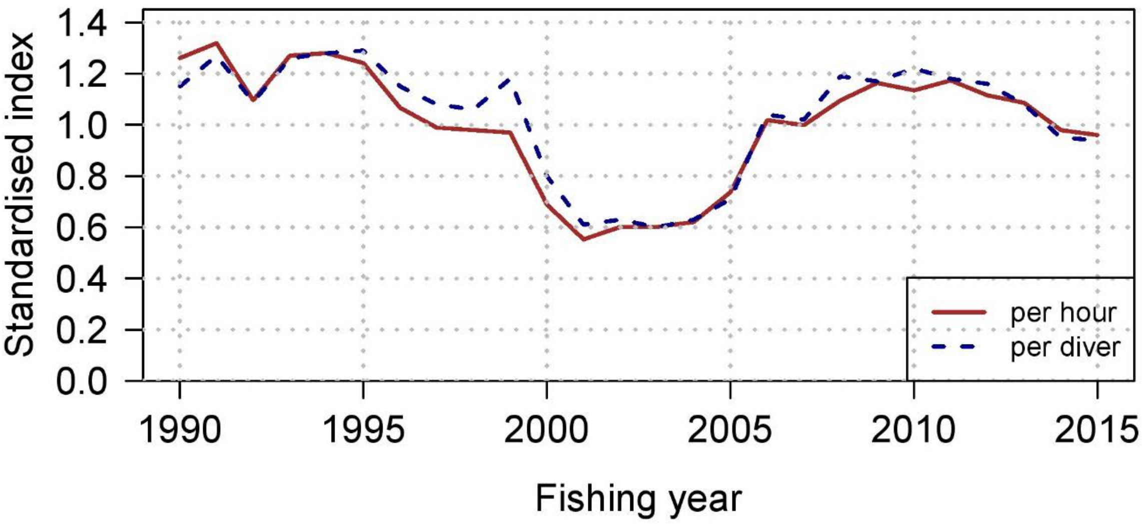


Figure 81: Comparing the standardised indices for the combined CELR/PCELR dataset using different measures of effort. Both indices are scaled to have a mean value of one.

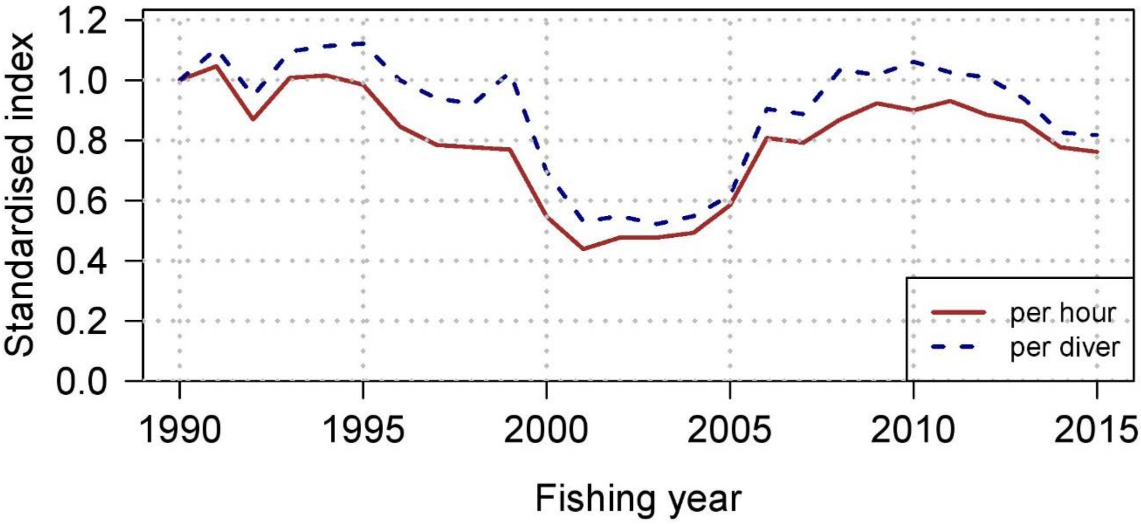


Figure 82: Comparing the standardised indices for the combined CELR/PCELR dataset using different measures of effort. Both indices are scaled to have the value one in 1990.

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 2015. This totalled 36 282 records containing 216 867 measurements from 1990–94 and 1998–2014. Deducing the statistical area for records prior to 2001–02 required some analysis as a variety of area codes were used. Statistical area information was obtained for 96% of records using a variety of fields in the data and lookup tables provided from previous assessments. Nine records were removed as they reported lengths less than 108 mm or greater than 200 mm. Records that were not from Statistical Areas 017 or 038 were excluded from further analysis (Table 26). Note that no area information was available for the 990 records from fishing year 1998 and these data were also excluded.

The number of samples from each subarea from 2002 onwards is shown in Table 27. Between 2002 and 2009, the number of landings sampled each year ranged between 20 and 70, and the number of shells measured ranged between 3000 and 9000. A few samples, mostly from between 2000 and 2005, had no area recorded (see Table 26). Sampling effort has increased significantly since 2008, (over 200 samples were taken in 2012 and 2013), resulting in catch samples being more representative of the fishery in terms of seasonal timing and location (Haist 2014). Between 2002 and 2004, the level of sampling was low even in areas with high catch levels and there was no sampling in many areas with low catches (Figure 83, left). However, between 2011 and 2014, both the spatial coverage and sampling intensity have improved considerably (Figure 83, right). Most of the increased sampling effort was focused in Fighting Bay south, Tory south, and Tory North, with 20 to 60 samples having been taken from each subarea every year since 2008. Although these areas accounted for most of the catch, the sampling in each subarea was not strictly proportional to the catch (Figure 84, left). The sampling coverage with respect to season was reasonably representative of the commercial catch in the fishery from 2008 to 2014 (Figure 84, right), although there appeared to be relatively more samples in October and November when the fishing season started.

There appeared to be a spatial trend in the mean length of the catch samples. In spite of the relatively large spatial variabilities (at the level of statistical areas, Figure 85), the mean length of the catch increased from Fighting Bay south to Tory South, then decreased moving further north and west (Figure 85). The low mean length in Fighting Bay south is likely to reflect the high fishing pressure there because of its easy access to fishers. The decrease in mean length in the northern part of PAU 7 is likely to reflect the slower growth rates in those subareas.

The scaled length frequency distributions for PAU 7 from 2002–2005 and 2010–2014 were calculated. The calculation was implemented using NIWA's 'catch-at-age' software (Bull & Dunn 2002). Between 1992 and 2001, the catch samples were stratified using two spatial strata based on the general Statistical Areas: 017 and 038. Between 2002 and 2013 the stratification was based on the sub-areas (see Table A3). Strata in which there were no samples were combined with adjacent strata (i.e., D'Urville Island was combined with Pelorus in 2005, 2006, and 2007). The length frequency distributions of paua from each landing were scaled up to the landing weight, summed over landings in each stratum, and then scaled up to the total stratum catch to yield length frequency disributions 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 are shown in Figure 86.

Table 26: Number of paua measured from the market shed sampling program in PAU 7 by General Statistical Area and by fishing year.

Fishing year	Removed	017	038	018	036	Unknown	Total
1990	0	1 736	2 990	0	0	0	4 726
1991	0	4 716	4 861	2837	0	0	12 414
1992	0	6 771	1 988	655	643	0	10 057
1993	0	4 552	2 475	1 623	0	0	8 650
1994	0	7 037	1 715	924	0	0	9 676
1998	0	0	0	0	0	990	990
1999	0	4 143	1 056	95	0	0	5 294
2000	0	5 382	0	212	409	1 886	7 889
2001	0	3 167	299	773	705	1 740	6 684
2002	0	6 418	0	1 184	0	337	7 939
2003	0	6 424	445	1 090	189	690	8 838
2004	0	4 305	0	0	0	673	4 978
2005	0	4 022	0	136	0	579	4 737
2006	0	2 641	0	0	0	542	3 183
2007	3	5 463	0	0	0	0	5 466
2008	1	9 101	253	152	0	0	9 507
2009	0	5 388	189	273	0	0	5 850
2010	0	10 632	216	582	283	0	11 713
2011	0	16 155	363	1 833	352	0	18 703
2012	4	22 479	234	1 891	212	0	24 820
2013	1	22 339	0	1 232	108	0	23 680
2014	0	18 438	106	2 529	0	0	21 073
2015	0	19 407	215	2 415	345	105	22 487

Table 27: Number of landings sampled from the market shed sampling program by subarea and by fishing year.

Fishing Year	East coast	Fighting Bay South	Tory north	Tory south	Northern Entrance	Pelorus	D'Urville	West Coast	Unknown	Total
2002	8	8	2	12	3	1	1	0	2	37
2003	7	5	5	5	5	6	2	1	4	40
2004	1	6	6	10	1	7	4	0	5	40
2005	1	8	8	10	5	3	0	0	5	40
2006	0	4	10	6	3	1	0	0	5	29
2007	0	6	8	9	7	5	0	0	0	35
2008	1	11	26	12	9	8	5	0	0	72
2009	5	7	13	19	2	5	3	0	0	54
2010	6	24	22	31	13	7	2	4	0	109
2011	24	48	33	36	15	5	7	4	0	172
2012	25	65	59	55	17	9	4	3	0	237
2013	14	60	65	46	18	11	2	1	0	217
2014	27	45	55	37	16	4	4	0	0	188
2015	30	82	39	29	12	8	5	3	1	209
Total	119	297	312	288	114	72	34	13	21	1270

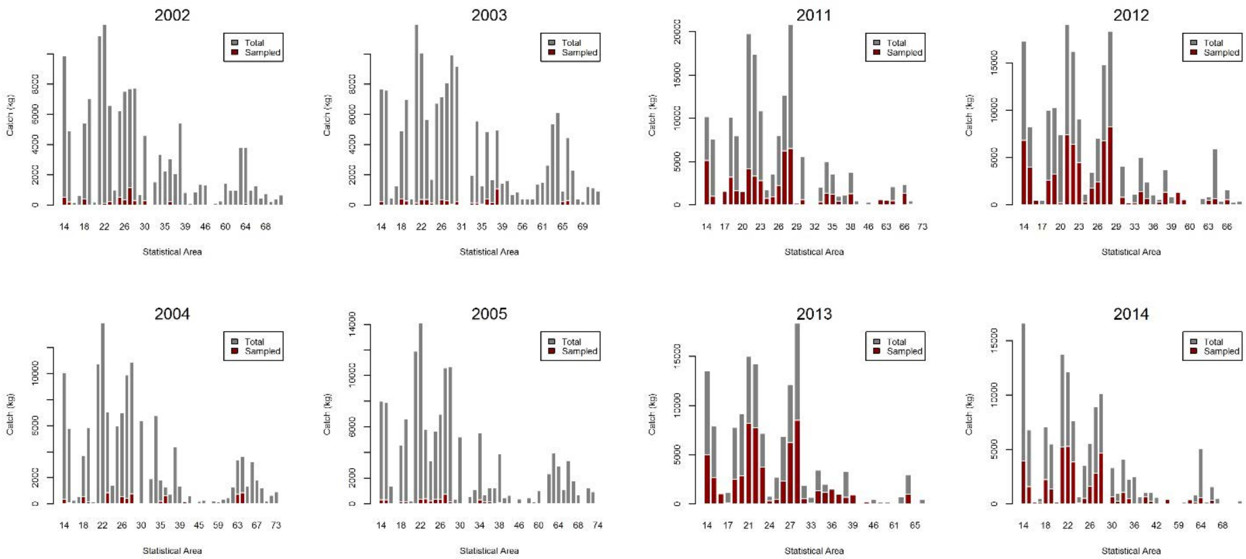


Figure 83: Sampled catch as a proportion of total catch by Paua Statistical Areas 2002–2005 (left) and 2011–2014 (right).

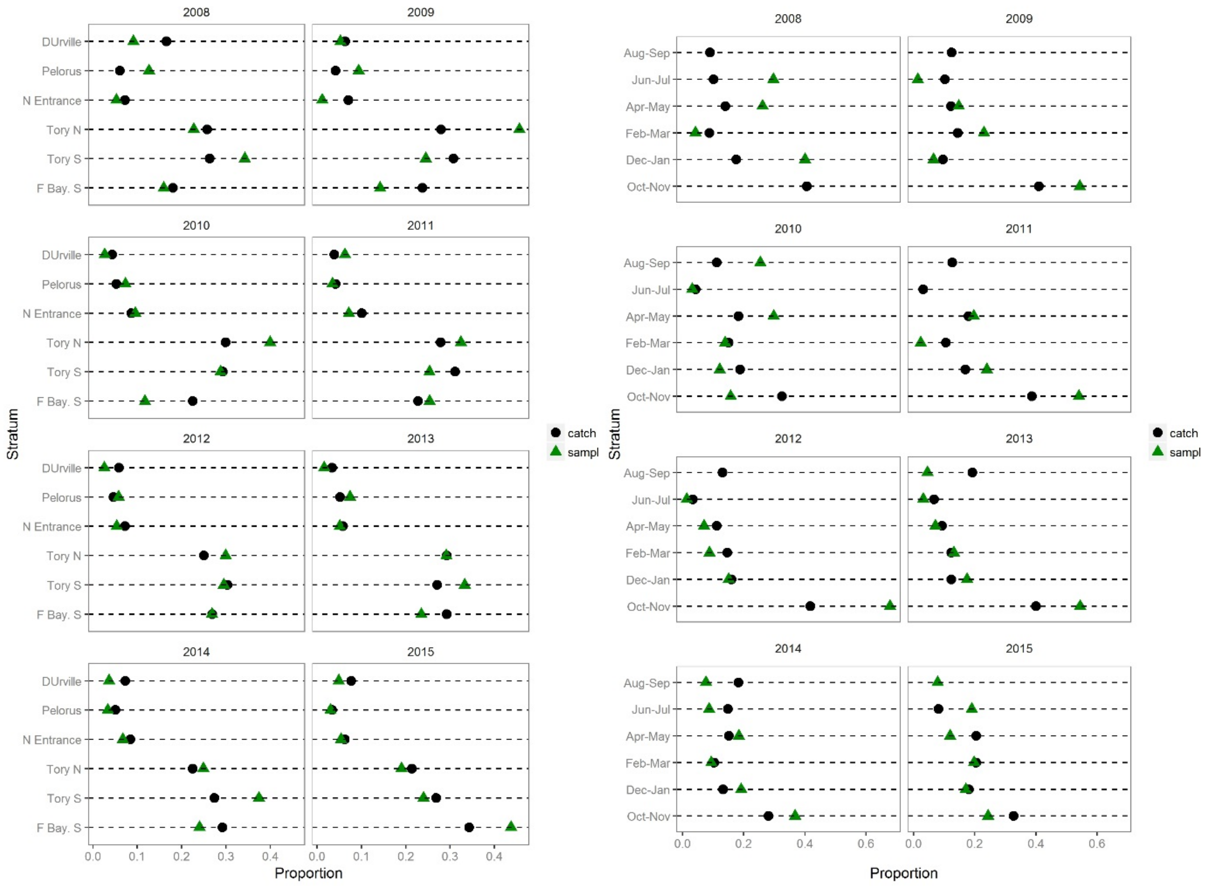


Figure 84: Sampled catch as a proportion of total catch by subarea (left) and by month (right) for the 2008–2015 fishing years.

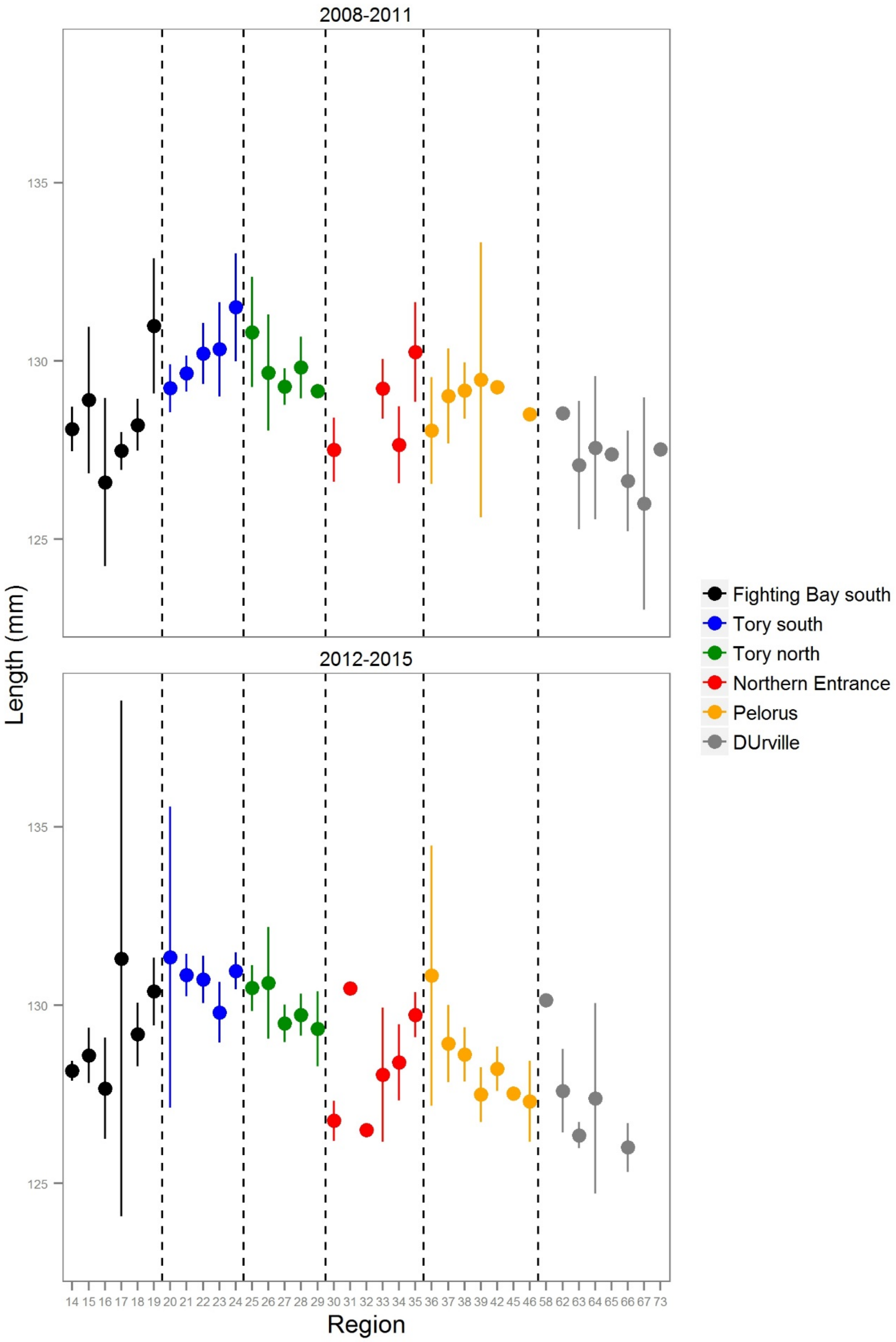


Figure 85: Mean length (dot) with one standard error (bar) of measured paua from market shed sampling by statistical area using data for period 2008– 2011 and for 2012–2015. The mean is calculated across sampled landings and the standard error is the standard deviation of the mean.

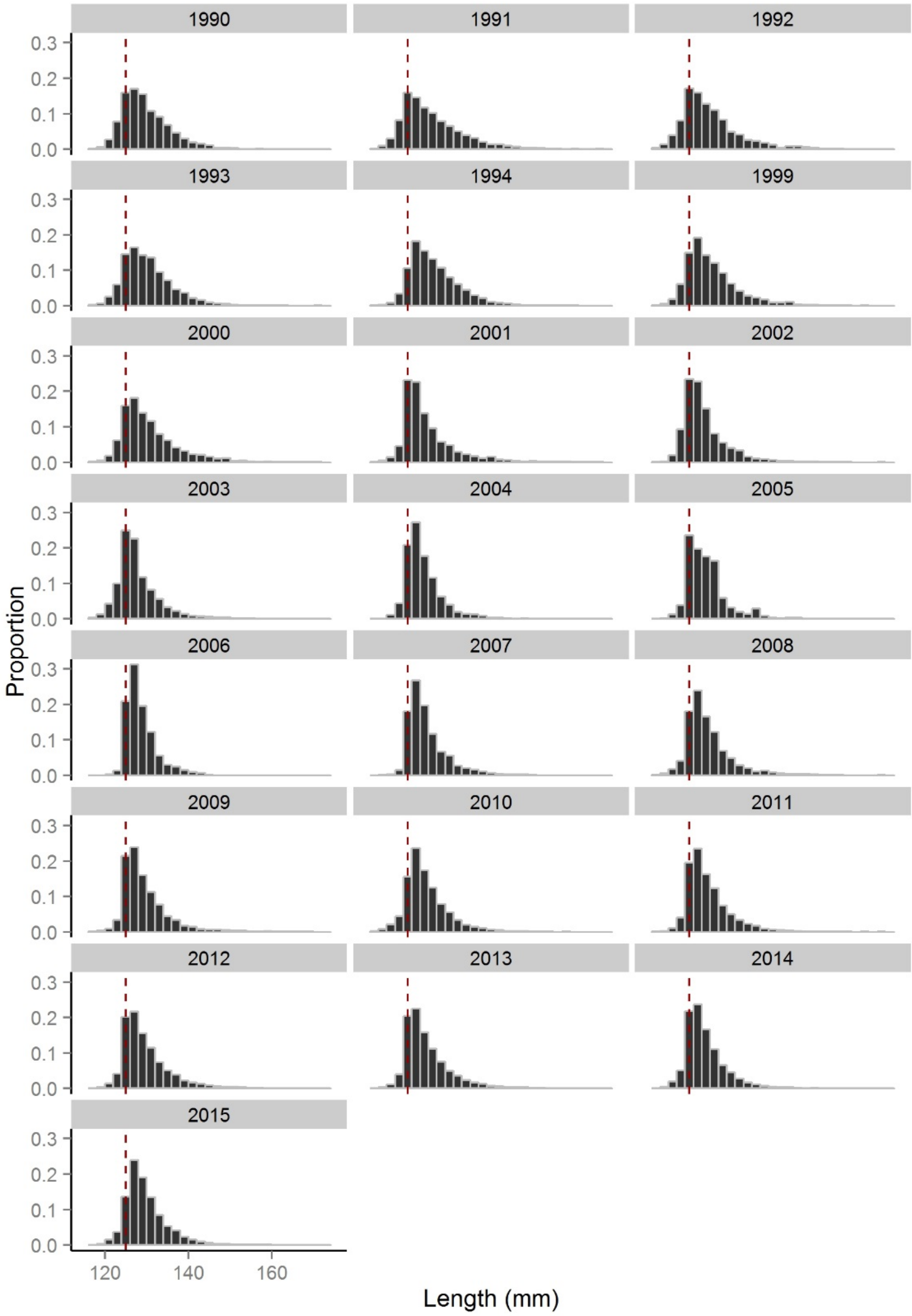


Figure 86: Scaled length frequency distributions for paua from commercial catch sampling in PAU 7 for fishing years 1990–1994, and 1999–2015 The dashed line indicates the MHS of 125 mm.

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. (2000b) 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 2008, and McKenzie & Smith 2009a). The previous stock assessment for PAU 7 used the RDSI developed from the survey data up to 2010 (Fu et al. 2012). There have been no new surveys since last assessment.

Concerns over the survey methodology and its usefulness in providing relative abundance indices led to a number of reviews. Andrew et al. (2000b) 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 (Fu 2013), PAU 7 (Fu 2012), PAU 5B (Fu 2014) RDSI and the associated length frequency data (RDLF) were not included in the base case. The same decision has been made here: the RDSI and RDLF were excluded from the base case but were included as a sensitivity run. The calculation of the relative abundance indices from the RDSI data were described by Fu et al. 2012

7. RESEARCH DIVER LENGTH FREQUENCY (RSLF)

The previous stock assessment for PAU 7 used the research diver length frequencies up to 2010 (Fu et al. 2012). There have been no new data since the last assessment. The RDLF data were not used in this assessment.

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Tag and recapture experiments were conducted at different times and at several sites in PAU 7 and were restricted to Statistical Area 017 and 018 (Breen & Kim 2003). Growth data collected from these experiments were available from Staircase (n=48), Rununder (n=63), Perano (n=68), Northern faces (n=505), and D'Urville (n=211). The data from D'Urville were collected from a stunted population and therefore were not used in the assessment as it is believed that this data is not representative of the commercial fishery. The growth dataset comprises 895 records with initial lengths ranging from 36 to 142 mm, time at liberty ranging from 237 to 634 days and annualised increments ranging from -5 to 93 mm. These data were incorporated into the PAU 7 assessment to estimate growth. No new tag recapture data for PAU 7 has been collected since the last assessment.

The growth-increment data used in paua assessment models were analysed using a number of length-increment growth models. With the inverse logistic model (Haddon et al. 2008) the expected annual growth increment for a paua of initial size L_k is:

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

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.

With the linear growth model (Francis 1988) the expected annual growth increment for an individual of initial size L_k is

$$(2) \qquad u_k = g_1 + (g_2 - g_1)(L_k - L_1)/(L_2 - L_1)$$

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:

$$(3) \qquad u_k = g_1(g_2 / g_1)^{(l_k - L_1)/(L_2 - L_1)}$$

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.

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

The assessment model included the 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):

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

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 87). 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.

These data suggested large variations in growth rates between areas: growth rates in Staircase were significantly lower than the rest of PAU 7 whereas Rununder and Perano appeared to have much faster growth rates (Figure 87). Anecdotal evidence suggests that Staircase is a very productive area where paua generally grow fast therefore, the data appear to not be representative of the population in that area. A detailed examination of the data found no anomaly, although the experiment was conducted about 10 years before the other areas, and the time-at-liberty was 634 days (they have experienced 2 summers).

An additional analysis was conducted by generating a hypothetical equilibrium population length distribution (assuming no fishing) using growth estimates from subareas, and comparing that to the length distribution collated from the Fighting Bay fish-down experiment (Abraham 2012). The comparison suggested that the growth estimates from Staircase were apparently too low, whereas the growth estimates from Perano and Rununder were more consistent with the Fighting Bay length distribution. One possible explanation for the low growth from Staircase is that this is a popular fishing spot and most fast growth animals have been caught and therefore what are left in the sample were biased towards slow growing animals.

The growth rates from Northern faces also appear low, this is consistent with the general view that paua grow much slowly in that area. However the sample was collected from one site in Cape Jackson. This is a sheltered area, which is considered to contain a micro population on its own, and its biology may be different to the rest of the northern coast of Marlborough Sounds. The perception is that the sample may not be able to represent the growth of the whole northern faces area, which is probably even slower than the data suggests.

It was therefore suggested to consider two options to use these data in the assessment model: (1) using all the data; (2) using data from Rununder, Perano and Northern faces (excluding Staircase), but weighting these data by the contribution of the catch. The second option was recommended by the paua stock assessment review workshop (Butterworth et al. 2015)

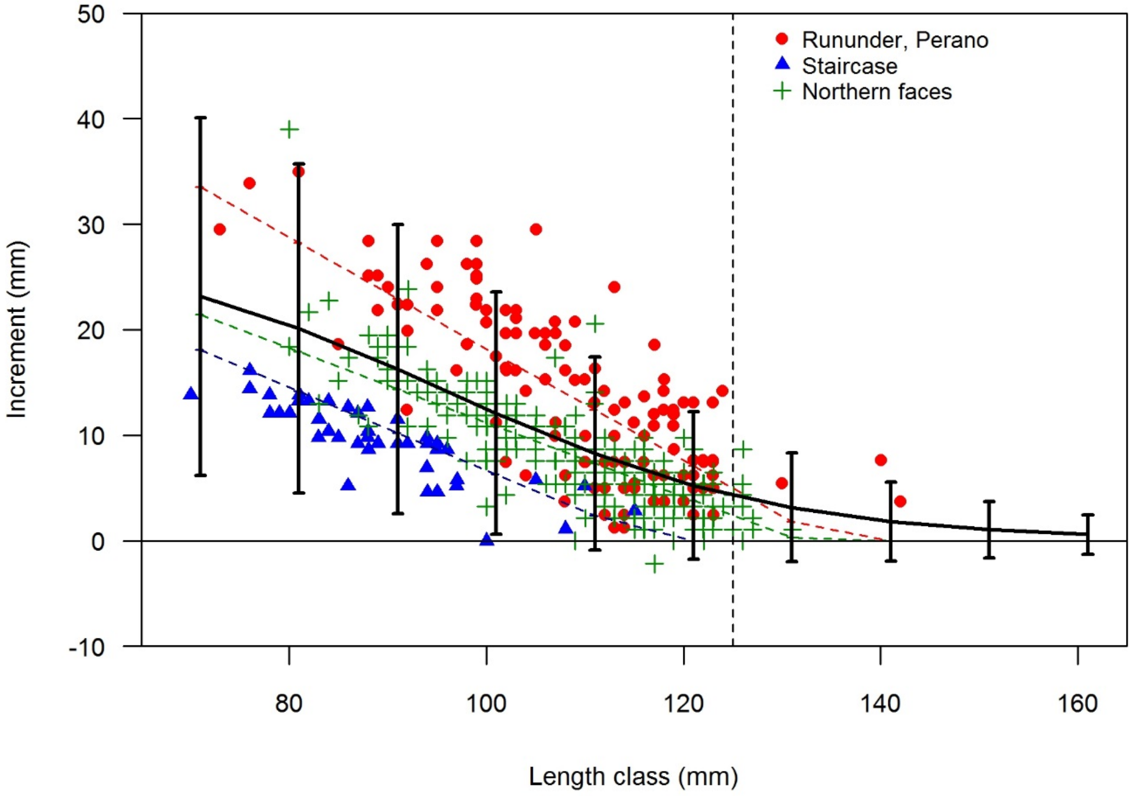


Figure 87: Initial size and mean annual increment from the tag-recapture data within PAU 7 excluding D'Urville. Black line (and 95% confidence intervals) indicates inverse growth curve estimated from all of these data; blue, green, and red dashed lines indicate basic models fitted to data from Staircase, Northern faces, Rununder and Perano, respective. Dashed vertical line indicates the legal size limit (125 mm).

9. MATURITY

Data had been collected between 1994 and 2013 at various sites from Campbell (n=86), Staircase (n=39), Rununder (n=250), Tory (n=127), Perano (n=230), Northern faces (n=425), and D'Urville (n=553) (Table 28). If mature, paua were checked for maturity and gender, and in all 1714 paua were examined. Data from Campbell were not considered in further analyses because they are outside the assessment area. Data from D'Urville were also excluded from the assessment because samples were taken from a slower growing population. The data were collated as the number examined and the number mature in 2-mm length bins. The new data available since the previous assessment were those collected in 2013.

The length of paua examined ranged from 22 to 147 mm. The proportion mature was fitted with a logistic curve using a binomial likelihood for each subarea as well as for all areas (Figure 88). The estimated proportion mature at length is very similar at Staircase, Rununder, Tory, and Perano. The length at 50% mature (L50%) for these areas ranged between 91 and 94 mm, and length at 95% mature (L95%) ranged between 101 and 104mm. The estimated Length at 50% mature in Northern faces is also similar (L50% = 83 mm), but length at 95% mature is much greater (L95% = 115 mm). This corroborates the suggestion that paua in the northern area of PAU 7 appear to have a different growth rate (see section 8). Because Northern faces accounted for a small proportion of the total catch in PAU 7, it is suggested that the assessment will use maturity data from Staircase, Rununder Tory, and Perano, and maturity data from northern faces will be included as a sensitivity analysis.

Table 28: Number of shells examined for maturity by research stratum area and year.

Year	Campbell	Staircase	Rununder	Tory	Perano	Northern face	D'Urville
1994		42					136
1995			126		118	302	
2002							416
2005							
2013	86		125	127	112	123	
Total	86	42	251	127	230	425	552

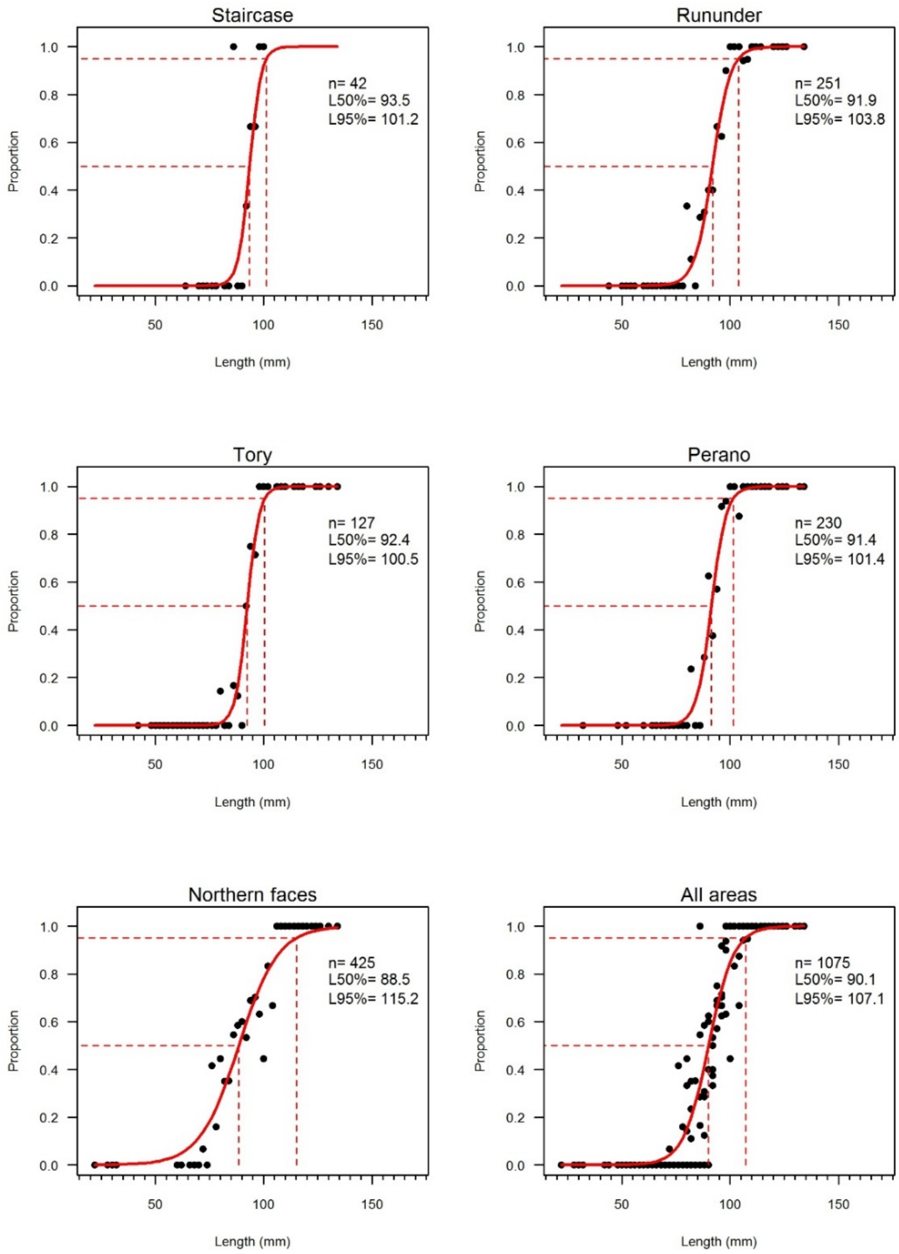


Figure 88: Proportion of maturity at length for PAU 7. The dots represent the observed proportion mature for each 2 mm length bin. The red line represents a fitted logistic maturity curve. The dashed lines represent estimated length at 50% and 95% maturity.

10. OTHER DATA

A fish-down experiment was conducted in Fighting Bay in the summer of 2011–12 (Abraham 2012). The aim of the experiment was to assess the utility of logger data to estimate local catch rates (Abraham 2012, Neubauer et al. 2015). During the experiment, an area previously closed to fishing was fished to deplete local biomass and fishing was conducted during several bouts of 2–3 consecutive days, over several months. During the course of the experiment, some paua from the catch were sampled to measure the length. These data can be used to derive the population length frequency distribution.

Because the aim of the experiment was mainly for estimating catch rates, rather than catch sampling, the sampling method was not clear. But presumably mainly legal sized paua were sampled. Data from the first two days of the experiment (n=256 on December 14th 2011 and n=222 on December 15th 2011, Figure 89, left) were likely to be representative of the length composition of an unfished population (the right hand side of the distribution). Samples from the later stage of the experiment (mid-January and March) were from a population that had already been fished down to low levels and therefore contained relatively a larger portion of smaller animals (see Figure 89-left). The samples from the first two days of the experiment were combined to derive the length frequency distribution, which is assumed to be from an unfished population of PAU 7.

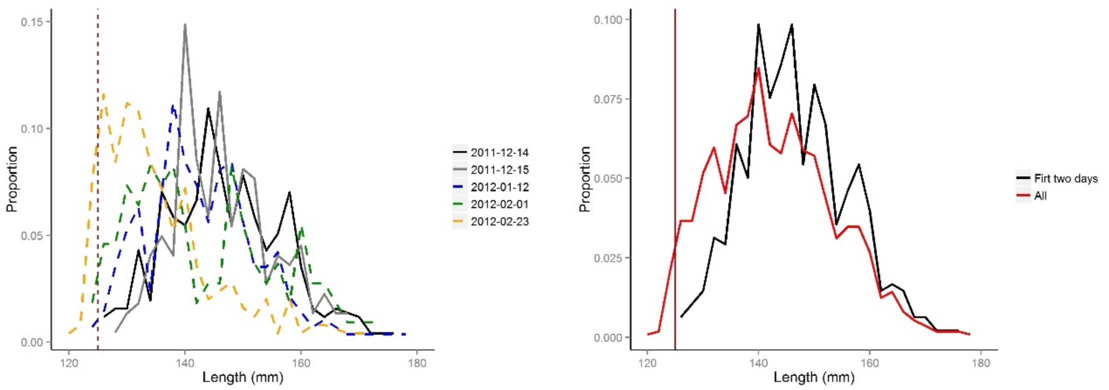


Figure 89: Length frequency distributions from paua measured from the Fighting Bay fish-down experiment (Abraham 2012). The left hand side shows the length frequency distributions from each sample. The right hand side shows the length frequency distributions from the first two days combined or from all days combined.

11. ACKNOWLEDGMENTS

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APPENDIX A: Area and strata codes

Table A1: PAU 7 general statistical area and associated fine-scale Paua Statistical Areas.

General Statistical Area	Paua Statistical Areas
018	P701–P709
017	P710–P764
038	P765–P790
036	P791–P797

Table A2: PAU 7 research strata and associated fine-scale Paua Statistical Areas.

Subarea and stratum	Paua Statistical Areas
Campbell	P701–P709
Staircase	P714
Rununder	P715–P723
Perano	P726–P729
Northern faces	P730–P748
D’Urville	P763–P773
West coast	P790–P797

Table A3: Some PAU 7 subareas and associated fine-scale Paua Statistical Areas used in the analysis.

Subarea	Paua Statistical Area
East coast	P701–P713
Fighting Bay South	P714–P719
Tory South	P720–P724
Tory North	P725–P729
Northern entrance	P730–P735
Pelorus	P736–P756
D'Urville	P757–P774
West coast	P790–P797

Table A3: Some PAU 7 area codes used by the shed sampling market database and associated sub areas

Zone	Sub area
M1	West Coast
M2	D’Urville
M2A	D’Urville
M3	Northern Faces
M4	Northern Faces
M4A	Perano
M4B	Rununder
M4C	Staircase
M5	Cape Campbell

APPENDIX B: CPUE standardisation recommendation

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

R- 1. [H/M] Robustness to the CPUE standardisation assumptions should be fully investigated by developing alternative CPUE series to test in model sensitivity runs. Alternative series potentially include: PCELR data collapsed to the CELR format to form a single CPUE series; standardising CELR data by diver day instead of by diver hour; and for PAU 5B, including data from all Statistical Area 25 and 30 observations into the CELR standardisation. Unless there is clearly no effect of the alternative standardisation approach, the alternative CPUE series should be fitted in the assessment model as sensitivities.

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

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

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