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SOME ASPECTS OF THE  
ECOLOGY OF THE INTERTIDAL BENTHIC  
BIOTA OF THE MANAWATU RIVER ESTUARY

A thesis presented in partial fulfilment of  
the requirements for the Degree of Master of  
Science in Zoology at Massey University

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This study was undertaken to investigate some of the aspects of the ecology of the benthic flora and fauna on mudflats at the Manawatu River estuary. Scientists and laymen alike are becoming generally aware of the dearth of information known about most New Zealand estuaries.

Four samples were taken at four stations along transects that were positioned up the estuary to give a transition from almost seawater to river water with no tidal influence.

Previous works on estuaries, and descriptions of the methods implemented are given, followed by the results obtained.

One section is devoted to the testing of salinity (chlorinity) tolerances and preferences of male Helice crassa (Dana), the common mud crab. This work is not in the depth of that carried out by Phillips (1968) on Hemigrapsus edwardsi (Hilgendorf), but it does give a hitherto undocumented account, albeit brief, of the effects of various salinities on the serum chloride content of male specimens of Helice crassa of varying body weights.

The author has tried to relate environmental salinities along with the other factors measured; Sediment size, pH, Redox potentials (Eh), Oxygen content and temperature, to the distribution of all the plants and animals found.

It appears that mainly sediment size, incorporating silt content, exposure time of the mudflat between tides and the water content of the sediments are the factors determining biotal distributions. Temperature is so variable seasonally that the animals adapt to the changes, oxygen appears in high enough concentrations as not to be significant, pH is reasonably constant and Eh is highly variable but within a range tolerated by all animals found.

A possible beach zonation is also discussed.

ACKNOWLEDGEMENTS

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GENERAL INTRODUCTION.

1.01 The importance of estuaries, as breeding grounds for marine organisms, and as wildlife havens, has in recent years become more generally known.

The New Zealand Ecological Society, devoted a section of its annual conference, in August 1975, to New Zealand estuaries. From this, it became apparent, that very little if anything at all, was known about most New Zealand estuaries.

Most of the work on estuaries, mainly on the Avon-Heathcote system, has come from the Estuarine Research Unit at Canterbury University. Other work has come from the Botany and Zoology Departments, Auckland University. The majority of this work is in the form of theses (Bascand, 1968a; Larcombe, 1971; Boyd, 1972;)

Evident from the Ecological Societies conference, was the lack of information concerning the Manawatu River estuary. The only work prior to this investigation were two, brief, water quality records by the Manawatu Catchment Board. At present the Board is engaged on a water quality survey of the lower Manawatu River-Foxton Loop area.

1.02 The present investigation was initiated, partly because of an interest in estuaries, especially their wildlife, and partly to alleviate the lack of information about the Manawatu River estuary.

The Manawatu region, like most 'growing'

regions, welcomes industry, and several large concerns are situated on the banks of the Manawatu River. Foxton township openly welcomes industry, as the area is rapidly expanding. Many of the 'waste producing' factories in Foxton are situated on the banks of the old bed of the Manawatu River, the Foxton Loop. The loop is now closed at one end, and water movement is tidal. Hot dye effluents, and other factory wastes are discharged into the loop, all of them finding their way to the estuary mudflats. Sewage treatment stations at Palmerston North and Foxton discharge into the Manawatu River. Foxton's sewage is only primarily treated, and it is not uncommon to see raw sewage floating in the estuary waters. Palmerston North's sewage undergoes secondary treatment prior to discharge.

This investigation is concerned with the intertidal flora and fauna of three mudflats along the estuary. It should indicate the biological diversity and species density on the mudflats, relating them to the environmental factors studied. This should provide a baseline for further studies.

As mentioned above, the sample sites were on three intertidal mudflats. One of these was at the head, one midway down the estuary, and one at the mouth. This gave a transition from approximately 75% seawater to freshwater. Along transects, taken across the mudflats, samples were taken at four stations. At each station some parameters were measured in the field, the

remainder required a sample of the substrate, and interstitial water to be taken back to the laboratory. The vegetation was sampled to determine species distribution.

1.03 As would be expected, the flora and fauna of the intertidal mudflats are found to be distributed in a manner that suggests they are governed by more than one of the environmental factors. Many of the animal species show a clumped distribution, this being related to the environmental requirements of that animal. In some cases, it appears that variations in the environmental factors along the mudflat, are not great enough to cause distinct population distribution patterns.

When comparing areas widely separated in space, a zonation model has useful parameters. Such a model permits the distinction of zones up a shore, discernable by the presence of species, specific to the various zones. The species would differ between similar zones around the world, but the strategies would be similar. Possibly zonation would not be strongly developed in estuaries, as the animals of both sandy and muddy shores burrow to escape the stresses caused by desiccation and temperature variations.

It is apparent from the literature, that marine biologists can discern, world-wide, a three zone, vertical scale for rocky shores. The features of these zones being broadly controlled by the rise and

fall of the tides. The upper zone, is affected by spray, and only covered at high spring tides. The mid zone, is covered and uncovered each day, the low zone is uncovered only at neap tide. Stephenson and Stephenson (1949), state that zonation is not to be defined by tidal levels, but "must be defined in terms of the distribution of organisms." Dahl (1952) considers exposed sandy shores in Europe and South America to be divisible into three universal zones, defined according to where the animals were found resting, rather than feeding. Both of these zonation models are used on exposed shores, whereas the shores of an estuary are sheltered. In this investigation, three vertical zones were detected. One from high tide to  $2/3$  high tide (upper zone), one from  $2/3$  high tide to  $1/3$  high tide (mid zone) and the lower zone from  $1/3$  high tide to low tide. The full high tide zone corresponds roughly to the upper zone of exposed shores, only animals and plants that can withstand brief submergence, and long exposure are found. The region between  $2/3$  high tide and  $1/3$  high tide corresponds to the mid tide region of the exposed shores. The  $1/3$  high tide to low tide region correspond to the lower zone of exposed shores. It must be emphasised that comparison of these exposed and sheltered shore models is only approximate, as the upper zone in the estuary is usually covered with water for approximately an hour every tidal cycle. The characteristic animals that make the zones discernable are:

UPPER: Helice crassa and/or Amphibola crenata

MID: A great variety of animals.

LOWER: A great variety but an absense of H.crassa  
and A.crenata

Salinity tolerances and preferences for the  
crab H.crassa are also discussed relative to distribution.

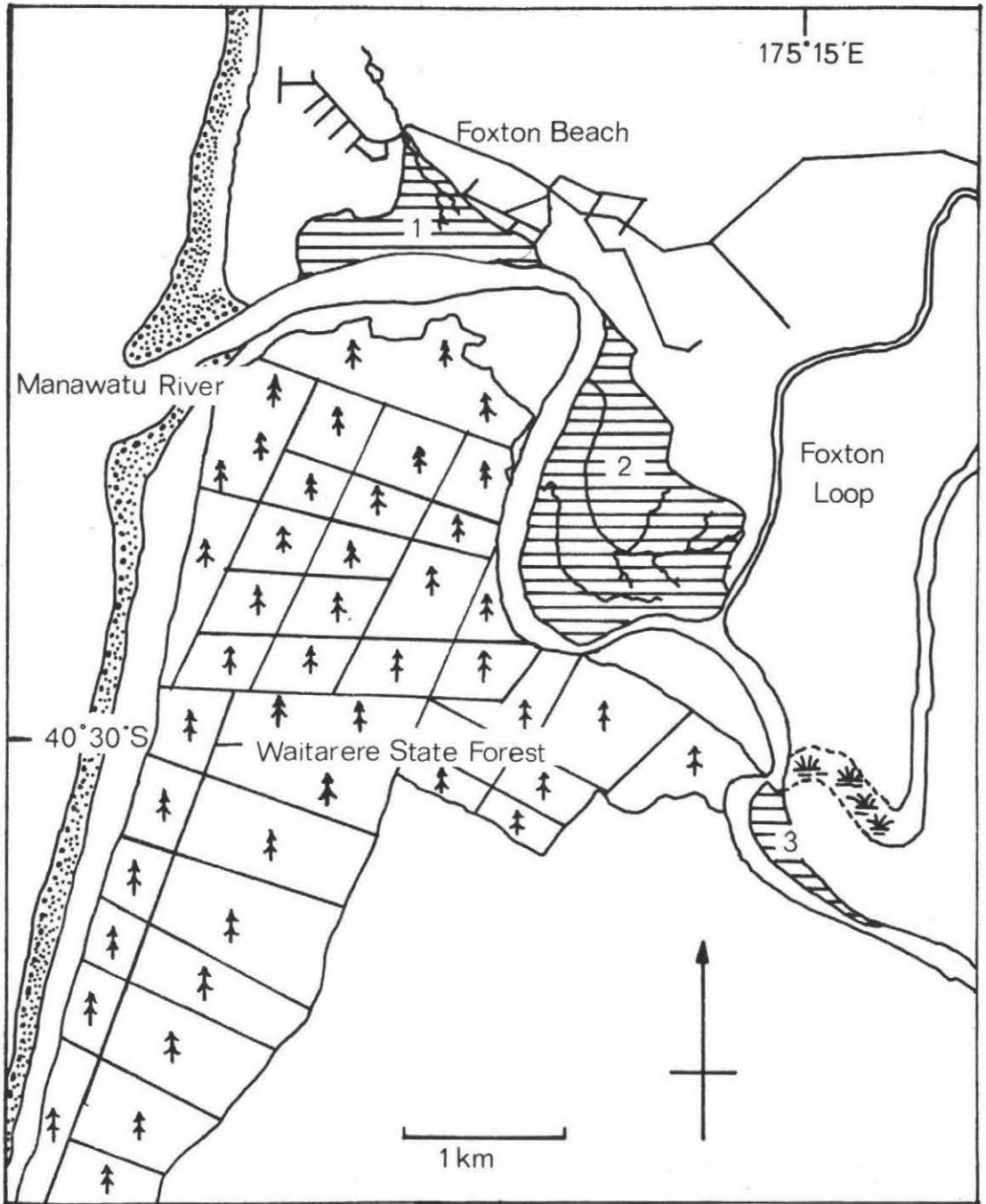
THE STUDY AREA.

2.01 The Manawatu River, arises in the foot hills of the Eastern Ruahine Ranges, NZMS 1 SHEET N145 reference 577747, and meanders through the undulating land of southern Hawkes Bay. It passes through the central North Island range system, via the Manawatu Gorge, at the junction of the Ruahine and Tararua ranges, and enters the relatively flat country of the Manawatu. The course continues West, to Palmerston North where it changes South East to Foxton, entering the sea at Foxton Beach. The estuary sampled lies between NZMS 1 SHEET N148 reference 740213 and NZMS 1 SHEET N152 reference 778168. At full high tide the dilute seawater may extend past the Whirokino Bridge on the main highway between Levin and Foxton, NZMS 1 SHEET N152 reference 794158.

2.02 The estuary itself (fig.1) consists of several intertidal mudflats, and short beaches where mudflats are absent. These short beaches are prominent on the Waiterere bank, on both banks near the estuary mouth and also in the Whirokino Cut. Much of the Waiterere bank, bordering the Waiterere State Forest is badly eroded by the river. The Pinus radiata forest is fairly young in this area, consequently the trees on the river bank have only developed deep tap roots with few main laterals. Within another ten to fifteen years they should have developed the densely matted adventitious root system that enables P.radiata to bind moving substrates, (NZPS pers com).

FIGURE ONE:

A map showing the whole of the Manawatu River Estuary. The three mudflats studied are indicated in relation to each other.



-  swamp
-  state forest
-  sandy beach
-  study areas

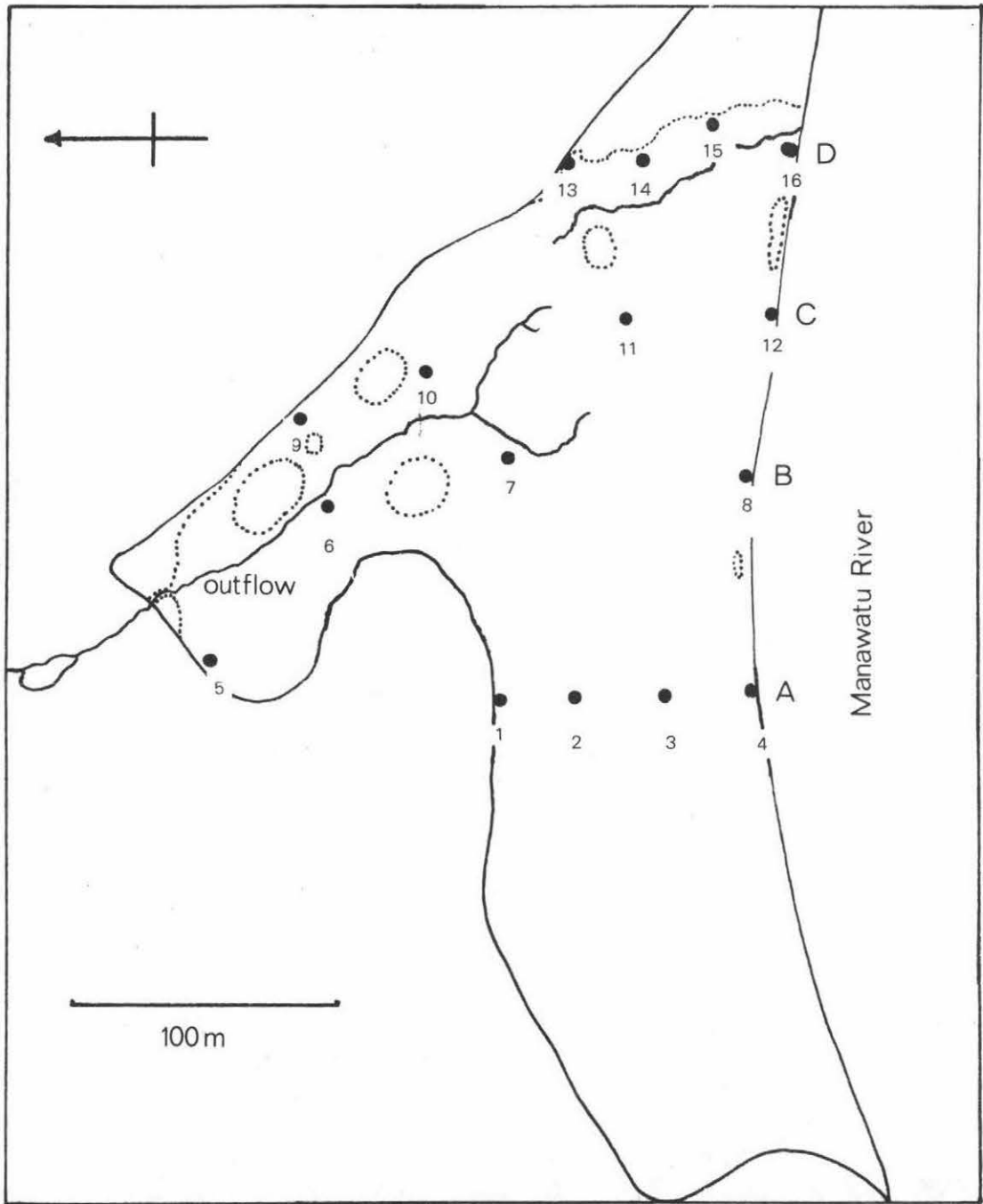
2.03 There are a number of freshwater creeks entering the estuary, two of these are near the township of Foxton Beach. One comes from the region of the boating pond and empties into the first major mudflat on the North bank of the river, (Mudflat 1) by the township. The other arises in the arable land to the North of the township, and has a channel, North-South, through the township emptying to the river through the boulder bank, East of the Manawatu Marine Boating Club rooms.

A third and relatively large creek, arises in the arable land-saltmarsh boundary of Mudflat 2 on the North bank, (fig.3) and flows across this mudflat to discharge into the estuary at the first southward bend in the river, moving upstream. Another, smaller creek, is found on the mudflat but it only drains the mudflat itself and is thus a tidal creek.

2.04 The transects were taken at approximately 100 metre intervals. The first four transects were on Mudflat 1 (fig.2), the samples taken from these, giving a representation of intertidal biota with preferences for higher salinity conditions. Six other transects were along Mudflat 2 (fig.3). The biota found in these samples prefer or tolerate weakly saline conditions. The remaining two transects (fig.4) were at the most landward end of the estuary, just prior to the Whirokino Cut. The environment here is very close to that of freshwater, (salinity is less than 0.5‰). Figs. 5 to 16 show the habitat types of each transect.

FIGURE TWO:

An enlargement of the study area - Mudflat 1. The sampling stations of the four transects are indicated. The piped freshwater discharge can be seen entering the mudflat at top centre.

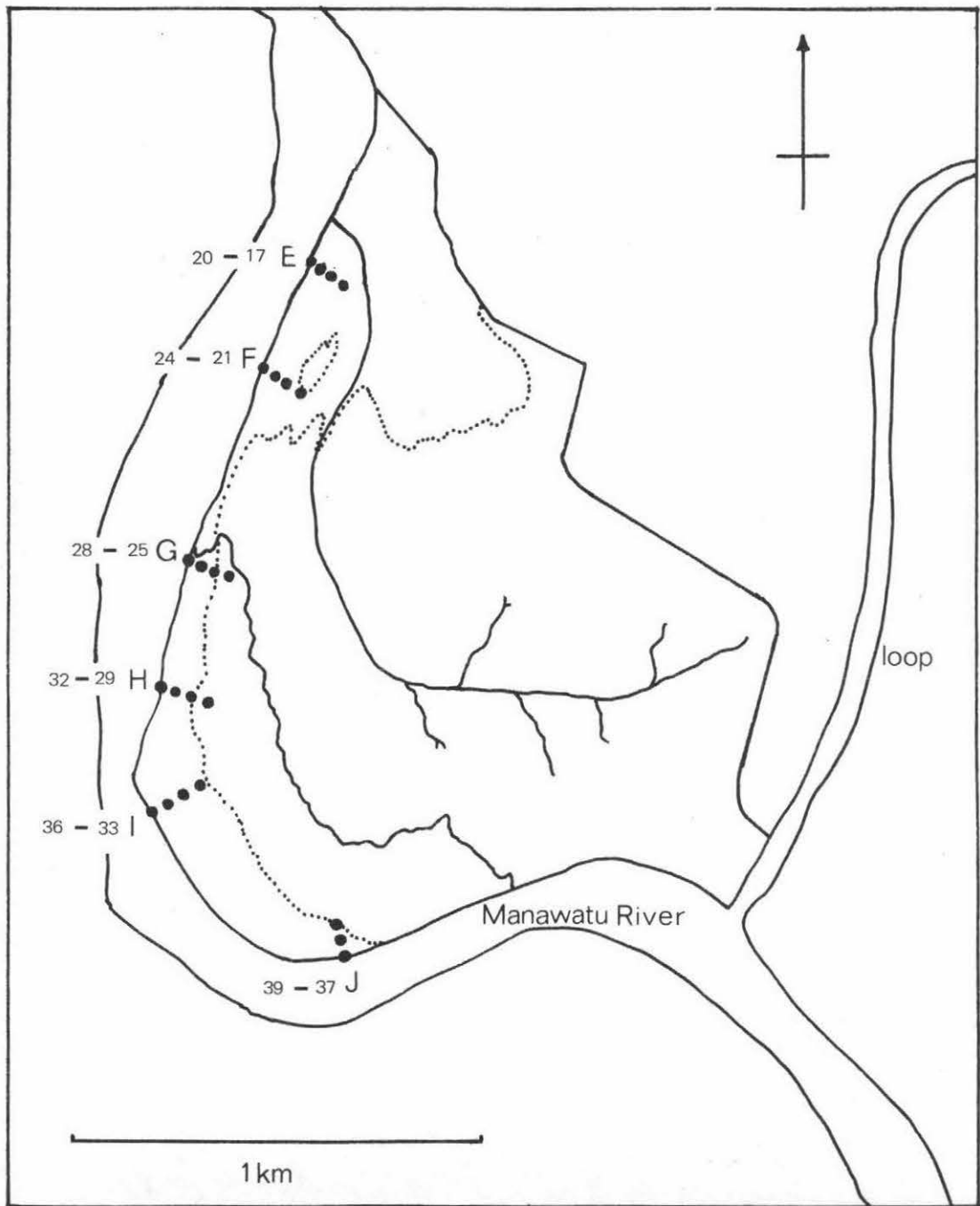


● sampling sites

○ vegetation

FIGURE THREE:

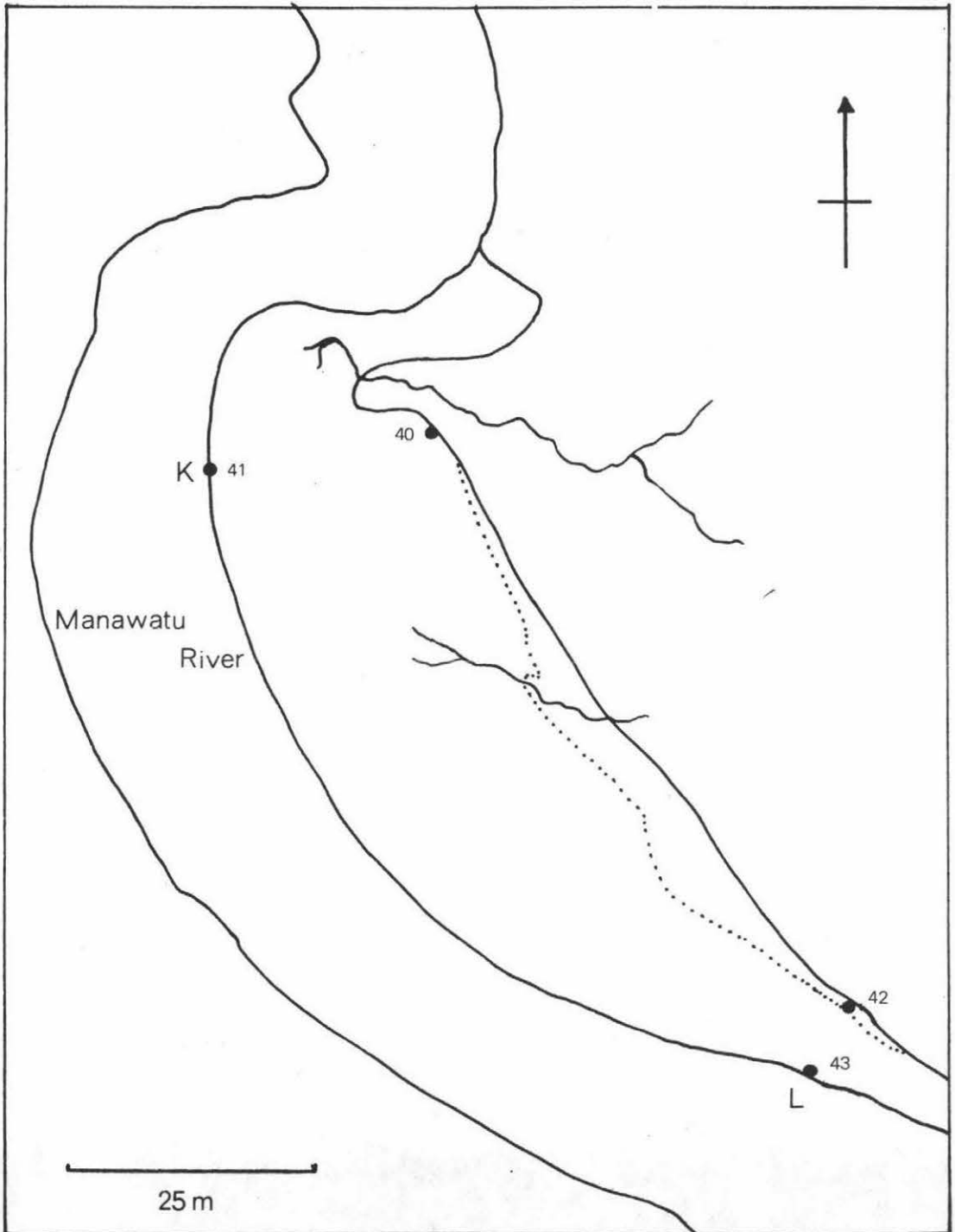
An enlargement of the study area - Mudflat 2. The sampling stations of the six transects are indicated. The drainage creeks from the surrounding farmland can be seen entering the river near transect E. The creek draining the mudflat cuts across the lower part of the mudflat, entering the river near transect G.



- sample sites
- ⋯ lower vegetation limit

FIGURE FOUR:

An enlargement of the study area - Mudflat 3.  
The shortness of the beach necessitated only  
taking samples at the low and high tide marks



● sampling sites

⋯ lower vegetation limit

FIGURE FIVE:

Transect A, station 4 is visible in the immediate foreground.

FIGURE SIX:

Transect B, station six is between the two Spartina beds at centre left.



FIGURE SEVEN:

Transect C, station 9 is just out of the photograph at centre right.

FIGURE EIGHT:

Transect D, station 13 is in the left foreground. Station 16 is between the two Spartina beds at centre right.



FIGURE NINE:

Transect E, station 20 is at the low tide mark. The lack of mud snails between low tide mark and  $1/3$  high tide mark is evident.

FIGURE TEN:

Transect F, station 24 is visible in the flotsam at centre left, station 21 at the high tide mark is behind the Spartina. Again the scarcity of snails at the lower tidal level is evident.



FIGURE ELEVEN:

Transect G, only one of the stations (27) is shown due to the difficulty of making all stations visible. This photograph was taken prior to the June flood, and the mixture of Spartina and Cotula that existed can be seen.

FIGURE TWELVE:

Transect H, with stations 29 (high tide) to 32 (low tide) visible.



FIGURE THIRTEEN:

Transect I, only the upper tidal stations (33 to 35) are visible, station 36 has been submerged by a flowing tide.

FIGURE FOURTEEN:

Transect J, station 39 is visible at the waters edge, station 38 is at centre left but station 37 is hidden by Fesuca spp.



FIGURE FIFTEEN:

Transect K, station 41 is in the foreground  
and the high tide station (40) is just  
visible at top centre.

FIGURE SIXTEEN:

Transect L, with station 43 in the foreground  
station 42 is visible at top centre.



SECTION ONE.PHYSICAL FACTORS:SEDIMENTS.3.01 INTRODUCTION.

There are a number of biologically important properties that are influenced by the size of the particles in a deposit. Small particles have a large surface area per unit volume, larger particles have a correspondingly smaller surface area. These surfaces are important for attachment and growth of bacteria. Bacteria form a very essential link in the food chain of estuaries, as one of the primary producers, along with organic debris, diatoms, and small algae, (Green, 1968). ZoBell (1938), has shown that greater concentrations of bacteria are found (in natural deposits) in the finer sediments.

Another property, important to animals living in intertidal areas, is the retention of water by the substrate at low tide. Water may be held in sediments in several ways: one of these is capillary lift. The height that water rises is determined by the sizes of the interstices. In fine sand, water may rise up to ten times higher than in coarse sand. The importance of this phenomenon is seen with animals unable to burrow to great depth. They would be in a situation that exposed them to desiccation each time the tide ebbed and the water table dropped below the maximum level they could burrow to.

A closely related phenomenon is the retention of water by surface forces. Webb (1958) found that coarse sand with a mean particle diameter of  $\phi=1$  (Appendix 1), retained little or no water, but sand with a mean particle diameter of  $\phi=3$  retained approximately 14% of its water against evaporation. These experiments were conducted in vitro. Evaporation in natural deposits would be influenced by temperature and windspeed. Evaporation then, in vivo, could thus be expected to be greater than that found by Webb. The upper regions of the intertidal zone may become completely dried out, if only covered by water for brief periods (up to two hours) several times a fortnight. If this region is sand it is then liable to wind erosion. In muddy areas, the surface hardens and cracks, possibly exposing animals in burrows to desiccation. The lower tidal regions of the mudflat would be effected to a lesser extent, being covered regularly by water for a relatively longer time every twelve hours.

The porosity of a soil, is the volume of spaces between the particles, expressed as a percentage of the total soil volume. This is affected by;

- i absolute grain size
- ii non-uniformity of grain size
- iii proportions of various sizes of grain
- iv shape of grains
- v method of deposition
- vi compaction during and following deposition
- vii solidification

(Frazer, 1935)

Natural sands often have porosities ranging from 20%

to 38%. Muds, with a high content of silt and clay, are much less porous because the smaller particles tend to fill the spaces between the larger particles. Newly deposited clays may have porosities up to 45% to 50%, but this falls to 20% or less after compaction.

The permeability of an estuarine deposit is also influenced by the size of the particles. Drainage through small particles is slower than through large particles. Webb (1958) found that the time taken to drain a standard column of water through a 10cm column of sand which had been passed through a 90 mesh/inch sieve was 150 times as long as the time taken to pass through a column of the sand retained by the sieve. Thus addition of silt to sand decreases the permeability.

Porosity and permeability are major factors in determining the water content of the soil. This is extremely important in intertidal regions as animals can burrow more easily in soils with a high water content.

Over the past forty years, the importance of sediment characteristics in determining the distribution of intertidal mudflat species has become generally recognised (Holme, 1949; Jansson, 1967; Cassie, 1969; Cassie and Michael, 1968; McKoy, 1970;) but it would be grossly incorrect to consider sediment characteristics as a sole factor.

### 3.02 METHODS: SIZE ASSESSMENT.

A sample of the substrate was taken at each of the four transect stations. These stations were

situated at: Low tide mark, 1/3 high tide mark, 2/3 high tide mark and high tide mark, which was in fact the top of the mudflat beach. The high tide mark, at slack water, was under 30cm of water on Mudflat 2, but on Mudflats 1 and 3, was the actual high tide mark.

In the laboratory, approximately 400 grammes of sample was soaked overnight in 6% hydrogen peroxide to remove any organic matter, filtered and soaked in 10ml of sodium hexametaphosphate (6.2g/l) in 200ml to 300ml of distilled water. This prevents adhesion of particles to each other. The sample was then dried at 110°C until constant weight was achieved. The substrate was then dry sieved, through a nest of Endecotts Laboratory Sieves (16,8,4,2,1,0.5,0.25,0.125,0.063mm meshes). Each fraction was weighed and expressed as a percentage of the total dry weight of the sample. The fraction passing through the 0.063mm mesh was further subdivided by pipette sedimentation into: 0.0315mm; 0.0157mm; 0.0078mm; and 0.0039mm components. These were included with the sand fractions and expressed as a percentage of the total dry weight of the sample.

#### ORGANIC CONTENT

A small sample of the sediment sample from each station was taken (prior to H<sub>2</sub>O<sub>2</sub> being added) and dried to constant weight. This sample was then incinerated at 700°C for twenty four hours, to remove any organic matter. The samples were then cooled in a desiccator and weighed. The weight of organic matter, the difference

between the dry weight and the incinerated weight was expressed as a percentage of the dry weight.

#### WATER CONTENT.

At each station, at low tide, two small glass tubes were slid horizontally into the mud. After one minute, caps were then clipped onto the tubes to prevent water loss from the sediment they now contained. In the laboratory, excess sediment was removed from the outside of the tubes, as were the caps and the system weighed to determine a wet weight. The open tubes then dried to constant weight, and reweighed. The weight difference is the weight of water in the sample expressed as a percentage of the sample dry weight.

#### 3.03 RESULTS.

Sediment sizes are expressed in Krumbeins (1936) phi ( $\phi$ ) scale.  $\text{Phi} = -\log_2$  of the particle diameter in millimeters, and has advantages over the commonly used Wentworth classification in that whole integers are used, being easier to work with than small metric fractions. This facilitates comparison of samples from different localities. A comparison of the Wentworth and Phi scales can be found in Appendix 1.

The results show that, with the exception of local deviations, the larger particles are predominant in the upper and lower reaches of the estuary, (fig. 17) The predominant sizes throughout the estuary are restricted to  $\phi$  values of 3 and 4. At some stations both these sizes made up the bulk of those found.

The substrarum found in transects A,B,C,and D have the larger particles ( $\phi=3$ ). The substrate of transects E,F,G,and H had the smaller particles ( $\phi=4$ ) and in the upper reaches, transects I,J,K,and L, the larger particles ( $\phi=3$ ) again predominate.

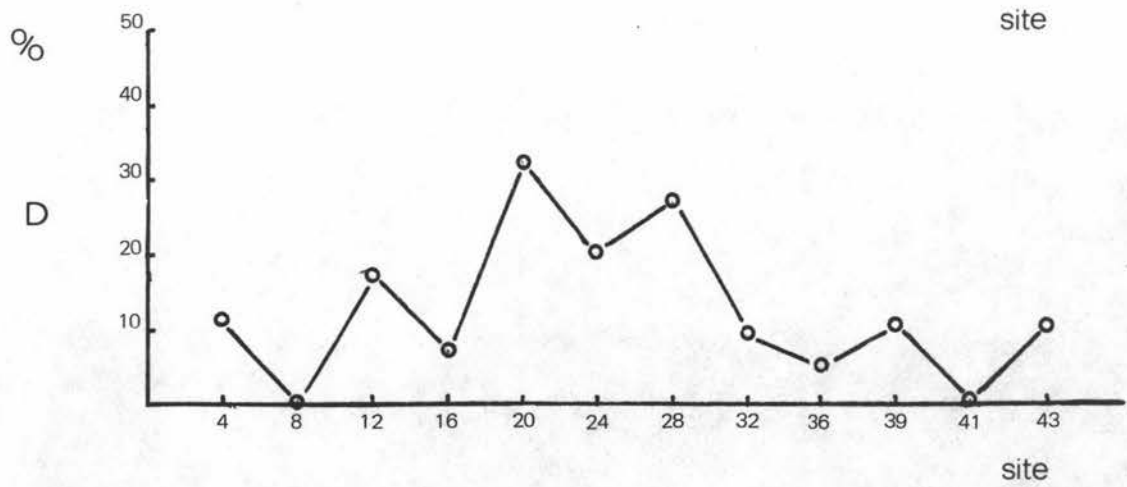
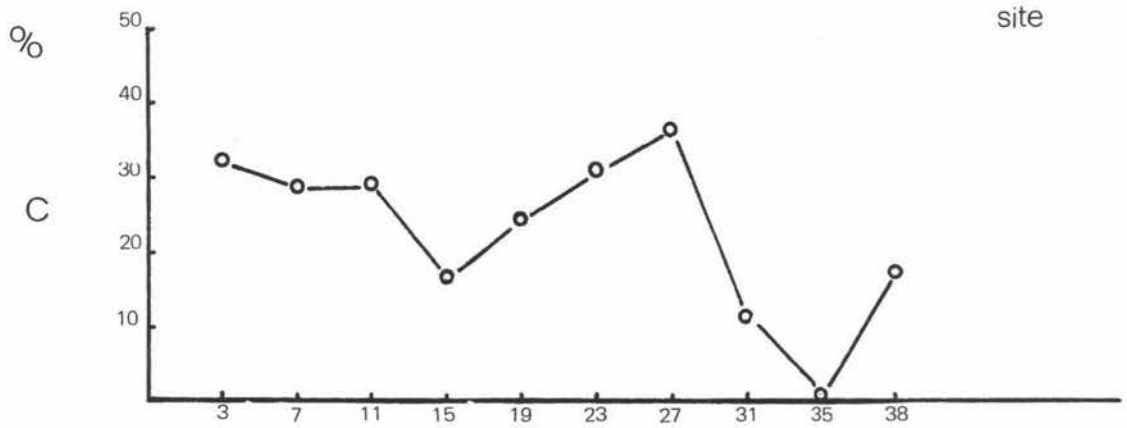
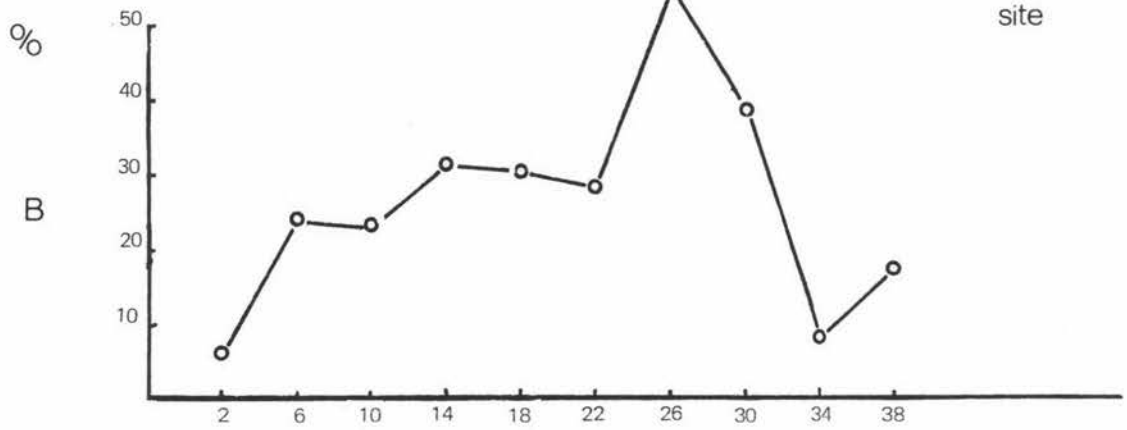
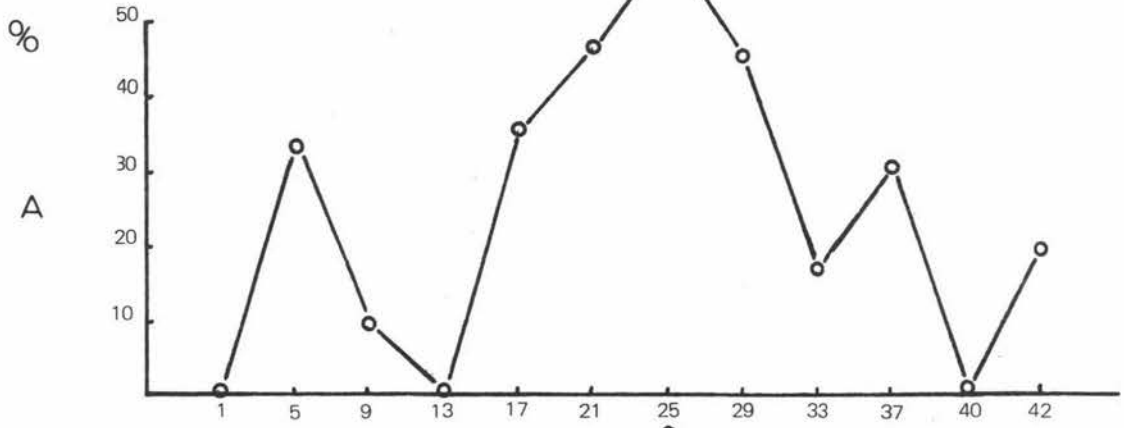
Transects I and J are on a different mudflat to transects K and L (figs.2&3).

Substrate at transect I had the largest particle size ( $\phi=2&3$ ) on this mudflat. This is probably because of the river channel being close to the South bank of the river, and aided by the presence of a large dead pine tree, sediments are deposited on the North bank of the river. The dead pine has the effect of slowing down the relatively shallow, near side of the river allowing particles ( $\phi=3$  or less) to settle out of suspension. Possibly this whole point, on a sharp bend in the river, is the result of the pine slowing the current in the vicinity, and consequent settling of the large particles. Downstream and underwater a sandy bar extents from the pine, adding some support to this idea (fig.18).

Stations 17 to 32 consist predominantly of particles with a phi value of 4. There were some isolated variations. Station 22 had two predominant particle sizes, ( $\phi=3&4$ ). It is on a slight rise and this could account for the high content of  $\phi=4$  sediment, smaller sediment being washed off the rise by tidal action. Stations 25 and 26 are close to

FIGURE SEVENTEEN:

A series of graphs showing the % silt content of the substrate at the various sampling stations. A.....high tide mark  
B..... $2/3$  HT mark  
C..... $1/3$  HT mark  
D.....low tide mark



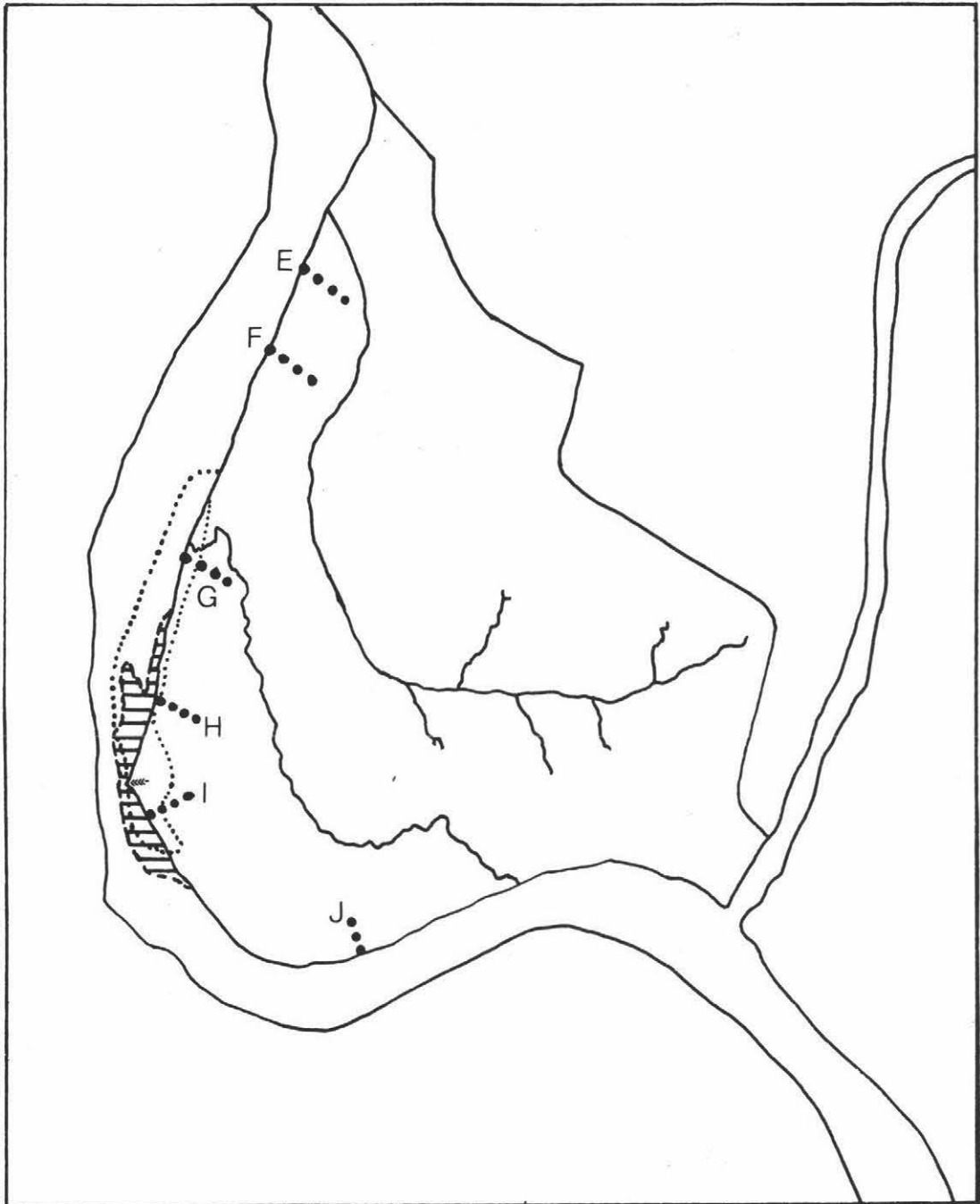
Spartina x townsendii beds. The presence of the vegetation tends not only to increase the rate of sedimentation (Harbord, 1949) but also the proportion of fine sediment retained. The high proportion of silt ( $\phi=5$ ) at these stations has been accredited to the close proximity of the S.x townsendii beds. Station 27 is 'normal' for the mudflat with a predominant phi value of 4. Station 28 is at the low tide mark. The presence of many dead trees at this level, in this region of the mudflat is considered responsible for the fine sand ( $\phi=3$ ) build-up. Stations 25 to 28 are in one transect, G. Station 32 is at the low tide mark of the transect immediately downstream of the large dead pine, transect I. This station has a predomination of very fine sand ( $\phi=4$ ), the presence of which is probably due to the accreting action of the pine.


The organic content of the substratum at stations 17 to 39 is higher than that at stations 1 to 16 or 40 to 43 (fig. 19). A common factor to stations 17 to 32 is the close proximity to growing vegetation. Any of the remaining stations that happen to be in close proximity to growing vegetation (e.g. stations, 14, 15 and 16) also have a relatively high substrate organic content. The stations that show an increased organic content, but are away from any vegetation, tend to be high in animal and unicell numbers. It is in these areas that 'faunal detritus' exceeds 'floral detritus'.


A profile of the sediments, taken near station


FIGURE EIGHTEEN:

An enlargement of Mudflat 2, showing the underwater sand bar prior to the flood of 29/6/1976, (shaded area) and the extension to this bar and the beach, by the sediment deposited by the flood, (dotted area).



 substrate deposited 29-6-1976

 under-water sand bar

 dead pine tree

E-J transects

31, shows a distinct layer of black, matted vegetative debris. The thickness of this layer varies from 20mm to 50mm and the layer lies between 70mm and 200mm below the surface. Polychaetes burrow through this layer but none were found resident in it.

On 29th June 1976, the Manawatu River flooded. At the Fitzherbert Avenue bridge in Palmerston North the water level was 5.95metres above normal. Flood water runoff and flooded tributaries increased this amount by the time the water reached the estuary. The high tide on the afternoon of the 29th June was slightly over 1 metre above normal high water spring tide level, (HWSTL). The flood had very marked effects on the upper reaches of Mudflat 2. Large amounts of silt and mud have been deposited, in some cases forming new low tide marks, by raising the level of the beach. Quite substantial beds of S. x townsendii were washed away or buried under new substrate deposits, as were Spartina beds in the proximity of transect H. Large areas of vegetation were flattened by the flood (fig.20).

The results of the substrate water content analysis tend to indicate that a high water content (40% to 45%) is found when the percentage of silt in the substrate is from 25% to 35% (fig.21).

FIGURE NINETEEN:

A series of graphs showing the % organic content of the substrate at each sampling station.      A.....high tide mark

B..... $2/3$  HT mark

C..... $1/3$  HT mark

D.....low tide mark

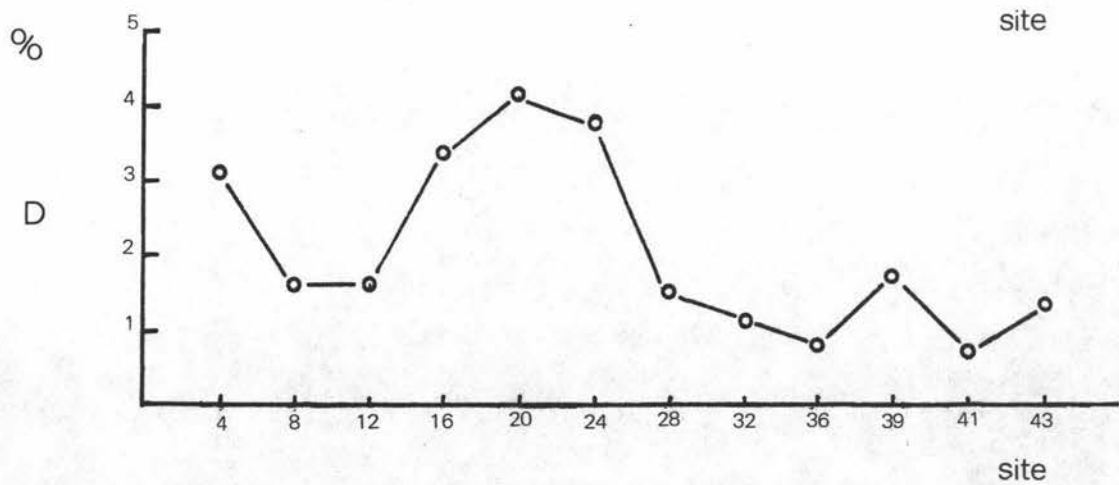
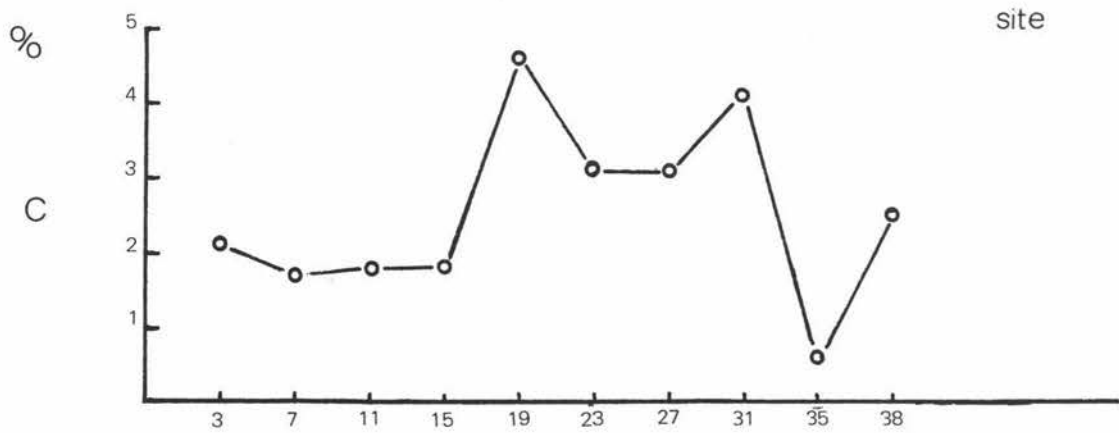
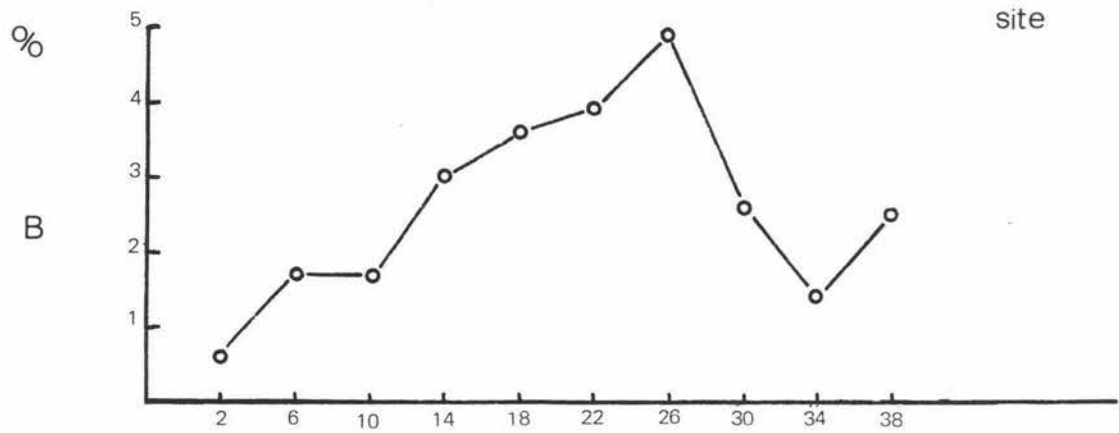
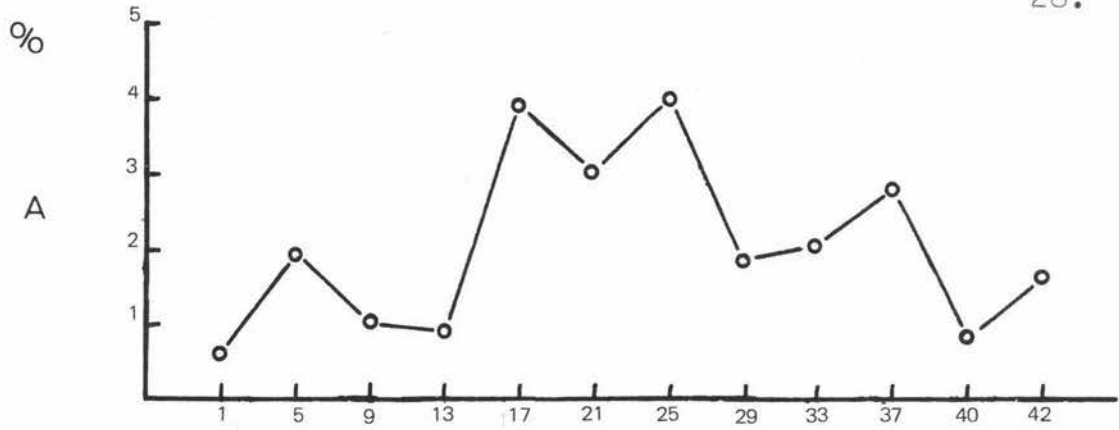


FIGURE TWENTY:

(a) A *Spartina* bed bent by an ebbing tide.

(b) *Spartina* flattened by the June flood, the bed in the centre of the photograph was saved by being on the highest part of a creek bank. Note the deep gouges in the substrate.



FIGURE TWENTY ONE:

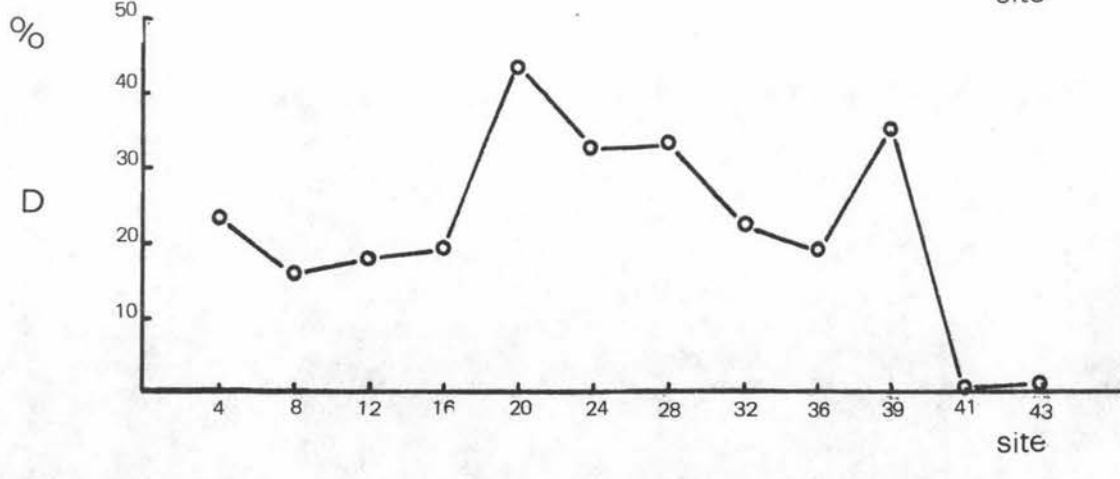
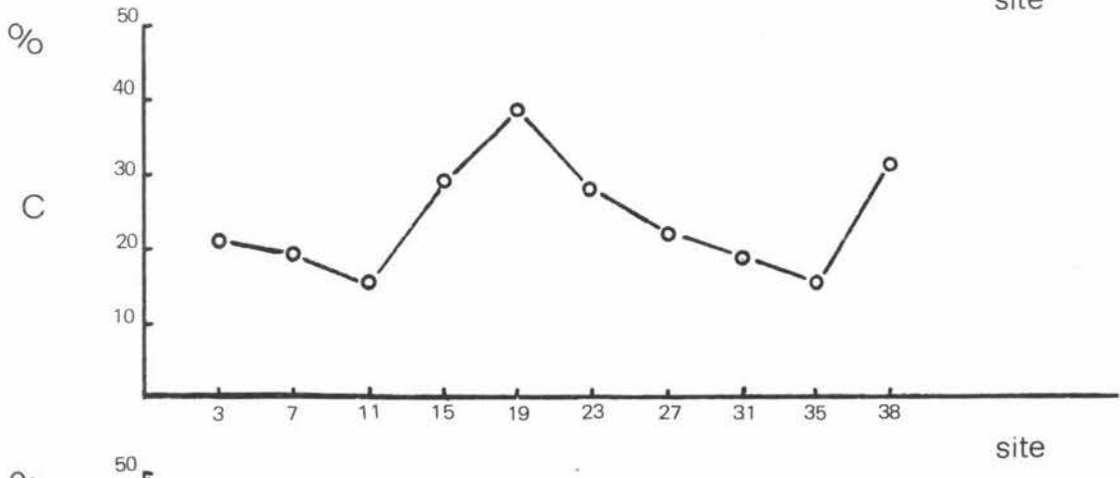
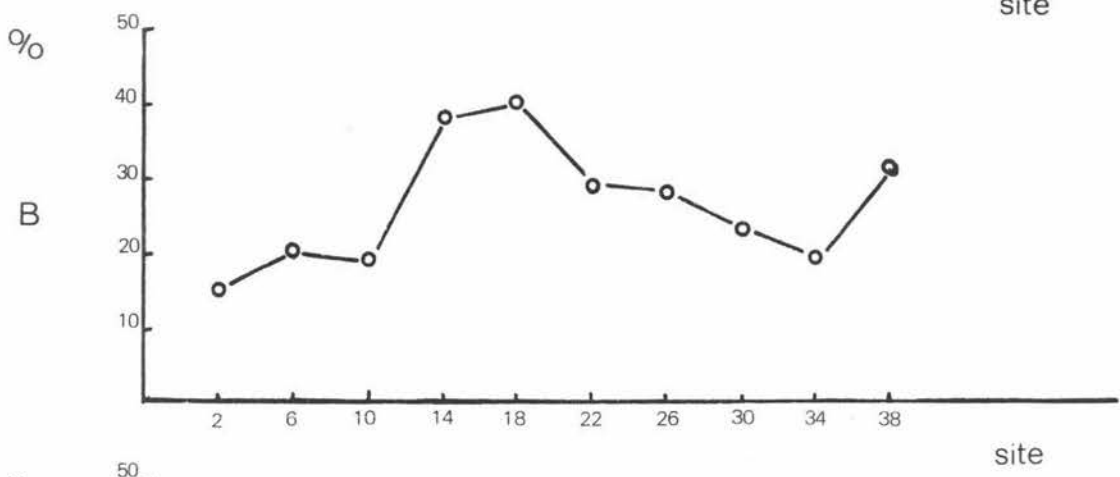
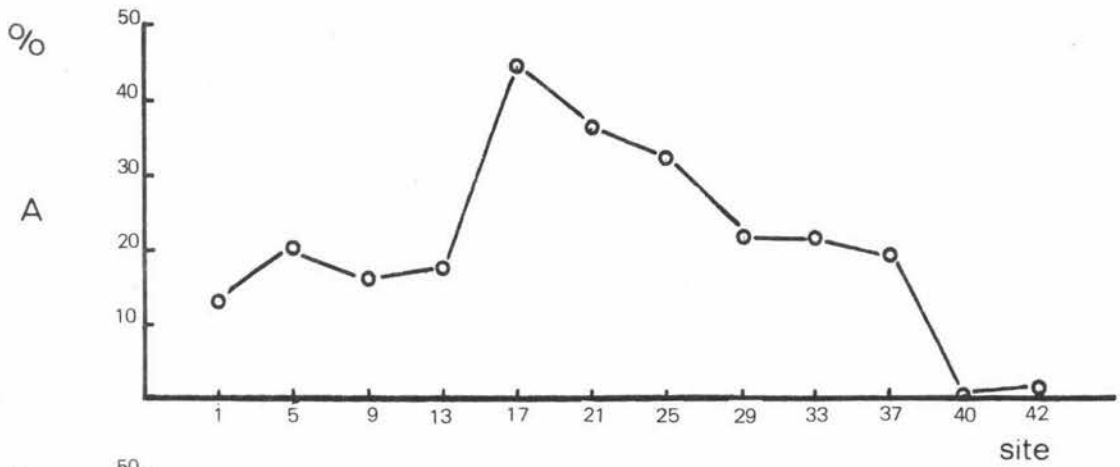
A series of graphs showing % water content  
of the substrate at the sampling stations.

A.....high tide mark

B..... $2/3$  HT mark

C..... $1/3$  HT mark

D.....low tide mark



INTERSTITIAL WATER:4.01 INTRODUCTION.

The various properties of interstitial water are of immense importance to the biota found on and burrowing in the mudflat substrate. Salinity is one of the more obvious of these. Animals burrowing in sediments may gain a certain amount of protection from the rapid salinity changes that occur in the open water. Reid (1930,1932) showed the buffering effect of estuarine substrates. At low tide, when the water flowing over the substrates is fresh, the salinity of interstitial water at 150mm depth is well above that of freshwater, and remains so until the tide flows again. The slope of the beach is also important in the regulation of interstitial water salinity. Reid found that beaches with a steep slope cause more rapid runoff. Thus the more saline water tends to drain away, allowing freshwater to penetrate to a greater depth.

Salinity also influences the solubility of oxygen in water and thus its availability to animal life. In brackish environments, temperature also plays an important role in oxygen solubility. Apart from lowering the oxygen content, when temperature is increased, metabolic rates of intertidal invertebrates is also increased, resulting in an increased oxygen demand. During the day light hours the oxygen content may be increased by the photosynthetic activity of plants and algae. At night oxygen levels decrease due to the

cessation of photosynthesis and continuation of plant and animal respiration. Broekhuysen (1935; IN Green, 1968) measured the oxygen concentration of the water in a Zostera bed. At night no oxygen was detectable but during the day, the level rose to 260% saturation. However this is an extreme example and less extreme ranges have been recorded with the same general pattern, low oxygen concentration at night and higher during the day. In some cases, where the waters of an estuary are very turbid, photosynthesis by planktonic algae is restricted to a narrow band near the surface of the water. The oxygen then produced is insufficient to balance the respiration of the phytoplankton and no diurnal changes in oxygen concentration are detectable. In the river channel proper the vertical distribution of oxygen is dependent upon the presence (or absence) of vertical salinity stratification. If the estuary is well mixed it is unlikely that any marked oxygen gradient will develop. As well as possible vertical differences, oxygen characteristically varies diurnally and seasonally within estuaries. The ranges of such variations differ, depending upon the freshwater source, the morphology of the basin, and tidal movements. In deep, turbid estuaries which lack contribution from an abundant bottom flora, diurnal oxygen pulses are apt to be relatively slight.

The solubility of oxygen in water decreases as water temperature increases and increasing salinity

also have this effect. Thus less oxygen can be dissolved in seawater than in freshwater. At 15°C oxygen saturated seawater (salinity 34.6‰) contains 5.8mls oxygen per litre of water, a litre of freshwater at 15°C holds 10.3mls oxygen (from Sverdrup et al 1942, IN Reid, 1961). Consequently estuary oxygen content may vary with the seasonal fluctuations of freshwater input.

Hydrogen ion concentration (pH) of interstitial water is dependent upon the concentration of carbon dioxide;



the temperature, and the oxygen concentration. Infact pH should vary inversely with the free carbon dioxide, and directly with the dissolved oxygen content.

The research into the Redox Potential (Eh) of field stations has been fruitful in contributing to our knowledge of chemical limnology and its influence on the activities and distribution of various organisms. The extent of total oxidation-reduction is dependent upon the concentration of oxidation-reduction systems and their products in 'solution'. Oxygen in natural waters produces a redox potential influenced by temperature and pH. Low redox potentials suggest the presence of reducing substances, which probably would utilize such free oxygen as might be brought into solution.

#### 4.02 METHODS: SALINITY

Four replicate samples of interstitial water were collected at each station and taken to the lab

laboratory. They were stored in sealed plastic bottles in a refrigerator and analysed for chloride within four days. Chlorinity was determined by titration with silver nitrate to excess, and back titrated with potassium thiosulphate, using ammonium ferric sulphate as an indicator. Total salinity was determined from the chlorinity by the use of the empirical formula:

$$\text{SALINITY} = (\text{CHLORINITY} \times 1.805) + 0.03$$

(Hoar, 1966)

This method was used because of the apparently large number of interfering substances in the water.

A further sample of interstitial water was subjected to atomic absorption spectrophotometry for calcium content, using an E.E.L. atomic absorption spectrophotometer burning an air/acetylene mixture. 65,000 parts per million (ppm) of lanthanum chloride was added to the sample to suppress iron and phosphate interferences. A standard curve of calcium concentrations was prepared on the machine and calcium concentrations of the samples determined from it.

Sodium and potassium were determined by flame photometry, using an E.E.L. flame photometer. Not all samples were tested for these ions.

#### OXYGEN AND TEMPERATURE:

At each station four core samples were taken and interstitial water seeped into the resulting holes. Without disturbance of the water the oxygen and the temperature were measured with a Y.S.I. portable oxygen

meter, which gave direct readings in degrees Celsius and parts per million of oxygen.

#### pH AND REDOX POTENTIAL:

After the oxygen concentration and temperature had been measured the pH and the redox potentials were determined. pH was determined with a METROHM portable pH meter. Redox potentials were determined with a METROHM portable pH meter with a platinum-calomel redox electrode.

#### 4.03 RESULTS:SALINITY

The salinity of interstitial water showed an expected decrease as sampling proceeded up river (fig,21). The highest average salinity for a transect (A) was 24.8‰. The range on Mudflat 1 was from 27.2‰ at station 2, to 6.1‰ at station 14. These relatively high readings decreased rapidly on Mudflat 2. The highest average salinity (on Mudflat 2) was 8.4‰ for transect E. The range being from 9.1‰ at station 17, to 1.3‰ at station 27. At the head of the estuary, Mudflat 3, the salinities are within the range of those of freshwater, 0.4‰ at station 42, 0.2‰ at station 43.

Calcium ion content also has a high variability, but this is not as directly related to site position on the mudflat as is chlorinity and hence salinity. Stations 1 to 6 exhibited a fairly high average calcium content (105 to 215 ppm). An outflow from a piped stream with a calcium content of 66.7ppm flows over the mudflat, parallel to and slightly beyond stations 5 and 6 (fig,2).

FIGURE TWENTY TWO:

A series of graphs showing the interstitial salinity of the interstitial water at the sampling stations. A.....high tide mark  
B..... $2/3$  HT mark  
C..... $1/3$  HT mark  
D.....low tide mark

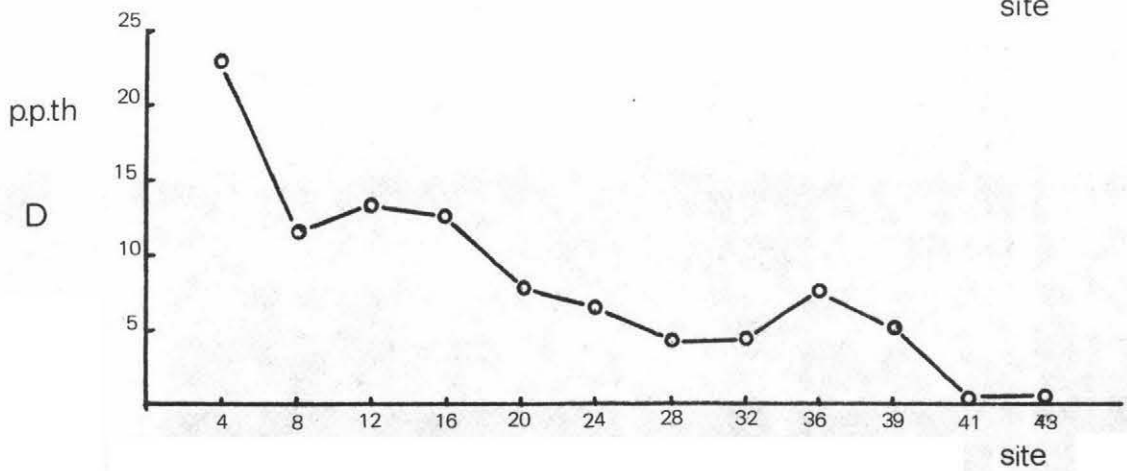
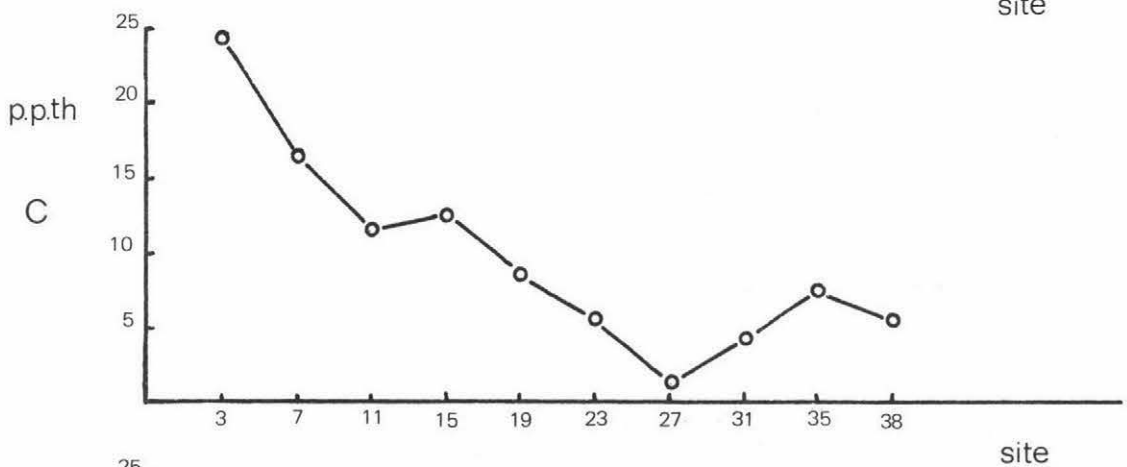
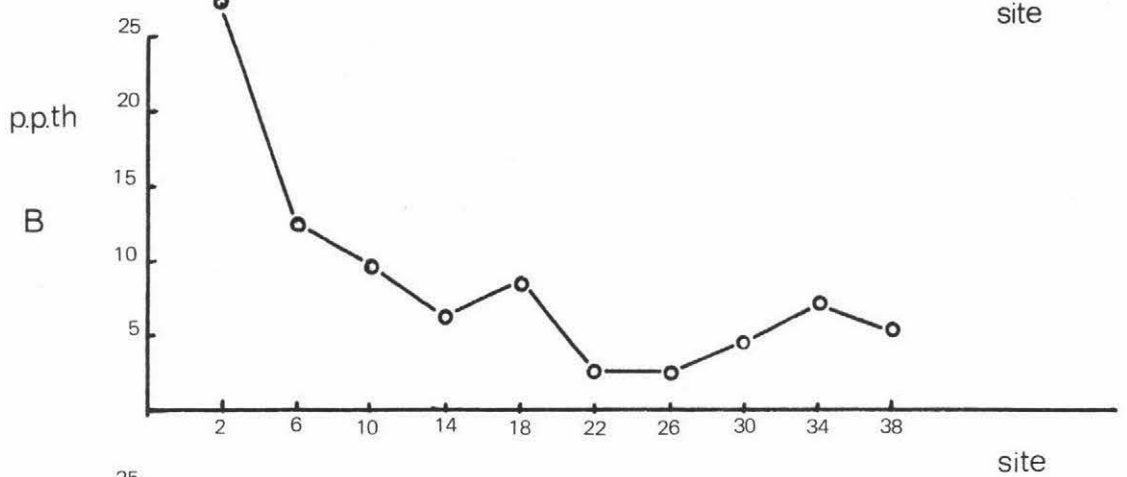
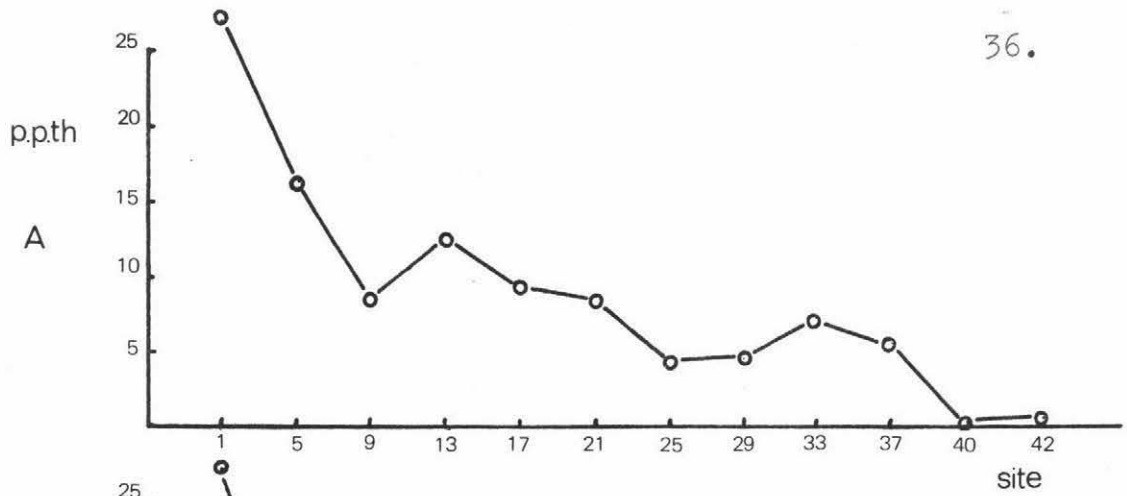


FIGURE TWENTY THREE:

A series of graphs showing the interstitial water oxygen concentration in parts per million, at each sampling station.

- A.....high tide mark
- B..... $2/3$  HT mark
- C..... $1/3$  HT mark
- D.....low tide mark

Two of the four water samples taken at station six show a distinct drop in calcium level as a result of receiving water from the outflow (table,1)

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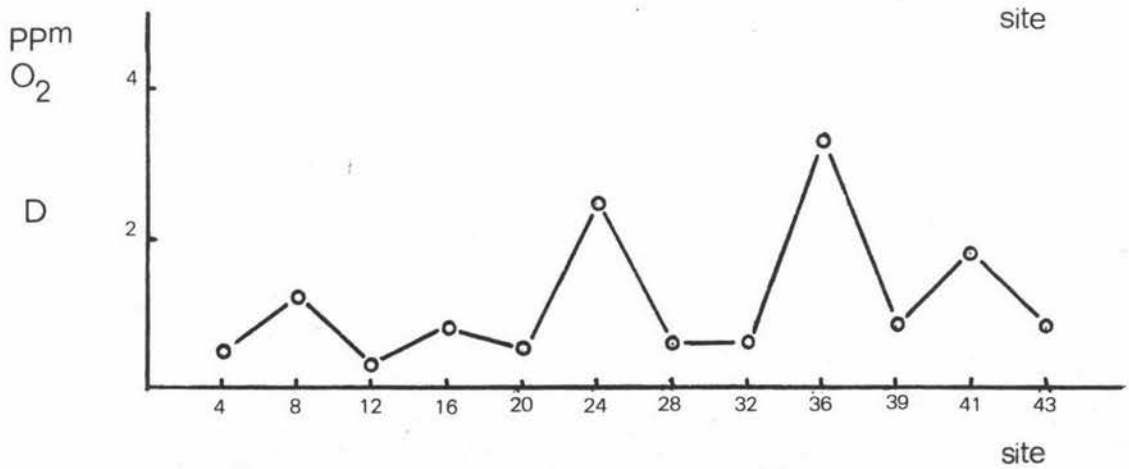
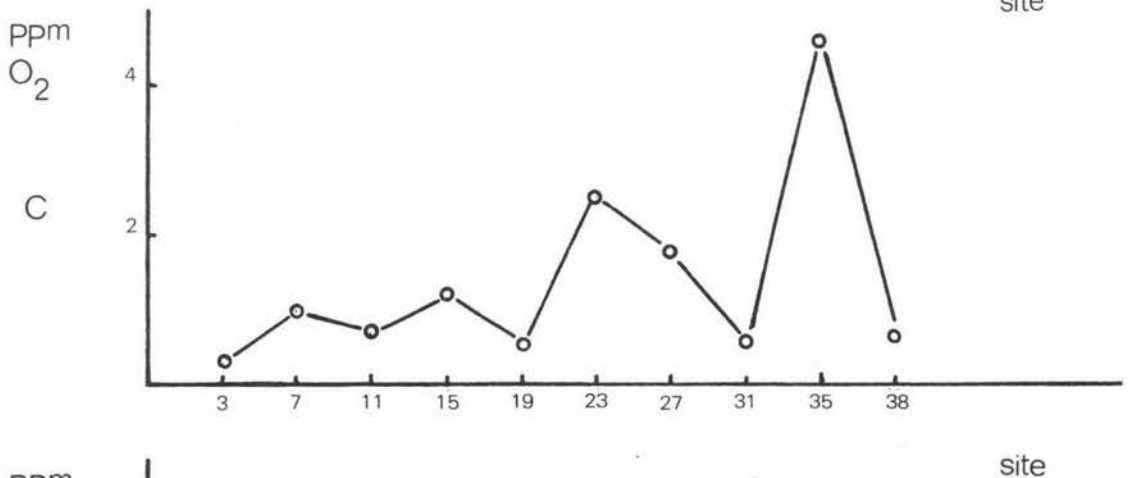
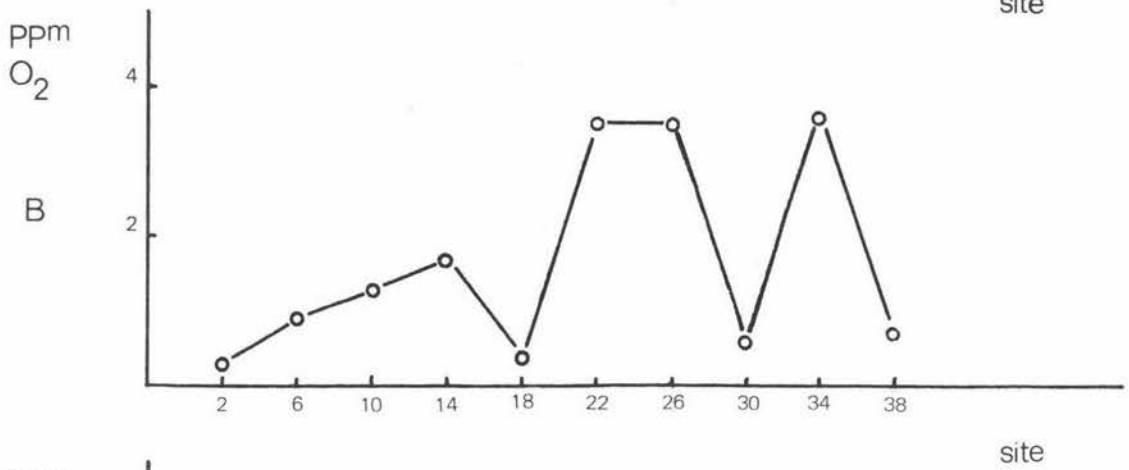
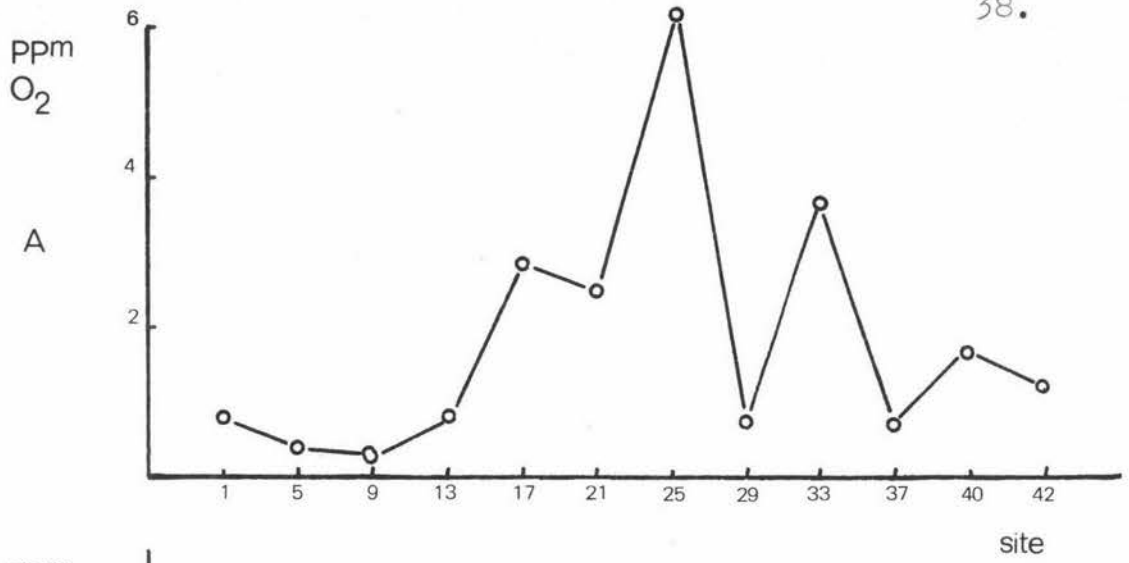
6	1	145.48	
6	2	153.53	- samples unaffected
6	3	57.50	
6	4	59.80	- samples receiving outflow

---

There is, however, a steady decrease in calcium as sampling proceeds upriver. The range of interstitial water calcium at stations 40 to 43 being 9.7ppm to 0.5ppm.

#### OXYGEN AND TEMPERATURE

The majority of the first twenty stations have a fairly low oxygen concentration, the range being from 0.3ppm at stations 2,3,9 and 12, to 1.7ppm at station 14. The high reading of 2.9ppm at station 17, (fig,22;Appendix 2) was probably caused by the substrate forming the rim of the hole falling into the water prior to the measurement being taken. The higher values obtained at stations 21 to 28 maybe related to the proximity of these stations to Spartina x townsendii beds, particularly as the readings were taken during the day when photosynthesis would be occurring. The high values obtained from transect I were probably related to the very loosepacking of the substrate, the interstices being full of air. When walked on, the impressions left in the sand were upto 25cm deep. Stations 37 to 43 return to a relatively low oxygen content, ranging from 0.7ppm to 1.8ppm.



The temperature of the interstitial water followed the ambient air temperature. It was usually  $1^{\circ}\text{C}$  to  $2^{\circ}\text{C}$  higher as the measurements were made in holes full of water but out of the direct effect of the prevailing West North West wind. The layer of air between the water surface and the top of the hole acted as a buffer zone thus reducing the evaporative cooling effect of the wind.

#### pH AND REDOX POTENTIAL

It can be seen from figure 23 (A,B,C,&D) that the range of pH values are from pH 6.0 to pH 8.0. The various tidal stations maintain an average pH slightly above pH 7.0. Figure 23 shows the average transect values of redox potential closely following those of pH. The redox potential varies from very oxidized (+0.25v) to moderately reduced (-0.12v). A low redox potential suggests the presence of reducing substances which in all probability would utilize any free oxygen present. Hence the stations with moderately reduced systems are found near decaying organic matter, e.g. stations 14,15 and 16.

FIGURE TWENTY FOUR:

A series of graphs showing the pH of the interstitial water at each sampling station.

A.....high tide mark

I..... $\frac{2}{3}$  HT mark

C..... $\frac{1}{3}$  HT mark

D.....low tide mark

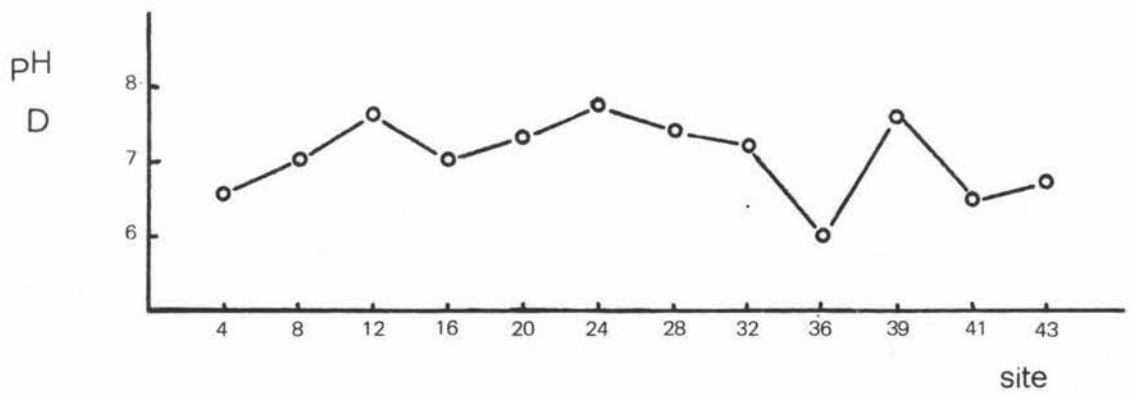
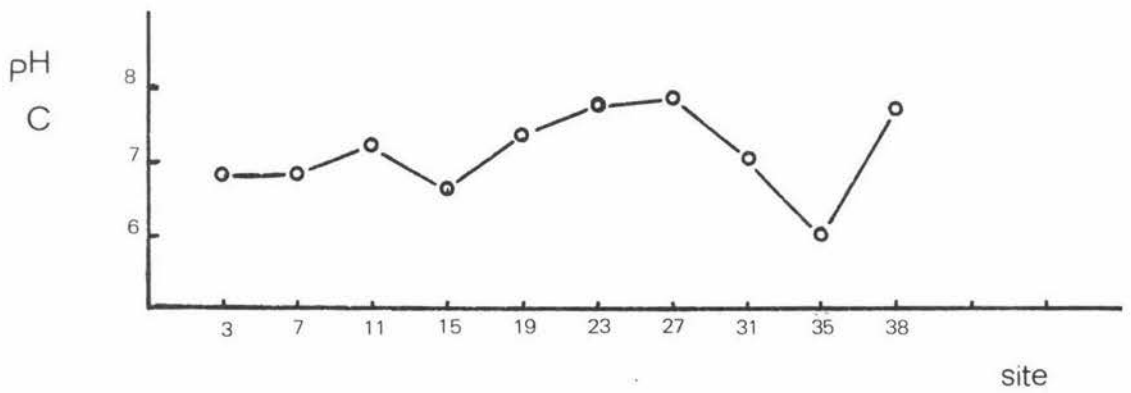
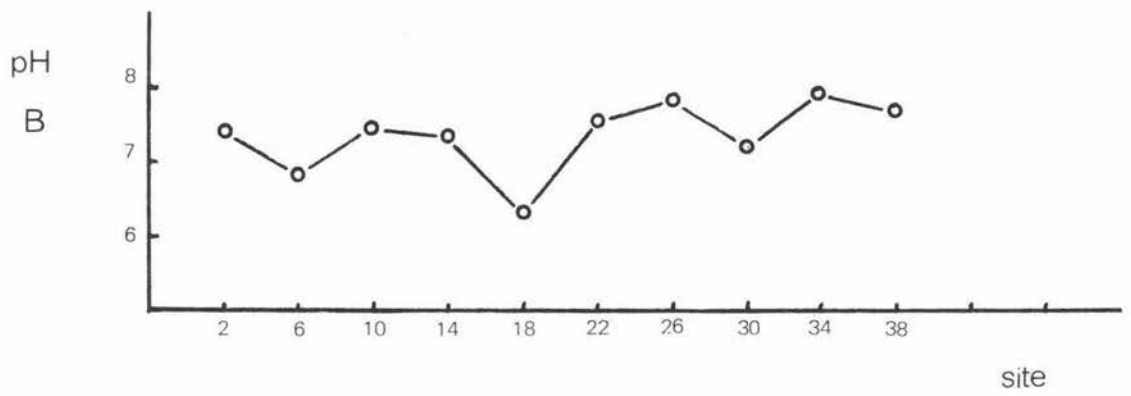
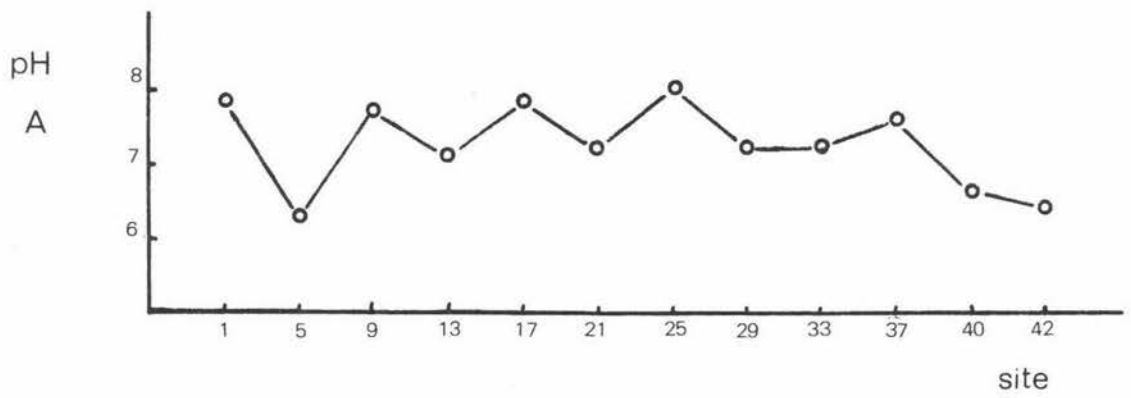


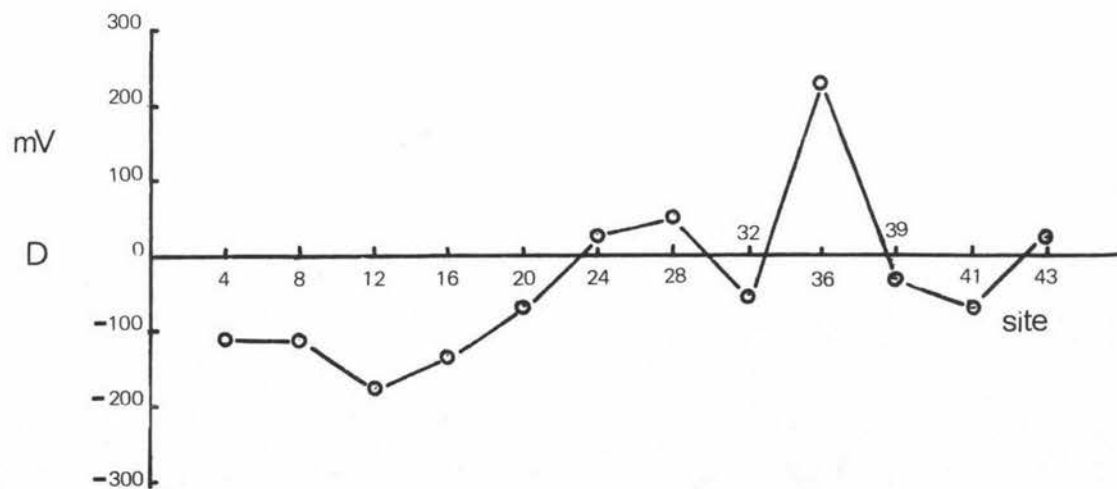
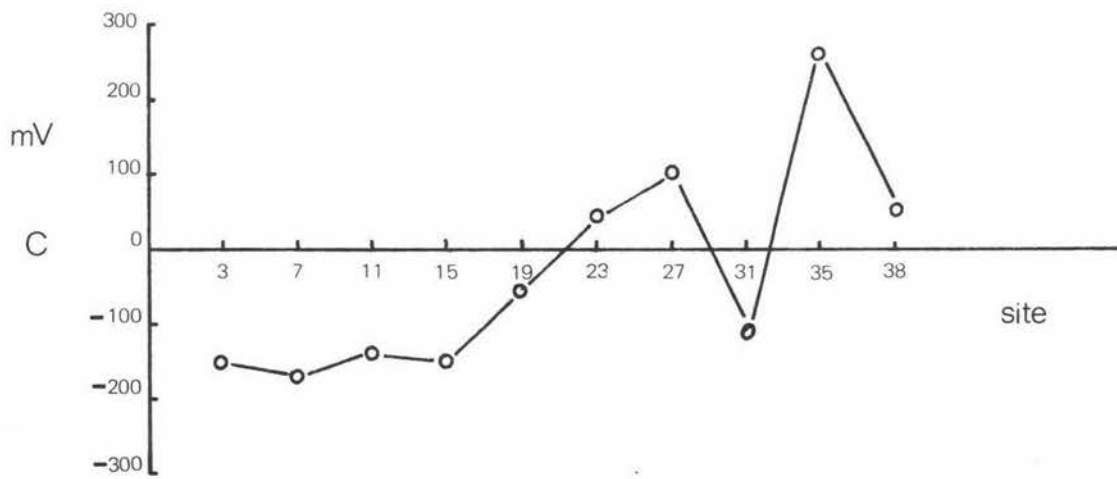
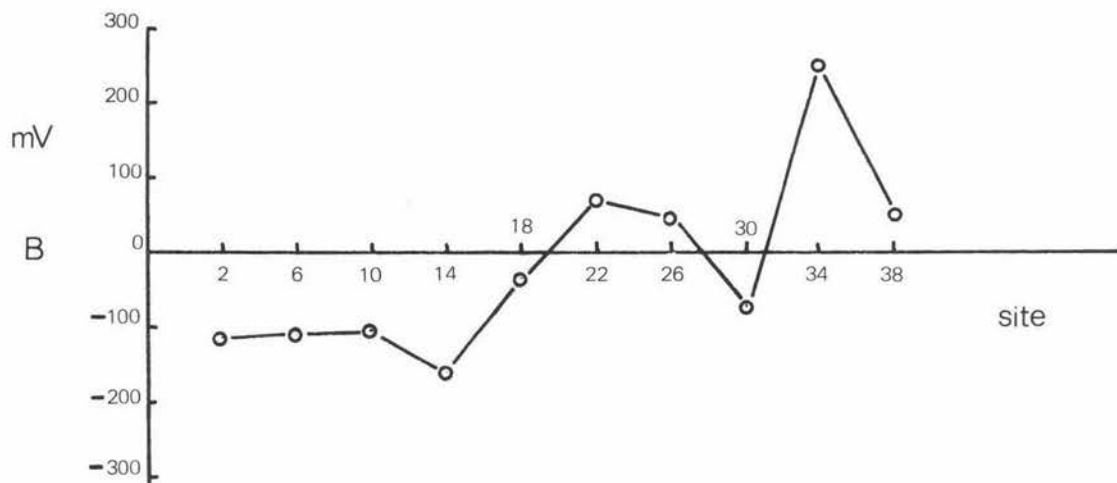
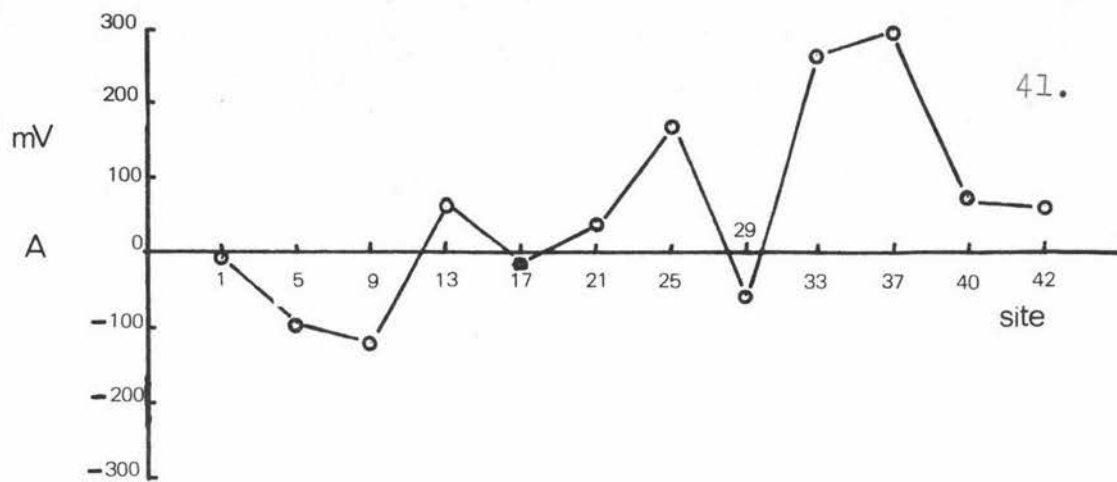
FIGURE TWENTY FIVE:

A series of graphs showing the oxidation  
reduction potential of the substrate (in mV)  
at each station. A.....high tide mark

B..... $2/3$  HT mark

C..... $1/3$  HT mark

D.....low tide mark



SECTION TWO:BIOLOGICAL FACTORS:MUDFLAT VEGETATION.5.01 INTRODUCTION.

Estuaries and salt marshes around the world have a similar colonization pattern. The vegetation changes as the mudflats become higher above the sea, and thus less susceptible to tidal inundation. The species found on the lower tidal levels may be very different to those at the higher tidal levels. In some cases a profound difference occurs, with only a few centimeters increase in height.

In time a stage is reached where no further increase in height of the mudflat is possible. This mark is the extreme high water mark of spring tides. At this upper limit the mudflat bears a specific type of vegetation, varying accordingly in different regions. In Europe it is dominated by Juncus maritimus, in New Zealand by Leptocarpus simplex or Juncus maritimus var. australiensis (Allen, 1940).

Mudflat vegetation has a strong influence on the rate of sediment accretion (Allen, 1930; Harbord, 1949; Blick, 1965; Bascand, 1968a, b;) in that sediment is precipitated out of suspension because the water velocity is lessened by the presence of fairly dense vegetation. If a high rate of accretion occurs naturally, in the absence of vegetation, it may be severe enough to prevent initial colonization. Ranwell (1972) gave

accretion values found by other workers; Chapman and Ronaldson (1958) found less than 0.2mm accretion per year on a tropical Mangrove swamp where roots and rhizomes are too widely spaced to retain much of the sand washed between them. Oliver (1929) found that Salicornia accretion was up to 30mm per year, and Jacobson et al (1955) found that Puccinella maritima can accrete sandy silt at the rate of 100mm per year. Ranwell (1964) found that Spartina anglica can accrete 50mm to 100mm per year and upto 150mm per year under favourable conditions. In New Zealand, at the Waihopai estuary, Spartina x townsendii was found to have increased the level of the mudflats by 200mm between the years 1941 (when it was first planted there) and 1946, (Harbord, 1949).

Several workers have shown that there is a yearly pattern of accretion. It is usually greatest in spring and summer, falls off in autumn with a tendency for erosion in winter, (Kamps, 1962; Ranwell, 1964;). Price and Kendrick (1963) show another relevant factor to be the flocculation effect of saltwater on silt. These workers believe that this could account for the seasonal changes in suspended silt in the River Thames and other estuaries.

'In the summer of 1959 the water became unusually free of silt and visibility increased from 15cm to 60 cm. During the late autumn and early winter the deposits again became muddy. This may be explained as follows:

In the dry summer of 1959 freshwater flow was minimal hence salinity upstream was higher than usual. Charges on the silt particles, neutralized by the electrolytic seawater, caused flocculation and deposition of silt higher upstream than usual. When the freshwater flow returned to normal it is possible that the charges on the deposited silt could be restored, mobilizing it again'

after Price and Kendrick (1963)  
IN Ranwell (1972).

The cord grass, S.x townsendii was introduced in to New Zealand and planted in the Manawatu River estuary by Mr. K.Dalrymple of Bulls in 1913, (Oliver, 1920). It was initially thought that only S.stricta had been introduced, but Allen (1930) showed the plants to be S.x townsendii, with possibly some, but not much S.stricta. From Foxton S.x townsendii has been introduced into several areas in New Zealand, (Allen, 1930;Harbord,1949; Blick,1965;Bascand,1968;). The initial introduction of Spartina spp into New Zealand was in line with the idea that soils as rich in nutrient as are the mudflats, should be reclaimed and brought into agricultural use. Initially stock are introduced onto the Spartina paddocks, mainly cattle and horses, this aids consolidation of the substrate, which after a few years will stand up to the strain of heavy cropping machinery. Spartina is used in Europe and North America as a hay or ensilage crop, (Blick, 1965; Hitchcock'72). The cropping of Spartina has not yet started in New Zealand.

5.02 METHODS

A scale map of the estuary (1:25000) was divided up into grids, 0.5cm x 0.5cm, (Appendix 3). On this the location limits of the various species was marked. Boundaries of vegetation species were determined from; aerial infrared colour, and colour slides, black and white aerial photographs and observation on the ground. Specimens of all species were collected and the location noted. This enabled later correlation of species distribution with various environmental factors.

5.03 RESULTS

The most widespread mudflat saltmarsh plants on the estuary flats are Spartina x townsendii and Salicornia australis (Soland), 30.25% of the flats being covered with S.x townsendii and 12.07% being covered with S.australis. Of the species found, Juncus acutus is found near the high tide mark, on a tightly compacted area of Mudflat one. It grows here in small tussocks upto 1 metre high. Juncus maritimus var australiensis is found only near the upstream bed of Mudflat two. It is found in small isolated clumps amongst other vegetation. Leptocarpus simplex (A.Rich) is found in one isolated patch, slightly down stream to transect H and at the high tide mark. The patch is approximately 2m<sup>2</sup> in area and grows to a height of approximately 1.2m. Cotula australis is found in small clumps (approx. 0.1m<sup>2</sup>) over a large area of Mudflat 2,

between transects H and I. Initially the clumps were amongst the S.x townsendii but this was washed out by the flood on June 29th 1976, surprizingly the C.australis remained. Agrostis stolonifera was found on Mudflat 2. Initially it occurred in small patches just down stream to transect I, but a few metres further upstream to transect I was the start of a large area covered with A.stolonifera. It is also one of the first 'pasture grasses' to appear. Juncus maritimus var australiensis and Festuca arundinacia also appear in this vacinity, both growing clumped in A.stolonifera patches. The Juncus is much more plentiful than the Festuca. Scirpus nodosus was only found in one locality on the Waiterere bank of the river, in a corner of a mudflat where Pinus radiata forest backs onto the mudflat. (It also occurred at the upper limits of the saltmarsh associated with Mudflat 2). Mudflat 3 is bear of vegetation except at H.W.S.T.L. where pasture grasses are sown, the mudflat backs onto a Catchment Board farm block. On the Waiterere bank, the dominant plant (apart from Pinus spp) is Ammophila arenaria which the N.Z.F.S. plant to bind the sand prior to planting Pinus spp. Consequently A.arenaria is very dominant on the Waiterere bank, and all along the duneland coast of the Manawatu region.

Small, isolated pockets of the sedge Scirpus cernuus (Vahl) appear in the Cotula and Salicornia. The taller sedge S.pungens (Vahl) is also found in isolated pockets. S.pungens has in the past been called Scirpus americanus (Pers), 'three square', by New Zealand authors.

An american, Dr.Schuyler, has shown that true S.americanus is confined to North and South America, the more widespread plant being S.pungens. (E.Edgar pers.com)

No Zostera spp were found at the estuary.

INTERTIDAL FAUNA:6.01 INTRODUCTION.

Estuarine faunae may be considered to have arrived at their present day habitat from several different sources. Mainly the animals are from; the sea, (marine component), from freshwater, (limnetic component) and from the land, (terrestrial component).

The marine component includes animals from groups, the majority of whose members live in the sea. Within this component three sub-components may be separated.

(i) The stenohaline marine component includes animals with limited powers of osmoregulation, and thus limited ability to penetrate estuaries. It consists mainly of the marine species found near the mouths of estuaries, where the salinity does not fall below 30‰.

(ii) The euryhaline marine component includes species which live in both the sea and brackish water, with the limit of penetration being less than 30‰. Remane (1958 IN Green, 1968) studied the very stable salinity conditions of the Baltic. He separated the euryhaline marine component into four further grades, based on the lowest salinity to which the animals could penetrate. It is, however, doubtful if these groupings can be applied to the more variable salinity conditions in estuaries.

(iii) The brackish water component includes animals of marine ancestry, which live in salinities below 30‰ and are not found in the sea.

(vi) The limnetic component consists mainly of species from groups that are predominantly freshwater inhabitants. So the estuarine limnetic fauna may be considered to have descended from similar freshwater forms. Remane (1958, IN Green, 1968) also separates out three sub-components of the limnetic component. He defines them by the lower limit of salinity penetration by the animals. Stenohaline limnobionts rarely occur in salinities above 0.5‰, whereas the euryhaline limnobionts enter brackish water. Remane defined three grades of euryhaline limnobionts, those that penetrate to 3‰, 8‰, and above 8‰ salinity.

One component difficult to classify as marine or limnetic, is the migratory component. This includes fish such as the salmon and eels, which differ from euryhaline animals because they pass from marine to freshwater to live and vice versa.

Adaptation by terrestrial animals to an estuarine environment have taken place mainly in the arthropods. Luxton (1964) studied the occurrence of soil dwelling Acari in salt marshes. He found that different species of the mite were dominant in regions where different plants were dominant. In general the detritus eating Orbatid mites were dominant over the predatory Mesostigmatid mites. Spiders, and several insect groups (Homopterans, Orthopterans, Diptera...) are found at estuaries especially salt marshes.

6.02 METHODS

At each station, four core samples, each of 1.104 litre capacity were taken and searched for animals. The number of each species present was noted at each station. It was also observed that at each station the sampling of 'inbenthos' in this way tended not to give a true representation of surface dwelling animals. To rectify this a quadrat (0.1156 sq m) was placed at four randomly selected points at each station. All animals included in these areas were counted. The results were averaged and this was taken as the average number of animals per 0.1156 m<sup>2</sup>.

Statistical correlations between each species found, and each ecological parameter studied, were performed on the raw data. (Appendix 4)

6.03 RESULTS

The animals tend to show a clumped distribution along the mudflats, although at the same time many of them are fairly ubiquitous, (Appendix 4). The lamellibranch molluscs, Mactra (Cyclomactra) ovata and Chione stutchbury only appear when the salinity exceeds 10‰ (approximately 30% sea water). Consequently they are only found near the mouth of the estuary and up river as far as transect C.

The gastropod molluscs are represented by Amphibola crenata, the mud snail, and Potamopyrgus estuarinus a much smaller snail, resembling its fresh-water counterpart Potamopyrgus antipidia. Both of the

estuary snails are surface dwelling animals but will burrow into the mud to escape adverse conditions. They are both ubiquitous along the estuary but A.crenata is not found in the lower tidal region (1/3 H.T. to L.T.)

The crustaceans were present in several forms. Mysids and shrimps are found but only in the streams and pools left by the receding tide. Sand-hoppers, Talorchestia quoyana, were present under logs and other debris above the high water mark. On the mudflats proper, the amphipoda are represented by Paracorophium excuvatum, a small burrowing crustacean, that will also live in the burrow of errant polychaetes and crabs. The decapod crustaceans found were the very numerous Helice crassa, an inhabitant of the upper and mid tidal regions, and two other crab species, but only one specimen of each, Hemigrapsus crenulatus was found slightly upstream to station 13, in a Spartina bed, and a specimen of Macrophthalmus (Hemiplax) hirtipes was found near station 1. The specimen of M.hirtipes was found after the flood of June 29th 1976, and its appearance lead to the conclusion it was introduced by a bird, the carapace having been holed in a similar manner as to the damage caused by gulls.

The polychaetes found were all errantia. Nicon aestuariensis (Knox), and Scolecopides benhami (Ehlers) were both plentiful and ubiquitous along the estuary. Searching the 'infauna' at station 4 revealed one specimen of Hemipodus simplex, the only specimen found at the estuary.

The correlation analysis produced the results presented in table 2. The symbols used and their numerical values are indicated in the key accompanying the table.

The surface quadrats (Appendix 5) indicated a greater number of snails, both A.crenata and P.estuarinus on the surface than **i**n the substrate. The quadrats also indicated the presence of mysids and juvenile sand flounders Rhombosolea plebeia in the small shallow tidal pools. This type of sampling also indicates the clumped distribution of the intertidal benthos, eg Potamopyrgus and Amphibola occur in fairly large numbers in some regions of the estuary, in other regions they are absent. A similar pattern can be seen in Helice, although the clumping is more spaced than is that of the gastropods. Also apparent is the fact that the majority of surface animals inhabit the most seaward six transects of the estuary.

TABLE 2

Results of the correlation analysis.

ECOLOGICAL PARAMETER	Interstitial O <sub>2</sub> Concentration			Interstitial water Salinity			Interstitial pH			SUBSTRATE Eh			% SILT			SUBSTRATE ORGANIC CONTENT			SUBSTRATE WATER CONTENT			MUDFLAT EXPOSURE TIME						
	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT	HT	$\frac{2}{3}$	$\frac{1}{3}$ LT				
PARACOROPHIUM	-	-	-	0	+	‡	+	-	-	+ 0 0	-	-	0	+	-	-	-	0	-	-	0	-	-	0	+	=	-	
HELICE	‡	-	+	-	-	+	+	0	+	+ = 0 0	‡	+	0	‡	0	0	+	‡	-	+	‡	-	+	+	‡	+	+	‡
POTAMOPYRGUS	‡	‡	+	-	-	-	-	0	+	- - - -	+	+	+	-	‡	+	0	0	+	‡	+	0	‡	+	0	‡	+	0
AMPHIBOLA	+	+	0	-	-	+	0	+	0	= 0 0 0	0	‡	+	‡	‡	-	+	+	-	+	+	-	‡	+	-	‡	+	-
SCOLECOLEPEDIS	0	+	-	-	=	-	+	‡	0	0 - ‡ -	‡	‡	-	+	0	-	‡	0	-	‡	0	-	‡	+	‡	‡	+	‡
NICON	+	0	+	0	=	-	0	=	+	= 0 0 0	+	‡	+	+	‡	+	+	‡	‡	+	‡	‡	+	‡	‡	+	+	-
MACTRA	0	-	0	0	‡	+	0	0	0	0 + - +	0	-	-	0	=	+	0	-	+	0	-	+	0	-	=	0	-	=
CHIONE	0	-	0	0	‡	0	0	0	0	0 + 0 0	0	-	0	0	‡	0	0	-	0	0	-	0	0	-	0	0	-	0

KEY:  
 ‡ +0.5 - +1.0  
 + +0.11 - +0.49  
 0 -0.1 - +0.1  
 - -0.49 - -0.11  
 = -1.0 - -0.5

SALINITY TOLERANCES AND PREFERENCES OF HELICE CRASSA.7.01 INTRODUCTION.

Similar basic physiological processes seem to be used in the regulation of body fluid composition and concentration in all animals. The extent to which special reliance is placed on a particular mechanism is dependent upon the group of animals and on the nature of the environment.

The majority of marine invertebrates have body surfaces which are permeable to ions and water, their body fluids being isotonic with seawater. If transferred to freshwater or diluted seawater, ions are lost by diffusion and water is taken up by osmosis, resulting in a decrease in blood concentration. Marine invertebrates can withstand such environmental changes only to the extent that their cells will tolerate cellular fluid dilution.

Brackish water invertebrates, however, are physiologically advanced in relation to their marine counterparts, in that either the general body cells can withstand changes in the blood concentration or the blood can be maintained hyperosmotic to the medium. Very few species rely entirely upon the salinity tolerance of their cells, consequently there are only a limited number of brackish water animals that are isosmotic with their medium over a wide concentration range. Usually brackish water inhabitants have body surfaces less permable to water and ions than their

marine counterparts. They can maintain their blood hypertonic to the medium over a considerable range of concentration and thus limit the extent of regulation required at the cellular level.

Most arthropods which occur naturally in brackish water maintain their blood hypotonic to the medium, with consequent loss of ions in the urine and by diffusion. These losses are corrected by active uptake of ions from the medium. This uptake requires energy expenditure, such that the rate of loss of ions is minimised to reduce energy expenditure during ion uptake. The animals minimise this ion loss by making the body surface less permeable, and maintaining a small rather than large concentration gradient between blood and medium.

In hyposmotic animals, (Those that maintain a blood concentration hyposmotic to the medium ) regulation is by the uptake of water and excretion of excess ions. This water is obtained by drinking the medium. Potts (1954) working with brackish and freshwater animals, found that, in freshwater species, reduction of the urine concentration so that it is isotonic with the medium can reduce the load on the osmoregulatory mechanism by as much as 90%. Even the production of urine hypotonic to the blood, but many times greater than the medium concentration reduces the osmotic work and is compatible with high osmoregulatory efficiency. In brackish water species

the production of urine hypotonic to the blood has only a very small effect upon the osmotic workload.

Gilbert (1959a,b,c,) working with the shore crab Carcinus moenas Pennant found that the osmotic pressure (OP) of both sexes of the crab decreased as body weight increased. At the same time, at any body weight the males' OP was greater than the females. When he measured the blood conductivity he found that it increased in both sexes until a body weight of 35g was reached, above which conductivity decreased. Below 35grammes body weight Gilbert showed there to be no significant difference in blood conductivity between males and females, but above 35grammes the males were significantly higher than the females. Similar results were found for blood sulphate levels (Higher in males than females over 35grammes) but the converse was found for blood chloride and blood non-protein nitrogen. The blood chloride increased in both sexes until a maximum body weight of 35grammes was reached, thereafter chloride levels decreased with weight increases. Padmanabhanaidu and Ramamurthy (1961) carried out similar tests with the freshwater crab Paratelphusa sp. They found that the OP increased in both sexes to a maximum of 40grammes in males and 35grammes in females, then the OP decreased with increasing weight, but the males tend to have a greater OP. The blood chloride levels of Paratelphusa sp also exhibited this pattern.

7.02        METHODS.

Approximately eighty specimens of Helice crassa males were collected from the estuary mudflats. They were kept in the laboratory, in aquaria prepared as follows. Estuarine substrate from the region near where the crabs were collected was washed in running freshwater for 48 hours to remove salts in the mud. Approximately 13cm depth of the mud was placed in each of five aquaria. The aquaria were then raised 3cm at one end, and seawater of varying strengths, 0%; 25%; 50%; 75%; and 100%; (Appendix 6) was added to the various aquaria so that the five aquaria represented environments with the five salinity concentrations. Fifteen crabs were placed in each system and allowed to acclimatise for five days, at room temperature. The water in the aquaria was aerated by a stone bubbler and air pump. The crabs were fed on a commercial fish food of a fine grain. The aquaria systems were enclosed in large plastic bags to maintain humidity and prevent escape of evaporated moisture, and possible alteration of the water salinity. Figure 26 shows the aquarium system without the plastic bag.

Over a six day period the number of crabs in each tank that died, were noted. Crabs were considered dead when they no longer responded to tactile stimuli, especially about the eye stalks. The dead crabs were dried with a paper towel and weighed. The remaining crabs were used in the serum chloride analysis.

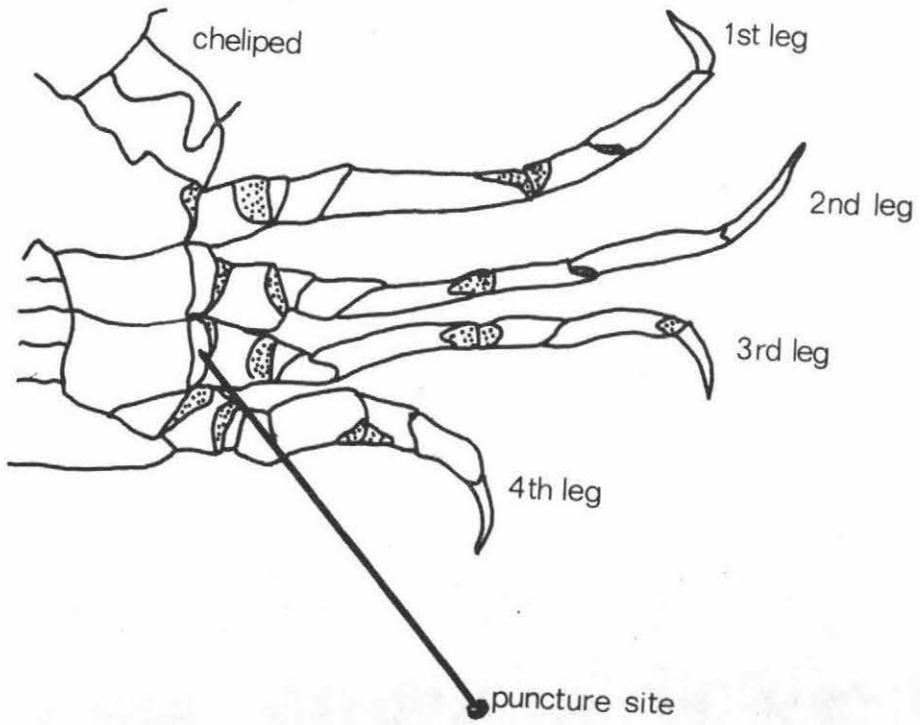
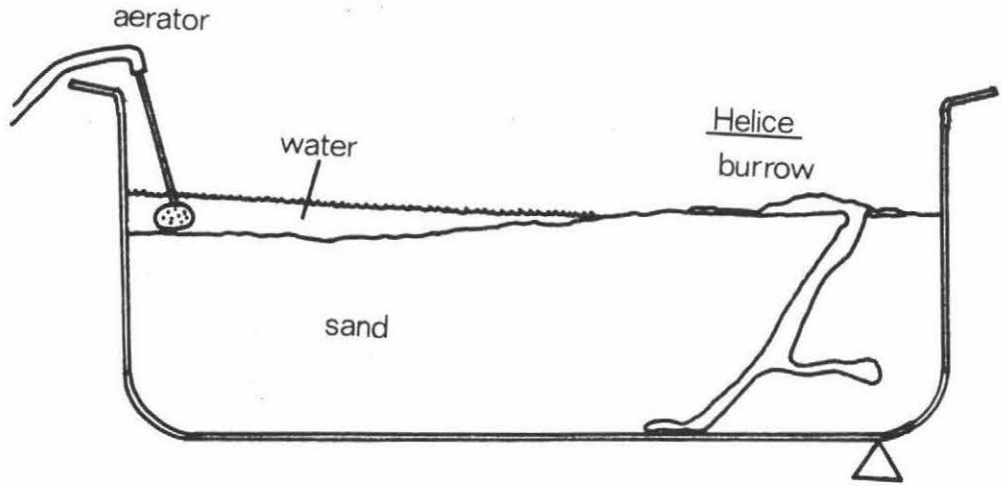
A 50ul sample of serum was removed from the

FIGURE TWENTY SIX:

A diagram of the crab keeping tank system.

FIGURE TWENTY SEVEN:

A diagram showing where the puncture should be made for extraction of a serum sample.



largest crabs in each system. This was removed from a towel dried crab by puncturing the membrane between the coxa and the thoracic sternum of the third leg, with a large dissecting pin (Fig.27).

A 50ul pipette was rinsed in an E.D.T.A. solution (1.5g/l) that acted as an anticoagulant. The pipette was inserted into the puncture wound and withdrawn when 50ul of serum had been drawn out by capillary action. The pipette contents were expelled into a vial which had been cleaned in hot chromic acid, rinsed in distilled water and dried at 50°C. A separate vial was used for each 50ul sample taken from different crabs..

The serum was analysed on a BUCHLER-COTLOVE CHLORIDOMETER automatic titrator. To each sample of serum 150ul of acid reagent (0.1N Nitric Acid in 10% Acetic Acid) was added. This caused precipitation of the protein in the blood, which was removed by adding 2ml of distilled water and then grinding the whole sample in a hand homogenizer. The resulting homogenate was centrifuged at 3500rpm for five minutes, the supernatant retained while the solid material was resuspended in 1ml of distilled water and the centrifuging repeated. The resulting supernatant was added to the first amount and the sample analysed with the titrator, in the usual manner. It was necessary to homogenize and rinse the protein precipitate in distilled water as it was found that up to 26% of the total chloride was adsorbed onto the floc, rendering it inaccessible to analysis.

7.03      RESULTS:

The large crabs survived better in all of the seawater concentrations, than did the smaller crabs. No deaths occurred until the second day, when three specimens in 0% S.W. and one specimen in 100% S.W. were found dead. All of these crabs weighed between 1.4g and 3.0g. By the fourth day all crabs under 3.0g were dead in 0% S.W. and 100% S.W. Also by this stage the smaller crabs in 75% S.W. were starting to die, two being dead on the fourth day. On the sixth day all crabs less than 3.0g had died in the 75% S.W. system. In the 25% S.W. and 50% S.W. systems no deaths occurred, and it appears that Helice crassa prefers 25% to 50% S.W. habitats but large specimens can tolerate from 0% to 100% S.W. (Appendix 8). The remaining large crabs, now considered to be able to tolerate these various salinities, and acclimatised to them, were used as donors for serum chloride analysis.

Specimens of Helice crassa, inhabiting the five concentrations of seawater (0% - 100%) have shown themselves to be very capable regulators of serum chloride concentrations, (Table 3).

In Helice the serum chloride content decreases slightly with an increase in medium chloride concentration, although the serum chloride concentration only decreases 1.5‰ over the whole range. The mean serum chloride concentrations for each of the seawater concentrations were analysed by the 'students' t-test against each other.

The results indicating that the difference between the means were indeed significant ( $P > 0.1$ ) (Appendix 7).

Table 3: Showing the relationships of serum chloride to medium chloride.

% S.W.	0	25	50	75	100
Cl <sup>-</sup> ‰ S.W.	0.35	4.78	9.6	14.4	19.2
Serum/med.ratio	39.83	2.86	1.33	0.88	0.65
N <sup>o</sup> crabs sampled	8	5	9	7	7
Serum Cl <sup>-</sup> ‰	11.815	13.723	15.084	10.751	8.645
	14.822	14.354	15.722	14.120	14.588
	17.573	12.382	13.332	12.028	17.793
	14.715	14.999	12.283	10.798	10.900
	12.772	12.666	11.481	13.708	11.333
	13.623		11.176	14.332	10.035
	12.730		11.489	12.964	13.829
	13.496		14.375		
			10.028		
Mean serum Cl <sup>-</sup> ‰	13.94	13.69	12.77	12.67	12.44
Standard dev	1.78	1.04	1.98	1.50	3.13
Std error of $\bar{x}$	0.63	0.46	0.65	0.56	1.18
Variance	3.17	1.08	3.81	2.27	9.83

GENERAL DISCUSSION:

The vegetation of Mudflat 1 is restricted to the region upstream of transect A, no vegetation grows on the sandy beach at the seaward end. The vegetation of this area is typical of an area inundated with salty waters. Spartina is the most abundant plant, but it is still a relative new comer to this area of the estuary. The Spartina beds are small relative to those on Mudflat 2, and are still isolated, the largest of them being 7 metres in diameter, although at the upstream end of this mudflat a region of Spartina 0.1ha is growing. This 0.1ha region is a mixture of Spartina, Salicornia, and Juncus acutus. The majority of the Salicornia at the estuary is within 1km of the mouth, only a small, patchy region is present between transects I and J. Juncus acutus can be seen in the township of Foxton Beach, in areas of unused land, and along the banks of Whitebait Creek (the second creek described in section 2.03).

Mudflat 1, at the most seaward limit of the Spartina has, in the upper and mid zone, a fairly high silt content (25% - 35%). Here the sediment is firm enough not to be strongly disturbed by the ebb and flow of the tide. The silt content of areas where Spartina is found on this mudflat doesnot go below 9%. Spartina doesnot survive well in areas that are of a coarser sediment type as it requires some mud or silt to become vigorous. Once established, however, the silt content

of the substrate will increase due to the deposition initiating properties of the vegetation.

The most downstream end of Mudflat 2 has Spartina growing near the H.W.S.T.M. against the stopbank (Appendix 3) but there is a fairly large area in front of this that is subject to vigorous disturbance by the ebbing tide, the velocity of the water being very high. In this immediate region no plants (except some Euglena spp) are present. Indeed, near the top of the beach little Spartina is present until one is downstream of transect F, but between transects E and F small Spartina beds are rapidly becoming established. The occasional clump may be seen slightly downstream from transect E also. In all cases the Spartina is found submerged by at least 15cm of salty water, for at least two hours each tidal oscillation. The Spartina found growing up the beach, along from transects F, G, and H, was in some cases completely submerged for up to 9 hours each tidal oscillation.

There were some areas of Spartina on the banks of the Whirokino Cut, but none grow in the vicinity of Mudflat 3.

Allen (1930) stated that only a small amount of the Spartina in the estuary was S.stricta the majority being S. x townsendii. In the course of this investigation the author found no S.stricta although the possibility of it coexisting with S. x townsendii is quite high as they were introduced together. The vigorous

spread of S. x townsendii on the other hand could of completely out-competed S.stricta. Presumably the presence of S.stricta would still be noticed if it had become as well established as S. x townsendii.

The initial reason for planting Spartina, the reclamation of the mudflats, is one that should be reconsidered, albeit too late, at least on this estuary. My reasons for this suggestion are two fold. Firstly, one must consider the aesthetic value of the estuary, something that cannot be considered in the monetary sense, a loss in wool, meat or crop production. Agriculture has never had the use of the land, so that it is not losing out on anything. Even the idea of cropping the Spartina for hay and ensilage should be reconsidered as man has created here, by the introduction of the Spartina a habitat for some of the most elusive birds in the world, elusive in the sense that they only inhabit the dense marsh vegetations of our swamps and estuaries (e.g. crakes and bitterns). The effects of Spartina on native vegetations must also be considered. The introduced Spartina rapidly increases the rate of sediment deposition on the mudflats. Over several years this leads to the level of the beds being high enough to only be submerged by a high spring tide. At this stage the Spartina dies off, or is out-competed by the native rushes and sedges. The swamps that follow in the natural succession of reclamation provide a habitat for the native flaxes, raupo, and other swamp plants. Secondly, the Manawatu River floods readily, especially in the winter months.

These flood waters carry much of eroded Ruahine Ranges and Hawkes Bay farmland and deposits large amounts of this sediment in the estuary. It can be correctly argued that when in flood, the river carries most of the sediment out to sea, but the trouble begins when the water level of the river drops, and the mudflats are again visible at low tide. It is at these times, when the waters go 'slack' that the depositions occur, once settled, the tides only manage to move the sediments a matter of metres up or downstream. During the flood of June 29th, some of the regions of Mudflat 2 had 60 to 75cm of sediment deposited, which still remains, although severe erosion of the banks is occurring. These enlarged mudflats allow for greater expansion of the Spartina regions. If, as is the case at Foxton, the Spartina is growing on both sides of the river, then the eventual conclusion is a narrowing of the main channel as the mudflats extend outwards. This is going to mean that; dredging of the channel is needed to deepen it, dredging a new channel, or straightening the old channel resulting in direct access to the sea. Unfortunately Spartina grows from vegetative fractions as well as seed set, the possible controls being chemical (Bascand, 1968b) or biological. The author has observed on many occasions, and Blick (1965) mentioned it in his paper on Spartina, that the native bird, Pukeko, Porphyrio melanotus, uproots the young plants, I have also seen the birds eating the Spartina.

Black Swan, Cygnus atratus; and Canada Geese, Branta canadensis; also favour young grass shoots. If the area is made a wildlife reserve, with due protection to its inhabitants then a large colony of birds could be used to slow down the spread of the *Spartina*, but not stop it altogether. It would be relatively simple to release birds, especially Pukeko, into the area, a flock of at least 50 are resident on Mudflat 2 at present.

Davies (1931) in his description of the vegetation growing on Nelson Haven, found a similar situation as was found at the Foxton estuary. Salicornia forms in places, a meadow surrounded in places by isolated clumps of Leptocarpus and Juncus, where there is reasonable freshwater influence, Scirpus cernuus is found in very small isolated patches.

Evans (1953) discussing the halophytic vegetation of Lake Ellesmere, found on the uppermost zone of the "Selwyn River area" a dense matt of Agrostis stolonifera. This was found at the Manawatu estuary above station 33 on transect I. It was at this stage that Mudflat 2 showed the characteristics of a Salt Marsh - agricultural boundary. In this region of Mudflat 2 the substrate is 60cm above H.W.S.T.L. and the salinity of the interstitial water is fairly low, less than 10‰, the conditions being favourable for A.stolonifera establishment.

The master factor controlling the zonation of plant communities appears to be the amount of

tidal flooding. The plants in the lower zones, (Spartina, Salicornia, Cotula) are directly affected by the flood waters, whereas the plants of the higher zones (Juncus, Leptocarpus, Scirpus, Agrostis) are affected indirectly, by the influence of the water on the soil properties. The rise in level from the waters edge, a factor controlling the flooding of the vegetation, is in part controlled by the plants themselves. Spartina is the main plant increasing silt deposits, whilst Salicornia and Cotula aid mainly by building up the layer of organic matter. Thus as Evans (1953) states "the succession is to some extent autogenic, but allogenic influences are probably also operative."

This investigation has also apparently indicated that the salinity (or chlorinity) of the waters and the length of time the beach zone is left exposed (fig,28) are important factors in determining the distribution of the benthic fauna.

In some cases salinity and sediment size are reasonably clear delimiters of lamellibranch penetration into the estuary. The salinity limiting penetration upstream whilst sediment size limits distribution in the area penetrated.

Both Chione stutchbury and Maetra ovata, the two lamellibranchs found at the estuary, are not present in exceptionally high numbers. They could be present below the low tide mark, on the bed of the channel, but as no grab sampling was carried out this

FIGURE TWENTY EIGHT:

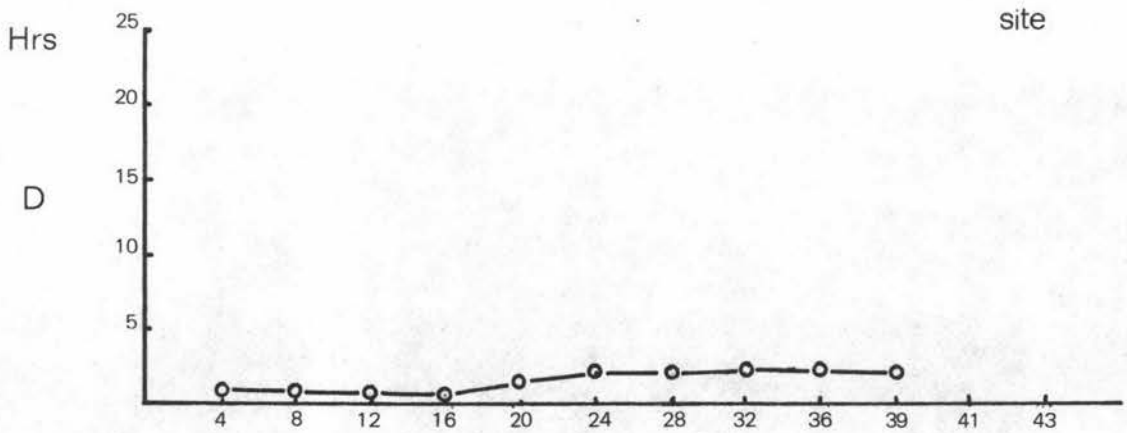
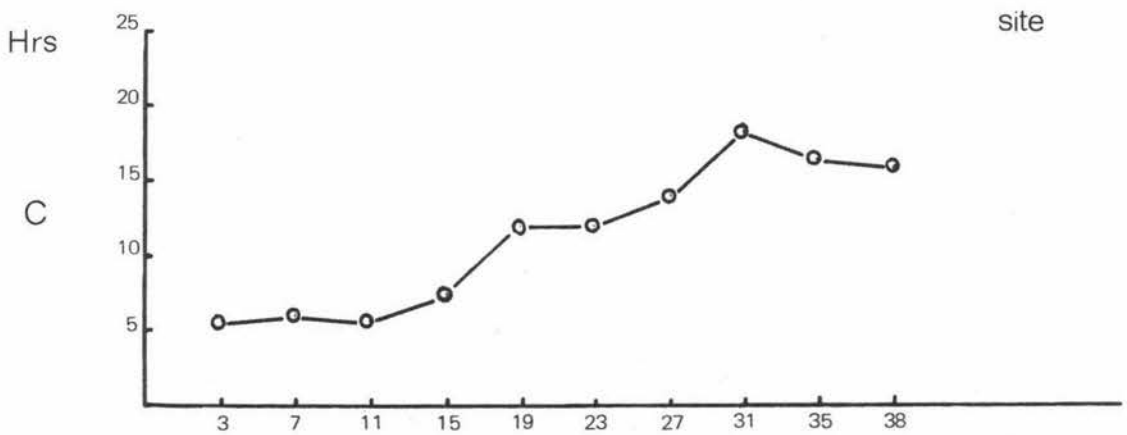
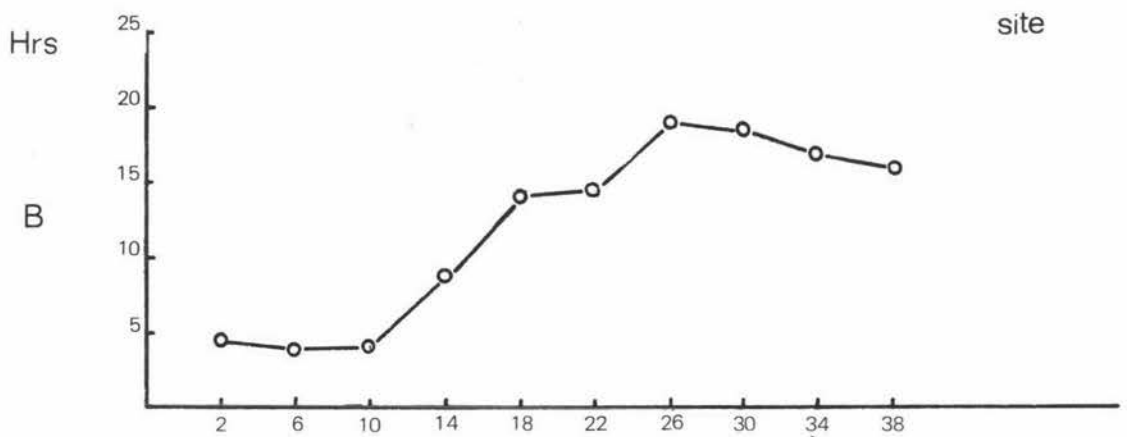
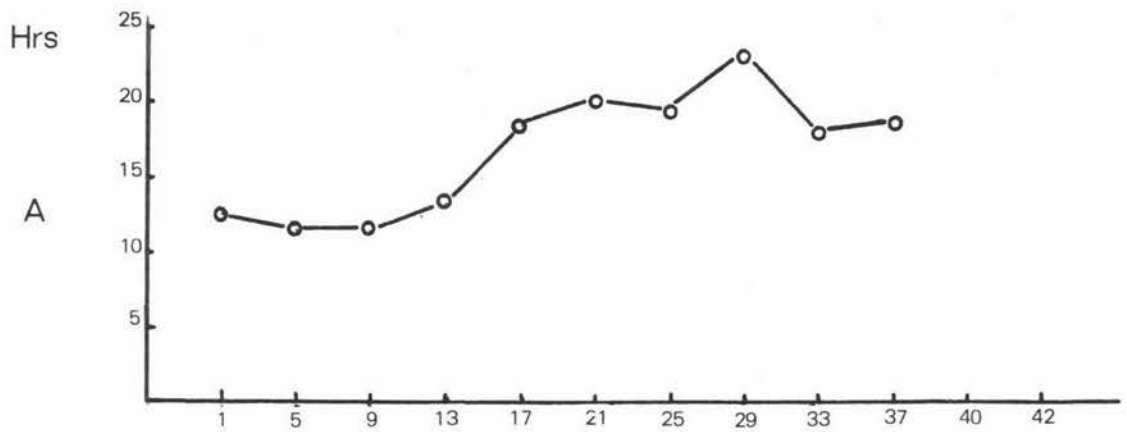
A series of graphs showing the exposure times  
of the sample stations, in hours.

A.....high tide mark

E..... $2/3$  HT mark

C..... $1/3$  HT mark

D.....low tide mark



site

cannot be varified. Geomorphological evidence points to there being, approximately 5000 years ago, very extensive beds of Chione, so much so that fossilized shells are found in large numbers but cemented together by meagre amounts of substrate (P.Hesp, pers.com). It also appears that Mactra ovata and other Mactra spp were abundant at this time, as Hesp (1975) found their fossils and those of Amphibola and Potamopyrgus in most of his bore samples.

Amphibola is very widespread on the estuary, but not in the lower beach zone. The surface numbers of this snail (Appendix 5) are fairly high and at first appearance Amphibola appears to be the most numerous surface dwelling animal on the mudflats.

The clumped distribution exhibited by Potamopyrgus estuarinus enabled a false impression of its abundance to be gained. This small estuarine snail is found in very high numbers especially near the banks and in the waters of the creeks flowing over the mudflats.

The two polychaetes that are common in the mud, Nicon aestuariensis and Scolecopedis benhami, are able to survive without competition with each other, probably due to their different feeding styles, Nicon being a carnivore whilst Scolecopedis is a deposit feeder.

Both worms are obviously able to tolerate, or adjust to, a wide range of salinities as is evident from their ubiquity along the estuary. They both seem

to be limited in their habitat by the same environmental factors, (i) Exposure time, i.e. how long the mudflat is uncovered, (ii) Silt content of the substrate.

Being burrowing animals they need to live in a medium that will not keep collapsing all the time. This is overcome in part by their choice of habitat and in part by a mucus lining they secrete for their burrows. (iii) The water content of the substrate must be within a favourable range. This is partly a function of the porosity of the sediments and also the permeability, (see section 3.01) and partly a function of the beach gradient. If the beach has a low gradient, then the water table is not far beneath the surface and the worms are able to burrow down to it. Nichols (1970) studied the distribution of polychaetes of a subtidal environment in Puget Sound, Washington, U.S.A. The depth of the stations below the water surface ranged from 2m to 34m. He found that adjacent assemblages show a high degree of similarity without noticeable discontinuities between them, with the exception of a deep station adjacent to a shallow one. The discontinuity was apparently caused by the combined effects of sediment, wide temperature and salinity fluctuations, and an active sedimentary process. It appears that clay content and sorting are highly correlated with station similarity. Although Nichols' work was carried out with subtidal assemblages I can see no reason why these causations may not apply or have an effect upon mudflat 'infaunal' assemblages.

Certainly clay and silt content are highly important and salinity presumably also, how ever estuarine polychaetes are not subjected to wide and rapid salinity changes unless they inhabit a region reached by almost pure seawater. To counteract the effects of salinity and temperature on the mudflats the worms need only to burrow in the mud which will act as a buffer unless sustained adverse conditions cause a change in it.

As was mentioned earlier only one specimen of Hemipodus simplex, an errant polychaete, was found. This was at station 4, on the most seaward transect A. Possibly this transect was near the upstream limit of penetration for H. simplex. Hemipodus and Glycera are the two genera of the family Glyceridae, the members of which are true sand burrowers (Morton and Miller, 1968). This could possibly account for the limited penetration of Hemipodus up the estuary, it remains in the more salty, sandy substrate.

The salinity tolerances and preferences of Helice crassa were tested to try to determine the factors limiting the distribution of Helice in the estuary, also to try to correlate the various environmental and physiological features with its distribution along the estuary.

Unfortunately no reproductive data was collected for Helice, but Helice specimens observed at the low tide mark were found to be females in berry. The females were found during most of the year and it

appears that Helice may breed at times similar to that of Hemigrapsus crenulatus, with a slightly longer period of non-breeding between June and September. Analysis of the data for Helice in Table 2 shows that many of the environmental factors favourable for spawning correlate with the numbers of Helice found at this level.

Specimens of Helice were found from station 3 to 38, but they are more numerous than the sampling indicates, mainly due to their clumped distribution of isolated populations. They are also found between transect J and the Foxton Loop outlet (fig,1).

From the results of the serum chloride analysis it appears that at the Foxton estuary Helice is living well within its tolerable salinities. The presence of Helice upstream to transect J, indicates that the populations of males and females of various sizes, are surviving in a salinity, tolerated in the tests only by the larger crabs. The effects of the lower salinities, where these populations survive, may be mitigated by the fact that the populations only have to withstand these low salinities for, at the most, six hours at a time. Phillips (1968) found a similar result with Hemigrapsus crenulatus. At Riverhead (Waitemata Harbour) H.crenulatus was found in salinities far lower than H.crenulatus from Westmere could tolerate. Phillips reconciles these facts by saying that either the crabs from Riverhead are phenotypically different from those at Westmere because of salinity

acclimatization, or they are genotypically different, i.e. a physiological race. This could possibly be so with populations from as far apart as Riverhead and Westmere, a distance of several kilometres, but the possibility of genotypical differences of race, between two populations, at the most, 500 metres apart in the Manawatu estuary is unlikely. It thus appears that the Helice populations may be physiological phenotypes, each population acclimatized to a small salinity range.

The Helice specimens used for salinity and chloride experiments were collected on Mudflat 2 from an area between transects F and G. The collection area was fairly small, so that only specimens of a single population were collected.

In some areas on the mudflats Helice is absent, even at high tide levels (Beer, 1959; Bennet, 1964; Stephenson, 1970). Some of these voids in Helices' distribution are considered by the author to result from unsuitable sediment deposition. Helice being a burrowing animal requires a habitat where the sediment is of such a consistency that it will remain firm when burrowed into, and also when the burrow is inundated with water. The areas uninhabited by Helice on Mudflats 1 and 2 are areas which do not seem to have a suitable substrate. In general the current has deposited either coarse sand or fine silt, such that the area is very hard sand or soft, waterlogged silt. Neither of these substrates can 'stand up to' the building of burrows, the most suitable

habitats for Helice have a phi 3:phi 4 particle size ratio of at least 1:1 but more commonly 1:3 or 1:4. It appears that the ratio of these two particle sizes, the most predominant ones at the estuary, is one of the limiting factors of Helice distribution.

The lack of reasonable populations of Hemigrapsus crenulatus and Macrophthalmus hirtipes<sup>1</sup> on the mudflats would preclude the concept of competition between them and Helice as a limiting factor of Helice. It does not however, preclude the possibility that Helice is so dominant in the Manawatu River estuary that it has excluded the other two species. Beer (1959) and several writers since then have indicated that M.hirtipes and H.crenulatus inhabit the shore at a lower level than Helice thus it seems improbable that Helice has displaced these species, but more likely that these species do not have a great distribution in the Manawatu estuary.

As was stated earlier, a zonation up the beach was detected, although it may have some possible seasonal variations. The upper zone lies between the high tide level (top of the beach) and the 2/3 high tide level. It is distinguished by the presence of

FOOTNOTE 1:

Barnes (1967) transferred the crab from Hemiplax hirtipes (Jacquinot 1853) to Macrophthalmus hirtipes (Jacquinot 1853). Wear (1968) considers the zoea larvae of M.hirtipes very similar to those of the genera Cyclograpsus, Helice and Hemigrapsus and believes that it is possible that the Family Ocypodidae is not a natural grouping.  
(both in Nye, 1974)

Helice crassa and the mud snail Amphibola crenata but in some areas other animals may occur. The mid zone, lying between  $2/3$  high tide and  $1/3$  high tide, has a great variety of animals including Helice crassa and Amphibola crenata. The final zone, the lower zone is from the  $1/3$  high tide to the low water mark. This region also has a great variety of animals in it but generally not H. crassa or A. crenata. Gravid females of H. crassa may be found in this zone as they remain near water prior to spawning. Hamel and Barr (1974) detected no zonation at Aramoana, and Stephenson and Stephenson (1949) do not relate zonation to tidal levels but to animal distributions. The author found that having stations at the various tidal levels enabled him to observe the restriction of the animal distributions in relation to the tidal levels. Dahl (1952) discussed zonation of exposed sandy beaches, detecting three distinct zones. The possibility of the cause of relative permanence of zones on exposed shores to the impermanence of zones on estuarine shores, being the sheltered nature of estuary shores and also their frequent inundation by freshwater from the rivers must not be discounted. This type of zonation was only found on Mudflat 2, but no apparent zonation was observed on Mudflats 1 and 3.

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APPENDIX 1.

A Comparison of Wentworth and Phi Scales for Particle Sizes.

Wentworth Classification		Phi Scale
Name	Range, mm.	
Boulder	256 +	-8
Cobble	128 - 255.99	-7
	64 - 127.99	-6
Pebble	32 - 63.99	-5
	16 - 31.99	-4
	8 - 15.99	-3
	4 - 7.99	-2
Granule	2 - 3.99	-1
Very Coarse Sand	1 - 1.99	0
Coarse Sand	0.5 - 0.99	1
Medium Sand	0.25 - 0.49	2
Fine Sand	0.125 - 0.24	3
Very Fine Sand	0.063 - 0.124	4
	0.0315 - 0.062	5
	0.0157 - 0.0314	6
	0.0078 - 0.0156	7
Silt	0.0039 - 0.0077	8
	0.0 - 0.0038	9
Clay		

## APPENDIX 2.

Station	Sal. ‰	O <sub>2</sub> conc(ppm)	pH	Redox Pot (mV)
1	27.5	0.8	7.8	+200
2	27.2	0.3	7.4	-115
3	24.1	0.3	6.8	-150
4	23.0	0.4	6.5	-115
5	15.9	0.4	6.3	- 95
6	12.6	0.9	6.8	-110
7	16.6	1.0	6.8	-170
8	11.6	1.2	7.0	-110
9	8.4	0.3	7.7	-120
10	9.7	1.3	7.4	-105
11	11.7	0.7	7.2	-140
12	13.2	0.3	7.6	-168
13	12.4	0.8	7.1	+ 60
14	6.1	1.7	7.3	-160
15	12.4	1.2	6.6	-148
16	12.4	0.8	7.0	-130
17	9.1	2.9	7.8	- 15
19	8.4	0.4	6.3	- 35
19	8.6	0.5	7.3	- 55
20	7.9	0.5	7.3	- 62
21	8.3	2.5	7.2	+ 40
22	2.7	3.5	7.5	+ 70
23	5.8	2.5	7.7	+ 45
24	6.6	2.5	7.7	+ 30
25	4.3	6.2	8.0	+170
26	2.5	3.5	7.8	+ 46
27	1.3	1.8	7.8	+105
28	4.1	0.6	7.4	+ 55
29	4.7	0.7	7.2	- 58
30	4.7	0.6	7.2	- 70
31	4.3	0.6	7.0	-110
32	4.4	0.6	7.2	- 50
33	7.1	3.7	7.2	+260
34	7.2	3.6	7.9	+250
35	7.4	4.6	6.0	+260

## APPENDIX 2 CONT'D.

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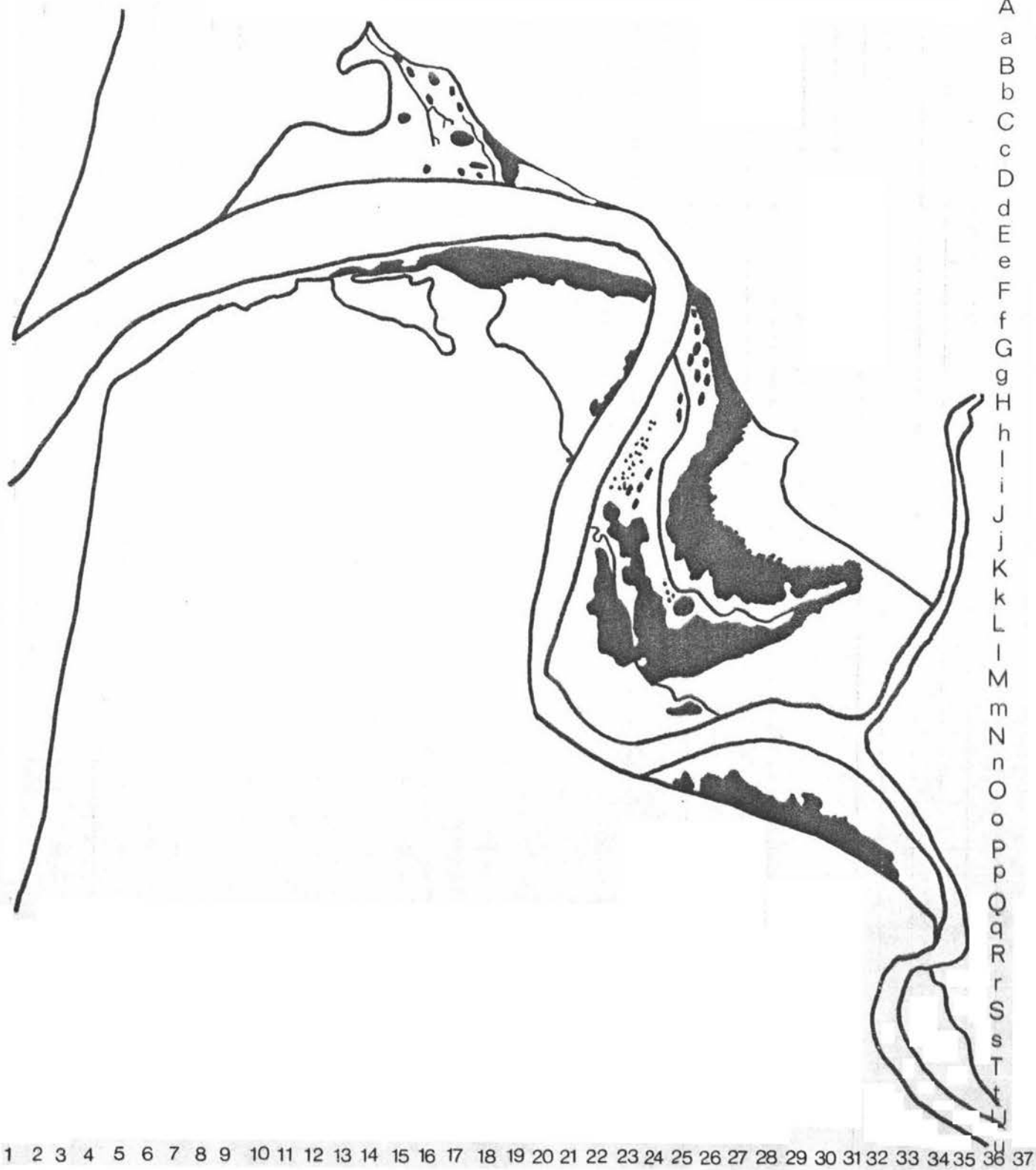
Station	Sal. ‰	O <sub>2</sub> conc(ppm)	pH	Redox Pot (mV)
36	7.7	3.3	6.0	+230
37	5.7	0.7	7.6	+290
38	5.3	0.7	7.7	+ 55
39	5.0	0.7	7.6	- 30
40	0.2	1.7	6.6	+ 74
41	0.2	1.8	6.5	- 68
42	0.4	1.2	6.4	+ 60
43	0.2	0.7	6.7	+ 25

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APPENDIX 3.

A sample of the data sheet used in determining vegetation

distribution. The sheet shown is that of Spartina x townsendii.



APPENDIX 4.

The numbers of animals found per 1104 cm<sup>3</sup> of substrate.

STATION	CHIONE	MACTRA	NICON	SCOLECOLEPEDIS	AMPHIBOIA	POTAMOPYRGUS	PARACOROPHIUM	HELICE
1							0.25	
2	0.75	0.25						
3							26.5	0.25
4		0.25	0.5					
5								
6			0.5	0.25			2.25	
7			1.25					
8		2.25	1.00					
9								
10			0.5			3.0	2.5	
11					1.25			
12		1.75	2.5					
13					0.25			
14			1.0		0.25			
15		0.25	2.25		0.75			
16			0.75					
17			1.75	0.25	0.25			
18			1.50					
19			1.75					
20			2.75					
21			0.75	0.25	0.75	0.25		0.25
22			0.75	0.5		7.25		
23			3.25		0.50	23.25	4.75	
24			4.25	0.75		2.75	1.25	
25								1.00
26			1.25	0.75	0.25	3.75		

APPENDIX 4 CONT'D.

STATION	CHIONE	MACTRA	NICON	SCOLECOLEPEDIS	AMPHIBOLA	POTAMOPYRGUS	PARACOROPHIUM	HELICE
27			1.25	1.75				
28			1.75	4.50		0.50		
29				0.25	1.50	1.75		
30			1.00	0.50		2.25		0.75
31				5.25				
32							10.25	
33								0.50
34								
35								
36								
37								
38			0.25	0.25				0.25
39			0.50	2.50				
40								
41								
42			1.25	0.25				
43			1.00	0.50			8.50	

## APPENDIX 5.

Numbers of Surface animals /  $\text{lm}^2$ 

STATION	MACTRA	CHIONE	HELICE	PARACOROPHIUM	AMPHIBOLA	POTAMOPYRGUS	POLYCHAETES <sup>++</sup>
1							
2	28.2					49.7	
3	19.5		4.3				2.1
4	25.9						
5			2.1		123.3		
6					116.8	257.4	
7					54.1	69.2	
8	21.6				2.1		
9			34.6		8.6		
10					108.1	151.4	
11	21.6				32.4		
12	28.1						
13					8.7		
14					121.1		
15					58.4	6.5	
16					2.1		
17					4.3		95.1
18						99.5	8.6
19							
20							
21			56.3			4.3	23.8
22			17.3		8.6	123.2	38.9
23					8.6	259.5	
24					38.9		
25			10.8		12.9		
26			8.6				
27							

## APPENDIX 5 CONT'D.

Numbers of Surface animals /  $\text{lm}^2$ 

STATION	MACTRA	CHIONE	HELICE	PARACOROPHIUM	AMPHIBOLA	POTAMOPYRGUS	POLYCHAETES <sup>++</sup>
28							
29							
30							
31							
32							
33			60.5				
34							
35							
36							
37			84.4 <sup>+</sup>				
38			41.0				
39						62.7	
40							
41							
42							
43							

- ++ Due to the difficulty in differentiating between the burrows of the two polychaetes common at the estuary, only 'polychaete' burrows were acknowledged.
- + Most of these crabs had a carapace diameter of less than 0.5 cm.

APPENDIX 6.

A description of the various seawater concentrations used in the work described in chapter 7.

100% seawater was taken to have a salinity of 34.6‰

0% S.W. tapwater.

25% S.W. Pukerua Bay seawater + an equal quantity of distilled water.

50% S.W. Pukerua Bay seawater.

75% S.W. Pukerua Bay seawater reduced by one quarter of the volume by boiling.

100% S.W. Pukerua Bay seawater reduced to one half the volume by boiling.

APPENDIX 7.

Results of the students t-test, analysing the means of the serum chloride levels described in chapter 7.

% sea water	0	25	50	75	100
0	-	-0.9206	0.0095	-0.0072	-0.00007
25		-	-0.0713	1.1715	-0.0446
50			-	0.0027	0.0008
75				-	0.0759
100					-

Degrees of freedom	Value of P		Means compared
12	0.1	1.782	0-25
	0.05	2.179	
15	0.1	1.753	0-50
	0.05	2.131	
13	0.1	1.771	0-75
	0.05	2.160	
13	0.1	1.771	0-100
	0.05	2.160	
12	0.1	1.782	25-50
	0.05	2.179	
10	0.1	1.812	25-75
	0.05	2.228	
10	0.1	1.812	25-100
	0.05	2.228	
14	0.1	1.761	50-75
	0.05	2.145	
14	0.1	1.761	50-100
	0.05	2.145	
12	0.1	1.782	75-100
	0.05	2.179	

APPENDIX 8.

The Results of the Salinity Tolerance Tests of Helice crassa (Dana).

The Tabulated Result is the weight of the Dead Crab in grammes.

DAY	SEAWATER CONCENTRATION				
	0%	25%	50%	75%	100%
1	-	-	-	-	-
2	1.40	-	-	-	3.00
	2.05				
	1.90				
3	1.10	-	-	-	2.10
	2.60				2.30
	2.10				1.80
4	2.30	-	-	1.80	3.00
				2.20	1.80
					2.10
					2.00
5	-	-	-	1.30	-
				1.00	
				2.40	
6	-	-	-	2.90	-
				1.70	