Fisheries New Zealand

Tini a Tangaroa

Summary of input data for the 2017 PAU 5B stock assessment

New Zealand Fisheries Assessment Report 2018/22

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ISSN 1179-5352 (online)
ISBN 978-1-77665-911-1 (online)

June2018

New Zealand Government

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EXECUTIVE SUMMARY

Marsh C.; McKenzie, A. (2018). Summary of input data for the 2017 PAU 5B stock assessment.

***New Zealand Fisheries Assessment Report 2018/22.* 82 p.**

This document summarises the data inputs used in the 2017 stock assessment of blackfoot paua (*Haliotis iris*) around Stewart Island (PAU 5B). The eight sets of data available for the assessment were: (1) a standardised CPUE series based on catch effort landing return (CELR) data (2) a standardised CPUE series based on paua catch effort landing return (PCELR) data (3) a standardised CPUE series based on combined CELR and PCELR data (4) a standardised research diver survey index (RDSI) (5) a research diver survey proportions-at-lengths series (RDLF) (6) a commercial catch sampling length frequency series (CSLF) (7) tag-recapture length increment data and (8) maturity-at-length data. Catch history was an input to the model encompassing commercial, recreational, customary, and illegal catch.

A new standardisation was done for the CELR data using fishing duration as the measure of effort, the standardised CPUE series based on PCELR data was updated to the 2016–17 fishing year, and the combined CELR and PCELR data standardisation was updated to the 2016–17 fishing year. There had been no research diver survey since the last assessment, and therefore the same RDSI and RDLF were available for this assessment as in the last assessment. Scaled length frequency series from the commercial catch sampling were updated to the 2016–17 fishing year, where the catch samples stratified by area and numbers at length were scaled up to each landing and then to the stratum catch. New maturity-at-length data had been collected and were analysed for this assessment, but there were no new tag-recapture data since the last assessment.

1. INTRODUCTION

This document summarises the data inputs used in the 2017 stock assessment of the PAU 5B stock, Stewart Island. The work was conducted by NIWA under the Ministry for Primary Industries' contract PAU2017-01 Objective 1. A separate document details the stock assessment of PAU 5B (Marsh 2018). PAU 5B was last assessed in 2013 (Fu 2014, Fu et al. 2014), before that in 2007 (Breen & Smith 2008b), and in 2000 (Breen et al. 2000). The fishing year for paua is from 1 October to 30 September and in this document, we refer to fishing year by the year ending; thus we call the 1997–98 fishing year "1998".

This report summarises the model input data available for PAU 5B up to the 2017 fishing year.

1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2017 based on PCELR data.
3. A standardized CPUE series covering 1990–2017 based on combined CELR/PCELR data.
4. A standardised research diver survey index (RDSI).
5. A research diver survey proportions-at-lengths series (RDLF).
6. A commercial catch sampling length frequency series (CSLF).
7. Tag-recapture length increment data.
8. Maturity-at-length data.

Methodologies for the standardised CPUE indices are similar to those for recent assessments: PAU 5D (Fu et al. 2017), PAU 5A (Fu et al. 2015), and PAU 7 (Fu et al. 2016).

2. FISHERY DESCRIPTION

A list of common acronyms used in this document are given in Table 1.

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

On 1 October 1999 a TAC of 155.98 t was set for PAU 5B, comprising a TACC of 143.98 t (a 5 t reduction) and customary and recreational allowances of 6 t each. Concerns of over-exploitation led to a series of management interventions to reduce the total allowable commercial catch (TACC). On 1 October, 1999, the industry agreed to shelve 25 t of quota in addition to the 5 t TACC reduction, resulting in an effective commercial catch limit of about 112 t. This shelving continued into 2000 at a level of about 22 t. In 2002, shelving was discontinued, and the TACC was set at 90 t, about 60% of the catch level in the 1995–96 fishing year. Since the 2007 fishing year the commercial fishers have undertaken a number of other voluntary management initiatives including a steady increase in the minimum harvest size from the MLS (125 mm) to 138 mm for all statistical areas throughout PAU 5B.

Prior to the 1995–96 subdivision, estimated catch on the CELR forms was reported at the spatial scale of the General Statistical Areas (024 to 032) (Figure 1) This spatial resolution of catch reporting continued until 1 November 1997, after which time the new QMAs, PAU 5A, PAU5B and PAU5D were further subdivided into 17, 16, and 11 Paua Statistical Reporting Areas for PAU 5A, PAU 5B, and PAU 5D, respectively.. The spatial scale of reporting was further reduced from 1 October 2001, when the specific PCELR forms were adopted and it became mandatory to report catch and effort on the finer-spatial scale statistical zones originally developed for the New Zealand Paua Management Company's voluntary logbook (Figures 2–3). A summary of the spatial resolution of reporting zones and research strata for PAU 5B are given in Tables 2–**3** and Figure 4.

Table 1: A list of acronyms used throughout this document.

CELR	Catch Effort Landing Return
PCELR	Paua Catch Effort Landing Return
RDSI	Research diver survey index
CDLF	Commercial diver length frequency
RDLF	Research diver length frequency
PAU	Paua management
QMR	Quota Management Reports
MHR	Monthly Harvest Returns
SWFG	Shellfish Working Group
CV	Coefficient of variation
TAC	Total Allowable Catch
TACC	Total Allowable Commercial Catch
MLS	Minimum Legal Size
MHS	Minimum harvest size

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

QMA		Statistical Reporting Areas		
1986/87–1994/95	Oct 1995–present	1986/87–30 Oct 1997	Nov 1997–Sep 2001	Oct 2001–present
PAU 5	PAU 5B	027	B6–B10	P5BS43–P5BS68
		028	N/A	
		029	B5	P5BS33–P5BS42
		025 (part of)	B11–B15	P5BS01–P5BS10 P5BS69–P5BS84
		030 (part of)	B1–B4 B16	P5BS11–P5BS32

Table 3: Summary of subareas and associated Paua Statistical Areas within PAU 5B. Each of the subareas are also research strata, except West and Ruapuke (see Figures 3–4). Statistical Areas P5BS11–P5BS14 are not covered by any research strata but are assumed to be Waituna in this report.

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

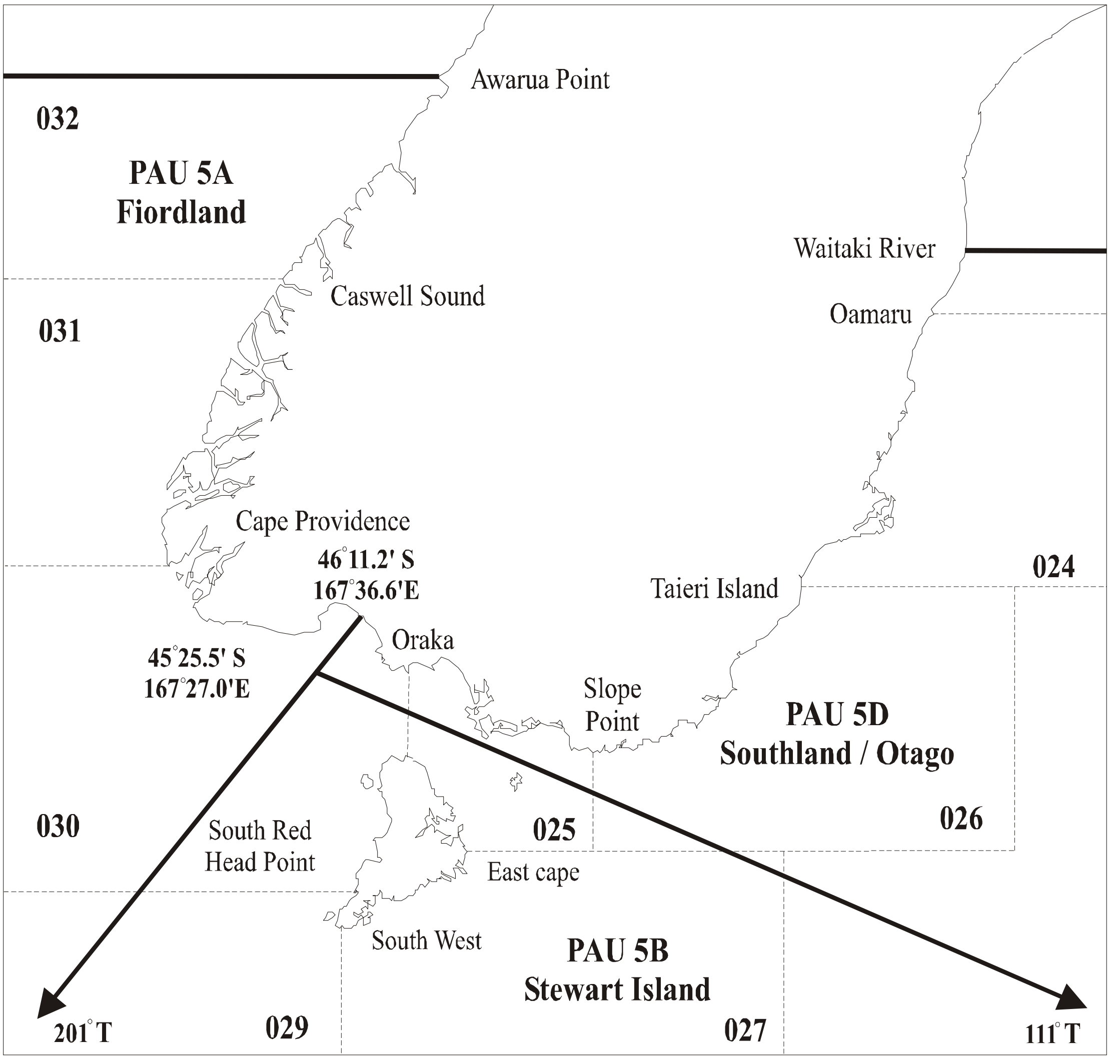


Figure 1: Map showing the new QMAs effective from 1 October 1995 and the old statistical area boundaries (dashed lines) of PAU 5.

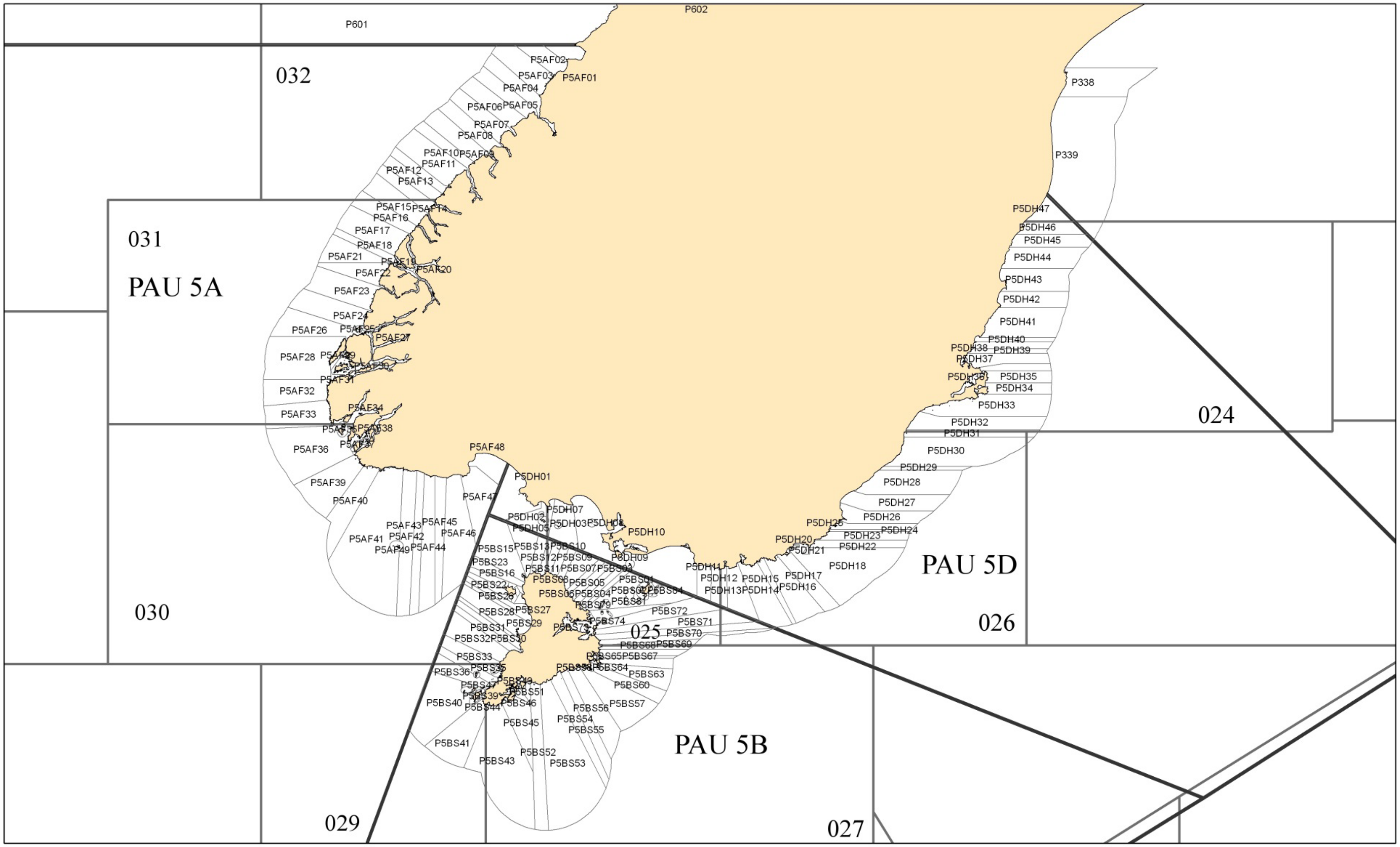


Figure 2: Map showing the location of fine-scale statistical areas within PAU 5 effective from 1 October 2001.

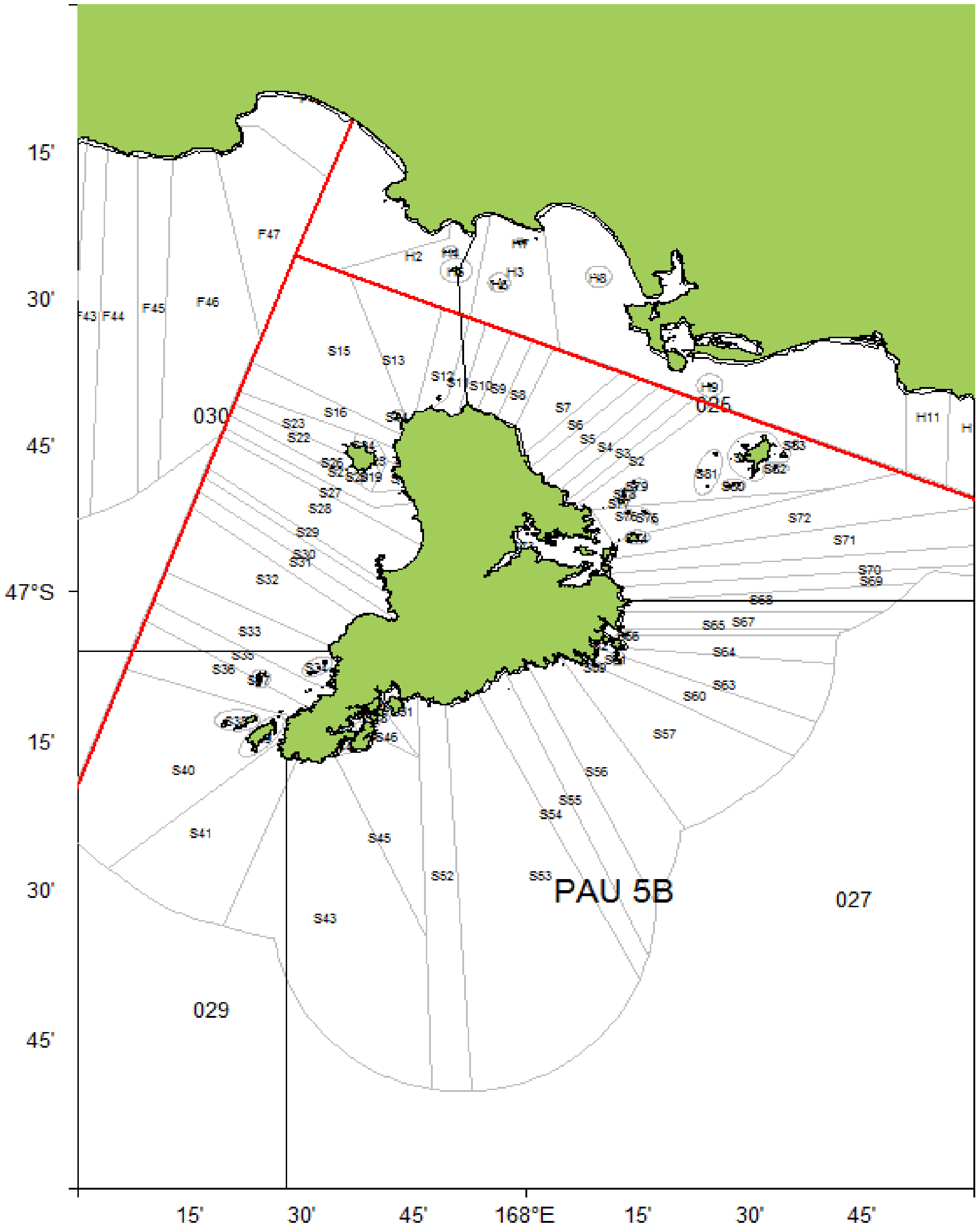


Figure 3: Map showing the location of fine scale Paua Statistical Areas within PAU 5B effective from 1 October 2001.

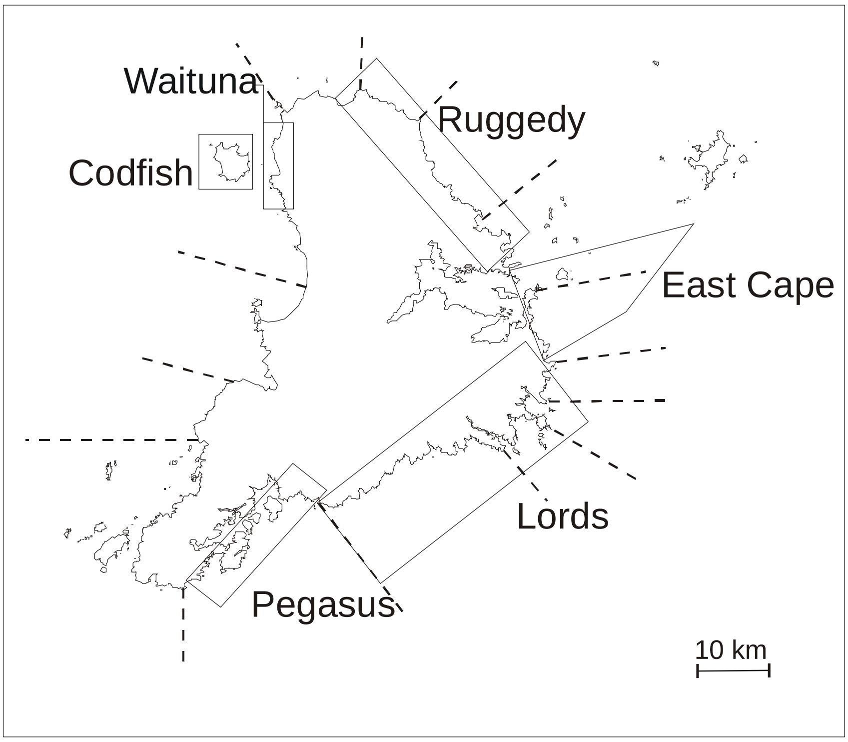


Figure 4: Map of research strata for PAU 5B stock.

3. CATCH HISTORY

3.1 Commercial catch

The subdivision of the PAU 5 stock and changes in the spatial scale of reporting commercial catch has led to complications in the allocation of catch data to the new QMAs. The historical catch series for the substocks within PAU 5 before 1995 cannot be determined with certainty, because some of the statistical areas used to report catch and effort straddle multiple stocks (e.g., Statistical Area 030 straddles PAU 5A, PAU 5B and PAU 5D - see Figure 1). Kendrick & Andrew (2000) described a method for estimating the pre-1995 catches from the substocks within PAU 5. The method was further explained by Breen & Smith (2008a), and was used to assemble the catch history for PAU 5A assessment in 2006 (Breen & Kim 2007), 2010 (Fu & McKenzie 2010) and 2014 (Fu et al. 2015) for the PAU 5B assessment in 2007 (Breen & Smith 2008b) and 2013 (Fu et al. 2014), and for the PAU 5D assessment in 2006 (Breen & Kim 2007), 2012 (Fu et al. 2013) and 2016 (Fu et al. 2017).

We repeated this procedure to calculate the catch history for PAU 5B. A constant proportion of 52% was applied to the Murray & Akroyd (1984) PAU 5 catch series to obtain catch estimates from 1974 to 1983. From 1983–84 to 1994–95, the annual proportion of catch for PAU 5B was firstly estimated, where 75% of the annual estimated catch in Statistical Areas 030 and 025 was assumed to have been taken from PAU 5B, and that proportion was applied to the QMR/MHR landings in PAU 5 to obtain the catch estimates. In the 2010 assessment for PAU 5A (Fu & McKenzie 2010), alternative assumptions were suggested by the SFWG concerning the proportion of catch in Statistical Area 030 that were taken from PAU 5A, PAU 5B, and PAU 5D between 1983–84 and 1995–96: (1) 18%, 75%, and 7% respectively, (2) 40%, 53%, and 7% respectively, and (3) 61%, 32%, and 7% respectively. These assumptions have been adopted here to obtain catch estimates for each of the substocks within PAU 5. Kendrick & Andrew (2000) also considered an alternative catch split of 67% to 33% between PAU 5B and PAU 5D for Statistical Area 025 between 1983–84 and 1995–96. This assumption was not used here because the difference it made to the catch estimates was insignificant. After the 1995 fishing year, the catch from Statistical Areas 025 and 030 are well determined (Figures 5–6)

Estimated commercial catch histories for PAU 5B are shown in Tables 4–5.

The estimated catches by Paua Statistical Area from the years of PCELR data are shown in Figure 7. Catches were taken throughout the stock and were widely distributed among subareas, with no signs of serial depletion in the last 17 years, at least at this scale.

The recorded resolution for the estimated catch and fishing duration for the PCELR data was low. About 70% of the catch was recorded as multiples of 50 kg, 25% of recorded fishing durations are multiples of one hour, and about 30% of fishing events the estimated catch was split equally amongst the divers (Figure 8). But there appeared to be no trend over time.

Table 4: TACCs and reported landings (kg) of paua for PAU 5 and substocks PAU 5A, PAU 5B, and PAU 5D. PAU 5 was subdivided into PAU 5A, PAU 5B, and PAU 5D on 1 October 1995 and reported landings for these fish stocks are given separately from 1995–96.

Fish stock	PAU 5		PAU 5A		PAU 5B		PAU 5D	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	550 515	–	N/A	N/A	N/A	N/A	N/A	N/A
1984–85*	352 459	–	N/A	N/A	N/A	N/A	N/A	N/A
1985–86†	331 697	–	N/A	N/A	N/A	N/A	N/A	N/A
1986–87†	418 904	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1987–88†	458 239	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1988–89†	445 978	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1989–90†	468 647	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1990–91†	510 335	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1991–92†	483 037	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1992–93†	435 395	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1993–94†	440 144	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1994–95†	434 708	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1995–96†	N/A	N/A	138 526	148 983	144 661	148 984	146 772	148 983
1996–97†	N/A	N/A	143 848	148 983	142 357	148 984	146 990	148 983
1997–98†	N/A	N/A	145 224	148 983	145 337	148 984	148 718	148 983
1998–99†	N/A	N/A	147 394	148 983	148 547	148 984	148 697	148 983
1999–00†	N/A	N/A	143 913	148 983	118 068	143 984	147 897	148 983
2000–01†	N/A	N/A	148 221	148 983	89 915	112 187	148 813	148 983
2001–02†	N/A	N/A	148 535	148 983	89 963	112 187	148 740	148 983
2002–03†	N/A	N/A	148 764	148 983	89 863	90 000	111 693	114 000
2003–04†	N/A	N/A	148 980	148 983	90 004	90 000	88 024	89 000
2004–05†	N/A	N/A	148 952	148 983	89 970	90 000	88 817	89 000
2005–06†	N/A	N/A	148 922	148 983	90 467	90 000	88 931	89 000
2006–07†	N/A	N/A	104 034	148 983	89 156	90 000	88 973	89 000
2007–08†	N/A	N/A	105 132	148 983	90 205	90 000	88 978	89 000
2008–09†	N/A	N/A	104, 823	148 983	89 998	90 000	88 770	89 000
2009–10†	N/A	N/A	105 741	148 983	90 227	90 000	89 453	89 000
2010–11†	N/A	N/A	104 400	148 983	89 673	90 000	88 699	89 000
2011–12†	N/A	N/A	106 234	148 983	89 589	90 000	89 230	89 000
2012–13†	N/A	N/A	105 560	148 983	90 575	90 000	87 914	89 000
2013–14†	N/A	N/A	102 298	148 983	88 841	90 000	84 592	89 000
2014–15†	N/A	N/A	106 954	148 983	89 457	90 000	71 879	89 000
2015–16†	N/A	N/A	106 843	148 983	88 393	90 000	65 951	89 000
2016–17†	N/A	N/A	97 370	148 983	80 007	90 000	54 508	89 000

* FSU data, † QMR/MHR data,

Table 5: Collated commercial catch histories (kg) for PAU 5A, 5B, and 5D for fishing years 1984–1995 under assumptions 1, 2, and 3 of the proportion of Statistical Area 030 catch to come from PAU 5A. The estimated commercial catches for PAU 5D are the same under all assumptions.

			Assumption 1 (18%)		Assumption 2 (40%)		Assumption 3 (61%)	
Year	PAU 5	PAU 5D	PAU 5A	PAU 5B	PAU 5A	PAU 5B	PAU 5A	PAU 5B
1984	550 515	148 451	107 360	294 704	146 179	255 885	183 233	218 831
1985	352 459	81 749	46 409	224 301	70 894	199 816	94 266	176 444
1986	331 697	65 240	50 646	215 811	69 949	196 508	88 374	178 083
1987	418 904	141 578	25 826	251 501	36 893	240 433	47 458	229 869
1988	458 239	93 068	37 310	327 861	56 492	308 679	74 803	290 369
1989	445 978	95 791	118 393	231 793	152 824	197 362	185 690	164 497
1990	468 647	140 170	74 372	254 105	106 101	222 376	136 388	192 089
1991	510 335	142 845	124 440	243 050	156 661	210 829	187 417	180 073
1992	483 037	128 904	100 107	254 026	133 056	221 077	164 507	189 626
1993	435 395	162 773	50 724	221 898	81 292	191 330	110 471	162 151
1994	440 144	148 878	57 733	233 533	86 016	205 249	113 015	178 251
1995	434 708	137 591	65 767	231 350	96 510	200 607	125 856	171 261

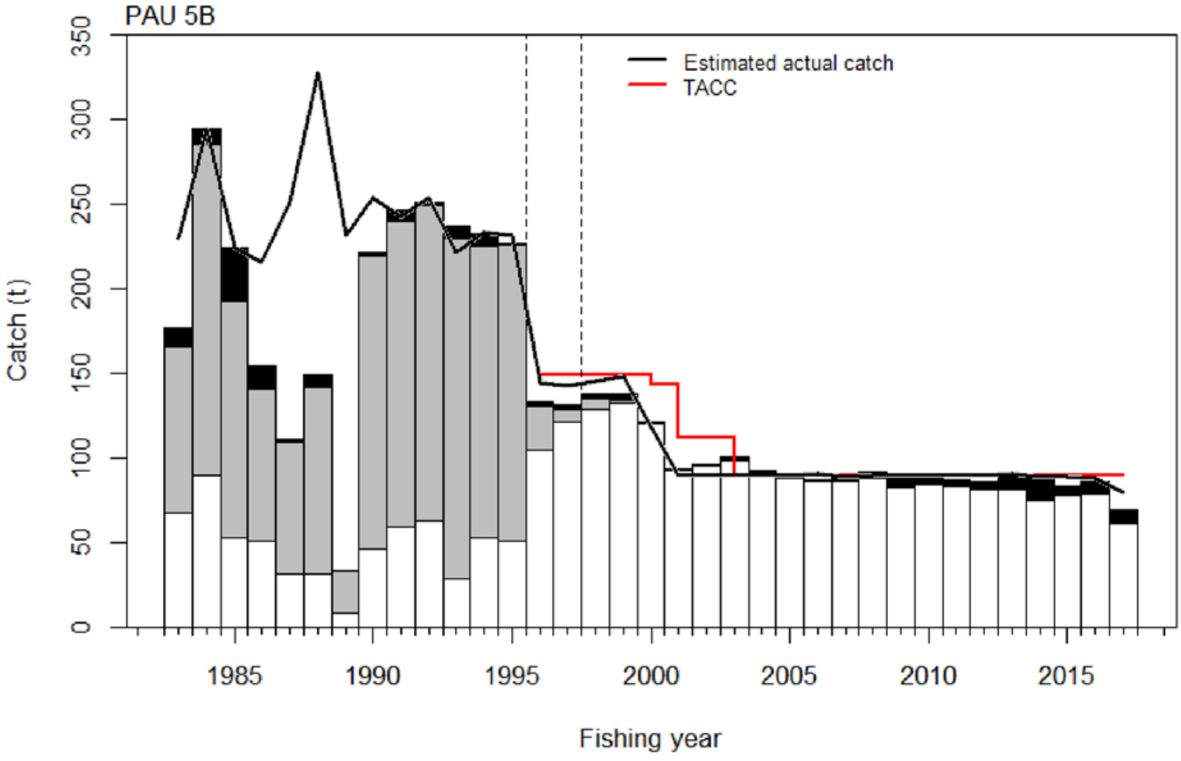


Figure 5: The estimated commercial catch history, TACC, and the FSU/CELR/PCELR catch (vertical bars) for fishing years 1983–2017 for PAU 5B. Black portion of the bar represents estimated catch removed through data grooming; grey represents the estimated catch from records reported to straddling Statistical Areas 025 and 030 but randomly allocated to PAU 5B.

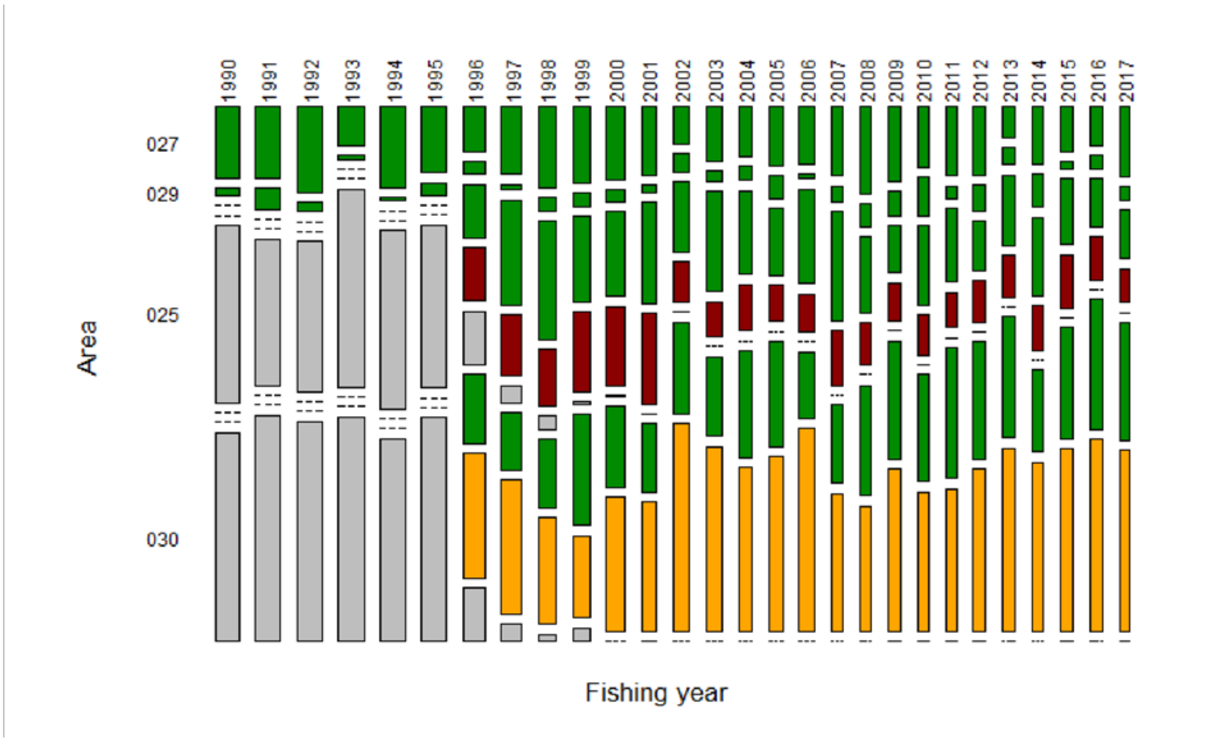


Figure 6: Estimated catch by statistical area and fishing year on the CELRs and PCELRs, 1990–2017. Green represents catch from within PAU 5B; red represents catch from Statistical Area 025 outside PAU 5B; orange represents catch from Statistical Area 030 outside PAU 5B; grey represents catch from areas with substock undetermined. The width of the bar is proportional to the total annual catch.

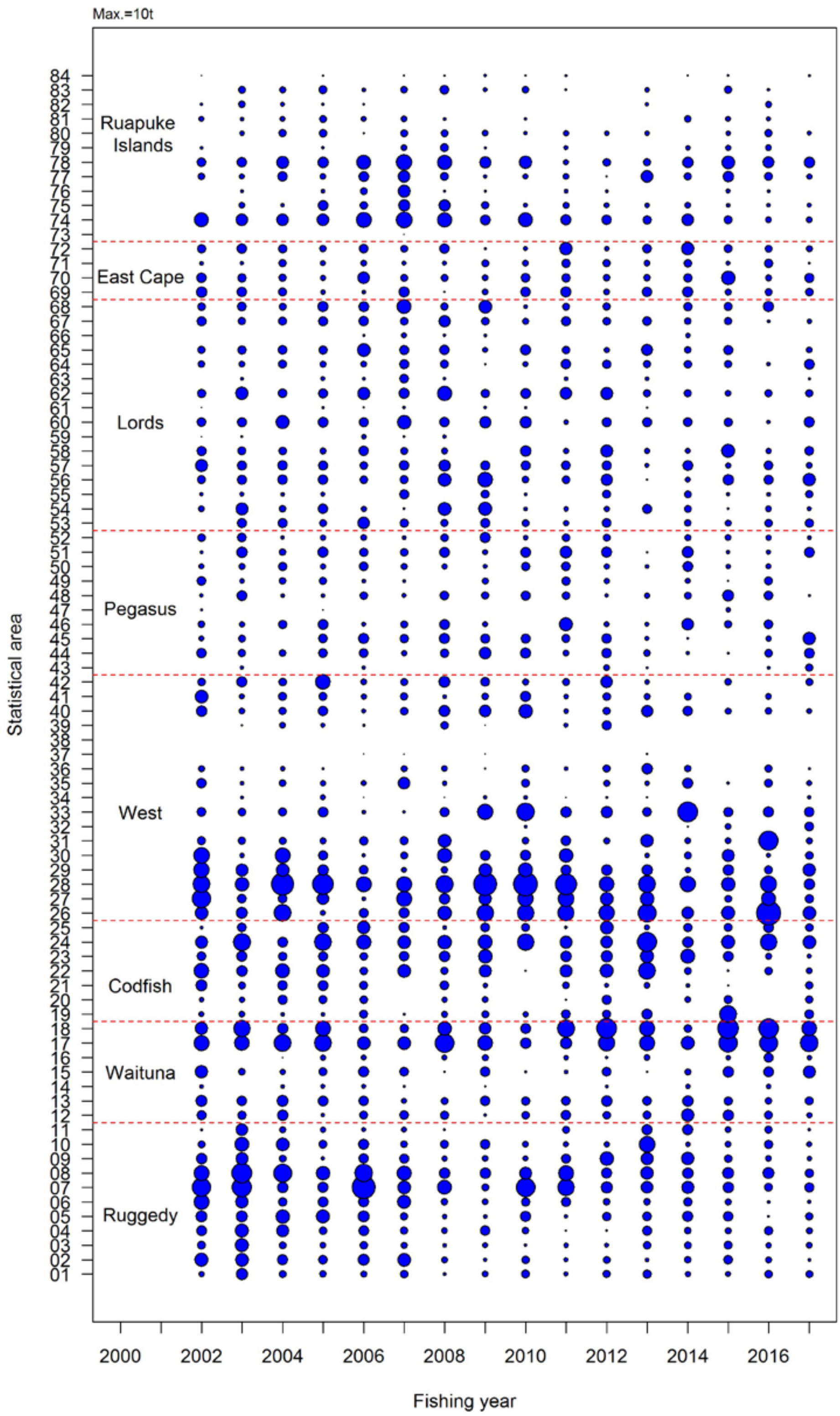
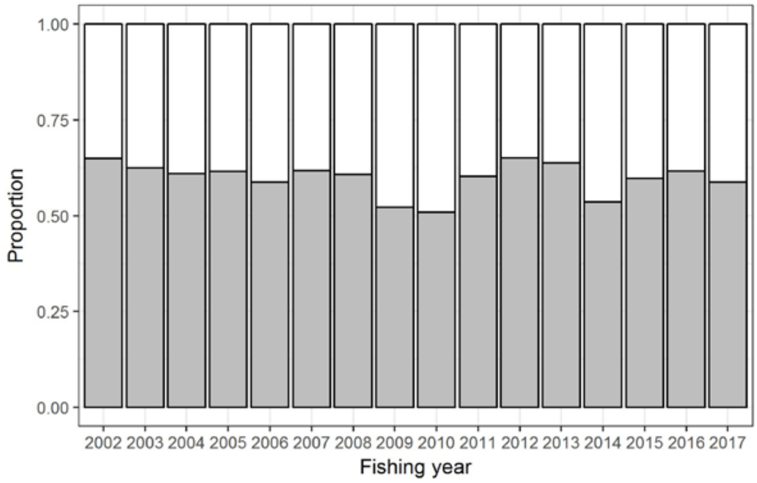
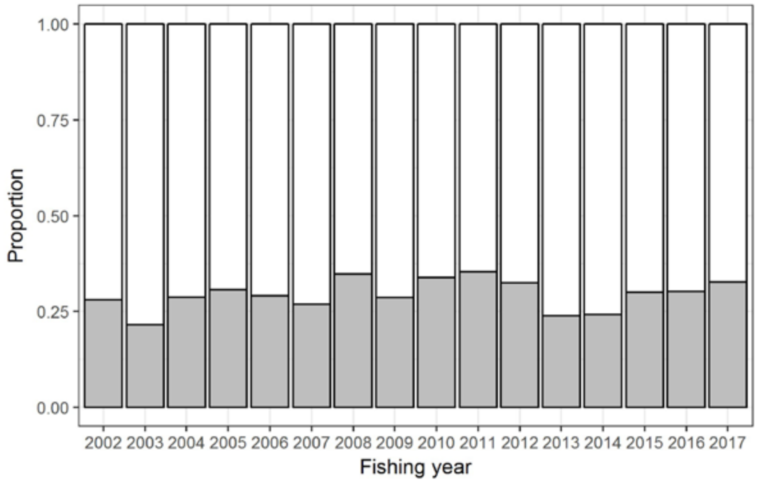


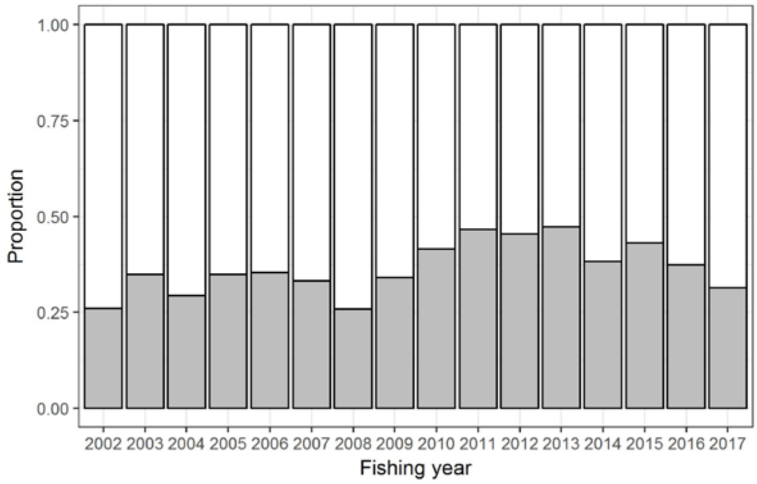
Figure 7: Annual estimated catch by Paua statistical area in PAU 5B for fishing years 2002–2017 from the PCELR forms. The size of the circle is proportional to the catch.



(a) Proportion of records that recorded estimated catch in a multiple of 50 kg.



(b) Proportion of records that recorded hours fished in an exact multiple of 1 hour.



(c) Proportion of fishing events where recorded estimated catch was equally split among divers.

Figure 8: Diagnostic of data resolution on the PCELR forms within PAU 5B: (a) multiples of 50 kg, (b) multiples of one hour, and (c) proportion of events equally split among divers.

3.2 Recreational catch

The 1996 and 1999–2000 National Recreational Fishing Surveys estimated that 37.1 t and 53.2 t respectively were taken from PAU 5 by recreational fisheries but with no substock breakdown. The Marine Recreational Fisheries Technical Working Group considered that some harvest estimates from the 1999–2000 and 2001–02 surveys for some fish stocks were unbelievably high. The Shellfish Fisheries Working Group (SFWG) examined estimates from national recreational surveys conducted in 1996 and 1999–2001, and following their discussions, the 2007 assessment for PAU 5B assumed that the 1974 recreational catch was 1 t, increasing linearly to 5 t in 2006. The New Zealand Recreational Marine Survey for 2011–12 estimated that the recreational harvest for PAU 5B was 0.82 t with a CV of 50% (Wynne-Jones et al. 2014). For this assessment, the SFWG agreed to assume that the recreational catch rose linearly from 1 t in 1974 to 5 t in 2006, and remained at 5 t between 2007 and 2017.

3.3 Customary catch

Reported annual customary catch is described in Table 6. In the assessment model estimated customary catch was assumed to be equal to 1 t from 1974–2017.

Table 6: Reported annual customary catch (in numbers) for PAU 5B under Te Runanga o Ngai Tahu. Assumed weight (kg) is derived assuming an average weight of 0.28 kg.

Year	Numbers harvested	Assumed weight (kg)
1999	90	25.2
2001	266	74.48
2002	460	128.8
2003	300	84
2004	510	142.8
2005	540	151.2
2006	260	72.8
2007	538	150.64
2008	3533	989.24
2009	2540	711.2
2010	3358	940.24
2011	988	276.64
2012	1460	408.8
2013	538	150.64
2014	130	36.4
2016	2003	560.84

3.4 Illegal catch

Illegal catch was estimated by the Ministry of Fisheries to be 15 t (Breen & Smith 2008a), but "Compliance express extreme reservations about the accuracy of this figure." For this assessment, the SFWG agreed to assume that illegal catch was zero before 1986, then rose linearly from 1 t in 1986 to 5 t in 2006, and remained constant at 5 t between 2007 and 2017.

Estimated commercial catch history including commercial, customary, recreational, and illegal catch for the 1974–2017 fishing years is shown in Figure 9.

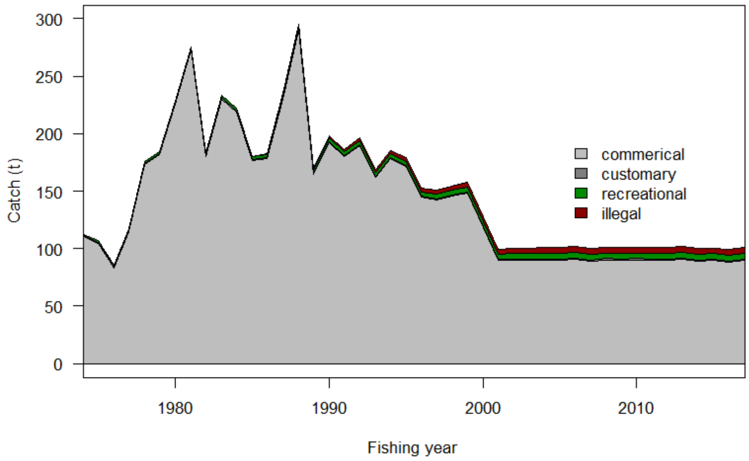


Figure 9: Estimated catch history including commercial, customary, recreational, and illegal catch 1974–2017 in PAU 5B, using assumption 3 for commercial catch between 1984-1995.

4. CPUE STANDARDISATIONS

4.1 Introduction

Earlier paua standardisations have included the Fisheries Statistics Unit (FSU) data covering the period from 1983–1988. However recent paua standardisations have excluded the FSU data because of problems regarding low coverage of the catch, lack of a vessel key, and undocumented corrections to the duration field (see for example Fu et al. 2016).

Data used in the standardisations included Catch Effort Landing Returns (CELR) covering 1990–2001, and Paua Catch Effort Landing Returns (PCELR) covering 2002–2017. 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 three standardisations were done:

1. CELR data (1990–2001)
2. PCELR data (2002–2016)
3. Combined CELR and PCELR data (1990–2016)

For the PAU 5B stock assessment, the combined CELR and PCELR data index was used with the CELR and PCELR indices examined as sensitivity analyses.

4.2 CELR data (1990–2001)

4.2.1 The CELR data standardisation approach

For the CELR data the Shellfish Working Group made decisions on the methodology:

1. NOT to randomly allocate catch-effort records from Statistical Areas 025 and 030 that overlap with PAU 5B, but are not entirely within it.
2. To use Fisher Identification Number (FIN) in standardisation procedures instead of vessel.
3. To filter the data to give a subset of the data for which the recorded fishing duration is less ambiguous, using the criteria: (i) just one diver, or (ii) fishing duration at least eight hours and at least two divers. Drop records with a fishing duration per diver of greater than 10 hours.
4. Not to put in a year:area interaction in the standardisations (to be used in the assessment), but to explore area differences in catch rates by doing separate standardisations where a year:area interaction is forced in at the start. For the CELR data the smallest possible areas sub-division is areas 025, 027, 029, 030.

Two differences from the previous PAU 5B CELR standardisation are:

1. Offering just fishing duration to the standardisation instead of both fishing duration and number of divers. This difference reflects the decision made for the previous paua standardisation in the PAU 5D area (Fu et al. 2017).

2. Including the non-filtered data as well, by scaling the recorded fishing duration for this by the number of divers. This was also done for the PAU 5A standardisation, for which the fishing duration characteristics looked similar (Fu et al. 2016).

Two sensitivity analyses were decided upon, these being based upon the review of the paua stock assessments (Appendix A):

1. Using records with just one diver. For one diver there were insufficient records to calculate a standardised index, so just a raw CPUE was calculated.
2. Using all the 025 and 030 data and calculating a standardised index. This was not recommended as a base standardised CPUE, but as a check to see how much difference it made.

4.2.2 The CELR data

The initial data set started with was CELR catch-effort records from PAU 5B. The Fisher Identification Number (FIN) and date were present for all records.

Some grooming of the catch-effort records was undertaken: records were retained only where paua was targeted by diving, and records were dropped with missing values for the estimated catch or number of divers (Table 7). This groomed data set has 3053 records (Table 8).

For the CELR data the fishing duration field was the total fishing duration for all divers. It has been noted in some past analyses that there is ambiguity as to what is recorded for fishing duration for the CELR data, because a mixture of total hours and per diver hours is put down, possibly attributable to the transition from the FSU forms to CELR forms.

For most trips the number of divers was three or less (Figure 10). One possible sign that fishing duration was incorrectly recorded as per diver, would be a decrease in the hours per diver as the number of divers go up. The hours per diver dropped by 25% going from one to two divers (Figure 11).

Another sign of incorrect recording for fishing duration would be a bimodal distribution for the fishing duration when there are two or more divers. What was seen for two divers was a single prominent mode that shifted further to the right compared to a single diver; and for three divers a smaller second mode to the right (Figure 12). This plot for the PAU 5B fishing duration distribution is similar to that for the nearby PAU 5A area (Figure 13), but somewhat different from PAU 5D where it is clearer that fishing duration was mostly recorded as hours per diver (Figure 14).

There is some ambiguity, but it appears that many of the records have fishing duration recorded on a hours per diver basis, with some recorded as total hours for divers. Hence it was decided to use the previous filtering criteria for PAU 5B (which retained records for which the total hours for divers was recorded), augmented with the procedure for PAU 5A where the rest of the data was also used by scaling the recorded fishing duration by the number of divers.

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

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Not targeting paua	0	2	2	0	0	0	1	1	3	6	1	0	16
Catch missing	0	0	0	0	0	0	0	0	0	1	0	0	1
Number divers missing	0	1	0	0	0	0	5	3	1	5	1	0	16
Fishing duration missing	0	0	0	0	1	1	3	17	17	6	2	1	48
Method not diving	27	48	62	40	43	47	102	145	104	174	70	60	922

Table 8: Number of records after initial grooming. Fishing year is shown in an abbreviated form, for example 90 = 1990, 01 = 2001.

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
After	128	129	165	73	144	179	286	344	400	371	435	399	3053

After scaling up fishing duration for non-subsetted data records, some final grooming was done in which records with NA for fishing duration were dropped (0 records), and a fishing duration per diver greater than 10 hours were dropped (7 records). The final subsetting retained 99.8% of the records from 1990–2001 (Table 9). Of the retained records 39% had one diver (Table 10).

For this data set the hours per diver increased by about half an hour from 1990–2001 (Figures 15–16). A raw CPUE using duration as the measure of effort gave a decline in catch rates that was slightly greater than if number of divers was used as the measure of effort (Figure 17). If all records were used then the CPUE decline was greater, compared to using records with just one diver (Figure 18).

One of the recommendations of the review, to reduce ambiguity in fishing duration, was to restrict records for the standardisation to just those with one diver. However, this restriction resulted in the number of records in each year becoming low, and this number would reduce by about another 75% when FIN subsetting for the standardisation was done (Table 11).

Table 9: Number of records in the dataset before and after final grooming. Fishing year is shown in an abbreviated form, for example 90 = 1990, 01 = 2001.

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
Before	128	129	165	73	144	179	286	344	400	371	435	399	3053
After	127	129	165	73	144	178	283	342	400	371	435	399	3046

Table 10: Distribution of the number of divers before and after final grooming.

Number of divers	1	2	3	4	5	6	7	8	9	Total
Before	1209	1339	382	56	21	26	14	4	2	3053
After	1203	1338	382	56	21	26	14	4	2	3046

Table 11: Number of records after restricting to records with one diver. Fishing year is shown in an abbreviated form, for example 90 = 1990, 01 = 2001.

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
Number of records	66	53	69	39	46	70	105	109	155	153	172	166	1203

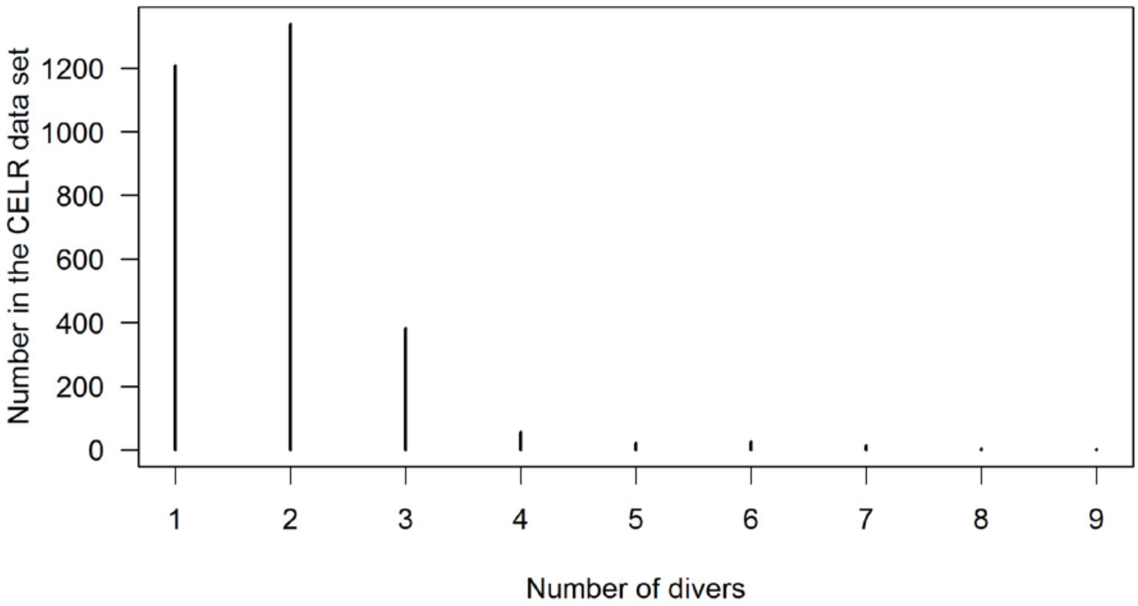


Figure 10: Distribution of the number of divers for a record.

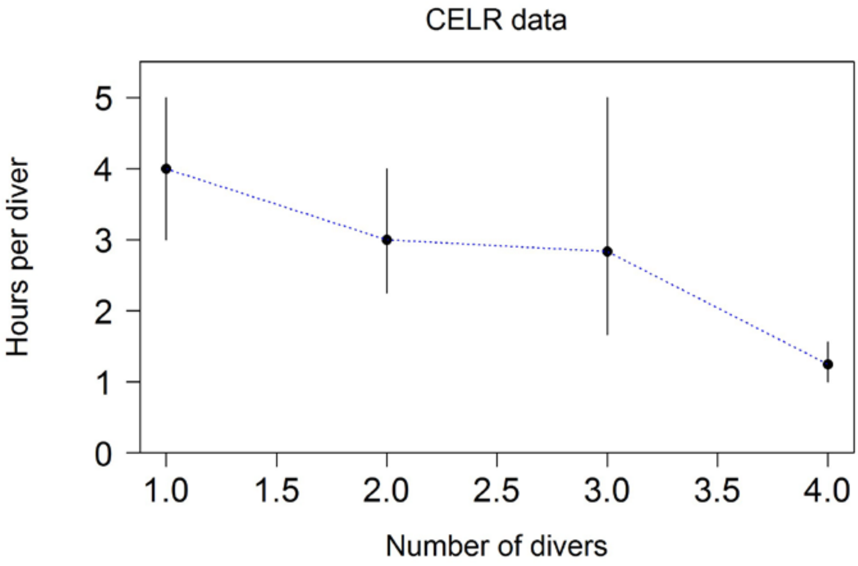


Figure 11: Quantiles by number of divers for the hours per diver: medians (dot) and lower and upper quartiles (vertical lines). The number of divers is restricted to four or less.

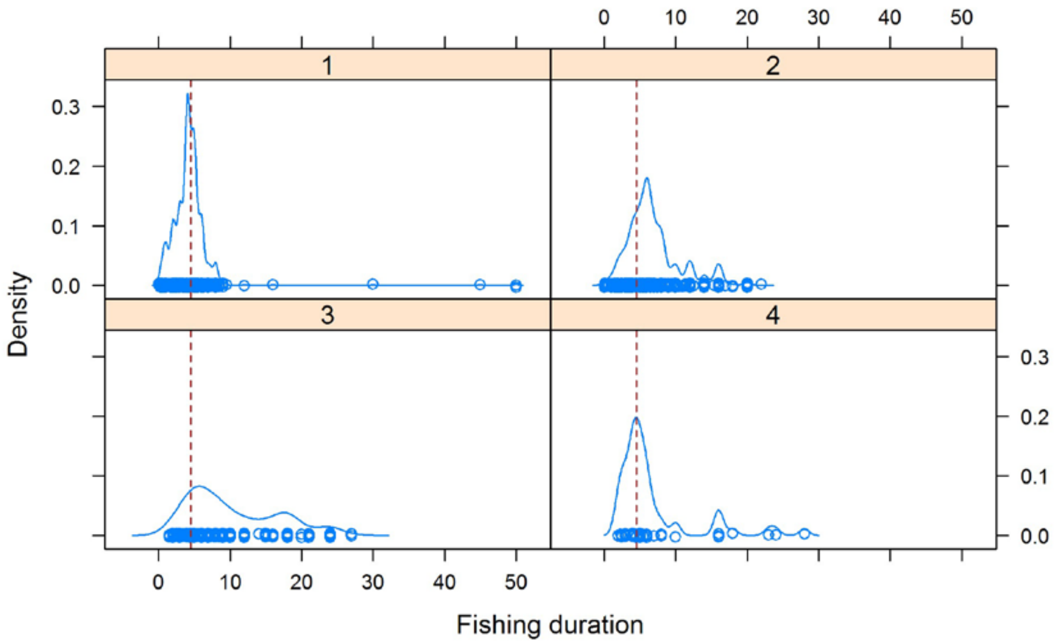


Figure 12: PAU 5B. Density and strip plot for the recorded fishing duration, given the number of divers on a trip (restricted to four or less). The vertical dashed reference line is at a fishing duration of 4.5 hours.

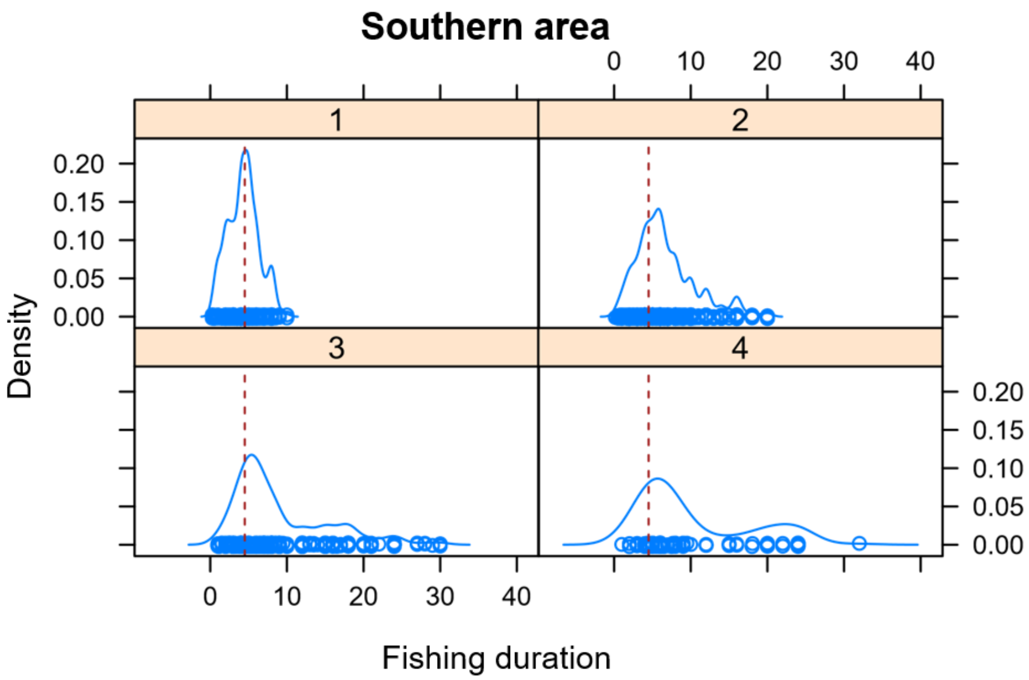


Figure 13: PAU 5A southern area. Reproduced from (Fu et al. 2015, p. 23) with a vertical dashed line added at 4.5 hours.

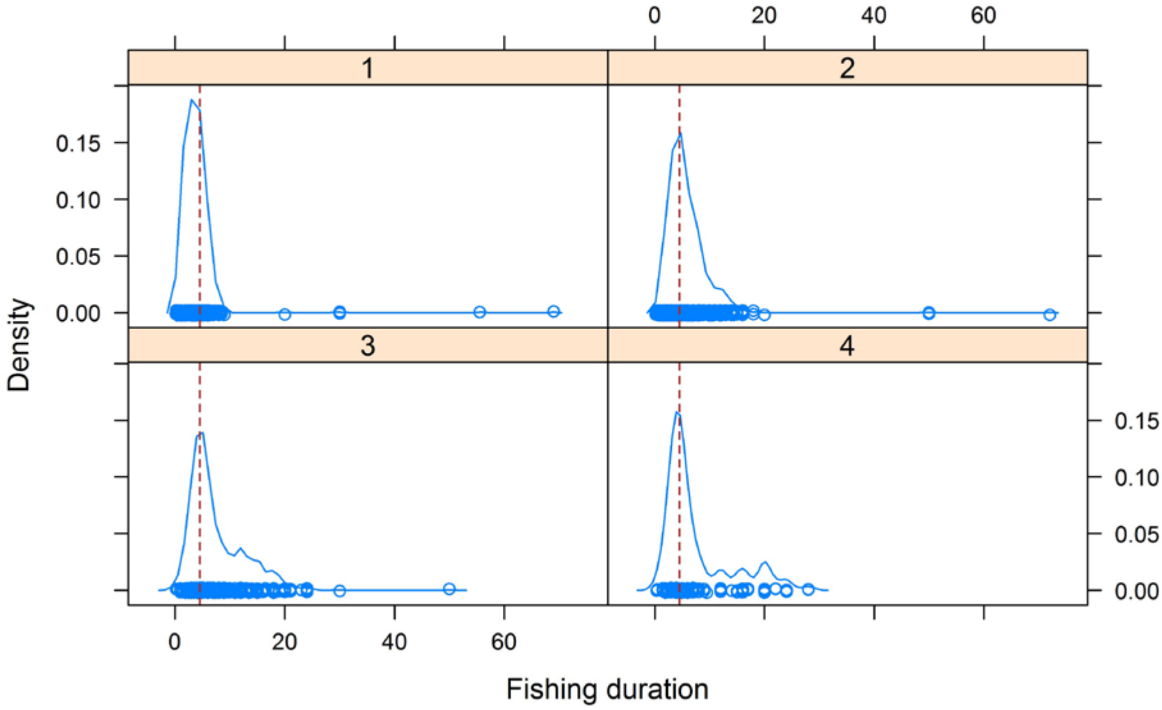


Figure 14: PAU 5D. Reproduced from (Fu et al. 2017, p. 28). The vertical dashed reference lines are at fishing durations of 4.5 and 10.0 hours.

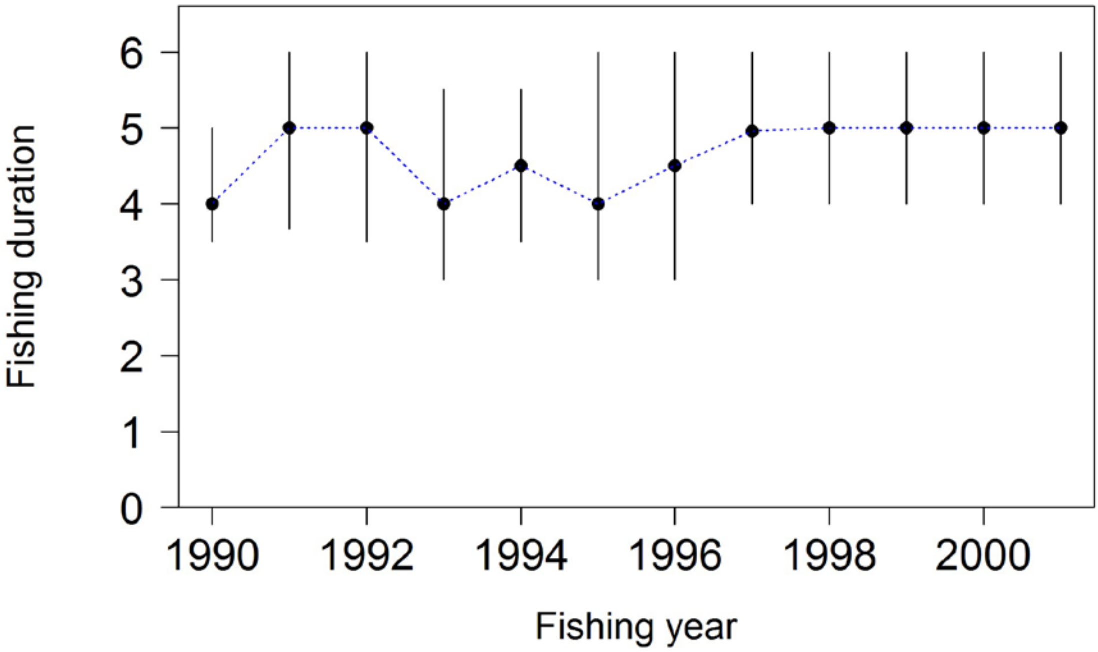


Figure 15: Quantiles by fishing year for the recorded daily fishing duration: medians (dot) and lower and upper quartiles (vertical lines). Records with a fishing duration greater than 10 hours are dropped.

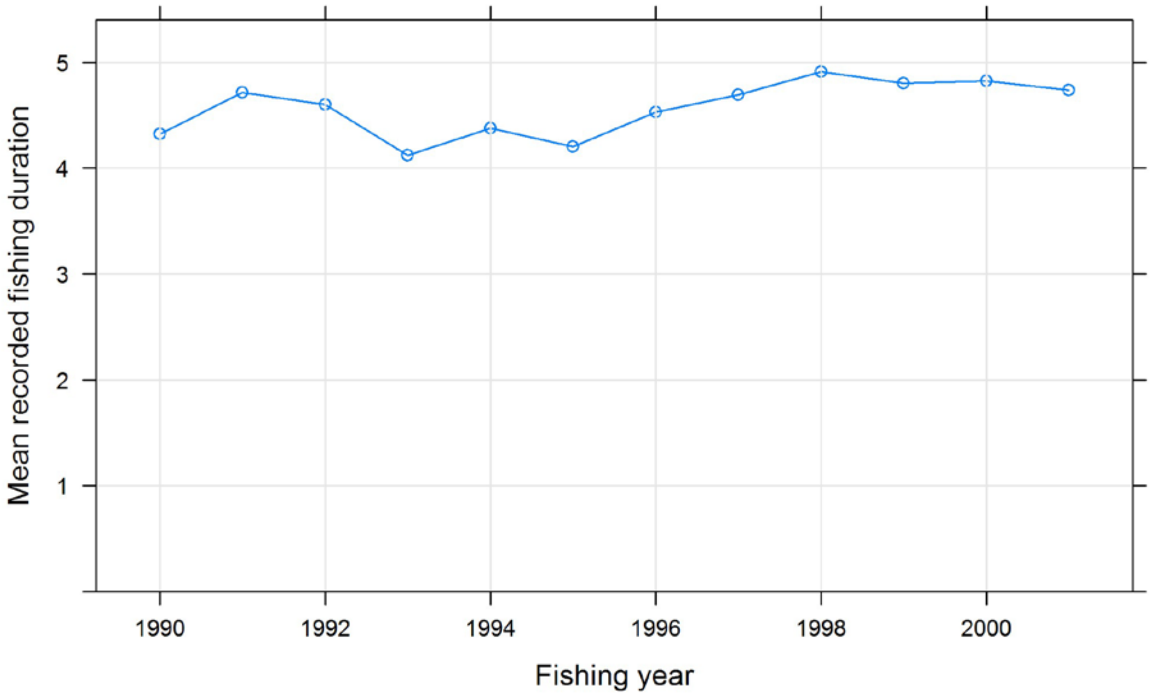


Figure 16: Mean values by fishing year for the daily fishing duration. Records with a fishing duration greater than 10 hours are dropped.

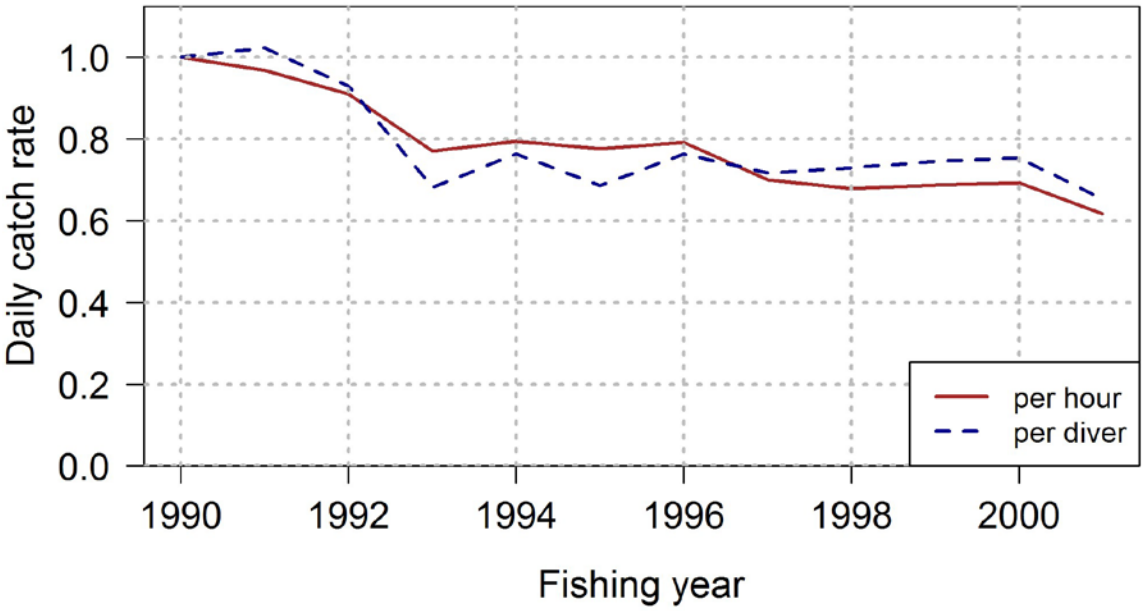


Figure 17: Geometric mean of the daily catch rate by year. The plots are scaled so that they both have the value one in 1990. Records with a fishing duration greater than 10 hours are dropped.

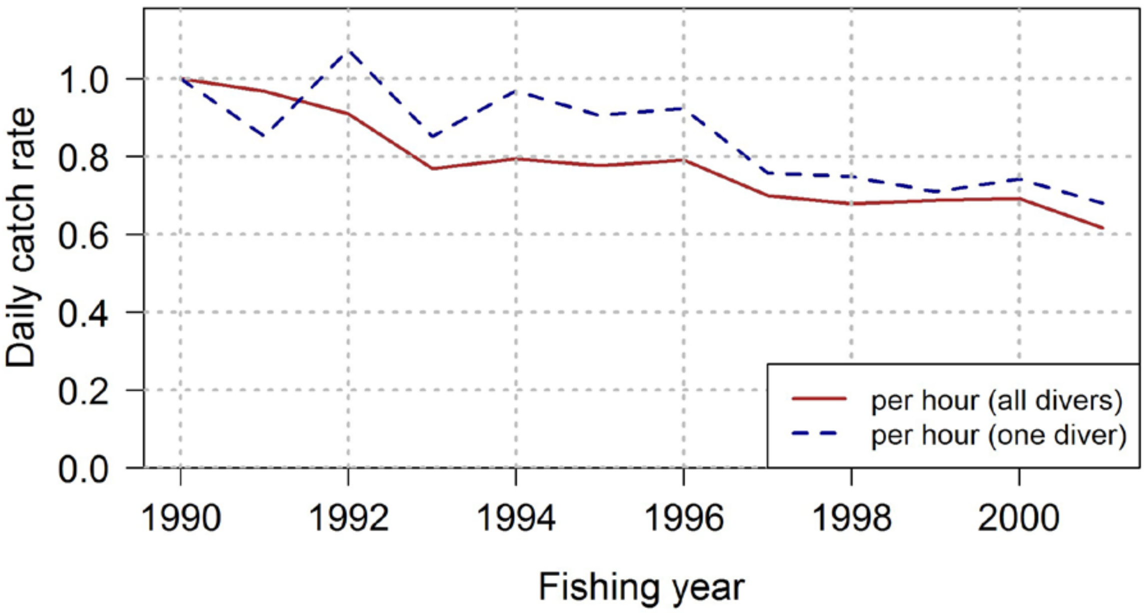


Figure 18: Daily catch rates for one diver versus all divers. Geometric mean of the daily catch rate by year. The plots are scaled so that they both have the value one in 1990. Records with a fishing duration greater than 10 hours are dropped.

4.2.3 Standardised CELR

The initial set was that left after grooming and removing records for which the fishing duration per diver was greater than 10 hours (see the previous section).

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 7 records per year for a minimum of 2 years was chosen, thus retaining 84% of the catch over 1990–2001 (Figure 19). While 84% of the catch was retained overall, it was slightly less than this for some years (Figures 20–21). Number of days of effort retained after subsetting was 57 or more for every fishing year (Table 12, Figure 22). The number of FIN holders dropped from 84 to 29 under the subsetting criteria.

After subsetting there was good temporal overlap for FIN holder effort (Figures 23–24). Similarly, for temporal overlap in statistical area and month of the year (Figures 25–26).

CPUE was defined as daily catch. Year was forced into the model at the start and other predictor variables offered to the model were FIN, Statistical Area (025, 027, 029, 030), month, and total fishing duration (as a cubic polynomial).

The model explained 56% of the variability in CPUE with fishing duration (41%) explaining most of this followed by FIN (10%) (Table 13). The effects appeared plausible and the model diagnostics good (Figures 27–28). There was an apparent plateauing effect for the catch taken after a fishing duration of 15 hours, though for most of the records fishing duration was less than 15 hours (Figure 29). The standardised index showed a decline in catch rate that was steeper than the unstandardised index (Table 14, Figure 30).

4.2.4 Sensitivities to the base standardised CELR

Most of the catch and effort for the CPUE data were from areas 025, 027, and 030 with little from 029 (Tables 15–16). A standardisation with a year:area interaction forced into the model, showed similar trends from 1996–2001 for the separate areas, with differences between 027 and 029 before this (Figure 31).

In the base standardisation only records from 025 and 030 were used which were known to be in PAU 5B. In an alternative standardisation all records from 025 and 030 were used, resulting in a similar index to the base standardisation index (Figure 32).

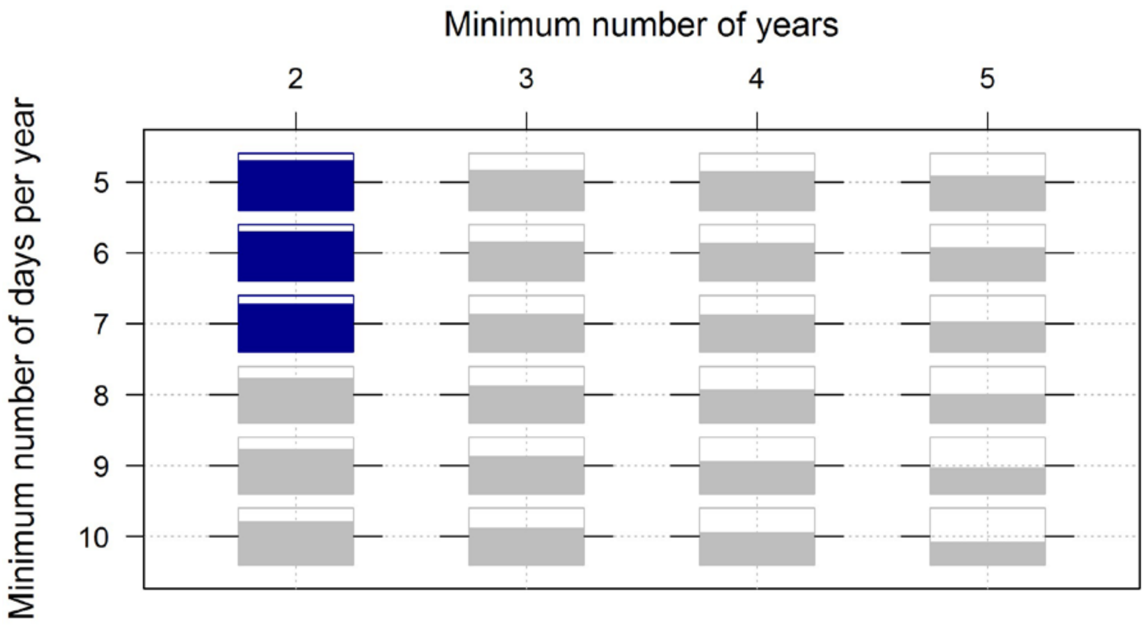


Figure 19: Proportion of the catch taken when subsetting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar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

Table 12: Number of records before and after FIN subsetting. Fishing year is shown in an abbreviated form, for example 90 = 1990, 01 = 2001.

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
Before	127	129	165	73	144	178	283	342	400	371	435	399	3046
After	90	77	124	57	128	147	236	298	376	359	406	333	2631

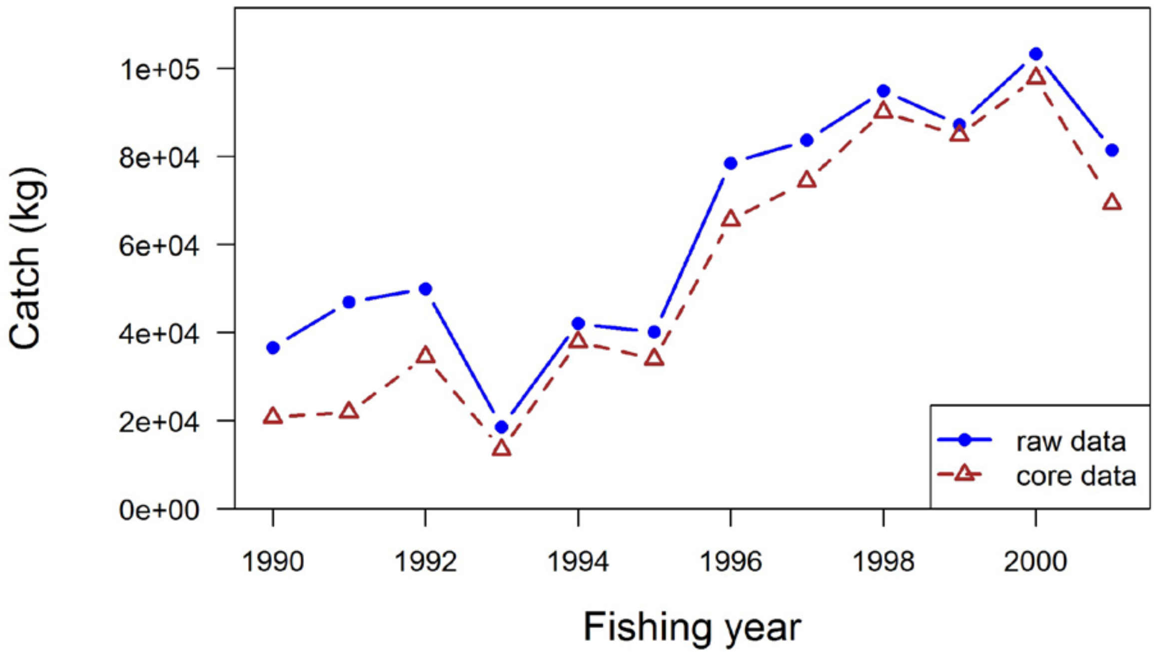


Figure 20: Catch by fishing year before FIN subsetting (raw data) and after (core data).

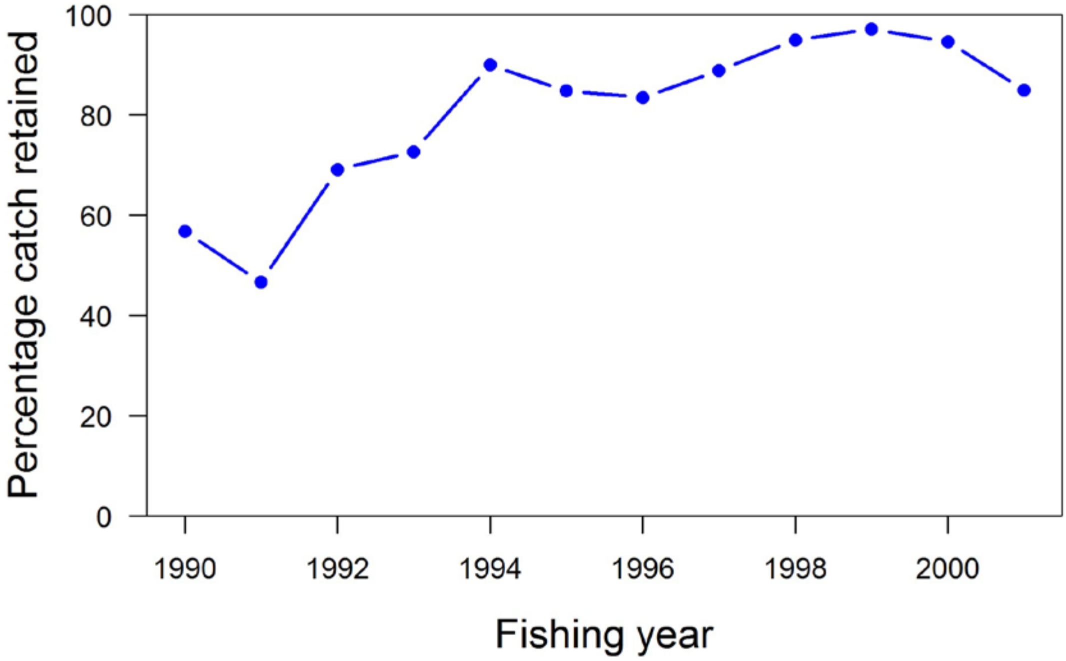


Figure 21: Percentage of the catch retained after FIN subsetting.

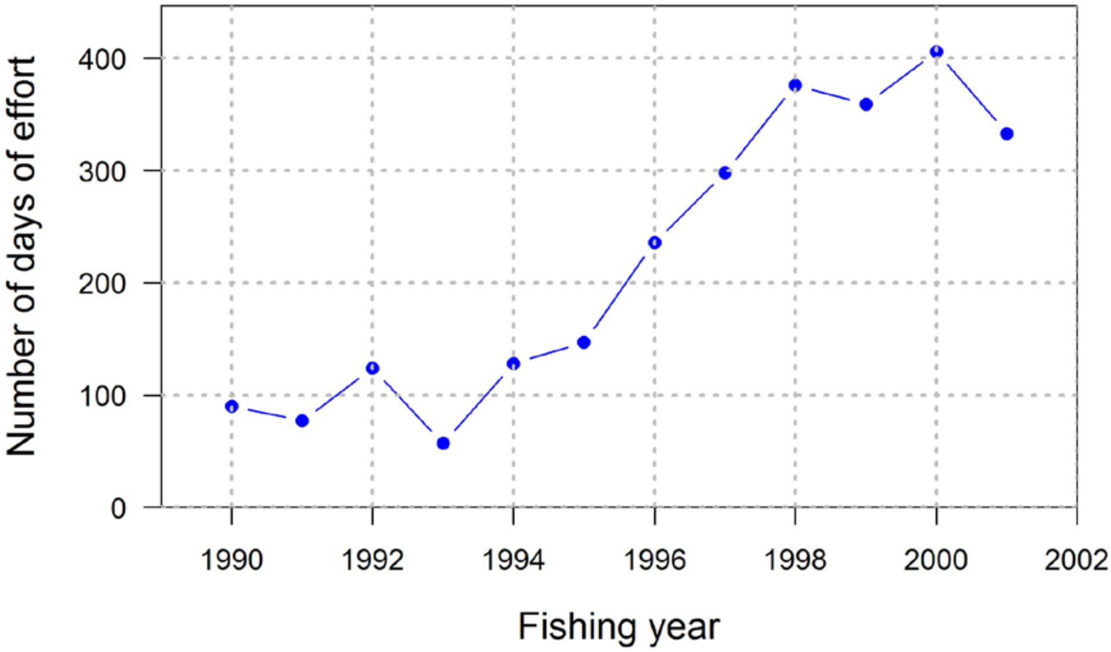


Figure 22: Number of days of effort retained after FIN subsetting.

Table 13: Variables accepted into the CELR standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish year	11	0.01
total fishing duration	3	0.42
FIN	28	0.52
statistical area	3	0.56

Table 14: Standardised CELR index, lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
1990	1.34	1.06	1.70	0.12
1991	1.57	1.24	1.99	0.12
1992	1.26	1.04	1.53	0.10
1993	1.31	1.01	1.71	0.13
1994	1.04	0.87	1.25	0.09
1995	0.98	0.83	1.16	0.08
1996	0.88	0.77	1.02	0.07
1997	0.89	0.78	1.02	0.06
1998	0.84	0.74	0.95	0.06
1999	0.79	0.70	0.90	0.06
2000	0.79	0.69	0.90	0.07
2001	0.68	0.59	0.79	0.07

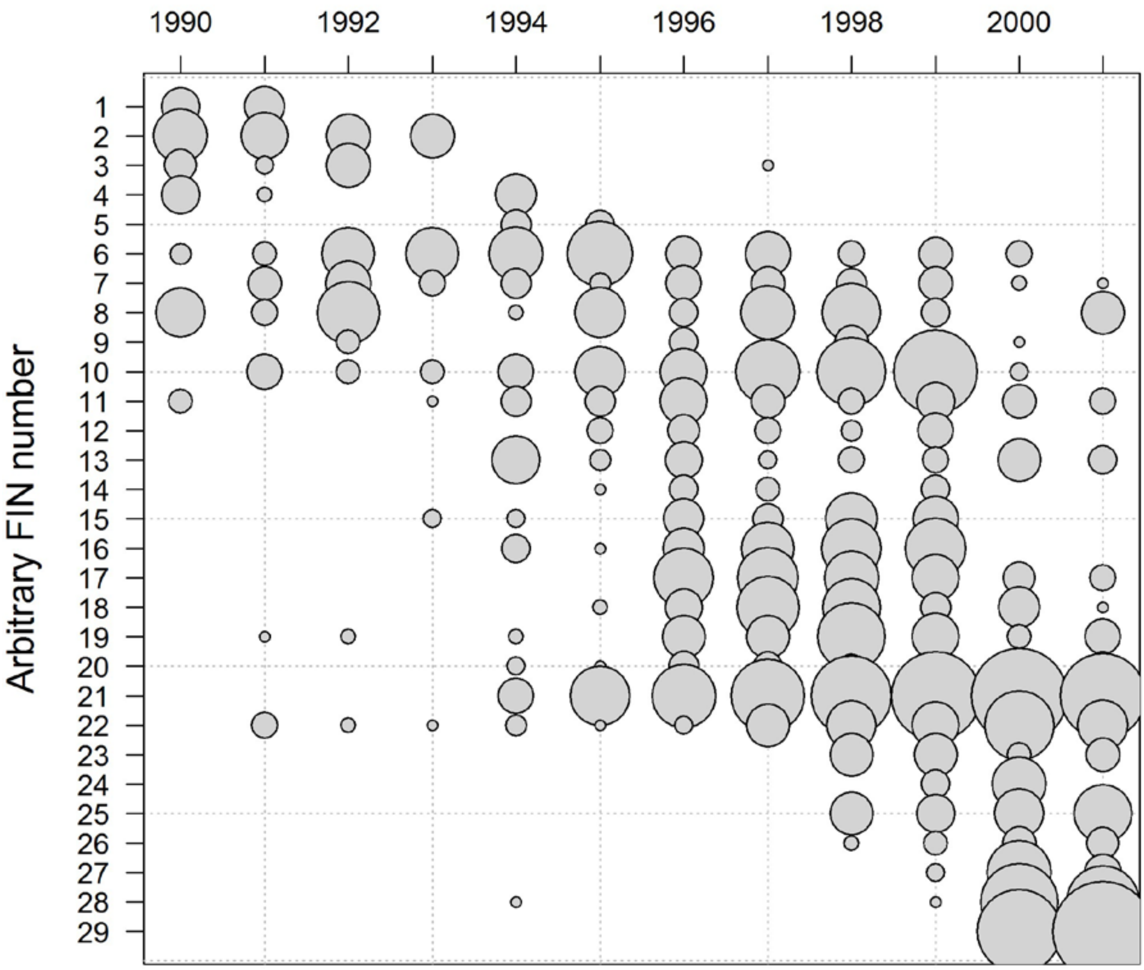


Figure 23: Days of effort in the CELR dataset by FIN and fishing year. The area of a circle is proportional to the days of effort.

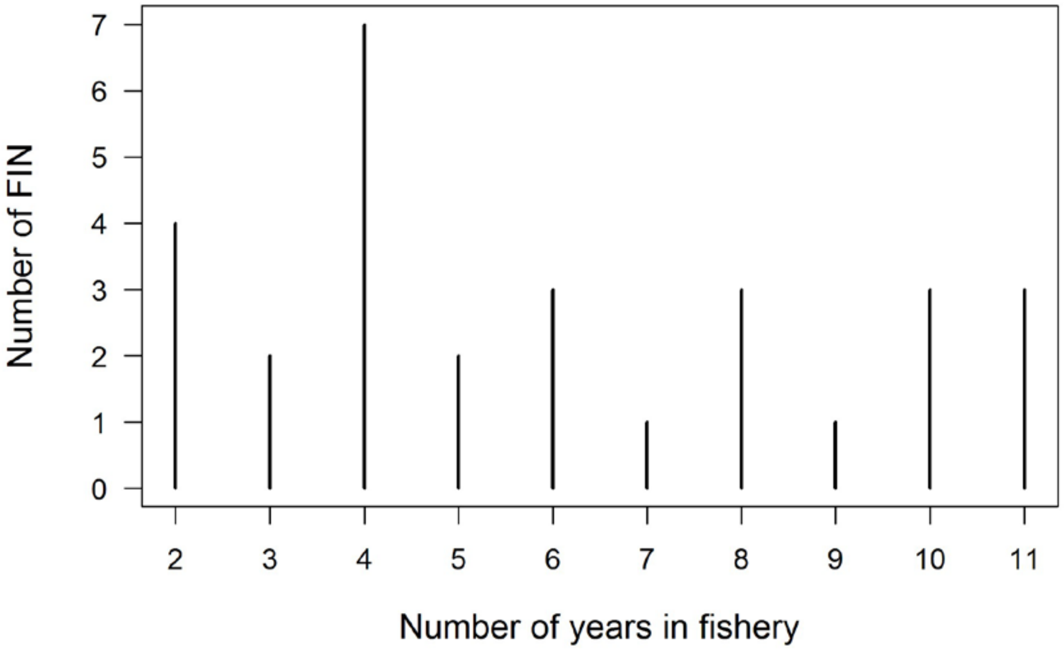


Figure 24: Number of years in the fishery for a FIN holder after subsetting by FIN.

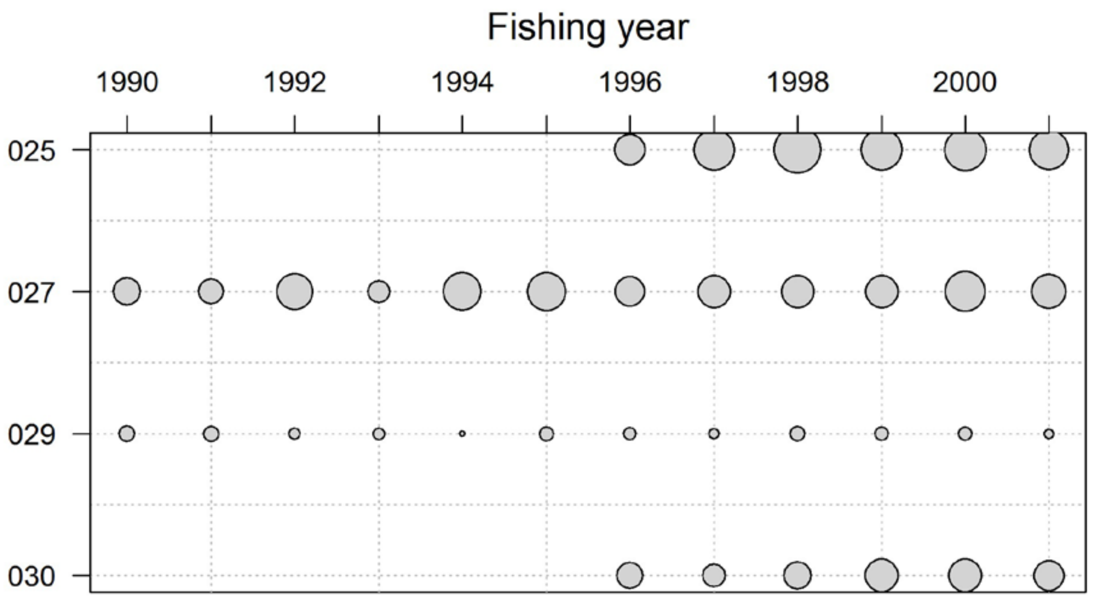


Figure 25: Days of effort in the CELR dataset by area and fishing year.

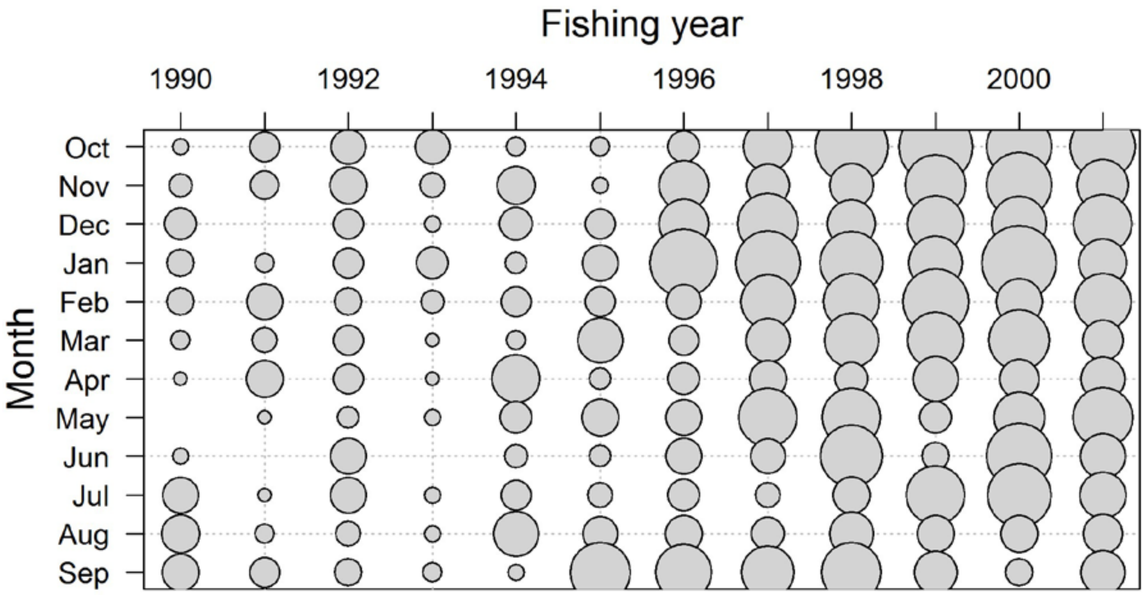


Figure 26: Days of effort in the CELR dataset by month and fishing year.

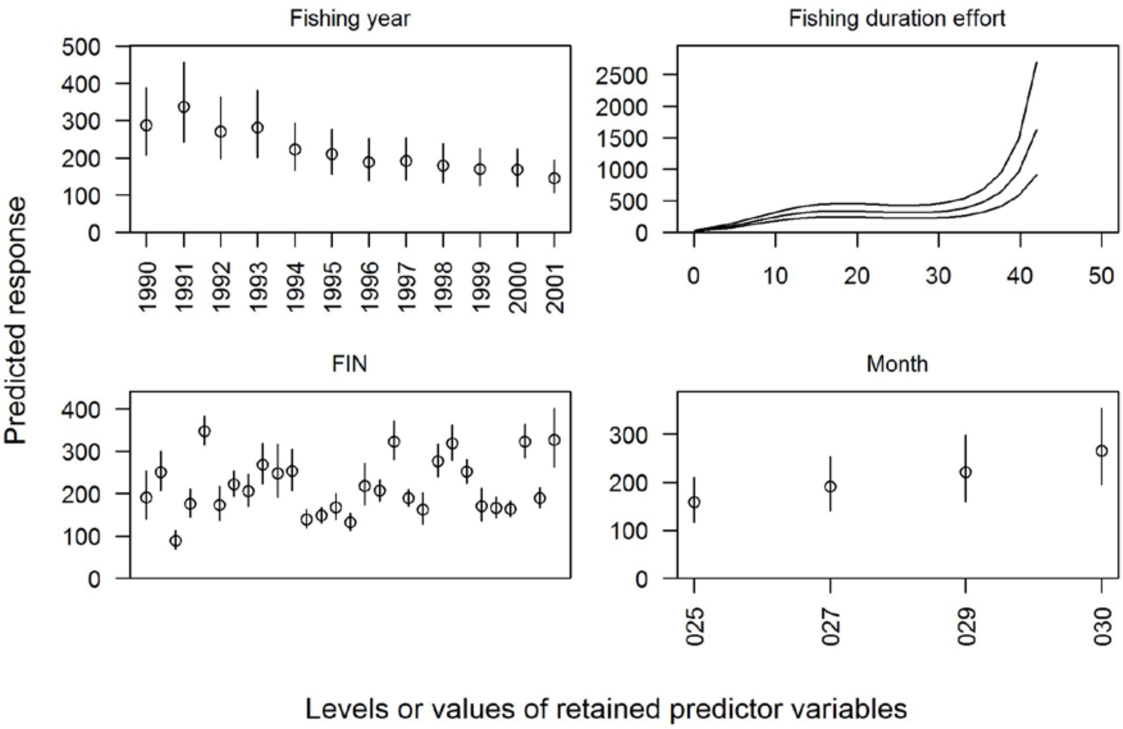


Figure 27: Effects catch rates from the CELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

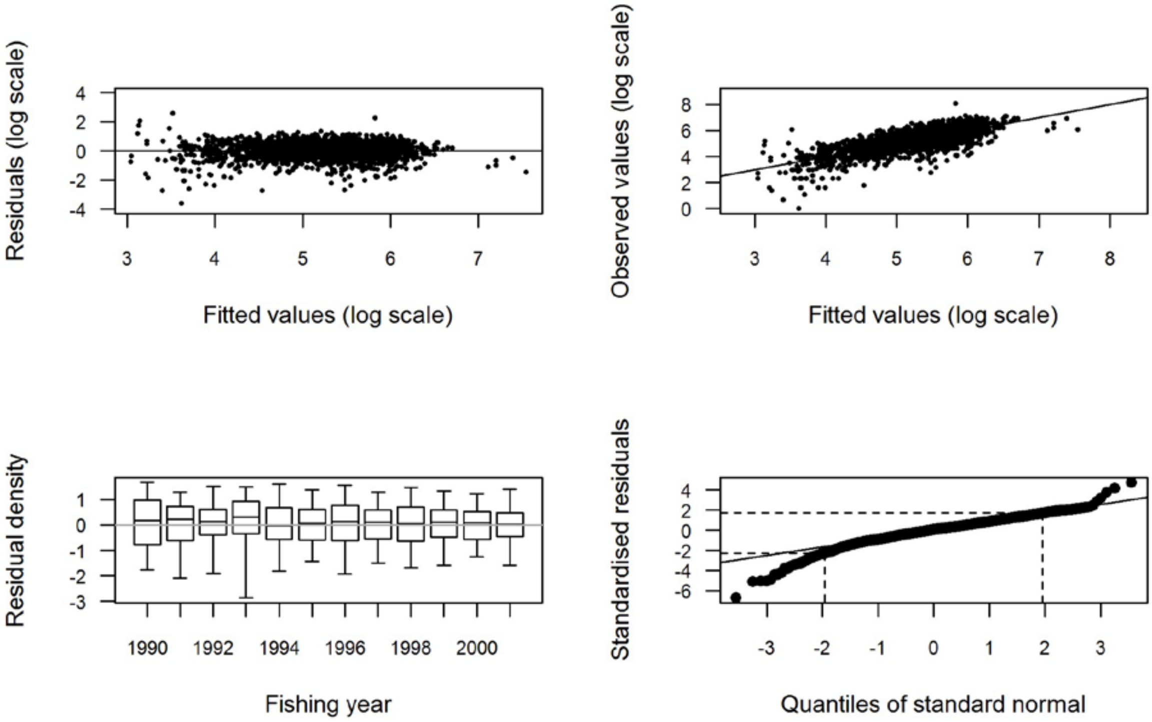


Figure 28: Residuals from the standardisation model for the CELR dataset.

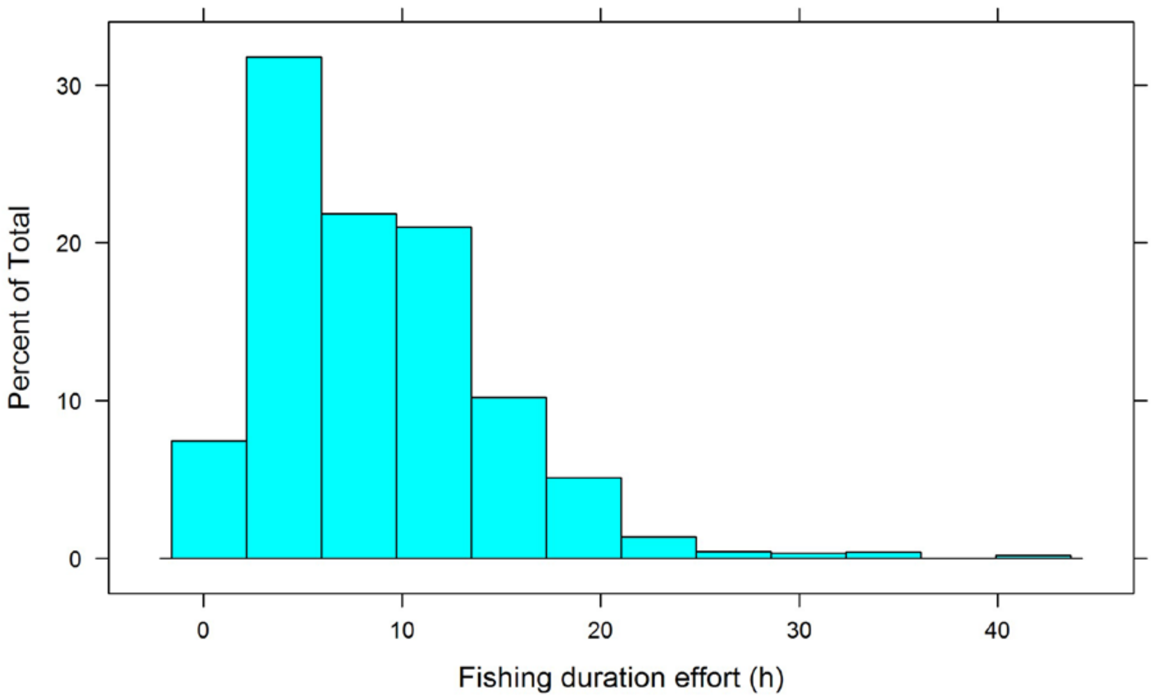


Figure 29: Distribution of fishing duration effort (h) in the CELR dataset.

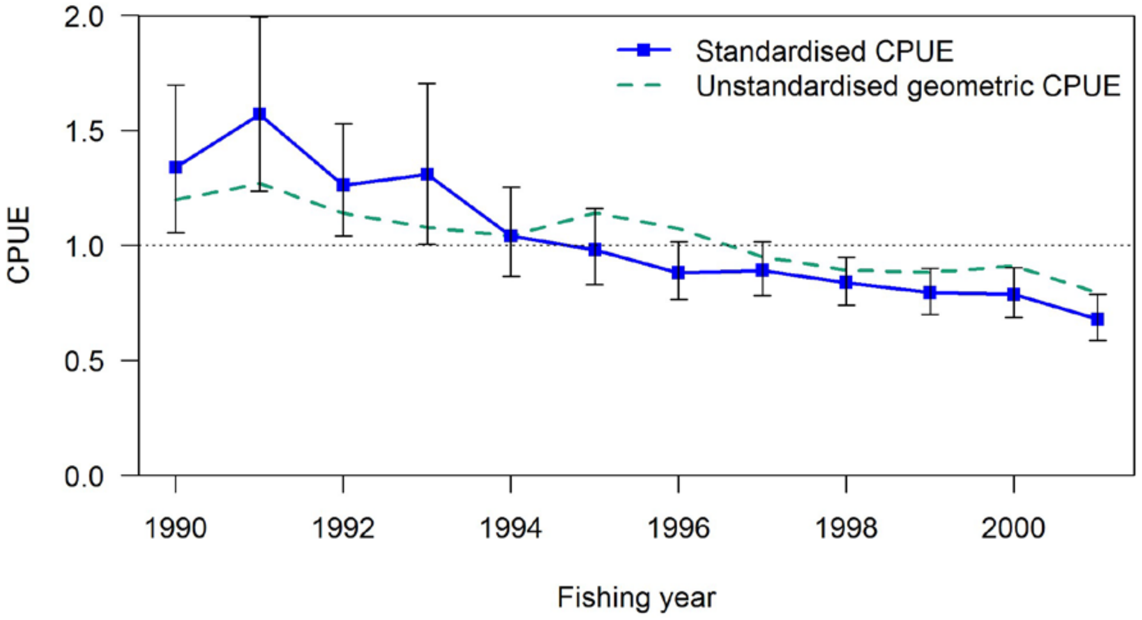


Figure 30: The standardised CPUE index with 95% confidence intervals for the CELR dataset. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

Table 15: Number of daily records by area for each year (for CPUE data).

Fishing year	025	027	029	030
1990	0	67	23	0
1991	0	56	21	0
1992	0	113	11	0
1993	0	44	13	0
1994	0	125	3	0
1995	0	129	18	0
1996	83	77	14	62
1997	147	95	9	47
1998	195	95	20	66
1999	151	94	17	97
2000	154	140	16	96
2001	139	105	8	81

Table 16: Percentage of catch by area for each year (for CPUE data).

Fishing year	025	027	029	030
1990	0	87	13	0
1991	0	70	30	0
1992	0	91	9	0
1993	0	84	16	0
1994	0	97	3	0
1995	0	80	20	0
1996	31	28	6	35
1997	45	29	4	21
1998	43	26	6	25
1999	29	25	5	41
2000	33	29	5	33
2001	39	32	3	27

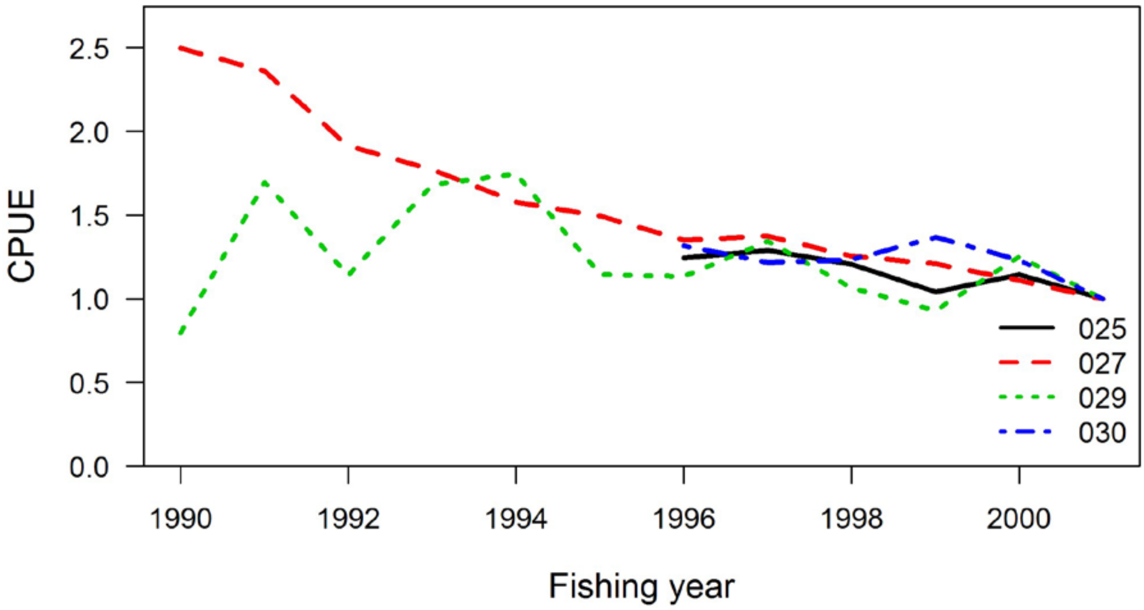


Figure 31: Standardised indices for the CELR dataset with a year:area interaction forced into the model. The indices are scaled to have the value one in 2001.

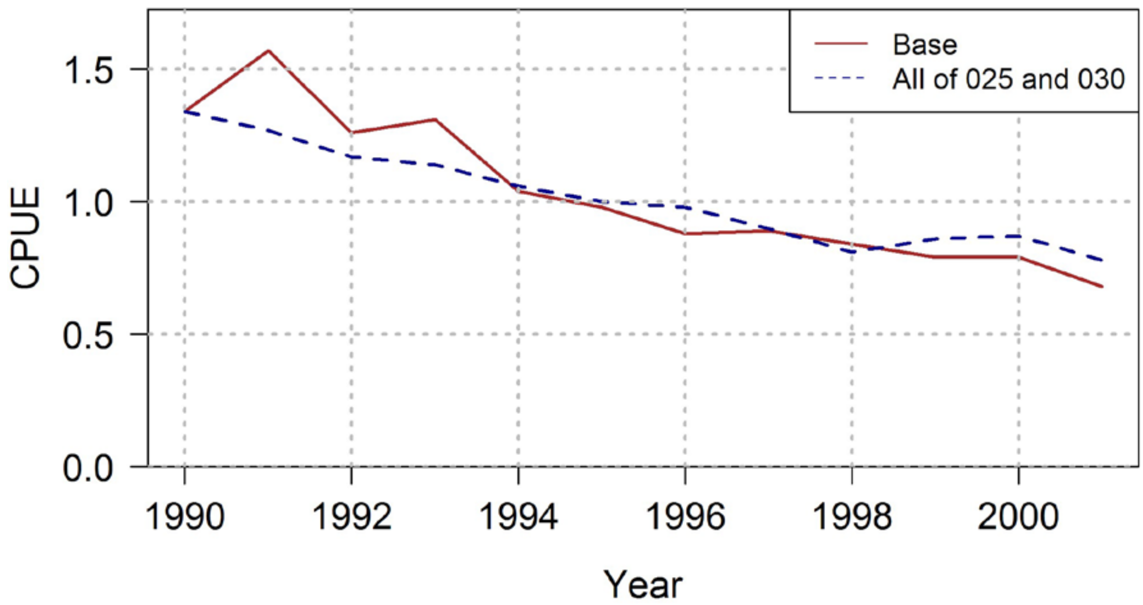


Figure 32: A standardised index using all the catch-effort records for areas 025 and 030, compared to the base standardisation.

4.3 PCELR data (2002–2017)

4.3.1 Introduction

For the PCELR data standardisation the same methodology was used as for the 2016 PAU 5D assessment (Fu et al. 2017). Some key aspects of this were:

1. To use Fisher Identification Number (FIN) in standardisation procedures instead of vessel.
2. Use FIN to subset out a core group of records.
3. Retain just the statistical areas and divers with ten or more records.
4. Not to put in a year:area interaction in the standardisations (to be used in the assessment), but to explore area differences in catch rates by doing separate standardisations where a year:area interaction is forced in at the start. For the PCELR data some natural divisions are based around the research strata (see Figure 4).

Further details of the standardisation methodology are in Section 4.3.3.

4.3.2 Data grooming and subsetting

The initial data set consisted of all records in which paua was targeted by diving. All records contained entries for FIN, fine scale statistical area, catch weight, fishing duration, and date. Records were removed from 2002 with no diver key (6 records). Some further grooming was done: 399 records were removed where no diving condition was recorded (Table 17).

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 3 years was chosen, thus retaining 87% of the catch over 2002–2016 (Figures 33–35). The number of FIN holders dropped from 42 to 21 under these criteria. There was good overlap in effort for the FIN holders after subsetting (Figures 36–37). The number of records retained after subsetting was 209 or more for every fishing year (Table 18, Figure 38).

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 (see Table 18). This dropped the number of statistical areas from 83 to 76, and the number of divers from 479 to 86 (50% of divers have only one diving day - this was partly an artefact of the fact that a spelling mistake in the divers name looks like a completely new diver). There was very good temporal overlap for the other predictor variables statistical area, month, dive conditions, and diver (Figures 39–42).

Table 17: Number of records removed by fishing year where diving condition was not recorded (02 = 2012).

Fishing year	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	Total
No diving condition	50	65	11	5	18	42	33	23	12	10	20	14	10	17	20	49	399

Table 18: Number of records remaining by fishing year (02 = 2012) in the PCELR dataset after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records without information needed for the standardisation were removed (see the table above).

	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	Total
Total records	549	662	664	582	586	590	566	425	452	570	486	460	403	419	463	292	8169
FIN subsetting	473	583	622	538	524	531	520	391	393	487	420	412	364	375	370	209	7212
Fine scale stat area>=10 dive days	470	582	622	537	517	522	517	389	392	487	418	408	361	374	369	207	7172
Divers with>=10 dive days	410	512	564	497	475	463	444	325	353	433	380	368	327	340	325	180	6396

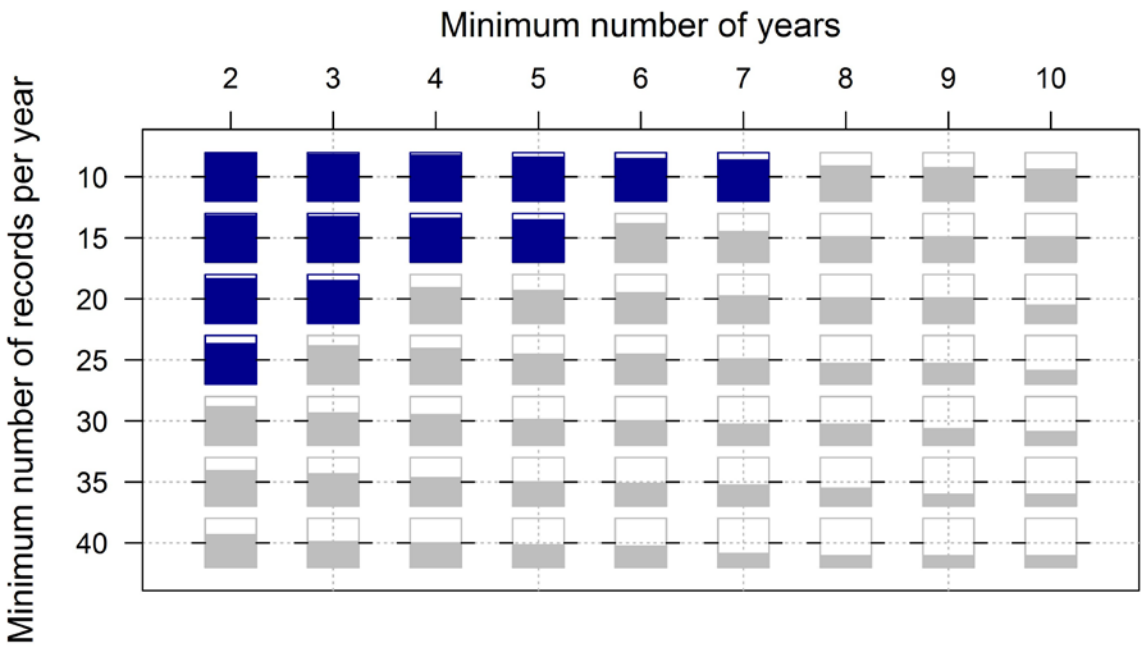


Figure 33: Proportion of the catch taken when subsetting the PCELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2015 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

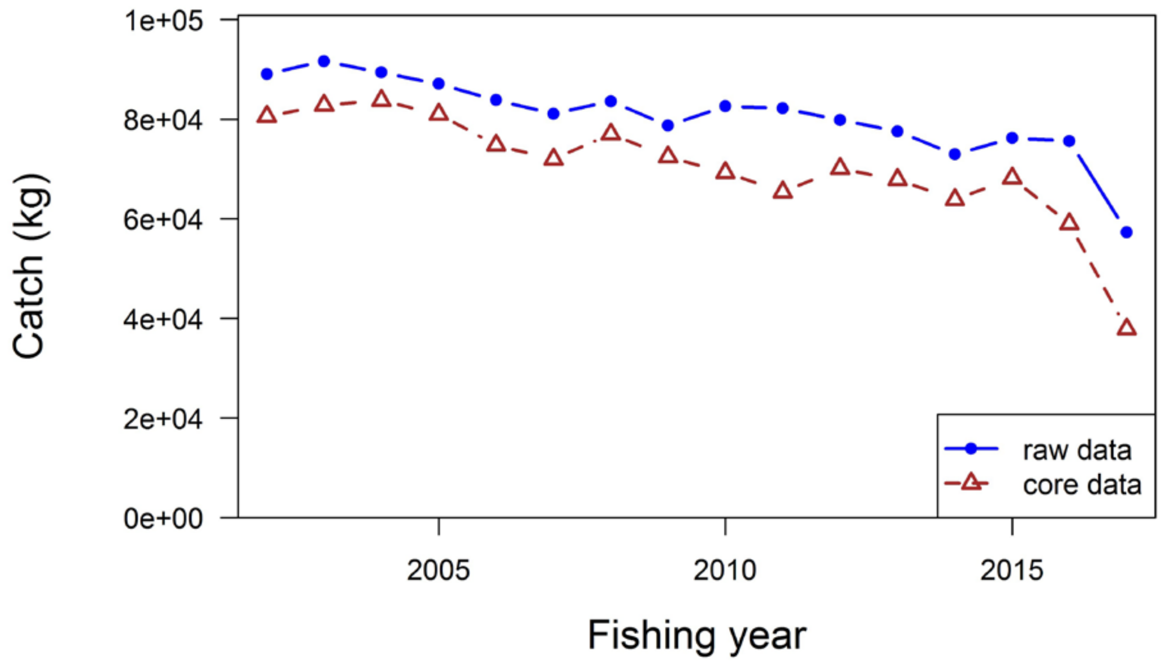


Figure 34: Catch by fishing year from the PCELR dataset before FIN subsetting (raw data) and after (core data).

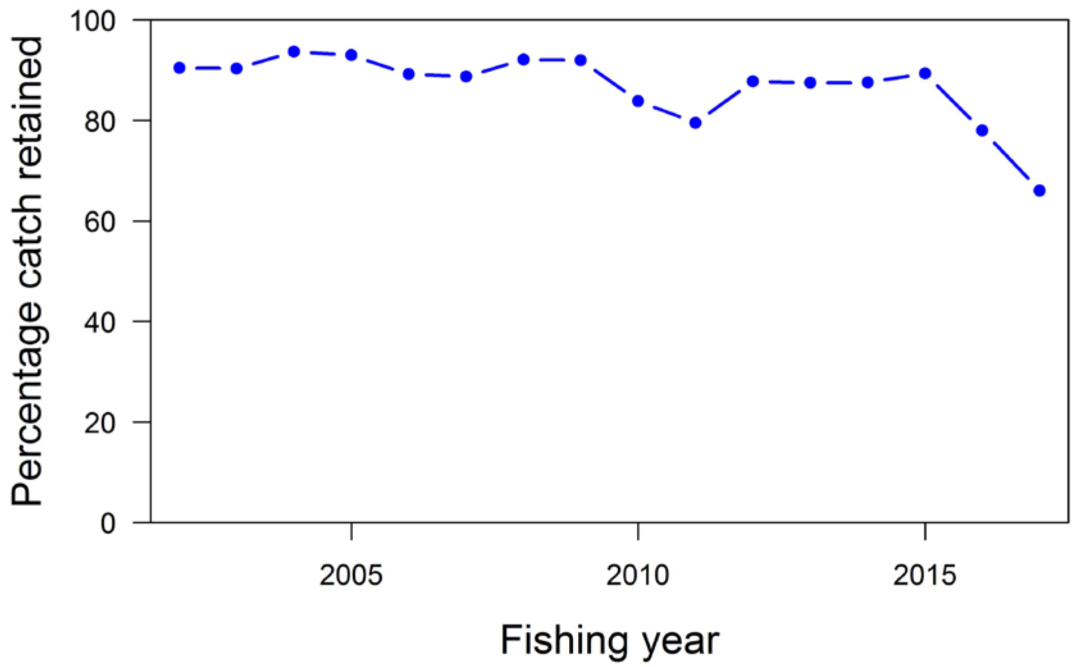


Figure 35: Percentage of the catch from the PCELR dataset retained after FIN subsetting.

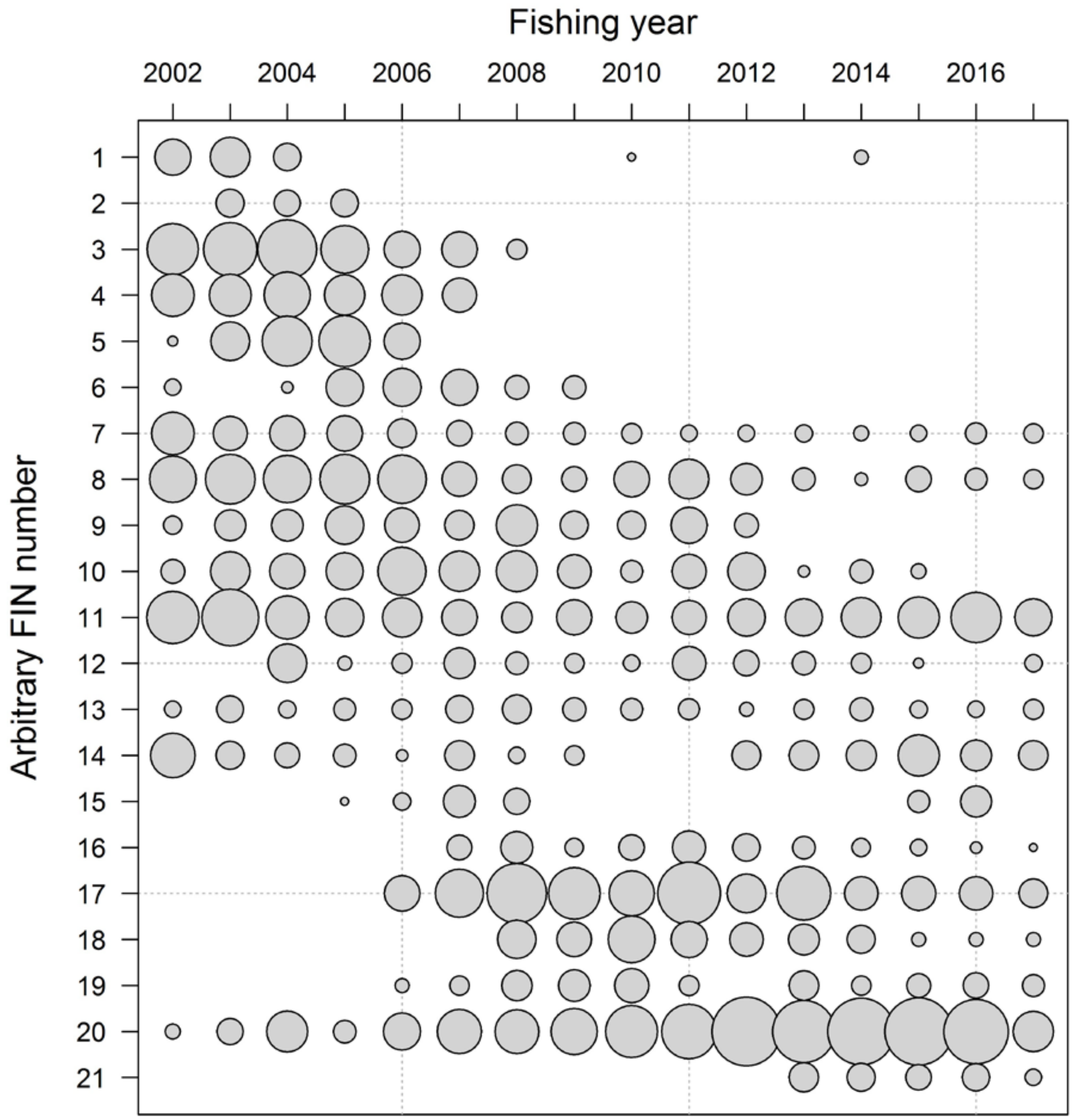


Figure 36: Number of records in the PCELR dataset by FIN and fishing year after subsetting by FIN. The area of a circle is proportional to the number of records.

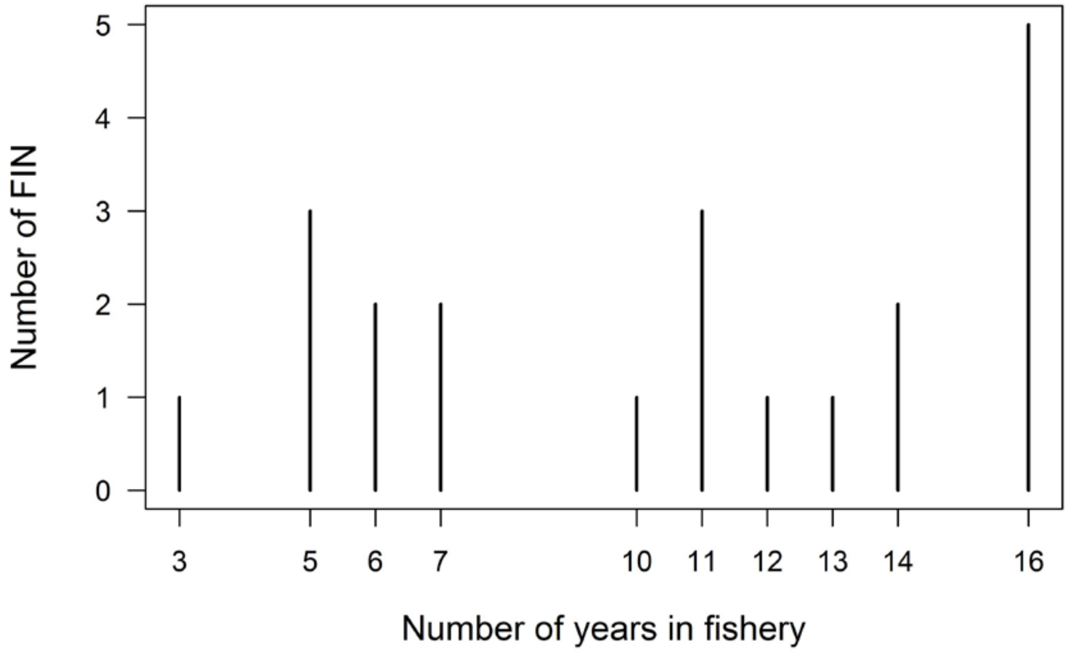


Figure 37: Number of years in the fishery for a FIN holder after subsetting by FIN, for the PCELR dataset.

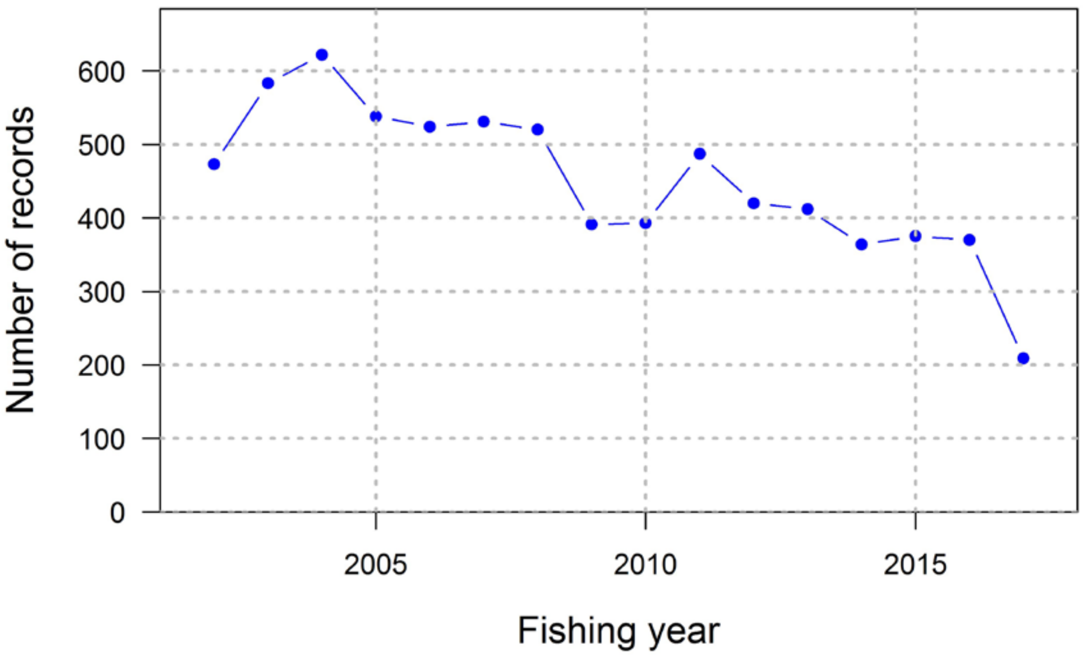


Figure 38: Number of records in the PCELR dataset retained after subsetting by FIN.

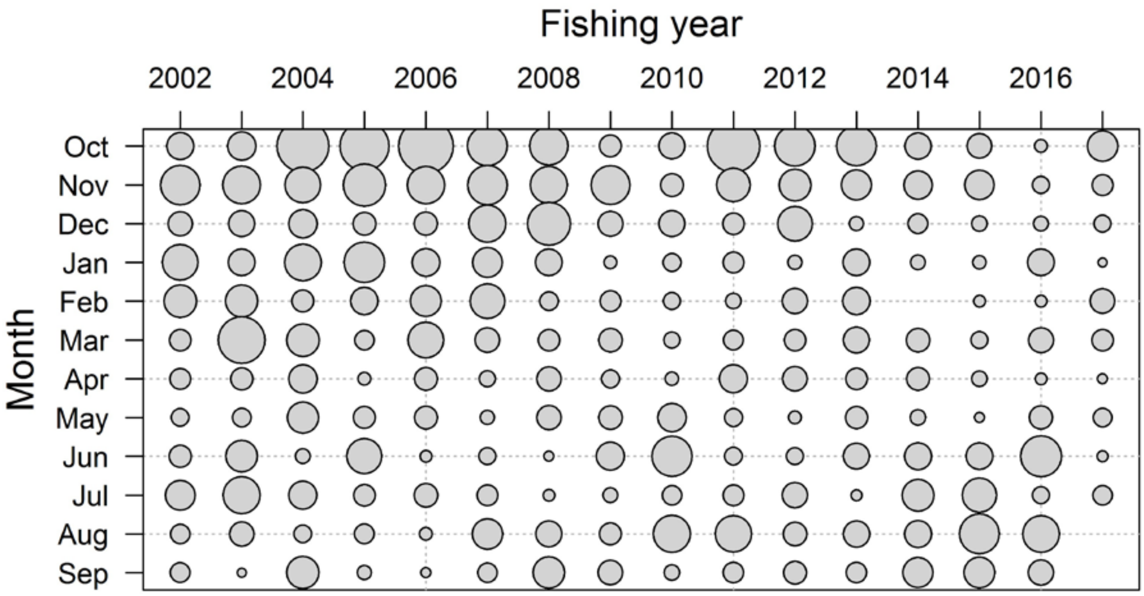


Figure 39: Number of records in the PCELR dataset by month and fishing year. The area of a circle is proportional to the number of records.

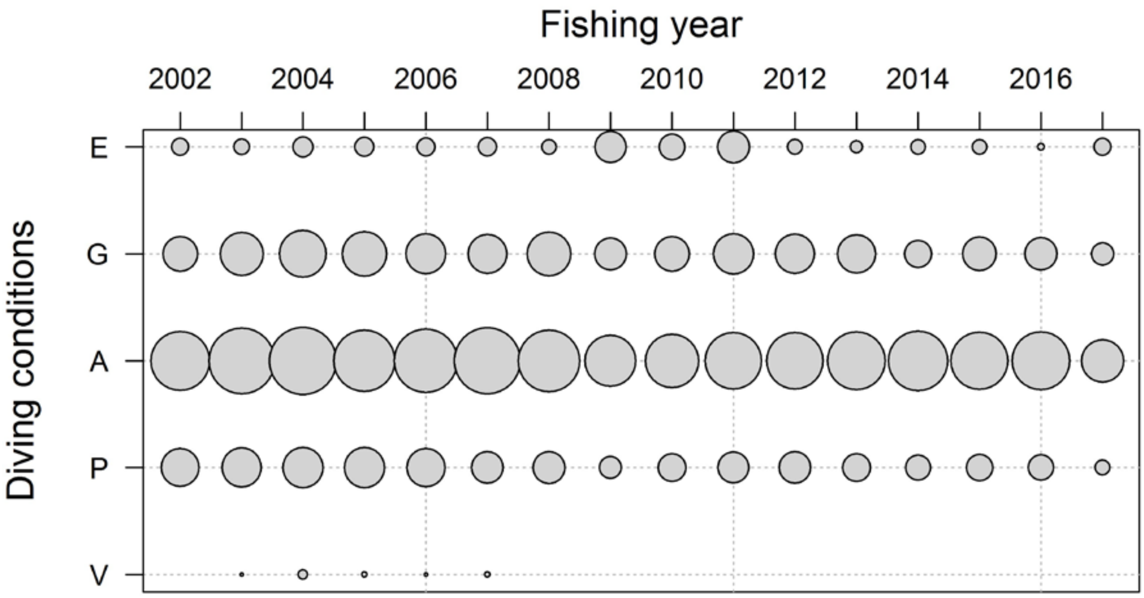


Figure 40: Number of records in the PCELR dataset by diving condition (excellent, good, average, poor, very poor) and fishing year. The area of a circle is proportional to the number of records.

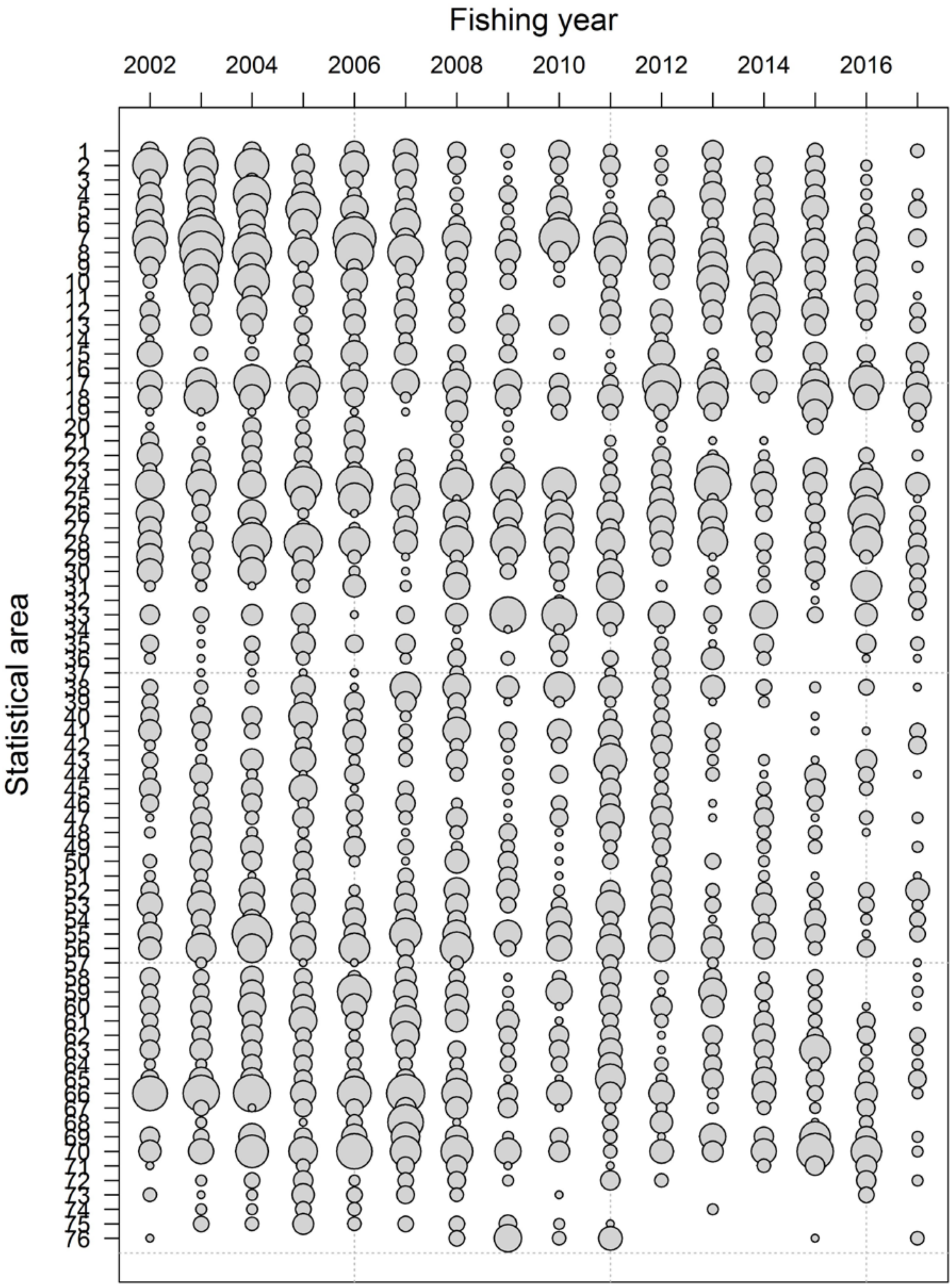


Figure 41: Number of records in the PCELR dataset by statistical area and fishing year. The area of a circle is proportional to the number of records. Arbitrary labels are used for the statistical areas.

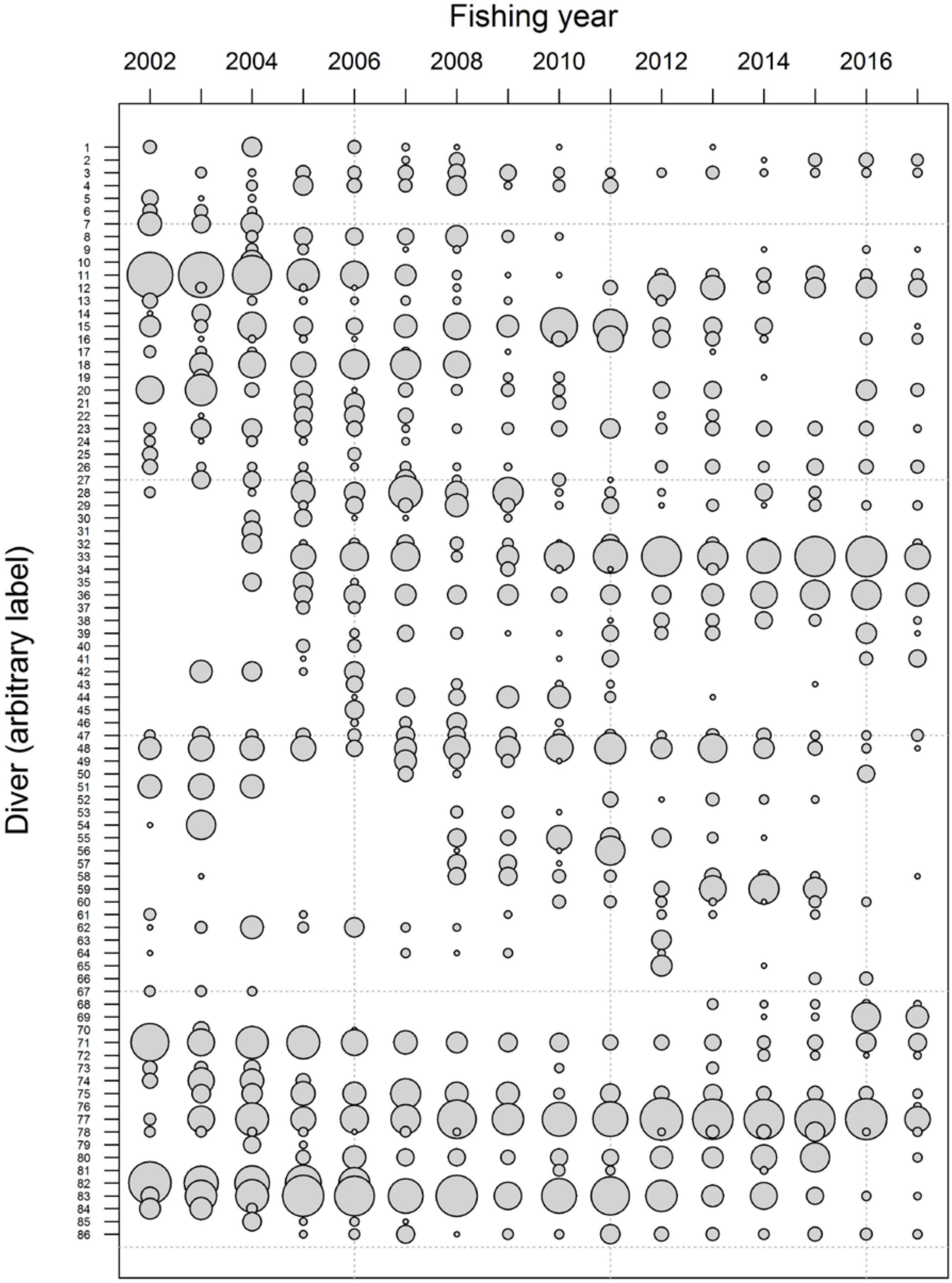


Figure 42: Number of records in the PCELR dataset by diver key and fishing year. The area of a circle is proportional to the number of records.

4.3.3 Standardised PCELR

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

Except for FIN, all variables were accepted into the model, which explained 81% of the variability in CPUE (Table 19). Most of the variability was explained by duration (66%) and diver (9%). The effects appeared plausible and the diagnostics were good (Figures 43–44). There was an apparent increasing effect for the catch taken after a fishing duration of 10 hours, although for most records fishing duration was less than 10 hours (Figure 45).

The standardised index showed an increase from 2002 to 2014, then a decline for two years followed by an increase in 2017 (Table 20, Figure 46).

Eight sub-areas for PAU 5B based on the research strata are given in Table 21. Each of these had a sizable number of records, allowing use in a standardisation with a year:area interaction, though the number was on the low side for East Cape and Pegasus where less of the catch was taken (Tables 22–23). Forcing a year:area interaction into the model gave similar indices for the different sub areas (Figure 47).

Table 19: Variables accepted into the PCELR standardisation model (1% additional deviance explained), and the order in which they were accepted into the model, their degrees of freedom (Df), and total variance explained (R-squared).

Predictors	Df	R-squared
fish year	15	0.02
fishing duration	3	0.68
diver key	85	0.77
stats area code	75	0.81

Table 20: Standardised PCELR index, lower and upper 95% confidence intervals, and CVs.

Year	Index	Lower CI	Upper CI	CV
2002	0.77	0.69	0.87	0.06
2003	0.80	0.72	0.88	0.05
2004	0.78	0.71	0.86	0.05
2005	0.86	0.79	0.95	0.05
2006	1.01	0.92	1.12	0.05
2007	0.88	0.80	0.97	0.05
2008	0.92	0.83	1.01	0.05
2009	1.10	0.98	1.23	0.06
2010	1.15	1.03	1.28	0.05
2011	0.95	0.86	1.05	0.05
2012	1.11	0.99	1.23	0.05
2013	1.17	1.05	1.30	0.05
2014	1.34	1.19	1.50	0.06
2015	1.15	1.03	1.29	0.06
2016	1.06	0.94	1.19	0.06
2017	1.16	1.00	1.35	0.08

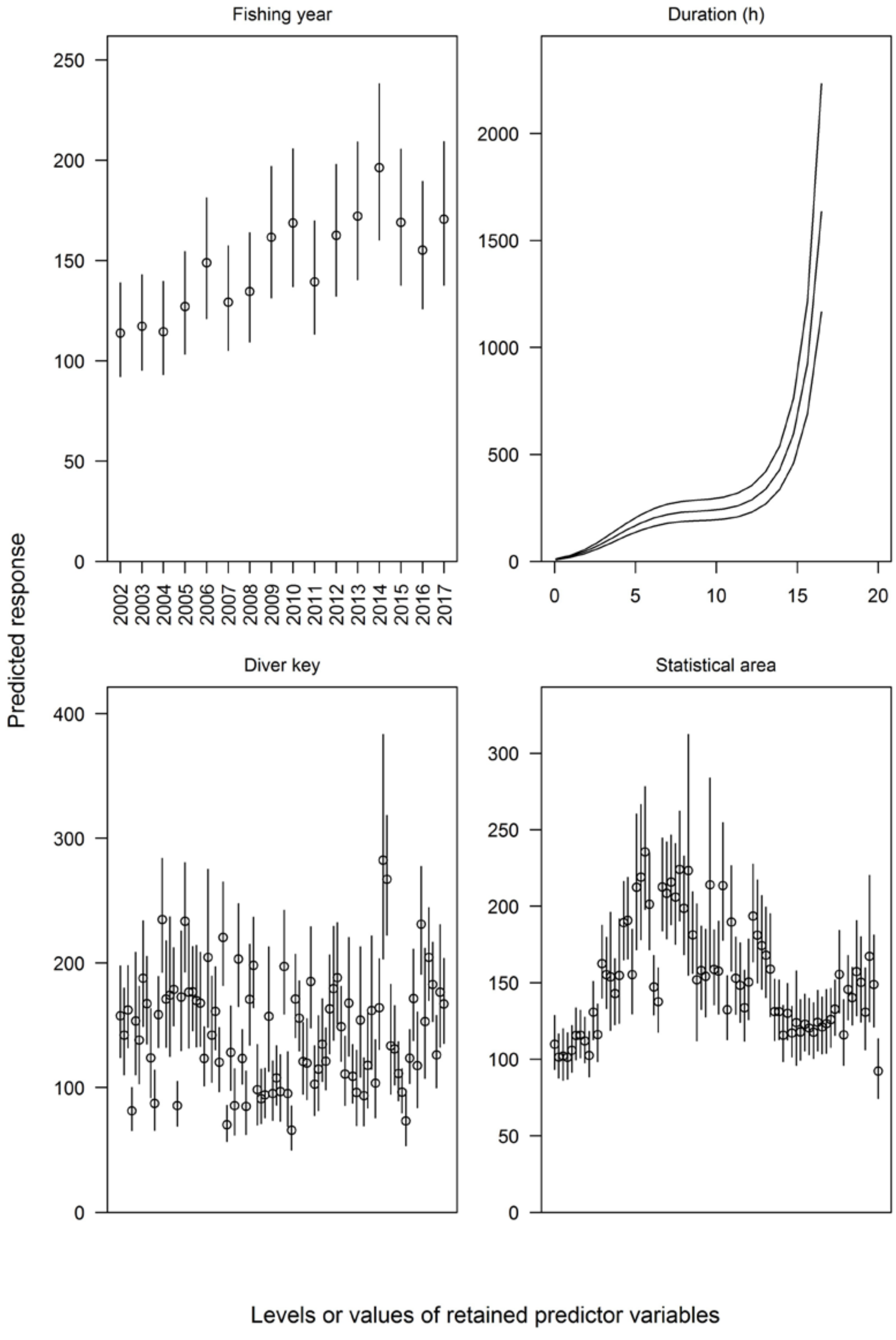


Figure 43: Effects catch rates from the PCELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

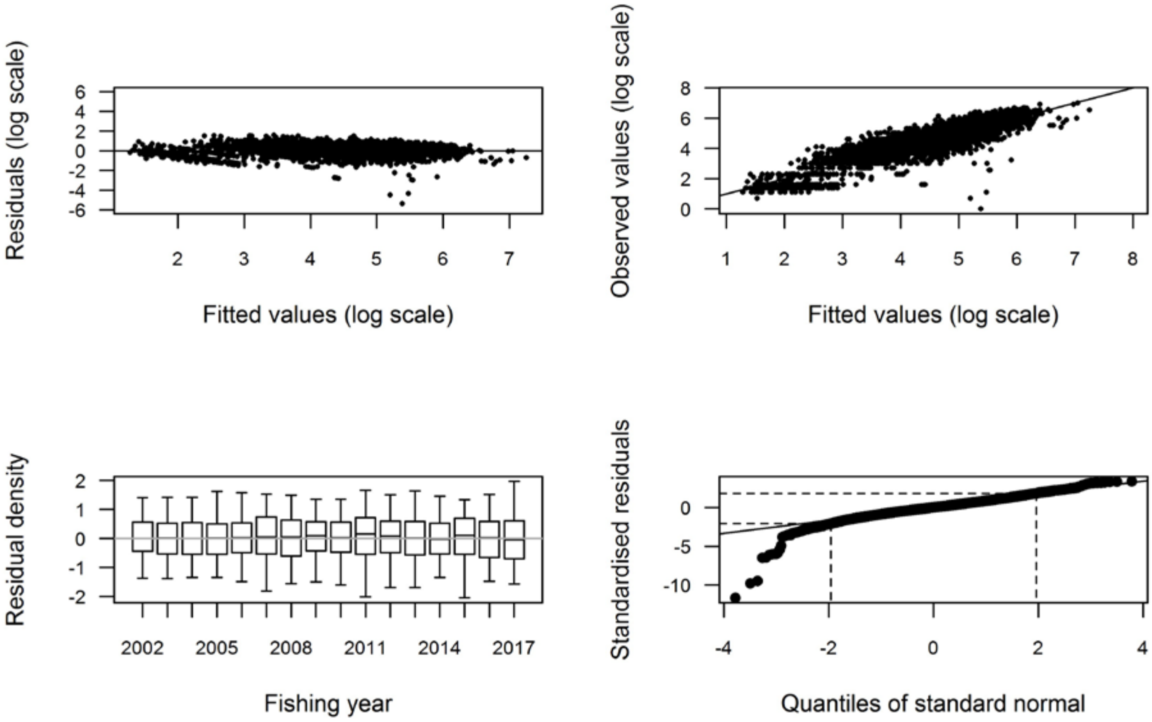


Figure 44: Diagnostic plots for the PCELR standardisation model.

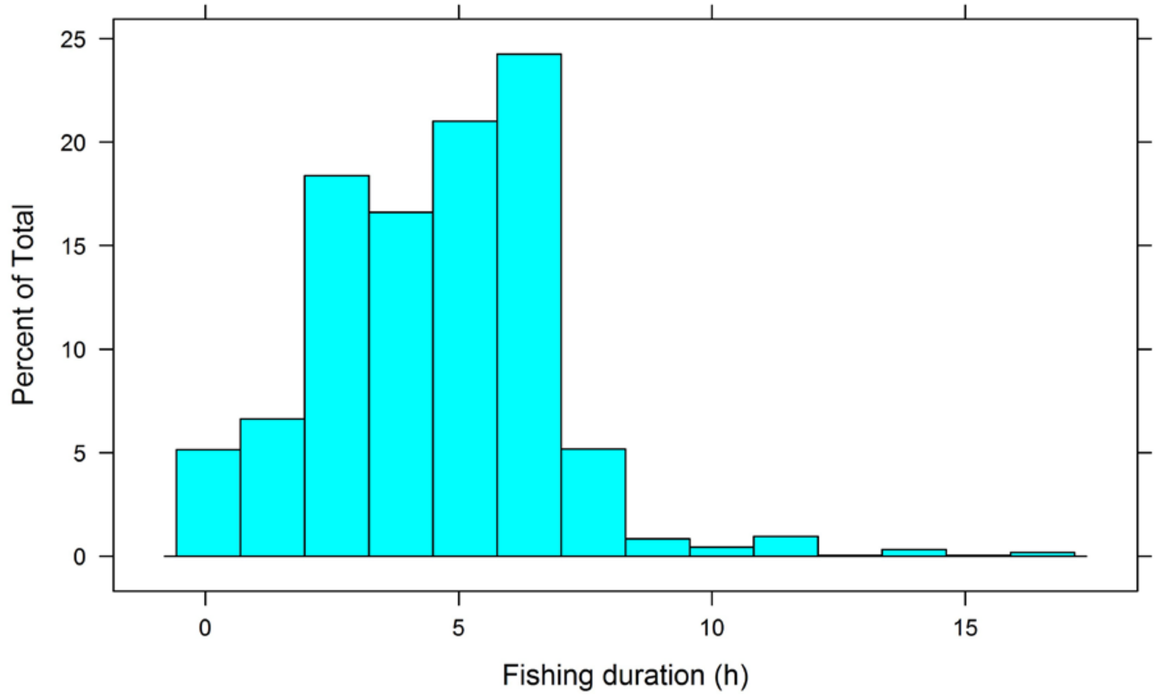


Figure 45: Distribution of fishing duration (h) for the PCELR dataset.

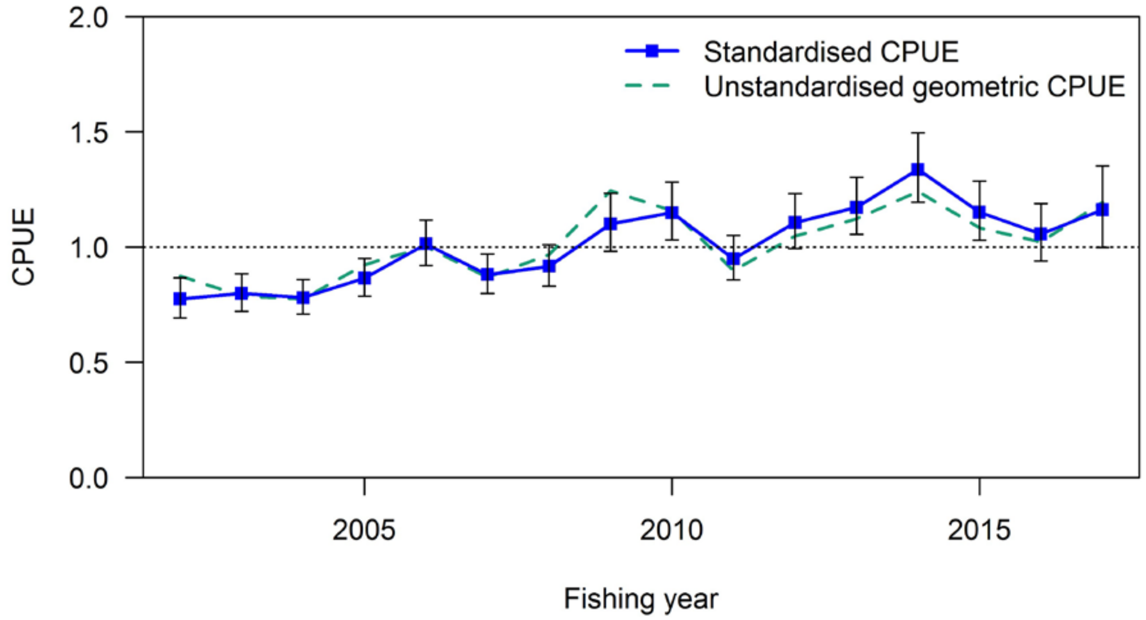


Figure 46: The standardised CPUE index for the PCELR dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

Table 21: Statistical areas associated with the sub areas, where each statistical area is prefixed by P5BS.

Sub area	Statistical area
Ruapuke Islands	73–84
East Cape	69–72
Lords	53–68
Pegasus	43–52
West	26–42
Codfish	19–25
Waituna	12–18
Ruggedy	01–11

Table 22: Number of records for each year and area (for PCELR CPUE data).

Year	Codfish	East Cape	Lords	Pegasus	Ruapuke Islands	Ruggedy	Waituna	West
2002	33	19	60	32	38	108	42	78
2003	33	24	84	37	50	190	47	47
2004	35	27	114	32	62	147	58	89
2005	50	20	87	43	62	89	48	98
2006	60	16	83	34	69	117	47	49
2007	31	27	91	23	96	93	39	63
2008	39	15	95	37	70	55	35	98
2009	33	13	55	20	45	38	39	82
2010	26	17	55	28	29	73	22	103
2011	21	38	77	69	37	73	30	88
2012	33	7	69	42	33	54	70	72
2013	47	21	52	14	24	95	48	67
2014	24	27	53	19	31	82	47	44
2015	35	27	39	23	50	70	60	36
2016	32	14	22	19	55	52	45	86
2017	19	13	27	12	11	18	39	41

Table 23: Percentage of catch by area for each year (for PCELR CPUE data).

Year	Codfish	East Cape	Lords	Pegasus	Ruapuke Islands	Ruggedy	Waituna	West
2002	8	4	12	6	5	23	12	30
2003	9	4	16	7	7	34	10	13
2004	9	4	16	5	9	21	12	25
2005	14	2	16	9	10	12	12	25
2006	11	3	18	8	14	26	8	11
2007	7	4	20	6	19	17	8	20
2008	9	3	21	10	13	7	10	27
2009	10	3	17	10	7	9	10	33
2010	6	5	13	9	5	15	6	41
2011	8	9	15	14	4	13	12	25
2012	13	1	19	9	4	9	18	26
2013	15	5	9	3	6	20	13	27
2014	8	9	15	8	6	17	14	23
2015	13	6	14	3	8	12	23	19
2016	11	3	5	6	7	6	19	41
2017	12	4	14	10	2	4	23	31

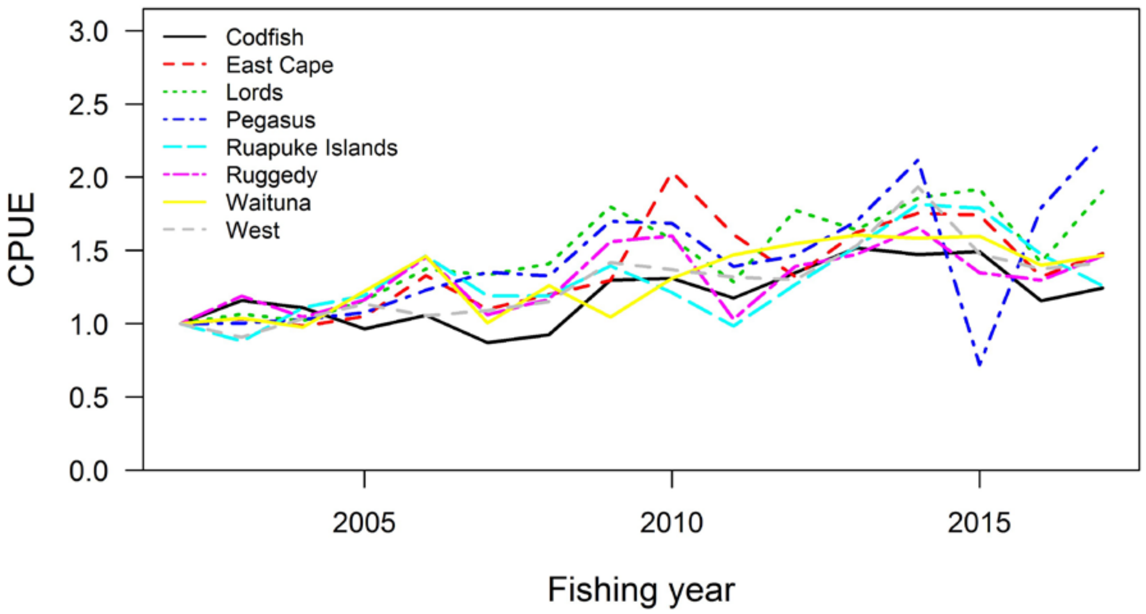


Figure 47: Standardised indices for the PCELR dataset with a year:area interaction forced into the model. The areas are sub-areas. The indices are scaled to have the value one in 2002.

4.4 Combined data (1990–2017)

4.4.1 The combined data set

For the years 1990–2001 the same data set was used as for the CELR standardisations. For the PCELR data the catch and fishing effort (both duration and number of divers) were collapsed down to a daily total for a given date, vessel, and large scale area (025, 027, 029, or 030). The collapsed PCELR data was then combined with the CELR data to give a dataset covering 1990–2017. All records with a fishing duration per diver greater than 10 hours were dropped (as was done for the CELR data) with the number of records remaining shown in Table 24 (the "before" column).

For the combined data set the daily hours per diver decreased from 1990 to 1995, then increased until about 2001, afterwards dropping until about 2012, then increasing again (Figures 48–49).

A raw CPUE based on either total daily duration or number of divers as the measure of effort showed a decrease until 2001, followed by an increase to 2009, then something of an irregular pattern (Figures 50–51).

Table 24: Number of records before and after FIN subsetting.

Fishing year	Before	After
1990	127	81
1991	129	74
1992	165	102
1993	73	57
1994	144	125
1995	178	133
1996	283	213
1997	342	286
1998	400	363
1999	371	330
2000	435	380
2001	399	368
2002	368	358
2003	426	397
2004	358	345
2005	307	291
2006	300	283
2007	287	267
2008	299	279
2009	201	192
2010	213	197
2011	244	229
2012	227	219
2013	208	191
2014	190	173
2015	187	162
2016	206	161
2017	153	127
Total	7220	6383

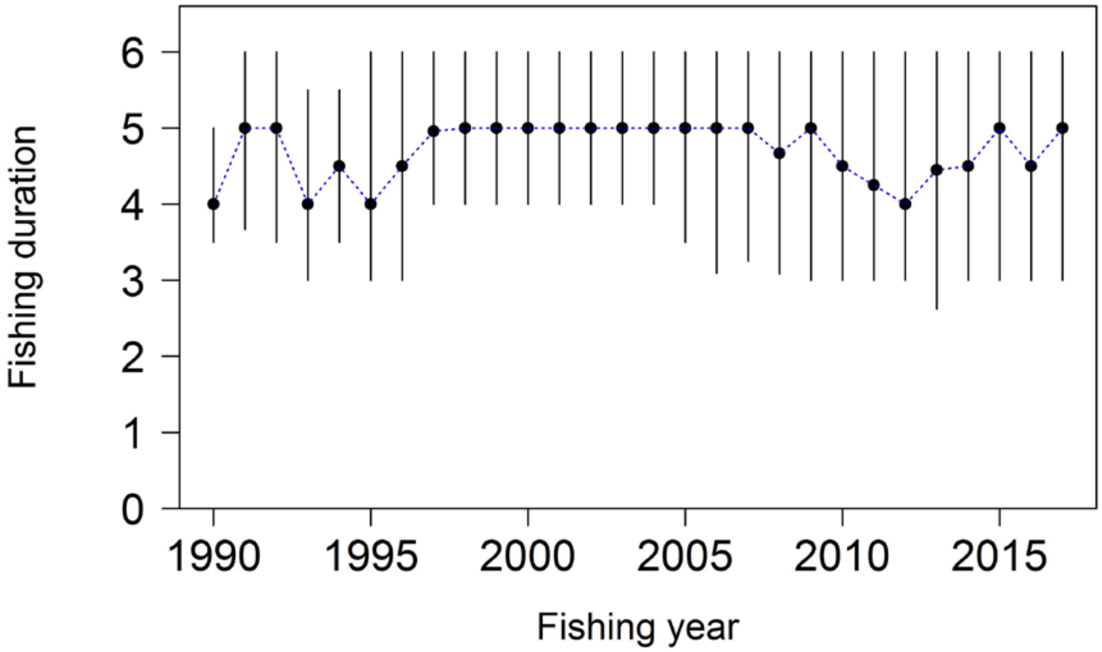


Figure 48: Quantiles by fishing year in the combined dataset for the daily fishing hours per diver: medians (dot) and lower and upper quartiles (vertical lines). Records with a value greater than 10 hours are dropped.

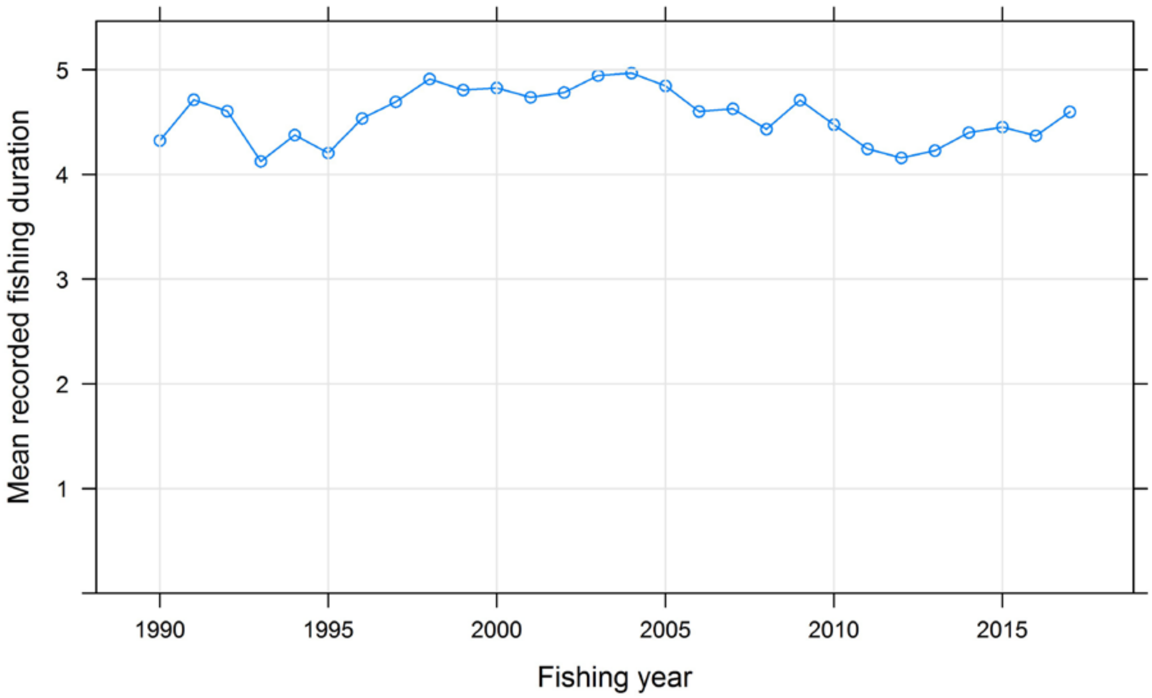


Figure 49: Mean values by fishing year in the combined dataset for the daily hours per diver. Records with a value greater than 10 hours are dropped.

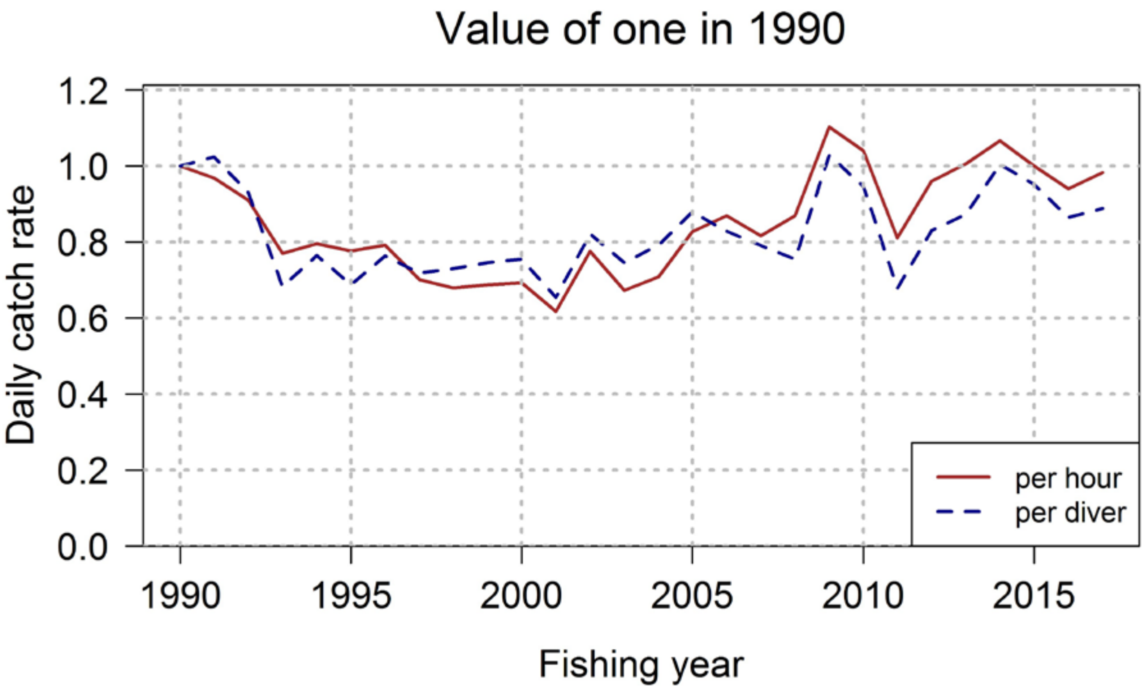


Figure 50: Geometric mean of the daily catch rate by year in the combined dataset where the plots are scaled so that they both have the value one in 1990. Records with a fishing duration per diver greater than 10 hours are dropped.

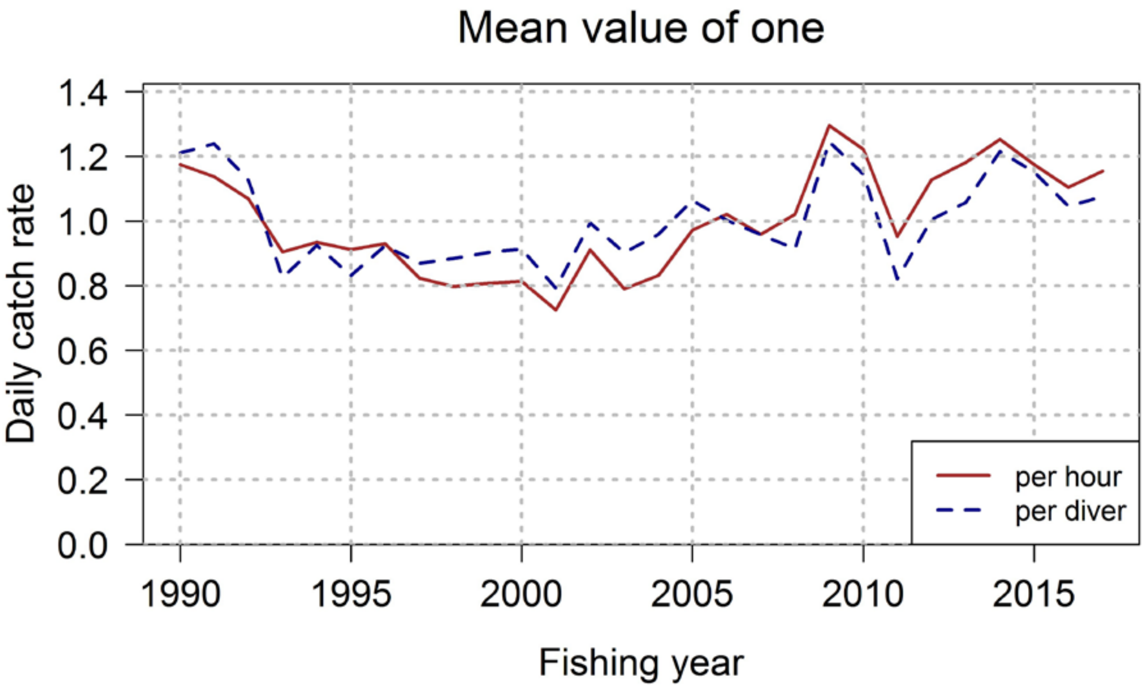


Figure 51: Geometric mean of the daily catch rate by year in the combined dataset where the plots are scaled so that they both have a mean value of one. Records with a fishing duration per diver greater than 10 hours are dropped.

4.4.2 The standardisation

FIN was used to subset out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 10 records per year for a minimum of 2 years was chosen, thus retaining 88% of the catch over 1990–2017 (Figure 52). While 88% of the catch was retained overall, it was less than this for some years although always more than 40% (Figures 53–54). Number of days of effort retained after subsetting was 57 or more for every fishing year (see Table 24, Figure 55). The number of FIN holders dropped from 105 to 34 under the subsetting criteria.

After subsetting there was good temporal overlap for FIN holder effort (Figures 56–57). Similarly, for temporal overlap for area and month (Figures 58–59).

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

The model explained 68% of the variability in CPUE with fishing duration (50%) explaining most of this followed by FIN (11%) (Table 25). The effects appeared plausible and the model diagnostics good (Figures 60–61). There was an apparent increasing effect for the catch taken after a fishing duration of 50 hours, though for most of the records fishing duration was less than this (Figure 62). The standardised index showed a decline from 1990–2001, followed by an increase until 2009, after which the index shows an irregular pattern (Table 26, Figure 63).

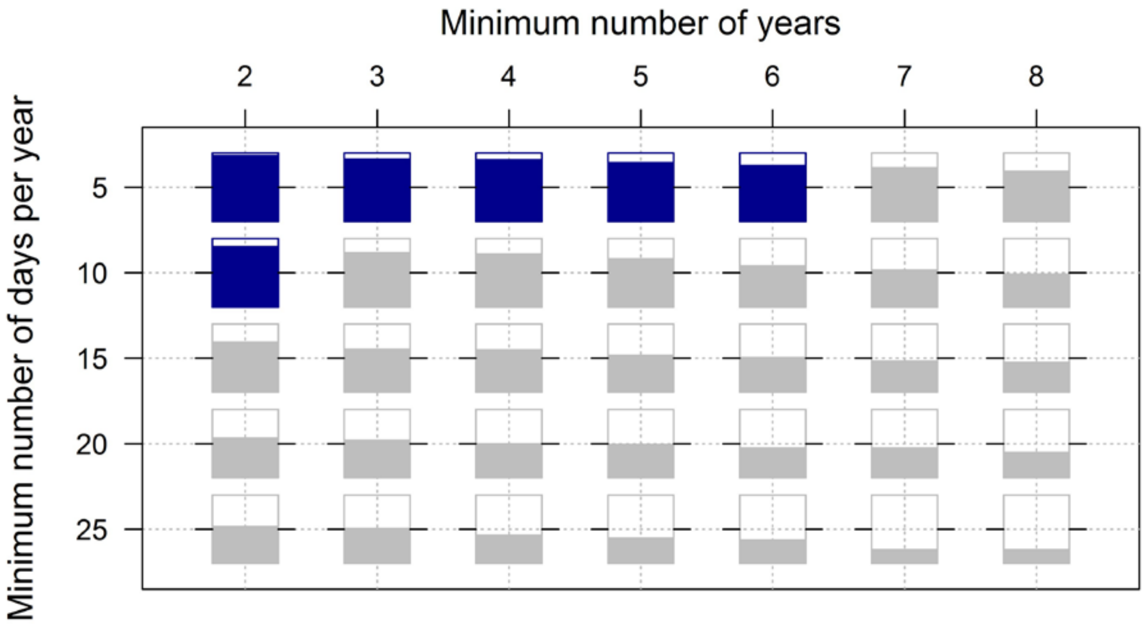


Figure 52: Proportion of the catch taken when subsetting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2017 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

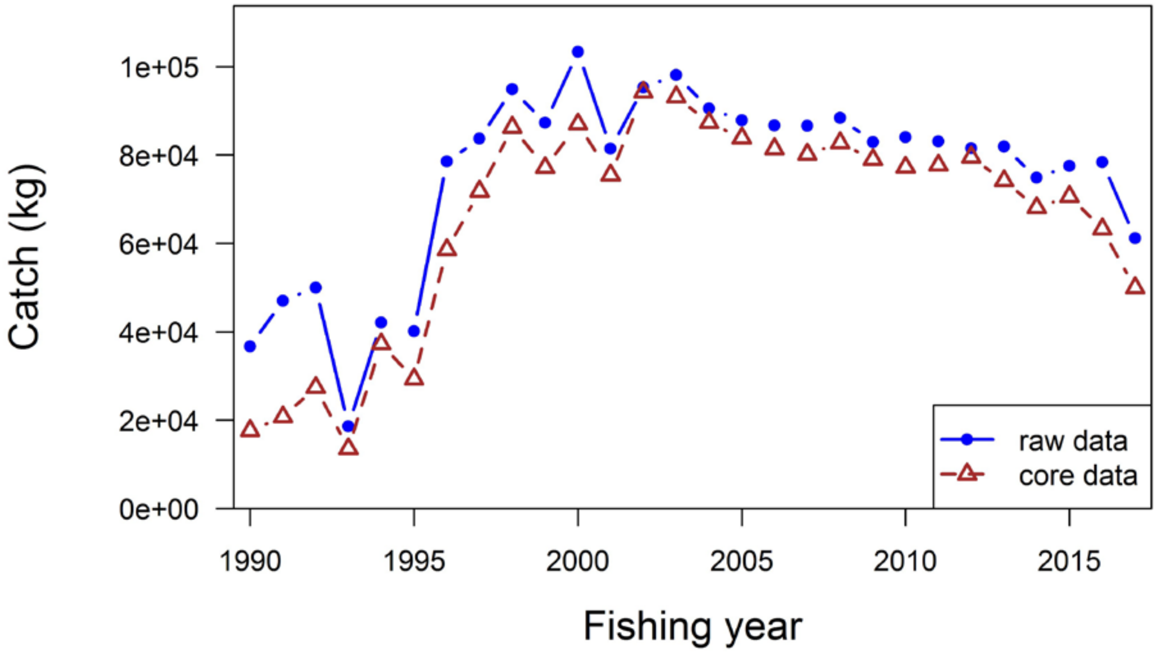


Figure 53: Catch by fishing year in the combined dataset before FIN subsetting (raw data) and after (core data).

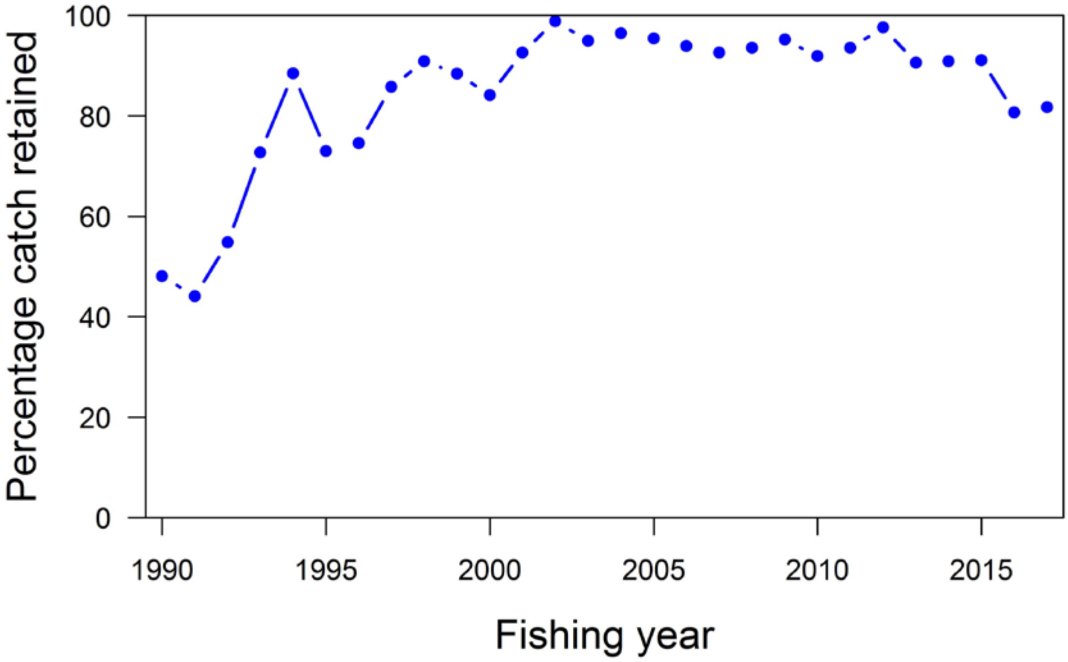


Figure 54: Percentage of the catch in the combined dataset retained after FIN subsetting.

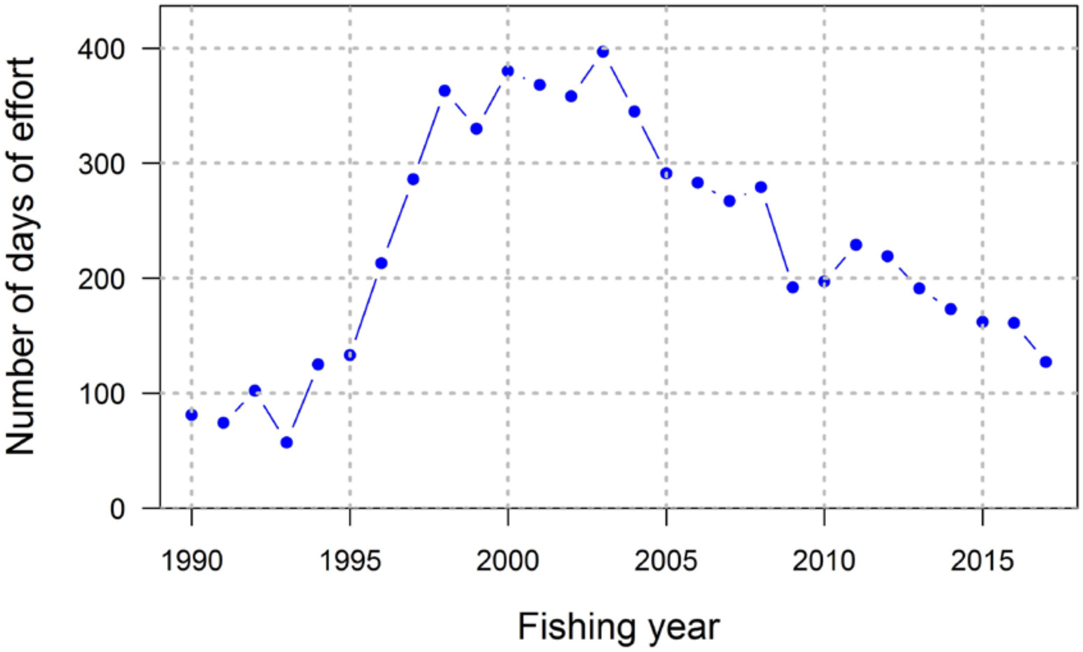


Figure 55: Number of days of effort retained in the combined dataset after FIN subsetting.

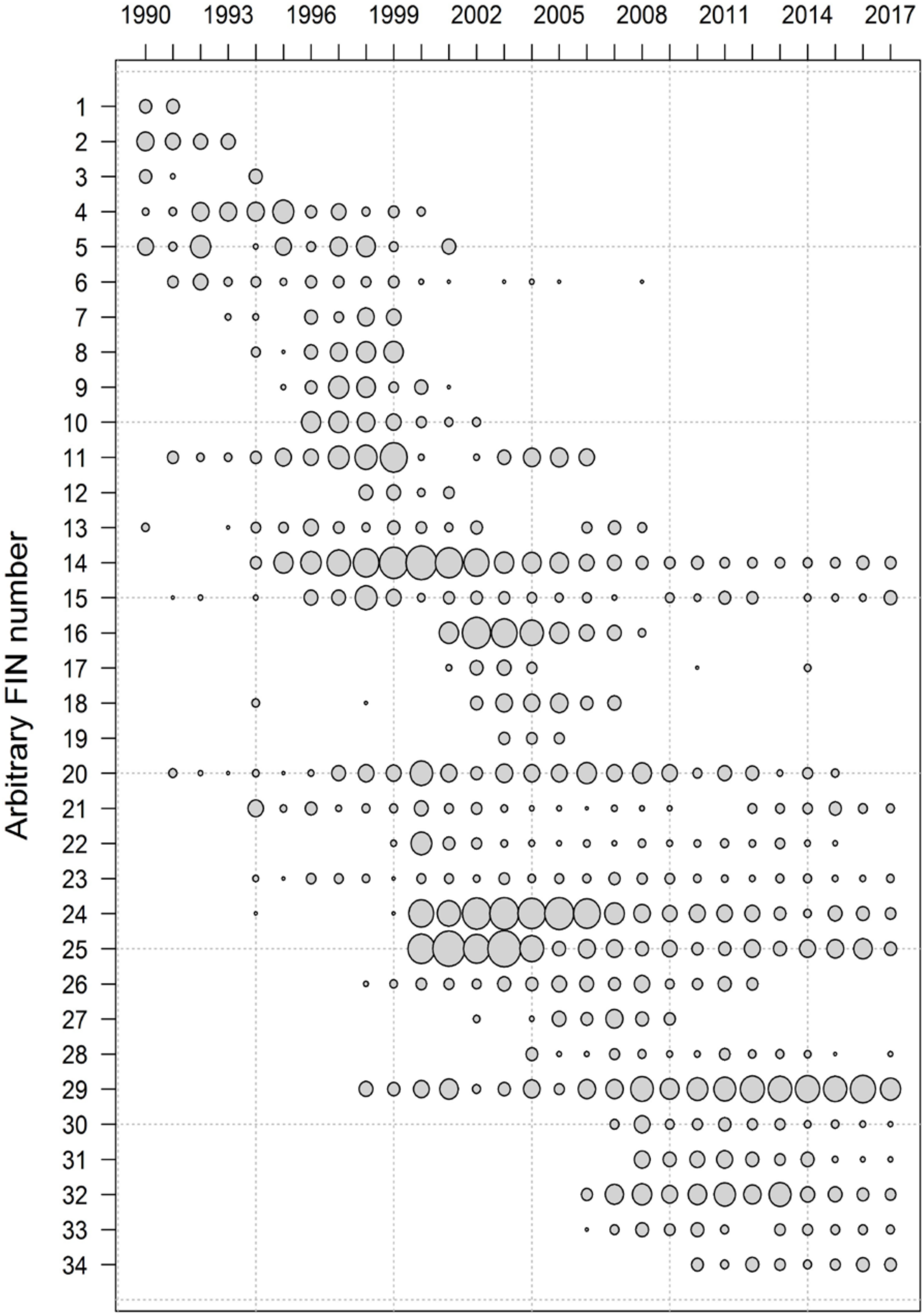


Figure 56: Days of effort in the combined dataset by FIN and fishing year. The area of a circle is proportional to the days of effort.

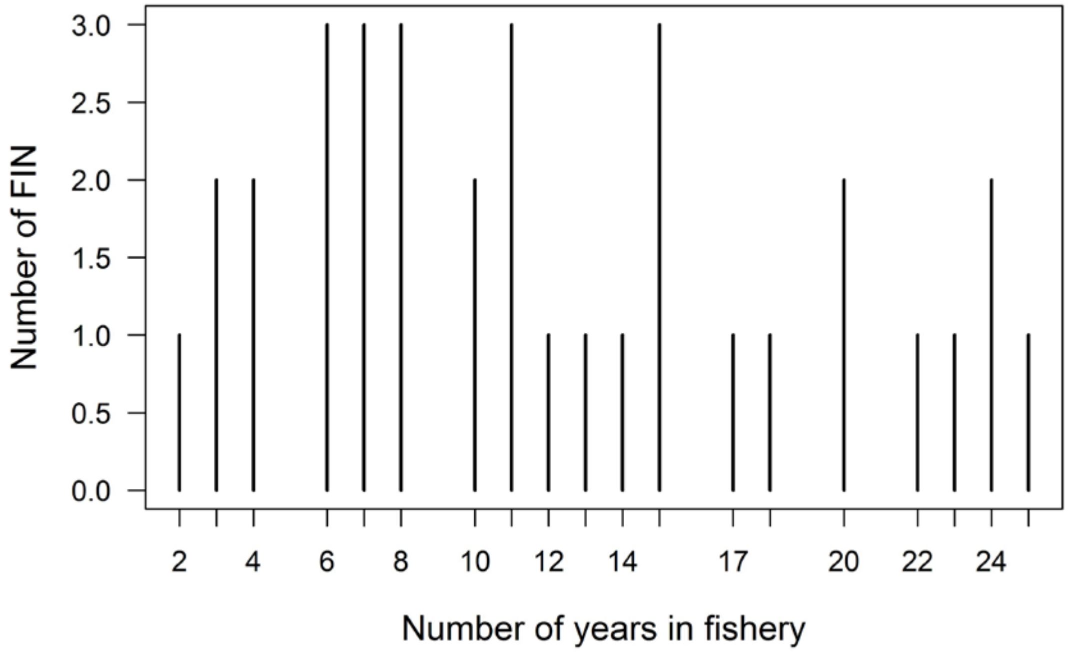


Figure 57: Number of years in the fishery for a FIN holder after subsetting by FIN.

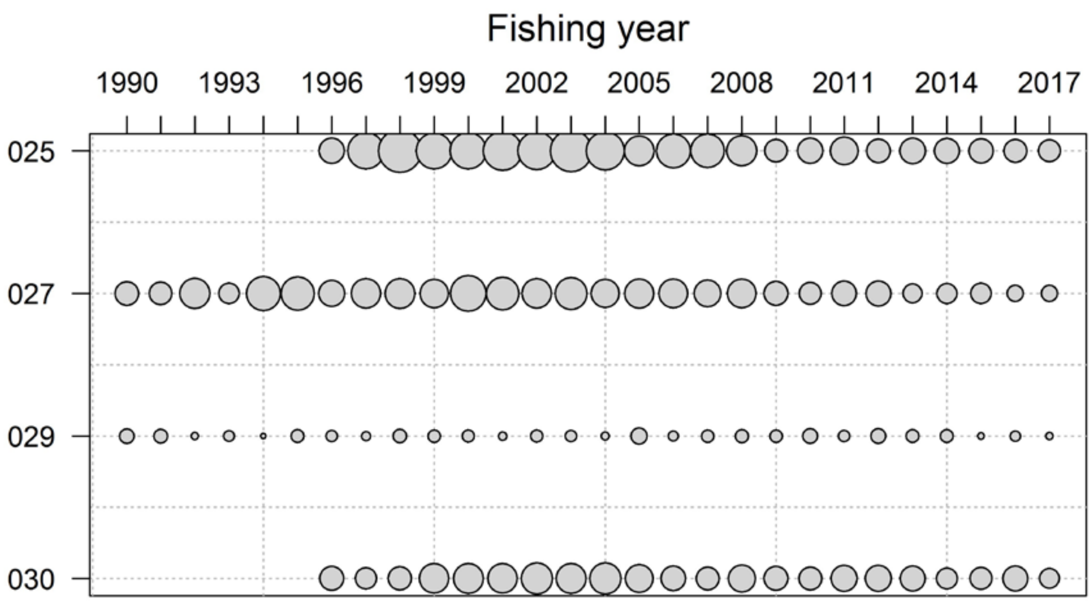


Figure 58: Days of effort in the combined dataset by area and fishing year.

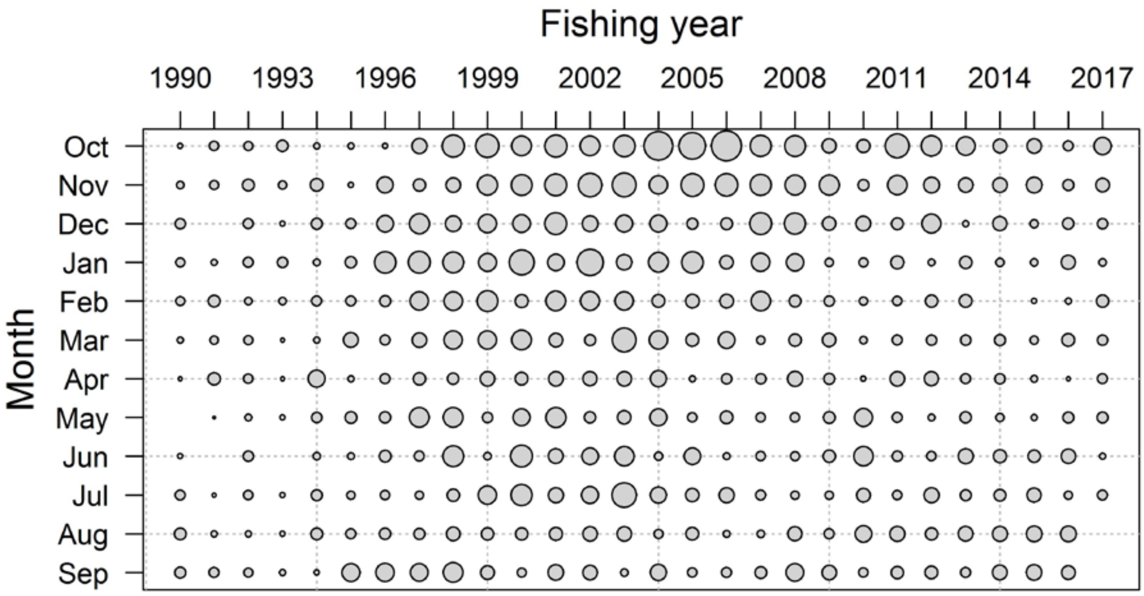


Figure 59: Days of effort in the combined dataset by month and fishing year.

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

Predictors	Df	R-squared
Fishing year	27	0.03
Fishing duration	3	0.53
Client key	33	0.64
Statistical area	3	0.68

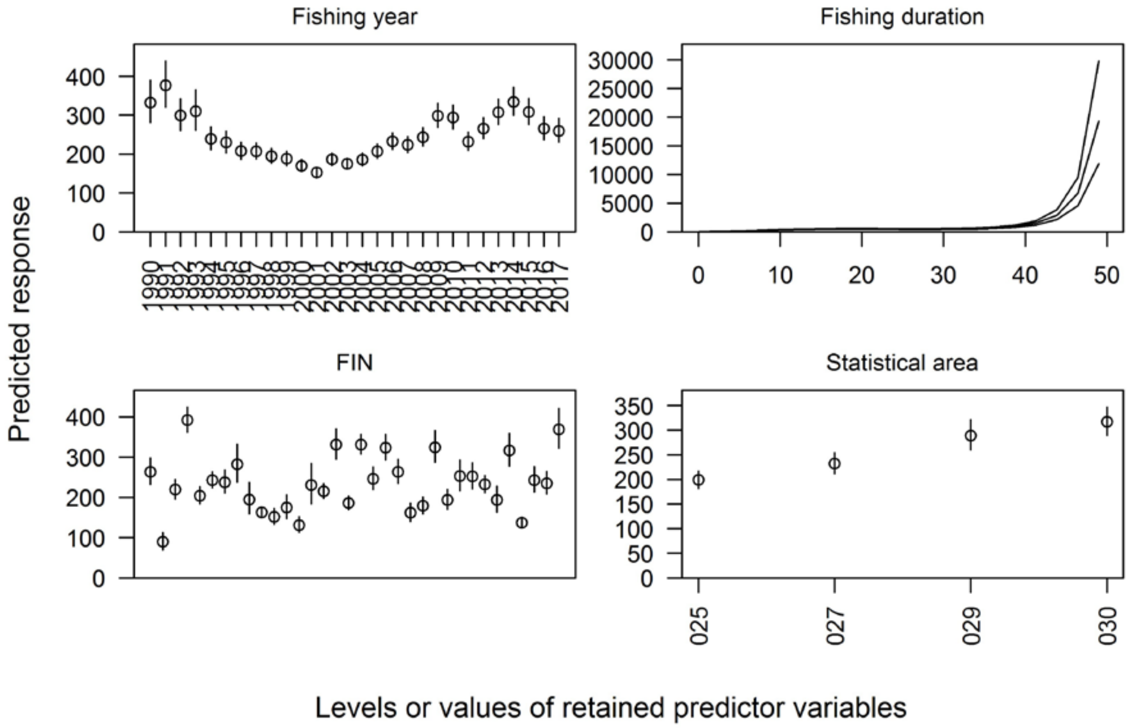


Figure 60: Effects catch rates from the standardisation model for the combined dataset. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

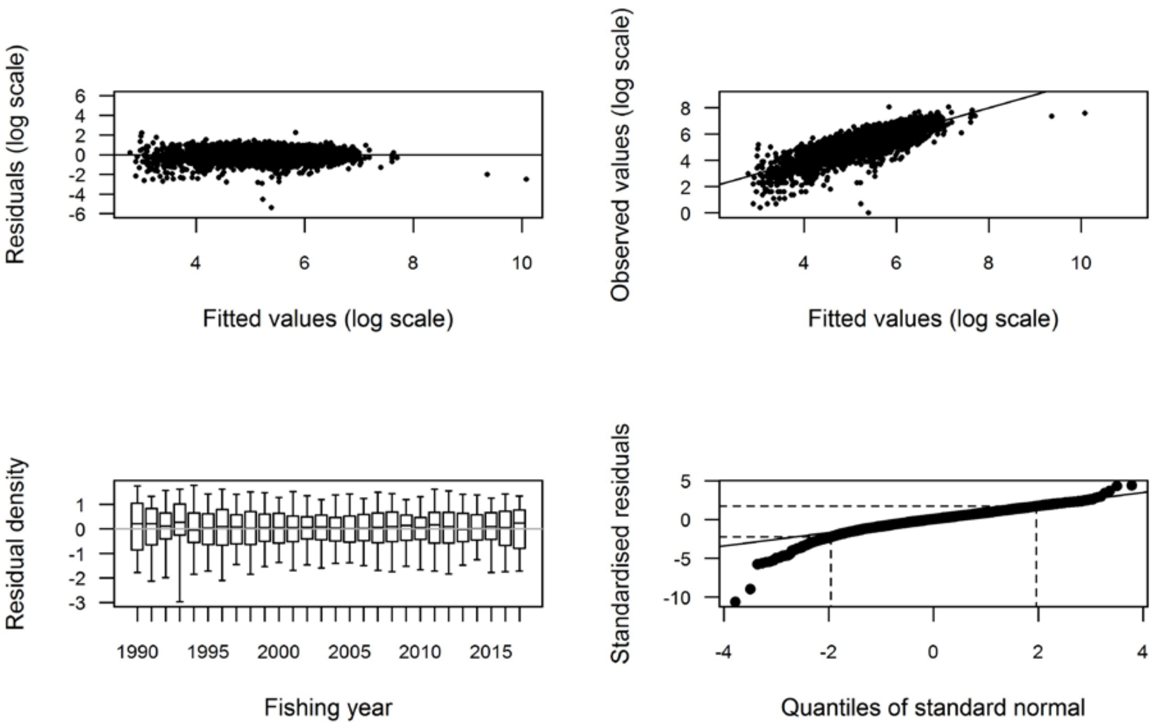


Figure 61: Residuals from the standardisation model for the combined dataset.

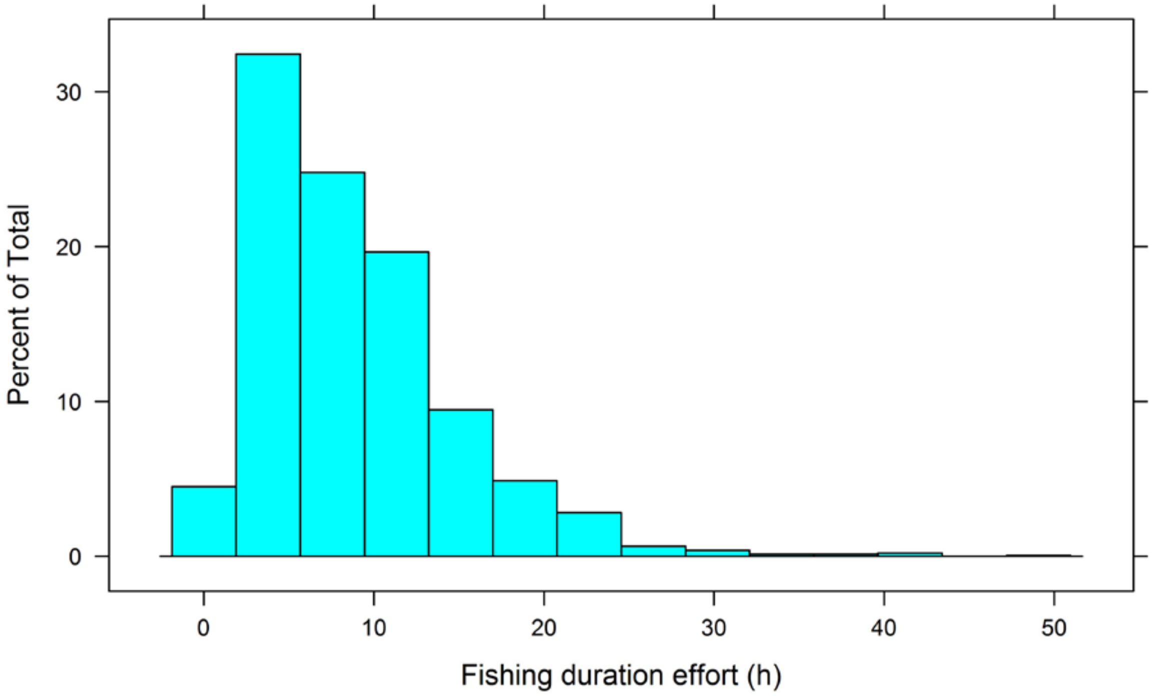


Figure 62: Distribution of fishing duration effort (h) in the combined dataset.

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

Year	Index	Lower CI	Upper CI	CV
1990	1.38	1.05	1.81	0.14
1991	1.56	1.20	2.03	0.13
1992	1.24	1.00	1.55	0.11
1993	1.29	0.97	1.71	0.14
1994	0.99	0.82	1.20	0.10
1995	0.95	0.79	1.15	0.09
1996	0.86	0.75	1.00	0.07
1997	0.86	0.76	0.98	0.06
1998	0.81	0.72	0.91	0.06
1999	0.78	0.69	0.88	0.06
2000	0.71	0.63	0.79	0.05
2001	0.63	0.57	0.71	0.06
2002	0.77	0.69	0.87	0.06
2003	0.73	0.65	0.81	0.06
2004	0.77	0.69	0.86	0.06
2005	0.86	0.76	0.97	0.06
2006	0.96	0.85	1.09	0.06
2007	0.93	0.82	1.06	0.06
2008	1.01	0.89	1.15	0.06
2009	1.24	1.07	1.44	0.07
2010	1.22	1.05	1.42	0.07
2011	0.96	0.84	1.11	0.07
2012	1.10	0.96	1.27	0.07
2013	1.28	1.10	1.49	0.08
2014	1.39	1.19	1.62	0.08
2015	1.28	1.09	1.50	0.08
2016	1.10	0.94	1.30	0.08
2017	1.08	0.90	1.29	0.09

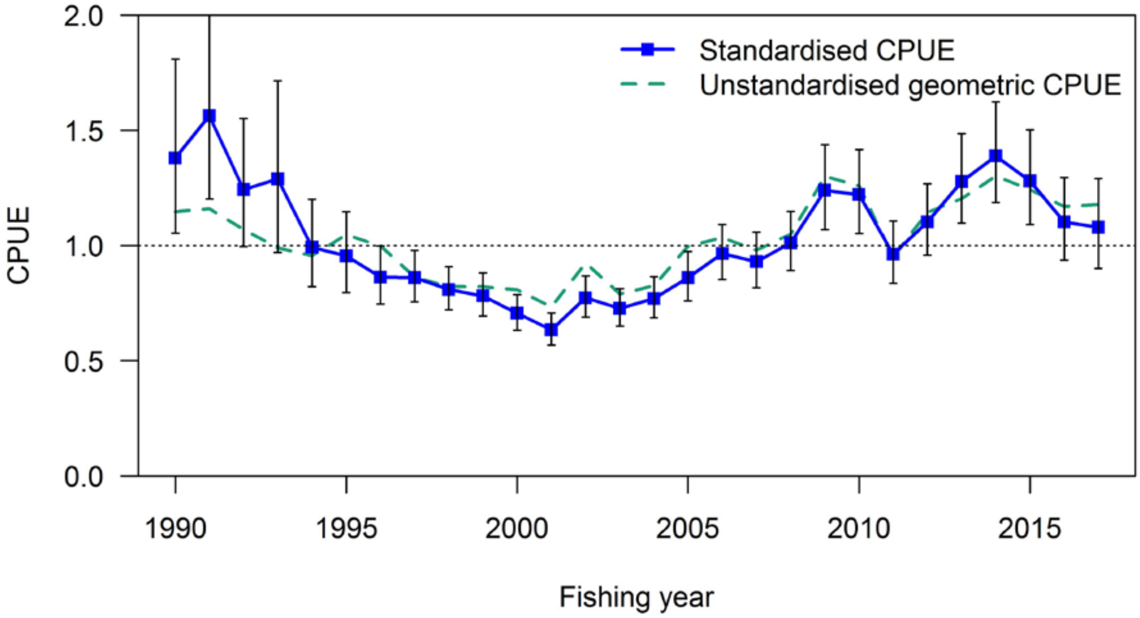


Figure 63: The standardised CPUE index for the combined dataset with 95% confidence intervals. The unstandardised geometric CPUE is calculated as daily catch divided by daily fishing duration.

5. COMMERCIAL CATCH LENGTH FREQUENCY (CSLF)

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

A new extract of Catch Sampling Length Frequency (CSLF) data was made from the *market* database on 6 September 2017. This totalled 147 841 measurements from 1992–94 and 1998–2016. Deducing the statistical area of records prior to 2001–02 required some analysis as a variety of area codes were used.

The number of catch landings sampled per year ranged from 30 to 116 from 1992 to 2017 except in 1998 when there were only 9 samples taken (Table 27). Typically, over 4000 paua were measured each year. Between 2000 and 2006, about 20% of samples had no area recorded, because some operators refused to supply the information. Since 2002 most subareas have been consistently sampled and sampling coverage was reasonably adequate, although West appears to have small sample sizes for most years relative to its catch level and between 2011 and 2013 there seemed to be oversampling between the months of October and November (Table 28, Figures 64–65).

There appeared to be a temporal trend in length for the catch samples. The mean length of measured paua has increased since 2007 in most areas (Figures 66–67). This is due to the voluntary minimum harvest size (MHS) being increased by a total of 10 mm over a 5-year period in PAU 5B (it was increased to 127 mm in 2007, 131 mm in 2009, 133 mm in 2010, 135 mm in 2011, and 137 mm in 2015). There were also spatial variations in the mean length between subareas: paua sampled from Ruggedy were smaller than those sampled from Waituna and Pegasus. This spatial contrast was evident for both the early years from 2002 to 2006 and the recent years from 2007 to 2013 (see Figure 66).

Breen & Smith (2008a) weighted the length frequency by the ratio of area catch to the mean area catch within each year. Data without area information were not added to the weighted length frequency distribution. We adopted a modified approach to calculate the length frequency using NIWA's 'catch-at-age' software (Bull & Dunn 2002). Between 1992 and 2001, the catch samples were stratified using three spatial strata based on the General Statistical Areas: 025, 030, and 027/029. Between 2002 and 2017 the stratification was based on the research strata (see Figure 4). Strata in which there were no samples were combined with adjacent strata (i.e., Ruggedy was combined with Waituna in 2002 and 2005, Pegasus was combined with West in 2005, 2008, 2009 and 2014; East Cape was combined with Ruapuke in 2003 and 2007). The length frequencies of paua from each landing were scaled up to the landing weight, summed over landings in each stratum, and then scaled up to the total stratum catch to yield length frequencies by stratum and overall. The CV for each length class was computed using a bootstrapping routine: fish length records were resampled within each landing which was resampled within each stratum. For samples where landing weight was unknown the landing weight was assumed to be equal to the sample weight, calculated from the number of fish in the sample and mean fish weight. The final scaled length frequencies are shown in Figures 68–69.

Late in the assessment process commercial length frequency sample data were received for the 2017 fishing year, and it was suggested by the Shellfish Working Group to also include these data in the model run. These data had not been entered into the market database at the time the model was initially run. The same stratification and bootstrapping procedure were applied to these new data (Figure 70) and the model re-run as a sensitivity.

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

	Number of landings sampled						Number of paua sampled					
Year	30	25	27	29	Unknown	Total	30	25	27	29	Unknown	Total
1992	13	34	7	0	1	55	4 528	11 654	2 287	0	346	18 815
1993	17	27	1	0	0	45	5 828	9 337	335	0	0	15 500
1994	13	22	8	0	1	44	4 253	6 663	2 474	0	658	14 048
1998	3	3	3	0	0	9	515	379	160	0	0	1 054
1999	9	17	16	1	1	44	944	1 770	1 725	102	115	4 656
2000	5	9	12	0	4	30	503	1 044	1 263	0	405	3 215
2001	7	10	4	0	11	32	875	1 332	500	0	1 438	4 145
2002	12	4	16	1	4	37	1 465	439	1 756	109	424	4 193
2003	10	11	11	0	9	41	1 122	1 230	1 236	0	1 009	4 597
2004	20	22	16	0	14	72	2 132	2 325	1 666	0	1 502	7 625
2005	5	14	9	1	16	45	520	1 459	917	106	1 654	4 656
2006	4	12	10	0	14	40	406	1 222	1 004	0	1 400	4 032
2007	5	16	4	2	0	27	640	2 180	487	230	0	3 537
2008	12	18	7	0	0	37	1 586	1 957	641	0	0	4 184
2009	26	11	11	1	0	49	2 748	1 200	964	104	0	5 016
2010	22	29	19	1	0	71	2 064	2 770	1 935	86	0	6 855
2011	25	36	18	0	0	79	1 865	2 752	1 212	0	0	5 829
2012	22	22	20	1	0	65	1 789	1 895	1 726	62	0	5 472
2013	31	42	13	2	0	88	2 371	3 560	1 182	203	0	7 316
2014	26	59	16	4	0	105	2 083	5 081	1 383	343	0	8 890
2015	29	45	20	0	0	94	2 042	3 249	1 803	0	0	7 094
2016	54	38	23	1	0	116	2 851	2 482	1 462	53	0	6 848
2017	39	18	26	9	0	92	2 776	1 471	1 999	679	0	6 925
Total	409	519	290	24	76	1318	45 906	67 451	30 117	2 077	9 215	154 766

Table 28: Number of landings sampled by stratum.

Fishing Year	Ruggedy	Waituna	Codfish	West	Pegasus	Lords	East Cape	Ruapuke	Unknown	Total
2002	0	4	2	7	7	9	1	3	4	37
2003	7	4	3	2	2	9	0	5	9	41
2004	18	4	8	7	2	14	1	4	14	72
2005	5	0	3	3	0	9	2	7	16	45
2006	5	2	1	1	1	9	3	4	14	40
2007	10	2	1	3	1	3	0	7	0	27
2008	9	8	2	1	0	7	3	7	0	37
2009	4	9	2	16	0	11	3	4	0	49
2010	17	4	5	14	1	18	6	6	0	71
2011	20	14	2	7	3	15	8	10	0	79
2012	14	14	3	5	4	16	2	7	0	65
2013	36	10	6	14	7	6	6	3	0	88
2014	36	13	6	7	0	16	10	17	0	105
2015	23	15	7	7	2	18	5	17	0	94
2016	20	18	9	25	5	18	6	15	0	116

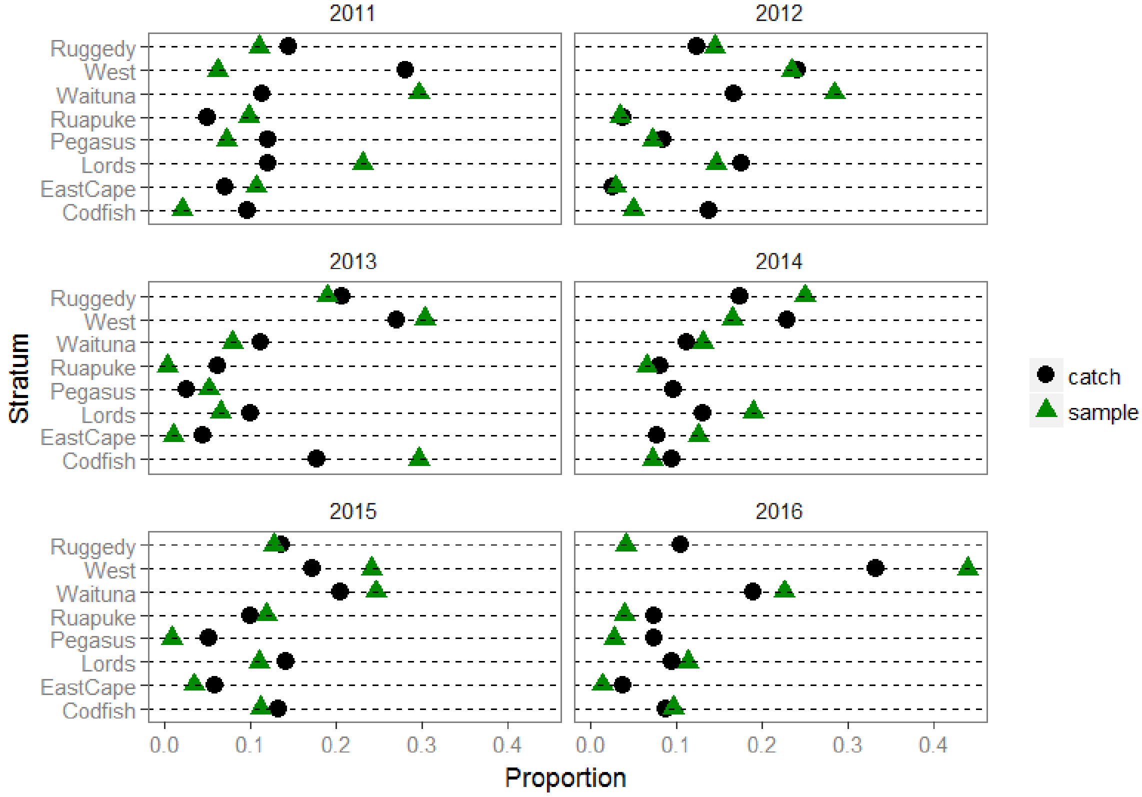


Figure 64: Proportion of total catch and sampled catch by subarea for the 2011–2016 fishing years.

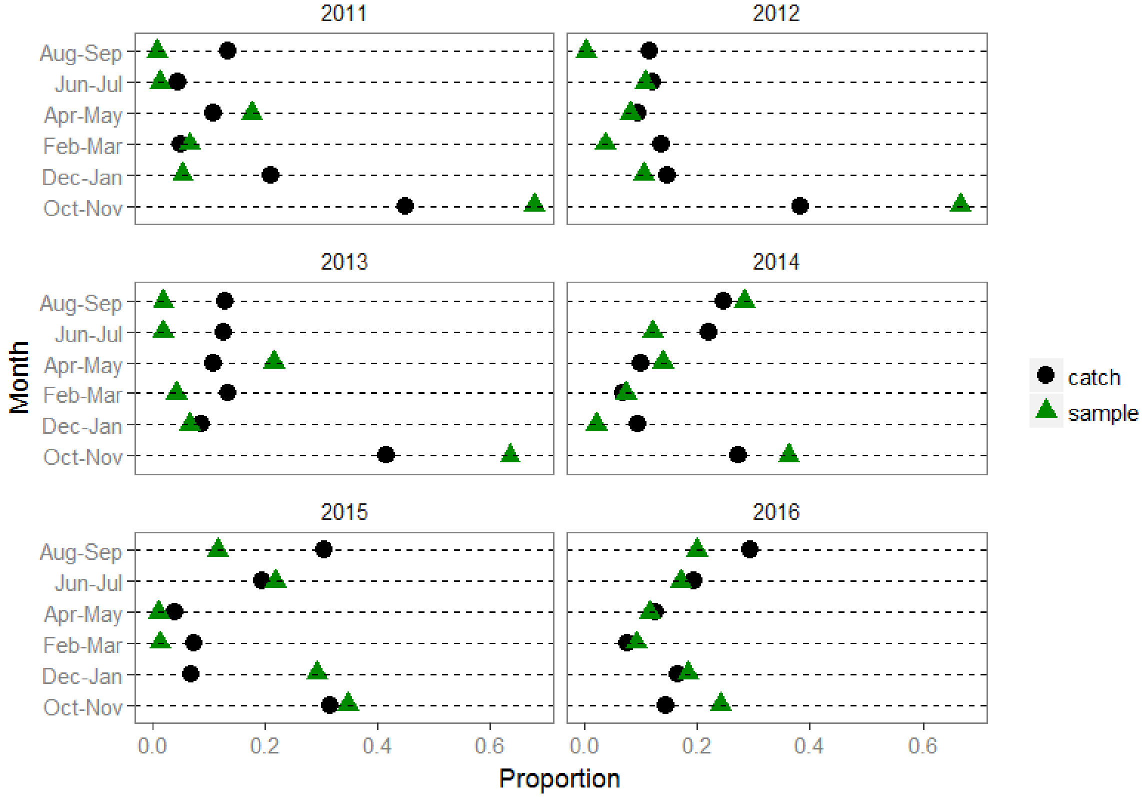


Figure 65: Proportion of total catch and sampled catch by month for the 2011–2016 fishing years.

Figure 66: Mean lengths over time by stratum.

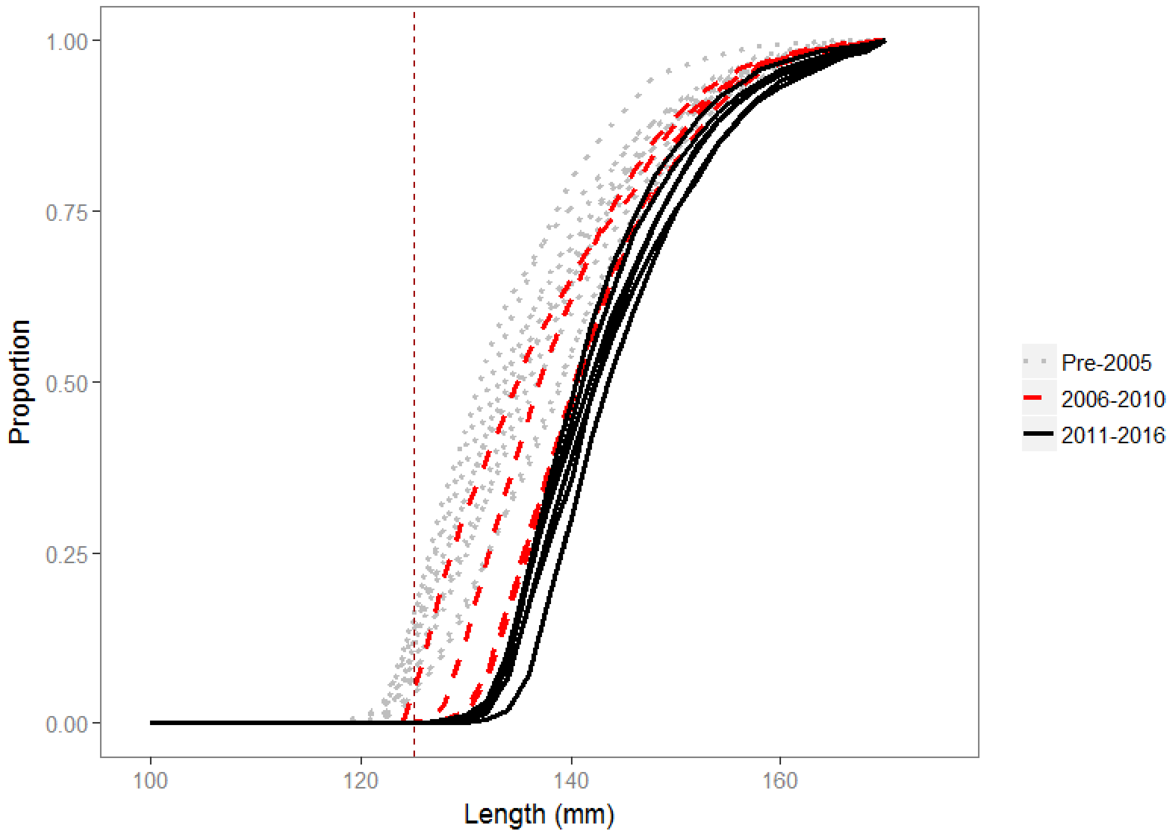


Figure 67: Cumulative length frequencies over time.

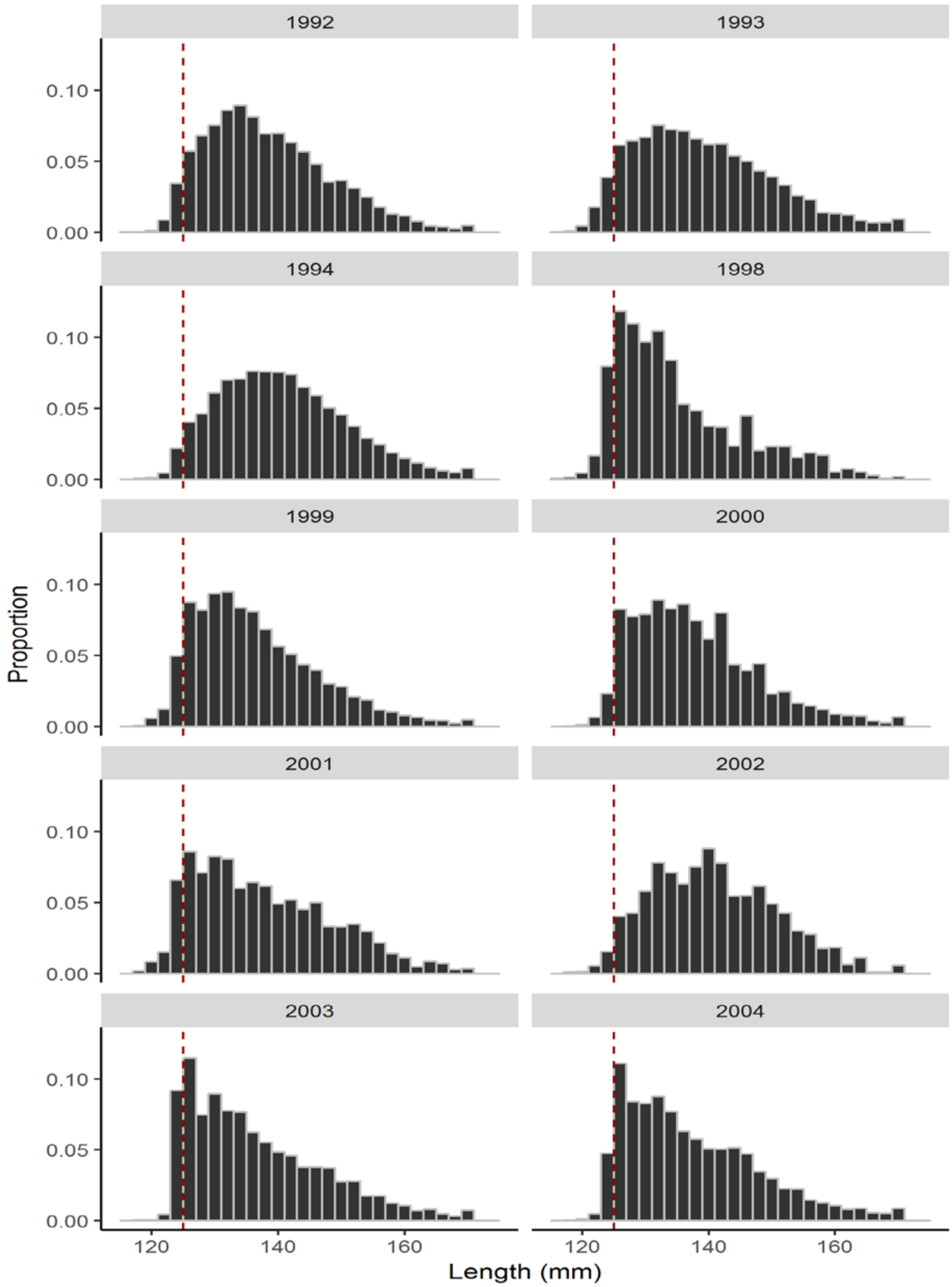


Figure 68: Scaled length frequency distributions for paua from commercial catch sampling for PAU 5B for fishing years 1992–1994, 1998–2004. The red dashed lines indicate the minimum legal size limit of 125 mm and the grey line indicated the voluntary minimum harvest size of 132 mm implemented more recently.

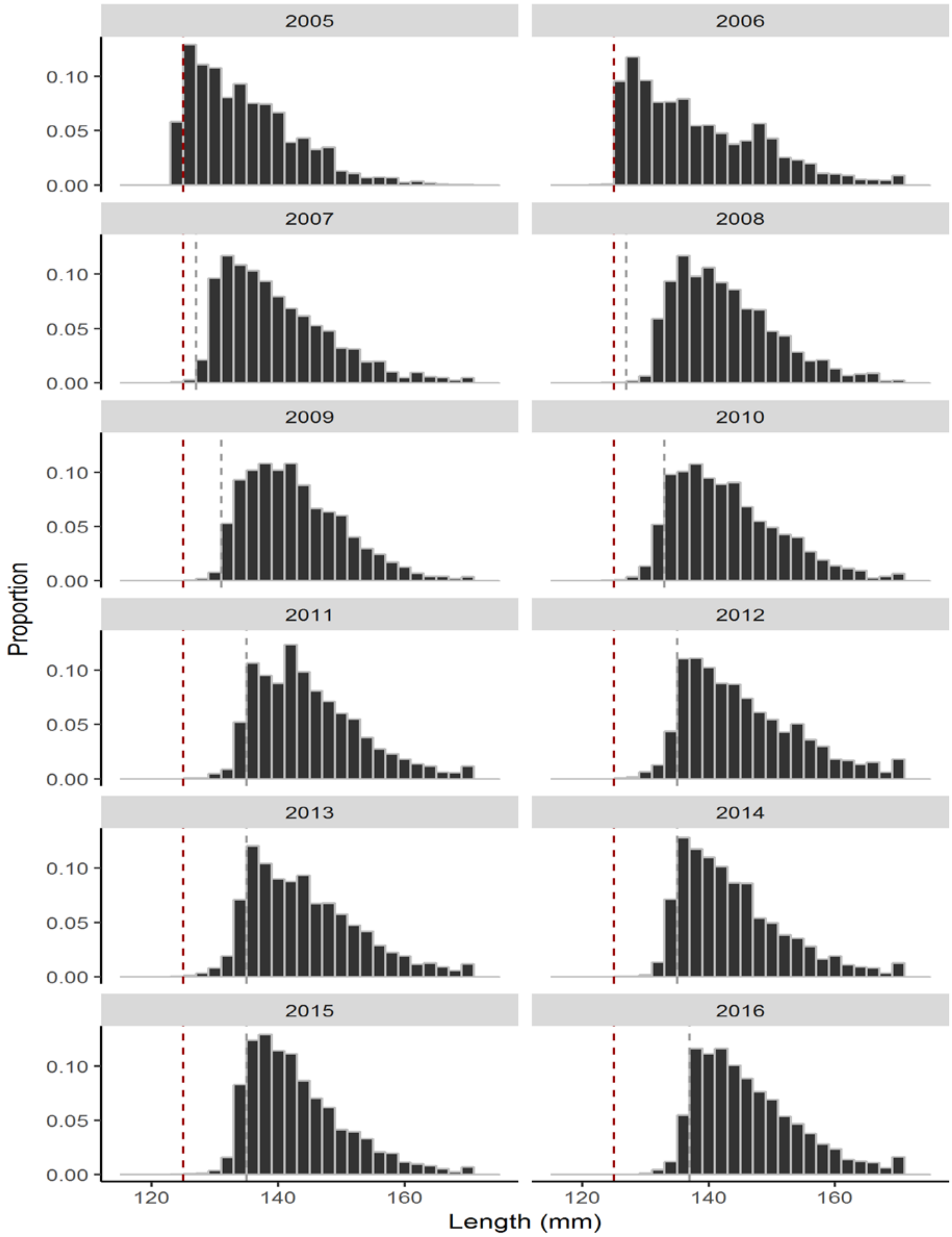


Figure 69: As in Figure 68 but for 2005–2016.

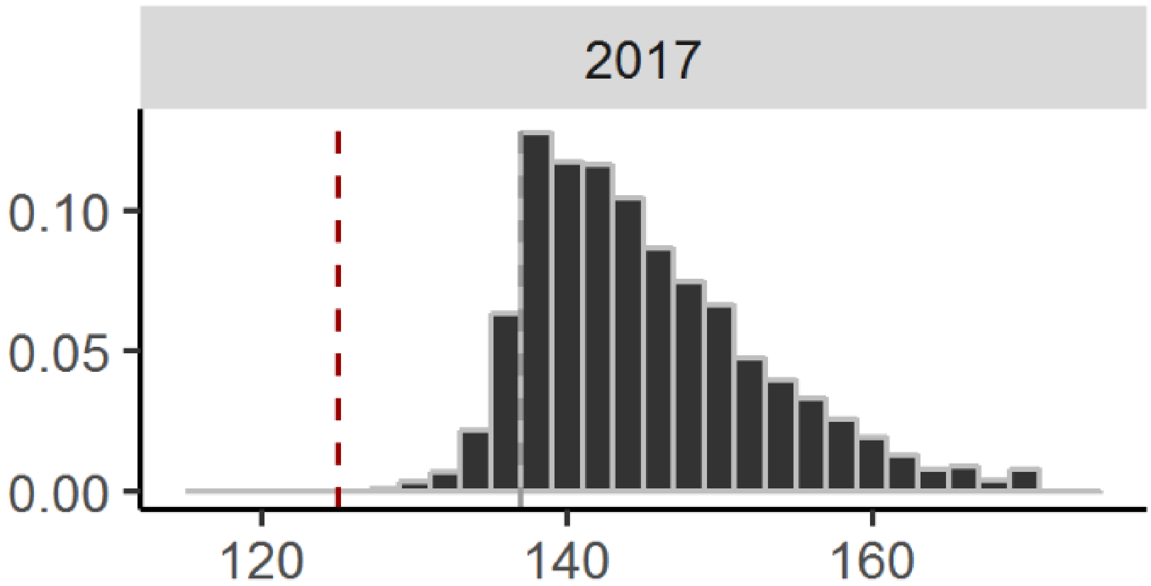


Figure 70: Scaled length frequency distributions for paua from commercial catch sampling for PAU 5B for the fishing year 2017. The red dashed lines indicate the minimum legal size limit of 125 mm and the grey line indicated the voluntary minimum harvest size of 138 mm implemented more recently.

6. RESEARCH DIVER SURVEY INDEX (RDSI)

Research diver surveys based on a timed-swim method developed by McShane (1994, 1995) and modified by Andrew et al. (2000a) have been conducted to assess the relative abundance of New Zealand paua stocks since 1991 (Andrew et al. 2000b, 2000c, 2002, Naylor & Kim 2004). Relative abundance indices estimated from the survey data (RDSI) have been routinely used in paua stock assessments in the past (Breen & Kim, 2007, McKenzie & Smith 2009, Breen & Smith 2008b). The previous stock assessment for PAU 5B used the RDSI developed from the survey data up to 2010 (Fu & McKenzie 2010). There have been no new surveys since the last assessment.

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

The calculation of the relative abundance indices from the RDSI data was re-worked for the last assessment (Fu 2014) to account for considerations of Haist (2010) and Cordue (2009), and is described in Fu et al. (2014). The RDSI relative abundance index is plotted in Figure 71.

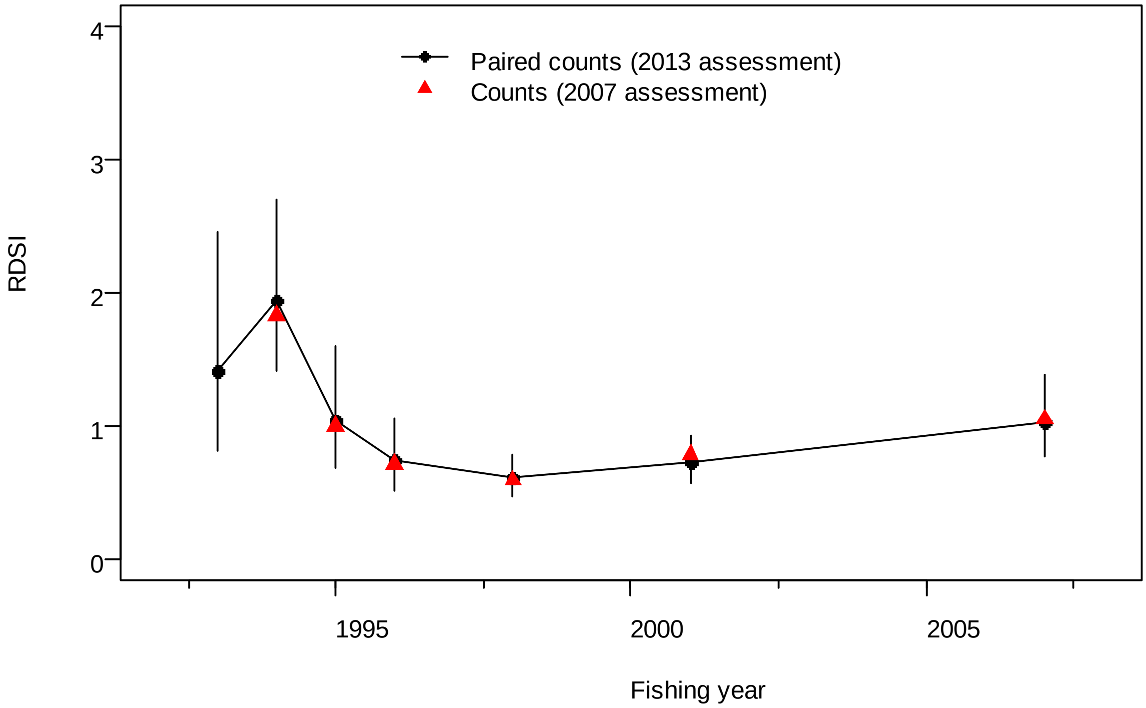


Figure 71: The standardised RDSI from the negative-binomial GLM models fitted to paired diver counts for surveys in PAU 5B. Also plotted are the estimated indices from the 2007 assessment in which individual diver counts were fitted by a Tweedie model (see Breen & Smith 2008a).

7. RESEARCH DIVER LENGTH FREQUENCY (RSLF)

Paua from the research diver survey were sampled to estimate the size composition at each site (Table 29). Since there have been no new surveys since the last assessment the RDLF has remained unchanged. The methodology for constructing these are described in Fu et al. (2014) and the scaled length frequency distributions are shown in Figure 72.

Table 29: Number of paua sampled from the research diver survey by stratum and fishing year.

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

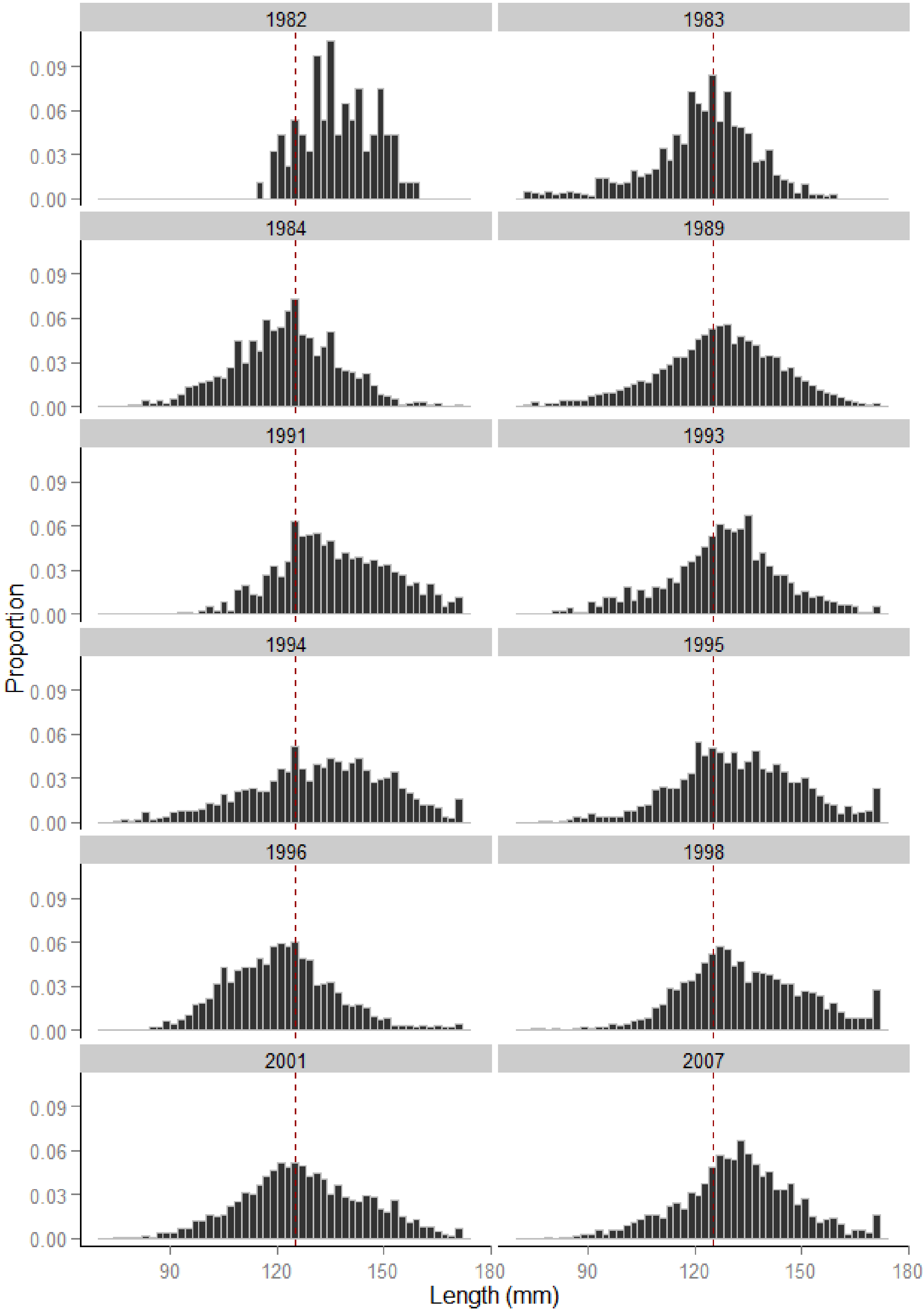


Figure 72: Scaled length frequency from research diver survey sampling in PAU 5B. The dashed line indicates the MLS of 125 mm.

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Tag and recapture experiments have been conducted at different times and at several sites in the PAU 5B (Breen & Smith 2008a) region. Growth data collected from these experiments were available from East Cape (n=116), Lords (n=52), Ruggedy (n=78), and Waituna (n=132). The growth dataset comprises of 333 records with initial tagged lengths ranging from 22 to 143 mm, time at liberty ranging from 214 to 364 days and annualised increments ranging from -2 to 54 mm. These data were incorporated into the PAU 5B assessment to estimate growth. No new tag recapture data since the last PAU 5B assessment have been collected.

Three models describing the rate of growth were available within the stock assessment model. With the linear growth model (Francis 1988) the expected annual growth increment for an individual of initial size L_k is

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

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

For the exponential growth model the expected annual growth increment is:

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

where Δl_k is the expected increment for a paua of initial size l_k; and g_1 and g_2 are the mean annual growth increments for paua with arbitrary lengths L_1 and L_2.

With the inverse logistic model (Haddon et al. 2008) the expected annual growth increment for a paua of initial size l_k is:

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

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

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 three growth models described above. 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) in this preliminary analysis. Variation in growth was assumed normally distributed with $\sigma^{\Delta l_k} = \max(a(\Delta l_k)^{\beta}, \sigma_{min})$, where Δl_k is the expected at length l_k truncated at zero, $\sigma_{\min}$ is the minimum standard deviation assuming fixed at 1 mm and $a(\Delta l_k)^{\beta}$ 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 likelihood function maximised was:

$$L_i(\Delta l_i, \sigma^{\Delta l_i}, \sigma_E) = \frac{1}{\sigma_E}\phi\left(\frac{y_i}{\sigma_E}\right)\Phi\left(-\frac{\Delta l_i}{\sigma^{\Delta l_i}}\right) + \frac{1}{\sqrt{\sigma^{\Delta l_i}{}^2 + \sigma_E{}^2}}\phi\left(\frac{y_i - \Delta l_i}{\sqrt{\sigma^{\Delta i}{}^2 + \sigma_E{}^2}}\right)\Phi\left(\frac{\sigma^{\Delta l_i}{}^2 y_i - \sigma_E{}^2 \Delta l_i}{\sqrt{\sigma^{\Delta l_i}{}^2 \sigma_E{}^2\left(\sigma^{\Delta l_i}{}^2 + \sigma_E{}^2\right)}}\right)$$

where y_i is the measured growth increment for the ith paua; Δl_i and $\sigma^{\Delta l_i}$ 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. The measurement error σ_E was assumed to be known as 1 mm.

The inverse logistic model had the best fit (Table 30), for which Figure 73 shows the fit and residual. The residual patterns suggest there was spatial variation in growth. The models were fit to the complete dataset and a subset that only included initial tag size greater than 70 mm. A customary practice in the paua stock assessment is to begin modelling the stock from 70 mm at length, thus rendering smaller tag recapture data redundant.

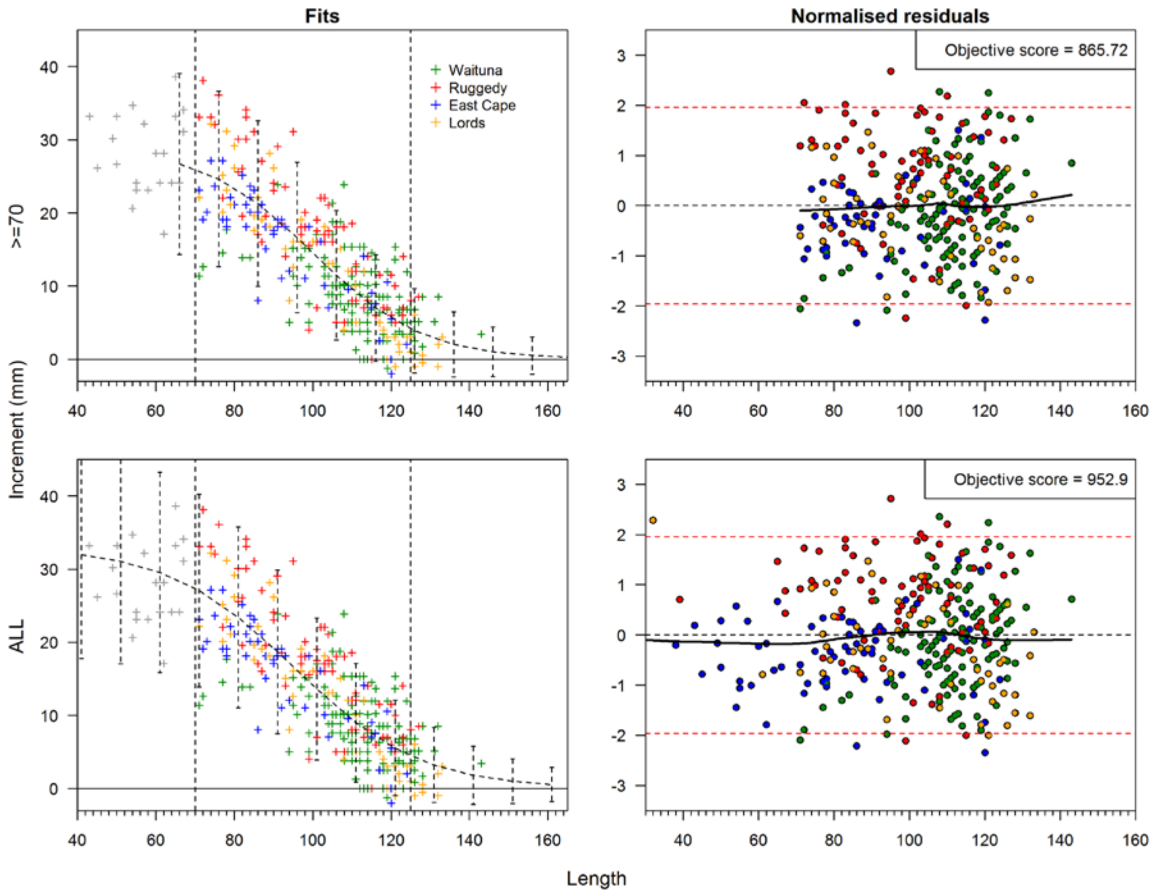


Figure 73: The fit and residuals for the inverse logistic model.

Table 30: Negative log likelihood values from the maximum likelihood routines for all growth models and across all data and for a subset of data where the model was only fit to data greater than 70 mm.

	All data	data ≥ 70mm
Linear	880.4	963.83
Exponential	866.27	999.28
Inverse logistic	865.72	952.9

9. MATURITY

Maturity data has been collected from several sites in the PAU 5B area since 1994 (Table 31). Figure 74 shows the spatial distribution of sampling. Latitude and longitude coordinates were available after 2014; before that only the research stratum was available. Length-at-maturity is described by the logistic ogive in the stock assessment model and is estimated internally within the model. We explored the data in a similar fashion to the growth data, in which a preliminary analysis was done fitting a generalised linear model with a logit link. For this analysis some sites were grouped together so that there was a large enough sample size to get an estimate of the key parameters: (i) Codfish, Waituna, and East Cape (2) Lords and Pegasus.

There was variability in maturity over time and across different sites, with the a_{50} parameter varying between 78 cm and 104 cm (Table 32). The combined data estimates of maturity suggested that 50% of fish at 95.8 cm would be mature, and by 116 cm the probability of being mature is about 95% (Figure 75).

Table 31: Number of paua sampled for maturation state in the PAU 5B stock by area and year.

	1994	1995	2006	2007	2014	2017
Big Kuri	0	0	0	0	120	0
Codfish	0	0	0	24	0	0
East Cape	0	73	9	0	0	0
Little Bangaree Bay	0	0	0	0	0	126
Lords	0	0	0	2	0	0
Pegasus	0	0	0	19	0	0
Pikaroro Bay	0	0	0	0	0	118
Ruggedy	0	0	0	151	123	0
Shelter Point	0	0	0	0	93	0
Waituna	31	0	0	0	0	0
Waterfalll	0	0	0	0	129	0

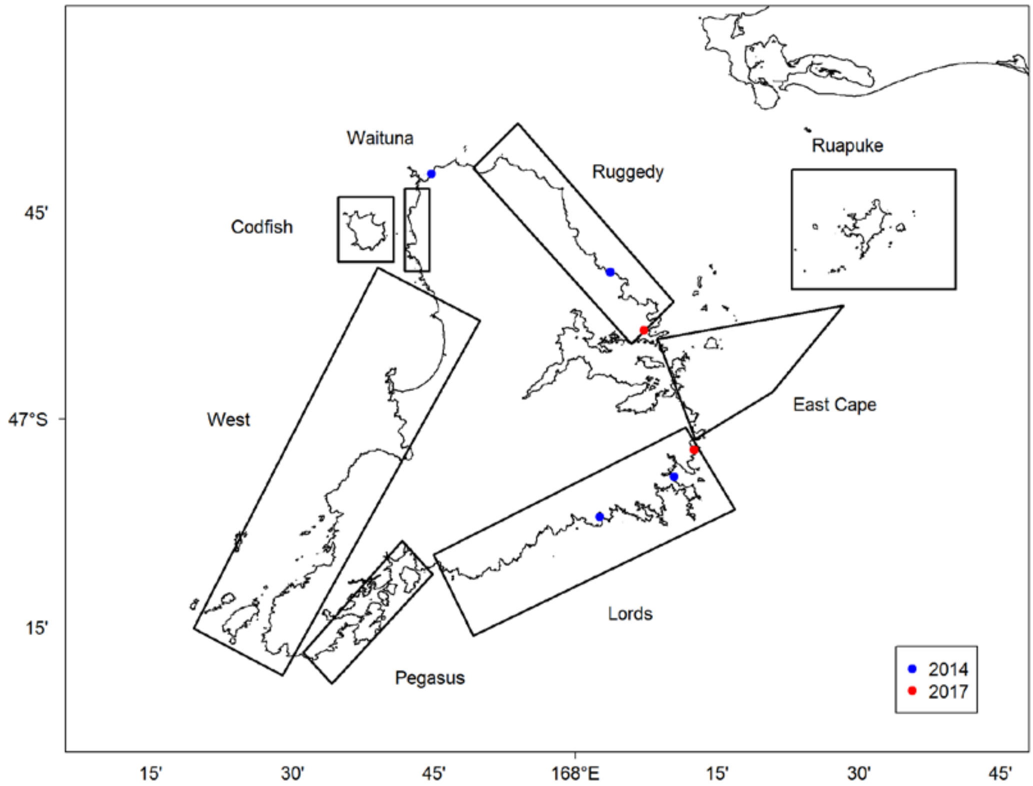


Figure 74: Stewart Island with research strata and sample sites from the most recent (2014 and 2017) maturity at age data.

Table 32: Estimates of the maturity ogive parameters for different the sites, from the preliminary analysis.

Site	Estimate l_{50}	Estimate l_{to95}
Waituna sites	78.3	26.7
EastCape sites	96.0	20.4
Ruggedy (2007)	90.7	15.6
Ruggedy (2014)	103.3	28.2
Big Kuri	99.1	9.0
Shelter Point	103.7	9.2
Waterfalll	98.9	14.3
Little Bangaree Bay	97.2	10.9
Pikaroro Bay	89.9	8.8

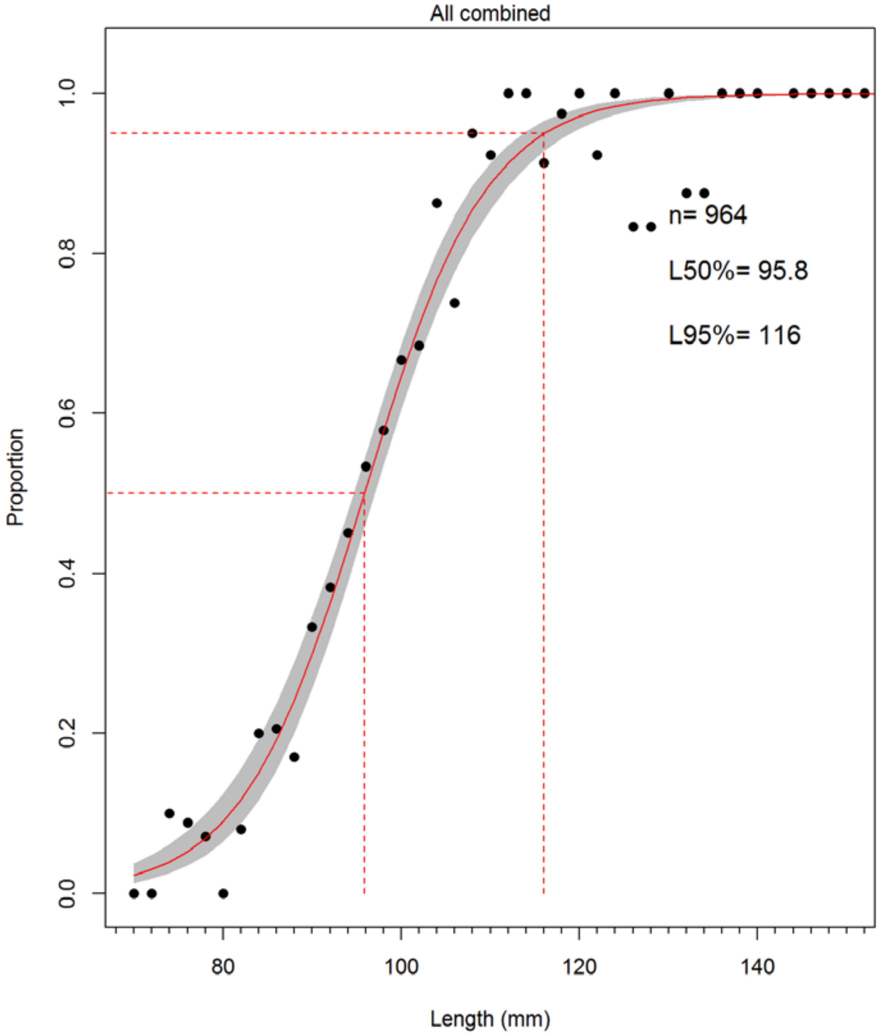


Figure 75: The estimated maturity ogive from all data combined.

10. ACKNOWLEDGMENTS

This work was supported by a contract from the Ministry for Primary Industries (PAU201701 Objective 1). Thanks to the Shellfish Working Group for all the advice provided throughout the assessment process, to Adele Dutilloy (NIWA) for a thorough review of an earlier version of this document, and Marianne Vignaux (MPI) for some very good editorial changes and suggestions.

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APPENDIX A

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

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

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

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

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