AN ECOLOGICAL SURVEY OF THE WAIRAU RIVER ESTUARY

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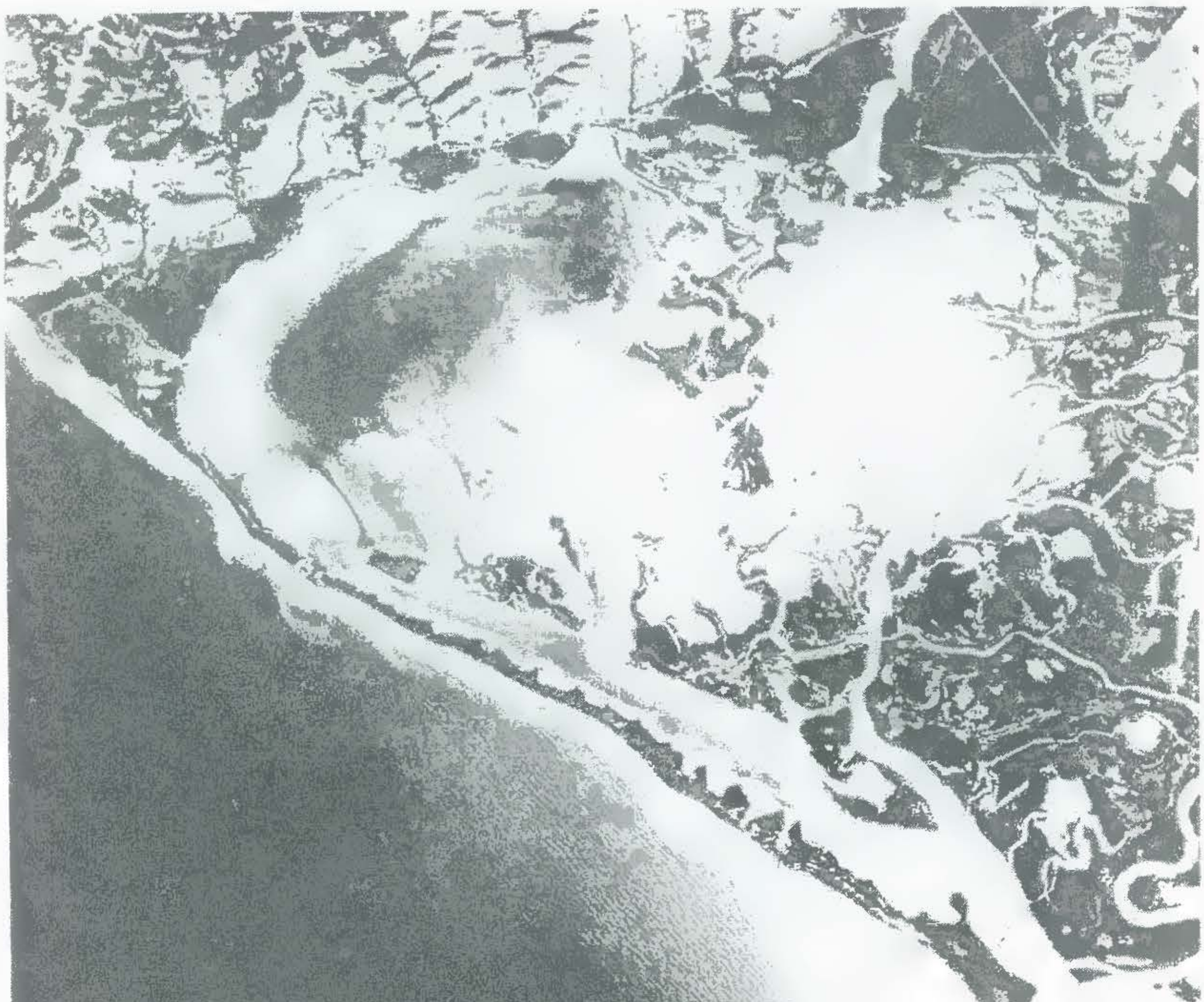
An aerial view of the Wairau River estuary and the Vernon Lagoons.



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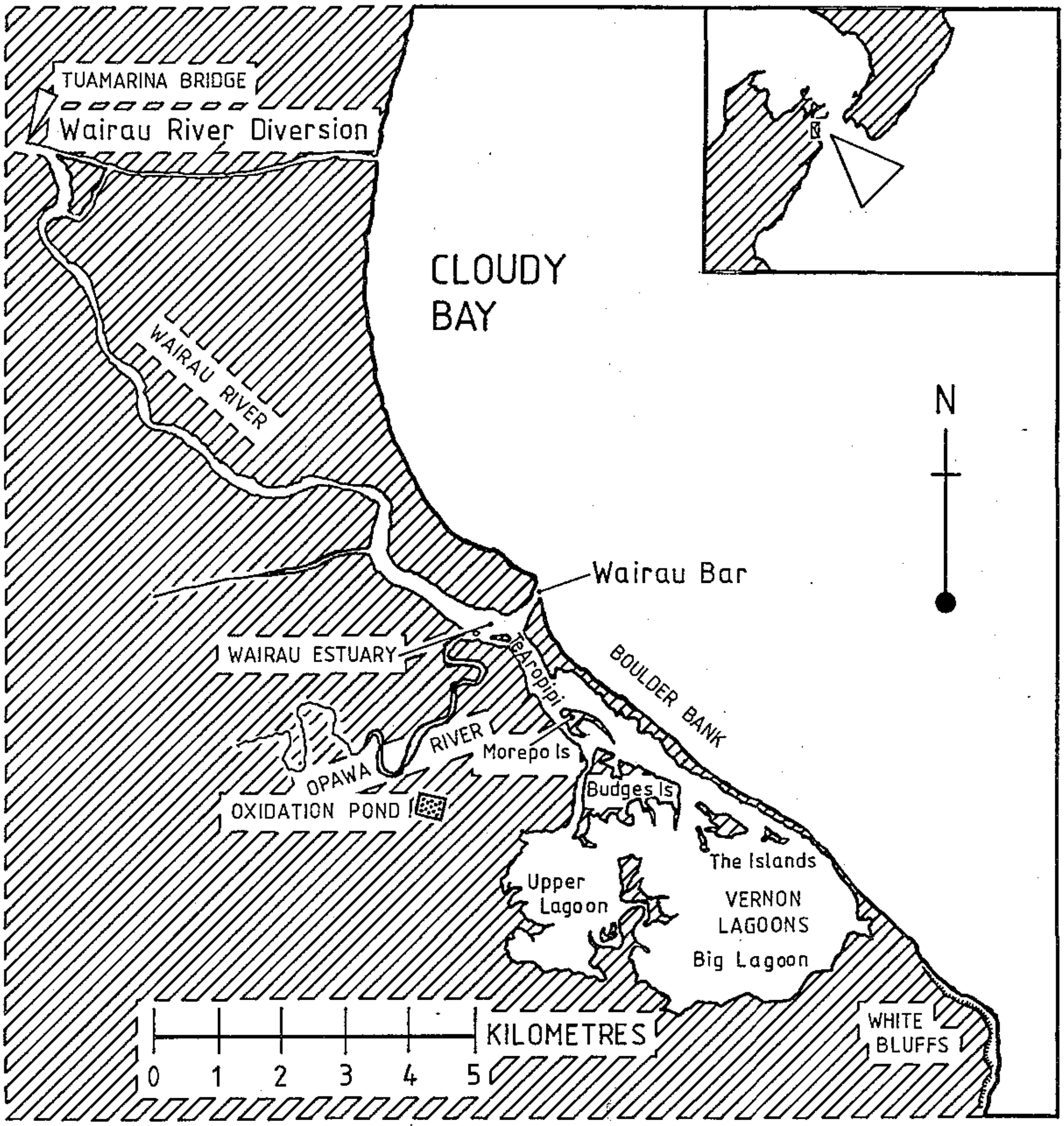

Fig. 1.1. Location map and major physiographic features of the area.

1. INTRODUCTION

This study arose from the Tribunal Hearing of the Water Right Application by Waitaki (N.Z.) Refrigerating Ltd to discharge treated meatworks process liquors to the Wairau River estuary. The wastes to be discharged comprise the normal wash water and process liquors from a freezing works which will pass through a "Save all" to remove grease and coarse solids before being discharged to an anaerobic pond. If fellmongery is carried out, the resultant effluent would be dealt with by a special treatment plant which will remove heavy metals and produce an effluent of neutral pH. Domestic waste from the employees amenities will also be discharged to the anaerobic pond with the meat waste. The biochemical oxygen demand (BOD) of the combined waste leaving the works is expected to be up to 1500 mg/l with a peak daily discharge of 4,500 m^3. These peak flows will occur from November to April (TSE Group Consultants Ltd, 1979).

Experience with installations similar to the proposed anaerobic pond indicate that a 10 day retention time would reduce the BOD by 75% from 1500 mg/l down to 375 mg/l. The wastes from the primary treatment anaerobic pond will undergo secondary treatment in an aeration pond. From the performance of aerobic ponds similar to that proposed it is calculated that the BOD will be further reduced from 375 mg/l to 50 mg/l. It was originally proposed that the treated effluent from the aerobic pond would be taken via a pipeline to a holding pond near the mouth of the Wairau River (Fig. 1.2). Subsequently it was decided that the holding pond would not be required.

The effluent quality standards set by the Marlborough Regional Water Board following the Tribunal Hearing were:

1. The effluent standard to be maintained shall be that of a spot sample taken at any time during any four hour discharge period, or a composite sample taken during the entire discharge period.

2. The effluent standard shall be maintained at all times when the plant is in operation, day or night, and no allowance shall be made for shock loading, starting up or any emergencies. Any discharge due to stormwater etc., when the plant is not in normal operation shall also comply to the standard.

3. The effluent colour shall be that of normal healthy oxidation pond effluent. There shall be no coloration of blood.

4. The effluent shall not cause the receiving water to emit objectionable odours.

5. There shall be no constituent of the effluent which emanates from the preparation of hides, other than from fellmongery. Any process using heavy metals, which would alter the effluent constituency from that indicated in the application, shall not contribute effluent to the treatment system.

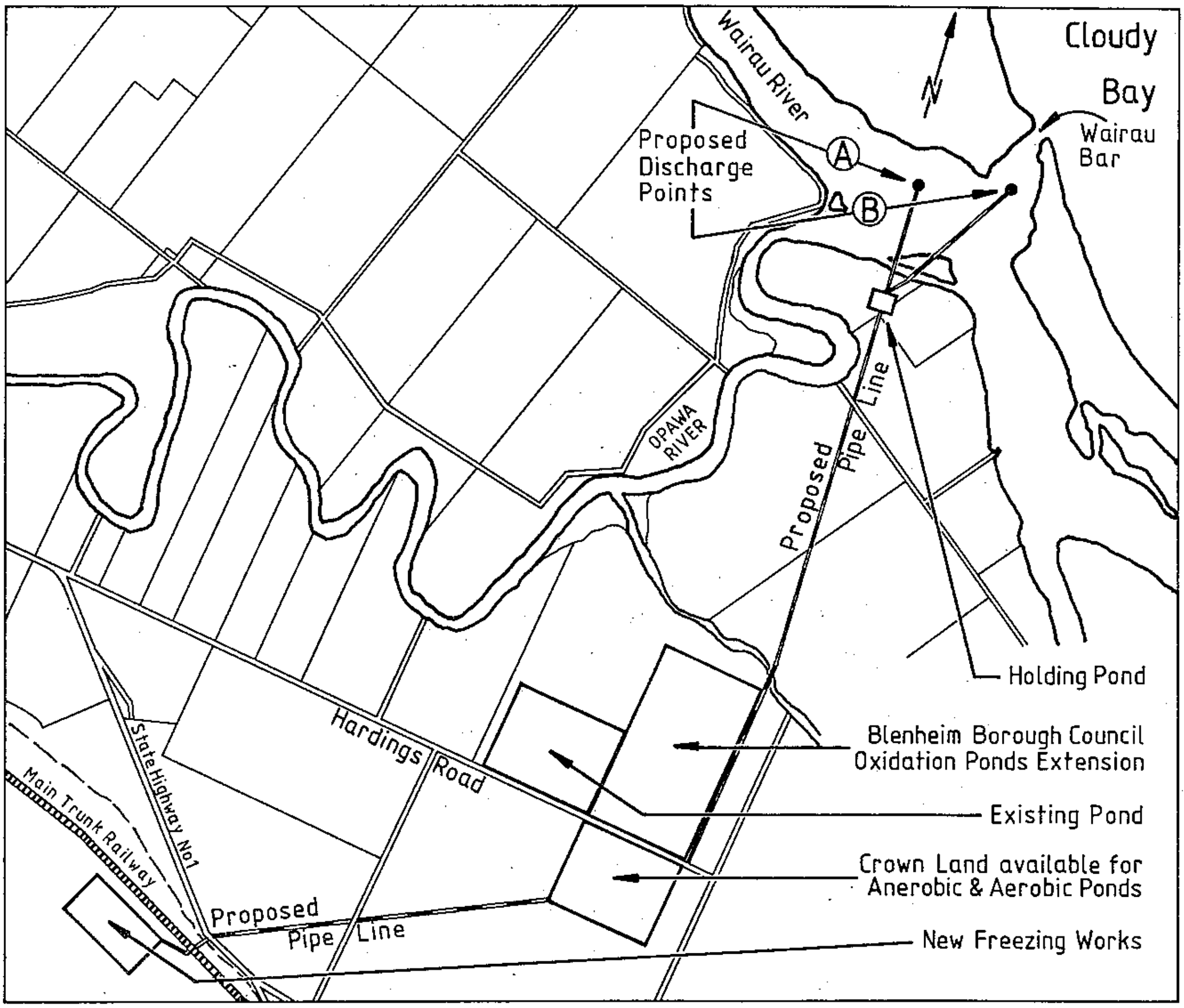

Fig. 1.2. Plan showing the freezing works site, the proposed sites of the aerobic and anaerobic ponds, the proposed route of the pipeline and alternative discharge points.

6. The following limits shall not be exceeded in final effluent analysis.

i)	BOD_5	150 g/m^3
ii)	Suspended solids	100 g/m^3
iii)	Sulphides	1 g/m^3
iv)	Ammoniacal nitrogen	100 g/m^3

N.B. After mixing with the receiving water, un-ionized ammonia shall not exceed .0225 g/m^3.

The final discharge point (Fig. 1.2) was to be determined after dye tests designed to determine the most efficient means of mixing. It was to be fitted with an effluent diffuser and situated in the deep water channel of the main Wairau River between a line drawn at right angles to the main channel and passing through the wharf, and a line at right angles to the channel, at a distance of 400 m upstream of a line through the wharf. The effluent is to be discharged on the outgoing tide, 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 point of discharge.

During the Tribunal Hearing the applicant company offered to support a baseline ecological survey of the estuarine complex likely to be affected by the discharge. Professor G.A. Knox of the Estuarine Research Group, Zoology Department, University of Canterbury, was invited to submit proposals for such a study in conjunction with the applicant, and the Regional Water Board. This report represents the results of the study which was proposed and accepted by the applicant and the Regional Water Board.

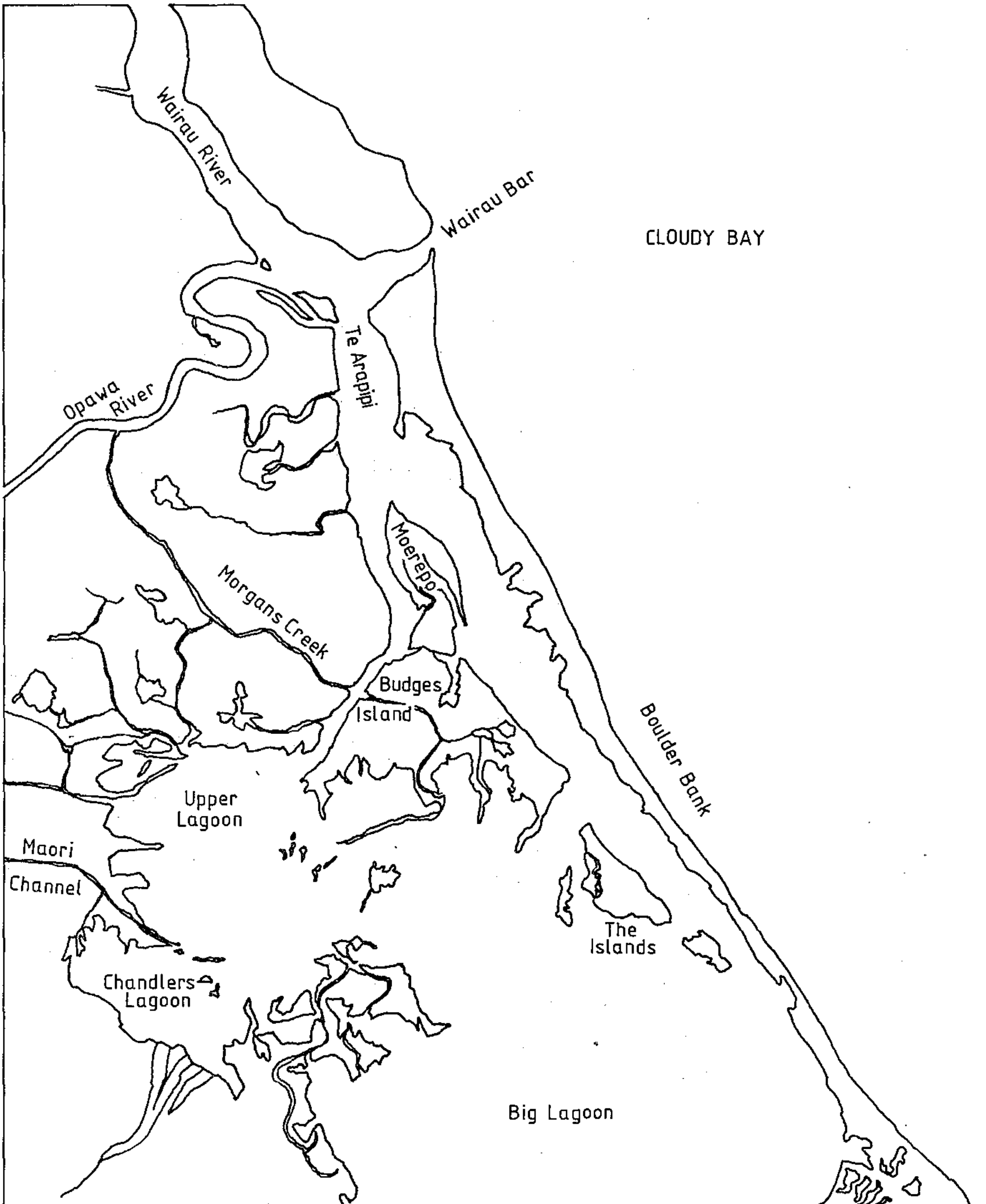

Fig. 2.1. Map of the Wairau River Estuary and the Vernon Lagoons.

2. PHYSICAL DESCRIPTION

2.1. Geomorphology

The lower reaches of the Wairau River flow across a flat plain resulting from the outwash of glacial material and subsequent reworking of this by both rivers and the sea during periods of rise and fall in sea level. Geomorphologically the area surrounding the Wairau River estuary is very complex (Figs 1.1 and 2.1). A remarkable feature is the very extensive lagoon system 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. Lagoon 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). At present the dominant northward movement of foreshore sediments, under the waves of the dominant southerly swell, is causing a progradation of the benches 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 1948 an event occurred which was to have a substantial impact on the area. This was the Marlborough earthquake of October 19, 1948, which is believed to have had a magnitude of 7½ 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 lagoon 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. 2.1). 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 estuarine 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 50 m wide in some places) and grade into the Wairau Plain on the west. A main channel (Te Aropipi) divides to drain 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 0.5 m) 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 are a feature of the water areas.

2.2. 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. 2.1. 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 Meteorological Service Station at Blenheim over the period 1946-74 show that for the months of November to April winds from the northeast to east and west to northwest dominate (Hume and Williams, 1981). The strongest winds (greater than 17 knots) invariably blow from the west to northwest sector. The average number of days for gusts exceeding 70 km per hour total 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 average 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	= 182 mm

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

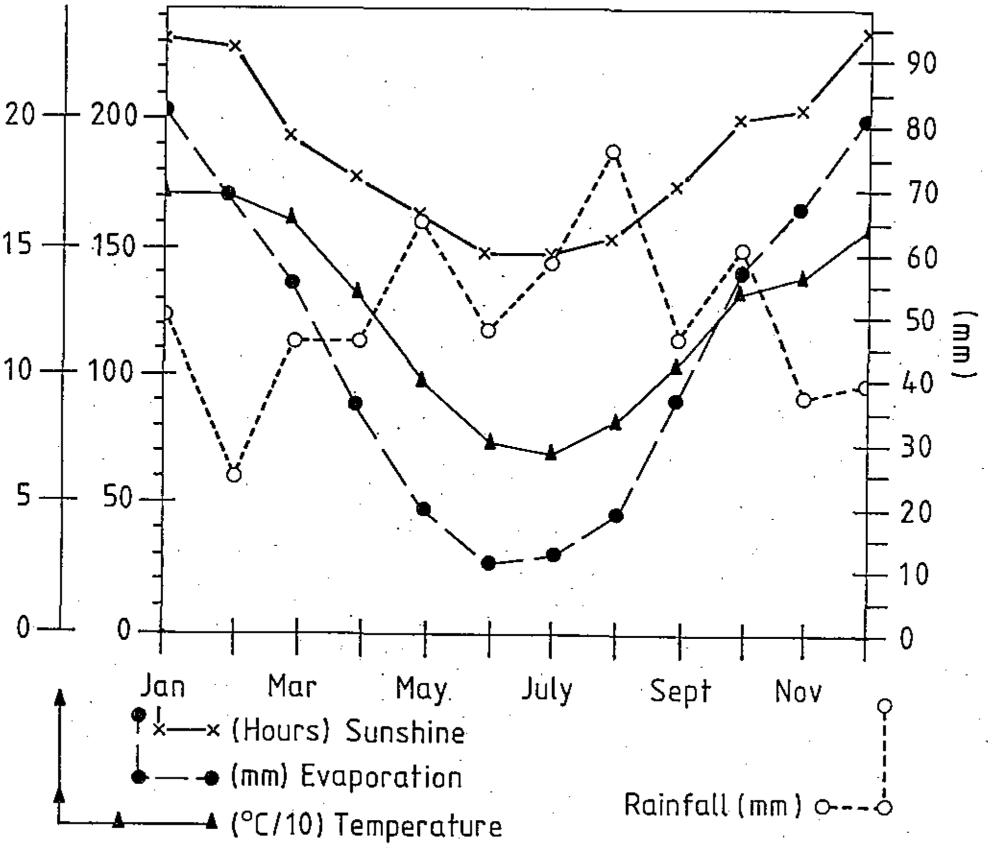

Fig. 2.2. Graph of mean monthly values for various climate parameters over the period 1970-1974. (After Black, 1978, Fig. 3 - based on data from the New Zealand Meteorological Service.)

Plate 1. View from the wharf area of the Wairau Bar. The rock retaining wall is on the left.

Plate 2. View from the wharf area into the entrance to the Vernon Lagoons (Te Aropipi Channel).

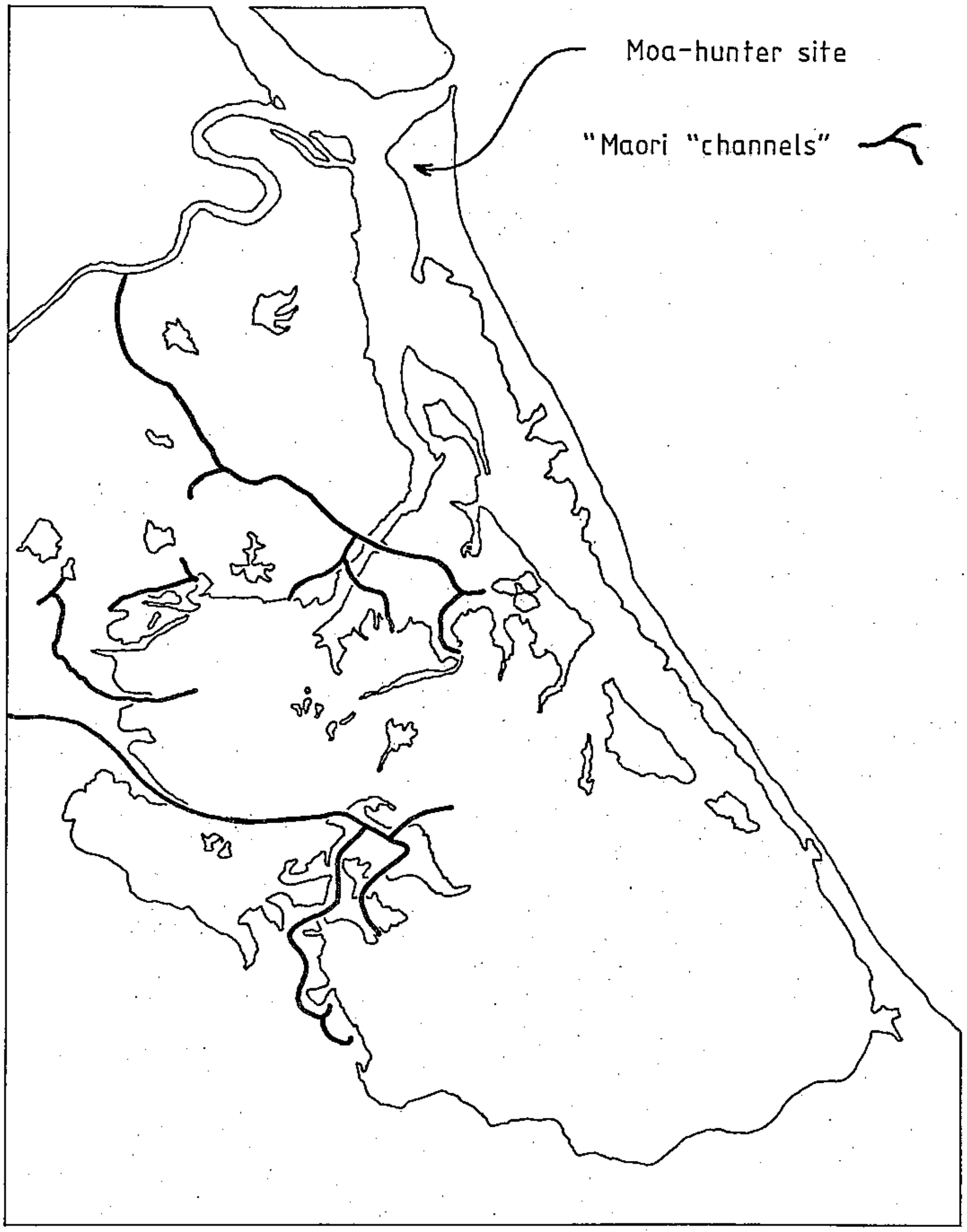

Fig. 3.1. Sketch map showing the Maori channels and the moa-hunter site.

3. HUMAN IMPACT

3.1. 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 archaeological 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 Roger Duff of the Canterbury Museum, provided a cornerstone for the reshaping of archaeological thinking in New Zealand (Duff, 1950).

Duff considered that Wairau Bar, at the northern end of the boulder bank, was a most suitable site for people having a fishing 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 accumulated the large quantities of firewood necessary in a treeless spot. Whitebait and kahawai ran seasonally into the river and lagoon; herrings, eels, and flounders formed a more permanent population; and banks of edible shellfish thrived inside the bar. In addition, the extinct swan must have flourished in this favourable estuary (as does the introduced swan of today), as well as great numbers of grey and paradise ducks, which still frequent the lagoons. Finally, in some manner which is still not finally decided, the site was well placed for hunting the large numbers of moas whose bones are spread today over the main occupation site. An obvious suggestion is that they were rounded up in the Wairau Plain or driven down from the Vernon Hills, and in either case herded round the base of the big lagoon and then driven along the trap of the boulder bank to the cul-de-sac provided by its northern end. 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 is the so-called "Maori channels" or "Maori canals" (Fig. 3.1). These were first reported on by Skinner in 1912. The total length of the channels is nearly 20 kilometres. A 1903 account describes them as averaging three metres wide and up to one metre deep though some on Bridges Island have recently been measured up to 15 metres wide (Trotter, 1979) indicating that the banks of the channels are eroding at a rapid rate. The exact function of these ditches is not known and indeed we still do not know if they are artificial. It has been postulated that they were dug to aid fowling or fishing.

Later archaeological sites around the lagoons, for instance on Bridges Island, are indicative of the changed economy of the Maori peoples as they killed off some of the bird species, burnt off considerable areas of forest and reduced the seal populations on the coast. These sites are principally shell middens indicative of a changed diet. This itinerant hunter-gatherer life style gave way about 300 years ago to a more settled existence with increasing dependence on agriculture.

While the Maori settlers brought about considerable change it was slight in comparison with that which followed European settlement.

3.2. European

The early European settlers first drained the low-lying land surrounding the Wairau River Estuary and the Vernon Lagoons and then 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 originally very large water fowl populations to a small remnant.

River diversion and stopbanking resulted in greater quantities of sediment reaching the lower river system (Thompson, 1976), 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 this inefficient outlet situation caused large quantities of silt laden water to enter the lagoon. 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 construction 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 upon the volume of the 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 the present volume. If no other factors affect the total tidal compartment, this will cause a 22% reduction in 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, 1975). Since the construction of the rock wall, this problem has not reoccurred and the mouth has remained open.

4. OBJECTIVES OF THE STUDY

The objectives of this study were:

1. To describe the hydrological regime within the Wairau Estuary with reference to river and tidal flow, current patterns and salinity regime.

2. To establish the current nutrient status of the estuary by determining the levels and patterns of distribution of the various forms of nitrogen and phosphorus.

3. To determine the patterns of plant and animal distributions within the estuary both tidally and subtidally in relation to substrate type, tidal patterns, salinity and other physical features.

4. To assess the current trophic status of the estuary.

5. To evaluate the probable impact of the effluent discharge from the meat treatment works and to make recommendations for the future management of the estuary.

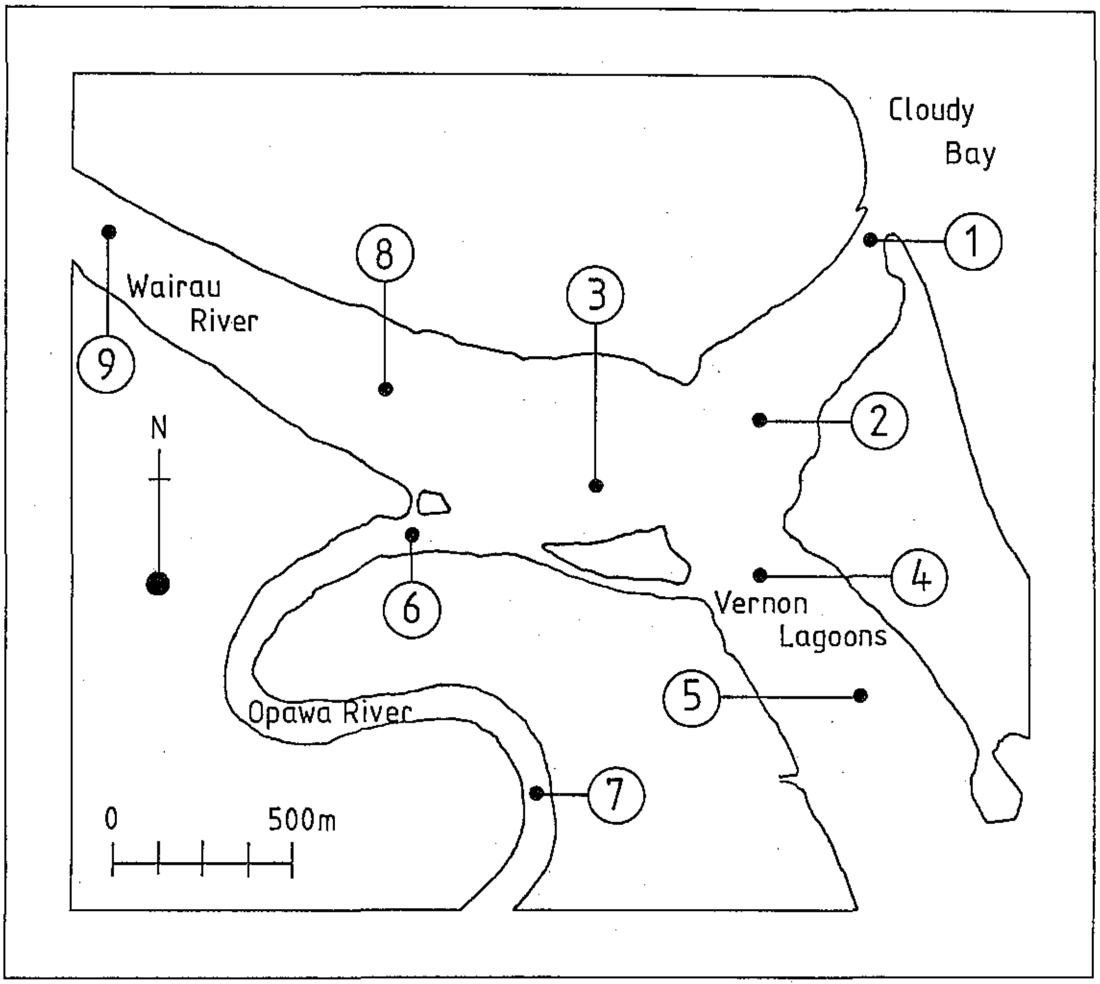

Fig. 5.1. Water sampling stations sampled in this study.

5. METHODS

5.1. Physical

5.1.1. Hydrology

This work was carried out by the Marlborough Catchment Board which in 1968 initiated hydrological surveys of the Wairau Estuary and the Vernon Lagoons in connection with proposals to use the lagoons as salt concentration ponds with the brine being pumped to Lake Grassmere for harvest. A tide level recorder has been operated by the Marlborough Catchment Board at the wharf in the estuary since 1975. The Catchment Board carried out detailed hydrological studies of the river-lagoon-estuarine system including measurement of tidal and river discharge, water slope and current velocity (Marlborough Catchment Board, 1970; Thompson, 1970, 1975, 1976).

In 1980 the coastal and estuarine group of the Hamilton Science Centre, Ministry of Works and Development was approached by the Marlborough Catchment Board to advise on a programme of hydrological studies in order to provide the hydrological data needed for this study. The recommended programme which was carried out over the period March-April 1981 included:

1. Preparation of a bathymetric map of the estuary and outlet region (Fig. 6.1 is based on the map produced by the Marlborough Catchment Board in collaboration with the Department of Lands and Survey and the Marlborough Harbour Board).

2. Preparation of plots of tidal records and Wairau River discharge hydrology.

3. Measurement of specified velocity profiles.

4. Measurements of temperature and salinity at various stages of the ebb tide. Nine stations (Fig. 7.6) were sampled at three depths (surface, mid-water and bottom) using a Yellow Springs T/S meter.

In this study the salinity temperature measurements were supplemented by three further series of measurements of temperature and salinity at nine stations (see Fig. 5.1 for positions). The first series (a) on 12.1.82 were taken over the time period 09.42 to 11.49 (H.W. 08.50) while the second series (b) were taken over the time period 16.00 to 18.65 (L.W. 15.30). A third series (c) on 13.1.82 was taken over the time period 09.50 to 11.55 (L.W. 11.00). Measurements were made with a Yellow Springs T/S meter.

Oxygen concentrations were also determined for surface and bottom waters at the same nine stations on 12.1.82 and 13.1.82. Measurements were made with a Yellow Springs O_2 meter.

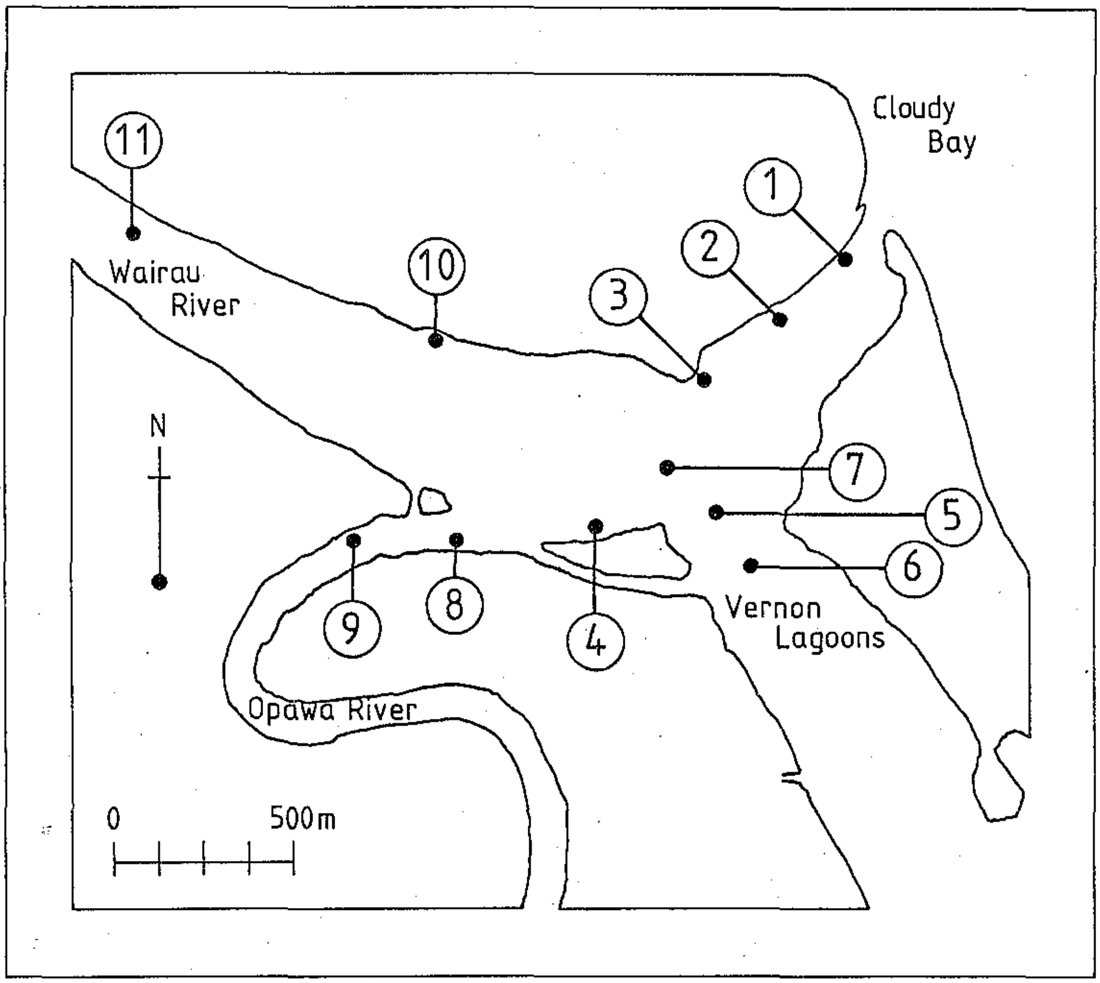

Fig. 5.2. Sediment sampling stations sampled on 7.4.81 by the Marlborough Catchment Board (the samples were subsequently analysed by the Hamilton Science Centre, Ministry of Works and Development).

5.1.2. Nutrients

On 13.1.82 surface and bottom samples at high water and mid-water samples at low water were taken for nutrient analyses. The samples were frozen and sent to the Cawthron Institute for analysis. Methods used were: Nitrate-N, cadmium column reduction then sulphanilamide reagents; Total Organic-N, photo-oxidation then nitrate analyses; Ammoniacal-N, phenol hypochlorite reagents; Soluble Reactive-P, filtered then ammonium molybdate reagents; Total-P, persulphate digestion then ammonium molybdate reagents.

5.1.3. Sediments

Eleven superficial sediment samples were collected on 7.4.83 by the Catchment Board and sent to the Hamilton Science Centre for analysis. On each sample visual estimates were made of sediment texture and the sand percentage was determined by sieving. Chemical analysis was carried out to determine total carbon (TC), total kjeldahl nitrogen (TKN) and total phosphate (TP).

In the present study sediment samples were taken at high, mid and low water on the faunal transects and at other selected sites. For these samples organic content was determined by loss on ignition.

5.2. Biological

5.2.1. Intertidal

Four transects were sampled in January 1981. Along each transect stations were established from the drift line to the low water mark. Distances between the stations were measured and recorded. At each station three cores were taken with a 10 cm diameter corer and the contents processed through a 0.5 mm sieve. The fauna retained on the sieve was preserved in 10% neutralised formalin for later identification and determination of the numbers of individuals present.

The transects sampled were:

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

Transect 2: Along the beach to the north of the wharf, 60 metres long, 12 stations 5 metres apart.

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

Transect 4: On the east side of the Vernon Lagoons entrance, 50 metres long, 3 stations 25 metres apart.

See Fig. 5.4 for transect positions.

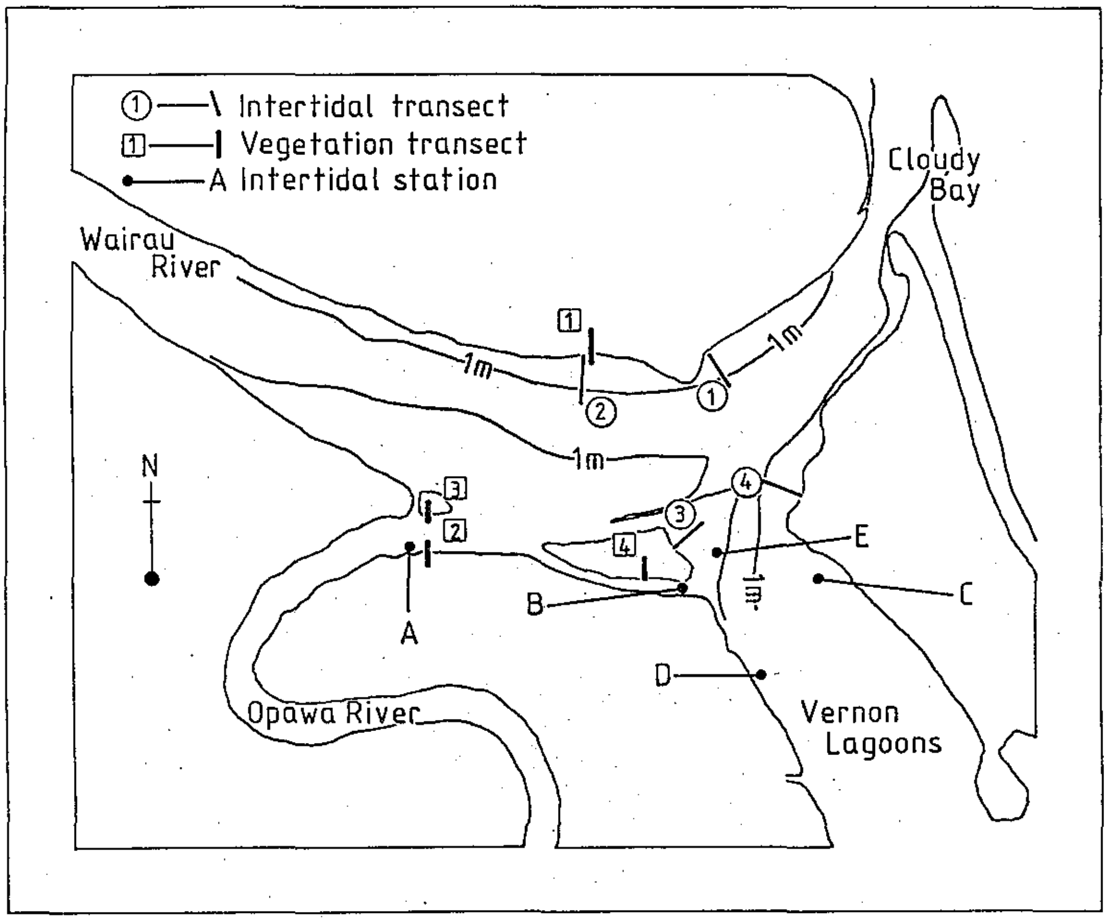

Fig. 5.3. Intertidal benthic macrofaunal transects and stations and vegetation transects sampled in this study.

5.2.2. Subtidal

Stations were established in the river estuary (see Fig. 5.2 for station positions). The stations were sampled by SCUBA divers. At each station three core samples were taken using a 10 cm diameter sampler and the contents were processed through a 0.5 mm sieve. The animals obtained were treated in the same manner as the intertidal samples.

5.2.3. Fish

Although no specific studies on fish distribution were carried out available data on fish distribution and occurrences was obtained from the literature.

5.2.4. Birds

Observations on bird distribution were made during visits to the estuary. Distribution records were obtained from the literature and much additional valuable unpublished information was supplied by Richard Holdaway who has been investigating the ecology of the birds in the Wairau River Estuary - Vernon Lagoons area for a number of years.

5.2.5. Vegetation

Vegetation distribution round the margins of the study area was investigated by determining plant distribution along a series of transects, by general observations on plant distributions, by the examination of infra-red falsecolour photographs taken by the Marlborough Catchment Board and a survey of the literature on the plants of the area.

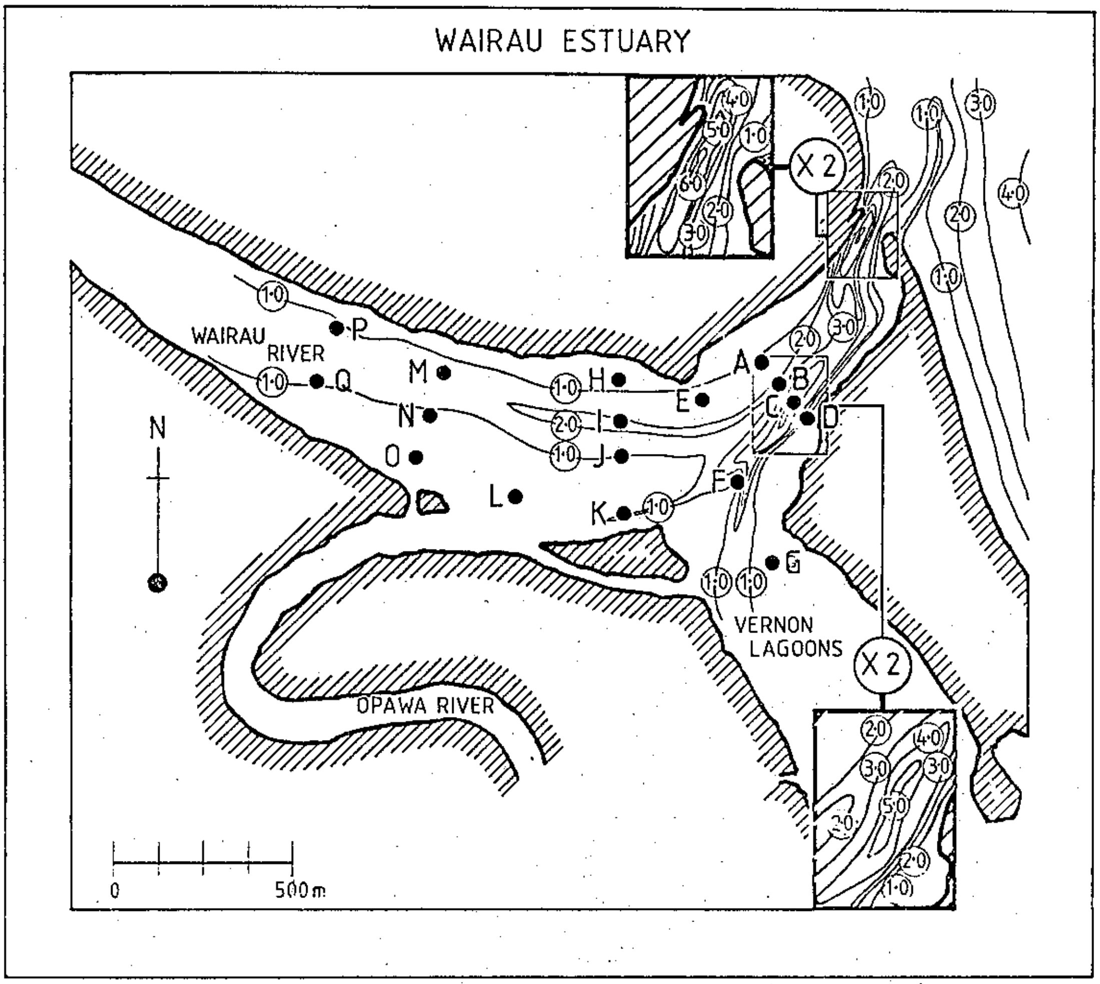

Fig. 5.4. Subtidal benthic macrofaunal stations sampled in this study.

6. BATHYMETRY

The bathymetric map compiled by the Marlborough Harbour Board (Fig. 2.2) shows the following features (Hume and Williams, 1981):

1. The estuary entrance area shallows upstream from the mouth, particularly at the boundary of the confluence with the Vernon Lagoons.

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

3. The channel east of the bar is shallow (-1.0 to MSL) and directed to the northeast, i.e. at an oblique angle to the coast. Air photographs show that 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.

4. 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 lagoon entrance with the deeper water on the south side of the entrance. Air photograph data suggests that the shoal may fluctuate in shape and extent.

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.

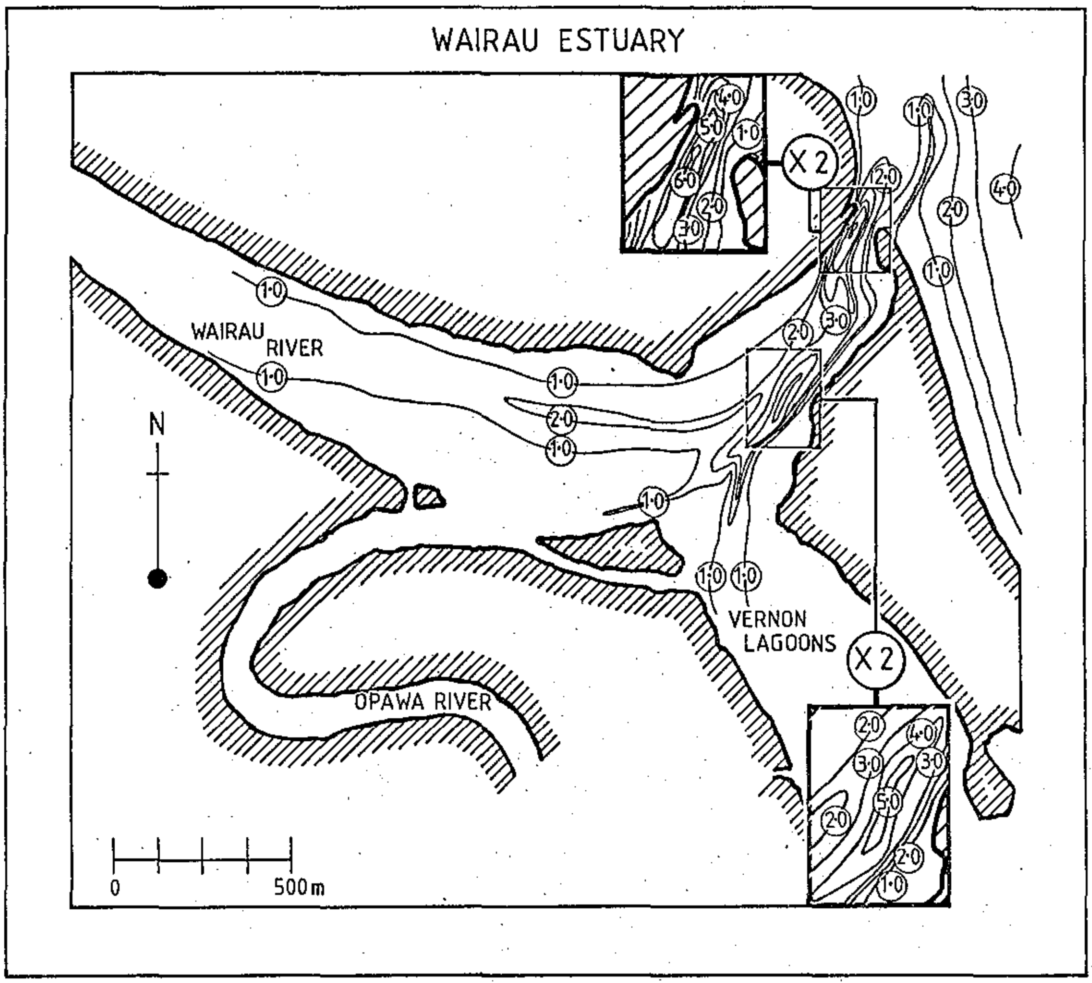

Fig. 6.1. Bathymetric map of the Wairau River Estuary and Wairau Bar (based on the map prepared by the Marlborough Catchment Board in association with the Marlborough Harbour Board and the Department of Lands and Survey).

7. HYDROLOGY

7.1. Tidal cycle

Hume and Williams (1981) examined records of the freshwater inflow hydrograph for the Wairau River at Tuamarina Bridge and tidal levels at the Wairau Bar Wharf for the period November 1979 to March 1980. The data showed that the tides were semidiurnal but that the tidal levels were markedly influenced by the freshwater flow to the estuary. The most important features revealed by the data were:

1. The tidal range varied from 0.4 (3.3.81) to 1.1 (24.1.81 and 22.2.81) metres.

2. Maximum and minimum observed tidal levels were -0.5 m and +0.85 m MSL respectively.

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

Tidal range is influenced both by river discharge and the state of bar entrance. Tidal ranges as small as 0.4 m 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 becomes restricted. Large freshwater inflows generally cause an increase in tidal height but a decrease in the tidal range.

7.2. Tidal compartment

Thompson (1975, 1976) has calculated the tidal compartment (the average volume of water moving from the Lagoon and River 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	$1,350 \times 10^3$
Total storage:			$4,205 \times 10^3$
River flow equivalent per tidal cycle:			6.5×10^3
Total effective volume of tidal compartment:			$4,820 \times 10^3\ m^3$

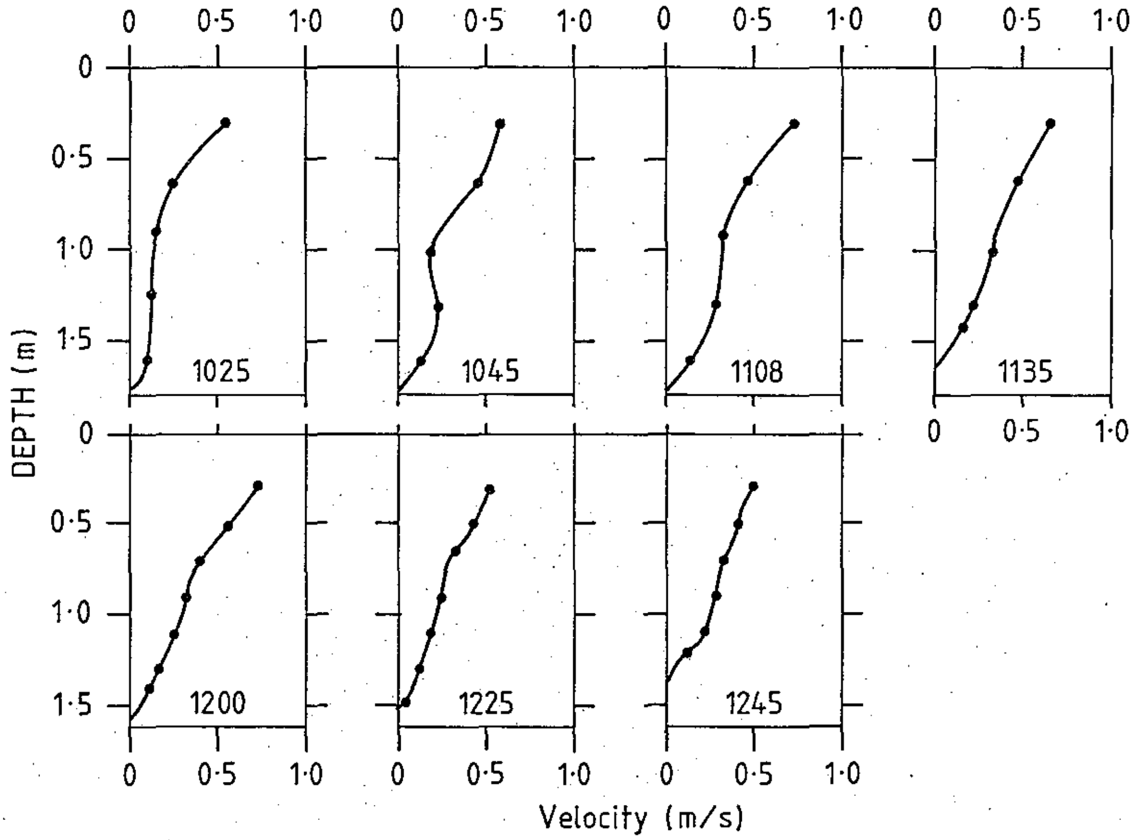

Fig. 7.1. Ebb tide velocity measurements taken on 6.4.81 at Site A (see Fig. 1.2.). High tide 0748 hr (+0.52 m), low tide 1411 hr (-0.42 m). Flow at Tuamarina 20 cumecs (approximately). (Modified from Hume and Williams, 1981, Fig. 5A).

The river flow in the above calculation is that which is exceeded 95% of the time.

The Upper and Big Lagoons comprise 20% of the total despite their large area. This is because the Big Lagoon, in particular, is very shallow. The magnitude of tidal movement decreases from an average range of 88 cm inside the river mouth to 9 cm at the top of the Big Lagoon. In comparison throughout the approximately 10 km of the Wairau River channel to above the Ferry Bridge at Spring Creek, tidal variations at low flow differ little from those at the river mouth.

7.3. Currents and flows

7.3.1. Velocity profile

Measurements of current velocity made by the Catchment Board on 6.4.81 at Site A (see Fig. 1.2) showed that there was a marked increase in velocity towards the surface (Fig. 7.1). Bottom velocities were greater than 0.1 m sec^{-1} and surface velocities greater than 0.5 m sec^{-1} for the duration of the measurements over the ebb tide period of H.W. + 2.5 hr - H.W. + 5 hr. Peak discharge occurred at about mid-tide, as is characteristic of tidal rivers where the tidal storage volume in the river is significantly greater than freshwater input.

At site B the salinity profile (Fig. 7.2) indicates marked stratification even as late as mid-ebb tide where the velocity at the base of the submarine flow indicates a reverse flow to that in the surface water. This reverse flow is probably indicative of an eddy flow in the hole which disappears later in the ebb discharge as indicated by the subsequent velocity profiles. These high velocities in the lower half of the profiles at 15.10 and 16.20 probably represent saline waters discharged from the lagoons flowing beneath the surface freshwater flow of the Wairau River.

7.3.2. Flow data

The Marlborough Catchment Board (Marlborough Catchment Board, 1970; Thompson, 1976) investigated flow relationships between the main water bodies in the lower estuary area. Tidal gaugings were carried out at the Bar entrance and the mouth of the Vernon Lagoons and flows determined by subtraction on a number of occasions. The discharge hydrographs suggest that peak flow at the Bar (i.e. river and estuary storage ranging from 400-1100 m^3sec^{-1}) is commonly twice that exiting the Lagoons (Fig. 7.4). 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 the tides, the freshwater flow, the storage compartment and the topography. After low water the tide begins to flow across the entrance bar as a head develops between the estuary and the coastal waters. Flood tide waters spread into 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

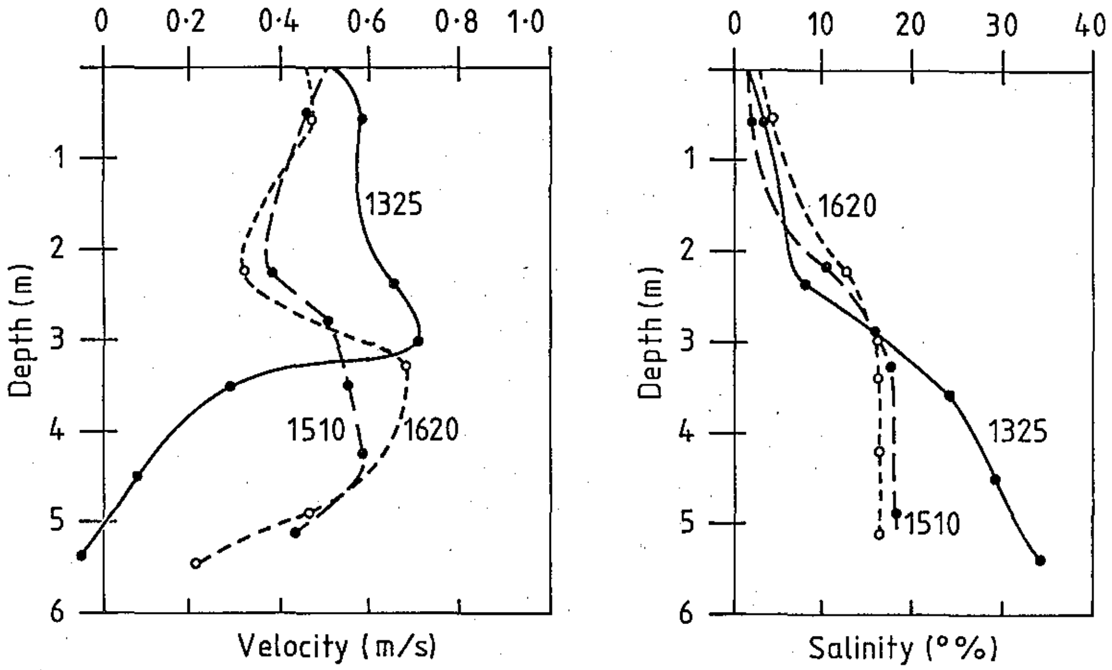

Fig. 7.2. Ebb tide velocity and salinity profile measurements taken on 22.6.81 at Site B (see Fig. 1.2). High tide 1005 hr (+0.53 m), low tide 1630 hr (-0.88 m). Flow at Tuamarina 90 cumecs (approximately). (Modified from Hume and Williams, 1981, Fig. 5B).

time on the slope increases filling the Te Aropipi Channel and eventually the Lagoons.

Black (1978) has discussed water movement within the Vernon Lagoons. This is dependent on 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 the river water to enter the lagoons 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 on the surface even in calm conditions). This mixed seawater and river water component travels up into the lagoons along Te Aropipi channel. The water flow then divides, part following the boulder bank up into Big Lagoon and part travelling up Morgans

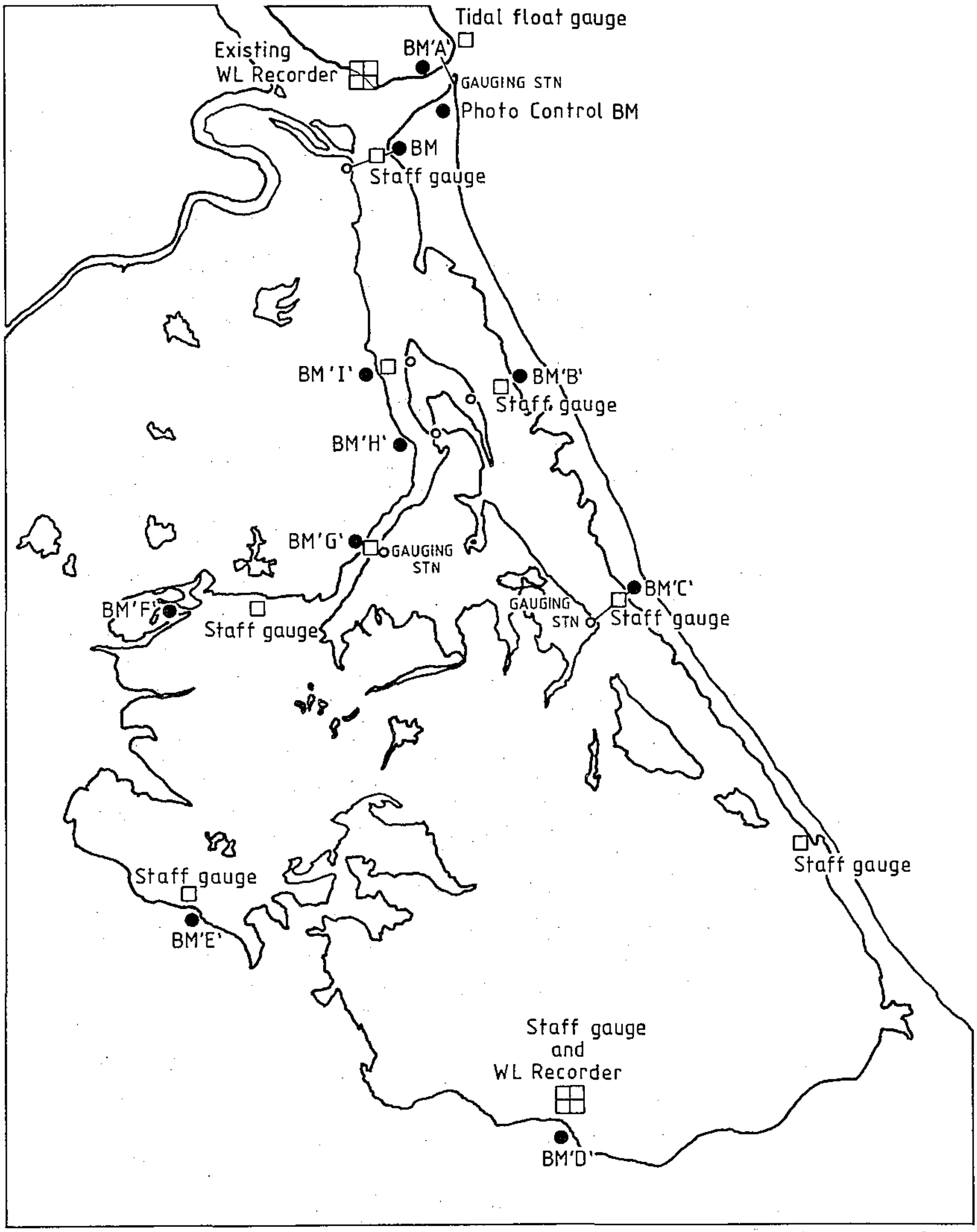

Fig. 7.3. Positions of the gauging stations from which the data for Fig. 7.4 was obtained.

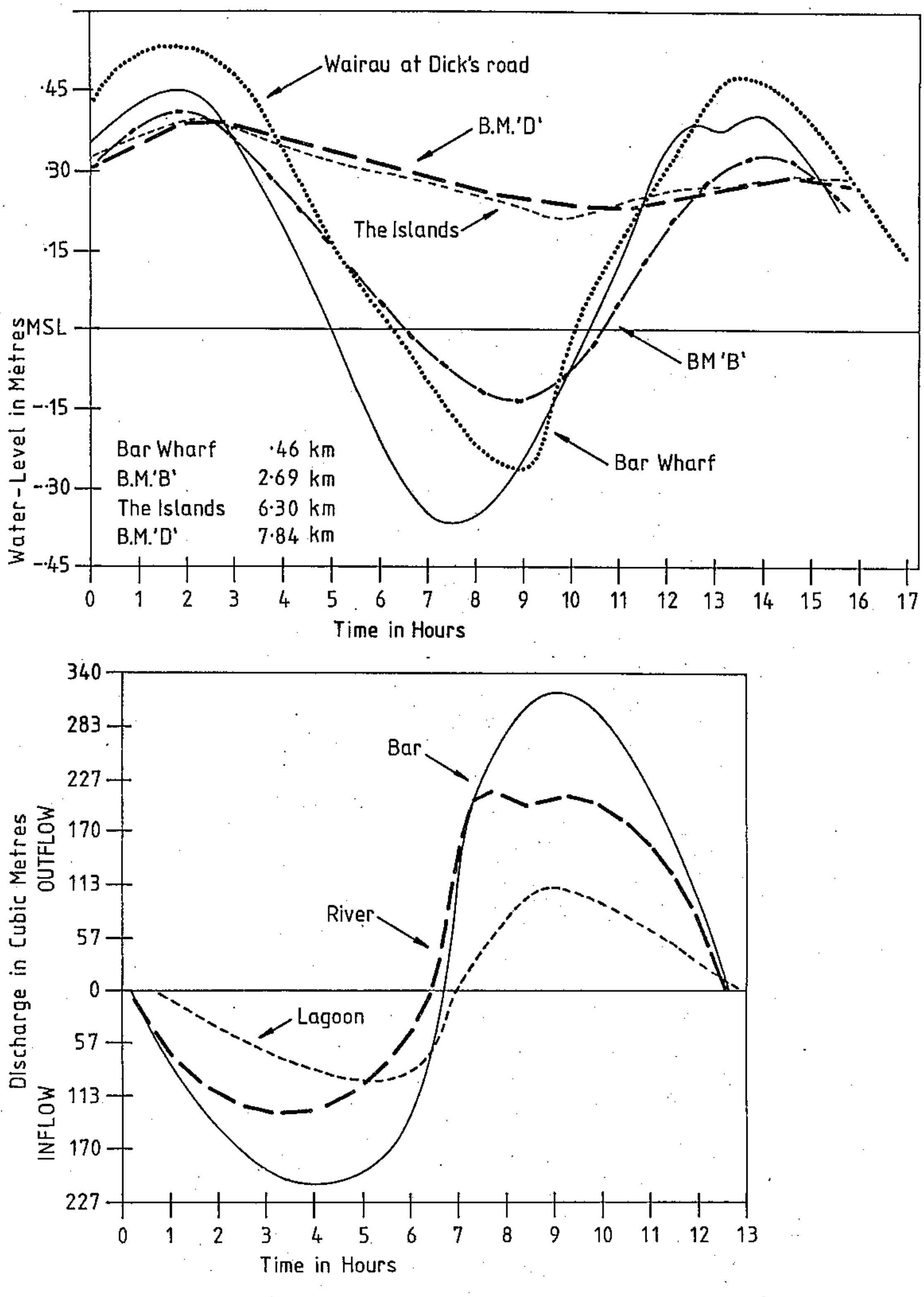

Fig. 7.4. A. Typical stage hydrographs at a series of gauging stations (see Fig. 7.3 for station positions) from the Wairau Bar wharf to the head of the Vernon Lagoons. (Modified from a figure supplied by the Marlborough Harbour Board.)

B. Typical hydrographs showing the distribution of flows in the river, the lower estuary (Wairau Bar) and Vernon Lagoons. (Modified from a figure supplied by the Marlborough Harbour Board.)

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 later followed by a mixed component with the saline water predominating except in flood conditions.

When the 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 ebb tide is delayed as one moves further up the lagoons. These delays result in the times of high and low water within the lagoon system deviating considerably from those for the open sea. Where the inflowing water is confined to a narrow channel, e.g. the lagoon mouth, tidal ranges of up to 1.5 m occur but as the water enters the lagoons 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 flow in the Wairau River can cause considerable changes in depth. If a strong northwesterly (the prevailing wind) is blowing, or if the Wairau is in flood, then the height of the water in the lagoons may rise as much as one metre above Mean High Water Neap tidal levels, flooding the surrounding *Salicornia* flats and farmland.

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

7.4. Salinity distributions

Data from the measurements made by the Marlborough Catchment Board staff in April 1981 revealed the following patterns.

High tide: Salinity decreased up the estuary from 32‰ near the entrance to 19‰ 2 km upstream. The data demonstrated a marked vertical stratification suggesting poor mixing at this state of the tide. The largest salinity gradient and therefore the poorest mixing occurred in the confluence area. In general the bottom and mid waters were the more saline and the freshwater formed a thin layer on the top less than one metre in depth. However nearer the source of freshwater further up the estuary and at the Opawa River sites the freshwater layer was deeper.

The field sampling was carried out over approximately 90 minutes immediately following high tide. The relatively low and very similar salinities (about 18%) at the upstream Wairau River, Opawa River and Vernon Lagoons entrance sites are interesting. At the river sites they demonstrate freshwater outflow on top of the more dense saline water. (Samples taken 1 hr - 1 hr 20 after HW). The low salinity at the lagoon entrance (Fig. 7.5) must suggest a flow of fresh water from the Opawa or Wairau River, into the lagoon entrance (salinities increase at half ebb tide (Fig.

7.5) as the lagoons empty). This interpretation is supported by discharge hydrographs which suggest river outflow starts before lagoon outflow.

Mid tide: Vertical stratification is much more marked than at the start of the ebb tide and is not confined to the confluence area. Most sites, particularly in the up-river reaches show evidence of a thick layer of fresh water flowing out over a thin residual tongue of seawater. In the mouth of the Te Aropipi Channel salinity increasing from 19% at low tide to 26% at mid tide indicates more saline tidal waters are being flushed from the lagoons.

Low tide: Salinity distributions indicate that freshwater has displaced most of the saltwater from the estuary. Salinities in the confluence area are lower than those at the mouth of the Opawa River suggesting that most of the freshwater in the area derived from the Wairau River. There is little evidence for stratification in the confluence area. However at the two uppermost Wairau River sites and at the Opawa River entrance more saline bottom waters suggest these "tongues" of more saline waters may remain trapped in the system. A denser sampling grid, particularly cross channel samples, is required to define the spatial extent of these "trapped" layers. The layers may be of important significance with respect to effluent flushing.

Highly saline (32%) water exiting the Te Aropipi Channel indicates flushing of marine waters from the Lagoons despite negligible freshwater input to the lagoons from upper lagoon sources. The fact that saline lagoon waters do not appear to be present in waters sampled at the Wairau Bar channel sites either reflects good mixing in this area or suggests ebbing lagoon waters hug the southern side of the channel on their way to the sea. Suspended solids distribution shown in air photographs supports this latter hypothesis.

Data from the measurements made in this study (see Tables 7.1 and 7.2 and Fig. 7.6) tend to confirm the results of the previous study. The first set of samples (*a* samples) covered a period on the ebb tide from high water + 0.52 hrs to high water + 2.59 hrs. High water was + 0.674 m and low water was - 0.534 m. The flow in the Wairau River at Tuamarina was approximately 22 m^{-3}/sec. The second set of samples (*b* samples) covered a period on the flood tide from low water + 0.40 hrs to low water + 2.30 hrs. Tidal heights and river flow as for the *a* samples. The third set of samples (*c* samples) covered a period on the late flood and early ebb tide from high water - 1.10 hrs to high water + 0.55 hrs. High water was + 0.755 m and low water - 0.552 m. River flow at Tuamarina was approximately 22 m^{-3}/sec.

On the first set of samples (*a*, ebb tide) surface salinities decreased up river from 6.00‰ near the mouth to 0.60‰ upstream while on the third set (*b*, flood + ebb tide) they decreased up river from 31.75‰ to 3.00‰. For the low water samples (*b*, flood tide) the corresponding range was 5.10‰ to 0.10‰. For all the *a* samples there was a pronounced salinity gradient with

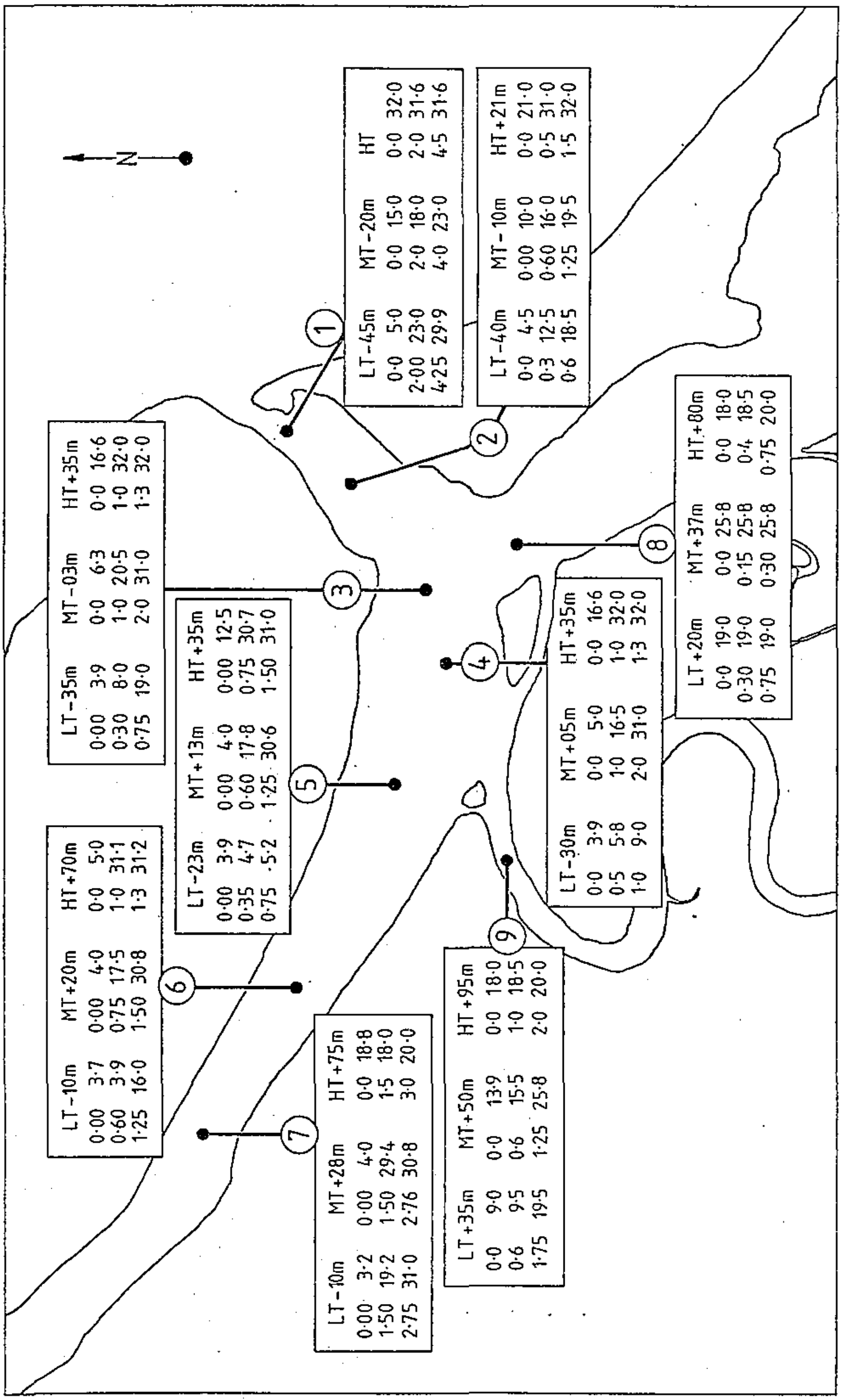

Fig. 7.5. Salinity profiles taken by the Marlborough Harbour Board on 16.4.81 at high, mid and low water.
High tide 0855 hr, measurement period 0855-1030 hr.
Mid tide 1155 hr, measurement period 1135-1245 hr.
Low tide 1510 hr, measurement period 1425-1545 hr.

Table 7.1. Temperature/Salinity/Depth data (D = depth; T = time; H.W. = high water; L.W. = low water).

Date: 12.1.82

A.M. High water: 08.50
Ebb tide

P.M. Low water: 15.20
Flood tide

Station	Depth (m)	Temp. (°C)	Salinity (‰)	Station	Depth (m)	Temp. (°C)	Salinity (‰)
1a	S	20.50	6.00	1b	S	21.00	5.10
D. 2.6 m	0.5	21.00	12.00	D. 2.3 m	0.2	21.00	5.10
T. 11.31	1.0	20.50	21.00	T. 16.00	0.7	21.50	9.50
H.W.+2.4	1.5	25.00	23.00	L.W.+0.40	1.2	21.50	19.50
	2.0	28.00	25.00		1.7	22.00	23.50
					2.2	22.00	26.00
2a	S	21.00	2.75	2b	S	20.50	2.75
D. 2.0 m	0.5	21.00	8.75	D. 1.5 m	0.2	20.50	2.75
T. 11.49	1.0	20.00	20.75	T. 16.25	0.7	21.00	3.75
H.W.+2.59	1.5	25.50	23.75	L.W.+1.05	1.2	21.50	6.00
	2.0	28.00	24.50				
3a	S	20.00	7.00	3b	S	20.50	1.00
D. 1.8 m	0.5	18.00	25.00	D. 1.6 m	0.3	20.50	1.25
T. 11.05	1.0	18.00	31.00	T. 17.05	0.8	21.00	2.25
H.W.+2.15	1.5	23.00	27.75	L.W.+1.45	1.3	21.00	3.35
4a	S	19.50	19.00	4b	S	22.50	29.25
D. 1.5 m	0.5	19.50	19.00	D. 0.7 m	0.7	22.50	29.25
T. 11.20	1.0	19.50	30.25	T. 16.38			
H.W.+2.30	1.5	20.00	30.00	L.W.+1.10			

Table 7.1. continued

Table 7.1. continued

5a				5b	S	23.50	30.00
				D. 1.4 m	0.3	23.50	30.00
				T. 16.50	0.8	23.50	30.00
				L.W.+1.30			
6a	S	20.50	5.75	6b	S	20.50	6.00
D. 2.3 m	0.5	20.00	8.50	D. 1.0 m	0.4	20.50	5.50
T. 10.27	1.0	23.00	27.00	T. 17.15	0.8	20.50	5.50
H.W.+1.37	1.5	23.00	27.50	L.W.+1.55			
	2.0	26.00	27.25				
7a	S	20.00	12.75	7b	S	20.50	4.00
D. 2.0 m	0.5	20.00	12.75	D. 1.8 m	0.5	20.50	5.00
T. 10.48	1.0	20.00	15.50	T. 17.25	1.0	20.00	6.00
H.W.+1.58	1.5	25.00	26.00	L.W.+2.05	1.5	20.25	7.00
	2.0	25.00	26.75				
8a	S	19.50	1.50	8b	S	21.00	0.75
D. 2.0 m	0.2	19.40	7.50	D. 1.3 m	0.5	21.00	0.75
T. 9.42	0.4	19.00	20.50	T. 17.50	1.0	21.00	4.00
H.W.+0.52	1.0	16.00	30.50	L.W.+2.30			
	1.5	16.25	29.75				
	2.0	16.75	29.75				
9a	S	20.00	0.60	9b	S	20.75	0.10
D. 2.4 m	0.1	20.00	0.75	D. 2.5 m	0.5	20.75	0.25
T. 10.11	0.2	20.00	0.80	T. 18.05	1.0	21.00	0.75
H.W.+1.21	0.4	20.00	3.30	L.W.+2.45	1.5	21.00	1.50
	0.5	19.50	20.00		2.0	20.75	2.00
	1.0	18.00	27.75		2.5	20.75	2.25
	1.5	17.00	30.50				
	2.0	17.00	30.50				

Table 7.2. Temperature/Salinity/Depth data (D = depth; T = time; H.W. = high water).

Date: 13.1.82

High water: 11.00

Flood + Ebb tide

Station	Depth (m)	Temperature (°C)	Salinity (‰)
1c	S	17.50	31.75
D. 2.6 m	0.4	17.75	31.50
T. 9.50	0.9	18.00	31.00
H.W.-1.10	1.4	18.00	31.00
	1.9	18.00	31.00
	2.4	18.50	31.00
2c	S	19.00	19.25
D. 2.6 m	0.4	18.50	21.25
T. 10.04	0.9	18.25	27.50
H.W.-0.56	1.4	18.00	31.25
	1.9	18.25	31.25
	2.4	18.50	31.00
3c	S	20.00	16.00
D. 2.0 m	0.3	19.75	17.50
T. 10.17	0.6	19.25	21.75
H.W.-0.43	0.8	19.00	27.75
	1.3	19.00	30.50
	1.8	19.50	30.50
4c	S	19.50	19.75
D. 1.2 m	0.5	19.25	27.50
T. 10.30	1.0	19.50	29.25
H.W.-0.30			
5c	S	19.25	24.75
D. 2.2 m	0.5	19.00	26.00
T. 10.40	1.0	19.25	26.25
H.W.-0.20	1.5	19.25	26.75
	2.0	19.75	27.25
6c	S	20.50	15.25
D. 1.9 m	0.2	20.00	15.25
T. 10.51	0.4	20.10	22.50
H.W.-0.09	0.7	18.50	30.00
	1.2	18.50	30.50
	1.7	18.50	30.50

Table 7.2. continued

Table 7.2. continued

Station	Depth (m)	Temperature (°C)	Salinity (‰)
7c	S	19.50	30.75
D. 1.7 m	0.5	19.00	30.50
T. 11.15	1.0	19.00	29.75
H.W.+0.15	1.5	18.75	25.50
8c	S	21.00	11.50
D. 2.3 m	0.1	21.00	13.75
T. 11.33	0.6	19.50	22.50
H.W.+0.33	1.1	19.00	31.00
	1.6	19.00	31.00
	2.1	19.75	31.00
9c	S	22.50	3.00
D. 2.7 m	0.5	22.25	3.00
T. 11.55	0.7	22.25	4.00
H.W.+0.55	0.8	22.25	7.00
	1.0	21.00	15.00
	1.2	21.00	25.00
	1.5	20.00	29.00
	2.0	19.50	29.50
	2.5	19.50	29.00

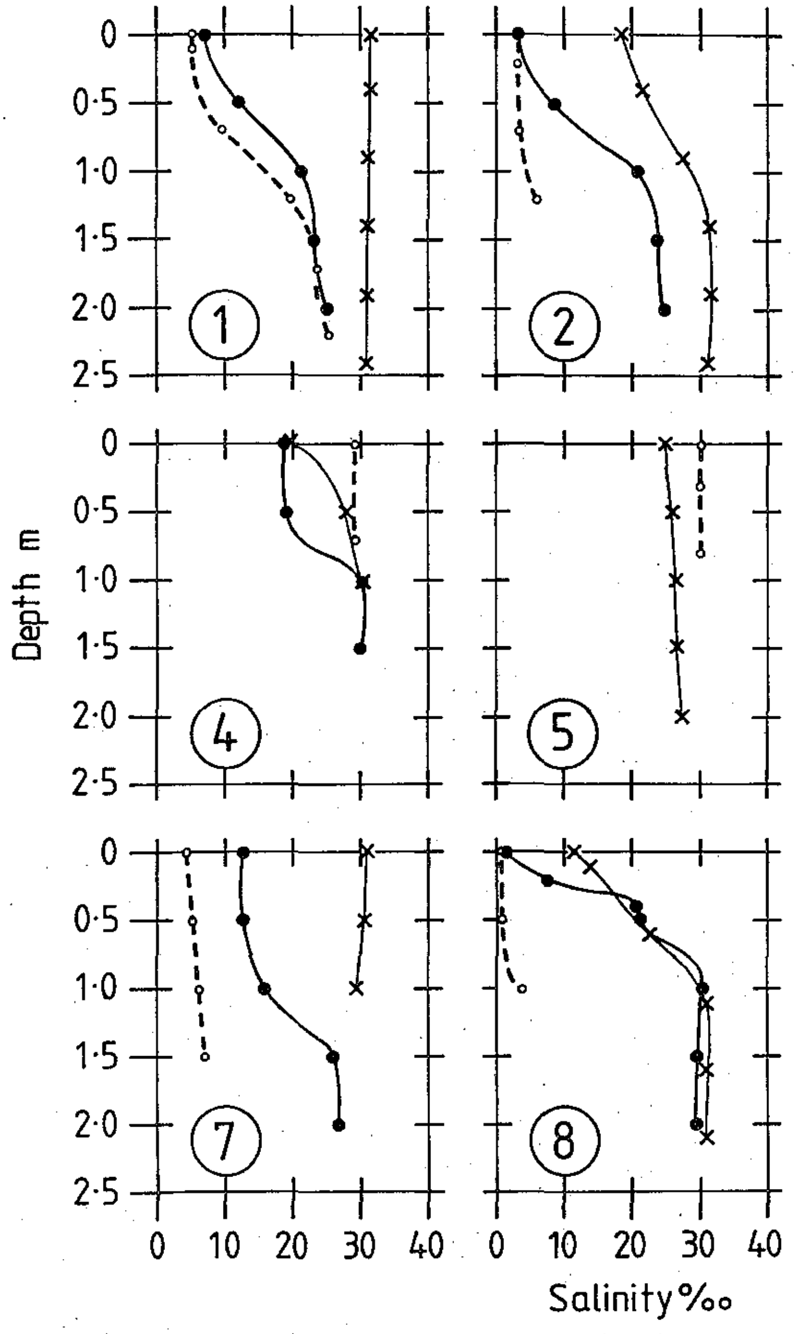

Fig. 7.6. Salinity profiles taken on 12.1.82; ●——●, ebb tide samples, high water +0.52 hr to high water +2.41 hr; o---o, flood tide samples, low water +0.40 hr to low water +2.45 hr; and on 13.1.82 x——x, flood and ebb tide samples. Station positions as shown in Fig. 5.1 (stations 1-3, 8 and 9 Wairau River Estuary; stations 4 and 5 entrance to Vernon Lagoons; stations 6 and 7 Opawa River). 12.1.82 high tide 0850 hr (+0.674 m), low tide 1520 hr (-0.534 m). 13.1.82 high tide 1100 hr (+0.755 m), low tide 1700 hr (-0.552 m). Flow at Tuamarina.

marked vertical stratification. The incoming salt-wedge underlying the less saline surface waters is evident in all the profiles. The lowest surface salinity that was found at Station 4 in the entrance to the Vernon Lagoons was 19.00‰.

The third set of samples (*c* samples) taken over a period covering approximately one hour before high water and one hour after high water showed at all stations, in contrast to the *a* samples, higher surface salinities, a much greater penetration of the salt water and less pronounced vertical stratification except at Stations 3, 6, 8 and 9. Stations 4 and 5 in the Te Aropipi Channel show that on the latter stages of the flood tide the water that enters the Vernon Lagoons, especially the surface water, is seawater diluted by Wairau River water (salinity range at the surface 19.75-24.75‰).

The second set of samples (*b*, low water flood tide samples) show some interesting trends. At Station 1 nearest the bar, the beginning of the salt wedge penetration is evident. At all other stations the salinities are low apart from the two stations in the Te Aropipi Channel; Wairau River stations (2, 3, 6, 8 and 9) have a range of 0.10-6.00‰ and Opawa River stations (6, 7) have a range of 4.00-6.00‰. The two stations in the Te Aropipi Channel have a range of 29.25-30.00‰ indicating that the water that enters the Vernon Lagoons is high salinity water from the incoming salt wedge.

7.5. Temperature distributions

From the measurements made by the Marlborough Catchment Board in April 1981, the following conclusions can be drawn.

High tide: Coastal water temperatures (14.8°C) were cooler than river temperatures (15-18°C) on average by about 1°C; there was little evidence for temperature stratification with the slightly warmer, less dense, fresh water overlying the sea water.

Mid tide: Mid tide temperatures were in general warmer than the high tide areas (16-16.5°C at the entrance). Upstream there was some evidence of stratification with the surface freshwater temperatures averaging 17.4°C.

Low tide: Vertical temperature gradients were small. Temperatures in the main estuary ranged from 16.5-17.8°C. Water still flowing out of the Vernon Lagoons was a uniform 19°C.

Temperatures recorded on 12 January 1982 during this study were much higher than those recorded in April 1981. Those recorded at high tide ranged from 16-28°C, while the low tide samples ranged from 20.5-23.5°C. In general the river water temperatures were higher than those of the incoming seawater. However the situation is complicated by the outflow of warm water from the shallow Vernon Lagoons. This is evident in the higher bottom temperatures at Stations 2, 3 and 4 in the first high tide sampling run. At low water there is little temperature stratification, but it is more marked in the high tide samples especially at Stations 8 and 9 when the warmer river water overlies the cooler water of the salt wedge.

7.6. Oxygen concentrations

Table 7.3 lists the oxygen concentrations measured during this study. As water temperatures were high during the period over which they were measured they can be considered as the minimal values that are likely to be recorded in the system. It is evident that the values in the high water samples (range 6.8-9.2, mean 8.1) were higher than those recorded in the low water samples (range 6.5-7.7, mean 6.3).

At low tide the lowest levels were recorded in the stations at the entrance to the Vernon Lagoons reflecting the higher temperatures in waters which had lost oxygen due to animal respiration and bacterial decomposition while covering the mudflats. At high tide the higher levels at Stations 1-4 in the higher salinity layer reflect the generally higher levels in the incoming sea water which has been subject to turbulence and wave action over the bar.

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 most of the processes required for successful fish life (Alabaster, 1973). Levels in the Wairau River estuary are well above this limit.

7.7. 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 a decreasing tidal range during floods. During summer months when freshwater inflow 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 Te Aropipi Channel for up to 2½-3 hours after high tide (N. Smith, *pers. comm.*, quoted in Hume and Williams, 1981).

Table 7.3. Oxygen concentrations (mg/l).

	Station	Depth	O_2 concentrations
12.1.82	1b	S	6.8
		2.0 m	7.7
Low water	2b	1.0 m	6.5
samples	3b	0.8 m	6.6
	4b	0.3 m	6.2
	5b	S	6.6
	6b	S	7.4
	7b	1.0 m	7.6
	8b	0.5 m	6.9
	9b	S	6.8
		2.5 m	6.8
13.1.82	1c	S	9.2
	2c	S	8.3
High water		2.5 m	8.7
samples	3c	S	6.8
		2.0 m	8.2
	4c	S	8.1
		1.2 m	8.8
	5c	0.5 m	8.5
	6c	S	8.8
		1.9 m	8.4
	7c	S	7.8
		1.5 m	7.7
	8c	S	7.6
		2.0 m	7.5
	9c	S	7.5
		2.5 m	7.4

The salinity 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 freshwater. On 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 as shown in Fig. 7.7 is the eddy which develops on the south side of the Wairau Bar. This eddy develops 1½-2 hours after high water and is maintained until the latter stages of the ebb tide. It is possible that effluent could be trapped in this eddy and at the start of the flood tide could be flushed back into the Te Aropipi Channel.

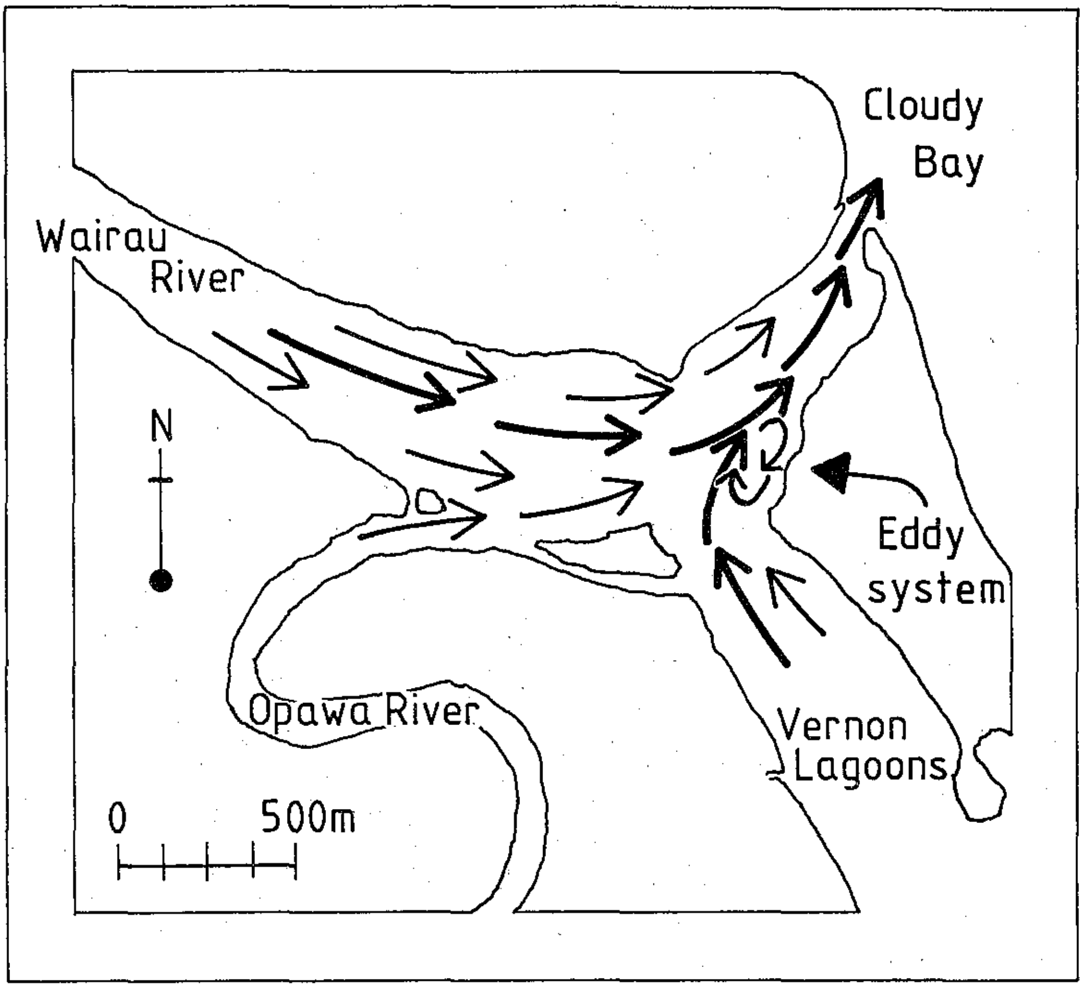

Fig. 7.7. Ebb tide circulation patterns in the Wairau River Estuary.

8. SEDIMENTS

8.1. General composition and distribution

No detailed study of sediments was undertaken. However general observations on substrate composition were made during the course of field investigations. In addition Brown (1978) has commented on the general distribution of substrates within the Vernon Lagoons and Hume and Williams (1981) made visual estimates of sediment texture and determined the percentage of sand by sieving for 11 stations in the Wairau River estuary (see Fig. 5.4 for sampling sites and Table 8.1 for data summary).

Fig. 8.1 depicts the general pattern of distribution of surface sediments grouped into the following categories:

stones
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 on sand substrate. Substrates in the vicinity of the Opawa River mouth are sandy muds grading into muds up the Opawa River.

The sediment samples taken by Hume and Williams (Table 8.1) varied from fine/medium through coarse/medium to coarse sands. The percentage of sand in the samples varied from 34.5 to 97.4%. The coarsest sediment occurred in the Wairau Bar region near the estuary mouth (Station 1). In general there was a correspondent 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 fine 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:

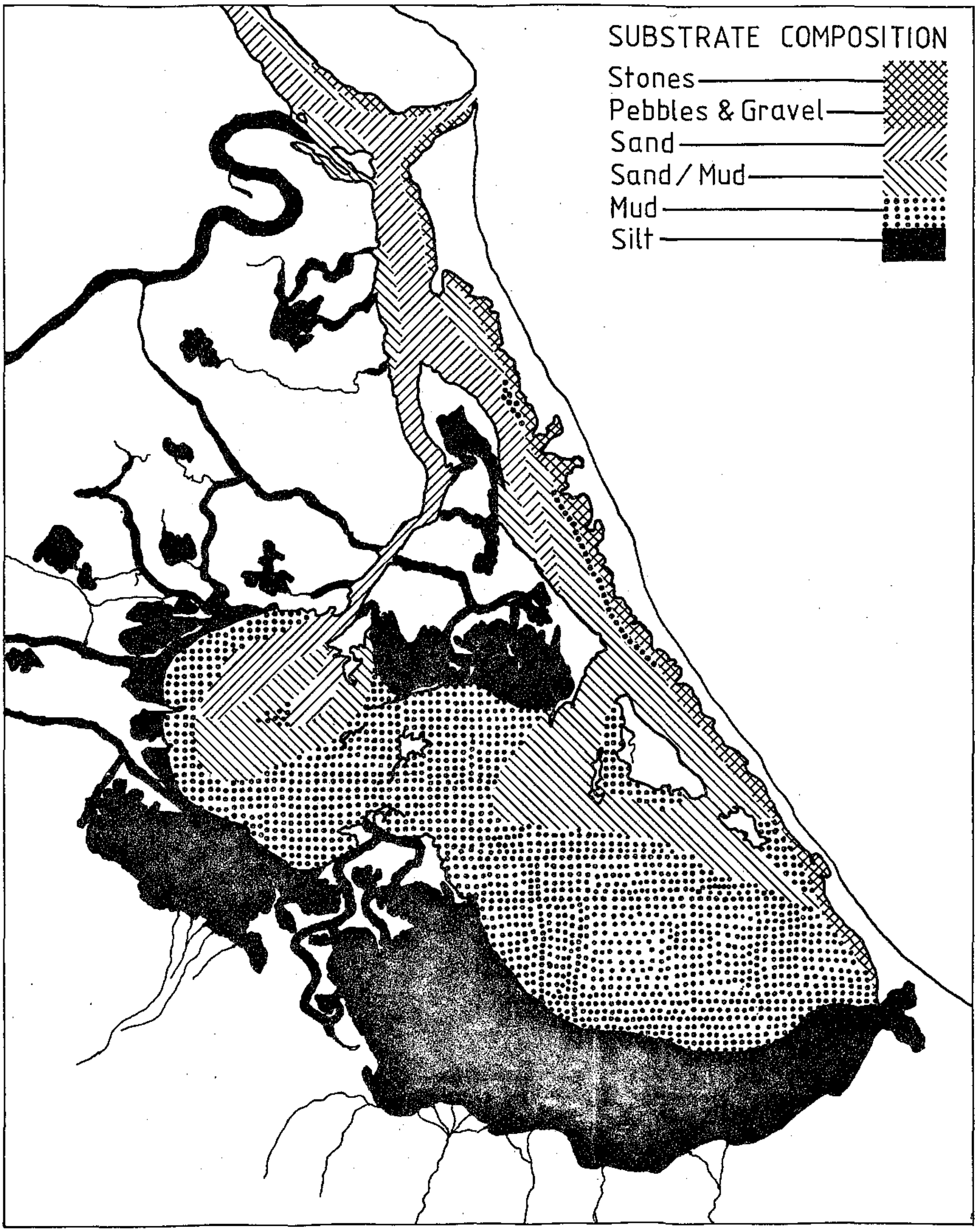

Fig. 8.1. Distribution of substrate types in the Wairau River Estuary and the Vernon Lagoons. (Based on a map prepared by Black (1978) and modified by data obtained during this study.)

Table 8.1. Sediment texture and nutrient data for surficial sediments from Wairau Estuary. (Samples collected 7 April 1981; see Fig. 5.4 for sample sites; after Hume and Williams, 1981, Table 1, p. 16).

Sample site	Texture				Nutrients			
	Granules	Sand type	Sand (%)	Organic debris	C (%)	TKN (mg/kg)	TP (mg/kg)	O.S.I.
W 1	-	cs	97.4	-	0.03	176	316	0.0005
2	-	f/ms	34.5	*	0.51	615	395	0.0314
3	-	m/cs	95.0	-	0.12	176	369	0.0021
4	-	f/ms	74.0	*	0.33	439	408	0.0145
5	-	f/ms	63.4	*	0.42	875	526	0.0351
6	-	f/ms	50.3	-	0.42	615	421	0.0258
7	-	c/ms	62.7	-	0.33	483	421	0.0159
8	*	f/ms	37.0	*	0.39	597	447	0.0233
9	*	c/ms	96.3	-	0.09	158	369	0.0014
10	*	c/ms	88.8	-	0.06	193	461	0.0012
11	-	c/ms	78.2	-	0.24	334	447	0.0080

* Present
\- Absent

Texture: fs = fine sand
ms = medium sand
cs = coarse sand

(1) Rocky shoreline: This extends along the west side of the boulder bank and consists of large (up to 20 cm 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 levels.

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

(3) Shallow channel (0.5 to 1.5 m deep): These either connect the lagoons with 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 0.5 m/sec^{-1}) but not as fast as those in the deep channels.

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

8.2. 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 $mg.kg^{-1}$ and total phosphates from 3.6 to 526 $mg.kg^{-1}$ (Table 8.1). There is a general correlation between high total organic carbon and total kjeldahl nitrogen levels and the fineness of the sediments. The relationship between sediment fineness and high total phosphorus levels is not so clear cut although the lowest level was in the coarsest sediment (Station 1).

Hume and Williams (1981) calculated the Organic Sediment Index (OSI) for the sediment samples. OSI values which are obtained by multiplying TOC as % by the TKN as % (Ballinger and McKee, 1971) were low, ranging between 0.0005 and 0.0351. In the Upper Waitemata Harbour (Bioresearches Ltd, 1980; Knox, 1983) 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. The Upper Waitemata Harbour values were generally higher than those which were recorded from the Pauatahanui Inlet. 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.

8.3. Sediment organic content

During the present study surface sediment samples were taken at three levels (upper shore, mid-tide, lower shore) along the four intertidal transects and at Stations A-D. The positions of the transects and stations are shown in Fig. 5.3. Table 8.2 gives the percentage loss on ignition for each of the samples. While the loss of weight after two hours in a furnace at 100°C does not accurately remove the organic content of the sediment it is a useful measure for comparative purposes.

Values for percent loss ranged from 1.840-3.751%. The results indicate that the sediments contain moderate amounts of organic matter. Much higher values have been recorded in estuaries with high levels of organic input. Along the transects the lowest levels were recorded for Transect 1, while the highest levels were recorded for Transect 4. Transect 1 was characterised by sandy sediments while Transects 2 and 4 had finer surface sediments which had been deposited following flooding of the Wairau River. Transect 3 had similar levels to those recorded for Transect 1 and Station 3.3 had the lowest recorded level. The lower part of the shore at Transect 3 is subject to strong currents from the outflow from the Vernon Lagoons.

It appears that the flooding of the Wairau River and the strong currents that can develop in the estuary inhibit the buildup of fine sediments and high organic content.

Table 8.2. Sediment organic content

Station	Percent loss on ignition
1.1	1.924
1.2	2.497
1.3	2.094
2.1	3.509
2.2	2.826
2.3	2.908
3.1	2.520
3.2	2.393
3.3	1.840
4.1	2.735
4.2	3.751
4.3	3.101
A	3.559
B	2.052
C	2.026
D	2.073

Plate 3. View of the beach to the south of the wharf area at low tide. Transect 1 was taken down this beach adjacent to the wharf area.

Plate 4. Coarse, stony sediments in the entrance to the Vernon Lagoons. The stones are encrusted with the small acorn barnacle *Elminius modestus* and dead cockle and pipi shells are abundant.

9. NUTRIENTS

Table 9.1 details nutrient levels in water samples taken at high tide and low tide at the stations shown in Fig. 5.1 on 12 January 1982. The data from this table is summarised below.

Nutrient g/m^3	Wairau Bar Stn 1-2	Upper Estuary Stn 8-9	Vernon Lagoons Stn 3-4	Opawa River Stn 6-7
Low tide:				
Nitrate-N	0.066-0.075	0.103-0.113	0.023-0.088	0.620-0.980
Ammoniacal-N	0.024-0.038	0.012-0.020	0.017-0.023	0.15 -0.16
Total organic-N	0.14 -0.23	0.05 -0.08	0.19 -0.20	0.66 -0.81
Soluble reactive-P	0.008-0.014	0.002-0.008	0.006-0.014	0.051-0.073
Total-P	0.049-0.13	0.014-0.031	0.072-0.120	0.094-0.140
High tide:				
Surface				
Nitrate-N	0.009-0.086	0.074-0.089	0.051-0.079	0.030-0.058
Ammoniacal-N	0.012-0.025	0.018-0.023	0.020-0.025	0.007-0.026
Total organic-N	0.12 -0.14	0.06 -0.10	0.09 -0.16	0.10 -0.69
Soluble reactive-P	0.018-0.02	0.010-0.014	0.016-0.022	0.012-0.014
Total-P	0.044-0.058	0.016-0.033	0.036-0.047	0.024-0.040
Bottom				
Nitrate-N	0.007	0.011-0.016	0.008-0.018	0.012-0.021
Ammoniacal-N	0.008	0.011-0.020	0.008-0.011	0.014-0.017
Total organic-N	0.14	0.09 -0.13	0.11 -0.14	0.10 -0.11
Soluble reactive-P	0.015	0.011-0.012	0.014-0.016	0.014-0.015
Total-P	0.036	0.039-0.044	0.021-0.036	0.030-0.034

A number of points are evident from Table 9.1 and the above summary.

1. The highest nutrient levels were those recorded at low tide for the two stations in the Opawa River with maximum levels (e.g. nitrate-N 0.98 g/m^3 and total organic-N 0.81 g/m^3) at Station 7 up the river. These levels reflect the discharge from the Blenheim oxidation ponds into the river.

Table 9.1. Nutrient concentrations (g/m^3) in the Wairau River Estuary.

Station		Salinity ‰	Nitrate-N	Ammoniacal-N	Total organic-N	Soluble reactive-P	Total P
<u>Low tide samples</u>							
1	surface	5.1	0.074	0.024	0.14	0.008	0.049
	bottom	23.5	0.075	0.038	0.21	0.014	0.130
2	-0.5 m	2.75	0.066	0.032	0.23	0.010	0.079
3	-0.5 m	2.25	0.088	0.023	0.19	0.006	0.120
4	-0.5 m	29.25	0.023	0.017	0.20	0.014	0.072
5	-0.5 m	30.00	0.023	0.037	0.24	0.026	0.160
6	-0.5 m	5.50	0.620	0.15	0.66	0.051	0.094
7	-0.5 m	20.50	0.980	0.16	0.81	0.073	0.140
8	-0.5 m	21.00	0.079	0.013	0.09	0.002	0.031
9	surface	0.25	0.103	0.020	0.08	0.002	0.014
	bottom	2.00	0.113	0.012	0.05	0.008	0.022
<u>High tide samples</u>							
1	surface	31.50	0.009	0.012	0.14	0.018	0.058
2	surface	19.25	0.086	0.025	0.12	0.020	0.044
	bottom	31.25	0.007	0.008	0.14	0.015	0.036
3	surface	16.00	0.079	0.025	0.16	0.022	0.047
	bottom	30.50	0.008	0.008	0.11	0.014	0.021
4	surface	19.75	0.051	0.020	0.09	0.016	0.036
	bottom	29.25	0.018	0.011	0.14	0.016	0.025
5	surface	26.00	0.029	0.021	0.14	0.014	0.041
6	surface	15.25	0.058	0.026	0.10	0.014	0.040
	bottom	30.00	0.021	0.017	0.11	0.014	0.030
7	surface	25.50	0.030	0.007	0.69	0.012	0.024
	bottom	30.75	0.012	0.014	0.10	0.015	0.034
8	surface	11.50	0.074	0.018	0.10	0.014	0.033
	bottom	31.00	0.016	0.011	0.13	0.012	0.039
9	surface	3.00	0.089	0.023	0.06	0.010	0.016
	bottom	29.00	0.011	0.020	0.09	0.011	0.044

2. In the high tide samples the freshwater influenced (lower salinity) surface waters tended to have much higher nutrient levels than the bottom saline waters (e.g. at Station 9 the surface nitrate-N value is eight times that of the bottom (0.089 as compared with 0.011 g/m^3)). This is indicative of the greater natural nutrient load carried by the river water.

3. At high water the samples taken at the entrance to the Vernon Lagoons are similar to those in the Wairau River estuary 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 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 0.014-0.031 g/m^{-3}). This indicates that the water has 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 the algal *Ruppia* mats.

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

The significance of these nutrient levels will be discussed further in section (trophic status).

Table 9.2 compares nutrient levels in the Wairau with those from the Avon-Heathcote Estuary (Knox and Kilner, 1973), Waimakariri River Estuary and Brooklands Lagoon (Knox and Bolton, 1978), Blaketown Lagoon (Knox, 1974) and Parapara Inlet (Knox, Bolton and Hackwell, 1977). The Avon-Heathcote Estuary is eutrophic, Brooklands Lagoon is mesotrophic while Parapara Inlet is oligotrophic.

Nutrient levels in the Wairau apart from those in the Opawa River estuary are higher than those recorded in Parapara Inlet but somewhat lower than those recorded in Brooklands Lagoon and much lower than those recorded in the main Avon-Heathcote estuary.

Table 9.2. A comparison of nutrient levels in the Wairau with other estuarine areas in the South Island (values in g/m^{-3}).

Nutrient	Wairau River	Upper Wairau River Estuary	Vernon Lagoons	Opawa River Estuary	Avon-Heathcote Estuary entrance	Avon-Heathcote Estuary upper estuary	Waimakariri River Estuary entrance	Brooklands Lagoon	Blaketown Lagoon	Parapara Inlet
Nitrate-N (NO_3-N)	0.007-0.086	0.011-0.113	0.008-0.088	0.012-0.980	0.020-0.250	0.010-0.430	0.170-0.500	0.014-0.820	0.130-0.131	<0.001-<0.002
Ammoniacal-N (NH_4-N)	0.008-0.038	0.011-0.23	0.008-0.025	0.007-0.160	0.005-0.280	0.005-1.200	0.008-0.013	0.017-0.071	-	-
Total organic-N (TN)	0.120-0.230	0.060-0.130	0.090-0.200	0.100-0.810	-	-	0.120-0.170	0.170-0.550	-	0.090-0.180
Soluble reactive-P (PO_4-P)	0.008-0.018	0.002-0.014	0.006-0.022	0.012-0.730	0.002-0.029	0.002-0.760	0.009-0.011	0.008-0.022	0.010-0.050	0.018
Total-P (TP)	0.036-0.130	0.014-0.044	0.021-0.120	0.024-0.140	0.020-0.800	0.010-0.688	0.021-0.032	0.033-0.140	0.062-0.080	0.010-0.340

10. VEGETATION

10.1. Species present

The vegetation surrounding the margins of the Wairau River estuary and the Vernon Lagoons is typical of other salt marsh communities occurring throughout the lower half of the North Island and the South Island. It contains salt tolerant plants (termed halophytes) in areas subject to tidal influence or heavy loads of salt spray. Regions of low lying land bordering the salt marsh that receive freshwater from streams or channels support a vegetation that is typical of low altitude freshwater swamps. This vegetation has been described by Martin (1932), Mason (1965), Walls (1976) and Wassilieff (1979).

Table 10.1 lists the common species recorded by the authors listed above. The list includes a number of introduced (adventive) species which characteristically invade disturbed areas such as the Californian thistle, the African boxthorn, wild briar, dock and gorse.

10.2. Transects

Three vegetation transects (see Fig. 5.3 for positions) were surveyed, two at the entrance to the Opawa River and one to the west of the wharf in the main estuary. The distribution of the vegetation along these transects is shown in Fig. 10.1.

Transect A. The lower 19 m of this transect had a pure sward of the three square sedge (*Samolus repens*). The plants were tall and growing vigorously. The top 4 m had clumps of the sea rush (*Juncus maritimus*) with a close growing under-sward of the glasswort (*Salicornica australis*). A few scrubby plants of the shore ribbonwood occurred at the steep bank at the top of the transect.

Transect B. This transect had a steeper profile than Transect A. The lower 5 m was covered with stunted three square sedge plants while the upper 11 m had vegetation similar to that in Transect A. Growing amongst the sea rush plants was the seaside barley grass (*Hordeum marinum*).

Transect C. Vegetation along this transect was similar to that along Transect B. However there was a much more extensive development of the shore ribbonwood in the upper part of the transect. The vegetation of these transects, especially in the upper half, had all been modified by grazing and trampling by stock.

10.3. Vegetation distribution

Estuarine margins form part of a dynamic system influenced by tidal rise and fall and a fluctuating salinity regime that provides, within a relatively small area, a diversity of habitat for vegetation. Salinity ranges from hypersaline to fresh and the substrate varies from muds to sand to boulders in various

Table 10.1. Common plants around the Vernon Lagoons, Wairau Estuary and Boulder Bank.

Aira caryophyllea	- Silver hair grass
Apium australe	- Sea celery
Atriplex novae-zelandiae	
Calystegia soldanella	- Sand convolvulus
Carex geminata	
Cassinia leptophylla	- Tauhinu
Cirsium arvense	- Californian thistle
Coprosma repens	- Taupata
Cordyline australis	- Cabbage tree
Cortaderia toetoe	- Toetoe
Cotula coronopifolia	- Bachelor's button
Cyperus ustulatus	- Sedge
Deyeuxia forsteri var. *maritima*	
Discaris toumatou	- Wild Irishman
Festuca arundinacea	- Fescue
Fumaria officinalis	- Fumitory
Geranium sp.	
Hordeum marinum	- Seaside barley grass
Hymenanthera crassifolia	
Hypochaeris radicata	- Catsear
Juncus maritimus var. *australiensis*	- Sea rush
Lagurus ovatus	- Harestail grass
Leptospermum ericoides	- Kanuka
Lilaeopsis sp. (coastal sp.)	
Lobelia anceps	
Lycium ferocissimum	- African boxthorn
Medicago sativus	- Lucerne
Mimulus repens	
Muehlenbeckia complexa	- Pohuehue
Phormium tenax	- Flax
Plagianthus divaricatus	- Shore ribbonwood
Poa annua	- Annual grass
P. laevis	
Plantago coronopus	- Shore plantain
Puccinella stricta	
Raoulia tenuicaulis	- Scabweed
Rhagodia triandra	
Rosa rubigonosa	- Wild briar
Rumex acetosella	- Sheep sorrel
R. conglomeratus	- Clustered dock
R. obtusifolius	- Broadleaved dock
Salicornia australis	- Glasswort
Samolus repens	- Shore primrose
Scirpus americanus	- Three square sedge
S. cernuus	
S. lacustris	
S. nodosus	
Selliera radicans	
Taraxacum officinale	- Dandelion

Table 10.1. continued.

Plate 7. *Salicornia* marsh on the island at the entrance to the Vernon Lagoons.

Plate 8. View looking up the Wairau River Estuary to the north of the wharf area. The beach in the foreground is covered with sediment deposited in a recent flood. Also evident is a considerable amount of debris deposited at the same time.

Table 10.1. continued.

Tillaea moschata	
Trifolium repens	- White clover
Triglochin striatum	
Typha orientalis	- Raupo, bulrush
Ulex europaeus	- Gorse
Verbascum thapsus	- Woolly mullein
Zostera muelleri	- Eelgrass, seagrass

states of consolidation and wetness.

A conspicuous feature of the vegetation is the vertical zonation of the species related to tidal level. The upper limit of high water spring tides demarcates the upper limit of the true salt marsh vegetation. The lower marsh is that area that is inundated daily. Thus several distinct plant associations can be recognised. They are:

a) Mudflats below L.W.N.T. (low water neaps)
b) Salt marshes and flats
c) Rushlands and swamplands of the south-western lagoon margins
d) Boulder bank

a) Mudflats

Beds of eelgrass (*Zostera muelleri*) are found throughout the lagoons where exposure, substrate and salinity conditions are suitable. This species is an important producer of organic detritus and the beds harbour a distinctive animal community. The introduced cordgrass (*Spartina x. townsendii*) occurs in some areas. Up until about 1958 large quantities of horse's mane weed (*Ruppia megacarpa*) grew in the Big Lagoon where it formed a large part of the food of waterfowl, particularly black swans.

b) Saltmarshes

The dominant species is the succulent glasswort (*Salicornia australis*) which typically grows on a very muddy substratum. These glasswort beds are extensively developed on the low lying areas adjacent to the lagoons but are of limited extent along the Wairau River estuary. Other species associated with the *Salicornia* beds include the sea primrose (*Selliera radicans*), the fleshy-leaved (*Chenopodium ambiguum* and *Triglochin striatum*), bachelor's button (*Cotula coronopifolia*), *Cotula dioica* and a maritime grass (*Hordeum marinum*).

Dominating the higher marsh is the physiognomic plant of the salt marsh, the sea rush (*Juncus maritimus* var. *australiensis*). This rush attains a height of 1.2 metres and grows in dense clumps. It is abundant along the Wairau River estuary and the estuary of the Opawa River. Elsewhere a common associate of the

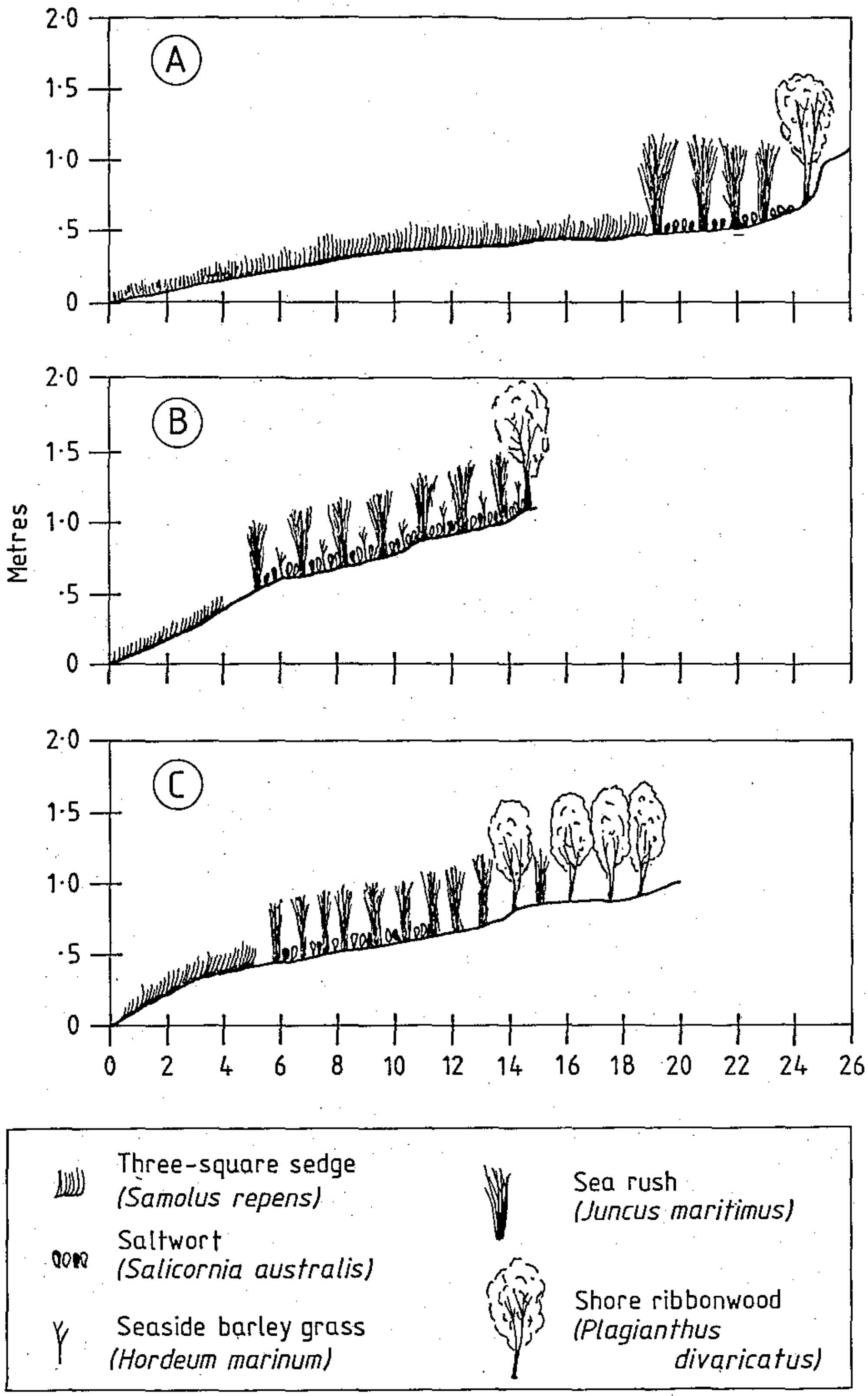

Fig. 10.1. Distribution of the dominant plants along the transects surveyed during this study.

Plate 5. Wetland vegetation in the lower reaches of the Opawa River (site of Vegetation Transect 1). Three square sedge in the foreground, the rush *Juncus maritimus* in the background.

Plate 6. Wetland vegetation on the north bank of the Wairau River Estuary upstream from the wharf area. Stunted three square sedge in the foreground, the rush *Juncus* at the back with the salt-marsh ribbonwood *Plagianthus divaricatus* in the background.

sea-rush is the jointed rush (*Leptocarpus similis*) but it is comparatively rare at this locality. Associated species are the shore plantain (*Plantago coronopus*), the shore celery (*Apium australe*), two maritime grasses (*Puccinella stricta* and *Deyeuxia forsteri* var. *maritima*), a species of *Lilaeopsis* and *Atriplex novae-zelandiae*.

Towards the higher margins of the *Juncus* zone the salt-marsh ribbonwood (*Plagiantus divaricatus*) with its distinctive growth form can be found.

Above the high marsh zone the original vegetation sequence led to a kanuka-manuka *Leptospermum ericoides - L. scoparium* shrubland on soils that were no longer subject to tidal influence. This sequence is now to be seen only on rocky and bouldery areas that have not been put into pasture. Where shrublands occur above the high marsh kanuka is the more important component although the introduced gorse (*Ulex europaeus*) and wild briar (*Rosa rubigonosa*) are also prominent.

c) Rushlands and swamplands

In freshwater sites around the creek deltas to the south and west of the Vernon Lagoons, the vegetation is dominated by lowland flax (*Phormium tenax*) and raupo (*Typha orientalis*) with some of the larger sedges (*Carex geminata, Scirpus lacustris, S. americanus, S. nodosa*) and the large introduced grass (*Festuca arundinacea*).

d) Boulder Bank

In contrast to the adjacent flats the Boulder Bank provides a dry desiccating environment for the vegetation. The most conspicuous feature of the vegetation is introduced African boxthorn (*Lycium ferocissimum*). The semi-prostrate shrub *Hymenanthera crassifolia* is scattered along the boulder bank together with clumps of the liane *Muehlenbechia complexa* or pohuehue. Gorse and the tauhinu (*Cassinia leptophylla*) are also members of the shrub component.

Undisturbed boulders are encrusted with yellow (*Xantheria* sp.) or blue-green (*Parmelia* sp.) lichens. The sand in between the boulders has plants characteristic of coastal sand dunes. The scabweed (*Raoulis tenuicaulis*), the sand convolvulus (*Calystezia soldarella*) and *Tillea moschata* are common species. A number of introduced grasses are plentiful including the harestail (*Laganus ovatus*) and the silver hair grass (*Aira caryophyllea*).

Much of the vegetation round the estuary and the lagoons has been considerably modified by human impact. The communities least modified are the mudflats and the salt marsh. The blocking and excavation of channels, erection of stop banks, fires, prolonged grazing by sheep and cattle and flax milling has drastically altered the plant communities. Fig. 10.2, sketched from an infra-red colour photograph, illustrates the limited amount of wetland vegetation that is left round the Wairau River Estuary.

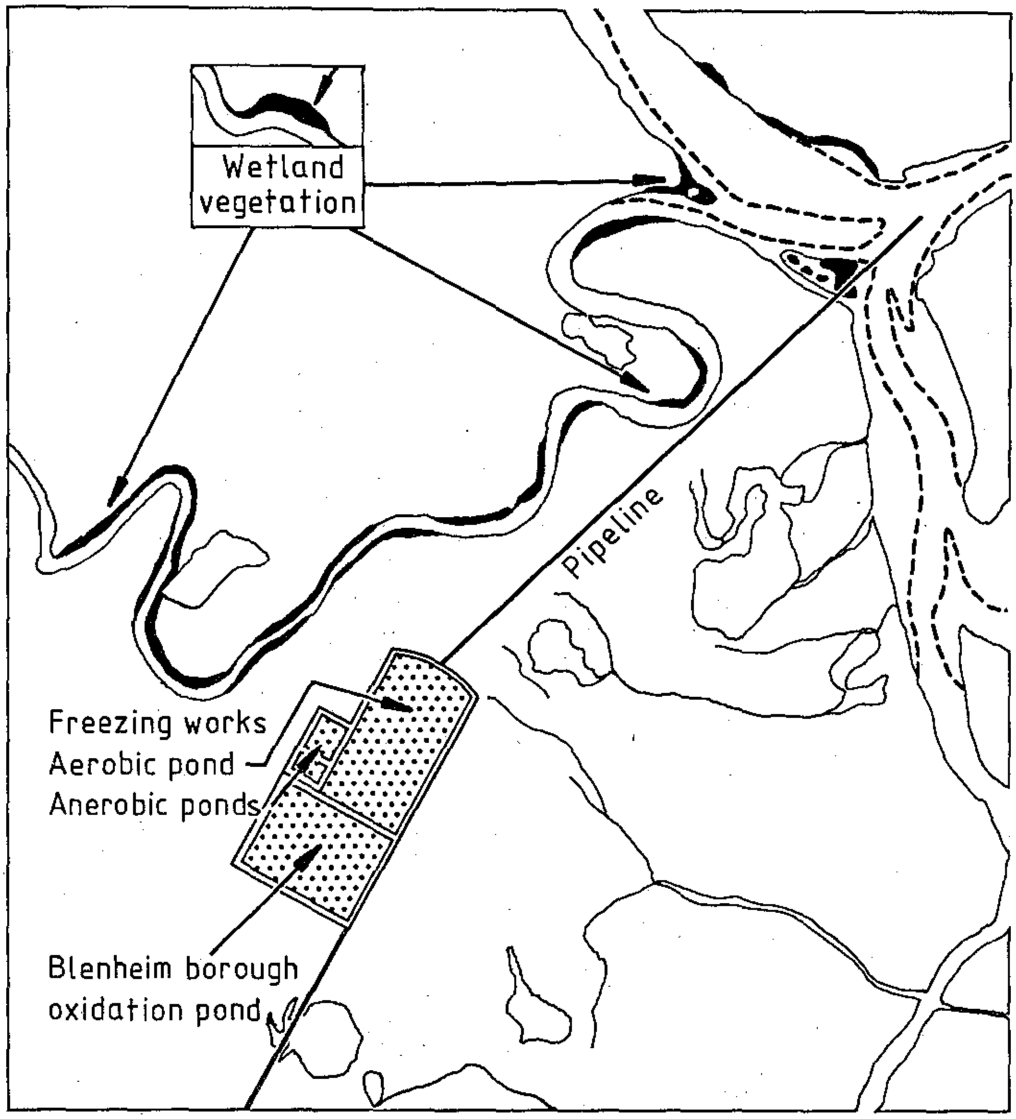

Fig. 10.2. Sketch map taken from an infrared colour photograph showing the present extent of wetland vegetation in the Wairau River Estuary and the Opawa River.

11. BENTHIC MACROFAUNA

11.1. Intertidal transects and stations

11.1.1. Species present

Twenty species (Table 11.1) were recorded from the intertidal transects and stations. The Crustacea were represented by 9 species, the Polychaeta by 7 and the Mollusca by 4. Within the Crustacea, there was one species of Amphipoda, one Isopoda, three Mysidicea and four Decapoda.

Along transects 1 and 2, which were sampled in January, there were large numbers of newly settled crab larvae. Also present were numbers of mysid crustaceans. These live in the surface sediments and migrate into the water column during the hours of darkness.

Species distributions are presented in Table 11.2.

11.1.2. Species distribution

A number of trends are obvious in the distributions shown in Table 11.2.

1. In all transects the dominant species is the tube-dwelling amphipod *Paracorophium lucasi* reaching a maximum density of 67,295/m^{-2} at station 4.2.

2. The other abundant species are the polychaetes *Heteromastus filiformis* and *Paraonides* sp.

3. The lowest densities are found on the upper shore. Densities increase with the maximum densities occurring at stations 4.2 (85,355/m^{-2}) and 4.3 (64,758/m^{-2}).

4. In transect 1 the upper four stations were devoid of animals. This upper beach was composed of coarse sand.

5. Polychaete worms were common at nearly all stations.

11.2. Subtidal species

11.2.1. Species present

Only 21 species (Table 11.3) were recorded from the subtidal stations although a number were not identified as known species. The Crustacea were represented by eight species, the Polychaeta by eight and the Mollusca by three. Within the Crustacea there were four species of Amphipoda, three Decapoda and one Isopoda.

Species distributions and numbers are presented in Tables 11.4 and 11.5.

Table 11.1. Species present along the intertidal transects and at the intertidal stations.

Amphipoda	
	Paracorophium lucasi
Isopoda	
	Exosphaeroma planulatum
Mysidicae	
	Tenagomysis novaezelandiae
	Tenagomysis chiltoni
	Gastrosaccus australis
Decapoda	
	Halicarcinus whitei
	Helice crassa
	Hemigrapsus edwardsii
	Macrophthalamus hirtipes
	Crab zoea larvae
Polychaeta	
	Aonides trifidus
	Boccardia syrtis
	Heteromastus filiformis
	Nicon aestuariensis
	Paraonides sp.
	Scolecolepides benhami
	Spionid sp.
Bivalvia	
	Chione stutchburyi
	Paphies australe
Gastropoda	
	Amphibola crenata
	Potamopyrgus aestuarinus

Table 11.2. Number of individuals/species/m^{-2} at the intertidal stations.

Station 1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	1.12	Total
Paracorophium lucasi	-	-	-	-	1032	1548	9804	9288	11223	19866	8729	9245	70735
Exosphaeroma planulatum	-	-	-	-	86	86	43	-	-	-	-	-	215
Mysids	-	-	-	-	-	-	43	-	-	-	-	129	172
Halicarcinus whitei	-	-	-	-	-	-	-	-	-	-	-	129	129
Helice crassa	-	-	-	-	-	-	43	86	43	-	-	-	172
Macrophthalmus hirtipes	-	-	-	-	-	-	-	-	-	-	215	516	732
Crab zoea	-	-	-	43	129	129	129	86	-	172	43	-	732
Aonides trifidus	-	-	-	-	-	129	129	172	129	86	129	129	903
Boccardia syrtis	-	-	-	-	-	-	-	-	559	-	-	559	1118
Heteromastus filiformis	-	-	-	-	516	3132	5332	5719	3782	3526	8944	5332	32157
Nicon aestuariensis	-	-	-	-	86	258	258	473	301	258	602	602	2760
Paraonides sp.	-	-	-	-	129	-	-	129	-	-	-	-	258
Scolecolepides benhami	-	-	-	-	-	-	-	-	-	258	258	-	516
Spionid sp.	-	-	-	-	-	-	-	-	-	-	258	258	516
Chione stutchburyi	-	-	-	-	-	-	-	-	-	43	129	215	387
Paphies australe	-	-	-	-	-	-	-	-	-	-	43	129	172
Potamopyrgus aestuarinus	-	-	-	-	-	-	-	-	-	43	129	-	172
Amphibola crenata	-	-	-	-	-	-	-	-	43	86	129	-	258
Total	-	-	-	43	1978	2582	15781	15953	15480	39818	20506	17243	129284

Station 2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10	2.11	2.12	Total
Paracorophium lucasi	43	1548	4558	5418	4171	7310	10062	8385	5461	22489	22489	11438	103552
Exosphaeroma planulatum	-	-	-	215	86	-	43	43	86	129	-	43	605
Mysids	-	-	-	-	-	-	258	-	860	344	430	-	1892
Halicarcinus whitei	-	-	-	-	-	-	-	86	-	43	-	43	172
Helice crassa	-	-	-	-	-	-	86	86	-	516	-	43	731
Macrophthalmus hirtipes	-	-	-	-	-	-	-	-	-	86	-	-	86
Crab zoea	129	43	43	43	86	129	-	129	86	602	129	43	1462
Aonides trifidus	-	-	-	-	-	-	-	-	-	-	-	-	0
Boccardia syrtis	-	-	-	-	-	-	2193	258	86	215	301	-	3053
Heteromastus filiformis	-	-	-	645	-	516	-	1806	2494	6278	3827	-	15566
Nicon aestuariensis	-	-	-	86	86	86	86	129	86	43	129	-	731
Paraonides sp.	-	668	1720	5868	8686	10191	-	-	-	-	86	-	27219
Scolecolepides benhami	-	-	-	516	-	-	-	-	-	-	301	-	817
Spionid sp.	-	-	-	1849	1290	1333	860	344	430	129	172	215	6622
Chione stutchburyi	-	-	-	-	-	-	-	-	-	43	129	215	387
Paphies australe	-	-	-	-	-	-	-	-	-		43	129	172
Amphibola crenata	-	-	129	129	43	43	-	-	-	-	-	-	344
Total	172	2259	6450	14769	14448	19600	13588	11266	9589	30917	28045	12169	191237

Table 11.2. continued.

Table 11.2. continued.

Stations 3, 4, A, B, C	3.1	3.2	3.3	4.1	4.2	4.3	A	B
Paracorophium lucasi	15695	22704	1634	26531	67295	50353	5590	14491
Exosphaeroma planulatum	86	43	43	129	86		86	1032
Mysids	86	86	473	43			258	774
Halicarcinus whitei	-	-	-	-			-	-
Helice crassa	86	-	-	-			86	-
Macrophthalamus hirtipes	-	-	-	-			-	-
Crab zoea	-	-	-	-			-	-
Aonides trifidus	-	-	-	-		129	-	-
Boccardia syrtis	-	-	-	86		43	-	-
Heteromastus filiformis	1032	1290	258	1333	10922	12040	2967	1849
Nicon aestuariensis	-	-	172	387	301	86	387	258
Paraonides sp.	989	1204	86	-	516	645	-	-
Scolecolepides benhami	998	1118	774	215	301	1204	-	-
Spionid sp.		129	-	-			-	-
Chione stutchburyi	-	43	129	-			-	86
Paphies australe	86	86	258	-			-	-
Potamopyrgus estuarinus	301	602	1462	5934	5590	387	7310	10449
Amphibola crenata	86	-	-	43			-	172
Total	18404	27305	5289	34615	85355	64758	16668	29111

Table 11.3. Species present at the subtidal stations.

Amphipoda
Allorchestes sp.
Gammaropsis thompsoni
Paracorophium lucasi
Paramoera sp.
Isopoda
Exosphaeroma planulatum
Mysidacea
Mysid sp.
Decapoda
Halicarcinus whitei
Helice crassa
Macrophthalmus hirtipes
Nematoda
Nematode sp.
Polychaeta
Aonides trifidus
Boccardia syrtis
Heteromastus filiformis
Nicon aestuariensis
Paraonides sp.
Polychaete sp.
Scolecolepides benhami
Spionid sp.
Bivalvia
Chione stutchburyi
Paphies australe
Gastropoda
Potamopyrgus aestuariensis

Table 11.4. Distribution of species present in the subtidal.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Allorchestes sp.			X														
Gammaropsis thompsoni					X				X				X				
Paracorophium lucasi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Paramoera sp.			X				X		X							X	
Exosphaeroma planulum	X	X										X				X	
Mysid sp.			X							X			X				
Halicarcinus whitei	X																
Helice crassa	X				X	X		X	X	X	X					X	
Macrophthalmus hirtipes	X										X						
Nematode sp.	X																
Aonides trifidus												X					
Capitellidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Boccardia syrtis	X									X	X	X	X	X	X		X
Nicon aestuariensis	X			X	X	X		X		X	X	X			X		
Paraonides sp.		X		X		X	X			X	X	X	X	X	X	X	X
Polychaete sp.			X														
Scolecolepides benhami	X				X	X			X	X	X	X	X	X	X	X	X
Spionid sp.	X		X			X		X	X	X	X	X	X	X	X	X	X
Chione stutchburyi	X	X	X	X	X	X	X	X	X		X		X	X	X		
Paphies australe	X	X	X	X	X	X	X		X	X	X		X	X		X	X
Potamopyrgus aestuarinus	X		X	X	X	X	X			X	X	X	X	X	X		
No. of species	14	6	10	7	9	10	7	6	9	11	12	10	11	9	9	9	7

Table 11.5. Number of individuals/species/m^2 for the subtidal stations.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	Total
Allorchestia sp.			25															25
Gammaropsis thompsoni					377				176				25					578
Paracorophium lucasi	13209	5927	427	1281	6404	9191	125	22954	10346	11226	9995	527	4319	5575	1908	4972	6831	115,217
Paramoera sp.			25				25		25							50		125
Exosphaeronum planulum	71	25										25				50		171
Mysid sp.			276							25				75				376
Halicarcinus whitei	25																	25
Helice crassa	75				75	25		201	25	50	100					50		601
Macrophthalmus hirtipes	25										25							50
Nematode sp.	25																	25
Aonides trifidus												75						75
Boccardia syrtis	75									804	427	75	25	427	402		427	2,662
Heteromastus filiformis	3038	402	402	2059	2686	1482	50	2737	753	4872	3838	3667	151	4897	2486	75	628	33,223
Nicon aestuariensis	50			50	75	25		25		75	25	75			75			475
Paraonides sp.		503		25		276	1833			226	402	25	703	1331	678	75	1532	7,609
Polychaete sp.			25															25
Scolecolepides benhami	226				50	1281			25	552	100	100	200	979	50	402	25	3,990
Spionid sp.	326		25			1431		25	75	854	1055	75	176	1356	427	251	25	6,101
Chione stutchburyi	50	100	25	126	25	75	75	25	25		126		25	50	25			752
Paphies australe	100	201	326	100	276	301	452		352	25	100		151	100		151	25	2,660
Potamopyrgus aestuariensis	75		25	25	75	25	226			75	151	151	25	50	422			1,325
	17370	7158	1581	3666	10043	14112	2786	25967	11802	18784	15344	4795	5875	14765	6473	6076	9493	176,090

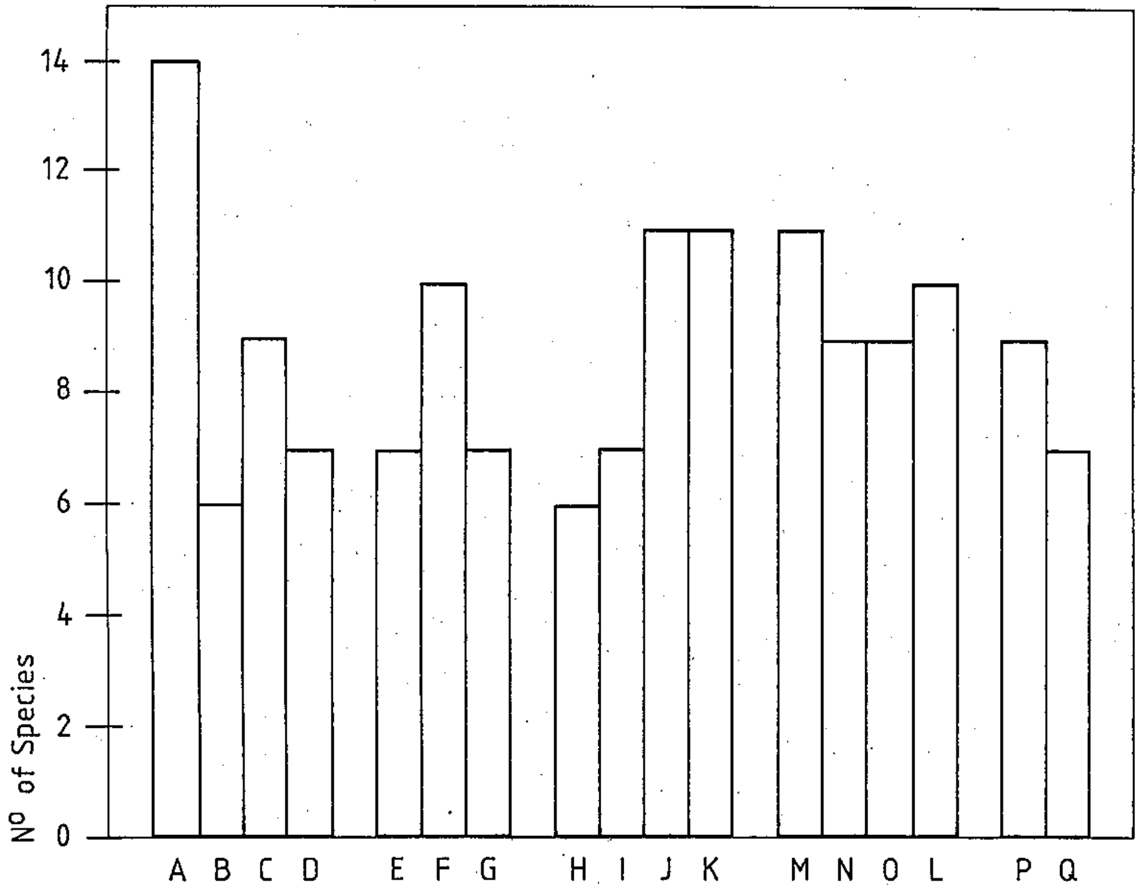

Fig. 11.1. Number of species at the subtidal stations (see Fig. 5.4 for station positions).

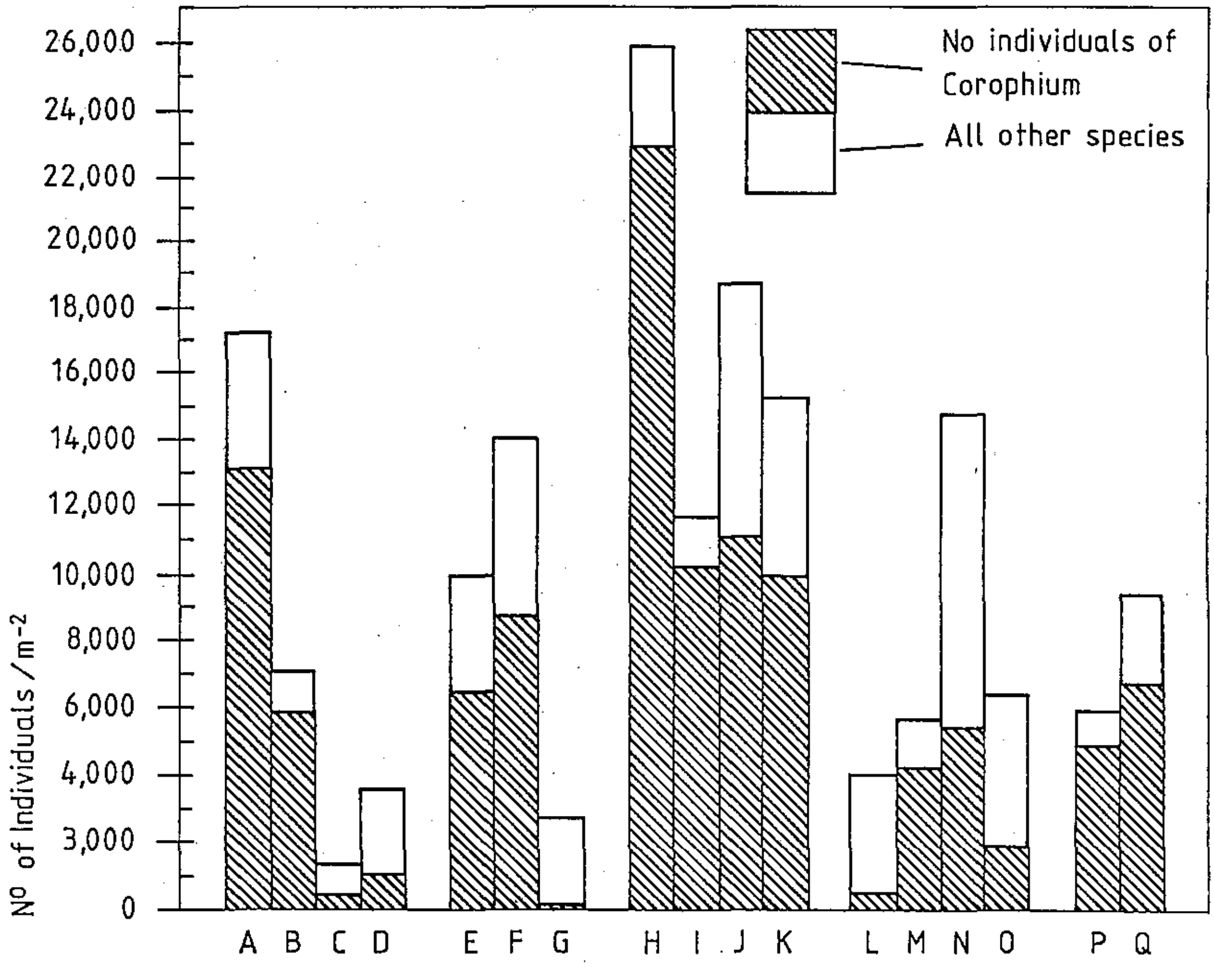

Fig. 11.2. Number of individuals present at the subtidal stations (see Fig. 5.4 for station positions).

11.2.2. Species distribution

A number of trends are obvious in the distributions shown in Tables 11.4 and 11.5 and in Figs 11.5 and 11.6.

1. The shallower stations such as stations A, F, J, K and M tend to have the greatest number of species. The number of species present ranged from a high of 14 at station A to a low of 6 at stations B and H.

2. The tube dwelling amphipod *Corophium* was the most abundant species occurring at all stations with the highest density of 22,954/m^{-2} at station H and the lowest of 125/m^{-2} at station G. At all stations apart from C, D, G, L and O it comprised the bulk of the individuals present.

3. Polychaete worms were present at all stations with the greatest number (12,990/m^{-2}) occurring at station M and the least number (452/m^{-2}) at station C.

4. The bivalve *Paphies australe* (pipi) occurred at all stations apart from stations H, L and O; while the cockle *Chione stutchburyi* occurs at all stations apart from stations J, L, P and Q.

5. Both the lowest number of species (6) and the lowest number of individuals (452/m^{-2}) occur at station C in the deepest part of the scour channel on the south side of the Wairau Bar.

6. The fauna is dominated by filter feeders or detritivores. Sediment dwelling carnivores are absent.

11.3. Distribution of the individual species

11.3.1. Mollusca

Includes the bivalves *Chione stutchburyi* (cockles) and *Paphies australe* (pipi), the estuarine gastropod *Potamopyrgus estuarinus* and the mudflat snail *Amphibola crenata*.

Chione stutchburyi (cockle). Fig. 11.3 shows the distribution of cockles in the Wairau River estuary and the Vernon Lagoons. Dense cockle beds are found on the north side of the island to the west of the Vernon Lagoons entrance and along the margins of the Te Aropipi Channel. Densities in these beds ranged from 340/m^{-2} to 1340/m^{-2}.

Low density cockle beds are distributed throughout the Wairau River estuary occurring at all subtidal stations apart from J, L, P and Q. Similar low density beds are widely distributed in the Vernon Lagoons (see Fig. 11.3).

A number of cockle samples were taken for size frequency distribution measurements. Two samples C_1 (340 individuals m^{-2}) and C_2 (460 individuals m^{-2}) at stations C and D and

(1010 individuals m^{-2}) at station D. The results of this analysis are shown in Fig. 14.4. In addition a random sample of cockle shells (E) was collected from the bank at the entrance to the Vernon Lagoons. The three live samples (C_1, C_2 and D) all show a similar length frequency distribution with the median size class being the 25-29 mm one. On the other hand the dead drift shell sample had a median size class of 45-49 mm indicating that low tide-subtidal beds of larger cockles must exist in the channels in the Vernon Lagoons. These median size ranges can be compared with those recorded from other estuaries as shown below.

Locality	Median size range
Nelson Haven	17-36 mm, depending on locality
Brooklands Lagoon	33-39 mm
Avon-Heathcote Estuary	33-39 mm
Upper Waitemata Harbour	16-20, or 21-25 mm
Wairau River Estuary	
Intertidal samples	25-29 mm
Drift shells	45-49 mm

Thus it can be seen that the sizes of the cockles in the Wairau River Estuary compare favourably with those in other estuaries.

Paphies australe (pipi). Pipis occurred in all the subtidal stations in the Wairau River Estuary apart from stations H, L and O. They extended further up the estuary than *Chione* as far as stations P and Q and probably extend beyond. At the majority of the subtidal stations this species was more numerous than the cockle reaching a maximum density of $452/m^{-2}$ at station G. This species has only a limited tolerance of fine sediments and Voller (1973) found that in the Avon-Heathcote Estuary it was found only in areas where the silt-clay content was less than 33.8%.

Potamopyrgus aestuarinus. This small brown snail is a characteristic species of the upper tidal areas in estuarine marshes throughout New Zealand where it is associated with the marsh vegetation (*Spartina, Juncus, Leptocarpus*) and green algal mats. *Potamopyrgus* is a detritivore ingesting the surface sediment layer. It can reach very high densities; a maximum density of $137,724/m^{-2}$ (Knox and Bolton, 1978) and over 78,000 in the Kaituna Marsh, Pelorus Sound (Odum *et al.*, 1983). In the samples taken in the Wairau River Estuary, the maximum density was $10,449/m^{-2}$ and densities around $5000/m^{-2}$ were recorded from some stations. These are much lower than for other estuaries, although much greater densities are likely to be recorded in the Vernon Lagoons.

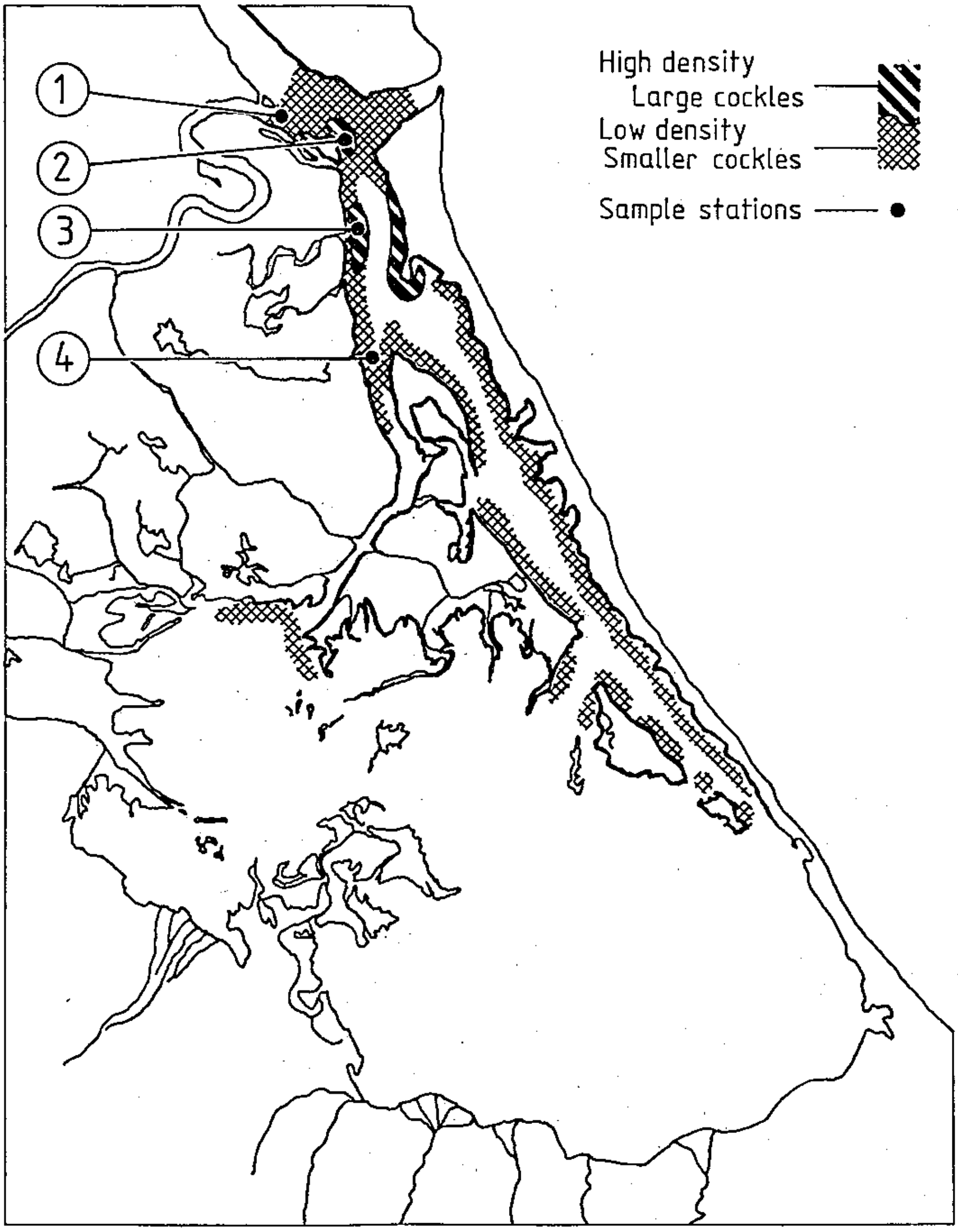

Fig. 11.3. Distribution of cockles (*Chione stutchburyi*) in the Wairau River Estuary and the Vernon Lagoons.

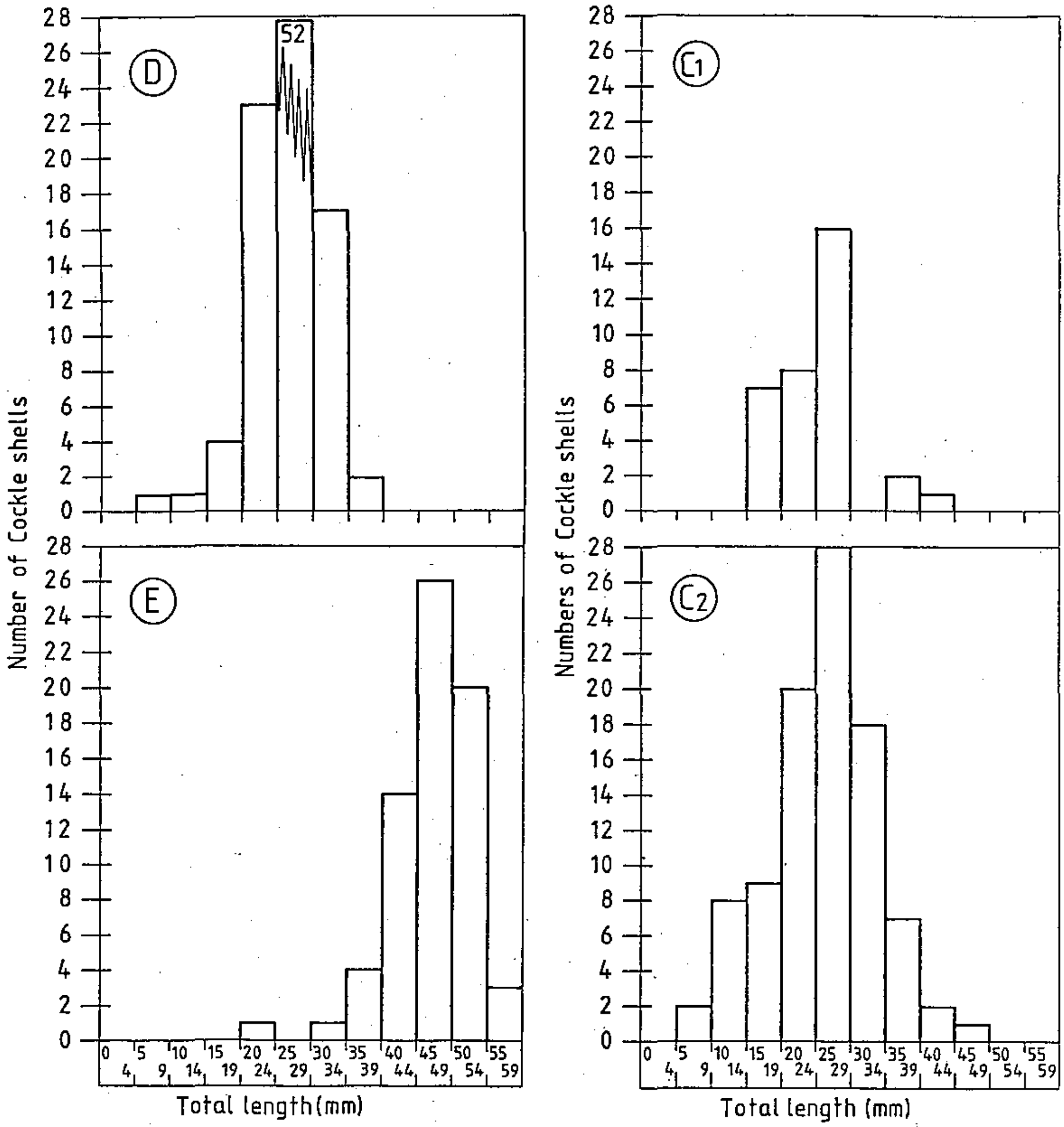

Fig. 11.4. Size class histograms of cockle samples taken at the intertidal stations shown in Fig. 5.3. E is based on dead drift shells from a bank at the Vernon Lagoons entrance.

Amphibola crenata. This is a deposit feeder, moving across the substrate sucking up the surface layer and passing out the ingested material in the form of a faecal string (Knox and Kilner, 1973). Densities of this mudflat snail ranged from 10 m^{-2} to a maximum of 129 m^{-2} with densities generally averaging 10-50 m^{-2}. These are low in comparison with other estuaries.

11.3.2. Crustacea

Amphipods. Includes the species *Allorchestia* sp., *Gammaropsis thompsoni*, *Paramoera* sp. and *Paracorophium lucasi*. Of these, *Paracorophium* has the widest distribution occurring along all transects and at all subtidal stations. The other species had much more limited distributions.

Paracorophium lucasi. This is a burrowing species which feeds on detritus either by filtering fine particles from the water passing over its tubes or it may emerge from the tube and crawl over the surface and pick up particles of food. In terms of numbers of individuals, it is the most abundant species in all transects and subtidal stations but was absent or reduced in numbers at the high tidal stations.

Decapods (crabs). Includes the species *Halicarcinus whitei*, *Helice crassa*, *Macrophthalamus hirtipes* and *Hemigrapsus crenulatus*. Of these the mudflat crab *Helice crassa* was the most abundant species reaching a maximum density of 516 m^{-2}. On the intertidal flats, densities were generally in the range of 10-50 m^{-2}. It was however very abundant along the banks of the Te Aropipi Channel and the lower reaches of the Opawa River.

11.3.3. Polychaeta

Includes the species *Aonides trifidus*, *Boccardia syrtis*, *Heteromastus filiformis*, *Nicon aestuariensis*, *Paraonides* sp., *Scolecolepides benhami* and a spionid.

Paraonides sp. was found at most of the subtidal stations but only at the lower stations in the transects. *Scolecolepides benhami* had a similar distribution pattern.

Heteromastus filiformis. This was the most abundant species being found at all subtidal stations and the majority of the intertidal stations reaching a maximum density of 4897 m^{-2} and 12,040 m^{-2} intertidally. *Heteromastus* is a deposit feeder and is characteristic of situations where there is a good supply of organic matter.

Nicon aestuariensis was more abundant intertidally where it reached a maximum density of 602 m^{-2}; subtidally the maximum density was 75 m^{-2}.

11.4. Factors affecting the distribution of the species

All the physical factors operating in an estuary to some extent have an effect on the distribution of the fauna. The most important of these factors are salinity, sediments and tidal heights and exposure.

11.4.1. Salinity

By definition an estuary is an area where seawater is measurably diluted by freshwater, hence the degree of dilution and the variations which occur are important in determining the distributions of the animals. As noted in the discussion on salinities in section 7.4, there is a decrease in the mean salinity from the mouth of the Wairau River Estuary to the limit of sampling (5.4 km from the mouth). Further decreases in mean salinity would occur upstream to the limit of saltwater penetration. A similar salinity gradient occurs in the lower reaches of the Opawa River. On the other hand the waters that enter the Vernon Lagoons are saline waters generally greater than salinity 20‰ and apart from the Te Aropipi Channel, those reaching the mid and upper lagoon areas, are in the 29-31‰ range.

The dominant species in the Wairau River Estuary are those tolerant to a wide range of salinities and are generally distributed at all the stations sampled. These are the species *Paracorophium lucasi, Potamopyrgus aestuarinus, Helice crassa, Amphibola crenata, Heteromastus filiformis, Paraonides* sp. and *Nicon aestuariensis*. Those species more limited in their distribution because of their intolerance of low salinities are *Paphies australe, Chione stutchburyi* and *Macrophthalmus hirtipes*.

Bennington (1970), Voller (1973) and Stephenson (1981) found that in the Avon-Heathcote Estuary *Chione* was most abundant in the mid-estuary with decreasing numbers upstream and downstream. By experimentation, Voller (1973) found that feeding only took place at salinities greater than 18‰ and that *Chione* would die if subjected to salinities of 4‰ or lower for an extended period.

Species that can tolerate low salinities are a number of the polychaetes especially *Scolecolepides benhami* and *Nicon aestuariensis*.

11.4.2. Sediment

The sediment type (whether predominantly sand or predominantly silt) is one of the factors determining the distribution of individual species.

Those species known to prefer sandy sediments (Knox and Kilner, 1973; Kilner and Akroyd, 1978) and which occur in sandy sediments in the Wairau River Estuary include *Chione stutchburyi, Paphies australe, Halicarcinus whitei* and *Exosphaeromum planulum*. Stephenson (1981) in a detailed study of the distribution of *Chione* found that it did not occur when the percentage of mud was greater than 50% and that the preferred percentage was 10-30%).

Species that do not appear to be limited in their distribution by sediment type are *Helice crassa, Amphibola crenata* and

Paracorophium lucasi.

11.4.3. Tidal height and exposure

Exposure has an important role in the distribution of some species as many animals are not able to survive if they are uncovered by water for any great length of time while other animals prefer to be exposed for most of the tidal cycle. Tidal height also affects animal distribution as areas subjected to large changes in tidal height are usually those with high current velocities, i.e. areas near the mouth of the estuary. Tidal height also affects the salinity of the interstitial water in the sediments and generally the greater the tidal height (i.e. higher up the shore) the higher the interstitial salinity (Knox and Kilner, 1973).

In the Avon-Heathcote Estuary Stephenson (1981) found that *Chione stutchburyi* was more abundant in regions from mid-tide down to the low tide channel and did not occur above mean high water neap tide. *Paphies australe* tolerates a wide range of exposure times but does show an increase in abundance towards the low tide channel. In contrast to these species, *Amphibola crenata, Paracorophium lucasi, Potamopyrgus estuarinus* and *Helice crassa* can tolerate exposure for most of the tidal cycle as they are widely distributed at all levels on the shore.

Plate 9. Sandy mud intertidal flat in the channel on the landward side of the small island at the entrance to the Vernon Lagoons. The mud-flat snail, *Amphibola crenata*, on the surface.

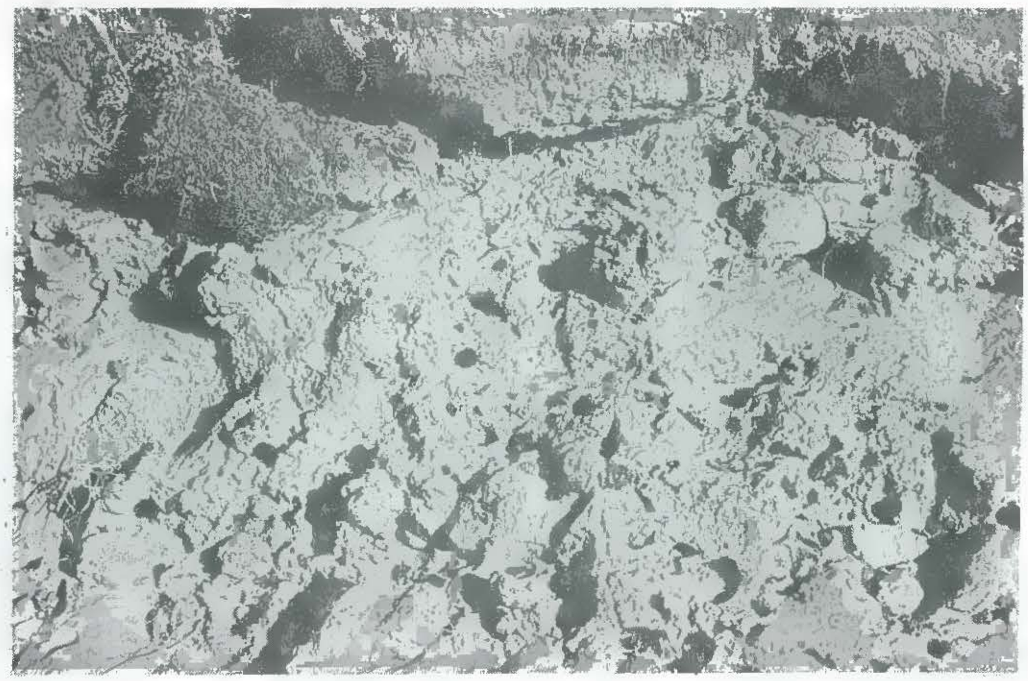

Plate 10. Slumped bank on the margin of Te Aropipi Channel with the burrows of the mud-flat crab, *Helice crassa*.

12. FISH

12.1. Species occurrence

Work on the fish of the area has been restricted to two general internal reports on the fishes of the Vernon Lagoons by the Fisheries Research Division, Ministry of Agriculture and Fisheries. Montgomery (1964) surveyed the flatfish within the lagoon system and Clarke (1976) made a general study of the fish species inhabiting the lagoons, and the study of Black (1978) on the distribution of flounders in the lagoons.

Table 12.1 lists 21 species that have been recorded from the estuary and the lagoons. This compares with 28 species recorded from the Avon-Heathcote Estuary (Knox and Kilner, 1974; Webb, 1967), 29 from the Ahuriri Estuary, Napier (Kilner and Ackroyd, 1978) and 21 from the Upper Waitemata Harbour (Knox, 1983). More intensive study on a seasonal basis would be expected to add a number of additional species. The area therefore can be considered to support a varied fish fauna comparable with that of other similar estuarine systems in New Zealand.

In considering the fishes, five distinct groups can be recognised:

1. Seasonal species that move into the estuarine waters to breed, e.g. some of the bullies. These species do feed while in the estuary, although feeding is secondary to the purpose of breeding.

2. Permanent species that breed along the shorelines of the estuary where stony substrates occur, e.g. common bully and probably spotty and rockfish. These are species which generally occupy territories throughout the year.

3. Species that migrate freely between the estuarine waters and the sea while spending a significant part of their life cycle in the estuary, e.g. sand flounder, yellow belly flounder, and yellow-eyed mullet. In numbers these constitute the predominant fish fauna and all feed within the Wairau River estuary and the Vernon Lagoons. All these species are euryhaline with wide salt tolerances.

4. Transitory species whose main habitat is the sea entering the estuary at irregular intervals. These include kahawai, barracoota, school shark, and eagle rays.

5. Finally there are those species that use the estuary principally as a migration route to other areas for the purpose of breeding, e.g. short-finned eel, inanga and brown trout.

Table 12.1. List of fish species recorded from the Wairau River Estuary and the Vernon Lagoons.

Acanthoclinus quadridactylus	rock fish
Aldrichetta forsteri	yellow-eyed mullet
Anguilla australis schmidtii	short finned eel
Anguilla dieffenbachi	long finned eel
Arripus trutta	kahawai
Clupea antipodum	sprat
Galaeorhinus australis	school shark
Galaxias maculatus attenuatus	inanga (whitebait)
Gobiomorphus basalis	common bully
Gobiomorphus gobiodes	giant bully
Gobiomorphus cotidianus	
Geniagnus monopterygins	stargazer (spotted)
Myliobatis australis	eagle ray
Physiculus bacchus	red cod
Pseudolabrus celidotus	spotty
Retropinna retropinna	common smelt
Rhombosolea leporina	yellow belly flounder
Rhombosolea plebeia	sand flounder
Rhombosolea tapirina	freshwater flounder
Salmo trutta	brown trout
Thyrsites atun	barracoota
Tripterygion nigripenne	cockabully

12.2. Distribution of the individual species

Of the migratory but long staying fishes, the flounders form the most numerous group. They are found in all parts of the estuary and the lagoons at high tide, feeding on the tidal flats and retreating on the following tide into the permanent channels.

Yellow belly flounder (*Rhombosolea leporina*). This is the predominant flounder in the Vernon Lagoons; it is found at all sizes throughout the lagoons from 1 cm to 16 cm in length (Black, 1978). The larger size classes move out of Big and Chandler's Lagoons though they can still be found in the Upper Lagoon at lengths from 16 cm to over 21 cm. Tagging has shown that the large adult yellow-bellies move out to sea; two fish tagged in the lagoons have been caught in Cloudy Bay and another at the Wairau Bar (Slack, 1979). Spawning of the yellow-belly is assumed to take place at sea with the young larvae and post-larvae being carried back into the lagoons on the incoming tide.

Sand flounder (*Rhombosolea plebeia*). This species is found less frequently in the Vernon Lagoons than the yellow bellies, except for the early juvenile stages. Up to a length of 16 cm they can be found in most of the areas occupied by the yellow-bellies, but sizes between 16 cm and 21 cm are only found north of Morgan's Creek; above 21 cm they can only be caught at the lagoon entrance and in the Wairau River estuary.

River flounder (*Rhombosolea tapirina*). This species is rare in the Vernon Lagoons but more abundant in the upper reaches of the Wairau River estuary.

Inanga (*Galaxias maculatus attenuatus*). While the adults of this species inhabit the rivers and streams of the Wairau catchment, the Wairau River estuary is the migration route of the 6 month old juveniles (whitebait) from the sea. The adults return to the estuarine waters in late autumn to spawn laying their eggs at high spring tide at the base of the marginal saltmarsh vegetation. Hence the maintenance of this vegetation is vital to the maintenance of the species and the whitebait fishery. Destruction of such vegetation is believed to be a major factor in the decline of the species.

Common smelt (*Retropinna retropinna*). This species is found in the lagoons and the estuary throughout most of the year. Large shoals of mature to ripe adults frequent the Opawa River estuary and at the mouth of the lagoons.

Yellow-eyed mullet (*Aldrichetta fosteri*). This species can be regarded as a long staying migrant visiting the sea at will but spending lengthy periods, at any stage of its life cycle, in the lagoons and the Wairau River estuary.

Short finned eel (*Anguilla dieffenbachi*). This species is less abundant throughout the system and appears to be a more casual visitor. Both eel species pass through the estuary on the annual migration to their spawning grounds in the deep sea. Ocean currents bring the larvae back to New Zealand, where, in the form of transparent "glass eels", they enter the river mouth. They stay in estuarine areas until they have developed dark pigmentation at which stage they are known as elvers. Elvers have been caught in the Vernon Lagoons in springtime. Some may stay in the lagoons and associated streams while others migrate up the Opawa and Wairau Rivers.

Kahawai (*Arripus trutta*). Kahawai use the lagoons and the Wairau River estuary as a feeding area.

Barracoota (*Thyrsites atun*), red cod (*Physicules bacchus*) and school shark (*Galeorhinus australis*) are occasional visitors to the estuary but do not enter the lagoons.

12.3. Feeding habits

Food studies of fish have proved useful in revealing ecological relationships among the various organisms in estuarine food webs. Darnell (1958, 1961) and Odum (1971) used this technique to determine trophic structure and pathways of energy flow in estuaries. On the basis of such analyses fish may be classified into several trophic levels (Odum, 1971): herbivores, omnivores, and primary, middle and top carnivores.

Feeding habits of the fishes were determined from an examination of the stomach contents of a small number of fish caught during this study, records of feeding from other studies carried out in the region (Black, 1978; Slack, 1979) and from studies carried out on the same species in other estuaries, especially in the Avon-Heathcote Estuary (Webb, 1967, 1972; Knox and Kilner, 1973), the Ahuriri Lagoon (Ackroyd and Kilner, 1978; Knox, 1979) and the Upper Waitemata Harbour (Briggs, 1980; Knox, 1983).

Food items found in the stomachs of the estuarine fish species are listed in Table 12.2. The food of the flounders changes as they grow. Juveniles feed on small crustacea, especially amphipods but detrital material makes up a considerable proportion of the stomach contents that have been examined. As they increase in size larger invertebrates, especially polychaete worms and the mud crabs *Helice crassa* and *Macrophthalmus hirtipes* comprise an increasing proportion of the diet. From Fig. 12.1 it can be seen that the sand flounder has a much greater proportion of mud and detritus (50.7%) in its food intake than the yellow belly (21.2%). The yellow-eyed mullet while taking some small invertebrates feeds principally on plant material (epiphytic microalgae and benthic microalgae) and detritus. They ingest the surface layer of mud with the organic detritus it contains along with microalgae, bacteria and microbenthic invertebrates. They also have been known to take midge larvae and some terrestrial insects. Adult short-finned eels feed mainly on shrimps, crabs and small fish, including smaller flounders, smelt, mullet and bullies. Kahawai and school shark feed mainly on crabs and small fish.

After determination of the food habits of the fishes it becomes possible to arrange them in a sequence based on the food items they ingest (Table 12.2). This technique enables analysis of the food web and the interdependence of one trophic level on another. Divisions may be made into several feeding categories as defined below:

<u>Herbivores</u>: Fishes feeding primarily on plant matter, phytoplankton or organic detritus; only occasionally taking small invertebrates.

<u>Omnivores</u>: Fishes showing no particular preference for plant or animal material, the one or the other predominantly, depending on the availability in the particular habitat.

In estuarine areas it is difficult in practice to separate the two groups. There is little utilisation directly of the phytoplankton. Species which graze on the surface sediments ingest a wide range of organisms. In all these fishes, organic detritus forms a major component of the diet.

<u>Primary carnivores</u>: Fishes feeding mostly on zooplankton and microbenthic animals but occasionally on plant matter and organic detritus.

<u>Mid carnivores</u>: Fishes feeding on both macrobenthic and microbenthic animals such as molluscs, amphipods, shrimps, sand crabs, small fishes of lower trophic levels and organic detritus.

Table 12.2. Trophic spectrum of the common fishes of the Wairau River Estuary and the Vernon Lagoons.

Fishes	Macrobenthic animals	Microbenthic animals	Nekton	Zooplankton	Phytoplankton	Macroalgae	Benthic microalgae	Organic detritus	Species	
		X					XX	XX	Yellow eyed mullet	Herbivore-Omnivore
		X					XX	XX	Juvenile sand flounder	
		X					XX	XX	Juvenile yellow belly flounder	
				XX	X				Common smelt	
				XX	X				Sprat	
	X	X					XX	XX	Sand flounder	
	X	XX							Rock fish	Mid Carnivore
X	XX		X						Short finned eel	
XX	X		X						Long finned eel	
	XX	X							Inanga	
	X	XX							Bullies	
	XX								Eagle ray	
	XX								Spotty	
	XX	X	X						Brown trout	
	XX								Yellow belly flounder	
XX			X						Kahawai	Top Carnivore
XX									Stargazer	
XX									Barracoota	

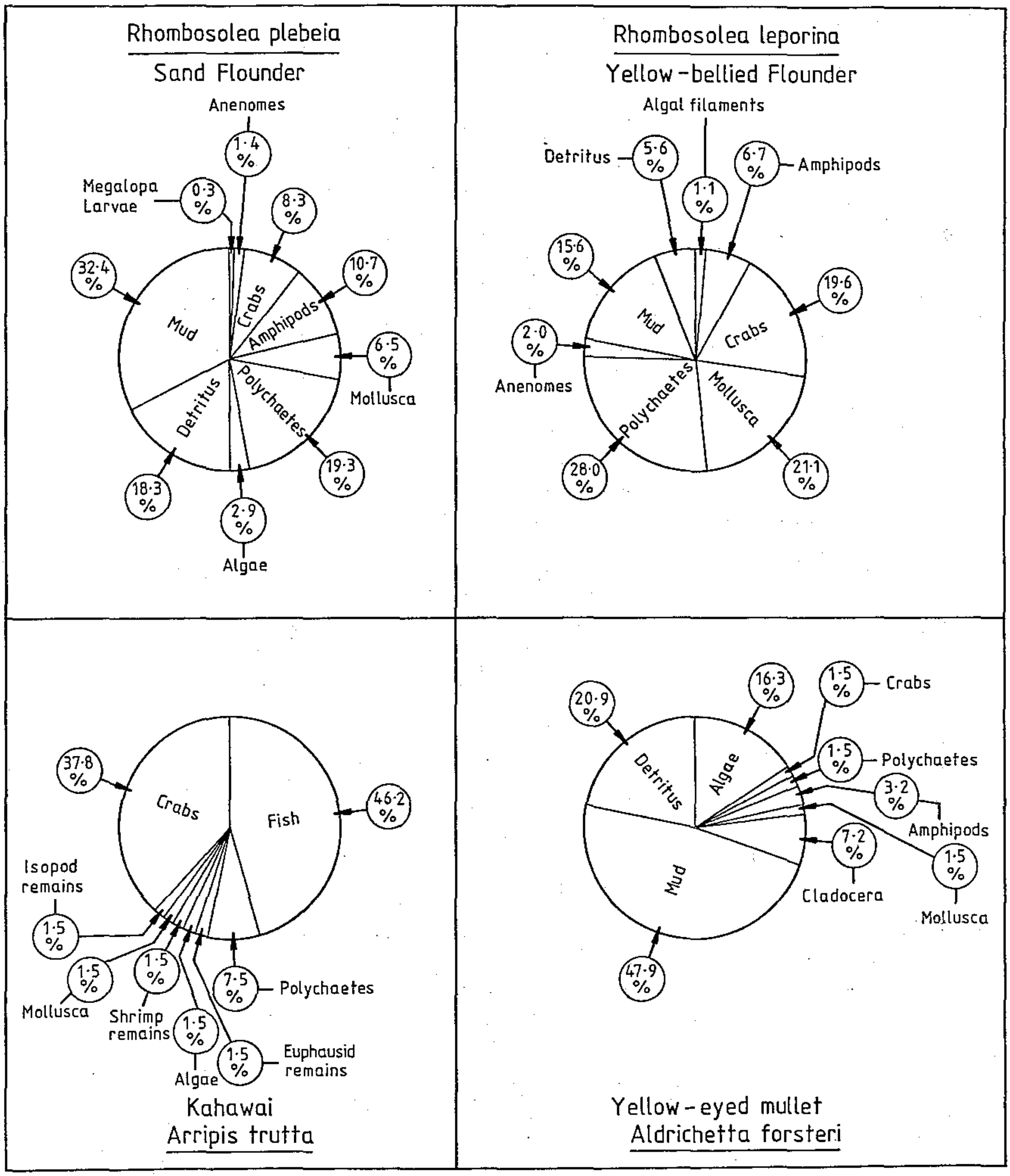

Fig. 12.1. Stomach content analyses of four of the fish species found in the Vernon Lagoons and the Wairau River Estuary. Based on data obtained by Webb (19) for the Avon-Heathcote Estuary.

The latter is probably taken incidentally in feeding on animals.

Top carnivores: Highly predaceous fishes feeding mostly on smaller fishes and larger invertebrates.

12.4. Commercial and recreational fisheries

The Wairau River Estuary is a valuable regional commercial and recreational fishery resource. Commercial fishing in the estuary has largely been restricted to set netting for kahawai. Commercial netting commenced on a large scale about 1978 and reached a peak in 1979 when some 10 fishermen were gill netting in the river to supply a company that exported whole frozen fish to Australia. About 250 ton were caught in that year. This venture ended in 1980 when trials were carried out to see if the fish were suitable for canning. The quality of the river caught fish proved unsuitable and the fishery ceased. No commercial flounder fishing is carried out in the estuary.

On the other hand, extensive use of the Wairau River Estuary is made by amateur fishermen (see Fig. 12.2). During the season whitebaiters fish from suitable spots along the entire length of the lower reaches 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 and both banks further up the river. There is also some trawling from small boats. 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. There is also some gathering of cockles in Te Aropipi Channel.

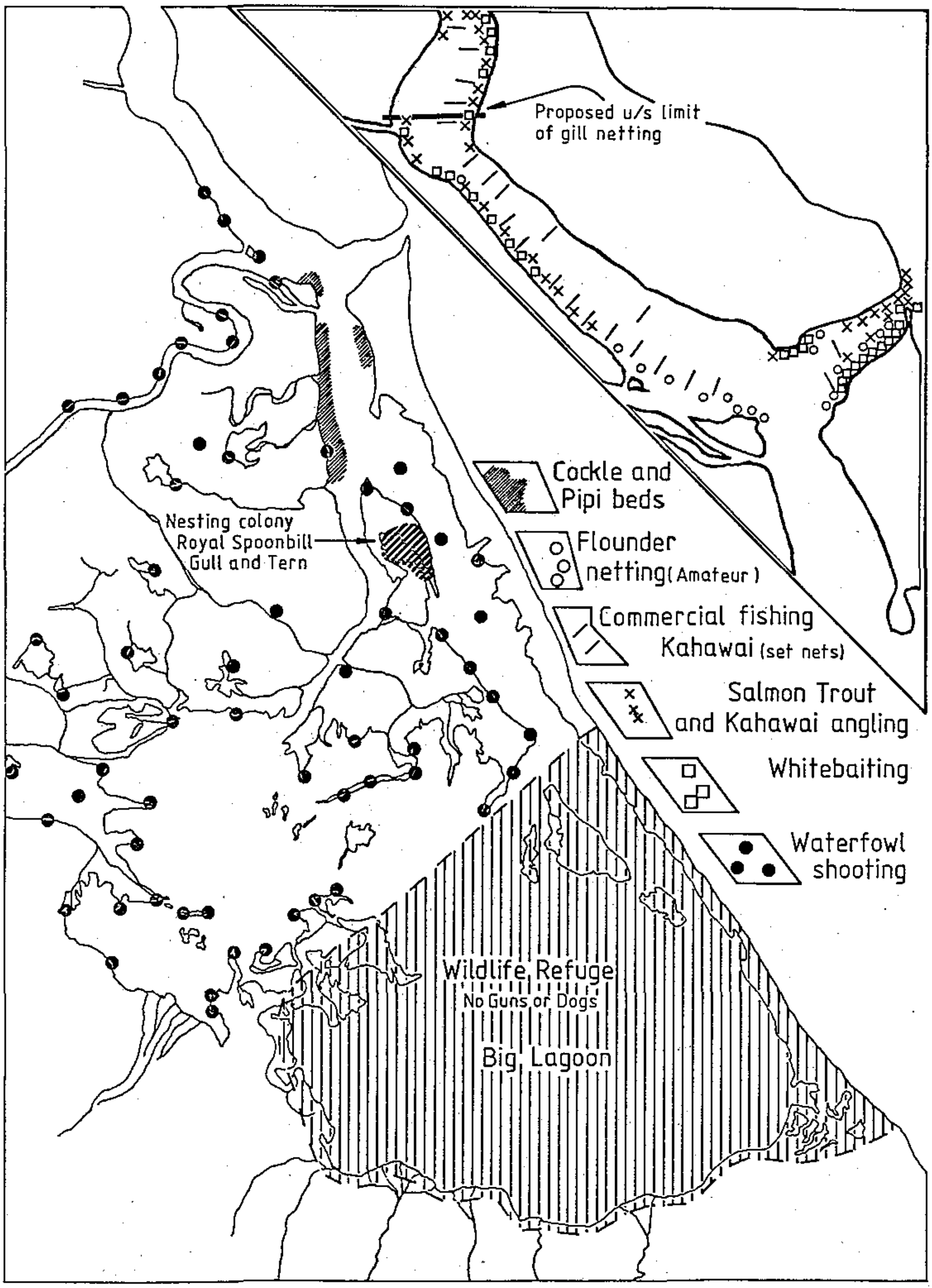

Fig. 12.2. Commercial and recreational fishing and waterfowl shooting activity in the Wairau River Estuary and the Vernon Lagoons. Based on data supplied by Mr R.G. Frost, Marlborough Acclimatisation Society.

13. BIRDS

13.1. Species present

Some 90 species of birds have been recorded from the Wairau River estuary and the Vernon Lagoons. Of these some 60 can be regarded as dependent upon the estuarine habitat wholly or in part. These are listed in Table 13.1 and an annotated list is given below.

Annotated list of the birds of the Vernon Lagoons area, Marlborough, with particular emphasis on birds dependent on the estuarine habitat (data supplied by Mr R. Holdaway).

1. Black shag (*Phalacrocorax carbo*). Breeds in small numbers on drift logs in the lagoon and Wairau River estuary proper. Feeds in the open lagoons and river channels.

2. Pied shag (*Phalacrocorax varius*). 50-100 pairs breed on drift logs at the Wairau/Opawa confluence and near the point of Moerepo Island. Have colonised the area since the 1950's (B.D. Bell, *pers. comm.*). Feeds in the main channels and particularly in and near the Wairau River mouth and just offshore.

3. Little black shag (*Phalacrocorax sulcirostris*). Not known to breed in the area. Up to 6 birds have been noted, roosting with pied shags near Moerepo Island. They feed in the main channels and lagoons.

4. Little shag (*Phalacrocorax melanoleucos*). A few pairs nest with the pied shags and other small colonies are known on the Opawa River, in willows. They feed in the channels and also fly inland to feed in rivers and streams.

5. Spotted shag (*Stictocarbo punctatus*). Birds from nesting colonies in Port Underwood, and possibly elsewhere, roost and preen on the Boulder Bank tip and feed in adjacent seas, occasionally in the river mouth and extreme lower reaches of the Wairau.

6. White-faced heron (*Ardea novaehollanidae*). Since its spread throughout the country in the 1950's, this heron has been reasonably common in the area although its presence was reported as early as 1894. Birds feed on the mudflats and channel edges, roosting on snags. They nest in trees and plantations further inland.

7. White heron (*Egretta alba*). Birds dispersing from the breeding colony near Okarito (and possibly new arrivals from Australia) use the lagoons and lower reaches of the Wairau as feeding grounds, roosting on snags and in trees near the coast. Up to about 6 birds are present at one time, usually from late summer into winter.

Table 13.1. Bird species recorded from the Wairau River Estuary and the Vernon Lagoons.

Species	Status
1. Aquatic zone	
Black shag (*Phalacrocorax carbo*)	B
Pied shag (*Phalacrocorax varius*)	B
Little Black shag (*Phalacrocorax sulcirostris*)	P
Little shag (*Phalacrocorax melanoleucos*)	B
Spotted shag (*Stilbocarbo punctatus*)	P
Southern black-backed gull (*Larus dominicanus*)	B
Red-billed gull (*Larus novaehollandiae scopulinus*)	B
Black-billed Gull (*Larus bulleri*)	P
White-winged black tern (*Chlidonias leucoptera*)	V
Black-fronted tern (*Sterna albostriata*)	P
Gull-billed tern (*Gelochelidon nilotica*)	V
Caspian tern (*Hydroprogne caspia*)	B
Eastern little tern (*Sterna albifrons*)	V
White-fronted tern (*Sterna striata*)	B
2. Bivalve and mudflat zone	
White-faced heron (*Ardea novaehollandiae*)	P
White egret (*Egretta alba*)	V
Little egret (*Egretta garzetta*)	V
Reef heron (*Egretta sacra*)	P
Cattle egret (*Bubuleus ibis*)	V
Glossy ibis (*Plegadis falcinellus*)	V
Royal spoon bill (*Platalea regia*)	B V
Black swan (*Cygnus atratus*)	B
Paradise shelduck (*Tadorna variegata*)	P
Chestnut-brested shelduck (*Tadorna tadornoides*)	V
Mallard (*Anas platyrhynchos*)	B I
Grey duck (*Anas superciliosa*)	B
Grey teal (*Anas gibberifrons*)	B?
N.Z. shoveller (*Anas rhynchotis variegata*)	B V
N.Z. scaup (*Anthya novaeseelandiae*)	P
South Island pied oystercatcher (*Haematopus ostralegus finschi*)	P
Variable oystercatcher (*Haematopus unicolor*)	P?
Least golden plover (*Pluvialis fulva*)	M V
N.Z. dotterel (*Charadrius obscurus*)	V
Banded dotterel (*Charadrius bicinctus bicinctus*)	B (G-S)
Large sand dotterel (*Charadrius leschenaulti*)	M V
Black-fronted dotterel (*Charadrius melanopus*)	M P
Wrybill (*Anarhynchus frontalis*)	M V
Far-eastern curlew (*Numenius madagascariensis*)	M V
American whimbrel (*Numenius phaeopus hudsonicus*)	M V
Little whimbrel (*Numenius minutus*)	M V (G-S)
Eastern bar-tailed godwit (*Limosa lapponica*)	M P
Terek sandpiper (*Tringa cinerea*)	M V
Turnstone (*Avenaria interpres*)	M P
Knot (*Calidris canutus*)	M P
Sharp-tailed sandpiper (*Calidris acuminata*)	M V

Table 13.1. continued

Table 13.1. continued

Pectoral sandpiper (*Calidris melanotus*)	M V
Curlew sandpiper (*Calidris ferruginea*)	M V
Red-necked stint (*Calidrus fuscicollis*)	M V
Pied stilt (*Himantopus himantopus leucocephalus*)	B
Black stilt (*Himantopus novaezealandiae*)	M V
3. <u>Marsh zone</u>	
Canada goose (*Branta canadensis*)	V I
Bittern (*Botarus stellaris*)	B
Marsh crake (*Porzana pusilla affinis*)	B
Spotless crake (*Porzana labuensis plumbea*)	P
Pukeko (*Porphyrio porphyrio melanotus*)	B
Kingfisher (*Halcyon sancta vagans*)	P
Welcome swallow (*Hirundo neoxena*)	B
Australian tree martin (*Hylochelidon nigricans*)	V
4. <u>Grass-scrub zone</u>	
N.Z. harrier (*Circus approximans gouldi*)	B
Rock pigeon (*Columbia livia*)	B I
Shining cuckoo (*Chalcites ludicus*)	M P
Little owl (*Athene noctua*)	P
Skylark (*Alauda arvensis*)	P I
Pipit (*Anthus novaeseelandiae*)	P
Dunnock (*Prunella modularis*)	P I
Brown creeper (*Finschia novaezeelandiae*)	P
Grey warbler (*Gerygone igata*)	P
South Island fantail (*Rhipidura fulginosa*)	P
Song thrush (*Turdus philomelus*)	P I
Blackbird (*Turdus merula*)	P I
Silvereye (*Zosterops lateralis*)	P
Bellbird (*Anthornis melanura*)	P
Yellowhammer (*Emberiza citrinella*)	P I
Cirl bunting (*Emberiza cirlus*)	P I
Chaffinch (*Eringilla coelebs*)	P I
Greenfinch (*Carduelis chloris*)	P I
Goldfinch (*Carduelis carduelis*)	P I
Redpoll (*Carduelis flammea*)	P I
House sparrow (*Passer domestica*)	P I
Starling (*Sturnus vulgaris*)	P I
Californian quail (*Lephortyx californica*)	B I
Spur-winged plover (*Lobibyx miles novaehollanidae*)	P O

B - breeding; P - present; M - migrant; V - rare or vagrant; I - introduced; (G-S) - also grass-scrub zone.

8. Little egret (*Egretta garzetta*). These small egrets are occasionally reported; they feed along the margins of the main channel and lagoons. They are vagrants from Australia. In New Zealand they frequent mainly estuarine mudflats.

9. Reef heron (*Egretta sacra*). Reef herons are now rarely seen in the area. The closest breeding probably occurs in Port Underwood. Birds feed along the muddy shores of the lagoons and channels when present.

10. Bittern (*Botaurus stellaris*). Bitterns are probably confined to the lower reaches of the Opawa River and a few other places where raupo (*Typha*) swamps occur. The total population is probably under 10 birds.

11. Glossy ibis (*Plegadis falcinellus*). These large wading birds are very rare vagrants from Australia and have been seen feeding on flooded paddocks at Dillons Point and on mudflats. They roost in trees.

12. Royal spoonbill (*Platalea regia*). The Vernon Lagoon area may now hold the only viable colony of this bird in the country. Breeding was first confirmed in the summer of 1979-80 and now about 9 pairs attempt to nest every year, using a variety of sites. These range from nests built on the ground in the black-backed gull colony on Moerepo Island, to appropriated pied shag nests on drift logs. The maximum count has been 42 birds. This is about 70% of the New Zealand population. They feed in the shallows of the main channels and lagoons and roost on snags and nearby trees.

13. Black swan (*Cygnus atratus*). The lagoons and channels provide a major feeding ground for this introduced species, several thousand birds being present on occasions. Birds from Lake Wairarapa, Farewell Spit, Lakes Ellesmere and Rotorua have been seen there. Many nest near the "Kidney Ponds" near the southeast corner of Big Lagoon and along the western margin of this lagoon.

14. Canada goose (*Branta canadensis*). Several dozen birds are usually present on lagoons and sewage treatment ponds. The flock includes birds from breeding grounds further south and locally released birds.

15. Paradise shelduck (*Tadorna variegata*). The lagoons have long been a moulting and feeding ground for this species. After a period of decline in the late 19th and early 20th centuries (probably associated with former large-scale taking of birds for the Wellington market) the late-summer/autumn flock now numbers over 1000 birds. These congregate mainly on the open water and raised banks of the oxidation ponds where they have both an unobstructed view and refuge.

16. Mountain duck (*Tadorna tadornoides*) (= chestnut breasted shelduck). This close relative of the paradise shelduck has only recently been recorded in New Zealand (apart from an early skin apparently from Lake Ellesmere). A flock of seven was found with 1000+ *T. variegata* on the new Waitaki-NZR oxidation pond on 2 April 1983.

17. Mallard (*Anas platyrhynchos*). The most abundant duck on the lagoon area. Birds breed on the vegetated islands, along the southern and south western shore and up the main rivers. Large flocks feed on the tidal flats and more open channels. The lagoon refuge and oxidation ponds are major moulting sites and retreats during the shooting season.

18. Grey duck (*Anas superciliosa*). Regular, in small numbers. Hybrids between this and the mallard are common. Moults on the open waters but is more likely found on smaller channels and creeks in this area.

19. Grey teal (*Anas gibberifrons*). Occurs at times with small flocks, rarely on the BBC oxidation ponds.

20. N.Z. shoveler (*Anas rhynchotis variegata*). Present and breeding on the lagoons in small numbers. Several hundreds flock on the oxidation ponds in later summer and autumn and, after the wing moults, fly out to other waters to feed.

21. N.Z. scaup (*Aythya novaeseelandiae*). A few birds are occasionally seen on the main lagoon and oxidation ponds.

22. N.Z. harrier (*Circus approximans gouldi*). Up to 12 birds present. Breeds in cover on the islands and elsewhere. Takes ducks, ducklings and other birds as well as carrion, etc.

23. California quail (*Lophortyx californica*). Small covies present where suitable cover exists around the lagoons especially on the southern side.

24. Marsh crake (*Porzana pusilla affinis*). Has been reported prior to 1972 ("in small numbers"). Probably still present in suitable habitat along the Opawa and Wairau Rivers and where *Juncus* and/or *Typha* marshes and swamps occur.

25. Spotless crake (*Porzana tabuensis plumbea*). Located in *Typha* swamps near the Redwood Pass Road in 1980. Probably present in all suitable areas at least along the southern shores and perhaps along the Opawa. As with the marsh crake, very secretive.

26. Pukeko (*Porphyrio porphyrio melanotus*). Not abundant, but up to 18 birds seen at once in swamp vegetation around the "Refuge". In all suitable habitat from the Opawa and Wairau Rivers around the western and southern sides. Comes out on to damp paddocks to feed.

27. South Island pied oystercatcher (*Haematopus ostralegus finschi*). One of the important estuarine birds, particularly from late summer through the winter. The approximately 200 birds present perhaps constitute the breeding population of the Wairau and Waihopai Valleys. They feed on exposed and shallowly covered mudflats, principally on cockles and roost at the Wairau Bar in the Upper Lagoon or on open paddocks at Dillons Point. In wet weather they may feed on earthworms in damp pastures.

28. Variable oystercatcher (*Haematopus unicolor*). An infrequent visitor? One or two birds occasionally noted.

29. Spur-winged plover (*Lobibyx miles novaehollandiae*). "Arrived" in the area in 1971. Have thrived and are now quite common with flocks of up to 50 seen in winter. Use mainly open pasture areas but also frequent small shallow pools, especially that destroyed during construction of the Waitaki/NZR oxidation ponds.

30. Least golden plover (*Pluvialis fulva*). An uncommon but probably regular Arctic migrant, e.g. at least 6 birds present at Moerepo Island in January 1979, and others (sometimes small flocks) seen in 1975-77 inclusive and in 1980. Uses open habitat and pools and pastures away from the coast as well as the mudflats.

31. Large sand dotterel (*Charadrius leschenaulti*). A rare straggler to N.Z., recorded once. Frequents mudflats, saltings and stony riverbeds at rivermouths.

32. N.Z. dotterel (*Charadrius obscurus*). Several records of individuals and, sometimes, small flocks of this rare endemic wader have been suggested to be evidence for a relict breeding population in the S.I. high country.

33. Banded dotterel (*Charadrius bicinctus bicinctus*). A common resident, on both dry paddocks (e.g. the Boulder Bank) and mudflats. Breeds in some numbers on the Boulder Bank and at other places, particularly near small pools. 27+ at (former) pool on site of Waitaki/NZR oxidation ponds is largest personal count at any one place.

34. Black-fronted dotterel (*Charadrius melanops*). A bird of muddy stretches along river backwaters but has been seen on the lower Opawa and on shallow pools in the area. A wintering flock of about 50 (probably the local population) has been seen on a paddock at Dillons Point. A recent Australian immigrant.

35. Wrybill (*Anarhynchus frontalis*). A regular passage visitor, in small numbers; on both mudflats and small freshwater pools. May be a "staging-point" during migration, particularly during bad weather in Cook Strait (migrates to/from Canterbury and Auckland).

36. Far-eastern curlew (*Numenius madagascariensis*). Probably regular, as single birds and flocks of up to 12. On mudflats, particularly at the north end of Moerepo Island and in the main channel.

37. American whimbrel (*Numenius phaeopus hudsonicus*). First N.Z. record in 1874, none known since at this site.

38. Little whimbrel (*Numenius minutus*). One present summer 1977/1978. Near small pond (where NZR/Waitaki oxidation ponds now sited) on short grassland (typical habitat).

39. Bar-tailed godwit (*Limosa lapponica*). The most important Arctic migrant. A flock of about 400 (rising gradually to a peak in late summer) is present each year, feeding on small invertebrates on the mudflats and about shallow pools and roosting near the small islands and in the upper lagoons. The area possibly serves as a staging point for flocks moving about the country near migration times.

40. Terek sandpiper (*Tringa cinerea*). One record, at the Wairau Bar.

41. Turnstone (*Arenaria interpres*). Probably a regular summer visitor to the area (Arctic migrant). A flock of 22+ was present at the Wairau Bar in January 1979, possibly on passage. Frequents stony and sandy beaches, in preference to mudflats.

42. Knot (*Calidris canutus*). Small flocks (e.g. 11, 24, 19) present during summer; possibly just "passing through". Although usually a strictly "mudflat" bird, here the main site was the (now vanished) pool near Morgans Creek (Waitaki/NZR oxidation ponds site).

43. Sharp-tailed sandpiper (*Calidris acuminata*). Probably a regular summer visitor in small numbers but difficult to locate in its typical habitat of small pools and lush vegetation, particularly now that the pool mentioned above has been destroyed.

44. Pectoral sandpiper (*Calidris melanotus*). Probably as for sharp-tailed but only three definite records, in 1975 and 1979.

45. Red-necked stint (*Calidris fuscicollis*). One record, in 1979. Probably a regular visitor, in small numbers, as at Lake Grassmere (in the unmodified section, near the airfield!).

46. Curlew sandpiper (*Calidris ferruginea*). Several records, including flocks of 7. Comments as for 45.

47. Pied stilt (*Himantopus himantopus leucocephalus*). A common, breeding resident. Colonies are usually in and near small freshwater pools; but feeding and roosting birds occur along all rivers, channels and lagoon margins as well as on fresh and brackish pools. Population usually 100-200 birds but larger flocks may use the area during late summer and early spring migration as southern birds move north to winter on northern harbours and return.

48. Black stilt (*Himantopus novaezealandiae*). One record, in 1964. May occur during post-breeding dispersal but total population is minute.

49. Southern skua (*Stercorarius skua lonnbergi*). One record, in 1980.

50. Arctic skua (*Stercorarius parasiticus*). One definite record, in 1978, of bird harrying white-fronted terns at the Wairau Bar but is certainly a regular offshore visitor to the area during the summer.

51. Southern black-backed gull (*Larus dominicanus*). An abundant, conspicuous breeding resident. Colony of 500-1000 pairs on Moerepo/Budges Island each year. Birds are present at all times about most of the area, including the oxidation ponds.

52. Red-billed gull (*Larus novaehollandiae scopulinus*). A common breeding resident and also non-breeding visitor from the Kaikoura colonies. Nesting may occur at many points about the area, usually on logs, but the main colony (25-30 pairs) is on the edge of the black-backed gull colony on Moerepo Island. Typical counts for the area are 150-200 birds in late summer.

53. Black-billed gull (*Larus bulleri*). A non-breeding visitor, usually in small flocks but up to 500 noted in spring, feeding on a wet paddock. Colonies further up Wairau and Waihopai Rivers.

54. White-winged black tern (*Chlidonias leucoptera*). Very rare vagrant, as far as known, but regular at river mouths further south which are more intensively watched. Feeds mostly over water, and marshland.

55. Black-fronted tern (*Sterna albostriata*). Winter visitor from riverbed breeding colonies. "Flocks" of c. 350-500 noted in April and May. Sometimes feed over lagoons and along channels but usually use the area to roost only, often feeding out of sight of land or at least offshore. An endemic species ("globally rare") and subject of investigations into population and movements - flocks noted above may represent entire Wairau Valley population, or even more.

56. Little tern (*Sterna albifrons*). A very rare straggler.

57. White-fronted tern (*Sterna striata*). A common, breeding tern which usually feeds offshore but often in the main channels and over the lagoons. Breeding occurs near the black-backed gull colony or on the southern point of the Wairau River mouth but both sites are often unsuccessful. Some hundreds are often present near the Wairau Bar.

58. Gull-billed tern (*Gelochelidon nilotica*). One recent record of this marsh tern, at the Wairau Bar, although there is strong evidence that a pair of this species is at present (summer 1982/1983) in the area.

59. Caspian tern (*Hydroprogne caspia*). Conspicuous, if not abundant, breeding species. The colony of 40-45 pairs near the black-backed gull colony is one of three regular colonies in the South Island and is thus one of the southernmost in the world. Feeds over inshore waters but perhaps mainly along the rivers, channels and over the lagoons, taking larger fish than the other tern species.

60. N.Z. kingfisher (*Halcyon sancta vagans*). Small numbers all around the lagoon area but not common. Breeding probably occurs in a few areas.

The variety and abundance of the birds in the area makes it one of the most important bird habitats in the South Island.

The estuary-lagoon complex provides an unparallelled habitat for aquatic birds and has done so for a considerable time. The moa-hunter culture was based on the area for a very simple reason, the abundance of food. This ranged from the large moas to the extinct goose, swan, coot and water fowl which frequent the area today.

13.2. Bird habitats and adaptations

The estuary, the lagoons, the marsh areas and the surrounding marginal lands provide a great variety of bird habitats. These can be grouped into major zones.

1. Aquatic zone - submerged at all times
2. Bivalve zone - cockles (*Chione*) and pipis (*Paphies*)
3. Sand-mudflat zone - crabs and polychaetes
4. Marsh zone -
5. Grass-scrub zone - fringe areas of grass and scrub

Each biological zone contains many different food items and the birds feeding in the zone have developed structural and behavioural adaptations to utilise the resources efficiently. The most obvious adaptations are to be seen in the morphology of the bird's foot and bill. To a large extent prey size and burrowing depth are correlated with the bill size of the birds concerned (Goss-Custard, 1977). Plovers have the shortest bill size of the estuarine waders and tend to feed mainly by surface pecking, taking small gastropods and crustaceans. Other waders of moderate bill length are able to probe the top 4 cm of the substratum, the zone inhabited by many of the invertebrates, including many polychaete worms and bivalves, as well as the tube-dwelling amphipod *Corophium*. Only the large-billed birds can cope with the deeper burrowing prey.

The availability of food, within the marine influenced aquatic, bivalve, sand-mudflat and marsh zones, is dependent upon the tidal ebb and flood. At high tide the aquatic zone covers the entire area up to the high water mark, while at low tide it is reduced to the system of low tide channels. The low tide extent is also dependent upon the flow of water in the Wairau River. Birds feeding in the bivalve or the sand-mudflat zone require either a minimum depth of water or the exposure of the flats to the air, before feeding takes place. This has been well documented for the South Island pied oystercatcher (Baker,1966, 1969). Some species of wading birds characteristic of the sand-mudflat zone also feed on the pastures of the grass-scrub zone. An important resource for the aquatic, bivalve and sand-mudflat zone species is the availability of high-tide roosts that provide freedom from disturbance. In the estuary-lagoon complex the Boulder Bank and the numerous islands of the Vernon Lagoons provide ideal sites for such high-water roosts.

It is evident that birds sharing the same zone possess somewhat similar body characteristics. Overall the birds exhibit a reduction in body size throughout the zones, progressing from larger seabirds down to smaller inshore species in the grass-scrub zone.

13.3. Seasonal abundance

The various species of aquatic birds fall into two groups: permanent residents, such as the black-backed gull, some of the shag species, and the majority of the marsh species; and seasonal species such as some of the waterfowl and the majority of the wading birds. The seasonal species fall into two groups: (1) overseas migrants such as the plovers, curlews, whimbrils, sandpipers, turnstones, knots and godwits; (2) New Zealand migrants, species that have a seasonal migration pattern within New Zealand such as Canadian geese, black swans, many of the ducks, white herons, royal spoonbills and the oystercatchers.

The overseas migrants breed in the Northern Hemisphere during the southern winter and migrate to New Zealand for the northern winter. The New Zealand migrants fall into two groups: (1) species which migrate to the area to breed such as some of the shag species, the royal spoonbills, black swans, some of the waterfowl species; (2) species which breed outside the area and migrate into the area during the non-breeding season, such as black-billed gulls, the white egrets, paradise shelducks and the oystercatchers. Thus the total number of species and the total number of individuals varies seasonally thus spreading out over the year the predation on the food resource.

13.4. Food habits

The food habits of the principal bird species are presented in Table 13.2. The wading birds can be divided into three groups, the herons feeding on small fishes, crabs and snails; the oystercatchers feeding mainly on bivalves; and the pied stilt and migrant waders feeding principally on small crustaceans and polychaete worms. The fishing birds (shags and terns) consume principally fishes but also take larger pelagic crustaceans. Gulls take a wide range of food items but also feed on carrion. Ducks consume principally plant material (up to 75%) and smaller amounts of animal material comprising mainly snails. Shore birds feed on small crustaceans, especially amphipods, small polychaete worms and molluscs, and insects. The pukeko feeds solely on marsh plants, the bittern on insects, crustacea, fish, lizards, frogs and mice, the spotless crake on insects, crustacea and molluscs, while the welcome swallow is insectivorous.

Tidal exposure and depth to which a prey animal burrows have a significant effect on the availability of food items. Animals living on the surface are easily captured but they have hard calcareous shells and carapaces to reduce desiccation during tidal exposure. They are thus difficult to utilise as food compared with the softer-bodied worms and crustaceans living 2 to 8 cm below the surface. To utilise these relatively numerous food items, birds need long thin bills to extract the delicate worms and tiny agile crustaceans, or the shorter heavier bill of the oystercatcher for the location and removal of bivalves from their shells. Thus the length of the bill is a critical factor in the utilisation of particular food items.

A considerable amount of research on the feeding characteristics and the factors controlling the numbers of estuarine birds, especially waders, over the last ten years especially in the United Kingdom (Evans, 1976; Goss-Custard *et al.*, 1977) has been carried out. Here in New Zealand Baker (1966, 1969, 1972) and

Table 13.2. Food habits of the principal estuarine birds.

Wading birds	
White-faced heron	Small fishes, crabs, snails
Royal spoonbill	Crustaceans, small fish, molluscs, insects
South Island pied oystercatcher	Bivalves, especially cockles, small invertebrates
Bar-tailed godwit	Crustaceans, polychaete worms, molluscs
Knot	Crustaceans, polychaete worms
Pied stilt	Crustaceans, polychaete worms, insects
Water fowl	
Black shag	Fishes
Pied shag	Fishes
Little shag	Fishes
Black swan	Water plants, especially *Ruppia*
Paradise shelduck	Aquatic vegetation, crustaceans
Mallard	Aquatic vegetation, crustaceans, molluscs
Grey duck	Aquatic vegetation, crustaceans, molluscs, insects
N.Z. shoveller	Aquatic vegetation, molluscs, insects
Black-backed gull	Carrion, bivalves, fishes
Red-billed gull	Carrion, crustaceans, fishes, insects
Black-billed gull	Fishes, insects, crustaceans
Black-fronted tern	Small fishes
White-fronted tern	Small fishes
Caspian tern	Small fishes
Kingfisher	Insects, crabs, fish, lizards, mice
Shore birds	
Banded dotterel	Crustaceans, small molluscs, insects
Black-fronted dotterel	Insects, crustaceans
Wrybill	Crustaceans, polychaete worms, insects
Turnstone	Crustaceans, polychaete worms, small molluscs
Marsh birds	
Bittern	Insects, crustaceans, fish, lizards, frogs
Spotless crake	Insects, crustaceans, molluscs
Pukeko	Shoots and roots of marsh plants
Welcome swallow	Insects

Best (1970) have studied the feeding activity of the South Island pied oystercatcher, the eastern bar-tailed godwit and the pied stilt on the Avon-Heathcote Estuary. The general conclusions arising from these studies are as follows (Prater, 1981):

(i) The number of birds studied to date are positively correlated with the biomass of food available both within an estuary and between estuaries.

(ii) There are preferred feeding areas which fill up first.

(iii) The feeding distribution of birds can be modified by sediment characteristics.

(iv) That intraspecific aggressive encounters increase as bird density rises.

(v) Prey availability may decrease due simply to the presence of more birds.

(vi) Feeding rates are highest in the mid-winter and lowest during the mid-summer.

(vii) Weather is a factor that influences feeding rates.

(viii) The availability of high tide roosts can be a limiting factor for some species.

13.5. Human impact

Changes in bird abundance and distribution have accompanied the development of the land surrounding the Wairau River estuary and the Vernon Lagoons. The draining of the surrounding swamp-lands has undoubtedly reduced the numbers of water native duck species although the introduced mallard has increased in numbers. Other species adversely affected have been marsh dwellers such as bitterns, crakes and pukekos. Pukekos are comparatively rare compared with swampy areas elsewhere in New Zealand.

White-faced herons, pied oystercatchers and gulls have increased in numbers in reaction to agricultural development, utilising new food resources by moving inland during high tide, or periods of bad weather to feed on worms and insects found regularly in ploughed fields and pasture areas. The Boulder Bank and the lagoon islands are of special value in providing roost and/or breeding areas for gulls, terns, spoonbills and waders.

The clearing of forest in the Wairau River catchment has increased flood volumes which have brought into the estuary and lagoons the drift trees and logs that provide nesting sites for the shag species. Without the trees and logs, breeding sites would not be available.

Thus the birds in the area exist in a state of dynamic balance with food supply, availability of nesting sites, predation pressure and human impact. One such impact is the annual shooting for duck species. As shown in Fig. 12.2 the estuary, lagoons and adjacent streams and ponds provide for a considerable number of shooters during the season. The spread of gorse and boxthorn on the Boulder Bank threatens the nesting sites of the banded dotterel (stony, sparsely grassed areas).

One feature of the area which has been prominent in recent years, has been the colonisation by new migrant species. Most have been the result of new species arriving from Australia. The white-faced heron while recorded at Wairau before the turn of the century never became a regular resident until the 1950's and was not common until the 1960's. More recently the welcome swallow and spurwinged plover became established. Two other species that are likely to become more prominent in the future are the little black shag and the black-fronted dotterel (Bell, 1979).

Thus the habitat and food resources of the area provide a range of habitats for a large number of bird species. Of particular importance is the breeding royal spoonbill colony representing about 70% of the New Zealand population.

14. THE ESTUARINE ECOSYSTEMS

14.1. The estuarine community

Communities are not random associations of independent organisms. Rather a community comprises an integrated set of interdependent species that are pre-adapted to the local set of physical conditions. The term community here is used in the sense as defined by Sanders (1960) as "a group of species that show a high degree of association by tending to re-occur together".

An analysis of the community structure of the subtidal areas is given in Table 14.1. It lists the frequency of a given species occurring as one of the 10 most abundant species at the 17 subtidal stations (maximum frequency = 17); and the quantitative importance of the species. The quantitative importance was determined by ranking the species from 1 to 10 by abundance at each station. A rank of 1 is given a value of 10 points; a rank of 2 equals 9 points; 3 is equivalent to 8 points; ... and a rank of 10 equals 1 point. Thus, if a species is ranked first at all 17 stations it will score 170 points, the highest possible score.

The results given in Table 14.1 show that there is dominance by the amphipod *Paracorophium lucasi* which is the most abundant species at 13 of the 17 stations and the second most abundant at another 3. Other species with high scores are the polychaetes *Heteromastus filiformis* (143), *Prionospio pinnata* (92), and *Paraonides* sp. (84) and *Scolecolepides benhami* (72).

The top 11 species from a very significant and relatively constant part of the subtidal biological assemblages are found in the subtidal zone. In general they are species with a relatively wide tolerance of environmental conditions.

When the species found in the intertidal zone are taken into account, it will be noted that there are changes in the species composition and dominance. Species which were not present in the subtidal include the mudflat snail *Amphibola crenata* and the crab *Hemigrapsus edwardsii*.

14.2. Comparisons with other New Zealand estuarine ecosystems

Table 14.2 compares the number of macroinvertebrate species found in the Wairau River Estuary with those recorded from a number of estuarine systems throughout New Zealand. The number recorded for the Wairau is only 20 which is 13 fewer than the locality with the next fewest number of species, the Ahuriri Estuary. However, in the Ahuriri Estuary study the smallest sieve used was 1.0 mm, while for all the other studies it was 0.5 mm, hence many of the smaller species may have been missed in the Ahuriri Estuary. The number of species in the Wairau River estuary is a half to one-seventh of those recorded in other estuarine systems. It can, therefore, be concluded that the species diversity is low indicating that the system is stressed.

Table 14.1. Faunal frequency evaluation for the subtidal samples.

		Ranking within a station										Frequency in the 17 stations	Frequency as one of the 10 most common species	Biological index (max. 170)	% of max. index
		1	2	3	4	5	6	7	8	9	10				
1	*Paracorophium lucasi*	13	3		1							17	17	164	96.1
2	*Heteromastus filiformis*	3	9	2		1	2					17	17	143	84.1
3	*Prionospio pinnata*			6	3	3	1					13	13	92	54.1
4	*Paraonides* sp.	1	3	1	1	2	4					12	12	84	49.4
5	*Scolecolepides benhami*		1	1	3	3	2		2			12	12	72	42.4
6	*Potamopyrgus estuarinus*			2		2	4	1	3			12	12	61	35.9
7	*Paphies australe*			1	1	2	2	3	3	1		13	13	60	35.3
8	*Chione stutchburyi*			1	1	2	2	3	3	1		13	13	60	35.3
9	*Boccardia syrtis*				3	1	3		1			8	8	45	26.5
10	*Nicon aestuariensis*				1	3		2	2	1		9	9	41	24.1
11	*Helice crassa*			1		1	3		3			8	8	38	22.4
12	*Paramoera* sp.					1	2	1				4	4	20	11.8
13	*Exosphaeroma planulum*						3	1				4	4	19	11.2
14	*Gammaropsis thompsoni*			1	1				1			3	3	18	10.6
15	Mysidae				1			1		1		3	3	13	7.6
16	*Aonides trifidus*					1						1	1	6	3.5
17	Polychaete sp.						1					1	1	5	2.9
18	*Macrophthalmus hirtipes*									2		2	2	4	2.4
19	*Halicarcinus whitei*									1		1	1	2	1.2
20	Nematode sp.									1		1	1	2	1.2
21	*Allorchestes* sp.										1	1	1	2	1.2

Table 14.2. Numbers of invertebrate macrobenthic species recorded from the Wairau River estuary and other estuaries in New Zealand.

	Crustacea	Mollusca	Polychaeta	Others	Total
Wairau River estuary - intertidal	10	3	7	0	20
Wairau River estuary - subtidal	8	3	8	1	20
Upper Waitemata Harbour (Auckland)[10]	21	31	25	10	87
Ahuriri Estuary (Napier)[1]	6	11	14	2	33
Parapara Inlet (Nelson)[2]	4	21	24	5	54
Waimea Inlet (Nelson)[3]	13	16	25	6	60
Nelson Haven (Nelson)[4]	5	11	17	3	36
Shakespeare Bay (Queen Charlotte Sound)[5] - intertidal	12	14	21	19	53
Shakespeare Bay (Queen Charlotte Sound)[6] - subtidal	25	35	51	27	138
Okarito Lagoon (Westland)[7]	15	7	3	17	42
Brooklands Lagoon (Canterbury)[8]	13	8	10	9	40
Avon-Heathcote Estuary (Canterbury)[9]	30	49	27	29	134

[1] Knox, 1979
[2] Knox *et al.*, 1977a
[3] Bolton and Knox, 1977
[4] Knox, 1979b
[5] Knox and Bolton, 1979
[6] Knox and Bolton, 1979
[7] Knox *et al.*, 1976
[8] Knox *et al.*, 1978
[9] Knox and Kilner, 1973
[10] Knox, 1983a

A comparison of the range of densities recorded in this study with those recorded in other estuaries is given in Table 14.3. From the data it can be seen that the density ranges are high in comparison with the Upper Waitemata Harbour and Parapara Inlet, and compare favourably with the more productive systems of Mapua and Brooklands Lagoon.

A comparison of the maximum species densities of the common invertebrates in the Wairau River Estuary with those recorded in other estuarine systems is given in Table 14.4. The maximum densities of the cockle *Chione stutchburyi*, the mudflat snail *Amphibola crenata* and the crab *Helice crassa* are low in comparison with the other estuaries. The maximum density of the pipi *Paphies australe* is low (452) in comparison with Brooklands Lagoon (9960). However, higher densities of both *Chione* and *Paphies* are certain to be found in unsampled areas in the Vernon Lagoons. The densities of the other species, especially the polychaetes, which are also common in the other estuaries, compare more favourably. The maximum density of the polychaete *Boccardia syrtus* is the largest recorded while that of *Heteromastus filiformis* is only exceeded in Brooklands Lagoon.

However, typical estuarine species that are not present in the Wairau River estuary are the gastropods *Zeacumantus lutulentus* and *Zediloma subrostrata*, the bivalves *Tellina liliana* and *Cyclomactra ovata*, and the polychaetes *Abarenicola affinis affinis*, *Aglaophamus macroura* and *Orbinia papillosa*.

This comparison with other New Zealand estuaries indicates that the Wairau River estuary, while having a low species diversity, has high densities of some of the species. These species in the main are detritivores feeding on organic matter with the associated microbial communities. This indicates that there is a substantial input of organic matter to the system.

Table 14.3. Comparison of the densities/m^{-2} recorded in the Wairau River Estuary with those found in other New Zealand estuaries.

		Density range	Mean density
Wairau River Estuary	Subtidal stations	1581-25967 (1154- 4961)*	
	Intertidal stations	172-19445 (129-12225)*	
Upper Waitemata Harbour[1]		115-611	377
Mapua, Waimea Inlet[2]		225-14907	5452
Parapara Inlet[3]		376-4760	2980
Brooklands Lagoon[4]		2383-160665	35830

1 Knox, 1983a
2 Bolton and Knox, 1977
3 Knox and Kilner, 1973; Voller, 1973
4 Knox *et al.*, 1978

* Numbers minus *Paracorophium* numbers.

Table 14.4. Comparisons of the maximum species densities/m^{-2} recorded in the Wairau River Estuary with those recorded from other estuaries.

	Wairau River Estuary	Upper Waitemata Harbour	Waimea Inlet	Parapara Inlet	Ahuriri Estuary	Avon-Heathcote Estuary	Brooklands Lagoon
Chione stutchburyi	1340	2050	2162	1426	7270	3050	3405
Paphies australe	452	-	pr	-	pr	-	9960
Amphibola crenata	95	268	166	63	580	425	1234
Potamopyrgus estuarinus	-	-	-	-	2500	45260	137724
Helice crassa	80	856	183	349	420	251	550
Macrophthalmus hirtipes	25	-	-	-	-	-	43
Paracorophium lucasi	22954	-	-	-	-	pr	47752
Aonides trifidus	172	-	4838	180	5000	6000	-
Boccardia syrtus	2193	-	1419	50	pr	1060	85
Heteromastus filiformis	8944	-	3000	50	pr	60	5873
Nicon aestuariensis	602	400	387	230	pr	1350	681
Prionospio pinnata	1431	-	5510	550	pr	128	-
Scolecolepides benhami	1281	-	-	50	1660	8000	1149

15. TROPHIC STATUS

15.1. Food webs in estuarine ecosystems

Estuaries, like all ecosystems, are dependent on the functions of primary production, primary consumption, predation and decomposition. However many of the biota are best described as particle producers and particle consumers. It is difficult to relate these two groups to the traditional primary producer/primary consumer categories. The primary producers in estuaries are the phytoplankton, the benthic (or sediment) microflora (Marshall *et al.*, 1971), the algal constituents of the periphyton (epiphytic algae) which coats all underwater surfaces such as the submerged parts of macrophytes, algal macrophytes such as the sea lettuce (*Ulva*) and vascular plants such as mangroves, rushes, sedges, *Spartina* and eel grasses. Of these, the vascular plants and the benthic microflora are the most important producers. Mann (1972) and Odum *et al.* (1973) have recently reviewed the role of vascular plants in estuarine ecosystems. Published data shows production ranging from 50 to 2,000 g C/m^{-2}/year with averages suggesting that annual production of 500 to 1,000 g C/m^{-2}/year is typical. This compares with the world averages quoted by Ryther (1969) for phytoplankton production of 50 g C/m^{-2}/year for the open ocean and 100 g C/m^{-2}/year for inshore waters.

The tendency for marine macrophytes to generate detritus rather than entering the grazing food chains has been noted many times. Teal (1962) showed that in the *Spartina* marshes of the Atlantic coast of North America only 5% of cord grass production is eaten by herbivores. The great bulk of the production enters the detrital food chains (Darnell, 1961, 1967). Data recently obtained from a study of the Kaituna marsh area at the top of Pelorus Sound (Odum, Knox and Campbell, 1983) has shown that detritus production from the *Spartina* and *Leptocarpus-Juncus* marsh areas is high, being in excess of ten tonnes dry weight per hectare per year (Odum *et al.*, 1983).

The process of decomposition of vascular plant litter in coastal waters takes the following form (Mann, 1972; Odum and Heald, 1975; Odum *et al.*, 1973). There is an initial period of autolysis during which soluble materials leach out. Bacteria and fungi then colonise the material (Odum and de la Cruz, 1967; Heald, 1969; Fenchel, 1970) and then begin to render soluble by enzyme action some of the previously insoluble material. The microorganisms absorb a proportion of the material they digest and some escapes. Populations of predators such as ciliates and nematodes begin to build up. Macro-benthic organisms begin to tear off pieces of the attached plant material with its attached community of micro-organisms. They strip off the micro-organisms as the detritus passes through their guts, the faeces are recolonised and the process is repeated by coprophagy (Fenchel, 1970; Johannes and Satomi, 1966; Newell, 1965). The cumulative results of this process are a steady reduction in particle size, with a consequent increase in the surface-area-to-volume ratio, an increase in microbial populations and a reduction in the C:N ratio of the detritus. Much of the detrital material so produced becomes incorporated in the sediments. It is thus available to deposit feeders of various kinds.

Organic matter in aquatic ecosystems exists as a continuum from organic matter in true solution, through macromolecules, colloids to true particles. Plant detritus in the process of breakdown follows the reverse of the sequence outlined in the previous sentence. For convenience an arbitrary division is made between DOM (dissolved organic matter) and POM (particulate organic matter). DOM is produced in two ways: (1) firstly by the direct release into the water as exudates and secondly the release of DOM in the processes of cell breakdown after death (autolysis or bacterial action).

Many algae, including blue-green, filamentous greens, diatoms and macro-algae, are known to release considerable amounts of organic material into the surrounding water. Data given in the literature range from 5-90%. Khaikov and Burlakova (1969) give a mean value of 37% of the gross production for seaweeds. Ribelin and Collier (1979) have drawn attention to the fact that benthic microalgae (both filamentous greens and diatoms) produce films of organic exudates on the surface of mudflats when they are exposed to the tide which are lifted by the flood tides to be transported later to settle to the bottom as fine particulate aggregates. For seaweeds Khailov and Burlakova (1969) estimated that 28% of the plant gross production is released during the course of cell breakdown and 6% as soluble material from the resulting detritus. Thus up to 71% of the organic matter produced ends up as dissolved organic matter (DOM).

Detrital input into estuarine ecosystems is from two sources - autochthonous (produced within the estuary) and allochthonous (originating outside the estuary). River inflow is the most important source of allochthonous detrital material. In a recent study of the sources of autochthonous and allochthonous organic carbon available to the Nanaimo Estuary, British Columbia (Sibert, 1979; Henley, 1979; Naimen and Sibert, 1978, 1979; Sibert *et al.*, 1978) it was found that annually the benthic microalgae produce 4-55 g $C/m^{-2}/year^{-1}$, the phytoplankton 7.5 g $C/m^{-2}/year^{-1}$, the macroalgae 0.9-7.5 g $C/m^{-2}/year^{-1}$, the eel grass (*Zostera*) 26.8 g $C/m^{-2}/year^{-1}$ and the sedge (*Carex*) 546 g $C/m^{-2}/year^{-1}$. The major producers in the system were those that entered the food web as detritus. Allochthonous sources were the most important contributors of carbon with organic matter from the river, especially dissolved organic matter (2,000 g $C/m^{-2}/year^{-1}$). The standing crop of detritus in the top 5 cm of sediments averaged from 58 to 233 g $C/m^{-2}/year^{-1}$ depending on the site. The investigators found that the timing of the organic inputs was important with 70 to 93 percent of the total annual river inputs occurring during autumn freshlets. *Zostera* entered the food web during the winter, *Carex* contributed most during the early spring and the algae were most productive over the summer months.

In the Wairau system, river input of organic matter is probably very significant. A proportion of this input will enter the Vernon Lagoons and settle out on the mud surface as the current velocity decreases in the shallow lagoon areas. This impact will decrease as the Wairau diversion takes an increasing proportion of the flood flows. Of the autochthonous input *Zostera* dead plant material will enter the food web during the winter, *Juncus* and other rushes during the early spring and algae over the summer.

15.2. A model of the Wairau River Estuary and Vernon Lagoons

The large amount of organic matter that enters the system represents a potential food source of considerable magnitude. There are at least four ways by which dead plant material may be utilised by the microbial community (Odum and Heald, 1975): (1) dissolved organic matter → micro-organisms → higher consumers; (2) dissolved organic matter → sorption of sediment particles → higher consumers either directly or by way of micro-organisms; (3) leaf material → higher consumers; and (4) leaf material → bacteria and fungi → higher consumers.

The phytoplankton and the benthic microalgae also produce dissolved organic matter to add to the pool of DOM. In estuaries in general the benthic microalgae are the more important contributors. This pool of DOM may follow one of three pathways: (1) direct utilisation by bacteria and incorporation into microbial biomass; (2) sorption into particles; and (3) aggregation by physical processes to form subparticulate and particulate organic matter (POM).

As an end result of these processes of production and decomposition, there is produced a particle pool (Fig. 15.1) consisting principally of bacteria, detrital particles (POM) and microalgae which is available to the next trophic level, the particle consumers (Correll, 1978). While these particle consumers are principally detritivores feeding on detrital particles with their attached microbiota, many also consume the benthic microalgae, the phytoplankton and the sediment micro- and macro-fauna. Odum and Heald (1975) group these particle consumers into mixed trophic levels comprising the herbivore, omnivore and primary carnivore trophic groups. These animals are often collectively termed 'detritivores' or detritus consumers. As we have seen these animals generally feed on a mixture of bacteria, fungi, protozoa, small multi-cellular animals (meio-fauna), and benthic microalgae. Haines (1979) considers that they should be more aptly termed "opportunistic omnivores". In this study of the mudflat snail *Amphibola crenata* which grazes on the surface sediments of the mudflats, Juniper (1982) found that while both the sediment bacteria and microalgae serve as significant sources of carbon for the snail (up to 50% of total requirements) a substantial input of additional carbon was required to meet its nutritional needs. Such additional sources could include micro- and meiofaunal animals and labile DOM and mucilaginous substances produced by bacteria and diatoms (Ribelin and Collier, 1979).

Odum and Heald (1975) found that the primary consumers of the estuarine system they studied could be placed in three

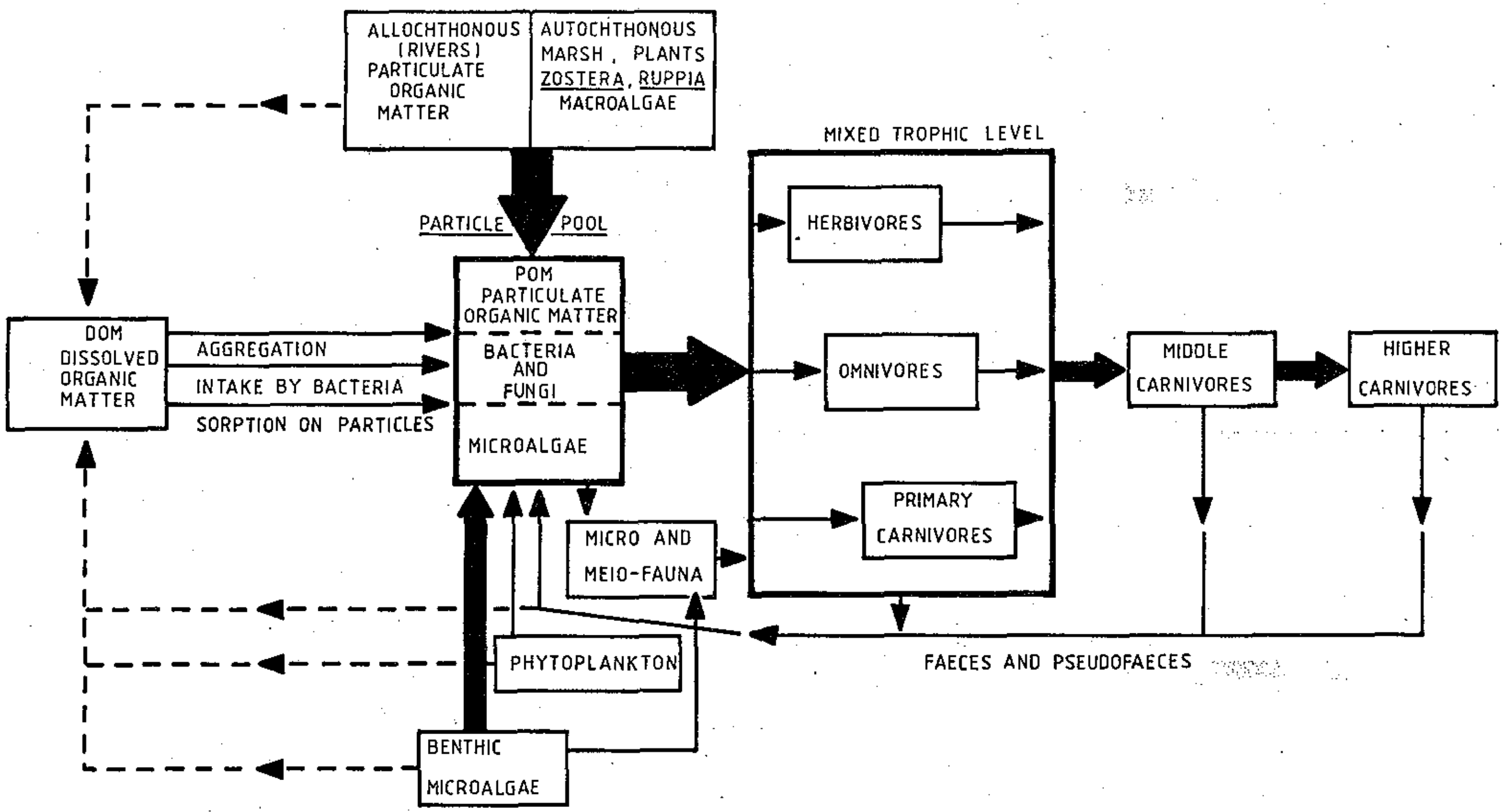

Fig. 15.1. A conceptual model of the Wairau River Estuary and the Vernon Lagoons food web.

functional groups: (1) grinders (also termed shredders) which take large leaf particles and chew them; (2) deposit feeders, which select smaller particles from the sediment surface; and (3) filter feeders, taking fine particles from suspension in the water above the sediment. Prominent among the shredders are some of the crustaceans, especially amphipods. The majority of the species fall into the deposit feeding category; included here are the mudflat snail (*Amphibola*), many bivalves such as the nut shell (*Nucula*), the wedge shell (*Tellina*), a range of polychaete species and fishes such as the yellow-eyed mullet.

Bacteria and detritus which settle at the sediment surface are easily brought into suspension a few cm above the sediment surface by currents, wave action or turbulence produced by the movements of animals. An additional factor now is the turbulence created by power boats. Hence filter feeding suspended particles just above the sediment surface is a very good way of obtaining food. It is found in a wide variety of benthic animals, including many of the dominants such as the cockles (*Chione stutchburyi*), the tube-dwelling amphipod (*Corophium*) and many polychaetes.

15.3. Eutrophication potential

The capacity of a body of water to produce living organisms is determined by its primary productivity. Within the Wairau River Estuary and the Vernon Lagoons the following contribute to the total primary production:

- marsh plants (rushes, sedges, etc.)
- seagrass (*Zostera*)
- macroalgae (*Enteromorpha, Ulva*)
- epiphytic microalgae (principally diatoms attached to the submerged parts of plants and solid substrates)
- benthic microalgae (diatoms and flagellates in the surface sediments)
- phytoplankton

The most important producers are the marsh plants and the benthic microalgae together with the seagrass and the macroalgae which are abundant in the Vernon Lagoons.

15.3.1. Nutrient inputs into the system

Apart from the data obtained during the present study, there is little information available on the nutrient levels of the Wairau and Opawa Rivers and the streams entering the system.

The supply of nutrients to the estuarine waters include the following:

(a) Freshwater drainage from the surrounding land;
(b) Input from the Wairau and Opawa Rivers and the various small streams;
(c) Direct waste discharges principally the sewage input from the Blenheim oxidation ponds;

(d) Decay of vegetation from marginal wetland areas;
(e) Regeneration from bottom sediments and oxidation of organic matter.

The major inputs are freshwater inputs and direct waste discharges. Input from the latter source will increase with the commissioning of the treatment plant for the Waitaki (N.Z.) Refrigerating Freezing Works. The degree of utilisation of the nutrients in the effluent for increased plant production will be dependent upon the residence time of such nutrients within the system.

15.3.2. The problem of eutrophication

The term "eutrophication" in its original context (Rodhe, 1969) applied to a natural process often described as the natural aging of lakes giving rise to increasing levels of plant production. The process of eutrophication may be vastly accelerated by man; under these conditions it has been called *cultural eutrophication* (Hasler, 1947). Thus the applied and popular definitions of eutrophication are usually man-centred (Likens, 1972). This is reflected in the definition adopted by the Organization for Economic Cooperation and Development.

"Eutrophication is the nutrient enrichment of waters which results in stimulation of an array of symptomatic changes amongst which increased production of algae and macrophytes, deterioration of fisheries, deterioration of water quality and other symptomatic changes that are found to be undesirable and interfere with water uses."

In estuaries the addition of excessive nutrients, usually nitrogen and/or phosphorus, can lead to an excessively eutrophic state. The high nutrient levels stimulated growth of a few algal species, which rapidly reach high population densities. Ketchman (1969) has discussed the eutrophication of estuaries and points out that in excess it leads to dramatic changes in the composition of the biotic community, with a progressive deterioration of water quality, often anoxic condition of sediments, advent of algal blooms, and the elimination of desirable (commercially important) fishes and shellfishes. Excessively eutrophic waters usually exhibit reduced species diversity, regular algal blooms and dissolved oxygen depletion. Normally algal blooms and oxygen problems associated with eutrophication occur in the warmer months of the year.

The severity of eutrophication in a water body is strongly controlled by the flushing rate. Rapidly flushed areas can tolerate higher levels of nutrient inflow than can stagnant areas. Shallow estuaries are generally well flushed and this tends to lessen the risk of eutrophication.

Numerous reviews of the nutrients controlling biological productivity in aquatic systems suggest that nitrogen and phosphorus either singly or in combination are usually the limiting factors (Stewart and Rohlich, 1967; Steel, 1972). In freshwater bodies phosphorus is generally the limiting nutrient. However, evidence has accumulated to show that nitrogen rather than phosphorus is the control factor limiting growth in coastal waters (Shapiro, 1970; Ryther and Dunstan, 1971).

Phosphorus as a limiting nutrient. Phosphorus exists in aquatic ecosystems as soluble and insoluble inorganic and organic phosphate. The concentration in estuaries depends on factors such as: (1) input from various sources related to run-off (river flow), the quantity in the incoming seawater, and the amount contained in incoming effluents and organic matter (allochthonous sources); (2) loss to and release from the sediments; and (3) organic reactions within the system.

In seawater as a whole the reported atomic ratio of nitrogen to phosphorus may be as high as 15:1 by atoms (the Redfield ratio; Redfield, 1958). Within algal cells the ratios of nitrogen to phosphorus may vary from 7-20:1 with an average ratio of 10:1 (Ryther and Dunstan, 1971; Healey and Hendzel, 1980). Thus as the two elements in the water are utilised by algae nitrogen compounds become depleted more rapidly and more completely than do the phosphorus ones. One might expect nitrogen to limit algal growth if the N/P ratio in the water is low (say less than 7/1) and, conversely, one might expect phosphorus to limit algal growth if the N/P ratio is high (say greater than 20/1). At intermediate ratios either N or P could be limiting.

Early work by Ketchman (1939) and Goldberg *et al.* (1951) indicated that phosphate-P concentrations above about 8-16 mg/m^{-3} were no longer limiting to algal growth. Whether phosphate limitation presently occurs in the Wairau system will be discussed below.

Nitrogen as a limiting factor. Nitrogen is available in aquatic ecosystems in the uncombined (N_2) state and as inorganic and organic compounds. The major sources of nitrogen input to an estuary include: (1) run-off (river flow); (2) input from effluents; (3) organic matter from allochthonous sources; and (4) nitrogen from *in situ* fixation (Stewart, 1969). Losses of nitrogen usually depend on the efficiency and demands of the ecosystem and occur through (1) outflow from the system; (2) loss to the sediments; or (3) the release of elemental nitrogen or ammonia through denitrification (Cairns *et al.*, 1972).

15.3.3. Present nutrient status

Data on nutrient levels measured during the current study are given in Table 9.1, while 15.1 summarises the available data.

From Table 15.1 it can be seen that both mean and maximum levels for all nutrient measures are highest in the Opawa River estuary. There are no significant differences between the levels in the Wairau River estuary and the Vernon Lagoons. The mean TON levels in the Opawa River estuary are 3 times those in the Wairau River estuary and the maximum TON levels nearly 4 times. For TIN the mean levels are 4.5 times and the maximum levels are 9.3 times

Table 15.1. Summary of nutrient concentrations in the Wairau River Estuary, the Opawa River Estuary and the Vernon Lagoons (upper line g/m^{-3}; lower line mg/m^3.

	Total organic nitrogen (TON)			Total inorganic nitrogen (TIN)			Total phosphorus (TP)			Dissolved reactive phosphorus (DRP)		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Wairau River Estuary	0.05 50	0.23 230	0.136 136	0.027 27	0.125 125	0.078 78	0.049 49	0.16 160	0.057 57	0.002 2	0.026 26	0.012 12
Opawa River Estuary	0.10 100	0.81 810	0.395 395	0.026 26	1.16 1160	0.353 353	0.024 24	0.14 140	0.06 60	0.012 12	0.073 73	0.028 28
Vernon Lagoons	0.09 90	0.20 200	0.148 148	0.016 16	0.140 140	0.068 68	0.021 21	0.12 120	0.054 54	0.006 6	0.016 16	0.015 15

higher. For TP the mean levels are only slightly higher while the maximum levels are slightly lower. On the other hand for DRP the mean levels are 2.3 times and the maximum levels 2.8 times higher. This clearly reflects the input of treated sewage effluent from the Blenheim oxidation ponds. The data from this study is compared in Table 15.2 with the average concentrations and perceived trophic state in several other New Zealand estuaries. The Wairau River Estuary and the Vernon Lagoons lie in the lower part of the table somewhat intermediate between Pauatahanui and Delaware Inlets which cope satisfactorily with their nutrient loads and could be regarded as slightly mesotrophic systems. The Opawa River Estuary on the other hand is more similar to the Nelson Haven where *Ulva/Enteromorpha* blooms occur.

15.3.4. Establishment of nutrient criteria

Various investigators who have studied algal growth requirements have discussed the concentrations of nitrogen and phosphorus needed to stimulate algal growth. The U.S. Department of the Interior, Federal Water Pollution Administration's (1980) Control Committee on Water Quality Criteria recommended an upper limit of 50 mg/m^{-3} of total phosphorus for estuarine waters. They made no recommendation for inorganic nitrogen other than that the naturally occurring ratio of nitrogen to phosphorus should not be radically changed.

Pritchard (1969) suggested that if total phosphorus concentrations in estuarine waters are kept below 30 mg/m^{-3} good water quality conditions would result. For the upper (freshwater) and middle (estuarine) regions of the Potomac Estuary, Jarowski *et al.* (1972) developed the nutrient criteria of 300-500 mg/m^{-3} of inorganic nitrogen and 30-100 mg/m^{-3} of total phosphorus for reversing the eutrophication process found there. Based on these and other studies and from experience gained in an intensive study of algal growth on nutrient levels in the Avon-Heathcote Estuary, Knox and Kilner (1973) suggested average upper limits of about 400 mg/m^{-3} for inorganic nitrogen and 40 mg/m^{-3} for total phosphorus.

From Table 15.1 it is noted that in the Wairau River Estuary the mean total phosphorus levels are 57 mg/m^{-3} and the mean inorganic nitrogen levels are 78 mg/m^{-3}. The mean total phosphorus levels are slightly above the recommended upper limit of 40 mg/m^{-3} while the mean inorganic nitrogen levels are only one fifth of the recommended upper limit of 400 mg/m^{-3}. It can therefore be concluded that in both the Wairau River Estuary and the lagoons, nitrogen not phosphorus is the limiting nutrient for plant growth.

15.3.5. Current trophic status and factors limiting primary production in the system

Nitrogen/phosphorus (N/P) ratios have been used as a measure of eutrophication potential. Table 15.3 lists a number of N/P ratios derived from the Wairau data. The mean TN/TP ratios in both the Wairau River Estuary and the Vernon Lagoons are less than

Table 15.2. Comparison of nutrient concentrations in several New Zealand estuaries (from Rutherford, 1982, Table 3).

Estuary	DRP mg.m^{-3}	TP mg.m^{-3}	TIN mg.m^{-3}	TN mg.m^{-3}	
Avon-Heathcote[1]	100^{+}	200	600	-	1960s sewage discharged continuously. Occasional nuisance blooms of *Ulva* and *Enteromorpha*.
Avon-Heathcote[2]	60	90	540	-	1975-6 sewage discharged on ebb tide. No nuisance blooms.
Ahuriri[3]	$143 \pm 14^{+}$	-	306 ± 33	-	'... comparable with Avon-Heathcote ...'[3]
Waimea Inlet[4]	-	158 ± 103	-	950 ± 530	Near outfalls, nuisance blooms
	-	28 ± 2	-	236 ± 8	
Nelson Haven[5]	89 ± 68	112 ± 73	82 ± 23	460 ± 270)	
Nelson Haven[6]	-	23 ± 3	76 ± 8	-)	'... an *Ulva/Enteromorpha* bloom situation ...'[6]
Nelson Haven[4]	-	45 ± 13	-	350 ± 124)	
Opawa River	28	60	353	395	
Mahurangi[7]	16 ± 2	95 ± 17	(29 ± 12)*	-	Productive oyster fishery
Upper Waitemata	15 ± 1	85 ± 5	240 ± 15	700 ± 100	
New River[8]	30	60	300	-	Turbid, *Spartina* problem
Pauatahanui[9]	12	-	(200)@	-	'... some enrichment evident ... coping satisfactorily with nutrient input ...'[9]

Table 15.2 continued.

Table 15.2 continued.

Vernon Lagoons	15	54	68	148	
Wairau River	12	57	78	136	
Delaware[10]	-	-	35	200	'... paucity of vegetative cover ... absence of significant polluting influence ...'[10]
Delaware[5]	14 ± 1	27 ± 3	40 ± 6	201 ± 12	
Parapara[3]	11	-	-	-	'... very clear water ...'[3]

Notes: + one figure denotes median, e.g. 100.
two figures denote mean ± standard error ($S/\sqrt{n}$), e.g. 143 ± 14

* NO_3 only

@ 300 in winter, <5 in spring, summer

1 Knox and Kilner (1973)
2 Unpub. University of Canterbury
3 Knox (1979)
4 Updegraff *et al.* (1977)
5 Unpub. Cawthron Institute
6 Unpub. Nelson Catchment Board
7 Reid (1978)
8 Unpub. Southland Catchment Board
9 Healy (1980)
10 Stanton *et al.* (1977)

Table 15.3. Nitrogen/phosphorus ratios of estuarine nutrient determination in the Wairau system (based on mean nutrient concentrations).

1. Total inorganic nitrogen (NH_3 + NO_3)/dissolved reactive phosphorus

	TIN/DRP ratios
Wairau River Estuary	11.3:1
Opawa River Estuary	14.1:1
Vernon Lagoons	9.9:1

2. Total nitrogen/total phosphorus

	TN/TP ratios
Wairau River Estuary	3.7:1
Opawa River Estuary	12.7:1
Vernon Lagoons	3.9:1

4:1. This is well below the 10:1 average ratio in algal material and indicates that in these waters nitrogen is the limiting nutrient.

The impact of sewage input is to be seen in the Opawa River Estuary where the TN/TP ratio is 12.7:1. This is close to the 10:1 ratio in algal material indicating that in these waters neither nutrient may be limiting. The mean TN/TP ratio of effluent from a domestic sewage treatment plant is about 6:1. This ratio is strongly in favour of nitrogen limited algal growth. Effluent from a meat treatment works has a TN/TP ratio of

Rutherford (1982) has modelled nutrient concentrations in the Upper Waitemata Harbour and from the model estimated the TP mass flow rates of inflow, washout, tidal exchange and retention. In spite of a fairly large uncertainty and variability it was possible to identify general patterns in the behaviour of nutrients in the estuary. At low flows, nutrient inputs were dominated by point sources and nutrient removal from the estuary by tidal exchange. At high flows nutrient input was dominated by stream inputs and removal by washout. The mass of nutrients retained within the estuary increased markedly with inflow rate with flood events being responsible for over threequarters of the TP retained. This may, in part, arise from the higher particulate TP fraction in the flood waters. At low inflow rates TP retention rates were close to zero.

The limited data that is available suggests that phytoplankton production within the estuary and the lagoons is low. Data from the Upper Waitemata Harbour Catchment Study (Knox, 1983a) indicate that phytoplankton production is highest in the regions of sewage input where the nutrient levels are highest. However in the Upper Waitemata Harbour phytoplankton production is limited by the turbidity of the water. It has been demonstrated that many estuaries have sufficient amounts of inorganic and organic turbidity to limit phytoplankton growth. Such conditions clearly are present in the shallow Vernon Lagoons.

The major microalgal production within the system occurs on the extensive mudflats of the Vernon Lagoons where the benthic microalgae in the surface sediment layer often develops a thin, clearly visible, blue-green film. Maximum production occurs when the tidal flats are exposed to the air. This microalgal production is an important source of food for sediment feeding fishes such as the yellow-eyed mullet and surface deposit feeding invertebrates such as the mud snail *Amphibola crenata* and the mud crab *Helice crassa*.

Large attached macroalgae such as the sea lettuce *Ulva lactuca* and species of *Enteromorpha* are present throughout the system especially in the Vernon Lagoons.

15.3.6. Possible impact of the discharge

It is anticipated that the effluent after treatment will have an ammonium nitrogen (NH_4^+-N) concentration of 40-70 mg/l and a nitrate nitrogen (NO_3^--N) concentration of 5-20 mg/l. If this is diluted a 1000-fold (the estimated dilution at the end of a 300 m mixing zone) the resulting concentrations would be .04-.07 mg/l and 0.005-0.02 mg/l respectively.

Measured concentrations of NH_4^+-N in the estuary proper range from 0.008-0.038 mg/l. Thus the resulting concentration of NH_4^+-N at the edge of the mixing zone would range from 0.13 to 0.058 mg/l. Levels of NH_4^+-N measured in the Opawa River range from 0.007-0.16 mg/l.

In view of (1) the NH_4^+-N will be rapidly oxidised to NO_3^--N and (2) that most of the water discharged on the outgoing tide will not return to the estuary, it is considered that the effluent discharge will have minimal impact on the estuary-lagoon complex. Whether this will be so could only be determined by monitoring the impact of the effluent discharge.

16. COLIFORM BACTERIA

16.1. Present coliform bacterial levels

16.1.1. Current coliform levels in shellfish from the Wairau River Estuary

Coliform bacteria present in the Wairau River Estuary are presently derived from a number of sources.

1. Domestic effluent discharged to the system
2. Surface runoff
3. Bird concentrations

To the above a fourth source will be added when the Meat Treatment Works are in operation.

There is little data available on coliform bacterial levels in the Wairau River estuarine system apart from some limited data for the Opawa River (Thompson, 1977). At a site upstream of the Blenheim Borough Oxidation Pond Outfall (approximately 750 m upstream from the confluence with the Wairau River) sampled on 26.1.77 the total coliforms were 12,500/100 ml and the faecal coliforms 4300/100 ml. On 2.2.82 at a site some 300 m upstream from the site sampled on 26.1.77, the corresponding levels were >250,000 and >23,000. Noonan (1982) states that typical effluents from oxidation ponds treating domestic effluent contain from 2.5-7.4 x 10^4 faecal coliform bacteria/100 ml. These elevated levels are to be anticipated in the lower Opawa River. They will be diluted downstream by mixing with the incoming tidal waters.

Farming activities in the catchment of the Wairau River provide a source of microorganisms in the river. There is however no data available on the levels in the river.

16.1.2. Faecal coliform levels in shellfish from the Wairau River Estuary

Over the period 15.6.80 to 5.8.80 the Fisheries Research Division, Ministry of Agriculture and Fisheries, carried out a preliminary investigation of faecal coliform levels in cockles (*Chione stutchburyi*) in the Wairau River Estuary (Hayden, 1980). Samples were taken at stations 2-4 shown in Fig. 11.7 and analysed using the most probable number technique as described in "Recommended Procedures for the Examination of Seawater and Shellfish", 4th Ed. 1970. The results of the analyses are given in Table 16.1.

Shellfish from all three stations contained faecal coliforms at levels that ranged from undetectable to very high (>24,000/100 g). There were no significant differences between the three stations and on the different sampling days the station showing the highest level varied in a random manner. There was also no significant trend in the coliform level with the flows recorded in the Wairau River at the time of sampling. The coliform bacteria may have originated from runoff from agricultural land in the Wairau River catchment, or from the discharge to the Opawa River

Table 16.1. Faecal coliform levels in cockles in the Wairau River Estuary.

Date sampled		Time sampled	High tide	Rainfall (mm in 24 hrs)	Flow in Wairau at noon on day of sample (m^3/sec)	Water temp °C	Faecal coliforms/100 g Station 2	Station 3	Station 4
June	13			4					
	14				190				
	15		0756		150		68	61	
	16		0855	4.7	125		20	40	
	17		0951						
	18			0.5					
	24		1516		60		45	230	45
	25		1557						
	29			0.9					
	30		0718	10.9	40		61	78	230
							45		
July	1		0814	1.1	480		91	20	<18
	2		0911						
	3			8.4					
	5			1.5					
	7	1630-1730	1347		90	8.5°C	230	20	<18
	8		1443	6.3					
	9			0.1					
	14	1615-1715	0728		85		110	20	540
			1956						
	15	1515-1615	0824	1.5	80	7.5°C	68	45	78
	16		0919						
	21	1630-1730	1310	3.3	40	7.5°C	9200	>24,000	>24,000
	22	1645-1745	1355	11.8	40	8°C	220	790	93
	23		1440	5.6					

Table 16.1. continued.

Table 16.1. continued.

	28	1430-1530	0556 1824		35	7.5°C	<18	<18	<18
	29	1545-1645	0648 1918		30	9-10.5°C	<18	45	170
	30		0746	1.2					
	31			1.0					
August	2			1.5					
	4	1645-1745	1235			10°C	170	45	<18
	5	1645-1745	1332			10.5°C	790	170	2,800
	6		1428						

from the Blenheim oxidation pond. A further possible source of bacteria are the concentrations of aquatic birds that are found in the area. Large concentrations of black swans were noted on a number of occasions in the vicinity of the sampling sites on the dates when elevated coliform levels were recorded.

16.2. Effects of microorganisms

The effects of microorganisms present in the waters of the Wairau River system can be divided as follows (Noonan, 1982):

1. Quality of the water in which fish are growing and being caught.

2. Quality of shellfish grown in water polluted by effluent.

3. Effect on contact recreation (swimming and water skiing in the estuarine waters).

1. Fish

Fish caught in the Wairau River estuary may have microorganisms from the wastes in the water sorbed onto their skin or present in their gut. However there is little evidence that the microorganisms multiply in the gut or pass into the flesh. Provided fish are cooked before consumption there is no danger to public health.

2. Shellfish

The sanitary status of shellfish exposed to domestic or meatwork's effluent has been a matter of concern since the beginning of the 19th century. Outbreaks of bacterial infection resulting from consumption of sewage polluted shellfish have been reported from many localities around the world (Metcalf, 1976).

This has led to a restriction being placed on the bacteriological quality of shellfish growing waters (e.g. in New Zealand the coliform count should not exceed 70/100 m^{-3}) or the level of faecal coliform bacteria in the shellfish themselves (less than 230 M.P.V. *Escherichia coli* per 100 g of shellfish flesh; Houser, 1965). Since a linear relationship exists between these two standards, either standard can be used.

From Table 16.1 it can be seen that on the majority of the sampling dates the coliform levels were below the recommended level of 230/100 g. However the level was exceeded at station 4 on 14 July, at all three stations on 21 July, at station 2 on 22 July, and at stations 2 and 4 on 5 August. It can therefore be concluded that for most of the time the shellfish were safe for eating but that some risk existed on a small number of occasions. It should also be noted that the samples tested were taken during the winter season and higher levels could be anticipated over the summer months. Noonan (1982) sampled shellfish (*Chione stutchburyi* and *Paphies australe*) on 7.11.77 and 7.2.78 in Brooklands Lagoon and found that levels on the second occasion (116-11,600/g) were much higher than on the first (80-3,770/g).

3. Concentrations of microorganisms in the water

For coastal and estuarine waters the SB classification which is the one specified for coastal aquatic recreation (swimming) requires that the median faecal coliform bacterial levels should not exceed 200/100 ml. Currently it is unlikely that such levels would be exceeded in the Wairau River estuary.

16.3. Probable impact of the meatwork's effluent on coliform bacterial levels

It is difficult at this time to evaluate the impact of the meatwork's discharge on coliform bacterial levels in the Wairau River estuary. Meatworks effluents generally have high coliform bacterial levels. While some reduction in these levels will be achieved during the treatment process, the effluent which will be discharged to the river will contain appreciable numbers of coliform bacteria (probably in the order of 2.5-7.5 x 10^4 faecal coliform bacteria per 100 ml).

The subsequent fate of these bacteria when discharged to the estuary will depend on a number of factors including:

1. The timing of the discharge.

2. The dilution of the effluent in the receiving water. The peak daily discharge will be 4,500 m^3. This treated effluent will be discharged over two daily periods of four hours on the outgoing tide giving a dilution factor of 1:1062 under average flow conditions.

3. The die-off of the bacteria in seawater.

4. The proportion of the water that leaves the estuary on one tide returning on the incoming tide. This has not been estimated. However the float tests carried out by Subsea Surveys Ltd indicate that water exiting from the estuary is rapidly dispersed well clear of the mouth and only a small percentage is likely to return.

It is therefore concluded that the impact of the effluent discharge on coliform bacterial levels can only be determined by monitoring after the treatment system comes into operation.

17. RECOMMENDATIONS FOR FUTURE MANAGEMENT

17.1. Location of outfall

Two sites were recommended for the location of the outfall (see Fig. 1.2). Site B in the estuarine channel was recommended by Hume and Williams (1981) from a hydrological point of view since:

1. The site is deeper and better mixing of the effluent would occur on the way to the surface.

2. Tidal current velocities are stronger in this area, particularly at the ebb tide, due to the outflow from the lagoons passing through this channel section.

3. The effluent will reach the entrance more rapidly enabling the effluent to be discharged for a longer period on the ebb tide.

4. Strong prevailing west-north-west winds will not blow effluent into the lagoons' entrance channel.

5. Effluent can be released early on the ebb tide without danger of it directly entering the lagoon entrance channel and there is less opportunity for accumulation in eddies.

6. The discharge is less likely to be affected by changes in channel configurations due to possible channel realignment works at the mouth of the Opawa River.

7. In the event of the channel diversion from the Wairau River altering the low flow fresh water input to the estuary, it is anticipated that site B could still enable effective flushing from the system because of the lagoon storage.

Now that the discharge pipe is located in the vicinity of site B, its operation should be monitored in order to see if it does perform as expected. In particular, it will be necessary to see if effluent accumulates in the eddy on the south side of the entrance channel (see Fig. 7.7). Observations should be made at intervals over the ebb and early flood tide at different levels of river flow (low to high).

17.2. Monitoring programmes

Monitoring of the effluent discharge has been recommended in the previous section. In addition, it is recommended that the following monitoring programmes be established.

1. Water quality

The water sampling that was carried out on 12 January 1982 should be repeated with a series of samples being taken at high, mid and low tide. These samples should be analysed for oxygen, nutrients (ammonium-N, nitrate-N, total-N, soluble reactive-P, total-P) and coliform bacteria. This monitoring should be planned to coincide with a period when killing at the works is in progress.

2. Shellfish coliform bacterial levels

Shellfish faecal coliform levels should be monitored at least twice a year; (a) during the winter when the works are not operating, and (b) during the peak of the killing season.

3. Biological

At a suitable interval (e.g. five years) a further limited biological survey be carried out to see if changes have occurred in the distribution and biomass of the benthic communities.

17.3. Erosion problems

One aspect that has been commented on is the degree to which the banks in the lower estuary, Te Aropipi Channel and throughout the lagoons are eroding. During the period of my own observations, this phenomenon was very obvious. The sediment from this erosion will add to the sedimentation or filling up of the Vernon Lagoons.

The reasons for this erosion are probably complex. It is not known to what extent the Wairau diversion channel has had an effect. One major contributing cause has undoubtedly been the changes which have occurred in the vegetation lining the banks of the channel. With sheep grazing down to the edge, most of the original vegetation which grew along them has been reduced by a grass sward. Gorse, which has grown along the banks in places, has been burnt, thus accelerating the erosion.

One suggestion that is made to see if the erosion can be lessened is to fence off a riparian strip along the Te Aropipi Channel and perhaps to combine this with some experimental planting of suitable plants.

17.4. Wetlands

Much of the original wetlands around the estuary have disappeared through a combination of drainage, burning and grazing. There are some remnants along the north side of the Wairau River estuary system from the wharf, along the lower reaches of the Opawa River and on the small island at the entrance to the Vernon Lagoons. It is suggested that these areas be fenced off (see Fig. 10.2) to prevent stock access and to allow the native plants to regenerate.

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