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Distribution, biomass and yield estimates of surf clams off New Zealand beaches

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

1. EXECUTIVE SUMMARY

The geographical and depth distributions of seven species of surf clams are described. The mactrids *Mactra murchisoni*, *M. discors*, and *Spisula aequilatera* dominated the beaches of central and southern New Zealand, the mesodesmatid *Paphies donacina* was commonest on beaches of central New Zealand, and the venerids *Dosinia anus*, *D. subrosea*, and *Bassina yatei* dominated the beaches of northern New Zealand. Surf clams occur in depths from low water to 10 m. Each species is most abundant over a distinct and narrow depth range, generally overlapping little with other species. Although the depth range of each species varies between locations, the pattern of zonation remains the same throughout the country. Stratified random dredge surveys have been used to estimate biomass of surf clams in Cloudy and Clifford Bays and yields estimated with $F_{0.1}$ estimated from yield per recruit analyses. Stratified random dredge surveys were used to estimate biomass in 450 m wide transects of beaches at 16 locations. There was sufficient data to estimate yields at 15 of them. The data indicate the relative magnitude of biomass and yields that can be expected at different locations. The highest yields were in Pegasus Bay (Canterbury) and Ohope (Bay of Plenty).

2. INTRODUCTION

2.1 Overview

This document describes the distribution of seven species of surf clams around New Zealand, reports estimates of virgin biomass at several sites, and estimates Maximum Constant Yield (MCY) with $F_{0.1}$ estimated from yield per recruit analyses.

2.2 The fishery

In 1986 a special permit was issued for the investigation of the distribution and commercial potential of surf clams off the Wellington west coast. Because of intense opposition to the dredging by local interest groups, the fisher relinquished his permit before he could meet his objectives. Special permits were subsequently issued for exploration off Farewell Spit (Olsen 1987), Rabbit Island, Nelson (Michael & Olsen 1988), Cloudy Bay (Cranfield & Michael 1987), and Clifford Bay in Marlborough. The investigation in Cloudy Bay and Clifford Bay suggested that surf clams there could be fished commercially. In 1988 the fisher in Cloudy and Clifford Bays contracted MAF Fisheries to estimate the biomass. A yield was calculated from these data and the fisher was subsequently issued a commercial permit and quota. The expansion of the fishery to other areas awaits legislative changes.

2.2.1 The species

Four of the seven species (Figure 1) belong to the Order Mactracea: the mactrids *Mactra murchisoni*, *M. discors*, and *Spisula aequilatera* and the mesodesmatid, *Paphies donacina*. Three belong to the Order Veneracea: the venerids *Dosinia anus*, *D.subrosea*, and *Bassina yatei*.

2.2.2 The habitat

Surf clams are found in and immediately beyond the surf zone of exposed sandy beaches from low water out to a depth of 10 m below chart datum[1].

All New Zealand species have short siphons and lie buried just below the surface of the sand. Large individuals with the foot fully extended can reach up to 150 mm below the surface of the sand. So far hydraulic dredges alone have proved capable of harvesting surf clams intact (Michael *et al.* 1990). Only small, easily manoeuvred vessels can be operated safely in the surf zone. These vessels are limited to using lightweight hydraulic dredges. Such a dredge, developed to harvest benthic shellfish in Japan (Nashimoto & Mitoya 1985), has proved to be very efficient in the surf zone (Michael *et al.* 1990).

2.3 Literature review

2.3.1 The surf zone

The surf zone functions as an almost self-contained ecosystem. Wave action pumps sea water through the sea bed (Longuet-Higgins 1983), filtering out algae and detritus which are converted to microbial, meiofaunal and macrofaunal biomass and inorganic nutrients. The regenerated nutrients return to the sea from the interstitial water (Pugh 1983) where they support the production of surf diatoms. The algal production of the surf zone can be as high as that found in areas of coastal upwelling (McLachlan & Bate 1984).

Blooms of surf diatoms which develop during periods of strong onshore winds are concentrated within the breaker zone (particularly along rip currents) during the hours of daylight (Sloff *et al.* 1984, Talbot & Bate 1987, 1988a). Beach bivalves are highly adapted to feeding on such transient high densities of algae (Ansell 1981). Blooms of surf diatoms have been recorded along the west coast of the North Island (Rapson 1954, Cassie & Cassie 1960). Such algae are probably the major food source in New Zealand for those surf clam species that attain the highest densities within the breaker zone. Detritus tends to be concentrated outside the breaker zone where detrital particulate carbon is up to 10 times more abundant than the particulate carbon of the algae in the surf zone (Talbot & Bate 1988b). Such concentrations of detritus could be an important food source for those surf clam species in New Zealand that occur outside the breaker zone.

2.3.2 Fisheries for clams in similar environments

Italy

In Italy a suite of inshore clam species have supported a hydraulic dredge fishery since the late 1960s. The dominant species, a venerid, *Chamelea gallina*, forms a 3.2 km wide band between the 3 and 13 m contours. Three other venerids occur offshore of this band and a solenid and a donacid occur inshore of it. *C. gallina* was the most valuable species, but serial depletion has forced targeting of the less preferred species inshore and offshore. Peak annual

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[1] All depths given in this FARD are below chart datum (extreme low water).

production of the fishery was estimated to have been 100 000 t (green weight) of shellfish caught by 607 vessels (Froglia 1989).

United States

Although the mactrid surf clam *Spisula solidissima* occurs in the surf zone, the fishery for it in the Mid-Atlantic Bight is primarily outside the surf zone in depths from 10 to 55 m (Ropes 1980) where this species occurs in high densities. Hydraulic dredges have been used in the fishery since 1945. Vessel numbers have fluctuated around 100 and the annual catch climbed to around 20 000 t (shucked meat) in the 1960s, and fluctuated around 25 000 t in the 1970s. The fishery has relied on dominant year classes that have resulted from localised recruitment in specific areas. The most recent episodes of recruitment gave rise to dominant cohorts off Chesapeake Bay in 1970, off New Jersey in 1976, and off Virginia in 1977. These cohorts have supported the fishery through the late 1970s and 1980s (Murawski & Serchuk 1989, McCay & Creed 1990).

South America

There is an important artisanal hand-picking fishery for the mesodesmatid, *Mesodesma donacium*, off the beaches of Chile. 5000 t of meat (equating to 15 000–20 000 t green weight) are exported annually to Japan (J. Castilla, Pontificia Universidad Catolica de Chile, Santiago, Chile, pers comm).

A smaller (200 t green weight annually) artisanal hand-picking fishery is pursued in Uruguay for *Mesodesma mactroides* (Defeo *et al.* 1986, Defeo 1989).

Japan

The Japanese surf clam *Spisula sachalinensis* (*Pseudocardium sybillae*) supports a hydraulic dredge fishery in Hokkaido (Nashimoto 1985a, 1985b) and a beam trawl fishery in Sendai Bay (Sasaki 1986, Nakamura *et al.* 1989). The latter covers a 5 km wide strip of sea floor out to a depth of 15 m. Fishing began there in 1976 and the catch has fluctuated between 253 and 386 t owing to variation in recruitment.

2.3.3 Management of similar fisheries

Use of catch restrictions

Only the U.S. surf clam fishery has used total quota to restrict fishing. The biology of *S. solidissima* and estimation of the yield in the fishery are well documented. *S. solidissima* grows relatively slowly (growth depending on depth), recruits to the fishery at between 6 and 7 years of age, and attains a maximum age of around 30 years (Ropes 1980, Murawski & Serchuk 1989). Natural mortality (*M*) is very high in the first year due to predation by crabs and snails, but thereafter is generally low (< 0.1), as shown by their longevity.

M was estimated to be 0.2 by Caddy & Billard (1976), and 0.25 by Murawski & Serchuk (1979). Recruitment is variable and for periods of up to 10 years the fishery has depended on one or two year classes (Ropes 1980). Chang *et al.* (1976) estimated yield per recruit (YPR) and maximum sustainable yield (MSY) for this fishery. The recruited biomass on the northeast Atlantic shelf and a recruitment index are estimated in annual surveys. The estimate of MSY in the original fisheries management plan (FMP) for this fishery was based on commercial landings from 1960 to 1976. MSY was approximately 50 x 10^6 lbs of shucked meats (22 680 t). In 1985 the quota was set equal to this MSY estimate (Mid-Atlantic Fishery Management Council 1985) and in that year represented 4.5% of the current biomass.

Between 1960 and 1976 the population declined substantially twice and rose once. Some catch came from areas not included in the FMP area but by 1988 the fleet was fishing entirely new areas. Hence, the average catches for any period were considered unlikely to represent the long term potential catch from the stock (Mid-Atlantic Fisheries Management Council 1989). In 1988, the yield was estimated from a stochastic simulation model which used a harvest strategy that maximised the constant yield yet buffered the effects of variable recruitment (Mid-Atlantic Fishery Management Council 1989). This robust analysis resulted in the same estimate of MSY, 50 x 10^6 lbs shucked meats (22 680 t), as the earlier analysis which had included some doubtful assumptions.

Use of effort restrictions

Vessel or fisher numbers were restricted to control fishing effort in the U.S and Italian fisheries. Both countries instituted moratoria on further entry to the fisheries after they had become greatly overcapitalised, fishing effort had became too great, and serial depletion had become a problem (Murawski & Serchuk 1989, Froglia 1989). This did not succeed in limiting effort. The restrictions failed to stop vessel numbers increasing, and fishing effort increased further as larger replacement vessels were introduced, the power of existing vessels was increased, and more efficient gear installed.

In North America, apart from the overall catch limit, quarterly quotas spread fishing through the year, and trip limits restricted effort. Thus, for most of 1985 and all of 1986, vessels were allowed to work only 6 hours every 2 weeks. ITQs were introduced in 1992, and vessel numbers have declined as quota was consolidated on fewer vessels (Moore 1993).

The Italian fishery expanded without regulation until 1979 when it was licensed and vessel numbers frozen at 500. To halt serial depletion, licences were issued for specific areas, and to avoid over-exploitation, a daily catch limit of 2.5 t was imposed. In 1980 dredge width was limited to 3 m in a further attempt to control effort. In 1981 vessel size (for supposedly replacement vessels) was limited to 10 t GRT and 150 HP. Despite these measures effort increased and by 1985 vessel numbers had reached 607. The daily catch limit was then halved to 1.2 t to further reduce effort but at the same time (and in contradiction) 10% more vessels were allowed to enter the fishery (Froglia 1989).

Size limits

In North America, the size limit of *S. solidissima* was initially set at 140 mm because of the higher value of larger clams. In 1983, a very abundant, slow growing year class was just below legal size which caused sorting problems and high discard mortality. To reduce the latter, the size limit was lowered to 127 mm. As surf clam YPR is maximised at 120–130 mm, the effect on the yield of lowering the size limit was not great (Murawski & Serchuk 1989).

In 1981, the Italian fishery specified the spacing of filtration grills on hydraulic dredges so that only clams greater than 25 mm were selected (Froglia 1989). The Japanese fishery also regulates a size limit by specifying the spacing of both filtration grill and dredge teeth of hydraulic dredges (Nashimoto *et al.* 1983, 1988, 1989, Nashimoto 1985a).

3. REVIEW OF THE FISHERY

3.1 Catch and effort data

In 1989 yields were estimated by species from biomass surveys in Cloudy Bay (total yield 39.7 t) and Clifford Bay (total yield 49 t) and in 1992 quota based on these yields was set for these areas (MAF Fisheries unpublished data). Landings of surf clams of all species in Cloudy Bay between 1990 and 1992 were less than 5 t in total with no commercial landings from Clifford Bay. The fishery is still in its infancy and landings have been small.

3.2 Traditional, Maori and recreational fishing

On the Wellington west coast, *Paphies subtriangulata* supported important Maori hand-picking fisheries. Steamed and dried tuatua meats were an important part of the diet of local Maoris (Carkeek 1966, Butts 1981, 1982a). Both oral tradition (Marsh & Craig 1988) and the numerous substantial middens of *P. subtriangulata* shell alone clearly show this fishery to have been important for several hundred years. Midden evidence shows that the equally accessible estuarine shellfish (pipi, cockle, and *Cyclomactra ovata*) have been the next most important shellfish hand picked by the Maori.

The offshore surf clam species are rare in middens. Without hydraulic dredges they have been as inaccessible to the Maori as to the European. Oral tradition, and midden occurrence, points to the offshore surf clams being harvested only when washed ashore in high tides after storms (Carkeek 1966). *M. murchisoni*, *S. aequilatera*, *B. yatei*, and *D. anus* have been found irregularly and make up only a small proportion of the shells in the few middens that contained them (Carkeek 1966, Best 1918, Butts 1981, 1982a, 1982b). Although we have not caught *Longimactra elongata* in dredging along this coast, Adkin (1948), recorded its presence in middens of the Horowhenua. Carkeek (1966) found that the intertidal toheroa (*Paphies ventricosum*) occurred more rarely in middens and in much lower proportion than its relative abundance on the beach at the time of his writing. These data suggest that species composition or dominance of particular shellfish along this coast may change over time. Review of the archaeological literature in other areas of New Zealand may reveal different patterns in the harvesting of the intertidal clams but is likely to show the same pattern in the harvesting of the offshore surf clams.

Maori fishing today is not so intense but is still focused on *P. subtriangulata* with some hand-picking of *P. ventricosum*. Recreational fishing has centred on hand gathering the accessible intertidal mesodesmatid species, the intertidal tuatua, *P. subtriangulata*, and the toheroa *P. ventricosum* with some limited handpicking of *P. donacina* just below low water (on those beaches where this species extends up to just below extreme low water). These species are included in non-commercial fishing regulations. Offshore species have been harvested only from occasional storm wracks (e.g., Eggleston & Hickman 1972).

4. RESEARCH

4.1 Stock structure

No information is available on stock structure in surf clams. All species probably have a free-swimming larval life of 20–30 days (cf. Redfearn 1964) so gene flow should not be restricted over moderate distances. Smith *et al.* (1989) studied the variation in electromorphs of the inter-tidal tuatua, *P. subtriangulata*, and found evidence that gene flow was restricted between northern and central New Zealand. They related this to the major current patterns. Similar patterns can be expected in surf clams.

4.2 Resource surveys

Exploratory resource surveys have been carried out off Cloudy Bay in 1987 (Cranfield & Michael 1987) and 1989 (Michael *et al.* in press (a)); Rabbit Island, Nelson in 1988 (Michael & Olsen 1988) and Clifford Bay, Marlborough in 1989 (Michael *et al.* in press (b)).

The distribution of surf clams around New Zealand, their zonation with depth, and biomass were studied in 450 m wide transects on beaches at 16 locations in 1991 (Figure 2). The east coasts of the North and South Islands, Southland and central New Zealand were sampled; weather conditions precluded sampling on much of the west coast of the North Island.

4.2.1 Distribution of species

There appears to be a gradient in the distribution of the three families of surf clams (Veneridae, Mesodesmatidae, and Mactridae) with latitude (Figures 3 & 4). Venerid clams dominate the beaches of northern New Zealand, the mactrids dominate the central and southern beaches, and the mesodesmatid was commonest in central beaches.

At the three northern locations, the venerids, *D. anus* and *D. subrosea*, make up the major proportion of the surf clam biomass, and *D. anus* is abundant at all other North Island locations. The mactrids and mesodesmatid become increasingly abundant south of Ohope. At Ohope, *S. aequilatera* accounts for 30% of the biomass. The mesodesmatid, *P. donacina*, is most abundant around central New Zealand from Nuhaka south to the Wellington west coast, Cloudy Bay and as far south as Pegasus Bay. The mactrids, *M. murchisoni*, *M. discors*, and *S. aequilatera* are most abundant in the South Island. *M. murchisoni* and *M. discors* dominate in Southland (Blueskin Bay, Te Waewae, and Oreti) where they account for more than 80% of the total biomass.

4.2.2 Zonation of species with depth

Surf clams were caught between low water and 10 m with each species distributed over a distinct depth zone. The species follow the same order of succession throughout New Zealand (Figure 5). The depth distribution of each species varied between locations (Figure 6).

P. donacina were most abundant between 2 and 3 m. At most locations in both the North and South Island, they occurred over quite a narrow depth range of 2–4 m. *S. aequilatera* were most abundant between 3 and 7 m. They were generally caught shallower in the North Island, (3–5 m), than in the South Island (4–8 m). *M. murchisoni* were most abundant between 4 and 8 m. They were generally shallower in the North Island, (4 m), than in the South Island (5–6 m). *M. discors* were most abundant between 3 and 7 m. They were generally caught in a narrower band in the North Island (4–6 m) than in the South Island (3–7 m). *D. anus* were most abundant between 4 and 10 m. They were generally shallower in the North Island (5–8 m) than in the South Island (6–10 m). *B. yatei* were most abundant between 6 and 9 m. *D. subrosea* were most abundant between 6 and 10 m. They were deeper in the North Island (6–10 m) than in the South Island (5–8 m).

The relative position of each species in the surf zone was the same at all locations. *P. donacina* was always found inshore of the primary wave break, *S. aequilatera* within the primary wave break, *M. murchisoni* just outside this, *M. discors* beyond this again with the venerids, *D. anus*, *D. subrosea*, and *B. yatei* most abundant outside the breaker zone. Although no systematic comparison has been made with the small number of samples here, it appears that the variation in depths occupied at different locations is related to the location of the primary wave break (which depends on the slope of the beach and height of the incident waves). The spread of depth zones dominated by each species at each location appears to be related to the tidal amplitude and hence the depth range the primary wave break covers in each tidal cycle.

4.3 Other studies

Studies on growth, mortality, and estimates of $F_{0.1}$ were presented by Cranfield *et al.* (1993).

4.4 Biomass estimates

4.4.1 Cloudy Bay

The virgin biomass of surf clams in Cloudy Bay was estimated in 1989 in a stratified random survey using a hydraulic dredge (Michael *et al.* in press a). As size at recruitment had not been estimated this estimate was for total biomass. Because of the small numbers of juveniles this estimate is unlikely to be more than 10% greater than recruited biomass.

The total biomass of 883 t was estimated by species: *M. murchisoni* 287 t, *M. discors* 54 t, *S. aequilatera* 62 t, *P. donacina* 172 t, *D. anus* 74 t, *D. subrosea* 22 t, and *B. yatei* 127 t. Biomass was greatest in the southern third of the beach (526 t, 60%), less in the middle third (258 t, 29%), and least in the northern third (99 t, 11%).

Brown & McLachlan (1990) compared the production of surf beaches by the biomass (dry weight) estimated in a metre wide strip from the shore to ten metres depth. Using this method of comparison in Cloudy Bay shows surf clams attained 178 kg (wet weight) per linear metre of beach in the southern third, in the middle third 85 $kg.m^{-1}$, and in the northern third 20 $kg.m^{-1}$.

4.4.2 Clifford Bay

The biomass of sub-tidal clams in Clifford Bay was estimated in the same way in September 1989 (Michael *et al.* in press b). The total biomass of 995 t was estimated by species: *M. murchisoni* 200 t, *M. discors* 107 t, *S. aequilatera* 359 t, *P. donacina* 287 t, *P. subtriangulata* 33 t, *D. anus* 9 t, and *B. yatei* 10 t. The biomass varied along the four sections the beach was divided into: 55 $kg.m^{-1}$ of beach in the southern quarter, 71 $kg.m^{-1}$ and 28 $kg.m^{-1}$ of beach in the central quarters, and 48 $kg.m^{-1}$ of beach in the northern quarter. These are about the same levels as in the middle and northern sections of Cloudy Bay.

4.4.3 Density of surf clams around New Zealand

The biomass of beaches at 16 locations around New Zealand was estimated in 1991. We estimated the biomass of only a small portion of the beach at each location because of time constraints. A section of beach that appeared to be uniform in sediment, profile, exposure to wave action, and riverine input was marked on the chart and a 450 m wide transect within that section chosen randomly. The biomass of surf clams in this transect was surveyed in a stratified random design. The transect was surveyed using differential GPS (DGPS) to fix position and integrated with depth recorded by the echosounder using the survey software HYDRO. Stratum boundaries were determined on board the vessel by contouring the data, the area of each stratum determined precisely with HYDRO, and three or four sampling stations determined randomly within each stratum. At each station the hydraulic dredge used in previous investigations was towed parallel to the beach for 50 m and the catch weighed and measured.

Preliminary estimates of the density of all species combined (Table 1) were calculated at each site using 0.65 as the dredge efficiency (Michael *et al.* 1990, in press (a)). The locations with the highest biomass (*see* Figure 2, > 10%) were at Otaki on the Wellington west coast and three locations in Pegasus Bay on the east coast of the South Island. The beaches from North Cape to Whangarei supported very small populations of surf clams, as did Te Waewae Bay in Southland.

4.4.4 Areal expansion of biomass estimates of transects to entire sections of beach

As each transect was selected randomly it was anticipated that the biomass estimate could be areally expanded to provide an unbiased estimate of the biomass of the entire section of beach. The technique was evaluated with biomass data from the 1989 survey of Cloudy Bay. That survey sampled three sections of the beach that appeared to be homogeneous. In 1991, one 450 m wide transect was randomly sampled in two of these sections. The 1991 estimate has been expanded to each section of the beach using areal and linear expansion techniques (Table 2).

The areal expansion estimate for each section of the beach is based on only one transect sample so the accuracy is not high. The lineal expansion method gave results more consistent with (but lower than) the estimate of 1989. The fishing between 1989 and 1991 was too limited to have reduced the population from virgin levels. However, in fast growing species like surf clams, which are also subject to variable and probably occasionally high mortality as well as variable recruitment (Cranfield *et al.* 1993), virgin biomass is likely to cover a wide range of values and change rapidly. Hence, estimates of biomass from areal expansion and those made of the whole area, are probably strictly comparable only when made in the same year. Whatever the cause of differences in the Cloudy Bay estimates, areal expansion of biomass estimates at other locations should be used cautiously.

4.5 Yield estimates

4.5.1 Estimates of Maximum Constant Yield (MCY)

The estimate of virgin biomass (883 t) in Cloudy Bay in 1989 was used to estimate yield. In the absence of any data from which to estimate mortality or $F_{0.1}$ for any of the surf clam species, MAF Fisheries looked to fisheries elsewhere for similar species to provide a basis for estimating sustainable yields in New Zealand. A review of the literature showed that the only documented fishery for a similar species was the U.S. surf clam (*S. solidissima*) fishery. In 1985, the yield for this fishery represented 4.5% of the recruited biomass. Because the U.S. fishery had been sustainable at this rate of exploitation for some years, it was used to estimate MCY for Cloudy Bay, i.e., MCY = 0.045 B_0.

$$MCY = 0.045 * B_0$$

$$MCY = 0.045 * 883 \text{ t}$$

$$= 39.7 \text{ t}$$

Method 1 for estimating yield for new fisheries (Annala 1993) is MCY = $0.25*F_{0.1}**B_0$, so 0.045 was used as a substitute for $0.25*F_{0.1}$ (or $0.25*M$) until further data on growth and mortality of surf clams were available. Because of the tight zonation of species, individual species could be targeted so the yield was estimated by individual species. It was assumed that each species would be similarly productive, so the 4.5% figure was used to estimate the yield of each species.

The yield for Clifford Bay estimated in the same way was 43.3 t for all species combined.

Yield per recruit analyses were used to estimate $F_{0.1}$ for five of the seven species of surf clam in Cloudy Bay in 1993 (Cranfield *et al.* 1993). These estimates for different levels of natural mortality are shown in Table 3.

The population of surf clams in Cloudy Bay will not have been reduced from the virgin state by the very low catches taken over the last 3 years (*see* Section 2.1). Assuming that the population has not changed significantly over this period, MCY can be calculated by summing the MCYs calculated for individual species following method 1 for new fisheries

(Annala 1993). The lowest estimates of $F_{0.1}$ were used in these calculations and result in an estimate of MCY for all species of 82.8 t (Table 4). In the same way, the estimate of the virgin biomass of surf clams in Clifford Bay in 1989 allows the calculation of an MCY of 155.8 t for all species there (Table 5).

The estimates of biomass at each of the 16 locations (see Table 1) have been broken down by species and the MCY at each transect has been estimated by summing the yield of each species using the estimates of $F_{0.1}$ from Peka Peka as representative of North Island surf clam populations and those from Cloudy Bay as representative of the South Island (Table 6). These data indicate the yields that could be expected from a selection of beaches around New Zealand. Because of the high yields from the more productive mactrid species (especially *S. aequilatera*), those beaches with a large biomass which was dominated by mactrids have the highest yields (transects 11, 12, 13 and to a lesser extent 4).

4.5 Estimation of Current Annual Yield (CAY)

As we have no estimates of the current biomass, CAY cannot be estimated for any of these populations.

5. FACTORS MODIFYING YIELDS

5.1 Precision of biomass estimates

The factors influencing the distribution of surf clams on New Zealand beaches are poorly understood so we are unable to stratify sampling designs to take sources of variation at all into account. On many beaches, the 1 metre depth contours in the productive breaker zone are only 40–50 m apart; small errors in measuring the stratum boundaries they define will result in large errors in estimates of stratum area. Where there are large changes in density between adjacent strata, these errors could result in inaccurate estimates of biomass.

The *c.v.* of biomass estimates in the 450 m transects is generally less than 20%. Although reliable comparisons can be made between transects, it is not clear how well transects sub-sampled the whole beach. The Cloudy Bay comparison suggests that beach biomass estimated from transects will be of the right order of magnitude and can be used to give indicative estimates of biomass and yield. The biomass of these beaches needs to be estimated from surveys covering the entire area before yields can be calculated for them.

5.2 Variability of recruitment

Year class strength of surf clams varies widely from year to year (Cranfield *et al.* 1993). Recruitment variability may be due to environmental variation, predation, or disease, but these must act very specifically to affect only one or two of the range of species at the localities investigated.

The turbulent nature of the surf zone suggests that surf clams could be prone to periodic catastrophic mortality from erosional events during storms, and therefore they should be well adapted to rapid recolonisation of beaches. Surf clams are present on many New Zealand beaches at below commercial densities. Settlement from larvae dispersed from any of these low density populations could rapidly replenish depleted stocks. This occurred in the U.S. surf clam fishery in 1976 after a widespread anoxic fishkill killed surf clams (Ropes 1980).

Sporadic and localised recruitment events have maintained the US surf clam fishery for up to 10 years. This suggests caution in the approach to harvesting until more is known of the reliability of recruitment in New Zealand. A CAY harvesting regime that estimates the biomass of surf clams annually would provide data on the local variation in recruitment, reduce the risks of recruitment overfishing, and result in a higher average yield to the fisher if biomass varies greatly from year to year.

5.3 Size and age at first harvest

Market research has yet to determine optimum market size for any species (in the U.S. and Italian hydraulic dredge fisheries this size has changed over the years). The YPR model has not been used to estimate optimum size limits for each species. Discarded undersize clams may be too slow to rebury to avoid being swept ashore or becoming the victims of predators. Regulations specifying filtration grill spacing on dredges can achieve the desired selectivity *in situ*. Because of the very different shapes of all the clam species, it could be difficult to optimise YPR for all species this way.

6. MANAGEMENT IMPLICATIONS

Variation in biomass: The biomass of surf clams on any beach is unique to that beach. Firstly, species composition of surf clams varies around New Zealand; secondly, factors that affect biomass vary widely between beaches and even within them — the profile of the beach, the distribution of its sediment, freshwater inflow, and the incident wave climate. Thus the biomass of every beach fished will need to be estimated to estimate yields. Although biomass can be estimated efficiently, this requirement will impose some costs in developing and managing the fishery.

To get the fishery started, it may be better to obtain preliminary biomass estimates and to set the initial harvest at a very conservative level. As the fishery develops, and provides better distributional data, improved estimates of the biomass could be made from which the sustainable yield could be estimated.

Serial depletion: Surf clams are highly localised sedentary stocks. Hydraulic dredging will be able to substantially deplete local stocks (cf. Italian and U.S. surf clam fisheries).

Variation in population parameters within and between species: Species may need to be managed individually as each has different growth and mortality rates and reference fishing mortality (Cranfield *et al.* 1993). The tight zonation of species with depth in the surf zone allows fishers to target individual species and makes such management feasible. Estimates of $F_{0.1}$ have been made at two locations that may be representative of other locations in the North Island and South Island. However, growth and mortality are affected by environmental variables that can differ between locations, and possibly even within locations.

CPUE: CPUE is used to measure the relative abundance of fished species and to monitor stocks. Because of the high efficiency of hydraulic dredges, CPUE could give a good measure of abundance of surf clams. However, fishers are likely to follow a rotational dredging strategy within the area fished and CPUE in any one year will cover only a proportion of that area and the population. Furthermore, even within the area fished, different species may be targeted (possibly differently in different years) depending on market needs. CPUE will probably be of limited value in monitoring biomass in this fishery.

Variation in recruitment and mortality: Variation in recruitment, and the probability of high mortality from storms, could result in the biomass varying greatly from year to year. An MCY strategy could increase the risk to the stock when biomass is low and result in under-exploitation when biomass is high. A CAY strategy would minimise the risks to the stock from overfishing when it is at very low levels. A CAY strategy could also result in higher yields from the fishery by fully exploiting the stock when biomass is high.

7. RESEARCH NEEDS

Measuring growth: The completion of mark-recapture studies of growth at Peka Peka are required to give more robust estimates of growth (and ultimately of mortality) for surf clams in this locality. The development of validated ageing techniques from shell sections will allow the age structure of populations to be analysed and give estimates of mortality. Shell sections could be used to estimate growth and mortality at other localities more readily than other methods.

Measuring natural mortality: Mortality for surf clams has not been estimated very precisely (Cranfield *et al.* 1993). As the yield per recruit model is very sensitive to the estimate of M, it is important to develop independent estimates of M.

Understanding distribution: The impact of beach profile, sand grain size, wave climate, and freshwater input on the distribution and abundance of surf clams needs to be understood to increase the precision of biomass surveys. Factors affecting dredge efficiency and the effect of fine scale patchiness of clam distribution on the precision also need to be understood.

8. ACKNOWLEDGMENTS

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Table 1. Preliminary estimates of biomass for 450 m-wide transects of beaches at 16 locations around New Zealand

Location	Biomass (t)	*c.v.*	95 % CI Lower Upper	Area m^2x10^{-3}	Biomass $kg.m^{-2}$	Biomass $kg.m^{-1}$
Great Exhibition Bay	1.03	21	0.3 - 1.9	270	0.003	2.2
Te Arai	1.02	37	0.6 - 1.5	190	0.005	2.2
Matakana	29.45	91	0 - 81.8	440	0.066	65.4
Ohope	47.87	17	31.6 - 65.0	1030	0.046	106.3
Nuhaka	63.75	31	24.4 -103.1	530	0.120	141.6
Waitarere	17.33	20	15.0 - 19.8	558	0.031	38.5
Otaki	66.30	18	46.0 - 57.8	525	0.126	147.3
Peka Peka	36.89	23	30.6 - 43.2	509	0.072	81.9
Fence	21.51	21	18.2 - 25.0	547	0.039	47.9
Wairau	36.73	22	30.2 - 43.2	827	0.044	81.6
Leithfield	63.29	21	36.3 - 90.3	985	0.064	140.6
Waikuku	68.72	12	53.0 - 84.8	404	0.170	152.7
Kainga	80.15	18	52.1 -108.3	751	0.106	178.1
Blueskin *	16.05	55	0 - 33.4	360	0.044	35.6
Te Waewae	2.24	56	0 - 4.7	1137	0.001	4.9
Oreti	32.85	14	23.8 - 41.9	730	0.045	73.0

* Survey not completed

Table 2. Expansion of biomass in two 450 m wide transects in Cloudy Bay in 1991 compared with the estimate of biomass within these sections of beach from a stratified random survey in 1989 (Michael *et al.* in press (a))

	Section 1	Section 2
1. Length of section of beach surveyed in 1989	2960 m	3020 m
2. Biomass 1989	525.7 t	257.6 t
3. Length of beach surveyed in 1991	450 m	450 m
4. Biomass 1991	36.7 t	21.6 t
5. Linear expansion (biomass of transect sampled in 1991 divided by the length of that transect (450 m) multiplied by the length of the section of beach surveyed in 1989 that contained this transect)	241 t	144.9 t
6. % of 1989	46%	56%
7. Areal expansion		
(mean biomass/stratum surveyed in 1991 x area of same depth strata surveyed 1989)	369 t	88.2 t
% of 1989	70%	34%

Table 3. Estimates of $F_{0.1}$ obtained from yield per recruit analyses for the five species of surf clams using figures for natural mortality that bracket those estimated from maximum ages taken from Cranfield *et al.* (1993).

M. murchisoni		*M. discors*		*S. aequilatera*		*P. donacina*		*D. anus*	
M.	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$	*M*	$F_{0.1}$
Cloudy Bay									
0.35	0.43	0.30	0.46	0.55	1.06	0.25	0.36	0.20	0.25
0.40	0.50	0.35	0.54	0.60	1.16	0.30	0.44	0.25	0.33
0.45	0.57	0.40	0.64	0.65	1.26	0.35	0.52	0.30	0.42
				0.70	1.37				
Wellington west coast									
								0.15	0.27
0.40	0.70	0.30	0.56	0.7	1.12			0.20	0.35
0.45	0.79	0.35	0.66	0.8	1.34			0.25	0.44
0.50	0.89	0.40	0.77	0.9	1.56			0.30	0.54
		0.45	0.87						

† Data inadequate to run YPR.

Table 4: MCY estimates for surf clams in Cloudy Bay. Virgin biomass estimates from Michael et al. (in press a)

	Virgin biomass (B_0) (t)	$F_{0.1}$	MCY
Paphies donacina	172	0.36	15.5
Spisula aequilatera	62	1.06	16.4
Mactra murchisoni	287	0.43	30.8
Mactra discors	54	0.46	6.2
Dosinia anus	74	0.25	4.6
*Dosinia subrosea**	22	0.25	1.4
*Bassina yatei**	127	0.25	7.9
Total			82.8

* In the absence of data on growth and mortality of these species, the estimate of $F_{0.1}$ for *Dosinia anus* has been used. As these species appear to be similar ecologically this assumption is unlikely to give rise to great errors.

Table 5: MCY estimates for surf clams in Clifford Bay. Virgin biomass (B_0) estimates from Michael *et al.* (in press b)

	Virgin biomass (B_0) (t)	$F_{0.1}$	MCY
Paphies donacina	287	0.36	25.8
Spisula aequilatera	359	1.06	95.1
Mactra murchisoni	200	0.43	21.5
Mactra discors	107	0.46	12.3
Dosinia anus	9	0.25	0.5
*Bassina yatei**	10	0.25	0.6
Total			155.8

* In the absence of data on growth and mortality of these species, the estimate of $F_{0.1}$ for *Dosinia anus* has been used. As this species appears to be similar ecologically this assumption is unlikely to give rise to great errors.

Table 6. MCY estimates from virgin biomass in 450 m transects at 15 of the 16 locations sampled around New Zealand (data at Blueskin Bay inadequate to estimate yields) summed by species and expanded to estimate yield per kilometre of beach at those locations

	$F_{0.1}$ North Island*	Great Exhibition Bay (1)	Te Arai (2)	Matakana Island (3)	Ohope (4)	Nuhaka (5)	Waitarere (6)	Otaki (7)	Peka Peka (8)
Paphies subtriangulata	0.36 **	0	0	0.02	0.037	0	0.002	0.059	0.004
Paphies donacina	0.36 **	0	0	0	0	2.830	0.052	2.307	1.328
Spisula aequilatera	1.12	0	0	0.03	4.584	0.050	0.028	0.133	0.181
Mactra murchisoni	0.70	0	0	0.03	0.989	0.327	1.046	1.098	0.714
Mactra discors	0.56	0	0	0.10	0.198	0	0.252	0.993	0.805
Dosinia anus	0.27	0.032	0.017	1.77	1.705	2.254	0.719	2.085	0.973
Dosinia subrosea	0.27 ‡	0.031	0.050	0.13	0.034	0.036	0.025	0.009	0
Bassina yatei	0.27 ‡	0	0	0.01	0.003	0	0.009	0.005	0.004
Total yield summed for all species		0.63	0.67	2.08	7.551	5.497	2.133	6.690	4.0627
Yield expanded to 1 km of beach		.141	.149	4.639	16.781	12.217	4.742	14.86	9.028

	$F_{0.1}$ South Island†	Fence (9)	Wairau (10)	Leithfield (11)	Waikuku (12)	Kainga (13)	Te Waewae (15)	Oreti (16)
Paphies subtriangulata	0.36 **	0	0	0	0	0	0	0
Paphies donacina	0.36 **	0.028	0.019	1.521	2.341	2.005	0	0
Spisula aequilatera	1.06	0.002	0.040	8.336	8.638	5.140	0.266	0.397
Mactra murchisoni	0.43	0.096	2.231	1.340	0.219	1.059	0.108	0.116
Mactra discors	0.46	0.083	0.098	0	0	0	0	3.487
Dosinia anus	0.25	0.200	0.357	0.107	0.163	1.773	0.014	0
Dosinia subrosea	0.25 †	0.055	0.038	0.040	0	.008	0	0
Bassina yatei	0.25 †	0.228	0.520	0.002	0	0	0	0
Total yield summed for all species		1.838	3.303	11.354	11.361	9.985	0.388	4.000
Yield expanded to 1 km of beach		4.086	7.34	25.231	25.248	22.189	0.864	8.890

* Assumes that $F_{0.1}$ estimated at Peka Peka will be the same (or similar) at all other North Island locations.

** No estimate of $F_{0.1}$ is available for *P. subtriangulata* so that for *P. donacina* from Cloudy Bay has been substituted. $F_{0.1}$ has been estimated only at Cloudy Bay so far for *P. donacina*. In the absence of North Island data this value has been used as a substitute.

† Assumes that $F_{0.1}$ estimated at Cloudy Bay will be the same (or similar) at all other South Island locations.

‡ Assumes that these species related to *D. anus* and living in the same part of the surf zone will be similar and $F_{0.1}$ for *D. anus* can be used as a substitute for their $F_{0.1}$.

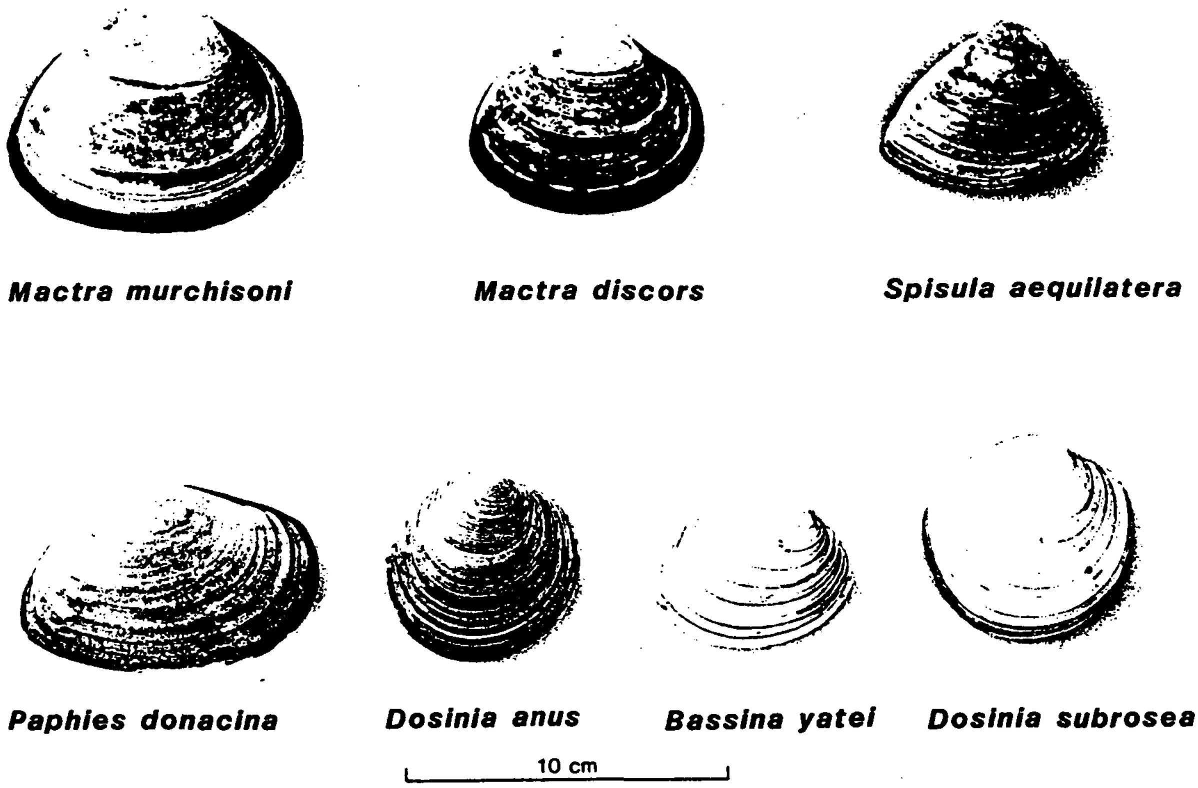

Figure 1: The seven most abundant surf clams off New Zealand beaches.

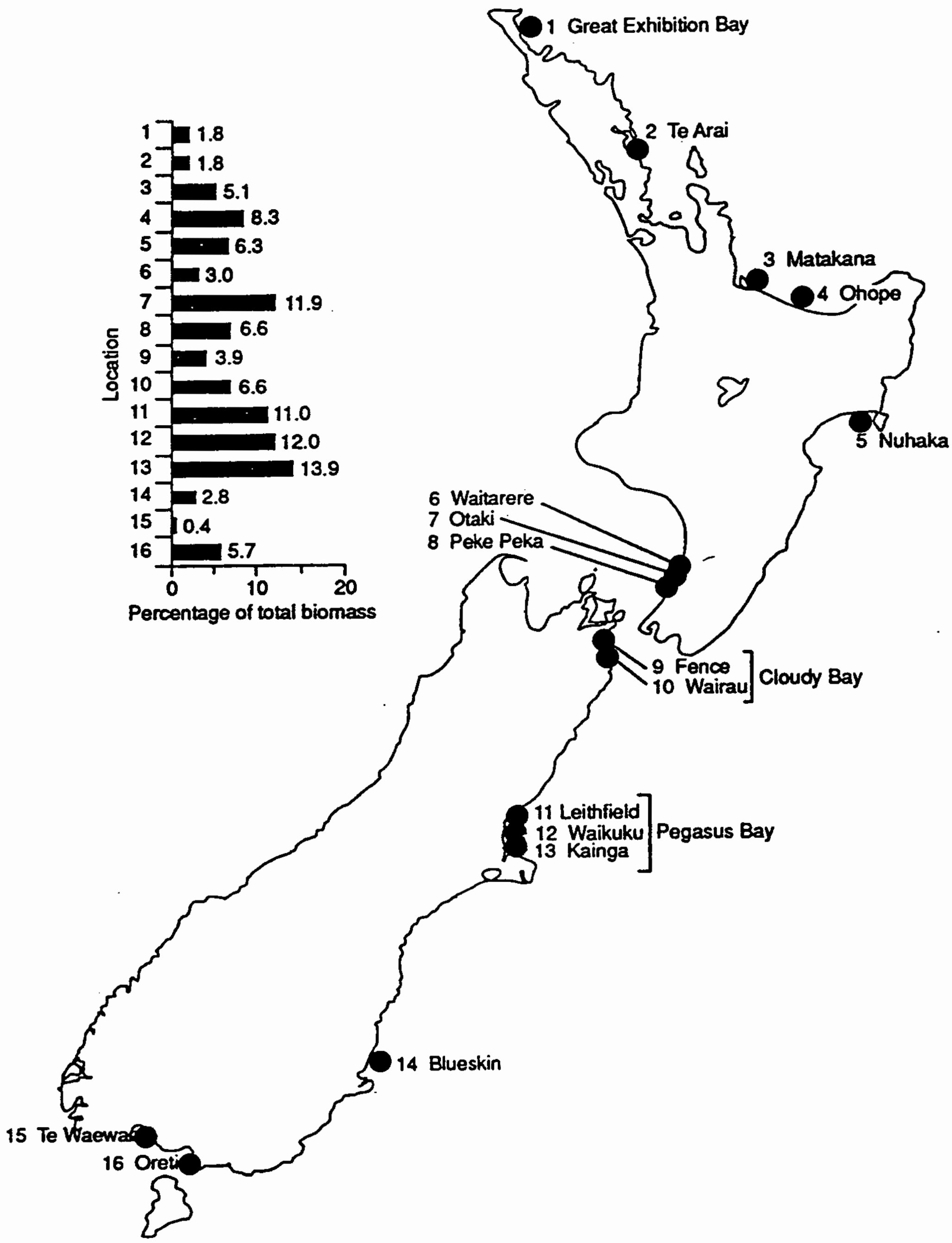

Figure 2: The 16 locations sampled and the total biomass of surf clams at each location as a percentage of the combined biomass from all locations.

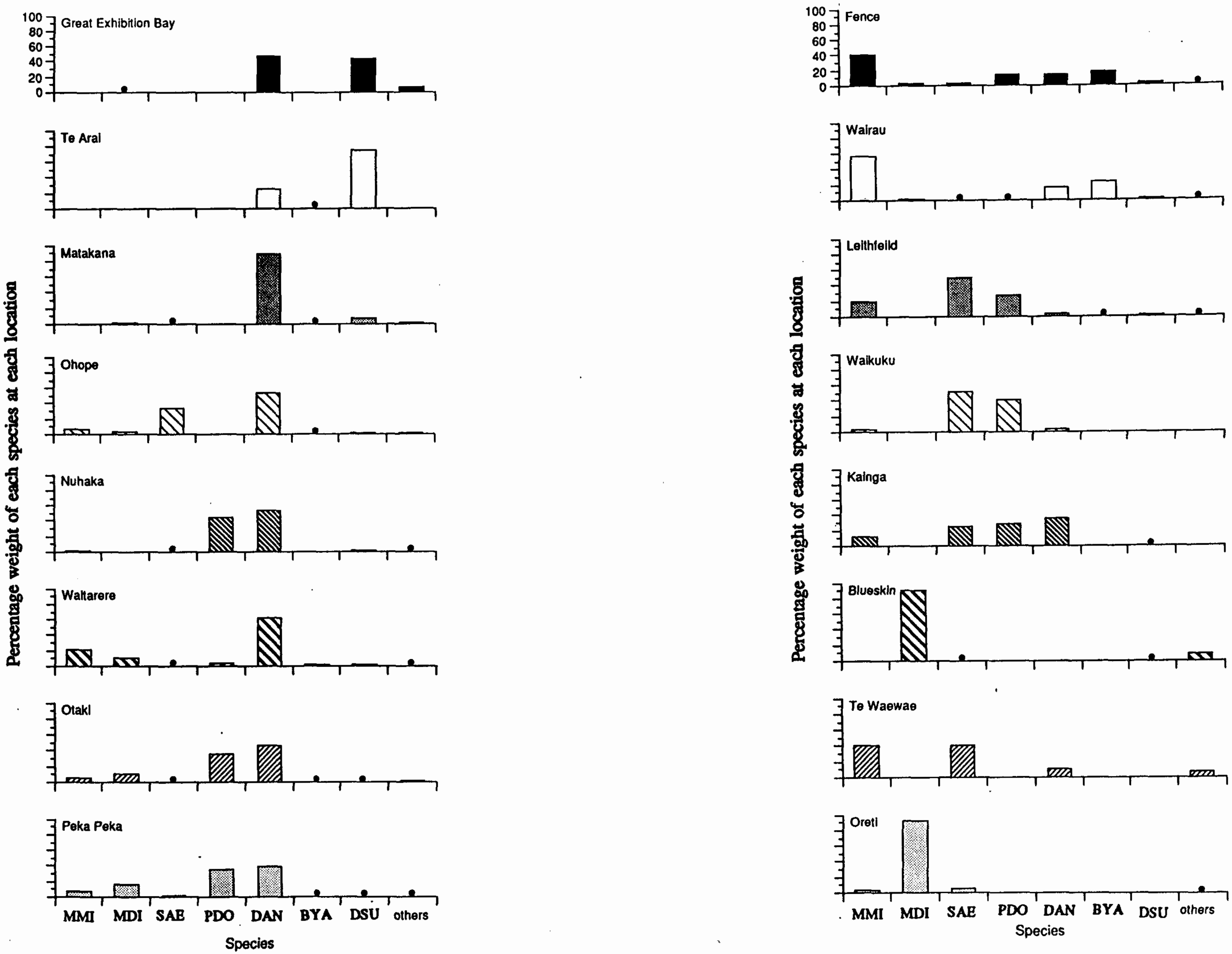

Figure 3: Percentage weight of each species at the 16 locations. (MMI, *Mactra murchisoni*; MDI, *Mactra discors*; SAE, *Spisula aequilatera*; PDO, *Paphies donacina*; DAN, *Dosinia anus*; DSU, *D. subrosea*; BYA, *Bassina yatei*; and •, species present but < 1% of the total weight.

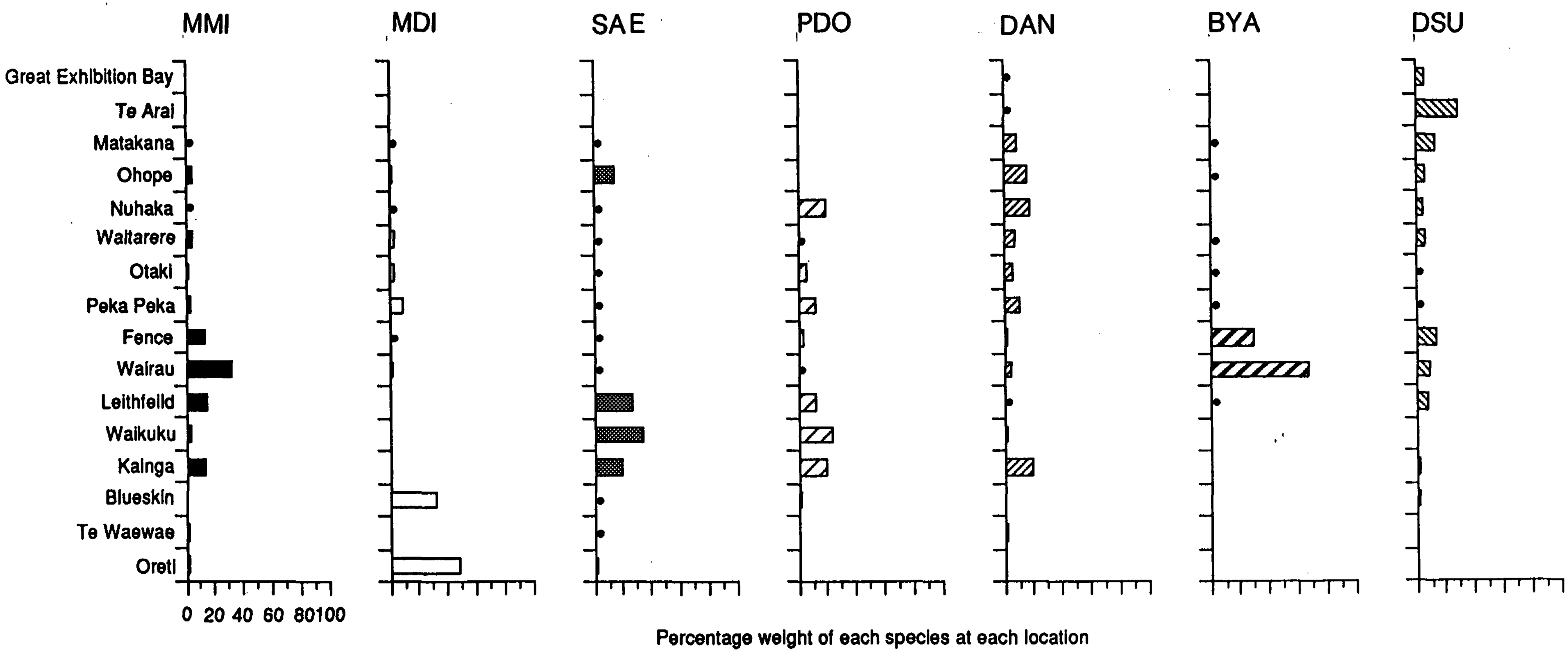

Figure 4: Percentage of the combined weight of each species from all locations. (MMI, *Mactra murchisoni*; MDI, *Mactra discors*; SAE, *Spisula aequilatera*; PDO, *Paphies donacina*; DAN, *Dosinia anus*; DSU, *D. subrosea*; BYA, *Bassina yatei*; and •, species present but < 1% of the total weight.

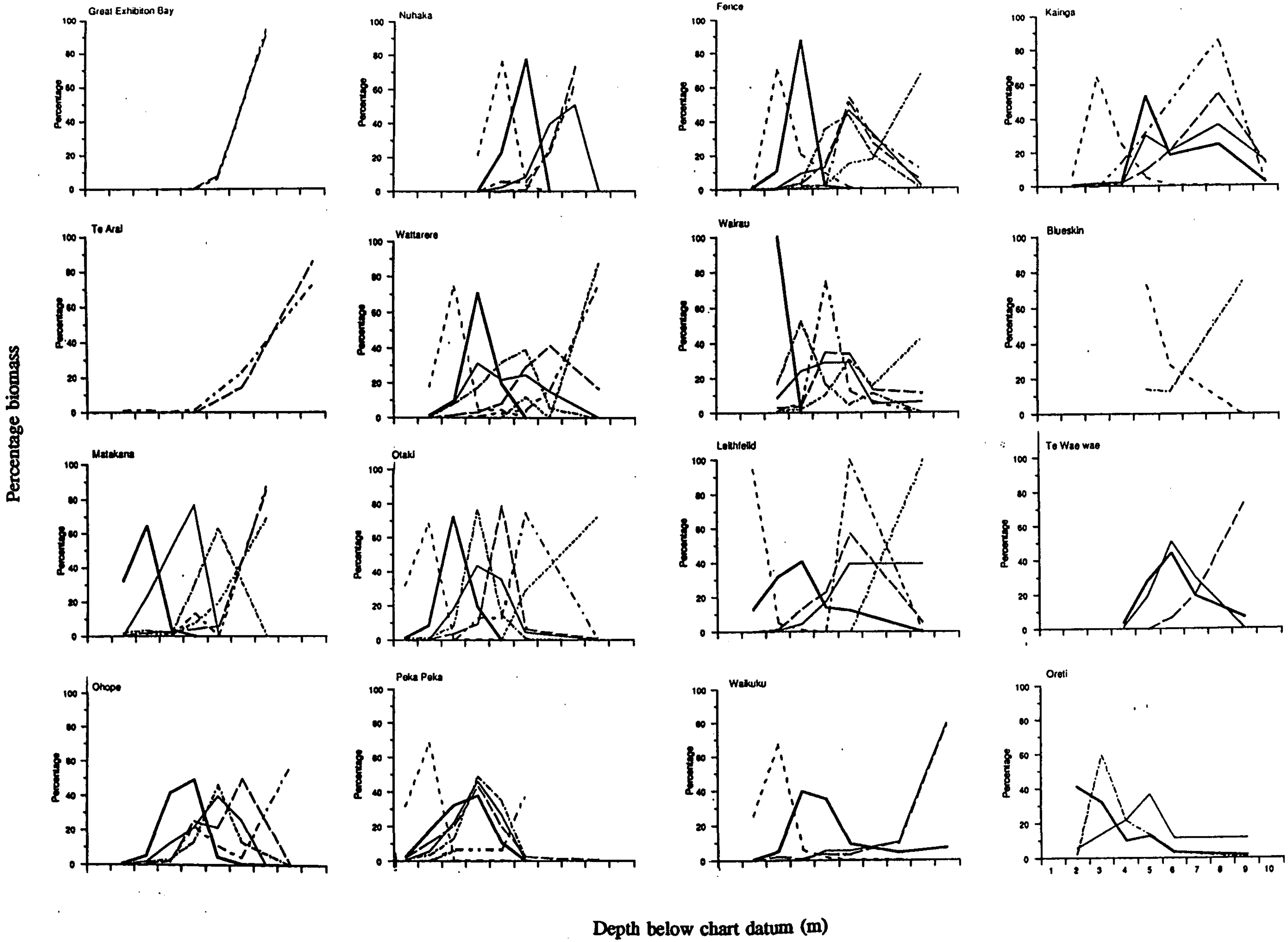

Figure 5: Distribution of the biomass of each species by depth at the 16 locations. (MMI, *Mactra murchisoni* (—); MDI, *Mactra discors* (---); SAE, *Spisula aequilatera* (—); PDO, *Paphies donacina* (- - -); DAN, *Dosinia anus* (- - -); DSU, *D. subrosea* (····); and BYA, *Bassina yatei* (-·-·-).

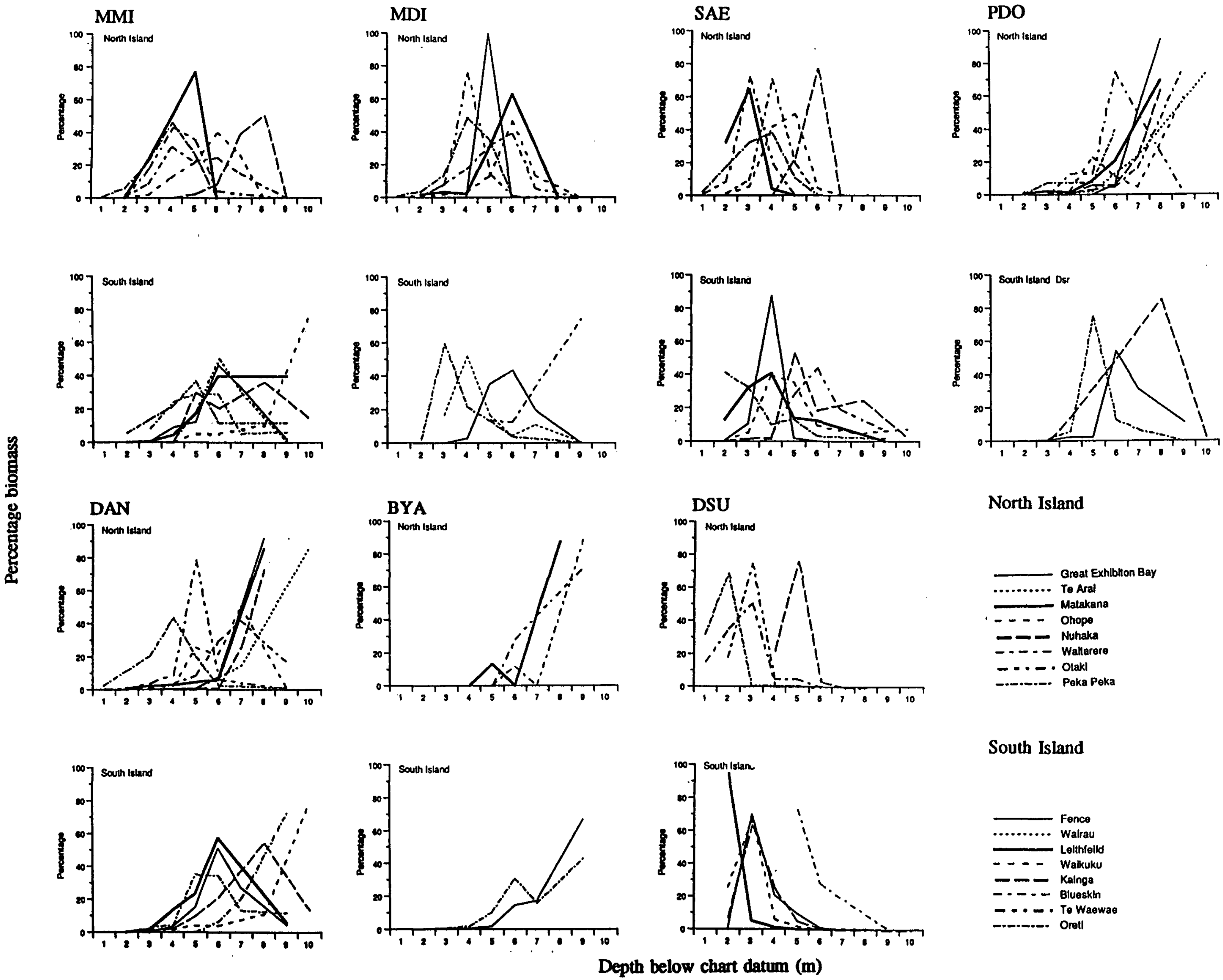

Figure 6: Distribution of the biomass of each species by depth for all North and South Island locations. (MMI, *Mactra murchisoni*; MDI, *Mactra discors*; SAE, *Spisula aequilatera*; PDO, *Paphies donacina*; DAN, *Dosinia anus*; DSU, *D. subrosea*; and BYA, *Bassina yatei*.