AN ECOLOGICAL STUDY
OF THE
WAIRAU RIVER ESTUARY
AND
THE VERNON LAGOONS

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1. INTRODUCTION

In 1981 the Estuarine Research Unit, Zoology Department, University of Canterbury carried out an ecological study of the Wairau River Estuary on behalf of Waitaki (N.Z.) Refrigerating Ltd and the Marlborough Catchment Board (Knox, 1983). This was a baseline study of the estuarine complex likely to be affeccted by the discharge of treated effluent from a meatworks to be constructed near Blenheim. Effluent quality standards for the discharge were set by the Marlborough Regional Water Board following a Tribunal Hearing on a Water Right Application by the company. Over the past two decades the Marlborough Catchment Board has carried out extensive investigations on the water quality and hydrology of the estuary, the inflowing rivers and the Vernon Lagoons (Marlborough Catchment Board, 1970; Thompson, 1970, 1976, 1977). The final discharge point for the effluent into the lower Wairau River Estuary was determined after detailed investigations of the hydrology of the Wairau River Estuary with special reference to the dispersal of the effluent (Hume and Williams, 1981). The effluent is discharged through a diffuser on the outgoing tide only, during a period of four hours, being one hour after high tide and one hour before low tide, the tide measurement being related to the poinbt of discharge.

In April 1985 the Department of Lands and Survey, Blenheim published a Draft Strategy Plan for the Wairau Lagoons (also known as the Vernon Lagoons) (Reynders, 1985). The strategy management plan was intended to be the forerunner of a management plan and was primarily intended to be a discussion document. It included a discussion of options and constraints and set out proposed objectives and policies for the management strategy. Public submissions were invited on the document but the development of the management plan was delayed due to the reorganization of the government agencies responsible for the environment. After the establishment of the Department of Conservation the Nelson-Marlborough Regional Office of the Department became responsible for the management of the Vernon Lagoons.

The Department of Conservation has expressed concern regarding the future management of the Vernon Lagoons, particularly from the water quality viewpoint. Options for future demands for effluent disposal to the Wairau River Estuary-Vernon Lagoons complex (including the option of discharge to the lagoons themselves) are currently under consideration. It was considered that the time was opportune for a resampling of some the 1981 sites in order to determine whether there had been any changes in the distribution and abundance of the benthic organisms in response to the increase which had occurred in the discharge of effluent to the system. In addition there was a need for a reassessment of the ecology of the lagoons in relation to the Waimea River Estuary and the surrounding wetlands and drainage basin with special reference to their future management. In view of his association with the previous investigation Prof. Knox was contracted by DOC to carry out such a study.

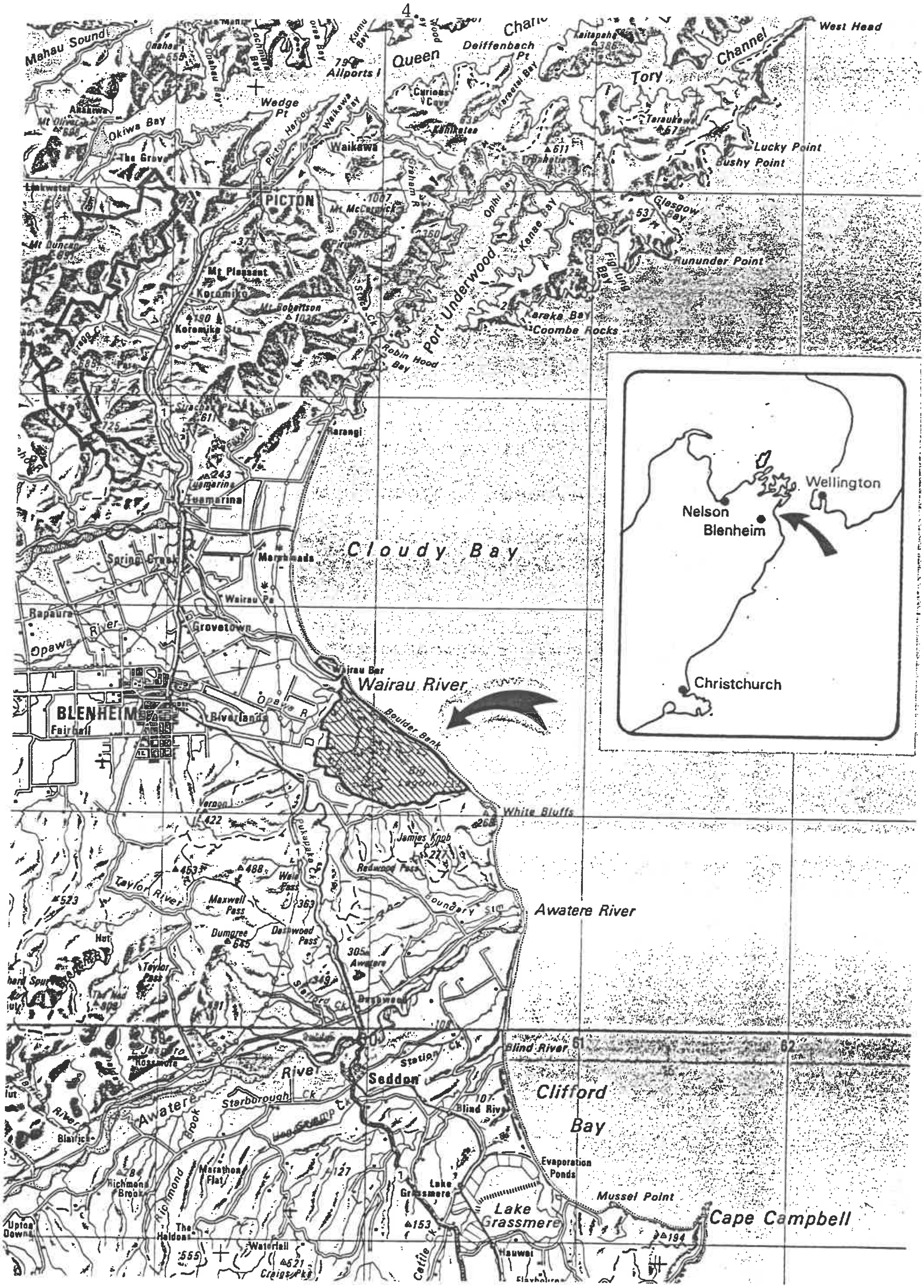

Fig. 1.1. Location map and major physiographic features of the Wairau River Estuary and the Vernon lagoons.

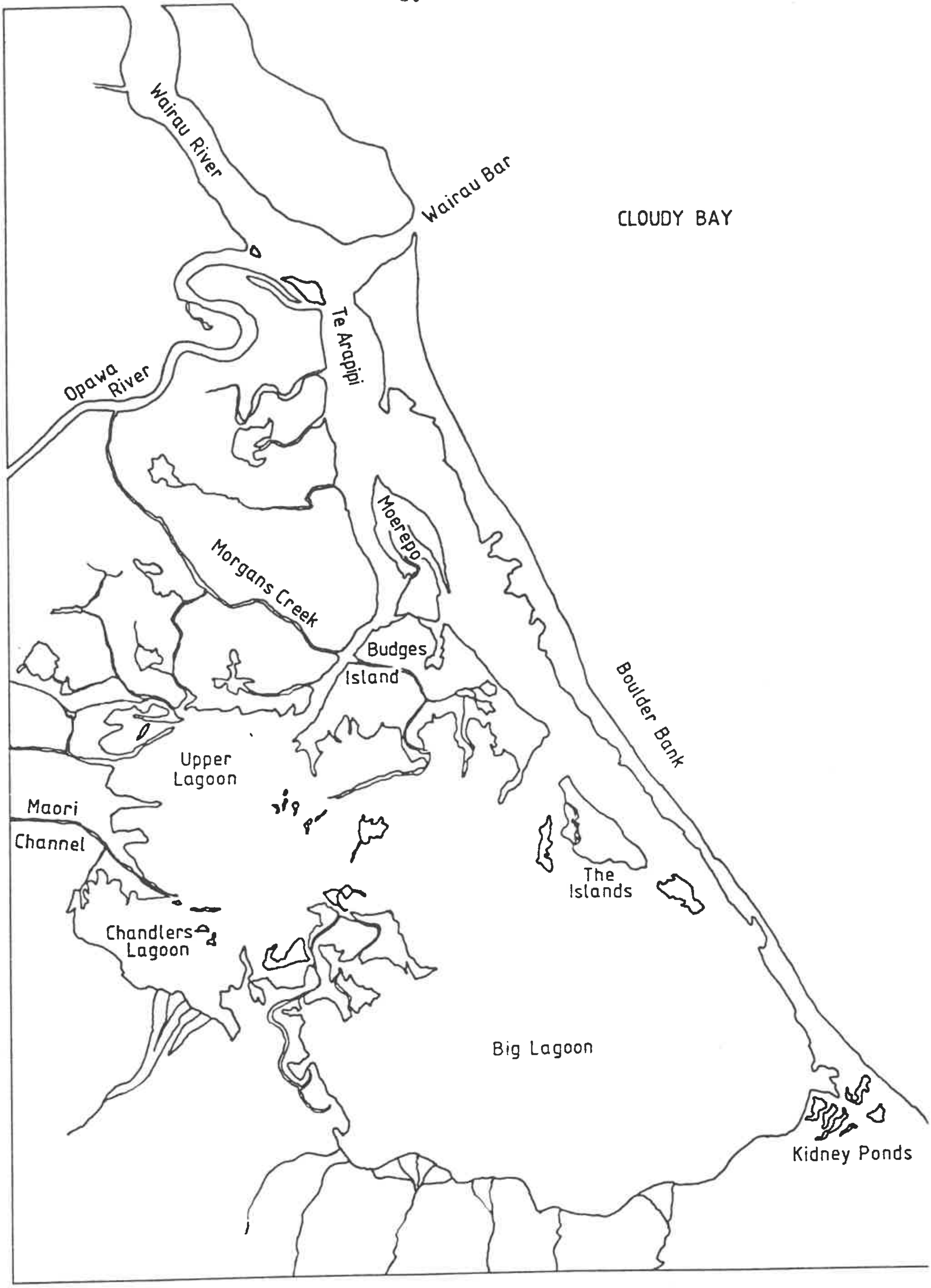

Fig. 1.2. Map of the Wairau River Estuary and the Vernon Lagoons.

2. OBJECTIVES OF THE PRESENT STUDY

The objectives of this study were to:

1. Provide a preliminary assessment of the ecological state/health of the Vernon Lagoons.

2. Describe how the Vernon Lagoon system functions ecologically and its relationship with the adjoining estuary.

3. Provide preliminary baseline data for future monitoring of the lagoon.

4. Comment on the possible ecological impacts of effluent discharge into the lagoons under different treatment regimes.

5. Comment on other possible management problems which the Department of Conservation should have regard for, including the use of the Council owned Sarcocornia flats adjacent to the existing oxidation ponds for future pond construction.

6. Resample strategic locations from the former study in 1981-82, and comment on any observed changes, particularly in relation to effluent discharge from the Council's sewage treatment facility, or from the freezing works.

7. Give recommendations regarding future management of the lagoons and estuary (particularly from a water quality viewpoint), and the need for any future research.

3. PHYSICAL DESCRIPTION

3.1 Geomorphology

The lower reaches of the Wairau River flow across a flat plain resulting from the outwash of glacial material and its subsequent reworking by both rivers and the sea during periods of rise and fall in sea level. The Wairau River follows the path of the Wairau fault to the sea. Geomorphologically the the area surrounding the Wairau River Estuary is very complex (Figs 1.1 and 1.2). A remarkable feature is the very extensive lagoon system , the Vernon Lagoons, lying to the south of the estuary and opening into it near the mouth. A smaller river, the Opawa, enters the estuary a short distance upstream from the entrance to the Vernon Lagoons. The lagoons and estuary are separated from the sea by the Wairau Boulder Bank that grew from the south as a free-form spit enclosing a shallow arm of the sea, after a steadying in the rate of rise of sea level about 6.500 years ago (Pickrill, 1976). The Boulder Bank is composed of material carried by the Awatere River and coastal debris south of Cloudy Bay. At present the dominant northward movement of foreshore sediments, driven by the waves of the dominant southerly swell, is causing progradation of the beaches of Cloudy Bay into which the estuary opens.

In the not too distant past, the lagoon system was much larger than it is at present and covered most of the land east of Blenheim (Thompson, 1976). However, in 1848 an event occurred which was to have a substantial impact on the area. This was the Marlborough earthquake of October 19, 1848, which is believed to have a magnitude of 7 1/2 and, large aftershocks are reported to have continued for at least six months. It has been suggested that ground levels were depressed by 1.5 metres. Additional changes in the estuary and lagoons were consequent upon the construction of rock groyne river training works at the bar entrance between 1960-61 to stabilize the river mouth.

The Vernon Lagoons (Fig 1.2). These extensive water bodies are not strictly lagoons which are defined as bodies of water separated from the sea by a bank or reef, and which are only open to the sea at intervals. The Vernon Lagoons open into the Wairau River Estuary and are subject to tidal flow during which water is exchanged with the estuary. They are therefore estuarine in character, although they do not have major freshwater streams or a river at their head as is the normal situation in a true estuary.

The lagoons form a large expanse (approx. 12 km^2) of semi-enclosed shallow water areas and spring-fed kidney ponds. They are separated from the sea on the east by the narrow, vegetation covered Boulder Bank (only 50m wide in some places) and grade into the Wairau Plain on the west. The main entrance channel (Te Aropipi) divides to open into the three largest lagoons (Big, Upper and Chandlers Lagoons) which have a limited freshwater inflow from the numerous kidney ponds and small streams. The majority of the lagoons and kidney ponds are very shallow (average 0.5m deep) with unconsolidated mud or silt bottoms, while the main channels have coarser sand or gravel bottoms. Typical marsh vegetation areas border the lagoons and extensive mats of green algae and Zostera beds are a feature of the water areas.

3.2 Climate

The climate of the region is characterized by temperature extremes, high average sunshine hours, average winds and low rainfall.

Temperatures. Mean annual monthly temperatures are shown in Fig. 3.1. Temperature variations between seasons are high and in the summer months of January and February, temperatures exceeding 24.0° C are frequent. In winter frosts are common and day temperatures can drop below 8.0° C.

Wind. Plots of hourly observations of wind data from the New Zealand Meterological Service at Blenheim over the period 1946-74 show that for the months of November to April winds from the north-east to east and west to north-west dominate (Hume and Williams, 1981). The strongest winds (greater than 17 knots) invariably blow from the west to north-west sector. The average number of days for gusts exceeding 70 km per hour lotal 30 which is approximately the New Zealand overall mean.

Sunshine. Blenheim is one of the sunniest areas in New Zealand being consistently at or near the top of the national averages. The overall mean is 2,400 hours of bright sunshine per year.

Rainfall. The low rainfall of the area is evident from the statistics listed below:

Mean total yearly rainfall	= 637 mm
Mean summer rainfall (3 months)	= 140 mm
Mean autumn rainfall	= 166 mm
Mean winter rainfall	= 186 mm

Rainfall is high in the winter and low in the summer.

3.3 Bathymetry

A bathymetric map of the Wairau River Estuary compiled by the Marlborough Harbour Board shows the following features (Hume and Williams, 1981):

1. The estuary entrance area shallows upstream from the mouth, from over 3 m to less than 1 m.

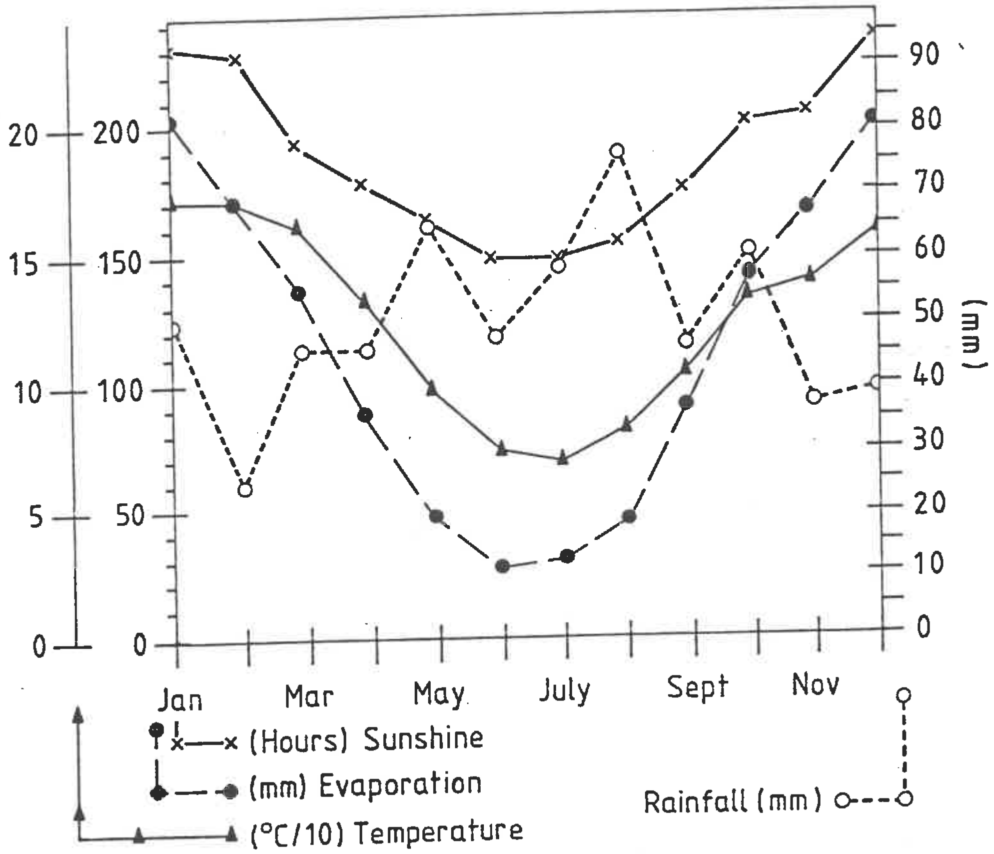

Fig. 3.1. Graph of the mean monthly values for various climate paramaters over the period 1970-74. (After Black, 1978, Fig. 3 -based on data from the New Zealand Meterological Service.)

2. Depths at the entrance to the Vernon Lagoons are shallow.

3. Water deeper than -2.0m MSL is restricted to a narrow (30m) shallow channel running through the central confluence area widening to a 100m wide channel in the bar area. In only two locations is the entrance channel deeper than -5.0m MSL.

4. The channel/shoal/shingle bar configurations are highly mobile presumably as a result of fluctuations in sediment supply, littoral currents and wave energy and direction.

5. A large tongue-like shoal projects eastwards from the Opawa River mouth into the Vernon Lagoons entrance resulting in a relatively shallow bar at the lagoons entrance with deeper water on the south side of the entrance. Ths shoal fluctuautes in shape and extent.

The lagooms themselves are shallow (-0.5 m MSL) on average except in the channels which may exceed -1.0 m MSL.

There is little quantitative data concerning the stability of the estuary bed and the rates of bed-load transport. It is believed that the bed is relatively stable.

3.4 Hydrology

3.4.1 Tidal cycle

Available data (Hume and Williams, 1981) show that the tides are semi-diurnal, but that they are markedly influenced by freshwater inflow into the system. The salient features are:

1. The tidal range varies from 0.4 to 1.1 metres.

2. Maximum and minimum observed tidal levels are -0.5m amd +0.85m respectively.

3. The maximum difference in water levels between successive low and high tides are 0.1 and 0.2m respectively.

Tidal range is influenced both by river discharge and the state of the bar entrance. Tidal ranges as small as 0.4m can be induced by high river discharge and during severe sea conditions when the bar entrance may become restricted. Under both these conditions the tidal flow to the estuary and lagoons becomes restricted. Large freshwater inflows generally cause an increase in tidal height but a decrease in tidal range.

3.4.2 Tidal compartment

Thompson (1975, 1976) has calculated the tidal compartment (the average volume of water moving from the lagoon and estuary system during each tidal cycle). This measured in cubic metres comprises:

River storage:	Opawa River	320×10^3	
	Wairau River	$2,535 \times 10^3$	$2,855 \times 10^3$
Lagoon storage:	Big Lagoon	475×10^3	
	Upper Lagoon	475×10^3	
	Other Lagoons (entrance etc.)	400×10^3	1.350×10^3
Total storage:			$4,205 \times 10^3$
River flow equivalent per tidal cycle:			6.5×10^3
Total effective volume of tidal compartment:			$4,820 \times 10^3$

3.4.3 Currents and flows

Velocity profiles. Measurements of current velocities made by the Catchment Board in the Wairau River Estuary showed that there was a marked increase in velocity towards the surface. Bottom velocities were greater than 0.5m sec , while surface velocities were greater than 0.5m sec over the ebb tide period.

Flow data. The Marlborough Catchment Board (Marlborough Catchment Board, 1970; Thompson, 1976) have investigated flow relationships between the main water bodies in the lower estuarine area. The discharge hydrographs (Fig. 3.2) suggest that peak flow at the Bar (i.e. river and estuary storage ranging from 400-1,100 $m^3 sec^{-1}$) is commonly twice that existing in the lagoons. On the ebb tide and during summer low flows, the discharge at the Bar is 10-15 times that of the freshwater input.

Flow patterns in the estuary are determined by tides, the freshwater flow, the storage compartment and topography. After low water the tide begins to flow across the entrance bar as a head develops between the estuary and coastal waters. Flood tide waters spread into the Te Aropipi Channel entrance to the Vernon Lagoons but it can be up to 2 hours before water levels at the wharf are higher than those at Moerepo Island. From this time on the slope increases filling the Te Aropipi Channel and eventually the Lagoons.

Black (1978) has discussed water movement within the Vernon Lagoons.

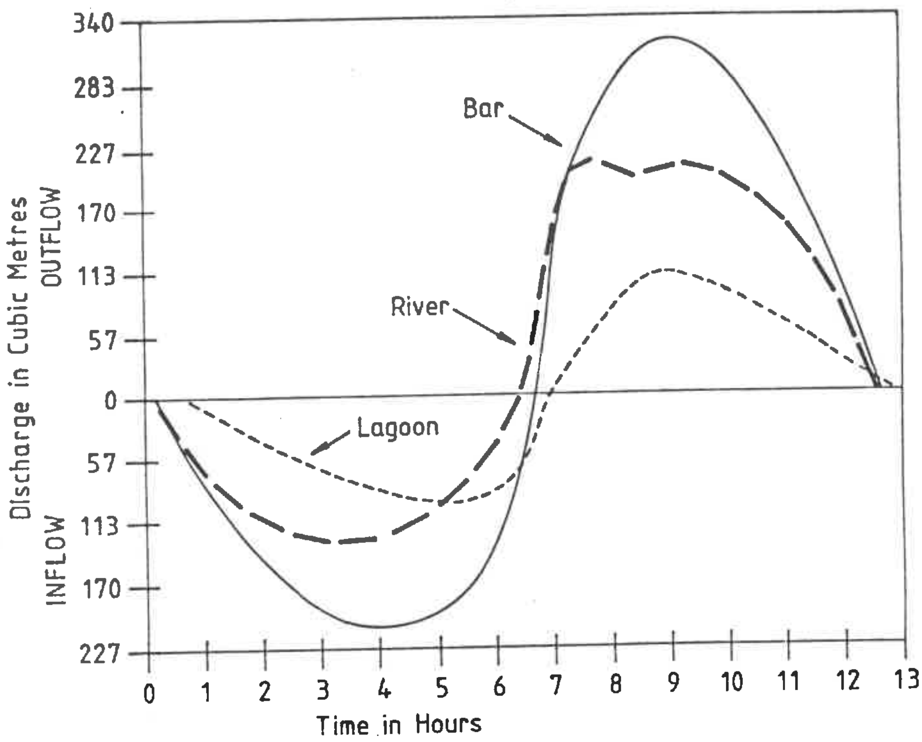

Fig. 3.2. Typical hydrographs showing the distribution of flows in the Wairau River, the lower Wairau River Estuary (Wairau bar), and the Vernon lagoons (from Knox, 1983).

This is dependent upon at least four factors: tidal flow, river flow, wind action and basin configuration. A summary of the general water movements within the lagoons based on Black's observations of semi-submerged floats and floating debris and salinity measurements follows. With the onset of the flood tide the incoming seawater over the bar begins to flow under the less saline (and therefore less dense) outgoing river water. The incoming tide results in a rise in the water level in the lower Wairau River Estuary causing a proportion of river water to enter the lagoon where it mixes with the higher salinity lagoon water. As the salt wedge approaches the confluence of the Lagoon entrance with the estuary, part continues up the estuary and part begins to enter the lagoon system. The spit at the Lagoon entrance causes a breakdown in the saline water/freshwater interface due to turbulent mixing (evident as a patch of turbulent water at the surface even in calm conditions). This mixed sea water and river water component travels into the lagoons along the Te Arapipi Channel. The water flow then divides, part following the Boulder Bank up into Big Lagoon, and part travelling up Morgans Creek past Moerepo and Budges Islands and into the Upper and Chandlers Lagoons. The further up the lagoon system the later the reversal of flow (from ebb to flood) occurs. The flood tide into the lagoons then consists of two components: firstly a river water component enters the lagoons, to be followed later by a mixed component with saline water predominating except under flood conditions.

When ebb tide begins the opposite flow to that discussed above occurs with the water from the lagoons passing into the estuary to mix with the outgoing water. As with the flood tide, the beginning of the ebbtide is delayed as one moves further up the lagoon. These delays result in the times of high and low water within the lagoon system deviating considerably from those of the open sea. Where the inflowing water is confined to a narrow channel, e.g. the lagoon mouth, tidal ranges of up to 1.5m occur but as the water enters the logoon proper, the water is spread over a larger area and the range is correspondingly reduced reaching only about 3.0 cm at the south end. Wind action, or the amount of water flowing in the Wairau River, can cause considrable changes in depth. If a strong northwesterly (the prevailing wind) is blowing, or if the Wairau River is in flood, then the height of the water witin the lagoons may rise as much as one metre above Mean High Water Neap Tide levels, flooding the surrounding Sarcorcornia flats and farmland.

Current velocities also vary throughout the lagoons dependent upon the location and the state of the tide. Currents of up to 0.75m sec^{-1} occur along the main channels at midtide and negligible currents (less than 0.1m sec^{-1}) at the upper ends of the three main lagoons.

3.5 Salinity distributions

Salinity distribution patterns in the Wairau River Estuary and in the entrance channel to the Vernon Lagoons have been studied by the

Marlborough Catchment Board and Knox (1983). At high water surface salinity decreased from 31.0 - 32.0‰ near the bar entrance to 19.0 - 3.0‰ 2 km upstream, depending on the river flow volume. The data demonstrated a marked vertical stratification with the low saline water forming a thin layer on top of the incoming saltwater wedge. At low water the low salinity freshwater had displaced most of the salt water from the Wairau River Estuary.

Samples taken at the entrance to the Vernon lagoons showed an interesting pattern. Samples taken by Knox (1983) over a period covering approximately one hour before high water and one hour after high water showed that on the latter stages of the flood tide the water entering the Vernon lagoons, at that state of the tide, especially the surface water, is seawater diluted by Wairau River water (salinity range at the surface 19.75 - 24.75 ‰). Whereas samples taken at low water and early flood tide have a range of 29.25 - 30.00 ‰ indicating that the water that entered the Veron lagoons in the early and mid stages of the flood tide was high salinity water from the incoming salt wedge. Thus the Vernon Lagoons with their limited freshwater input are characterised by relatively high salinities.

3.6 Temperature Distributions

Temperatures within the Wairau River estuary are generally higher than those of the coastal seawater, while those of the outflowing waters from the Vernon lagoons, especially in summer, are even higher. This is due to the warming of the shallow waters in the lagoons.

3.7 Oxygen Concentrations

Oxygen concentrations measured by Knox in January 1982 gave high water values of 6.8 - 9.2 mg l^{-1} (mean 8.1) which were higher than those recorded in low water samples (range 6.2 - 7.7 mg l^{-1}, mean 6.3).

At low tide the lowest levels recorded in the stations sampled at the entrance to the Vernon Lagoons reflected the lower temperatures of the waters in the lagoon which had lost oxygen due to animal respiration and bacterial decomposition while covering the mud flats. However, the levels recorded indicate that they do not fall below levels critical for aquatic life. It is generally agreed that 5.0 mg l^{-1} is a satisfactory lower limit for successful fish life (Alabaster, 1973). Levels in the estuary and lagoons are well above this limit.

3.8 The Hydrological Regime

Flow mechanisms within an estuary are dependent on a number of parameters including basin configuration, river flow, tidal range and wind.

During periods of high flow when the river is in flood, flushing is dominated by river discharge. This is to be seen in the decreasing tidal range during floods. During summer months when the freshwater flow is low, flows are dominated by the tides and wind. While there is little data on wind generated circulation patterns within the system it is likely that the role of the wind is considerable due to a number of factors including:

1. The low tidal range, especially in the Vernon Lagoons where the range decreases with distance from the entrance. In these shallow lagoons wind driven circulation dominates under windy conditions.

2. The most frequently occurring and strongest winds (i.e. west, north-west and east-north-east) parallel the major area of the Wairau River Estuary.

3. Strong north-west winds have been known to retard ebb tide flow from the Te Arapipi Channel for up to 2 1/2 - 3 hours after high tide (N. Smith, pers. comm., quoted in Hume and Williams, 1981).

The salinty and temperature data show that the estuary is a typical 'salt wedge' estuary in that on the flood tide the incoming coastal saline water penetrates as a wedge below the outflowing fresh water. On the ebb tide the saline waters are gradually displaced from the estuary by the flow of the Wairau River and to a lesser extent the Opawa River, and the flushing of the Vernon Lagoons. Flow patterns in the lower estuary are complicated by the time lag in the outflow from the Vernon Lagoons.

A prominent feature is the eddy which develops on the south side of the end of the Wairau Bar. This eddy develops 1 1/2 - 2 hours after high water and is maintained until the latter stages of the ebb tide.

3.9 Sediments

3.9.2 General composition and distribution

Fig. 3.3 depicts the general pattern of distribution of the surface sediments grouped into the following categories:

stone
pebbles and gravel
sand
sand/mud
mud
silt

In the seaward portion of the Wairau River Estuary there are mainly coarse sediments. Pebble and gravel beaches occur along the south side of the Wairau Bar. In the vicinity of the wharf river pebbles and stones form beach areas with sand below. The lower intertidal beach areas on the north side of the Wairau River Estuary are composed of sandy muds with coarser sandy sediments on the south side. The main channels have a coarse sand substrate. Substrates in the vicinity of the Opawa River are sandy muds grading into muds up river.

Sediment samples taken by Hume and Williams (1981) in the Wairau River Estuary varied from fine/medium through coarse/medium to coarse sands. The percentage sand in the samples varied from 34.5 to 97.4%. The coarsest sediments occurred in the Wairau Bar region near the estuary mouth. In general there was a correspondence in coarseness and proximity to the main channels. Organic debris was recorded as being present only in those sediments with a fine sand component.

Substrate composition in the Vernon Lagoons is typical in that there is a transition from predominantly sand at the entrance to fines in the upper reaches. There is also a transition from coarser sediments in the channels to finer sediments on the intertidal flats. These trends are similar to those found in other estuarine areas such as the Avon-Heathcote Estuary (Webb, 1972; Knox and Kilner, 1973) and the Ahuriri Estuary (Kilner and Ackroyd, 1978).

Clarke (1976) in his work on the Vernon Lagoons proposed the following classification of the lagoon substrates:

(1) Rocky shoreline: This extends along the west side of the Boulder Bank and consists of large (up to 20cm diameter) stones. These remain unsedimented in the intertidal zone due to wave action but sedimentation does occur (albeit lightly) below Mean Low Water Spring Tide level.

(2) Deep channel (over 1.5 m deep): These channels link the lagoon system with the estuary of the Wairau River. They have coarse sandy bottoms grading up to finer deposits in the intertidal zone. The coarse deposits are maintained by strong tidal currents, Te Arapipi Channel is typical of this habitat.

(3) Shallow channel (0.5 to 1.5 m deep): These either connect the lagoons to the deep channels or with other lagoons. The largest area of such channels occurs where the Upper Lagoon/Chandlers Lagoon system connects with the Morgan Creek deep channel habitat through a series of braided channels. The substrate is usually sand or mud (coarse to medium sediment grades) in the channels with finer sediments on the associated flats which are exposed by tide or wind action. The currents in these channels are reasonably strong (0.25 to 0.5m sec^{-1}) but not as fast as

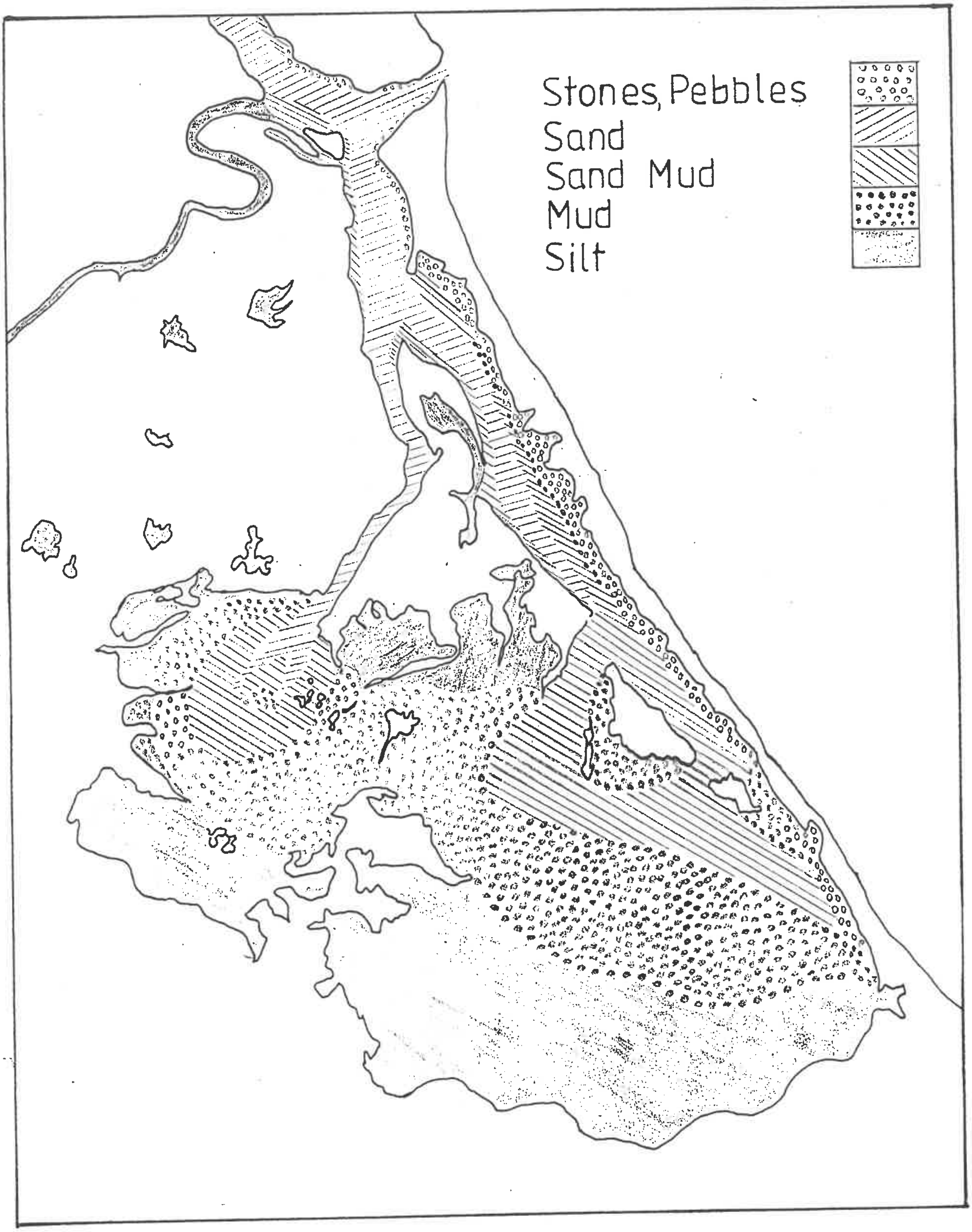

Fig. 3.3. Distribution of the substrate types in the Wairau River Estuary and the Vernon lagoons. (Based on a map prepared by Black (1978) and modified by data obtained during this study.)

those in the deep channels.

(4) Lagoon-type habitat (less than 0.5m deep): This includes the majority of the lagoon area where the water depth approximates 50cm. However, the depth can be deeper or shallower depending on the tides (neaps or springs), wind intensity and direction, and water flow in the Wairau River. The substrate is unconsolidated mud or silt (fine or very fine sediment grades) while current velocities vary from negligible ro slight.

3.9.2 Sediment nutrients

In the samples examined by Hume and Williams (1981) total organic carbon (TOC) ranged from 0.03 to 0.51%, total kjeldahl nitrogen (TKN) from 158 to 835 mg kg and total phosphorus (TP) from 3.6 to 526 mg kg . These as expected showed a general correlation between high total organic carbon content and total kjeldahl nitrogen levels and fineness of the sediments. They also calculated the Organic Sediment Index (OSI) for the sediment samples. OSI values which are obtained by multiplying TOC as a percentage by the TKN as a percentage (Ballinger and McKee, 1971) were low, ranging from between 0.0005 and 0.0351. In the Upper Waitemata harbour (Knox, 1983a) OSI values ranged from 0.12 to 1.17 with a mean of 0.35. This mean is ten times higher than the highest value recorded in the Wairau River Estuary. OSI values are highest in fine sediments with large amounts of organic matter. Thus it can be concluded that the OSI values for the Wairau River Estuary reflect the relatively coarse sediments, low organic content and low nutrients. It would be expected that OSI values for sediments on the Vernon Lagoon tidalflats would be considerably higher.

3.9.3 Sediment organic content

During Knox's 1981 study surface sediments were taken at three levels (upper shore, mid-tide, lower shore) along four intertidal transects and at four station (A-D). Sediment organic content was determined by loss on ignition.

Values for percent loss ranged from 1.840 to 3.751%. The results indicated that the sediments contained moderate amount of organic matter. Much higher levels have been recorded in estuaries with high levels or organic input.

3.10 Nutrients in the estuarine water

Knox (1983) determined nutrient levels in water samples at a series of stations in water samples taken at low tide and high tide (surface and bottom) in the lower and upper Wairau River Estuary, the entrance to the Vernon Lagoons, and the lower reaches of the Opawa River. From the data the following conclusions were drawn:

1. The highest nutrient levels were those recorded at low tide for the two stations on the Opawa River, with maximum levels (e,g, nitrate-N 0.98 g m and total organic-N 0.81 g m) at the up-river station. These levels reflect the discharge of effluent from the Blenheim oxidation ponds.

2. In the high tide samples the freshwater influenced (lower salinity) surface waters tended to have much higher nutrient levels that the bottom saline waters (e.g. at Station 9 the surface nitrate-N value was eight times that of the bottom, 0.089 as compared with 0.011 g m). This is indicative of the greater natural nutrient load carried by river water.

3. At high water the samples taken at the entrance to the Vernon Lagoons are similar to those in the Wairau River Estaury, indicating that they are from the same body of water.

4. At low tide the water flowing out of the Vernon Lagoons has higher nutrient levels than the water in the upper Wairau River Estuary, especially for total organic-N (0.19 - 0.20 compared with 0.05 - 0.08 g m^{-3}) and total-P (0.072 - 0.120 compared with 0.013 - 0.031 g m^{-3}). This indicates that the water had acquired additional nutrients during its stay in the lagoons, probably from exchange across the mud-water interface of the extensive mudflats, or from decomposition processes of _Ruppia_ and algal mats.

5. At low tide the levels in the Wairau Bar samples are very similar to those in the samples taken at the entrance to the Vernon Lagoons and higher than those in the upper estuary samples (apart from nitrate-N) indicating that the water sampled probably originated mainly from the Vernon Lagoons outflow.

The significance of these results will be discussed below.

4. METHODS

4.1 Resampling of the Transects and Stations Sampled in 1981

Three of the Four Transects (Transects 1. 3, and 4) sampled in 1981 were resampled. In addition Stations A and B were resampled (see Fig. 4.1 for the positions of the Transects and Stations). At each station three cores were taken with a 10 cm diameter corer and the contents processed through a set of sieves (the finest being 0.2 mm). The animals retained on the sieves were preserved in 10% neutralised foirmalin for later identification and determination of the numbers of individuals present.

The Transects resampled were:

Transect 1: Along the beach on the southern side of the wharf, 60 m long, 12 stations 5 metres apart.

Transect 3: On the northeast side of the island to the west of the entrance to the Vernon Lagoons, 50 m long, 3 stations 25 m apart.

Transect 4: On the east side of the Vernon Lagoon entrance, 50 m long, 3 stations 25 m apart. This transect was opposite the freezing works discharge point.

4.2 Mid-tide Sampling Stations.

In addition to Stations A and B a number of Stations throughout the lagoons were also sampled (see Fig. 4.2 for their positions).

4.3 Cockle Sampling Stations

A number of stations (see Fig. 4.3 for the Station positions) were sampled for cockles (*Chione stutchburyi*). At each station an area of 1/10 m was dug to a depth of 20 cm and the sediment washed through a coarse sieve (2 mm mesh). The cockles retained on the sieve were preserved for subsequent counting and size analysis.

4.4 Epibenthic Sledge Sampling Stations

A series of trawls were made with an epibenthic sledge (this sampler skims off the top of the sediment and the surface-dwelling animals are retained in the attached net). See Fig. 4.4 for the positioms of the trawls. At each station the sledge was towed behind a dinghy powered by an outboard motor for 15 minutes.

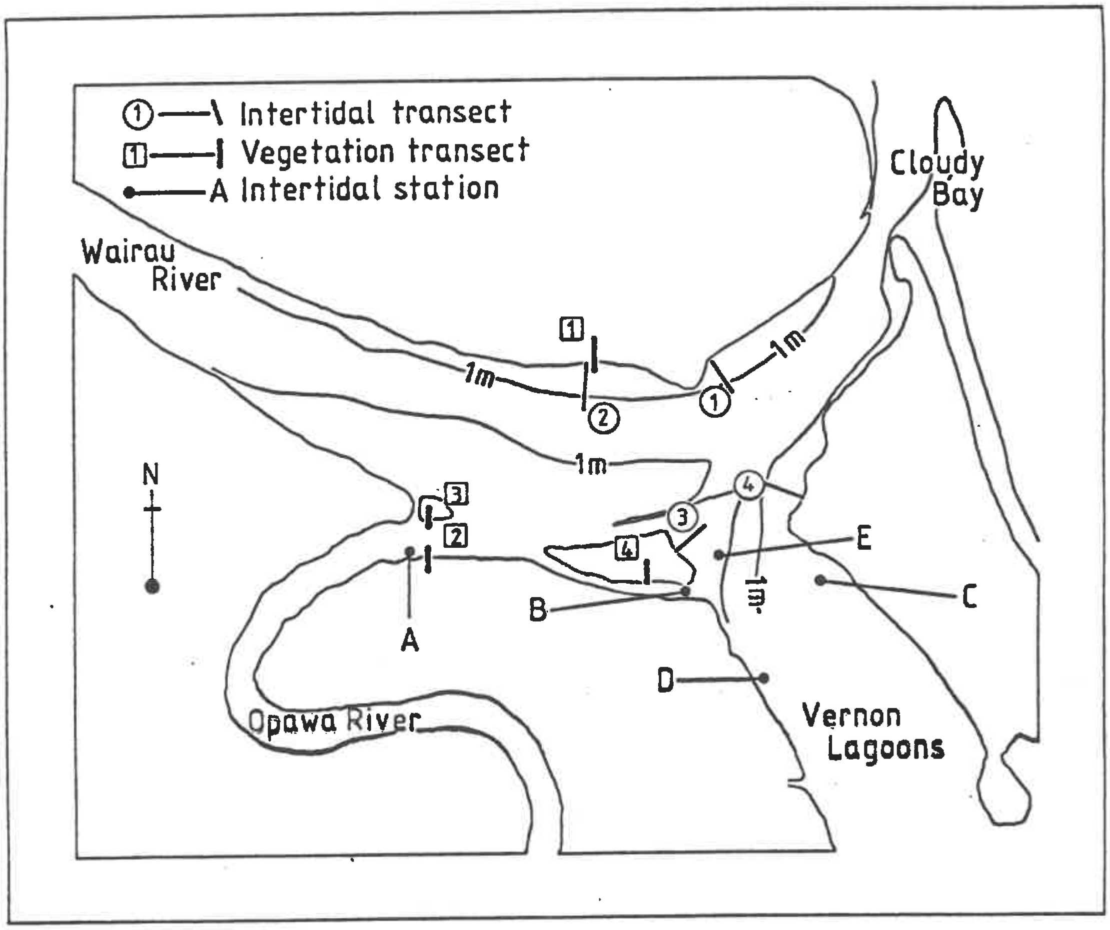

Fig. 4.1. Intertidal benthic macrofaunal transects and vegetation transects sampled in 1981.

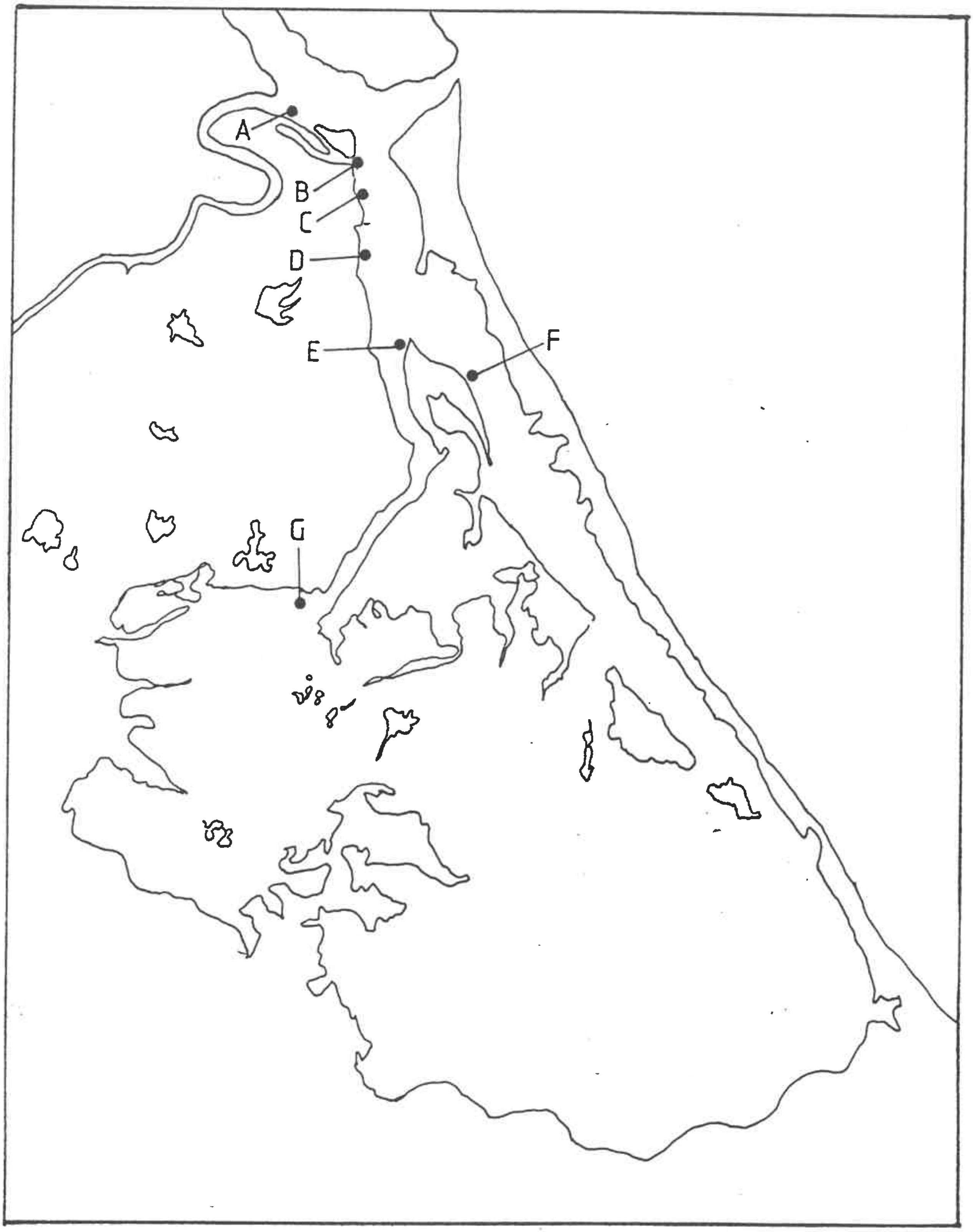

Fig. 4.2. Positions of the mid-tidal stations sampled in 1989.

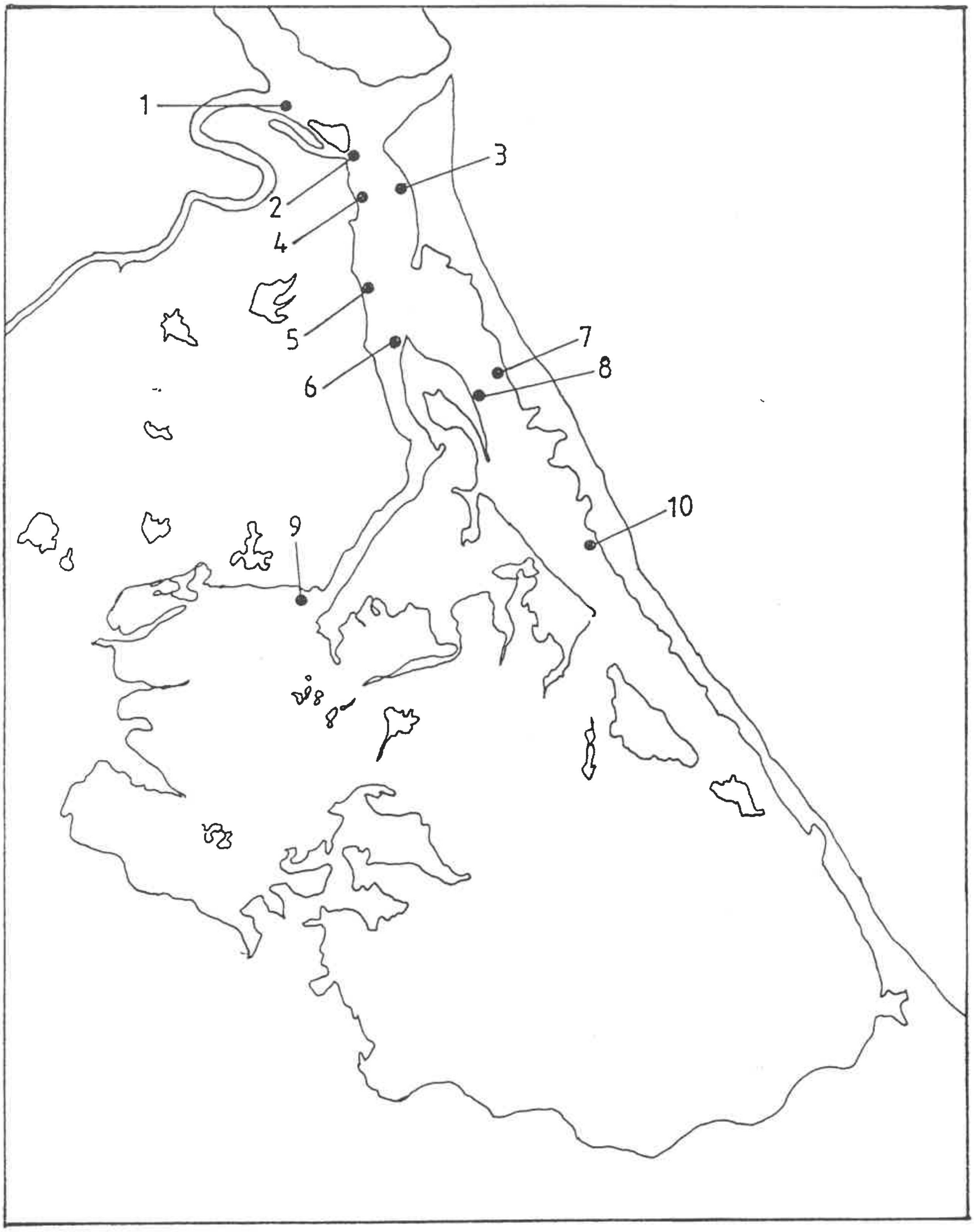

Fig. 4.3. Positions of the below mid-tide stations which were sampled for cockles (<u>Chione stutchburyi</u>).

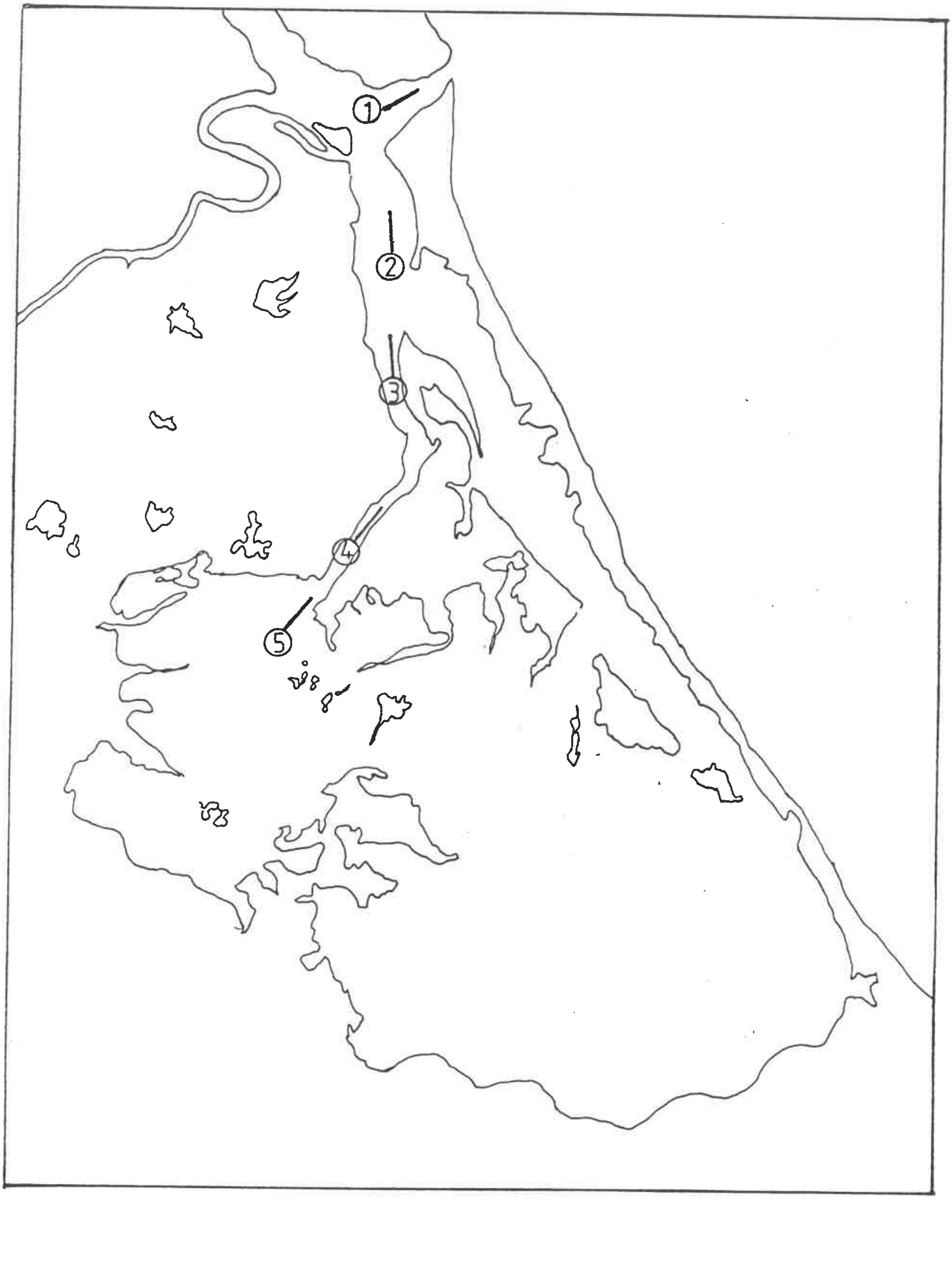

Fig. 4.4. Positions of the epibenthic sledge sampling stations.

5. RESULTS

5.1 Intertidal Transects and Stations

Nineteen species were recorded from the intertidal transects and stations. The Crustacea were represented by 7 species, the Polychaeta by 7 the Nemertinea by 1, and the Mollusca by 4.

Species distributions are presented in Tables 5.1 to 5.6. A number of trends are obvious in the distributions shown in the tables.

1. In all transects and stations the dominant species was the tube-dwelling amphipod Paracorphium lucasi, reaching a maximum density of 12,225 m^{-2} at Station 3.3.

2. The other abundant species were the polychaetes Aonides trifidus, Boccardia syrtis, Nicon aestuarensis and Scolecolepides benhami.

3. In the transects total densities increases down shore with the exception of Transect 4 where the greatest density occurred at the uppermost station (4.1). The maximum densities occurred at Station 4.1 (17,157 m^{-2}).

5.2 Comparisons of the 1981 and 1989 Results.

Table 5.2 compares the species recorded in 1981 and 1989. Data for the individual stations along the three intertidal transects and for the intertidal stations are compared in Tables 5.3 and 5.4, while Tables 5.5 and 5.6 compare the total numbers of each species along the three transects. A number of points emerge for these tables.

1. The number of species is comparable in the two years. A species of nemertine worm recorded in Transect 3 in 1989 was not found in 1981, while the crab Macrophthalamus hirtipes was not found in 1989.

2. Total numbers for the individual stations were in general very much higher in 1981 than in 1989 (e.g. at Station 4.3 only 9,159 individuals were recorded in 1989 compared to 64,758 m^{-2} in 1981).

3. On the other hand the numbers of individuals at Stations 1.1 to 1.6 were much higher in 1989 than in 1981 (this was most marked for Station 1.1 to 1.3 where invertebrates were absent in 1981 but occurred in densities of 344, 3,331 and 2,021 m^{-2} respectively in 1989.

4. Numbers of the tube-dwelling amphipod Corophium lucasi were in general much lower in 1989 than in 1981, especially along Transect 4 where there was total of 28,165 in 1989 compared to 144,179 in 1981.

TABLE 5.1 SPECIES PRESENT ALONG THE INTERTIDAL TRANSECTS AND STATIONS IN 1981 AND 1989.

	1981	1989
Amphipoda		
Paracorophium lucasi	+	+
Isopoda		
Exosphaeroma planulatum	+	+
Mysidacae	+	+
Decapoda		
Halicarcinus whitei	+	+
Helice crassa	+	+
Hemigrapsus edwardsii	+	+
Macrophthalmus hirtipes	+	−
Crab zoea larvae	+	+
Polychaeta		
Aonides trifidus	+	+
Boccardia syrtis	+	+
Heteromastus filiformis	+	+
Nicon aestuariensis	+	+
Paraonides sp.	+	+
Scolecolepides benhami	+	+
Spionid sp.		
Nemertinea		
Nementine sp.	−	+
Mollusca		
Bivalvia		
Chione stutchburyi	+	+
Paphies australe	+	+
Gastropoda		
Amphibola crenata	+	+
Potamopyrgus aestuarinus	+	+

Table 5.2 NUMBER OF INDIVIDUALS PER SPECIES PER SQ.M. ALONG TRANSECT 1 IN 1981 AND 1989

STATION	1.1		1.2		1.3		1.4		1.5		1.6	
YEAR	1981	1989	1981	1989	1981	1989	1981	1989	1981	1989	1981	1989
Paracorophium lucasi	-	301	-	1806	-	1736	-	4343	1023	4773	1548	5805
Exosphaeroma planulatum	-	-	-	-	-	43	-	-	86	43	86	43
Mysids	-	-	-	-	-	-	-	-	-	-	-	-
Halicarcinus whitei	-	-	-	-	-	43	-	-	-	43	-	172
Helice crassa	-	-	-	-	-	-	-	-	-	-	-	-
Macrophthalmus hirtipes	-	-	-	-	-	-	-	-	129	-	-	-
Crab zoea	-	-	-	-	-	-	43	-	-	-	129	-
Nemertinea sp.	-	-	-	-	-	-	-	-	-	43	-	43
Aonides trifidus	-	-	-	1677	-	43	-	-	-	344	129	172
Boccardia syrtis	-	-	-	516	-	-	-	559	-	473	-	215
Heteromastus filiformis	-	-	-	215	-	-	-	-	516	258	3132	43
Nicon aestuariensis	-	-	-	43	-	129	-	43	86	172	258	172
Paraonides sp.	-	-	-	473	-	-	-	-	129	43	-	-
Scolecolepides benhami	-	43	-	587	-	-	-	-	-	774	-	301
Spionid sp.	-	-	-	-	-	-	-	-	-	-	-	43
Chione stutchburyi	-	-	-	-	-	-	-	-	-	-	-	-
Paphies australe	-	-	-	-	-	-	-	-	-	-	-	-
Potamopyrgus aestuarinus	-	-	-	-	-	-	-	-	-	-	-	-
Amphibola crenata	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	0	344	0	3311	0	2021	43	4945	1978	6966	2528	7009

Table 5.2 (Continued) NUMBER OF INDIVIDUALS PER SPECIES PER SQ.M. ALONG TRANSECT 1 IN 1981 AND 1989

STATION	1.7		1.8		1.9		1.10		1.11		1.12	
YEAR	1981	1989	1981	1989	1981	1989	1981	1989	1981	1989	1981	1989
Paracorophium lucasi	9804	1204	9288	6364	11223	8256	19866	4515	8729	3741	9245	2279
Exosphaeroma planulatum	43	-	-	-	-	-	-	-	-	-	-	-
Mysids	43	-	-	-	-	-	-	-	-	-	129	-
Halicarcinus whitei	-	-	-	-	-	86	-	-	-	-	129	-
Helice crassa	43	-	86	-	43	-	-	-	-	-	516	-
Macrophthalmus hirtipes	-	-	-	-	-	-	-	-	215	-	-	-
Crab zoea	129	-	86	-	-	-	172	-	43	-	-	-
Nemertinea sp.	-	-	-	-	-	-	-	-	-	-	-	86
Aonides trifidus	129	-	172	43	129	-	86	129	129	344	129	-
Boccardia syrtis	-	43	-	-	559	-	-	-	-	7921	559	4343
Heteromastus filiformis	5332	43	5332	215	3782	86	3526	172	8944	989	5332	2881
Nicon aestuariensis	258	-	258	86	301	258	258	86	602	86	602	-
Paraonides sp.	-	-	-	-	-	-	-	129	-	-	-	-
Scolecolepides benhami	-	86	-	43	-	43	258	-	258	86	-	215
Spionid sp.	-	-	-	-	-	-	-	-	-	-	258	-
Chione stutchburyi	-	-	-	86	-	-	43	-	43	-	215	-
Paphies australe	-	-	-	43	-	-	-	-	-	-	129	43
Potamopyrgus aestuarinus	-	-	-	-	-	-	43	-	43	-	-	-
Amphibola crenata	-	-	-	-	43	-	86	-	86	-	-	-
TOTAL	15781	1376	15953	6880	15486	8772	24338	5031	20506	13167	17243	8947

Table 5.3 NUMBER OF INDIVIDUALS PER SPECIES PER SQ.M. ALONG TRANSECTS 3 AND 4 IN 1981 AND 1989

STATION	3.1		3.2		3.3		4.1		4.2		4.3	
YEAR	1981	1989	1981	1989	1981	1989	1981	1989	1981	1989	1981	1989
Paracorophium lucasi	15695	8256	22707	8686	1634	12225	26531	15480	67295	6757	58353	5934
Exosphaeroma planulatum	86	-	43	-	43	-	129	-	86	-	-	-
Mysids	86	-	86	-	473	86	43	-	-	-	-	86
Halicarcinus whitei	-	-	-	-	-	-	-	-	-	-	-	-
Helice crassa	86	-	-	-	-	-	-	-	-	-	-	-
Macrophthalmus hirtipes	-	-	-	-	-	-	-	-	-	-	-	-
Crab zoea	-	-	-	-	-	-	-	-	-	-	-	-
Nemertinea sp.	-	-	-	129	-	-	-	-	-	-	-	-
Aonides trifidus	-	-	-	86	-	-	-	430	-	86	129	559
Boccardia syrtis	-	129	-	-	-	-	86	-	-	43	43	86
Heteromastus filiformis	1032	-	1290	-	258	43	1333	129	10992	-	12040	129
Nicon aestuariensis	-	86	-	129	172	172	387	43	301	301	86	301
Paraonides sp.	989	43	1204	86	86	129	-	86	516	129	645	301
Scolecolepides benhami	989	172	1118	430	774	-	215	989	301	817	1204	1763
Spionid sp.	-	-	129	43	-	-	-	-	-	-	-	-
Chione stutchburyi	-	-	43	-	129	-	-	-	-	-	-	-
Paphies australe	86	-	86	-	258	-	-	-	-	-	-	-
Potamopyrgus aestuarinus	301	-	602	-	1462	-	5934	-	5590	-	387	-
Amphibola crenata	86	-	-	-	-	-	-	-	-	-	-	-
TOTAL	18404	8901	27305	9589	5289	12085	34615	17157	85333	8127	64758	9159

Table 5.4 NUMBER OF INDIVIDUALS PER SPECIES PER SQ.M. FOR THE MIDTIDAL STATIONS IN 1981 AND 1989

STATION	A		B		E		G	
YEAR	1981	1989	1981	1989	1981	1989	1981	1989
Paracorophium lucasi	5590	1677	14491	4773	-	559	-	344
Exosphaeroma planulatum	86	-	1032	-	-	-	-	-
Mysids	258	-	774	86	-	-	-	-
Halicarcinus whitei	-	-	-	-	-	-	-	-
Helice crassa	86	-	-	-	-	129	-	43
Macrophthalmus hirtipes	-	-	-	-	-	-	-	-
Crab zoea	-	86	-	43	-	-	-	-
Nemertinea sp.	-	-	-	-	-	-	-	-
Aonides trifidus	-	-	-	-	-		-	-
Boccardia syrtis	-	-	-	-	-	-	-	-
Heteromastus filiformis	2967	43	1849	-	-	-	-	-
Nicon aestuariensis	387	215	258	43	-	43	-	-
Paraonides sp.	-	-	-	-	-	-	-	-
Scolecolepides benhami	-	-	-	344	-	602	-	215
Spionid sp.	-	-	-	-	-	-	-	-
Chione stutchburyi	-	-	86	-	-	-	-	-
Paphies australe	-	-	-	-	-	-	-	-
Potamopyrgus aestuarinus	7310	8772	10449	-	-	-	-	-
Amphibola crenata	-	86	172	-	-	-	-	-
TOTAL	16668	10879	29111	5289		1333		602

TABLE 5.5 NUMBER OF INDIVIDUALS PER SPECIES PER SQ.M. FOR THE 12 STATIONS ALONG TRANSECT 1.

	1981	1989
Paracorophium lucasi	70735	45123
Exosphaeroma planulatum	215	129
Mysids	172	-
Halicarcinus whitei	129	344
Helice crassa	172	-
Macrophthalmus hirtipes	732	-
Crab zoea	732	-
Nementine sp.	-	172
Aonides trifidus	903	2752
Boccardia syrtis	1118	13991
Heteromastus filiformis	32157	4902
Nicon aestuariensis	2760	1075
Paraonides sp.	258	645
Scolecolepides benhami	516	1935
Spionid sp.	516	43
Chione sutchburyi	387	86
Paphies australe	172	86
Potamopyrgus aestuariensis	172	-
Amphibola crenata	258	0
TOTAL POLYCHAETA	39217	25477

TABLE 5.6 NUMBER OF INDIVIDUALS PER SPECIES PER SQ.M. FOR THE 3 STATIONS ALONG EACH OF TRANSECTS 3 AND 4.

	Transect 3		Transect 4	
	1981	1989	1981	1989
Paracorophium lucasi	40042	29167	144179	28165
Exosphaeroma planulatum	172	0	215	0
Mysids	645	86	43	86
Halicarcinus whitei	0	0	0	0
Helice crassa	86	0	0	0
Macrophthalmus hirtipes	0	0	0	0
Crab zoea	0	0	0	0
Nementine sp.	0	129	0	0
Aonides trifidus	0	86	129	1075
Boccardia syrtis	0	129	129	129
Heteromastus filiformis	2580	43	24365	258
Nicon aestuariensis	172	387	774	645
Paraonides sp.	2188	258	1161	516
Scolecolepides benhami	2881	602	1720	3569
Spionid sp.	129	43	0	0
Chione stutchburyi	172	0	0	0
Paphies australe	516	0	0	0
Potamopyrgus aestuariensis	2365	0	11911	0
Amphibola crenata	86	0	0	0
TOTAL POLYCHAETA	16029	1548	28278	6192

5. Numbers of the small deposit-feeding polychaete Heteromastus filiformis, which was the dominant polychaete species in 1981, were very low in 1989 (e.g. a total of 258 along Transect 4 compared to a total of 24,365 in 1981).

6. On the other hand the numbers of the other polychaete species were comparable in the two years. Scolecolepides benhami was abundant along Transects 1 and 4 in 1989.

7. Molluscs, especially the small gastropod Potamopyrgus aestuarinus, were much less abundant in 1989.

5.3 Possible Explanations for the Changes Which had Occurred.

There are a number of possible explanations for the changes that were detected in the distribution and abundances of the various species. These include:

1. Seasonal, and year-to-year differences in the abundances of particular species.

2. Possible changes in the salinity regime.

3. Possible changes in the nutrient status of the estuarine system.

4. Changes in sediment composition and percent organic matter in the sediments.

Each of these will be discussed in turn.

1. Seasonal and year-to year differences

Invertebrate species, especially the short-lived polychaetes and amphipods, exhibit strongly seasonal patterns of recruitment and mortality (Levinton, 1970; Grey, 1981). The samples taken in 1981 were post the main reproductive period for some of the species. Others, however, are continuous breeders. This could be a possible explanation for the lower numbers of the amphipod P. lucas, the mysids and the crab zoea. In addition recent studies of the long-term fluctuations in the composition of marine and estuarine benthic communities have shown that they can vary considerably. Some species show long-term decline or increase in abundance, others exhibit marked ephemeral population eruptions, while others fluctuate about a mean population level (Boesch et al., 1976; Ziegelmeier, 1970). Thus the changes in the densities of some of the polychaete species could be due to such population fluctuations.

A somewhat surprising result was the marked decline in the population of the small polychaete Heteromastus filiformis. This species is characteristic of disturbed environments with high inputs of organic matter (Rhoads et al., 1977; Pearson and Rosenberg, 1978). It was found in very high densities off the marine sewage outfalls in Hawke Bay (Knox and Fenwick, 1978, 1982; Knox, 1988). From an examination of the sediments it appeared that the amount of organic detritus present in 1989 was greater than that in 1981. Therefore the decline in the H. filiformis population is puzzling. Further studies would be necessary in order to determine whether the H. filiformis populations has declined permanently.

2. Salinity regime

While salinity measurements were not made during this survey it is unlikely that there has been any marked changes in the salinity regime. In any case the species present are typical estuarine species adapted to fluctuating salinity regimes.

3. Nutrient status

As discussed below without further studies it is not possible to determine what changes, if any, have occurred in the nutrient status of the system since 1981.

4. Sediment changes

As discussed below in the section on the distribution and abundance of cockles it is clear that changes in the characteristic of the sediments have taken place. While no sediment analyses were carries out during the present study visual observation of the sediments identified the following changes.

(1) In 1981 the beach where the the upper four stations of Transect 1 were devoid of animals was composed of coarse sand, whereas in 1989 a substantial number of animals were present at all four stations, and the sediments were composed of fine sand with substantial amounts of organic debris. The sediment changes would account for the changes that had occurred in the fauna.

(2) Along Transect 4, especially at the lower stations, the surface had a thin layer of fine yellowish sediment similar to that which I have observed in the vicinity of other marine sewage outfalls. This layer was not present in 1981. This transect is opposite the discharge point for the freezing works effluent and the fine sediment layer would be due to the deposition of the suspended solids in the effluent. Changes in species numbers, especially the considerable reduction in the numbers of the amphipod Paracorphium lucasi, could be the result of such sediment changes.

(3) Where accelerated bank erosion is taking place I have the impression

that the sediments in the intertidal zone have become finer with increasing amounts of the silt/clay fractions. Such changes would affect the faunal composition and density of the fauna, especially of the surface dwelling gastropods such as Amphibola crenata and the burrowing crabs.

(4) The deposition of fine sand along the inner side of the Boulder Bank in the Te Arapipi Channel region has smothered and eliminated the previously existing benthic communities (see Section 5.4 below).

5.4 Bivalve Distributions

The stations at which samples were taken for the estimation of bivalve densities are shown in Fig. 4.3. In addition non-quantitative sampling observations were made at a number of locations within the Vernon Lagoons. Table 5.7 compares the density, size range and median size of the cockle (Chione stutchburyi) samples taken in 1981 and 1989.

Densities tend to be lower in 1989 than they were in 1981, while the median size is roughly comparable in the two years. However, the median size at Station 2 in 1989 was low (20-24 mm), while those of Stations 4 and 6 were higher (30-35 mm) than for the living cockle samples taken in 1981 (25-29 mm) (Table 5.7).

Fig. 5.1 plots the size frequency distributions of the samples taken in 1989 and these can be compared with those of the samples taken in 1981 (Fig. 5.2). The 1989 samples did not have any specimens in the 5-9 mm range and very low numbers in the 20-14 mm range. Both of these size classes were well represented in the 1981 samples. Also individuals in the size classses 40-44 mm and 45-49 mm were absent in the 1989 samples. The absence of the smaller size classes and of any post-larval settled spat in the sediments indicates that recruitment has been low or absent in recent seasons.

There have also been considerable changes in the distribution and density of the cockles in the Vernon Lagoons. In my 1983 report (Knox, 1983) I figured a map of the distribution of cockles in the Wairau River Estuary and the Vernon Lagoons based on previous studies and personal observations (reproduced here as Fig. 5.3). Based on the work carried out during the present survey a new distribution map is given in Fig. 5.4. It is clear that not only have there been changes in the distribution pattern but also in the overall population densities. One of the most dramatic changes is that which has occurred in the area of the previous high population density on the Boulder Bank side of the Te Arapipi Channel. Throughout this area cockles are now absent. This is due to the deposition of a layer of fine sand over the intertidal area. This layer has smothered the previous benthic community and currently there are no invertebrates present. This layer appears to be a mobile one with well-defined ripple marks on the surface (Fig. 5.5). The area covered by

TABLE 5.7 DENSITIES, SIZE RANGE AND MEDIUM SIZE OF SAMPLES Of COCKLES TAKEN IN 1981 AND 1989 (SEE FIG. 4.3 FOR POSITIONS)

STATION	No. M^{-2} 1981	1989	Size Range(mm) 1981	1989	Median Size(mm) 1981	1989
1.	-	About	-	-	-	-
2.	1220	880	-	10-39	-	20-24
3.	1340	About	5-49	-	25-29	-
4.	340	360	5-39	20-39	25-29	30-35
5.	-	260	-	10-35	-	25-29
6.	-	230	-	15-39	-	30-35
7.	-	About	-	-	-	-
8.	-	5	-	-	-	-
9.	-	30	-	25-34	-	25-29
10.	-	About	-	-	-	-

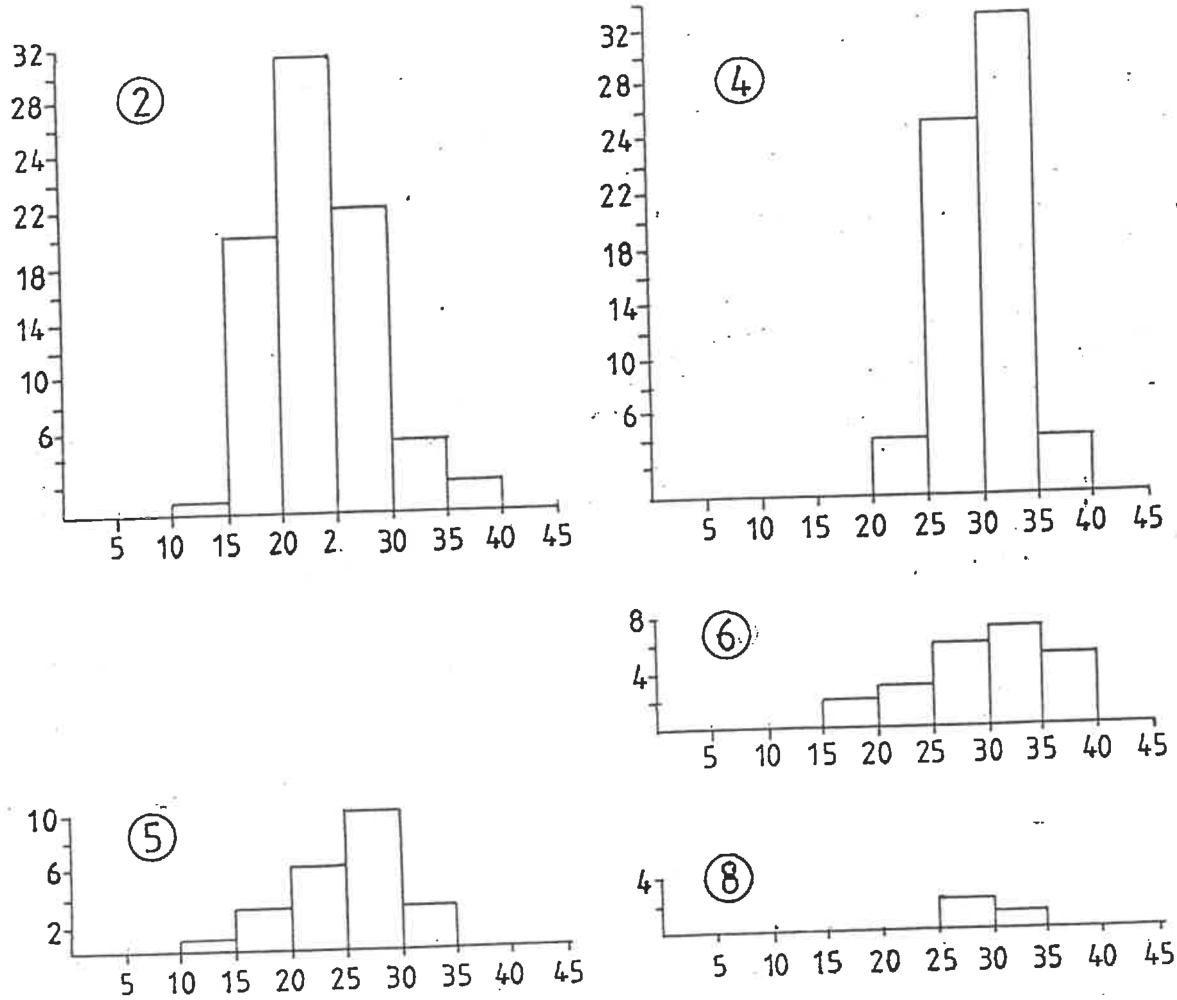

Fig. 5.1. Size class histograms of cockle samples taken at the cockle sampling stations shown in Fig. 4.2.

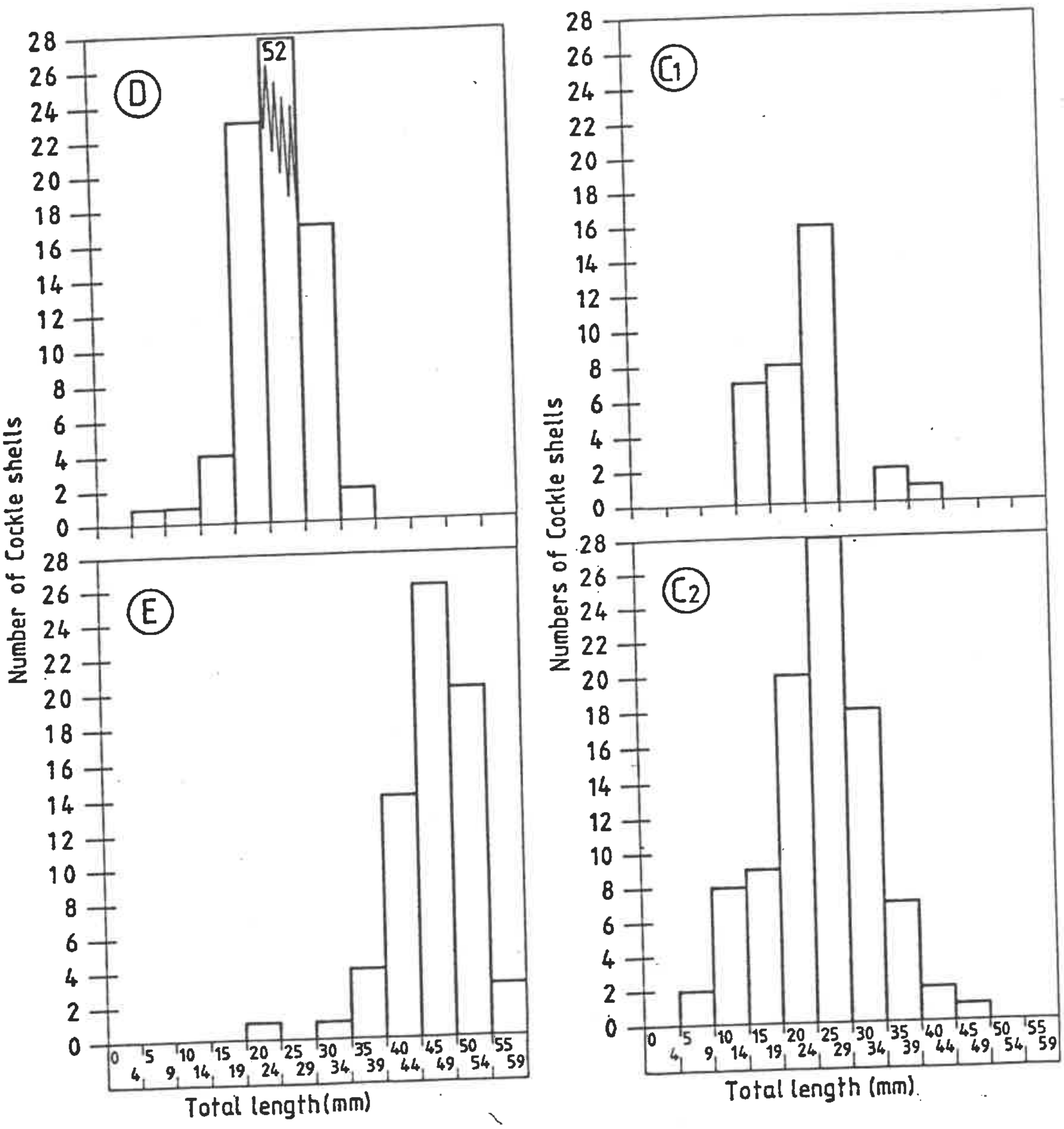

Fig. 5.2. Size class histograms of the cockle samples taken in 1981. Station D is in the same position as Station 4 in the 1989 survey. Station C is on the Boulder Bank side of the Te Arapipi Channel (no cockles were found at this site in 1989). E is based on dead drift shells from a bank at the entrance to the Vernon Lagoons.

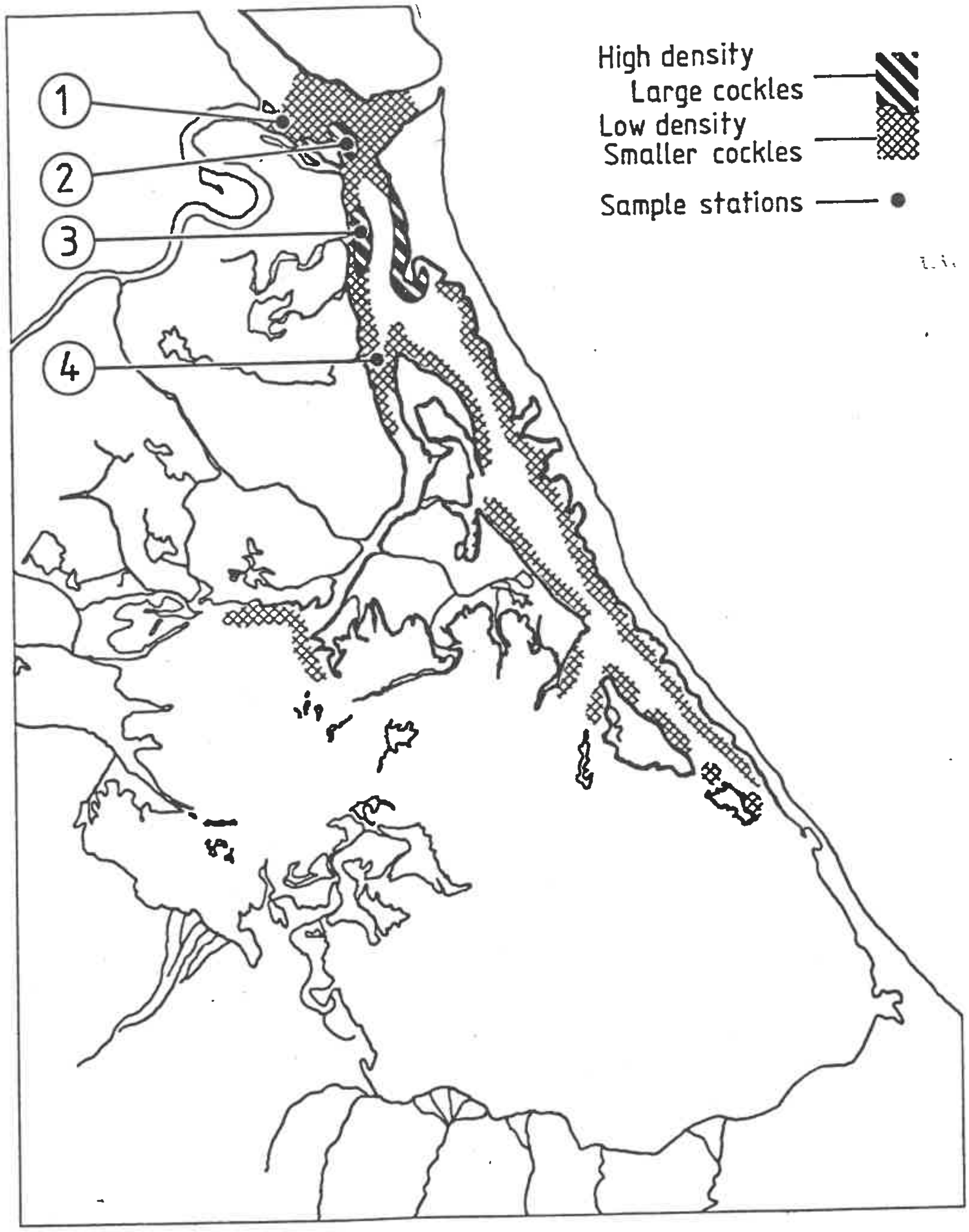

Fig. 5.3. The 1983 map of the distribution of cockles. (From Knox, 1983.)

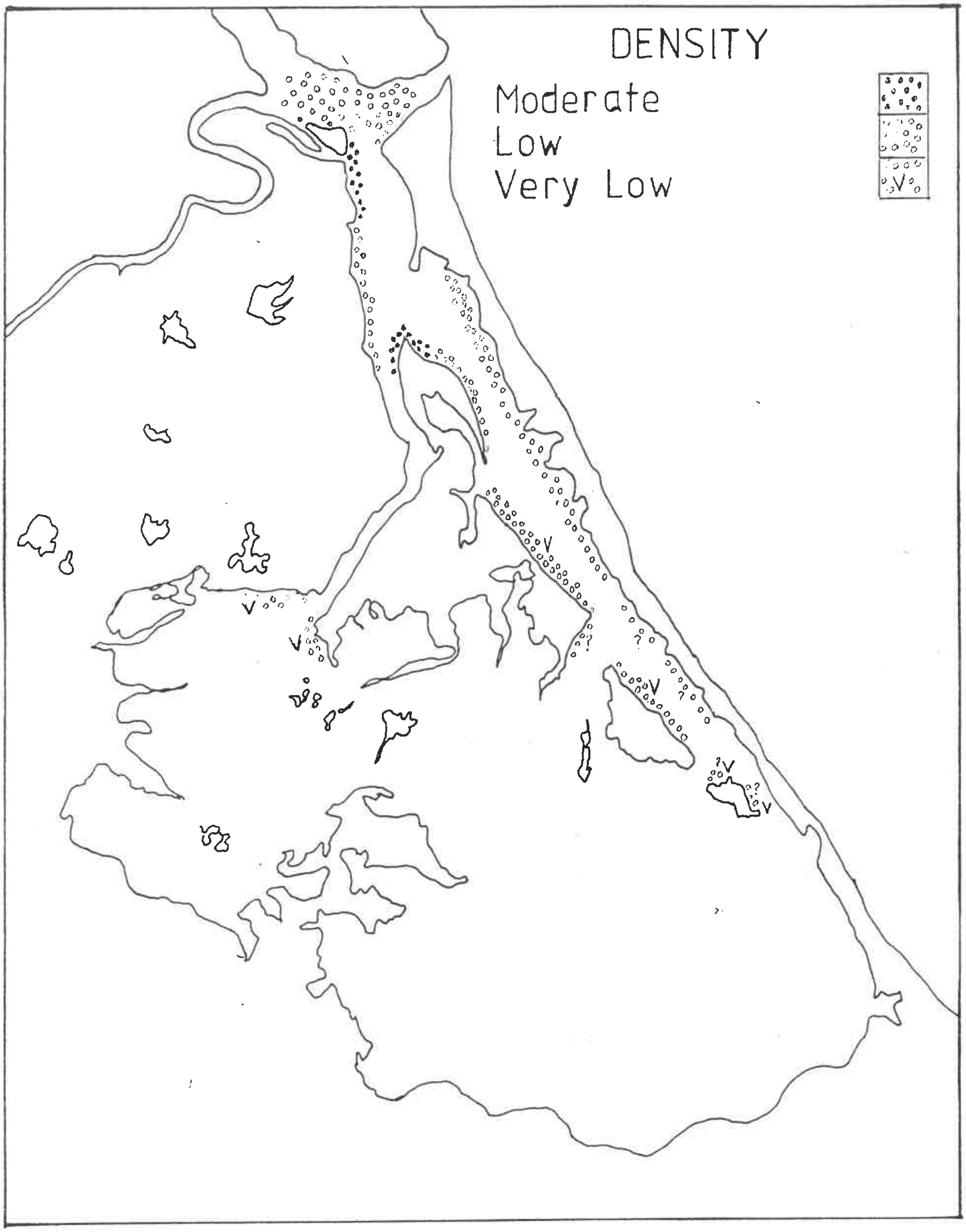

Fig. 5.4. Revised map of the distribution of cockles (based on the results of the present study).

Fig. 5.5. Photograph of the fine sand deposits on the inner side of the Boulder Bank near the entrance to the Vernon Lagoons.

this layer of fine sand is shown in Fig. 5.6. While previous studies have shown that the cockle populations decline up the lagoon system this decline now appears to be more pronounced.

The reasons for the decline in the cockle populations are probably complex but it is probable that changes in sediment composition is the major cause. There have been a number of studies of the factors controlling the distriburion of cockles (Wood, cited in Morton and Miller, 1973; Larcombe, 1971; Richardson et al., 1979; Grange, 1977, Stephenson, 1981). The most comprehensive study is that of Stephenson (1981). He found that C. stutchburyi was restricted in its distribution to the shore below the lowest high water neap tide, and to sediments containing less that 50% mud (silt and clay fractions 5 to 10-14 ϕ), and with a mean sand particle size smaller than 2.25 ϕ (medium sand), i.e fine and very fine sands. Thus the distribution is restricted by both coarse and muddy sediments. Although no investigation of the composition of the sediments was carried out during the present survey it is clear that in some parts of lagoons the sediments have become finer. This change may be due to the erosion of the banks along the west side of the Te Arapipi Channel and other parts of the lagoon system, especially in the channels. Such erosion is particularly noticeable along the west side of the Te Arapipi Channel where there has been a marked decline in the cockle populations. This change has been accompanied by the development of populations of the larger soft-shelled bivalve Cyclomactra ovata (Fig. 5.7.). This bivalve lives much deeper in the sediment (10-15 mm) than C. stutchburyi and occurs at a population density of 50-140 m^{-2} (mean 86 m^{-2}). It is of interest that this species has not been reported in previous studies.

In my 1983 report I figured a sample of drift shells from a bank at the entrance to the lagoons (see Fig. 5.2). This sample had a median size class of 45-49 mm, indicating that low-tide-subtidal bed of larger cockles probably exixted in the deeper waters. Dead cockle shells occur through out the Te Arapipi Channel region but examination of a number of low-tide sites did not reveal any living cockles.

Pipis (Paphie australe) were present in low numbers in the subtidal areas of the 1981 survey with even smaller number intertidally. No adult pipis were found during the present survey.

5.5 Epibenthic Sledge Samples

The results of the epibenthic sledge samples are given in Table 5.8. Only five species, the bivalves Chione stutchburyi and Cyclomactra ovata, the mudflat snail Amphibola crenata, the crab Hemigrapsus edwardsii and juvenile sand flounders were captured by the six trawls. The numbers of all species were low. The channels generally have hard sandy bottoms and a sparse fauna. This evidence of a sparse epifauna is supported by the results of the 1981 subtidal survey in which Station G in the Te Arapipi

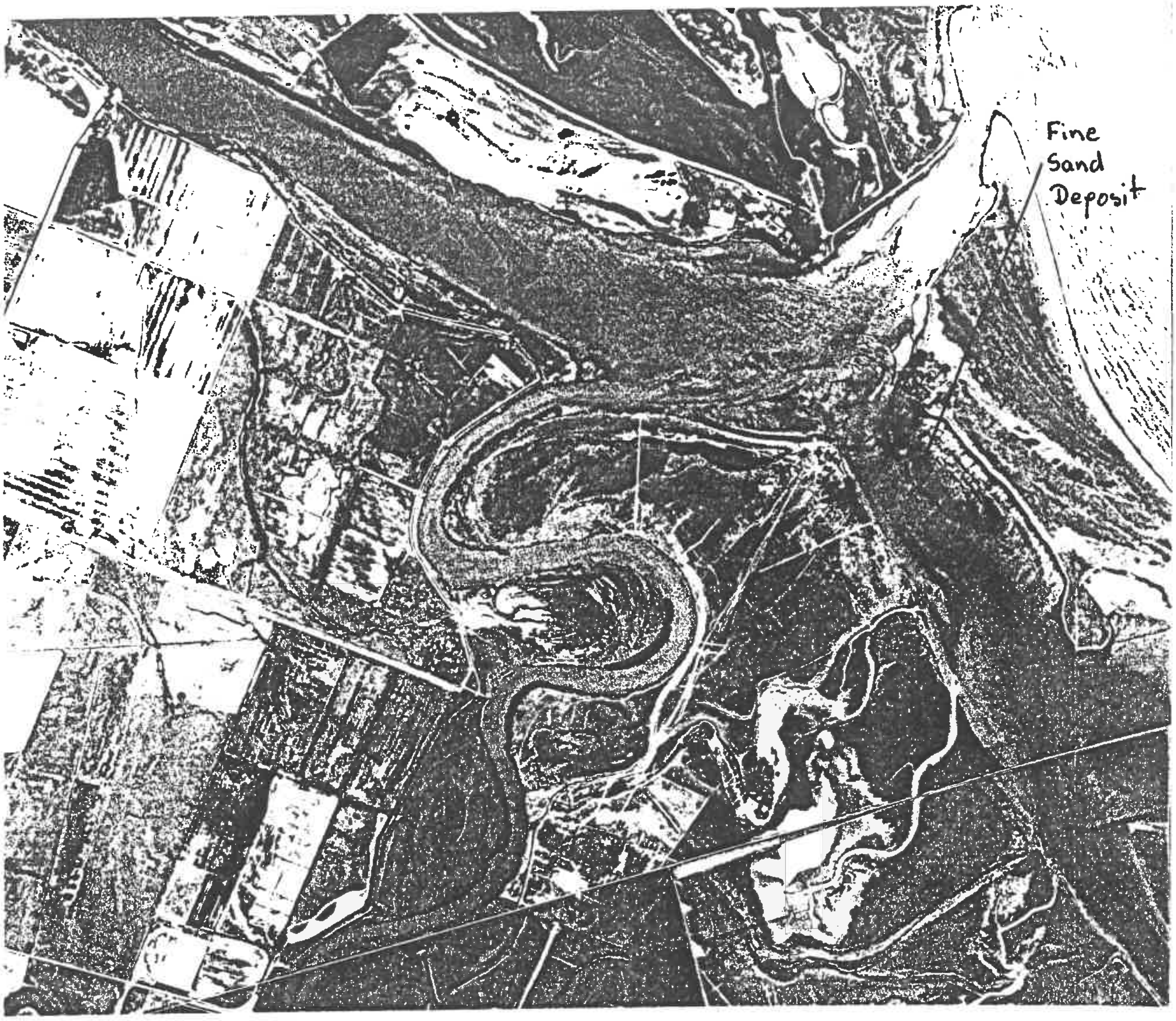

Fig. 5.6 Aerial photograph showing the location of the fine sand deposits shown in Fig. 5.5.

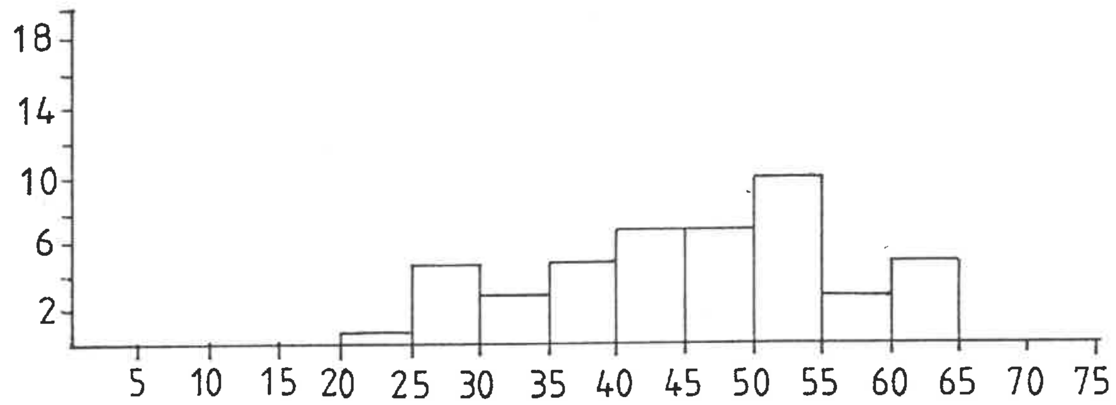

Fig. 5.7. Size class histograms of a population of Cyclomctra ovata sampled at Station 4.

TABLE 5.8 RESULTS OF THE EPIBENTHIC SLEDGE TRAWLES (SEE FIG. 4.3 FOR STATION POSITIONS)

TRAWL	DEAD COCKLE SHELLS	LIVE COCKLES		CYCLO-MACTRA	AMPHIBOLA		HEMIGRAPSUS EDWARDSII	YOUNG FLOUNDER
		No.	Size range (mm)		Live	Dead		
1.	None	20	16-38	1	-	-	-	-
2.	Many	-	-	-	-	-	-	2
3.	Few	-	-	-	-	-	2	-
4.	Few	1	29	-	-	-	-	-
5.	Few	15	16-28	-	-	Few	1	-
6.	Many	6	15-31	1	2	Many	-	-

Cannel had the lowest number of species (6) and the lowest number of individuals (452 m^{-2}).

1. THE ECOLOGY OF THE LAGOONS

6.1 Vegetation

A detailed description of the vegetation of the lagoons and the surrounding wetland and coastal areas was given in my 1983 report (Knox, 1983) and this will not be repeated here. The surrounding vegetated marsh areas represent one of the most extensive areas of this type to be found in the South Island. While much of the area has been modified through direct and indirect human action there are nevertheless considerable areas of unmodified vegetation. Areas subject to grazing in the past have a diverse adventive flora. In particular gorse (Ulex europaeus) is widespread and on the Boulder Bank the African boxthorn (Lycium ferocissimum) dominates large areas.

6.2 Benthic Macrofauna

In my 1983 report (Knox, 1983) I gave a detailed analysis of the estuarine community of the Wairau River Estuary and the Vernon Lagoons. Table 6.1 lists the current species recorded from the area. It was noted in 1983 that in comparison with other New Zealand estuaries the number of species is low (a half to one-seventh of that of other estuaries). Low species diversity is a characteristic of a stressed system. However in some instances the density of individual species is high.

This study has revealed changes in species composition and density at previously surveyed sites. The underlying causes of the changes are complex and more detailed investigations would be required to elucidate them. Changes in the distribution and density of bvivalve molluscs have been considerable and these should be studied in more detail.

Fig. 6.1 depicts a diagrammatic cross section through the lagoon benthic ecosystem. At and above EHWS the plant community is domimated by the rushes Juncus maritimus and Leptocarpus similis and the salt-marsh ribbonwood Plagianthus divaricatus. Below this depending on the slope is a variable area of the saltwort Sarcocornia australis. Burrows of the mudflat crab Helice crassa occur in the lower parts that are more frequently flooded. These areas comprise pure associations of S. australis. The upper areas which lack Helice crassa burrows are only flooded at extreme high water spring (EHWS) tides or when the river is in flood. Here associated adventive plant species are common. The reduction in the flow in the Wairau River, especially in flood events, due to the operation of the diversion channel, could result in these upper areas being flooded less frequently. This could result in an increase in the adventive species as the soil became less saline.

At the lower end of the Sarcocornia flats there is in most places a steep bank of varying height with often a dense concentration of H. crassa

TABLE 6.1 THE BENTHIC INVERTEBRATE FAUNA OF THE WAIRUA RIVER ESTUARY AND THE VERNON LAGOONS.

Nemertea
- Nemertine sp.

Polychaeta
- *Aonides trifidus*
- *Boccardia syrtis*
- *Heteromastus filiformis*
- *Nicon aestuariensis*
- *Paraonides* sp.
- *Scolescolepides benhami*
- Spionid sp.

Mollusca
- Gastropodn
  - *Amphibola crenata*
  - *Potamopyrgus aestuarinus*
- Bivalvia
  - *Chione stutchburyi*
  - *Cyclomactra ovata*
  - *Paphies australe*

Crustacea
- Cirripedia
  - *Elminius modestus*

Amphipodn
- *Allorchestes* sp.
- *Gammaropsis thompsoni*
- *Paracorophium lucasi*
- *Paramoera* sp.
- *Talarchestia quoyana*

Isopoda
- *Exosphaeroma planulatum*

Mysidacea
- *Tenagomysis novaezelandine*
- *Tenagomysis chiltoni*
- *Gastrosaccus australis*

Decapodn
- *Halicarcinus whitei*
- *Helice crassa*
- *Hemigrapsus edwardsii*
- *Macrophthalamus hirtipes*

Pisces
- Juvenile sand flounders

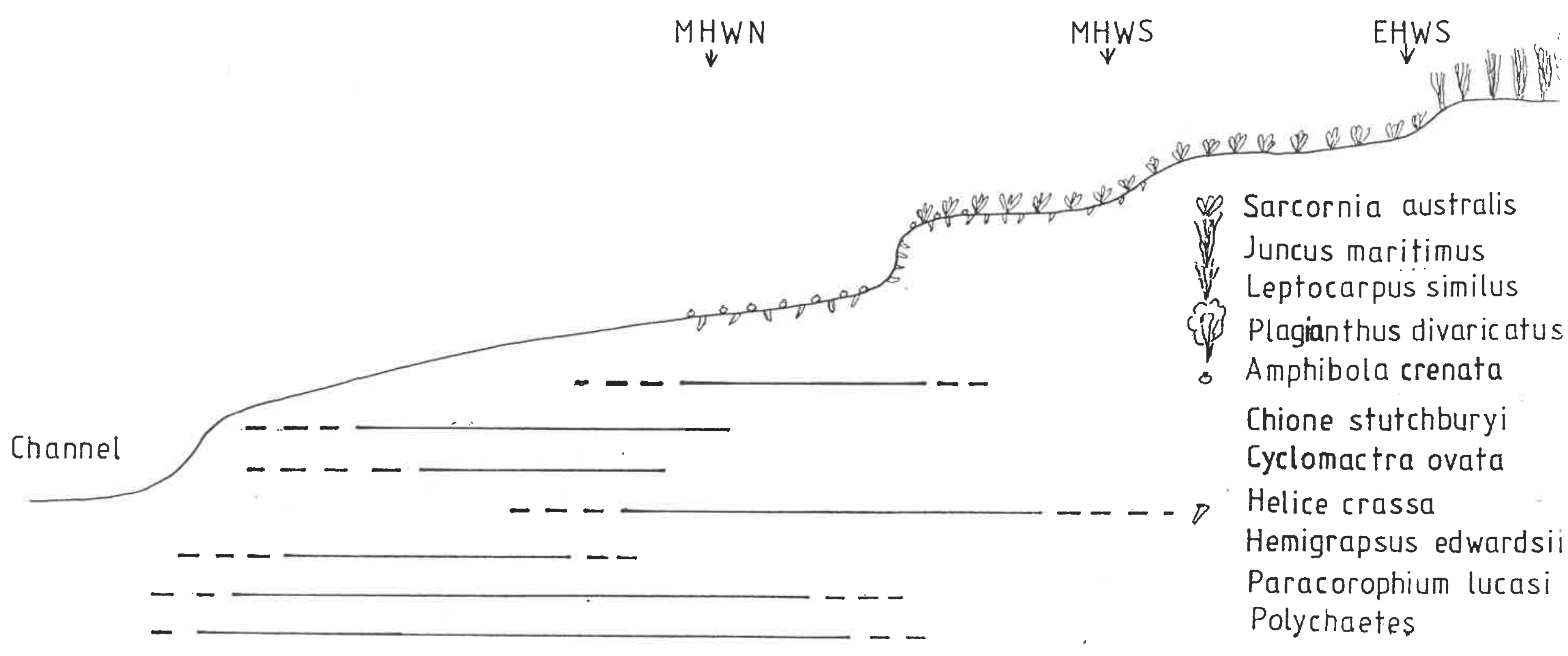

Fig. 6.1. A diagrammatic cross section through the Lagoon ecosystem.

burrows. On the upper part of the intertidal mudflats the dominant species are the mudflat snail Amphibola crenata and Helice crassa. Counts of population densities of these species at a variety of locations around the lagoon margins gave densities of 0 - 80 m^{-2} for Amphibola with mean densities varying from 3.5 to 20 m^{-2}, and 0 to 135 m^{-2} for Helice.

6.3 Fish

A species list was given in the 1983 report (Knox, 1983). There is nothing to add to this at this stage. Little quantitative data is available in fish numbers.

6.4 Birds

Some 90 species of birds have been recorded from the Wairau River Estuary-Vernon Lagoons complex. They use the area as permanent habitats, as visitors for breeding, or feeding, or as casual visitors. A detailed discussion of the ecology of the avifauna was given in the 1983 report (Knox, 1983). No studies of bird distribution were undertaken during the present survey.

6.5 Trophic Status and Eutrophication Potential

A detailed account of the trophic status and eutrophication potential was given in the 1983 report (Knox, 1983). Since no studies of nutrient levels in the water or sediments was undertaken during the present survey, and since no other investigations have been carried out since those of 1981 there is nothing further to add at this time. However, increases in the effluent discharge from the Blenhein Borough oxidation ponds to the Opawa River and the additional effluent from the freezing works discharge will have impacted on the trophic status of the system. Considerable growths of filamentous green algae were observed in many parts of the lagoons. However without seasonal studies over several years it is not possible to say whether such growths are increasing.

7. RESOURCE USE AND HUMAN IMPACT

7.1 Pre-European

In the general vicinity of the Vernon Lagoons there are numerous archaeological features that reflect the importance of the area throughout the prehistoric period of human occupation (Trotter, 1979). A very famous early Maori archaelogical site, the so-called Moa-hunter camp on the Boulder Bank was discovered in 1939 when a local schoolboy, Jim Eyles, dug up a human skeleton. This site, excavated and researched from the early 1940's by the late Roger Duff of the Canterbury Museum, provided a cornerstone for the reshaping of archaeological thinking in New Zealand (Duff, 1950).

Duff considered that the Wairau Bar, at the northern end of the Boulder Bank, was the most suitable site for people having a fish and fowling economy. Here the river mouth (he wrote) gave access to the sea, for fish and for trading expeditions, while along the sea beaches there accumulated the large quantities of firewood necessary in a treeless spot. Whitebait and kahawai ran seasonally into the river and lagoon; mullet, eels, and flounders formed a more permanent population. In addition, the extinct swan must have flourished in the lagoon (as does the introduced swan of today), as well as great numbers of grey and paradise duck. Finally, in some manner which is still not finally decided, the site was well placed for the hunting of large numbers of moas whose bones aré spread over the main occupation site. Subsequent investigations (Trotter, 1975) showed that the early Maori occupation dated back some 650 years before the present.

Without doubt the most puzzling aspect of the prehistory in the Vernon Lagoons area are the so-called "Maori channels" or "Maori canals". These were first reported by Skinner in 1912. The total length of the channels is nearly 20 kiolmetres. The exact function of these ditches is not known and indeed we still do not know if they were manmade. Thompson (in Anon, 1985) considers that they possibly are of natural origin.

Later archaeological sites round the lagoons, for instance on Budges Island, are indicative of a changed economy as the inhabitants killed off some of the bird species, burnt off considerable areas of forest and reduced the seal populations. These sites are principally shell middens indicative of a changed diet. This intinerant hunter-gatherer life style gave way about 300 years ago to a more settled existance with increasing dependence on agriculture. The low-lying land between the lagoons and the Vernon Hills show outlines of low earthern walls. These are typical of walls associated with Maori gardens and provide evidence of cultivation, probably kumera. It is thus clear that the exploitation of the natural resources of the area by the pre-European Maori populations had had a considerable impact.

7.2 European

The first recorded european settlement in the area occurred in 1847, when James Wynen built an inn at the Wairau Bar. Two years later Francis MacDonald built another inn across the river on the Boulder Bank. In the same period a Mr. Budge settled on a point between the Wairau and Opawa Rivers. These inns existed because bullock waggons, passing to and from the Awatere station used the bar to cross the Wairau River. The 1855 earthquake deepened the Wairau Bar enough to navigate schooners across it and up the Opawa River as far as Beaver (now Blenheim).

The early European settlers first drained the low-lying land surrounding the Wairau River Estuary and the Vernon Lagoons and undertook measures to control the periodic floods that menaced their farms and settlements. Drainage ditches were dug, rivers were diverted and their lower reaches stopbanked. These developments have had a profound effect on the ecology of the area. The original wetlands have been reduced to a fraction of their original extent and this, coupled with shooting and other factors, has reduced the original very large water fowl population to a small remnant.

River diversion and stopbanking resulted in greater quantities of sediment reaching the lower river system (Thompson, 1976), while littoral drift of gravel up the coast resulted, prior to 1960, in the migration of the river mouth some 1.7 km north of its original position. When floods occurred, the banking up of water by an inefficient outlet situation caused large quantities of silt laden water to enter the lagoons. According to Thompson (1976) evidence from aerial photographs dating from 1947 indicate that quite a rapid build-up of sediments occurred around the margins of the lagoons. The inefficient outlet situation required the periodic breakdown of the gravel spit to form a channel straight out to the sea in order to avoid stopbanks being overtopped during floods.

Problems with flood control resulted in the 1960's in further measures to alleviate the problem. In 1963 the Wairau Diversion was opened to provide a flood outlet (Thompson, 1975). Since its development this channel has continued to enlarge and at its full development it will take approximately two thirds of the flood flows. As the size of the river channels depends on the volume of flood flows, the lower section of the Wairau River will gradually become narrower as the dominant channel forming floods become smaller and silt build-up occurs (Thompson, 1976). This will reduce the tidal compartment within the river channel to an estimated 58% of its present volume. If no other factors affect the total tidal compartment, this will cause a 22% reduction of the total tidal compartment; and a corresponding decrease in the size of the river mouth. According to Thompson (1976) the expected changes are essentially long-term and it may be 50 to 100 years before equilibrium is achieved.

In 1960 a rock formed training wall was constructed on the north side of the river mouth in order to stabilise its position. Prior to 1960 the effects of tidal storage and flood flows had at times been barely sufficient to maintain an open river mouth during periodic storms (Thompson, 1976). Since the construction of the rock wall, this problem has not roccurred and the mouth has remained open.

In the past much of the surrounding area has been grazed although the productivity of the area was low due to low soil fertility and a high water table. Such grazing has now ceased in the area controlled by the Department of Conservation.

7.3 Recreational Use

7.3.1 Commercial and recreational fishing

The Wairau River Estuary is a valuable although limited commercial and recreational fishery resource. Although commercial gill-netting for kawahai was carried out from 1978 to 1980 no commercial fishing is now operating. On the other hand, extensive use of the Wairau River Estuary is made by amateur fishermen. During the season whitebaiters fish from suitable spots along the entire length of the estuary. Salmon, trout and kahawai angling is also carried out, especially along both banks of the Wairau Bar, the south bank north of the Opawa River mouth and both banks further up river. Amateur flounder fishing is limited mainly to drag netting in a few suitable areas in the Wairau Bar area and in the vicinity of the Opawa river. In the past there has been some gathering of cockles in the Te ArOpipi Channel area.

7.3.2 Shooting

Duch shooters utilize most of the area , apart from the Wildlife Refuge in the Big Lagoon. During the duck shooting season it is estimated that some 2,000 birds are shot by approximately 60 shooters (Reynders, 1985).

7.3.3 Passive recreational use

The area provides excellent opportunities for passive recreation such as hiking, bird watching, picnicking, beachcombing, excursions to the archaeological sites and the like. For an area of the size and variety of opportunities that it offers recreational use has been very modest. Increased use has followed the development of the walkways.

8. FUTURE MANAGEMENT

8.1 Monitoring Programmes

8.1.1 Effluent discharges

In the conditions of the Water Right granted to Waitaki N.Z. Regrigerating Co. Ltd. limits for BOD , suspended solids, sulphides and ammoniacal nitrogen were set for the final effluent and the Company was required to monitor the the influent flow rates, continuous and cumulative, to the treatment system and to monitor in terms of BOD , solids, pH, greases and fats at regular intervals. Records of the continuous flow from the oxidation pond to the outfall were to be kept and composite samples were to be analysed for BOD , suspended solids, fats and grease, ammonia, sulphides and pH. This monitoring is carried out by the Company and the results supplied to the Regional Water Board. It has not been possible to examine such records in detail. A similar monitoring programme is carried out by the Blemheim Borough for the discharge from the oxidation pond to the Opawa River.

However, no monitoring of the nutrients (apart from ammoniacal nitrogen) in the discharges from the oxidation ponds to the Wairau River Estuary and the Opawa River has been carried out. This needs to be done for the various forms of nitrogen and phosphorus so that when related to the discharge volumes the input of nutrients to the system can be estimated.

In the Water Right it was a requirement that the freezing works effluent should be discharged only on the outgoing tide, during a period of four hours, being one hour after high tide and one hour after low tide, the tide measurement being related to the point of discharge. It was assumed that this would ensure that the effluent would be discharged to the sea and that little, if any, would find its way into the lagoons. However, the behaviour of the discharge is likely to be influenced by a number of factors, including: (1) the state of the tide (spring or neaps); (2) the volume of flow in the Wairau River; (3) wind direction and intensity; and, (4) the volume of the effluent discharge. It is the responsability of the Regional Water Board to monitor the performance of the outfall. I have been given to understand that such monitoring has consisted of an annual inspection of the diffuser and casual observation of the appearance of the effluent discharge. No systematic monitoring of the fate of the effluent discharge has benn carried out. I have been informed that on occasions the effluent has been observed to pass upriver indicating that most of it would be retained within the estuarine system. There is a need for some systematic monitoring of the fate of the discharge as recommended in my 1983 report (p. 131).

8.1.2 Water quality

8.1.2.1 Nutrients

As discussed in Section 6.5 no investigation of water quality has been carried out since 1981. In my 1983 report I recommended that a monitoring programme with water quality analyses similar to those undertaken in 1981 be carried out. In the granting of the Water Right the Tribunal stated that: "Monitoring of the effluent at all stages should be carried out by the grantee, with monitoring of the receiving waters being done by the Regional Water Board." While the first of these monitoring requiremnts has been carried out by the grantee the second has not.

8.1.2.2 Coliform bacteria

There is a paucity of data on coliform bacterial levels. The Water Right did not set any standards for coliform bacteria in the effluent discharged from the freezing works. However, the coliform bacterial levels in the receiving waters, after allowance for mixing, would need to conform to the classification of such waters. Since freezing works effluent is likely to contain high numbers of coliform bacteria (Noonan in Knox and Wilson, 1982) there is a need for the monitoring of the impact of the discharge on the coliform bacterial levels of the receiving waters.

8.1.2.3 Shellfish coliform bacterial levels

The last survey of coliform bacterial levels in the cockles (Hayden, 1979) was carried out before the freezing works commenced its operations. In the 1983 report (Knox, 1983) it was concluded theat "the impact of the effluent discharge on coliform bacterial levels (in shellfish) can only be determined by monitoring after the treatment system comes into operation", and it was recommended that such monitoring be carried out. This has not been done.

8.2 Recommendations

8.2.1 Effluent discharges

8.2.1.1 That the effluent discharges from the oxidation ponds to the Wairau River Estuary and the Opawa River be monitored (for ammoniacal-N, nitrite-N, nitrate-N, total-N, soluble reactive-P, and total-P) at intervals to cover periods of high and low flows, summer and winter conditions, and for the freezing works discharge during periods of high and low killing volumes.

8.2.1.2 That a systematic study of the behaviour of the effluent discharged from the freezing works outfall be carried out, covering periods of high and low effluent flows, and different tidal conditions (e.g. spring and neap tides), wind direction and intensity, and volumes of river flow.

8.1.2 Water quality

8.1.2.1 That the water sampling programme that was carried out on 12 January 1982 be repeated with a series of samples being taken at high, mid and low tide. The samples to be analysed for oxygen and nutrients (ammoniacal-N, nitrite-N, nitrate-N, total-N, soluble reactive-P, and total-P).

8.1.2.2 That a study of the levels of coliform bacteria in the Wairau River Estuary and the Vernon Lagoons be carried out at the peak of the killing season and during a period when the works are not in operation.

8.1.2.3 That shellfish coliform bacterial levels be monitored on two occasions in one year: (a) during the peak of the killing season; and, (b) during a period when the works are not operating.

8.2.3 Erosion problems

In the 1983 report and also in this report I have commented on the extent of bank erosion in the lagoons. It will be important to assess the rate of such erosion and to develop means of slowing it down.

8.2.3.1 That the rate of bank erosion at selected sites in the Vernon lagoons be monitored.

8.2.3.2 That experimental planting be carried out at selected sites to determine if the rate of erosion can be checked.

8.2.4 Adventive plants

The incidence of exotic plants in the wetlands and on the Boulder Bank has been commented upon in Section 6.1. With the cessation of grazing vegetation changes are likely to take place with the populations of some species declining and others increasing. Such changes should be monitored.

8.2.4.1 That representative vegetation plots be established as sites for monitoring vegetation changes.

8.2.4.2 That efforts be made to eliminate woody exotics such as gorse and African boxthorn from the surrounding wetland area and the Boulder Bank.

8.2.5 Future resource exploitation

8.2.5.1 In view of the regional and national significance of the Vernon Lagoons and the surrounding wetlands it is recommended that: (a) no commercial developments such as aquaculture be permitted; and, (b) that no further encroachment on the wetland areas, such as the development of further oxidation ponds, be permitted.

8.2.6 Management Plan

8.2.6.1 That the Draft Management Strategy be revised as a Management Plan taking into account the submissions received and the results and recommendations of this study.

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