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EXECUTIVE SUMMARY

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The relative abundance of emergent paua in PAU 5B declined significantly between the fishing years 1993–94 and 1997–98. Mean relative abundance of paua increased slightly between 1997–98 and 2000–01, but the mean counts were not significantly different. In statistical areas 025 and 030 of PAU 5B there were slight increases in mean estimates of relative abundance between 1997–98 and 2000–01, while in area 027 there was a slight decline over the same period. The estimates of relative abundance in PAU 5D were imprecise and, overall, there was no statistically significant decline in mean relative abundance. Within PAU 5D, there was a statistically significant decline in relative abundance in Catlins West but not in Catlins East between 1993–94 and 2000–01. The number of large patches (those with more than 20 paua) and the number of paua in those large patches declined in PAU 5B and PAU 5D in the first three years of surveys, but have remained at similar levels since. The size-frequency distributions of paua in PAU 5B have remained relatively constant through time, with the exception of 1993–94. It is likely that the large difference observed between this and other years was caused by non-representative sampling. Similarly, in PAU 5D, there has been relatively little change in the size structure of paua, except in a year in which relatively few paua were measured. The counts of emergent paua per 10 minutes were standardised and these, along with the length-frequency distributions reported here, were used in stock assessments of PAU 5B and PAU 5D.

1. INTRODUCTION

1.1 Overview

This document presents estimates of the relative abundance and population length-structure of paua in PAU 5B and PAU 5D since 1993. Surveys done in 2000–01 extend the time series of estimates reported previously (McShane 1995, McShane et al. 1996, Andrew et al. 2000b). These results, standardised catch rates, estimates of growth (Naylor & Andrew unpubl. results), and information from previous biological studies are incorporated into stock assessments of PAU 5B and PAU 5D (Breen et al. 2002a, 2002b). Previous estimates of biomass and yield were summarised by Annala et al. (2001).

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 (Figure 1). Between 1997–98 and 2000–01 catch and effort were reported by 16 smaller areas in PAU 5B, and 11 in PAU 5D. Since 1 October 2001, catch and effort are reported by 84 zones in PAU 5B and 47 zones in PAU 5D.

Before 1995–96, PAU 5 was the most important paua QMA by number of quota holders and TACC. The TACC peaked in PAU 5 in 1991–92 at 492 t, having grown steadily from a provisional TACC of 390 t in 1985–86. This TACC increase resulted from the quota appeal process. Concerns about the status of the PAU 5 fishery led to a voluntary 10% reduction in the TACC in 1994–95. On 1 October 1995, PAU 5 was divided into three QMAs (PAU 5A, PAU 5B, and PAU 5D; see Figure 1) and the TACC subdivided equally among them. It is widely considered that this led to a large redistribution of catch from Stewart Island to Fiordland and the Catlins/Otago coast (Elvey et al. 1997). The exact reduction in catch in Stewart Island caused by subdivision cannot be determined with certainty because several Statistical Areas used to report catch and effort straddled PAU 5B and PAU 5D (Figure 1). An assessment of the PAU 5B fishery (Breen et al. 2000a) confirmed fears of over-exploitation and the TACC was reduced by 30 t from 1 October 1999. A subsequent assessment (Breen et al. 2000b) indicated that a further catch reduction was required and 29 t was removed, using a mixture of shelving (voluntary non-catching of quota) and TACC reduction. The commercial catch in 2000–01 was 90 t. This series of management interventions has reduced the reported commercial catch in PAU 5B by at least 40% since 1998–99, and probably by as much as 60% since 1994–95.

2. METHODS

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

The coastline in PAU 5B and the Catlins area of PAU 5D was divided into strata (Figure 2). The strata consisted of areas of coastline containing paua habitat from which most (more than 90%) of the commercial catch is taken (McShane et al. 1995, Elvey et al. 1997). Areas in PAU 5B 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. In PAU 5D much of the coastline north of the Catlins is sandy beach, except for the Otago Peninsula, most of which is closed to commercial fishing (Elvey et al. 1997).

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 using surface supplied air. The areas searched were not overlapping and were constrained to be 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. Between 1993 and 1998, 92% of the 3947 patches counted contained fewer than 21 paua. There was no statistically significant difference between the estimates derived from the two methods (Andrew et al. 2000a). In PAU 5D, 30 counts done in December 2001 were pooled with those done during the 2001–01 fishing year.

The estimates of the mean number of paua per timed-swim have not been scaled to account for differences in searching time. Searching time is influenced by the time required to process each patch (collect paua and record data). McShane et al. (1996) estimated that it took 8 seconds to process each patch. Based on this estimate, in 1993–94, in PAU 5B, a mean of 79 seconds (SE = 5) was spent per timed-swim processing patches, thereby reducing the nominal 10 minute search by 13%. In 1997–98, processing time had fallen to 50 seconds (± 4) or 8% of searching time. This suggests that the reported estimates of relative abundance for this QMA for 1997–98 may be over-estimates relative to 1993–94. In 2000–01, however, the processing time in PAU 5B had risen to 79 (± 5) seconds, similar to the 1993–94 estimate. Processing time was previously greatest in Catlins West, where in 1996–97, a mean of 169 (± 21) seconds or 28% of the search was spent processing paua per timed-swim. In 2000–01, mean processing time in Catlins West fell to 118 (± 16) seconds.

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 to produce annual indices for the assessment model. The timed-swim counts were first 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 5D 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).

In both PAU 5B and PAU 5D, diver 4 consistently had higher counts than all other divers in the same stratum and year combination. The sensitivity of the standardisation to that diver was tested by removing him from the dataset and repeating the standardisation. In PAU 5D, only Catlins West was sampled in 1996–97, so the sensitivity of the standardisation to the removal of that year was tested.

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 9228 paua counted during surveys in PAU 5B and PAU 5D between 2000 and 2002, 44% were measured. Population length-frequency data gathered in 1988–89 were from collections of all emergent paua in haphazard searches within sites (Schiel & Breen 1991). 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 5B and PAU 5D, and for Statistical Areas within PAU 5B.

3. RESULTS

3.1 Relative abundance

The mean relative abundance of emergent paua in PAU 5B declined significantly between 1993–4 and 1997–8 (Figure 3), but in 2000–01 this decline had halted and the mean counts were greater than those in 1997–98. Nevertheless, mean numbers per timed swim in 2000–01 were still less than half of those in 1993–4. The variability associated with the annual estimates was least in 1997–8.

Not all research strata in PAU 5B were surveyed in all years (Tables 2 and 3), nor was the same number of timed swims done across strata or years. The Ernest Island stratum (see Figure 2) was sampled only once, in 1994–95, and was removed from the dataset. In PAU 5B, surveys were completed in all Statistical Areas in all years except Area 030 in 1995–6. In 1997–98, the mean relative abundance of paua in Area 030 was less than in the other two areas, suggesting that the estimate used for all PAU 5B in 1995–6 was an over-estimate compared with the other years (Figures 3–6).

The large and statistically significant declines observed in all of PAU 5B between 1993–94 and 1997–98 had halted within all statistical areas, but the areas differed thereafter (Figures 4-6). In Areas 025 and 030, mean counts had increased and, in Area 030, had more than doubled between 1997–98 and 2000–01 (Figure 6). The estimated number of paua per timed-swim in Area 030 in 2000–01 was about half that of the 1993–4 estimate. In Area 025, there was a slight increase in the mean counts and variability was similar to the 1995–96 estimates (Figure 4). Mean numbers per timed swim in 2000–01 were about one-third of those in 1993–

4 (Figure 4). In Area 027 the estimates of relative abundance were imprecise, particularly in 1994–95 (Figure 5). This imprecision limits the inferences that can be made about differences in relative abundance among years. Nevertheless, mean counts in Area 027 since 1995–96 have remained relatively stable (Figure 5).

The relative abundance of paua in the Catlins area of PAU 5D was poorly estimated in both 1993–94 and 1996–97 (Figure 7). In both areas, particularly in 1993–4, estimates of mean number of paua per timed-swim were accompanied by wide confidence intervals. Although mean numbers per timed swim nearly halved between 1993–4 and 2000–01, the variability associated with these estimates was such that there were no significant differences between years.

Not all research strata were surveyed in all years (Tables 2 and 3), nor were the same number of timed swims done across strata or years. There was no sampling in Catlins East in 1996–7. In 1998–99 and 2000–01, the mean relative abundance of paua in Catlins East was greater than in Catlins West, suggesting that the estimate used for all PAU 5D in 1996–7 underestimated the true relative abundance across all of the Catlins. The effect of this imbalance in sampling effort on trends in the survey indices is considered below.

In Catlins West there was a significant decline in the mean number of paua per timed-swim between 1993–94 and 2000–02 (Figure 8). The estimated number of paua per timed-swim in 1993–94 was about three times that in 2000–02. In Catlins East (Figure 9) there is no apparent change in mean relative abundance, but care should be taken in interpreting this pattern because of the very large confidence intervals around the estimates of mean counts.

In both PAU 5B and PAU 5D, particularly in 1993–4, large patches of paua were recorded in some, but not all, counts (Figure 10). In both QMAs, the relative abundance of paua in patches of more than 20 individuals has been relatively consistent since 1995–96; in PAU 5B about 5% of the total number estimated in the surveys have been in large patches, and in PAU 5D, about 20% of the animals observed were in large patches (Figure 10).

3.2 Population length-frequencies

The length structures of populations of emergent paua in PAU 5B have been estimated in few places and only in five fishing years. For the five years in which all statistical areas were sampled, the percentage of paua smaller than the MLS declined from 64% in 1988–89 to 37% in 1997–98, but increased in 2000–01, to 46% (Figure 11). Associated with this change, the relative percentage over 170 mm has increased over the four years sampled until 1997–98 (Figure 11). The mode of the length-frequencies has remained between 120 and 130 mm.

Paua in Statistical Area 025 have been sampled in 11 fishing years (Figure 12). In years when more than 400 paua were measured, the observed length-frequency distributions were relatively consistent through time, apart from the recent decrease in the number of paua longer than 170 mm. The mode of the distributions was near the MLS for the fishery.

More large paua were observed in Statistical Area 027 than in Area 025 (Figures 12 and 13). The modes of the length-frequency distributions in Area 027 were between 130 and 150 mm (Figure 14). More than 900 paua were measured in 1993–94, 1997–98, and 2000–01; samples in all other years were insufficient to provide representative estimates of population structure. The mode of the distributions is similar between 1993–94 and 2000–01 (see Figure 12). The size distributions of paua in Areas 029 and 030 were also dominated by a single mode of large paua, between 126 and 145 mm (Figure 14).

Changes in the size structure of paua in PAU 5D were less consistent among years than those in PAU 5B (Figures 11 and 15). Both the modes of the distributions and the relative frequency of smaller paua changes considerably among years. Of particular concern are the large changes between 1993–94, 1996–97, and 1998–99. Changes of this magnitude are inconsistent with available estimates of growth rate in paua and suggest that the sampling was not representative. The total sample size in 1996–97 was relatively small. The length frequency distribution in 2000–01 was relatively consistent with that from 1996–97 sample and suggests either increased recruitment or more representative sampling. The effect of these patterns in size structure on the stock assessment are considered in Breen et al. (2002b).

3.3 Standardisation of timed swims

In the standardisation of timed swim estimates in PAU 5B, all explanatory variables offered to the standardisation model improved the fit, and in total they explained 19% of the variation in the dataset (Tables 4 and 5). The standardisation exaggerated the differences among years apparent in the unstandardised counts (Figure 16), making both the decline in the first three years and the subsequent increase to 2000–01 greater. The unstandardised abundance (mean number per 10 minute search) in Figure 16 is not the same as the raw abundance count (Figure 3). The unstandardised abundance count is calculated from the mean of log of each abundance count whereas the raw abundance count is simply the average of observed abundance counts within a year. In PAU 5D, the most important explanatory variables were fishing year and diver and together they explained 12% of the variation (Table 5); the remaining variables accounted for less than 1% of variation and were excluded. In contrast to PAU 5B, the standardisation of counts in PAU 5D produced a more linear decline in the relative abundance of paua between 1993–94 and 2001–02 (Figure 17a).

In the sensitivities, the removal of diver 4 had very little effect on the year effects (Figures 17 and 18). In PAU 5D, removal of diver 4 had a greater impact, making the standardised trend in the year effects very similar to the raw data (Figure 17a). In the second sensitivity test applied in PAU 5D, the fishing year 1996–97 was removed because only Catlins West was surveyed. Removal of this year had little impact on the year effects when compared to the base case standardisation (Figure 17).

4. CONCLUSIONS

The relative abundance of emergent paua in PAU 5B and in the Catlins West area of PAU 5D declined significantly between 1993–94 and 2000–01. In PAU 5B, both the raw counts and the standardised indices have increased from lows in the late 1990s, but not significantly so. The increase in PAU 5B was most evident on the western coastline (Area 030), and to a lesser extent on the north eastern coastline (Area 025). On the southeast coast, the mean estimates of relative abundance are similar to those in 1995–96. The estimates of relative abundance in PAU 5D were imprecise and, overall, there was no statistically significant decline in relative abundance. However, there was significant decline in the Catlins West area, but not in Catlins East. In addition to the decline in relative abundance, the proportion of paua in large patches (over 20 paua) declined in PAU 5B and PAU 5D over the same period, as did the number of paua in those large patches. The aggregation structure in paua may be interpreted as an indication of the relative probability of fertilisation success (see Andrew et al. 2000a).

The length frequency distributions of paua in PAU 5B were estimated only for a few years and, for some, the sample sizes were too small to provide reliable estimates of the length-distributions. The length-distributions in 2000–01 indicate increasing recruitment to the fishery. Similarly, in PAU 5D, there is a much greater proportion of paua beneath the MLS in 2000–01 than there was in the 1990s.

The information summarised here, along with growth information (Naylor & Andrew 2002) and fishery-derived data, was used as inputs to the assessments of PAU 5B and PAU 5D (Breen et al. 2002a, 2002b).

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: Summary of timed-swim surveys completed within PAU 5B. Strata are defined in Figure 2. – indicates no sampling done.

Year	Stratum	Statistical Area	Replication
1993–94	East Cape	25	18
	Ruggedy	25	–
	Lords	27	12
	Pegasus	27	16
	Codfish	30	22
	Waituna	30	36
1994–95	East Cape	25	8
	Ruggedy	25	8
	Lords	27	8
	Pegasus	27	6
	Codfish	30	7
	Waituna	30	14
1995–96	East Cape	25	20
	Ruggedy	25	34
	Lords	27	10
	Pegasus	27	–
	Codfish	30	–
	Waituna	30	–
1997–98	East Cape	25	36
	Ruggedy	25	36
	Lords	27	40
	Pegasus	27	40
	Codfish	30	14
	Waituna	30	14
2000–01	East Cape	25	30
	Ruggedy	25	30
	Lords	27	30
	Pegasus	27	30
	Codfish	30	14
	Waituna	30	30

Table 3: Summary of surveys completed within Statistical Area 026 in PAU 5D. Strata are as defined in Figure 2. – indicates no sampling done.

Year	Stratum	Replication
1993–94	Catlins East	20
	Catlins West	20
1996-97	Catlins East	–
	Catlins West	20
1998–99	Catlins East	30
	Catlins West	30
2000–01	Catlins East	20
	Catlins West	30

Table 4: Unstandardised and standardised indices of relative abundance of paua in PAU 5B and PAU 5D.

Fishing year	Standardised index	Standard error	Unstandardised abundance	Standardised abundance
PAU 5B				
1993–94	2.75	0.32	49.58	74.25
1994–95	0.93	0.21	25.92	25.02
1995–96	0.33	0.28	25.14	8.84
1997–98	0.83	0.22	16.58	22.41
2000–01	1.43	0.21	26.55	38.66
PAU 5D				
1993–94	1.24	0.23	44.36	42.30
1996–97	1.11	0.35	48.93	38.02
1998–99	0.93	0.27	25.51	31.83
2000–01	0.78	0.25	24.77	26.79

Table 5: Order of fit and model R^2 for the base case and sensitivity tests for PAU 5B and PAU 5D. – indicates variable improved fit by <1% and was excluded.

	PAU 5B		PAU 5D		
	Basecase	Sensitivity	Basecase	Sensitivity 1	Sensitivity 2
Fishing year	0.069	0.061	0.039	0.004	0.004
Month	0.142	0.134	-	-	-
Stratum	0.178	0.175	-	-	-
Diver	0.195	0.187	0.123	0.037	0.033

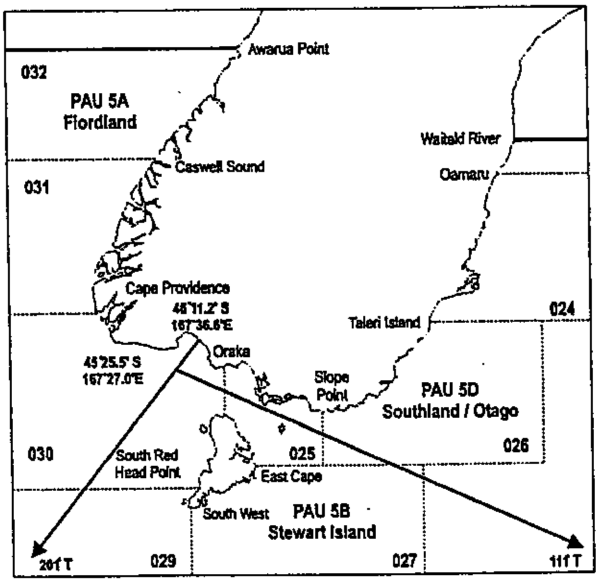

Figure 1: Map showing the boundaries of the new QMAs in the subdivided PAU 5 and Statistical Areas used before 1 October 1997.

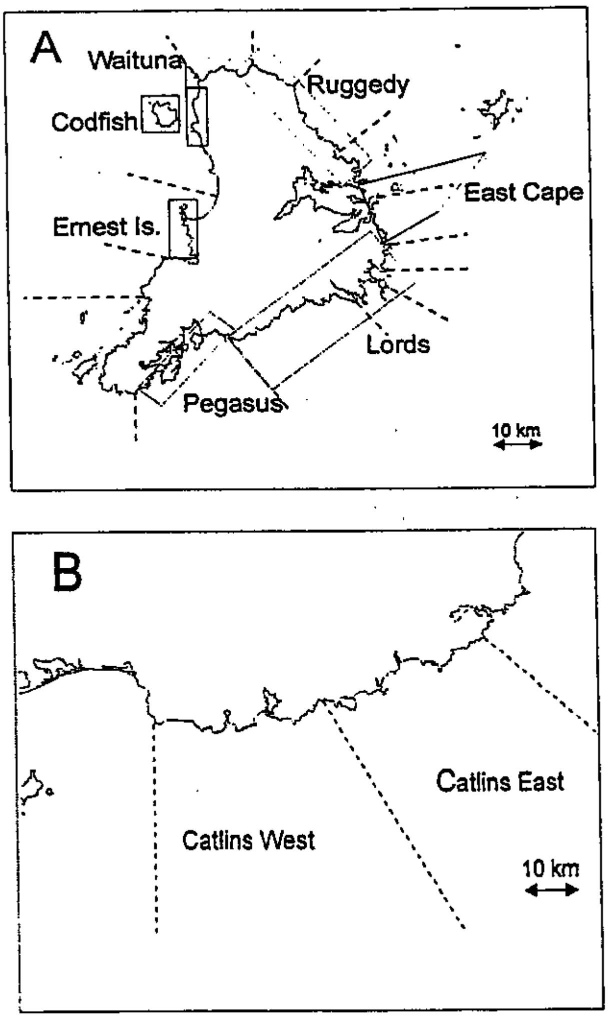

Figure 2: Research strata surveyed in (A) PAU 5B and (B) PAU 5D. In (A) solid lines indicate research strata and dotted lines represent CELR areas introduced from 1 October 1997.

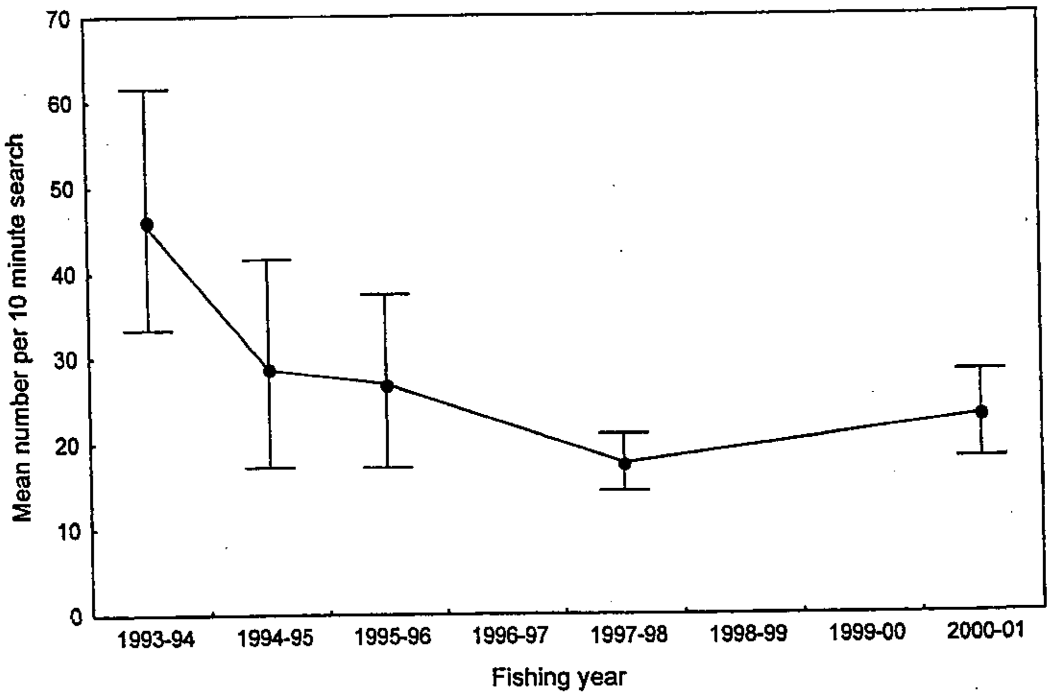

Figure 3: Mean number of paua per 10 minute search in PAU 5B (± 95% bootstrapped confidence intervals).

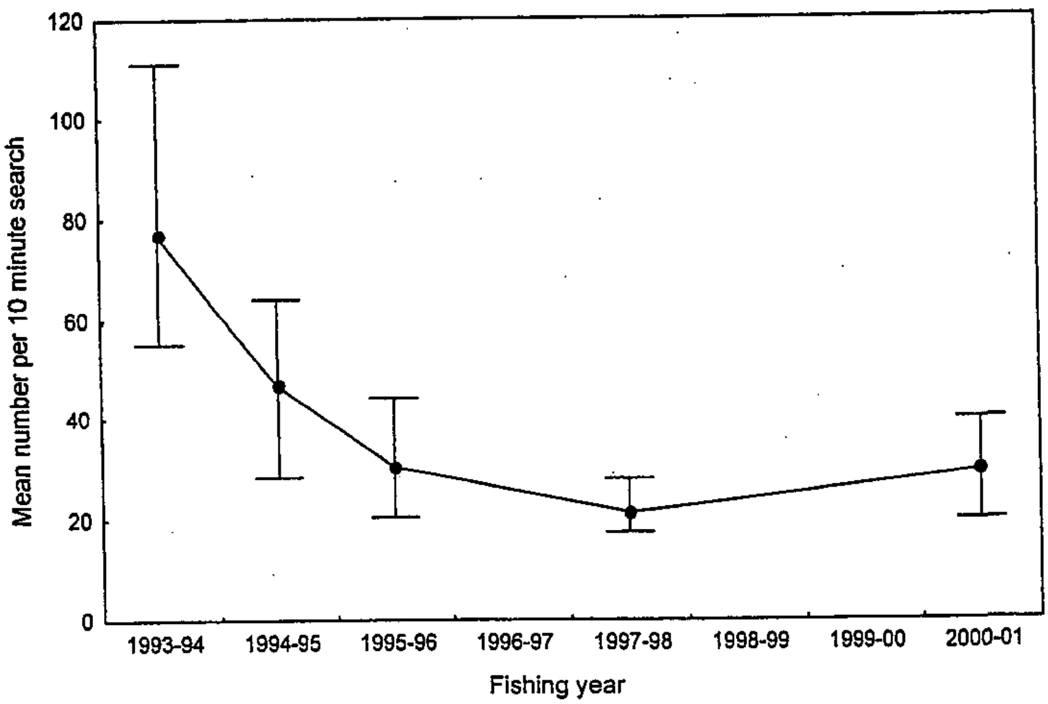

Figure 4: Mean number of paua per 10 minute search in Statistical Area 025 (± 95% bootstrapped confidence intervals) in PAU 5B.

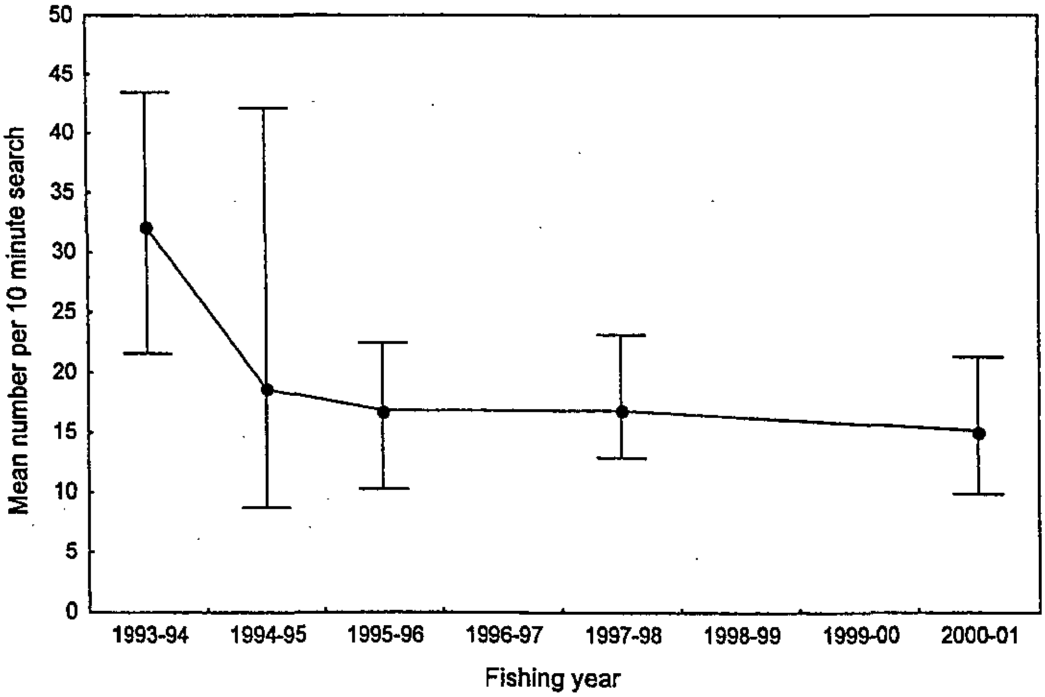

Figure 5: Mean number of paua per 10 minute search in statistical area 027 (± 95% bootstrapped confidence intervals) in PAU 5B.

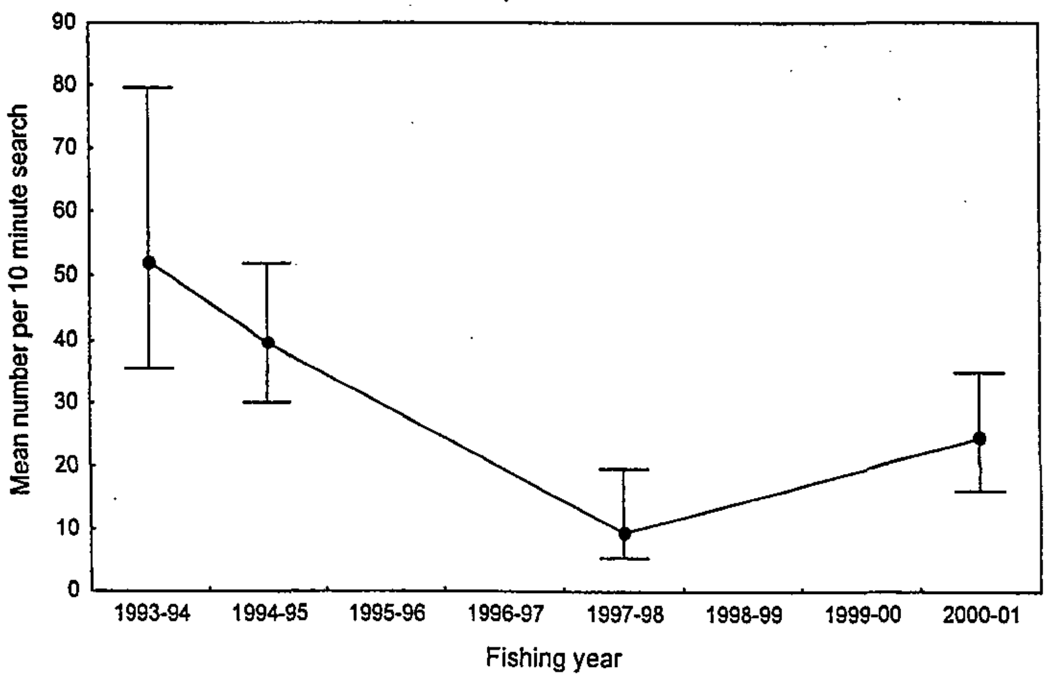

Figure 6: Mean number of paua per 10 minute search in Statistical Area 030 (± 95% bootstrapped confidence intervals) in PAU 5B.

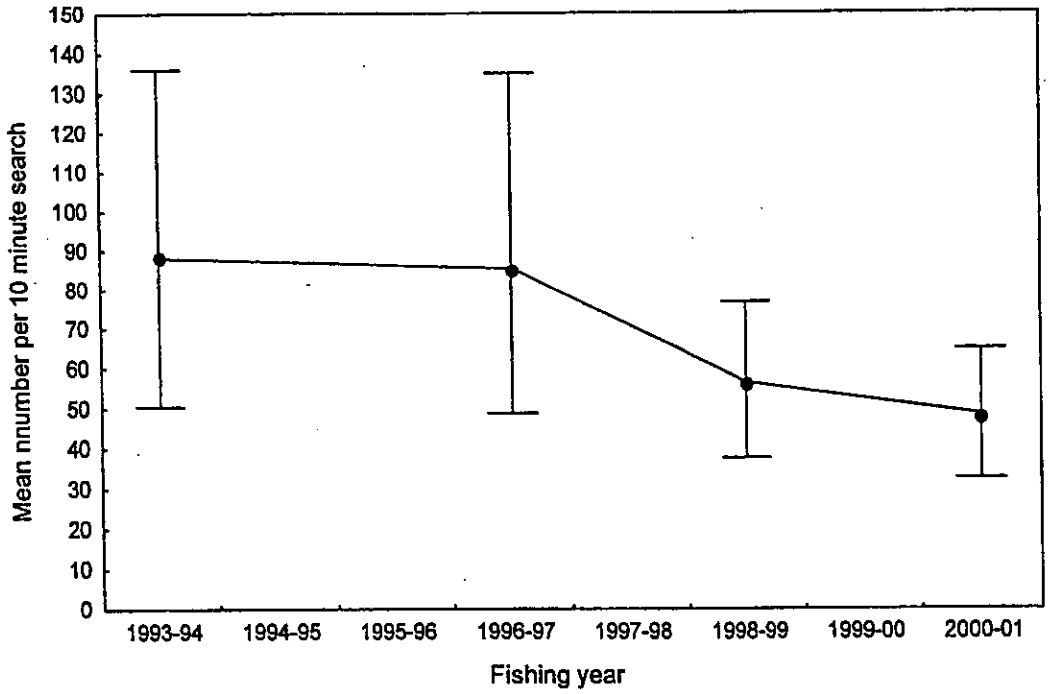

Figure 7: Mean number of paua per 10 minute search (± 95% bootstrapped confidence intervals) in the Catlins (PAU 5D).

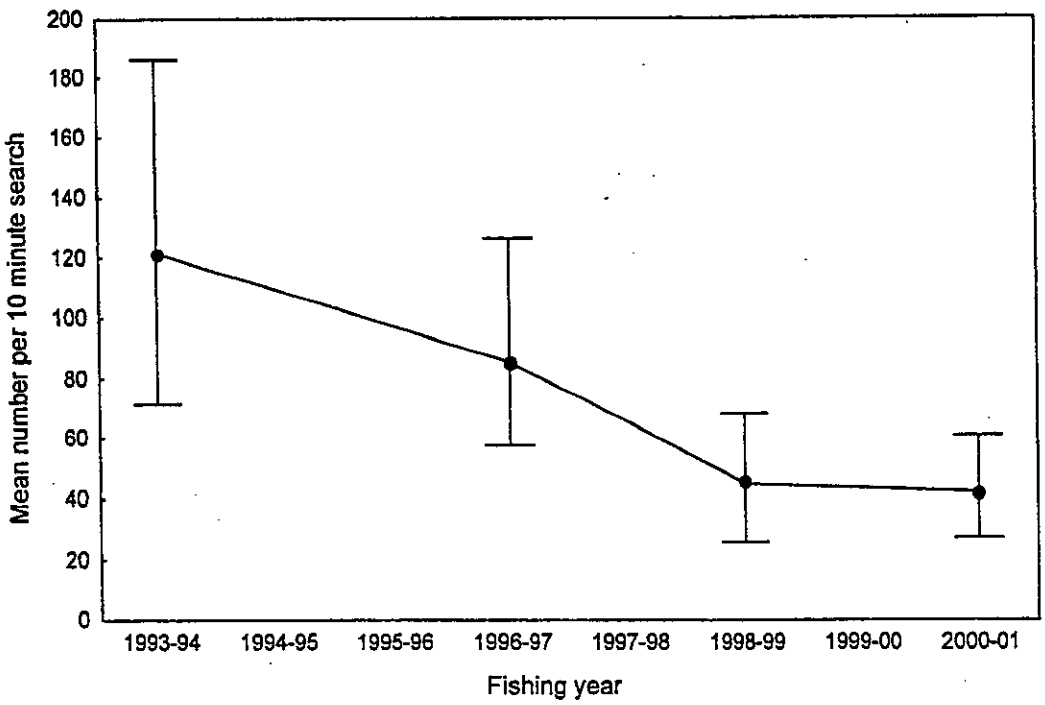

Figure 8: Mean number of paua per 10 minute search in Catlins West in PAU 5D(± 95% bootstrapped confidence intervals).

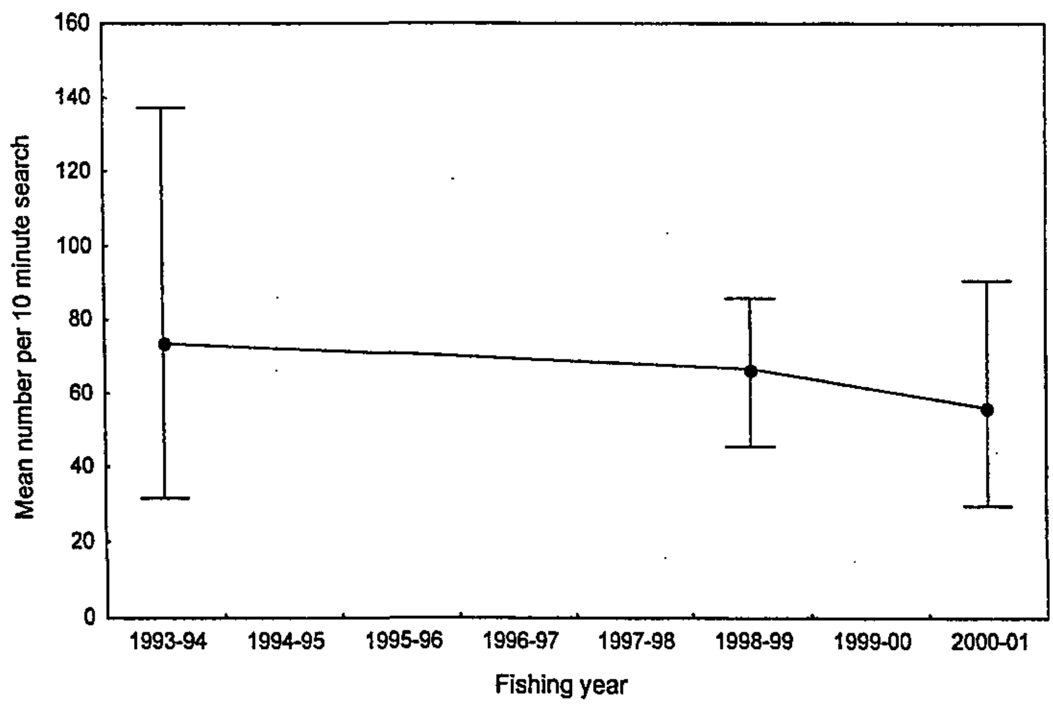

Figure 9: Mean number of paua per 10 minute search in Catlins East in PAU 5D (± 95% bootstrapped confidence intervals).

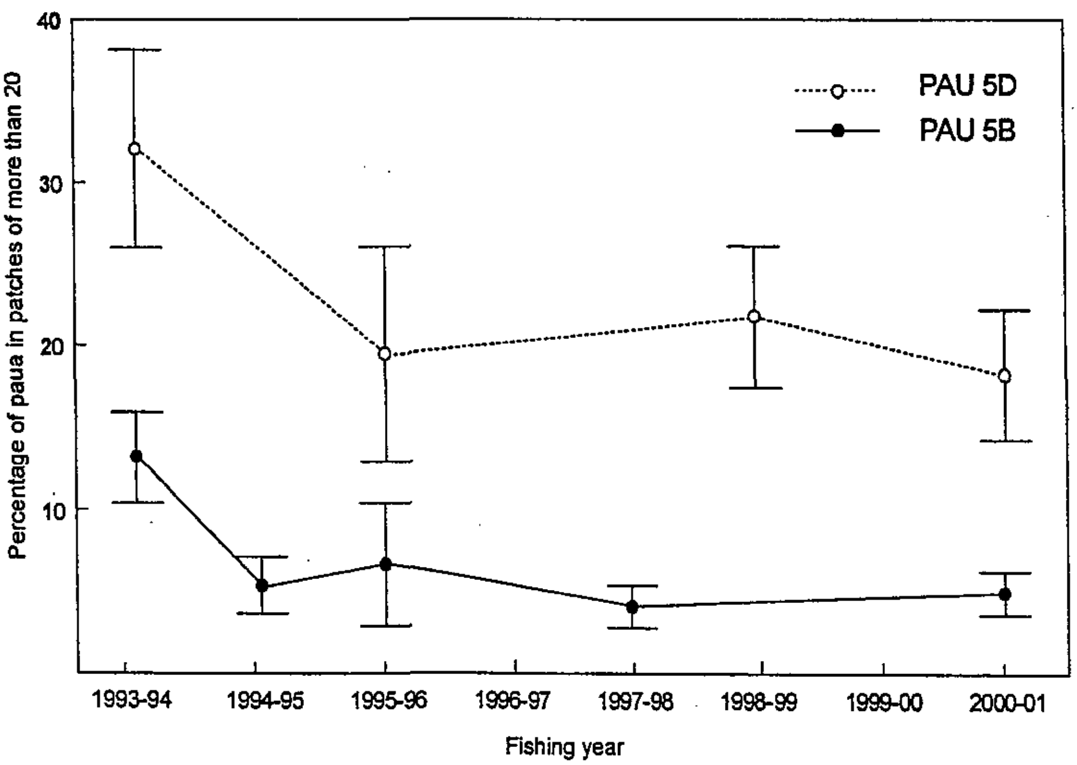

Figure 10: Mean percentage (± SE) of paua occurring in aggregations of more than 20 in sites sampled in PAU 5B and 5D.

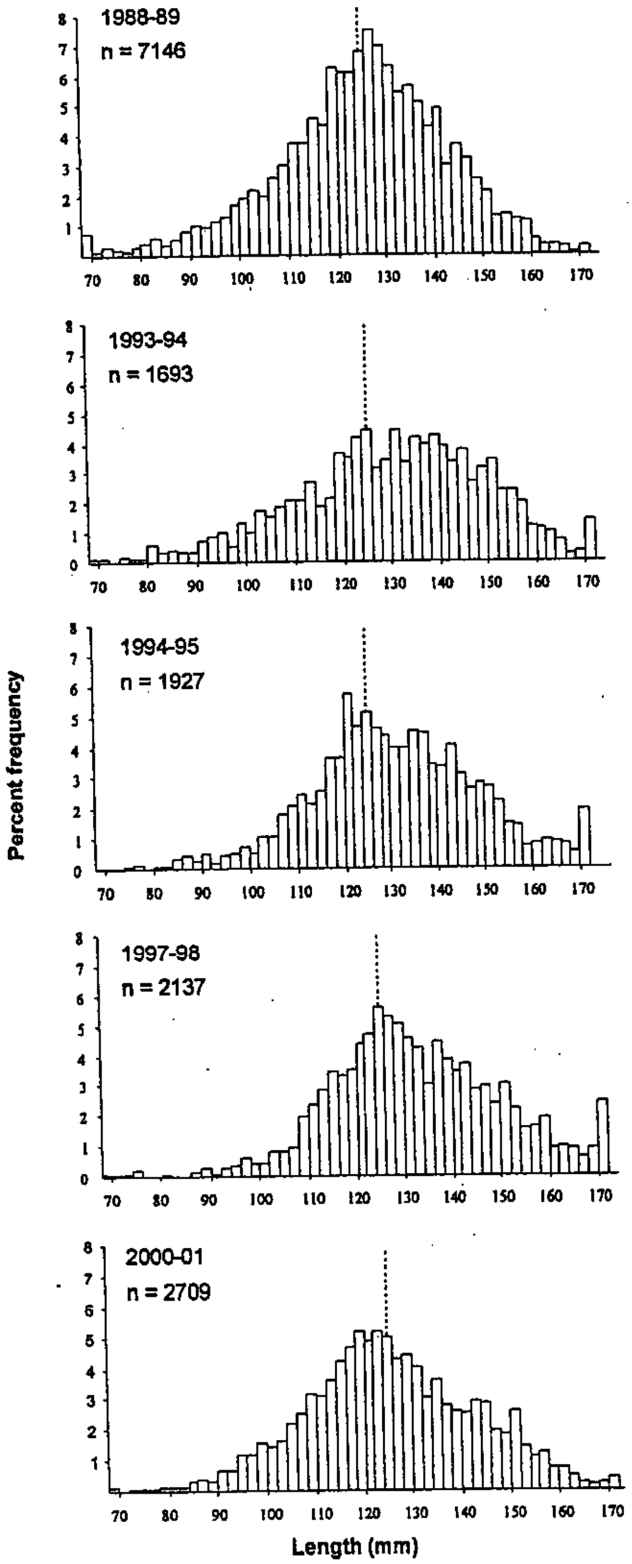

Figure 11: Length frequency distributions of paua sampled from PAU 5B. Minimum legal size of 125 mm is indicated. Paua >170 mm shell length are pooled into a single size class.

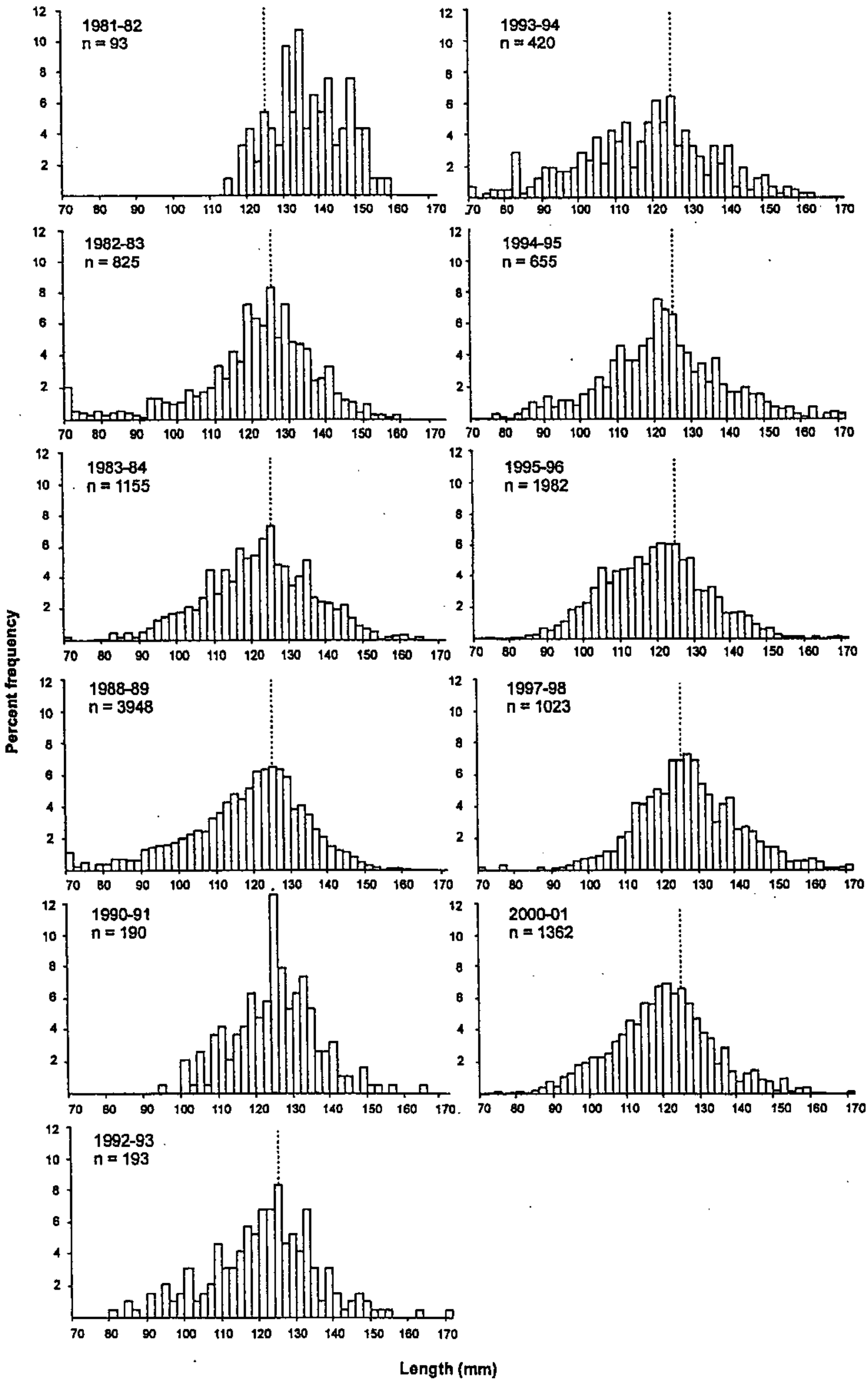

Figure 12: Length frequency distributions of paua sampled from Stewart Island in Area 025. Minimum legal size of 125 mm is indicated.

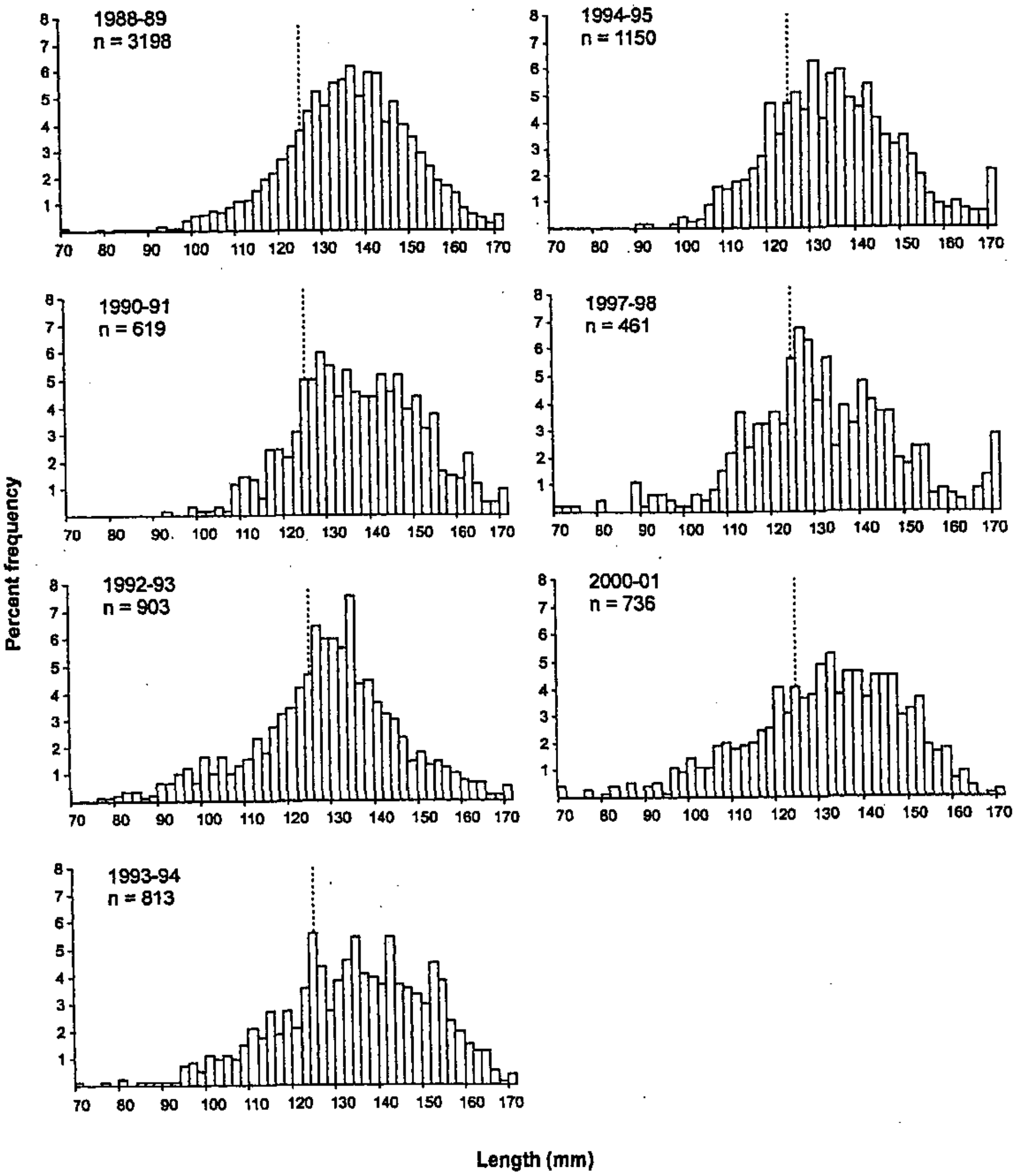

Figure 13: Length frequency distributions of paua sampled from Stewart Island in Areas 029 and 030. Minimum legal size of 125 mm is indicated.

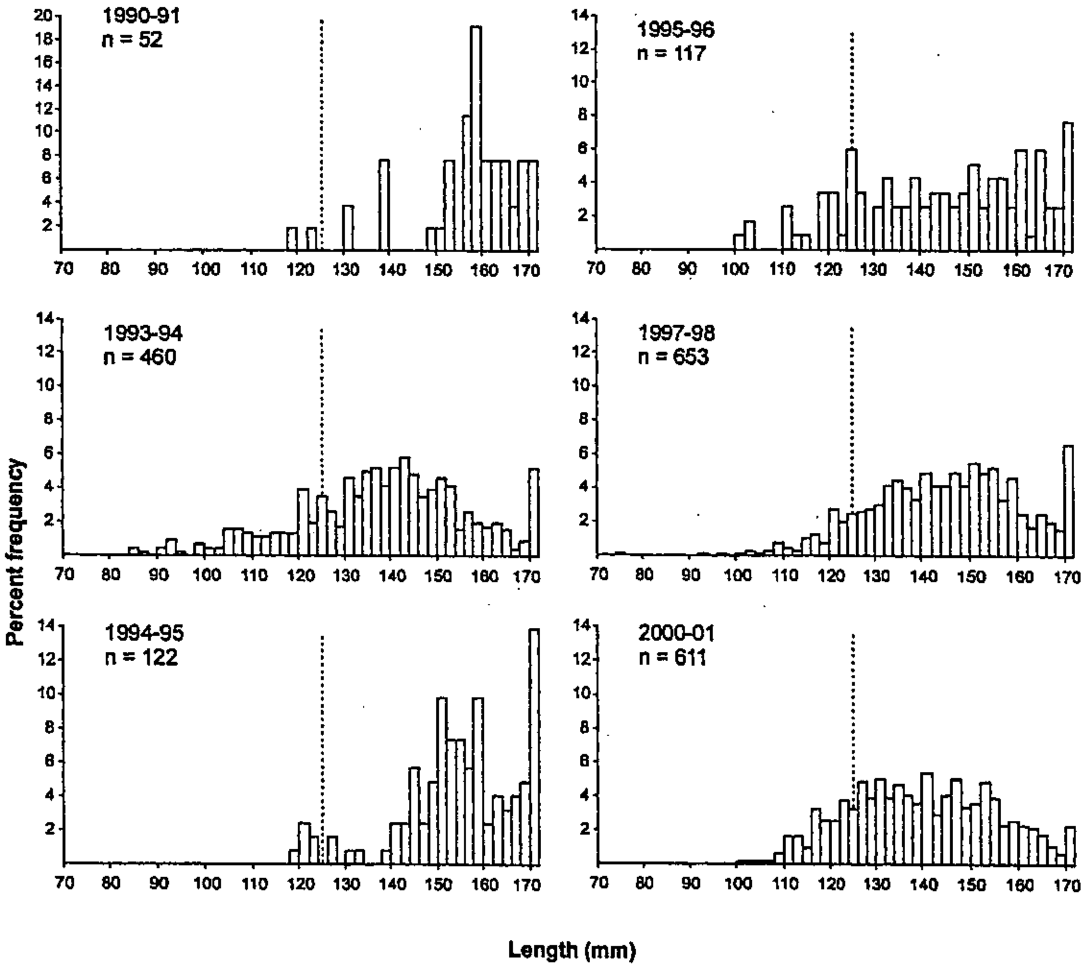

Figure 14: Length frequency distributions of paua sampled from Stewart Island in Area 027. Minimum legal size of 125 mm is indicated.

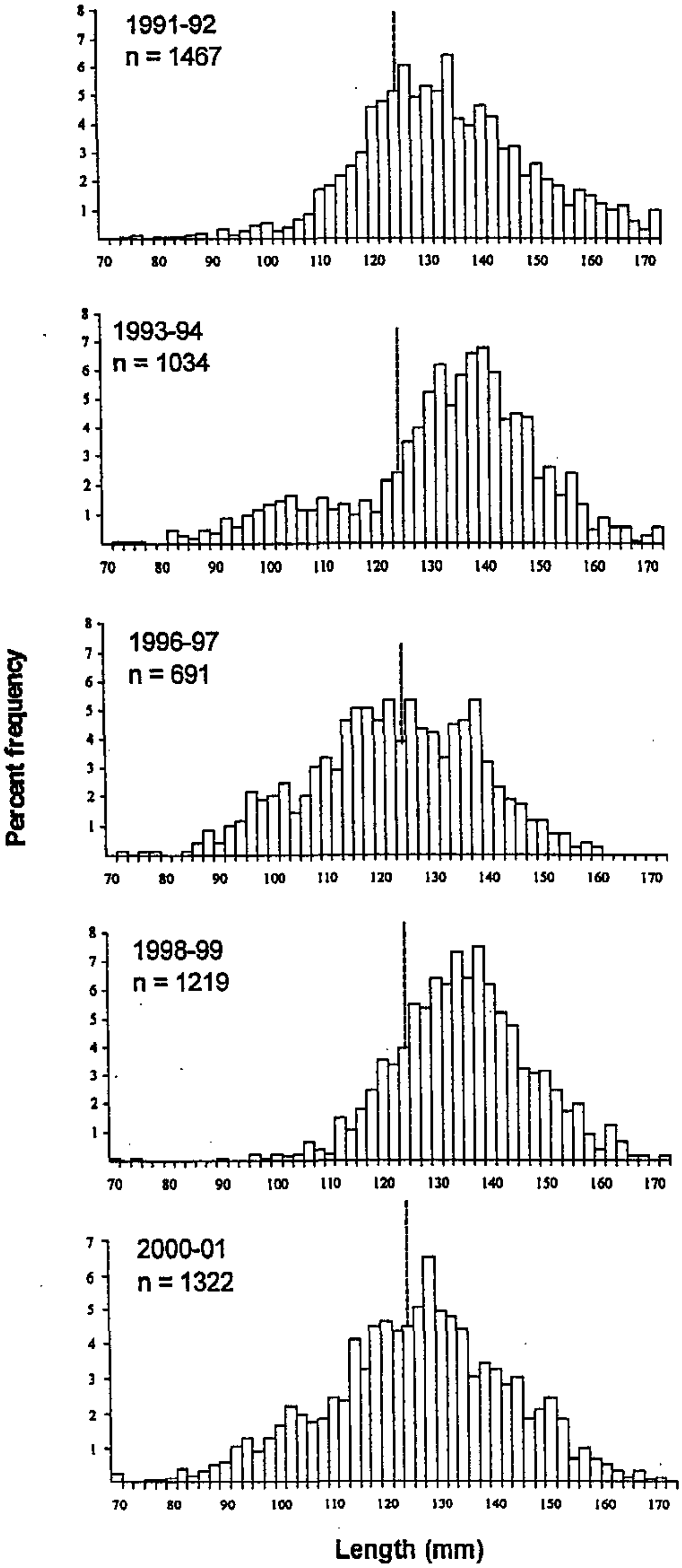

Figure 15: Length frequency distributions of paua sampled from PAU 5D. Minimum legal size of 125 mm is indicated.

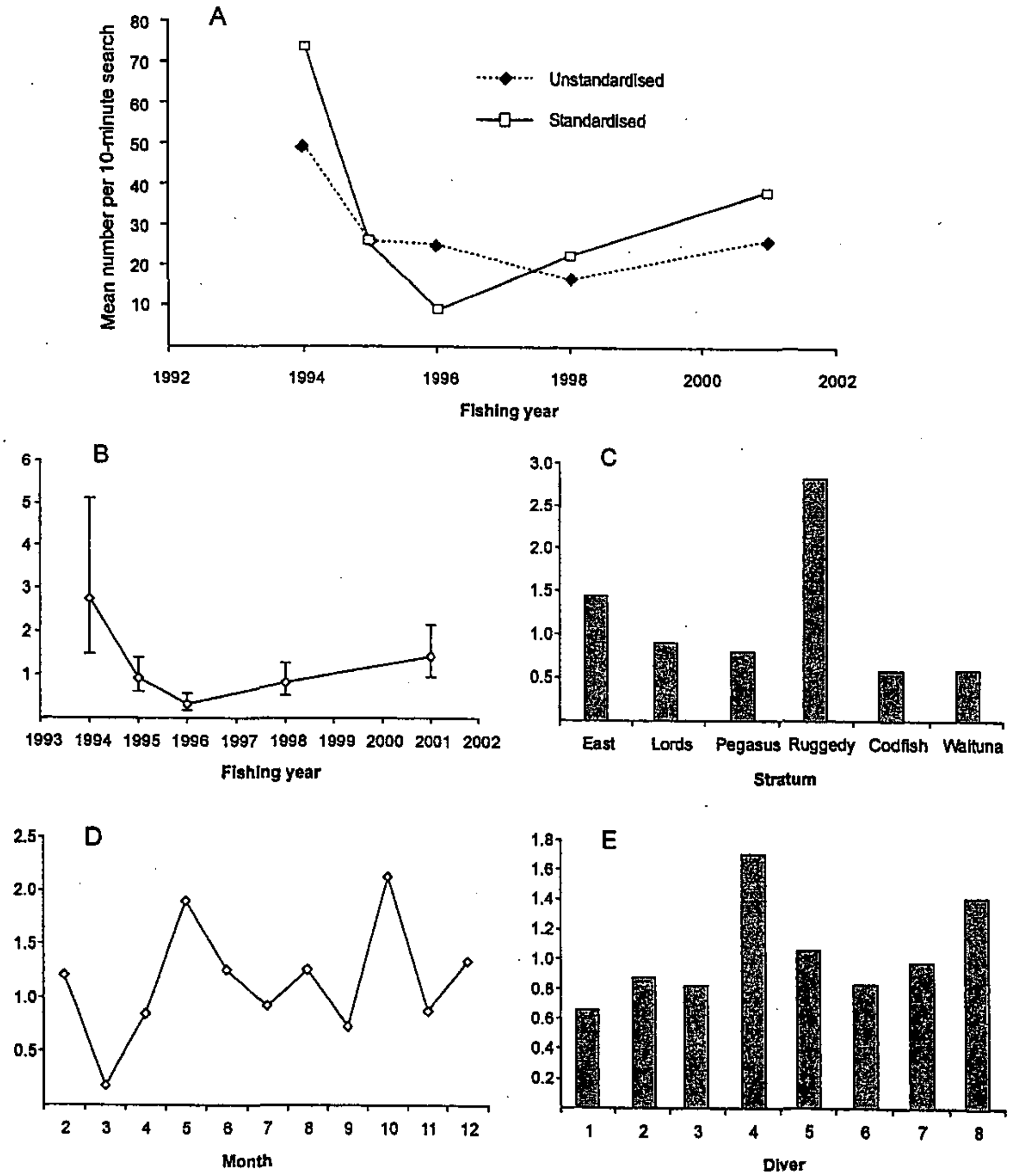

Figure 16: Basecase standardisation of count data from PAU 5B: (A) Standardised vs unstandardised mean counts; (B) Year effects; (C) Stratum effects; (D) Month effects; (E) Diver effects. The error bars in year index are 95% confidence intervals.

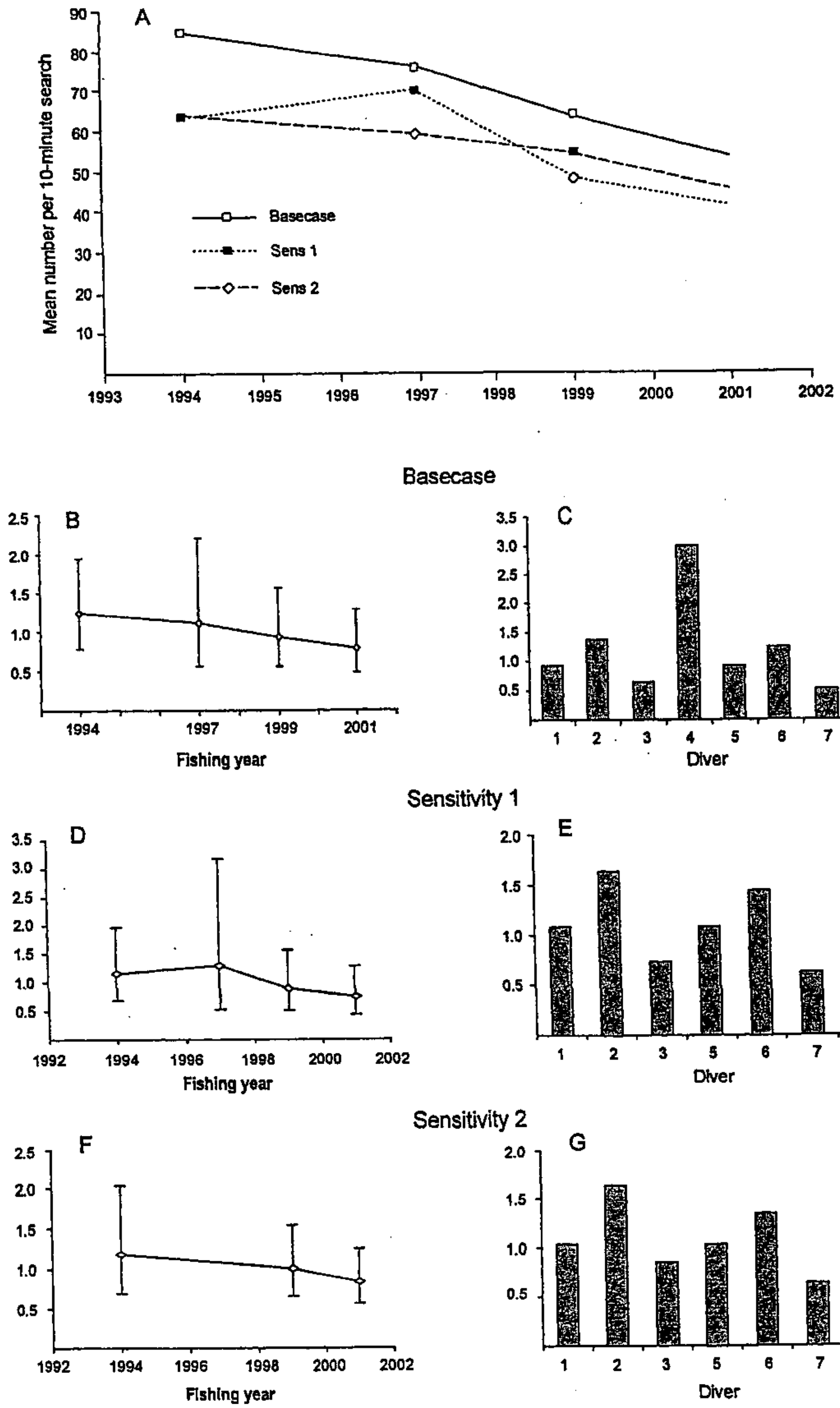

Figure 17: Standardisation of counts in PAU 5D. (A) Comparison of year effect between the base case and two sensitivities; (B) Base case year effects (± 95% confidence intervals); (C) Diver effects; (D) Sensitivity 1 year effects (± 95% confidence intervals); (E) Diver effects; (F) Sensitivity 2 year effects (± 95% confidence intervals); (G) Diver effects.

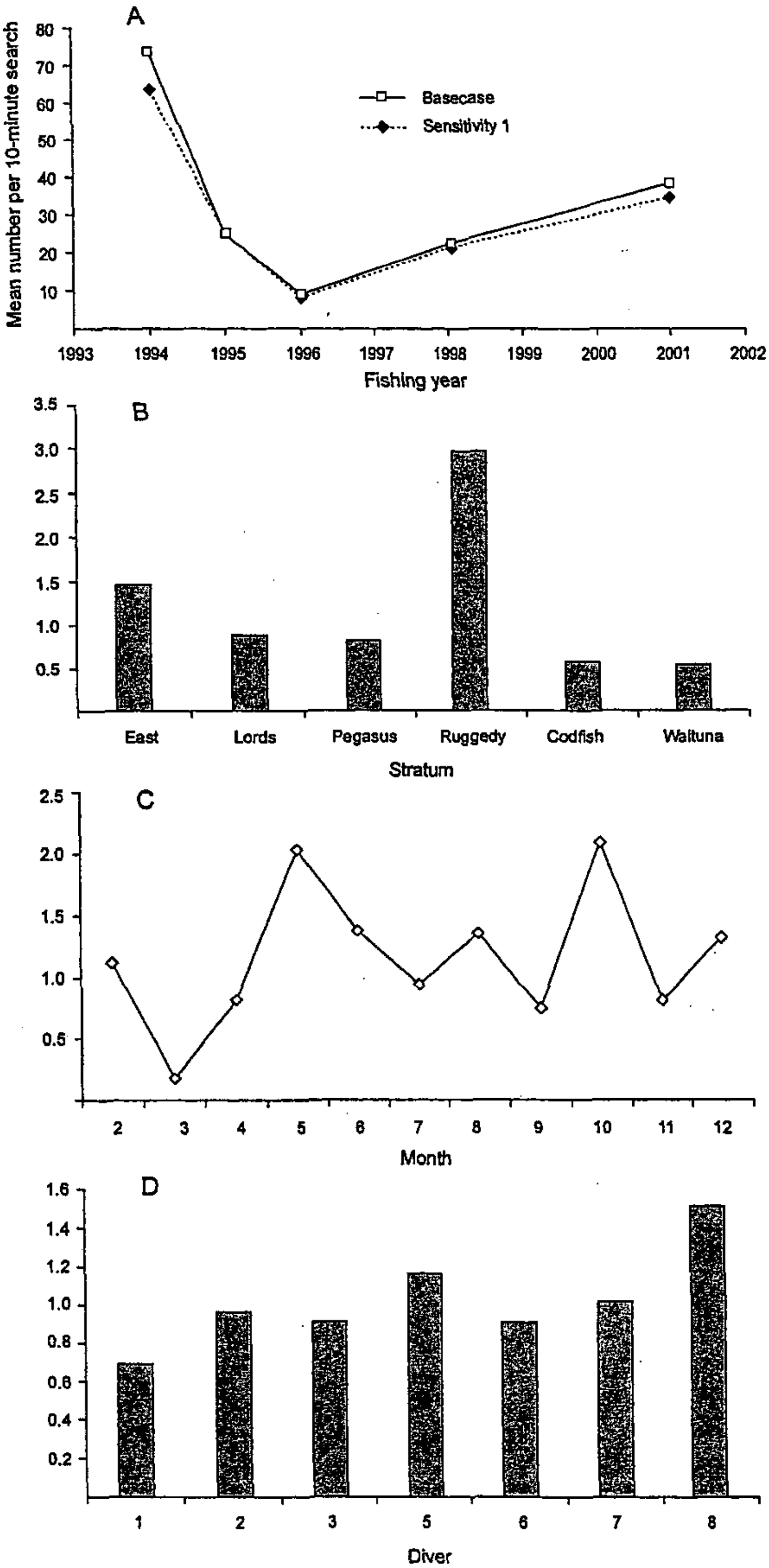

Figure 18: Standardisation of counts in PAU 5B. (A) Comparison of year effect between the base case and sensitivity test; (B) Sensitivity stratum effects; (C) Month effects; (D) Diver effects.