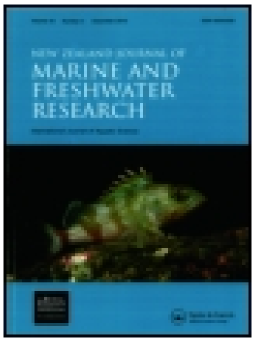

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LITTORAL BENTHOS–SEDIMENT RELATIONSHIPS IN MANUKAU HARBOUR, NEW ZEALAND

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ABSTRACT

Sampling of 57 littoral stations in Manukau Harbour, Auckland, (37° 02′ S, 174° 41′ E) for species composition, distribution, and abundance as part of a base-line ecological survey of the harbour shows that the community trophic structure is related to the sediment grain size. Deposit feeders such as the bivalves *Macomona liliana* and *Nucula hartvigiana* and the gastropod *Zeacumantus lutulentus* are most abundant in fine sand, whereas suspension feeders such as the bivalves *Chione stutchburyi* and *Paphies australe* are most abundant in medium sand. The proportion of deposit feeders in the sample increases with decreasing grain size of the sediment. Most stations conform to this general trend, although when the results are plotted as the percentage of deposit feeders against the median and mean grain sizes of the sediment in which they occur, three groups of stations appear anomalous. These stations, at Waiau Pa, Pollok Beach, and Fosters Bay, may be unstable and undergoing a change in community structure or sediment characteristics. Identification of unstable areas using this method may be useful to monitor effects caused by environmental changes.

INTRODUCTION

The coastal areas around New Zealand are coming under increasing pressure for housing or industrial reclamation or as dumping areas for industrial and domestic wastes. The importance of coastal inlets and estuaries as nursery grounds for pelagic fish, as areas of oxygenation, and as areas of abundant food resources, have been summarised by Perkins (1974), but still relatively little is known about the natural variability of populations living in such inlets.

Manukau Harbour is a large, shallow harbour situated on the west coast of the North Island, south of Auckland City (Fig. 1). It was chosen because very extensive (145 km^2) sand-flats are exposed at low spring tides (Heath 1976), and because parts of the harbour receive treated sewage effluent; it is also a possible site for a future thermal power station. At present, most of the harbour, other than the upper reaches, is unspoilt. The results of a preliminary programme of littoral benthic sampling are reported here, and a method whereby possibly unstable sites may be identified is introduced.

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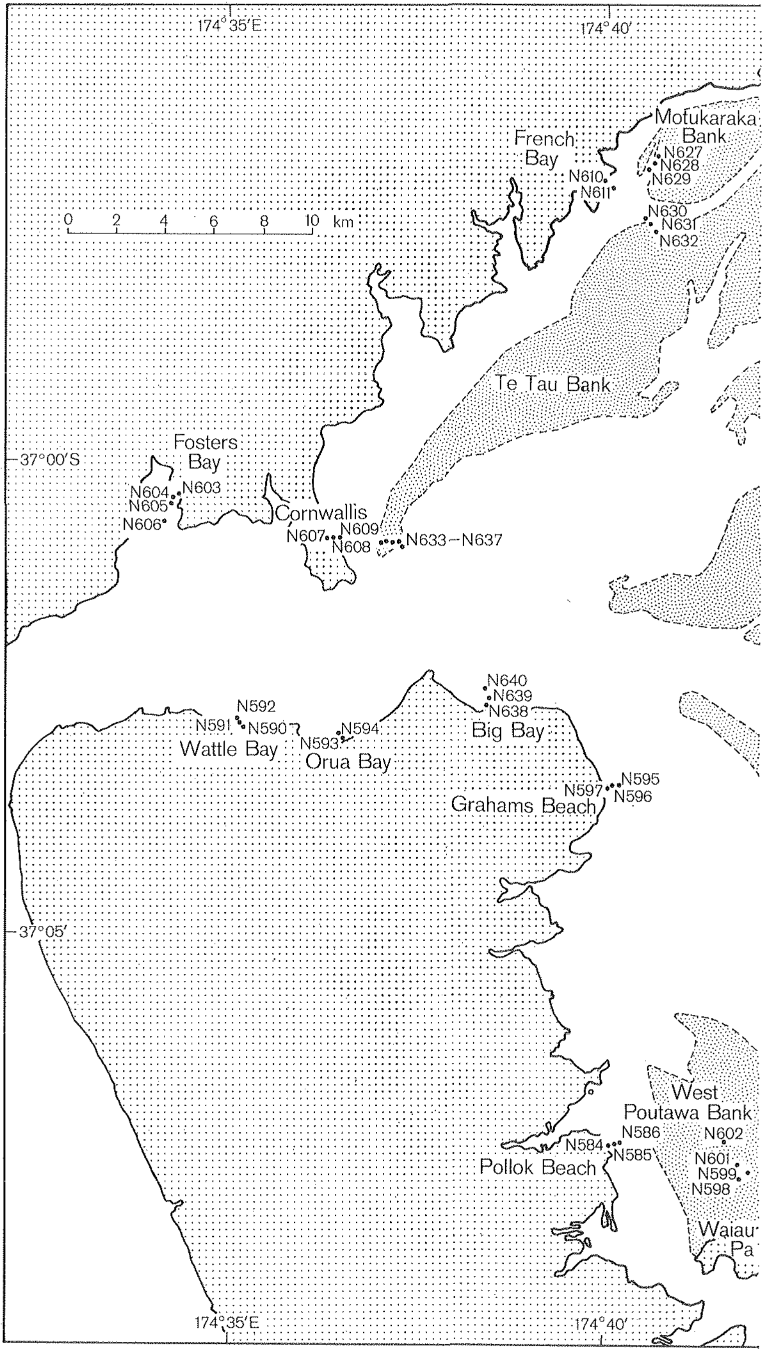
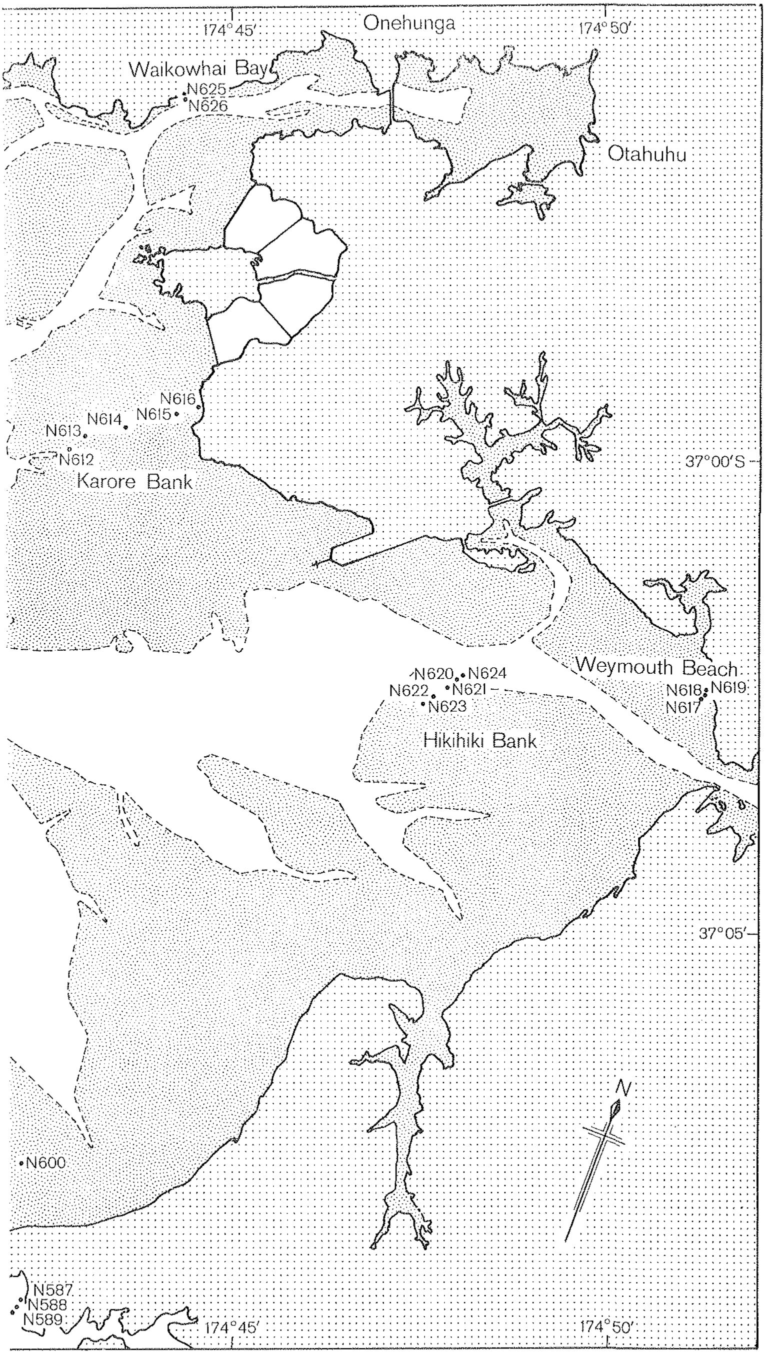


FIG. 1—Stations in Manukau Harbour at which littoral



benthic organisms and sediments were sampled, August 1975.

METHODS

Seventeen different intertidal sand-flat areas were sampled during August 1975 for species composition and sediment type; a total of 57 stations (NZOI Stns N584–N640) were occupied. Station sites were selected so as to cover most of the expected different habitats within the harbour, but the reaches above Onehunga were not included because they are under stress from industrial pollution; the intent of the study is to give background information on the "natural" ecology of a harbour of this type. Stations were sited both in bays and on offshore banks (Fig. 1).

Although the number of stations is inadequate to give detailed information on any one part of the harbour, data obtained allow definition of several morphologically distinct areas and of the composition of the biological communities and sediments.

All stations were sampled using a soft-sediment sampler which removes a 0.1 m^2 slab of sediment to a depth of 10 cm (Grange & Anderson 1976). The complete sample was washed through a 1.0 mm sieve, and all biological material retained by the sieve was preserved in 70% isopropyl alcohol for later analysis. Specimens were identified, counted, and categorised into one of four feeding classes: deposit feeders, suspension feeders, carnivores and scavengers, and herbivores.

A sediment sample 5 cm $\times$ 5 cm $\times$ 2 cm deep was collected from each station, and a profile of the sediment down to a depth of 50 cm was removed using a clear perspex tube 9 cm in diameter, fitted with a vacuum seal on the top. The untreated sediment samples were washed through a series of six sieves and the fractions coarser than -1ϕ, -1ϕ to 0ϕ, 0ϕ to 1ϕ, 1ϕ to 2ϕ, 2ϕ to 3ϕ, 3ϕ to 4ϕ, and finer than 4ϕ were separated and weighed ($\phi = -\log_2$ grain size in mm). Cumulative percentages were calculated, plotted on arithimetic graph paper, and the graphic mean diameter (M_d) and the mean grain size (M_z) from the 5, 16, 50, 84, and 95 percentiles calculated (Folk 1965).

RESULTS

The biology and feeding methods of many of the species collected are not well known, but species were assigned to feeding classes after examining gut contents, from evidence in the literature, and from discussions with workers who have studied similar species (Table 1). Some species are capable of more than one mode of feeding, e.g., the polychaete *Owenia fusiformis* is normally a suspension feeder, but is capable of detrital feeding by bending over from its tube and feeding on the surface detritus when suspended food is in short supply (I. N. Estcourt, NZOI, pers. comm.). In the intertidal zone, however, wave action and tidal currents are likely to keep sufficient food in suspension, so this species has been classified here as a suspension feeder.

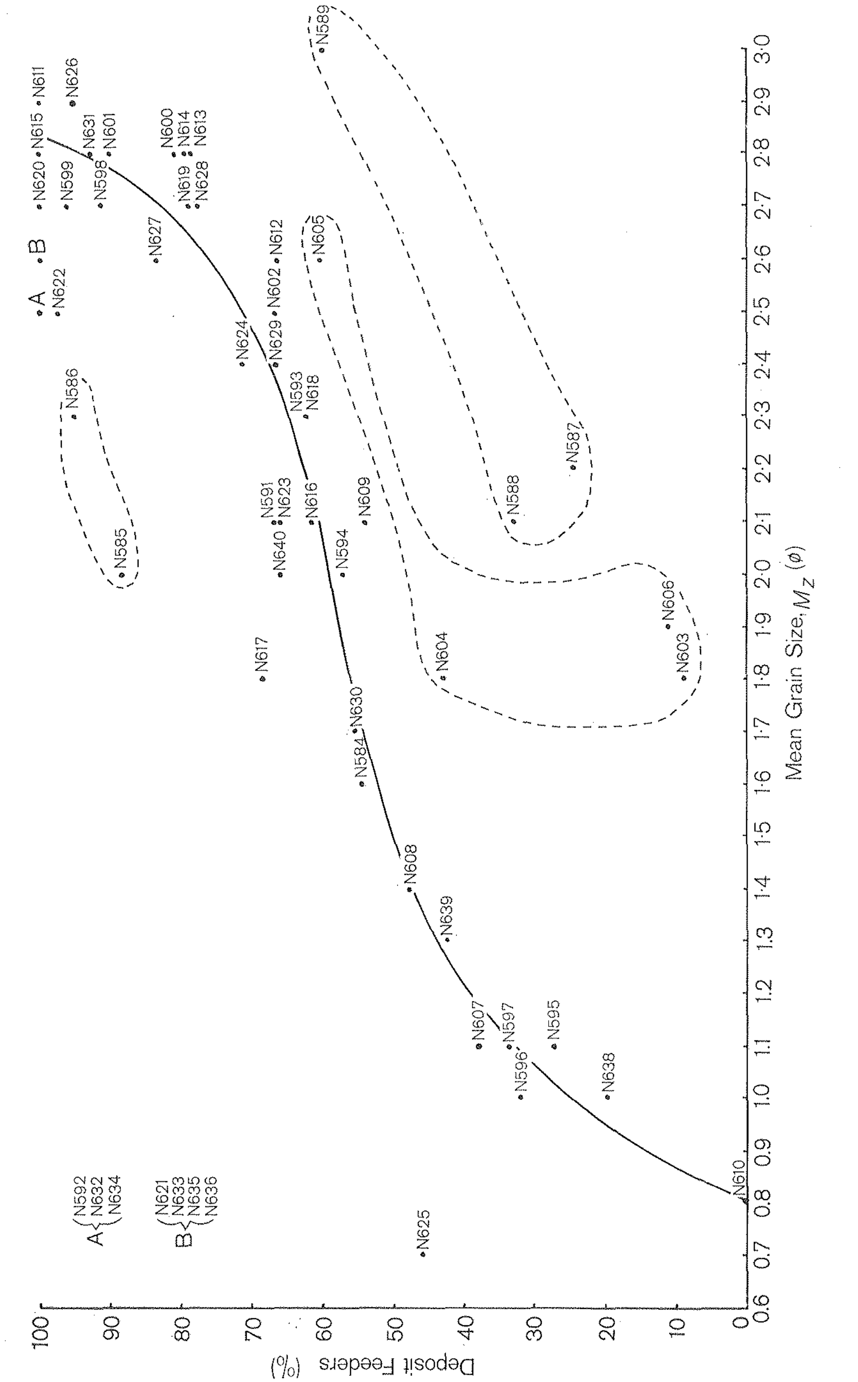
The most widespread species are the bivalves *Macomona liliana*, *Chione stutchburyi*, *Soletellina siliqua* and *Nucula hartvigiana*, the anemone *Anthopleura aureoradiata*, and the polychaete *Owenia fusiformis* (Table 1). Table 1 also gives the average of the mean grain sizes (M_z) of the stations where each species occurs, as well as the mean grain size of the station where the greatest number of individuals of each species occurs (Optimum M_z). By averaging the optimum mean grain sizes for all members of each feeding class, average optimum grain size values by class are:

Deposit feeders = 2.6ϕ
Carnivores/scavengers = 2.4ϕ
Suspension feeders = 1.9ϕ

Thus, deposit feeders favour the finer sediments (fine sand), while suspension feeders favour medium sand.

The percentage of deposit feeders at each station plotted as a function of grain size (Fig. 2) again shows that a clear relationship exists between the trophic level of the benthos and the fineness of the sediment; the proportion of deposit feeders increases with a decrease in the grain size of the sediment. Both mean grain size and median grain size have been used because, in some stations, sorting is poor and mean grain size gives a bias when much very fine or very coarse material is present. Stations on the graphs are not grouped according to locality, nor to tidal level; the sediment characteristics determine the type of community present.

Three groups of stations (N585, N586; N587, N588, N589; N603, N604, N605, N606) do not lie near the line of best fit on either graph. These stations appear to have a community composition incompatible with the grade of sediment in which they occur and therefore are believed to represent unstable situations. The anomalous Stns N587, N588, N589, which all lie well below the line of best fit, are all from a single beach near Waiau Pa, indicating that there are not enough deposit feeders for the sediment grade, or alternatively that there is an over-abundance of suspension feeders. All the suspension feeders present at these stations were adult specimens of *Chione stutchburyi*, while all the deposit feeders were juvenile *Macomona liliana*, *Nucula hartvigiana*, *Helice crassa*, *Macrophthalmus hirtipes*, and *Haploscoloplos cylindrifer*. No juvenile suspension feeders or adult deposit feeders were collected, indicating that a change in community structure is occurring. The result will be an increase in the proportion of deposit feeders, since no suspension feeding species are settling. Sediment profiles at these stations show a layer of silt up to 5 cm deep covering a deeper layer of sand; silt thus appears to be accumulating on this beach. The larvae of the two feeding classes are responding to this top layer, and only deposit feeders are settling. The adult filter feeders present probably settled before the finer sediment began accumulating and have survived by maintaining themselves above the smothering effect of the sediment. *Chione stutchburyi* is a very mobile bivalve and would have no



Deposit Feeders (%)
Mean Grain Size, M_Z (ø)
0 10 20 30 40 50 60 70 80 90 100
0·6 0·7 0·8 0·9 1·0 1·1 1·2 1·3 1·4 1·5 1·6 1·7 1·8 1·9 2·0 2·1 2·2 2·3 2·4 2·5 2·6 2·7 2·8 2·9 3·0
A {N592 N632 N634
B {N621 N633 N635 N636
A
B
N620 N615 N611 N626 N599 N631 N601 N598 N600 N614 N613 N619 N628 N627
N622 N612 N602 N624 N629 N593 N618 N605 N589 N586 N585 N591 N623 N616 N640 N609 N594
N587 N588 N606 N603 N604 N617 N630 N584 N608 N639 N607 N597 N595 N596 N638 N610 N625

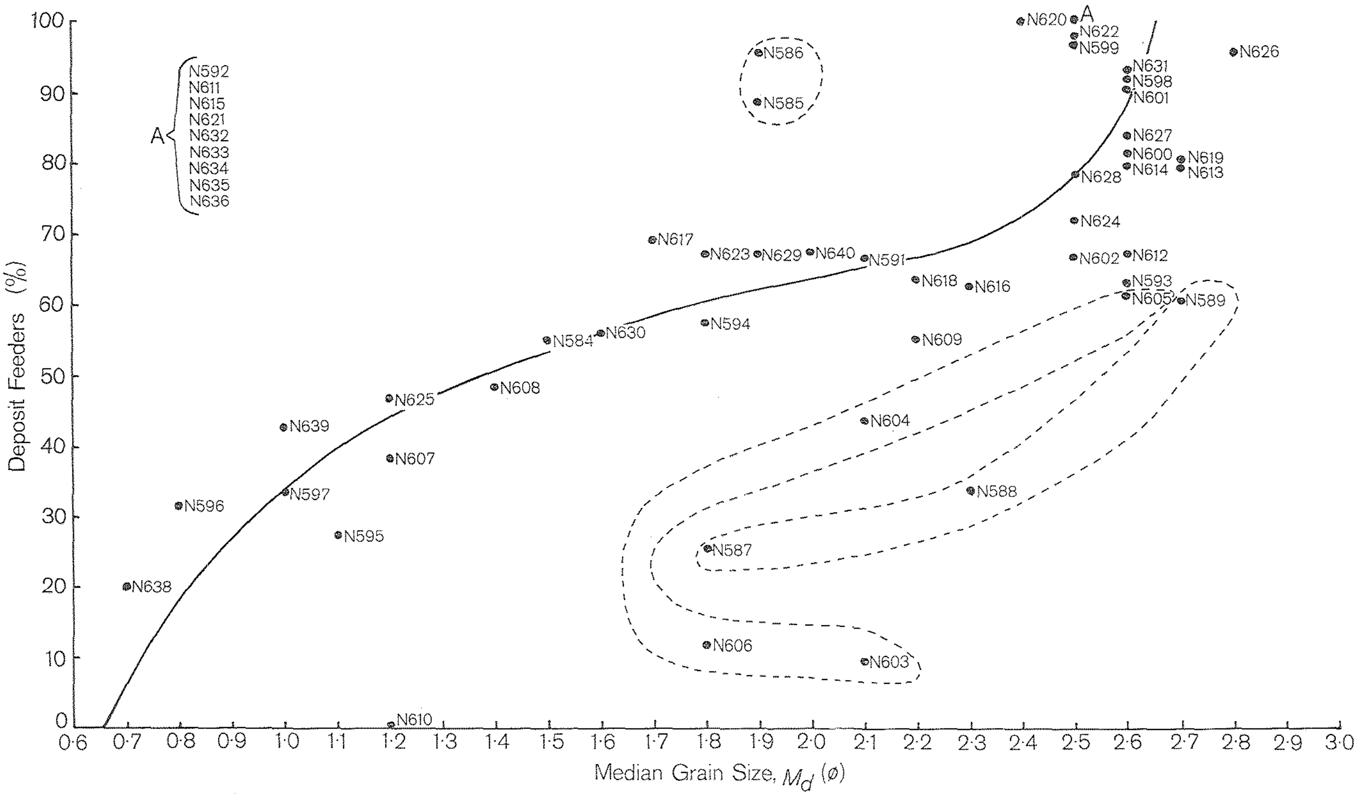


FIG. 2—Percentage of deposit feeding individuals plotted against mean (*upper*) and median (*lower*) grain size of the sediment at each station, Manukau Harbour, August 1975 ('unstable' stations enclosed within broken lines).

TABLE 1—Species collected at littoral sampling stations, Manukau Harbour, August 1975 (references indicate the authority from which methods of feeding were established; C = Carnivore or Scavenger, D = Deposit feeder, H = Herbivore, S = Suspension feeder; *Mz* = mean grain size in phi units)

Species	Feeding Type	Reference	No. of Stns Where Found	Average M_z (ϕ)	Optimum M_z (ϕ)
AMPHINEURA					
Amaurochiton glaucus	H	Morton & Miller (1968, p. 96)	2	1.8	1.8
Sypharochiton pelliserpentis	H	Morton & Miller (1968, p. 96)	1	2.8	–
BIVALVIA					
Macomona liliana	D	Morton & Miller (1968, p. 488)	30	2.3	2.7
Chione stutchburyi	S	Morton & Miller (1968, p. 488)	27	2.0	2.1
Soletellina siliqua	D	Morton & Miller (1968, p. 464)	24	2.1	2.8
Nucula hartvigiana	D	Morton & Miller (1968, p. 517)	20	2.3	2.9
Paphies australe	S	Morton & Miller (1968, p. 488)	13	1.4	1.8
Cyclomactra ovata	S	Morton & Miller (1968, p. 516)	5	2.3	2.0
Dosinia subrosea	S	Morton & Miller (1968, p. 463)	4	2.4	2.1
Theora lubrica	D	Pers. observ.	3	2.3	2.3
Myadora striata	S	Pers. observ.	2	2.1	2.1
Paphies subtriangulatum	S	Miller & Batt (1973, p. 88)	1	2.1	–
Paphirus largillierti	S	Morton & Miller (1968, p. 543)	1	1.9	–
Dosinia maoriana	S	Pers. observ.	1	2.1	–
Pecten novaezelandiae	S	Morton & Miller (1968, p. 548)	1	2.0	–
Diplodonta zelandica	D	Pers. observ.	1	2.7	–
Myadora boltoni	S	Pers. observ.	1	2.4	–
GASTROPODA					
Cominella glandiformis	C	Morton & Miller (1968, p. 444)	12	2.3	2.3
Cominella adspersa	C	Morton & Miller (1968, p. 490)	11	2.5	2.7
Pervicacia tristis	C	Morton & Miller (1968, p. 492)	9	2·4	2·4
Baryspira australis	C	Grange (1976)	8	2·5	2·4
Diloma novaezelandiae	D	Pers. observ.	7	2.5	2.6
Zeacumantus lutulentus	D	Morton & Miller (1968, p. 520)	3	2.3	2.5
Xymene plebeius	C	Morton & Miller (1968, p. 546)	3	1.7	1.7
Zethalia zelandica	D	J. E. Morton (pers. comm.)	2	2.6	2.6
Epitonium jukesianum	C	Morton & Miller (1968, p. 546)	1	2.3	–
Amphibola crenata	D	Morton & Miller (1968, p. 520)	1	2.1	–
Notoacmea helmsi	H	Morton & Miller (1968, p. 488)	1	2.1	–
Philine auriformis	C	Morton & Miller (1968, p. 544)	1	2.7	–
Struthiolaria papulosa	D	Morton (1951)	1	2.4	–
POLYCHAETA					
Owenia fusiformis	S	I. N. Estcourt (pers. comm.)	23	2.3	2.3
Platynereis australis	D	I. N. Estcourt (pers. comm.)	11	2.0	1.6
Aglaophamus macroura	C	Morton & Miller (1968, p. 548)	10	2.4	2.5
Goniada emerita	C	Morton & Miller (1968, p. 494)	10	2.1	2.7
Haploscoloplos cylindrifer	D	I. N. Estcourt (pers. comm.)	8	1.9	2.8
Pectinaria australis	D	Morton & Miller (1968, p. 500)	5	2.5	2.5
Glycera americana	C	Morton & Miller (1968, p. 548)	4	2.1	2.5
Glycera lamellipodia	C	Pers. observ.	4	1.8	2.1
Phyllodoce castanea	C	I. N. Estcourt (pers. comm.)	3	2.5	2.5
Scolecolepides benhami	D	I. N. Estcourt (pers. comm.)	3	2.1	2.7
Macroclymenella stewartensis	D	Morton & Miller (1968, p. 498)	2	2.7	2.7
Maldanid sp.	D	Pers. observ.	2	2.7	2.8
Lumbrinereis sp.	D	I. N. Estcourt (pers. comm.)	2	2.1	2.1
Prionospio pinnata	D	Pers. observ.	1	2.8	–
Capitella capitata	D	Morton & Miller (1968, p. 530)	1	2.5	–
Travisia olens	D	Morton & Miller (1968, p. 499)	1	2.7	–
Nephtys macroura	C	I. N. Estcourt (pers. comm.)	1	2.5	–
Sabellaria kaiparaensis	S	Morton & Miller (1968, p. 65)	1	1.3	–
Polydora sp.	S	Pers. observ.	1	1.7	–
CRUSTACEA					
Helice crassa	D	Morton & Miller (1968, p. 522)	3	2.0	2.2
Hymenicus cooki	D	Pers. observ.	7	2.5	2.7
Isocladus armatus	C	Morton & Miller (1968, p. 481)	6	1.8	2.0
Macrophthalmus hirtipes	D	Morton & Miller (1968, p. 522)	9	2.5	2.9
Pontophilus australis	C	Pers. observ.	4	2.4	2.8
Callianassa filholi	D	Morton & Miller (1968, p. 458)	1	2.5	–
Elminius modestus	S	Morton & Miller (1968, p. 59)	1	0.8	–
Alpheus sp.	C	Morton & Miller (1968, p. 524)	1	1.8	–

TABLE 1—(*continued*)

SPECIES	FEEDING TYPE	REFERENCE	NO. OF STNS WHERE FOUND	AVERAGE M_z (ϕ)	OPTIMUM M_z (ϕ)
ANTHOZOA					
Anthopleura aureordiata	C	Pers. observ.	26	2.1	2.6
HEMICHORDATA					
Balanoglossus australiensis	D	Morton & Miller (1968, p. 502)	1	2.5	–
HOLOTHUROIDEA					
Trochodota dendyi	D	Morton & Miller (1968, p. 503)	5	2.7	2.8
Kolostoneura novaezelandiae	D	Pers. observ.	2	2.6	2.6
ECHINOIDEA					
Fellaster zelandiae	D	Morton & Miller (1968, p. 504)	5	2.6	2.6
OPHIUROIDEA					
Amphiura aster	D	Morton & Miller (1968, p. 505)	4	2.5	2.5
PISCES					
Rhombosolea plebeia	C	Pers. observ.	1	2.7	–

difficulty in moving through the soft sediments to position its short siphons above the sediment surface.

A very similar situation occurs at Fosters Bay, Huia (Stns N603, N604, N605, N606). The suspension feeders are here dominated by adult *Paphies australe* and *Chione stutchburyi* and, although no obvious layer of fine silt covers the whole beach, fine sand has accumulated amongst the *P. australe*, which lie only partially buried. At Stn N606, 54 adult *P. australe* (up to 5 cm in shell length) were collected, but there were no juveniles. Such a large number of shells protruding from the surface may cause a decrease in current across the bottom, allowing finer particles to settle out of suspension and accumulate around the shells. Larvae about to settle would respond to this upper layer of silt, which thus favours deposit feeders. Since no juvenile *P. australe* were found but juvenile *Macomona liliana* were common, a community change seems inevitable as the adult *P. australe* die.

At Pollok Beach (Stns N585, N586) there is an over-abundance of deposit feeders for the coarseness of the sediment, i.e., the sediment on this beach is not as fine as would be predicted from the community structure. Profiles of the sediment at these two stations show a shell and sand mixture from the surface down to 20 cm, where a layer of consolidated grey clay occurs. The predominant species at Stn N585 are the deposit feeders *Nucula hartvigiana* and *Soletellina siliqua*, which have optimum grain sizes of 2.9ϕ and 2.8ϕ respectively (Table 1); Stn N586 is dominated by *Nucula hartvigiana*. The mean grain sizes of Stns N585 (2.0ϕ) and N586 (2.3ϕ) (Table 2) are well above these optimum grain sizes. Some species may thus be living in conditions to which they are not fully suited, and some could be replaced by others

TABLE 2—Mean grain size (M_z), median grain size (M_d), and the percentage of deposit feeders at each littoral sampling station, Manukau Harbour, August 1975. (Percentage of deposit feeders at each station = Number of deposit-feeding individuals/Total number of deposit-feeding + suspension feeding individuals × 100; – = no deposit or suspension feeders present)

NZOI STN NO.	POSITION Latitude (° 'S)	Longitude (° 'E)	M_z (ϕ)	M_d (ϕ)	DEPOSIT FEEDERS %
N 584	37 07.25	174 40.08	1.6	1.5	54.5
N 585	37 07.25	174 40.12	2.0	1.9	88.4
N 586	37 07.22	174 40.23	2.3	1.9	95.1
N 587	37 08.03	174 42.10	2.2	1.8	25.0
N 588	37 08.93	174 42.18	2.1	2.3	33.1
N 589	37 08.86	174 42.28	3.0	2.7	60.0
N 590	37 02.80	174 35.20	2.0	1.8	–
N 591	37 02.76	174 35.18	2.1	2.1	66.7
N 592	37 02.72	174 35.11	2.5	2.5	100.0
N 593	37 02.98	174 36.58	2.3	2.6	62.5
N 594	37 02.92	174 36.52	2.0	1.8	57.1
N 595	37 03.48	174 40.10	1.1	1.1	27.3
N 596	37 03.52	174 40.04	1.0	0.8	31.8
N 597	37 03.53	174 40.00	1.1	1.0	33.4
N 598	37 07.60	174 41.87	2.7	2.6	91.5
N 599	37 07.65	174 41.95	2.7	2.5	96.6
N 600	37 07.40	174 42.30	2.8	2.6	80.7
N 601	37 07.42	174 41.80	2.8	2.6	90.0
N 602	37 07.12	174 41.63	2.5	2.5	66.7
N 603	37 00.38	174 34.36	1.8	2.1	9.1
N 604	37 00.40	174 34.34	1.8	2.1	43.3
N 605	37 00.45	174 34.29	2.6	2.6	60.8
N 606	37 00.66	174 34.15	1.9	1.8	11.1
N 607	37 00.84	174 36.32	1.1	1.2	38.3
N 608	37 00.84	174 36.36	1.4	1.4	48.1
N 609	37 00.84	174 36.42	2.1	2.2	54.5
N 610	37 57.05	174 39.96	0.8	1.2	0.0
N 611	36 57.13	174 40.10	2.9	2.5	100.0
N 612	36 59.86	174 42.90	2.6	2.6	66.7
N 613	36 59.70	174 43.18	2.8	2.7	78.6
N 614	36 59.64	174 43.64	2.8	2.6	79.4
N 615	36 59.50	174 44.38	2.8	2.5	100.0
N 616	36 59.42	174 44.61	2.1	2.3	62.0
N 617	37 02.44	174 51.23	1.8	1.7	68.6
N 618	37 02.48	174 51.25	2.3	2.2	63.0
N 619	37 02.51	174 51.30	2.7	2.7	79.1
N 620	37 02.34	174 48.06	2.7	2.4	100.0
N 621	37 02.60	174 47.56	2.6	2.5	100.0
N 622	37 02.52	174 47.73	2.5	2.5	97.8
N 623	37 02.41	174 47.91	2.1	1.8	66.7
N 624	37 02.29	174 48.15	2.4	2.5	71.4
N 625	36 56.11	174 44.39	0.7	1.2	46.6
N 626	36 56.16	174 44.41	2.9	2.8	95.3
N 627	36 56.80	174 40.61	2.6	2.6	83.6
N 628	36 56.83	174 40.68	2.7	2.5	77.8
N 629	36 56.98	174 40.72	2.4	1.9	66.7
N 630	36 57.44	174 40.50	1.7	1.6	55.6
N 631	36 57.51	174 40.55	2.8	2.6	93.0
N 632	36 57.58	174 40.62	2.5	2.5	100.0
N 633	37 00.09	174 37.10	2.6	2.5	100.0
N 634	37 00.09	174 37.15	2.5	2.5	100.0
N 635	37 00.09	174 37.21	2.6	2.5	100.0
N 636	37 00.09	174 37.28	2.6	2.5	100.0
N 637	37 00.10	174 37.31	2.6	2.5	–
N 638	37 02.60	174 38.41	1.0	0.7	20.0
N 639	37 02.55	174 38.46	1.3	1.0	42.9

with optimum grain sizes nearer that of the existing sediment, such as *Chione stutchburyi* (optimum grain size 2.0ϕ). Several juvenile *C. stutchburyi* were collected at Stn N585, but none were found at Stn N586. At Stn N586, juveniles of the suspension feeding tube-dwelling polychaete *Owenia fusiformis* (with an optimum grain size of 2.6ϕ) were collected.

Pollok Beach is across a narrow tidal channel from Waiau Pa (Fig. 1), where silting up appears to be occurring. The current through this channel may have formerly swept along the eastern side nearer Waiau Pa, preventing fine sand and mud from settling there, and perhaps a recent change in current position has occurred so that the main current now sweeps the western side of the channel, removing the fine sediment previously deposited at Pollok Beach, and the reduced currents on the eastern side allow silt to accumulate on Waiau Pa. No direct evidence could be found to support or reject this hypothesis from hydrographic charts or aerial photographs, although recent data are not available. Some dredging is being done in Waiuku Channel, near Waiuku, and the spoil placed along the shoreline. An associated increase in suspended sediment may be accumulating on the beach at Waiau Pa, or the dredging may have caused changes in the channel currents. These two beaches will be monitored on subsequent visits to record any changes which may occur.

DISCUSSION

Sediment preferences of deposit feeders, suspension feeders, and carnivores have been reported from many subtidal studies, including Sanders (1958, 1960); McNulty *et al.* (1962a, 1962b); McKoy (1970); Pearson (1971); Young & Rhoads (1971), and the same general trend found to that demonstrated here: deposit feeders favour the finer sediments, carnivores and scavengers favour the intermediate grades, and suspension feeders are most abundant in coarser sediments. The reasons for these trends were first suggested by Sanders (1958) and have been summarised by Rhoads (1974). The size of particle theoretically most easily moved by currents is 0.18 mm (2.4ϕ), and sediment composed largely of particles of this size might represent optimum conditions for suspension feeders, because the presence of this sediment indicates stable conditions under which it is not likely to be easily moved into suspension and thus clog the filtering mechanisms of suspension feeders (Sanders 1958). In the intertidal, however, physical movement of particles is likely to be controlled more by wave action than by currents; the larger preferred grain size for suspension feeders, 0.27 mm (1.9ϕ), found in this study could thus be a reflection of the different physical environment.

Spatial segregation of deposit feeders and suspension feeders has been noted on a world-wide scale and termed "trophic group amenalism" (Rhoads & Young 1970). In the present study, a large difference in the optimum grain sizes of the two feeding groups was demonstrated, although the two groups are not mutually exclusive, perhaps because all stations sampled lie within a narrow range of sediment type (medium and fine sands); sites with large proportions of mud were sampled in some of the subtidal studies quoted above.

The data from Manukau Harbour permit the identification of three areas which appear unstable (Fig. 2). The remaining 46 stations lie close to the line of best fit on the graph and have a community structure appropriate for the sediment grade; juveniles and adults of both deposit and suspension feeders are present and the optimum grain sizes for the individual species are similar to the mean grain size of the sediment in which they occur. These stations are thought to be stable as long as the sediment grade does not change.

Changes in community structure at any one site will lag behind any changes in sediment grade because of the longevity of the individuals. If a change in sediment grade occurs rapidly and is long lasting, it will be followed by a slower change in community structure (e.g., Waiau Pa, Pollok Beach, and Fosters Bay). Monitoring these three areas will allow subsequent shifts in community structure and/or sediment grade to be recorded.

Plotting the percentage of deposit feeders against mean and median grain sizes of the sediment may be useful in identifying unstable, or at least suspect, sites in the intertidal area. Any change in the environment that causes the community structure and sediment grade to move out of equilibrium may produce an inherently unstable situation. This method may, therefore, have an application in pollution studies, but first the theory must be tested by long-term studies in several estuarine and harbour systems.

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