An Ecological Study of a Sandy Beach near Auckland, New Zealand

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[*Received by the Editor, December 6, 1966.*]

Abstract

During 1961 a quantitative survey of the distribution of the macro-fauna of Howick Beach, 14 miles east of Auckland on the Hauraki Gulf, was carried out together with a survey of the physico-chemical factors: (1) exposure to wave action; (2) tidal levels; (3) temperature; (4) sand grade; (5) calcium carbonate (shell) content; (6) organic content; (7) water content; (8) oxygen content; (9) hydrogen ion concentration; (10) salinity. The distribution of the fauna in relation to these physical factors, particularly sand grade, is discussed, and three physico-biological regions are delimited. The occurrence of the same species in association on Howick and other beaches, and the designation of these groups as Associations, is also discussed. The division of the beach into three zones based on the occurrence of the larger crustaceans as suggested by Dahl (1953) is commented upon.

INTRODUCTION

Little ecological study has yet been made of the faunas of the extensive sandy intertidal areas of New Zealand. In his classical pioneering survey of littoral marine communities in New Zealand, Oliver (1923) classified the animal associations in sandy areas by the dominant bivalves, and lists a few of the subordinate species. The only other published work is the short article by Ralph and Yaldwyn (1956) who investigated the differences between the *Austrovenus stutchburyi* (= *Chione stutchburyi** in this paper where molluscan nomenclature follows Powell, 1962) association of the sand banks, and the *Maoricolpus roseus* association of the channels of the Otago Harbour.

In the present study the qualitative and quantitative distributions of the macrofauna on a sandy beach (Howick) were investigated and the physico-chemical factors: (1) exposure to wave action; (2) tidal levels; (3) temperature; (4) sand grade; (5) calcium carbonate content; (6) organic content; (7) water content; (8) oxygen content; (9) hydrogen ion concentration; (10) salinity, of the beach were examined. A comparative study, between the fauna and physical properties of the sandy beach and those of an adjacent small sheltered beach and an area of *Zostera nana,* will be published as a separate paper.

HOWICK BEACH

(a) *Location, shelter and topography*

Howick Beach is typical of the moderately sheltered sandy beaches of the southern Hauraki Gulf outside the Waitemata Harbour. The most frequent and strongest winds of the Auckland area blow from the south and west and do not

produce erosive wave action on this beach. It is also sheltered from north and north-easterly storms by the arc of islands Rangitoto, Motutapu, Motuihe, Waiheke which limit the length of fetch for waves to a maximum of 12.8km (see Fig. 1).

The eastern extremity of the beach is marked by a cliffed headland (Fig. 2, A), though at low water of spring tides the sand flats extend along the coast for several miles past this point. The western boundary is a low reef of Waitemata sandstone (B) which breaks surface at about mid-tide. The rock basement (C) is free of sand except at its northern end where a small sandy area (D) occurs. This small beach is sheltered by reefs B and E which form a narrow entrance to the area at low tide. Directly on the landward side of the main reef (B), where its sheltering effect is greatest, a small patch of *Zostera nana* (F) had become established, some 300m long and varying from 5–50m wide.

The main beach is backed by a 1.8m-high retaining wall protecting a grassy terrace. Early in January, 1961, a topographical survey was carried out. From the retaining wall the beach sloped relatively steeply for 25m, then less steeply for a further 100m, and beyond this was almost flat to extreme low water of spring tides (Fig. 3). From a culvert in the retaining wall, fresh-water flowed across the middle of the beach area. Usually this water formed a small confined stream (Fig. 2, K) but sometimes split into several streamlets before finally becoming dispersed in the standing water between the ripple marks of the extensive flat area of the beach. A second small stream (L) followed a path across the main reef to the sea, and never approached the sandy area of the beach. During spells of dry weather in the summer these outflows of water dried up.

FAUNAL SAMPLING METHODS

(a) *Transect and stations; tidal levels*

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A transect line was set out from the foot of the stone steps in the sea wall on a bearing of 67 degrees true North (Fig. 2). The line was located in that part of the beach least likely to be affected by the fresh-water flow from the culvert. Stations were measured out with a tape every 45m along this transect. At every station two samples, each $0.1m^2$ in area and 20–25cm in depth, were taken, one from each side of the transect line.

Numbers per $0.1m^2$

OTHER SPECIES MENTIONED IN TEXT (FULL NAMES)

Arenicola assimilis Ashworth
Helice crassa Dana
Hemigrapsus crenulatus (M.-Edwards)
Lysiosquilla spinosa Wood-Mason
Arachnoides zelandiae Gray

Amphibola crenata (Martyn)
Maoricolpus roseus roseus (Quoy and Gaimard)
Modiolus neozelanicus (Iredale)
Solemya parkinsoni A. Smith
Zeacumantus lutulentus (Kiener)
Zediloma corrosa (A. Adams)

In order to determine the relative absolute heights of the transect stations, a calm day was chosen on which a tide of known recorded height (obtained from harbour authorities in Auckland) covered station 1. At the time of full tide the depth below the surface of station 1 was measured with a metre rule, thus giving a known height with respect to sea level of station 1. When the tide level had dropped to station 1 the depth below the surface of station 2 was measured and so on down the transect. A profile of the transect was then plotted on graph paper and the mean tidal levels given in the local tide tables were drawn in to scale (Fig. 3).

(b) *Sampling and sieving*

The sampler consisted of a pipe of 3mm thick iron, 40cm tall and 36cm diameter, with loops for an iron bar to fit across the top. This sampler was forced into the sand by pressing down on it and at the same time rotating it slowly until it sank to the required depth. In front of the sampler a small trench was then dug, and a spade pushed beneath the sampler, cutting off the contained sand from that below. The sampler was then tipped on its side, lifted out and its core of sand slipped into the top sieve of a tier of 3 square-mesh sieves. The mesh gauge of the top sieve was 12.5mm, of the middle sieve 3.125mm, and of the bottom sieve 1.25mm. The three sieves were clamped together and worked as a unit, the sieving being carried out in sea-water inside a circular galvanised iron tub. At stations 4 and 5 a hose was used to wash the sample through the sieves, but this tended to damage the polychaetes severely and the practice was discontinued.

The animals (macro-fauna) and debris retained by each sieve were bottled in sea-water and taken to the laboratory for sorting. No attempt was made in this survey to deal with species not retained by the 1.25mm mesh sieve, as the coarse nature of the material on much of Howick Beach made the use of a finer sieve impracticable.

This sampling and sieving technique enabled one person to collect and sieve two samples during the relatively short time (1–2 hours on the lower spring tides) the stations on the lower part of the beach were exposed. The method also avoided contamination of the sample from collapse of the surrounding sand, and furthermore enabled most of the delicate polychaetes to be collected without damage.

The weight of sand prohibited the taking of a larger sample by this method. Accepted practice in ecological work of this kind has been to take samples of $0.25m^2$ (Bruce, 1932; Moore, 1940; Holme, 1949; Southward, 1953). Comparisons between the two samples taken at each station on Howick Beach show that the smaller $0.1m^2$ samples were of sufficient size to assess the quantitative distribution of the numerically common species living in the sand. They did not give reliable quantitative data on the rarer species, nor on the animals with a clumped distribution pattern (e.g., *Cominella* spp.).

(c) *Sorting*

The sievings were sorted while still fresh in a large black-bottomed dish filled with sea-water. The material retained by the fine sieve at stations 1, 2 and 3 contained a large quantity of shell fragments. Small bivalves and gastropods were difficult to sort from this and so the following flotation technique was devised and adopted. The fine sievings were treated with alcohol, and after filtering, stirred in a beaker containing ethylene dibromide. The floating material (animals and a small amount of dead shell) was skimmed off and the animals sorted out. Stirrings were repeated until three consecutive ones each failed to disclose further animals.

DISTRIBUTION OF THE FAUNA OF THE MAIN BEACH (Table I)

(a) *Lamellibranchs* (Fig. 4)

Seven species were recorded, two of which, *Divaricella huttoniana* and *Myadora striata,* were represented by single specimens and are not shown in Figure 4.

Of the common bivalves recorded, the pipi, *Amphidesma australe,* occurred highest up the beach—from just below M.H.W.N. to just below M.S.L. *A. australe* is a filter feeder with a compressed, smooth, solid shell of average adult height 18mm and length 40mm (height was measured on a vertical from the umbo to the ventral margin; length was measured as the greatest distance between the anterior and posterior). It rests in the sand with its long axis vertical so that the posterior part of its shell just protrudes above the surface; its siphons are short and do not protrude past the edge of the shell. The large numbers (*c.* $1400/m^2$) at the upper limit of its range, with the exception of one individual, were all juveniles less than 5mm in height. The density of the adult animals which were localised around M.S.L. was about $400/m^2$.

The small (average adult height 5mm, length 6mm) deposit-feeding protobranchiate *Nucula hartvigiana* had a similar distribution to the adult pipis, living just below the surface of the sand in numbers of from $160/m^2$ to $320/m^2$.

The most numerous bivalve on the beach was the New Zealand cockle, *Chione stutchburyi,* a venerid with a moderately thick, swollen shell, concentrically and radially ribbed and of average adult height 30mm, length 36mm. A filter feeder possessing short siphons, it lives for the most part buried just beneath the surface of the sand. It is capable, however, of moving over the surface of the sand and was often observed doing so at low tide. *C. stutchburyi* dominated the beach from just below M.S.L. where the *A. australe* zone ended to just below M.L.W.N. Around M.L.W.N., where the cockles attained their maximum density, they occurred in numbers as high as $1930/m^2$.

Below this cockle zone down to E.L.W.S. there occurred a rather sparse ($20/m^2$) population of *Dosinia subrosea,* another filter feeding venerid with a moderately thick, somewhat compressed shell with fine concentric lamellae and of adult height about 48mm, length 45mm.

Macomona liliana was present on the beach from M.S.L. to M.L.W.S. This tellinid lies on its side in the sand at a depth of from 5 to 10cm. The fine, tentacle-like siphons reach above the sand to suck up the surface deposits on which it feeds. The shells are moderately thick, smooth and compressed, adult size about 45mm high and 70mm long. The only two individuals taken on the lower part of the beach (around M.L.W.S.) were of this size, while those between M.S.L. and M.L.W.N. where the population was denser ($40/m^2$) were about half the size.

(b) *Gastropods* (Fig. 5)

Commonly occurring on the beach were two herbivorous and three carnivorous species. The herbivores, *Notoacmea helmsi helmsi,* a small (adults 11.5mm long) thin-shelled acmaeid limpet, and *Zediloma subrostrata,* a sturdy-shelled trochid (adults 15mm × 14mm), were only found at stations 3, 4 and 5 where coarse shell material over which they grazed was abundant on the beach (Plate 1).

The carnivorous species, *Cominella glandiformis* (adults 24.5mm × 13mm), *C. adspersa* (adults 59mm × 35mm) (Cominellidae) and *Baryspira australis* (34mm × 19mm) (Olividae) were found at stations 3 to 9 where they ploughed through or over the sand in search of prey. *B. australis* occurred mainly on the lower parts of the beach, and was not as common as either of the two cominellids which ranged over the middle section of the beach. There was also a certain degree of segregation of the two cominellid species. *Cominella adspersa* was most common in the lower part of the middle of the beach, where it often occurred in heaps of between 30 and 40 individuals with only a few *C. glandiformis* present, while *C. glandiformis* occurred in heaps of up to 80 individuals higher up with few or no *C. adspersa* present. Because of the way these two species gathered around a *Chione stutchburyi* which they were devouring, the $0.1m^2$ samples used throughout the survey were too small and gave a very imperfect picture of the quantitative distribution of these two species.

A third *Cominella* species, *C. maculosa* occasionally occurred on the beach, but was never taken in a sample.

(c) *Polychaetes* (Fig. 6)

In the absence of recent comprehensive systematic work on New Zealand polychaetes from the North Island, it was not feasible to identify specifically the representatives of a number of genera encountered. For certain species which have been dealt with in a recent unpublished study by Mr J. S. Whitley, I am indebted for specific names. Specific and generic nomenclature in general follows Fyfe (1952). A full range of examples of the polychaetes studied has been deposited in the invertebrate reference collection of the University of Auckland, Zoology Museum.

Twenty-three species of polychaete worms were recorded, but nine of these were represented by only one or two individuals, and so are not shown in Figure 6.

Platynereis australis, an errant polychaete which builds a very thin parchment-like tube in which to live, and *Orbinia papillosa,* a more typical sedentary worm, were common at stations 2 and 3 but only one or two isolated individuals were recorded from stations lower down the beach.

The remaining 21 species except for two juvenile (< 4cm long) individuals of *Glycera* sp. and one individual of *Polydora* sp. were all taken from that part of the beach below station 3. Four species occured throughout this area—two errant forms which actively burrowed below the surface of the sand in search of food, a glycerid *Glycera* sp. and a nephthydid *Aglaophamus macroura,* and two sedentary species, a capitellid *Notomastus* sp. and a tube-building maldanid *Axiothella australis,* both of which " eat " sand and void it in the form of typical worm casts and pellets on the surface of the beach (Plate 1). *Glycera* sp. was not common anywhere on the beach and four of the six specimens taken at station 9 were juveniles. Adult *Aglaophamus macroura,* the commonest large polychaete had a relatively even distribution (*c.* 20 per m^2). Juveniles (< 3cm long) were taken throughout its range but at stations 8 and 9 they occurred in very high densities (*c.* 550 per m^2) (see Fig. 6).

Oridia sp. (Sabellidae), *Chaetozone* sp. (Cirratulidae), and *Travisia olens* (Opheliidae) all occurred only at E.L.W.S. (station 10), an area of the beach which was exposed only three times during 1961 (the period of the survey). Most of the *T. olens* taken were juveniles (< 2cm long), adults never being more common than one per sample. One adult did occur above E.L.W.S. at station 9. Both *Oridia* sp. and *Chaetozone* sp. were small enough to be washed through the finest sieve used for the study, so that the numbers of individuals recorded are probably a low estimate of the actual numbers which were present. Confined also to this lowest part of the beach were three of the less common species, *Sigalion* sp. (Sigalionidae), *Asychis* sp. (Maldanidae) and *Magelona papillicornis.*

The small spionid, *Polydora* sp. was almost invariably found living in a U-shaped tube formed in the prismatic layer of live *Chione stutchburyi* shells over 1.6cm high, but occasionally occurred in *Amphidesma australe* shells. Its distribution thus coincided with that of the suitable sized *C. stutchburyi* on the lower-beach. Of the remaining species no other information than that recorded in Figure 8 and Table I was collected.

(d) *Crustacea* (Fig. 5)

The talitrid amphipod *Talorchestia quoyana* was recorded only from station 1. Widely differing counts obtained for this species in the two samples taken can be attributed to the great activity of individuals when disturbed, with consequent escape of many during sieving, and to their habit of congregating under drift material unevenly scattered over the beach.

Several species of amphipods inhabited the beach below M.L.W.N. The two commonest were identified to their families—Phoxocephalidae and Haustoriidae, while the few remaining individuals were classed as "other amphipods", and are not shown in Figure 5. Four species of ostracods were also taken in this area of the beach, one of which, a "giant" ostracod, was identified as *Cyclasterope,* probably *C. zeylandica.* Except for one cirolanid individual, *Isocladus armatus* was the only isopod recorded from the beach and it was common only at stations 2 and 3.

The common sand shrimp, *Pontophilus australis,* was distributed relatively evenly over most of the beach below station 3, while the two commonest crabs, *Halicarcinus cooki* and *Hemiplax hirtipes,* were more or less restricted to stations 4, 5 and 6. A single specimen of *Hemigrapsus edwardsi* was also taken in this area and *Hemigrapsus crenulatus,* though not found on the sandy areas of the main beach, inhabited burrows beneath the clumps of *Modiolus neozelanicus* attached to the exposed rock basement bordering the middle of the beach.

Callianassa filholi was recorded only once in samples from the transect. Since it lives in burrows deeper than 20–25cm (the full depth of sampling) deeper diggings were carried out some distance from the transect line. These revealed that *C. filholi* was moderately common on the beach from about M.L.W.N. down, but no quantitative assessments were made of its numbers. For the same reason *Lysiosquilla spinosa* was not recorded from the transect stations, but it did occur on the beach below about M.L.W.N.

Another species not shown in Figure 5, *Elminius modestus,* was taken in small numbers attached to the shells of living *Amphidesma australe* and *Chione stutchburyi.*

(e) *Other fauna* (Fig. 4)

The large yellow acorn worm, *Balanaglossus australiensis,* was present on the beach from just below M.S.L. (station 4) down. Its density increased down this area to below M.L.W.S. (station 10), where up to 100 adults and 450 juveniles ($<$ 5cm long) per m^2 were recorded.

Three species of Echinodermata were taken on the beach. *Amphiura aster,* a burrowing ophiuroid, and *Trochodota dendyi,* a burrowing synaptid holothurian, were both taken in transect samples but the cake urchin, *Arachnoides zelandiae,* was found only once when digging was carried out off the transect line at about M.L.W.S.

Nemertines were present on the beach but no specific identifications were made. Their tendency to fragment, and their habit of actively crawling through the sieve mesh, made accurate estimation of their numbers practically impossible.

Anthopleura aureoradiata, a small sea-anemone attaching itself to the shells of *Amphidesma australe* and *Chione stutchburyi* was common only in a restricted belt between about M.S.L. and M.L.W.N. even though *C. stutchburyi,* but not *Amphidesma australe* was present in large numbers well below M.L.W.N. It was not clear what factors prevented *Anthopleura aureoradiata* from occurring in greater numbers below M.L.W.N. though possibly it lacked a really suitable substratum, since it was found to be far more commonly attached to *Amphidesma australe* than to *C. stutchburyi* where these two species occurred together.

THE BEACH MATERIAL, WATER TABLE, AND SAND-GRADE ANALYSIS

(a) *Methods*

At each station samples of sand were collected from the top 2.5cm, and from between 8cm and 12cm below the surface. Contamination of the sub-surface samples by material from above was avoided by taking the samples from within the iron pipe sampler described earlier. After the top samples had been taken, the sand was cleanly dug out to a depth of 8–9cm and the sub-surface samples then taken.

To obtain a suitably sized sub-sample on which to carry out the particle size analysis, oven-dried (about 105° C) sand was put through a sample splitter which worked on the principle of dividing a sample into two equivalent halves. Each of the halves in turn could be divided into quarters of the original sample, and so on, until a sub-sample of the required size was obtained. In construction, the splitter consisted of a rectangular hopper from the bottom of which 24 shutes (each 1.2cm wide) ran off alternately to the left and right. Sand, poured into the hopper, passed down the shutes into tins on either side.

Analysis was carried out by dry sieving in a mechanical shaker about 100g of the oven-dry sand for 20 minutes through six sieves of the B.E.S.A. series. The sieves chosen had mesh openings of 2.057mm, 1.003mm, 0.500mm, 0.251mm, 0.124mm, and 0.066mm, since these very closely approximate to the Wentworth series recommended by Morgans (1956) as most suitable for the gradation of marine sediments. Material retained by the 2.057 sieve has here been called coarse shell; by the 1.003 sieve, fine shell; by the 0.500 sieve, coarse sand; by the 0.251 sieve, medium sand; by the 0.124 sieve, fine sand; by the 0.066 sieve, very fine sand; and that which passed through the 0.066 sieve, silt and clay. No treatment other than drying was carried out on the sand prior to sieving, nor was the silt and clay fraction analysed further as it was never more than 5% of a sample.

(b) *Results*

The grade of sand at the different levels down the beach was compared by graphing the values of the arithmetic means of the sand samples taken (Figs. 8a and 9a). To obtain the arithmetic mean, the mean of the upper and lower limits of each particle size class was multiplied by the percentage weight in that class. The products were then summed and the total divided by 100. Three main " texture types " were evident.

The beach material on the surface at station 1 was composed of broken shells of the bivalves *Amphidesma australe* and *Chione stutchburyi,* generally loose dry sand (at low tide there was no free water in the sand), and a small amount of algal and other debris. There was no " black-sand " layer above the bedrock.

The arithmetic mean was 0.806, " texture type " 1. Medium and fine sand formed the bulk (72.23%) of the deposit (Fig. 7a), and the remaining 28% was all coarser material except for negligible amounts (see Appendix I) of very fine sand, silt and clay.

At stations 2 and 3 the surface material was much more compacted than at station 1, containing many whole valves of *Amphidesma australe* and *Chione stutchburyi* (Plate 1), as well as a high proportion of broken shell. The water table here lay 15cm below the surface at low water of spring tides, and water never stood on the surface after the tide had receded. At a depth of 10–12cm the brown surface sand merged gradually into grey sand which extended to bedrock. No grey sand was present when the rock basement was less than 15cm below the surface.

As shown by the arithmetic means (1.018 at station 3, 1.287 at station 2) the beach material at these two stations was coarser (type 2) than at station 1. This was due to the higher coarse shell content (22% at station 3, 33.29% at station 2, cf. 14.87% at station 1) and correspondingly lower medium sand content, the percentages of the remaining sand grades being similar for all three stations (see Appendix I).

Stations 6–10 were exposed only during spring tides, and even then standing water was always present between the ripple marks. Very few shell fragments were present in the beach material, and at a depth of 4–5cm the brown surface sand was fairly sharply demarcated from a " grey-black sand " layer which continued downward for more than 60cm (the full depth of digging). No odour of hydrogen sulphide was ever detected from this sub-surface sand. The texture of the surface sand was much finer than at stations 1, 2 and 3, arithmetic means ranging between 0.175 and 0.128 (type 3). At station 6, 92% of the beach material was fine or very fine sand, and at station 10 the combined percentage of these two grades reached 99% (Fig. 7e, f).

Stations 4 and 5 had a similar water table and " grey-black sand " layer as stations 6–10, but the texture of the beach material was intermediate between the fine deposit at the stations lower down the beach and the very coarse deposit at the stations higher up the beach. However, station 5 was more similar to stations 6–10 than to stations 2 and 3, 80% of the deposit being fine or very fine sand and only 7% coarse shell (Fig. 7d). Station 4 on the other hand, was more like stations 2 and 3 than stations 6–10, the deposit containing 19.78% coarse shell, and only 41.37% fine or very fine sand (Fig. 7c).

The analysis of the sub-surface material showed it to be finer than the surface material at most of the stations 4–10, much finer than the surface material at station 1, but coarser than the surface material at 2 and 3 (Appendix I). However, the trend in the change of texture down the beach was very similar to that of the surface deposit (Fig. 9a cf. 8a).

This analysis shows that the beach deposit was far from uniform in texture throughout the beach. Minor changes of the beach were noticed, but the three main " texture types " remained a characteristic feature of the beach during the whole time of the study.

FAUNAL ASSOCIATIONS AND THE DIVISION OF THE BEACH INTO PHYSICO-BIOLOGICAL REGIONS

(a) *Associations*

At station 1 the beach harboured only one species of the macro-fauna, *Talorchestia quoyana.* An association somewhat less restricted in the variety of its macro-fauna species occurred on the beach at stations 2, 3 and 4, the dominant species being *Amphidesma australe. Nucula hartvigiana, Zediloma subrostrata, Isocladus armatus* and *Platynereis australis* were also confined in their distribution to these stations, and *Notoacmea helmsi helmsi* and *Anthopleura aureoradiata* attained their maximum densities here (see Table I).

Chione stutchburyi was the dominant species at stations 5, 6 and 7. Together with it were four dependent species—*Cominella adspersa, C. glandiformis* (predators), *Polydora* sp. and *Anthopleura aureoradiata* (using the shells for substrate), and eight species which were ubiquitous from stations 4–10—*Macomona liliana, Axiothella australis, Notomastus* sp., *Aglaophamus macroura, Glycera* sp., *Halicarcinus cooki, Pontophilus australis and Balanoglossus australiensis* (see Table I). Two further species should also be included in this association, *Hemiplax hirtipes* which occurred only at stations 4, 5 and 6, and *Lepidastheniella comma* at stations 5 and 6.

Another association at stations 8, 9, and 10 could be distinguished and characterised by the bivalve *Dosinia subrosea.* Other species included *Baryspira australis, Amphiura aster, Leanira* sp., *Podarke* sp., a goniadid polychaete, *Nebalia* sp., haustoriid, phoxocephalid and other amphipods, ostracods, and the eight species previously mentioned as being ubiquitous from stations 4–10.

Six polychaetes *Chaetozone* sp., *Magelona papillicornis, Oridia* sp., *Sigalion* sp., *Asychis* sp., and *Travisia olens* occurred at station 10 and nowhere else on the beach. These species probably represented the shoreward fringe of a completely sub-littoral association as station 10 was uncovered only three times during 1961 by extremely low spring tides.

Thus three main associations can be distinguished on Howick Beach, and these can be characterised by the bivalve species in them, namely:

(1) *Amphidesma australe–Nucula hartvigiana* association.

(2) *Chione stutchburyi–Macomona liliana* association.

(3) *Dosinia subrosea–Macomona liliana* association.

Possibly there was the edge of a fourth association at the very bottom of the beach, and at the top of the beach an association containing only one species of the macro-fauna, *Talorchestia quoyana,* was manifestly present.

(b) *Physico-biological regions*

On correlating the distribution of the fauna with the sand grade and general features of the beach it was possible to divide the beach into three main physico-biological regions.

At station 1 the beach sloped steeply and the moderately coarse deposit was consequently well drained. Algal and other organic debris lay about on the surface making the area ideal for *Talorchestia quoyana,* the only species recorded of the macro-fauna. These conditions extended for 25m down the beach and this region was designated the upper beach region (Fig. 2, G).

The beach at stations 2, 3 and 4 was characterised by having a high proportion of coarse often unbroken shell in with the relatively coarse sand, and very little of the finest sand and silt grades. It sloped less steeply than the upper beach and was fairly well drained, the water table standing at 15cm below the surface at low tide except at station 4. M.L.W.N. was below station 4 so the area was almost always uncovered at low tide. Coincident in extent with this freely drained coarse deposit was the *Amphidesma australe–Nucula hartvigiana* association, and this region was termed the middle beach region (Fig. 2, H, and Plate 1).

The remainder of the beach (stations 5–10) was uncovered, to varying extents, only by spring tides. It was practically flat, poorly drained, and a "grey-black sand" layer was present not far below the surface. The texture of the deposit was fine. Throughout this region a rich fauna was found of burrowing and tube building polychaetes, small crabs, a shrimp, amphipods and other smaller crustaceans, gastropods, filter and deposit feeding bivalves, a burrowing brittle star, a burrowing holothurian, and an acorn worm. Though the fauna showed some zonation within the region, two, possibly three, associations being distinguishable, many animals were ubiquitous throughout the area, and physico-biologically it was considered one, and called the lower beach region (Fig. 2, J, and Plate 1).

OTHER PHYSICO-CHEMICAL FACTORS (METHODS)

Other physico-chemical factors studied included (a) organic matter, (b) calcium carbonate, and (c) water content of the beach material, (d) salinity, (e) oxygen, and (f) hydrogen ion concentration of the interstitial water, and (g) temperature.

At each station samples of both sand and interstitial water were collected from the top 2.5cm of sand, and from between 8cm and 12cm below the surface as described earlier. All samples were taken around the time of low water of spring tides. To obtain suitably sized sub-samples on which to carry out the organic content and calcium carbonate content analyses oven-dried sand was put through the sample splitter.

(a) Organic content determinations were carried out on 2–3g samples of sand using Tinsley's method of oxidation by dichromate solution as described by Bremner and Jenkinson (1960). Organic content, which represented: (1) plant detritus in the sand; (2) micro-fauna in the sand; (3) faecal material; (4) conchiolin of shell fragments; (5) organic matter in solution in the interstitial water, was expressed as milligrammes of carbon per gram of oven-dry sand. A correction factor for chlorides also oxidised in the reaction was worked out from the water content of the sand and its salinity (Appendix II). No correction was necessary for ferrous iron since tests showed it to be absent from sand pretreated similarly to that analysed for organic content.

(b) Calcium carbonate percentages were calculated from the loss in weight of about 10g of oven-dry sand following treatment with 2 N hydrochloric acid (Barnes, 1959). Since this method gives the percentage of carbonates and other soluble salts, a correction for the salt content was applied. At Howick where the shell content of the sand is relatively high, the results can be, for working purposes, identified with the shell content.

(c) Water content was determined by drying about 500g of wet sand for 24 hours at 105° C–110° C, the loss in weight being expressed as a percentage of the wet weight. All the large animals and those small animals easily noticed were removed before weighing and drying.

(d) Salinity determinations were made on water samples obtained by filtration under slight suction pressure from sand samples brought to the laboratory in air-tight jars. The Mohr method for estimating salinity by titration with silver nitrate was followed, using the titration procedure recommended by Barnes (1959), and Knudsen tables (1953) for the calculations.

(e) The equipment devised to obtain the interstitial water samples for the oxygen determinations consisted of a rubber bulb with an inlet and outlet valve enabling water to be sucked in at one end and ejected the other. The inlet was attached to a glass tube (12cm long, 7.5mm diameter) ending in a filter of nylon thread (0.085mm diameter), 28 meshes to the centimetre, and held in place by a short length of rubber tubing slipped over the end of the glass tube. The first water (contaminated by air in the dead-space of the tube) and the air bubble were expressed through the outlet valve, and the tube and bulb then filled with from 30–50cc of water, assumed uncontaminated. An evacuated rubber balloon was slipped over the plastic nozzle, the water discharged into it, and the neck of the balloon sealed with a screw clip. The water sample was analysed in the laboratory within one hour after collection.

The modified micro-Winkler method of Fox and Wingfield (1938) was used to analyse the water. First the neck of the balloon was held in a wooden clamp which, when released slightly, allowed the water to well up and overflow. A syringe pipette similar to that described by Barnes (1959) was then slipped into the neck of the balloon and filled. The instructions of Barnes (1959) were followed both for the titration method and for the calculation of the oxygen concentration from the titration result.

(f) Determinations of hydrogen ion concentration were made in the field to the nearest 0.1 of a pH unit using a Lovibond Comparator and Di-phenol purple indicator. A glass tube (48cm long, 7.5mm diameter) with a rubber bulb wired to the top, and a nylon filter as described in (e) over the bottom, was used to suck the water from the sand.

(g) Sub-surface temperatures on the beach were recorded by maximum and minimum thermometers permanently buried in the sand 10–15cm deep. The thermometers were read at regular intervals over a period of eight months. On the days of reading temperatures were also taken in the top 2cm of sand.

Other Physico-chemical Factors (Results and Discussion)

(a) *Organic content of the sand*

On Howick Beach the organic content was found to be relatively low. At stations 1–4 the top 2.5cm of sand or beach material contained 1.04–1.48mg/$_{g}$ organic carbon while the sub-surface layers contained 0.86–1.01mg/$_{g}$. The amounts at stations 6, 7, 8 and 10 were more variable, 2.05–2.85mg/$_{g}$ at the surface and 1.97–4.59mg/$_{g}$ about 12cm down, while the sand from stations 5 and 9 contained somewhat lower amounts (Appendix I).

(b) *Calcium carbonate or shell content of the beach material*

Howick Beach supports a large bivalve fauna and at station 1 the shells of the dead animals constituted 21% of the surface and 11% of the sub-surface material. The percentage of shell at stations 2 and 3 was even higher, 32%–43% but at these two stations the surface contained about 10% less than the sub-surface layers. At station 4 the shell content was still high at the surface but was down to 16% in the sub-surface material. Markedly lower percentages, 3%–6%, were recorded for stations 5–10 except in the surface material at station 5 and the subsurface material at station 7 where the percentages were a little higher (Appendix I).

(c) *Water content of the sand*

There was a general increase in the percentage of water in the sand from the top to the bottom of the beach (Figs. 8c and 9c). The coarse loose surface sand at station 1 retained hardly any water (0.75%) but at stations 2 and 3 there was 14% and 17.9% respectively, and the percentages gradually increased at stations lower down the beach to a maximum value of 32% at station 10 (Appendix I). The sub-surface sand at stations 1–3 contained 2%–5% more water than the surface sand, however at the remaining stations, 4–10, the sub-surface sand contained 3%–6% less water than the surface sand.

(d) *Salinity of the interstitial water*

No interstitial water could be obtained from the sand at station 1. The salinity of the water from the surface 2.5cm of sand at station 2 was $23.4^{0}/_{00}$, and at station 3, $31.11^{0}/_{00}$, both low. Salinities higher than that of local sea-water ($35.3^{0}/_{00}$) were recorded at stations 4, 5 and 6, and at the remaining stations they ranged closely around $35.3^{0}/_{00}$ (see Appendix I).

The salinity values of the sub-surface water followed a similar but much less pronounced trend to that of the surface interstitial water (Fig. 9d, cf. Fig. 8d). The lowest value ($33.2^{0}/_{00}$) occurred at station 2, the highest ($36.33^{0}/_{00}$) at station 4, and values of about $35.3^{0}/_{00}$ (that of sea-water) at all stations below 4 on the beach.

(e) *Oxygen content of the interstitial water*

Very high values for oxygen content of interstitial water were recorded at stations 2 and 3 (about 5.45 ml/$_{l}$), which was only a slightly lower concentration than occurred in local sea-water at high tide (5.60ml/$_{l}$). A considerably lower average value (3.15ml/$_{l}$) was obtained at stations 4, 5, 6, 8, 9 and 10. In the sub-surface interstitial water the oxygen concentration was again higher at stations 2 and 3 (*c.* 3.35ml/$_{l}$) than at the other stations (Appendix I) for which the average figure was 2.03ml/$_{l}$. Station 7 gave an anomalously high reading for both surface and sub-surface samples and the readings were not used in obtaining the average figures.

(f) *pH of the interstitial water*

The pH values for both the surface and sub-surface water were constant 7.8–8.0) over most of the beach (Appendix I), these values being slightly less alkaline than the sea reading of 8.3.

(g) *Temperature of the sand*

The sub-surface temperature of the beach ranged from 10° C to 26.1° C (Appendix III), the range near station 3 being greater by 3.3° C than the range near station 6. Temperatures taken in the top 2cm of sand (Appendix III) also showed a wider range near station 3 where a maximum of 27.7° C was recorded compared with 23.6° C maximum near station 6, and a minimum of 13.5° C compared with 14.0° C respectively.

(h) *Discussion*

If the above results are examined in the light of the three beach regions described previously (upper beach, station 1; middle beach, stations 2–4; lower beach, stations 5–10), the factors investigated show quantitative patterns which fit well into the tripartite division. The organic content analyses showed that on the average the lower beach region contained about twice the amount of organic carbon than either the middle or upper beach regions. The shell content results were very clear cut and showed the lower beach had a low shell content, the middle beach a very high and the upper beach a medium–high content. Looking at the water content, again the values obtained were distinctive for the three regions—high, moderate and very low on the lower, middle and upper beach, respectively. At station 4, however, the readings were intermediate between typical values for the lower and middle beach regions. Salinity values low on the middle beach and high to normal on the lower beach, and oxygen content very high and high respectively also fit into the divisions, again except for station 4 which seems to be more closely allied to the lower than the middle beach region with regard to these two factors. pH of the interstitial water showed practically no variation, being just alkaline throughout the beach. Finally, the temperature of the sand on the lower beach was less variable than on the middle beach where the maximum and minimum temperatures for the beach were recorded.

The somewhat intermediate nature of station 4, which previously was included within the limits of the middle beach region, resulted from its situation, at the very foot of the general slope of the middle beach (see Fig. 3). It was consequently not so freely drained as stations 2 and 3, and thus the sand had a fairly high water content.

This together with a more pronounced "black sand" layer than was present at stations 2 and 3 probably explains the lower oxygen content of the interstitial water compared with that recorded at 2 and 3. The intermediate nature of station 4 is commented upon further in the discussion of the animal associations.

Summarising (Table II), the physico-chemical factors evaluated, with the exception of pH, support the establishment of the three physico-biological regions set up on the basis of faunal distribution and sand texture alone.

Examining the physico-chemical differences between the regions it is interesting that despite the large bivalve population supported by the lower beach (see Fig. 4), the shell content of the sand there was low, and most of the shells of the dead bivalves must get rapidly washed up the beach and deposited in the middle beach region where the shell content was extremely high. Further, on a beach such as Howick where shell is abundant, the texture of the beach material, as evidenced by the arithmetic mean, is closely related to the shell content. This can be seen by comparing the graphs of the arithmetic mean and shell content in Figures 8 and 9. The small rise in the graph at station 7 (Fig. 9b) resulted from a thin bed of dead shells which lay below the surface at this station.

On the flat, waterlogged, lower beach the surface sand contained more water than the sub-surface sand in contrast to the middle beach where the surface sand contained less than the sub-surface layers. Though exposure time for the lower beach was short thus limiting evaporation time, two more probable reasons for the higher content of the surface sand were the standing water between the ripple marks, and the looser nature of the wave disturbed surface sand compared with the much more compacted sub-surface sand. A small rise in the water content of the sub-surface sand at station 7 (see Fig. 9(c)) seems to be correlated with the relatively high shell content at this station, since the shell has a lower specific gravity than the sand and the percentage of water present is a percentage by weight.

The high salinities recorded at the bottom of the middle beach (station 4) and the top of the lower beach regions must have been developed through evaporation caused by the high temperatures (recorded maximum 27.7° C for surface sand), together with an off-shore breeze usually present at Howick in clear fine weather.

The low salinities of the middle beach, where evaporation time was even longer, must have resulted from water percolating through the well-drained beach material of this region from the fresh-water stream, and possibly from other subterranean fresh-water drainage at the interface of the bed rock and the beach deposit (only about 15cm below the surface in some places on the middle beach).

The higher summer temperatures and lower winter temperatures of the middle beach compared with the lower beach reflect the longer exposure time of the middle beach to the more extreme atmospheric temperatures compared to sea-water temperatures generally.

Comparing the results of the physico-chemical analyses with those of other workers, the organic content of Howick beach would seem to be low. Jones (1956), who worked on deposits from 10 fathoms depth off the Cumberland coast and 30 and 50 fathoms depth off the Isle of Man, obtained organic carbon values of 8.3 mg/$_g$, 4.0mg/$_g$ and 9.8mg/$_g$ respectively. These deposits contained 19%, 13% and 34% material < 0.0313mm diameter respectively. Since Howick deposits all contained $< 5\%$ material < 0.066mm diameter and since organic matter seems to be correlated with the sub-sieve fractions of the deposit (i.e., particles < 0.066mm diameter) (Morgans, 1956), the low values for organic content at Howick would seem to be of about the right magnitude.

The low salinities ($23^0/_{00}$–$31^0/_{00}$) found up to 150m down the beach are very similar to salinities recorded by Smith (1955) at Kames Bay, Millport. He gave values of about $23^0/_{00}$–$25^0/_{00}$ for interstitial water up to 80m down the beach in an area where no surface outflow of fresh-water occurred, and suggested (p 42) . . . " that geological features permit it (the intrusive fresh-water drainage) to flow into the sands of the beach with a sufficient head to maintain brackish conditions in the sand even at high tide. Such conditions may be peculiar to this beach . . . That they may be more common than hitherto noted is suggested by the fact that interstitial salinity lower than that of sea-water has been observed beneath the ebbing tide at Fintray Bay, Isle of Cumbrae, where the beach is totally unlike that at Kames Bay, being exposed, steeply sloped, and of very coarse, loose, gravelly sand and pebbles ". The beach at Howick where the low salinities were recorded contained up to 33% material of a grade > 2.057mm, all of which was broken shell, and up to 42% sand 0.500mm–0.251mm. The beach texture at Howick would thus seem to be somewhere between that at Fintray, gravelly sand and pebbles, and that at Kames Bay where 93%–97% of the substratum was of the particle size class 0.5mm–0.2mm (Watkin, 1942). No attempt was made at Howick to record interstitial salinities while the tide overlay the stations, nor was the origin of the fresh-water investigated, but though the small outflow on to Howick Beach was some 25m–50m from the stations showing the low salinities, it presumably must have had some influence on the brackishness recorded.

A rise in the salinity of the interstitial water of $1^0/_{00}$ above that of local sea-water was observed by Southward (1953) on two beaches in the Isle of Man where the maximum surface sand temperature was 25° C. The reading of just over $3^0/_{00}$ above local sea-water at station 4 at Howick could have been brought about by higher temperatures (maximum recorded at Howick nearly 28° C) helped by an off-shore breeze, as noted earlier, causing greater evaporation.

The oxygen content of the interstitial water on both the middle and lower beach was high compared with findings on other beaches. Pearse, Humm and Wharton (1942) recorded 4.67 cc/$_l$ for open sea-water (cf. 5.60ml/$_l$, Howick) and a maximum of 1.9cc/$_l$ (cf. 5.45ml/$_l$, Howick) for interstitial water in the surface sand on Beaufort beaches, North Carolina. Lower values still (maximum 0.35ml/$_l$) for interstitial water 7.5cm below the surface (cf. 3.4ml/$_l$ maximum sub-surface value at Howick) were recorded by J. D. Jones (1955) at Robin Hood's Bay, Filey, and Scarborough Harbour. However, Jones stated that the organic content of the sand at Scarborough was high and the water polluted by fishery activities, but did not give values for the organic content. The freely porous nature of the substratum and virtual absence of a " black sand " sub-surface layer on the middle beach, where the highest oxygen concentrations were recorded, and the absence of a well-developed " very black sand " layer on the lower beach were perhaps the factors which allowed the high values at Howick to be developed.

The constant pH values for interstitial water throughout the beach and the value of 8.3 for the open sea are very similar to the results obtained by Bruce (1928) at Port Erin. The interstitial water of sandy beaches appears to be well buffered against changes in pH.

Discussion of Associations and Zonation on the Beach

(a) *Associations*

Having shown that on Howick beach several associations exist, and that these can be correlated with the physical factors of the environment particularly sand texture, we can compare the species composition of the associations and the substratum texture with the findings on other New Zealand beaches.

The *Amphidesma australe–Nucula hartvigiana* association at Howick contained *Zediloma subrostrata, Notoacmea helmsi helmsi, Isocladus armatus, Platynereis australis* and *Anthopleura aureoradiata,* and was found where the beach material contained up to 43% shell.

In their article on sea-floor animals of Otago Harbour, Ralph and Yaldwyn (1956) described *Isocladus armatus, Notoacmea helmsi helmsi* and *Platynereis australis* (page 62) as an " atypical faunal assemblage " which occurred 1ft above M.L.W. on a substratum consisting almost entirely of dead shells with little sand. They also recorded *Zediloma corrosa,* a South Island form later merged with *Z. subrostrata* (Clark, 1958) and an *Aricia* (= *Orbinia*) sp. in what they suggested was (page 59) an " ecotone between the *Austrovenus* (= *Chione*) and *Maoricolpus* associations " of the sand banks and shelly-bottomed channels respectively. Further, they recorded *Nucula hartvigiana* at a station in the shipping channel 5 fathoms below M.L.W., where the bottom material was composed of much dead shell.

Thus at varying depths in the Otago Harbour, but always on a shelly type of substratum, there occurred six of the eight species of the *Amphidesma australe–Nucula hartvigiana* association on Howick's shelly middle beach which lay roughly between 2ft and 5ft above M.L.W. It would seem, therefore, that the grade of material forming the middle beach was probably the most important factor influencing the composition of the faunal association there.

The rich fauna of Howick's lower beach could be grouped into two distinct associations. The first, which centred about M.L.W.N., included the dominant *Chione stutchburyi* together with *Cominella adspersa, C. glandiformis, Polydora* sp. *Anthopleura aureoradiata,* and eight species which were ubiquitous on the lower beach—*Macomona liliana, Axiothella australis, Notomastus* sp., *Aglaophamus macroura, Glycera* sp., *Halicarcinus cooki, Pontophilus australis* and *Balanoglossus australiensis.* This assemblage of species is very similar to the *Austrovenus* (= *Chione*) association of the muddy sand banks in Otago Harbour described by Ralph and Yaldwyn (1956). However, in contrast to the Otago Harbour sand bank associations, no *Arenicola assimilis* or *Solemya parkinsoni* occurred on Howick main beach, and *B. australiensis, Notomastus* sp., and *H. cooki* did occur here, yet were not present at the sandy stations of the Otago Harbour survey.

The *Antigona* (= *Chione*) *stutchburyi* association of a muddy sand beach at Tauranga (Oliver, 1923), also differed only slightly from that at Howick. The subsurface fauna consisted of burrowing crabs, *Helice crassa* (absent from Howick main beach) and *Hemiplax hirtipes* (present at Howick), worms (not named by Oliver) and pelecypods, *Antigona* (= *Chione*) *stutchburyi* and *Tellina* (= *Macomona*) *liliana* (both present at Howick). The surface fauna included *Cominella lurida* (= *glandiformis*), *C. adspersa, C. maculosa* and *Monodonta* (= *Zediloma*) *subrostrata* all of which were present at Howick but also included *Cerithidia bicarinata* (= *Zeacumantus lutulentus*), and *Amphibola crenata,* both characteristic of a muddy sand and therefore understandably absent from Howick.

Thus the species associated together on the upper part of the lower beach at Howick are basically the same as those found grouped together on the sand banks of Otago Harbour and on a muddy sand beach at Tauranga.

It is interesting that at station 4 and to a much lesser extent at station 5 there was a mixed population, the species of the *Amphidesma australe–Nucula hartvigiana* association of the middle beach occurring together with species characteristic of the *Chione stutchburyi–Macomona liliana* association of the lower beach. It has been noted that distribution of these animals seems to be governed largely by the texture of the sand, and the fact that this mixed population was developed in an area where sand texture was intermediate between that of the middle and lower beach (see grade analysis) further emphasises this point. However, both the faunal composition and the sand texture at station 4 was considered to be much more like that of the middle beach than the lower beach, and even though several other physico-chemical factors suggested otherwise, station 4 was included in the middle beach region, the importance of sand texture outweighing, in the opinion of the author, that of the variant factors.

On the lower part of Howick's lower beach a *Dosinia subrosea–Macomona liliana* association was recognised. Other species included *Amphiura aster, Baryspira australis, Leanira* sp., *Podarke* sp., a goniadid polychaete, *Nebalia* sp., haustoriid, phoxocephalid and other amphipods, ostracods, and the several species previously mentioned as being ubiquitous on the lower beach. A *Dosinia–Tellina* (= *Macomona*) association on Cheltenham beach was described by Oliver (1923) though he only mentioned the dominant species which were the same as at Howick. However, Rainer (unpublished) recorded also *Leanira leavis, Aglaophamus macroura,* and *Balanoglossus australiensis* as common on the lower part of Cheltenham beach. Thus the association of species on the lower part of the lower beach at Howick were basically the same as the *Dosinia–Tellina* (= *Macomona*) association recorded for Cheltenham beach.

Rainer also noted *Chaetozone* sp. and *Magelona papillicornis* at E.L.W.S. on Cheltenham Beach. Comparison of specimens showed that the same two species existed at Howick, and, together with *Travisia olens, Oridia* sp. and *Sigalion* sp., formed at E.L.W.S. what probably represented the fringe of a sub-littoral association.

That the three main associations recognised at Howick have some validity is shown by the fact that the same or closely comparable groups of animals have been found associated together in the only other areas of sheltered sandy beach so far investigated and recorded for New Zealand.

(b) *Zonation*

After investigating the zonation on sandy beaches throughout the world, Dahl (1953) concluded that three zones, a sub-terrestrial, a mid-littoral and a sub-littoral fringe can be recognised on the basis of the occurrence of the larger crustaceans. In temperate regions the sub-terrestrial fringe harbours talitrid amphipods; the mid-littoral zone characteristically contains cirolanid isopods; and the sub-littoral fringe is characterised by haustoriid, phoxocephalid, and oedocerotid amphipods. Though Dahl's classification was based on exposed sandy beaches, similar zones could be distinguished on the relatively sheltered Howick Beach.

* Not specifically identified.

** Two $0.1 m^2$ samples were taken at each station.

* The full names and authors of all species quoted through the paper are listed in Table I.

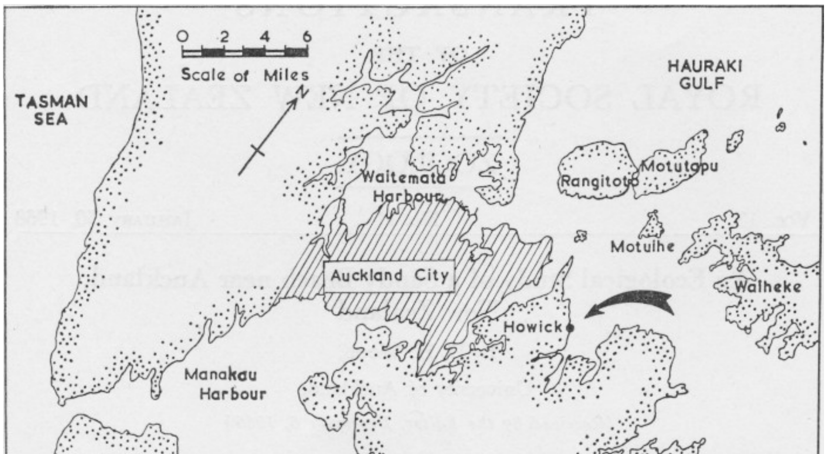

FIG. 1.—Locality map.

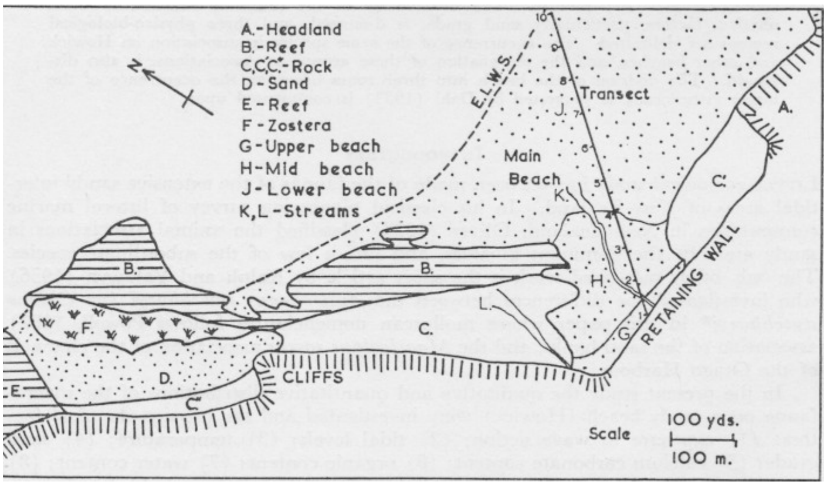

FIG. 2.—Howick Beach.

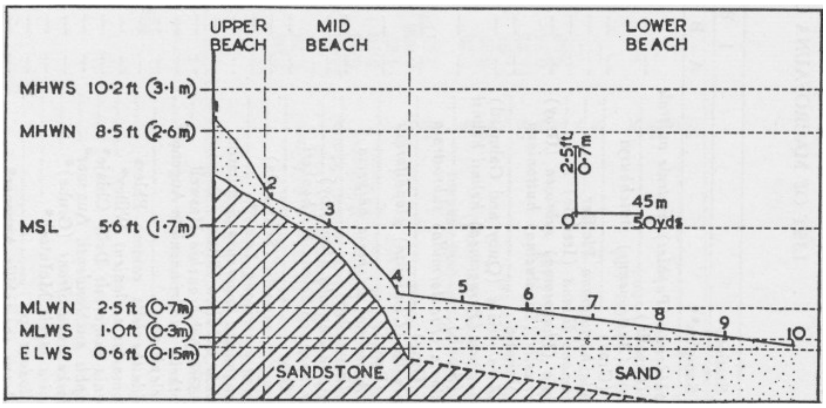

FIG. 3.—Diagrammatic profile of main beach transect.

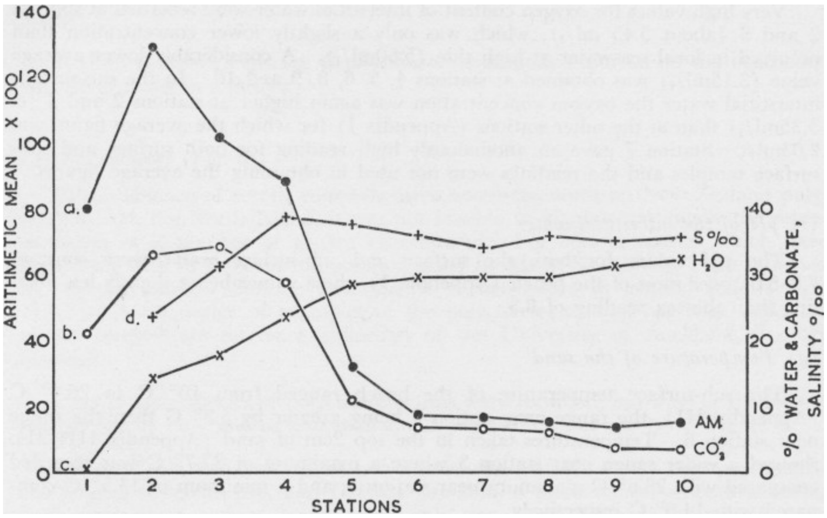

FIG. 8.—Surface sand data.

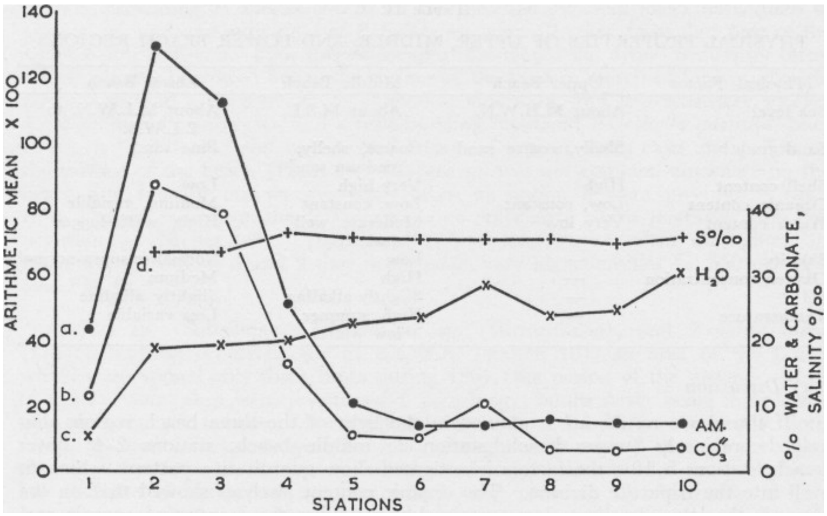

FIG. 9.—Sub-surface sand data.

Stations	1		2		3		4		5		6		7		8		9		10	
Samples**	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Amphidesma (*Paphies*) *australe australe* (Gmelin)	—	—	133	152	54	66	33	50	—	—	—	—	—	—	—	—	—	—	—	—
Chione (*Austrovenus*) *stutchburyi* (Gray)	—	—	—	—	19	16	167	115	192	193	153	154	105	121	2	1	—	—	—	—
Nucula hartvigiana Pfeiffer	—	—	—	—	13	19	38	26	—	—	—	—	—	—	—	—	—	—	—	—
Macomona liliana (Iredale)	—	—	—	—	—	—	6	5	2	4	1	0	—	—	1	0	1	0	—	—
Dosinia (*Phacosoma*) *subrosea* (Gray)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	1	2	2	2	0
Divaricella (*Divalucina*) *huttoniana* Vanatta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0
Myadora striata (Quoy and Gaimard)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	1	—	—	—	—
Notoacmea (*Parvacmea*) *helmsi helmsi* (Smith)	—	—	—	—	20	25	16	14	4	4	—	—	—	—	—	—	—	—	—	—
Zediloma (*Fractarmilla*) *subrostrata* (Gray)	—	—	—	—	4	2	0	1	—	—	—	—	—	—	—	—	—	—	—	—
Cominella (*Cominista*) *glandiformis* (Reeve)	—	—	—	—	0	2	5	0	3	1	1	0	2	1	—	—	—	—	—	—
C. (*Acominia*) *adspersa adspersa* (Bruguière)	—	—	—	—	—	—	1	0	2	3	—	—	1	0	—	—	—	—	—	—
Baryspira australis (Sowerby)	—	—	—	—	—	—	—	—	0	1	1	0	—	—	3	2	0	4	—	—
Acanthochiton zelandicus hookeri Gray	—	—	—	—	1	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Platynereis australis (Schmarda)	—	—	6	7	2	3	—	—	1	0	—	—	—	—	—	—	—	—	—	—
Glycera americana Leidy*	—	—	1	1	—	—	—	—	—	—	1	0	—	—	0	1	0	6	2	1
Aglaophamus macroura Schmarda	—	—	—	—	—	—	3	3	0	10	14	14	8	4	60	49	55	48	7	17
Orbinia papillosa Ehlers	—	—	—	—	1	3	—	—	0	1	—	—	—	—	1	0	—	—	—	—
Polydora polybranchia Haswell	—	—	—	—	1	0	—	—	22	24	10	10	3	13	—	—	—	—	—	—
Axiothella quadrimaculata Augener*	—	—	—	—	—	—	0	1	1	3	2	5	2	5	0	4	0	1	0	1
Scolelepis sp.	—	—	—	—	—	—	0	1	—	—	—	—	—	—	—	—	—	—	—	—
Lepidastheniella comma Ehlers	—	—	—	—	—	—	—	—	1	1	0	2	—	—	—	—	—	—	—	—
Notomastus zeylanicus Willey*	—	—	—	—	—	—	—	—	0	2	—	—	1	1	1	3	1	0	7	1
Owenia fusiformis Delle Chiaje*	—	—	—	—	—	—	—	—	—	—	1	0	—	—	—	—	—	—	—	—
Onuphis aucklandensis Augener*	—	—	—	—	—	—	—	—	—	—	—	—	1	0	—	—	—	—	—	—
Podarke angustifrons (Grube)*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	2	1	—	—
Leanira laevis McIntosh*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2	1	0	—	—
Phyllodoce sp.	—	—	—	—	—	—	—	—	—	—	0	1	—	—	1	0	—	—	—	—
Thelepus spectabilis Augener*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0	—	—
Travisia olens Ehlers	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0	12	13

E TEXT

Stations	1		2		3		4		5		6		7		8		9		10	
Samples**	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Oridia limbata (Ehlers)*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8	14
Chaetozone cincinnata (Ehlers)*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	19	30
Sigalion sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	3
Asychis theodori Augener*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	1
Magelona papillicornis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	0
Goniadidae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	4	3	5	1	1
Scoloplos sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0	—	—	—	—
Isocladus armatus (M.-Edwards)	—	—	51	62	32	38	—	—	0	2	—	—	—	—	—	—	—	—	—	—
Cirolanidae	—	—	—	—	—	—	—	—	0	1	—	—	—	—	—	—	—	—	—	—
Talorchestia quoyana Milne-Edwards	65	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Phoxocephalidae	—	—	—	—	1	0	—	—	—	—	—	—	—	—	5	2	7	4	8	6
Haustoriidae	—	—	—	—	—	—	—	—	—	—	1	0	1	0	65	49	79	53	40	37
Other amphipods	—	—	—	—	—	—	—	—	—	—	3	1	—	—	—	—	1	1	4	5
Pontophilus australis (Thomson)	—	—	—	—	—	—	2	2	2	2	3	1	2	4	—	—	1	4	2	6
Halicarcinus cooki (Filhol)	—	—	—	—	—	—	1	4	1	0	0	1	—	—	1	0	0	1	—	—
Hemiplax hirtipes Heller	—	—	—	—	—	—	7	1	3	0	0	5	—	—	—	—	—	—	—	—
Hemigrapsus edwardsi (Hilgendorf)	—	—	—	—	—	—	1	0	—	—	—	—	—	—	—	—	—	—	—	—
Callianassa filholi A. Milne-Edwards	—	—	—	—	—	—	—	—	—	—	0	1	—	—	—	—	—	—	—	—
Nebalia sp.	—	—	—	—	—	—	—	—	—	—	1	0	—	—	6	9	1	3	1	2
Elminius modestus Darwin	—	—	—	—	13	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ostracoda	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13	7	7	7	11	7
Anthopleura aureoradiata Stucky	—	—	—	—	8	7	27	37	12	15	3	6	3	0	—	—	—	—	—	—
Nemertini	—	—	—	—	1	3	1	1	2	0	—	—	0	1	—	—	—	—	2	2
Balanoglossus australiensis (Hill)	—	—	—	—	—	—	1	2	4	5	1	2	13	10	6	2	13	10	55	41
Amphiura aster Farquhar	—	—	—	—	—	—	—	—	—	—	—	—	1	1	3	3	1	1	1	2
Trochodota dendyi Mortensen	—	—	—	—	—	—	—	—	—	—	—	—	0	1	—	—	—	—	1	0

Table I.

OF MACROFAUNA OF HOWICK BEACH AND OTHER SPECIES MENTIONED IN TH

LIST

Physical Factor	Upper Beach	Middle Beach	Lower Beach
Sea level	About M.H.W.N.	About M.S.L.	About M.L.W.N. to E.L.W.S.
Sand grade	Shelly, coarse sand	Coarse, shelly, medium sand	Fine sand
Shell content	High	Very high	Low
Organic content	Low, constant	Low, constant	Medium, variable
Water content	Very low	Moderate, well drained	High, water-logged
Salinity	—	Low	Normal to supra-normal
Oxygen concentration	—	High	Medium
pH	—	Slightly alkaline	Slightly alkaline
Temperature	—	High summer, low winter	Less variable

TABLE II.

PHYSICAL PROPERTIES OF UPPER, MIDDLE, AND LOWER BEACH REGIONS