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Summary of input data for the 2013 PAU 3 stock assessment

New Zealand Fisheries Assessment Report 2014/42

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EXECUTIVE SUMMARY

Fu, D.; McKenzie, A; Naylor, R. (2014). Summary of input data for the 2013 PAU 3 stock assessment.
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This document summarises the data inputs for the 2013 stock assessment of blackfoot paua in PAU 3. The four sets of data fitted in the assessment model were: (1) a standardised CPUE series based on CELR data (2) a standardised CPUE series based on PCELR data (3) a commercial catch sampling length frequency series (4) 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, and unlike previous standardisations fishing duration was offered to the model. The standardised CPUE series based on PCELR data was updated to the 2012–13 fishing year. Scaled length frequency series from the commercial catch sampling were updated to the 2011–12 fishing year, where the catch samples were stratified by area and numbers at length were scaled up to each landing and then to the stratum catch.

The growth data available for the PAU 3 assessment were collected from several sites on Banks Peninsula. Because most of the paua at these sites were stunted, incorporating those data into the assessment would under-estimate growth for the whole stock. There were also some growth measurements from Cape Campbell (within PAU 7) which is close to the northern boundary of PAU 3, but the sample size was too small to be useful. Therefore no growth data were used in the PAU 3 stock assessment model.

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1. INTRODUCTION

This document summarises the data inputs for the 2013 stock assessment of PAU 3. The work was conducted by NIWA under the Ministry for Primary Industries contract PAU201202 Objective 1. A separate document details the stock assessment of PAU 3 (Fu 2014). Data used in the 2013 assessment were:

1. A standardised CPUE series covering 1990–2001 based on CELR data.
2. A standardised CPUE series covering 2002–2013 based on PCELR data.
3. A commercial catch sampling length frequency series (CSLF).
4. Maturity-at-length data.

The fishing year for paua is from 1 October to 30 September and in this document we refer to fishing year by the second year that it covers; thus we call the 1997–98 fishing year “1998”.

2. DESCRIPTION OF THE FISHERY

The PAU 3 Quota Management Area covers the coastal area from the Clarence River on the east coast of the South Island, southward to the Waitaki river mouth (Figure 1). PAU 3 was introduced into the Quota Management System in 1986–87 with a TACC of 57 t. As a result of appeals to the Quota Appeal Authority, the TACC was increased to 91.62 t in 1995 and has remained unchanged to the current fishing year. The reported landings and TACC for PAU 3 and the subdivided stocks are shown in Table 1.

Catches were reported on the scale of the General Statistical Areas until 30 September 2001. On 1 October 2001 it became mandatory to report catch and effort using fine-scale reporting areas that had originally been developed by the New Zealand Paua Management Company for their voluntary logbook programme (Figure 1). A summary of the spatial resolution of reporting areas for PAU 3 is given in Table 2.

Since 2001, a redistribution of fishing effort within PAU 3 has been undertaken by the industry, as a response to fears that the more accessible northern part of the fishery was being depleted because the majority of fishing was occurring there. A voluntary subdivision was agreed by the PauaMAC 3 which divided PAU 3 into four management zones (Table 3), and a proportion of the total annual catch entitlement (ACE) was allocated to each zone (AOP 2010/2011). To ensure that harvesting is spread across the fishery in proportion to stock abundance, each of the management zones has a voluntary harvest cap placed on it (30 t for 3A, 14 t for 3B, 27.615 t for 3D, and 20 t plus for 3E for the 2010–11 fishing year). Members also agreed to implement increased minimum harvest size (MHS) on top of the current Minimum Legal Size (MLS) in place, in some parts of the fishery, to better reflect population biological parameters. MHS was set to 130 mm in Statistical Areas P301–303 (Clarence to Mussel rock), and to 127 mm in P304 (Mangamaura), P305–P310 (Hapuku to Conway), and P318 (Just Motonau Island).

Table 1: TACCs and reported landings (kg) of paua for PAU 3. 2012–13 landings are assumed to be the same as the TACC as the data were requested a few months before the end of the fishing year.

Fishing year	Landings	TACC
1983–84*	100 190	–
1984–85*	80 806	–
1985–86*	45 116	–
1986–87†	54 023	57 000
1987–88†	63 795	60 490
1988–89†	62 191	66 480
1989–90†	74 475	69 430
1990–91†	89 396	77 240
1991–92†	90 105	91 500
1992–93†	92 931	91 500
1993–94†	85 146	91 500
1994–95†	93 260	91 500
1995–96†	93 120	91 620
1996–97†	88 710	91 620
1997–98†	93 879	91 620
1998–99†	92 540	91 620
1999–00†	90 302	91 620
2000–01†	93 185	91 620
2001–02†	89 656	91 620
2002–03†	90 915	91 620
2003–04†	91 583	91 620
2004–05†	91 429	91 620
2005–06†	91 597	91 620
2006–07†	91 606	91 620
2007–08†	91 670	91 620
2008–09†	90 844	91 620
2009–10†	91 612	91 620
2010–11†	90 399	91 620
2011–12†	91 137	91 620
2012–13†	91 620	91 620

* FSU data, † QMR/MHR data,

Table 2: Summary of statistical areas for reporting catch and effort within PAU 3.

General Statistical Area (–Sep 2001)	Paua Statistical Areas (Oct 2001–present)
018 (part of)	P301–P314
020	P315–P328
022	P329–P339

Table 3: Summary of the management zones within PAU 3 as initiated by PauaMac3.

Management zone (since 2001)	Area	Paua Statistical Areas
3A	Clarence to Hapuku	P301–P304
3B	Hapuku to Conway	P305–P310
3D	Conway to Waipara	P311–P321
3E	Waipara to Witaki	P322–P329

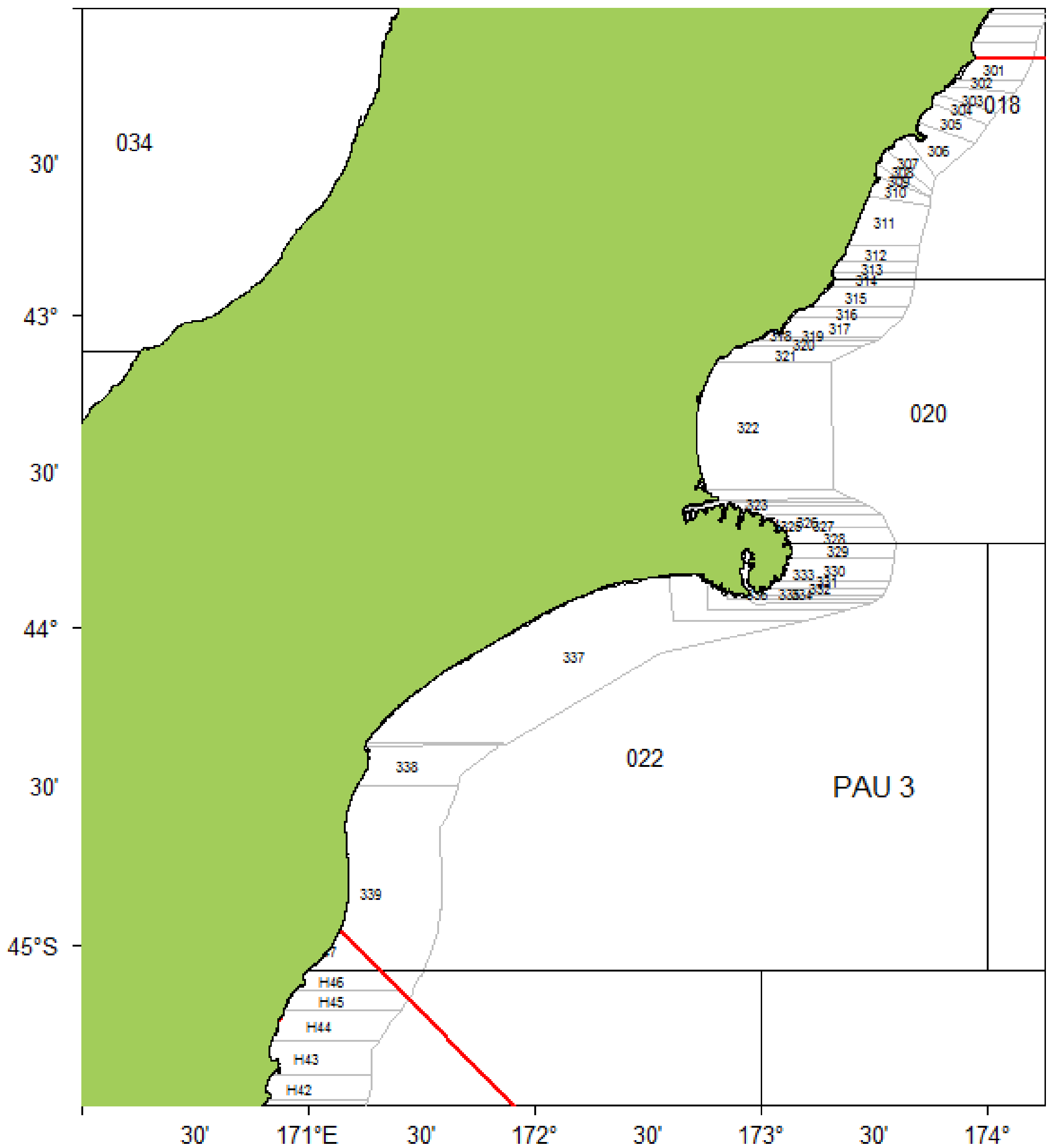

Figure 1: Map showing the location of fine scale Paua Statistical Areas within PAU 3 effective from 1 October 2001.

3. CATCH HISTORY

3.1 Commercial catch

The catch history between 1974 and 1983 was estimated by Murray & Akroyd (1984). Murray & Akroyd (1984) stated that landings before 1974 were unreliable. Catches for 1984–86 were estimated using FSU data which was reported using General Statistical Areas in which Statistical Area 018 intersects both PAU 7 and PAU 3. Therefore the percentage of the catch that was taken from PAU 3 was estimated using the more recent PCELR data in which the fine scale statistical areas can be used to delineate PAU 3 and PAU7. This percentage averages 89% between 2002 and 2013 and is generally stable over time. The catch history for 1984–86 was therefore taken to be the sum of the catch in Statistical Areas 018 (adjusted for the estimated proportion from PAU 3), 020, and 022. Catches from 1987 onwards were based on the reported landings captured on QMR/MHR forms. The estimated commercial catch history is shown in Figure 2. The proportion of catch taken from Statistical Areas 018, 020, and 022 is shown in Table 4.

The majority of the catches were taken from the northern part of the stock including management zones 3A, 3B, and 3D (P301–320), which accounted for about 85% of the total catch (Table 5). Management zone 3A is the most important area and over 30 t of paua were caught annually from its four statistical reporting areas (P301–304). The annual catch in 3B was between 20 and 25 t and on average was about 10 t more than the harvest cap in place. The annual catch in 3D was between 14 and 23 t. Catches in 3E were typically much less than the harvest cap (20 t or 20+ t) and have been concentrated in the southern part of the zone, with almost no catch from the northern area between Waipara and Banks peninsula (Figure 3). In 2013, the catch (up until the end of July) in 3E exceeded 20 t and the catch was reduced considerably in 3A as a result of redistribution of the fishing effort initiated by the industry.

Table 4: Proportion of estimated catch for fishing years 2002–2013 from PCELR forms in each of the General Statistical Areas within PAU 3.

Fishing year	018	020	022	Total (kg)
2002	0.81	0.11	0.08	91 696
2003	0.69	0.12	0.19	89 516
2004	0.74	0.14	0.13	88 080
2005	0.69	0.18	0.12	88 005
2006	0.82	0.13	0.05	89 981
2007	0.78	0.15	0.07	89 337
2008	0.70	0.19	0.11	88 834
2009	0.73	0.13	0.14	88 899
2010	0.69	0.12	0.18	90 487
2011	0.70	0.18	0.13	88 447
2012	0.61	0.22	0.17	88 465
2013	0.55	0.17	0.28	81 037

Table 5: A summary of estimated catch and voluntary harvest caps by sub-management zones for PAU 3 for 2002–2013.

Fishing			3A			3B			3D			3E
year	Catch	Proportion	Harvest cap	Catch	Proportion	Harvest cap	Catch	Proportion	Harvest cap	Catch	Proportion	Harvest cap
2002	38 289	0.42		33 881	0.37		11 835	0.13		7 691	0.08	
2003	28 896	0.32	25 650	23 334	0.26	15 600	19 179	0.21	20 000	18 108	0.20	30 200
2004	31 021	0.35	29 000	23 617	0.27	19 000	22 282	0.25	23 500	11 160	0.13	20 000
2005	26 400	0.30	29 000	25 672	0.29	19 000	24 691	0.28	23 500	11 242	0.13	20 000
2006	28 404	0.32	29 000	37 780	0.42	19 000	18 972	0.21	23 500	4 825	0.05	20 000
2007	33 084	0.37		29 761	0.33		20 095	0.22		6 397	0.07	
2008	34 142	0.38		26 194	0.29		18 802	0.21		9 696	0.11	
2009	36 649	0.41	34 000	25 521	0.29	14 000	13 782	0.16	23 500	12 947	0.15	20 000+
2010	35 534	0.39	30 000	23 458	0.26	14 000	14 468	0.16	27 615	17 027	0.19	20 000+
2011	31 102	0.35	30 000	23 752	0.27	14 000	22 353	0.25	27 615	11 241	0.13	20 000+
2012	31 047	0.35		19 268	0.22		22 795	0.26		15 355	0.17	
2013	23 571	0.29		16 977	0.21		18 154	0.22		22 335	0.28	

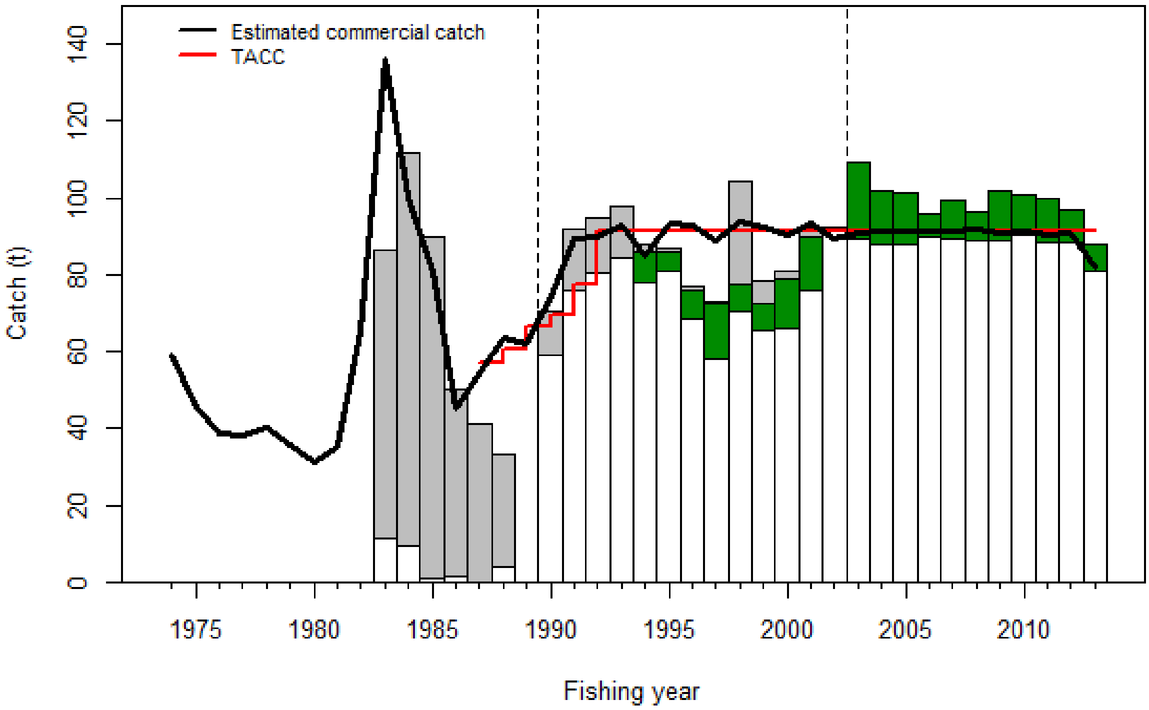

Figure 2: Estimated catch (bar) for 1984–1989 on FSU, 1990–2001 on CELR, and 2002–2013 on PCELR forms, overlaid with estimated commercial catch history for 1974–2013 for PAU 3. The extracted data included catches from Statistical Areas 018, 020, and 022. The green portion of the bar indicates the catch from Statistical Area 018 that was taken from PAU 7; the grey indicated the catch whose stock origin was unknown (either PAU 3 or PAU 7).

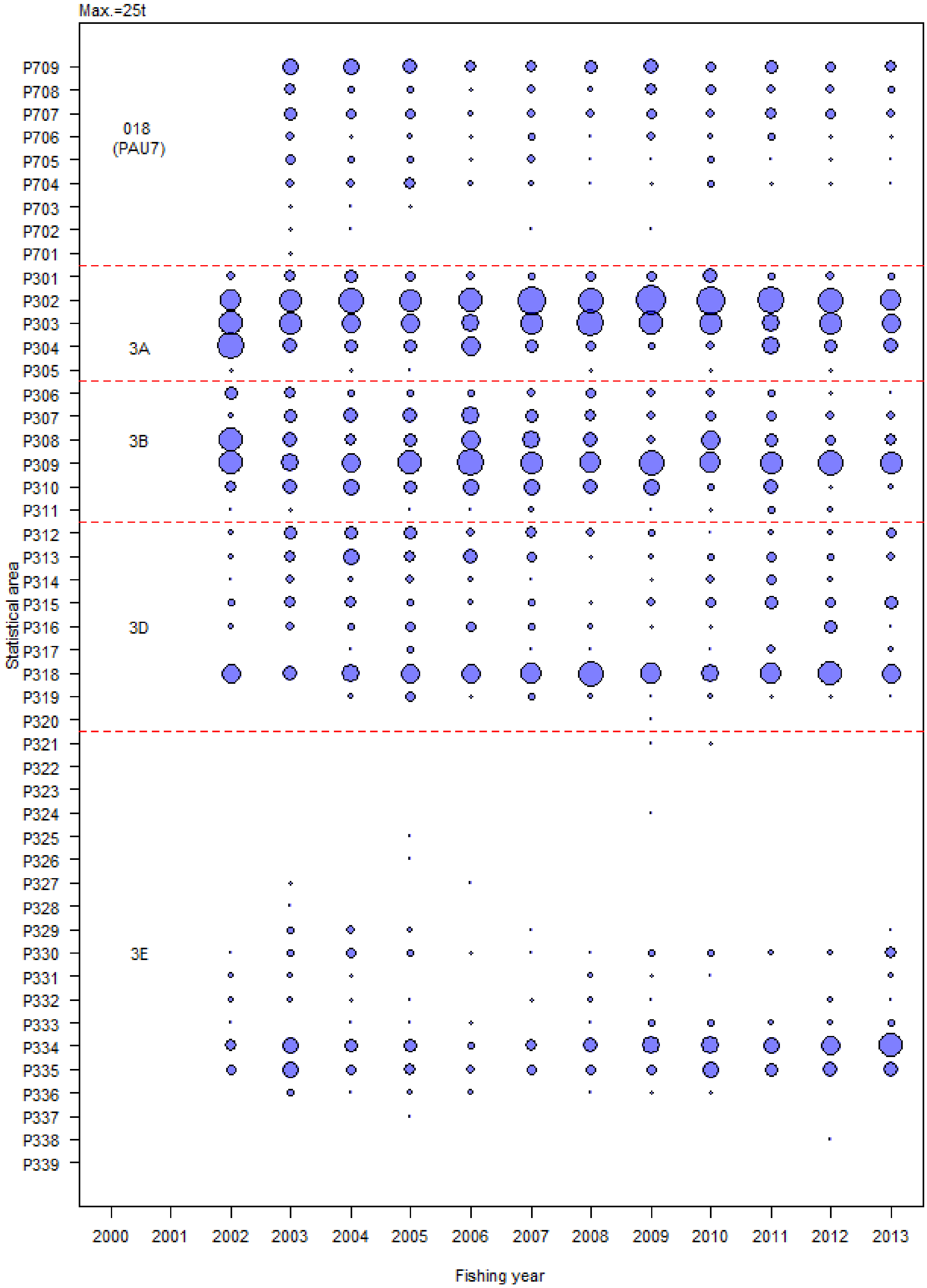

Figure 3: Annual estimated catch by Paua Statistical Area in PAU 3 for fishing years 2002–2013. The size of the circle is proportional to the catch. The dashed lines separate management zones 3A, 3B, 3D, and 3E as well as part of General Statistical Area 018 that falls across the boundary into PAU 7.

3.2 Recreational catch

The New Zealand Recreational Marine Survey for 2011–12 estimated that the recreational harvest for PAU 3 was 16.98 t with a CV of 30%. For this assessment, the SFWG agreed to assume that the recreational catch rose linearly from 5 t in 1974 to 17 t in 2013.

3.3 Customary catch

There are no published estimates of customary catch. For the purpose of the stock assessment model, the SFWG agreed to assume that the customary catch rose linearly from 1 t in 1974 to 4 t in 2013.

3.4 Illegal catch

For the purpose of the stock assessment model, the SFWG agreed to assume that illegal catches rose linearly from 5 t in 1974 to 15 t in 2000, and remained at 15 t between 2001 and 2013.

4. CPUE STANDARDISATIONS

Two separate standardised CPUE series were calculated: (i) based on CELR data from 1990 to 2001, and (ii) based on PCELR data from 2002 to 2013. The standardisation methodologies follow those for the recent PAU 5A assessment (Fu et al. 2010), PAU 7 assessment (Fu et al. 2012), and PAU 5D (Fu et al. 2013). The datasets used, methods, and results are described in the following sections.

The SFWG decided, following previous paua CPUE standardisations, to drop the FSU data from 1983 to 1989 inclusive. Subsequent to this decision the utility of this data was investigated in more detail, and it appeared to have some use, although potential problems still remain, and it was decided by the SFWG not to use FSU data for the current set of standardisations (Section 4.2).

For the CELR data standardisation a subset of the groomed data was used for which the recorded duration would be less ambiguous, and duration was offered to the standardisations, in contrast to previous standardisations for PAU 5B (Section 4.3).

4.1 Initial dataset for the CELR/PCELR data standardisations

Catch effort data reported to the Catch and Effort Landing Return system capturing fishing events that either caught or targeted paua between 1 October 1990 and 30 August 2013 were requested from the Ministry for Primary Industries database “warehou” (extract 9066), including the CELR data until October 2001, and the PCELR data from the 2001–02 fishing year onwards. The FSU data were also extracted from the NIWA-managed database for the period between January 1983 and September 1988 (extract. CL0088), but they were not used for the CPUE standardisation (Section 4.2). The data were groomed, using methods similar to those described by Kendrick & Andrew (2000) and by Breen & Kim (2007).

The hours per diver show a decline with the number of divers (Figure 4). This is indicative of some ambiguity in what is recorded for duration (sometimes correctly as total hours for all divers, and at other times the hours per diver). However, for a subset of this data, what was recorded for fishing duration is less ambiguous (Section 4.3).

The recorded resolution for the estimated catch and fishing duration for the PCELR data is comparable to other areas and is low. About 40% of the catch is recorded as multiples of 50 kg, and about 70% of recorded fishing durations are multiples of one hour (Figure 5a, b). In about 25% of fishing events the estimated catch was split equally among the divers (Figure 5c).

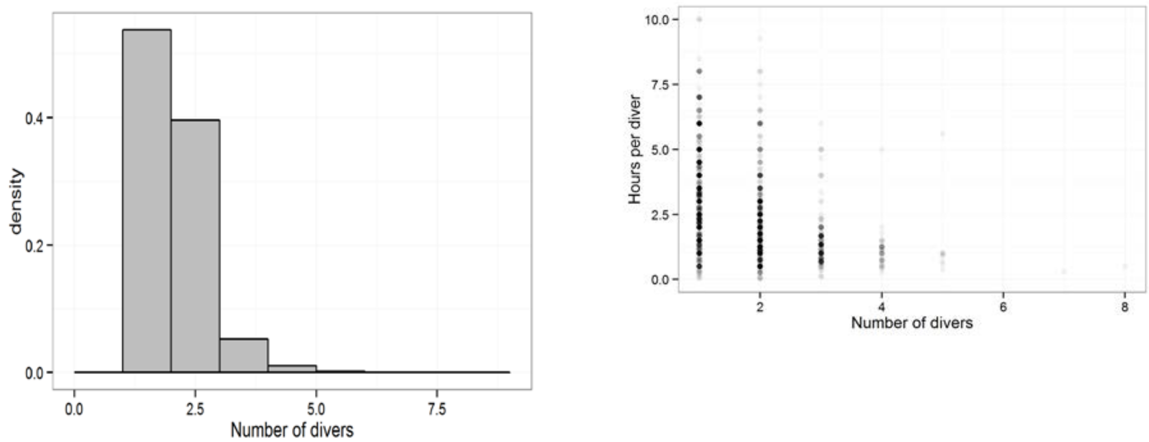

Figure 4: Distribution of the number of divers (left) and the calculated fishing hours per diver (right) on CELR forms within PAU 3 for fishing years 1990–2001 combined.

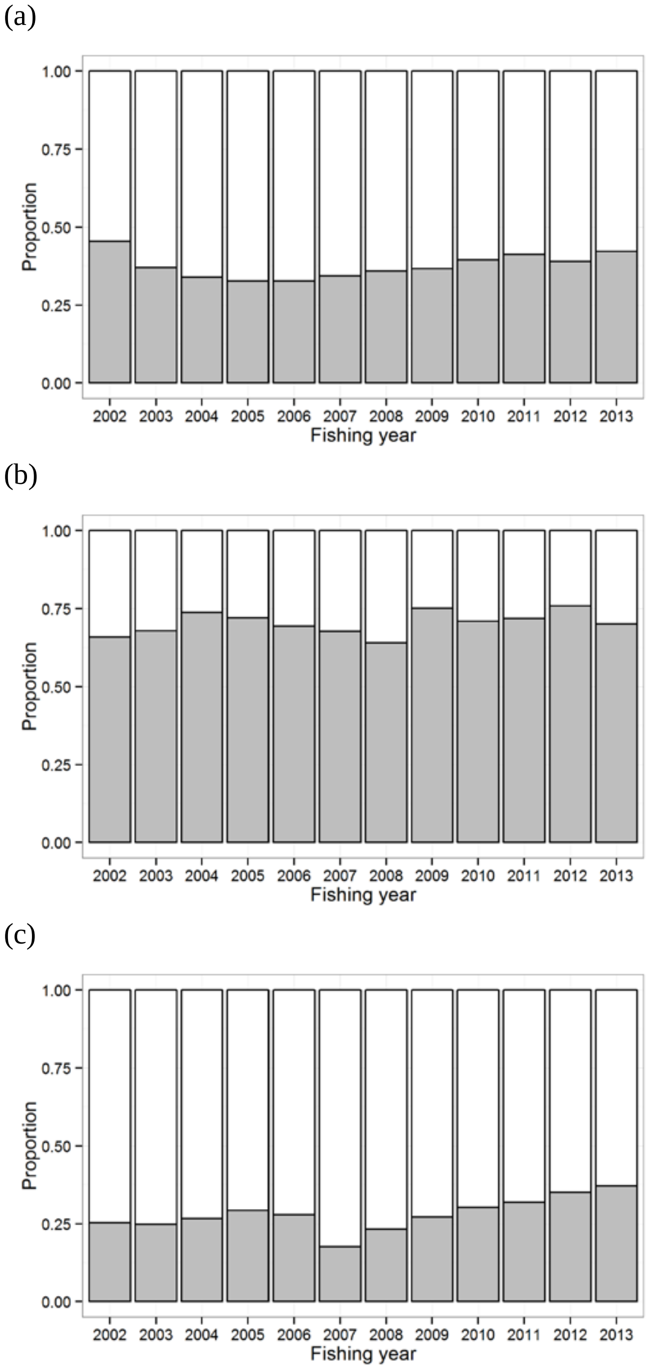

Figure 5: Diagnostic of data resolution on PCELR forms within PAU 3: (a) proportion of records that recorded estimated catch in a multiple of 50 kg; (b) proportion of records that recorded hours fished in an exact multiple of 1 hour; (c) proportion of fishing events where recorded estimated catch was equally split among divers.

4.2 Utility of the FSU data

The FSU data were extracted from the NIWA-managed database (newly established) for the period between January 1983 and September 1988 (extract. CL0088), but they were not used for the CPUE standardisation.

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

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

There is a paucity of catch-effort records associated with FSU catch identified as being from PAU 3 (denoted by the white bars in Figure 2). Of the 166 records 25% are missing a vessel key. From 1985 to 1989 there are fewer than 20 records a year, and they represent only a small proportion of the catch. In 1983 and 1984 there about 70 records each year, but these also represent a relatively small proportion of the catch. The concern with such a small number of records is that any standardised indices derived from them would be highly uncertain and biased (and hence either uninformative or misinformative for a stock assessment). Based on this, and the number of missing vessel keys, the FSU data from PAU 3 is unsuitable to derive a standardised CPUE index from.

4.3 Changes in fishing duration for the CELR data

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

Before subsetting some grooming of the catch-effort records was undertaken: records were retained only where paua was targeted by diving, and records were dropped if they had missing values for the estimated catch or the number of divers (Table 6). The FIN (Identification Number for the permit holder), General Statistical Area (018, 019, 020, 022) and date were present for all records. This groomed dataset has 3390 records with 244 or more records in each year (Table 7).

Table 6: Number of catch-effort records dropped during grooming of the CELR dataset.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Not targeting paua	1	0	1	0	0	4	0	0	0	0	1	0	7
Catch missing	0	0	0	0	0	0	0	1	1	1	0	0	3
# divers missing	0	0	1	0	0	0	0	0	0	0	0	0	1
Method not diving	37	49	61	38	42	24	11	1	0	2	4	2	271

Following a procedure similar to that used for PAU 5D, the criteria used to subset the data were: (i) just one diver, or (ii) fishing duration at least 6 hours, and at least two divers. For criterion (ii) it was recommended by the SFWG that 6 hours was suitable as a duration cut-off for PAU 3 instead of 8 hours as was used for PAU 5D. Some further grooming was done in which records with NA for fishing duration were dropped (18 records), and a fishing duration per diver greater than 10 was dropped (one record). The subsetting retained 60% of the records from 1990–2001 (Table 7). Of the retained records, 92% had one diver, with most of the dropped records being for trips with two divers for which the recorded fishing duration was less than six hours (Table 8).

Table 7: Number of records in the groomed CELR dataset before and after subsetting on the diver. The fishing year 1990 is written as 90, and 2001 as 01.

Fishing year	90	91	92	93	94	95	96	97	98	99	00	01	Total
Before	260	285	307	303	310	320	251	244	265	237	259	349	3390
After	193	170	171	157	171	127	147	148	170	141	178	251	2024

Table 8: Distribution of the number of divers in the CELR dataset before and after subsetting.

Number of divers	1	2	3	4	5	6	7
Before	1873	1323	154	33	6	0	1
After	1857	149	16	2	0	0	0

For the subsetted data, the recorded duration for each record was divided by the number of divers to calculate the fishing duration per diver (hours per diver). Due to rounding in the fishing duration recorded there is some clumping in the fishing duration per diver (Figure 6). The median and mean fishing duration per diver both show an increase from about 1995 onwards (Figures 7–9).

Catch rates (daily kilograms per unit effort) were calculated using the units of effort: (i) the number of divers, or (ii) total daily diving duration. Comparing the yearly geometric means of these (i.e. a standardisation with just a year effect) shows that using diving duration gives an index that is greater before 1995, but less from 1996 onwards.

Based on the changes in fishing duration, and the impact on raw catch rates that using this instead of the number of divers had, it was decided by the SFWG to use the subsetted dataset for the standardisation and to offer fishing duration as a predictor variable for this.

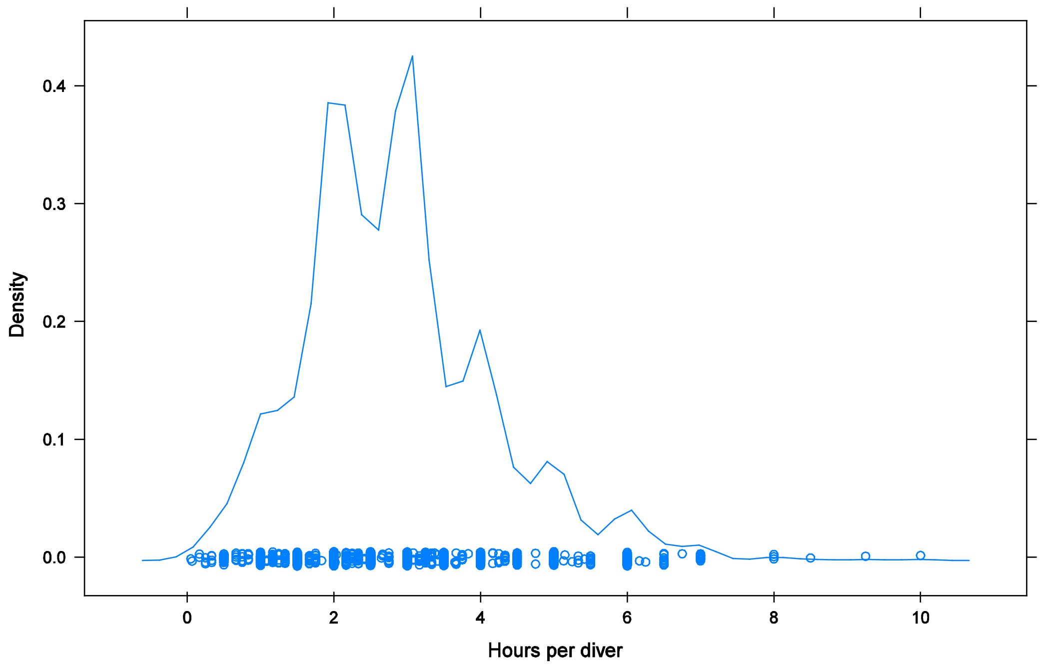

Figure 6: Density and strip plot for the number of hours per diver reported on CELR forms.

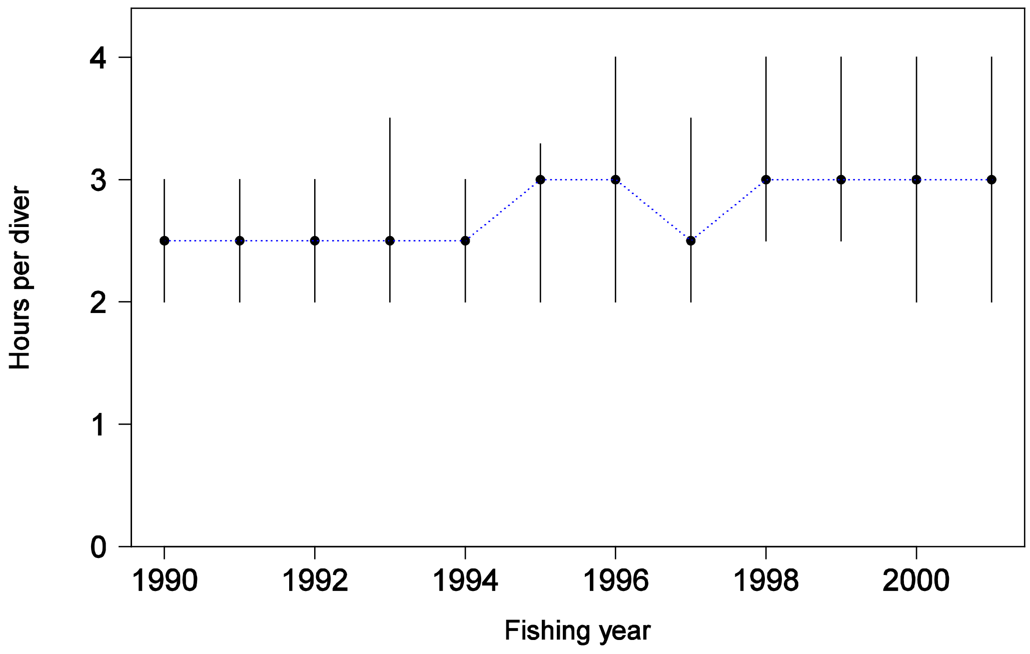

Figure 7: Quantiles by fishing year for the daily fishing duration per diver reported on CELR forms: medians (dot) and lower and upper quartiles (vertical lines).

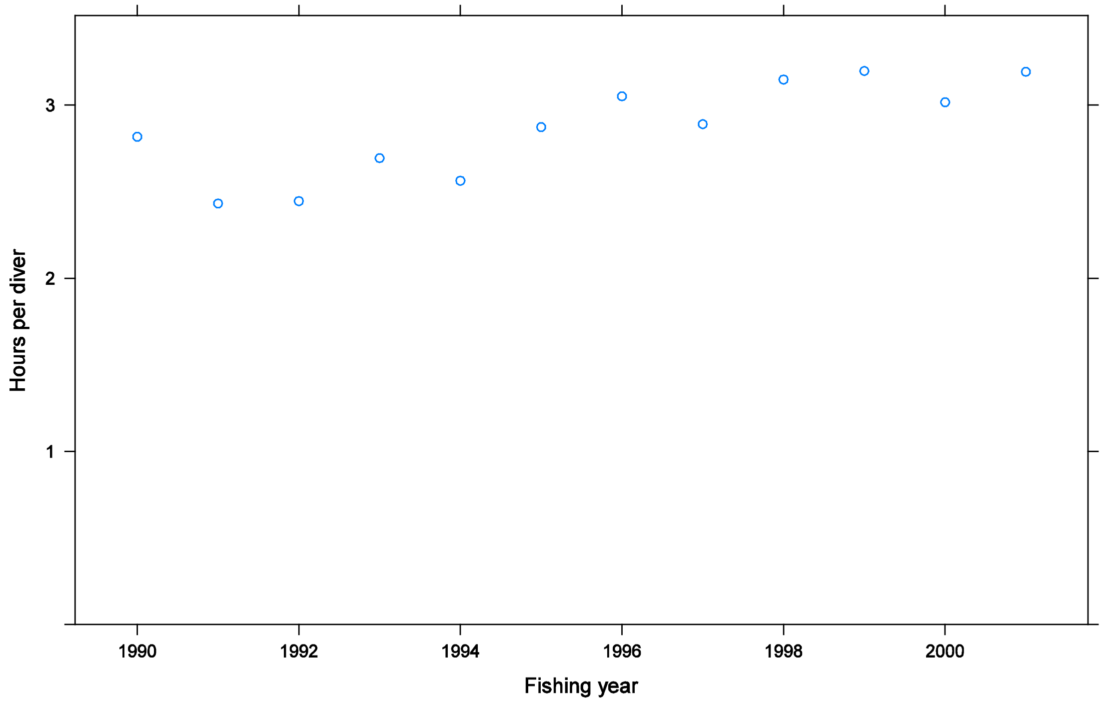

Figure 8: Mean values by fishing year for the daily fishing duration per diver reported on CELR forms.

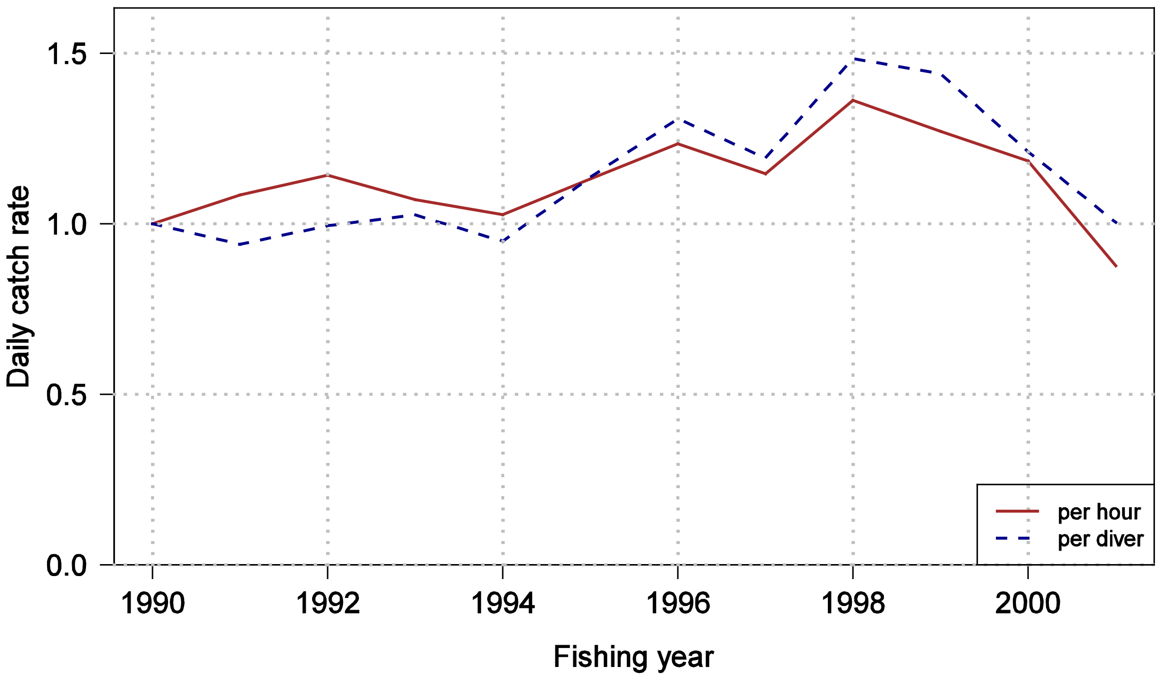

Figure 9: Geometric mean of the daily catch rate by year on CELR forms using either fishing duration or number of divers as the measure of effort. Both indices are scaled so as to have the value one in 1990.

4.4 CELR Standardisation (1990–2001)

Because of ambiguity in what is recorded for fishing duration it has not used in past standardisations as a measure of effort, instead the number of divers has been used. However, the fishing duration for a diver changes over time, and because of this a subset was taken of the groomed dataset for which the recorded fishing duration recorded would be less ambiguous (Section 4.3).

FIN was then used to identify 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 6 records per year for a minimum of two years was chosen, this retaining 84% of the catch over 1990–2001 (Figure 10). For most years 80% or more the catch is retained, while it is less than 70% for only one year (Figures 11–12). Number of days of effort retained after subsetting is 96 or more for every fishing year (Table 9). The number of permit holders drops from 67 to 22 under the subsetting criteria.

There is good overlap in effort over time for the permit holders after subsetting (Figures 13–14). Similarly for General Statistical Area and month (Figures 15–16).

Table 9: Number of catch-effort records retained in the CELR dataset before and after FIN subsetting.

Fishing year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Before	193	170	171	157	171	127	147	148	170	141	178	251	2024
After	145	163	157	143	167	96	129	113	127	106	162	221	1729

CPUE was defined as daily catch, and year was forced into the model at the start. Other predictor variables offered to the model were FIN, statistical area (018, 020, 022), month, fishing duration (as a cubic polynomial), number of divers, and a month:area interaction. Following previous standardisations, no interaction of fishing year with area was entered into the model, as the stock assessment for PAU 3 is a single area model. However, a separate standardisation is also done where a year:area interaction is forced in at the start.

The model explained 70% of the variability in CPUE, with fishing duration (45%) explaining most of this followed by FIN (20%) (Table 10). The effects appear plausible and the model diagnostics good (Figures 17–18). There is a plateauing effect for the catch taken after a fishing duration of 7 hours, although for the majority of records fishing duration is less than this (Figure 19). The standardised index shows a slight rise from 1994 to 1998 then a decline afterwards (Table 11, Figure 20).

The standardised index differs from an unstandardised index (where CPUE is daily catch divided by daily fishing duration) in that it is flatter (Figure 20). Most of this difference is due to the FIN predictor variable (Figure 21). As a sensitivity to the impact of using the subsetted dataset (in which the fishing duration field is less ambiguous) another standardisation was done using the full dataset with a CPUE of daily catch divided by the daily number of divers. The pattern in this index is similar to that using the subsetted dataset (Figure 22).

Forcing in a year: area interaction indicates that there are differences in standardised CPUE between the area 018 and the two areas 020 and 022 (Figure 23). However, in the years where they differ there are very few records to estimate the year effects for areas 020 and 022 (Table 12).

Table 10: Variables accepted into the CELR standardisation model (1% additional deviance explained), and the order in which they were accepted into the model.

Predictors	Degrees of freedom	Percentage deviance explained
Fishing year	11	4
Fishing duration	3	49
FIN	21	69
Month	11	70

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

Year	Index	lower CI	upper CI	CV
1990	0.92	0.77	1.11	0.09
1991	0.98	0.83	1.16	0.08
1992	0.96	0.81	1.13	0.09
1993	1.04	0.87	1.24	0.09
1994	0.91	0.77	1.08	0.08
1995	0.95	0.77	1.16	0.10
1996	0.96	0.81	1.15	0.09
1997	1.05	0.87	1.26	0.09
1998	1.14	0.95	1.36	0.09
1999	1.09	0.90	1.32	0.10
2000	1.07	0.90	1.26	0.08
2001	0.97	0.83	1.13	0.08

Table 12: Number of records in the subsetted CELR dataset by year and area.

Fishing year	018	020	022
1990	142	3	0
1991	163	0	0
1992	153	4	0
1993	141	2	0
1994	161	6	0
1995	74	19	3
1996	93	27	9
1997	84	29	0
1998	96	28	3
1999	83	23	0
2000	142	20	0
2001	195	14	12

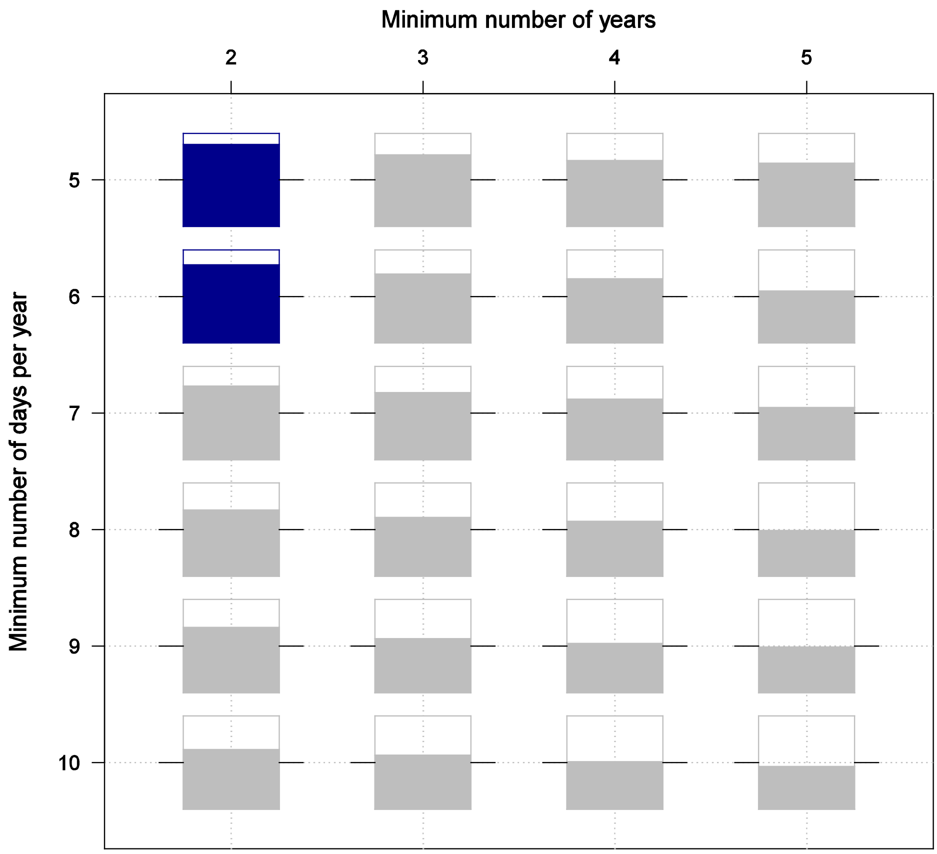

Figure 10: Proportion of the catch taken when subsetting the CELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 1990–2001 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

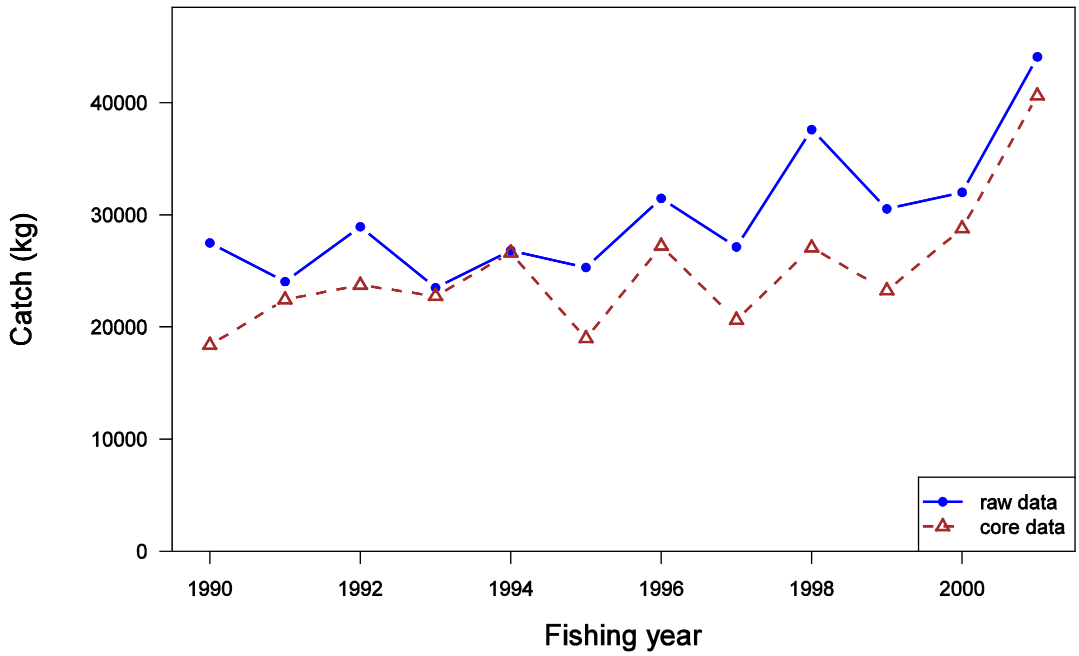

Figure 11: Catch by fishing year from the CELR dataset before FIN subsetting (raw data) and after (core data). The subsetting uses the criteria of a minimum of six days per year for a minimum of two years.

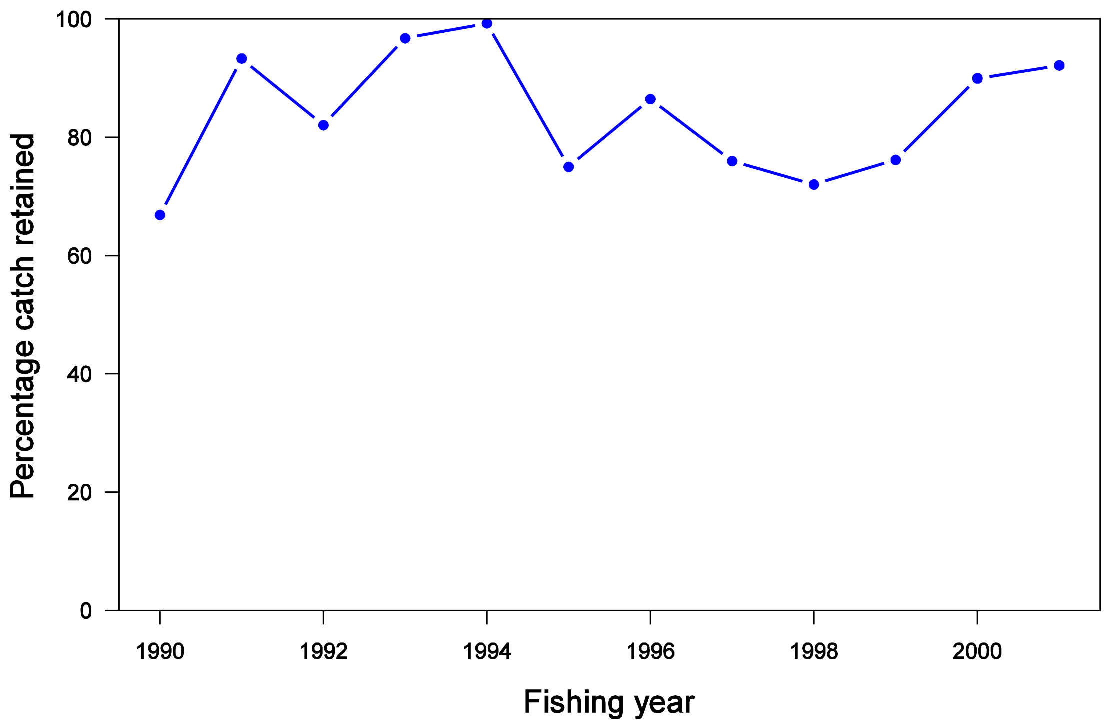

Figure 12: Percentage of the catch retained from the CELR dataset after FIN subsetting using the criteria of a minimum of six days per year for a minimum of two years.

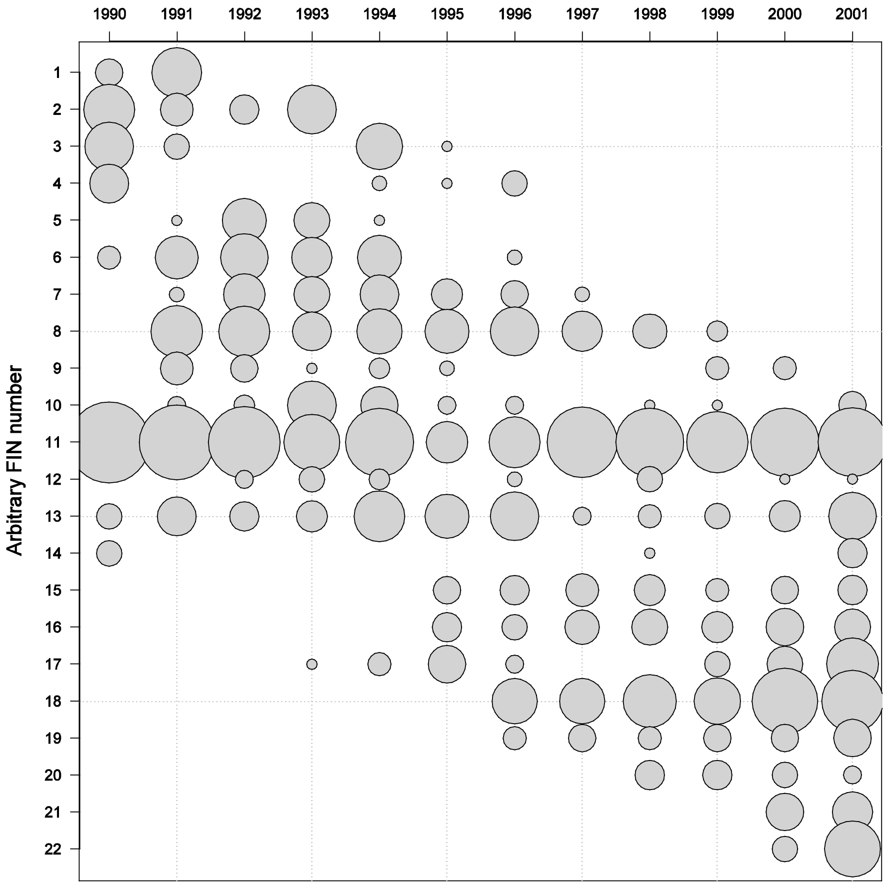

Figure 13: Overlap in days of effort in the CELR dataset by FIN. The area of a circle is proportional to the number of days of effort; the largest circle represents 61 days.

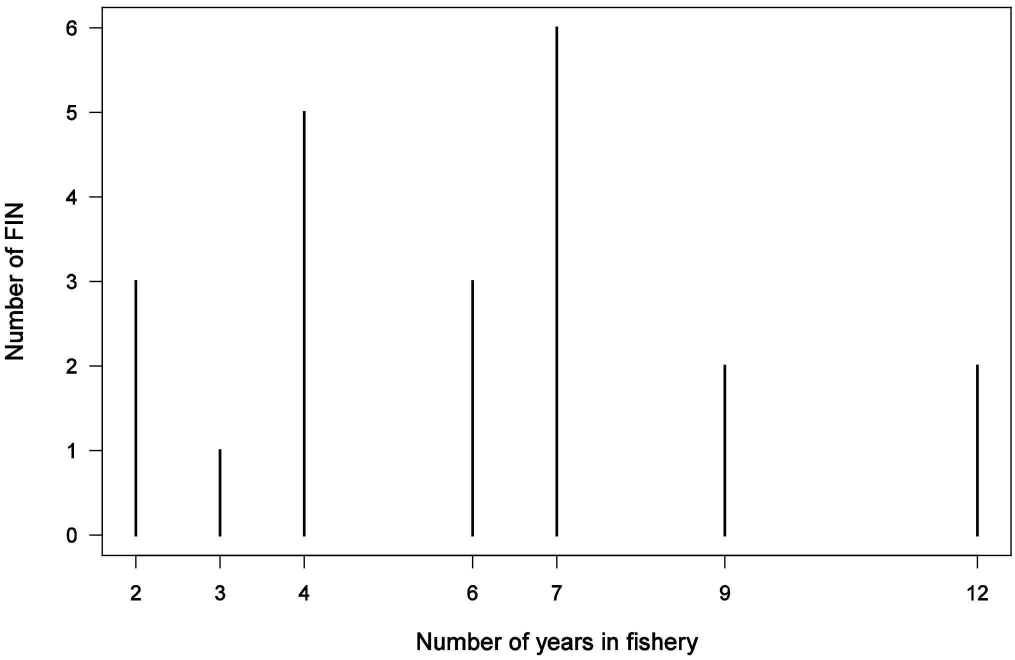

Figure 14: Histogram of the number of years in the fishery for each FIN holder after subsetting by FIN.

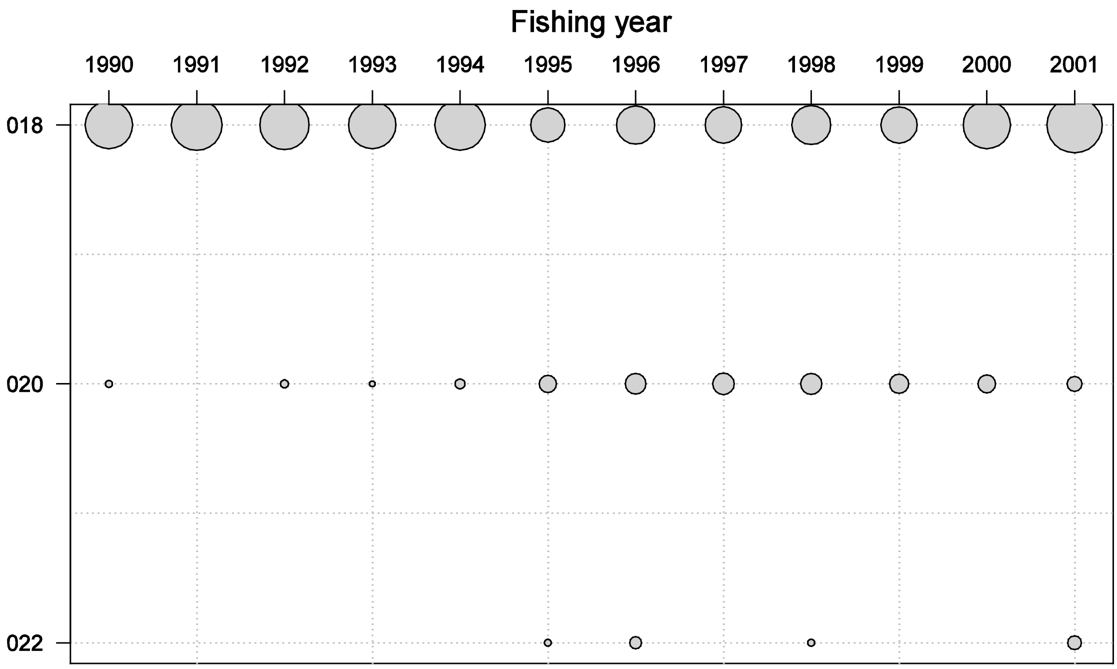

Figure 15: Number of days of effort in the CELR dataset by Statistical Area and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 195 days.

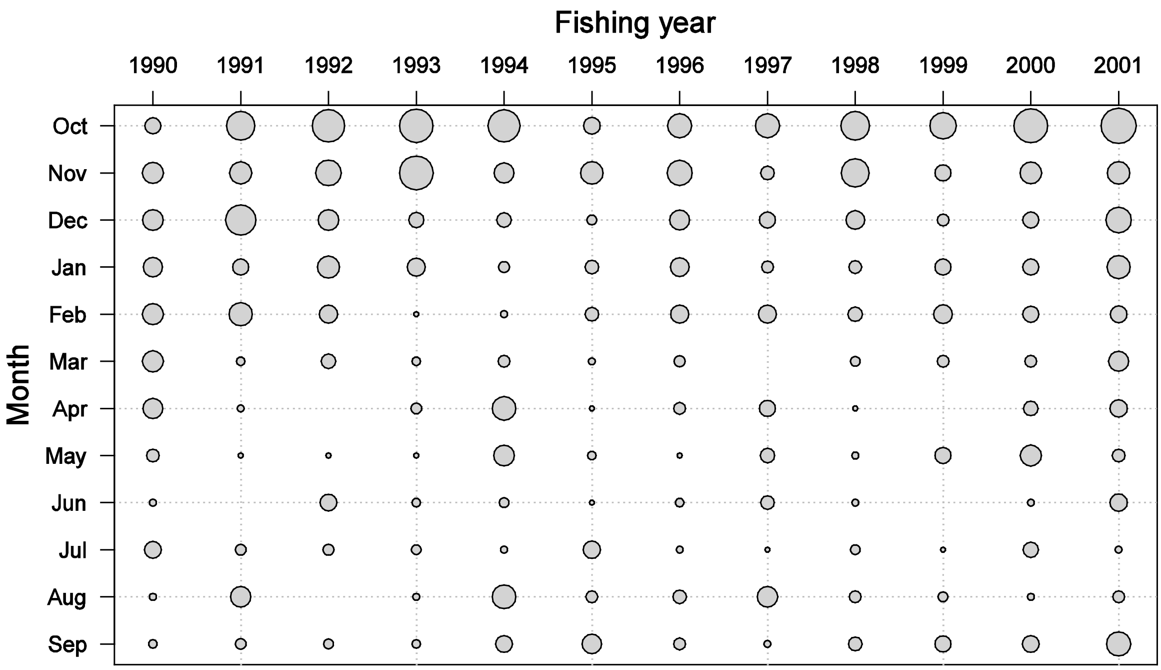

Figure 16: Number of days of effort in the CELR dataset by month and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 53 days.

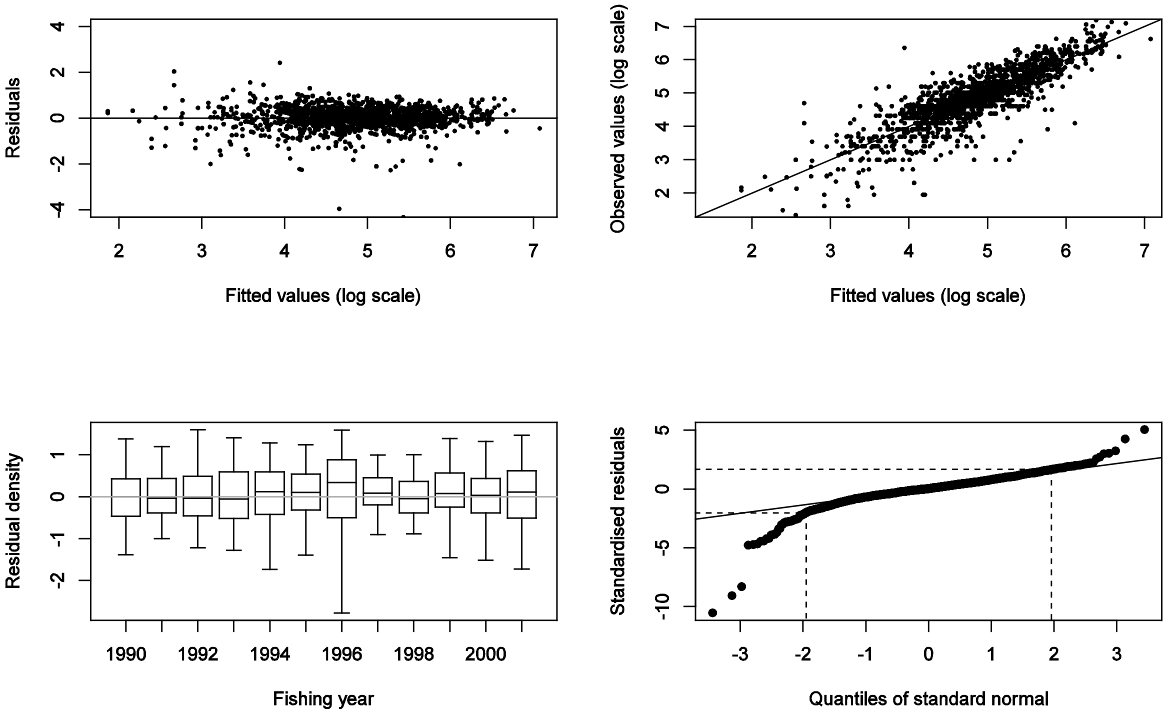

Figure 17: Diagnostic plots for the CELR standardisation model.

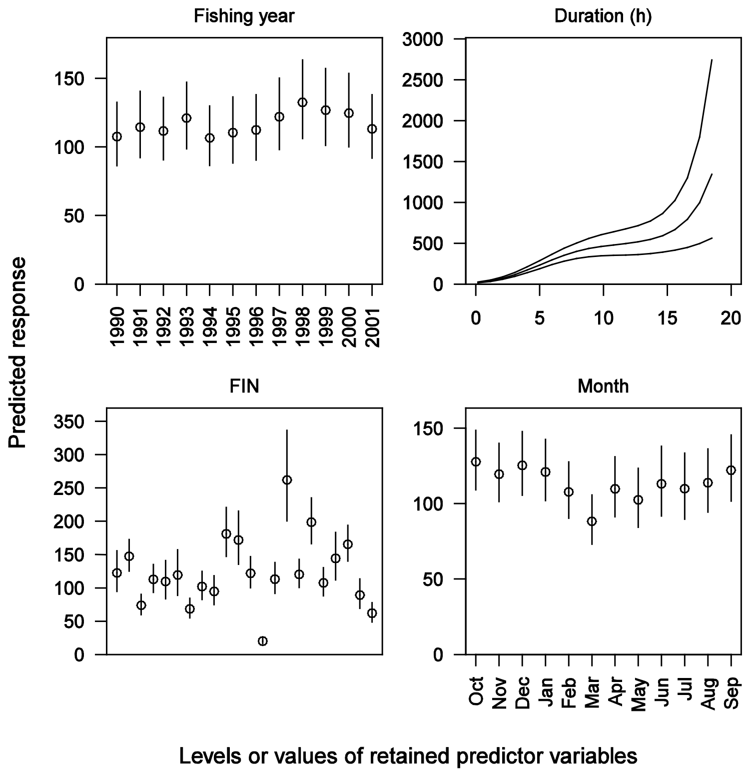

Figure 18: Effects for the CELR standardisation model. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

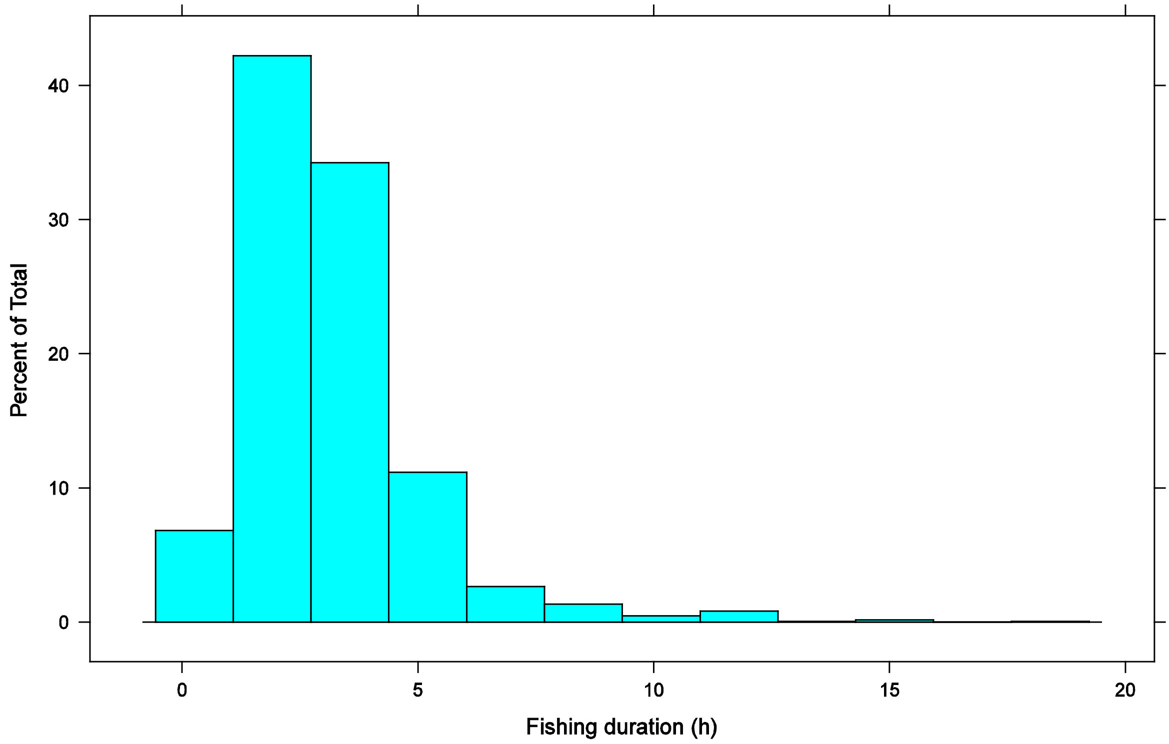

Figure 19: Distribution of fishing duration in the CELR dataset.

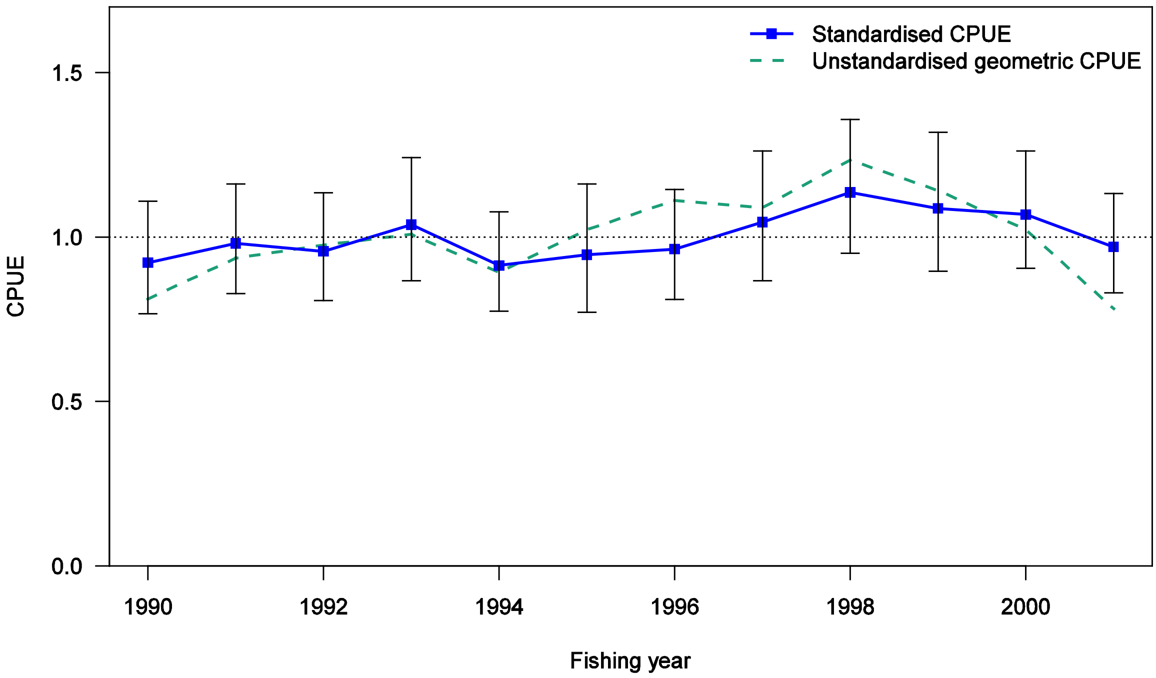

Figure 20: The standardised CPUE index for the CELR dataset with 95% confidence intervals. The "unstandardised geometric CPUE" is calculated as daily catch divided by daily fishing duration.

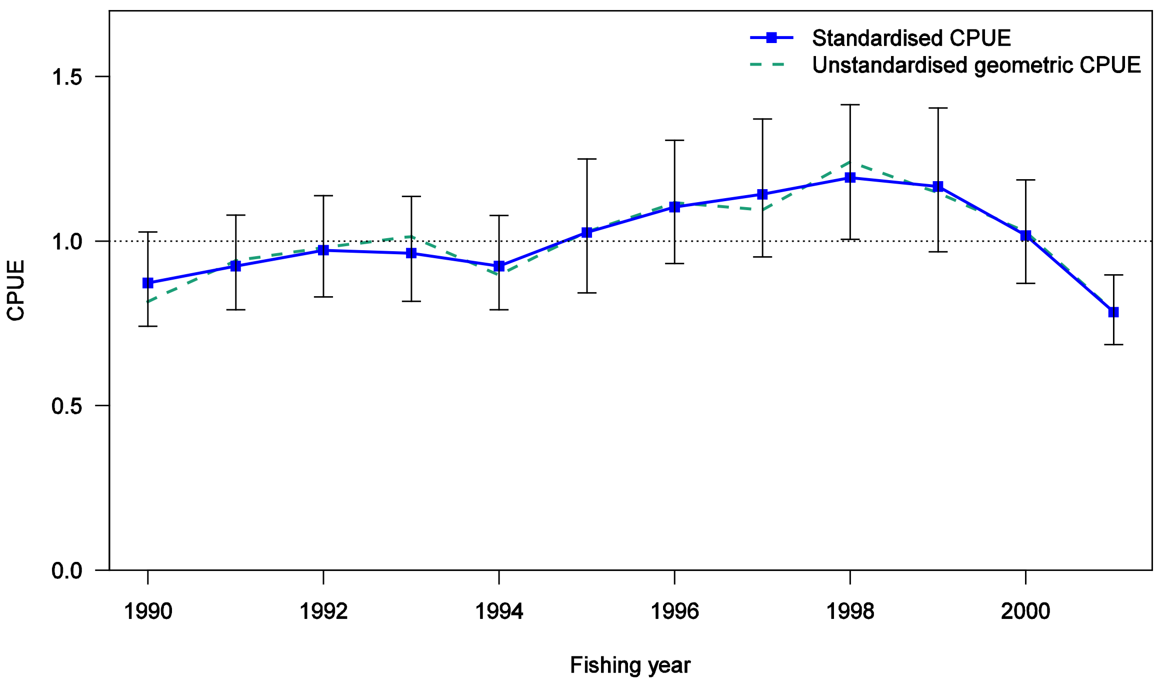

Figure 21: The standardised CPUE index for the CELR dataset without FIN in the final standardisation model. The "unstandardised geometric CPUE" is calculated as daily catch divided by daily fishing duration.

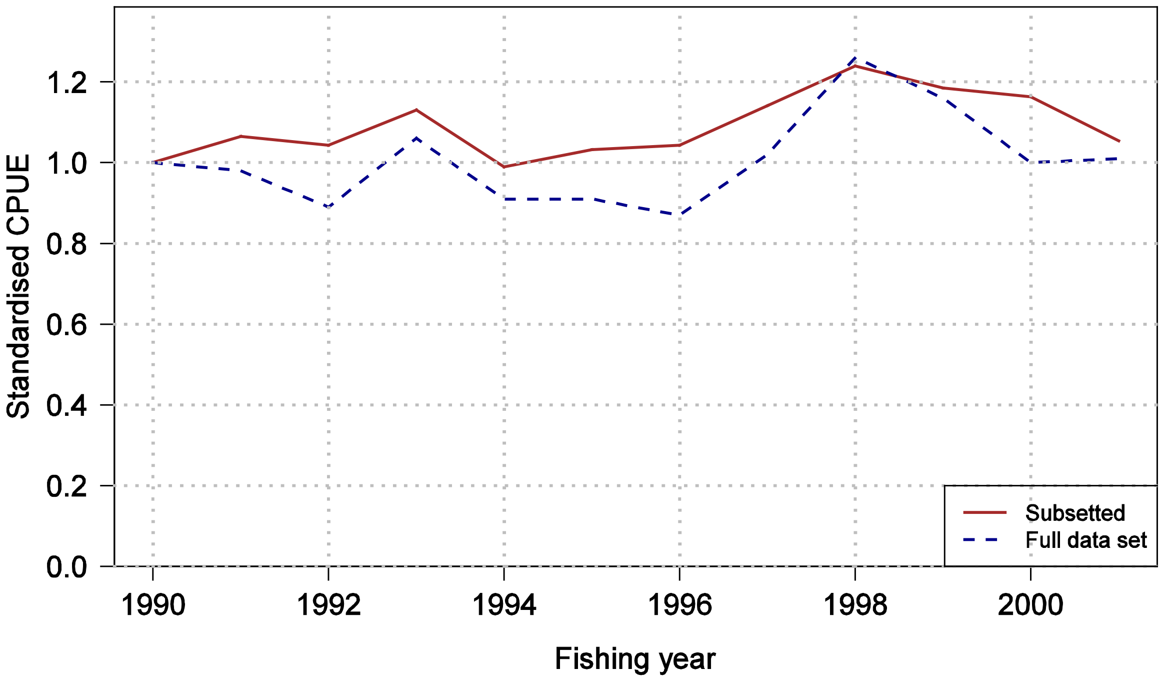

Figure 22: Comparing standardised indices calculated using the full CELR dataset and the subsetted dataset (to give a dataset for which the fishing duration field is less ambiguous). Both standardised indices are scaled so as to have the value one in 1990.

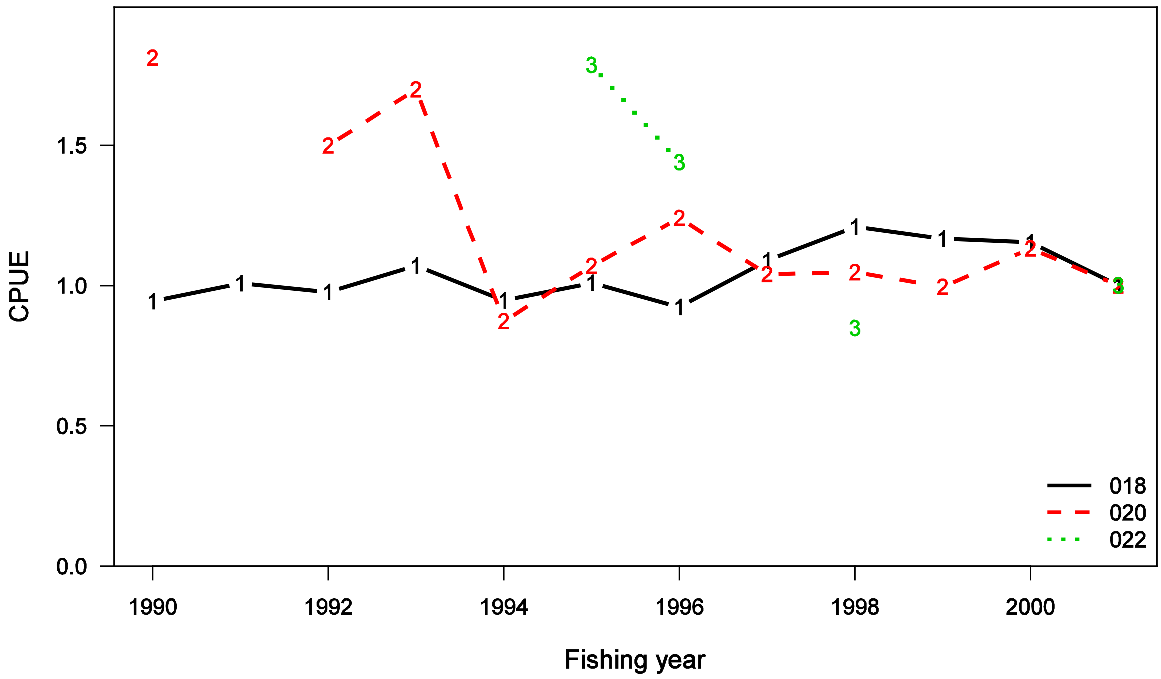

Figure 23: Standardised indices of the CELR dataset using the subsetted data with a year:area interaction forced into the model. The indices are scaled so as to have the value one in 2001.

4.5 PCELR standardisation (2002–2013)

The initial dataset PCELR dataset included all records in which paua were targeted by diving, and contained FIN, Paua Statistical Area, catch weight, fishing duration, diver key, diving conditions, and date. For the standardisation some further grooming was made: records were removed where no diving condition was recorded (Table 13).

Table 13: Number of catch effort records removed during grooming of the PCELR dataset.

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
No diving condition	25	40	17	19	13	23	10	15	10	18	14	24	228

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 Paua Statistical Area). CPUE was defined as the catch for a diver with fishing duration offered as a predictor in the model.

FIN was used to sub-set out a core group of records, with the requirement that there be a minimum number of records per year for a FIN, for a minimum number of years. The criteria of a minimum of 20 records per year for a minimum of two years was selected; this retained 84% of the catch over 2002–2013 (Figures 24–25). The number of FIN holders dropped from 44 to 18 under these criteria. There is good overlap in effort for the 18 FIN holders after subsetting (Figures 26–27).

To ensure that there were enough data to estimate statistical area and diver effects in the standardisation, only those Paua Statistical Areas and divers with 10 or more diver days were retained (Table 14). This dropped the number of statistical areas from 34 to 26, and the number of divers from 188 to 40 (47% of divers had only one dive day). The number of days of records retained after this subsetting is 284 or more for every fishing year (Table 14).

There is very good temporal overlap for the other predictor variables, statistical area, month, dive conditions, and diver (Figures 28–31).

Table 14: Number of records remaining in the PCELR dataset after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records were removed for which diving condition was not recorded (Table 13).

Fishing year	02	03	04	05	06	07	08	09	10	11	12	13	Total
Total records	472	519	461	494	467	455	532	497	536	472	455	419	5779
FIN subsetting	318	380	367	425	407	411	482	444	466	437	405	363	4905
Paua Statistical Area with >=10 dive days	316	369	367	422	406	411	481	441	464	437	404	362	4880
Divers with >= 10 dives days	284	338	350	401	387	397	448	423	443	403	363	338	4575

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 conditions. Following previous standardisations, no interaction of fishing year with area was entered into the model, as the stock assessment for PAU 3 is a single area model. However, a separate standardisation was also done where a year: area interaction was forced in at the start.

Except for month, all variables were accepted into the model, which explained 75% of the variability in CPUE (Table 15). Most of the variability was explained by duration (63%) and diver (6%). The effects appear plausible and the diagnostics are good (Figures 32–33). Catch appears to increase greatly once the fishing duration nears 15 hours, but there is little data for fitting this relationship (Figure 34).

The standardised index shows a slow decline from 2002 to 2013 (Table 16, Figure 35). A separate standardisation was done in which a year: area interaction term was forced into the model at the start, using management zones as the areas (see Section 2). There are sufficient records to estimate these interactions (Table 17) and the indices are similar for the different management zones (Figure 36).

Table 15: Variables accepted into the standardisation model for the PCELR dataset (1% additional deviance explained) and the order in which they were accepted into the model.

Predictors	Degrees of freedom	Percentage deviance explained
Fishing year	11	0.01
Fishing duration	3	0.63
Diver key	39	0.69
Statistical area	25	0.72
Diving conditions	4	0.74
FIN	17	0.75

Table 16: Standardised index for the PCELR dataset, lower and upper 95% confidence intervals, and CV.

Year	Index	lower CI	upper CI	CV
2002	1.07	0.94	1.22	0.07
2003	1.06	0.95	1.19	0.06
2004	1.03	0.92	1.15	0.06
2005	1.00	0.90	1.10	0.05
2006	1.04	0.94	1.16	0.05
2007	1.00	0.90	1.11	0.05
2008	1.03	0.94	1.14	0.05
2009	0.96	0.87	1.06	0.05
2010	0.99	0.90	1.09	0.05
2011	0.95	0.85	1.06	0.05
2012	0.92	0.82	1.03	0.06
2013	0.96	0.85	1.08	0.06

Table 17: Number of records for the subsetted PCELR dataset by year and management zone.

				Zone
Fishing year	3A	3B	3D	3E
2002	97	130	28	29
2003	96	99	62	81
2004	112	119	67	52
2005	119	138	94	50
2006	120	188	66	13
2007	139	171	69	18
2008	155	176	76	41
2009	163	160	57	43
2010	188	143	54	58
2011	139	116	92	56
2012	131	87	86	59
2013	111	67	68	92

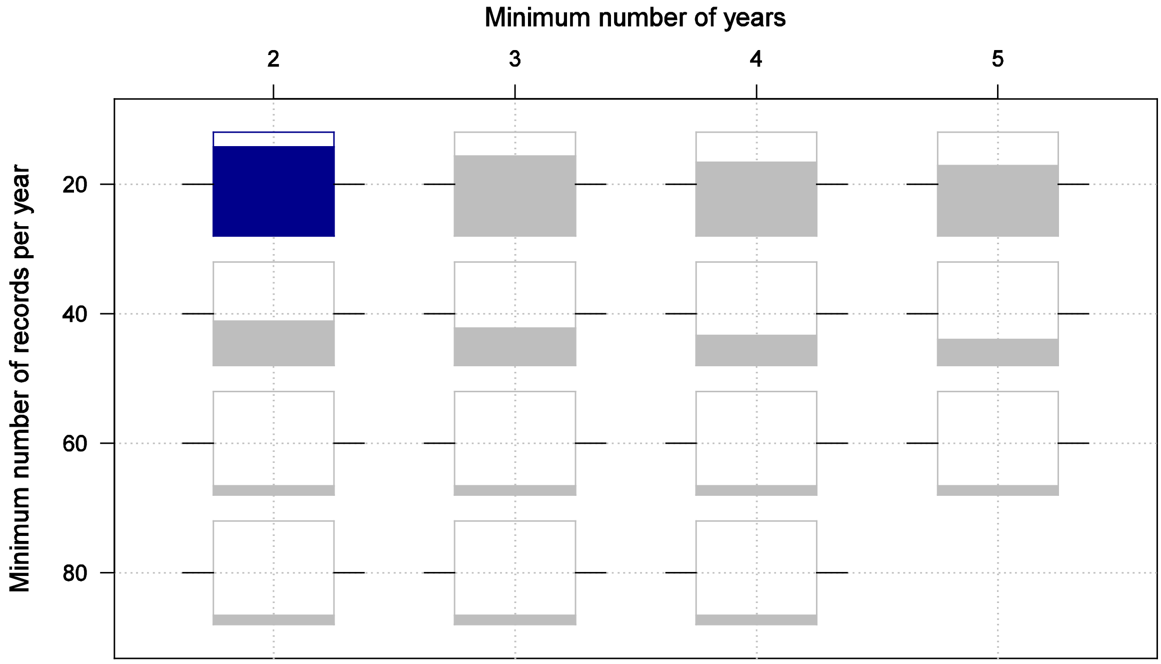

Figure 24: Proportion of the catch taken when subsetting the PCELR data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2013 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 80% or more of the catch, otherwise they are coloured grey.

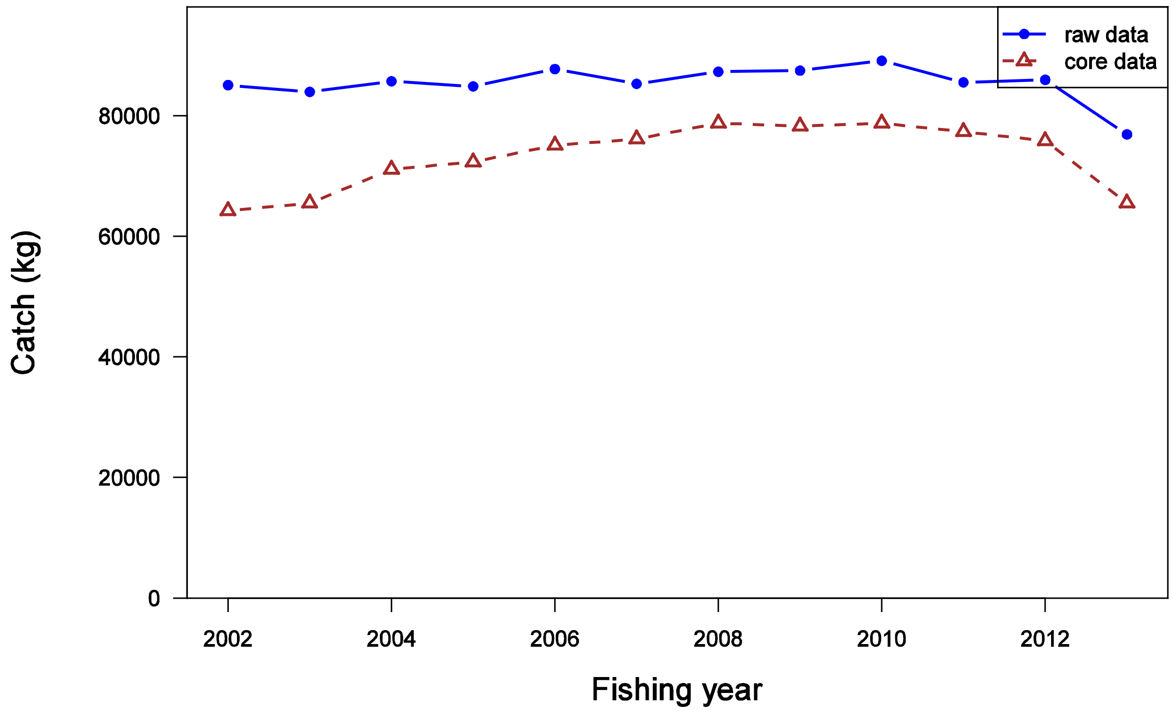

Figure 25: Catch by fishing year from the PCELR dataset before FIN subsetting (raw data) and after (core data). The subsetting uses the criteria of a minimum of 20 records per year for a minimum of two years.

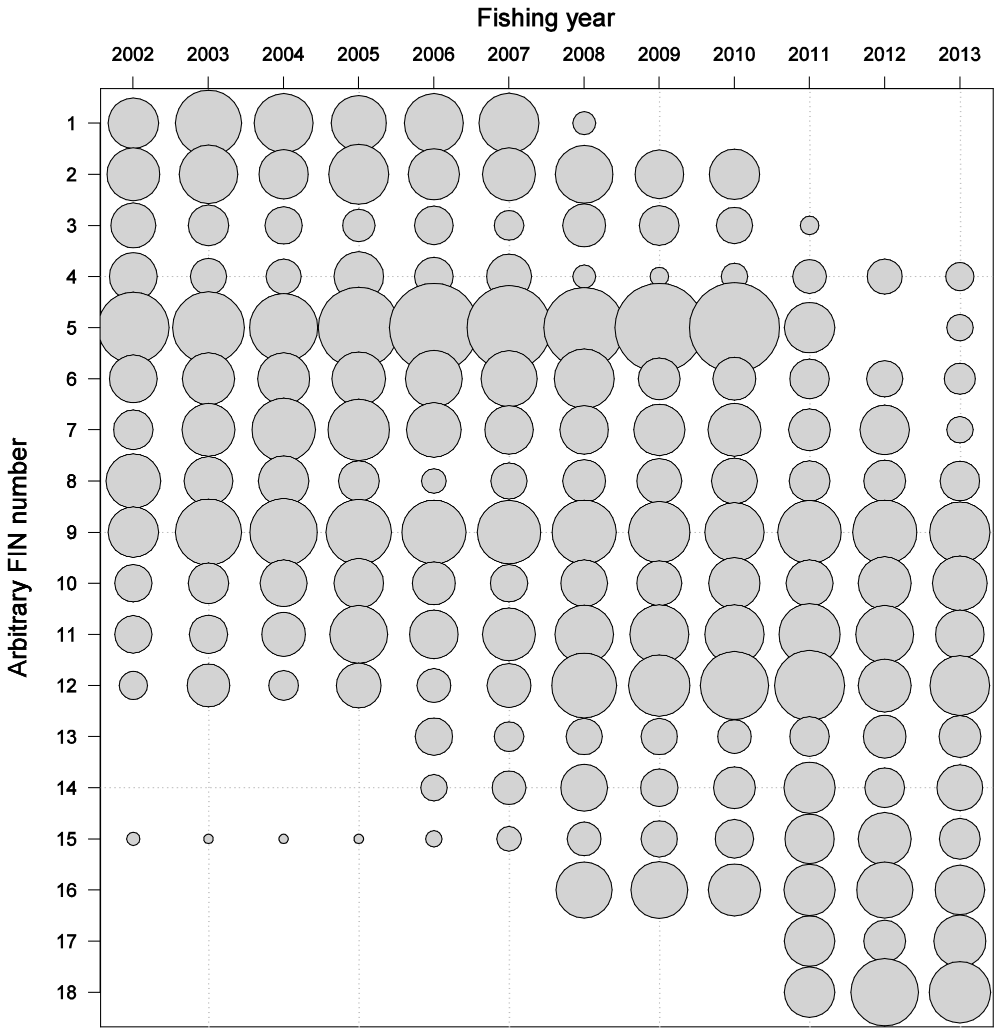

Figure 26: Overlap in number of records in the PCELR dataset by FIN after subsetting by FIN. The area of a circle is proportional to the number of days of effort; the largest circle represents 93 records.

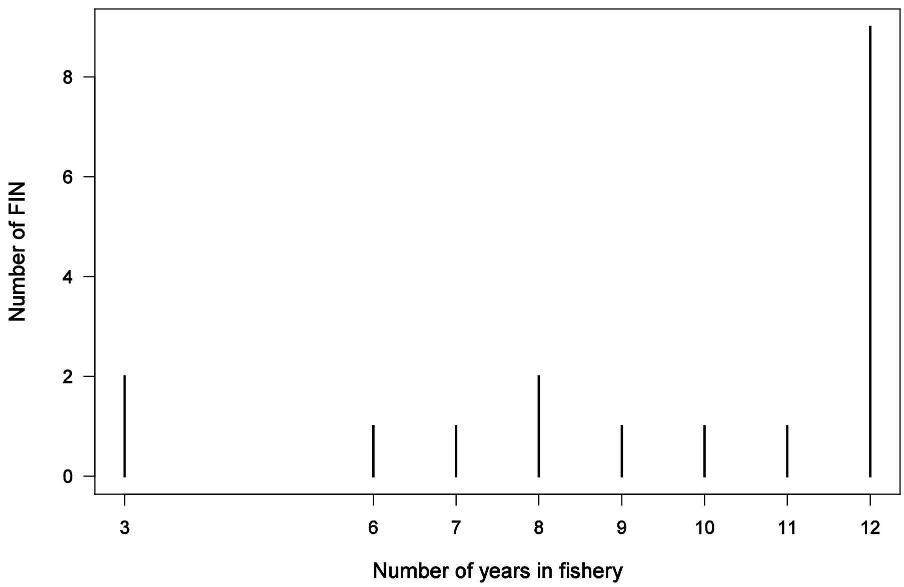

Figure 27: Histogram of the number of years in the fishery for each FIN holder in the PCELR dataset after subsetting by FIN.

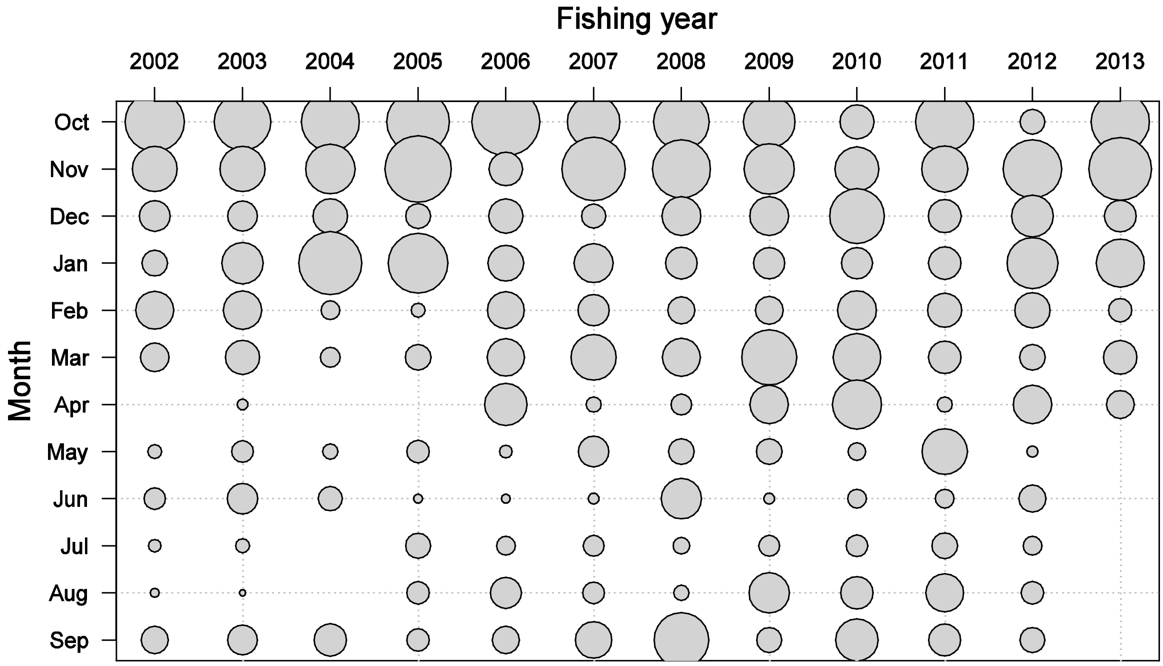

Figure 28: Number of PCELR records by month and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 119 records.

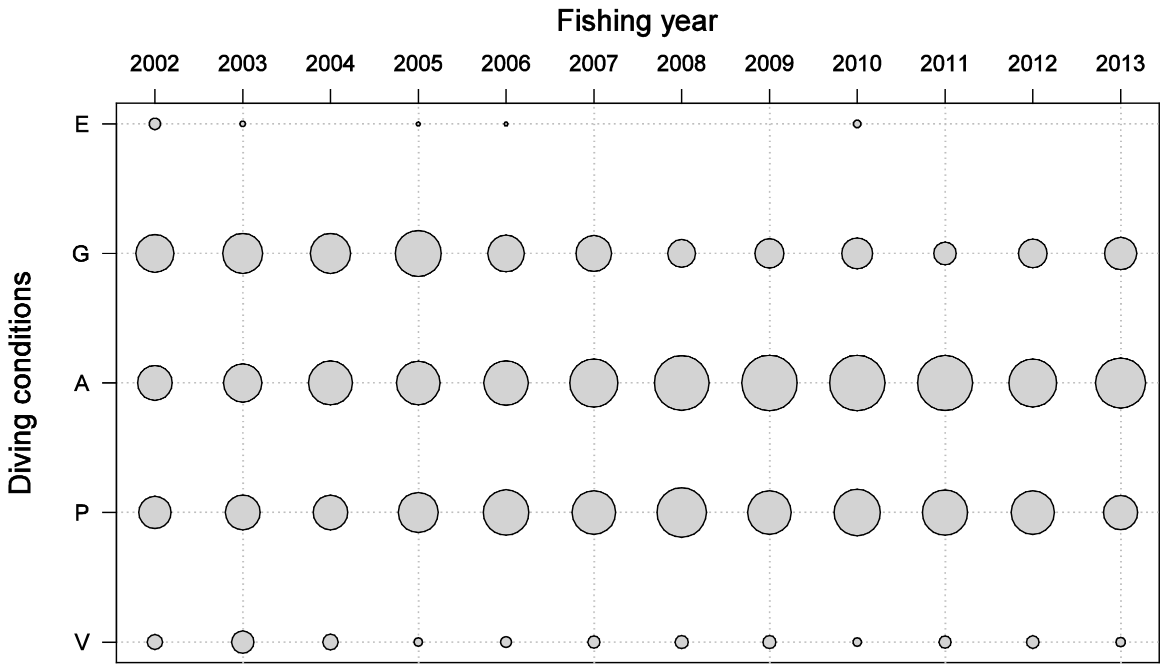

Figure 29: Number of PCELR records by diving condition (excellent, good, average, poor, very poor) and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 217 records.

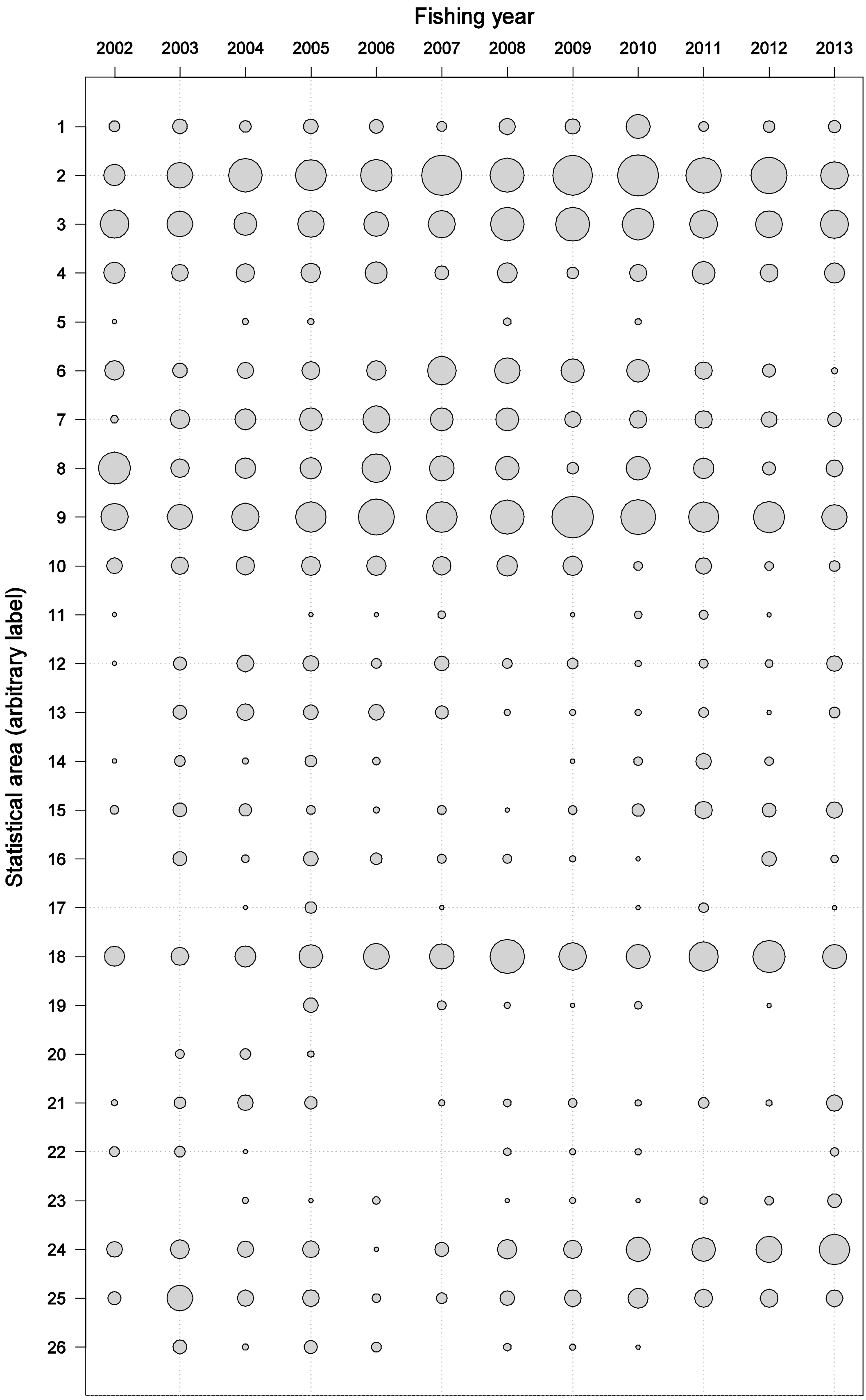

Figure 30: Number of PCELR records by statistical area and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 90 records.

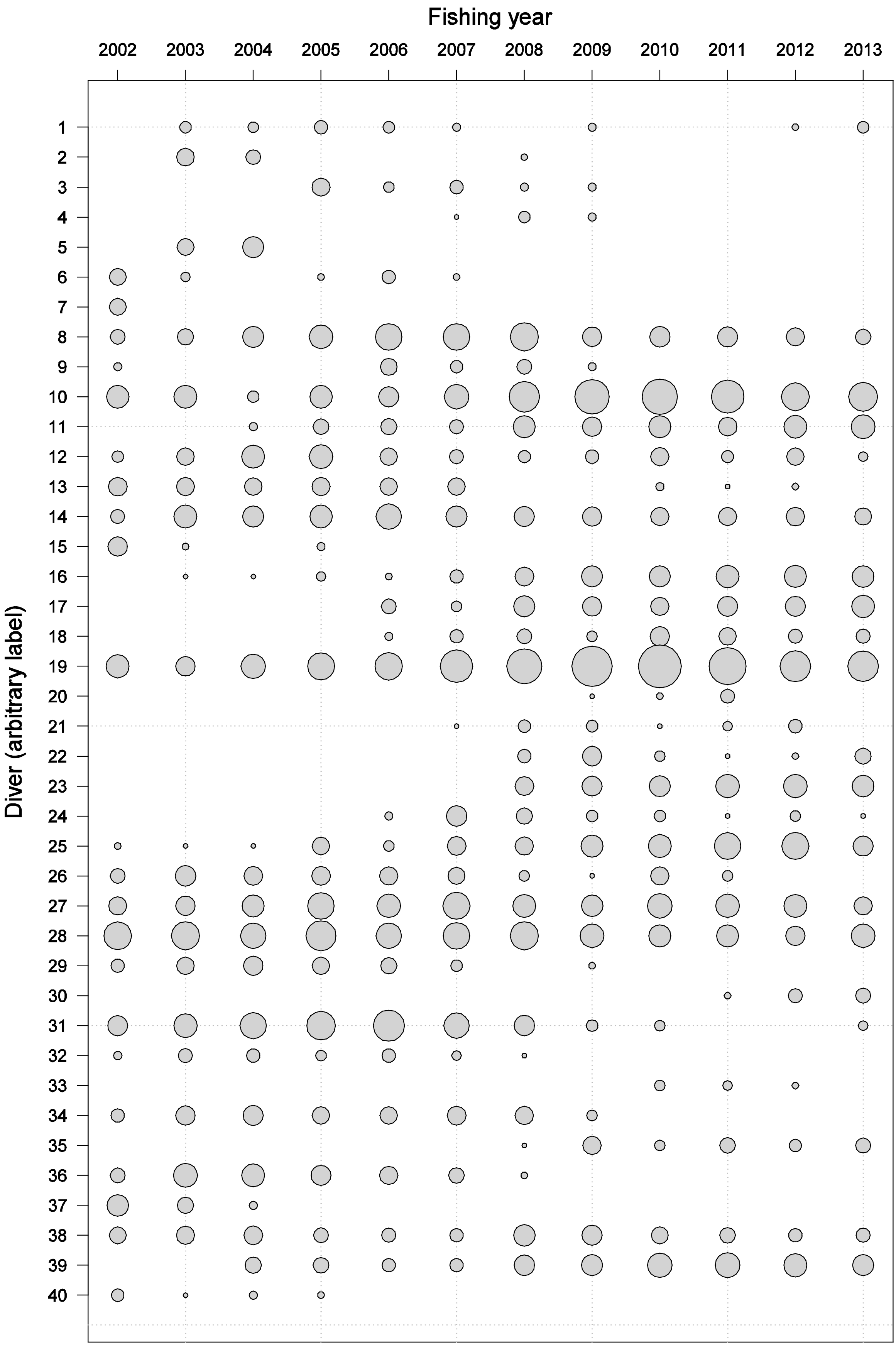

Figure 31: Number of PCELR records by diver key and fishing year. The area of a circle is proportional to the number of days of effort; the largest circle represents 83 records.

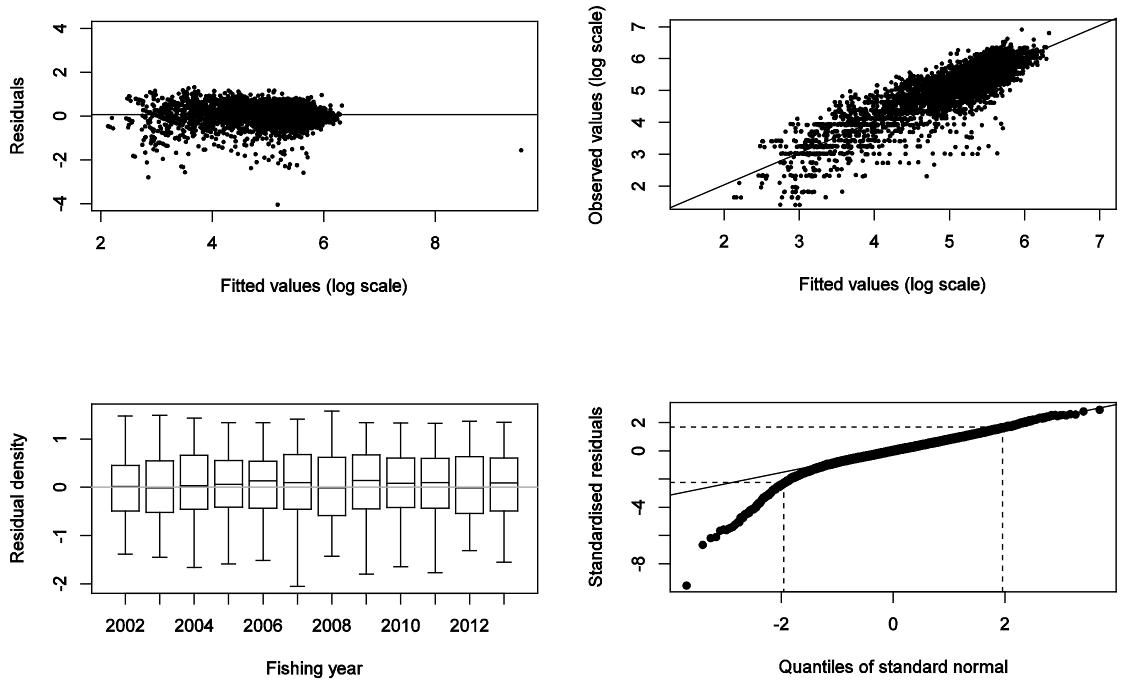

Figure 32: Diagnostic plots for the PCELR standardisation model.

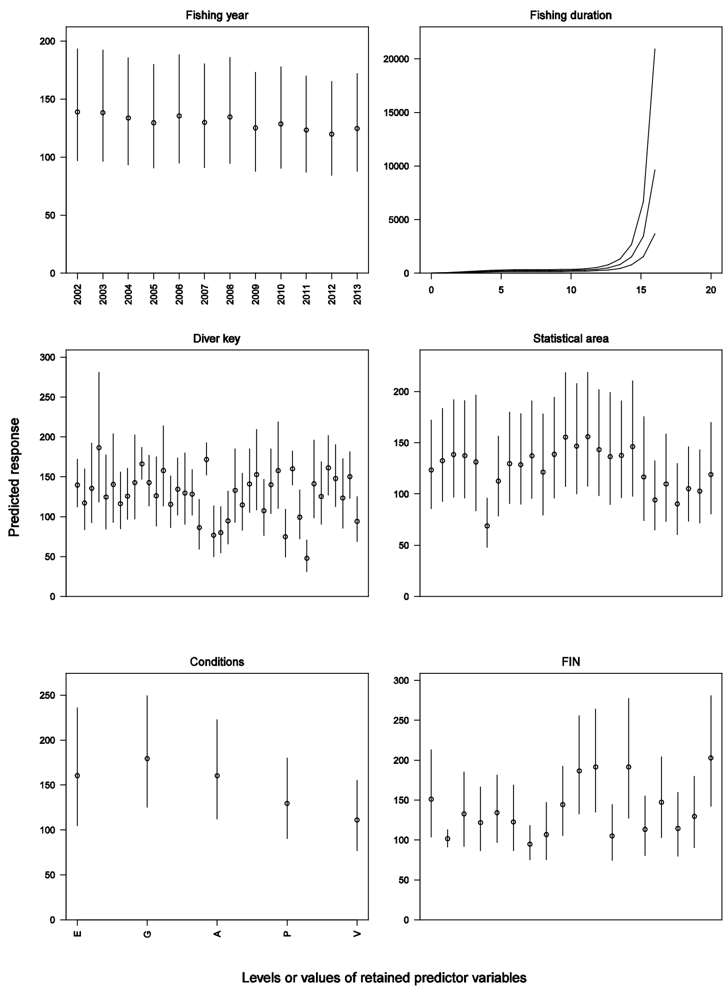

Figure 33: Effects for the PCELRmodel. Effects catch rates are calculated with other predictors fixed at the level for which median catch rates are obtained. Vertical lines are 95% confidence intervals.

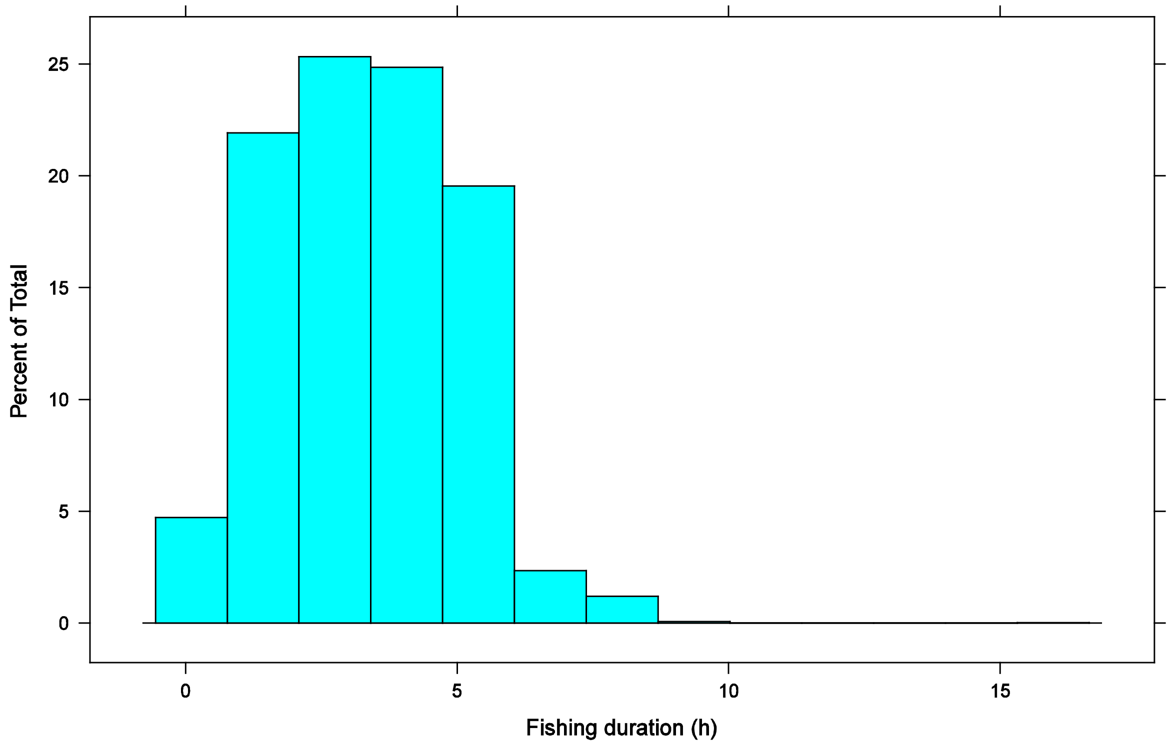

Figure 34: Distribution of fishing duration in the PCELR dataset.

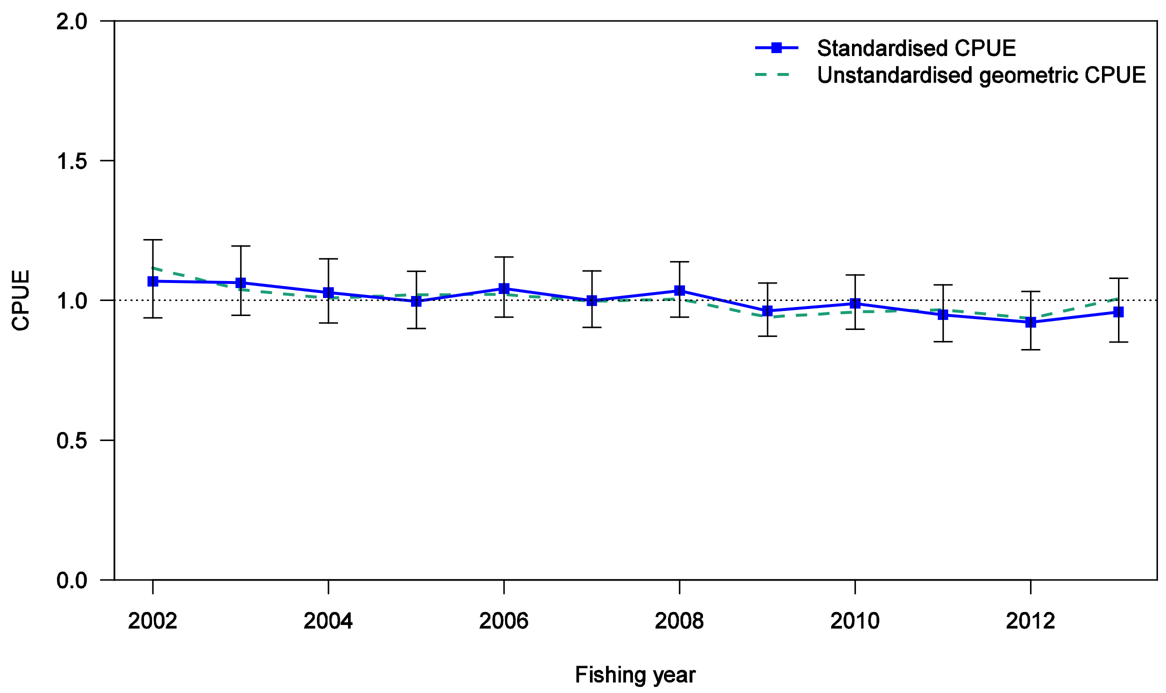

Figure 35: The standardised CPUE index for the PCELR dataset with 95% confidence intervals. The "unstandardised geometric CPUE" is calculated as the geometric mean for each year of the catch divided by fishing duration.

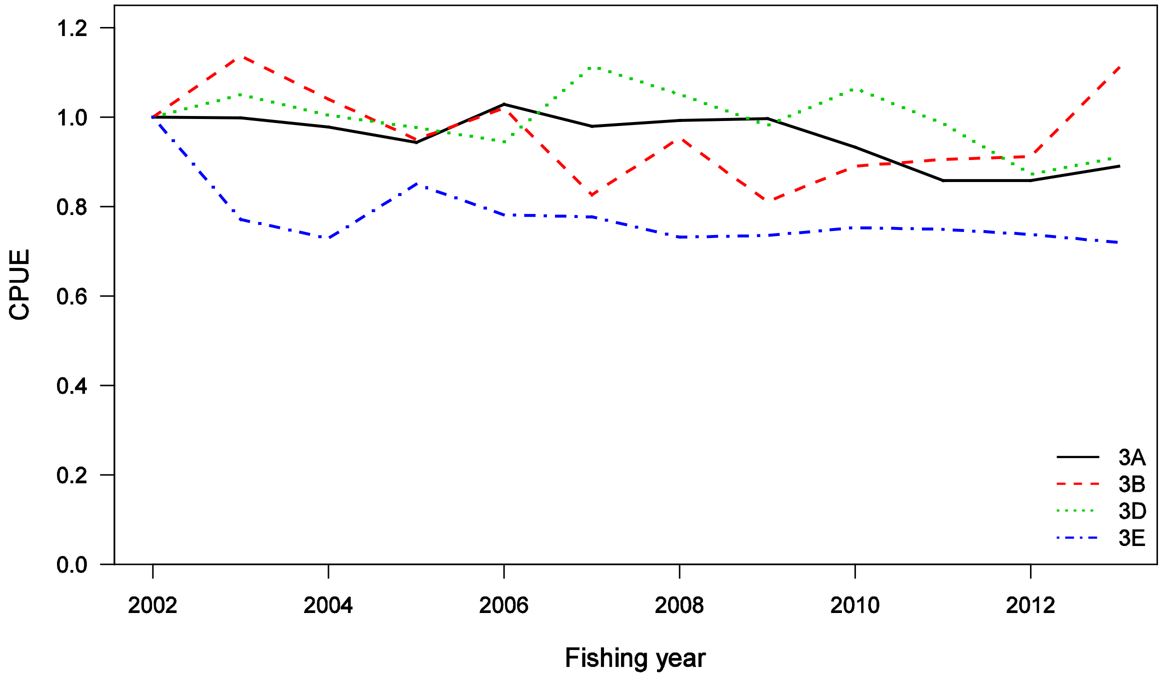

Figure 36: Standardised indices of the PCELR dataset with a year:area interaction forced into the model. The areas are management zones (see Section 2).

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 1 September 2012. This totalled 15 255 records containing 82 838 measurements from 2000–2012.

The number of landings sampled ranged from 17 to 97 (Table 18). For most years about 40 samples were taken. The sampling effort has increased significantly over the last few years, with 78, 89, and 97 landings sampled in 2010, 2011, and 2012 respectively. Typically over 4000 paua were measured each year. The sampling coverage was reasonably adequate, with sampling effort spread throughout the four management zones (Table 18). Most samples were taken from zones 3A and 3B from which most of the catch was taken. In 2001, almost all samples were from unknown area. A comparison of the mean length between landings suggested that the mean length in the northern area was much higher than in the southern area (Figure 37).

We calculated the length frequency using NIWA's 'catch-at-age' software (Bull & Dunn 2002). Preliminary analyses suggested that there was strong spatial difference in the distribution of mean length in the commercial length samples (see Figure 37). We post-stratified the catch samples using four spatial strata based on management zones 3A, 3B, 3D, and 3E (the one sample from Statistical Area P311 in 2002 was allocated to 3B). The length frequencies of paua from each landing were scaled up to the landing weight, summed over landings in each stratum, and then scaled up to the total stratum catch to yield length frequencies by stratum and overall. The CV for each length class was computed using a bootstrapping routine: fish length records were resampled within each landing which was resampled with each stratum. For samples where landing weight was unknown the landing weight was assumed to be equal to the sample weight, calculated from the number of fish in the sample and mean fish weight.

Data from 2001 were excluded because areas were unknown for most samples. Scaled length frequencies for the whole of PAU 3 as well as for each management zone separately are shown in Figure 38. The length frequencies for PAU 3 were generally stable over time and there were very few paua greater than 160 mm (Figure 38–left). The length distributions in zone 3E contain much smaller paua than in the other management zones (Figure 38–right).

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Table 18: Number of landings sampled from the market shed sampling program by Paua Statistical Area and by fishing year.

Area	00	01	02	03	04	05	06	07	08	09	10	11	12
3A													
P301			2		1	1			1	4			2
P302	2		5	5	17	6	2	2	3	20	19	18	16
P303	3		2	5	2	2	2	1	7	8	10	7	6
P304	8		3	4	5	2	2			1		9	1
Total	13	0	12	14	25	11	6	3	11	33	29	34	25
3B													
P305	3		8								1		
P306	7		4	1	1	1	2				1		
P307	8			3	1	7	3		3	2	4		3
P308	3		4	1			3	1	3	3	7	6	2
P309	1		1	6	4	10	7	3	7	13	15	5	15
P310			2		3		5	1	3	2		5	2
Total	22	0	19	11	9	18	20	5	16	20	28	16	22
3D													
P311			1									1	
P312	2			1	2				1	1		1	4
P313	1			2			1			1	3	3	1
P314												5	1
P315				4			1			1		6	7
P316				1							4		5
P317						1			1				
P318	2	2			3	1	8	5	7	3	1	9	15
P319	1							1	3		1	1	
Total	6	2	1	8	5	2	10	6	12	6	9	26	33
3D													
P321			1										
P325			1										
P327				1									1
P329				1									
P330											3	1	2
P331	2									1	1		
P332				1	1		1						1
P333							2				2	1	1
P334				2		2	1	2	5	2	3	8	9
P335				1		4			2	2	3	3	3
P336						1				1			
Total	2	0	2	6	1	7	4	2	7	6	12	13	17
Unknown	2	39		1	1	2		1	1				
Total	45	41	34	40	41	40	40	17	47	65	78	89	97

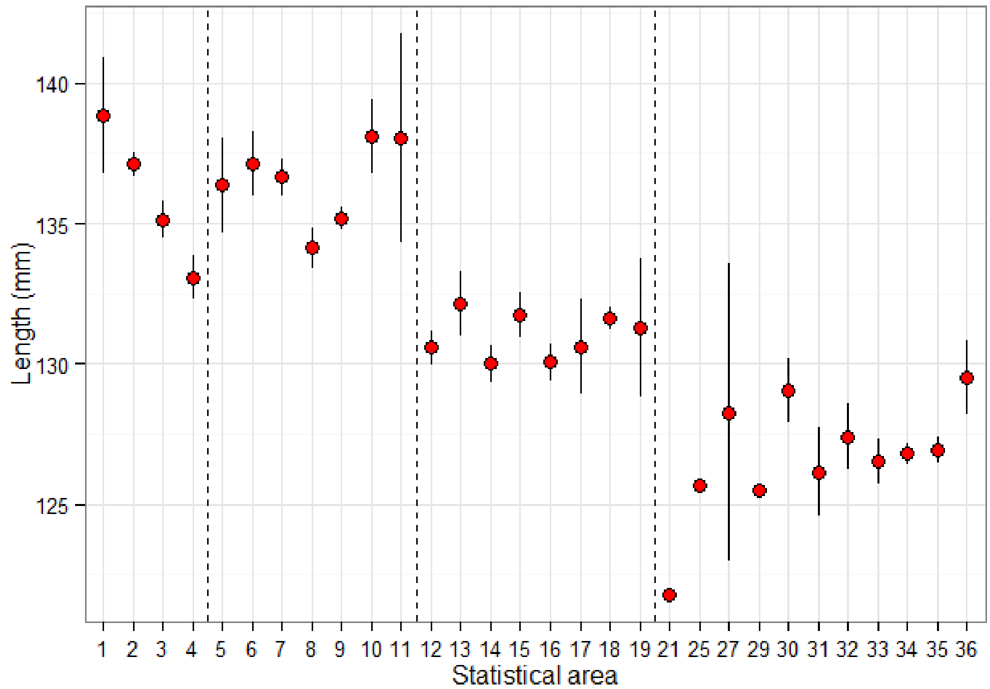

Figure 37: Mean length with standard error for sampled landings from market shed sampling by Paua Statistical Areas using data from 2002 to 2011.

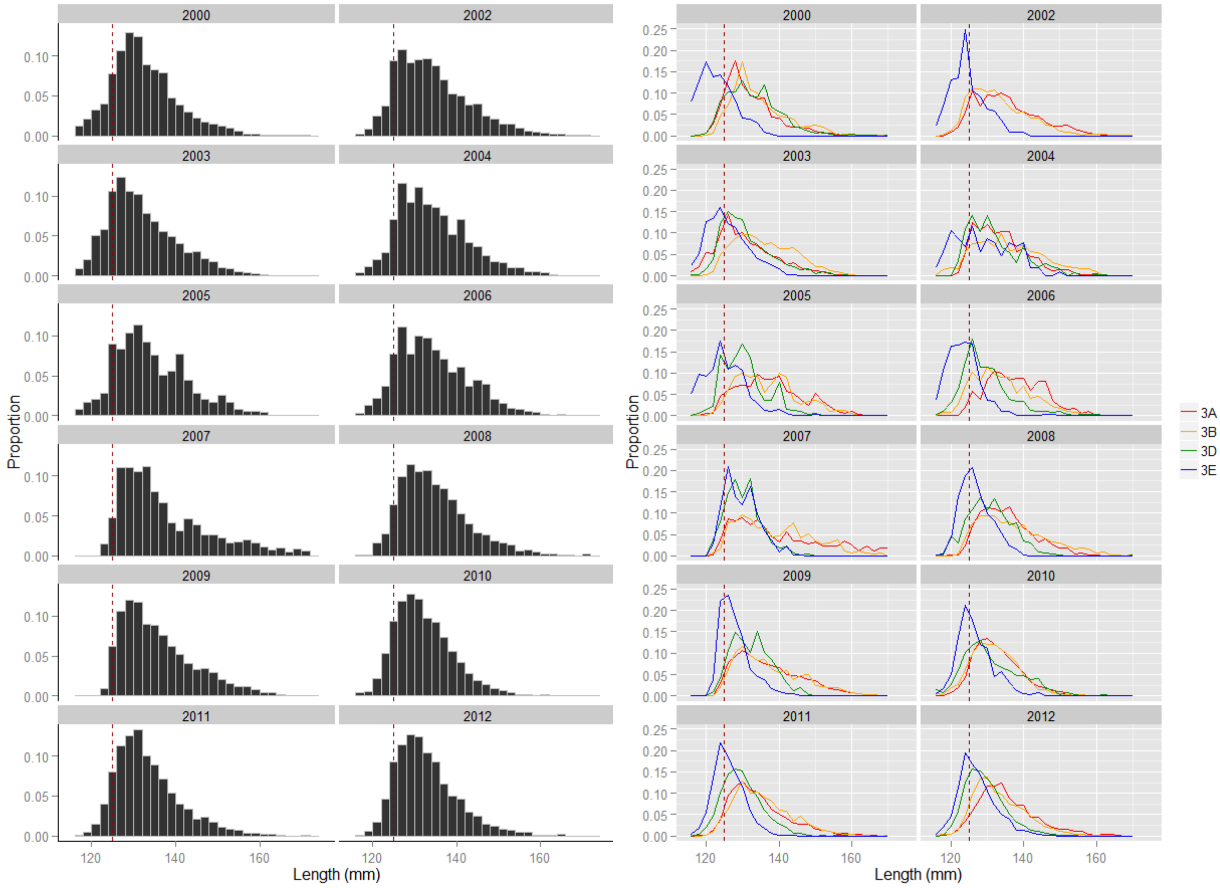

Figure 38: Scaled length frequency distributions for all management zones combined (left) and for each management zone separately (right) from commercial catch sampling in PAU 3 for 2000 and 2002–2013 The dashed line indicates the MLS of 125 mm.

6. GROWTH TAG DATA AND GROWTH ESTIMATES

Tag and recapture experiments were conducted in 1998 at several sites on Banks Peninsula, including Pigeon Bay (n=34), Squally Bay (n=66), and Akaroa (n=82). The growth dataset comprises 182 records with initial lengths ranging from 67 to 121 mm, time at liberty ranging from 398 to 401 days and annualised increments ranging from 0 to 19 mm. However, most of the paua measured in this experiment were stunted, and incorporating these data in the assessment would under-estimate the growth for the whole stock. These data were analysed here but were not included in the final assessment model.

Tag recapture data were also available from work done at Cape Campbell in 2003. Cape Campbell lies within PAU 7, and is close to the northern part PAU 3. The Cape Campbell data comprises only 10 records with initial lengths ranging from 72 to 131 mm, and annualised increments ranging from 1.9 to 22.8 mm. This data were also analysed here but were not included in the assessment model.

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

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

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

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

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

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

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

Variation in growth was normally distributed with $\sigma_k = \max\left(\alpha(u_k)^\beta, \sigma_{\min}\right)$ where u_k is the expected growth at length L_k truncated at zero, $\sigma_{\min}$ is the minimum standard deviation and $\alpha(u_k)^\beta$ is the standard deviation of growth at length L_k (if β is fixed at 1 α will be the coefficient of variation and if β is fixed at 0 α will be the standard deviation). The parameters were estimated using maximum likelihood as defined in Dunn (2007):

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

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

The linear growth model was fitted to the annual growth increment measurements (Figure 39). For Banks Peninsula, the growth parameters at $L_1 = 75$ mm and $L_2 = 120$ mm were estimated as $g_1 = 8.83$ mm and $g_2 = 0.96$ mm, and α (CV in growth, as β fixed at 1) was estimated to be about 0.62. For Cape Campbell, g_1 and g_2 were estimated to be 20.45 and 6.62 mm respectively, and the CV was assumed to be 0.2 (the sample size is too small to estimate α or β). The minimum standard deviation (σ_{min}) and the measurement error (σ_E) were assumed to be known as 0.5 mm each).

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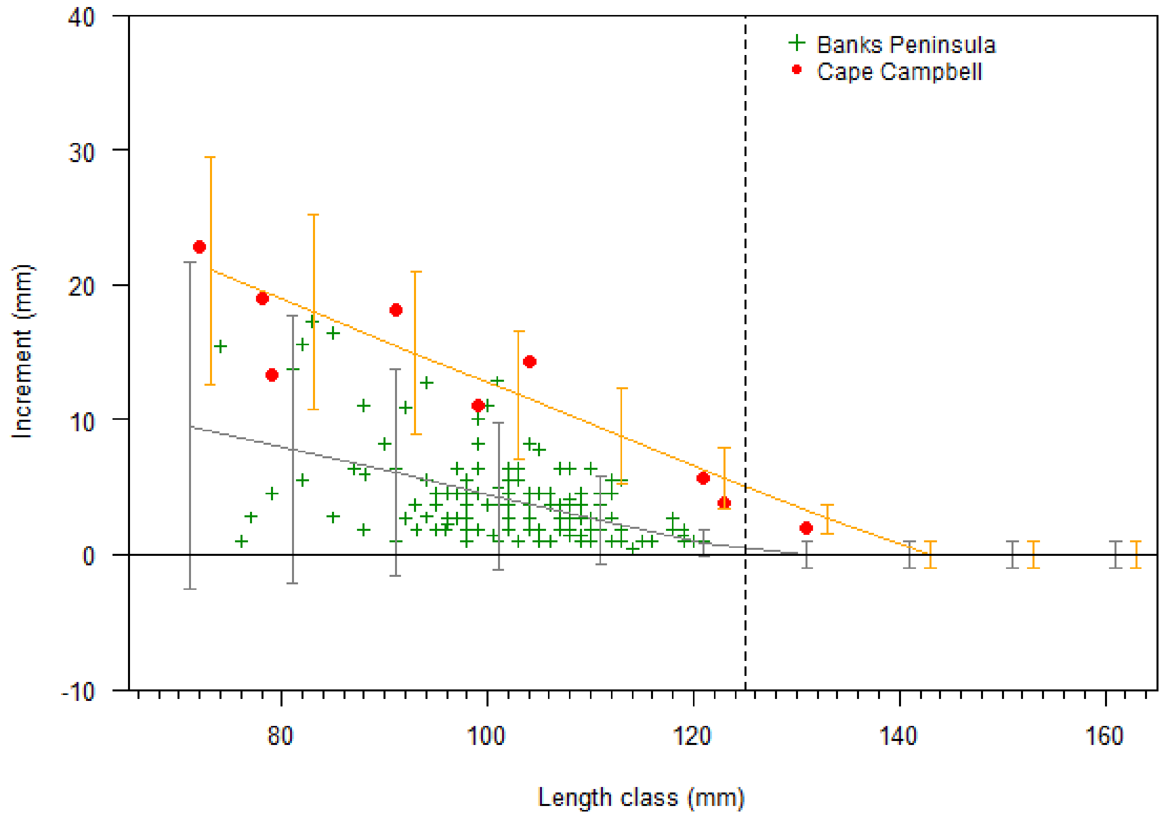

Figure 39: Initial size and mean annual increment from the tag-recapture data from Banks Peninsula and from Cape Campbell. The lines (and 95% confidence intervals) indicate size-based linear growth curves estimated from these data. Dashed line indicates the legal size limit (125 mm).

7. MATURITY

Maturity data had been collected from several sites within PAU 3 in 2012 and 2013. These included samples taken from Okiwi Bay (n=114), Paparoa (n=101), Jorgies Rock (n=110), Motunau (n=112), inside Akaroa (n=120) and Scenery Nook (n=103). Paua were examined for maturity and for sex if mature. The sample size was small and data were aggregated for the assessment across all sites and dates. They were collated as the number examined and the number mature in 2-mm length bins (Table 19).

The length of paua examined ranged from 49 to 153 mm but the sample size in each length bin was small (see Table 19). Paua less than 70 mm (n=1) were dropped out of the dataset. The proportion mature data were fitted with a logistic curve using a binomial likelihood for each zone (Figure 40). Length at 50% maturity (L50%) was estimated to be about 79 mm for 3A (Okiwi Bay and Paparoa), 89 mm for 3B (Jorgies Rock), 91 mm for 3C (Motunau), and 89 mm for 3E (Akaroa and Scenery Nook). Length at 50% maturity was estimated to be about 85 mm and length at 95% maturity was estimated to be about 98 mm for all data combined**.**

Table 19: : Number of paua observed and proportion mature by 2 mm length class from the samples collected within PAU 3.

Bin (mm)	Sample size	No. mature	Proportion mature
70	2	0	0.00
72	4	1	0.25
74	4	2	0.50
76	3	0	0.00
78	7	1	0.14
80	4	2	0.50
82	10	1	0.10
84	15	7	0.47
86	17	11	0.65
88	22	16	0.73
90	20	13	0.65
92	24	20	0.83
94	27	24	0.89
96	35	31	0.89
98	25	24	0.96
100	28	28	1.00
102	40	39	0.98
104	37	37	1.00
106	37	37	1.00
108	29	29	1.00
110	44	44	1.00
112	34	34	1.00
114	24	22	0.92
116	22	22	1.00
118	29	29	1.00
120	20	20	1.00
122	22	21	0.95
124	13	11	0.85
126	11	9	0.82
128	2	1	0.50
130	2	2	1.00
132	3	3	1.00
134	2	2	1.00
136	5	5	1.00
138	3	3	1.00
140	4	4	1.00
142	3	3	1.00
144	2	2	1.00
146	2	2	1.00
150	1	1	1.00
152	1	1	1.00

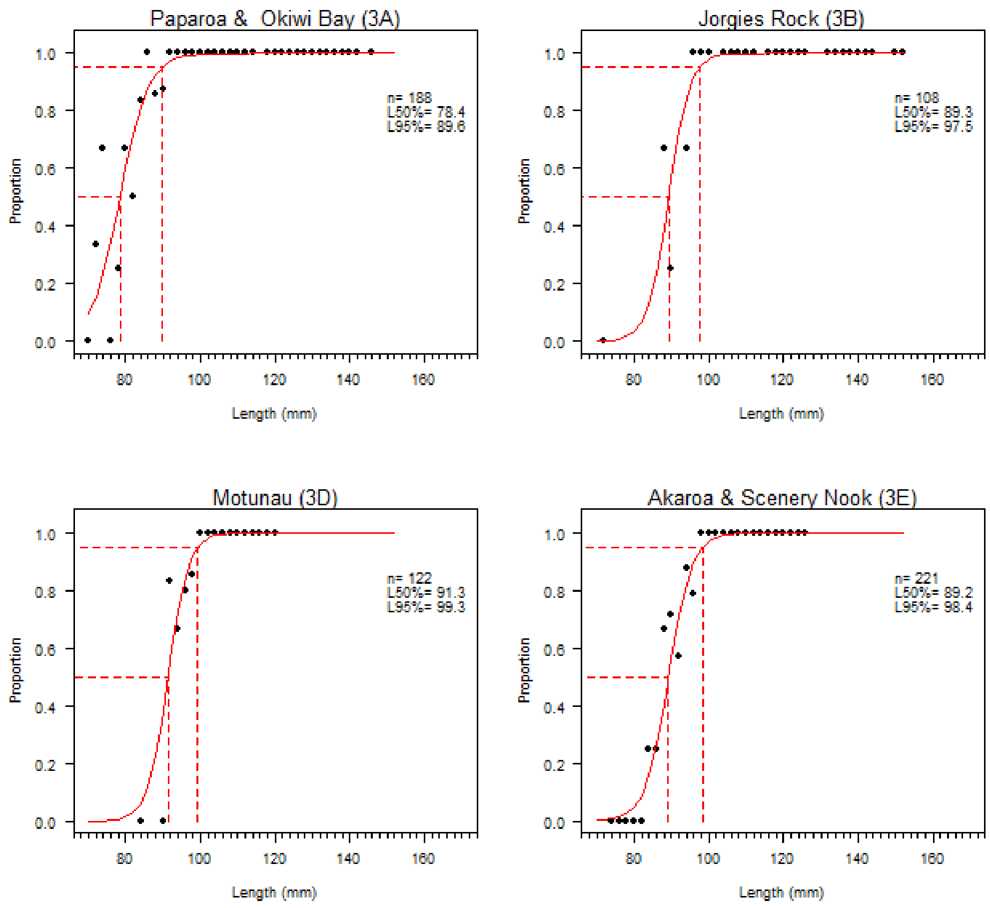

Figure 40: Proportion of maturity at length for subareas in PAU 3. The dots represent the observed proportion mature for each 2 mm length bin. The red line represents a fitted logistic maturity curve. The grey area represents the 95% confidence interval of estimated proportion. The dashed lines represent estimated length at 50% and 95% maturity.

8. ACKNOWLEDGMENTS

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