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EXECUTIVE SUMMARY

Breen, P.A.; Smith, A.N.H. (2008). Data used in the 2007 assessment for paua (*Haliotis iris*) stock PAU 5B (Stewart Island).

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This document summarises the data used in the 2007 Bayesian stock assessment of blackfoot paua (abalone, *Haliotis iris*) in PAU 5B (Stewart Island). This work was conducted by NIWA under Ministry of Fisheries (MFish) contract PAU200603, Objective 2.

The assessment is based on the results of a population model fit to six datasets: these are commercial fishery catch per unit effort (CPUE), an independent research diver survey index (RDSI), commercial catch sampling proportions-at-length or length frequency data (CSLF), research diver length frequency data (RDLF), maturity-at-age data tag-recapture data. In addition, total catch is used as an input, comprising catches from four fishery sectors: commercial, recreational, customary and illegal.

In this document, based on material presented to the Shellfish Fisheries Assessment Working Group, we describe the data sources, describe exploratory analyses and present the results of data weighting and standardisation.

CONTENTS

1. INTRODUCTION

This document presents data used in the 2007 Bayesian stock assessment of blackfoot paua (abalone, *Haliotis iris*) in PAU 5B (Stewart Island). This work was conducted by NIWA under Ministry of Fisheries (MFish) contract PAU200603, Objective 2.

A description of the stock assessment, including the model and its results, is presented in a companion document (Breen & Smith 2008). This report documents the data sets used in the assessment, exploratory analyses and weighting and standardisation of the datasets.

The dataset that drives the model (or upon which the model is "conditioned") is the total weight of paua removed from the stock each fishing year. This is the sum of four components: commercial, recreational, customary and illegal catches.

Two indices of abundance were used in the model. One is a catch-per-unit-of-effort (CPUE) series derived from commercial catch and effort data reported to MFish. Catch and effort data are available from three different databases, reflecting different historical versions of the catch and effort data collection system. These were combined to produce a single commercial CPUE series for this assessment.

The second abundance index is from independent research diver surveys of paua abundance, and is called the research diver survey index (RDSI). This survey has been undertaken since 1994, and was described by Andrew et al. (2000, 2002). Both abundance indices were standardised using a modelling procedure and a number of covariates, described below.

The stock assessment used a length-based model. Two sets of proportions-at-length or length frequency (LF) data were used: one from commercial catch sampling (CSLF) and one from the research diver surveys (RDLF). A set of research tag-recapture data is used for part of the growth parameter estimation. Finally, observed maturity-at-length is used to estimate two maturity parameters.

The paua fishing year runs from October through September, and the convention used here is to use the second year as the short name; e.g. the 2002–03 fishing year is referred to as '2003'.

2. CATCH

2.1 Commercial catch

The commercial catch vector used for 2007 is nearly the same as that used for the 2000 and 2002 PAU 5B stock assessments (Breen et al. 2000, 2003), save for the addition of subsequent years' data.

The PAU 5B stock has existed as a discrete stock only since 1996, before that having been part of the omnibus stock PAU 5 which also contained PAU 5A and 5D (Figure 1). This division into three stocks created a problem for estimating the historical catch from PAU 5B, because data before 1996 were reported by statistical area. The boundaries of the statistical areas were not respected by the new stock boundaries, so some statistical areas straddled two or three of the new stocks. This problem was addressed by Kendrick & Andrew (2000). These authors do not show much of the data they used to estimate PAU 5B catches, but they do describe their methods and their work is repeatable.

Kendrick & Andrew (2000) began by assembling the catch estimates for PAU 5 from 1974 through 1995. They used the PAU 5 commercial catch estimates of Murray & Akroyd (1984) for 1974–83, treating these calendar year estimates as if they had been fishing year estimates. For 1985–95, they used data reported in the annual MFish Plenary Reports. The most recent Plenary Report (Ministry of Fisheries 2006), attributes these to the Fisheries Statistics Unit (FSU) for 1984–89 and to the Quota Management System (QMS) for 1990 onwards. However, in the 1989 report (Annala 1989), the first Plenary Report to include a chapter for paua, these data are attributed to the FSU for 1984–86 and to the QMS for 1987 onwards. This earlier attribution appears to be correct.

From 1996 onwards, landings were reported to the QMS by the new substocks PAU 5A, 5B and 5D, and "PAU 5" landings are their sum.

To check the catch data for this assessment, we requested an FSU extract of monthly PAU 5 catches, comprising paua statistical areas 025 through 032 but excluding 028 (the Snares) (Table 1). We also requested the monthly Quota Management Returns (QMR) catches from the earliest date through 2001. We collated commercial catches reported in the most recent Plenary Report (MFish 2006), and established that earlier Plenary Reports (not all were checked) give the same values. Finally, we summed the estimated catches from the FSU/CELR data from the dataset used for the 2002 PAU 5B assessment (Breen et al. 2003), which was used for subsequent PAU 5 substock assessments and for the 2007 CPUE analyses reported below.

These data are shown in
Table 2 and Figure 2. They suggest, first, that the Plenary report values for 1987 onwards come from the QMRs, as suggested by Annala (1989), and not from the FSU as they are attributed by MFish (2006).

Second, the data suggest that the low catches from 1986 may represent data loss during the transition between systems: catches reported to the FSU were declining steeply while those reported to the QMS were rising steeply, and 1986 may be the year that MFish succeeded in catching the least of the landings. Third, the data suggest a reasonably good agreement from 1983 through 1986 in the catch attributed to the FSU by Plenary Reports and the estimated catches in the FSU database used by Kendrick & Andrew (2000). There is also good agreement from 1987 onwards between the reported catch history in Plenary Reports and the catches reported to the QMR system in the 2007 QMR extract.

In contrast, however, the annual sums of estimated catches from the CELRs are consistently less than the QMR catch sums for 1987–98. It is not clear, and cannot be established without a major exploratory investigation, why this is so. To eliminate grooming as a potential source of the discrepancy, the comparison reported here is based on ungroomed data. (From 2002 through 2005 the agreement between PCELRs and MHRs is very good.)

So much is known about PAU 5 commercial catch. To obtain PAU 5B commercial catch estimates, Kendrick & Andrew (2000) reported several approaches, and additional approaches were explored but not reported, apparently as a result of discussions of the SFWG. We focus on a catch estimate series that Kendrick & Andrew (2000) tabulated as "the 1999 series 2 / 2000 base case". The 2000 and 2002 assessments for PAU 5B (Breen et al. 2000, 2003) both used this; for simplicity we call it the "2000 base case series".

To obtain the 2000 base case series, Kendrick & Andrew (2000) first estimated the PAU 5B catches as 52% of the PAU 5 catch for 1974–83. For 1984–95, they first estimated the annual proportion of PAU 5B catches in the FSU/CELR data, and then applied this proportion to the PAU 5 commercial catch series.

While statistical areas 027 and 029 are entirely within PAU 5B, areas 025 and 030 are partly in PAU 5B and partly in other stocks (Figure 1). For 1984–95 Kendrick & Andrew (2000) assumed that 75% of catches from areas 025 and 030 came from PAU 5B. Thus, for each year they compiled the estimated catches in the FSU/CELR data, taking all the area 027 and 029 catches plus 75% of the area 025 and 030 catches. They reported only the resulting catch series, not the annual FSU/CELR catches, nor their estimated annual proportions of PAU 5B catch, nor the PAU 5 catch series they worked from.

We repeated the procedure they described. We compiled the PAU 5 catch series from the source described above. We applied 52% to the Murray & Akroyd (1984) PAU 5 catch series for 1974–83. We calculated the proportion of PAU 5B catch in the FSU/CELR data for each year, 1984–95, as described above, and applied those proportions to the PAU 5 series. For 1996 onwards we collated the PAU 5B QMR values. Our grooming of the FSU/CELR dataset was not necessarily the same as that done by Kendrick & Andrew (2000). The resulting catch series is compared with the published Kendrick & Andrew (2000) series in Figure 3, and shows relatively small differences concentrated in four years.

This exercise suggests that we understand how Kendrick & Andrew (2000) arrived at the 2000 base case catch series and that their base data were similar to those we obtain now.

In 2000, or perhaps 2002, the SFWG agreed that the 1986 catch for PAU 5B was suspiciously low, perhaps for the reasons discussed above and shown in Figure 2, and agreed that it should be replaced with the mean of 1985 and 1987 catch estimates. This was done (Breen et al. 2003) and the same change has been used to produce the PAU 5B catch series for the 2007 assessment.

2.2 Non-commercial and total catch

The SFWG agreed on non-commercial catch assumptions. These were: that recreational catch was 1 t in 1974, increasing linearly to 5 t in 2006; that customary catch was a constant 1 t and that illegal catch was zero through 1985, was 5 t in 1986, increasing linearly to 15 t in 2006.

These assumptions were translated into annual estimates of catch by source, and are shown in Figure 4. The commercial catch contributes most of the catch estimate in all years.

We have no catch data before 1974, but it may be unrealistic to start the model in 1974 as if the stock were unfished. Recent practice, continued here, has been to "ramp up" the catch data from tens years, so that catch increases linearly from zero to the 1974 estimate.

3. CATCH per UNIT of EFFORT (CPUE)

3.1 Data sources

Catch and effort data have been collected by three systems: the Fisheries Statistics Unit (FSU) system from 1983 through July 1989, the Catch and Effort Landing Return (CELR) system for fishing years 1988–2001 and the Paua Catch and Effort Landing Return (PCELR) system from 2002 onwards. The FSU system involved reporting catch for each month, with effort reported in both days and hours. The CELR system captured estimated catch each day, with effort by days and hours. The PCELR forms capture estimated daily catch and effort from individual divers, and are reported on a system of finer-scale statistical areas (Figure 10 and Figure 11).

The subdivision of PAU 5 into three substocks, with statistical areas that straddle the new stocks, is a problem for calculating pre-1996 PAU 5B CPUE, just as it was for catch. Records from areas 027 and 029 belong to PAU 5B, but records from areas 025 and 030 could be from PAU 5B or from other stocks. Kendrick & Andrew (2000) addressed this problem by randomly assigning records from these two areas to PAU 5B with a probability of 0.75, which was the assumed proportion of PAU 5 catch that came from PAU 5B. The randomisation was repeated in 2002, but the procedure was the same. The data used for this assessment are the same as those used in 2002 by Breen et al. (2003).

The FSU/CELR and PCELR datasets were analysed both separately, to produce two different CPUE series, and in combination as a single series. For the single series, the PCELR data were converted into the same format as the CELR, with each record representing one vessel's fishing in one area in one day, with fields for the number of divers and the total catch. Results of separate and combined standardised CPUE series were presented to the SFWG, which agreed to use the combined series. This procedure discards some of the finer-scale recent data, but requires the assessment model to estimate one fewer parameter and uses all the data to estimate the effects of each standardisation variable.

Catch per diver day was used as the measure of effort for CPUE for each record, because the hours reported to the FSU/CELR system are not reliable (Breen et al. 2003). The hours in the FSU data appear to be on a different scale from the rest of the data, perhaps having been multiplied by 10 at some stage. Further, in the CELR dataset, it is suspected that in some records the number of hours was recorded as the total across divers and, in others, on a per diver basis.

3.2 Grooming

The FSU/CELR and PCELR datasets were groomed separately before they were combined. Table 3 and Table 4 list the criteria that were used to groom the FSU/CELR and PCELR data and the numbers of records removed by each. Table 5 shows the number of records from each source in each statistical area.

The data were investigated for landings on the same date by the same vessel in the same statistical area. Duplicate records totalled 108 by this criterion, all of which were FSU/CELR records. Both copies of the duplicates were removed from the data.

In some previous year's assessments, only those records that came from the vessels that landed the top 75% of the total catch in any given year were used (Breen & Kim 2007). This was not the case in the present assessment.

3.3 Exploratory analyses

CPUE values in the combined dataset (Figure 5) have a mean catch per diver per day of 188.6. The frequency of the numbers of divers in records of the combined data is shown in Table 6.

The catch by fishing year in each of the four large-scale statistical areas is shown in Figure 6. This shows that overall statistical areas 025 and 030 have contributed most of the catch, followed by area 027, and very small contribution from 029. Figure 7 shows the catch rates in each area, and indicates that, although not often fished, area 029 had very high catch rates before 1990. For most of the series, area 030 had the highest catch rates and area 025 had the lowest.

Numbers of vessel codes over-represent the true numbers of vessels, because new codes were assigned when operators changed their vessels. Diver codes may not fairly represent the true number of individual divers because the same diver may be coded differently on different days or vessels, and conversely because a code such as "diver1" may be used for different divers. Lack of clear identification of divers was identified to the SFWG previously by David Middleton of the Seafood Industry Council (SeaFIC, unpub. data).

3.3.1.1 Grain size of the data

We examined data precision by looking at the percentage of records with estimated catch recorded as a multiple of 50 or 100 kg, and the percentage of "hours" recorded as an exact multiple of one hour. For the PCELR data, where a separate record is provided for each diver, we collated the records where more than one diver fished on the same vessel and same day in the same area, and compared the estimated catch with the preceding record.

Results (Table 7) suggest better resolution in the data than was seen in PAU 5A in 2006 (Breen & Kim 2007), where almost two-thirds of the estimated catches were multiples of 50 kg. Hours, however, were estimated to the nearest hour in 72% of the PCELR records. Where more than one diver fishes, Table 7 suggests that most operators apportion the total day's catch among the divers on the PCELR forms: 82% of the relevant records are the same as the preceding record from the same fishing event. The even division of catches among divers was previously described to the SFWG for PAU 7 by David Middleton (SeaFIC, unpub. data).

3.4 Standardisation

CPUE was standardised by a number of factors with a log-normal generalised linear model (Vignaux 1993, Hinton & Maunder 2004, Maunder & Punt 2004). The regression procedure partitions variation in CPUE among factors (including year) to minimise the sum of the squared residuals. The standardised index and associated standard errors are then derived from the coefficients and error of the year effect. Standardisation has the effect of "removing" variation that results from factors other than year, such as changing fishing patterns in space and time; the year effect is more likely to reflect annual changes in abundance than the raw yearly means.

Factors offered to the linear model were *fishing year*, *vessel* (MFish replace actual vessel identifiers with randomised identifiers that are consistent among years), *statistical area* (the large-scale areas shown in Figure 1) and *month*. The Akaike Information Criterion (AIC, Akaike 1973) was used to assess whether any of these factors should be dropped from the model: the AICs of the models were calculated with each of the terms removed in turn. Under this criterion, all factors remained in the model. The contributions to the model in terms of variation explained by each factor are shown in Table 8. An alternative model that included an interaction term between vessel and month was also examined, but was rejected because the addition of this term made very little improvement to the model according to the AIC.

The resulting model is summarised by an ANOVA table in Table 8. The vessel variable contributed by far the most explanatory power to the model, adding 20.8% to the total variance explained. The standard diagnostic plots reveal a reasonably good fit of the model, though there are some problems (Figure 9). In the Q-Q plot, the lower tail of the residuals is overly dispersed; the plot of residuals versus predicted shows that a number of sites are overestimated by the model. This is largely a symptom of the log CPUE data having a long lower tail. The sensitivity of results to this problem was evaluated by running the standardisation procedure again using only those records with a catch rate of 50 kg/day or greater: standardised CPUE estimates changed very little from those in the base case.

The standardised CPUE series shows high catch rates, but with high uncertainty, in the first few years of the series (Figure 8 and Table 9). From 1987 onwards there appears to be stock depletion, and then catch rates stabilise during the late 1990s. There appears to be a slight increase in catch rates since 2001.

The standardised effects of vessel, month and statistical area on CPUE are presented in Figure 12, Figure 13 and Figure 14 respectively. The vessel effects show a wide range, spanning two orders of magnitude. The month effect is small, but CPUE tends to be highest at the beginning of the fishing year in October, and slowly decreases through September. Among statistical areas, area 030 scored highest and 025 scored the lowest. The wide confidence interval around the estimate for area 029 reflects a much smaller sample size in this area.

3.5 Differential weighting

In the stock assessment model, the CPUE dataset was not weighted directly by the standard error estimated by the standardisation model. Standard errors from different parts of the series were scaled by arbitrary multipliers to reflect the differences in the reliability of different parts of the data (
Table 10). The best data are from 2002 onwards, where the PCELR and QMS catches match; the next best are from 1996 through 2001, where the stock was reported as "PAU 5B". The FSU data from 1983–85 are at least based on all the catch that was reported. The least reliable data are probably from the late FSU and early CELR series, 1986–89. The original and revised standard errors are compared in Figure 15.

3.6 An additional CPUE analysis

An additional exploratory standardised CPUE series was suggested by David Middleton (SeaFIC). In this, all records that had been allocated to PAU 5B by the randomisation procedure described by Kendrick & Andrew (2000) were removed from the dataset. The records removed were those from statistical areas 025 and 030 from before fishing year 1997. This was nearly half of the total records, bringing the total from 10 072 to 5636 (Table 11). The same standardisation model as for the base CPUE series was used for this data subset.

The resulting series is shown on Figure 8. The removal of these records appears to create some fluctuations in the CPUE. Also, the standardisation model is able to fit the reduced dataset slightly better, with an r^2 of 0.39 as opposed to 0.37. However, trends in the two series are substantially the same.

4. RESEARCH DIVER SURVEY INDEX (RDSI)

4.1 Introduction and raw data

The timed-swim method used by research divers was described by Andrew et al. (2000, 2002). Divers make a timed swim of 10 minutes after sighting the first paua, and they record the patch size by grade in the older data or by actual count in the newer data. The index for a swim in the older data is the sum of products, by patch grade, of numbers of patches and mean numbers per patch; in the newer data it is the sum of paua counted.

PAU 5B is divided into six strata: Codfish Island, East Cape, Lords, Pegasus, Ruggedy and Waituna (Figure 16). A large number of candidate sites were listed, of which a subset was randomly selected for each survey. The numbers of swims and sites sampled in each survey are presented in Table 12, along with the number and proportion of s wims in which no paua were seen. All six strata were sampled in each survey except that in 1994 and 1996, five and three were sampled respectively (Table 13).

Because research divers now count the numbers in all patches, we used the actual numbers counted for each patch grade. In the older data, the mean number of paua in each patch grade was assumed, but this can now be estimated from actual counts from the 2001 and 2007 survey results (Table 14). This procedure assumes that the mean number per patch has not changed over time, and that older patch grade assignments by divers were reasonably accurate.

The information in Table 14 was used to estimate the number of paua seen on each swim in the older data: the number of patches in each grade for each swim was multiplied by the estimated class mean, then rounded to the nearest integer to preserve the integer distribution of the paua counts.

A diver is diverted from searching while counting the number of paua in a patch, collecting a sample of up to four paua and recording the count or patch grade. McShane et al. (1996) found average "handling time" to be 7.8 seconds per patch. Divers now count paua in each patch, but this does not greatly increase patch handling time, and divers stop their watch when the patch size looks larger than 20. Searching time in a 10-minute swim can be estimated as the swim time minus handling time:

$$\textit{search time} = 600 - (7.8 \times \textit{number of patches found})$$

Search time was used in the standardisation model as an offset, which is equivalent of modelling the number of paua counted per unit of search time.

Divers record visibility in a code (
Table 15) from 1 (very clear) to 5 (very murky).

4.2 Data grooming

In four records, visibility was not recorded, but was imputed from other data from that survey. The first two such records were from site 44, statistical area 025 and dated 14 October 1995. Sixteen of the other 18 records from this statistical area on this date had visibility rating of 3, and two had rating 4. The value of 3 was then assigned to the missing records. The other two records were from site 84, statistical area 025 and dated 7 November 2006. All other records from this statistical area on this date had visibility rating 2, so this value was entered.

4.3 Standardisation

The RDSI data were standardised using a generalised linear model (GLM) to remove variation that was attributable to other factors (Vignaux 1993, Kendrick & Andrew 2000).

Results are presented in canonical form as described by Francis (1999), giving estimates that are independent of the reference year.

The GLM family used in the standardisation model was negative binomial, which is commonly used to model the occurrence of discrete events that are "contagious" and thus too over-dispersed to be modelled using the Poisson error distribution (Lawless 1987). The structure of the model is the same as a Poisson GLM, and uses the log link function. However, instead of fixing the variance to the mean, μ, it uses the function $\mu + \mu^2/\theta$, where θ is an estimated parameter (Venables & Ripley 2002). This provides for the variance to be greater than the mean. Model fitting is by maximum likelihood, and was done in R (R Development Core Team 2005).

The natural log of the search time was used as an offset in the model. Adding a variable in this way forces the coefficient to be 1 which has the effect of subtracting the log of search time from the log of the raw count (because a log link function is used). When taken out of log space, this is equivalent to dividing the mean raw count by the search time, and equivalent to using a discovery rate (Venables & Ripley 2002). This is a more robust method of modelling a discovery rate because it preserves the integer distribution of the response variable. For the final index to be comparable to other RDSI datasets, the search time (in seconds) was divided by 600 seconds (10 minutes) before modelling.

Variables offered to the model were *fishing year*, *diver*, *stratum*, and *visibility*. The fishing year was forced to be in the model as an explanatory variable. A model with all variables was fit first, and a backwards stepwise procedure used the Akaike Information Criterion (AIC, Akaike 1973) for removal of variables from the model. The stepwise procedure saw the removal of two of the variables – first *visibility* and then *diver*, leaving only *fishing year* and *stratum* (and the search time offset) in the model. A GLM analysis of deviance table for the final model is presented in
Table 16. The estimate of the dispersion parameter θ was 0.6654.

Standard diagnostic plots are shown in Figure 17. The residuals show a slight systematic trend: this occurred in all models that were explored for these data (log-normal, Poisson, quasi-Poisson), and is not great enough to be of any major concern. They seem to be driven largely by the zero counts.

The standardised and raw RDSI values are presented in
Table 17 and Figure 18. The highest value of the RDSI was observed in 1994, and the standardised value is even greater than the raw value. This inflation may result from this year but not containing any records for Ruggedy (Table 13), the stratum with the highest estimate of catch rate (Figure 19).

When an interaction between stratum and fishing year was added to the model, it came out as statistically significant (p = 0.0016), indicating that the trend across years is different among strata. Mean RDSI for each stratum is shown in Figure 20. The main difference in trend appears to be that Ruggedy, Codfish and Waituna increased between 1998 and 2001 and then decreased in 2007, whereas the other strata appeared to increase between 2001 and 2007. The interaction term was not included in the standardisation model, as this would destroy the meaning from the coefficients of the year effect which are used as the index.

5. CATCH SAMPLING LENGTH FREQUENCY (CSLF)

What we refer to as "catch sampling" data are technically "market sampling" data: they comprise measurements of landed fish and do not represent the lengths of all fish that are caught, because some measuring is done at the surface and undersized fish are returned to the water. In early assessments these data were also referred to as "shed sampling" data.

Length frequency data from catch sampling were extracted from the MFish database *market* in November 2006. Only paua with lengths of 108 mm or greater are summarised here and used for the stock assessment; there are few such small paua because the MLS is 125 mm.

Some paua less than 125 mm are found in this sampling because the catch samplers measure slightly differently from fishers. For the fishery, the MLS applies to total length, which may include a barnacle on the posterior shell margin, or parts of the shell that overhang the aperture. The catch samplers measure the length between shell edges at the aperture. Some small paua may also slip through the system into processing sheds.

Within each year, we weighted the length frequency by the area catches. Data without area information were not used in this weighted length frequency distribution. To do this weighting, we used the estimated catches for each statistical area from the CELR data (four large-scale areas) and PCELR data (80 fine-scale areas).

Weighted relative proportion-at-length $p_{s,a,y}^{CSLF}$ in length bin s in statistical area a in year y is calculated as:

$$p_{s,a,y}^{CSLF} = \left(\frac{n_{s,a,y}}{\sum_s n_{s,a,y}} \right) \left(\frac{c_{a,y}}{\sum_a c_{a,y}} \right)$$

where $n_{s,a,y}$ is the number of fish measured in bin s, area a and year y, and $c_{a,y}$ is the catch in area a and year y from the CELR or PCELR forms. This is a relative proportion-at-length because proportions do not sum to unity unless every area has been sampled; that is not material because each year's data record is normalised by the model. Each year's record is then weighted by the normalised square root of the weighted number of fish measured and which have area information.

The number of catch sampled landings for each year from PAU 5B is shown in

Table 18. Most measurements were accompanied by area information before 2001, but in 2001–2006 the proportion lacking area information sometimes exceeded half.

The number of catch sampled landings for each statistical area from PAU 5B, pooled across years, is shown in
Table 19. This shows that there are very few records from S29, and a very large number that have unknown origin.

All CSLF graphs use 2 mm bins, as does the model. The weighted length frequency data to be used in the model for each fishing year (pooled across areas) is shown in Figure 21, and for each statistical area (pooled across years) in Figure 22.

Figure 23 shows the CSLFs by year before and after weighting. The unweighted data include those without area information. Exclusion of data from unknown areas and weighting by statistical area catches make very little difference to the final length frequencies.

6. RESEARCH DIVER LENGTH FREQUENCY (RDLF)

Length frequency data were collected during the research diver surveys. Divers collect four paua from each patch (they take the whole patch if the patch is four or fewer) for later measurement at the surface, and these paua are then returned to the water.

Earlier data are available from diver surveys made before the timed-swim system was begun. The model begins at 70 mm shell length, so the relatively small number of paua less than 70 mm are not used.

The research diver length frequency from each swim was weighted by the ratio of the abundance estimate for that swim to the mean abundance estimate:

$$L_{s,j} = L'_{s,j} \frac{IS_j}{\sum_j IS_j / n_j}$$

where $L'_{s,j}$ is the raw frequency at size s from the jth sample, IS_j is the time-scaled abundance of the jth sample and n_j is the number of fish in the jth sample. For each year's dataset, we weighted the record by the normalised square root of the weighted number of fish measured.

For weighting to take place, the length frequency data had to be matched to the abundance sample from which they came. This was done for 9255 of the 12 723 records. Some of the remainder were from length sample surveys that were not part of an abundance swim. Unmatched records were used in the weighted length frequencies by giving them a relative weighting of 1.

The weighted annual records are shown for each year, summed across all areas, in Figure 24. Length frequency distributions before and after the weighting procedure are shown in Figure 25.

The records were not evenly distributed among strata, nor were they consistent among years (Table 20), which may result in some biased estimates of length frequencies.

7. MATURITY

Before the most recent research diver survey, 88 records of maturity-at-length were available and were used in previous assessments. Additional records were collected in the 2007 survey, making a total of 293 records (Table 21). An attempt was made to collect data evenly from the length bins of interest. We fitted a logistic curve to the binned raw data (Table 22) outside the model, using a simple least-squares estimator: this suggested (Figure 26) that 50% of paua are mature near 90 mm length, and 95% are mature near 115 mm.

This analysis was done on the proportion of mature at length irrespective of sex. An implicit assumption is that males and females have the same pattern of maturity-at-length. It is not possible to explore this assumption, because many immature animals cannot be sexed.

A comparison between the simple fitted relation for PAU 5B and relations from the adjoining areas PAU 5D and PAU 5A (Breen & Kim 2007) suggests, as did the small data set available before this assessment, that PAU 5B is intermediate between the two adjacent areas: paua in PAU 5B tend to mature later than in PAU 5D and earlier than in PAU 5A. However, in all three areas most paua are mature at lengths near 115 mm.

8. TAG-RECAPTURE DATA

The tag-recapture data set is identical to the one used in the 2002 stock assessment (Breen et al. 2003). It comprised recapture data from tagging experiments in four strata (Table 23). All the East Cape releases were made at Ocean Beach; the Lords releases at Port Adventure and the Ruggedy releases at Christmas Village. The database does not record where the Waituna releases were made.

The Waituna recoveries were made from 214 to 289 days after release. Recaptures in the other strata were made almost exactly a year (363–364 days) after release.

Of 333 recoveries, 25 were from paua tagged at lengths less than 75 mm (22–67 mm); these were not used. The size frequency of the remainder is shown in Figure 28. Increments, adjusted proportionally by the length of time at liberty, are shown in Figure 29. These are shown by stratum in Figure 30 with the common regression line as a reference: there is high similarity among the strata; Ruggedy growth appears slightly higher than in the other strata.

The growth model was fitted to these data in exploratory fits, using the stock assessment model but fitting only to the tag-recapture data and estimating only the growth parameters. The growth sub-model has two options: a linear and an exponential model. Both were fitted using the Excel Solver™, estimating the two growth increment parameters *galpha* and *gBeta* and the variance parameter *growthCV*. These describe growth at lengths *alpha* (75 mm) and *Beta* (120 mm). The parameter *sigmaMin* was fixed at 1 after experimentation, and the parameter *sigmaObs* (the standard deviation of observation error) was fixed at 3, which gave the best fit.

Although the linear model gave a better fit in terms of total negative log-likelihood (Table 23), the exponential model fitted the large observed increments better (Figure 31). The two growth curves are compared in Figure 32: they are similar in the region with most of the data, but the linear model implies that growth stops near 140 mm length and the exponential model allows growth of much larger fish.

Both fits showed good residual patterns. The sdnrs were close to 1, the median of absolute normalised residuals was close 0.67 for the exponential model, and the largest normalised residual was about 3, suggesting that the normal likelihood is appropriate for fitting these data.

9. DISCUSSION

Data handling was straightforward and mostly followed the procedures used in previous assessments.

The older commercial catch estimates are uncertain. This is because first, the 1974–83 estimates for PAU 5 have some uncertainty: Murray & Akroyd (1984) used procedures that are not fully described, and second the proportion of PAU 5 catch that came from PAU 5B is unknown. The SFWG obviously agreed that much of the pre-1996 catch came from PAU 5B (Kendrick & Andrew 2000), and that subdivision of PAU 5 shifted catch from PAU 5B into the two new stocks, so that the 1996 proportion of catch from PAU 5B is not useful for calculating the older proportions. This problem is essentially intractable.

For 1996 onwards, the uncertainty about commercial catch is much less, but the non-commercial catch levels are virtually unknown.

CPUE estimates are also uncertain for 1983–95 because of the unknown relation between PAU 5 and PAU 5B. If the assumption by the SFWG in 2000 is correct, and 75% or more of PAU 5 catch was taken from PAU 5B, then the procedure of Kendrick & Andrew (2000) is probably a reasonable one. Otherwise, the approach may still be a good approximation if the CPUE in PAU 5B was similar to that in PAU 5A and PAU 5D. In 1996, raw CPUE in PAU 5A, 5B and 5D was 211, 143 and 135 kg per diver-day respectively.

Although it is encouraging that PAU 5B standardised CPUE was similar when records for areas 025 and 030 were excluded, the procedure is dubious if the underlying assumptions are violated, particularly the assumption of a high proportion of catch from PAU 5B. Some members of the SFWG objected strongly to the procedure used by Kendrick & Andrew (2000), and the SFWG agreed that this should be revisited in any future PAU 5 substock assessments.

A further uncertainty for CPUE is that the catch encompassed by the catch and effort data for PAU 5 is much less than the catch reported to the QMR/MHR system (Figure 2). Resolution of this problem would be a major investigative exercise, outside the scope of a standard stock assessment.

Proportion-at-length data suffer from possible representativeness problems. The catch sampling data have not been collected in proportion to area catches. We attempt to address this by weighting the data by area catches, which had little effect. The research diver data cannot be weighted by catch because catches by stratum are unknown, but they can be weighted by the levels of abundance seen in the research surveys. In both data types, weighting causes little change from the raw data.

A further problem with the research diver length data is that they may not be a random sample of the population. The diver selectivity curve may not be a simple curve, and paua size may interact with patch size: smaller patches are sampled more intensively than larger ones.

Finally, tag-recapture data are an important dataset (sensitivity testing described by Breen & Smith (2008) shows that), but a relatively small number of records are available from a smaller number of sites; inter-site variability may be higher than shown in the selection of sites available, and tagging has an unknown effect on paua growth.

10. ACKNOWLEDGEMENTS

This work described here was conducted under MFish contract PAU2006-03. We are grateful to Reyn Naylor and Pete Notman for providing datasets they collected and working with us to collate them, Peter Todd for non-commercial catch estimates, and the Shellfish Working Group for helpful and stimulating discussions.

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Table 1: PAU 5 catches (kg) by fishing year and statistical area, excluding area 028, from the FSU system, extracted February 2007. We were informed (D Fisher, NIWA, pers. comm.) that "FSU PAU data start in 1983".

Stat area	1983	1984	1985	1986	1987	1988	Total
025	79 568	95 112	104 474	73 883	87 324	108 262	548 623
026	25 743	45 294	35 142	18 087	13 437	8 680	146 383
027	64 921	75 380	52 822	36 780	24 154	30 981	285 038
029	5 290	15 653	9 652	14 731	7 294	834	53 454
030	61 900	176 450	111 295	62 540	22 814	37 543	472 541
031	1 948	69 835	26 376	23 964	7 605	7 914	137 642
032		5 764		879		1 393	8 036
Total	239 370	483 487	339 761	230 864	162 628	195 607	1 651 716

Table 2: PAU 5 catch data (kg), for 1983–2001, from the February 2007 FSU extract, from the February 2007 QMR extract, from the most recent Plenary report (Ministry of Fisheries 2006) and the sum of estimated catches on FSU/CELR forms in the database used as the basis for CPUE estimates.

Fishing year	Feb 07 FSU	Feb 07 QMRs	Plenary	PAU 5 sum of CELRs
1983	239 370			242 484
1984	483 487		550 000	520 919
1985	339 761		353 000	309 902
1986	230 864	331 697	228 000	214 339
1987	162 628	418 904	418 900	187 976
1988	195 607	458 239	465 000	190 592
1989		445 978	427 970	119 148
1990		468 647	459 460	335 836
1991		510 335	528 160	356 887
1992		483 037	486 760	330 117
1993		435 395	440 150	382 870
1994		440 144	440 390	327 590
1995		434 708	436 130	329 971
1996		429 959	429 790	310 437
1997		433 195	430 230	301 523
1998		439 279	439 280	382 570
1999		444 638	444 320	486 777
2000		409 878	410 000	411 222
2001		386 949	385 770	359 038

Table 3: Grooming criteria and the number of records removed from the FSU/CELR dataset.

Criterion	No. records removed
Statistical area = 28	37
Statistical area unknown	0
Duplicate records	108
Catch weight unknown	6
Catch weight = 0	2
Number of divers unknown	19
Number of divers > 9	3
Number of divers = 0	0
Vessel unknown	13
CPUE > 2000 kg/diver-day	2
Total	190

Table 4: The grooming criteria and the number of records removed from the PCELR dataset.

Criterion	No. records removed
Time in water = 0, blank, or >10 hours	0
Vessel key = blank	0
Diver key = blank	6
Catch weight = blank	14
Statistical area unknown	0
Duplicate records	40
Catch per hour > 100 kg/hr	10
Catch per hour < 1 kg/hr	1
Dive conditions = blank	149
Total	220

Table 5: The number of records from each source in each statistical area.

	Statistical Area				
Source	025	027	029	030	Total
FSU/CELR	3 790	2 141	244	2 221	8 396
PCELR	714	442	81	439	1 676
Total	4 504	2 583	325	2 660	10 072

Table 6: The frequency of records with various numbers of divers in the two datasets. Column percentages are shown in brackets.

			Frequency
No. divers	FSU/CEL	PCELR	Total
1	3347 (39.9)	820 (48.9)	4167 (41.4)
2	3589 (42.7)	596 (35.6)	4185 (41.6)
3	1136 (13.5)	192 (11.5)	1328 (13.2)
4	191 (2.3)	38 (2.3)	229 (2.3)
5	49 (0.6)	13 (0.8)	62 (0.6)
6	51 (0.6)	11 (0.7)	62 (0.6)
7	17 (0.2)	6 (0.4)	23 (0.2)
8	10 (0.1)	0 (0)	10 (0.1)
9	6 (0.1)	0 (0)	6 (0.1)
Total	8396	1676	10072

Table 7: The percentages of records in which the estimated catch is a multiple of 50 or 100 kg, and for the PCELR data where the time is a multiple of 1 hour and, where a record from the same vessel, date and area has the same estimated catch as the preceding record.

		PAU 5B
FSU/CELR	50 kg	35
	100 kg	24
PCELR	50 kg	38
	100 kg	20
	1 hour	72
	Est. catch	82

Table 8: ANOVA table showing the factors of the linear model used to standardise the CPUE index.

Factor	df	Sum of squares	Mean squared error	Cumulative r^2(%)	F value	Pr(>F)
Fishing year	23	824.2	35.8	11.5	75.8574	< 0.0001
Vessel	301	1488.6	4.9	32.3	10.4688	< 0.0001
Statistical area	3	210.2	70.1	35.3	148.32	< 0.0001
Month	11	28.5	2.6	35.7	5.4796	< 0.0001
Residuals	9733	4598	0.5	100.0		

Table 9: Raw and standardised CPUE based on combined FSU/CELR and PCELR data, with 95% confidence intervals.

Fishing year	Data type	No. records	Raw CPUE	Standardised CPUE	Upper 95% CI	Lower 95% CI
1983	FSU	357	296.4	372.2	423.5	327.1
1984	FSU	650	303.5	324.5	362.4	290.5
1985	FSU	388	337.3	362.2	407.4	322.1
1986	FSU	273	349.2	366.1	415.3	322.8
1987	FSU	282	257.4	267.6	303.5	236.0
1988	FSU	321	233.6	264.3	293.1	238.3
1989	FSU/CELR	224	223.8	238.8	265.9	214.4
1990	CELR	485	192.8	217.6	234.6	201.9
1991	CELR	523	177.9	200.7	216.2	186.3
1992	CELR	564	174.2	186.7	200.9	173.5
1993	CELR	565	157.7	171.4	184.4	159.3
1994	CELR	566	151.0	155.3	166.8	144.5
1995	CELR	592	149.9	145.1	155.7	135.3
1996	CELR	302	142.5	127.2	138.7	116.6
1997	CELR	387	136.4	152.0	164.5	140.4
1998	CELR	466	139.8	142.8	153.9	132.5
1999	CELR	526	138.3	136.3	146.4	126.8
2000	CELR	485	143.7	146.2	157.6	135.7
2001	CELR	440	119.7	115.6	125.5	106.6
2002	PCELR	341	166.2	154.6	168.7	141.7
2003	PCELR	388	141.4	157.0	171.1	144.0
2004	PCELR	352	152.9	159.9	175.5	145.6
2005	PCELR	304	174.1	174.9	192.2	159.1
2006	PCELR	291	173.2	194.9	215.1	176.6

Table 10: Multipliers applied to the various periods of CPUE standard errors as described in the text.

Period	Multiplier
1983 through 1989	2.0
1990 through 2001	1.5
2002 onwards	1.0

Table 11: The number of records in each statistical area and fishing year in the reduced dataset.

	Statistical area				
Fishing year	25	27	29	30	All areas
1983	0	133	9	0	142
1984	0	161	20	0	181
1985	0	88	11	0	99
1986	0	80	19	0	99
1987	0	75	15	0	90
1988	0	85	2	0	87
1989	0	51	8	0	59
1990	0	103	10	0	113
1991	0	109	19	0	128
1992	0	163	11	0	174
1993	0	72	14	0	86
1994	0	137	4	0	141
1995	0	150	11	0	161
1996	0	83	13	0	96
1997	204	98	5	80	387
1998	228	123	23	92	466
1999	229	142	21	134	526
2000	196	161	16	112	485
2001	197	127	13	103	440
2002	147	84	15	95	341
2003	185	97	14	92	388
2004	155	83	11	103	352
2005	101	91	30	82	304
2006	126	87	11	67	291
All years	1 768	2583	325	960	5 636

Table 12: Numbers of swims, zero records and sites sampled in each fishing year of the research diver survey.

Fishing year	No. of records	No. of zeros (percentage)	No. of sites
1994	114	9 (7.9)	41
1995	51	4 (7.8)	21
1996	64	8 (12.5)	31
1998	180	31 (17.2)	75
2001	166	9 (5.4)	64
2007	118	13 (11.0)	52
All years	693	74 (10.7)	129

Table 13: Number of RDSI records in each stratum in each year.

	Fishing year						
Stratum	1994	1995	1996	1998	2001	2007	Total
Codfish	32	7	0	14	14	12	79
East Cape	18	8	20	36	30	26	138
Lords	12	8	10	40	32	24	126
Pegasus	16	6	0	40	30	22	114
Ruggedy	0	8	34	36	30	30	138
Waituna	36	14	0	14	30	4	98
Total	114	51	64	180	166	118	693

Table 14: Patch grades used by research divers before 2001, the assumed mean number per patch by grade, the number of patches in each grade that were counted in 2001 and 2007 surveys and the observed mean number per patch.

Patch grade	Nominal	Assumed	N	Actual
1	0 to 4	1.28	2 004	1.49
2	5 to 10	7.50	256	6.56
3	11 to 20	15.50	90	14.42
4	21 to 40	30.50	33	28.33
5	41 to 80	60.50	9	54.33
6	81 plus	120.50	0	n.a.

Table 15: Definitions of visibility codes used by research survey divers.

Visibility code	Definition
1	>10 m
2	6–10 m
3	3–6 m
4	1.5–3 m
5	<1.5 m

Table 16: Analysis of deviance table for the model used to standardise RDSI.

Term	Df	Deviance	Resid. Df	Resid. Dev	P(>|Chi|)
Null model			692	905.36	
Fishing year	5	46.67	687	858.68	< 0.0001
Stratum	5	31.68	682	827.01	< 0.0001

Table 17: Raw and standardised RDSI by fishing year, with lower (LB) and upper (UB) 95% confidence intervals.

Fishing year	No. records	Raw	Standardised	LB	UB
1994	114	54.4	67.6	53.7	85.0
1995	51	34.2	37.0	27.5	50.0
1996	64	31.9	26.4	19.9	35.2
1998	180	20.8	22.1	18.4	26.6
2001	166	28.5	29.1	24.2	35.1
2007	118	36.3	38.7	31.3	47.8

Table 18. The number of CSLF landings and paua records in the database, by year, that have known and unknown statistical area. Fine scale statistical areas (S1-S84) were used from 2003 to 2006 and large scale statistical areas (25, 27, 29, 30) were used before 2003.

	No. landings			No. paua measured		
Fishing year	Area unknown	Area known	Total	Area unknown	Area known	Total
1991	0	1	1	0	264	264
1992	1	52	53	346	17 863	18 209
1993	0	39	39	0	13 537	13 537
1994	0	42	42	0	13 377	13 377
1998	0	9	9	0	1 054	1 054
1999	1	43	44	115	4 541	4 656
2000	4	26	30	405	2 810	3 215
2001	11	21	32	1 438	2 707	4 145
2003	9	32	41	1 009	3 588	4 597
2004	14	58	72	1 502	6 123	7 625
2005	16	29	45	1 654	3 002	4 656
2006	14	26	40	1 400	2 632	4 032
Total	70	378	448	7 869	71 498	79 367

Table 19: The number of CSLF landings and paua records in the database with known and unknown statistical area. This table only shows totals the large-scale statistical areas, although fine scale statistical areas were used from 2003 to 2006.

Statistical area	No. paua measured	No. of landings
025	25 919	144
027	26 705	134
029	949	9
030	17 925	91
Unknown	12 002	108
Total	83 500	486

Table 20: The numbers of research diver length frequency records by stratum and fishing year.

Fishing year	Codfish	Earnest Is	East Cape	Lords	Pegasus	Ruggedy	Waituna	All strata
1991	142	316	190	52			161	861
1992	463		193		72		148	876
1994	405		418	230	163		613	1 829
1995	83		300	74	49	178	107	791
1996			173	474		1 448		2 095
1998	61		374	355	298	649	99	1 836
2001	267		282	303	308	938	469	2 567
2007	151		328	346	394	642	7	1 868
All years	1 572	316	2 258	1 834	1284	3 855	1 604	12 723

Table 21: Numbers of paua examined for maturity-at-length by calendar year and research stratum.

	Year				
Stratum	1994	1995	2006	2007	Total
Codfish				24	24
East Cape		57	9		66
Lords				2	2
Pegasus				19	19
Ruggedy				151	151
Waituna	31				31
Total	31	57	9	196	293

Table 22: Binned raw maturity-at-length data from PAU 5B.

Length	N	N mature	Propn
72.5	11	0	0.000
77.5	17	4	0.235
82.5	15	3	0.200
87.5	33	11	0.333
92.5	36	22	0.611
97.5	31	21	0.677
102.5	38	30	0.789
107.5	23	20	0.870
112.5	42	41	0.976
117.5	39	39	1.000

Table 23: Summary of PAU 5B tagging experiments.

Stratum	Date released	Number recaptured	Number used
Waituna	May 1995 to Sep 1996	132	132
East Cape	Jan 2000	71	52
Lords	Jan 2000	52	50
Ruggedy	Jan 2000	78	74
Total		333	308

Table 24: Estimates from the two growth models fitted to tag-recapture data.

Quantity	Linear	Exponential
galpha	24.7	28.6
gBeta	5.6	6.7
growthCV	0.255	0.273
sigmaMin	1	1
sigmaObs	3	3
Sum of negative log-likelihoods	875.73	885.72
Std. dev. of normalised residuals	1.00	1.00
Maximum of absolute residuals	3.03	3.16
Median of absolute residuals	0.63	0.66

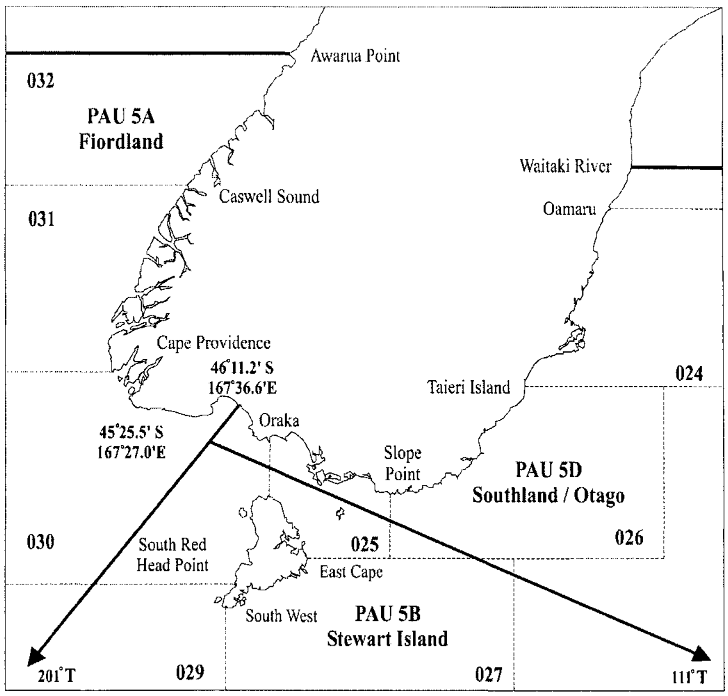

Figure 1: PAU 5 and the 1996 split into three new stocks, also showing the large-scale statistical areas: note how areas 025 and 030 straddle the new stock boundaries.

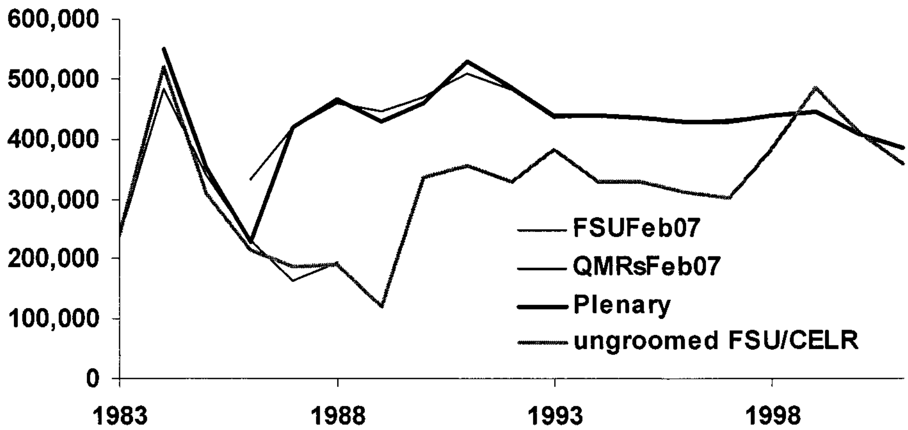

Figure 2: PAU 5 catch estimates from the various sources discussed in the text.

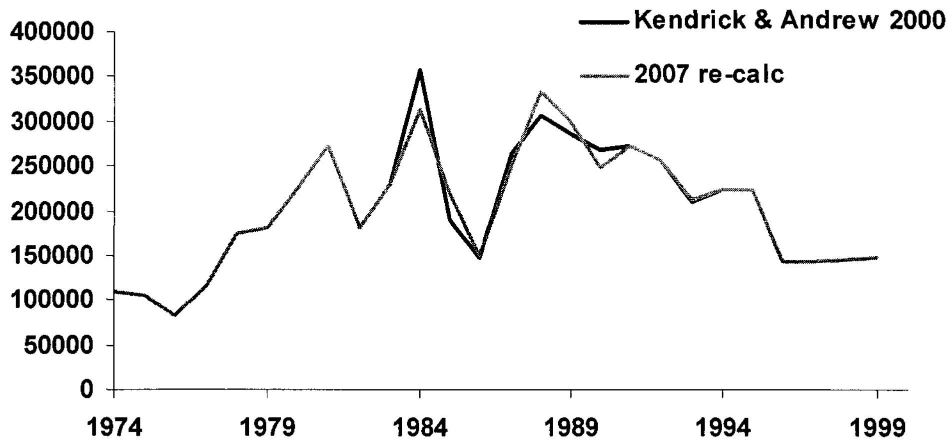

Figure 3: The "2000 base case" catch series for PAU 5B from Kendrick & Andrew (2000) compared with a 2007 re-calculation.

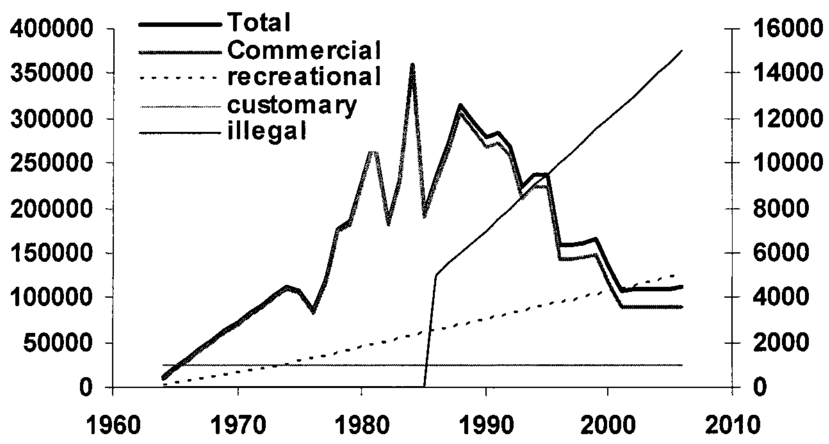

Figure 4: The base case catch series (kg) for PAU 5B. Note that the three non-commercial series are plotted on the secondary axis.

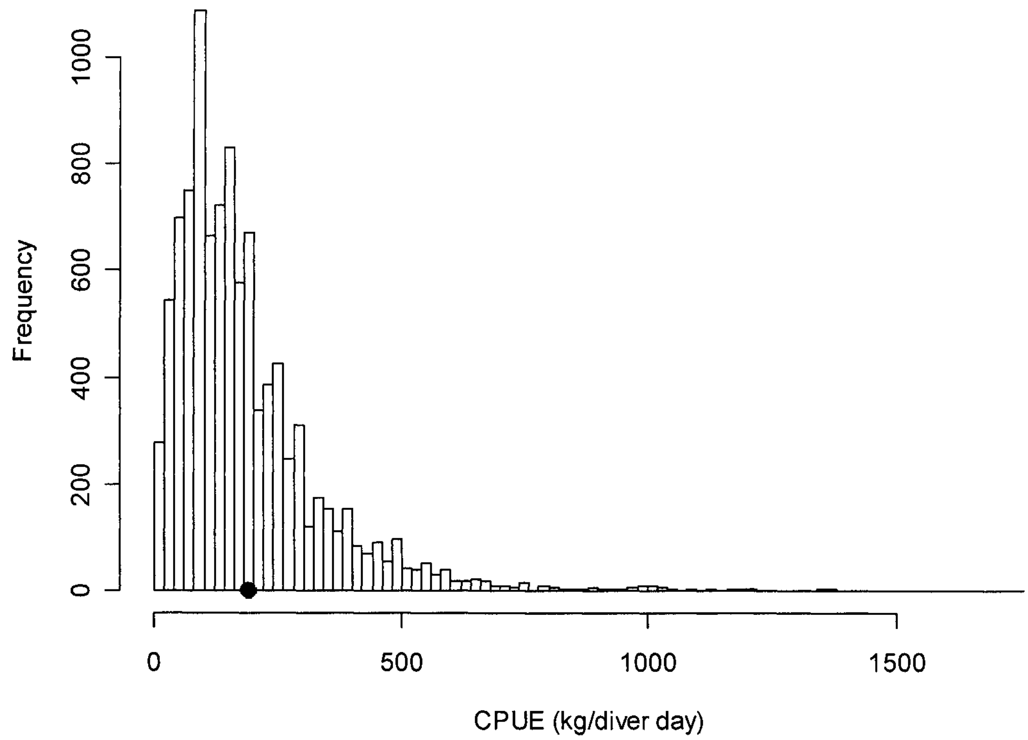

Figure 5: Histogram of CPUE values. The dot shows the mean value.

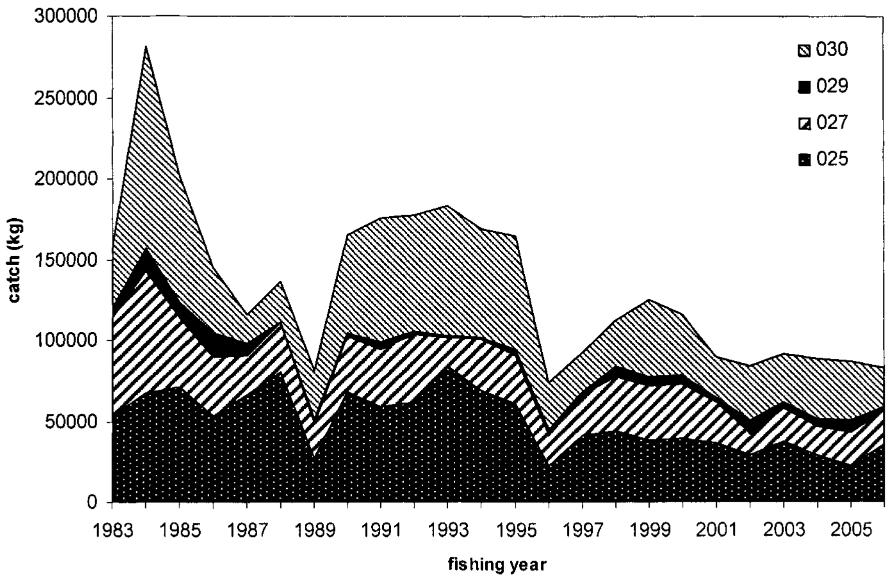

Figure 6: Distribution of catch among statistical areas in the groomed FSU/CELR and PCELR catch and effort data.

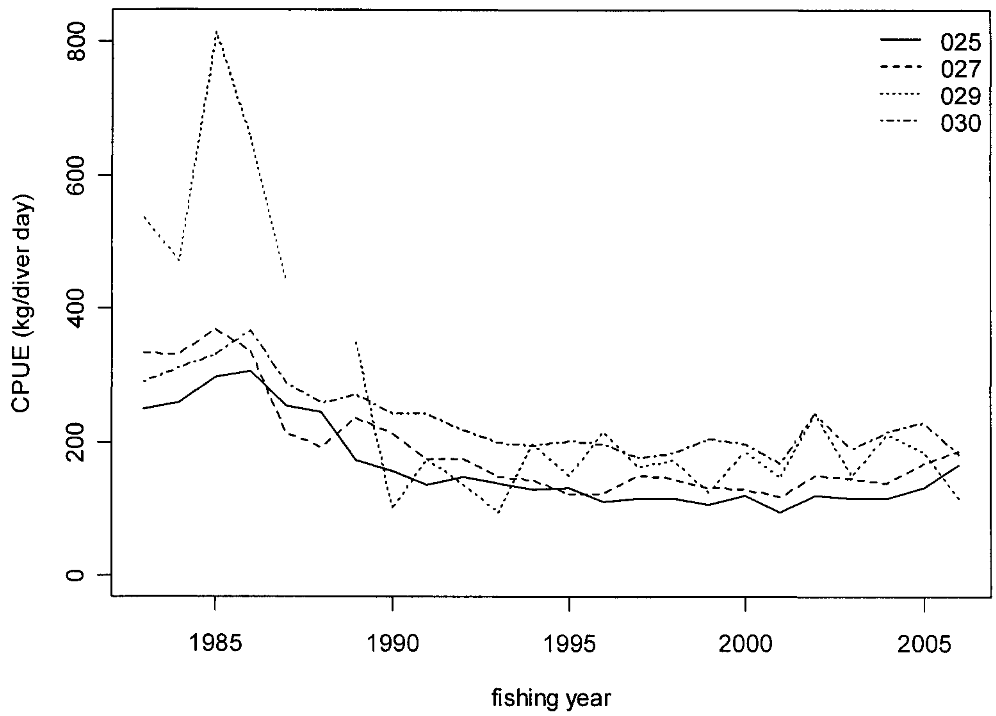

Figure 7: The mean unstandardised catch rates in each statistical area. The mean for 029 in 1988 is not shown because it comes from fewer than three vessels.

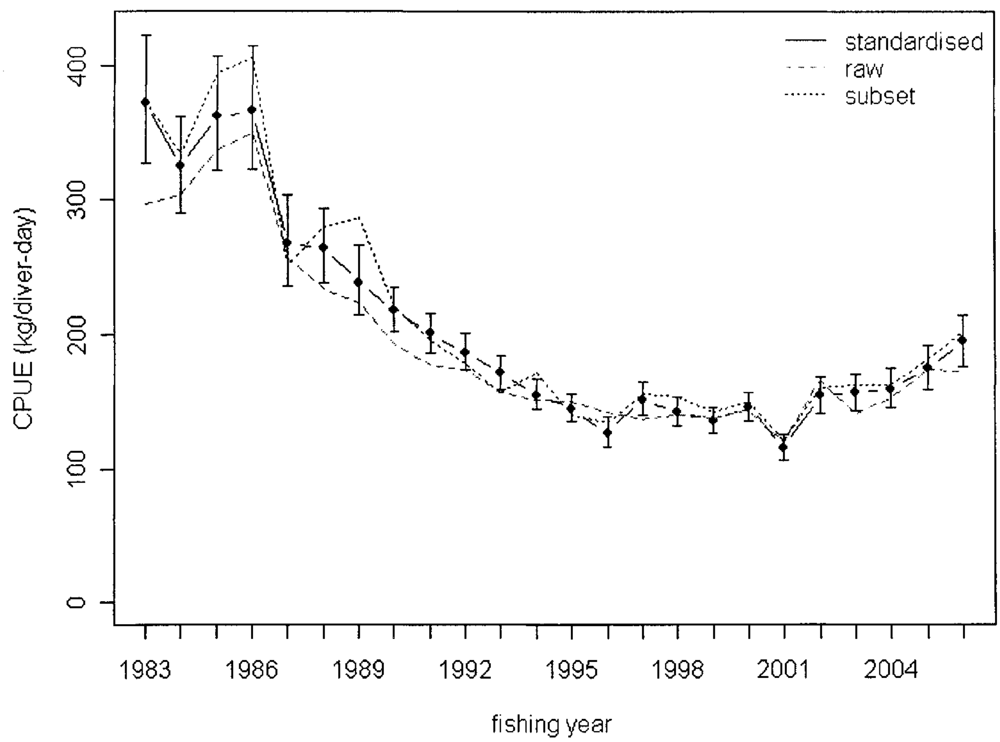

Figure 8: Raw and standardised CPUE index, based on combined FSU/CELR and PCELR data. Error bars show 95% confidence intervals. The "subset" line is from an additional standardised CPUE analysis whereby records that were randomly allocated to PAU 5B by Kendrick & Andrew (2000) are removed.

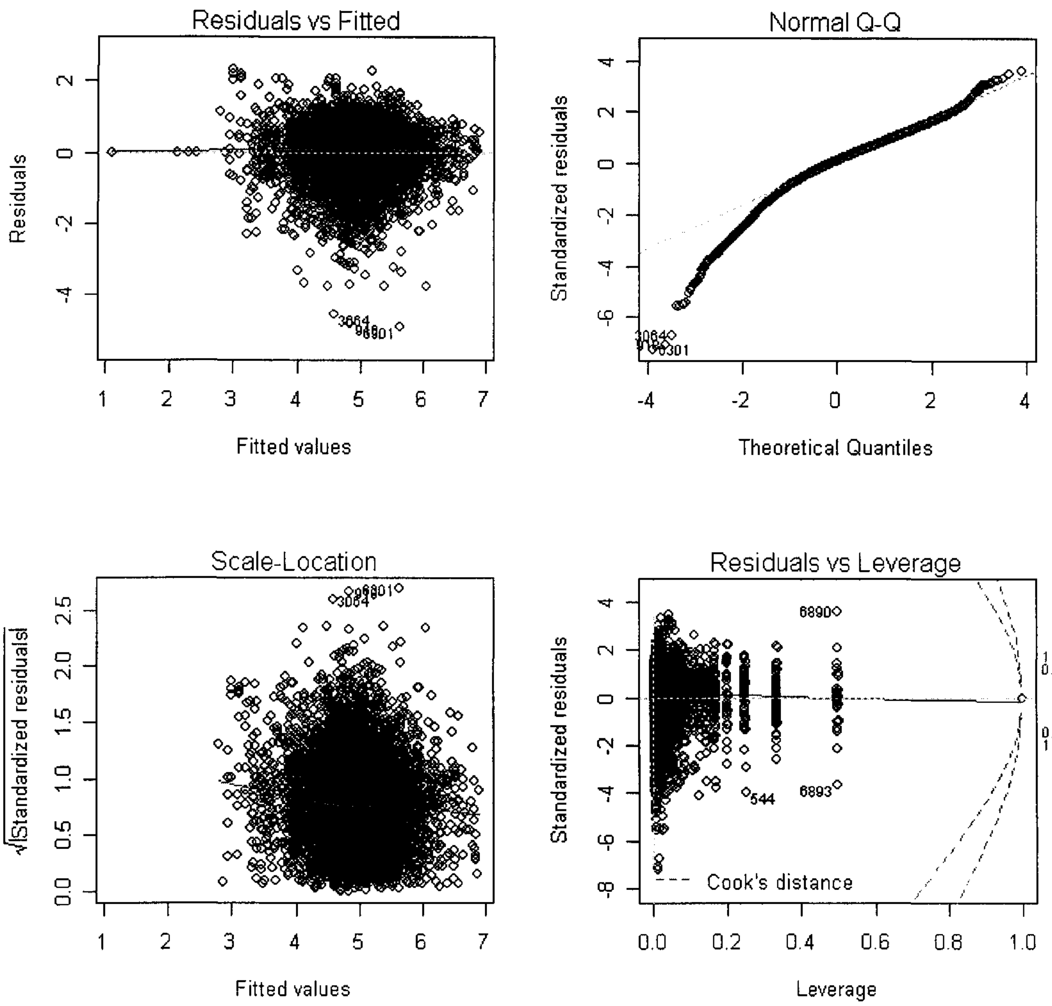

Figure 9: Diagnostic plots for the linear model used to standardise the CPUE index, which uses the combined FSU, CELR and PCELR data.

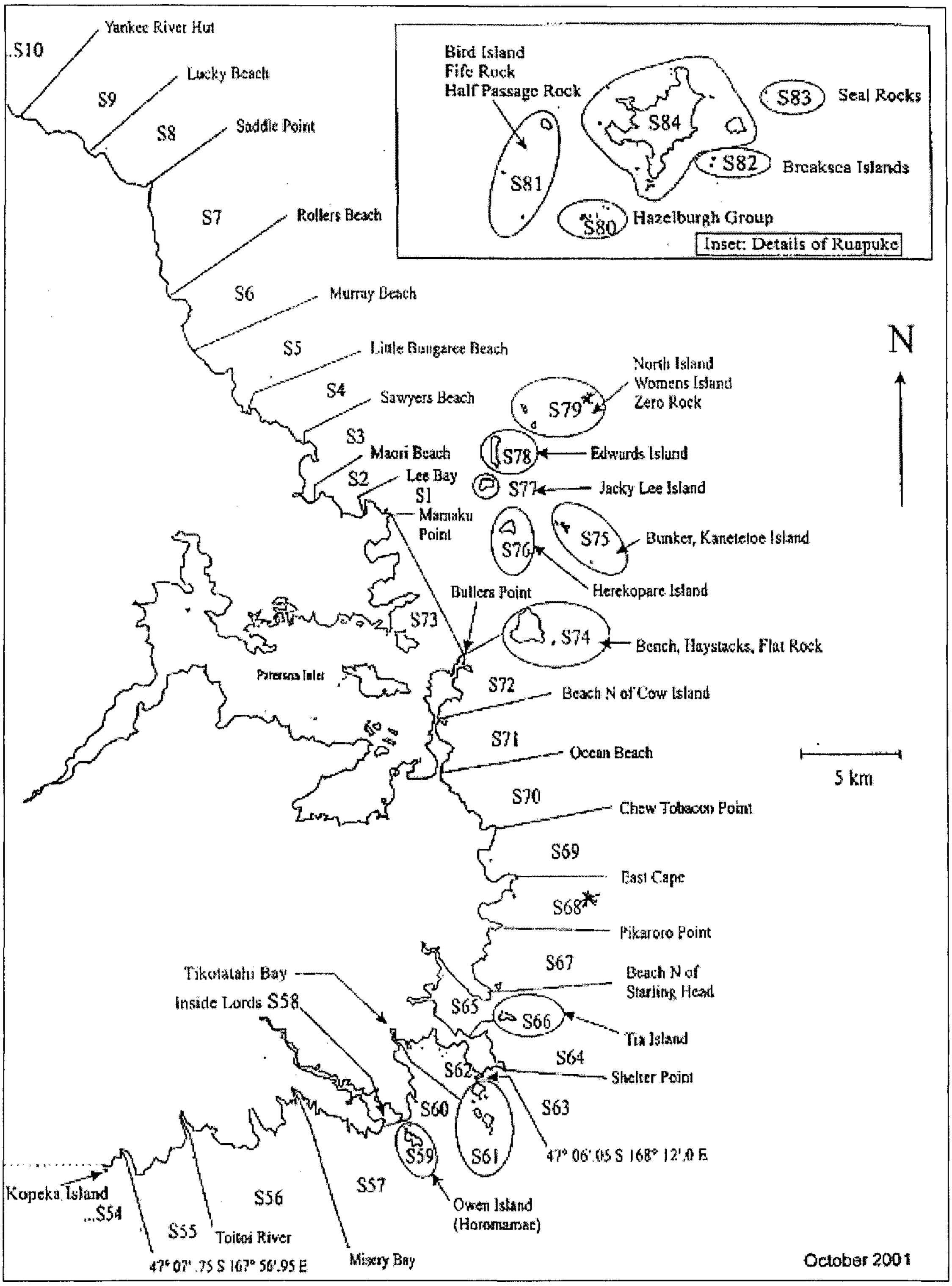

Figure 10: MFish map of fine-scale statistical areas for the east coast of Stewart Island.

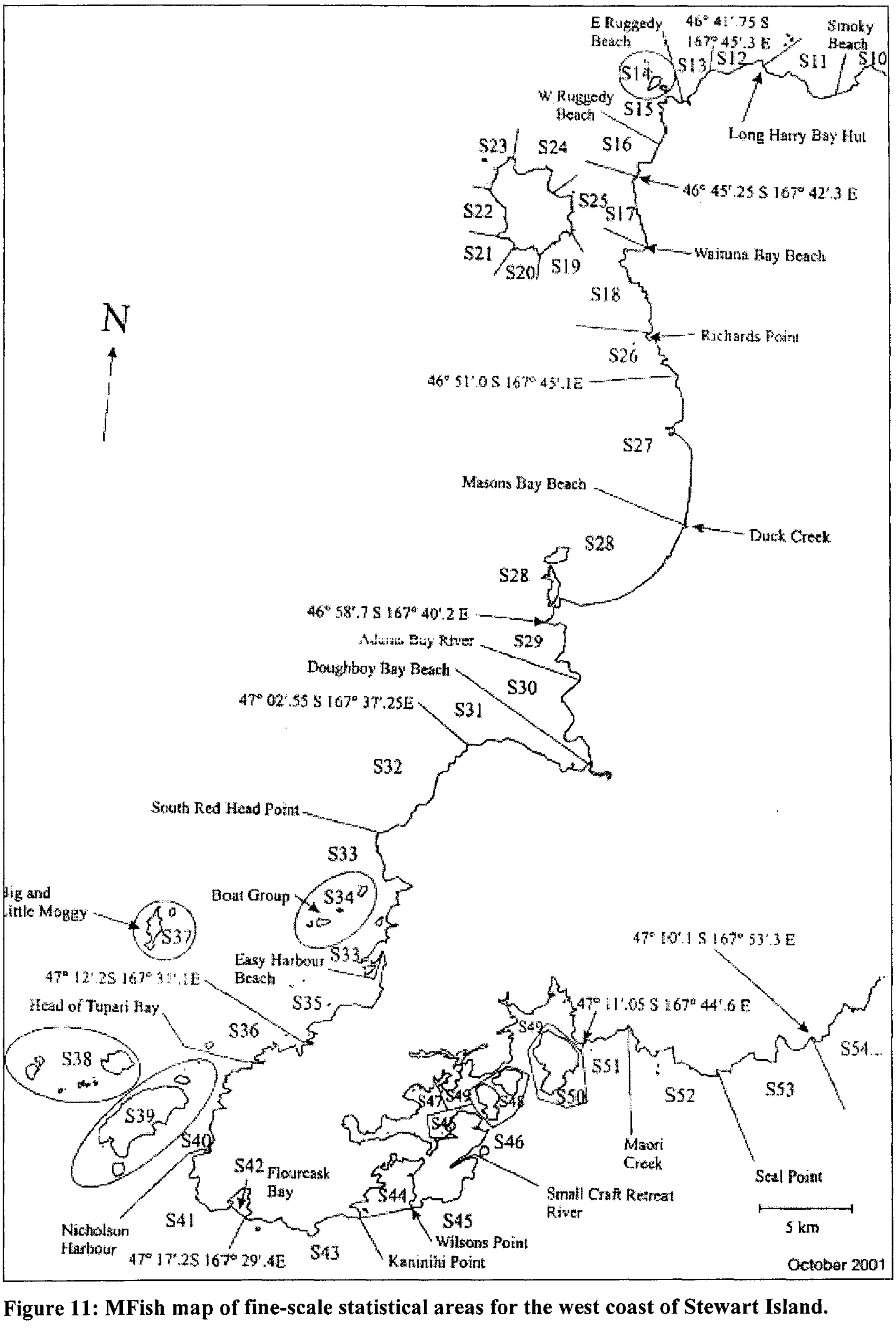

Figure 11: MFish map of fine-scale statistical areas for the west coast of Stewart Island.

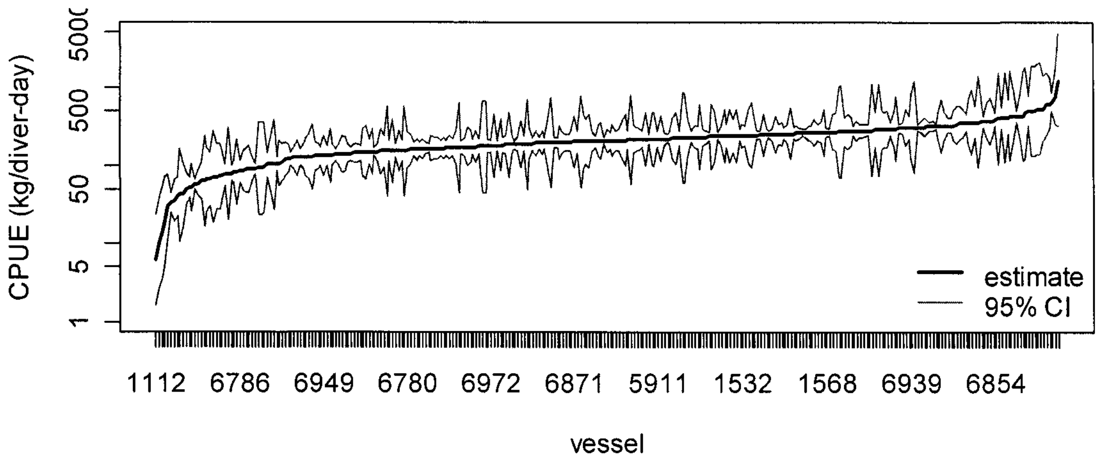

Figure 12: Ranked standardised effects of vessel on CPUE, with 95% confidence intervals.

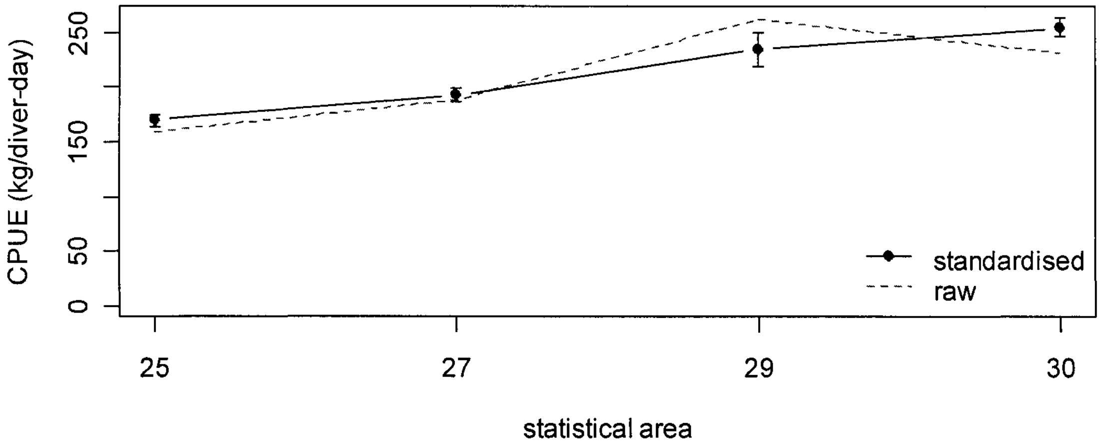

Figure 13: Raw and standardised effects of statistical area on CPUE, with 95% confidence intervals

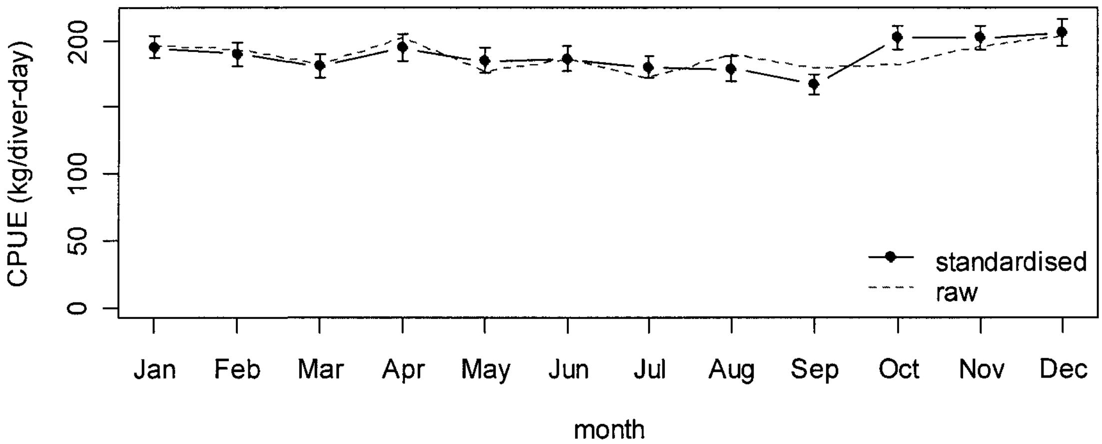

Figure 14: Raw and estimated effects of month on CPUE, with 95% confidence intervals.

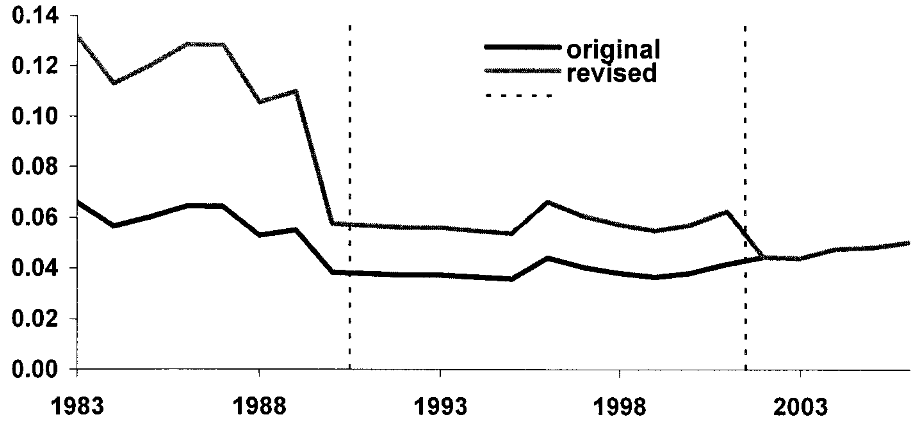

Figure 15: The original standard errors from the CPUE standardisation model, compared with values revised using the multipliers in

Table 10. Dotted lines indicate where the multiplier changes.

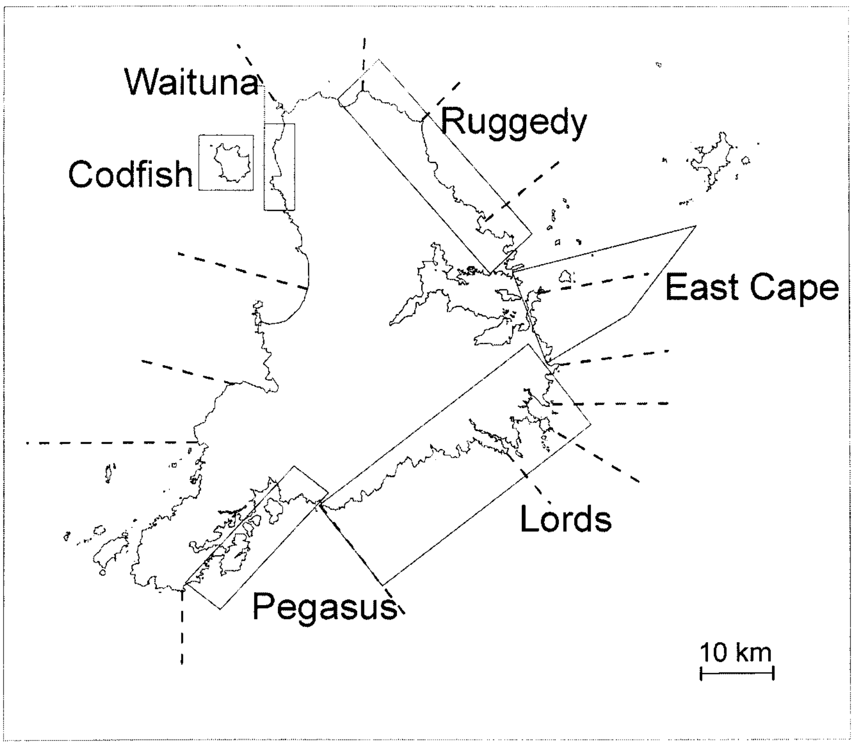

Figure 16: Map of Stewart Island showing the strata for research diver surveys.

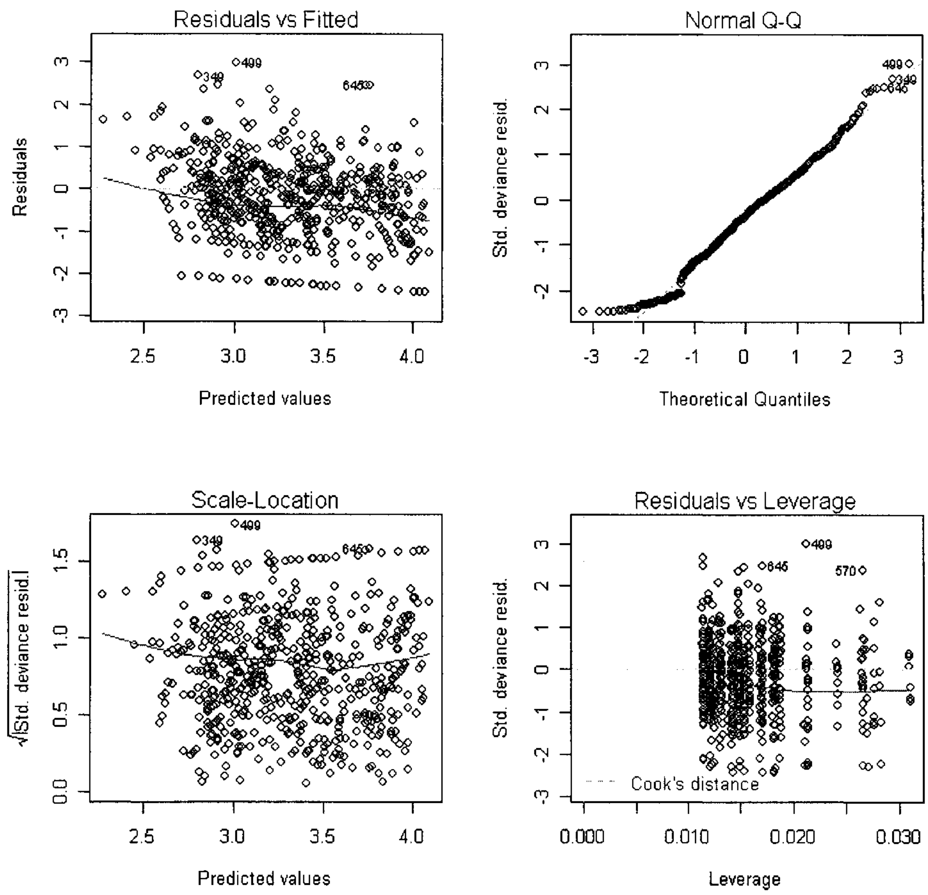

Figure 17: Diagnostic plots for the GLM used to standardise RDSI.

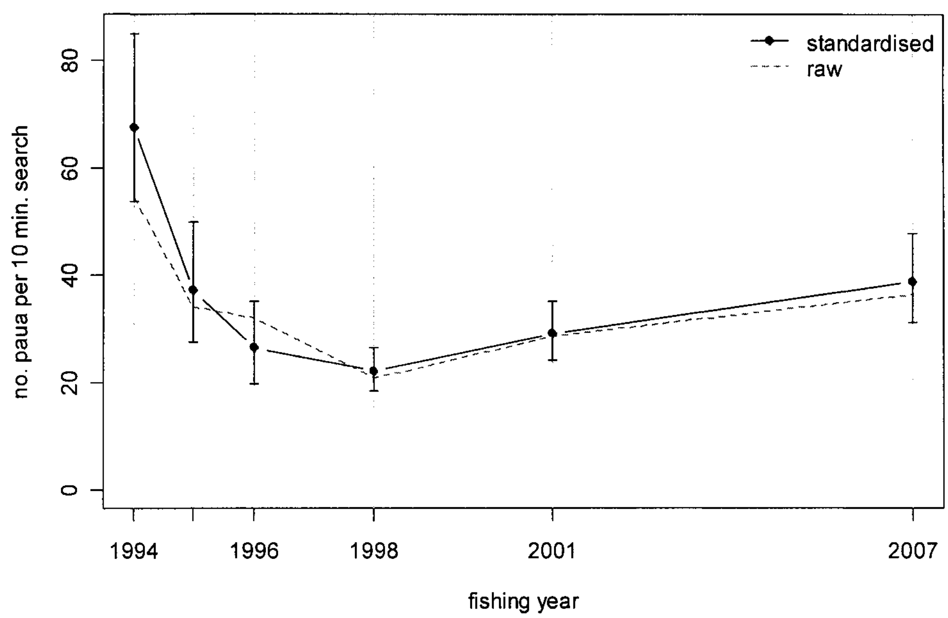

Figure 18: Standardised and raw year effects on the number of paua counted per 10-minute swim, with 95% confidence intervals.

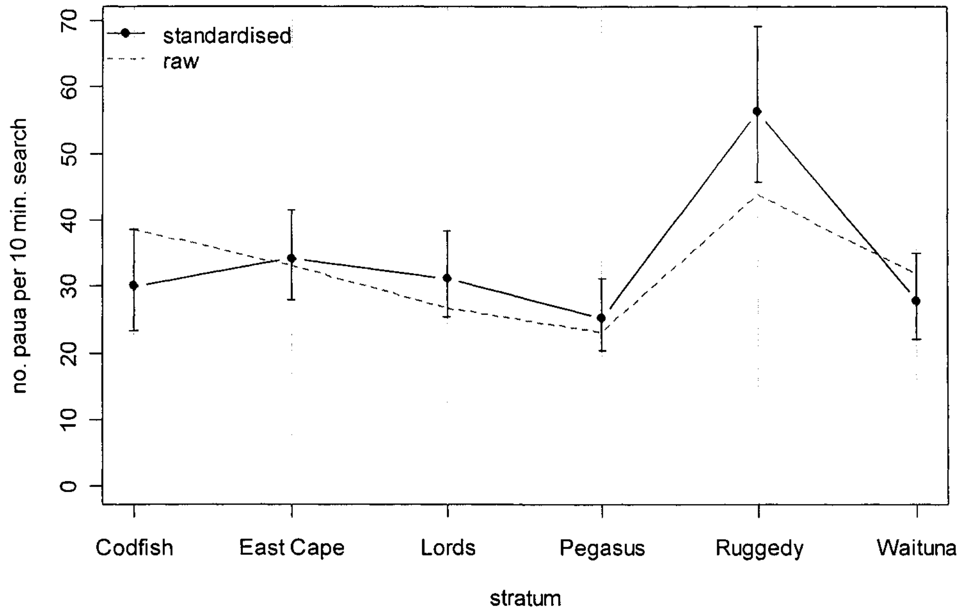

Figure 19: Standardised and raw stratum effects, with 95% confidence intervals.

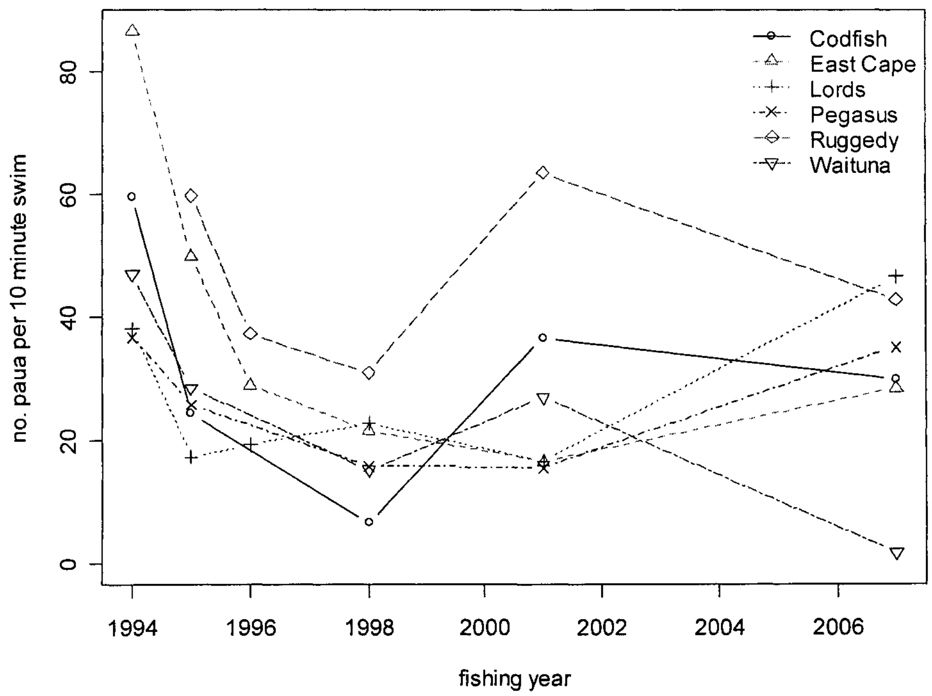

Figure 20: A plot demonstrating the interaction between fishing year and stratum for RDSI.

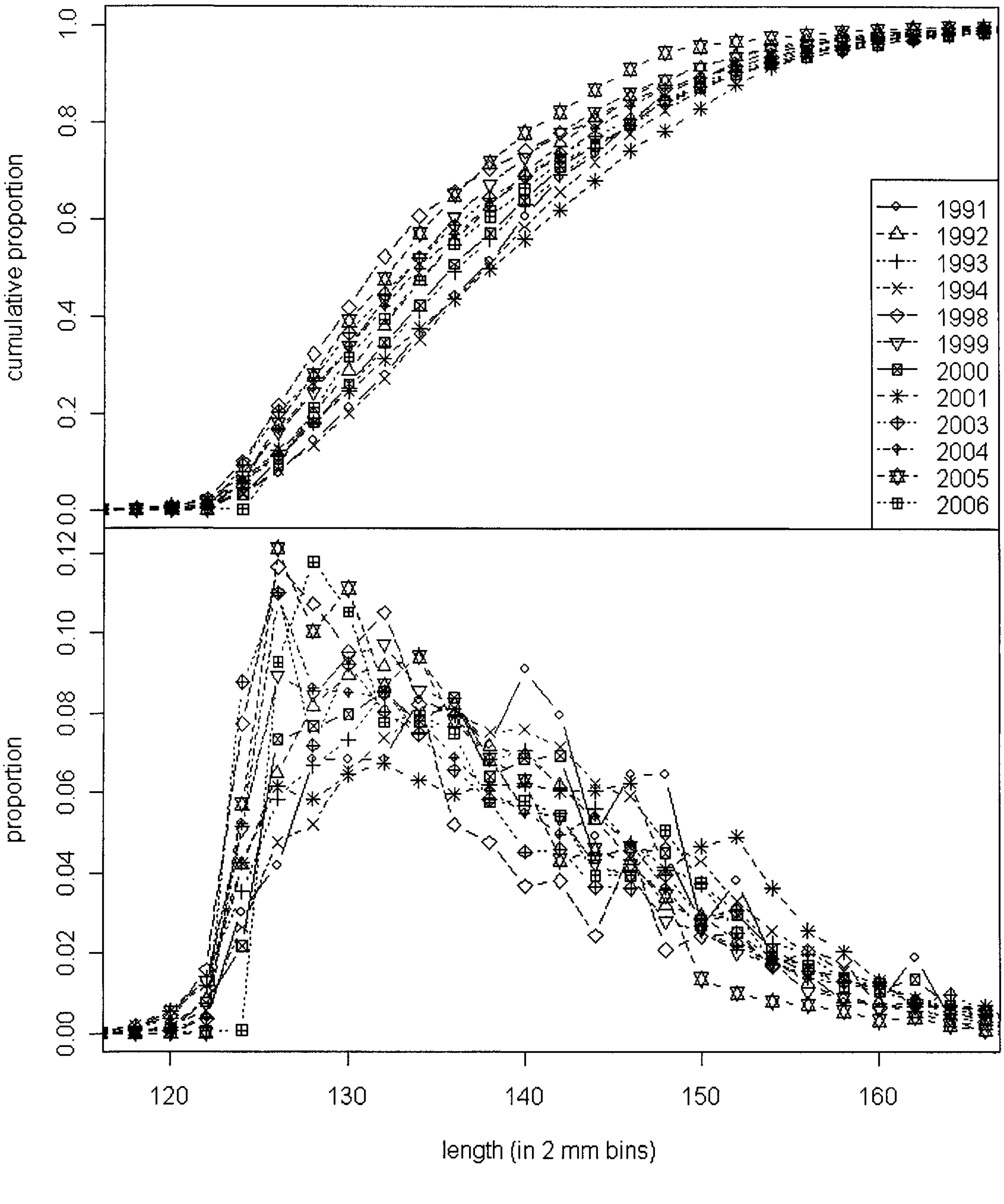

Figure 21. The commercial sampling length frequency data by year, shown cumulatively (top) and individually (bottom). These data have been weighted by area catches within years.

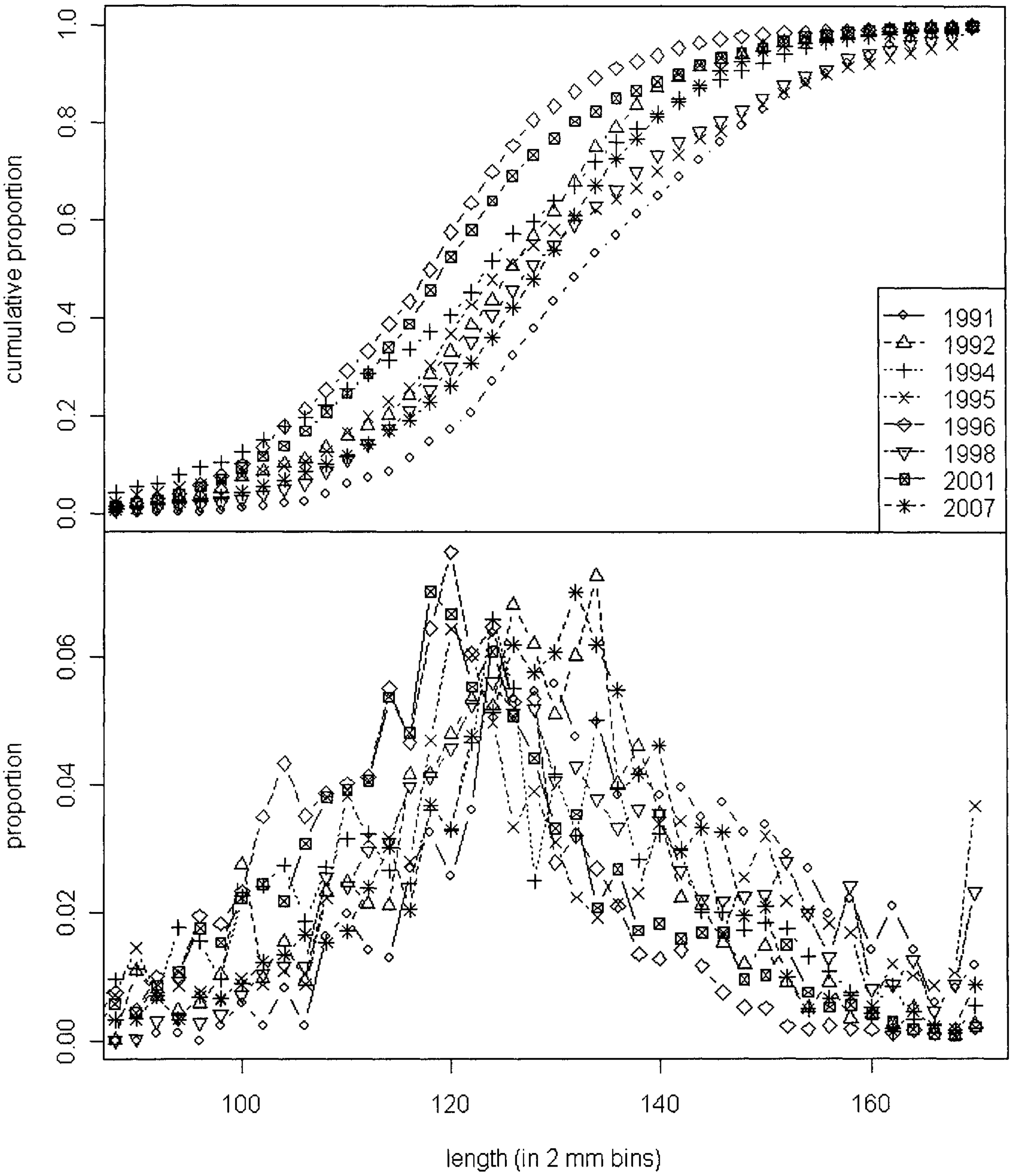

Figure 22. The unweighted commercial sampling length frequency data by statistical area, pooled across years, shown cumulatively (top) and individually (bottom). Data with unknown statistical area are shown as their own series.

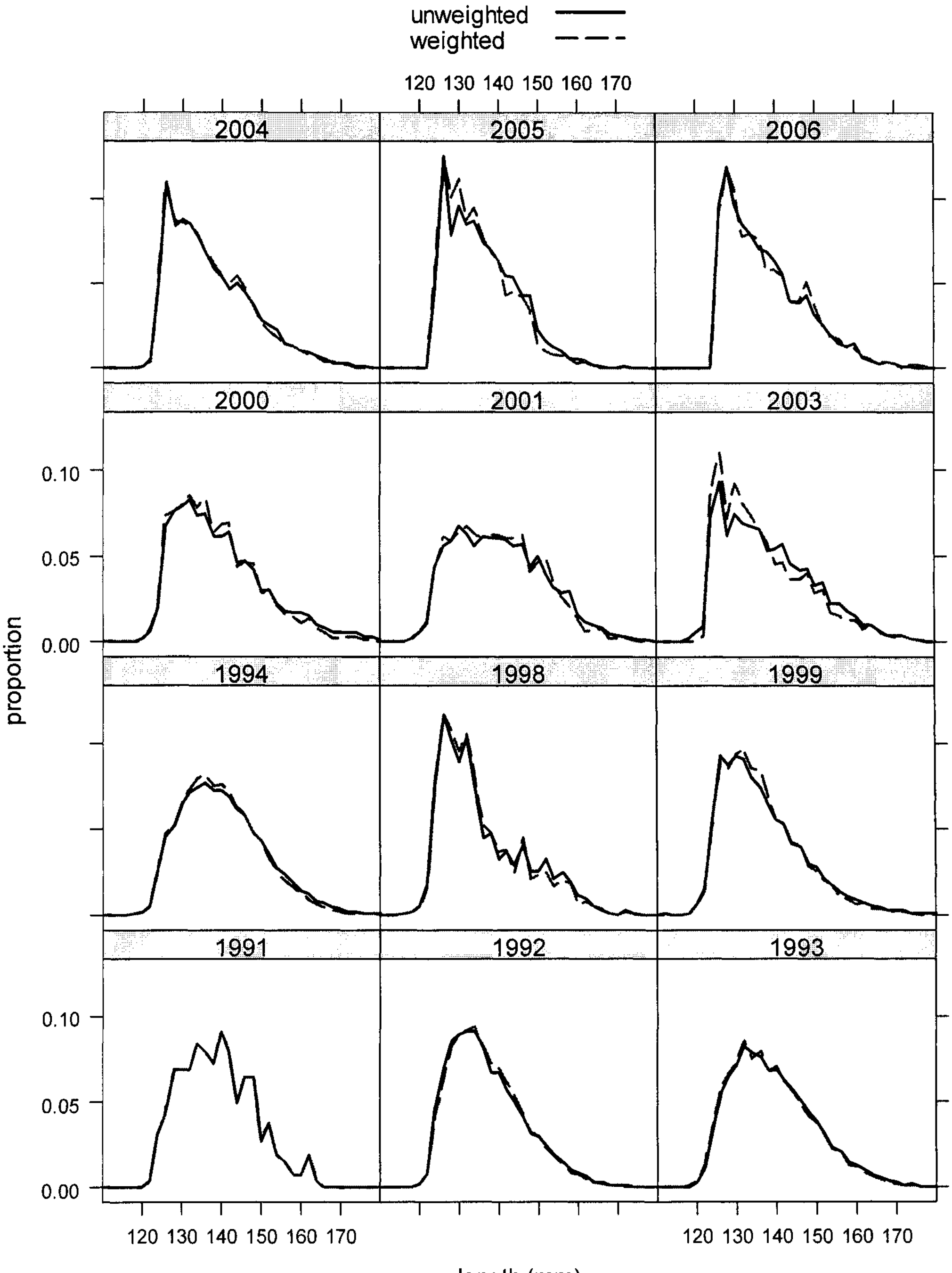

Figure 23. The commercial sampling length frequency data by year, before and after weighting by area catches within years.

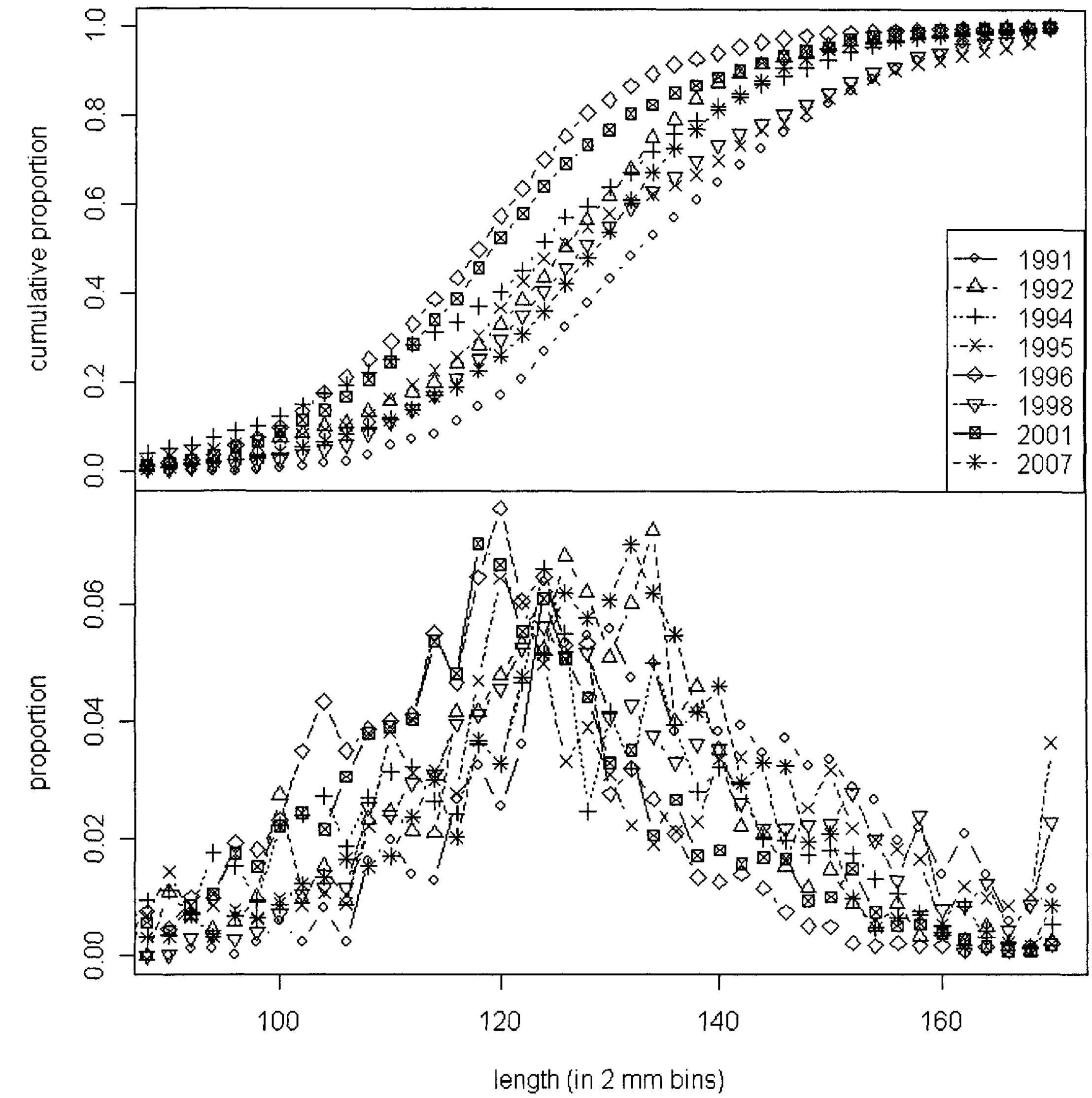

Figure 24: The proportion and cumulative proportion of length frequencies of paua from the research diver surveys, by year, after weighting by the timed-swim abundance.

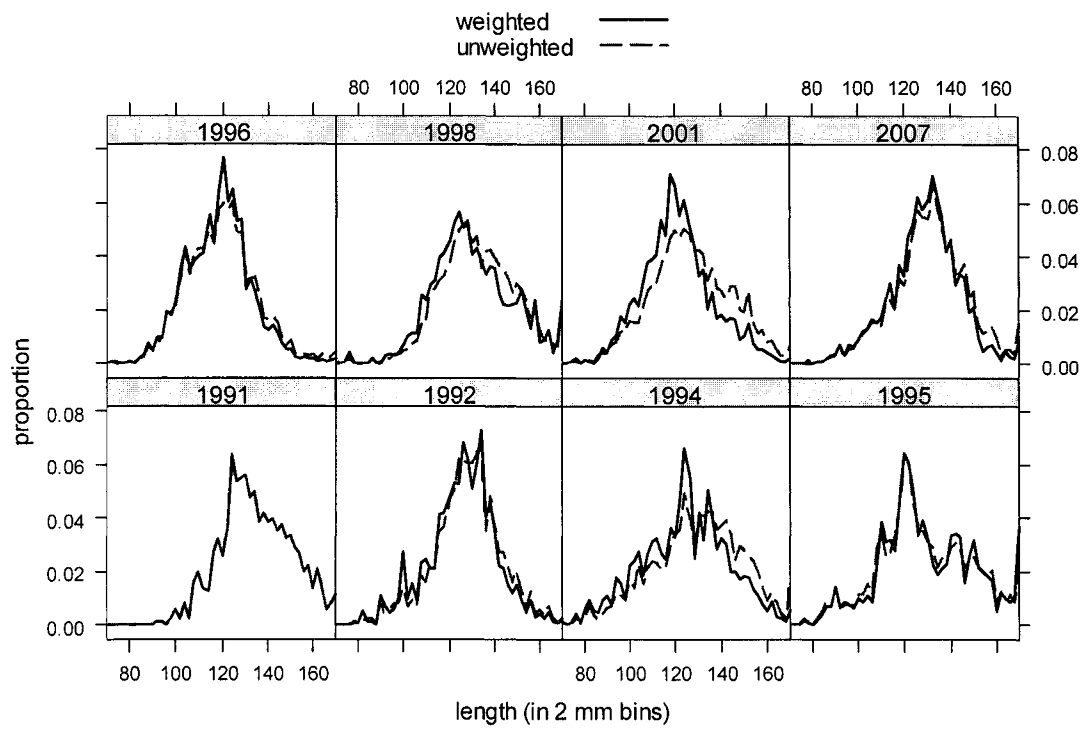

Figure 25: Length frequency distributions of paua by year from the research diver surveys, before and after records were weighted by the timed-swim abundance.

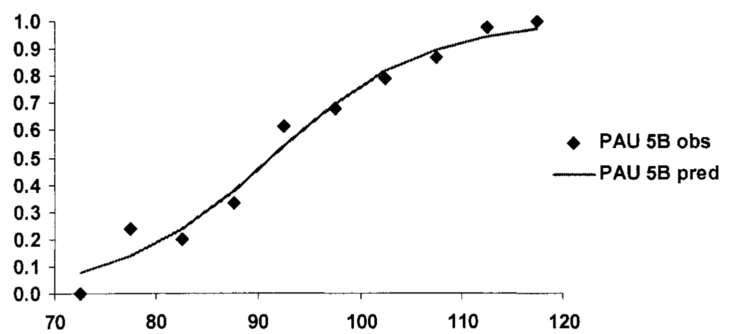

Figure 26: The binned maturity-at-length data (diamonds) and the fitted ogive for PAU 5B.

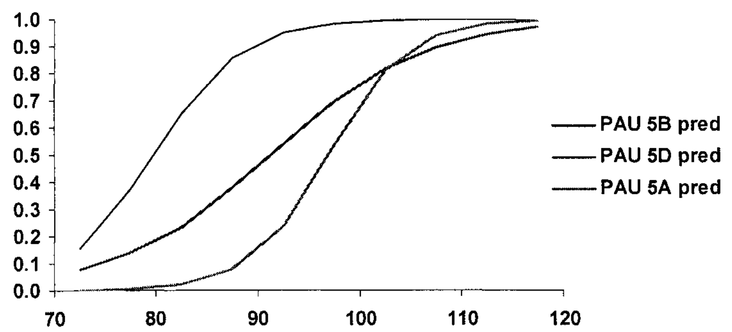

Figure 27: Maturity-at-length relations from PAU 5B, as calculated above, with model fits for PAU 5D and PAU 5A.

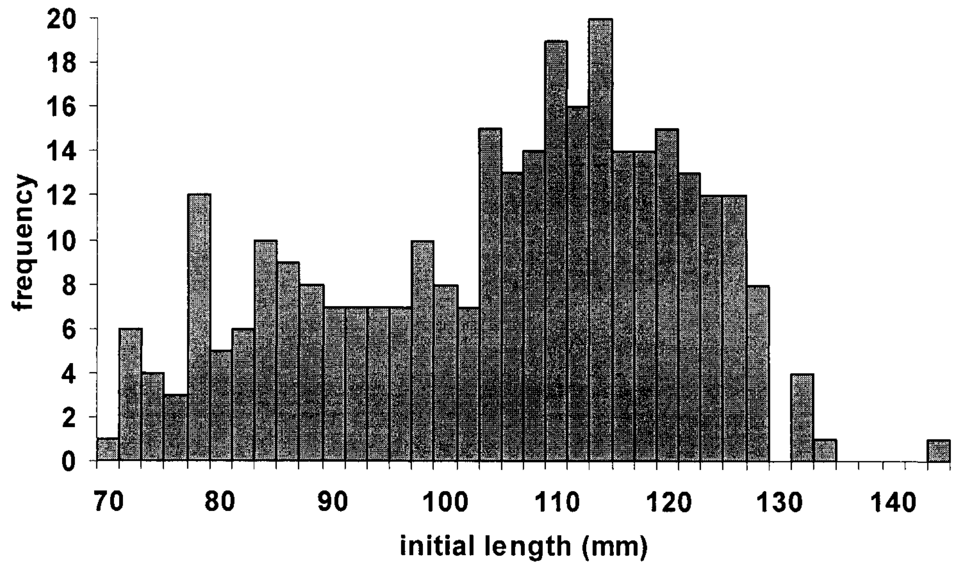

Figure 28: Size frequency of initial lengths of recovered tagged paua in PAU 5B.

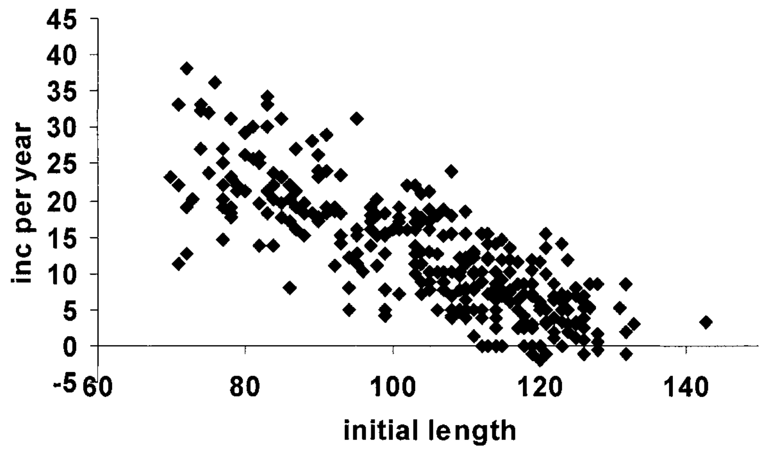

Figure 29: Increments of recovered tagged paua, corrected proportionally for this figure to 1 year's time at liberty.

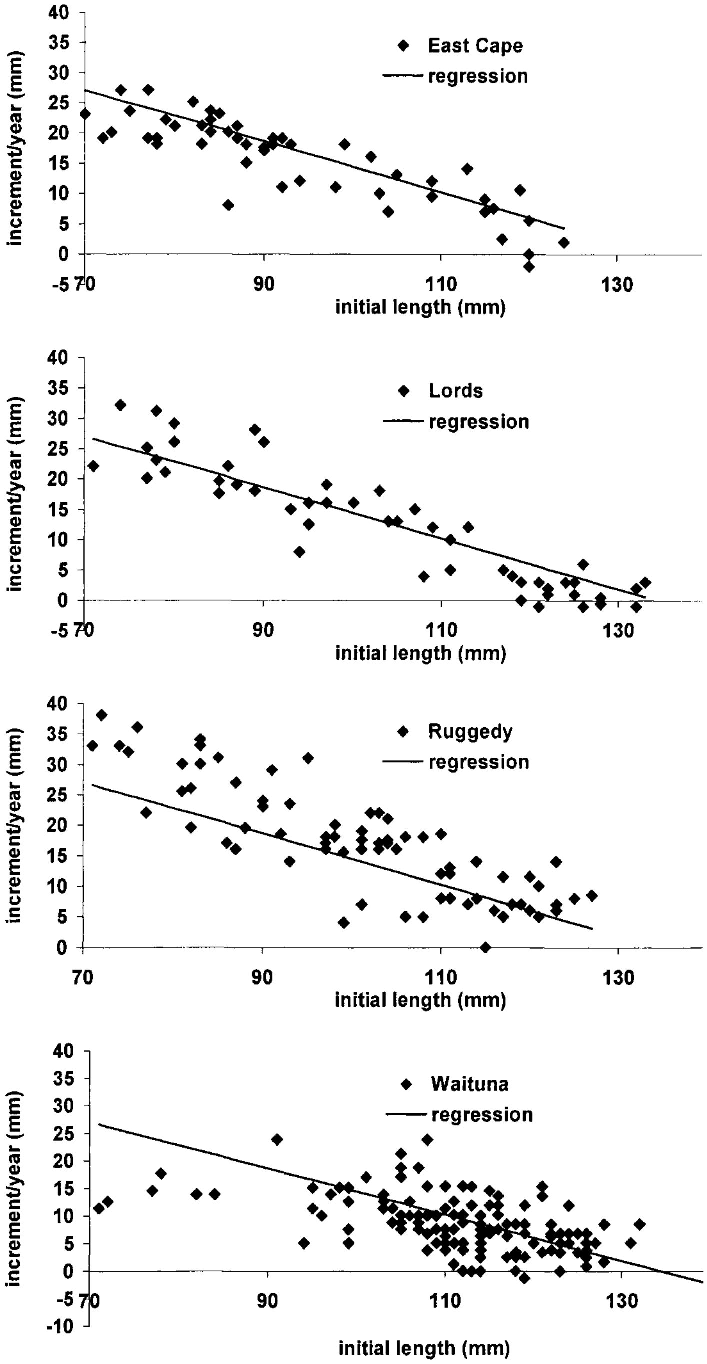

Figure 30: Increments from Figure 29 plotted by stratum, with a common regression line shown for reference.

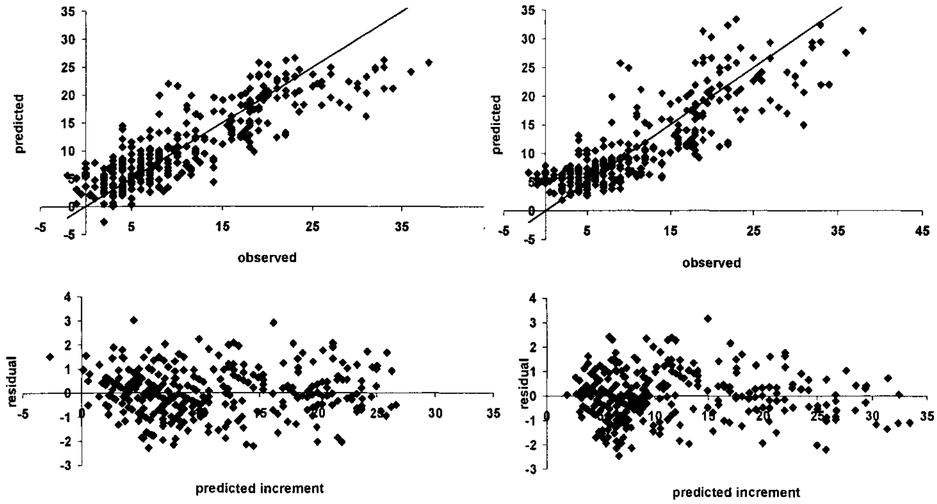

Figure 31: Fits from the two growth models. Upper figures: predicted vs. observed increments; lower figures: normalised residuals vs. predicted increments; left: linear model; right: exponential model.

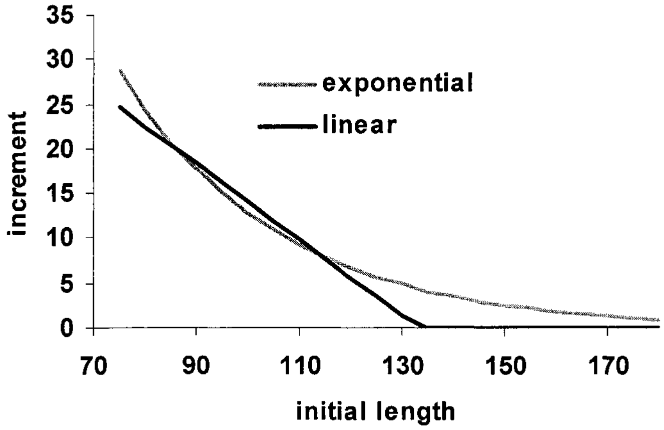

Figure 32: Growth curves from the two growth models.