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EXECUTIVE SUMMARY

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This document presents estimates of growth, and of the relative abundance and population length-structure of paua in PAU 4 in the 1993–94 and 2001–02 fishing years. There were no previous estimates of growth in PAU 4, and there was no significant difference in the relative abundance of paua between 1993–94 and 2001–02. Few surveys were done, however, in 1993–94, and the estimates were imprecise. The mode of the length frequencies remained between 110 and 130 mm, but there was a decrease in the relative frequency of paua over 130 mm between the two survey years.

1. INTRODUCTION

1.1 Overview

This document presents estimates of the relative abundance and population length-structure of paua in PAU 4. Surveys were done in 2001–02 to provide the first time series of relative abundance for the fishery. A few of surveys were done in 1993–94, and estimates of relative abundance and length structure from these surveys are also presented.

1.2 Description of the fishery

The paua (*Haliotis iris*) fishery has been managed under the Quota Management System since 1986–87. The Minimum Legal Size (MLS) has remained 125 mm shell length since the inception of the fishery. The fishery is divided into 10 Fishstocks, although PAU 1, PAU 6, and PAU 10 each have Total Allowable Commercial Catches (TACCs) of less than 2 t (Annala et al. 2001). Paua are harvested by free-diving only. All fishers are required to submit details of catches (total green weight) and time spent fishing on Catch, Effort and Landing Returns (CELRs). Before 1 October 1997, catch and effort were recorded by Statistical Area. Since 1 October 2001, catch and effort in PAU 4 are reported by 58 zones.

Between 1989–90 and 1994–95 the TACC in PAU 4 remained at 287 t. The present TACC of 326.5 t was introduced in 1995–96 as a result of a decision by the Quota Appeal Authority. Since the subdivision of PAU 5 into three areas, PAU 4 has been the largest paua stock.

In 1993–94 a few fishery independent surveys were conducted in PAU 4. Recent concerns about the status of the stock led to a more comprehensive survey in the 2001–02 fishing year. The commercial catch in 2000–01 was 326.9 t, marginally greater than the TACC.

2. METHODS

2.1 Relative abundance

The relative abundance of paua was estimated using a timed-swim method developed by McShane (1995) and modified by Andrew et al. (2000a). The revised method has been applied in PAU 5B, PAU 5D, and PAU 7 (Andrew et al. 2000b, Breen et al. 2001). We briefly summarise the method below.

The coastline in PAU 4 was divided into four strata (Figure 1). The strata consisted of areas of coastline containing paua habitat from which more than 90% of the commercial catch is taken (1999–2000 CELR data). Areas in PAU 4 outside the chosen strata had unsuitable habitat, such as sandy beaches or steeply sloping reef, were generally inaccessible, or were considered by paua divers to support too few paua to be commercially viable.

Each stratum to be surveyed was subdivided into 250 m wide strips, each of which was considered a potential sampling site. Each year, sites were randomly selected within strata. If a randomly chosen site contained unsuitable habitat, it was permanently discarded from the list of potential sites and another chosen. Sites were selected with replacement among years, but not within. The number of sites sampled within each stratum was based on the area of the stratum and on the variance estimated from previous surveys.

Two 10 minute searches were done at each site by divers. The areas searched were not overlapping and were within 100 m of the vessel. In each search, the relative abundance of paua found in the open on the reef (typically over 70 mm) was estimated using the frequency of patches corresponding to various aggregation sizes (Table 1). Because paua usually occur in shallow habitat, divers search reef in less than 10 m of water and seek to maximise the number of paua found. Paua were considered to be in the same patch if they were separated by less than two body lengths.

The number of paua encountered per 10 minute search (T) was calculated as the product of the frequency of each patch category, f_i, and the midpoint, M_i, of that category summed across all patch categories:

$$T = \left(\sum_{i=1}^{6} (f_i M_i) \right)$$

Before 1997 only the patch category was recorded. In 1997–99, the number of paua in patches was also recorded and estimates of mean number per timed-swim were calculated using the mid-point of the patch category. For patches of more than 20 paua the clock is stopped while they are counted. This change does not introduce bias among years in searching time because, in practice, the numbers of paua in patches with less than 21 paua were counted in previous years, but not recorded. There was no statistically significant difference between the estimates derived from the two methods (Andrew et al. 2000a).

The estimates of the mean number of paua per timed-swim have not been scaled to account for differences in searching time.

The statistical significance of differences in raw means among years and places was tested using 95% bootstrapped confidence intervals. The bootstrapping was done in S-PLUS by replicating the structure in the data (replicate counts paired within sites and sites grouped within strata).

Following Breen et al. (2001), the estimates of relative abundance generated in these surveys were standardised using the method of Vignaux (1993) and then converted into a canonical form by dividing each index by the geometric mean of the set (Francis 1999). The standardisation was done initially on the natural log of the count. The explanatory variables offered to the model were fishing year, month, stratum, and diver. With the exception of fishing year (the effect of interest), variables were excluded if they improved model fit by less than 1%. Interaction terms were tested and in all cases did not improve the model fit. In the PAU 4 analysis, month did not increase the coefficient of variation substantially and was excluded. The standard error of each canonical index was estimated using the covariance matrix from the standardisation (Francis 1999).

The size composition of paua at each site was estimated by collecting four randomly selected paua from each patch. 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. Of the 18 580 paua counted during surveys in PAU 4 in 2001–02, 33% were measured. All length-frequency data were grouped into 2 mm size classes for presentation, with paua longer than 170 mm being pooled into a single size class. Length-frequency distributions are presented for all of PAU 4 and for strata within PAU 4.

2.2 Estimation of growth

Growth estimates were derived from mark-recapture methods. About 800 emergent and cryptic paua across the available size range were collected from each site (Figure 1, see Table 2). Paua were tagged with numbered 6 mm diameter polyethylene discs attached adjacent to the spire of the shell with cyanoacrylate glue. The shells were cleaned of epibiota if necessary, and lightly dried with a towel. Emersion times were minimised and always less than 1 hour. Tagged paua remained at liberty for about one year and were then recovered by thorough searching at and around each site. Shell lengths of recovered paua were measured to the nearest millimetre.

Growth of recaptured paua was estimated using the maximum likelihood approach of Francis (1988, 1995). This model expresses observed increments in length as functions of the observed length at tagging and time at liberty, and describes growth in terms of average annual growth for individuals of a given size (Francis 1988). Parameters estimated during this process included the mean annual growth rates at two lengths, parameters for growth variability, and the influence of outliers in parameter estimation. Four growth models describing growth variability (equations 5–8, Francis 1988) were fitted to the data.

The lengths used to compare growth rates among sites were chosen after inspection of the length-frequency distributions of recaptured tagged paua. To facilitate comparison with previously published estimates of paua growth, the von Bertalanffy growth parameters K and $L\infty$ were also estimated (using equation 1, Francis 1988).

3. RESULTS

3.1 Relative abundance

Estimates of relative abundance are available for only two fishing years, 1993–94 and 2001–02, and in 1993–94 only two strata were adequately surveyed (Table 3). For strata surveyed in both years, there is a small increase in mean relative abundance of paua over the eight-year period (Figures 2 & 3). The estimates of relative abundance are imprecise and limit the inferences that can be made about differences in relative abundance among years. The mean number of paua per 10 minute timed search over all PAU 4 strata in 2001–02 was about 160 (Figure 4). This is about five times the relative abundance reported for PAU 5B and 5D in the 2000–01 fishing year (Breen et al. 2002a, 2000b) and about three times that reported for PAU 7 in the same year (Breen et al. 2001). There was no significant difference in the estimates of relative abundance between strata in either survey year. The number of paua observed in patches of more than 20 animals was similar between the two survey years (Figure 5).

3.2 Population length frequencies

The length structures of populations of emergent paua in PAU 4 have been estimated in four strata in 2001–02, and only two strata in 1993–4 (Table 2). In all strata sampled, the mode of the length frequencies was between 110 and 130 mm. The main change in the size distribution over time was in stratum 1, where a large decline in the relative frequency of paua larger than about 130 mm was evident (Figure 6). This is reflected in the percentage of paua smaller than the MLS in all strata sampled, increasing from 57.5% in 1993–94 to 75.9% in 2001–02. There were more large paua in stratum 1 than in stratum 3 in 1993–94, and the length structure of paua in this stratum appears relatively consistent over time. Significantly more paua were measured in 2001–02 than in 1993–94 (Figure 6), and different sample sizes may account for some differences in length structure between years and strata.

3.3 Standardisation of timed swims

In the standardisation of timed swim estimates in PAU 4, all explanatory variables, except month, improved the fit to the model, and in total they explained 12.5% of the variation in the dataset (appendix 1). The standardisation reduced the differences between years apparent in the unstandardised counts (Figure 7). The unstandardised abundance (mean number per 10 minute search) in Figure 7 is not the same as the raw abundance count (Figure 4). The unstandardised abundance count is calculated from the mean of the log of each abundance count whereas the raw abundance count is simply the average of observed abundance counts within a year.

3.4 Estimation of growth

The numbers of paua tagged and recaptured and the time at liberty at each site is shown in Table 3. Fewer than expected tagged paua were recovered from the Wharekauri and the The Horns sites. Migration and the cryptic habitat provided by the reef may have contributed to these low recoveries. Some negative growth associated with measurement error or shell damage was recorded, and is included in analyses.

Using GROTAG (Francis 1988), the model was initially fitted to incremental growth data to estimate the mean annual growth rates at two lengths, with parameters to estimate the influence of outliers and growth variability (according to equation 5 of Francis 1988). The introduction of more complex relationships describing growth variability (equations 6–8 of Francis 1988) occasionally resulted in a significant improvement to the model fit. Mean annual growth estimates at lengths α and β, the growth variability equations used in their estimation, and the von Bertalanffy growth parameters derived from these are shown in Table 4. The addition of Francis's (1995) general growth model did not significantly improve the fit of the model to any of the tag recapture data sets.

The length-frequency distributions of tagged paua are shown in Figure 8, and incremental growth of paua recaptured PAU 4 is shown in Figure 9. Asymptotic lengths at the three sites were similar, ranging from 135 mm to about 138 mm (Table 4).

4. DISCUSSION

The relative abundance of emergent paua in PAU 4 was similar between 1993–94 and 2001–02. Few surveys were done in 1993–94, and estimates were imprecise. There was no significant difference in the numbers of paua occurring in large patches between the two years. The most notable change observed was in the structure of the length-frequency distribution, where in stratum 1, the surveys indicated a decline in the relative frequency of paua larger than 130 mm (Figure 2). This change in length structure is consistent with an increase in fishing pressure, but the relative abundance of paua in PAU 4 is considerably greater than recent estimates for PAU 5B, 5D, and 7.

The estimated asymptotic lengths of paua from tagging sites in PAU 4 is lower than most estimates from other sites around New Zealand (Table 5). The asymptotic lengths for tagging sites at Waitangi West and The Horns (see Figure 1) are supported by the respective length frequencies of tagged paua (Figure 8). The estimated asymptotic length for the Wharekauri site is not consistent with the length-frequency distribution of tagged paua at the site (Figure 8), and this is likely to be an artifact of the tag recapture data, where few paua and no large paua were recaptured.

The estimates of relative abundance and size frequency presented here provide important baseline data, against which future trends in relative abundance may be assessed.

5. ACKNOWLEDGMENTS

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Table 1: Patch categories and their assumed midpoints (M_i) (McShane 1995).

Patch category	Number of paua	Mid–point (M_i)
1	1–4	1.3
2	5–10	7.5
3	11–20	15.5
4	21–40	30.5
5	41–80	60.5
6	More than 80	120.5

Table 2: Number of paua tagged and recaptured and time at liberty.

Site	Number tagged	Number recovered	% recovered	Days at liberty
Wharekauri	842	31	3.7	362
Waitangi West	826	120	14.5	363
The Horns	820	36	4.4	363

Table 3: Summary of timed-swim surveys completed within PAU 4. Strata are defined in Figure 1. – indicates no sampling done.

Year	Stratum	Statistical Area	Replication
1993–94	1	25	22
	2	25	2
	3	27	10
	4	27	–
2001–02	1	25	30
	2	25	24
	3	27	30
	4	27	30

Table 4: Mean annual growth estimates (mm/year) of paua at lengths α and β, and von Bertalanffy growth parameters from sites in PAU4.

Site	Mean growth (g_{75})	Mean growth (g_{125})	Growth Variability Model	L_∞	K
Wharekauri	21.25	4.34	1	137.85	0.41
Waitangi West	19.43	3.24	4	135.01	0.39
The Horns	16.34	3.09	1	136.68	0.31

Table 5: von Bertalanffy growth parameters of paua sampled at other sites around New Zealand.

Area	K	L_∞	Source
Peraki Bay	0.164	131.9	Sainsbury (1982)
Kaikoura	0.34	144.4	Poore (1972)
Kaikoura	0.26	148.5	Poore (1972)
D'Urville	0.21	133–147.8	McShane & Naylor (1995)
D'Urville	0.38	141.6	Schiel & Breen (1991)
Kahurangi	0.23	131.5	Naylor et al. (1998)
Waituna	0.25	149.95	McShane et al. (1996)
Marlborough	0.29	144.5	Schiel & Breen (1991)
Stewart Island	0.26	160.9	Breen et al. (2002a)
Turakirae	0.44	140.8	Naylor & Andrew (2002)
Mataikona	0.45	125.3	Naylor & Andrew (2002)
Breaker Bay	0.47	140.1	Naylor & Andrew (2002)
Poison Bay	0.21	136.0	Naylor & Andrew (2002)
Landing Bay	0.38	153.6	Naylor & Andrew (2002)
Red Head Point	0.26	148.6	Naylor & Andrew (2002)

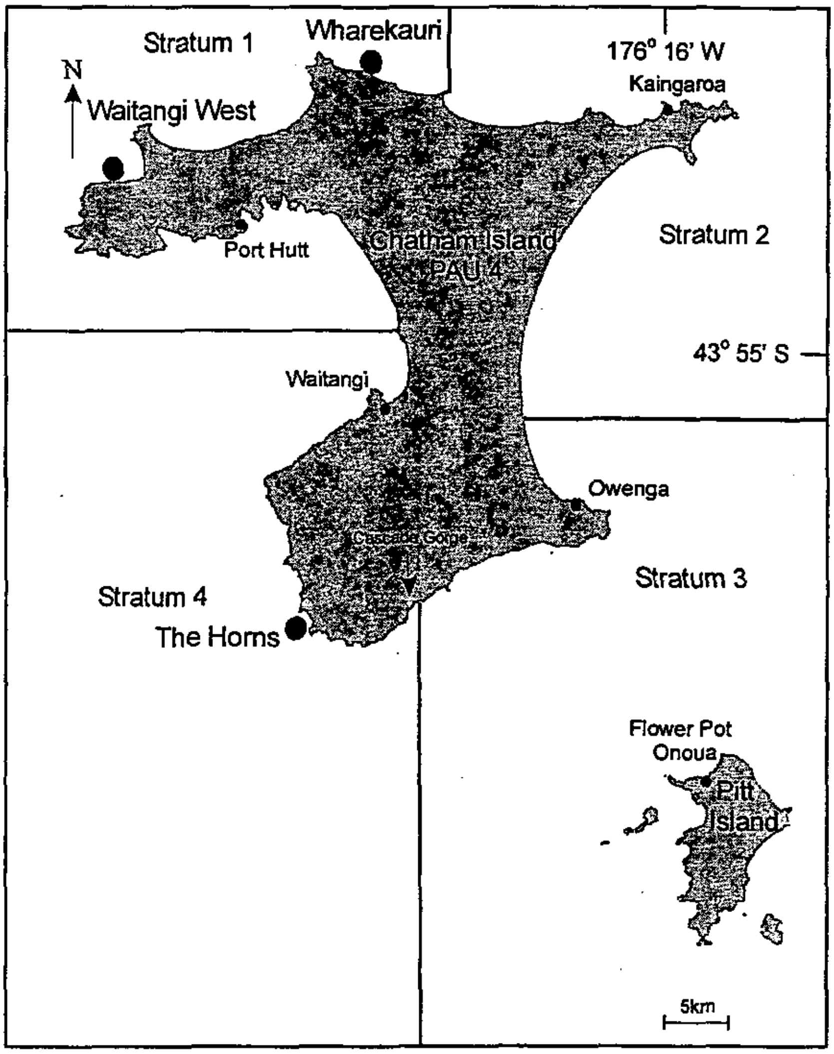

Figure 1: Survey strata and location of tagging sites in PAU 4.

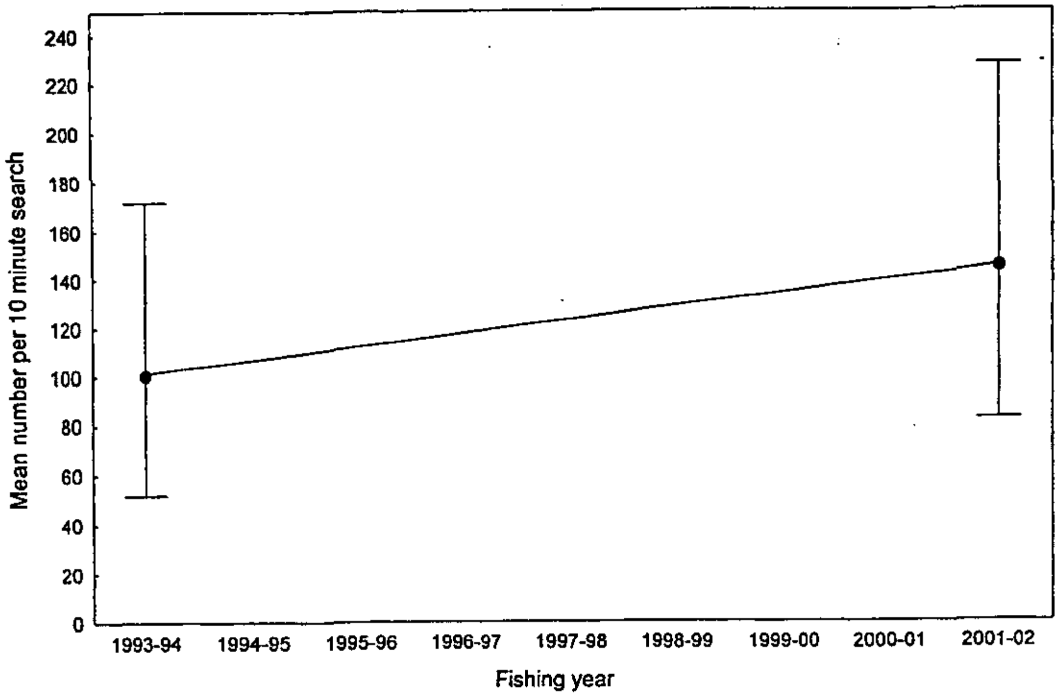

Figure 2: Mean number of paua per 10 minute search in stratum 1 of PAU 4 (± 95% bootstrapped confidence intervals).

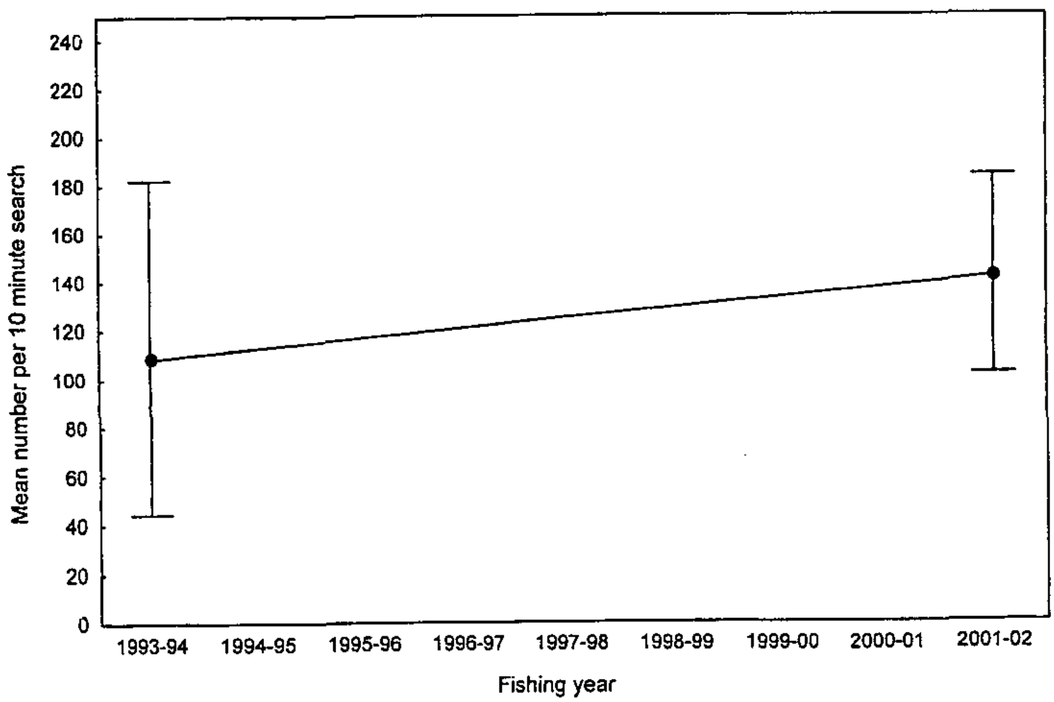

Figure 3: Mean number of paua per 10 minute search in stratum 3 of PAU 4 (± 95% bootstrapped confidence intervals).

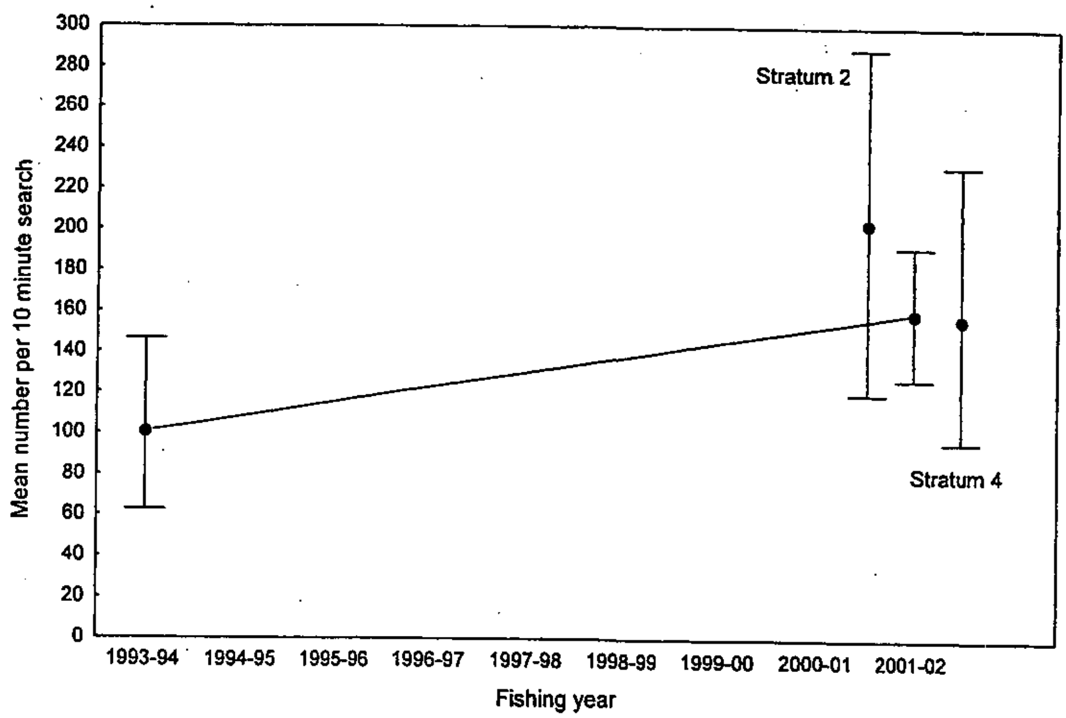

Figure 4: Mean number of paua per 10 minute search in all surveyed strata of PAU 4, and as indicated, for strata 2 & 4 in 2001–02 only (± 95% bootstrapped confidence intervals).

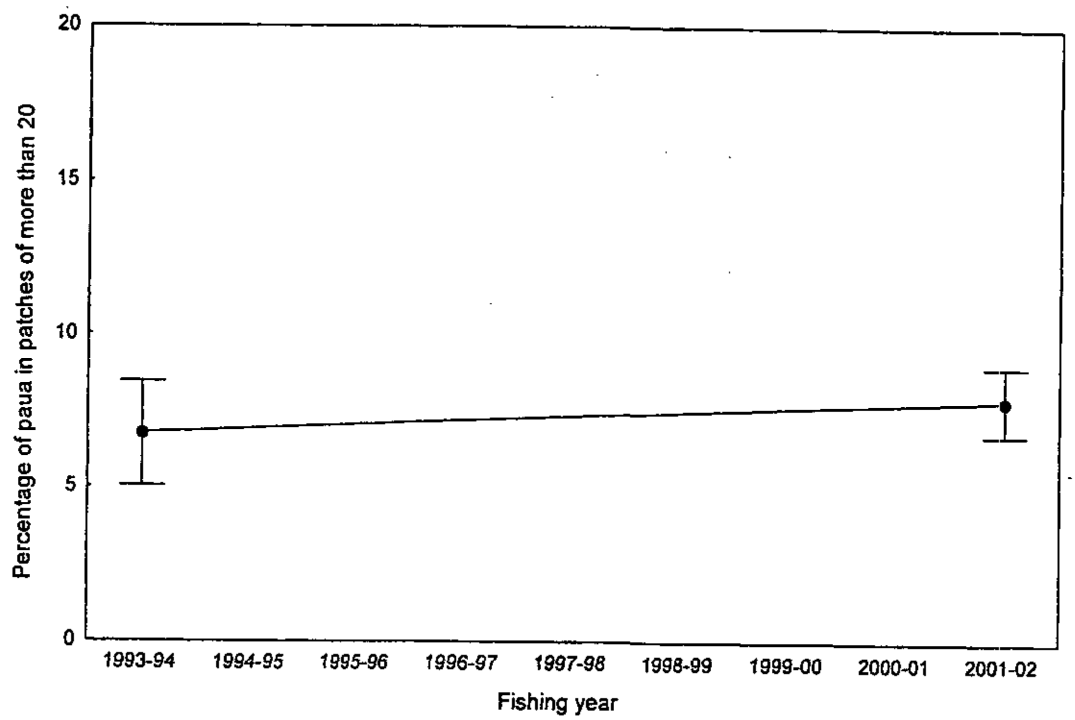

Figure 5: Mean percentage (± SE) of paua occurring in aggregations of more than 20 in sites sampled at the Chatham Islands (PAU 4).

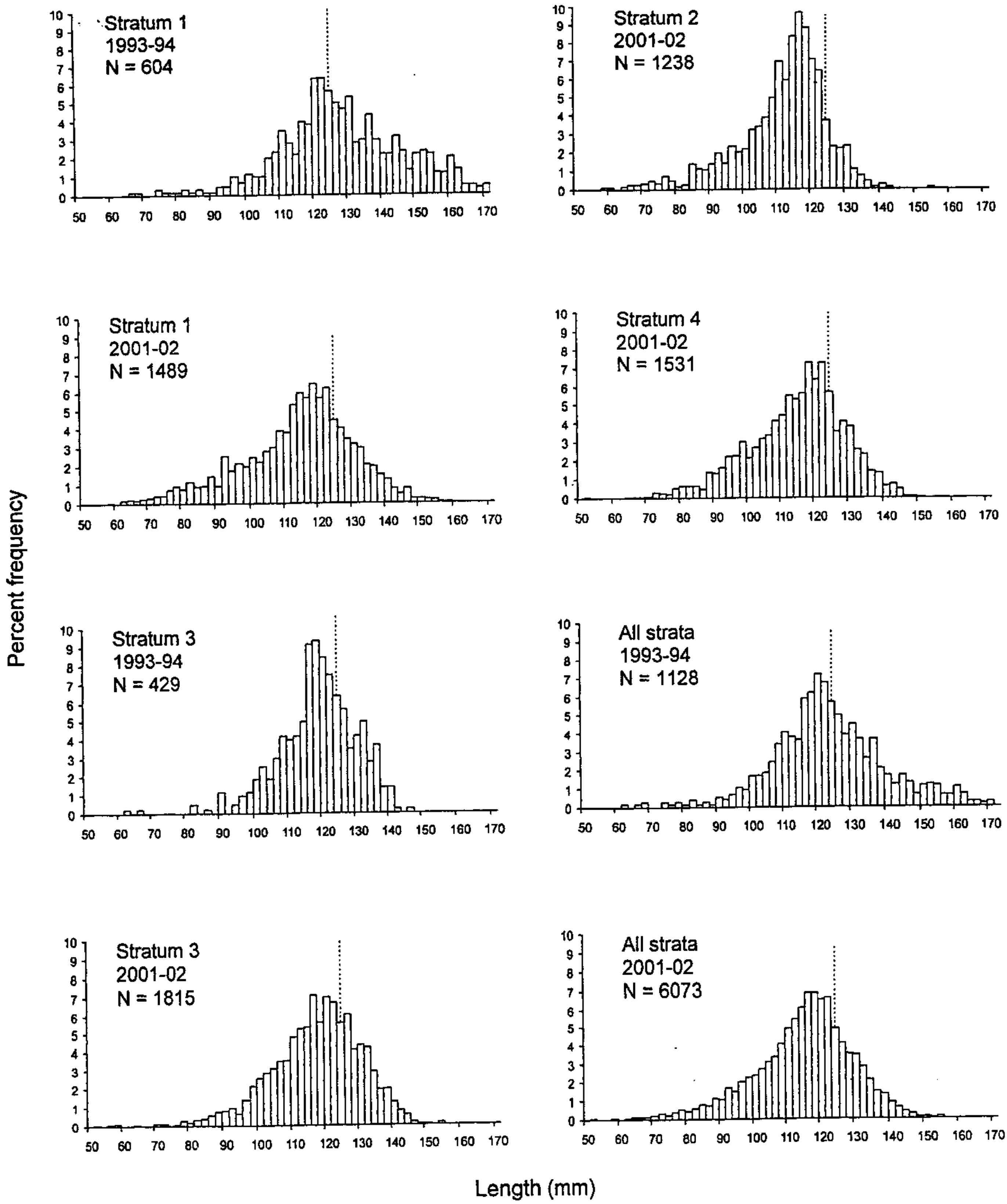

Figure 6: Length frequency distribution of paua sampled from strata in PAU 4 in 1993–94 and 2001–02. Minimum legal size of 125 mm is indicated.

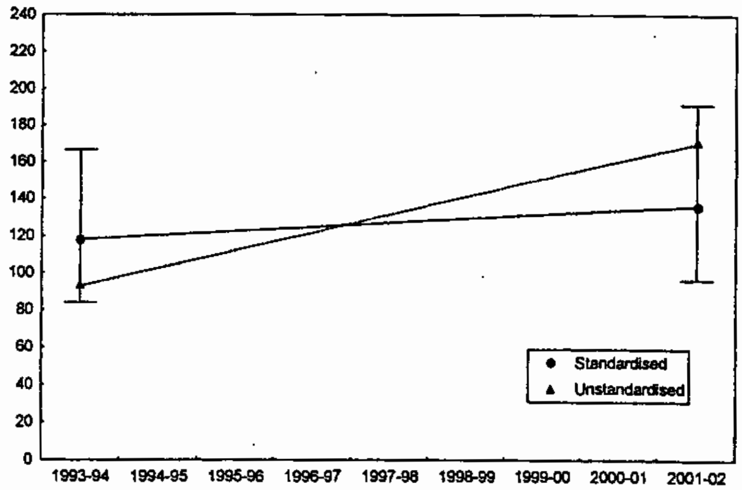

Figure 7: Standardised (± 95% confidence intervals) and unstandardised research diver survey indices for PAU 4.

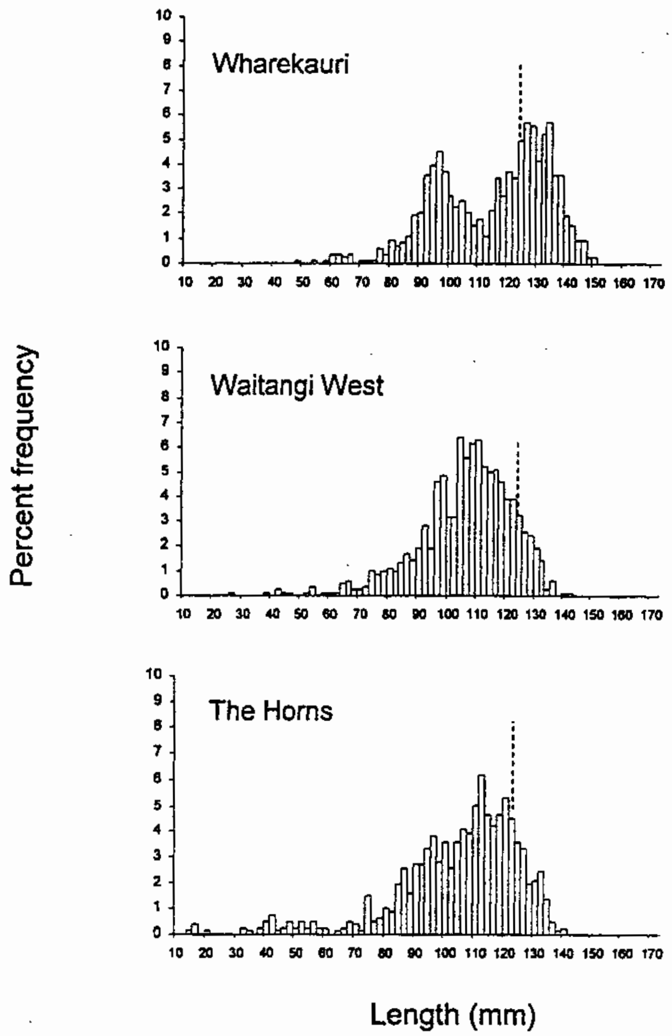

Figure 8: Length frequency distribution of *H. iris* tagged at sites in PAU 4. Minimum legal size of 125 mm is indicated.

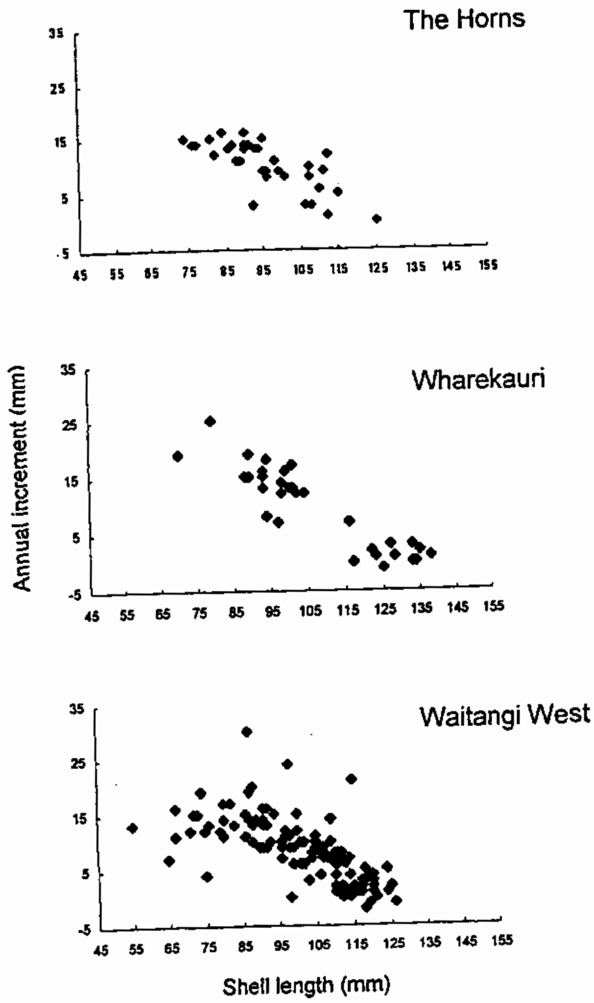

Figure 9: Incremental growth of paua at sites in PAU 4.

Appendix 1. The order in which variables were selected into the GLM model of survey indices and their cumulative effect on the model r^2.

Variable	Model r^2
Fishing year	0.0595
Diver	0.0898
Stratum	0.1251
Month	0.1256