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Summary of input data for the 2011 PAU 7 stock assessment

New Zealand Fisheries Assessment Report 2012/26

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EXECUTIVE SUMMARY

Fu, D.; McKenzie, A; Naylor, R. (2012). Summary of input data for the 2011 PAU 7 stock assessment.

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This document summarises the data inputs for the 2011 stock assessment of blackfoot paua in PAU 7 (upper South Island). The seven sets of data fitted in the assessment model were: (1) a standardised CPUE series based on FSU/CELR data (2) a standardised CPUE series based on PCELR data (3) a standardised research diver survey index (RDSI) (4) a research diver survey proportions-at-lengths series (5) a commercial catch sampling length frequency series (6) tag-recapture length increment data and (7) maturity-at-length data. Catch history was an input to the model encompassing commercial, recreational, customary, and illegal catch.

The standardised CPUE series based on PCELR data was updated to the 2010–11 fishing year. There is no research diver survey since the last assessment, but the indices were revised incorporating modifications on the standardisation procedure from recent reviews. Scaled length frequency series from the commercial catch sampling were updated to the 2010–11 fishing year, where the catch samples were stratified by area and numbers at length were scaled up to each landing and then to the stratum catch. Tag-recapture length increment data and maturity-at-length data were reanalysed incorporating data available since the last assessment.

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1. INTRODUCTION

This document summarises the data inputs for the 2011 stock assessment of PAU 7. The work was conducted by NIWA under the Ministry of Fisheries contract PAU200106 Objective 1. A separate document details the stock assessment of PAU 7.

The PAU 7 area covers the upper part of the South Island and is delineated by the fine scale Paua statistical areas P701 to P797 (Figure 1). The larger scale Statistical Areas 017, 018, 036, 037, 038, and 039 all have coastline that is at least partially contained within PAU 7 (although there is only one record from Statistical Area 037 in 1993). However previous stock assessments for PAU 7 have included data from Statistical Areas 017 and 038 only, because some of the other areas straddle two paua Quota Management Areas (QMAs), and because data from research diver surveys and commercial length frequency measurements only exist for these two areas (Breen et al. 2001, Breen & Kim 2003, 2005, and McKenzie & Smith 2009a, 2009b). Most of the catch is taken from these two areas so the 2011 stock assessment followed the approach of previous years and focused only on Statistical Areas 017 and 038.

PAU 7 was last assessed in 2008 (McKenzie & Smith 2009a, 2009b) and before that in 2005 (Breen & Kim 2005) and in 2003 (Breen & Kim 2003). Data used in the 2011 assessment were:

1. A standardised CPUE series covering 1983–2001 based on FSU/CELR data.
2. A standardised CPUE series covering 2002–2011 based on PCELR data.
3. A standardised research diver survey index (RDSI).
4. A research diver survey proportions-at-lengths series (RDLF).
5. A commercial catch sampling length frequency series (CSLF).
6. Tag-recapture length increment data.
7. Maturity-at-length data.

New observational data available for 2011 were three more years of PCELR data and the additional years 2008–11 for the CSLF. Also there are some additional observations for the maturity-at-length dataset. 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”.

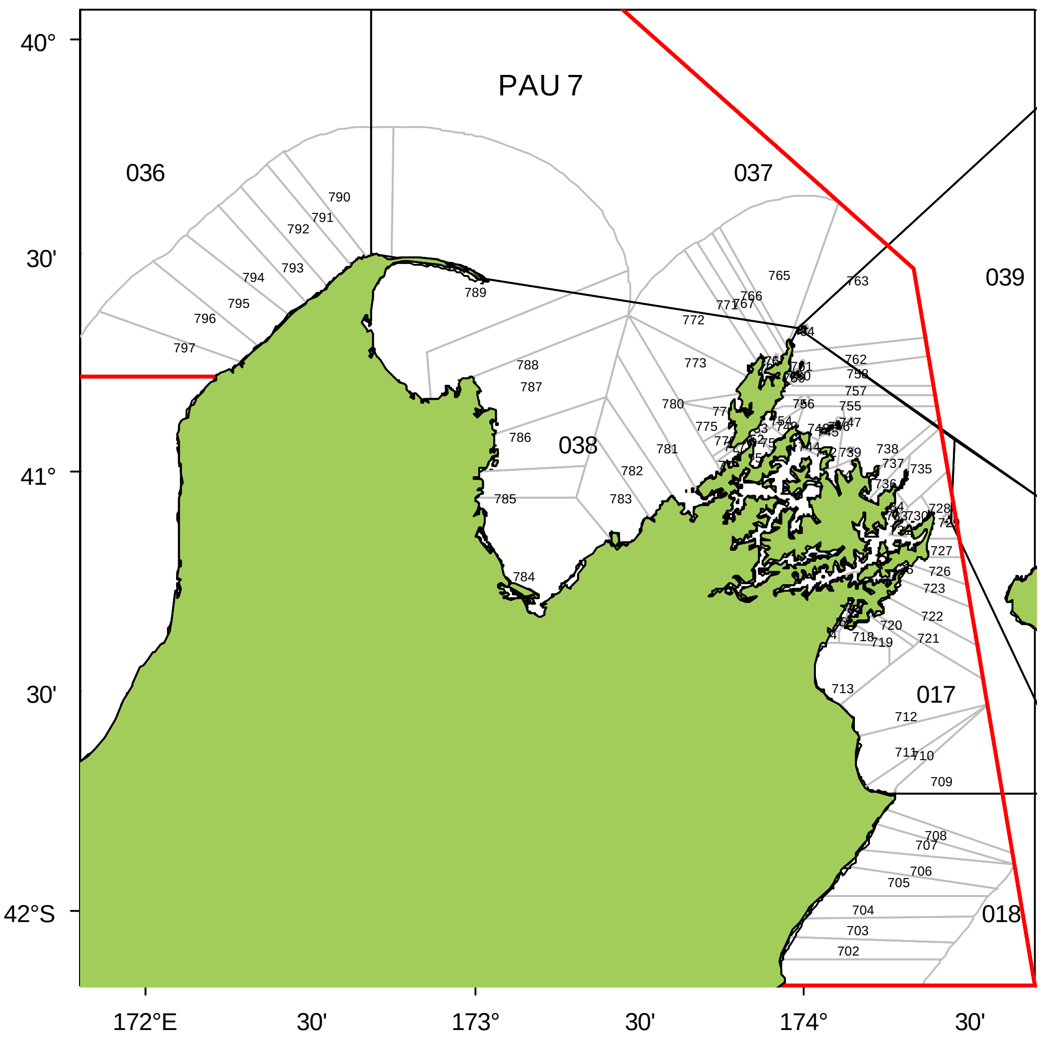

Figure 1: PAU 7, General Statistical Areas and new fine scale Paua statistical areas.

2. DESCRIPTION OF THE FISHERY

PAU 7 was introduced into the Quota Management System in 1986–87 with a TACC of 250 t which increased to 267.48 t as a result of the appeal process. As a result of poor catches in 2000–01 the commercial sector voluntarily shelved 20% of the TACC. In 2001–02 the TACC was reduced by 10% and in 2002–03 the TACC was reduced to 187.24 t. For 2003–04 to 2006–07 the industry shelved 15% of the TACC. There was no shelving between 2007–08 and 2010–11.

In recent years the commercial paua fishery has implemented a number of voluntary management actions within most QMAs (Ministry of Fisheries 2010). Agreement to these actions has been formalised in each QMA through the development of an Annual Operational Plan (AOP) that is agreed to and signed by all Quota and ACE holders within the fishery. The plan explains the voluntary management actions that will be undertaken for the fishing year. The main actions of the AOP for PAU 7 for the 2009–10 fishing year are outlined in Table 1. The effect of the change of Minimum Harvest Size on the stock assessment is ignored because the west and east coast areas are outside of the assessment area and the combined area of Ocean Bay and Robin Hood Bay is very small.

Estimated catch was reported on the scale of the general statistical areas using the CELR forms (Catch Effort and Landing Return) until 30 September 2001. The scale of reporting was reduced from 1

October 2001 when the PCELR forms (Paua Catch Effort and Landing Return) were adopted and it became mandatory to report catch and effort on the finer-scale statistical zones developed for the New Zealand Paua Management Company's voluntary logbook (see Figure 1)

Table 1: Main actions of the AOP for PAU 7 for the 2009-10 fishing year (Ministry of Fisheries 2010)

	West Coast	East Coast	Ocean Bay and Robin Hood Bay	All other parts of PAU7
Area	Kahurangi Point to Cape Farewell	Wairau River to Clarence River	Ocean Bay and Robin Hood Bay Point to Point	
Minimum Harvest Size	130mm	130mm	127mm	125mm
Data Collection – CATCH SAMPLING	Each fishing operation is required to collect a minimum of four samples ("red bag" sample kits will be supplied) during the course of their fishing year.			
Data Collection – DATA LOGGERS	Selected Dive Teams will have one diver who carries and uses a data logger and downloads the data to PAUAMAC7.			
General Operating Procedures	Details on procedures are available in the AOP			

3. CATCH HISTORY

3.1 Commercial catch

The catch history for 1974–83 was estimated by Murray & Akroyd (1984) and for 1984–88 by Schiel (1989). Murray & Akroyd (1984) stated that landings before 1974 were unreliable. Schiel (1992) revisited the estimates for 1981–85 and the effect of this change (affecting mostly the 1981 and 1982 catches) was explored by Andrew et al. (2000a) and found to be small. The 1986 catch appears suspiciously low and as in previous years the average of 1985 and 1987 catches is used (Table 2). Catches from 1989 onwards were captured on QMR forms and reported in Plenary documents (e.g. Ministry of Fisheries 2010). Catches from the 2008 assessment (McKenzie & Smith 2009a) were used up to 2001 and recent data for 2002–2010 were supplied by Ministry of Fisheries (data log 8223).

For 2002–2007 the catch history was calculated following the methodology of the 2008 assessment (McKenzie & Smith 2009a). In order to confine the stock assessment to Statistical Area 017 and 038 the percentage of the catch that came from these two areas was estimated using the estimated catches from the catch effort data. Table 3 shows the estimated catch from the PCELR forms from between 2002 and 2010 in all areas. In Table 4 the percentage of the catch that was taken from 017 and 038 was calculated using the PCELR data. This averages 89% over the nine years and is generally increasing over time indicating that the other areas are becoming less favoured by fishers. These percentages were then used to estimate the total catch from 017 and 038 by multiplying each year's catch from Monthly Harvest Returns (MHR) by the percentages. Following McKenzie & Smith 2009a we included P764 in statistical area 017 when in fact it lies within area 039 (Figure 2).

The estimated catches by finer statistical area from the years of PCELR data are shown in Figure 3. This shows that areas within 017 have the majority of the catch. The areas where the highest consistent catches were taken are Staircase, Rununder, and Perano, which are all on the east coast of the Marlborough Sounds.

3.2 Recreational catch

The 1996 National Marine Recreational Fishing Survey estimated 23 000 paua taken in PAU 7. The 1999–2000 and 2000–2001 national surveys estimated 15.8 t and 7.7 t respectively. The Marine Recreational Fisheries Technical Working Group (RFTWG) considered the harvest estimates from the national surveys and concluded that the estimates from the 1996 survey are unreliable due to a methodological error. The RFTWG also concluded that some harvest estimates from the 1999–2000 and 2000–2001 surveys for some fish stocks were unbelievably high. For the PAU 7 stock assessment the Shellfish Fisheries Assessment Working Group agreed to assume that recreational catch was 5 t in 1974 and that it increased linearly to 15 t in 2000 and then remained at 15 t subsequently (Table 2).

3.3 Customary catch

Customary catch was incorporated into the PAU 7 TAC in 2002 as an allowance of 15 t. No historical estimates are available. The Working Group agreed to assume that customary catch was 4 t in 1974 increasing linearly to 10 t between 1974 and 2000 and then remaining at 10 t subsequently (see Table 2).

1.1 Illegal catch

The Working Group agreed to assume that illegal catch was 1 t in 1974 and that it increased linearly to 15 t between 1974 and 2000, remaining at 15 t from 2000 to 2005, then decreasing linearly to 7.5 t in 2008, and then remaining at 7.5 subsequently (see Table 2).

1.2 Total catch for areas 017 and 038

The total catch trajectory for the 2011 stock assessment based on the sum of the commercial and non-commercial catches for Statistical Areas 017 and 038 is shown in Table 2. The commercial catch trajectory is plotted in Figure 4.

Table 2: Catch data used in the 2011 stock assessment. The table shows the sources of the data by fishing year. The "All PAU 7" catch (kilograms) is calculated from the QMA or MHR. "CELR/QMR" is the ratio of the (P)CELR catches to the reported catches. The proportion of the estimated catch from general statistical reporting areas 017 and 038 is used to calculate the commercial catch in areas 017 and 038. The illegal, recreational, and customary catch are added to estimate the total catch in areas 017 and 038. This is compared to the TACC and the effective catch limit after shelving.

Source	Year	All PAU 7	CELR/ QMR	017 and 038	Comm. 017 and 038	Illegal	Rec.	Cust.	Total 017 and 038	TACC (t)	Limit after Shelving
Murray & Akroyd 1984	1974	147 440		100.0	147 440	1 000	5 000	4 000	157 440		
	1975	197 910		100.0	197 910	1 538	5 385	4 231	208 987		
	1976	141 880		100.0	141 880	2 077	5 769	4 462	154 034		
	1977	242 730		100.0	242 730	2 615	6 154	4 692	255 961		
	1978	201 170		100.0	201 170	3 154	6 538	4 923	215 478		
	1979	304 570		100.0	304 570	3 692	6 923	5 154	319 955		
	1980	223 430		100.0	223 430	4 231	7 308	5 385	239 892		
Schiel 1992	1981	490 000		100.0	490 000	4 769	7 692	5 615	507 538		
	1982	370 000		100.0	370 000	5 308	8 077	5 846	388 615		
	1983	400 000	52.4	100.0	400 000	5 846	8 462	6 077	419 692		
	1984	330 000	82.9	100.0	330 000	6 385	8 846	6 308	350 769		
	1985	230 000	75.3	100.0	230 000	6 923	9 231	6 538	251 846		
Breen & Kim 2005	1986	236 090	38.0	100.0	236 090	7 462	9 615	6 769	259 013		
	1987	242 180	45.3	100.0	242 180	8 000	10 000	7 000	266 180	250	250
	1988	255 944	24.4	100.0	255 944	8 538	10 385	7 231	281 021	250	250
	1989	246 029	24.6	100.0	246 029	9 077	10 769	7 462	272 183	250	250
	1990	267 052	80.2	99.8	266 509	9 615	11 154	7 692	293 740	263.53	263.53
	1991	273 253	82.9	98.4	268 782	10 154	11 538	7 923	297 090	266.24	266.24
	1992	268 309	93.2	93.1	249 789	10 692	11 923	8 154	279 173	266.17	266.17
	1993	264 802	90.8	96.3	255 045	11 231	12 308	8 385	285 507	266.17	266.17
	1994	255 472	100.5	97.2	248 285	11 769	12 692	8 615	279 823	266.17	266.17
	1995	247 108	103.5	96.1	237 571	12 308	13 077	8 846	270 187	266.17	266.17
	1996	268 742	91.9	90.1	242 057	12 846	13 462	9 077	275 749	267.48	267.48
	1997	267 594	91.4	86.2	230 570	13 385	13 846	9 308	265 339	267.48	267.48
	1998	266 655	89.1	81.9	218 479	13 923	14 231	9 538	254 325	267.48	267.48
	1999	265 050	86.9	86.5	229 198	14 462	14 615	9 769	266 121	267.48	267.48
	2000	264 642	111.6	75.0	198 419	15 000	15 000	10 000	238 419	267.48	267.48
	2001	215 920	120.4	65.2	140 731	15 000	15 000	10 000	180 731	267.48	213.98
From data extract Aug-11	2002	187 152	98.7	74.3	139 112	15 000	15 000	10 000	179 112	240.73	240.73
	2003	187 222	98.4	88.2	165 102	15 000	15 000	10 000	205 103	187.24	187.24
	2004	159 551	99.0	91.2	145 502	15 000	15 000	10 000	185 503	187.24	159.15
	2005	166 940	99.0	85.6	142 826	15 000	15 000	10 000	182 826	187.24	159.15
	2006	183 363	101.0	95.3	174 728	12 500	15 000	10 000	212 228	187.24	159.15
	2007	176 052	98.3	92.6	162 970	10 000	15 000	10 000	197 970	187.24	159.15
	2008	186 845	98.1	93.3	174 366	7 500	15 000	10 000	206 866	187.24	187.24
	2009	186 846	98.3	90.5	169 136	7 500	15 000	10 000	201 636	187.24	187.24
	2010	187 022	97.3	90.8	169 809	7 500	15 000	10 000	202 309	187.24	187.24
	2011	187 240	91.1	89.3	167 216	7 500	15 000	10 000	199 716	187.24	187.24

Table 3: Estimated catch for PAU 7 by statistical area and fishing year from paua-specific catch effort landing return forms (PCELR) which began in 2002. All catches are in kilograms.

Fishing year	017	018	036	038	Total
2002	132 610	41 810	5 617	4 727	184 764
2003	150 653	20 102	1 662	11 797	184 214
2004	134 572	13 814	95	9 488	157 969
2005	132 089	13 450	10 422	9 303	165 264
2006	163 008	5 897	2 828	13 540	185 273
2007	149 766	10 078	2 788	10 507	173 139
2008	154 727	7 745	4 498	16 334	183 304
2009	159 994	12 853	4 558	6 285	183 690
2010	160 850	10 381	6 364	4 340	181 935
2011	149 309	11 244	7 005	3 084	170 642
Total	1 487 578	147 374	45 837	89 405	1 770 194

Table 4: Catches from MHR (kg) multiplied by the proportion of catch from 017 and 038 as estimated from PCELR data to calculate the catch from these two areas only.

Fishing year	Catch (MHR)	Proportion of catch from 017 and 038	Catch for 017 and 038
2002	187 152	74%	139 112
2003	187 222	88%	165 102
2004	159 551	91%	145 502
2005	166 940	86%	142 826
2006	183 363	95%	174 728
2007	176 052	93%	162 970
2008	186 845	93%	174 366
2009	186 846	91%	169 136
2010	187 022	91%	169 809
2010	187 022	91%	169 809
2011	178 323	89%	159 253

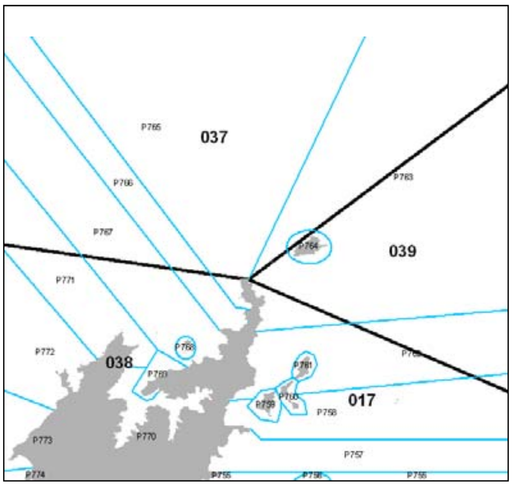

Figure 2: Map showing Stephens Island and the tip of D'Urville Island where four general statistical areas meet. This shows that Stephens Island P764 physically lies within Statistical Area 039.

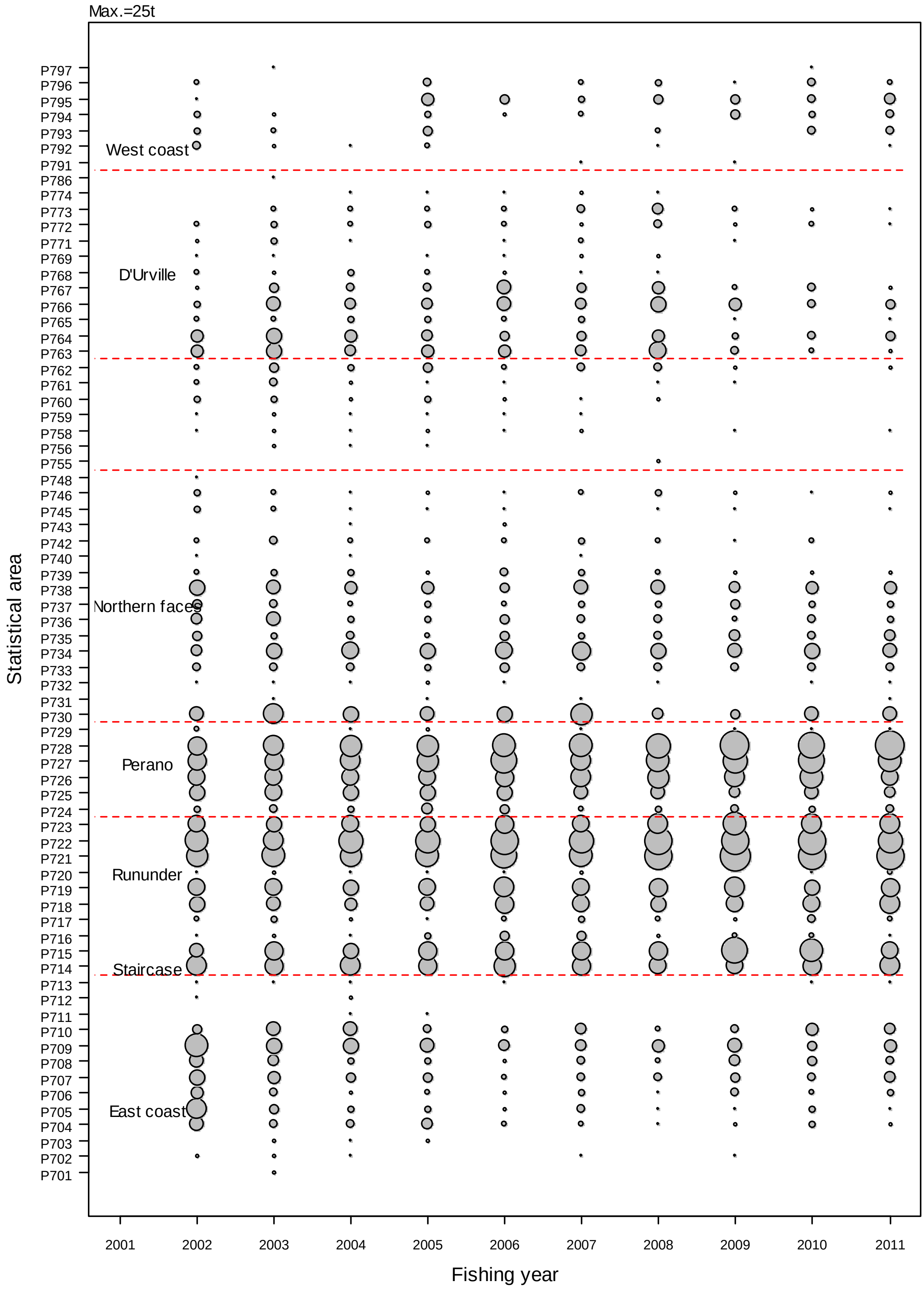

Figure 3: Annual estimated catch by Paua statistical area in PAU 7 for fishing years 2002–2010. The size of the circle is proportional to the catch.

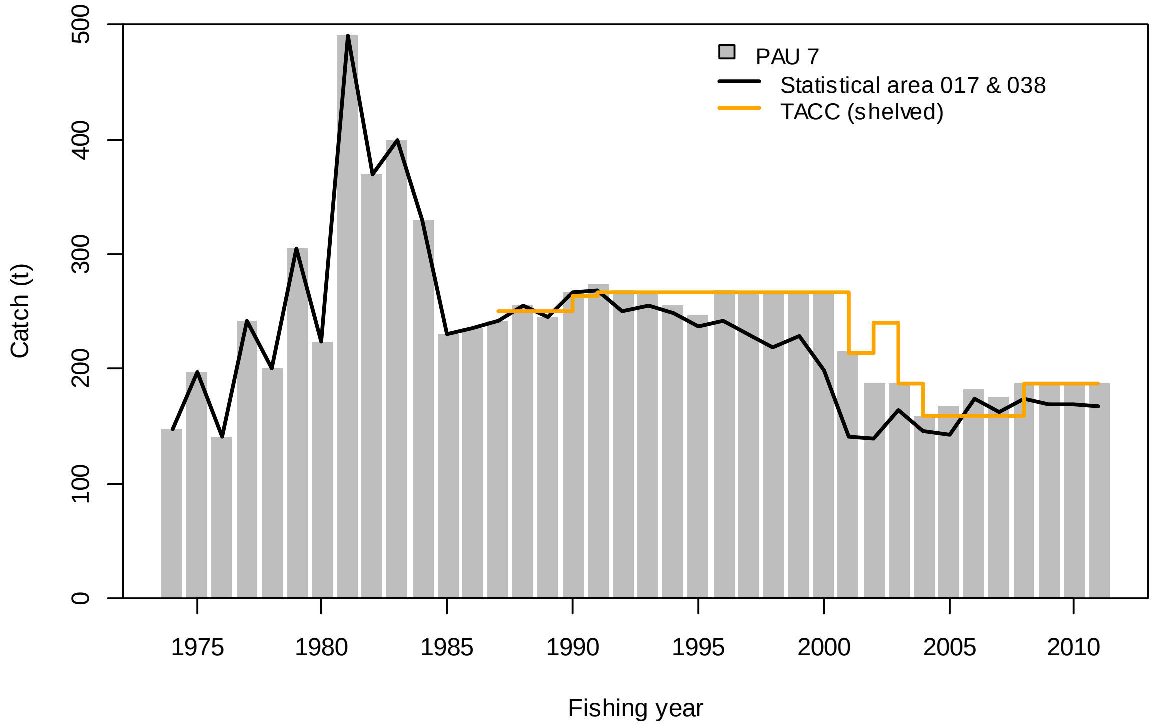

Figure 4: Reported commercial catches for PAU 7, estimated commercial catch history for Statistical Area 017 and 038 only and TACC (after shelving).

4. CPUE

4.1 Overview

In the 2008 PAU 7 stock assessment (McKenzie & Smith 2009b) two standardised CPUE indices were used: one based on FSU/CELR data covering 1983–2001, and another based on PCELR data covering 2002–2007. In this section three standardised CPUE indices are presented.

1. One using FSU/CELR data covering 1983–2001. This is not a new analysis, but simply a re-presentation of the index that was used in the last assessment.

2. An updated index using PCELR data covering 2002–2011.

3. An updated index, using the same methodology as that for the updated index using PCELR data, except the Fisher Identification Number (FIN) number was used for data sub-setting instead of vessel.

The Shellfish Working Group decided to use standardised indices one and three above in the assessment (i.e. one based on the FSU/CELR data, the other on the PCELR data with FIN number for sub-setting).

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

A step forward procedure was used to select predictor variables, and they were entered into the model in the order which gave the maximum decrease in the Akaike Information Criterion (AIC). Predictor variables were accepted into the model only if they explained at least 1% of the deviance.

4.2 FSU/CELR data: 1983–2001

The standardised index from the 2005 assessment is re-presented here. The unit of catch used was the total estimated daily catch for a vessel. As the diver hours field on the CELR forms contains a high number of errors, the unit of effort used is the total number of diver days (total number of divers on a vessel for a day). Records were restricted to those from vessels that fished the top 75% of catch in any given year, and from areas 017 and 038 (Breen & Kim 2005). The standardised index is shown in Table 5 and Figure 5.

Table 5: Standardised CPUE indices from CELR data for areas 017 and 038 of PAU 7. The standard error shown is on the index in log space. The table is extracted from Breen & Kim 2005.

Fishing year	Standardised CPUE (kg/day)	SE	Diver days
1983	228.8	0.0322	726
1984	225.5	0.0288	1 060
1985	220.2	0.0310	626
1986	199.7	0.384	378
1987	185.2	0.393	562
1988	196.4	0.0470	373
1989	163.0	0.0429	355
1990	137.7	0.0249	1 292
1991	136.3	0.0224	1 415
1992	115.6	0.0226	1 894
1993	133.0	0.0235	1 544
1994	130.9	0.0250	1 624
1995	126.0	0.0246	1 630
1996	124.6	0.0245	1 632
1997	109.9	0.0245	1 736
1998	111.1	0.0253	1 601
1999	118.8	0.0264	1 529
2000	80.7	0.0257	2 111
2001	60.0	0.0274	2 246

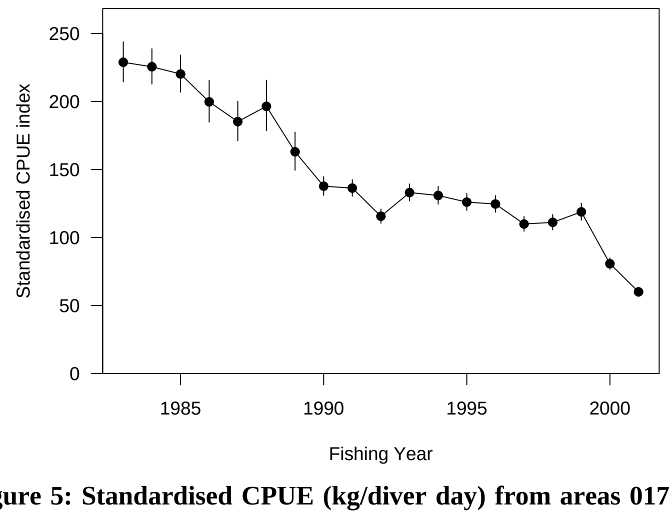

Figure 5: Standardised CPUE (kg/diver day) from areas 017 and 038 combined, taken from FSU/CELR data.

4.3 PCELR data: 2002–2011

4.3.1 The dataset

PCELR data were extracted in October 2011 for the period 1 October 2001 to 31 September 2011. Records will be incomplete for September 2011 and part of August 2011. Records were collapsed to daily format: total catch and dive time over a day for a diver (associated with a specific vessel, diving conditions, and fine scale statistical area). Only records for which the species was blackfoot paua (species code PAI) were retained (20 656 records).

Some sub-area groupings are of interest to the PAU 7 management company (Table 6), and unstandardised catch rates are shown for these in Figure 6. Trends in unstandardised catch rates are similar for the six sub-areas that take the most catch, (Figure 7).

The data were groomed to ensure that records contained the information needed for analysis such as diver keys, diving condition, and vessel key (Table 7). A further reduction of the data set was made based on the landed catch (greenweight) taken by vessels. For each year, the vessels were ordered in terms of decreasing landed catch. Corresponding to each vessel in this ordering is a cumulative total catch for this and the previous vessels in the ordering, reaching 100% for the last vessel, which lands the least catch. For each year, records were retained only from the vessels in the top 75% for the cumulative total catch landed (Tables 8–9). Following this, only records from large scale statistical areas 017 and 038 were retained (see Table 8).

Finally, to ensure that there was enough data to estimate fine scale statistical area and diver effects in the standardisation, only those fine scale statistical areas and divers with 10 or more diver days were retained (see Table 8). This reduced the number of fine scale statistical areas from 54 to 43, and the number of divers from 364 to 87 (48% of divers have only one dive day).

The number of vessels in the original data set, after vessel sub-setting, and in the final CPUE data set are shown in Table 9. Percentiles for the catch, effort, and catch per unit effort are summarised for the records in Table 10. Most of the catch and effort is outside the winter months of June to September (Figures 8–9).

Table 6: Some sub-areas of PAU 7. For their locations see Figure 1. Note that the sub-area definitions here are specific to this section of the document.

Sub-area name	Statistical areas
East Coast	P701–P713
Fighting Bay South	P714–P719
Tory South	P720–P723
Tory Channel	P724–P725
Tory North	P726–P729
Northern Entrance	P730–P735
Pelorus	P736–P756
D’Urville	P757–P774
West Coast	P789–P979

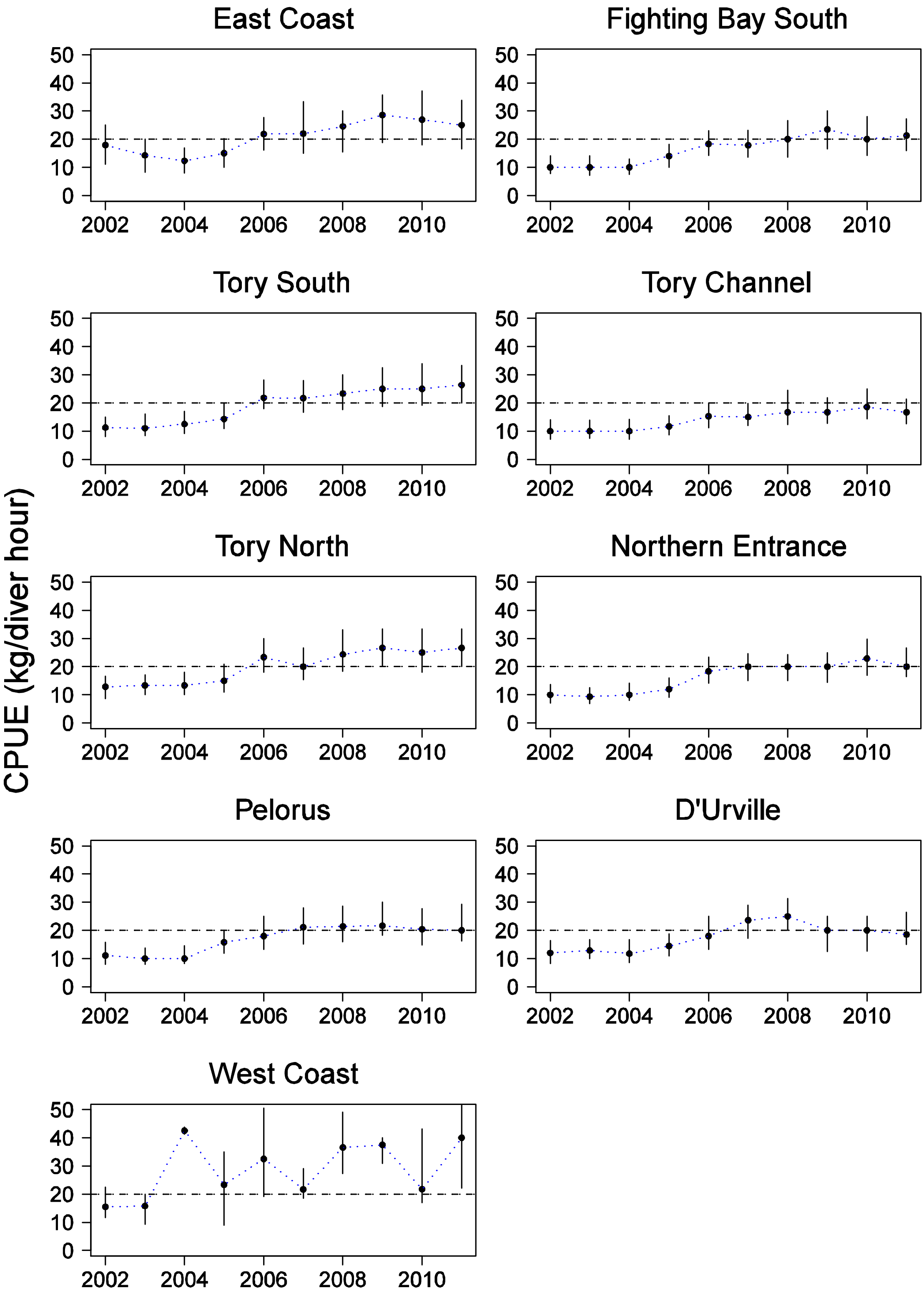

Figure 6: Unstandardised catch rates by sub-area showing medians (dots) and lower and upper quartiles. For reference purposes a dashed horizontal line is shown at a catch rate of 20 kg/h.

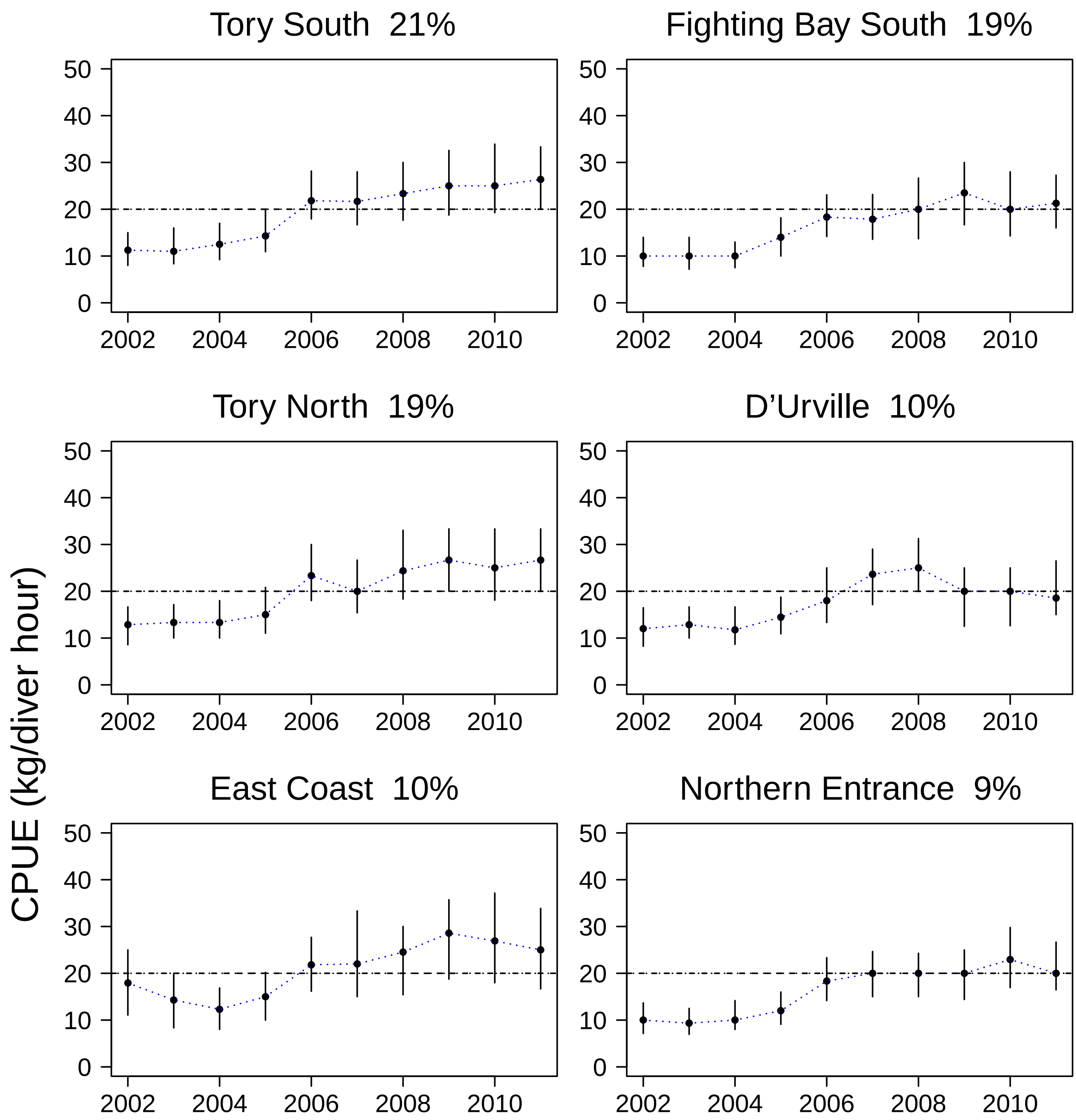

Figure 7: Unstandardised catch rates for the six sub-areas with the highest catch totals over 2002–2010. Shown are median (dots) and lower and upper quartiles. The percentage of the catch taken in the sub-area over this period is given in the title for each panel. For reference purposes a dashed horizontal line is shown at a catch rate of 20 kg/h.

Table 7: Number of records removed.

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
No Diver key	0	1	0	1	0	0	0	0	0	1	3
No Diving condition	110	63	71	66	54	69	32	32	37	29	563
No Vessel key	0	10	15	3	0	0	0	0	0	0	28
kg/hr > 200	5	6	1	1	1	0	2	0	1	1	18

Table 8: Number of records remaining in the data set after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records that didn't contain information needed for the standardisation were removed (see Table 7).

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
Total PAI records	2 830	3 053	2 618	2 413	1 844	1 776	1 598	1 521	1 566	1 437	20 656
Top 75% for vessel catch	1867	2108	1827	1550	890	962	860	907	872	823	12 666
Areas 017 and 038 only	1552	1952	1768	1380	849	896	814	802	741	717	11 471
Fine scale stat area with >=10 dive days	1545	1943	1761	1379	849	890	806	802	741	717	11 433
Divers with >= 10 dive days	1450	1852	1698	1315	815	865	779	775	689	673	10 911

Table 9: Number of vessels for each year in the original, after vessel sub-setting, and in the final CPUE data set.

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Initial groomed data	76	61	48	45	43	42	31	34	35	28
After vessel sub-setting	25	19	17	18	12	14	11	11	11	11
Final CPUE data set	25	19	17	18	12	13	11	11	11	11

Table 10: Percentiles for daily catch, effort, and catch per unit effort.

Percentiles	Catch weight	Dive duration	PCPUE
0%	1	0.083	1
5%	15	1.5	6.364
50%	75	5	16
95%	190	7	35.455
100%	900	14	188.25

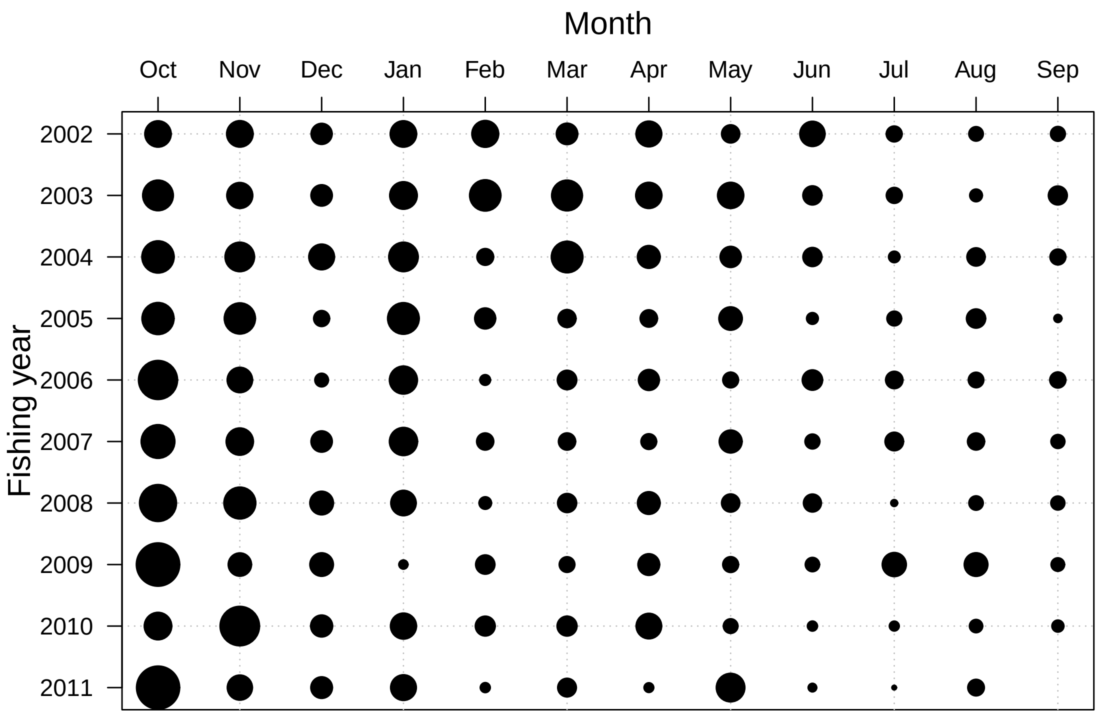

Figure 8: Graphical representation of the catch totalled by month and year for the CPUE data set. The area of a circle is proportional to the catch; the largest circle represents 29 020 kg.

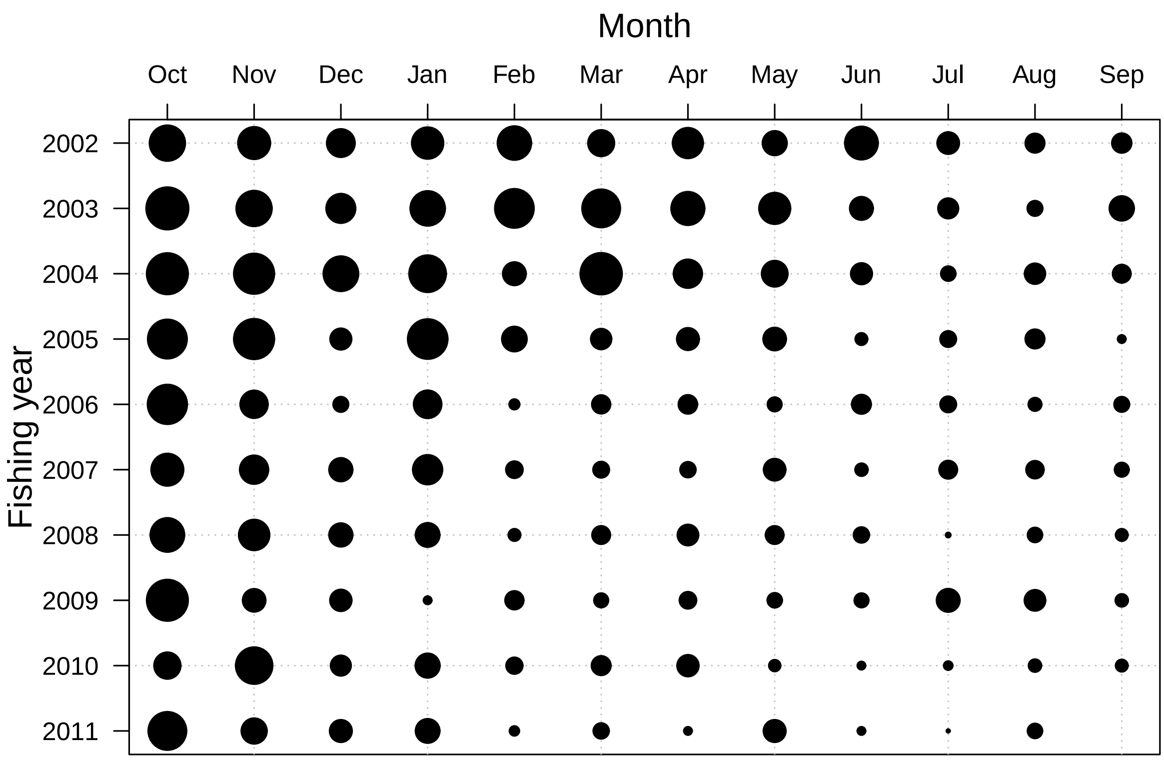

Figure 9: Graphical representation of the total diver effort (hours) by month and year for the CPUE data. The largest circle represents 1 280 hours.

4.3.2 Updated Standardisation for PCELR data: 2002–2011

The same standardisation model was used as in McKenzie & Smith (2009a). Catch rate (the dependent variable) was modelled as log(daily catch per diver) with a normal error distribution. Variables offered to the model were fishing year, month, diver key, statistical area, duration, and diving conditions. The year variable was forced into the model at the start, as the aim of a standardised CPUE analysis is to produce a relative biomass indexed by year. Interactions terms (such as vessel:month, area:month) were excluded as they are poorly estimated (McKenzie & Smith 2009a).

Except for dive condition and vessel, all variables were accepted into the model which explained 77% of the variability in CPUE (Table 11). Most of the variability was explained by duration predictor (45%) and diver predictor (25.8%); both statistical area and month explained less than 2%. The effects appear plausible and the diagnostics are satisfactory (Figure 10).

The standardised PCPUE index is similar to the unstandardised indices (Figure 11). It increases slightly for the first three years, with substantial increases for the following two years, and then is flat or slightly increasing for the last five years (Figure 12, Table 12). This is very similar to the pattern shown for the 2010 standardised index (Figure 13).

Table 11: Variables included in the standardisation model (1% additional deviance explained), and the order in which they were accepted into the model. Shown in the columns are degrees of freedom (Dof) and Akaike Information Criterion (AIC). Variables marked with an asterisk were accepted into the final model.

	Dof	AIC	Percentage deviance explained	Additional % deviance explained
Fish year*	8	22 714	18.0	18.0
Duration*	3	13 961	63.3	45.2
Diver*	86	10 382	74.0	10.7
Statistical area*	42	9 640	75.9	1.9
Month*	11	9 091	77.1	1.2
Dive Conditions	4	8 753	77.8	0.7
Vessel	40	8 496	78.5	0.7

Table 12: Standardised PCPUE index and c.v.s.

Fishing year	**Number of records**	**Index**	**c.v.**
2002	1 450	46.9	0.045
2003	1 852	48.5	0.044
2004	1 698	51.2	0.045
2005	1 315	60.9	0.045
2006	815	87.1	0.046
2007	865	86.8	0.047
2008	779	98.4	0.047
2009	775	98.3	0.047
2010	689	102.4	0.047
2011	673	101.4	0.048

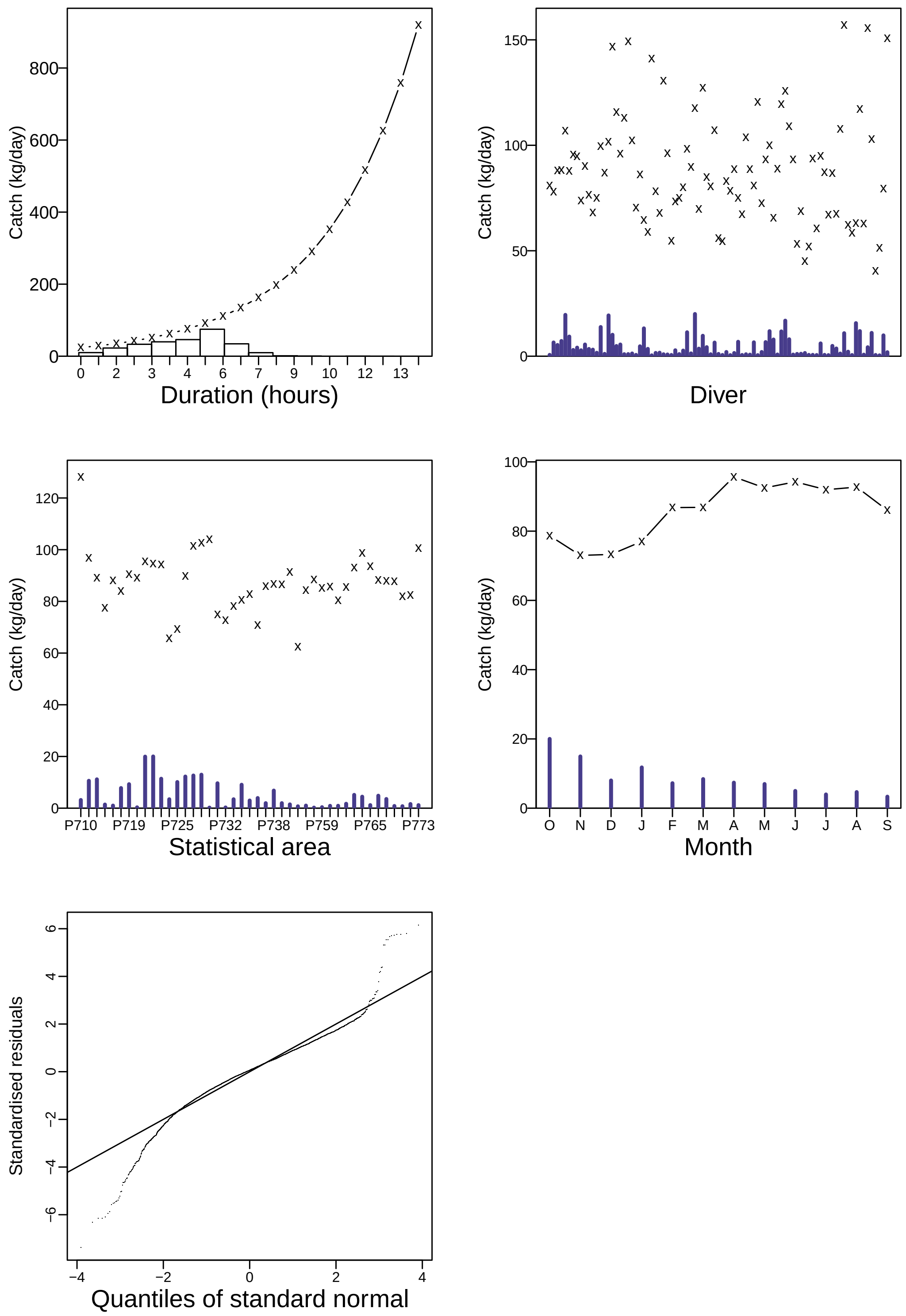

Figure 10: Effects and diagnostics for the updated standardisation model. Effects catch rates are calculated with other predictors (e.g., diver, area, and month) fixed at the level for which median catch rates are obtained. Bar graphs show the distribution of data for each predictor. The diagnostic plot is shown in the bottom left-hand corner, and shows the sorted normalised residuals from the standardisation model (y-axis) plotted against the corresponding quantiles of the standard normal distribution (x-axis).

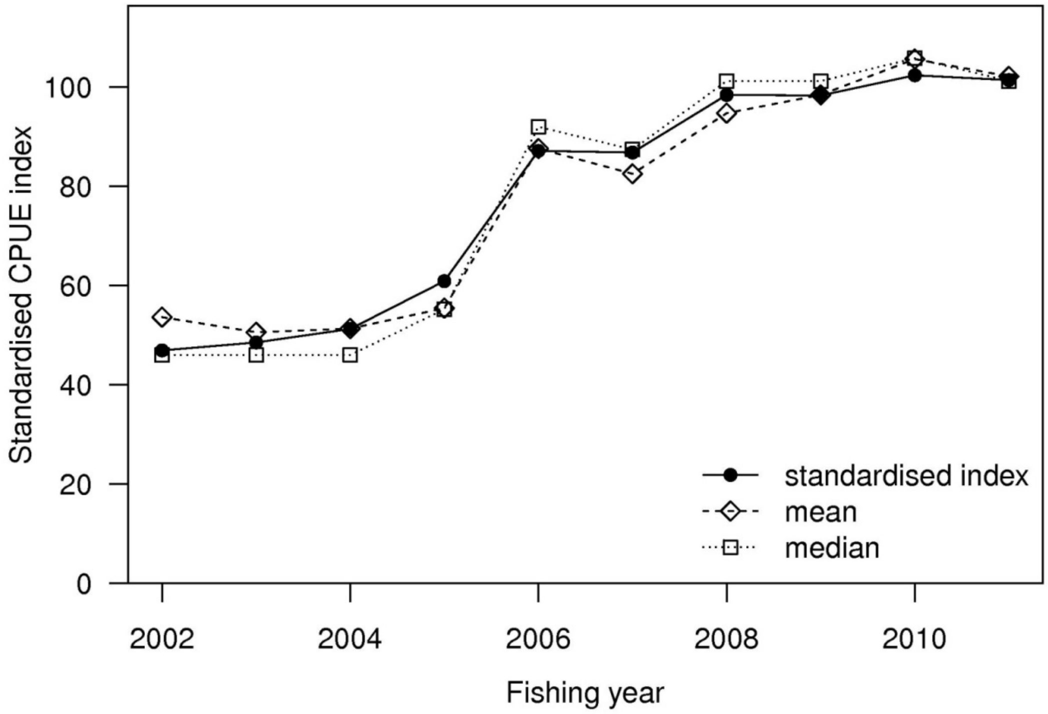

Figure 11: The standardised PCPUE compared to the mean and median. The unstandardised indices in both cases are scaled so as to have the same mean as the standardised PCPUE index.

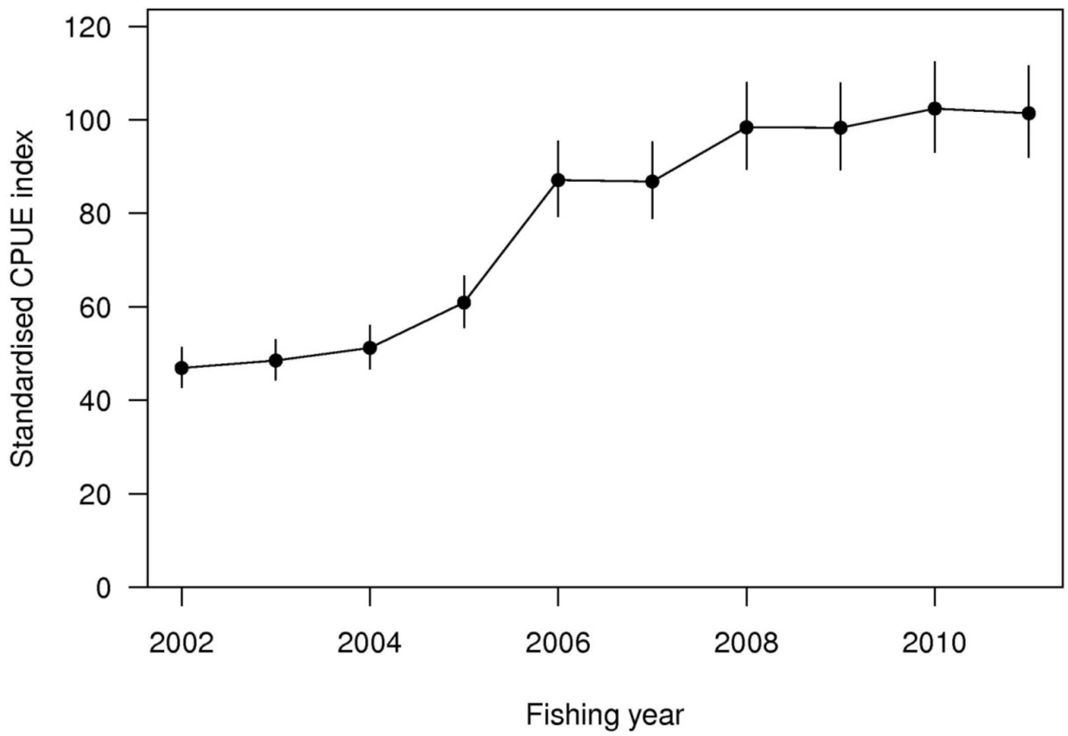

Figure 12: The standardised CPUE index with 95% confidence intervals.

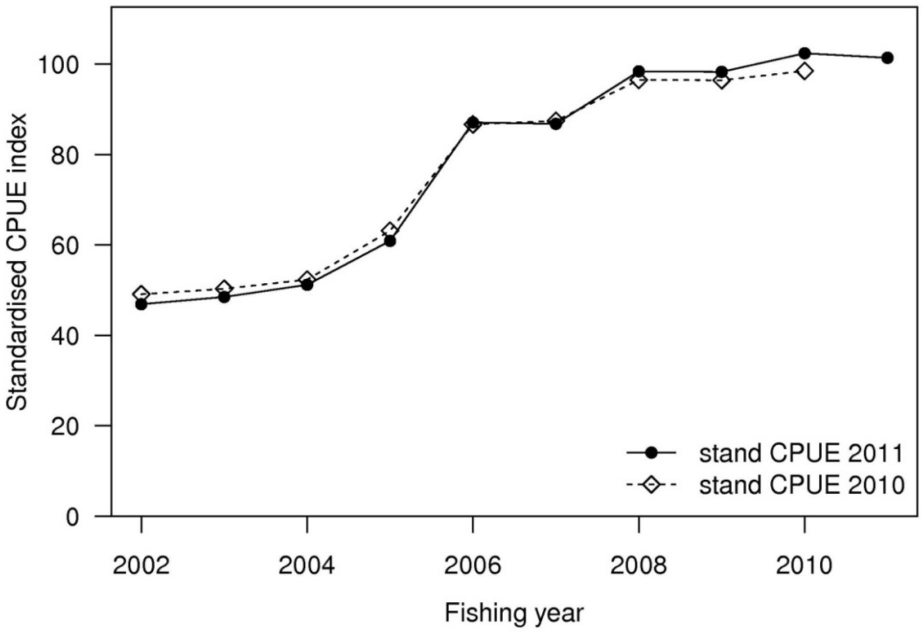

Figure 13: Comparing the updated standardised index with that calculated in the previous year.

4.3.3 Standardisation model: using FIN number

The Shellfish Working Group preferred that FIN be used in the standardisation instead of vessel. The reason for this is that the FIN is associated with a permit holder, who has a number of vessels, which are operated as a group instead of independently. To replace the data sub-setting criterion of using the top 75% of vessels in a year, it was decided to use the criterion of a minimum number of records per year for a minimum number of years for each FIN. Other than these two changes, the standardisation using FIN was done in the same way as the updated standardisation, as is explained below.

Records were collapsed to daily format: total catch and dive time over a day for a diver (associated with a specific FIN, diving conditions, and fine scale statistical area). Only records for which the species was blackfoot paua (species code PAI) were retained (20 645 records). The data were groomed to ensure that records contained the information needed for analysis such as diver keys, diving condition, and vessel key (Table 13).

Instead of sub-setting using the top 75% of vessels in each year, the FIN is used with the requirement that there be a minimum number of records per year, for a minimum number of years. The criteria of a minimum of 40 records per year, for a minimum of four year was selected, this retaining 76% of the original catch over 2002–2011 before any grooming (Figure 14). The number of FIN permit holders drops from 72 to 20 under the criteria.

Only records from the large scale statistical areas 017 and 038 were retained (Table 14). Finally, to ensure that there was enough data to estimate fine scale statistical area and diver effects in the standardisation, only those fine scale statistical areas and diver with 10 or more diver days were retained (Table 14). This dropped the number of fine scale statistical areas from 54 to 45, and the number of divers from 379 to 82 (51% of divers have just one dive day).

There is very good temporal overlap for the predictor variables FIN, statistical area, month, dive conditions, and diver (Figures 15 – 19).

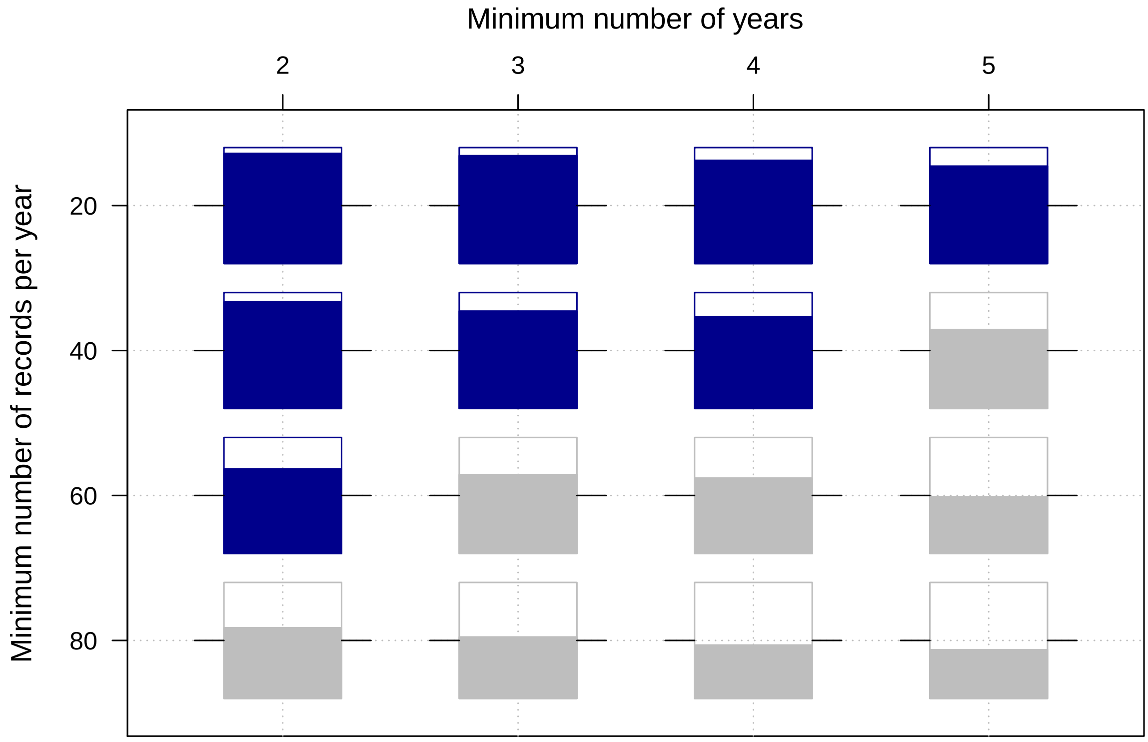

Figure 14: Proportion of the catch taken when sub-setting the data by FIN with the requirement of a minimum number of daily records per year, for a minimum number of years. Each bar shows the percentage of the total catch from 2002–2011 retained under the criteria, where the horizontal line for each bar represents 50%. Bars with a fill colour of blue retain 70% or more of the catch, otherwise they are coloured grey.

Table 13: Number of records removed.

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
No Diver key	0	1	0	1	0	0	0	0	0	1	3
No Diving condition	110	63	71	66	54	69	32	32	37	29	563
kg/hr > 200	5	6	1	1	1	0	2	0	1	1	18

Table 14: Number of records remaining in the data set after grooming, where grooming takes place in the order shown in the table. Prior to these grooming steps some records that didn't contain information needed for the standardisation were removed (Table 13).

Fishing year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
Total PAI records	2 834	3 055	2 621	2 414	1 844	1 780	1 569	1 523	1 567	1 438	20 645
FIN sub-setting	1 356	1 944	1 979	2 014	1 567	1 405	1 284	1 225	1 222	1 201	15 197
Areas 17 and 38	1 125	1 776	1 823	1 756	1 511	1 299	1 202	1 112	1 081	1 087	13 772
Fine scale stat area with ≥10 dive days	1 122	1 769	1 816	1 753	1 508	1 296	1 198	1 112	1 081	1 084	137 39
Diver>= 10 dives days	1 057	1 683	1 750	1 669	1 443	1 251	1 181	1 093	1 014	1 026	13 167

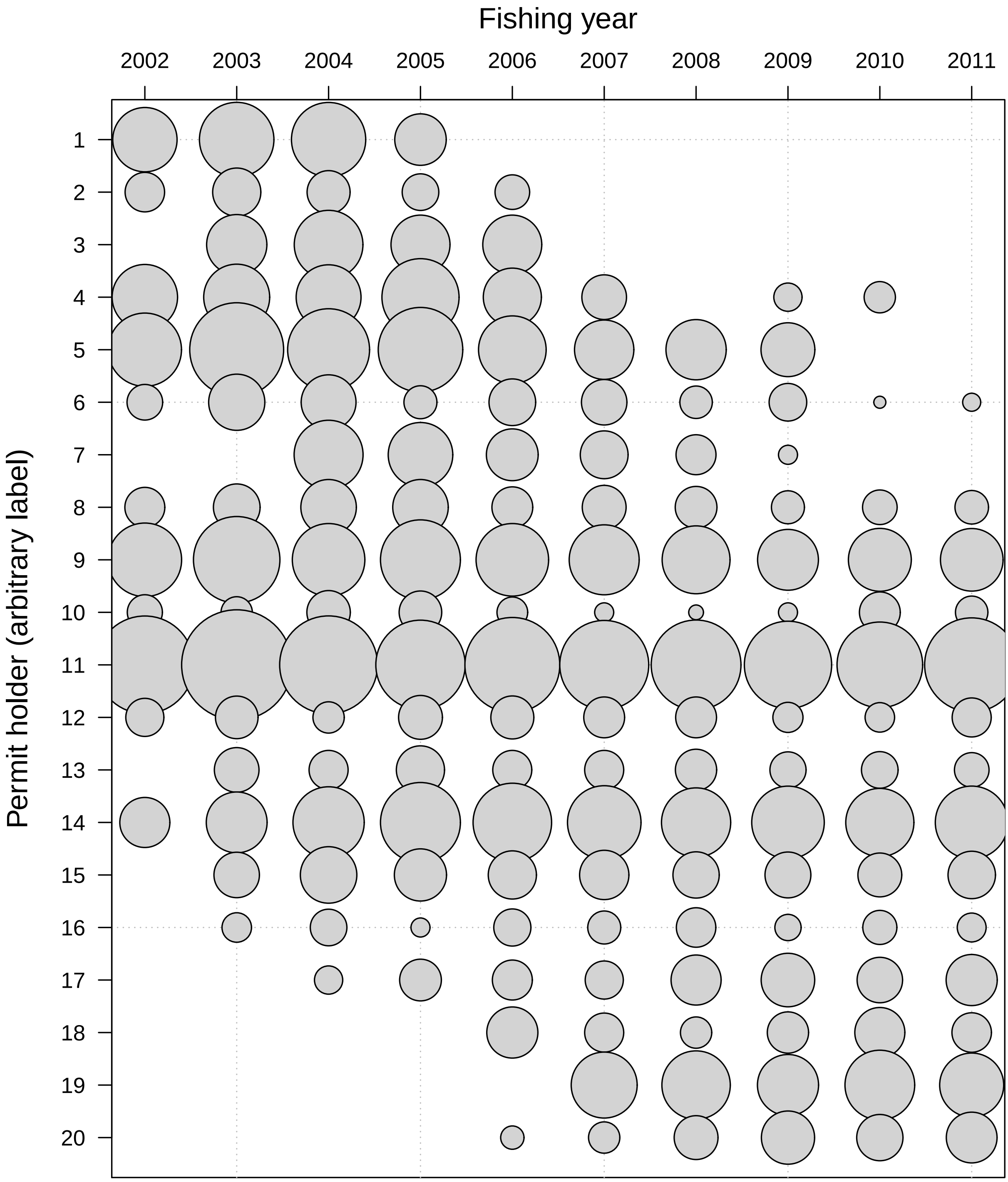

Figure 15: Number of daily records (diver days) by permit holder after data sub-setting. The area of the circle is proportional to the number of diver days; the maximum value is 335.

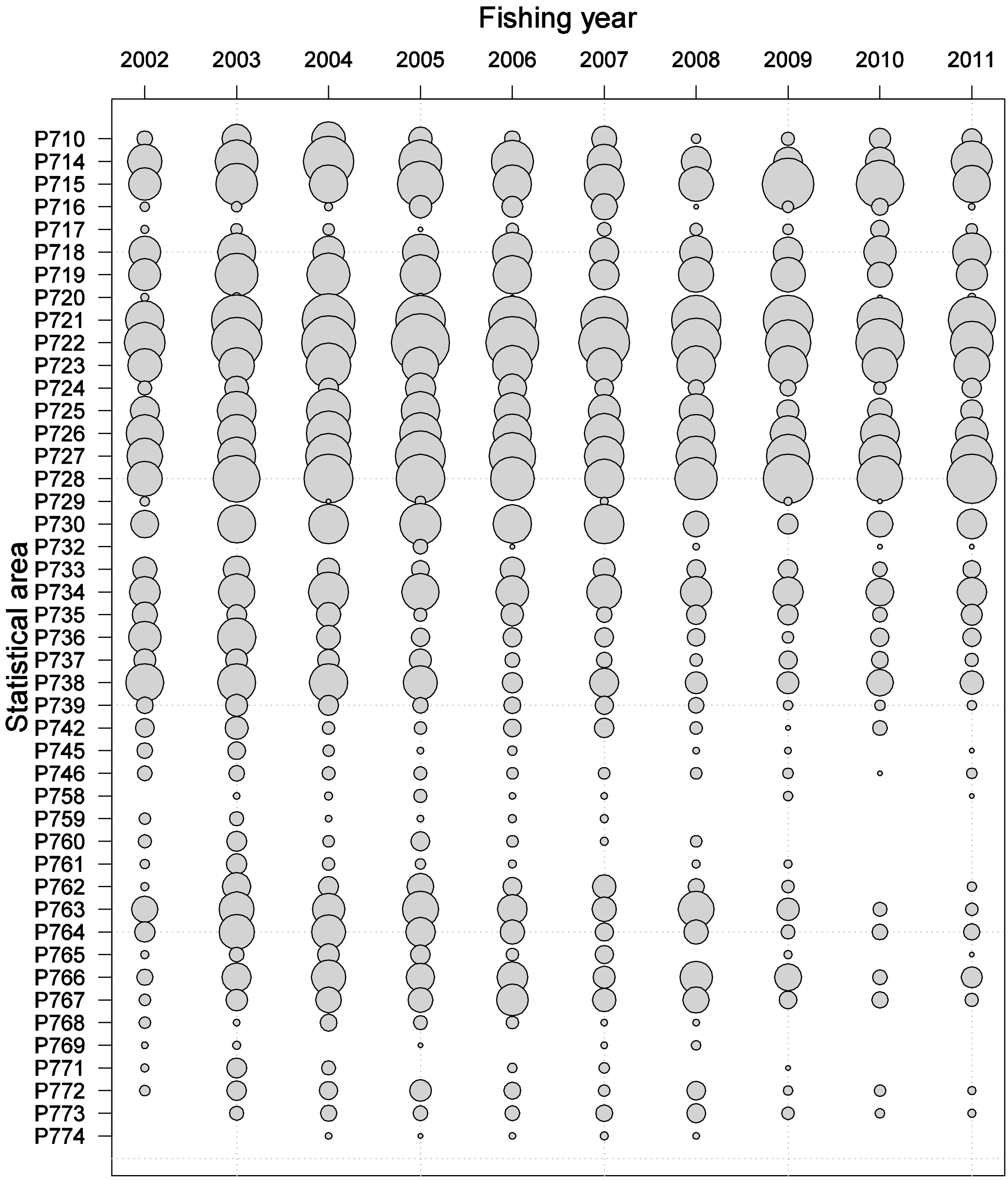

Figure 16: Number of days of effort by statistical area and fishing year. The area of the circle is proportional to the number of days of effort; the maximum value is 152.

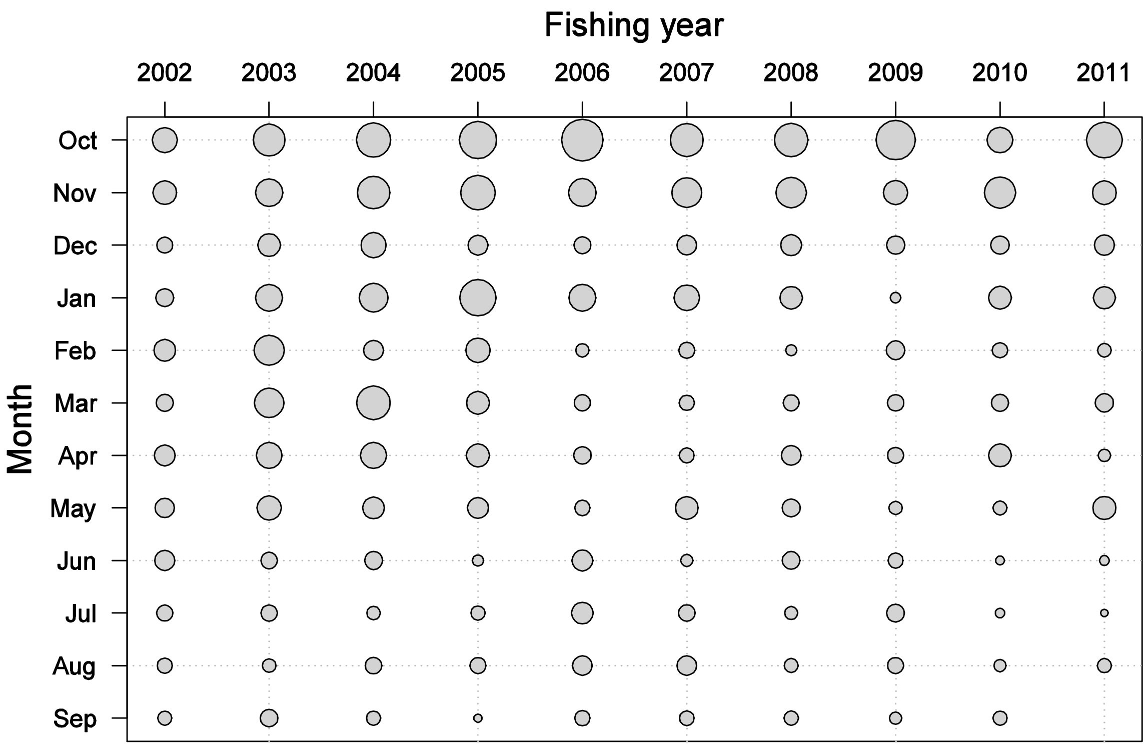

Figure 17: Number of days of effort by month and fishing year. The area of the circle is proportional to the number of days of effort; the maximum value is 415.

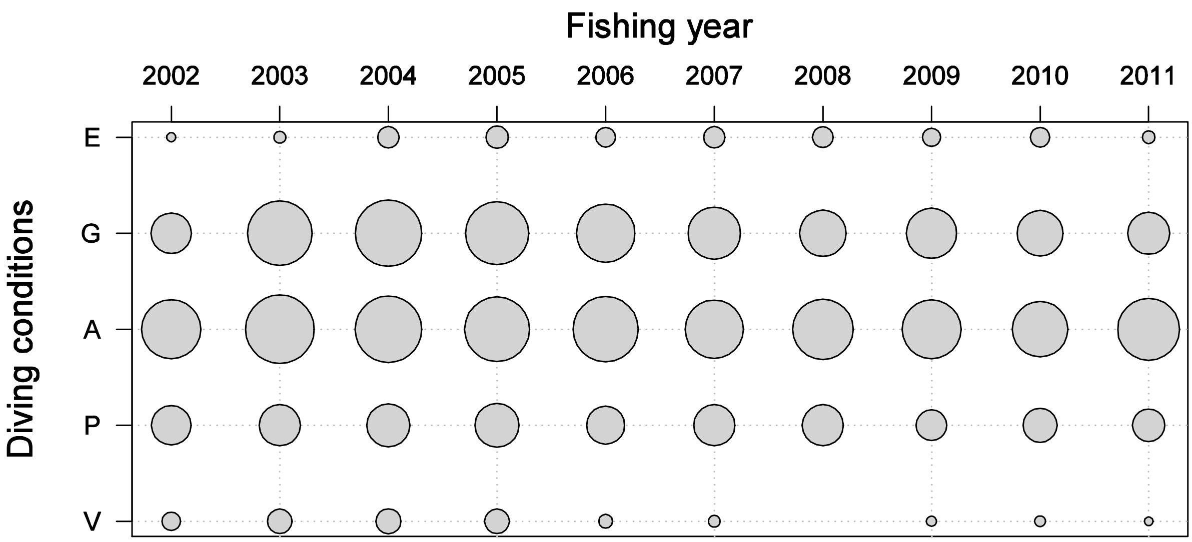

Figure 18: Number of days of effort by diving condition (excellent, good, average, poor, very poor) by fishing year. The area of the circle is proportional to the number of days of effort.

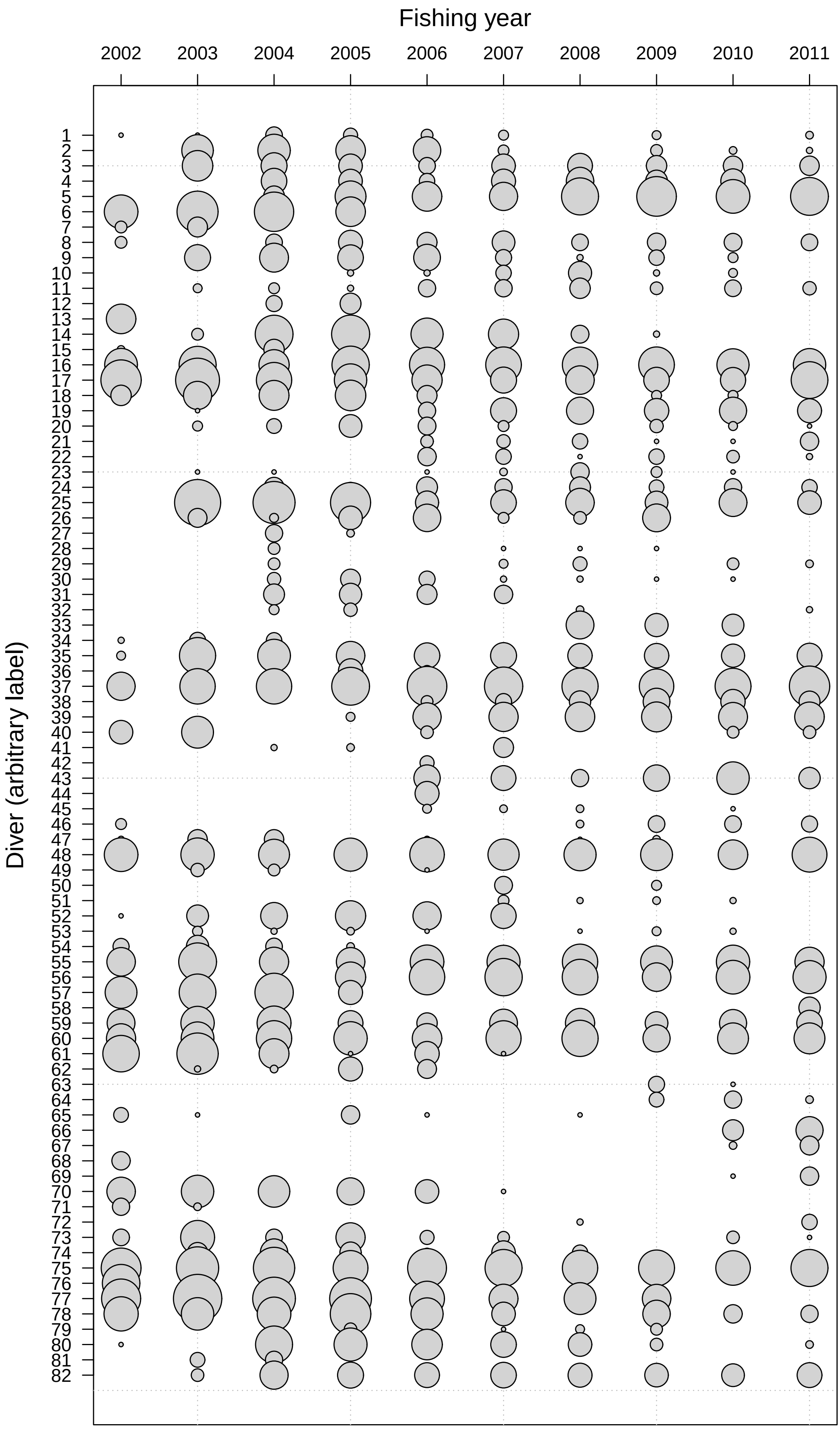

Figure 19: Number of days of effort by diver key and fishing year. The area of the circle is proportional to the number of days of effort; the maximum value is 118.

For the standardisation model catch rate (the dependent variable) was modelled as log(daily catch) with a normal error distribution. Variables offered to the model were fishing year, month, diver key, FIN (instead of vessel), statistical area, duration, and diving condition.

Except for dive condition and FIN, all variables were accepted into the model (Table 15), which explained 79% of the variability in CPUE. Most of the variability was explained by duration (47%) and diver (11%); both statistical area and month explained less than 2%. The effects appear plausible and the diagnostics are satisfactory (Figure 20).

The standardisation using FIN number is similar to the standardisation using vessel for data sub-setting, but has lower catch rates from 2006 onwards (Table 16, Figures 21–22).

For the FIN sub-setting the criterion of a minimum of four years with at least 40 records per year was used; this retained 76% of the original total catch (Table 17). However, in the 2002 and 2003 years the percentage of catch retained was 50% and 61% respectively, which is less than the desired 70% level. Changing the criterion to a minimum of four years with 20 records per year still leaves a catch percentage retained of less than 70% for 2002 and 2003 (Table 17). In any case, the standardised index is insensitive to the FIN data grooming (Figure 23), so the original criterion of a minimum of four years with at least 40 records per year is used.

Table 15: Variables included in the standardisation model (1% additional deviance explained), and the order in which they were accepted into the model. Shown in the columns are degrees of freedom (Dof) and Akaike Information Criterion (AIC). Variables marked with an asterisk were accepted into the final model.

	Dof	AIC	Percentage deviance explained	Additional % deviance explained
Fish year*	8	28559	18.5	18.5
Duration*	3	17222	65.6	47.1
Diver*	81	12373	76.5	10.9
Statistical area*	44	11384	78.3	1.8
Month*	11	10701	79.4	1.1
Dive Conditions	4	10271	80.1	0.7
FIN	18	10118	80.4	0.3

Table 16: Standardised PCPUE index and c.v.s.

Fishing year	Number of records	Index	c.v.
2002	1057	44.8	0.086
2003	1683	46.2	0.085
2004	1750	48.4	0.085
2005	1669	57.9	0.085
2006	1443	79.3	0.085
2007	1251	80.7	0.084
2008	1181	87.6	0.085
2009	1093	89.8	0.085
2010	1014	90.5	0.085
2011	1026	92.1	0.086

Table 17: Percentage of original catch by fishing year remaining after sub-setting on the FIN. The column "% total" is the percentage of the original catch remaining over the years 2002–2011 after the FIN sub-setting.

Min # years	Min # records	% total	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
4	40	76	50	61	74	81	85	83	82	82	82	86
4	20	87	60	68	82	91	95	96	96	92	93	96

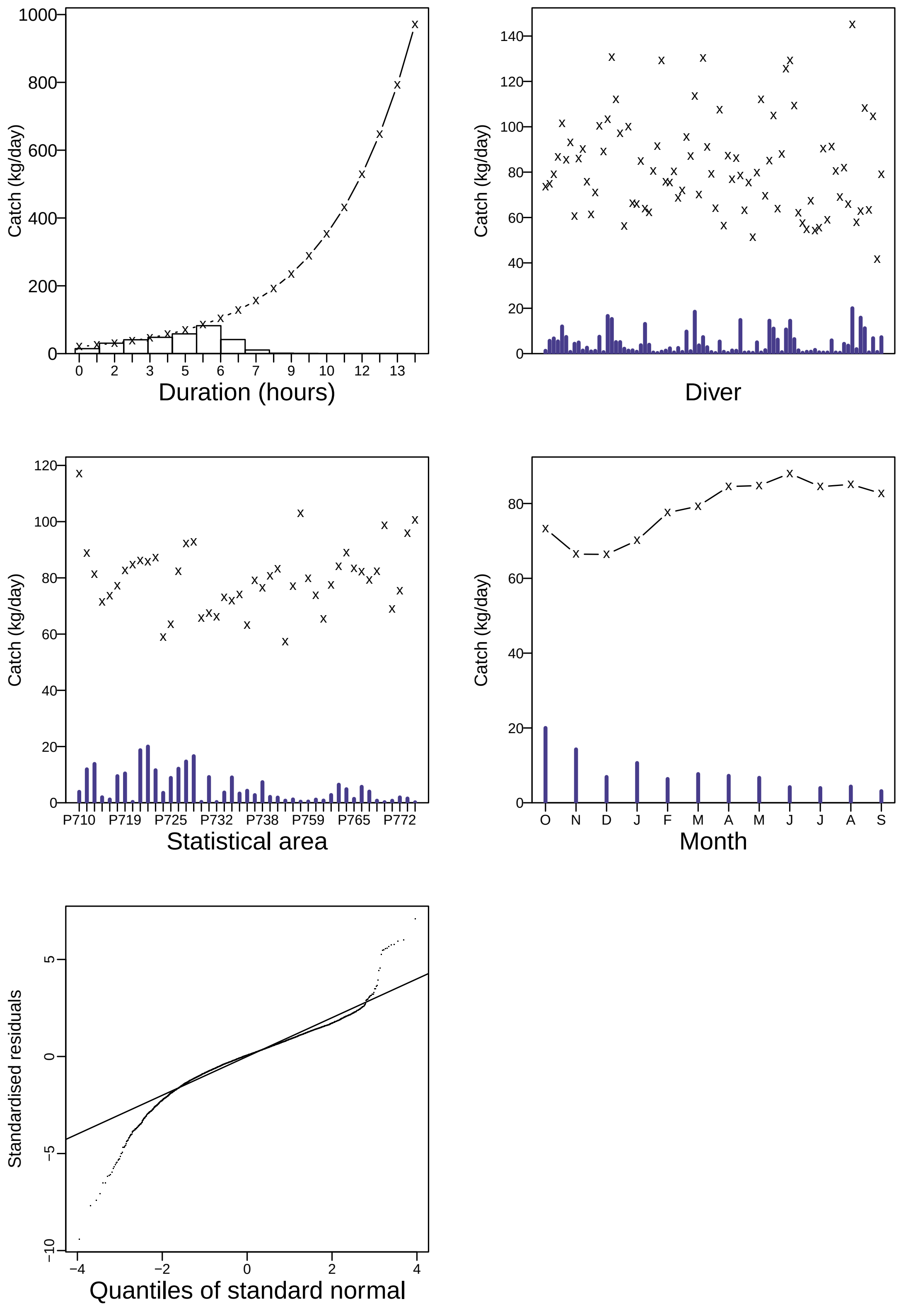

Figure 20: Effects and diagnostics for the standardisation model using FIN for data sub-setting. Effects catch rates are calculated with other predictors (e.g., diver, area, and month) fixed at the level for which median catch rates are obtained. Bar graphs show the distribution of data for each predictor. The diagnostic plot is shown in the bottom left-hand corner, and shows the sorted normalised residuals from the standardisation model (y-axis) plotted against the corresponding quantiles of the standard normal distribution (x-axis).

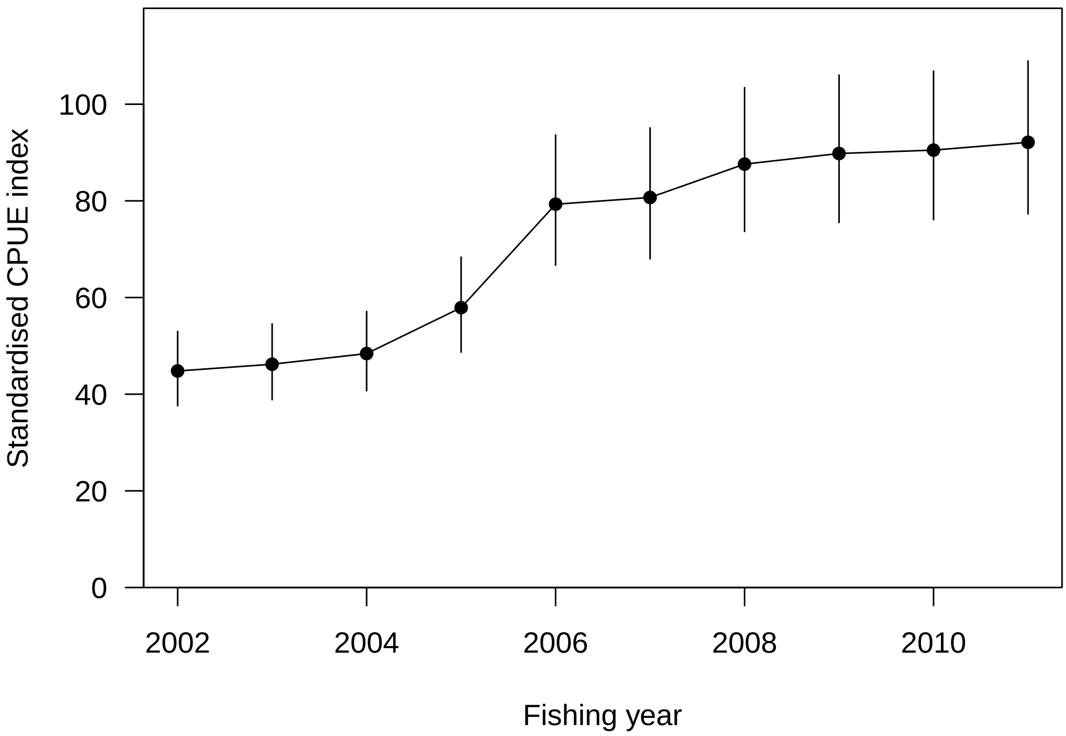

Figure 21: The standardised CPUE index using FIN for sub-setting with 95% confidence intervals.

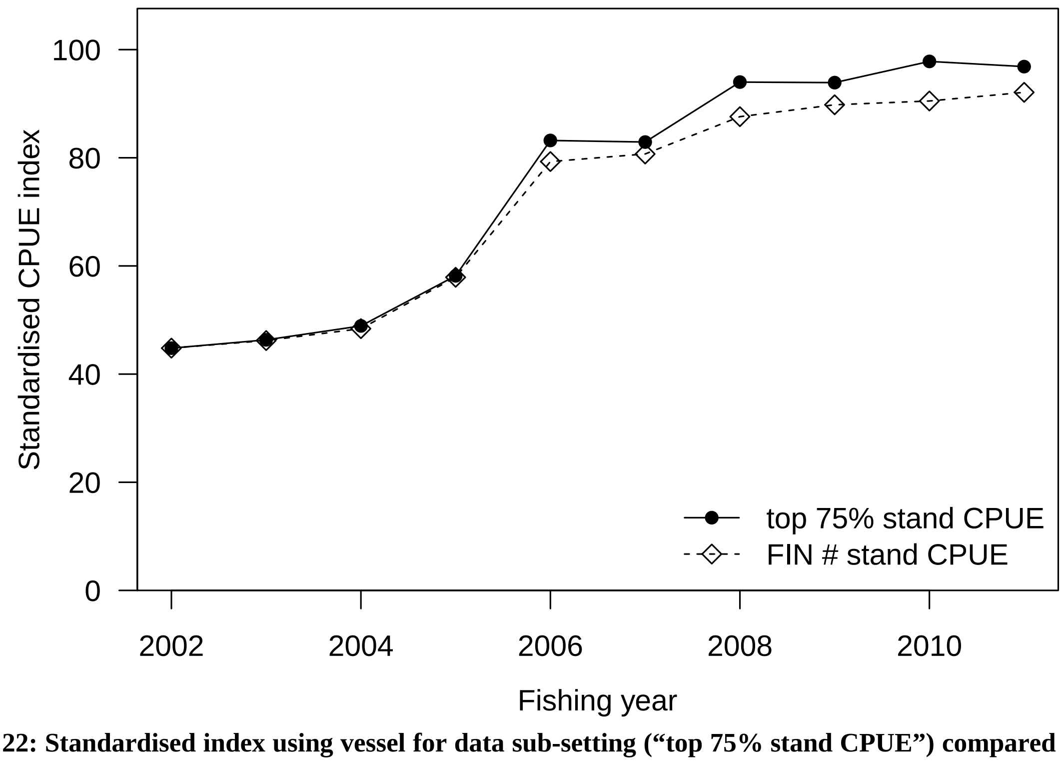

Figure 22: Standardised index using vessel for data sub-setting ("top 75% stand CPUE") compared to the index based on data sub-setting using the FIN ("FIN # stand CPUE"). The updated standardised index is scaled so that is has the same value in 2002 as the other index.

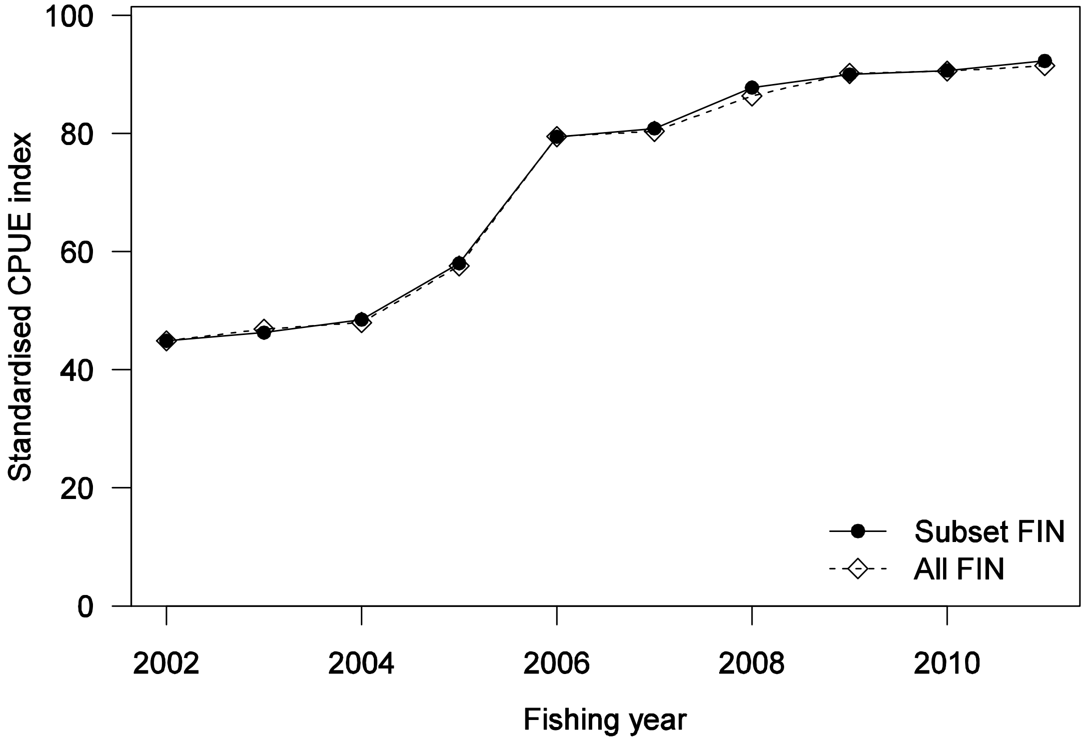

Figure 23: Comparing the standardised indices. The subset FIN index uses the sub-setting criterion of a minimum number of four years with at least 40 records in each year. For the "All FIN" index no sub-setting on FIN is done.

5. COMMERCIAL CATCH LENGTH FREQUENCY (CSLF)

5.1 Extracting and grooming

A new extract of Catch Sampling Length Frequency (CSLF) data was made from the *market* database on 1 September 2011. This totalled 18 234 records containing 129 424 measurements from 1990–94 and 1999–2010. Deducing the statistical area of each record required some analysis as it is not straightforward for much of the dataset. Statistical area information was obtained for 92% of records using a variety of fields in the data and lookup tables provided from previous assessments. Three records were removed as they reported lengths less than 108 mm or greater than 200 mm. Records that were not from Statistical Areas 017 or 038 were excluded from further analysis.

The number of records from each statistical area in each fishing year is shown in Table 18. The results are identical to the 2008 assessment except for the number of records with invalid length. This might be due to changes in the market database since the last assessment. Note that no area information was available for the 990 records from fishing year 1998.

The number of samples from each subarea is shown in Table 19. Most of the sampling effort was focused in Rununder, Perano, and Northern faces, which accounted for 65% of the samples taken in all years. The sampling coverage was reasonably representative of the commercial catch in the fishery from 2002 to 2010 (Figure 24)

McKenzie & Smith (2009a) weighted the length frequency by the ratio of area catch to the mean area catch within each year where data without area information were not added to the weighted length frequency distribution. We adopted a modified approach to calculate the length frequency using NIWA's 'catch-at-age' software (Bull & Dunn 2002). Preliminary analyses suggested there was no apparent temporal or spatial trend in the distribution of mean length in the commercial length samples. However the tag-recapture data suggested possible differences in growth rates between regions and paua collected from the southern part of PAU 7 appeared to have faster growth rates (see Section 8). Therefore it was decided to post-stratify the catch samples by area and two spatial strata were used: a northern stratum from Statistical Areas P710 to P729 (Staircase, Rununder, and Perano areas), and a southern stratum from Statistical Areas P730 to P789 (Northern faces and D'Urville). For samples collected before 2001 where fine-scale catch information was not available, a stratification based on Statistical Area 017 and 038 was used. 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 c.v 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.

Scaled length frequencies for all areas within PAU 7 combined are shown in Figure 25. The cumulative distributions of the scaled length frequencies suggest that paua in the commercial catch were smaller in the years since 2001 (Figure 26). The length frequencies appeared to be similar among subareas after 2002 (Figure 27). However, in Staircase, a significant number of large paua were sampled in 2007; In D'Urville, larger paua were sampled in earlier years than in recent years.

Table 18: Number of paua measured in each statistical area in each fishing year.

Fishing year	Removed	017	038	018	036	Unknown	Total
1990	0	1 736	2 990	0	0	0	4 726
1991	0	4 716	4 861	2 837	0	0	12 414
1992	0	6 771	1 988	655	643	0	10 057
1993	0	5 485	2 475	1 623	0	0	9 583
1994	0	7 037	1 715	924	0	0	9 676
1998	0	0	0	0	0	990	990
1999	0	4 143	1 056	95	0	0	5 294
2000	0	5 382	0	212	409	1 886	7 889
2001	0	3 167	299	773	705	1 740	6 684
2002	0	6 418	0	1 184	0	337	7 939
2003	0	6 424	445	1 090	189	690	8 838
2004	0	4 305	0	0	0	673	4 978
2005	0	4 022	0	136	0	579	4 737
2006	0	2 641	0	0	0	542	3 183
2007	3	5 463	0	0	0	0	5 466
2008	1	9 101	253	152	0	0	9 507
2009	0	5 388	189	273	0	0	5 850
2010	0	10 532	216	582	283	0	11 613
Total	4	92 731	16 487	10 536	2 229	7 437	129 424

Table 19: Number of market shed length frequency samples by subarea and by fishing year.

Fishing year	East coast	Staircase	Rununder	Perano	Northern faces	D'Urville	West coast	Other	Unknown	Total
1990					4	4				8
1991	8				11	11				30
1992	2				19	6	2			29
1993	5	6	2		5	7				25
1994	3	7	5	8	1	5				29
1998									8	8
1999	1		4	1	27	6				39
2000	4	2	22	10	6		4	6	18	72
2001	5		6	3	4	1	5	2	14	40
2002	8	4	6	8	4	1		4	2	37
2003	7	1	8	6	11	2	1	1	3	40
2004	1	2	10	10	8	4			5	40
2005	1	2	12	5	8			7	5	40
2006		2	10	5	4			3	5	29
2007		1	13	9	12					35
2008	1	3	31	11	17	4		5		72
2009	5	3	17	19	7	3				54
2010	6		44	28	20	2	3	5		108
Total	57	33	190	123	168	56	15	33	60	735

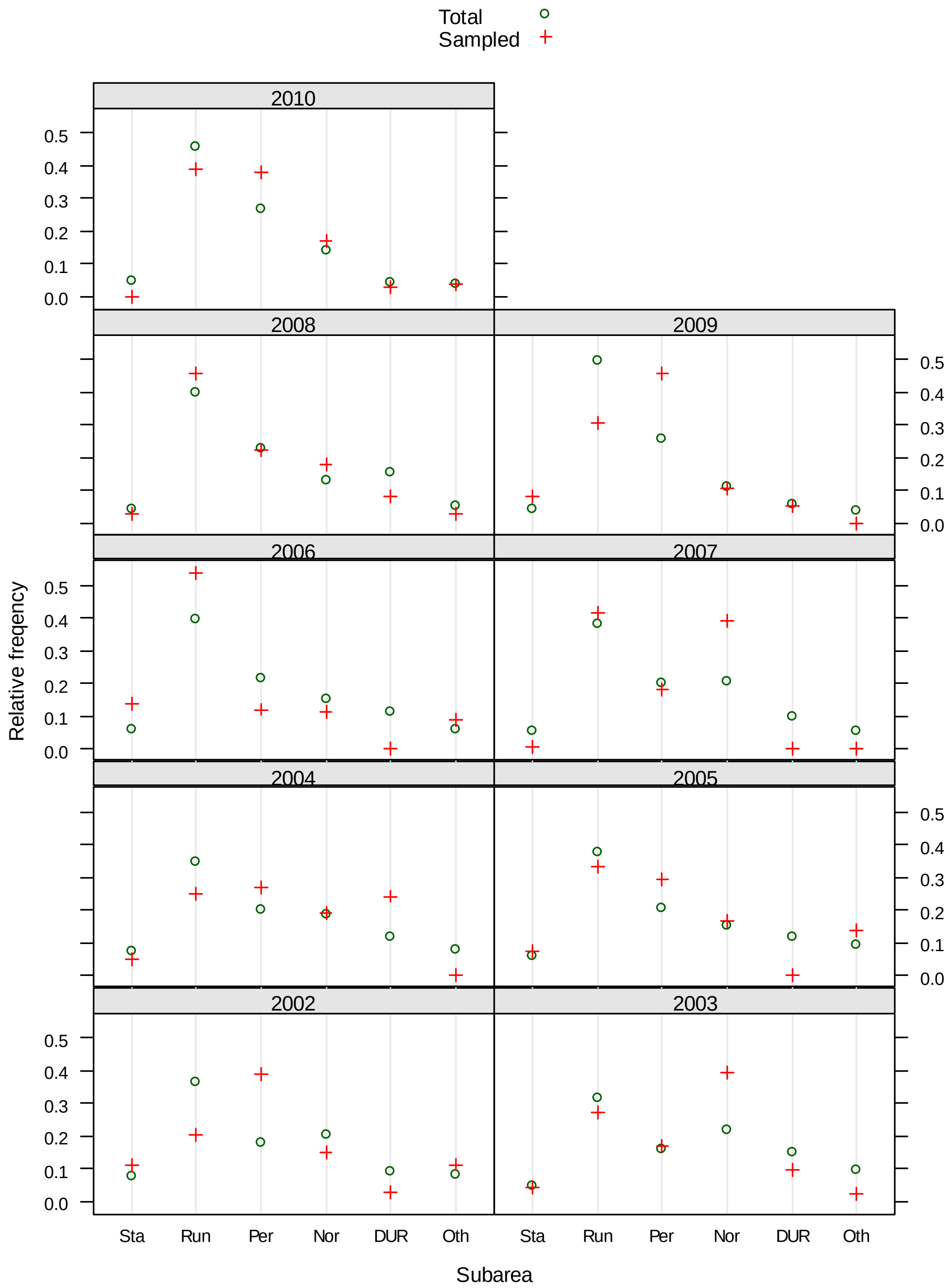

Figure 24: Proportion of total PCELR estimated catch (circles) and the proportion of sampled catch (crosses) that occurred in each subarea from Statistical Area 017 and 038 for 2002–2010 fishing years. "Sta" Staircase; "Run" Rununder; "Per" Perona; "Nor" Northern faces; "DUR" D'Urvelle; "Oth" Other.

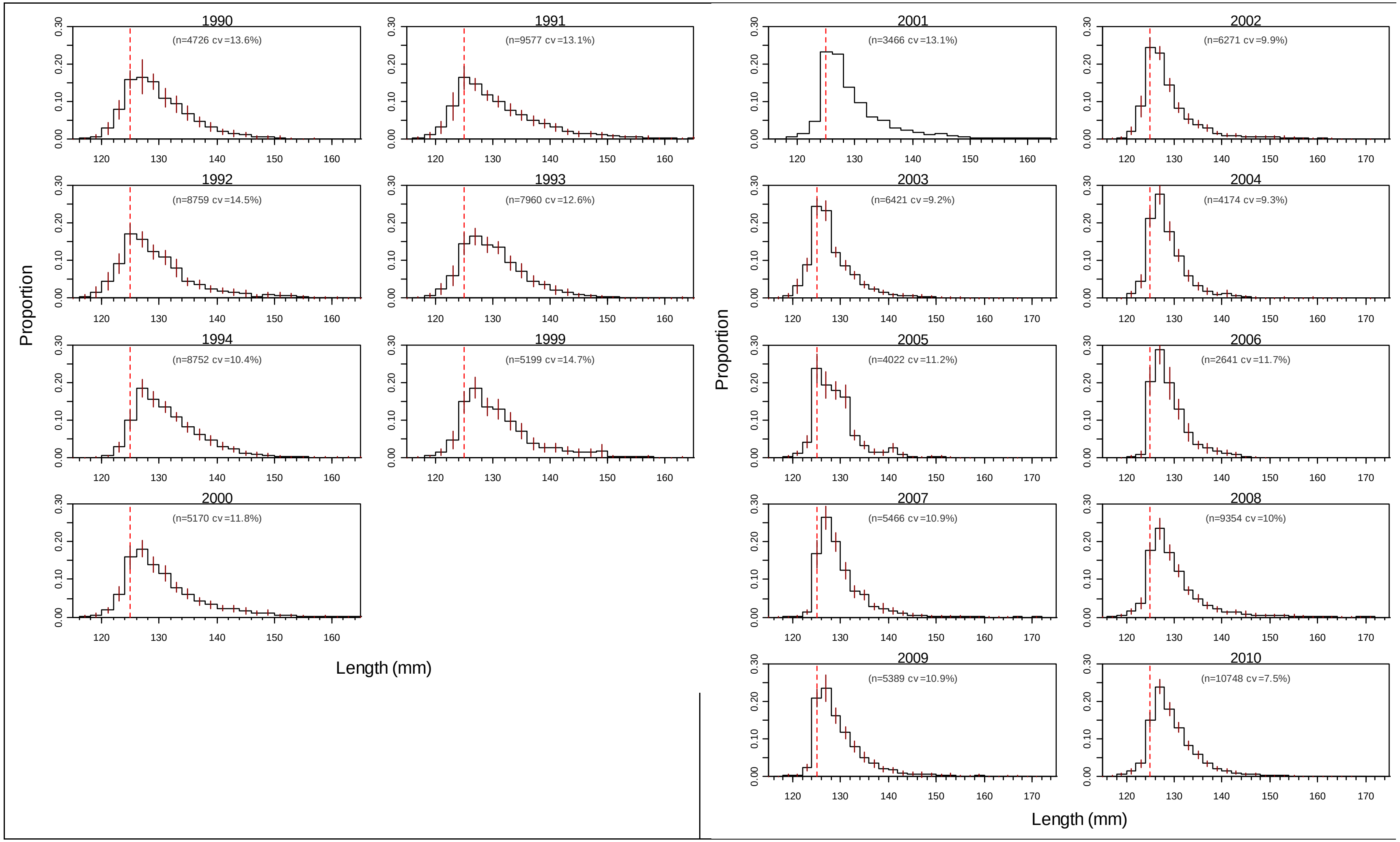

Figure 25: Scaled length frequency from commercial catch sampling in PAU 7 for fishing years 1990–1994 1999 and 2000 (left) and 2001–2010. The dashed line indicates the MLS of 125 mm.

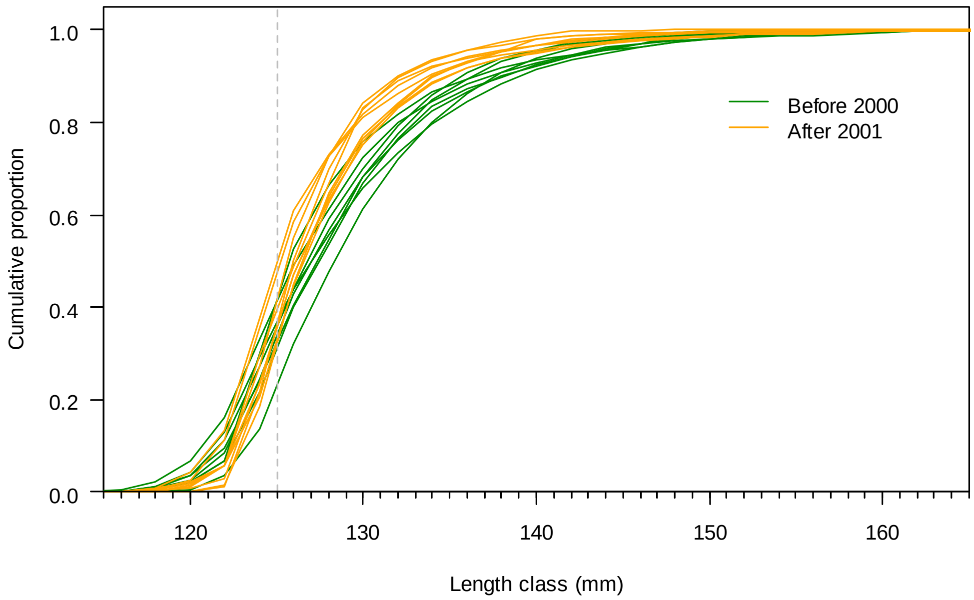

Figure 26: Cumulative distribution of the scaled length frequency from commercial catch sampling in PAU 7 for 1990–1994, 1999 and 2000 (green) and 2001–2010 (orange). The dashed line indicates the MLS of 125 mm.

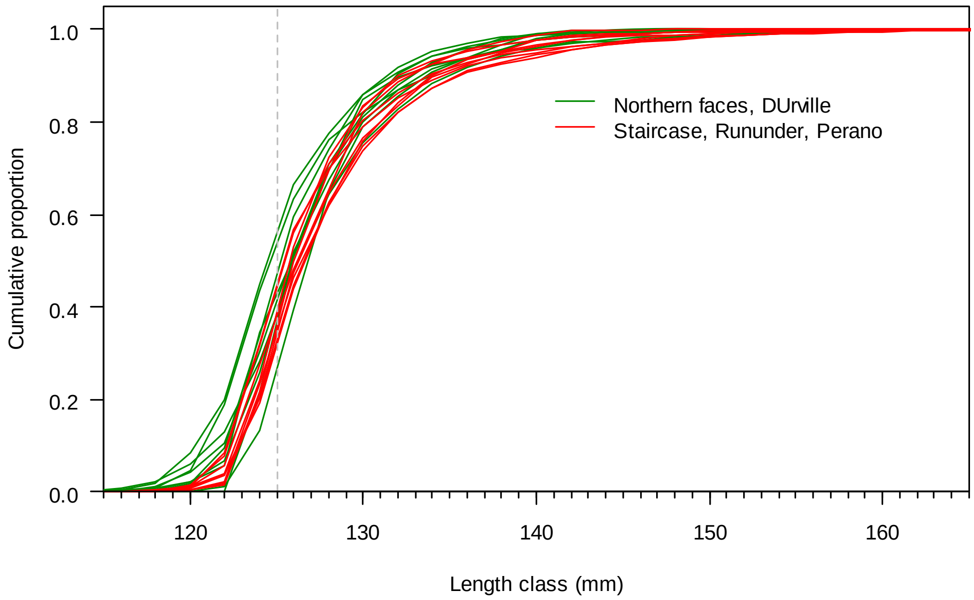

Figure 27: Cumulative distribution of the scaled length frequency from commercial catch sampling in PAU 7 by subarea samples collected between 2002 and 2010. The dashed line indicates the MLS of 125 mm.

6. RESEARCH DIVER SURVEY INDEX (RDSI)

Research diver surveys based on a timed-swim method as developed by McShane (1994, 1995) and modified by Andrew et al. (2000a) have been conducted to assess the relative abundance of New Zealand paua stocks since 1991 (Andrew et al. 2000b, 2000c, 2002, Naylor & Kim 2004). Relative abundance indices estimated from the survey data (RDSI) have been routinely used in paua stock assessment (Breen & Kim 2003, 2005, Breen & Smith 2008a, 2008b). The previous stock assessment for PAU 7 used the RDSI developed from the survey data up to 2005 (McKenzie & Smith 2009a, 2009b). There has been no new survey since last assessment and the same survey data was used for this assessment.

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

The survey follows a stratified-random design (Naylor & Kim 2004). The coastline of PAU 7 was divided into six strata (Figure 28). Each stratum was subdivided into 200 m wide strips, each of which was considered a potential sampling site. Each year sites were randomly selected within strata (chosen sites containing unsuitable habitat were replaced and also permanently discarded from future surveys). Not all strata were surveyed each year and the number of sites sampled within each stratum was chosen to provide mean relative abundance with c.v.s less than 20% based on the variance estimated from previous surveys.

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

Before 1997 only the patch category was recorded and total counts were inferred from estimates of the mean of the patch category (Table 20). Since 1997 the actual number of paua in patches was recorded. Paua are considered to be in the same patch if they are separated by less than two body lengths. Recent swim data therefore provide integer counts of paua whereas the previous estimates will generally be non-integer.

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

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

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

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

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

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

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

where t is the recorded time to the first paua found (for early surveys an average of the time to first paua from later surveys was used), n_1, n_2 and n_3 are the number of patches in categories 1, 2 and 3 (see Table 20) and 4, 9 and 14 are the estimated times for processing respective patch categories. The search time was included in the standardisation model as an offset term.

To minimise the effects of visibility and differences between divers on estimates of relative abundance, the timed-swim counts were standardised using GLMs (Venables & Ripley 2002). However, a range of standardisation methods has been used in previous studies: Breen & Kim 2005 used a standard linear regression for calculating RSDI for the 2005 PAU 7 assessment; More recently a negative binomial model has been used to standardise the RSDI indices (Breen & Smith 2008a, Cordue 2009). Middleton (2009) examined alternative models fit for PAU 7 RSDI indices and suggested that the negative binomial model provides a better fit than the normal model.

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

The number of paired-swims by stratum is summarised in Table 21. Stratum Campbell lies mostly in Statistical Area 018 (Figure 28) and therefore was excluded from the standardisation. Data from 1993 and 1994 fishing year were combined and were assigned fishing year 1993. The unstandardised RDSIs (mean diver counts) for each stratum are shown in Figure 29 and the standardised RDSIs for all areas combined in Figure 30 (RDSI were derived for each fishing year as opposed to the calendar year used in the 2005 assessment).

Table 20: Definition of patch type by number of paua and the estimates of mean number per patch for PAU 7 (also see Table 13 of Breen & Kim 2005).

Patch type	Patch size	estimates
1	1–4	1.48
2	5–10	6.76
3	11–20	14.05
4	21–40	28.15
5	41–80	54.15
6	>80	155.63

Table 21: Number of paua research survey divers (paired swims) in PAU 7 by stratum and fishing year.

	Campbell	Staircase	Rununder	Perano	Northern faces	D'Urville
1993	–	–	–	–	14	14
1994	–	–	16	15	–	–
1995	–	2	2	–	15	–
1996	–	3	22	15	–	12
1999	–	5	20	20	19	20
2001	–	4	16	16	16	20
2003	15	6	15	15	15	15
2005	3	6	11	19	16	15

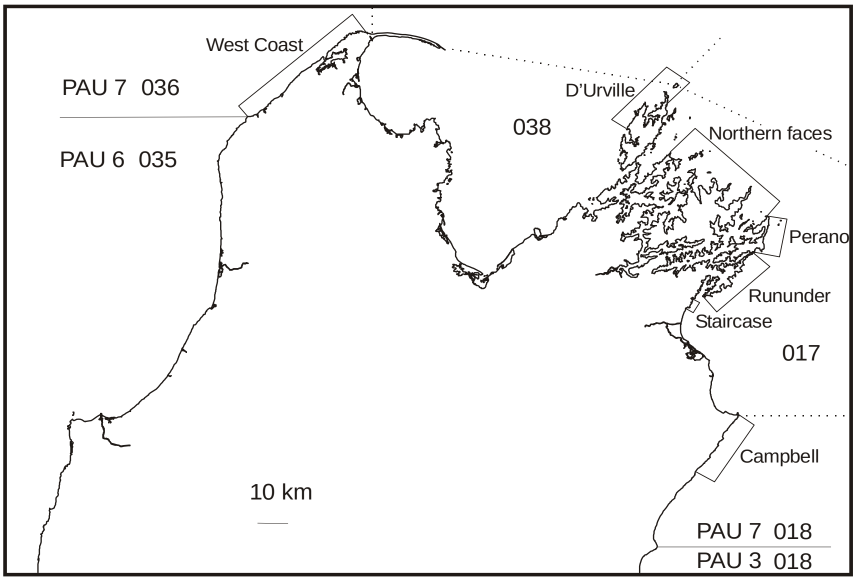

Figure 28: Research survey strata within PAU 7.

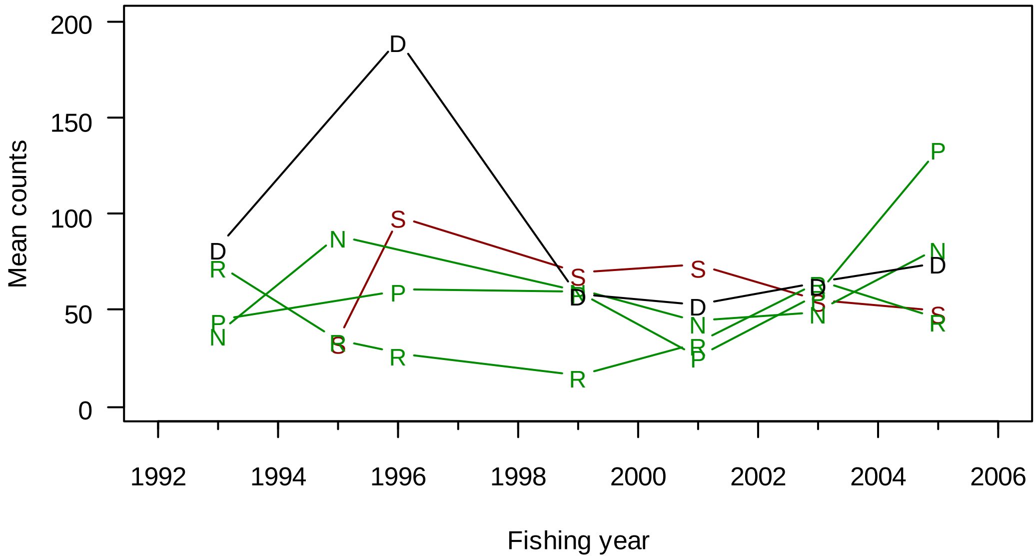

Figure 29: Mean diver counts by research stratum and fishing year for PAU 7. S Staircase; R Rununder; P Perano; N Northern faces; D D'Urville.

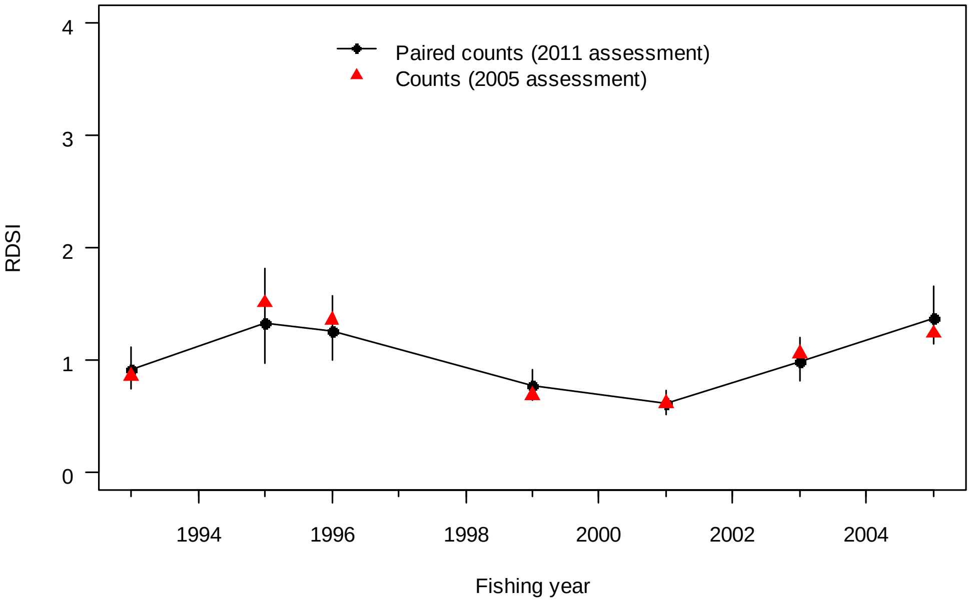

Figure 30: The standardised RDSI from the negative-binomial GLM models fitted to paired diver counts for surveys in Statistical Area 017 and 038 within PAU 7.

7. RESEARCH DIVER LENGTH FREQUENCY (RSLF)

Paua were sampled to estimate the size composition at each site from the research diver survey where the first four paua encountered from each patch were collected (Table 22). This protocol meant that relatively more paua from small patches were measured than from larger patches; we assume there are no differences in the length composition of paua in patches of different size. Shells were measured to the nearest millimetre with vernier calipers at their longest basal length. Basal length does not include any overhang of the shell spire and in this respect differs from total length (lowest measurement on the anterior-posterior axis) which is used in the commercial fishery to define minimum legal size (125 mm). The data were grouped into 2 mm size classes for presentation with paua longer than 170 mm being pooled into a single size class. A few paua less than 70 mm were excluded from the length frequencies.

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

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

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

We adopted a modified approach to calculate the length frequency by scaling the length frequency from each sample (as per paired swim) up to the total counts at each stratum:

$$L_{s,j,y} = L'_{s,j,y} \frac{N_{j,y}}{n_j}$$

where $L'_{s,j,y}$ is the raw frequency at size s from the j^{th} stratum in year y $N_{j,y}$ is the paua count in the j^{th} stratum in year y and n_j is the number of paua in the sample at the j^{th} stratum.

The scaled length frequencies were then combined across strata to obtain the overall length frequency for each year. As the total number of paua in the population is unknown at stratum level each stratum is assumed to carry the same weight in combining the length frequency across strata. Scaled length frequencies were calculated for all strata combined (Figure 31). Note that only paua greater than 70 mm in length were included.

Table 22: Number of paua sampled from the research diver survey by stratum and fishing year.

	Staircase	Rununder	Perano	Northern faces	D'Urville
1990	127	53	0	526	333
1992	0	785	616	0	0
1993	0	0	0	63	1 717
1994	0	1 135	694	0	0
1995	492	106	0	2 818	0
1996	491	785	677	0	1 621
1999	530	693	662	1 714	2 076
2001	432	496	583	1 161	1 677
2003	438	857	745	1 016	1 618
2005	452	601	911	1 459	1 576

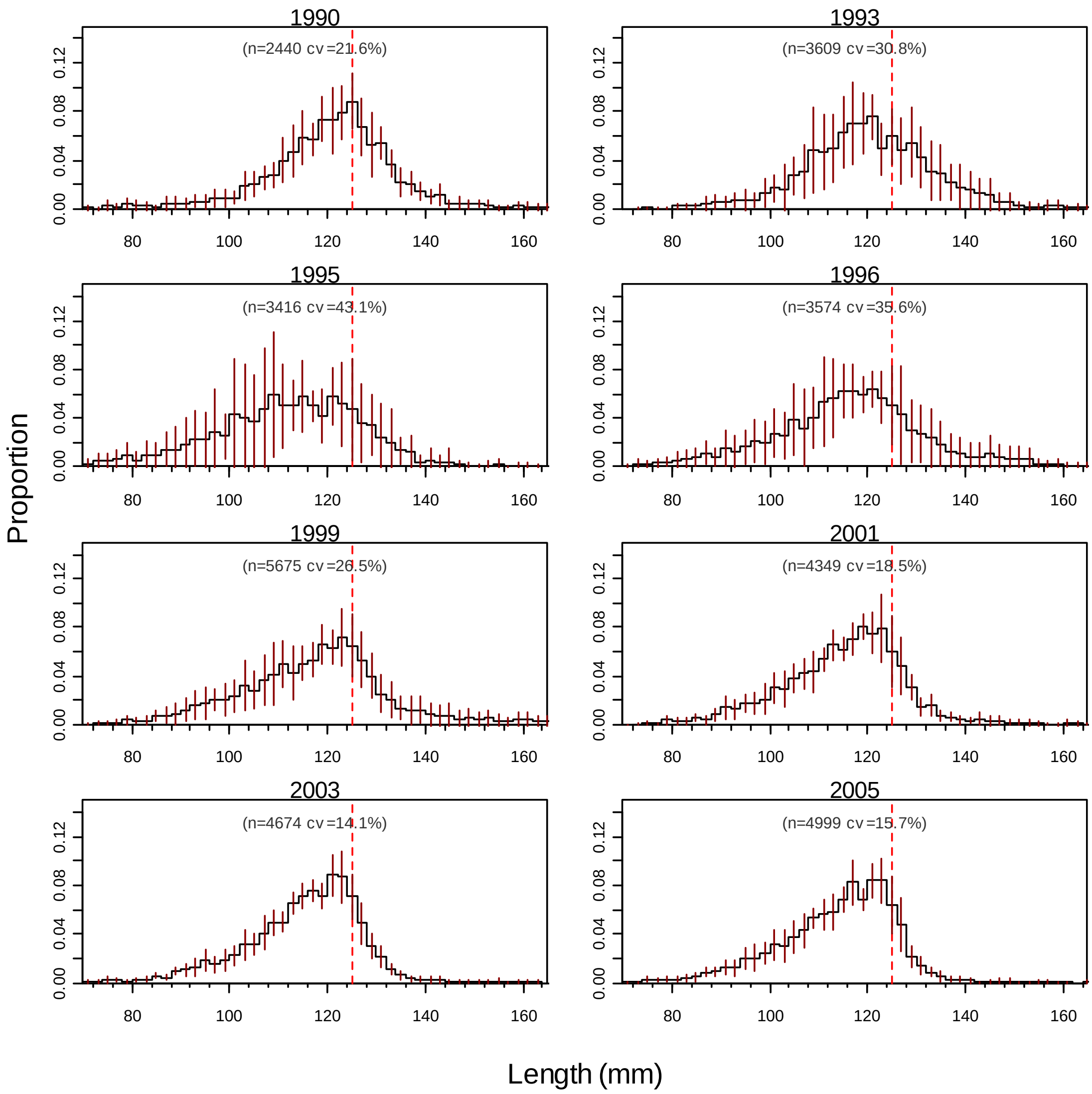

Figure 31: Scaled length frequency from research diver survey sampling in PAU 7 for fishing years 1990, 1993, 1995, 1996, 1999, 2001, 2003, and 2005. The dashed line indicates the MLS of 125 mm.

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Tag and recapture experiments were conducted at different times and at several sites in PAU 7 and were restricted to Statistical Area 017 and 018 (Breen & Kim 2003). Growth data collected from these experiments were available from Staircase (n=48), Rununder (n=63), Perano (n=68), Northern faces (n=505), and D'Urville (n=211). The growth dataset comprises 895 records with initial lengths ranging from 36 to 142 mm, time at liberty ranging from 237 to 634 days and annualised increments ranging from -5 to 93 mm. These data were incorporated into the PAU 7 assessment to estimate growth. No new tag recapture data for since the last PAU 7 assessment have been collected.

Following Breen & Kim (2003).we removed all records for paua tagged at sizes smaller than 70 mm (176 records nearly all from D'Urville) because the model does not represent paua less than 70 mm in length. We also removed records for paua with growth increment greater than 40 mm (6 records) which are likely to be measurement errors.

The data were analysed using a number of length-increment growth models. With the linear growth model (Francis 1988) the expected annual growth increment for an individual of initial size L_k is

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

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

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

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

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

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

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

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

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

Annual growth increment measurements were considered. The exponential growth model was fitted to the data for all areas combined assuming a constant coefficient of variance at length (Figure 32). The growth parameters at $L_1 = 75$ mm and $L_2 = 120$ mm were estimated as $g_1 = 15.4$ mm and $g_2 = 6.8$ mm. Variation in growth had an estimated c.v. of 0.46 and $\sigma_{\min} = 1.12$ mm; and estimated measurement error σ_E was 2.46 mm.

These data suggested large variations in growth rates between areas: growth rates in D'Urville were significantly lower than the rest of PAU 7 whereas Rununder and Perano appeared to have much faster growth rates (Figure 32). Because D'Urville is comprised of mostly stunted paua and this area has contributed only a small proportion of the total catch, the Shellfish WG suggested tag-recapture data from D'Urville should be excluded when estimating growth in the assessment model. Figure 33 shows a number of estimated growth curves from various subsets of data (D'Urville was excluded in all cases). In the base case model run, the growth was estimated using data from Rununder, Perano, Staircase, and Northern faces.

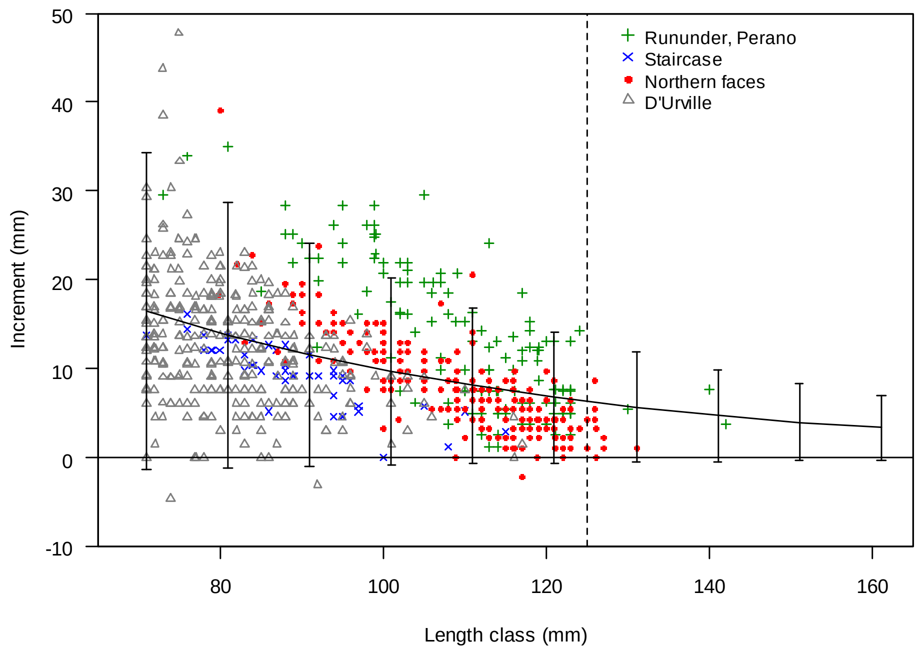

Figure 32: Initial size and mean annual increment from the tag-recapture data within PAU 7 for all areas combined. Lines (and 95% confidence intervals) indicate size-based exponential growth curves estimated from these data. Dashed line indicates the legal size limit (125 mm).

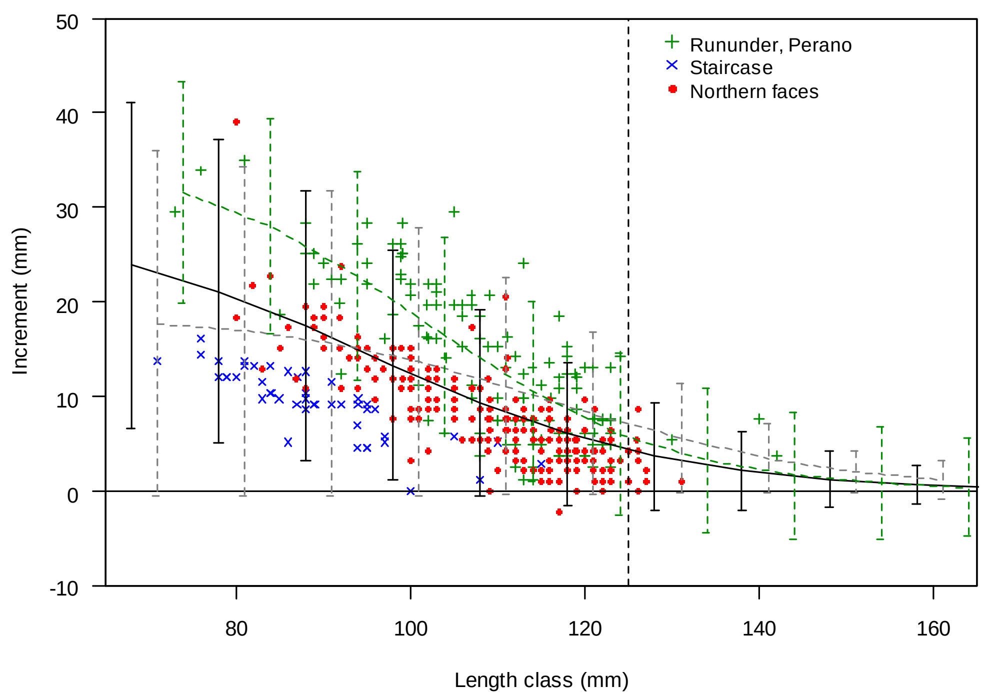

Figure 33: Initial size and mean annual increment from the tag-recapture data within PAU 7 excluding D'Urville. Black line (and 95% confidence intervals) indicate exponential growth curves estimated from all of these data; Grey line (and 95% confidence intervals) indicate exponential growth curves estimated from data excluding Northern faces; Green line (and 95% confidence intervals) indicate exponential growth curves estimated from data excluding both Northern faces and Staircase. Dashed line indicates the legal size limit (125 mm).

9. MATURITY

Data had been collected from one site at Staircase (n=39) and six sites (n=135) at D'Urville in March and May 1994 and from 15 sites at Northern faces (n=295) in May 1995. More data were collected during January 2005 during research diver surveys at Perano (n=116) and Rununder (n=124). Paua were checked for maturity and for sex if mature. In all 724 paua were examined. Data were aggregated for the assessment across all areas and dates. They were collated as the number examined and the number mature in 2-mm length bins (Table 23). There are no new maturity data for PAU 7 since January 2005.

Paua below 70 mm were discarded from the dataset. The proportion mature data were fitted with a logistic curve using a binomial likelihood (Figure 34). Length at 50% maturity ($L_{50\%}$) was estimated to be about 87.9 mm and Length at 95% maturity ($L_{95\%}$) about 106.5 mm. The estimated length at maturity was different to that from the last assessment in which data from Northern faces were not used ($L_{50\%}$ = 90.7 mm and $L_{95\%}$ = 102.3 mm). This is because about 25% of the animals less than 80 mm from Northern faces are mature whereas there were no mature paua less than 80 mm from other areas. The Working Group suggested excluding data from Northern faces in the base case model run.

Table 23: Number of paua observed and proportion mature (with lower and upper limit) by 2 mm length class from the samples collected within PAU 7.

Bin (mm)	Sample size	No. mature	Proportion mature	Lower limit	Upper limit
70	7	0.00	0	–	–
72	17	0.06	1	0.00	0.29
74	21	0.00	0	–	–
76	29	0.34	10	0.18	0.54
78	30	0.13	4	0.04	0.31
80	29	0.28	8	0.13	0.47
82	43	0.35	15	0.21	0.51
84	44	0.32	14	0.19	0.48
86	35	0.54	19	0.37	0.71
88	69	0.51	35	0.38	0.63
90	44	0.57	25	0.41	0.72
92	38	0.47	18	0.31	0.64
94	57	0.77	44	0.64	0.87
96	51	0.76	39	0.63	0.87
98	45	0.87	39	0.73	0.95
100	24	0.92	22	0.73	0.99
102	21	1.00	21	–	–
104	21	0.95	20	0.76	1.00
106	25	0.96	24	0.80	1.00
108	37	0.97	36	0.86	1.00
110	16	1.00	16	–	–
112	3	1.00	3	–	–
114	1	1.00	1	–	–
116	1	1.00	1	–	–
124	1	1.00	1	–	–

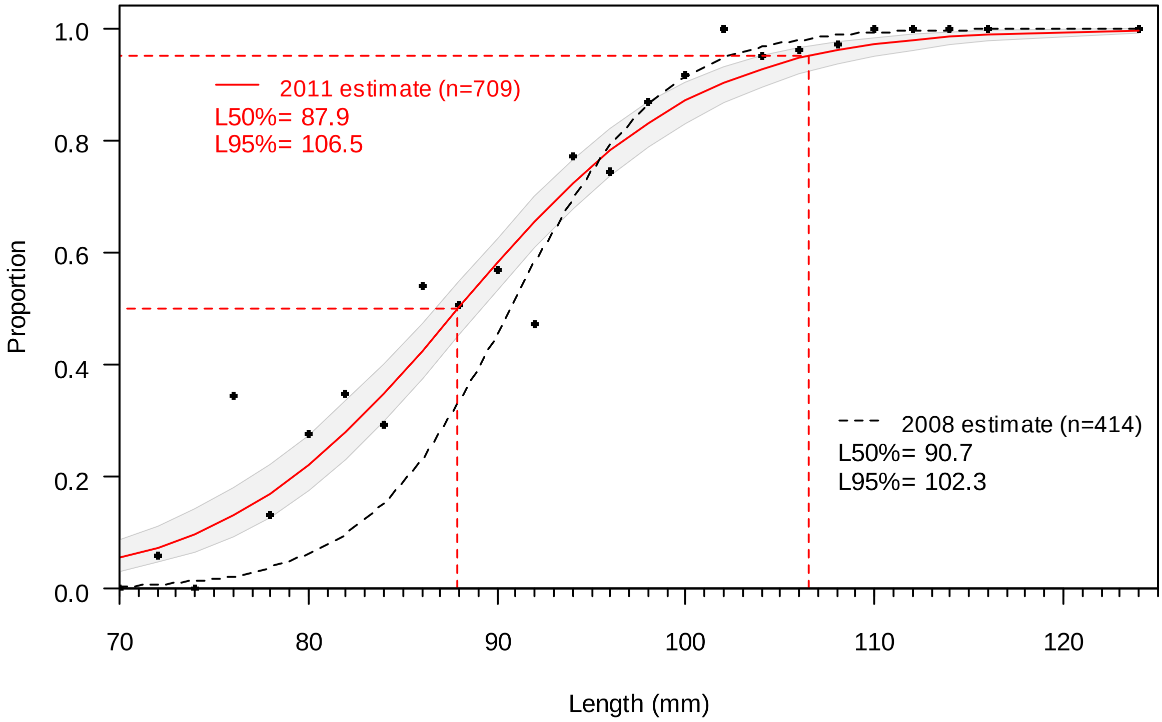

Figure 34: Proportion of maturity at length. The dots represent the observed proportion mature for each 2 mm length bin. The red line represents a fitted logistic maturity curve. The grey area represents the 95% confidence interval of estimated proportion. The dash lines represent estimated length at 50% and 95% maturity.

10. ACKNOWLEDGMENTS

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APPENDIX A

Table A1: PAU 7 general statistical area and associated fine-scale paua statistical areas

General statistical area	Paua statistical areas
018	P701–P709
017	P710–P764
038	P765–P790
036	P791–P797

Table A2: Some PAU 7 sub-areas and research strata and associated fine-scale paua statistical areas

Subarea and stratum	Paua statistical areas
East coast	P701–P710
Campbell	P701–P709
Staircase	P714
Rununder	P715–P723
Perano	P726–P729
Northern faces	P730–P748
D'Urville	P763–P773
West coast	P790–P797

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

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