Summary of input data for the 2010 PAU 5A stock assessment

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EXECUTIVE SUMMARY

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The stock assessments for PAU 5A were previously carried out at the QMA level. The Shellfish Working Group suggested conducting the 2010 stock assessment for two subareas of PAU 5A separately: a southern area including Chalky and South Coast, and a northern area including Milford, George, Central, and Dusky. This report summarises the data inputs for the 2010 stock assessment of blackfoot paua (*Haliotis iris*) for the two subareas.

The data for the assessment were: (1) standardised CPUE series based on CELR data; (2) standardised CPUE series based on PCELR data; (3) standardised research diver survey indices; (4) research diver survey proportions-at-lengths series; (5) commercial catch sampling length frequency series; (6) tag-recapture length increment data; (7) maturity-at-length data.

Catch history encompassed commercial, recreational, customary, and illegal catch. Three alternative assumptions were made for estimating the commercial catch history for PAU 5A: 18% (lower bound), 40% (base case), and 61% (upper bound) of the catch in Statistical Area 030 was assumed to have been taken from PAU 5A between 1985 and 1996. Assumptions have also been made on the split of the catch between the northern and southern strata for the period when the split proportion can not be inferred from available data.

The CPUE analyses for the southern strata were carried out on a number of subsets of the CELR data, as the data for Chalky and South Coast can not be separated from those for Stewart Island before the 1995–96 fishing year. The standardised indices based on the CELR data from Statistical Area 030 were recommended in the stock assessment. The standardised indices based on the CELR data for the northern strata are dubious and are considered unable to track the changes of abundance. The standardised indices based on the more recent PCELR data showed a general declining trend across all strata, but the indices have declined slightly more in the southern strata than the northern strata.

Commercial catch sampling data have been collected since 1992 except for 1995–97 and 1999–2000. However, the sampling coverage was poor since 2006, and was dubious before 2001 (areas of the associated landings were unknown). Scaled length frequencies were derived from the commercial catch sampling for the northern and southern strata, where the catch samples were stratified by area and numbers at length were scaled up to each landing and then to the stratum catch. It was suggested that CSLF data between 2002 and 2005 be used for the 2010 stock assessment base case model.

Research diver surveys have been conducted to assess the relative abundance of paua in PAU 5A since 1996. However, before 2005–06 surveys were conducted only in the area from Dusky south. The usefulness of the research diver survey in providing relative abundance estimates has been an ongoing concern. Research diver survey indices were derived for the southern and northern strata separately, having incorporated modifications on the standardisation procedure from recent reviews.

1. INTRODUCTION

The stock assessments for PAU 5A have previously been conducted assuming a homogeneous area covering the whole of PAU 5A, with model input data collocated at the QMA level. There were concerns about the applicability of the last assessment to the entire QMA, although there was general agreement that biomass decline had occurred in the southern region of the stock over recent years. Before 2005–06 fishery-independent surveys were conducted only in the area from Dusky south, which has accounted for about 60% of the catch over the last four years. Recent studies suggested that trends in the changes of abundance may have varied between subareas within PAU 5A (Cordue 2009). A model assuming a homogeneous area is therefore unlikely to reflect the different exploitation histories between subareas or to predict the current status of the stock.

The SFWG suggested conducting a separate assessment for the southern strata including Chalky and South Coast, and a northern strata area, including Milford, George, Central, and Dusky for the 2010 stock assessment. The decision was based on the availability of data and differences in exploitation histories and management initiatives.

This report summarises the data for PAU 5A including fishery data up to the 2008–09 fishery year and data from the February 2010 research diver survey, including (1) a standardised CPUE series based on catch effort data, (2) a standardised CPUE series covering 2002–07 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. We summarise the availability of data by subarea and collate model input data for the southern and the northern strata respectively. Data were also compiled for the entire substock for completeness of the time series.

2. DESCRIPTION OF THE FISHERY

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

Landings in PAU 5 were reported to the single management stock (PAU 5) before 1 October 1995, and then to the three separate substocks PAU 5A, PAU 5B, and PAU 5D (although a number of fishers continued to use the code PAU 5). Estimated catch on the CELR forms was reported on the scale of the general statistical areas until 1 November 1997, when these areas were further subdivided into 17, 16, and 11 Paua Statistical Areas for PAU 5A, PAU 5B, and PAU 5D, respectively. The scale of reporting was further reduced from 1 October 2001, when the specific PCELR forms were adopted and it became mandatory to report catch and effort on the finer-scale statistical zones developed for the New Zealand Paua Management Company's voluntary logbook (Figure 2). A summary of the spatial resolution of reporting areas for PAU 5A is given in Table 2.

PAU 5A includes the coastal areas and islands of Fiordland, from the Waiau River (west of Riverton) to Awarua Point (north of Big Bay). The TACC for PAU 5A has remained at the initial level of 145 t since the 1995–96 fishing year t. Landings have been close to the TACC since 1998–99.

Since 1 October 2006, a voluntary catch reduction of 30% has been in place. The harvest caps are designed to reduce effort in the southern three zones (Dusky, Chalky, and South Coast) and to reduce the catch in these areas by 50%. This effectively reduces the allowable catch from 148 983 to 104 290 kg. Initially the shelving was for 3 years but at the 2009 PauaMAC5 AGM it was agreed to roll this over for another 2 years, reviewable annually.

Since October 2006, a voluntary subdivision was agreed which divided PAU 5A into six fishing management zones, based on the research strata, and a proportion of the total annual catch entitlement (ACE) was allocated to each zone. To ensure harvesting is spread across the fishery in proportion to stock abundance, each of the management zones has a voluntary harvest cap placed on it (Table 3), which take into account the voluntary catch reduction. PauaMAC5 members also agree to implement an 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.

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

	PAU 5		PAU 5A		PAU 5B		PAU 5D	
Fishstock	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	550 515	–	N/A	N/A	N/A	N/A	N/A	N/A
1984–85*	352 459	–	N/A	N/A	N/A	N/A	N/A	N/A
1985–86†	331 697	–	N/A	N/A	N/A	N/A	N/A	N/A
1986–87†	418 904	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1987–88†	458 239	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1988–89†	445 978	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1989–90†	468 647	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1990–91†	510 335	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1991–92†	483 037	492 062	N/A	N/A	N/A	N/A	N/A	N/A
1992–93†	435 395	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1993–94†	440 144	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1994–95†	434 708	443 000	N/A	N/A	N/A	N/A	N/A	N/A
1995–96†	N/A	N/A	138 526	148 983	144 661	148 984	146 772	148 983
1996–97†	N/A	N/A	143 848	148 983	142 357	148 984	146 990	148 983
1997–98†	N/A	N/A	145 224	148 983	145 337	148 984	148 718	148 983
1998–99†	N/A	N/A	147 394	148 983	148 547	148 984	148 697	148 983
1999–00†	N/A	N/A	143 913	148 983	118 068	143 984	147 897	148 983
2000–01†	N/A	N/A	148 221	148 983	89 915	112 187	148 813	148 983
2001–02†	N/A	N/A	148 535	148 983	89 963	112 187	148 740	148 983
2002–03†	N/A	N/A	148 764	148 983	89 863	90 000	111 693	114 000
2003–04†	N/A	N/A	148 980	148 983	90 004	90 000	88 024	89 000
2004–05†	N/A	N/A	148 952	148 983	89 970	90 000	88 817	89 000
2005–06†	N/A	N/A	148 922	148 983	90 467	90 000	88 931	89 000
2006–07†	N/A	N/A	104 034	148 983	89 156	90 000	88 973	89 000
2007–08†	N/A	N/A	105 132	148 983	90 205	90 000	88 978	89 000
2008–09†	N/A	N/A	104, 823	148,983	89,998	90,000	88,770	89,000

* FSU data, † QMR/MHR data

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

	QMA			Statistical areas	Research stratum
–Sep 1995	Oct 1995–present	1983–Oct 1997	Nov 1997–Sep 2001	Oct 2001–	
PAU 5	PAU 5A	032	A1–A5	P5AF01–P5AF13	Milford, George
		031	A6–A12	P5AF14–P5AF33	Central, Dusky
		030 (part of)	A13–A17	P5AF34–P5AF49	Chalky, South Coast

Table 3: Voluntary harvest cap and Minimum harvest size placed on each of the management zones since October 2006.

Management Zones	Milford	George	Central	Dusky	Chalky	South Coast
Harvest Cap (kg)	2 990	30 510	25 770	14 260	9 680	21 070
MHS (mm)	125	127	130	130	130	130

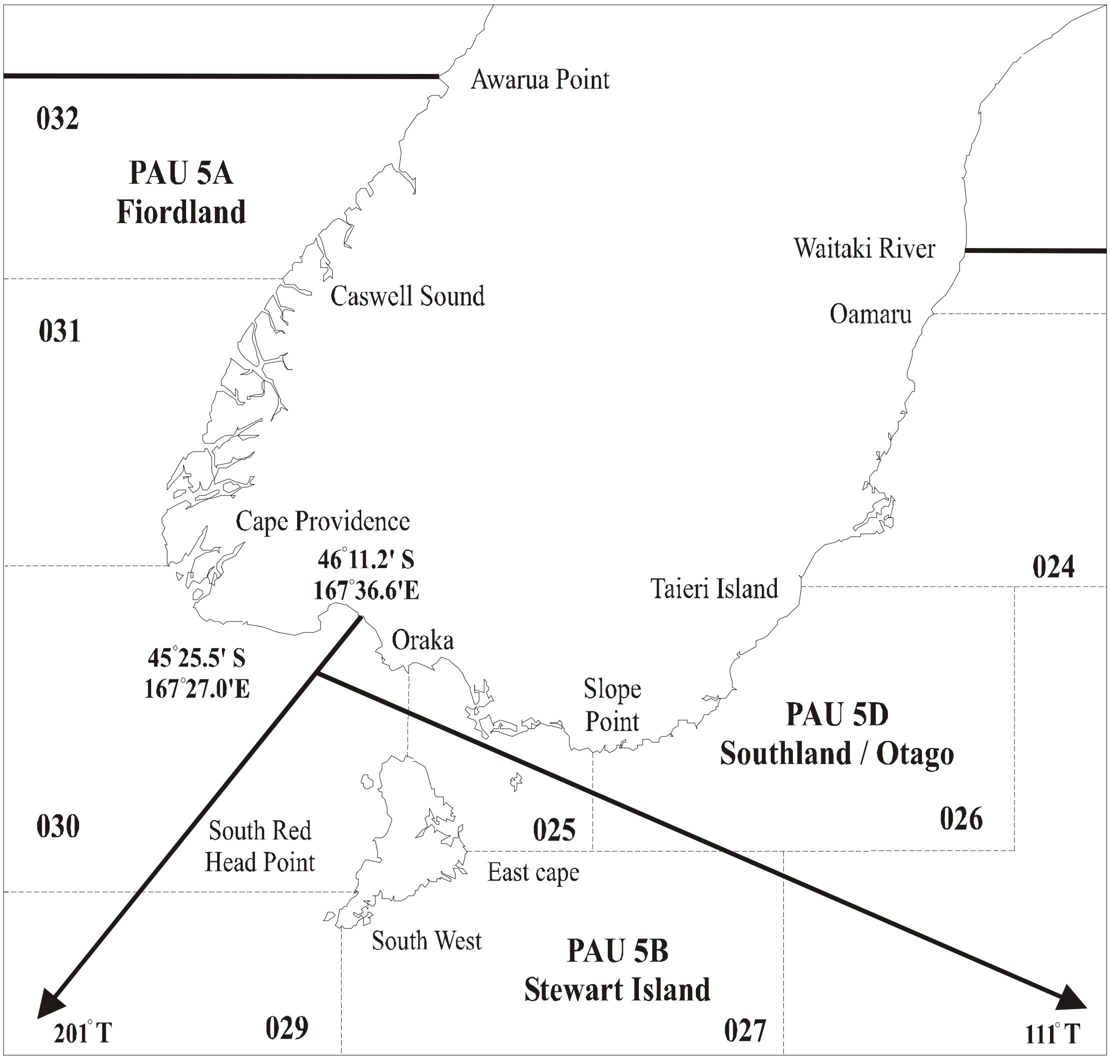


Figure 1: Map showing the new QMAs effective from 1 October 1995 and the old statistical area boundaries (dashed lines) of PAU 5.

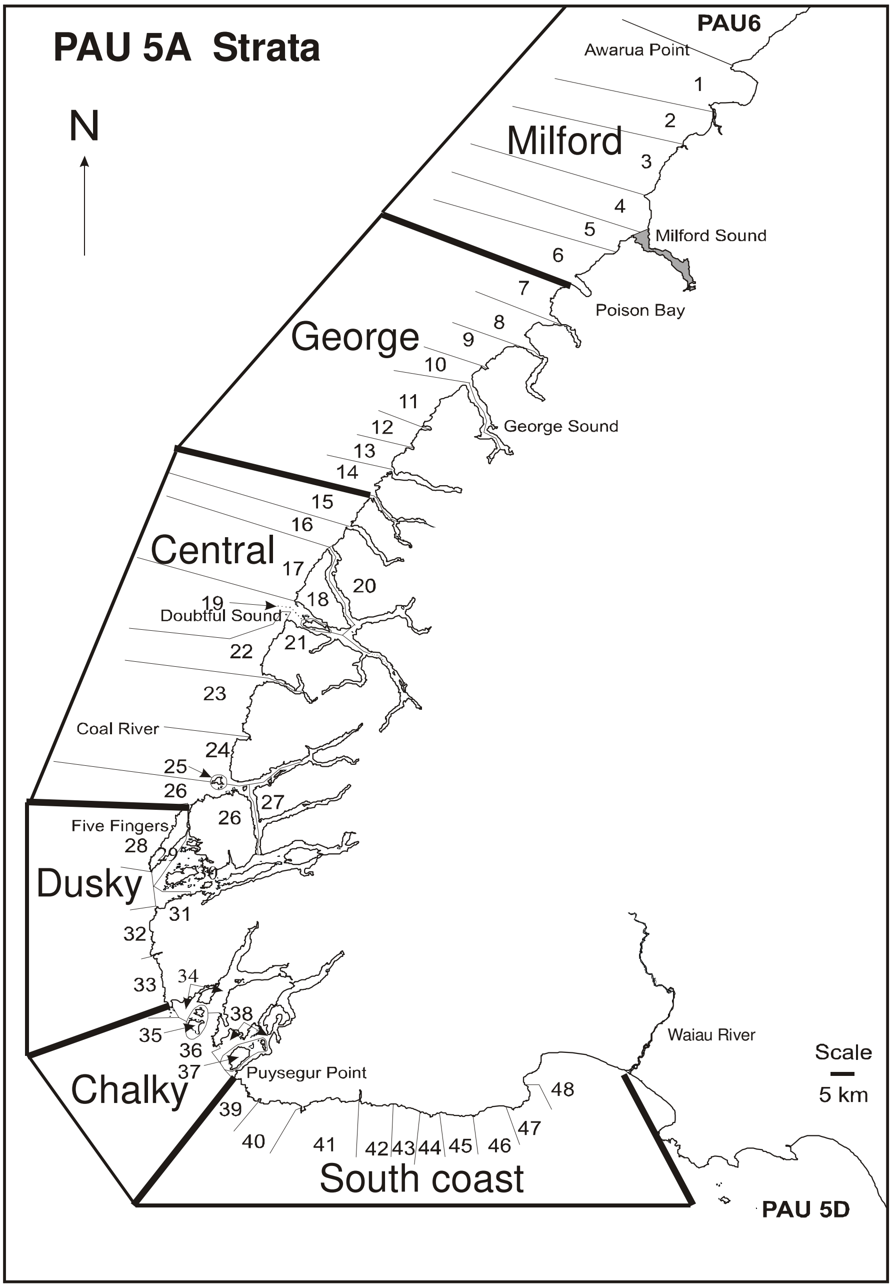


Figure 2: Map of fine-scale statistical areas and research strata for PAU 5A.

3. CATCH HISTORY

3.1 Commercial catch

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

Fu (unpublished) repeated this procedure to calculate the catch history for PAU 5A, PAU 5B, and PAU 5D. For PAU 5A, a constant proportion of 23% was applied to the Murray & Akroyd (1984) PAU 5 catch series to obtain catch estimates from 1974 to 1983. From 1983–84 to 1994–95, the annual proportion of catch for the PAU 5A was firstly estimated, where 18% of the catch in Statistical Area 030 was assumed to have been taken from PAU 5A, and then that proportion was applied to the QMR/MHR landings in PAU 5 to obtain the catch estimates for PAU 5A. From 1995–96 onwards, the catch estimates are available from the reported QMR landings. The estimated catch history under this assumption for each substock from 1974 to 2009 is given in Table 4 ("assumption 1")

The estimated commercial catch history between 1984 and 1995 shows a marked difference from the previous assessment (Figure 3). In previous assessments (Breen & Kim 2004a, 2007), the PAU 5A catch was determined by subtracting Kendrick & Andrew's estimates of the PAU 5B and PAU 5D catch from the total PAU 5 catch. However, the data used by Kendrick & Andrew (2000) for calculating the catch history were not available, although the method was thoroughly documented. Breen & Smith (2008a) repeated this method to assemble the catch history for PAU 5B (assuming 75% of the catch in Statistical Areas 030 and 025 were from PAU 5B), and reported that their estimates were similar to those of Kendrick & Andrew (2000). The data used for their analysis were provided in an Excel workbook (P. Breen, NIWA, pers. comm.) and were compared to the data used in this study in an attempt to address the inconsistency in the catch estimates between those analyses. A number of differences were found.

- Breen & Smith (2008a) used the reported landings from the Plenary Report (Ministry of Fisheries 2006) as the total PAU 5 catch for 1984–95, which was based on the FSU catch for 1984–86 and the MHR/QMR landings for 1987–95. For this study, we used the FSU catch for 1984 and 1985, and the MHR/QMR landings for 1986–95 from the extracted data (log 7376A). The catches were almost identical, except that for 1986 the FSU catch was 230 t where as the MHR/QMR landings were 332 t (Figure 4, part a).

- The FSU/CELR estimated catch (used for calculating the proportion of catch in PAU 5B) used by Breen & Smith (2008) differed markedly from the extracted data used in this study, especially from 1990 onwards (Figure 4, part b), where the CELR estimated catch in the early dataset generally fell short of the MHR/QMR landings by 30%. A closer examination found marked differences between the two datasets in the catch by statistical area for the early years. This difference is likely to be a result of the changes in the catch effort database.

Those factors explained the differences in collated catch history between the analyses (Figure 4, part c). In previous assessments for PAU 5A, catch history estimates were made using assumptions described above. For the 2010 assessment, alternative assumptions have been suggested by the SFWG concerning the proportion of catch in Statistical Area 030 which was taken from PAU 5A between 1983–84 and 1995–96: (1) 18% (lower bound) as described above, (2) 40% (base case), and (3) 61% (upper bound). The third assumption was based on one of the sensitivities used for the previous PAU

5B assessment (Breen et al. 2008a). Estimated catch histories for PAU 5A, PAU 5B, and PAU 5D under each of the three assumptions are given in Table 4.

The catch histories for the northern and southern strata were obtained by splitting the estimated PAU 5A catch 1974–2009 between the two regions using a proportion determined annually from:

- 1996–2009 estimated catch on the CELR/PCELR by Statistical Areas 030, 031, and 032 within PAU 5A.
- 1984–1995 estimated catch on the FSU/CELR by Statistical Areas 030, 031, and 032, assuming a fixed proportion (18%, 40%, or 61%) of the catch in 030 was taken from PAU 5A.
- 1974–1983 the total estimated catch 1984–1995 by Statistical Areas 030, 031, and 032, assuming a fixed proportion (18%, 40%, or 61%) of the catch in 030 was taken from PAU 5A.

Estimated catch histories for the northern and southern strata under the lower bound assumption (18%) are shown in Figure 5. For the 2010 assessment, the catch history estimated under the base case assumption (40%) was used in the base case model run, and the other estimates were used in sensitivity trials.

Table 4: Collated commercial catch histories (kg) for PAU 5A, 5B, and 5D for fishing years 1974–2009 under the lower bound (assumption 1), base case (assumption 2), and upper bound (assumption 3) assumptions.

	Assumption 1 (18%)				Assumption 2 (40%)			Assumption 3 (61%)		
Year	PAU 5	PAU 5A	PAU 5B	PAU 5D	PAU 5A	PAU 5B	PAU 5D	PAU 5A	PAU 5B	PAU 5D
1974	212 670	48 914	110 588	53 168	48 914	110 588	53 168	48 914	110 588	53 168
1975	201 180	46 271	104 614	50 295	46 271	104 614	50 295	46 271	104 614	50 295
1976	160 110	36 825	83 257	40 028	36 825	83 257	40 028	36 825	83 257	40 028
1977	221 400	50 922	115 128	55 350	50 922	115 128	55 350	50 922	115 128	55 350
1978	333 460	76 696	173 399	83 365	76 696	173 399	83 365	76 696	173 399	83 365
1979	349 960	80 491	181 979	87 490	80 491	181 979	87 490	80 491	181 979	87 490
1980	433 100	99 613	225 212	108 275	99 613	225 212	108 275	99 613	225 212	108 275
1981	524 340	120 598	272 657	131 085	120 598	272 657	131 085	120 598	272 657	131 085
1982	346 560	79 709	180 211	86 640	79 709	180 211	86 640	79 709	180 211	86 640
1983	442 980	101 885	230 350	110 745	101 885	230 350	110 745	101 885	230 350	110 745
1984	550 515	107 360	294 704	148 451	146 179	248 276	156 060	183 233	211 222	156 060
1985	352 459	46 409	224 301	81 749	70 894	191 458	90 107	94 266	168 086	90 107
1986	331 697	50 646	215 811	65 240	69 949	188 216	73 532	88 374	169 791	73 532
1987	418 904	25 826	251 501	141 578	36 893	225 028	156 983	47 458	214 464	156 983
1988	458 239	37 310	327 861	93 068	56 492	288 564	113 182	74 803	270 254	113 182
1989	445 978	118 393	231 793	95 791	152 824	191 590	101 563	185 690	158 725	101 563
1990	468 647	74 372	254 105	140 170	106 101	212 681	149 865	136 388	182 394	149 865
1991	510 335	124 440	243 050	142 845	156 661	203 192	150 482	187 417	172 436	150 482
1992	483 037	100 107	254 026	128 904	133 056	212 908	137 073	164 507	181 457	137 073
1993	435 395	50 724	221 898	162 773	81 292	181 583	172 520	110 471	152 404	172 520
1994	440 144	57 733	233 533	148 878	86 016	196 333	157 794	113 015	169 335	157 794
1995	434 708	65 767	231 350	137 591	96 510	192 424	145 774	125 856	163 078	145 774
1996	429 959	138 526	144 661	146 772	138 526	144 661	146 772	138 526	144 661	146 772
1997	433 195	143 848	142 357	146 990	143 848	142 357	146 990	143 848	142 357	146 990
1998	439 279	145 224	145 337	148 718	145 224	145 337	148 718	145 224	145 337	148 718
1999	444 638	147 394	148 547	148 697	147 394	148 547	148 697	147 394	148 547	148 697
2000	409 878	143 913	118 068	147 897	143 913	118 068	147 897	143 913	118 068	147 897
2001	386 949	148 221	89 915	148 813	148 221	89 915	148 813	148 221	89 915	148 813
2002	387 238	148 535	89 963	148 740	148 535	89 963	148 740	148 535	89 963	148 740
2003	350 320	148 764	89 863	111 693	148 764	89 863	111 693	148 764	89 863	111 693
2004	327 008	148 980	90 004	88 024	148 980	90 004	88 024	148 980	90 004	88 024
2005	327 739	148 952	89 970	88 817	148 952	89 970	88 817	148 952	89 970	88 817
2006	328 320	148 922	90 467	88 931	148 922	90 467	88 931	148 922	90 467	88 931
2007	282 163	104 034	89 156	88 973	104 034	89 156	88 973	104 034	89 156	88 973
2008	284 315	105 132	90 205	88 978	105 132	90 205	88 978	105 132	90 205	88 978
2009	283 591	104 823	89 998	88 770	104 823	89 998	88 770	104 823	89 998	88 770

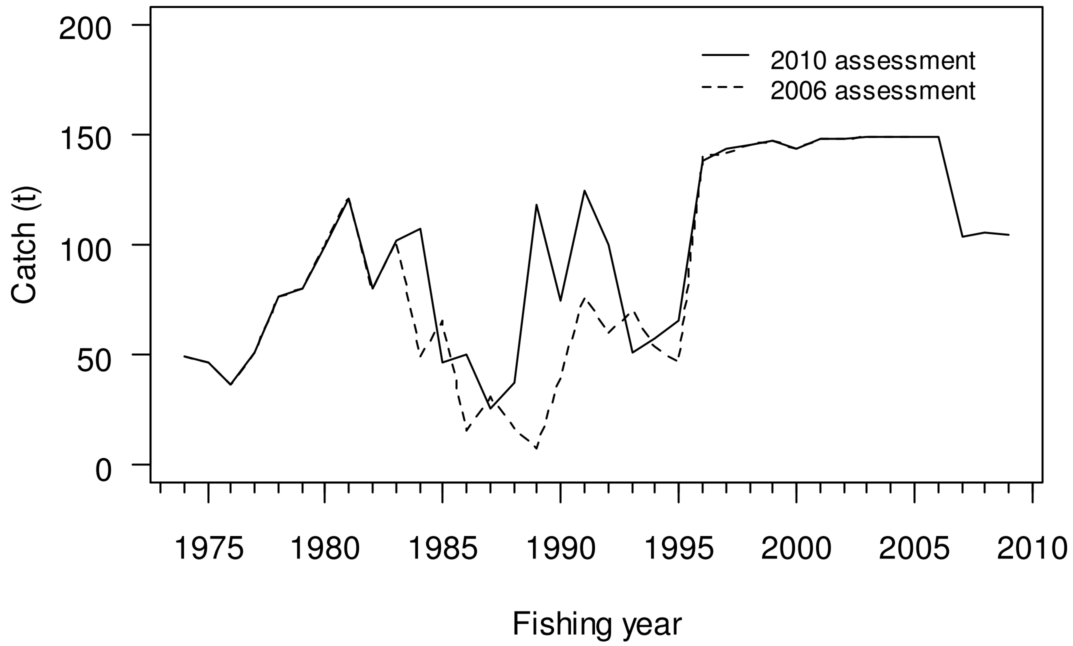


Figure 3: A comparison of the estimated commercial catch histories for PAU 5A (under the lower bound assumption) with those estimated from the previous assessment.

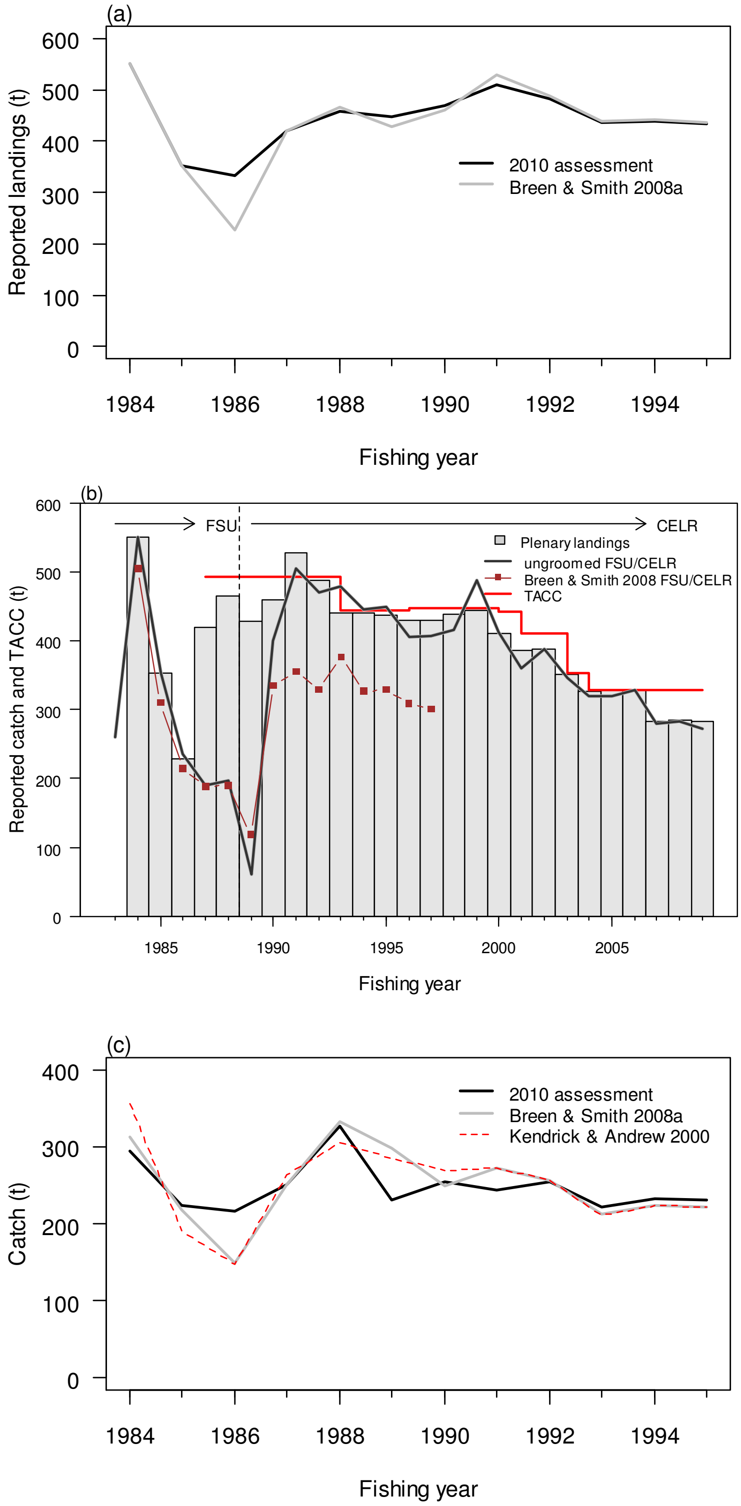


Figure 4: A comparison of the datasets used to derive the catch history in this study and the study by Breen & Smith (2008a). (a) The total PAU 5 catches for 1984–1995; (b) Estimated catch from FSU/CELR for 1983–2009 used for this study, and for 1984–1997 used by Breen & Smith (2008a); (c) Derived catch history for PAU 5B for 1984–1995.

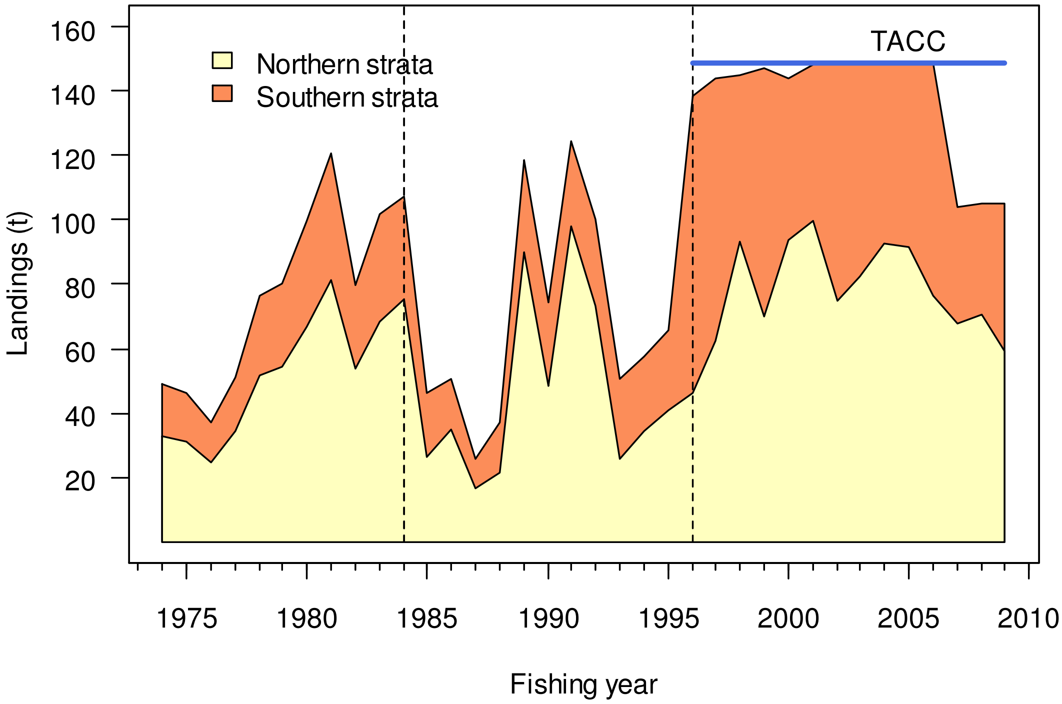


Figure 5: Estimated catch history for the northern and southern strata under the lower bound assumption, 1974–2009 fishing years.

3.2 Recreational catch

The 1996 and 1999–2000 National Recreational Fishing Surveys estimated 37.1 t and 53.2 t were taken respectively from PAU 5 by recreational fisheries but with no substock breakdown. The 2000–01 survey estimated a recreational harvest of 8000 paua from PAU 5A. At an average weight of 357 g, these numbers equate to a recreational harvest of 2.8 t. The Marine Recreational Fisheries Technical Working Group considered that some harvest estimates from the 1999–2000 and 2002–01 surveys for some fish stocks were unbelievably high. The Shellfish Fisheries Working Group (SFWG) examined estimates from national recreational surveys conducted in 1996 and 1999–2001, and following their discussions, the 2004 assessment assumed that the 1974 recreational catch was 1 t, increasing linearly to 2 t in 2005. For this assessment, the SFWG agreed to assume that the recreational catch has remained constant at 2 t between 2006 and 2009.

On the catch and effort forms used since 2002, fishers can report paua they land as part of a recreational catch entitlement (destination code “F”). The sum of such catches for 2002 through to the partial data for 2006 was only 124 kg for PAU 5A.

3.3 Customary catch

There are no published estimates of customary catch. Records of customary non-commercial catch taken under the authority of customary fishing permits show that only 70 paua were taken in 2000; no catches have been recorded since then. For the stock assessment model, the SFWG agreed to assume that customary non-commercial catch has been constant at 1 t. The customary catch is estimated at less than 1 t as the rununga have a rahui on the issue of customary permits for Fiordland.

3.4 Illegal catch

There are no estimates of illegal catch for PAU 5A. Illegal catch is not considered to be a major problem because PAU 5A is isolated and exposed to prevailing weather conditions. It is anticipated that any poaching that does occur would happen in the more accessible areas in the southern and northern parts of the QMA. For the purpose of the stock assessment model, the SFWG agreed to assume that illegal catches have been a constant 5 t.

We further assume that 80% of the recreational, customary, and illegal catches in PAU 5A were taken from the southern area, and the rest from the northern area. As in the previous assessment, total catches for 1964 to 1973 were assumed, based on linear interpolation from zero in 1962 to the level of the 1974 catch. The combined total of commercial, recreational, customary, and illegal catch for the southern and northern strata respectively is shown in Figure 6.

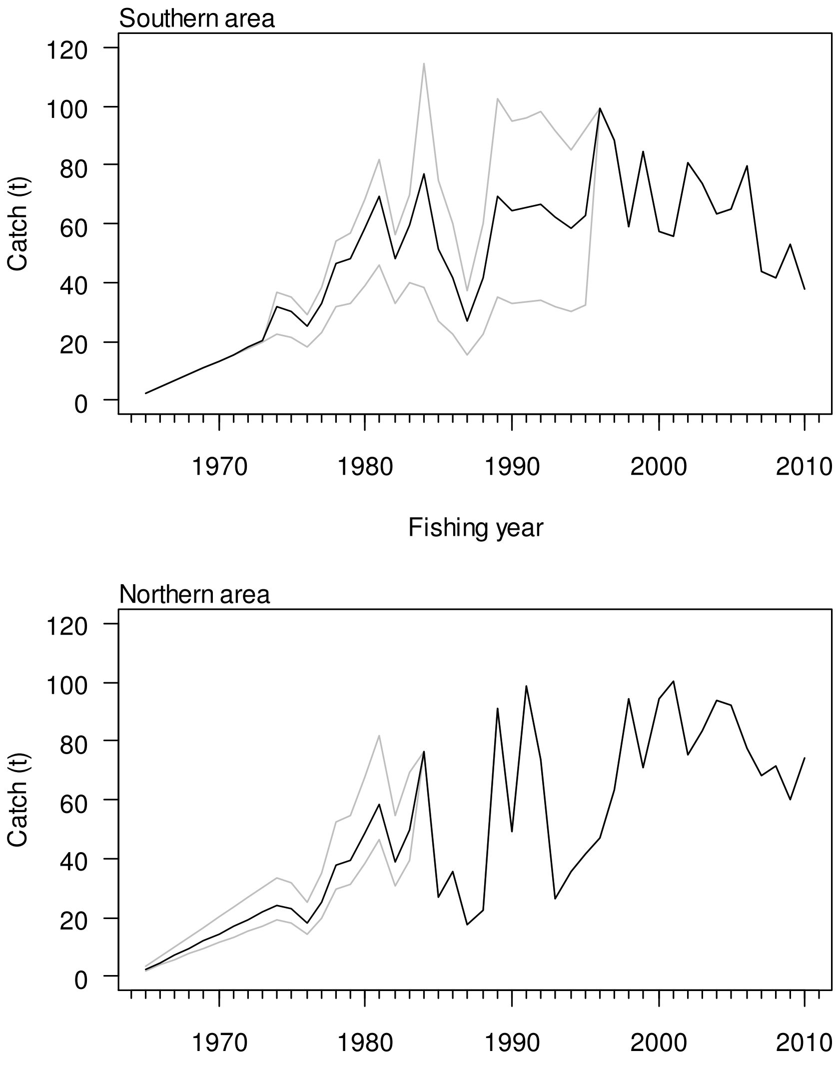


Figure 6: Estimated catch history including commercial, recreational, customary, and illegal catch for the southern and northern strata from 1964 to 2009 under the lower bound (corresponding to a lower catch history for the southern strata, but a higher catch history for the northern strata), base case (black lines), and upper bound assumptions (corresponding to a higher catch history for the southern strata, but a lower catch history for the northern strata).

4. CPUE

Standardised CPUE indices have been used as relative abundance indices for paua stock assessments (Breen & Kim 2004a, 2004b, 2005, 2007, Breen & Smith 2008a). The 2006 assessment for PAU 5A used combined FSU, CELR, and PCELR data for the CPUE standardisations, with pre-1996 catch and effort from the straddling statistical area allocated to the substocks using the randomisation procedure described by Kendrick & Andrew (2000). The SFWG suggested omitting the CPUE indices before 1989, and also suggested not using FSU data in future assessments. Fu (unpublished) updated the standardised CPUE indices up to 2007–08 for PAU 5, where he calculated both a combined CELR and PCELR series and a short PCELR series for each of the PAU 5 substocks. For this assessment, the standardised CPUE indices were calculated for catch effort data up to 2008–09, where the CELR and PCELR datasets were analysed separately to produce two different CPUE series. Only the main methods and results are presented here.

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 September 2009 were requested from the Ministry of Fisheries database "warehou" (extract 7376), including the CELR data until October 2001, and the PCELR data from the 2001–02 fishing year. The FSU data were also extracted from the NIWA-managed database for the period between January 1983 and September 1988 (extract. CL0088), but they were not used for the CPUE standardisation. The data were groomed, using similar criteria described by Kendrick & Andrew (2000) and by Breen & Kim (2007).

Following Kendrick & Andrew (2000), the catch and effort records reported to the straddling Statistical Area 030 before 30 September 1995 were randomly allocated to PAU 5A in proportion to its assumed contribution to the catch in that statistical area. The SFWG had previously agreed that 18% of records reported to 030 were assigned to PAU 5A. Randomly allocated records were included in only one of the sensitivity standardisation analyses for the southern strata. From 1 October 1995 to 30 October 1997, the new substock for the straddling statistical areas were determined by the substock of the green weight landings reported on the bottom half of the CELR forms if the catch was reported to a unique substock on the same form, otherwise the record was randomly allocated to a substock in proportion to the annual catch reported to that stock.

Core CPUE datasets were derived for each of the CELR, PCELR, and combined CELR/PCELR series. For the CELR series, the CPUE data were restricted to vessels that had fished in the fishery for at least three years; for the PCELR series, only the divers that had fished for at least three years were included. This is to allow vessel or diver effects to be standardised independently of year effects. For the combined series, PCELR data were collapsed into the same format as the CELR data with catch and effort amalgamated for a unique combination of vessel, statistical area, and fishing day, and the combined data were restricted to vessels that had fished in the fishery for at least three years.

Estimates of year effects and the associated standard errors were obtained using a Generalised Linear Model (GLM) (McCullagh & Nelder 1989), where the data were fitted using the lognormal model. The catch per diver day was used as a measure of CPUE for both the CELR series and the CELR/PCELR combined series. The catch per diver-hour was modelled as the response variable for the finer resolution PCELR series.

The lognormal model expressed the catch per unit effort as dependent upon individual effects in a multiplicative manner, i.e., the combined effect of two predictors is the product of their individual effects. Variables *fishing year*, *month*, *vessel key*, and *stat area* were offered to the model as candidate predictors for both the CELR and the CELR/PCELR combined series, and variables *fishing year*, *month*, *catcher key*, *finer stat area,* and *diving condition* for the PCELR series. The variable *diver-hours* is not offered to the models, as they were sometimes recorded as average hours per diver and sometimes as total fishing hours (Kendrick & Andrew 2000)

A forward stepwise multiple regression-fitting algorithm was used to select variables for the lognormal models. The algorithm generated a final regression model iteratively. The reduction in residual deviance (denoted r^2) was calculated for each single term added to the base model. The term that resulted in the greatest reduction in the residual deviance was then added to the base model, where the change was at least 1%. The algorithm was then repeated, updating the base model, until no more terms were added. Interaction terms were ignored.

The variable *fishing year* was forced to be included in the model as the relative year effects calculated from the regression coefficients represent the change in CPUE over time, which is the trend of primary interest. The relative year effects were presented in canonical form so that the indices are independent of the reference year (Francis 1999).

For the PCELR data, the areal differences in the changes of relative abundance were investigated using a model incorporating year*stratum interaction. The standardised CPUE indices were then calculated for the southern and the northern strata separately, as well as for both strata combined.

For the CELR data, the standardised CPUE indices for the northern strata were based on subsets of data in Statistical Areas 031 and 032. For the southern strata, as the areal stratum for records from Statistical Area 030 can not be determined (especially before 1995–96), the CPUE was calculated using three subsets of data: (1) based on all the records for Statistical Area 030 (including those from PAU 5B and 5D) for 1990–2001, (2) based on records in Statistical Area 030 with known stock for 1996–2001, (3), based on records in Statistical Area 030 with known stock plus those assigned to PAU 5A through the randomisation procedure for 1990–2001. The randomly assigned records were included in the calculation of standardised CPUE indices for PAU 5A. A description of those models is given in Table 5.

Table 5: Description of the CPUE models used for the CPUE standardisation analyses.

Model	Data	Subsets	Description
M1	PCELR	PAU 5A	Model investigating year * stratum interaction
M2	PCELR	Chalky, South Coast	CPUE 2002–2009 for the southern strata
M3	PCELR	Milford, George, Central, Dusky	CPUE 2002–2009 for the northern strata
M4	PCELR	PAU 5A	CPUE 2002–2009 for PAU 5A
M5	CELR	030 within PAU 5A	CPUE 1996–2001 for the southern strata
M5.1	CELR	030 with random records	CPUE 1990–2001 for the southern strata plus random records
M5.2	CELR	030	CPUE 1990–2001 for Statistical Area 030
M6	CELR	031, 032	CPUE 1990–2001 for the northern strata
M7	CELR	PAU 5A with random records	CPUE 1990–2001 for PAU 5A plus random records

4.1 CPUE datasets

The estimated catches for the groomed dataset are shown in Figure 7. Catch excluded from grooming was generally minor, except for an apparent error in the estimated catch in 1999. Records assigned through the randomisation procedure accounted for a substantial amount of the data between 1983 and 1995. Catches with unknown stock were from Statistical Areas 030, mostly before 1996. There was also a small amount of catch after 1995 where the stock was unable to be determined, because some fishers had continued to report their catch by the old general statistical area (Figure 8).

The distribution of estimated catch on the PCELRs by stratum is summarised in Table 6. South Coast and Chalky accounted for 35–45% of annual total catch between 2002 and 2009. Since the 2006–07 fishing year, there has been a voluntary quota shelving of 30%, or 45 t, with catch caps designed to ensure a 50% catch reduction in the Dusky, Chalky and South Coast Strata.

Table 6: Proportion of catch on the PCELRs by stratum and fishing year, 2002–09.

Fishing year	Milford	George	Central	Dusky	Chalky	South Coast	Total (t)
2002	0.03	0.22	0.15	0.12	0.13	0.36	138
2003	0.02	0.11	0.22	0.2	0.11	0.34	141
2004	0.01	0.22	0.1	0.31	0.13	0.24	135
2005	0.02	0.21	0.15	0.23	0.12	0.27	139
2006	0.03	0.19	0.15	0.14	0.18	0.3	146
2007	0.04	0.25	0.23	0.13	0.1	0.25	101
2008	0.03	0.29	0.18	0.17	0.16	0.18	101
2009	0.02	0.26	0.14	0.14	0.12	0.32	100
Total	0.02	0.21	0.16	0.18	0.13	0.29	999

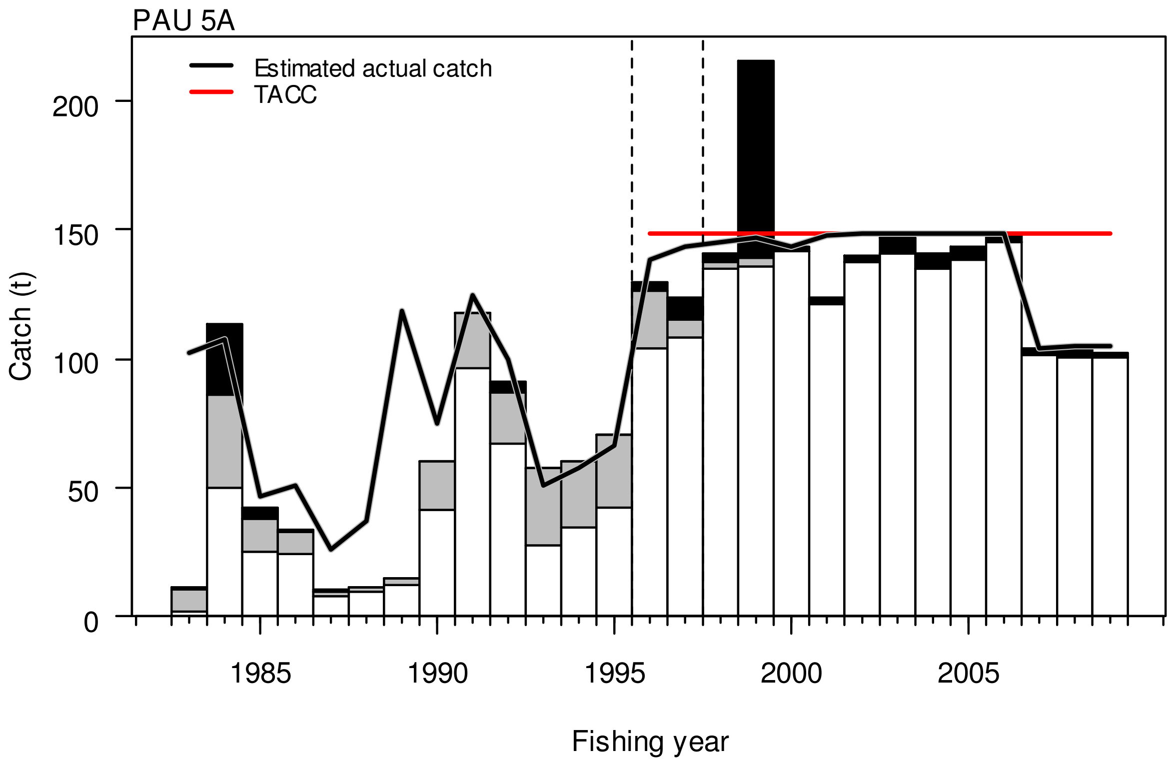


Figure 7: The estimated catch history, TACC, and the FSU/CELR/PCELR estimated catch (vertical bars) for fishing years 1983–2009 for PAU 5A. Black portion of the bar represents estimated catch removed through data grooming; grey represents the estimated catch from records randomly allocated to PAU 5A.

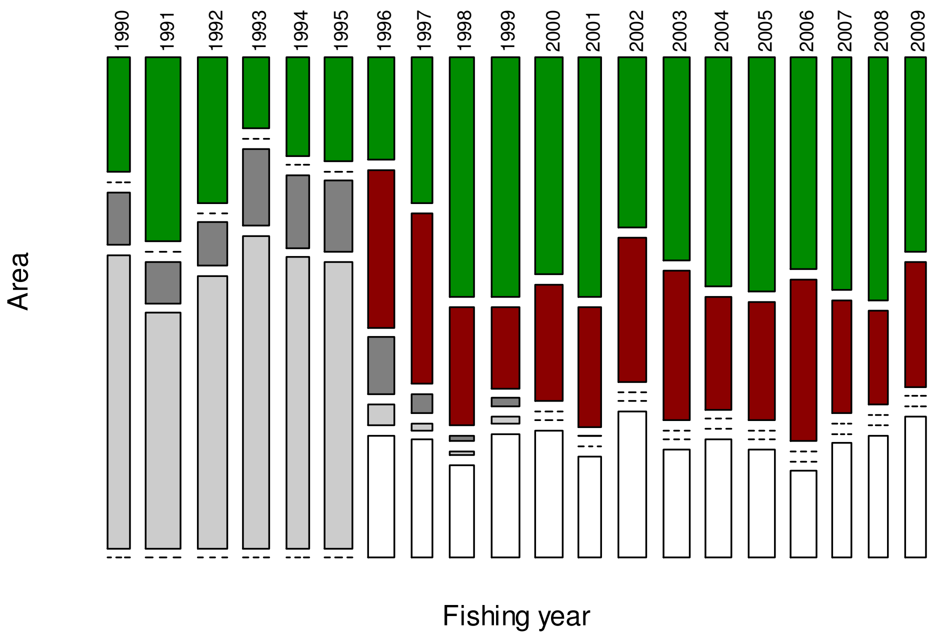


Figure 8: Estimated catch by area and fishing year on the CELRs and PCELRs, 1990–2009. Green represents catch from Statistical Areas 031 and 032 combined (northern strata); red represents catch from Statistical Area 030 within PAU 5A (southern strata); white represents the catch from Statistical Area 030 outside PAU 5A; grey represents catch from Statistical Area 030 with unknown stock, where dark grey represents catch randomly assigned to PAU 5A, and light grey represents catch randomly assigned to PAU 5B or PAU 5D. The width of the bar is proportional to the total annual catch.

4.2 PCELR series: 2002–09

The standardised CPUE from the model with year*stratum interaction (M1.0) showed differences in trends between strata. The CPUE for the four northern strata showed similar trends up to 2005 and Milford exhibited a large amount of inter-annual variability (Figure 9, part a). The CPUE for South Coast declined till 2006 and increased over the last three years; the CPUE for Chalky increased from 2001 to 2003, and since then has showed a similar trend to the South Coast (Figure 9, part b).

Subsequent standardisation analyses were restricted to statistical areas which accounted for 95% of the total catch. This effectively excluded most reporting zones in Milford which has seldom been fished. The standardised CPUE indices for the southern and northern strata (M2.0 and M3.0) are shown in Figure 10. The CPUE for the southern strata showed a steeper decline than the northern strata, with the trend reversed after 2008. The standardised indices for PAU 5A (M4.0) are shown in Figure 11.

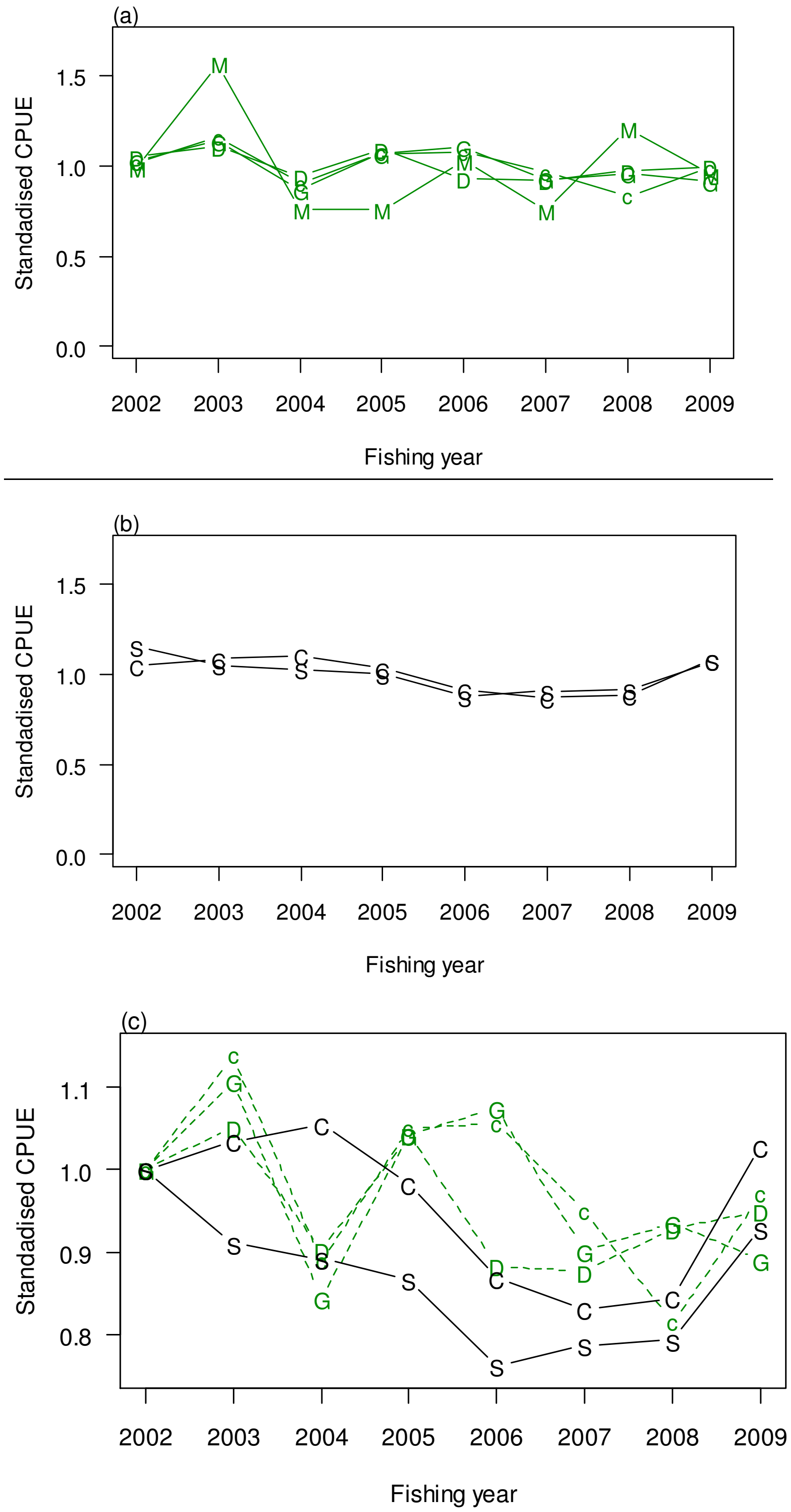


Figure 9: Standardised CPUE indices from the model fitted to the PCELR data with a year*stratum interaction (M1): (a) for Milford (M), George (G), Central (c), and Dusky (D); (b) for Chalky (C) and South Coast (S). In (a) and (b), each index series were standardised to have a mean of 1; in (c) each series were standardised to start from 1.

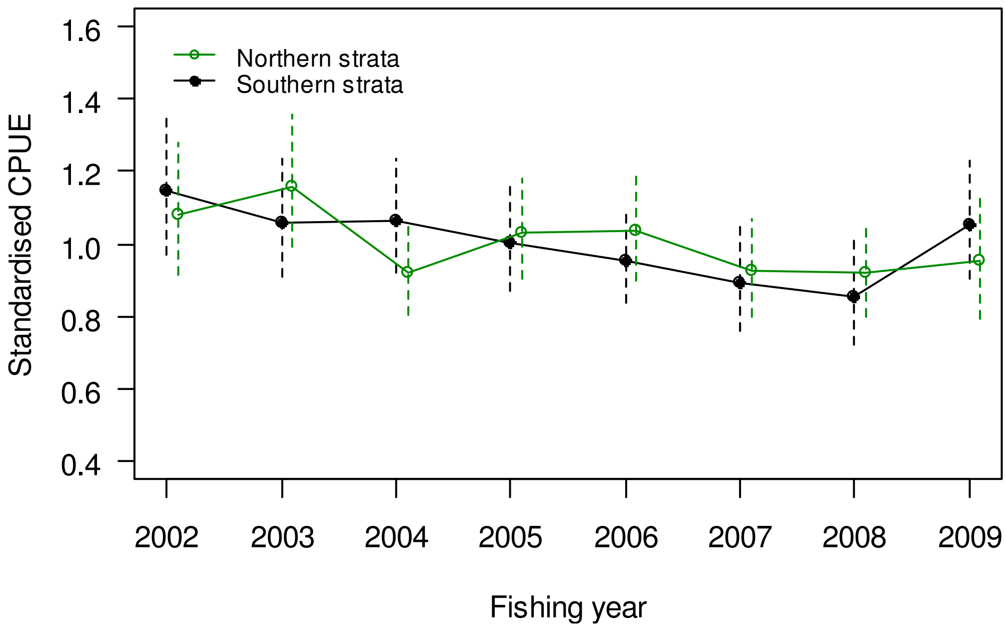


Figure 10: Standardised CPUE indices with 95% confidence interval from the PCELR data 2002–09 for the Southern strata (M2), and for the northern strata (M3). The northern strata are Milford, George, Central, and Dusky; the southern strata are Chalky and South Coast.

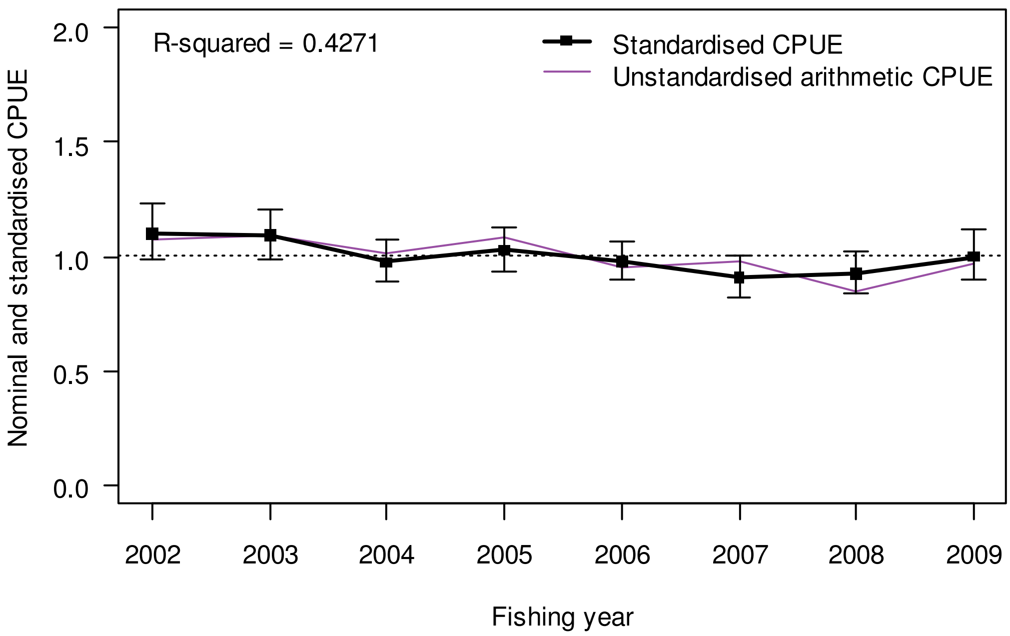


Figure 11: Standardised CPUE indices with 95% confidence interval and unstandardised indices for the PCELR data 2002–09 for PAU 5A (Model M4).

4.3 CELR series: 1990–2001

For the southern strata, CPUE indices based on records with known stock only (M5.0) showed a decline from 1996 to 1999; CPUE indices based on all records from Statistical Area 030 (M5.2) showed a large decline between 1990 and 1996; CPUE incorporating randomly assigned records showed a similar trend overall, but a much steeper decline in the first year (Figure 12). For the northern strata, the standardised CPUE indices showed an upward trend until 1996 and then remained flat (Figure 13). The standardised CPUE indices for PAU 5A are shown in Figure 14.

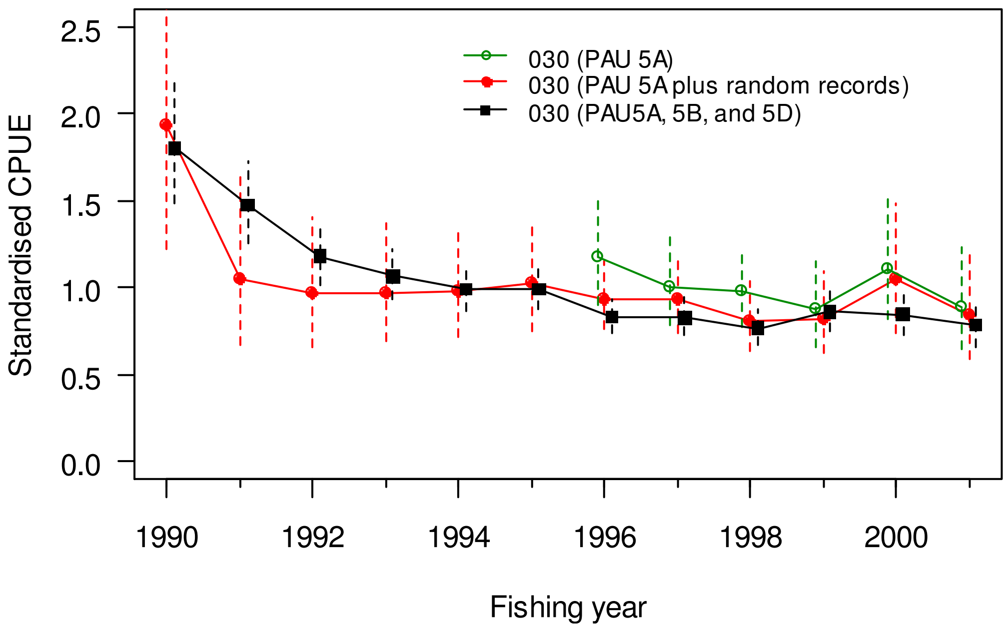


Figure 12: Standardised CPUE indices with 95% confidence interval from the CELR data for the southern strata based on: (1) Statistical Area 030 within PAU 5A only (M5); (2) Statistical Area 030 within PAU 5A, including randomly assigned records (M 5.1); and (3) Statistical Area 030 (M 5.2).

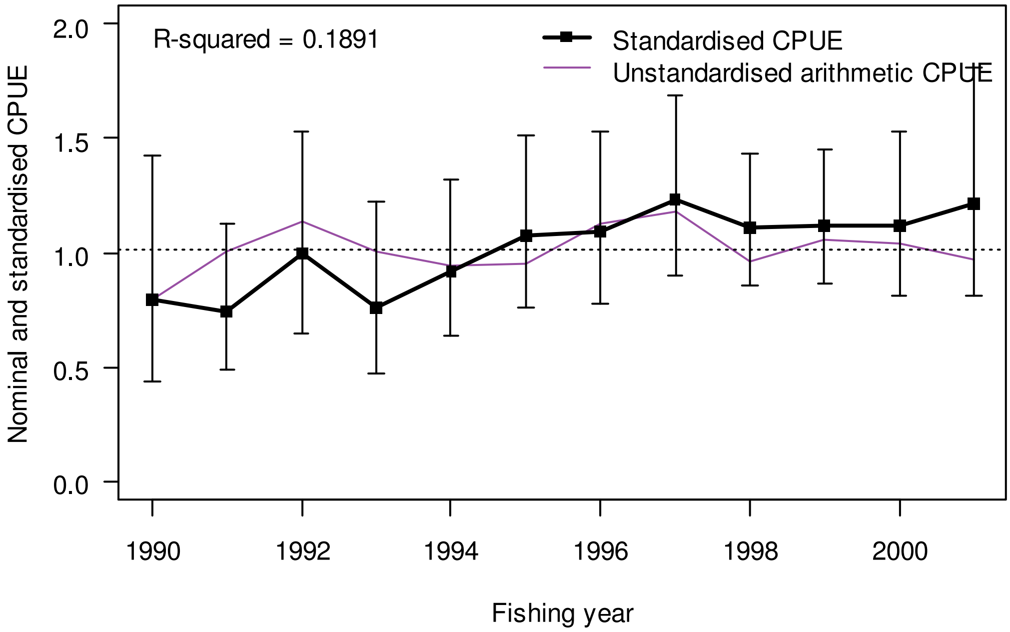


Figure 13: Standardised CPUE indices with 95% confidence interval and unstandardised indices from the CELR data for the northern strata 1990–2001 (M6).

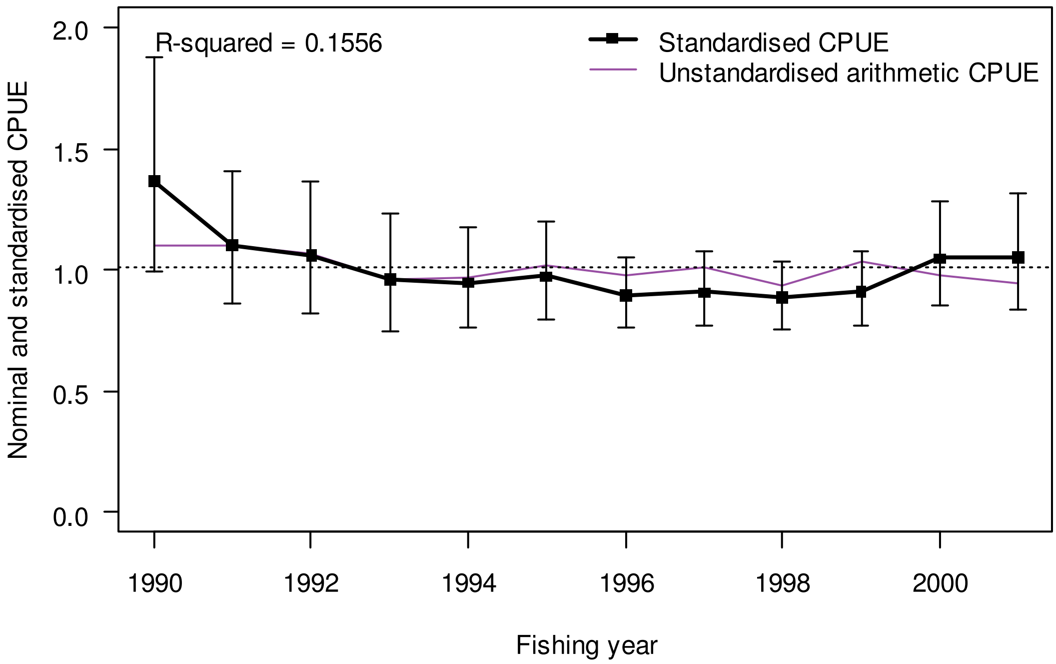


Figure 14: Standardised CPUE indices with 95% confidence interval and unstandardised indices for the CELR data 1990–2001 for PAU 5A (M7).

5. COMMERCIAL CATCH LENGTH FREQUENCY (CSLF)

The paua catch sampling data comprise measurements of landed paua shells from the commercial catch (paua market sampling). The length frequencies used are of the basal length of the paua shell. This is the longest measurement along the anterior-posterior axis of the shell lip (as defined by the limit of the shell nacre when viewed with the shell upside down). It does not include the spire if it overhangs the base of the shell, or any encrusting organisms. Industry now also measure and record overall length including the spire as well as basal length. Basal length differs from the measurement protocol in the commercial fishery, where the longest overall length is measured. For this reason, a small proportion of the market samples appear to be below the MLS of 125 mm.

Only a few landings were sampled before 1998, and there was no sampling between 1995 and 1997. In general, over 20 samples were taken from the landed catch each year from 1999 until 2009 (Table 7). Between 2000 and 8000 paua were measured in most years except for the first few years, with an average of about 3500 measured. About a third of the samples had no area recorded, mostly between 2000 and 2004 as some operators refused to supply the information (see Table 7). About 10% of samples had no landing weight recorded, and landing weight was unknown for all the samples in 1994 and 1998 (Table 8). The distribution of sampling effort by stratum is shown Table 9. From 2002 to 2008 the sample area was recorded using finer reporting zones, and this allowed the representativeness of the samples to be examined on smaller spatial scales. The sampling coverage was reasonably good from 2002 to 2005, with samples spread across the stock (Figure 15). The sampling was patchy in South Coast, Chalky, and Milford between 2006 and 2009. In 2009, the samples were taken from only six finer statistical areas.

Breen & Kim (2007) weighted the length frequency by the ratio of area catch to the mean area catch within each year, where data without area information were not added to the weighted length frequency distribution. Weighted length frequency $L^{CSLF}_{s,a,y}$ in length bin *s*, statistical area *a*, and year *y* was calculated as:

$$L^{CSLF}_{s,a,y} = L'^{CSLF}_{s,a,y} \frac{c_{a,y}}{\sum_a c_{a,y} \big/ n_y}$$

where $L^{CSLF\prime}_{s,a,y}$ is the raw length frequency in length bin *s*, statistical area *a*, and year *y*, $c_{a,y}$ is catch in statistical area *a* in year *y*, and n_y is the number of statistical areas that have been fished in year *y*.

We adopted a modified approach to calculate the length frequency using NIWA's 'catch-at-age' software (Bull & Dunn 2002). For each year, the catch samples were stratified by area (general statistical area before 1996, and finer statistical area after). The software scaled the length frequency of paua from each landing up to the landing weight, summed over landings in each stratum, scaled up to the total stratum catch, to yield length frequencies by stratum and overall. It computed the c.v. for each length class using a bootstrapping routine: fish length records are resampled within each landing, landings are 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. As in previous assessments, samples with area unknown were excluded from the analysis.

Scaled length frequencies were calculated for each stratum (Figure 16), for the southern strata (Figure 17), for the northern strata (Figure 18), and for the all strata in PAU 5A combined (Figure 19)

The SFWG suggested that for the 2010 stock assessment, only the 2002–05 catch sampling length frequency be included in the base case model. The full series are used in sensitivity trials.

Table 7: Number of sampled landings and number of paua measured with areas known or unknown from the shed sampling programme for PAU 5A for 1992, 1993, 1998, 2000–09.

	No. landings			No. paua measured		
Fishing year	Area unknown	Area known	Total	Area unknown	Area known	Total
1992	NA	9	9	NA	4515	4515
1993	NA	3	3	NA	1162	1162
1994	NA	1	1	NA	348	348
1998	NA	4	4	NA	527	527
2000	23	2	25	3420	201	3621
2001	32	3	35	4069	365	4434
2002	13	31	44	1532	3598	5130
2003	14	40	54	1634	4830	6464
2004	15	46	61	1713	5620	7333
2005	4	34	38	477	3505	3982
2006	3	18	21	349	2091	2440
2007	NA	20	20	NA	3490	3490
2008	NA	22	22	NA	2548	2548
2009	NA	25	25	NA	1653	1653
Total	104	258	362	13194	34453	47647

Table 8: Number of sampled landings and number of paua measured with landing weight known or unknown from the shed sampling programme for PAU 5A for fishing years 1992–2009

	No. landings			No. paua measured		
Fishing year	Weight unknown	Weight known	Total	Weight unknown	Weight known	Total
1992	5	4	9	2866	1649	4515.00
1993	1	2	3	508	654	1162
1994	1	NA	1	348	NA	348
1998	4	NA	4	527	NA	527
2000	8	17	25	1391	2230	3621
2001	NA	35	35	NA	4434	4434
2002	NA	44	44	NA	5130	5130
2003	2	52	54	221	6243	6464
2004	NA	61	61	NA	7333	7333
2005	9	29	38	774	3208	3982
2006	5	16	21	436	2004	2440
2007	NA	20	20	NA	3490	3490
2008	NA	22	22	NA	2548	2548
2009	NA	25	25	NA	1653	1653
Total	35	327	362	7071	40576	47647

Table 9: Number of market shed length frequency samples by research stratum 1992–2009

Fishing year	Milford	George	Central	Dusky	Chalky	South Coast	Total
1992		1	4	1	3		9
1993				1	1	1	3
1994					1		1
1998		2	1			1	4
2000			2				2
2001		1	1			1	3
2002	4	5	3	3	4	12	31
2003	1	4	5	3	4	23	40
2004		15	6	8	5	12	46
2005	1	11	2	4	8	8	34
2006		6	1	1		10	18
2007		3	4	3	7	3	20
2008		7	9	3		3	22
2009		1	14		1	9	25
Total	6	56	52	27	34	83	258

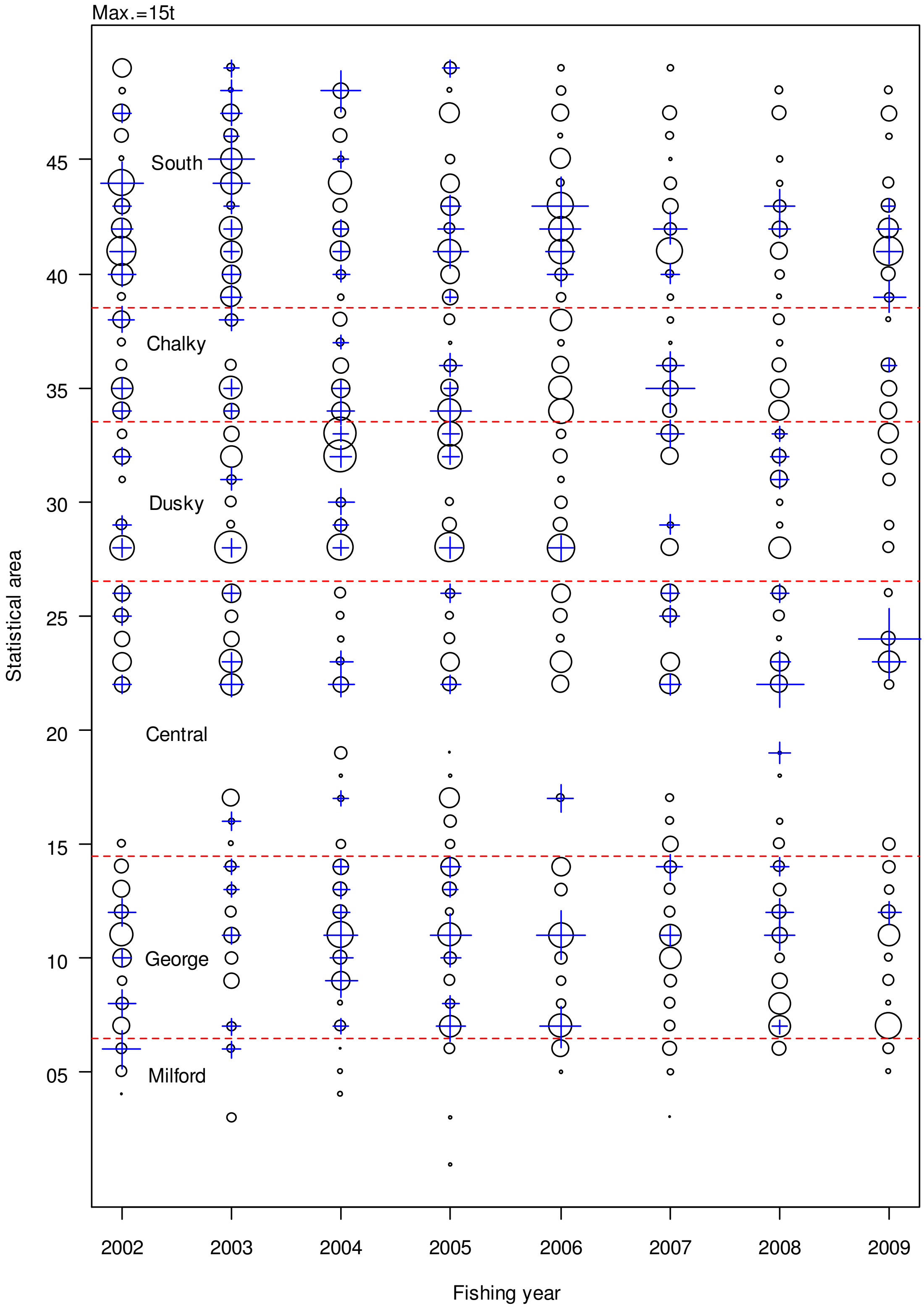


Figure 15: Representativeness of catch sampling of paua catch by finer statistical area in PAU 5A for fishing years 2002–09. Circles show the proportion of catch in for each year and statistical area. Crosses indicate the proportion of sample paua for the same cells. Perfect representation is demonstrated if the cross matches the circle diameter.

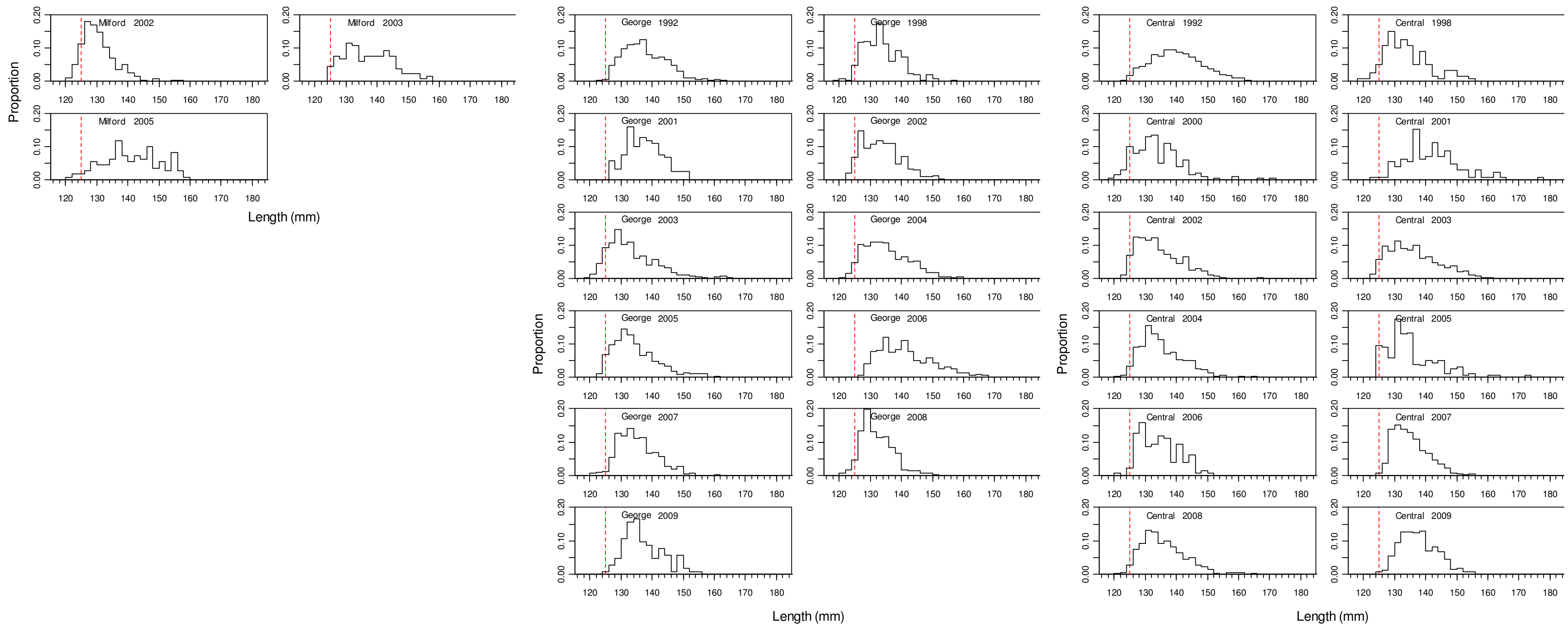
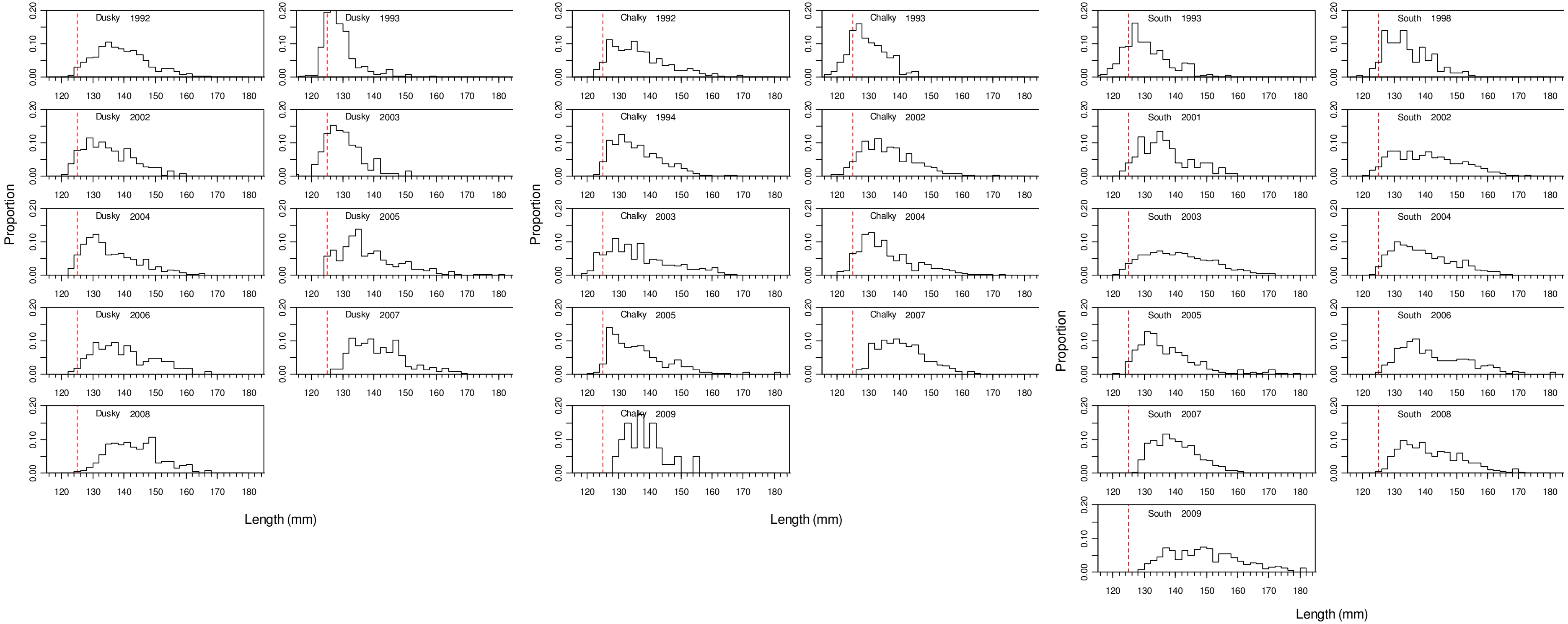


Figure 16: Scaled length frequency from commercial catch sampling by stratum and by fishing year. The dashed line indicates the MLS of 125 mm.

Figure 16-continued



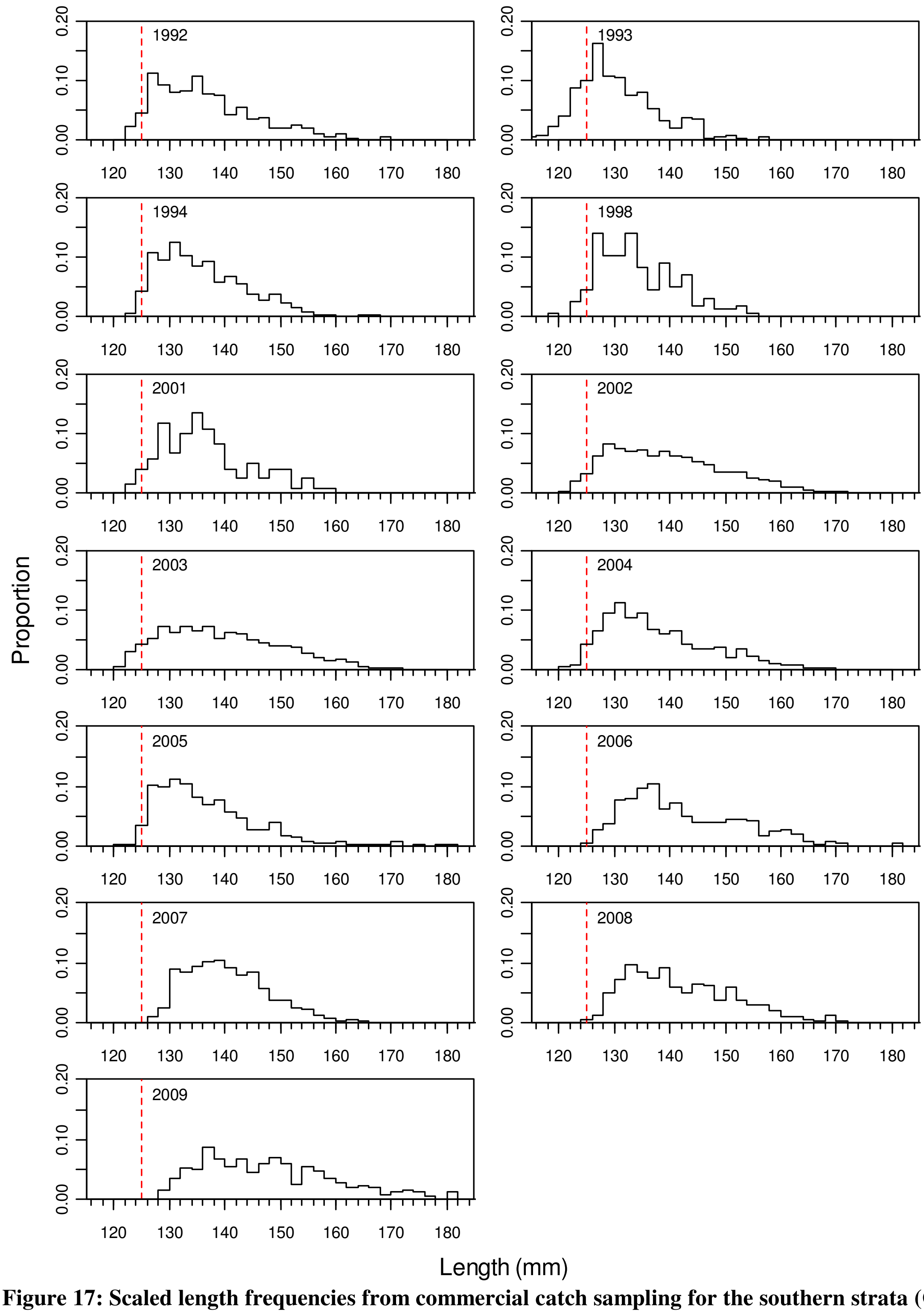


Figure 17: Scaled length frequencies from commercial catch sampling for the southern strata (Chalky and South Coast combined) for 1992–94, 1998, 2000–09. The dashed line indicates the MLS of 125 mm.

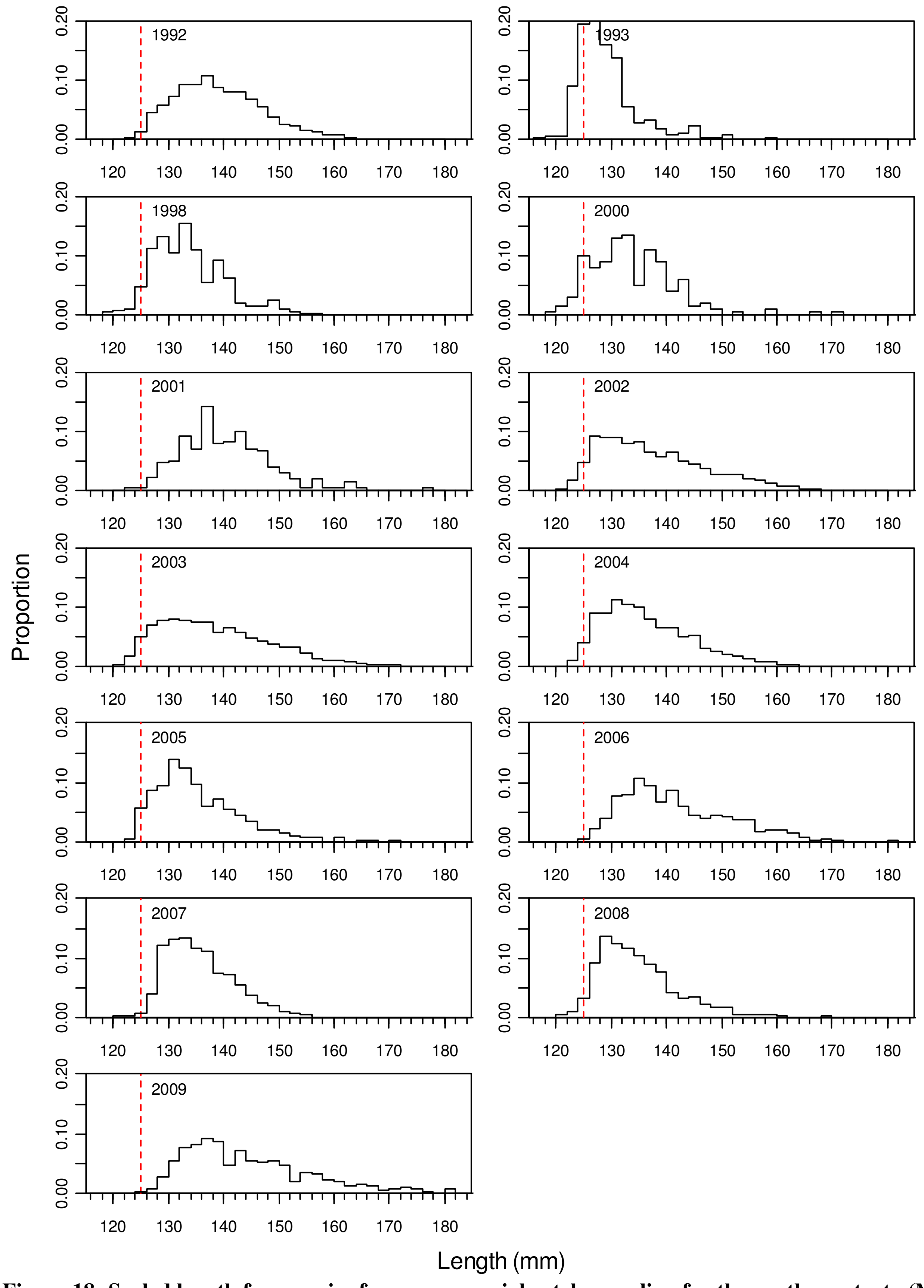


Figure 18: Scaled length frequencies from commercial catch sampling for the northern strata (Milford, George, Central, and Dusky combined) for 1992, 1993, 1998, and 2000–09. The dashed line indicates the MLS of 125 mm.

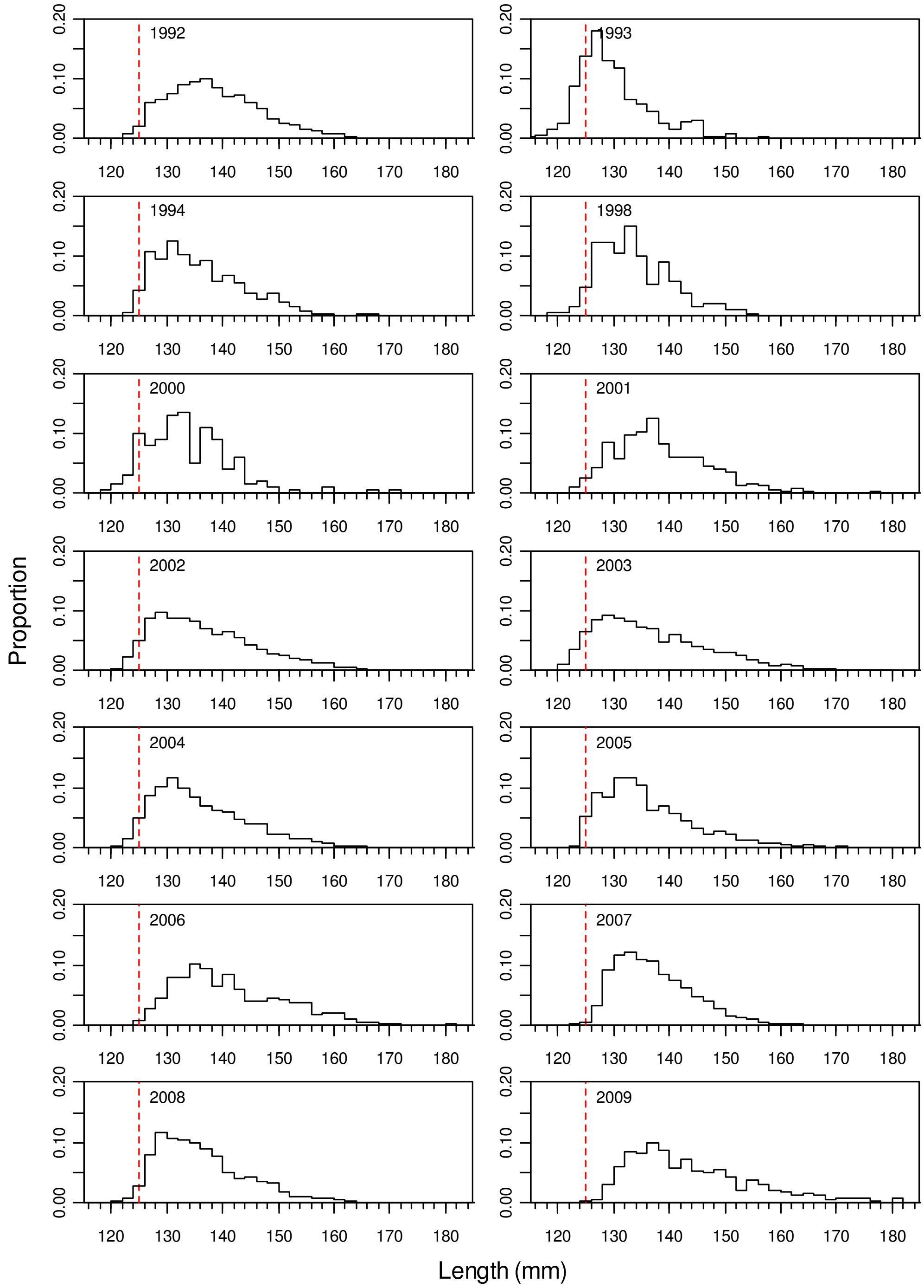


Figure 19: Scaled length frequencies for PAU 5A for 1992–94, 1998, 2000–09. The dashed line indicates the MLS of 125 mm.

6. RESEARCH SURVEY DIVER 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, 2002, Naylor & Kim 2004). Relative abundance indices estimated from the survey data (RDSI) have been routinely used in paua stock assessment (Breen & Kim 2004b, McKenzie & Smith 2009, Breen & Smith 2008b). The previous stock assessment for PAU 5A used the RDSI developed from the survey data up to 2006 (Breen & Kim 2007).

Concerns over the survey methodology and its usefulness in providing relative abundance indices led to a number of reviews. Andrew (2002) recommended slight modifications, which have been adopted and were subsequently reviewed by Hart (2005). More recently, 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. A current review of survey methodology 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 5A was divided into six strata (see Figure 2). 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 side, two 10 minute searches were done 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 covers 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 10). 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 started from when the first paua was encountered (the clock was stopped when large paua patches were encountered, see above). 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 analysis 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 (V. Haist, pers. comm.). For PAU 5A, the early surveys (1996 and 2002) have only recorded paua counts for the total swim, and the later survey (2006–10) have recorded paua counts for both the total swim and the first 10 minutes. Therefore for the early surveys, 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, a number of amendments were made (V. Haist, pers. Comm.) 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 10), 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 the 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; Breen & Kim (2007) used a tweedie model to standardise the RSDI for the 2006 PAU 5A 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 11. Before 2005–06 surveys were conducted only in the area from Dusky south. The 2010 survey was conducted in the northern strata only. The unstandardised RDSIs ((mean diver counts) for each stratum are shown in Figure 20. The standardised RDSIs for the southern and northern strata are shown in Figure 21, and for all areas combined in Figure 22.

Table 10: Definition of patch type by number of paua, the old assumed average number (used in 2006 assessment), and the updated estimates of mean number per patch for PAU 5A.

Patch type	Patch size	Old estimates	Updated estimates
1	1–4	1.6	1.5
2	5–10	6.9	6.8
3	11–20	14.4	14.4
4	21–40	27.4	28.1
5	41–80	51.5	52.7
6	>80	129.9	140.3

Table 11: Number of paua research survey divers (paired swims) in PAU 5A by stratum and fishing year.

	1996	2002	2003	2006	2008	2009	2010
Milford	–	–	–	–	–	1	14
George	–	–	–	14	–	15	8
Central	–	–	–	–	15	–	6
Dusky	–	15	–	12	–	15	–
Chalky	21	16	–	11	–	10	–
South Coast	2	–	15	12	6	11	–
Total	23	31	15	49	21	51	14

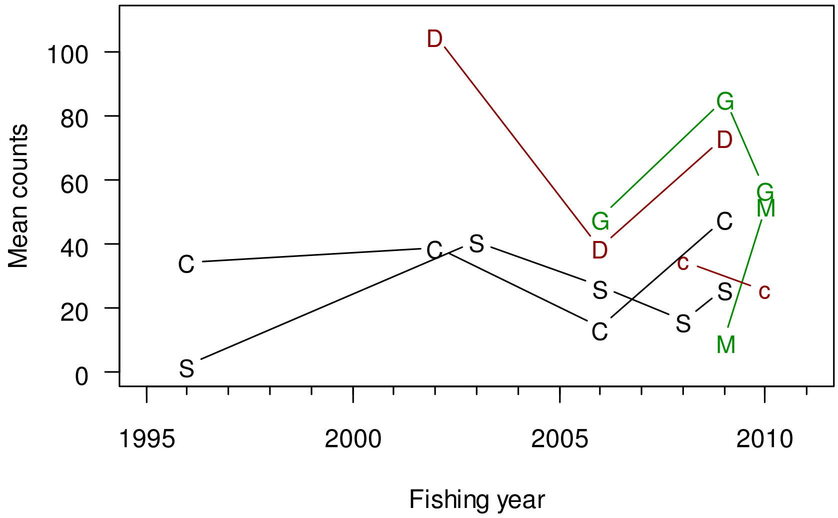


Figure 20: Mean diver counts by stratum and fishing year. M, Milford; G, George; c, Central; D, Dusky; C, Chalky; S, South Coast.

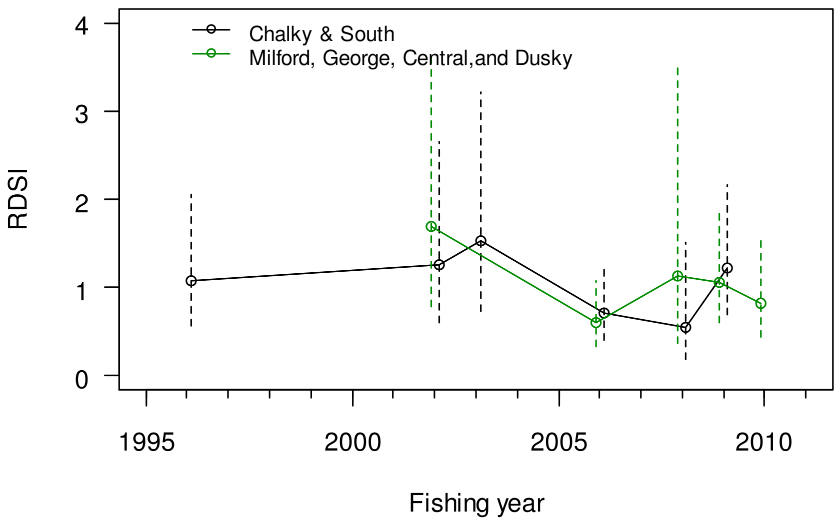


Figure 21: The standardised RDSI from the negative-binomial GLM models fitted to paired diver counts for surveys in the southern strata (Chalky and South Coast), and for surveys in the northern strata (Milford, George, Central, and Dusky).

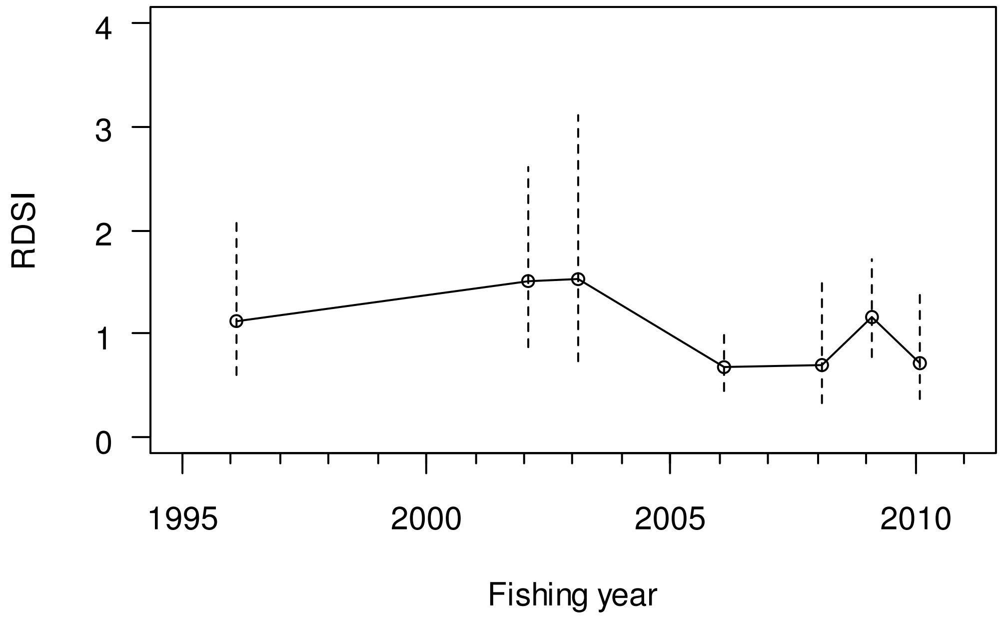


Figure 22: The standardised RDSI from the negative-binomial GLM models fitted to paired diver counts for surveys in PAU 5A.

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 12). 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 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 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 site:

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

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

The scaled length frequencies were then combined across sites within a stratum to obtain the estimated length frequency for each stratum, and combined over 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 each stratum (Figure 23), for the southern strata combined (Figure 24), for the northern strata combined (Figure 25), and for all strata combined (Figure 26).

One-way ANOVAs analysis suggested that the difference in mean paua length (across swim sites) was statistically insignificant between two southern strata for both the 2006 and 2009 surveys (Table 13), and between the northern strata for the 2006 and 2010 surveys (Table 14), but the difference was statistically significant between George and Dusky for the 2009 survey.

Table 12: Number of paua sampled from the research diver survey by stratum and fishing year.

Fishing year	Milford	George	Central	Dusky	Chalky	South Coast
1991				1272		
1996					798	13
2002				1174	657	
2003						637
2006		612		376	230	330
2008			579			93
2009	33	793		513	318	393
2010	533	318	253			

Table 13: Summary of the one-way ANOVAs analysis comparing the mean length (across sites) of the paua sampled from the research diver survey between Chalky and South Coast, for the 2006 and 2009 survey respectively.

2006 (Chalky, South Coast)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Stratum	1	174.5	174.5	1.2	0.292
Residuals	16	2348.9	146.8		

2009 (Chalk, South Coast)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Stratum	1	185.8	185.8	2.1	0.162
Residuals	17	1477.7	86.9		

Table 14: Summary of the one-way ANOVAs analysis comparing the mean length (across sites) of the paua sampled from the research diver survey between George and Dusky for the 2006 survey, Milford, George, and Dusky for the 2009 survey, and Milford, George, and Central for the 2010 survey.

2006 (George, Dusky)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Stratum	1	133.7	133.7	1.7	0.204
Residuals	21	1630.8	77.7		

2009 (Milford, George, and Dusky)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Stratum	2	1120.9	560.5	7.5	0.002
Residuals	28	2084.8	74.5		

2009 (Milford, George, and Central)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Stratum	2	187.9	93.9	0.7	0.517
Residuals	20	2751.5	137.6		

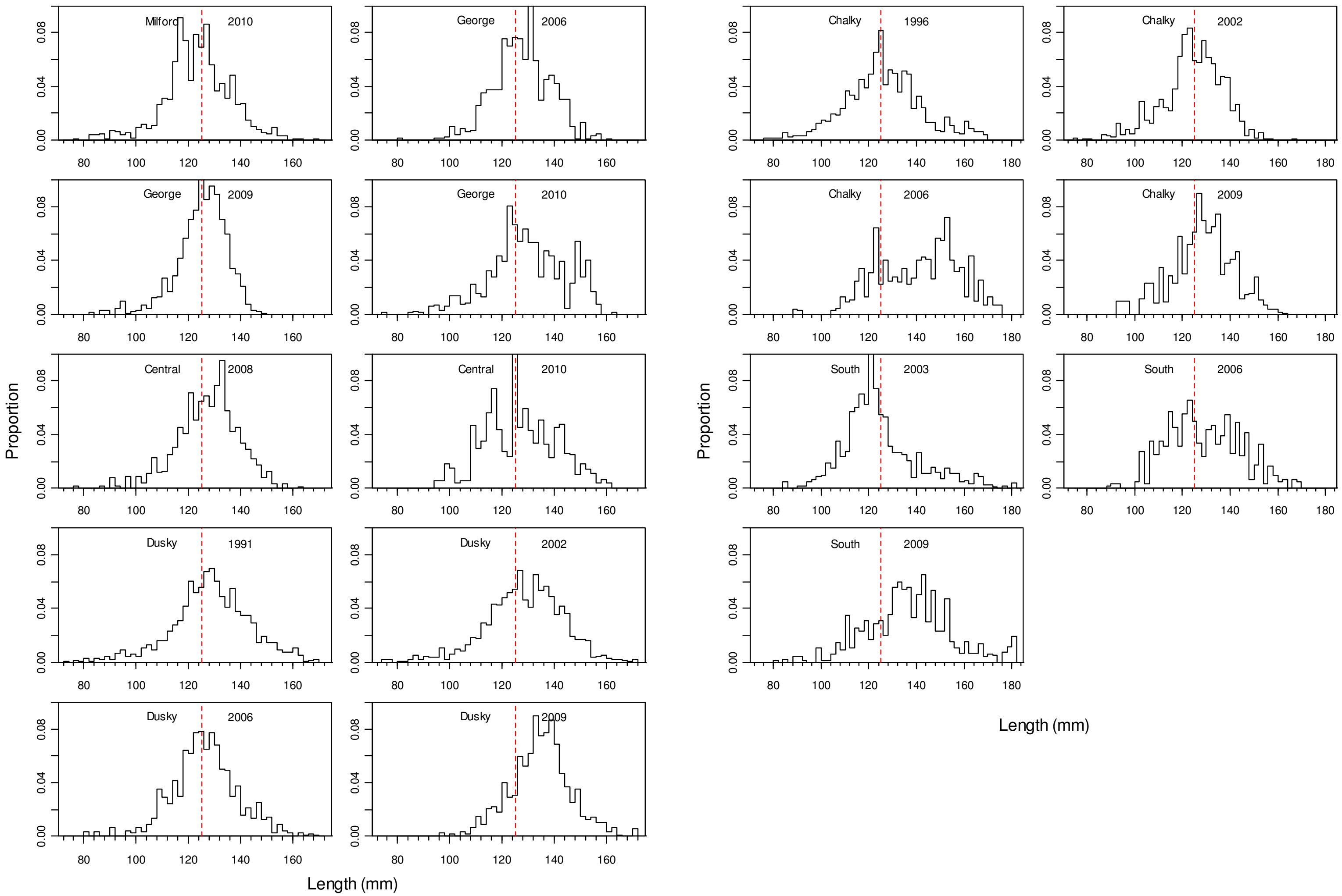


Figure 23: Scaled length frequencies from research diver surveys by stratum and fishing year. The dashed line indicates the MLS of 125 mm.

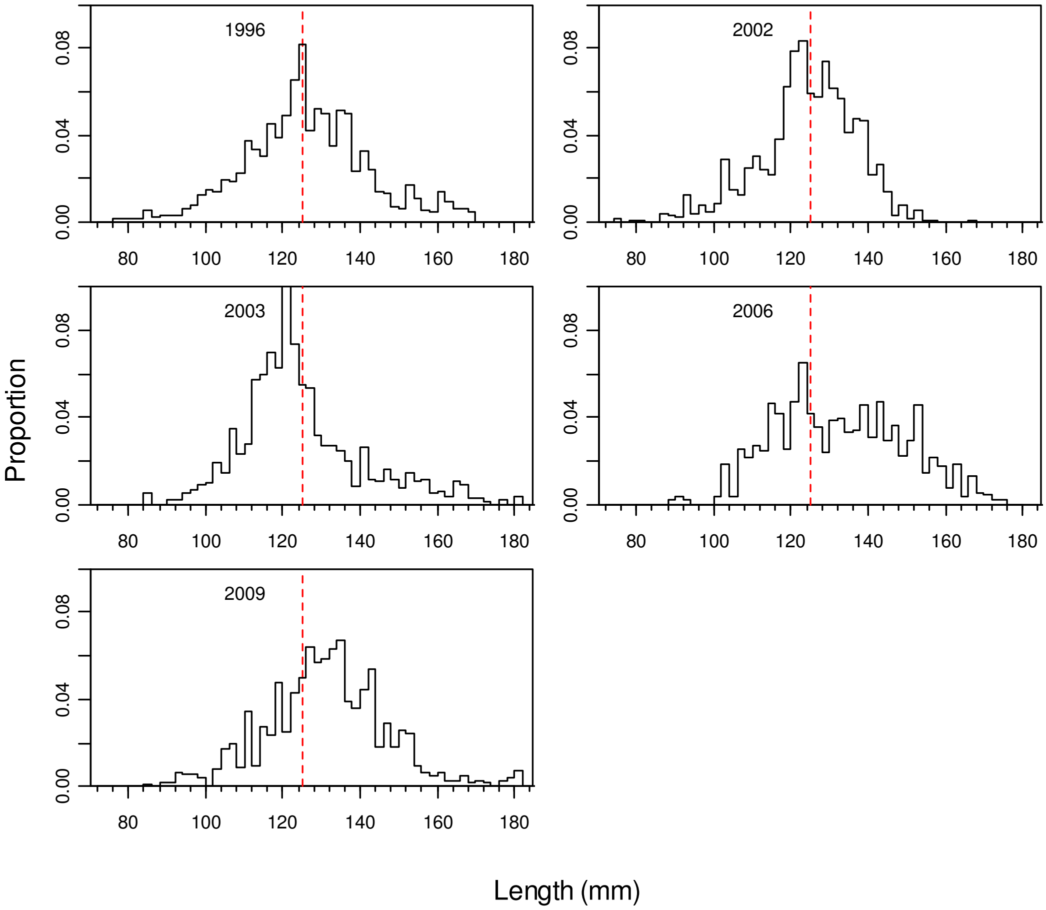


Figure 24: Scaled length frequencies from research diver surveys by fishing year for the southern strata (Chalky and South Coast combined). The dashed line indicates the MLS of 125 mm.

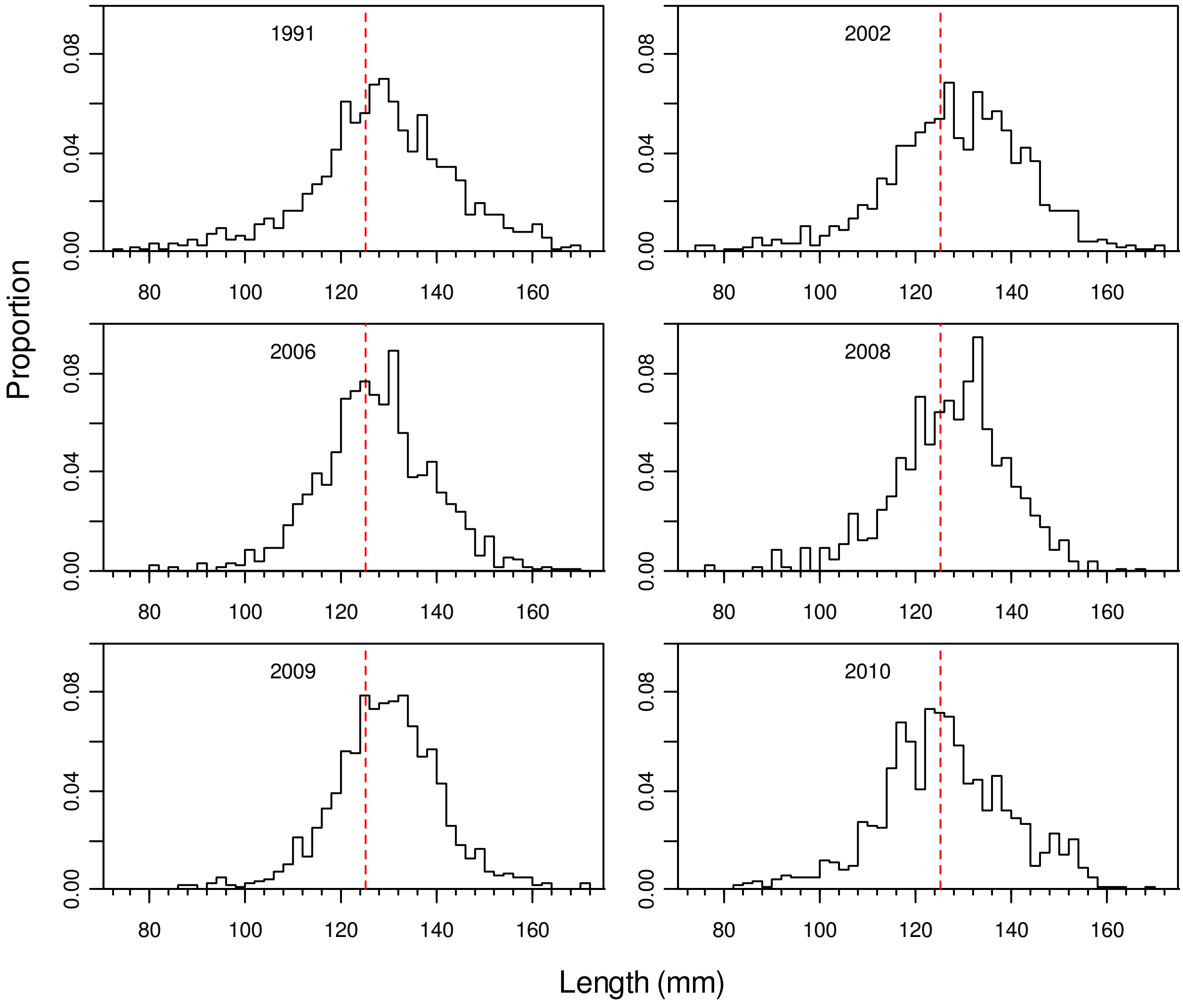


Figure 25: Scaled length frequencies from research diver surveys by fishing year for the northern strata (Milford, George, Central, and Dusky combined). The dashed line indicates MLS of 125 mm.

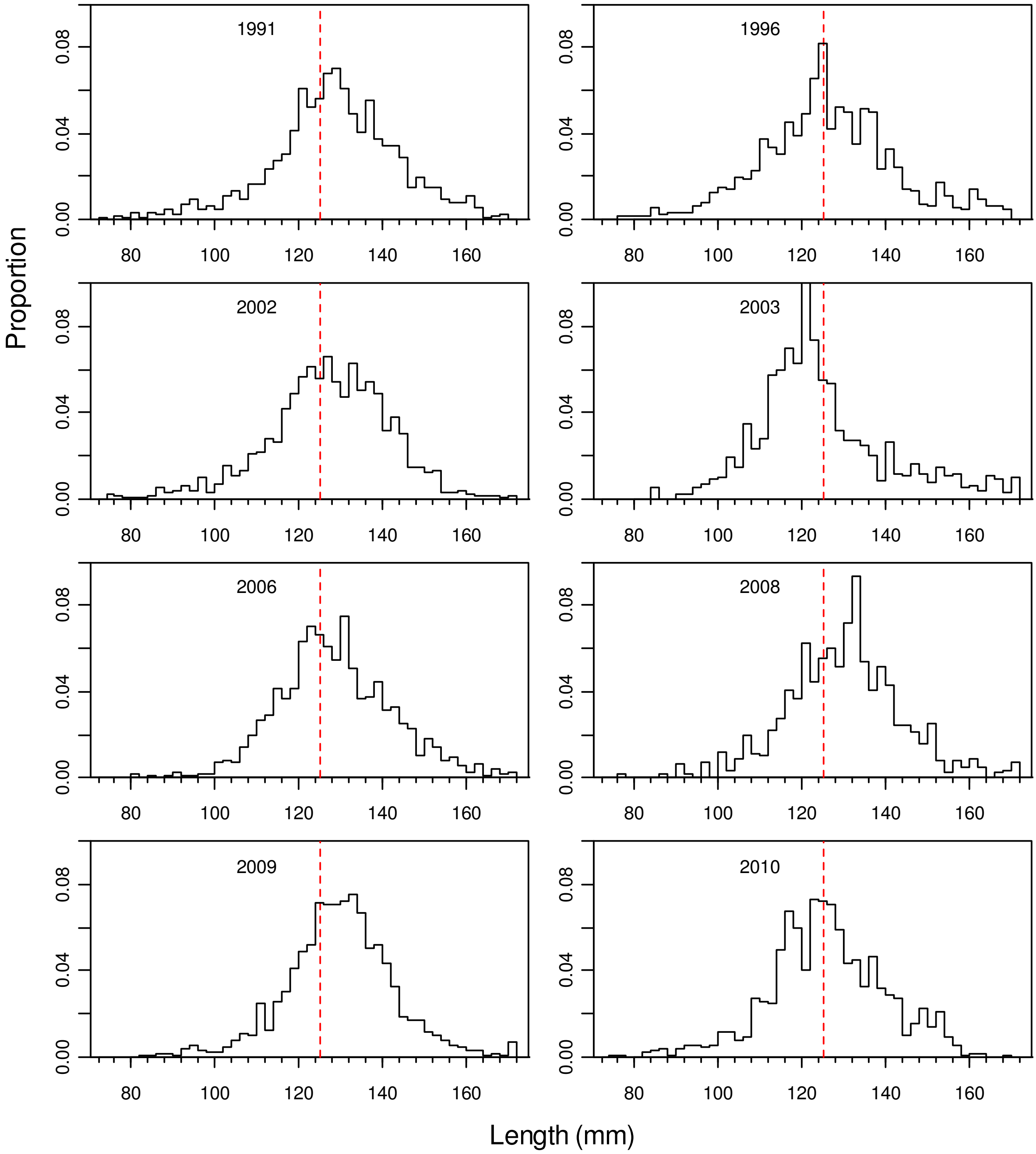


Figure 26: Scaled length frequencies from research diver surveys by fishing year for PAU 5A. The dashed line indicates the MLS of 125 mm.

8. GROWTH TAG DATA AND GROWTH ESTIMATES

Growth data for the New Zealand paua were collected from 30 sites around the New Zealand coast by tag-recapture methods during 2000–02 (Naylor et. al 2006), where growth data for PAU 5A (Naylor & Andrew 2002) were available from three locations – Landing Bay (n=135) , Red Head (n=73), and Poison Bay (n=91). The tag recapture data comprises 299 records, with initial lengths ranging from 81 to 155 mm, time at liberty ranging from 369 to 381 days, and increments ranging from -4 to 28 mm. These data were incorporated into the 2006 assessment to estimate growth.

Naylor & Breen (2008) conducted an isotopic study using 30 paua shells collected from 10 sites in PAU 5A, where the annual temperature cycle as preserved by the $^{18}O/^{16}O$ ratio of the carbonate along the growth axis of the paua shell was used as a year tag or marker, which allowed growth be estimated for individual shells. A total of 143 individual growth increment data (consecutive growth increments from the same shell were treated as independent observations) were available for the stable isotopic analysis from research strata Chalky (n=33), Dusky (39), George (n=25), and South Coast (46). The initial lengths ranged from 70 to 129 mm (two records with initial length below 70 cm were excluded), time interval ranged from 275 to 427 days, and increments ranged from -3 to 28 mm.

Chalky and South Coast accounted for 55% of the available growth data (Table 15). The SFWG suggested dropping out Milford as this stratum has just one site, and the paua at this site seem to be abnormally stunted. The resulting growth data (without Milford) can be fitted in the model for either a southern or northern assessment.

Table 15: Number of growth-increment pairs by stratum for the tag-recapture and Isotopic growth datasets.

Stratum	Tag-recapture	Isotopic growth	Total	Percent
Milford	135		135	31
George		25	25	6
Central				
Dusky		39	39	9
Chalky	164	33	197	45
South Coast		46	46	10
Total	299	143	442	100%

Naylor & Breen (2008) analysed the growth increment data using an inverse logistic model and found that the growth curve estimated from the isotopic data was remarkably similar to that from the Chalky Inlet tag recapture data. The tag-recapture and the isotopic growth increment data were pooled together to be included in the assessment model. In this study, they were analysed using a length-increment, maximum likelihood von Bertalanffy growth model based on the parameterisation of Francis (1988), i.e.,

$$\Delta l_k = g_\alpha \left(g_\beta / g_\alpha \right)^{(l_k-\alpha)/(\beta-\alpha)}$$

where ΔL is the expected increment for a paua of initial size L_k; g_α and g_β are the mean annual growth increments for paua with arbitrary lengths α and β. Variation in growth was normally distributed with $\sigma = \max(c\mu_i, \sigma_{\min})$ (where c is the coefficient of variation, $\sigma_{\min}$ is the minimum standard deviation, and μ_i is the expected growth at length L) truncated at zero. The likelihood was defined as (M.H. Smith, NIWA, pers. comm., also see 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 function respectively. The fits to the growth data are show in Figure 27.

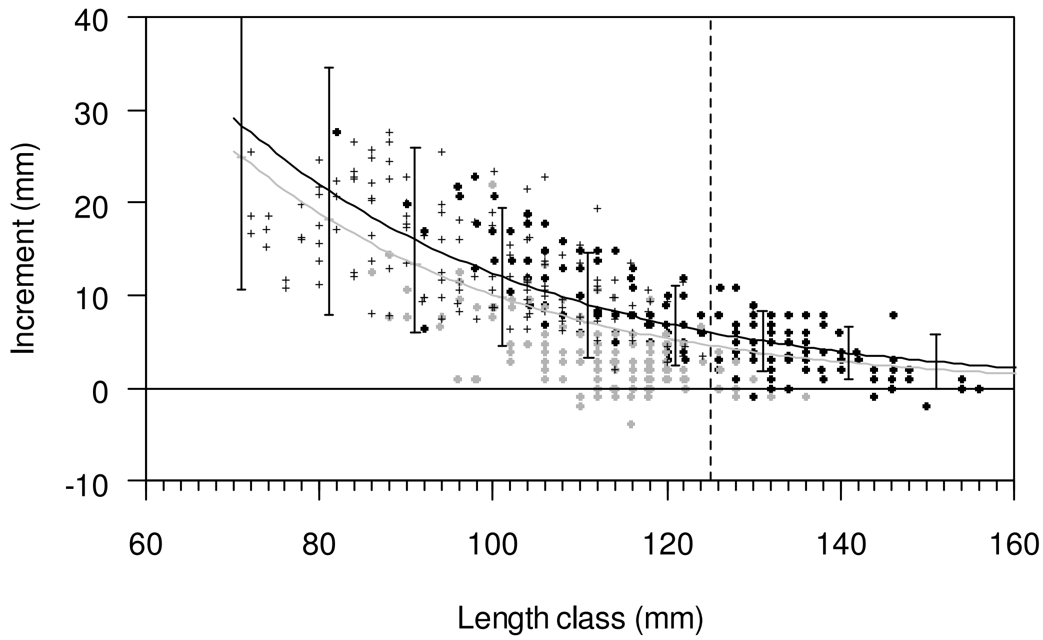


Figure 27: Initial size and mean annual increment data from the tag-recapture data (dots) (Naylor & Kim 2002), and the isotopic data (cross) (Naylor & Breen 2007). Grey dots represent tag-recapture samples collected from Milford. Lines (and 95% confidence intervals) indicate size-based exponential growth curves estimated from these data: Grey, based on all the data; black, based on data excluding Milford. Dashed lines separate the legal size limit.

9. MATURITY

Data were collected during February 2006 (Reyn Naylor, NIWA, unpublished data) at sites in the Dusty, George, and Milford areas, with the bulk of the samples taken from the Dusky area (Table 16). Three hundred and eighty-five paua of various sizes were sampled visually for sex and maturity (217 were available for the 2006 assessment). Following Breen & Kim (2007), maturity was determined collectively for both sexes combined, assuming that males and females mature at approximately the same rates with increasing length.

Paua below 70 mm were discarded from the dataset. The estimated proportion mature along with exact 95% confidence interval in 5-mm length class is shown in Table 17. The sample size is small, but most animals are mature by 110 mm and 50% maturity probably lies between 90 mm and 105 mm. The proportion mature data were fitted with a logistic curve using a binomial likelihood (Figure 28).

Table 16: Number of paua sampled for maturity by stratum.

Stratum	Sample size
Milford	33
George	39
Central	0
Dusky	290
Chalky	10
South Coast	0

Table 17: Number of paua observed, number mature, and proportion mature from the samples collected in the Dusky areas: the bin size is the mid-point.

Bin (mm)	sample size	no. mature	proportion mature	lower limit	upper limit
72.5	7	0	0.000	–	–
77.5	15	1	0.067	0.002	0.319
82.5	30	5	0.167	0.056	0.347
87.5	34	10	0.294	0.151	0.475
92.5	40	26	0.650	0.483	0.794
97.5	32	20	0.625	0.437	0.789
102.5	43	31	0.721	0.563	0.847
107.5	49	48	0.980	0.891	0.999
112.5	38	38	1.000	–	–
117.5	23	23	1.000	–	–
122.5	25	25	1.000	–	–
127.5	11	11	1.000	–	–
132.5	25	25	1.000	–	–

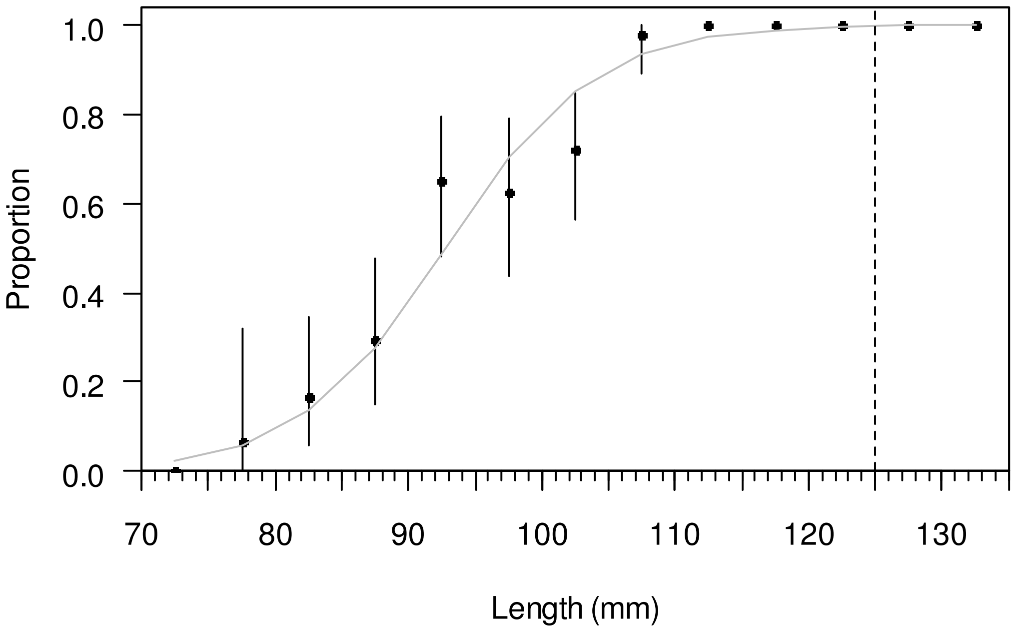


Figure 28: Proportion of maturity at length, vertical bar represents 95% confidence interval of estimated proportion mature at each length bin. The grey line represents a fitted maturity ogive with mat50=92.8, mat95=109.1. Dashed line represents the legal size limit of 125 mm.

10. DISCUSSION

This report summarises data collocated for the 2010 stock assessment of PAU 5A. The 2010 assessment will be conducted for the two subareas of PAU 5A separately: one for the southern strata Chalky and South Coast, and one for the northern strata Milford, George, Central, and Dusky. Catch history and data used as model inputs were compiled for each of the two strata, including (1) standardised CPUE series based on CELR data, (2) standardised CPUE series based on PCELR data, (3) standardised research diver survey indices, (4) research diver survey proportions-at-lengths series, (5) commercial catch sampling length frequency series, (6) tag-recapture length increment data, and (7) maturity-at-length data. Although the collection of fishery data, coverage of research surveys and sampling of biological data have not been in balance between subareas of the stock in the past, these data were generally adequate to allow development of an assessment model at a smaller spatial scale.

The catch history included commercial, recreational, customary, and illegal catch. Several alternative assumptions were proposed to estimate the commercial catch history for PAU 5A and for its subareas, with respect to the split of the pre-QMA catch between substocks of PAU 5. There is little information on the historic catches in Fiordland but anecdotal evidence suggested that the catch between 1981 and 1984 was about 60–70 tonne annually (Storm Stanley, pers. comm.). The general consensus is that there had been a redistribution of catch when the quota was split among the sub-stocks, but the extent to which this happened is unknown.

The CPUE for the northern strata based on the CELR showed an upward trend from 1990 to 1996, while the unstandardised catch rates generally remained flat. The stepwise model fitting suggested the trend in the CPUE is largely influenced by vessel effects. Further investigation showed that the fishery was dominated by two vessels: one operated between 1991 and 1993, and the other operated from 1994 onward, with the early vessel having a much higher catch rate. Both vessels belonged to the same fisher and the second vessel was purchased as a replacement. One option is to treat the two boats as one in the standardisation as the divers were largely from the same diver pools. However, this may not be appropriate as the second vessel was much faster and was able to cover much more ground, and therefore may allow better access to paua habitat. The SFWG concluded that the CPUE based on CELR for the northern strata (M6) was unlikely to track the abundance changes.

Ideally the CPUE for the southern strata should be based on records from Chalky and South Coast only. However, this would lead to exclusion of the pre-QMA data, resulting in a much shorter time series. The recent practice of including randomly assigned records in standardisations was criticised for not being able to retain catch rate differences between subareas (Middleton 2007), and that the results can not be repeated in between analyses as the choice of data is random. The SFWG suggested using the standardised CPUE indices based on all the CELR records from Statistical Area 030 (M5.2) as estimates of relative abundance for the stock assessment. This assumed that the changes in population abundance in the southern strata of Fiordland were the same as those at Stewart Island between 1990 and 2001.

Other changes of fishing practice have been noted. Since 2001, some fishers have used larger and more powerful tenders, which are deployed from the mother vessel with the divers. The larger tenders could hold more and didn't need to return to the mother vessel as often to unload. These tenders were also able to cover much more fishing ground than the older, smaller, and slower tenders. The catch is still reported under the mother boat, therefore the "tender" effect is not incorporated in the model. It was not known to what extent the employment of new tenders has influenced the catch rates. However, if the timing of those changes coincided with the split of the CPUE series (between CELR and PCELR), this would not have influenced on the interpretation of CPUE indices.

11. ACKNOWLEDGMENT

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APPENDIX A: CPUE MODEL DIAGNOSTICS AND STANDARDISED INDICES

Table A1: Predictor variables and R^2 values from GLM stepwise regression analysis for selected models. Variables are shown in order of acceptance by the model with associated cumulative R^2 value. Only variables entered into the model are shown.

PCELR series

	M2.0		M3.0		M4.0
Variable	R^2	Variable	R^2	Variable	R^2
fishing year	0.04	fishing year	0.06	fishing year	0.03
diver	0.31	diver	0.20	diver	0.26
diving condition	0.41	diving condition	0.34	diving condition	0.36
stats area	0.42	stats area	0.40	stats area	0.42
month	0.43	month	0.41	month	0.43

CELR series

	M5.0		M5.1		M5.2
Variable	R^2	Variable	R^2	Variable	R^2
fishing year	0.03	fishing year	0.03	fishing year	0.04
vessel	0.15	vessel	0.15	vessel	0.19
month	0.18	month	0.22	month	0.22

	M6.0		M7.0
Variable	R2	Variable	R2
fishing year	0.01	fishing year	0.005
vessel	0.18	vessel	0.143
month	0.19	month	0.156

Table A2: Standardised CPUE indices for selected models.

PCELR series

		M2.0		M3.0		M4.0
Year	Indices	cv	Indices	cv	Indices	cv
2002	1.15	0.08	1.08	0.08	1.10	0.06
2003	1.06	0.08	1.16	0.08	1.09	0.05
2004	1.06	0.07	0.92	0.07	0.98	0.05
2005	1.01	0.07	1.03	0.07	1.03	0.05
2006	0.95	0.06	1.04	0.07	0.98	0.04
2007	0.89	0.08	0.92	0.07	0.91	0.05
2008	0.86	0.09	0.92	0.07	0.93	0.05
2009	1.05	0.08	0.95	0.09	1.00	0.05

CELR series

		M5.0		M5.1		M5.2
Year	Indices	cv	Indices	cv	Indices	cv
1990			1.94	0.24	1.80	0.10
1991			1.05	0.23	1.48	0.08
1992			0.97	0.19	1.18	0.07
1993			0.97	0.17	1.07	0.07
1994			0.98	0.16	0.99	0.07
1995			1.03	0.15	0.99	0.06
1996	1.17	0.13	0.94	0.10	0.83	0.06
1997	1.01	0.12	0.93	0.11	0.83	0.06
1998	0.98	0.12	0.81	0.13	0.77	0.07
1999	0.87	0.14	0.82	0.14	0.86	0.07
2000	1.11	0.15	1.05	0.18	0.85	0.08
2001	0.89	0.16	0.84	0.18	0.79	0.09

		M6.0		M7.0
Year	Indices	cv	Indices	cv
1990	0.79	0.30	1.36	0.16
1991	0.75	0.21	1.10	0.12
1992	1.00	0.22	1.06	0.13
1993	0.76	0.24	0.96	0.13
1994	0.92	0.18	0.95	0.11
1995	1.07	0.17	0.97	0.10
1996	1.09	0.17	0.89	0.08
1997	1.23	0.16	0.91	0.08
1998	1.11	0.13	0.88	0.08
1999	1.12	0.13	0.91	0.08
2000	1.12	0.16	1.05	0.10
2001	1.21	0.20	1.05	0.11

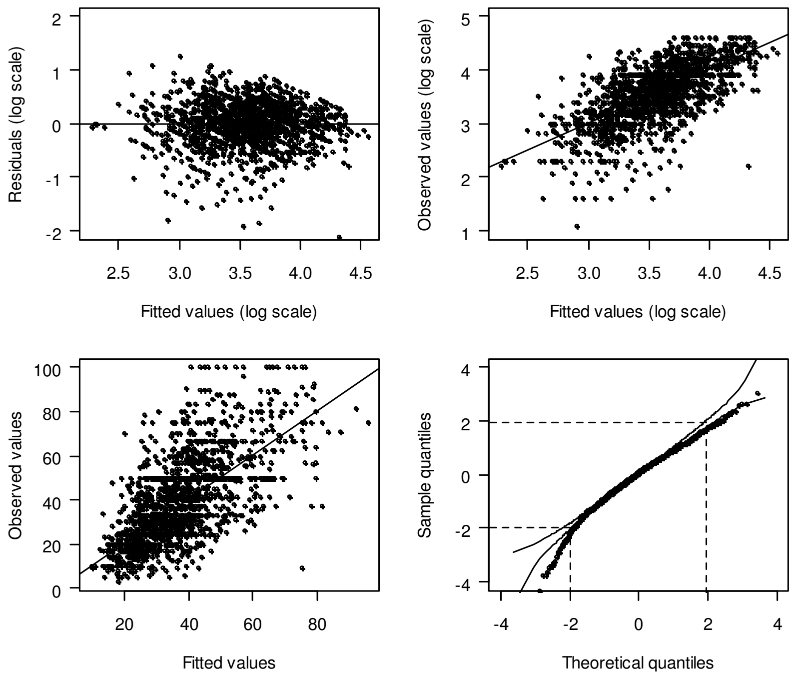

Figure A1: Residual diagnostic plots for CPUE model M2. The dotted lines on the QQ plot represent the 95% quartiles

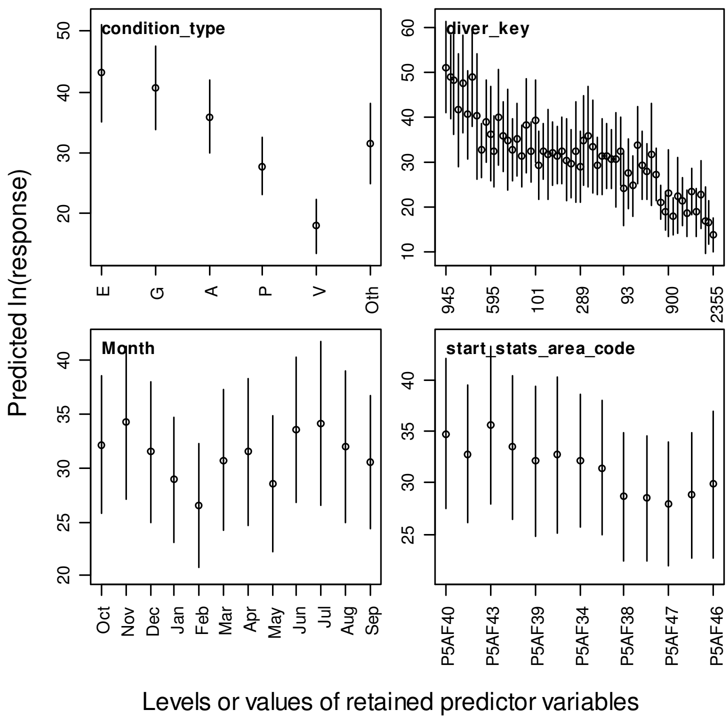

Figure A2: Expected catch rates (kg per diver day) for variables *condition type*, *diver key*, *month*, and *stats area* for CPUE model M2. Bounds show the expected values ± 2 standard deviations.

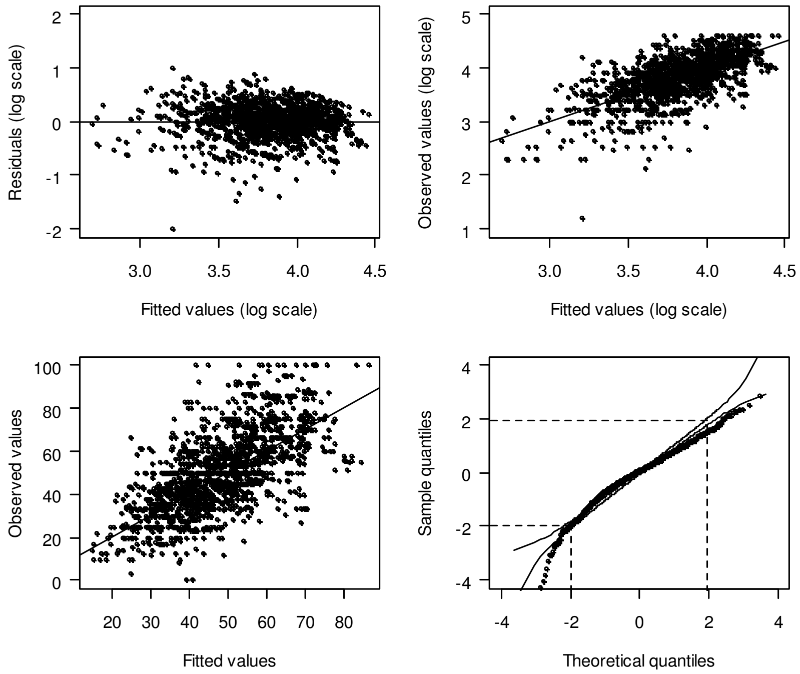

Figure A3: Residual diagnostic plots for CPUE model M3. The dotted lines on the QQ plot represent the 95% quartiles.

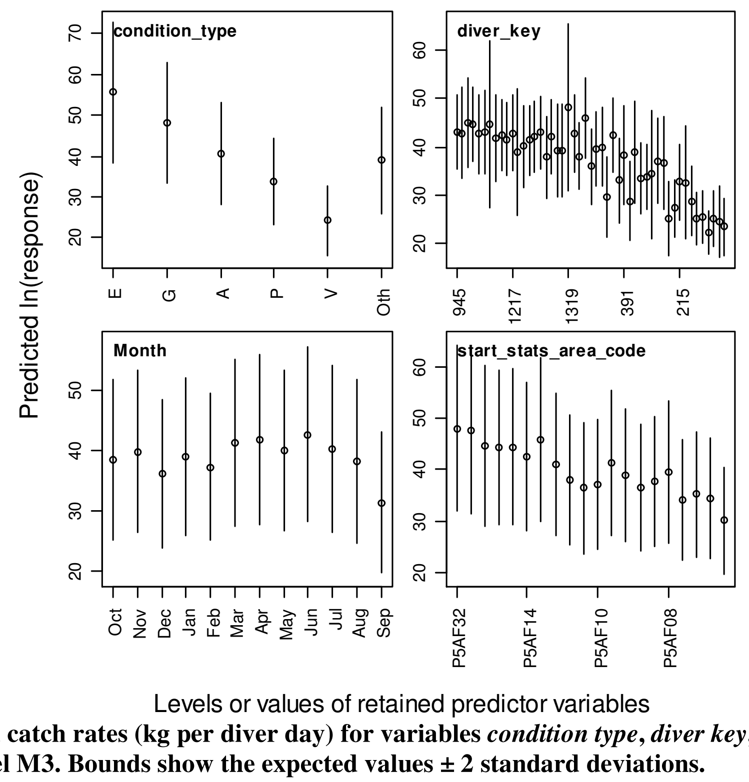

Figure A4: Expected catch rates (kg per diver day) for variables *condition type*, *diver key*, *month*, and *stats area* for CPUE model M3. Bounds show the expected values ± 2 standard deviations.

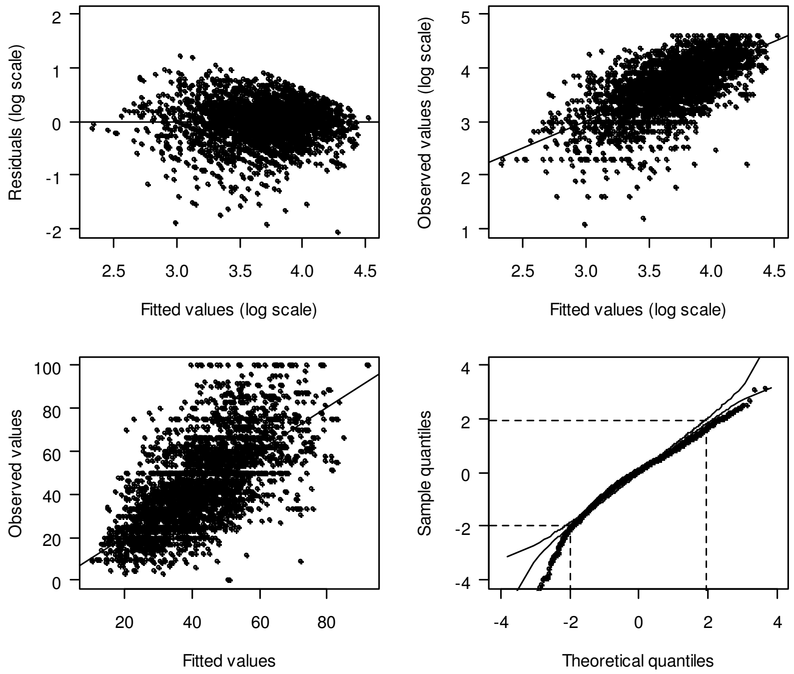

Figure A5: Residual diagnostic plots for CPUE model M4. The dotted lines on the QQ plot represent the 95% quartiles.

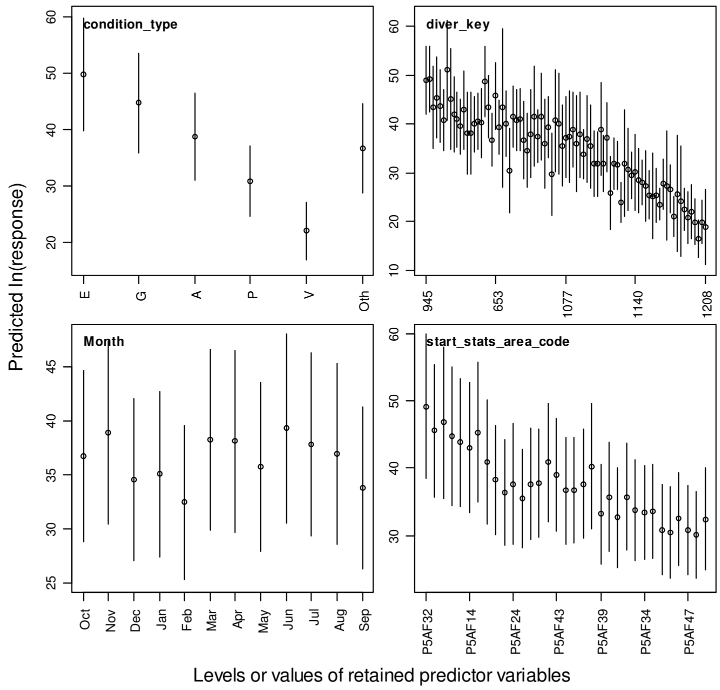

Figure A6: Expected catch rates (kg per diver day) for variables *condition type*, *diver key*, *month*, and *stats area* for CPUE model M4. Bounds show the expected values ± 2 standard deviations.

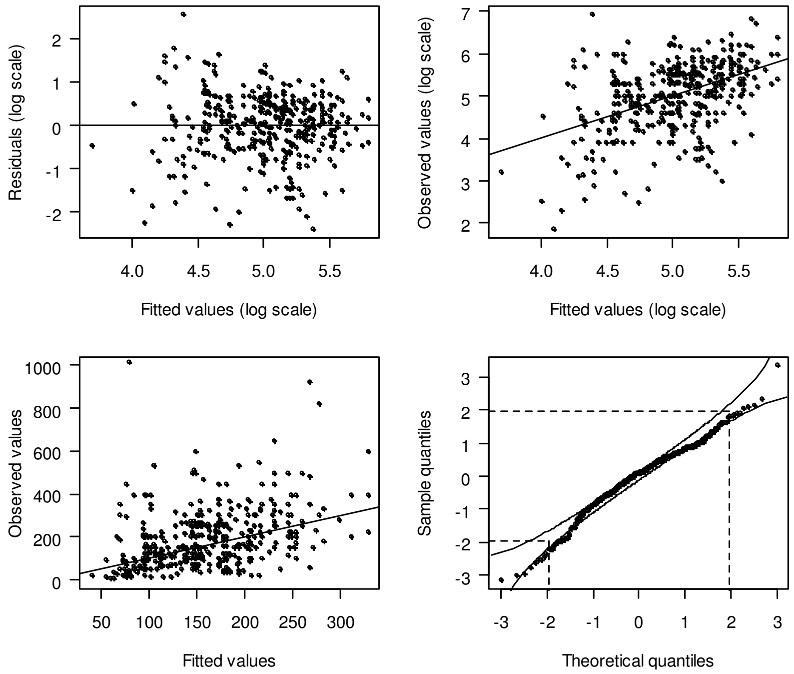

Figure A7: Residual diagnostic plots for CPUE model M5. The dotted lines on the QQ plot represent the 95% quartiles.

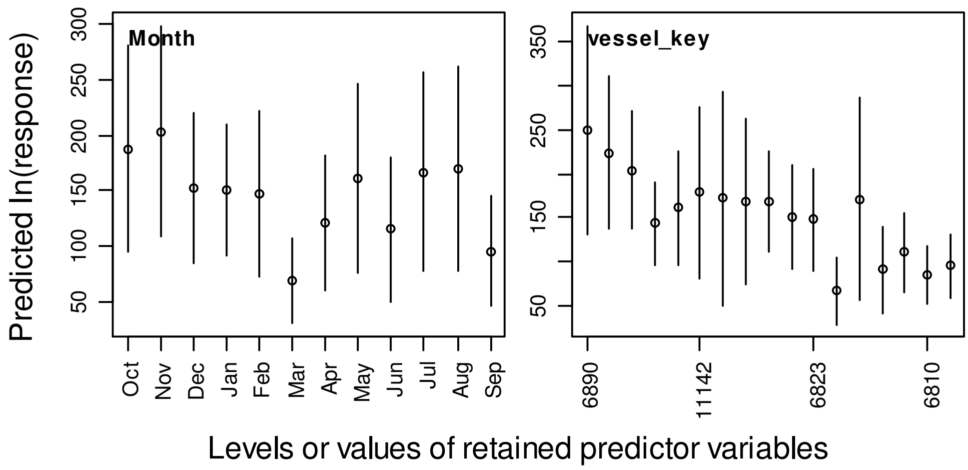

Figure A8: Expected catch rates (kg per diver day) for variables *vessel and month* for CPUE model M5. Bounds show the expected values ± 2 standard deviations.

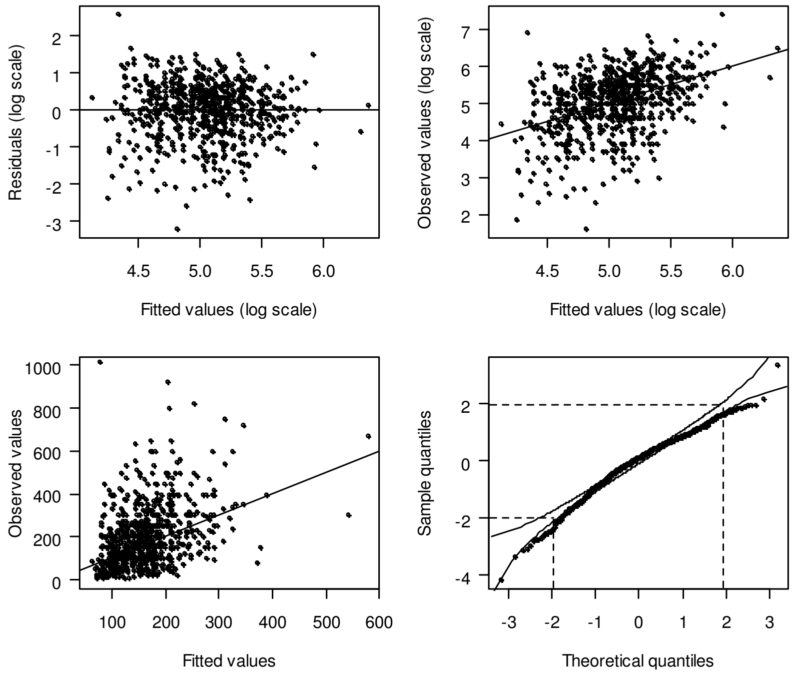

Figure A9: Residual diagnostic plots for CPUE model M5.1. The dotted lines on the QQ plot represent the 95% quartiles.

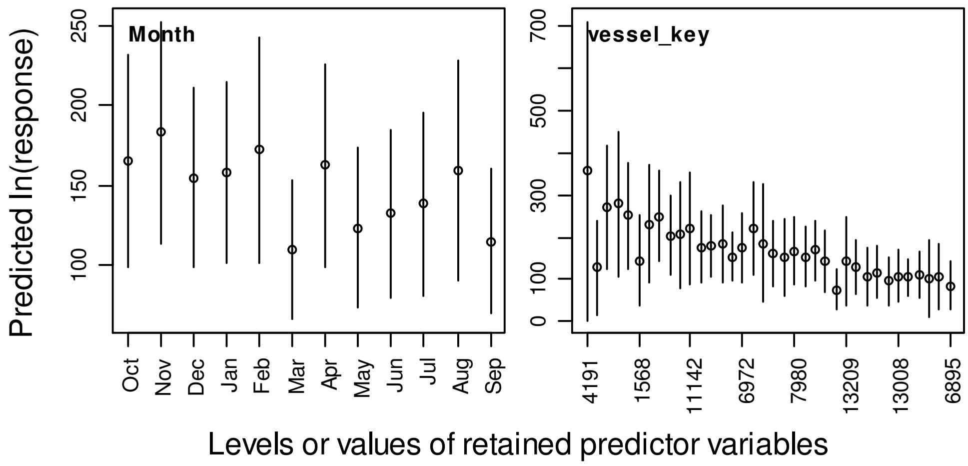

Figure A10: Expected catch rates (kg per diver day) for variables *vessel and month* for CPUE model M5.1. Bounds show the expected values ± 2 standard deviations.

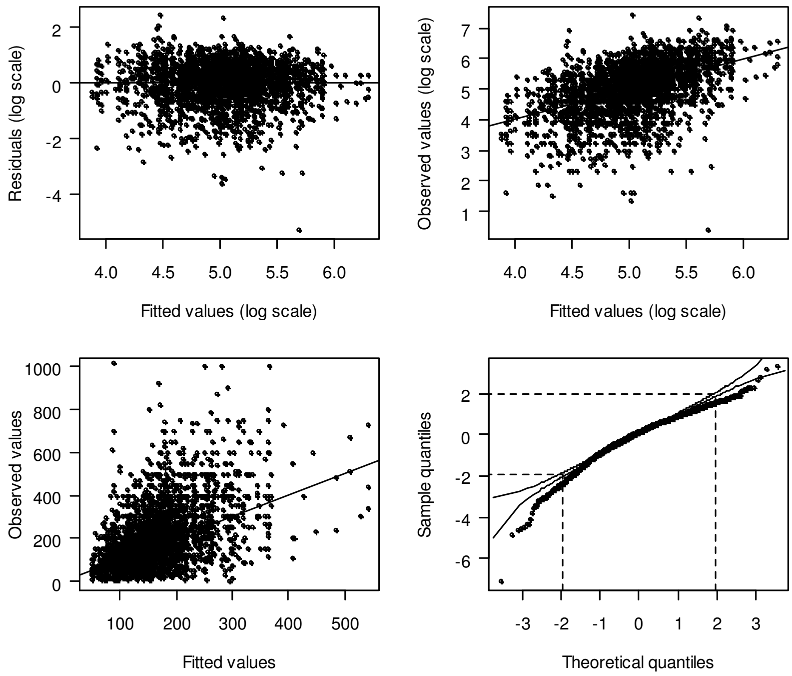

Figure A11: Residual diagnostic plots for CPUE model M5.2. The dotted lines on the QQ plot represent the 95% quartiles.

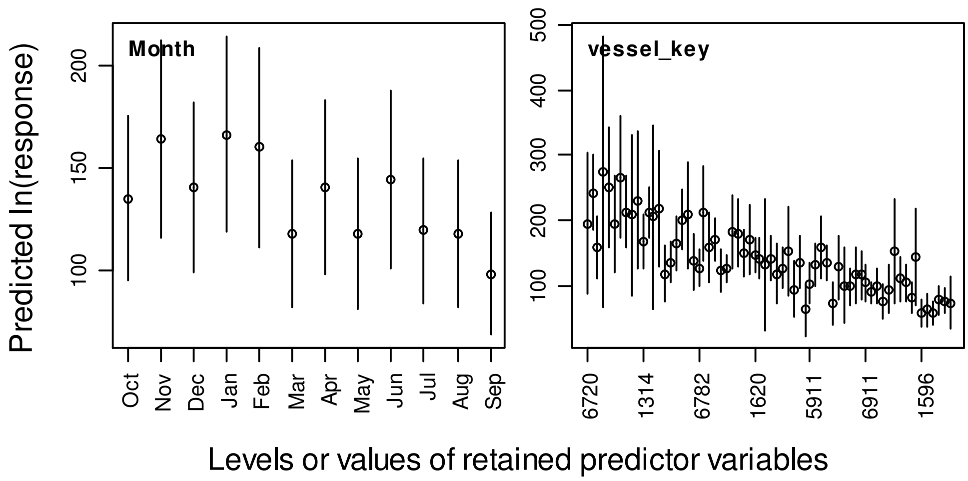

Figure A12: Expected catch rates (kg per diver day) for variables *vessel and month* for CPUE model M5.2. Bounds show the expected values ± 2 standard deviations.

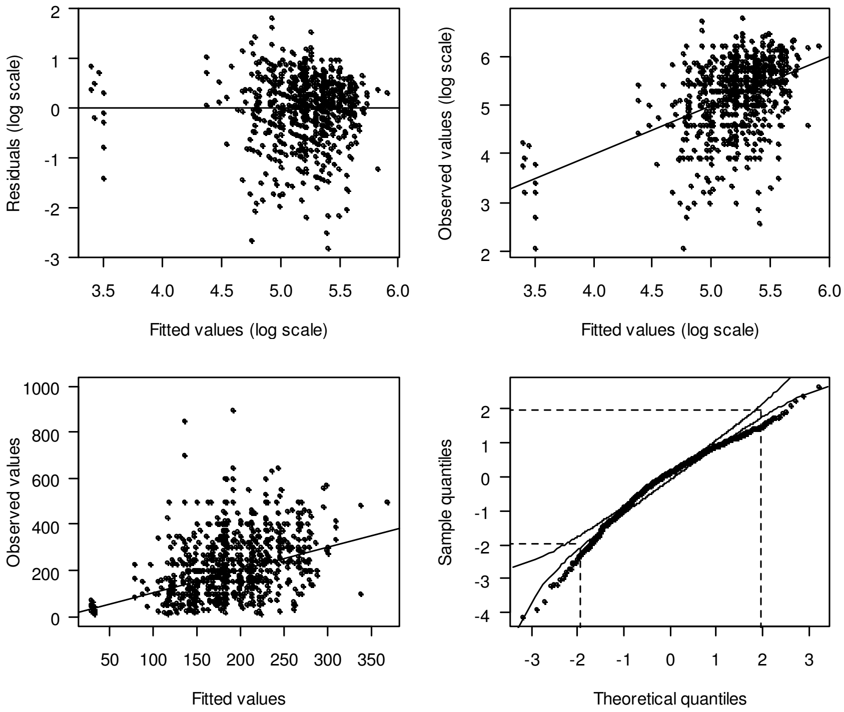

Figure A13: Residual diagnostic plots for CPUE model M6. The dotted lines on the QQ plot represent the 95% quartiles.

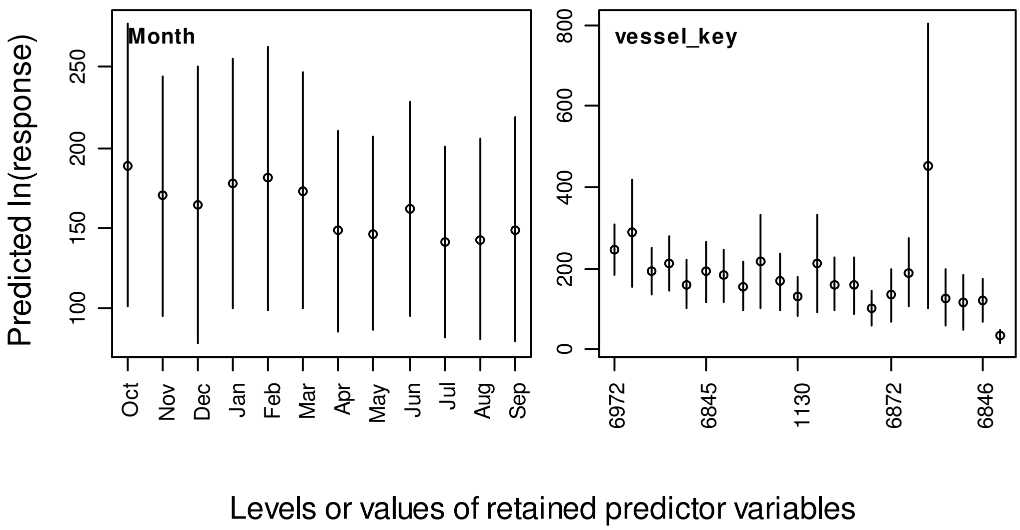

Figure A14: Expected catch rates (kg per diver day) for variables *vessel and month* for CPUE model M6. Bounds show the expected values ± 2 standard deviations.

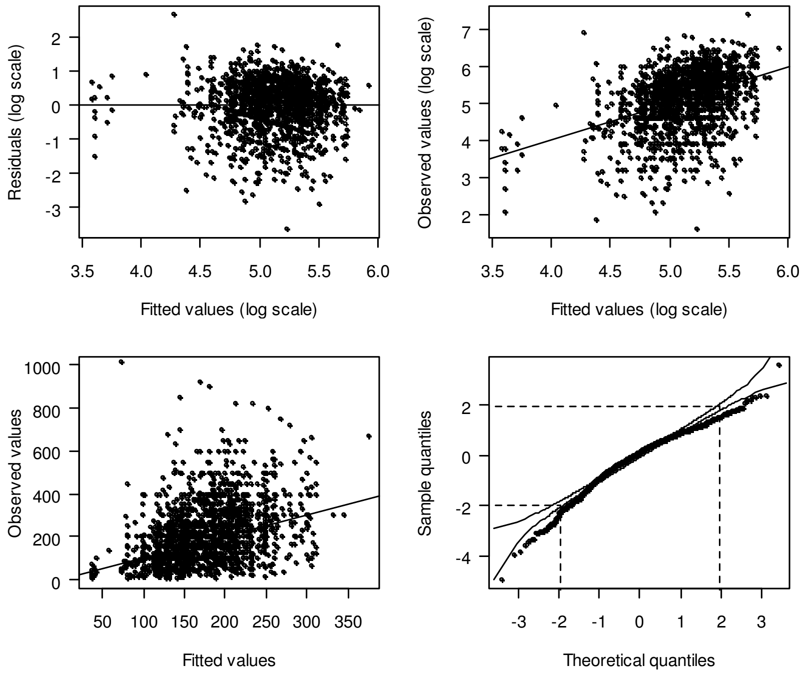

Figure A15: Residual diagnostic plots for CPUE model M7. The dotted lines on the QQ plot represent the 95% quartiles.

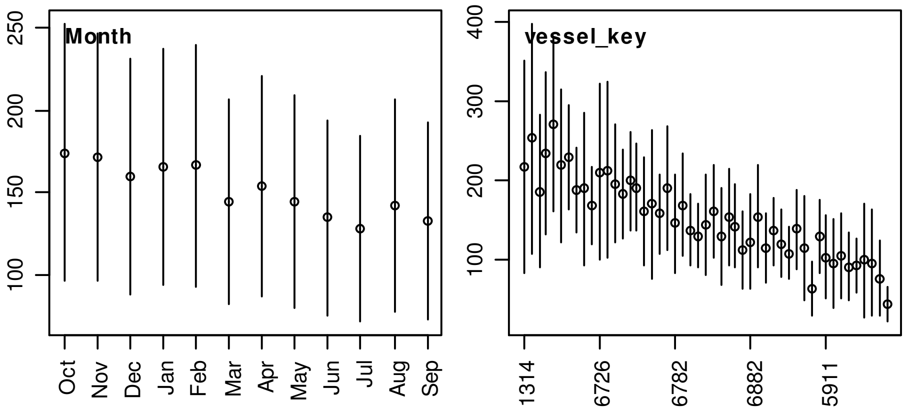

Figure A16: Expected catch rates (kg per diver day) for variables *vessel and month* for CPUE model M7. Bounds show the expected values ± 2 standard deviations.