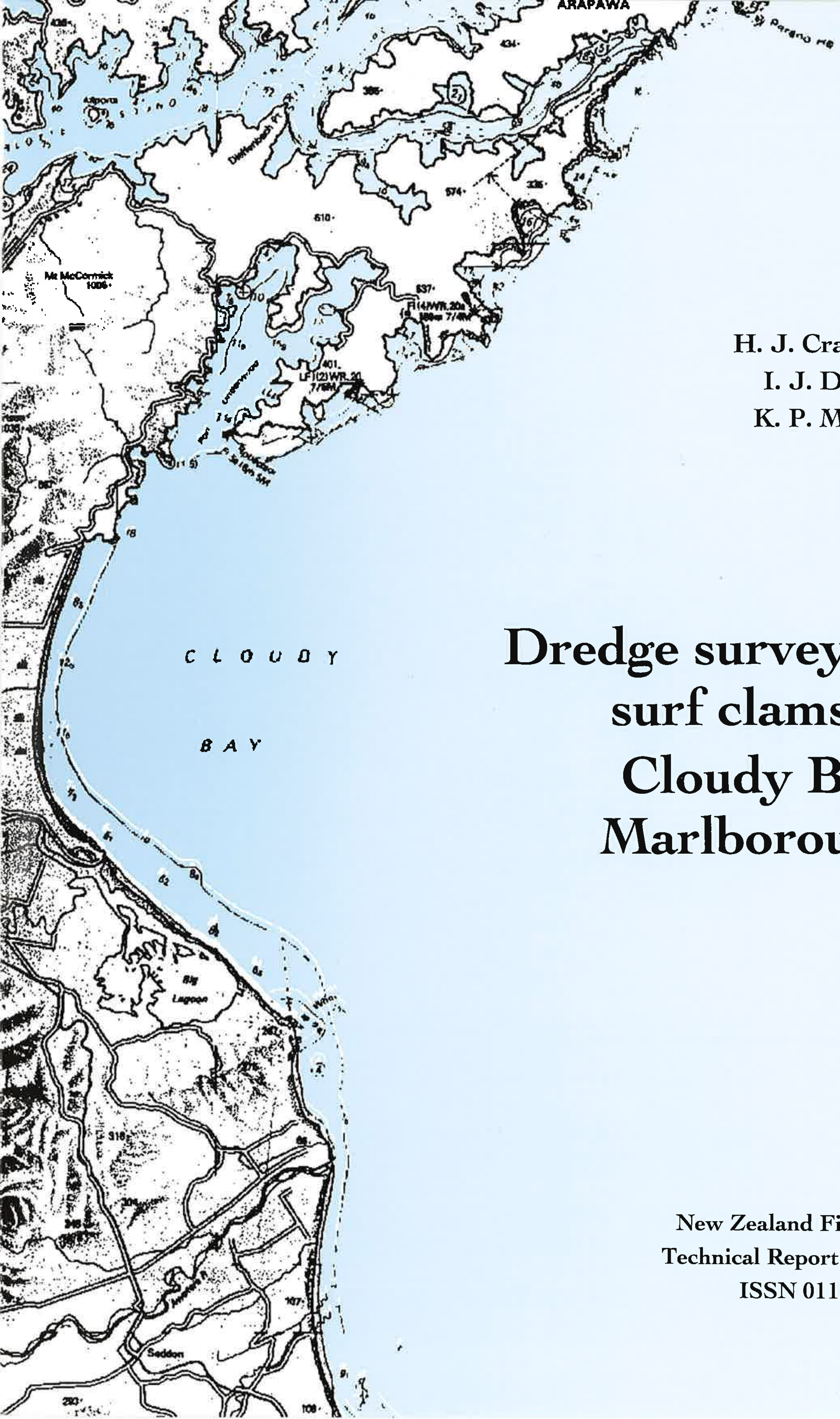

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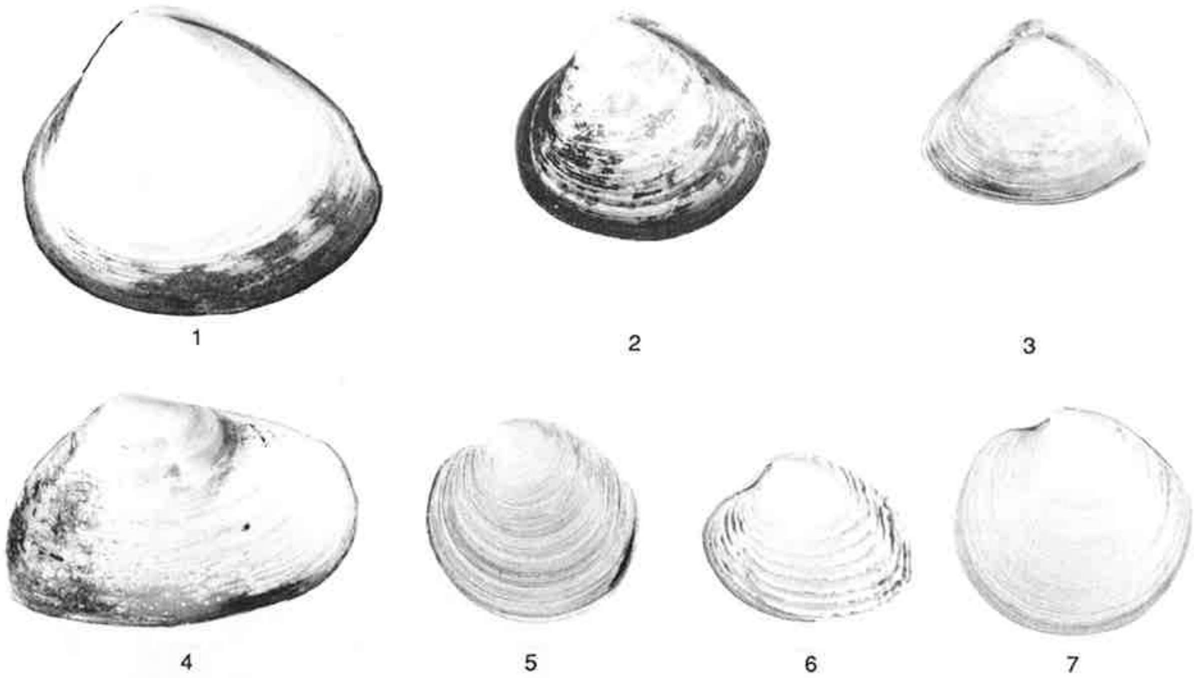


Figure 1: Surf clam species of Cloudy Bay: 1, *Mactra murchisoni*; 2, *M. discors*; 3, *Spisula aequilatera*; 4, *Paphies donacina*; 5, *Dosinia anus*; 6, *Bassina yatei*; 7, *D. subrosea*.

Abstract

Cranfield, H. J., Doonan, I. J., & Michael, K. P. 1994: Dredge survey of surf clams in Cloudy Bay, Marlborough. ***N.Z. Fisheries Technical Report No. 39.*** **18 p.**

Seven species of surf clams (orders Mactracea and Veneracea) are found in the surf zone of exposed sandy beaches in New Zealand. In 1989, the biomass of surf clams in Cloudy Bay was investigated in a stratified random survey using a hydraulic dredge. Dredge efficiency was estimated and its variance incorporated in the estimates of biomass by bootstrapping. This report gives estimates of biomass for the individual species, describes their distribution and population size structure, and discusses the sources of error in biomass estimation by dredge surveys.

The estimated total biomass of surf clams was 725 t (95% confidence interval 445–1386 t). Individual species were abundant over narrow (but different) depth ranges, which will enable fishers to target individual species. The estimated biomass of individual species with distance from the shore was: *Paphies donacina*, 154 t; *Spisula aequilatera*, 53 t; *Mactra murchisoni*, 248 t; *M. discors*, 55 t; *Dosinia anus*, 72 t; *D. subrosea*, 21 t; and *Bassina yatei*, 123 t.

Introduction

Two species of surf clam, *Paphies ventricosum* (toheroa) and *P. subtriangulata* (tuatua) are common in the intertidal zone of many exposed sandy beaches around New Zealand. They have been handgathered by traditional and recreational fishers since the arrival of Maori and Europeans in New Zealand. Seven other species of surf clam are common in the surf zone of many of the same beaches: four, *Mactra murchisoni, M. discors*, *Spisula aequilatera*, and *Paphies donacina*, belong to the order Mactracea, and three, *Dosinia anus*, *D. subrosea*, and *Bassina yatei*, to the order Veneracea (Figure 1). The distribution and abundance of these species was largely unknown until recently when suitable gear became available to fish them. The abundance of subtidal surf clams appears sufficient to support a new commercial fishery (Cranfield *et al.* 1994).

In the mid 1980s, fishers using small vessels and lightweight hydraulic dredges began investigating the fishery potential of surf clams in central New Zealand. One of them studied Cloudy Bay (Cranfield & Michael 1987), and in 1988 contracted MAF Fisheries to estimate the biomass of surf clams there. This report describes the stratified random survey which was carried out in January 1989 and discusses the chief sources of error in biomass estimation by dredge surveys: variation in dredge efficiency, inaccuracies in measuring the area of each stratum, variation in tow length, and variation between samples. The report provides biomass estimates for the seven subtidal species and describes their distribution and population size structure.

Survey area and methods

Cloudy Bay is a northeast facing bay on the east coast of the South Island (Figure 2). The 11 km of sandy beach between the Wairau River mouth and Rarangi was surveyed: the beach south of the Wairau River consisted of boulders and cobbles and could not be dredged.

The foreshore beach is steep (1 in 8 to 1 in 13) and the sediments are mixed sand and gravel with much coarse sand and cobble (Pickrill 1977). Offshore, at depths of 1–2 m, the beach changes in gradient to between 1 in 60 and 1 in 100 and the sediments become predominantly fine, well-sorted sand with some silt beyond 6–7 m depth (authors' data).

Survey design

A stratified random survey design was used to reduce the variance of the biomass estimate. The stratification took into account known variations in surf clam distribution. Individual species are abundant over narrow (but different) depth ranges (Cranfield & Michael 1987, Cranfield *et al.* 1994), so sampling was stratified by depth. The beach was stratified in 1 m depth contours from 1 m below chart datum to 7 m (all depths in this report are corrected for state of the tide to depth below chart datum). The distribution of surf clams varies with wave climate and freshwater input, and, as these varied systematically, the survey area was stratified into three blocks (*see* Figure 2) to minimise variance from these factors.

The depth profile of the subtidal beach was surveyed in nine transects over the survey area (transects 1–9, Figure 2). A coincident optical rangefinder (Wild TM2) was used to measure the distance of each 1 m contour from the shore. This instrument could measure distances between 80 and 5000 m (± 2 m at 300 m and ± 15 m at 1000 m). Distances below 80 m were judged by eye. The area between every contour in each block was estimated by summing the area of consecutive quadrilaterals formed from the intersection of the transects and depth contours.

Each stratum (block × depth) was subdivided into 10 equal sections along the beach to give 180 quadrilaterals with a total sampling area of 6.05 km^2. Four quadrilaterals in each depth stratum of each block were randomly selected (with replacement) for sampling. Tows began at the midpoint of each quadrilateral with the vessel towing the dredge parallel to the shore.

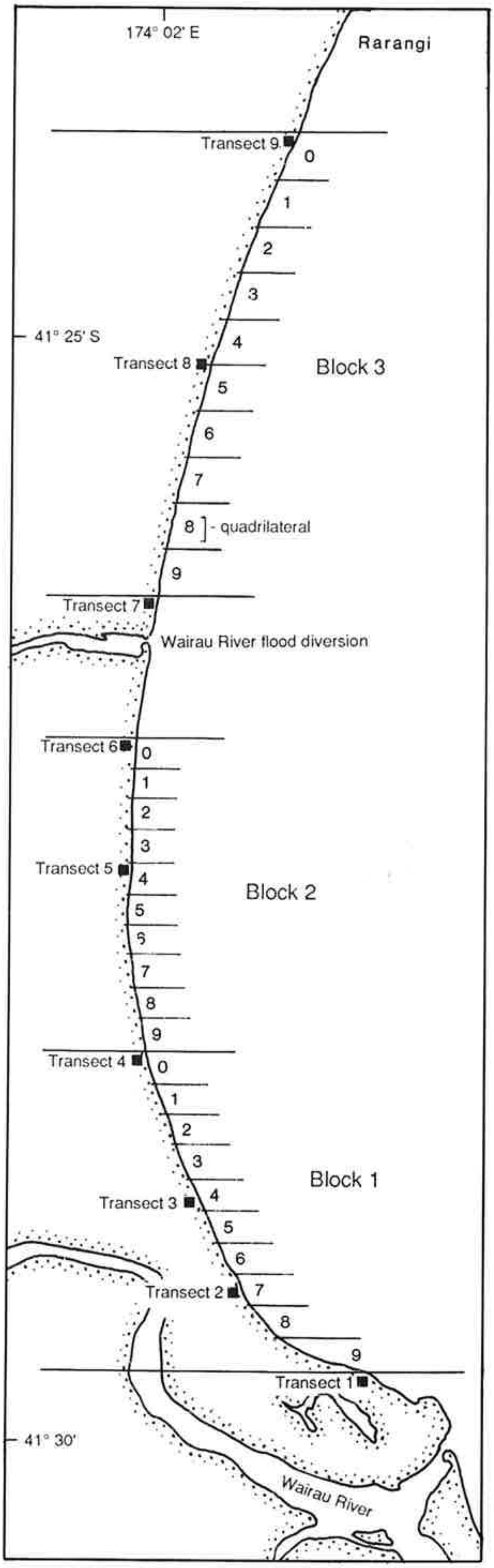


Figure 2: Cloudy Bay showing the survey area, blocks, and the nine transects at which the distances between depth boundaries were measured.

Sampling

The hydraulic dredge used was similar to the Rabbit dredge described by Michael *et al.* (1990). It was 0.8 m wide and weighed 100 kg. The digging jet manifold, located 100 mm ahead of and 150 mm above the bit, had 24 jets each 4 mm in diameter (Veejet model no. H¼U-SS2540) which directed fans of water 35 ° from vertical into the sea bed just ahead of the bit. Another 10 jets of the same diameter directed fans of water from a manifold on to the filtration grill as a wash-back jet. The bars on the filtration grill were 12 mm apart and retained most shellfish over 20 mm long (the greatest distance along the anterior-posterior axis). A hydraulically powered centrifugal pump delivered water to the dredge through a 23 m length of 100 mm diameter fire hose. Water pressure was maintained at 280–300 kPa to give flow rates of 400 $l.min^{-1}$ into the substrate and 150 $l.min^{-1}$ through the wash-back jets.

MAF Fisheries' research vessel *Rangatahi* (a 10 m aluminium catamaran) was anchored upwind of the sampling position and 150 m of wire anchor cable was paid out as the vessel backed down to the sample station, keeping within the correct depth stratum. The dredge was dropped off the stern of the vessel and the vessel winched forward on the anchor cable. When the tow warp of the dredge and the water hose were fully paid out, the water pump was turned on and the tow started (*see* Michael *et al.* 1990). Winching speed was maintained at 6 $m.min^{-1}$ (Michael *et al.* 1990) by timing the retrieval of the marked cable. Tow length was controlled by retrieving precisely 50 m of cable. Each tow sampled 40 m^2 of the sea floor and the 72 tows sampled 2880 m^2 (0.05% of the beach).

Dredge efficiency

Dredge efficiency was assessed by comparing the catches from replicate tows in an area where mean densities of surf clams had been established by a diver-operated airlift sampler (Appendix 1). This calibration required moderately clear water (0.5–1.0 m visibility) and no swell. As these conditions did not occur during sampling in Cloudy Bay, the calibration was done at a similar beach in Clifford Bay (Marfells Beach), 20 km to the south and outside the influence of the muddy plume of the Wairau River.

Data collection

Surf clams were identified to species and the total weight of each determined to 0.01 kg in every tow. The lengths of individual clams were measured with vernier callipers to the nearest millimetre down.

Biomass estimation

Biomass was estimated from the usual formula for stratified random sampling (Snedecor & Cochran 1980, pp. 444–445). For the variance estimate, a bootstrap method was used to include the variability in both dredge efficiency and catch in the variance of the biomass. Estimates of biomass variance usually ignore the variance of the dredge efficiency because of computational difficulties; in this study the variance of the dredge efficiency was large and could not be ignored.

There were three steps in the bootstrap process. First, the data from the dredge efficiency experiment were resampled and dredge efficiency was re-estimated. Then for each resampling of the dredge efficiency we simulated a relative biomass from its sample distribution and then divided it by the bootstrapped dredge efficiency to estimate the absolute biomass. This bootstrap was repeated 1000 times.

Let x_{ij} be the weight of a species in dredge tow j in stratum i. The value of j runs from 1 to 4 and of i from 1 to 18 (three blocks multiplied by six depth strata). The estimate for total biomass of all species, x_{ij}, is given by

$$\sum_{k}^{n} x_{ijk}$$

where n is the number of species and x_{ijk} is the weight of species k in tow j in stratum i.

Total biomass, B, is given by

$$B = \frac{1}{d} \sum_{i} B_i \; area_i \qquad (1)$$

where $B_i = \bar{x}_i$ /(area of 1 tow) and d is the estimated efficiency of the dredge.

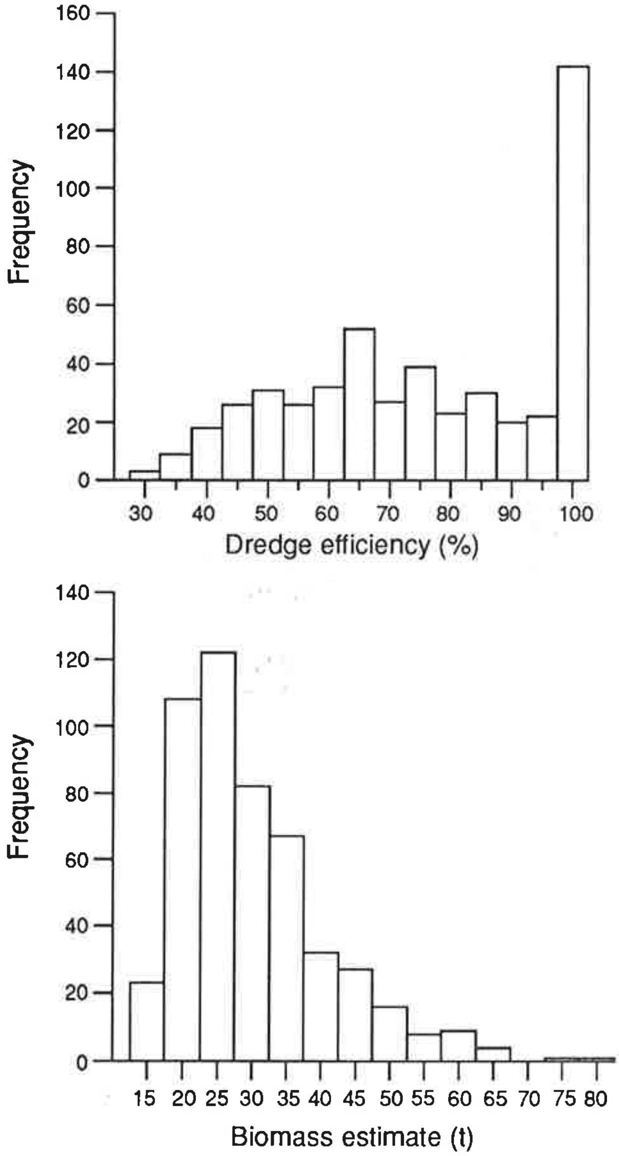
Dredge efficiency, d, was estimated from $\bar{r} / \bar{t}$ where $\bar{r}$ is the mean of r_i, $i = 1, 2 .. 20$, r_i is the number of clams per square metre from the airlift sample i (sampling assumed to be 100% efficient), and $\bar{t}$ is the mean of t_m ($m = 1, 2, 3$) the number of clams per square metre from dredge tow m.

The bootstrap dredge efficiency, b_d, is given by $\bar{br} / \bar{bt}$ where $\bar{br}$ is the mean of 20 random samples drawn with replacement from r_i, and $\bar{bt}$ is the mean of three random samples drawn with replacement from t_i. As a dredge cannot catch more than 100% of the surf clams present, when the value of $\bar{br} / \bar{bt}$ exceeded 1, it was reduced to 1.

To bootstrap the catches from the clam survey, the sample distribution of $\bar{B}$ is assumed to be normal, with mean and variance

$$\frac{1}{d^2} \sum_{i} s_i^2 \; area_i^2 / 4$$

where s_i^2 is the sample variance of the x_{ij} in stratum i. The accuracy of this approximation depends on the sample size (it is better for larger sample sizes) and the skewedness of the distribution of x_{ij}. Bootstrap biomasses, B_b, are drawn randomly from



this distribution. These bootstrap values assume that the dredge efficiency is d, which must be replaced by the bootstrap dredge efficiency, b_d. The bootstrap biomass corrected for dredge efficiency, A_b, is then given by

$$A_b = B_b \frac{d}{b_d}$$

The bootstrap was repeated to give 1000 estimates of total biomass, from which the variance can be calculated. After sorting these estimates, the 95% confidence interval is found by taking the 25th and 975th values.

Figure 3 shows examples of the distributions of A and b_d that result from using this method.

Figure 3: Distribution of bootstrap dredge efficiencies (*above*) and distribution of bootstrap biomasses for *Mactra murchisoni* (*below*).

Results and discussion

Dredge efficiency

Mean dredge efficiency was estimated to be 73%, similar to that estimated for the Rabbit dredge on the Wellington west coast (*see* Michael *et al.* 1990).

Errors in biomass estimation

Apart from variation due to the patchiness of the distribution of surf clams, three main sources of error affect biomass estimates from dredge survey data; variation in dredge efficiency, errors in measuring strata areas, and variation in tow length.

Variation in dredge efficiency is the greatest potential source of error. Efficiency is affected by sea conditions, substrate type, and variability in surf clam density. Variation due to sea condition can be minimised by sampling only in calm seas. Variation due to substrate type can be minimised by reducing the winching speed in muddy substrates or by increasing the water pressure and volume to the dredge.

Precision in determining dredge efficiency requires enough samples to obtain reliable direct estimates of density and sufficient dredge tows. These conditions were not fully met in this study as lack of time and deteriorating weather precluded more extensive sampling. This resulted in a *c.v.* of 35% for the present survey in which the lack of precision of the estimate of dredge efficiency contributed 71%. This imprecision was primarily due to the sparseness of surf clams in Clifford Bay and the small size (0.5 m^2) of the diver-operated airlift sampler used to estimate absolute density. In a similar survey on the Wellington west coast with a slightly wider (1.3 m) Rabbit dredge (*see* Michael *et al.* 1990) and the same number of airlift samples to estimate absolute density of surf clams, the imprecision of the estimated dredge efficiency contributed only 2% to the variance of the estimate of absolute biomass. This higher precision of estimated dredge efficiency was due to the higher and more uniform densities of surf clams compared with Clifford Bay.

The next most important error is in the measurement of strata areas. To calculate strata areas, bathymetric contours defining the boundaries were assumed to follow straight lines between transects. Should this assumption not hold true, the biomass estimate will be biased by the product of the differences in clam density between neighbouring strata multiplied by the errors in the areas of the respective strata. When neighbouring strata have similar densities, this error is insignificant, but if there are major changes in density between neighbouring strata, the error can be large. Later surveys used a differential global positioning system to determine vessel position accurately and survey software to integrate this with depth data, map depth contours, and to calculate the exact area between them (*see* Cranfield *et al.* 1994).

The length of winching warp retrieved during the tow was used as a measure of tow length. This method does not account for any slippage of the anchor, which is not easily measured. In shallow water (less than 5 m), and particularly where standard tow lengths are used, a lead line may be paid out behind the vessel to precisely measure the distance towed (V. Anderlini, Victoria University of Wellington, pers comm.). The differential global positioning system used on subsequent surveys allowed tow length to be determined to within 1 m (Cranfield *et al.* 1994).

Distribution of biomass

Seven species of surf clams, *Paphies donacina*, *Spisula aequilatera*, *Mactra murchisoni*, *M. discors*, *Dosinia anus*, *D. subrosea*, and *Bassina yatei*, were caught. (Station details and the number and weight of each species in each tow are available from the authors.)

The mean biomass estimated for each species from the distribution of simulated biomasses is given in Table 1. The total biomass estimated from the combined catch weights of all species was 725 t (95% confidence limits 455–1386 t).

The highest stratum biomass was in the outer stratum of block 1 (Figure 4), but this was partly

Table 1: Mean biomass (t), standard deviation (*s.d.*), and 95% confidence intervals for each species estimated from the distribution of simulated biomasses

	Mean biomass	*s.d.*	95% confidence interval Lower	Upper
Paphies donacina	154	60	81	304
Spisula aequilatera	53	22	25	109
Mactra murchisoni	248	96	136	506
M. discors	55	28	13	124
Dosinia anus	72	30	33	148
D. subrosea	21	10	6	45
Bassina yatei	123	50	61	255

because it had the largest area (Table 2). The highest biomass of all species combined was in block 1 and the lowest in block 3.

Six species made up most of the biomass. *Mactra murchisoni* was the most abundant species in all three blocks (Figure 5). *Paphies donacina* was the next most abundant species and predominated in the inshore strata, particularly of block 1, appearing more commonly further offshore in block 2 and even further out in block 3. *Bassina yatei* and *Dosinia anus* predominated in the outer strata of block 1, to a lesser extent in block 2, and were not common in block 3.

Table 2: Area (m^2) of depth strata in each block

	Block		
	1	2	3
Stratum (m)			
1	78 000	136 900	89 300
2	195 000	221 400	217 900
3	385 400	214 800	99 000
4	481 200	197 600	483 400
5	722 500	253 500	249 900
6	1 236 500	228 300	559 300
Total	3 098 600	1 252 500	1 698 800
Total area surveyed			6 049 900

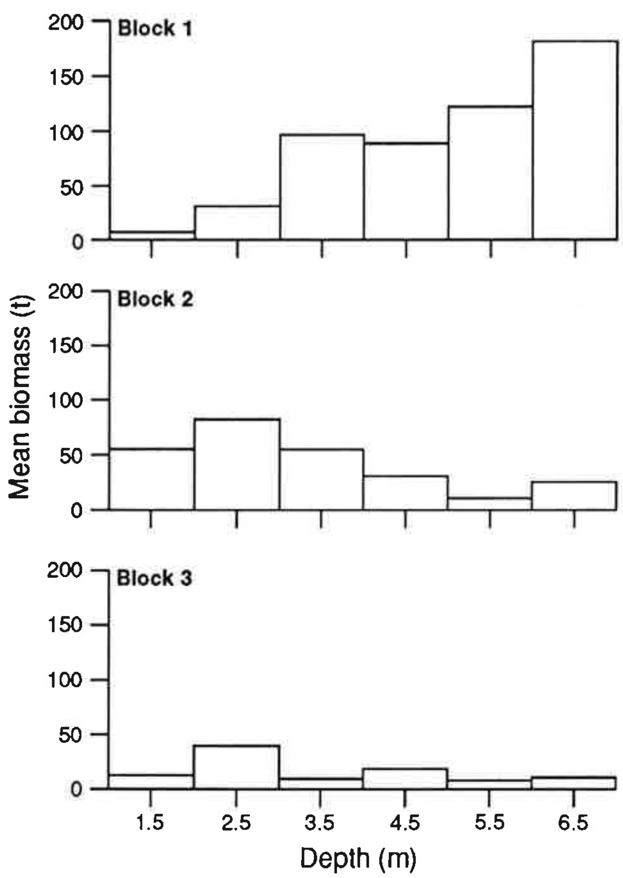


Figure 4: Distribution of mean total biomass (for all species) by depth and block.

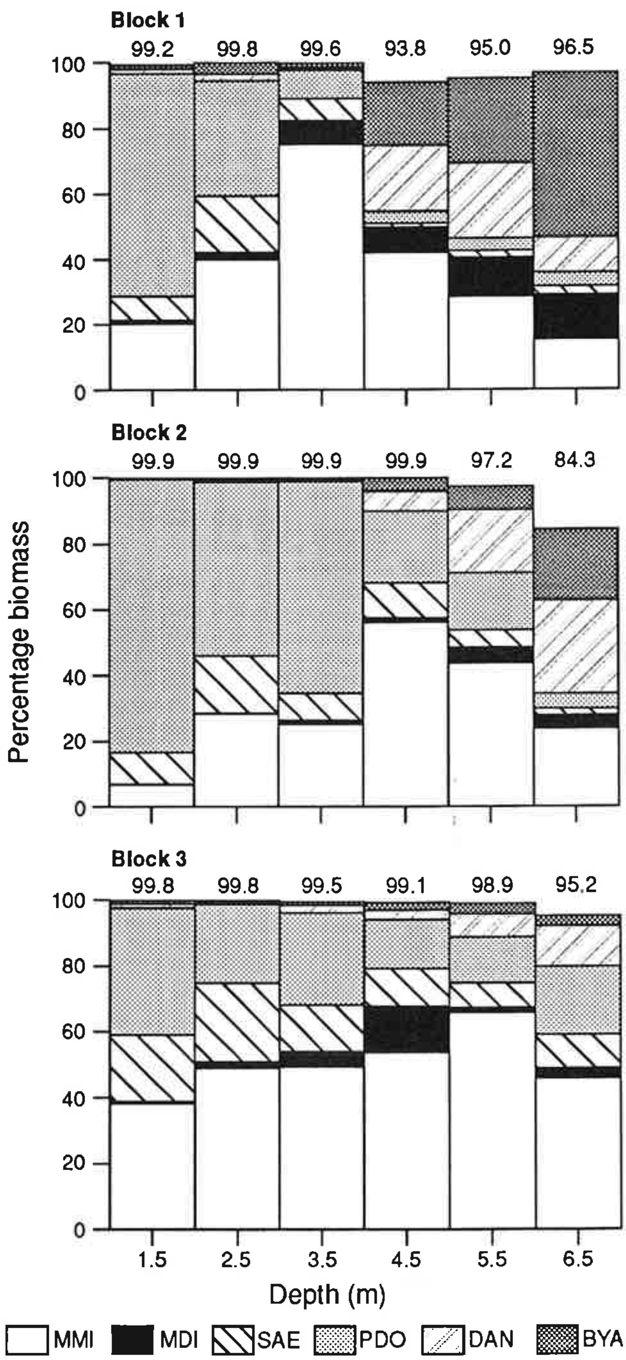


Figure 5: Species composition of each stratum: MMI, *Mactra murchisoni*; MDI, *M. discors*; SAE, *Spisula aequilatera*; PDO, *Paphies donacina*; DAN, *Dosinia anus*; BYA, *Bassina yatei*. Difference between 100 and figure at the head of each column is the percentage of *Dosinia subrosea*.

The mean weight per square metre of each species in each block and depth stratum is shown in Figure 6. Systematic trends along the beach can only be inferred from comparison between blocks as tows were randomised within strata. *Paphies donacina* predominated in the centre of the beach (block 2), whereas *M. discors* was absent from this block. The biomass of the offshore species *D. subrosea*, *D. anus*, and *B. yatei* decreased from south to north (block 1 to block 3); their distribution appeared to become deeper to the north. The subtidal beach profile becomes progressively steeper from south to north and exposure to wave action increases in the same direction. The mean grain size of the predominant sand increased from south to north (authors' data). The silt fraction was highest in the deeper strata of block 1, and lowest in the deepest strata in block 2. Although changes in the distribution of the deeper water species may relate to sediment changes along this gradient, it is difficult to see how they could have influenced the distribution of *P. donacina* and *M. discors*.

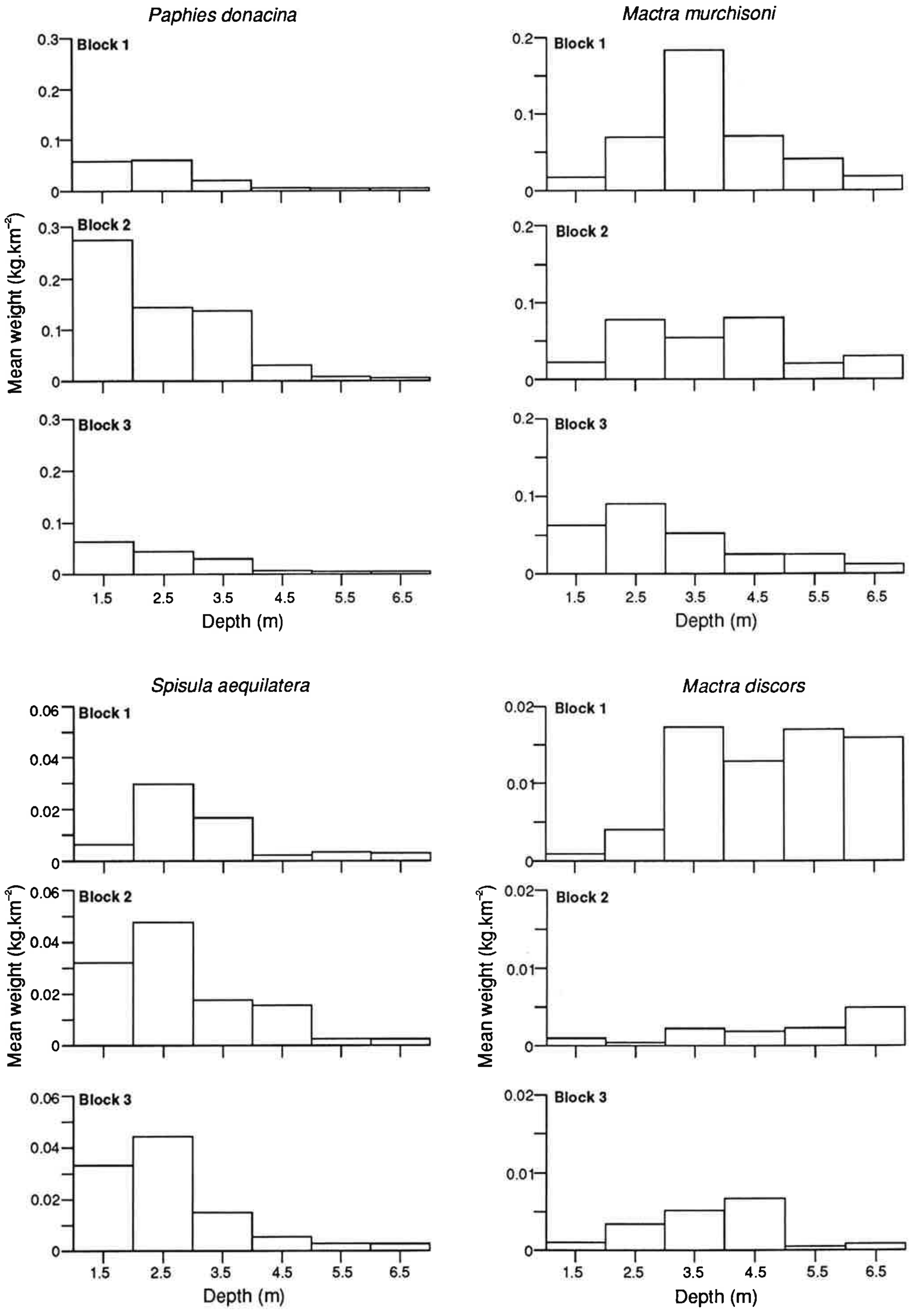
Population size structure

The length frequency distributions of *Paphies donacina*, *Spisula aequilatera*, *Mactra murchisoni*, *M. discors*, *Dosinia anus*, and *Bassina yatei* are shown in Figures 7–12. Only 73 *D. subrosea* were caught, not enough to give a useful length frequency distribution. Juveniles made up less than 10% of the catch of any species. Juveniles of *Spisula aequilatera* and *P. donacina* were caught in the middle to inshore strata and those of *M. murchisoni* mainly in offshore strata. As the dredge retained surf clams 20 mm long, the absence or rarity of clams of this size is a reflection of the true population structure. The length frequencies suggest that recruitment has been low in the last 2 years, particularly in *B. yatei*, *D. anus*, *M. discors*, and *M. murchisoni*. Recruitment of *S. aequilatera* and *P. donacina* has been higher.

Juveniles may have been too small (less than 20 mm) to be taken by the dredge during the sampling in January, but further dredging in Cloudy Bay later that year (by which time the juveniles would have grown much longer than 20 mm) failed to capture significant numbers of them. Clearly, there were few juvenile surf clams in Cloudy Bay in 1989. Large variations in recruitment from year to year have been found in populations of *Spisula aequilatera* (Cranfield *et al.* 1993) and *Mactra discors* and *M. murchisoni* (Conroy *et al.* 1993, Cranfield *et al.* 1993), and may relate to variation between species in spawning and settlement success rather than the variation in juvenile mortality found important in North American populations of *S. solidissima* (*see* Mackenzie *et al.* 1985). The presence of juvenile *Paphies donacina* and *Spisula aequilatera* in the inshore strata suggests that their spat settle inshore and migrate out to the depth zone of the adults later.

Acknowledgments

We thank John Hadfield for running RV *Rangatahi* and assisting in the field work and Bosun Huntley for his assistance and support during the field work and for permission to publish the results. We thank Paul McShane and Martin Cryer for helpful comments on earlier versions of the manuscript.


Paphies donacina
Mactra murchisoni
Spisula aequilatera
Mactra discors
Block 1
Block 2
Block 3
Mean weight (kg.km⁻²)
Depth (m)
1.5
2.5
3.5
4.5
5.5
6.5
0
0.1
0.2
0.3
0.01
0.02
0.04
0.06

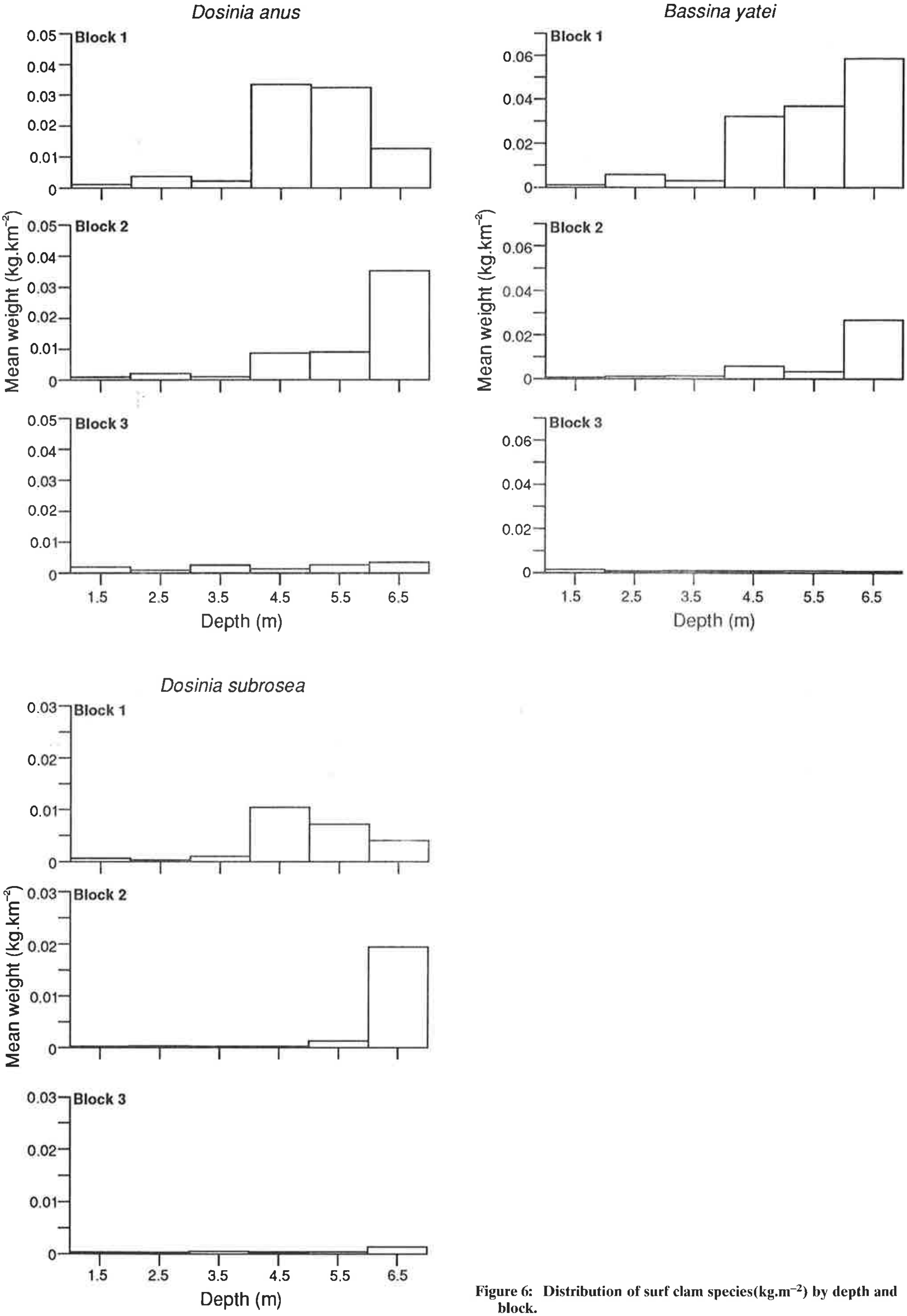


Figure 6: Distribution of surf clam species(kg.m^{-2}) by depth and block.

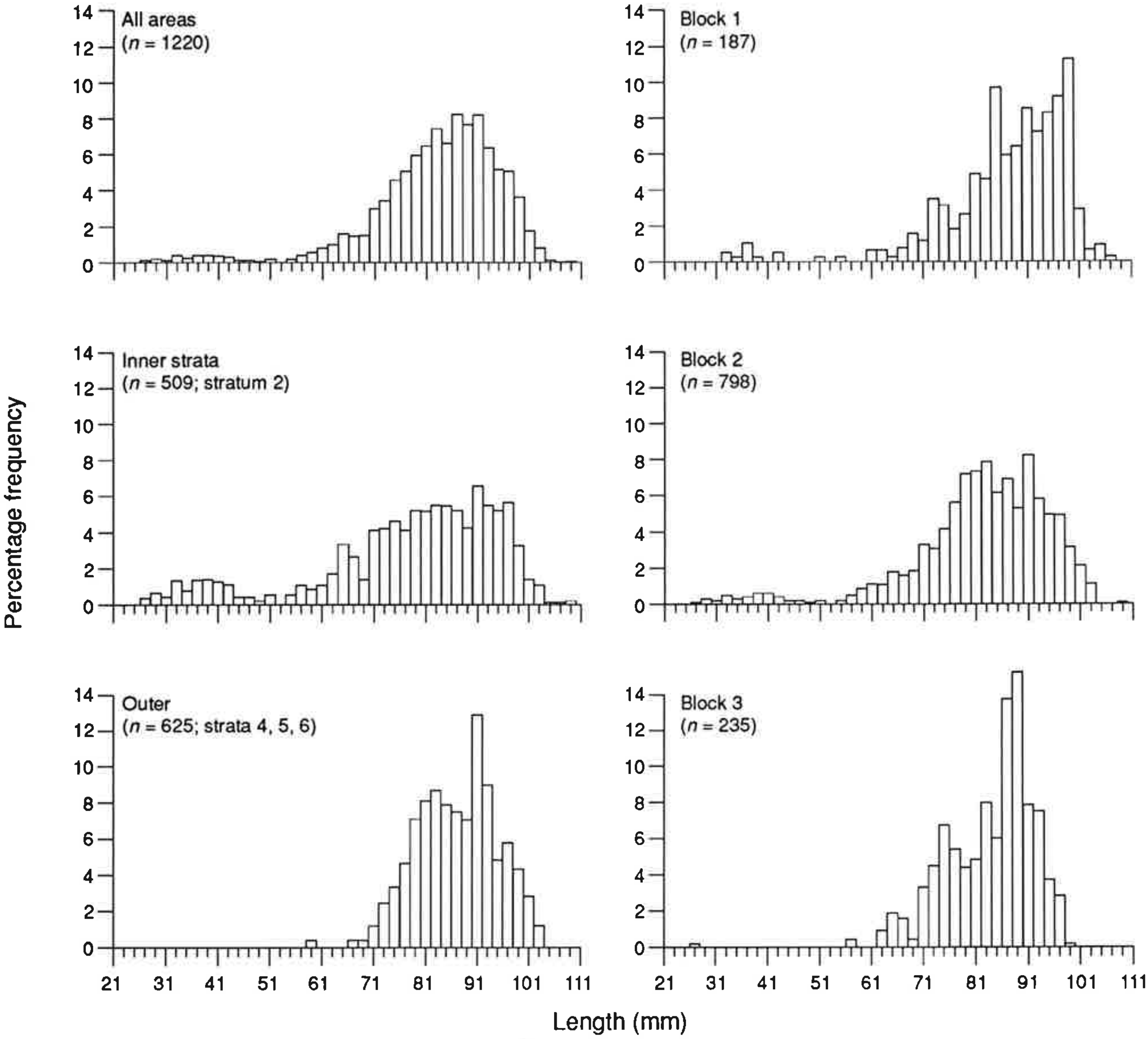


Figure 7: Length frequency distribution of *Paphies donacina*.

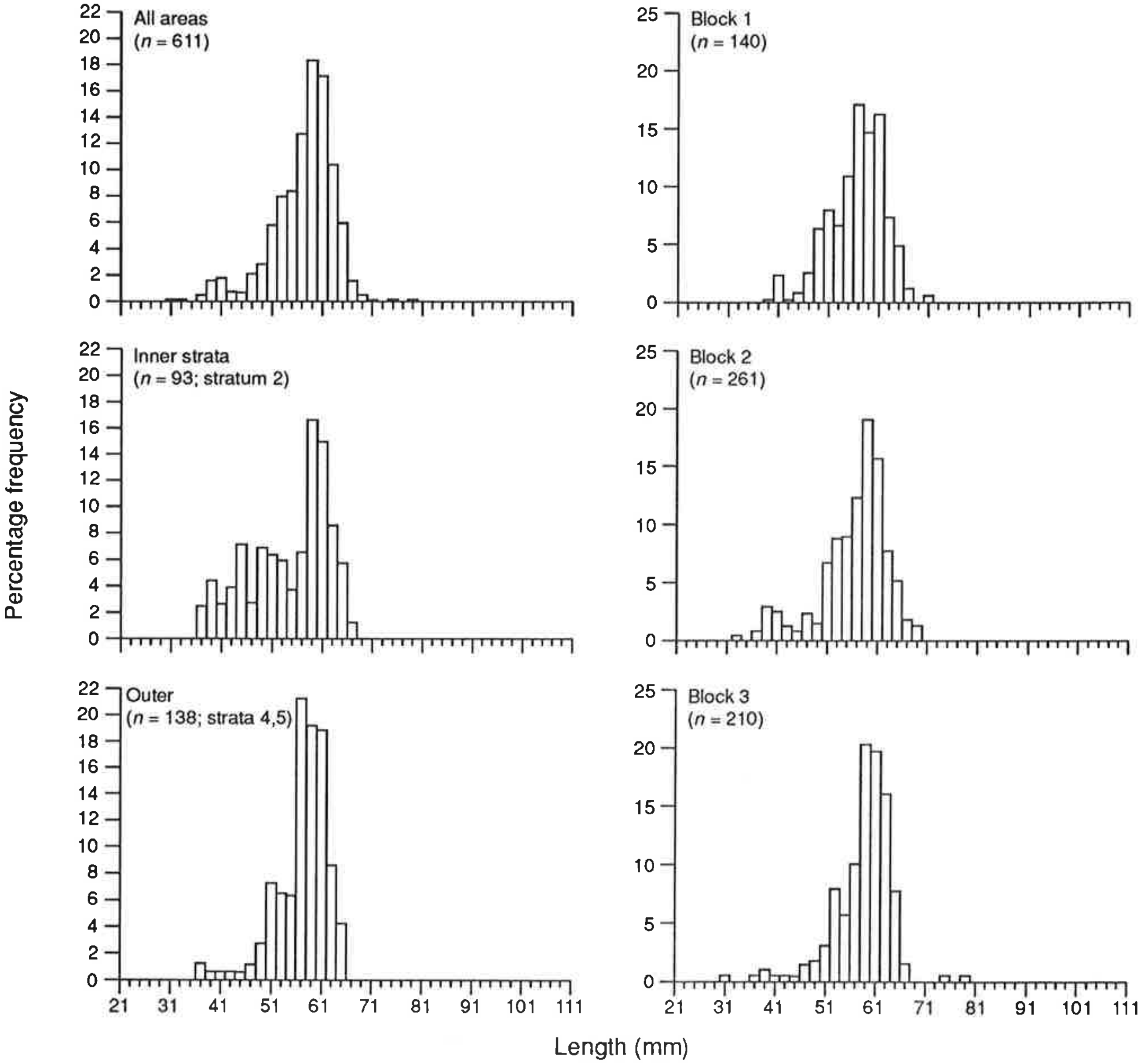


Figure 8: Length frequency distribution of *Spisula aequilatera*.

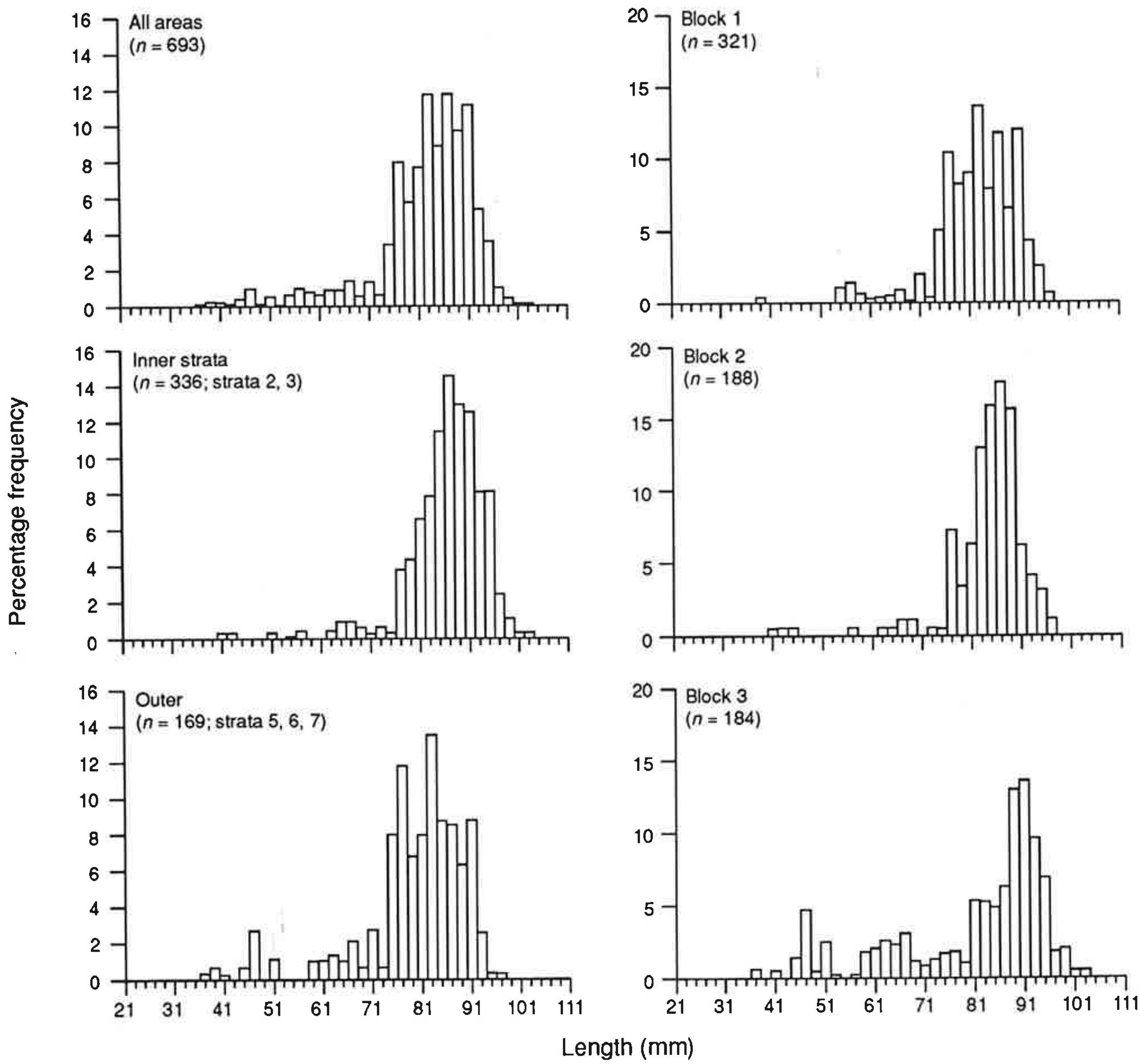


Figure 9: Length frequency distribution of *Mactra murchisoni*.

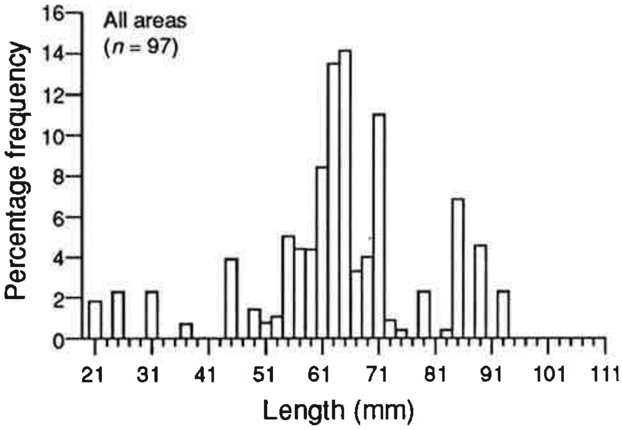


Figure 10: Length frequency distribution of *Mactra discors*.

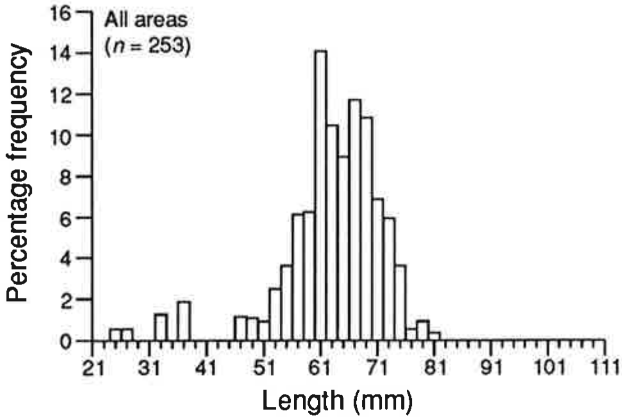


Figure 11: Length frequency distribution of *Dosinia anus*.

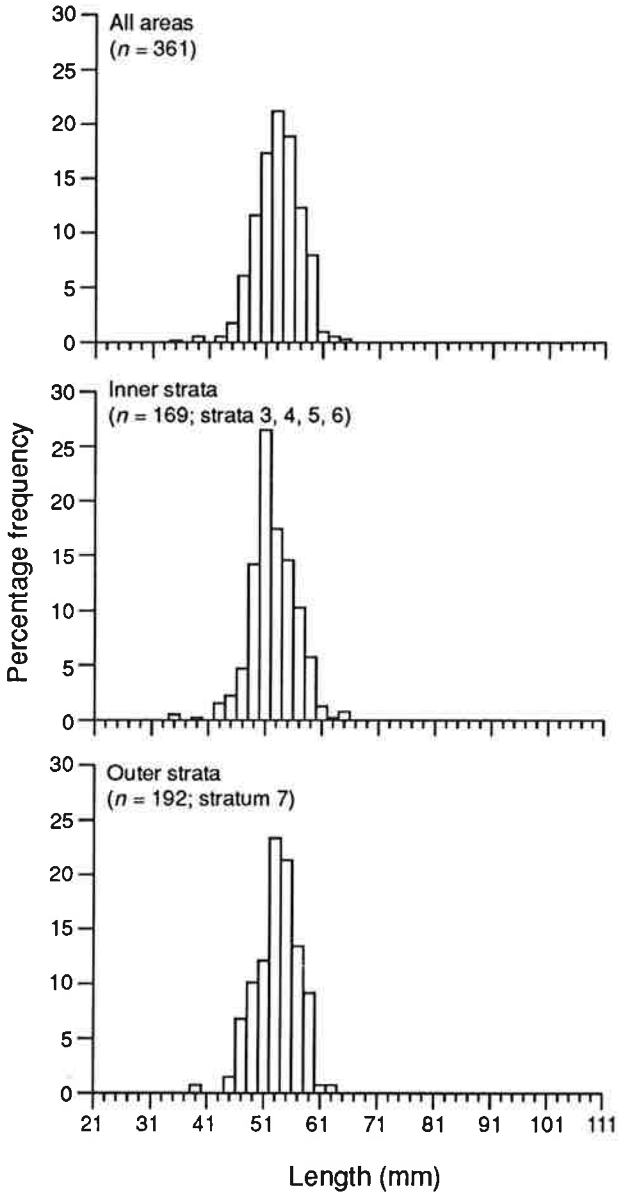


Figure 12: Length frequency distribution of *Bassina yatei*.

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Appendix 1: Dredge efficiency trial

The trial was conducted at Marfells Beach, at the south end of Clifford Bay, in depths between 1 and 2 m. The subtidal beach had a shallow gradient (1 in 100) and the substrate was firm, fine sand. A 250×50 m area parallel to the shore was buoyed and a transect line laid along each side of it.

A diver-operated airlift sampler (*see* Michael *et al.* 1990) was used to sample absolute surf clam density in 20×0.5 m^2 quadrats. The sampling frame (0.71×0.71 m) was weighted and penetrated 30 cm into the substrate to prevent sediment cave-in which could include surf clams from outside the quadrat (*see* Meyer *et al.* 1987). Ten random quadrats were sampled along each transect line.

Nineteen surf clams were caught in the 20 airlift samples (each 0.5 m^2), so the mean density was 1.9 per square metre (*s.d.* 1.83).

Three dredge tows of about 40 m were then made along the 1.5 m contour through the buoyed area. Divers measured the lengths of the dredge tracks on the bottom with a 50 m tape measure and recorded all discarded surf clams. Underwater visibility was about 1 m and discarded clams in and on each side of the dredge track were clearly visible on the surface of the substrate. Dredging was carried out in calm conditions, but curtailed by an abrupt weather change.

Catches in the three dredge tows are shown below. The mean density of surf clams sampled by dredging was 1.43 per square metre (*s.d.* 0.30).

Details of the three tows made at Marfells Beach to establish dredge efficiency

	Tow		
	1	2	3
Distance towed (m)	43	40	40
No. of surf clams caught	50	55	38
Relative density of surf clams (per m^2)	1.45	1.72	1.12
No. of surf clams recovered from the dredge track by divers	9	0	0

Surf clam density was low in the area sampled and numerous airlift samples had no surf clams because of the patchy distribution. This resulted in the bimodal distribution of efficiencies estimated by bootstrapping with a poorly defined mode at 65%. The mean dredge efficiency was estimated to be 73%.

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