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Moutere Inlet Ecosystem Investigation

Report for: Tasman District Council

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EXECUTIVE SUMMARY

In this report we present the results of an investigation of the environmental status of Moutere Inlet, located approximately 24km northwest of Nelson near the town of Motueka. The study was carried out by Cawthron under contract to, and in collaboration with, the Nelson-Marlborough Regional Council (now part of the Tasman District Council). The overall goal was to establish and define the relative state of health of the Moutere Inlet ecosystem, in comparison to other similar inlets, in order to provide a basis for coastal planning decisions in the Nelson region.

Achievement of the study aim was accomplished by addressing the following specific objectives:

- To assess the state of enrichment of sediment habitats at representative sites in Moutere Inlet.
- To assess the quantity and quality of fresh water tributaries and discharges into the Inlet and their significance to the estuarine environment.
- To comment on the effects of embayments on the ecology of Moutere Inlet.
- To collect relevant information on the physical, chemical and biological characteristics of Moutere Inlet to provide a baseline for future monitoring.
- To identify present and potential threats to the estuarine environment of Moutere Inlet.
- To define an ongoing low-level programme to monitor changes in estuarine health in Moutere Inlet.

The state of enrichment of sediment habitats

The impacts of nutrient enrichment on sediment habitats in Moutere Inlet were investigated at 22 sites representative of the range of habitats found in the Inlet (see Figure 2). A series of sediment characteristics known to be affected by nutrient enrichment were assessed and evaluated in relation to enriched and unenriched intertidal sediments from other, nearby, locations (Delaware Inlet, Nelson Haven, Waimea Inlet). Table 19 demonstrates the levels of enrichment of the study sites as indicated by five key sediment descriptors. The sites are divided into four categories according to their ranking relative to the comparative inlets. Those assigned an N (non enriched) ranking were within a range observed at unenriched sites of similar textures in Delaware Inlet, Nelson Haven, and Waimea Inlet. Those ranked S (slightly enriched) were above the "normal" range but not to an extent that would indicate a deviation from normal habitat function. Those ranked E (enriched) were sufficiently elevated to indicate an altered habitat function. The ranking of H (highly enriched), was reserved for sites where deviation from normal habitat function resulted in major changes in benthic ecology: *i.e.* within a range observed at highly polluted sites in Waimea Inlet.

The majority of the 22 sites tested remain largely unenriched with respect to the suite of indicators evaluated. The only consistently elevated rankings occurred at sites 5A, 6A and 7 in the vicinity of the northern, Port Motueka, tidal outlet. The levels of enrichment observed there, with the exception of one site (Site 7) were insufficient to result in severe ecological alteration. The enrichment status of Site 7 was strongly influenced by a heavy macroalgal cover and this is probably due, largely, to the interruption of tidal flushing by Wharf Road and nutrient input via Thorp Drain.

Sites in the vicinity of the Kina outlet were not similarly enriched. Site 15, near the southern end of the Inlet, however, was characterised by elevated organic nutrients but other symptoms of enrichment were not expressed; probably because of its higher tidal elevation.

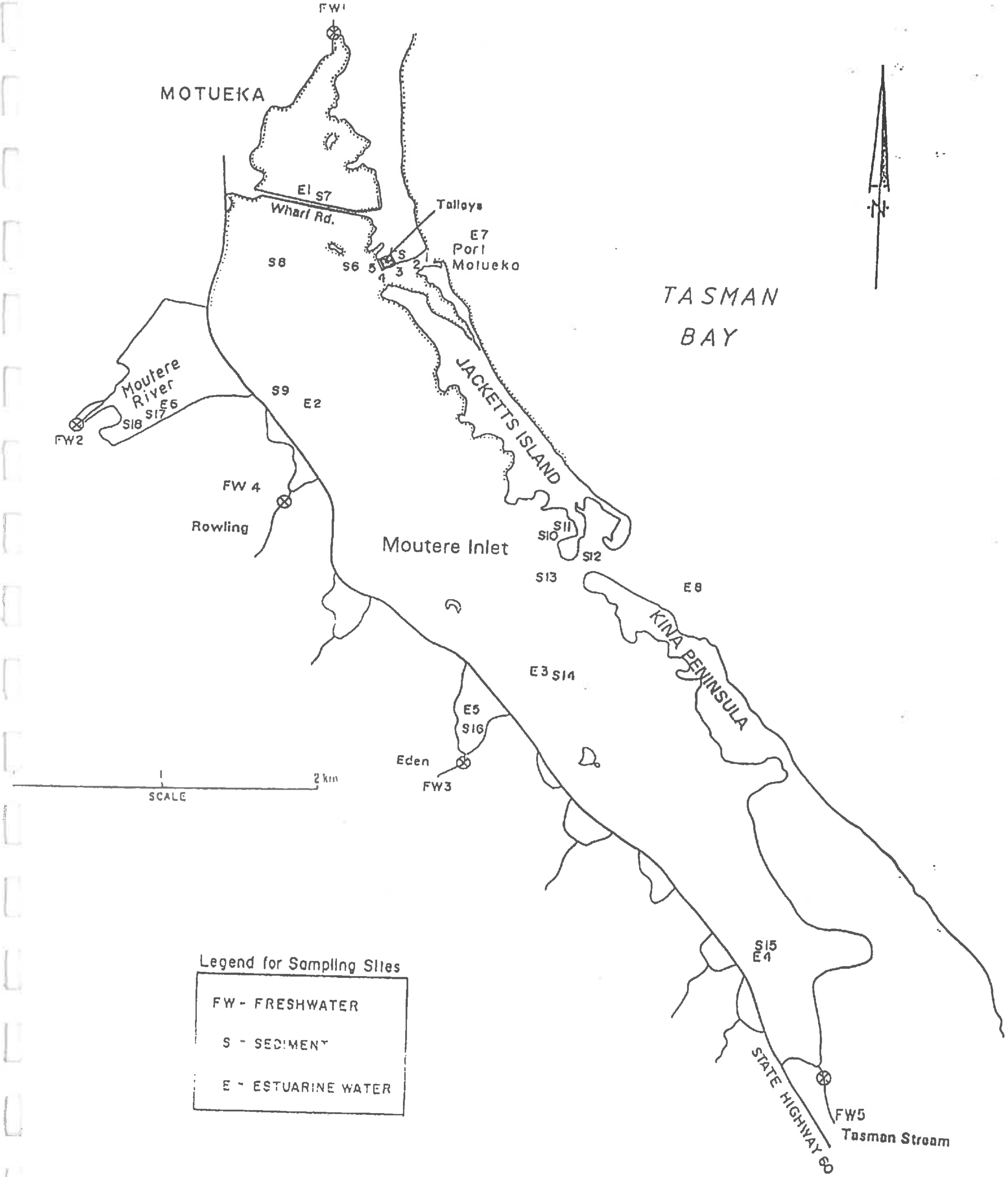

Figure 2. Moutere Inlet and site locations. Sediment collection subsites 5A, 6A, 12A and 13A were within 50m of corresponding sites 5, 6, 12 and 13 respectively.

Table 19. Comparative state of enrichment of Moutere Inlet sediments according to individual descriptors (N = No enrichment, S = Slight enrichment, E = Enrichment, H = Highly enriched, - = No data, * = Extreme patchiness, ** = Results invalidated by interference).

Site	SEDIMENT DESCRIPTOR				
	Macrophytes	**Chl *a***	**Min. Pot.**	**Organic nutrients**	**Profile**
1	N	N	N	N	N
2	N	N	N	N	N
3	N	N	N	N	S
4	N	N	N	N	N
5	E	N	-	N	-
5A	N	N	S	S	N
6	S	N	-	N	S
6A	S	N	S	S	S
7	H	N**	S	S	S
8	N	N	N	N	N
9	E	N	N	N	N
10	N	N	N	S	N
11	N	N	N	S	N
12	N	N	N	N	-
12A	N	N	N	S	S*
13	N*	N	N	N	-
13A	N	N	N	N	N
14	N	N	N	N	N
15	N	N	N	E	N
16	N	N	N	N	N
17	N	N	N	N	N
18	N	N	N	N	N

Sources of nutrients and other contaminants

The pattern of enrichment shown in Table 19 probably reflects, in part, the fact that the major fresh water inflow (Moutere River) is located in the northern arm of the Inlet, but other nutrient sources in this vicinity also contribute. As an example, we have compared total N inputs from inflowing freshwaters, seawater and known discharges. These comparisons suggest that nutrient discharges from Talley's Fisheries Limited are high relative to natural sources and therefore probably dictate the present state of enrichment of sediment habitats in parts of the Inlet. It is important to note, however, that, with the exception of Site 7, symptoms of excessive enrichment have not developed. This is probably due to the near-complete flushing of Inlet waters with each tide. As noted in Section 5.1, flushing is not complete at Site 7 due to flow restriction where Wharf Road bisects the Inlet. Nutrient sources affecting the upper end of the Inlet (*e.g.* Thorp Drain), in conjunction with less efficient flushing, result in a much increased potential for over-enrichment on the northern side of Wharf Road.

Faecal coliform levels of fresh water inflows and Moutere shellfish suggest some bacterial contamination; particularly in the upper Inlet. Because the highest MPN values occurred in the Moutere River arm, this tributary would appear to be the main source of bacterial contamination.

Shellfish and sediment trace metal concentrations were all within ranges observed in other unpolluted intertidal habitats of the region, however a later report by Woodward-Clyde (NZ) Ltd. (1993) of higher arsenic levels in Moutere cockles (approximately 10 times those observed here) indicate a possible new source of contamination that may warrant further investigation.

Organochlorine and organophosphate concentrations in Moutere sediments were all below detection limits for the methods used, indicating that, in general terms, Moutere Inlet is not grossly contaminated with these potential pollutants. However, we did not investigate the possibility that low, but potentially environmentally significant, levels may be present. A later report of low levels of DDE (an environmentally persistent breakdown product of DDT) in Moutere mudsnails (Woodward-Clyde ,NZ Ltd. 1993), suggests that sufficient background levels of this contaminant were present to account for some bio-accumulation.

Effects of embayments.

Removal of salt marsh from the periphery of the Inlet has the effect of decreasing its ability to absorb excess nutrients (see Section 3.6.1), however where embayments are converted to freshwater impoundments, interruption of the freshwater nutrient input is probably of overriding importance. Peripheral salt marshes are also significant for ecological reasons. They provide important habitat, including feeding and nursery areas for a variety of fish and invertebrate species. Loss of such habitat diminishes estuarine production with follow-on effects to the coastal food web.

Our sampling design included two embayments where partial flow restrictions occur (the Moutere River and Eden Stream arms). Neither showed signs of over enrichment. This is probably due, in part, to the relatively high tidal elevation of the embayments but it also suggests that flushing is sufficient to prevent accumulation of excess nutrients.

Present and potential threats to the estuarine environment.

In general, the Inlet seems to be in a relatively healthy condition with respect to plant and animal assemblages and the indicators of sediment enrichment, however some danger signs are evident. Macroalgal blooms (primarily *Ulva lactuca* and/or *Enteromorpha* sp.) were observed covering large areas of the Northern third of the Inlet. In most instances this increased plant productivity has not resulted in a deterioration of macrofauna community structure as defined by species diversity, indicator species, etc. Other characteristics of the sediments in the vicinity of the Port Motueka outlet also suggest some enrichment but again, with one possible exception, these changes are not to a degree that would indicate severe ecological alteration. They do, however, provide warning that these locations are sensitive to enrichment and that the potential for over-enrichment does exist.

Shellfish faecal coliform numbers (MPNs) were considerably in excess of N.Z. Department of Health guidelines for the maximum tolerance in foods (*i.e.* 230 per 100g) at six of nine sites tested during low-rainfall conditions. Although these results represent one point in time only, they suggest that shellfish in the Inlet should not be used for human consumption without depuration.

Gross contamination of Inlet sediments or shellfish was not observed with regard to trace metals, organochlorines or organophosphates. As indicated by later reports, however, low but environmentally significant levels of arsenic and DDE may be present at some locations. Further work would be required to determine if these represent a threat to the ecology of biological habitats.

Future monitoring.

We have assessed the trophic condition of sediment habitats in Moutere Inlet and identified nutrient sources likely to contribute to the observed variation amongst sites. Repeat analyses of the same variables on four occasions at sites 5A and 14 (23 March-13 April 1993) show a slight decline in trophic state as compared to the 1991 sampling (Gillespie, unpublished) but this could be due to normal year to year variation. To date, we do not have enough information to know if these habitats have reached a stable state or if the process of enrichment continues. It is likely that the 1991 observations are largely related to the immediate past history of nutrient input (*i.e.* one or two months) but this could also be superimposed on a longer term build-up of sediment organic contents where inputs exceed the microbes ability to decompose and recycle. As pointed out in the previous section, some danger signs are evident. For this reason, monitoring of selected sites would provide useful information for assessment of long term changes. Ideally, repeating the field surveys of all 18 sites with analyses of chl *a*, mineralisation potential, and organic nutrients at Sites 5A, 6A, 7, 9, 10, 11, 12A and 15 would provide a good indication of change over a monitoring interval *(e.g.* 4-5 years). The sites specified include those showing some degree of enrichment in the vicinity of the northern outlet as well as comparative sites near the southern outlet. If other sites show visual signs of change these could be investigated further as well.

The possibility of low-levels of contamination of Inlet sediments and/or biota with metals (e.g. arsenic) or organochlorines (e.g. DDE) may require further investigation. If levels of environmental concern are consistently observed at particular sites and potential sources are identified, these contaminants could also be incorporated into a monitoring programme.

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5	13/1211	S4	Habitat
6	21/1211	S4	Sediment profile
7	15/1211	S5	Habitat
8	6/1221	S5A	Habitat; note microalgal mat
9	19/1241	S5A	Sediment profile
10	2/1212	S6	Habitat (March 1993)
11	17/1241	S6	Sediment profile (March 1993)
12	-	S6A	Habitat
13	-	S6A	Sediment profile
14	7/1211	S7	Habitat
15	17/1242	S7	Sediment profile
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25	20/1212	S11	Habitat
26	10/1214	S11	Sediment profile
27	16/1212	S12	Habitat
28	6/1241	S12A	Habitat; note bank erosion
29	4/1241	S12A	Sediment profile
30	20/1213	S13	Habitat
31	12/1241	S13A	Sediment profile
32	25E/1241	S14	Sediment profile
33	2/1241	S14	Habitat
34	0/1212	S15	Habitat
35	14/1242	S15	Sediment profile
36	23/1211	S16	Habitat
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1.0 INTRODUCTION

1.1 Tidal inlets in the Nelson region

Estuarine systems are a vital and integral part of the coastal marine resource. Sustainable management of the coastal environment is critically dependant on understanding the biological habitat structure of estuaries and the processes that control their function.

In the Nelson region there are a considerable number of bar-built, tidal inlets with relatively small freshwater input and near complete drainage with the ebbing tide. They are generally characterised by open mud flats fringed with salt marsh in peripheral regions and productive sand flats in central regions colonised by microalgae, macroalgae or eelgrass. The Moutere Inlet, which is the subject of this investigation, along with Waimea Inlet, Delaware Inlet and the Nelson Haven are all typical of this type of estuary.

Primary (plant) and secondary (animal) production are important aspects of the contribution of tidal inlets to the coastal ecosystem. Intertidal habitats are also important for assimilating and recycling key nutrients. They act as a buffer zone to facilitate the processing of terrestrial run off so that the nutrients can be utilised in a beneficial way to support coastal productivity. To some extent these buffer zones dampen the "feast or famine" situation which might otherwise exist whereby coastal nutrient levels fluctuate widely, increasing the likelihood of troublesome phytoplankton blooms. Peripheral salt marsh is a prime example of such a coastal buffer zone. Infilling or roading development, for example, have in many cases disrupted the continuity of the salt marsh "buffer" zone thus diminishing natural estuarine "waste treatment" processes.

Now that coastal infilling is strictly regulated and kept to a minimum, one of the most serious threats to estuarine health in the Nelson region is nutrient enrichment. Excess organic and/or inorganic nutrients may enter estuaries through contributing fresh water catchments, direct land run off or via effluent discharges.

Nutrient inputs may be enhanced by agricultural or industrial development and increased population pressures to the point where over enrichment of benthic habitats can interfere with estuarine function. The distinction between beneficial and detrimental levels of enrichment is not always obvious until a state of severe over-enrichment is reached. This can result in a build up of decomposing organic materials in surface sediments leading to depletion of the levels of oxygen available to biological communities and production of toxic levels of hydrogen sulphide gas.

The levels of enrichment of estuaries could be compared to a continuum similar to that used to describe the process of eutrophication in lakes:

Oligotrophic (low nutrient) → Mesotrophic (moderate nutrient) → Eutrophic (high nutrient)

In tidal inlets there are additional complexities that must be considered. Owing to the dilution effect of tidal flushing, large short term fluctuations in nutrient concentrations of inlet waters may occur. Thus, it is difficult to detect changes in trophic status by analysing the water layer, except in the immediate vicinity of point sources of enrichment.

Sediment biological communities, on the other hand, can effectively integrate such fluctuations as they are able to respond in measurable ways to periodic or intermittent bathing in nutrient-rich waters or to enrichment by particulate matter. Thus it is much easier to characterise inlet sediments to determine enrichment status than the overlying waters. Variables that indicate sediment enrichment may vary widely amongst different habitats in the same inlet making it difficult to assign an overall trophic classification at the inlet level. For this reason, care must be taken to use similar habitats when comparing the enrichment status of different inlets.

Other contaminants can also affect the health of the estuarine and adjacent marine ecosystem. Heavy metals or pesticides, for example, could enter estuaries through land run off, where catchments are used intensively for horticulture, or through rubbish tip leachate. Those contaminants, if present in high enough concentrations could be toxic to estuarine biota or in some cases (*e.g.* lead or mercury) they could be carried on through the food chain and concentrated at higher trophic levels.

1.2 Moutere Inlet ecosystem investigation

In this report we present the results of an investigation of the environmental status of Moutere Inlet, located approximately 24 km northwest of Nelson near the town of Motueka (Fig. 1). The study was carried out by Cawthron Institute under contract to, and in collaboration with, the Nelson-Marlborough Regional Council (now part of the Tasman District Council).

1.2.1 Study aim

The study was designed to establish and define the relative state of health of the Moutere Inlet ecosystem in comparison to other similar inlets in the Nelson region.

The main purposes for the study were:

1. To provide a guide for considering resource consent applications to take water from, or discharge into, Moutere Inlet or contributing catchments.

2. To provide a basis for coastal planning (including other similar inlets) in the Nelson region.

1.2.2 Study objectives

Achievement of the study aims was accomplished by addressing the following specific objectives:

- To assess the state of enrichment of sediment habitats at representative sites in Moutere Inlet.
- To assess the quantity and quality of fresh water tributaries and discharges into the Inlet and their significance to the estuarine environment.
- To comment on the effects of embayments on the ecology of Moutere Inlet.
- To collect relevant information on the physical, chemical and biological characteristics of Moutere Inlet to provide a baseline for future monitoring.
- To identify present and potential threats to the estuarine environment of Moutere Inlet.
- To define an ongoing low-level programme to monitor changes in estuarine health in Moutere Inlet.

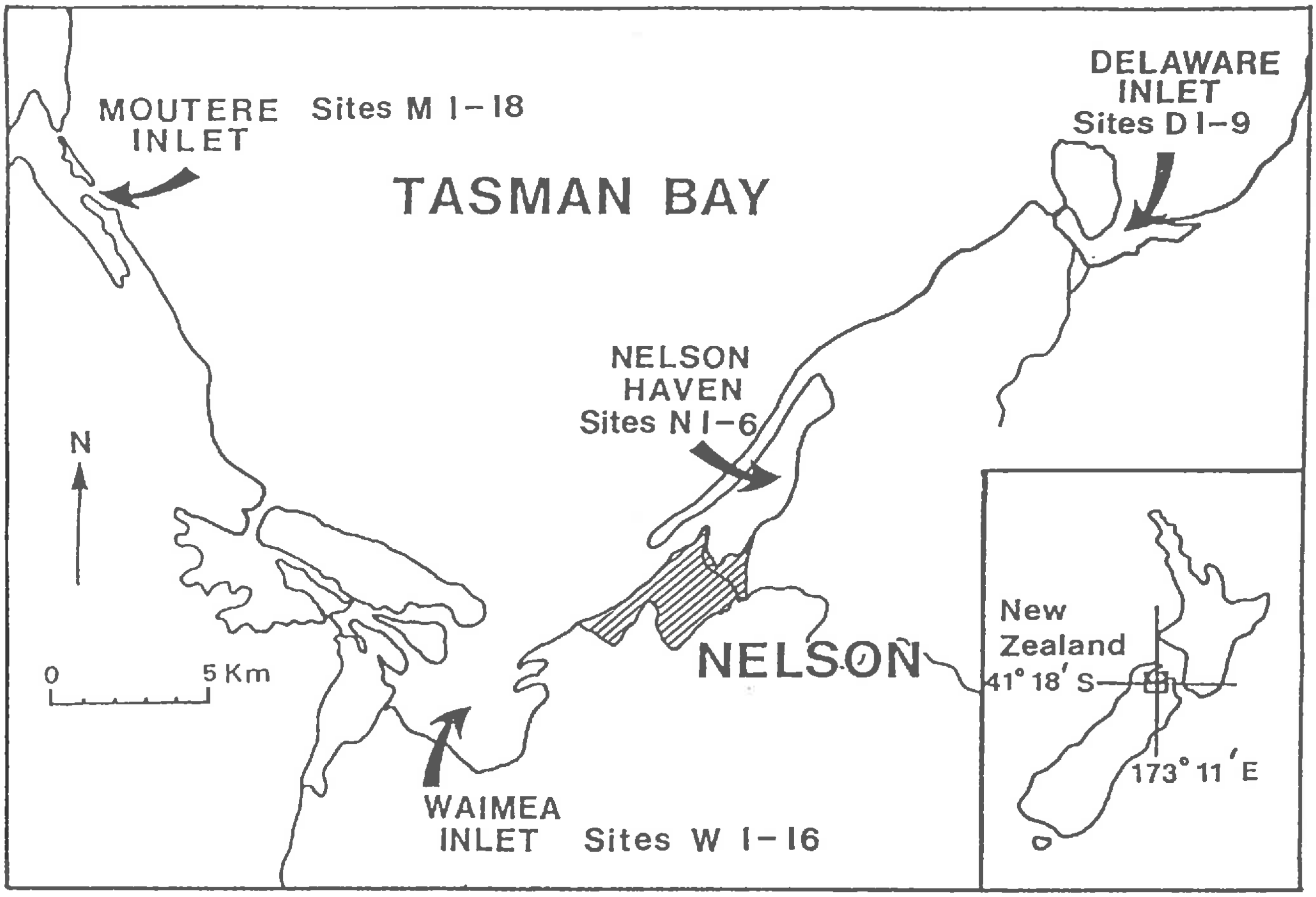


Figure 1. Study region: Location of Moutere Inlet and comparative inlets.

2.0 STUDY AREA

2.1 Moutere Inlet

Moutere Inlet (Fig.1) is typical, in general respects, to the description given in Section 1.1 for tidal inlets in the Nelson region. Comprising a total intertidal area of 713 hectares (Spencer and Westcott 1980) and extending approximately 8.5 km to the southeast from Motueka, the Inlet is open to the sea at two locations (Port Motueka and the northwestern end of Kina Peninsula).

The Inlet receives nutrient runoff from surrounding horticultural lands via the Moutere River (mean annual flow ~ 1280 $l.s^{-1}$) and a number of smaller inflow streams (total mean flow ~ 450 $l.s^{-1}$) as shown in Figure 2. Additional nutrients, both organic and inorganic, are discharged into the Inlet via other sources, some of which are covered by discharge permits and monitoring requirements. These sources include a fish and a vegetable processing factory, a refuse tip, sawdust dumps and urban stormwater.

2.1.1 Study sites

Eighteen intertidal sites and four subsites were selected to represent a range of sediment habitats (Table 1) within contrasting areas of the Inlet; *i.e.* the two outlets to the sea, the main body of the Inlet and peripheral embayments (Fig.2).

Table 1. Description of Sediment habitats sampled in Moutere Inlet (L, M & H = low, mid and high intertidal elevation).

Site	Location (WGS84)		Elev.	Substrate	Major Associations	
	Latitude	Longitude			Flora	Fauna
1	41 08 16,799 S	173 01 27,616 E	L	Cobble/Sand	None	Encrusting/polychaetes
2	41 08 17,413 S	173 01 25.837 E	L	Cobble/gravel/sand	None	Polychaetes/encrusting
3	41 08 17,860 S	173 01 24,933 E	L	Concrete rubble/cobble/sand	None	Polychaetes (*Capitella*) encrusting
4	41 08 20.395 S	173 01 14.707 E	M	Cobble/sand/shell	None	Cockle
5	41 08 20.287 S	173 01 12.895 E	M	Cobble/sand	Macroalgae	Cockle/black mussel
5A	41 08 18.792 S	173 01 12.935 E	M	Mud	Microalgae	Mud snail/mud crab
6	41 08 19.799 S	173 01 11.385 E	M	Sand/Shell	Macroalgae	Cockle
6A	41 08 18.306 S	173 01 11.047 E	M	Silty sand/shell	Macroalgae	Cockle
7	41 08 02.749 S	173 01 00.826 E	H	Mud/sand	Macroalgae	Cockle
8	41 08 12.240 S	173 00 53.550 E	H	Sand/Silt	None	Mud crab
9	41 08 50,235 S	173 00 49.703 E	M	Sand/gravel/shell	Macroalgae	Cockle/anemone
10	41 09 22.423 S	173 02 01.815 E	M	Mud/Sand	Macroalgae	Anemone/tube worm
11	41 09 21.961 S	173 02 02.784 E	M	Mud	Macroalgae (Sparse)	Cockle/anemone
12	41 09 27.741S	173 02 10.806 E	M	Cobble/gravel/sand	Macroalgae (Sparse)	Encrusting
12A	41 09 26.239 S	173 02 12.062 E	M	Sand/Silt	None	Polychaetes
13	41 09 33.519 S	173 02 02.226 E	M	Cobble/sand	Drift Macroalgae	Encrusting
13A	41 09 27.658 S	173 02 01.376 E	M	Fine sand	None	Topshell/whelk
14	41 09 58.283 S	173 02 00.392 E	H	Mud/sand	None	Mud crab
15	41 10 47.176 S	173 02 47.600 E	H	Mud	Macroalgae (Sparse)	Mud snail/cockle
16	41 10 03.690 S	173 01 41.118 E	H	Mud/sand	None	Mud snail/mud crab
17	41 08 49.061 S	173 00 21.053 E	H	Sand/silt	None	Mud snail/mud crab
18	41 08 53.172 S	173 00 08.723 E	H	Mud	*Juncus* marsh	Estuarine snail/mud crab

Sites were marked with 50mm x 50mm wooden stakes driven into the substratum. Most sites were located adjacent to a channel at approximately mean low tide, however a few were located at higher tidal elevations on tidal flats and in embayments. The sites were subsequently defined to within a 5m diameter area using a global positioning system.

Estuarine water samples were collected at three sites within the main body of the Inlet, three in peripheral embayments and one immediately outside each tidal outlet (Fig.2).

Freshwater surveys were carried out in the Moutere River, Thorp Drain, Tasman Stream, and tributaries of the Eden Road and Rowling Road embayments (Fig.2).

2.2 Comparative inlets

Results were compared with those of a previous investigation (Gillespie and MacKenzie 1990) of three similar inlets in the Nelson region: (1) Delaware Inlet, a largely unpolluted estuary northeast of Nelson, (2) Nelson Haven, a slightly enriched tidal extension of Nelson Harbour and (3) Areas of Waimea Inlet adjacent to point sources of high nutrient industrial effluents (prior to their reticulation into the regional sewerage treatment ponds at Bells Island). The results of an additional study of the impacts of the regional sewerage effluent on Waimea Inlet, carried out concurrently with the present study (Gillespie *et al.* 1992), have also been used to expand the comparative data base.

2.2.1 Study sites

Locations of sampling sites of the comparative studies are shown in Figure 1 and the sediment habitat of each is described in Table 2

Table 2. Description of benthic habitats of comparative inlets; D = Delaware Inlet, N = Nelson Haven, W = Waimea Inlet. (from Gillespie & MacKenzie 1990).

Site	Description
D1, N1, N4	Eelgrass beds on sand flats along main channels
D2, N2, N6	Cockle beds on sand flats colonised by sea lettuce
D3, N3	Cockle beds on sand flats colonised by *Enteromorpha* sp.
D4	Mud flats; uncolonised by macrophytes, microalgal mats or epifauna
D5, N5	Sand flats with a visible surface growth of microalgae
D6	Mud flats grazed by mud snail *(Amphibola crenata)*
D7	Saltmarsh (near seaward margin); predominantly sea rush (*Juncus maritimus*)
D8	Saltmarsh (near freshwater inflow); predominantly sea rush (*Juncus maritimus*)
D9	Open mud flats within marsh; grazed by mud snails
W1	Mud flats adjacent to fruit processing plant effluent pipe; highly reduced (anoxic)
W2	Mud flat adjacent to freezing works effluent; dense microalgal mat; highly reduced
W3	Mud flat adjacent to mechanical wood chip mill; uncolonised; darkly stained (tannins) but not highly reduced

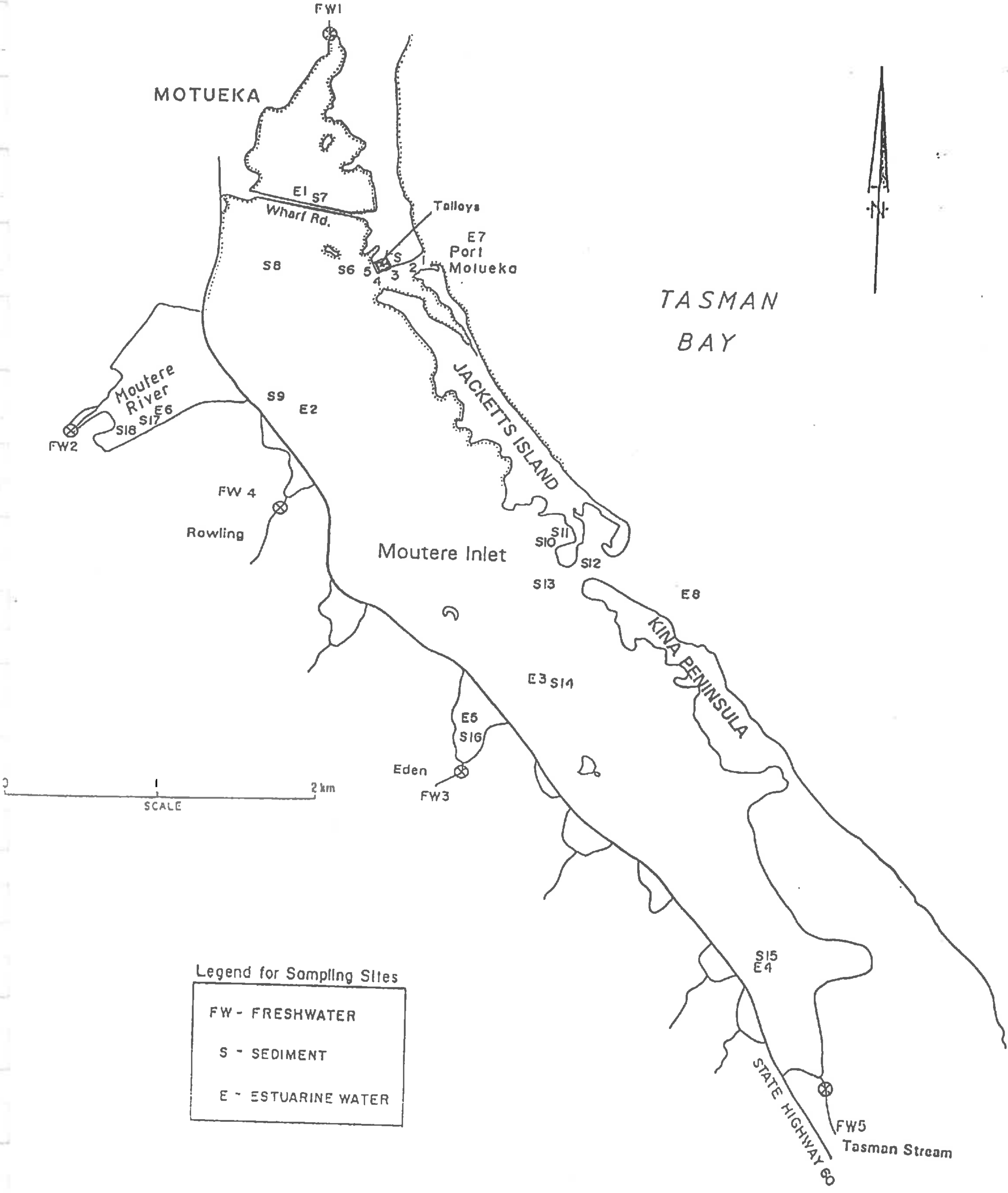


Figure 2. Moutere Inlet and site locations. Sediment collection subsites 5A, 6A, 12A and 13A were within 50m of corresponding sites 5, 6, 12 and 13 respectively.

3.0 METHODS

3.1 Field survey

Intertidal sites in Moutere Inlet were surveyed at low tide during the period December 1990 through March 1991. The field procedure was to photograph the site to provide a visual record of the habitat and to record observations of the following:

- General location (including tidal elevation).
- Sediment type (mud, sand, cobble, shell, etc.).
- Depth of soft sediment (five random probings using a solid brass rod 8 mm diameter and 950 mm length).
- Visible macrofauna (relative abundance of major species assessable in the field; *e.g.* crab holes, shellfish and surface fauna; O = occasional, L = low, M = medium and H = high population density).
- Macrophyte species and per cent coverage (mean of five 0.0625 m^2 quadrats).
- Sediment profiles (62 mm diameter cores extruded, photographed and described according to stratification of colour and texture).
- Obvious signs of enrichment or pollution (*e.g.* H_2S odours, fats, oils, unnatural debris)

3.2 Sediment grain size

An approximately 40 g (wet weight) subsample was taken from each of the sediments collected for chemical and microbiological analyses. These were washed through a 63 µm mesh sieve and the fraction greater than 63 µm from each sample was dried for more than 24h at 55°C. Dried fractions were weighed and the sample % moistures (see section 3.8) were used to calculate the percentages >63µm (sand) and <63µm (silt/clay).

3.3 Sediment microbial mineralisation

The microbial decomposition or mineralisation of organic materials in intertidal sediments is a critical process in the coastal marine environment. In estuaries this process perpetuates the food web by making organic debris more palatable to detritus-feeding animals (shellfish, crustaceans, etc.) and recycling inorganic nutrients for plant growth. The complex community of sediment microbes is able to respond rapidly to different forms of enrichment. They respond by increasing their numbers (biomass) and the rate that they are able to produce CO_2 from the organic substances they feed on. One way of determining the rate that sediment microbes are able to mineralise organic matter is to measure the rate of CO_2 production in natural sediments after additions of trace quantities of ^{14}C-labelled sugars. The rates of CO_2 evolution, which we call mineralisation potential, can be compared among similar habitats in a standardised way as an indicator of their relative enrichment status.

During this procedure, the top 1.0 cm of sediment was scraped off 15 replicate, 0.0625 m^2 area, circles using randomly placed PVC core tubes as a guide. Five replicates each were pooled into three composite samples. The samples were transported to the laboratory and refrigerated (4°C) until subsampled for microbial analysis (within 12 hours). The remaining samples were frozen (-20°C) for subsequent chemical and physical analyses.

The rate of mineralisation of added ^{14}C-glucose was measured in sediment slurries composed of $1cm^3$ sediment and 2ml filtered estuarine water. The technique was identical to that used by Gillespie and MacKenzie (1990). The maximum velocity of glucose mineralisation (mineralisation potential) was calculated according to Wright and Hobbie (1966) and used as a relative measure of the activity of heterotrophic microbial communities (microbes that decompose organic matter) in the sediments.

3.4 Sediment nutrients and organic content

Nutrients can also be measured directly in sediments, however it must be taken into consideration that rapid fluctuations can occur as they are transformed from one form to another or consumed by estuarine biota. Organic and inorganic nitrogen and phosphorus concentrations were determined on subsamples of the same composite samples used for microbial mineralisation estimations (Section 3.6). Inorganic nutrients (NO_2^-, NO_3^-, NH_4^+ and PO_4^{3-}) were determined on 1 molar KCl extracts of the sediments using standard analytical techniques for sea water analyses (Strickland and Parsons 1968; Solarzano 1969; APHA 1980). Dissolved inorganic nitrogen (DIN) levels were recorded as the sum of NO_2^-, NO_3^- and NH_4^+ concentrations. Total N (Kjeldahl + NO_3^--N) and total P determinations were according to Henrikson (1970) and APHA (1985) respectively.

Sediment moistures (weight loss after drying at 105°C) and total organic contents (loss on combustion at 550°C) were determined on subsamples of the same composite samples used for microbial mineralisation and nutrient analyses.

3.5 Benthic microalgae

Microscopic algae can often take advantage of excess nutrients under conditions which do not favour the larger forms (*e.g.* soft muds). In extreme cases of nutrient loading, dense green mats can be seen covering the sediment surface.

3.5.1 Sediment chlorophyll *a*

As an estimation of benthic microalgal biomass, chlorophyll *a* was extracted from the top 5 mm of 15 mm diameter sediment cores (in duplicate or triplicate) with 90% acetone and analysed according to Strickland and Parsons (1968) and Lorenzen (1967).

3.6 Benthic macrophytes

3.6.1 Salt marsh vegetation

Salt marsh grass such as the sea rush (*Juncus maritimus*) and jointed rush (*Leptocarpus similis)* often form a peripheral buffer at the land/sea interface of tidal inlets. They act as a sink for terrestrial nutrient runoff thus reducing the overall enrichment effects of macro- and microalgal growth in the estuarine and greater coastal environments.

Assessments of biomass or production rates of salt marsh plant species were not carried out during this study, however general locations of significant stands were noted and and their percent coverage estimated for the Inlet. Possible effects of historical changes on salt marsh habitat are discussed in Section 4.6.1.

3.6.2 Macroalgae

One of the most obvious signs of intertidal enrichment is the excessive growth and build-up of green macroalgae, such as sea lettuce (*Ulva lactuca*) and *Enteromorpha* spp., on tidal flats. Under favourable conditions they may form a continuous layer over the sediment reaching peak accumulations during late summer. Where a significant macroalgal cover existed (see section 3.1), surface vegetation was harvested from within 3-5 replicates of a randomly placed 0.0625m^2 quadrat. Samples were washed, dried and weighed to estimate macrophyte biomass. Estimates were made on two occasions, December 1990 (summer) and September 1991 (spring).

3.6.3 Eelgrass (*Zostera muelleri*)

Eelgrass beds often constitute a significant proportion of the total plant production of tidal inlets in the Nelson region. They generally occur at lower tidal elevations along channel margins however under enriched conditions their habitat area and growth can be limited due to over-growth by macroalgae. Eelgrass beds are not a major feature of Moutere Inlet and were therefore not included in the survey. Casual observations of the extent and distribution of eelgrass in the Inlet will be discussed in relation to enrichment status.

3.7 Benthic macroinvertebrates

Increasing levels of nutrient enrichment result in changes in sediment-living animal communities. All macroinvertebrates have particular habitat requirements or preferences (*e.g.* with respect to tidal elevation, substratum type, water quality, current velocity). For example, some species increase in numbers in response to enrichment, whereas others cannot exist in such conditions. Macroinvertebrate community structures of sediment habitats were assessed using two complementary techniques.

3.7.1 Surface counts

Counts of macroinvertebrates within 0.0625m^2 quadrats were recorded in the field. Between two and ten quadrats were examined per site. The number of 'crab holes' (burrows) present were recorded also.

3.7.2 Cores

To detect subtle changes in community structure, five replicate cores were collected to a depth of ~120mm at each of 18 sites using a 131 mm diameter PVC tube (area 0.0135m^2). Cores were washed through a 0.5 mm mesh sieve and macroinvertebrates were preserved with 70% ethanol/4% formalin for storage prior to sorting and counting.

3.8 Sediment and shellfish trace metals and pesticides

Composite sediment samples were collected from sites 3, 7, 12, 15, 16 and 17 by scraping the top 1 cm from five or more randomly selected points within 10 m of the site marker and transferring them to either acid washed polycarbonate jars (metals) or plastic bags (pesticides). Shellfish samples were collected from sites 12, 15, 16 and 17 and frozen until the analyses were carried out (within 30 days).

The various analytical procedures were as follows:

- Hg (shellfish and sediments) - cold vapour atomic absorption spectrometry.
- Pb, Cd, Zn, Cr, Cu (shellfish and sediments) - perchloric/nitric acid digestion and atomic absorption spectrometry.
- Se (shellfish and sediments) and As (sediments) - perchloric/nitric acid digestion and hydride generation atomic absorption spectrometry.
- As (shellfish) - Dry ashing with magnesium nitrate and hydride generation atomic absorption spectrometry.
- Organochlorines (aldrin, heptachlor, lindane, DDT, DDE, DDT, dieldrin) - samples extracted with solvent, concentrated and cleaned up prior to gas chromatography with electron capture detector.
- Organophosphates - samples extracted with solvent, concentrated and cleaned up prior to thin layer chromatography with visualisation by specific spray. This is a general screening technique to test for contamination with a broad range of organophosphate compounds including Gusathion, Lorsban and others.

3.9 Hydrology and water quality

Assessing the state of enrichment of sediment habitats is the first step to identifying appropriate management practices, however it is also necessary to identify the major sources of nutrients. Nutrients enter the estuary from both terrestrial (fresh water) and marine (tidal) sources. Obviously a detailed nutrient budget over a full year would be preferable for evaluating the relative significance of specific sources, and other contributing factors, such as catchment development, would have to be considered. Since this was not feasible in this case, we adopted a less detailed survey carried out under two different conditions of rainfall. Nutrient concentrations and flow rates of major freshwater inflows were compared with concentrations in the inlet at full tide and in sea waters immediately outside the inlet.

As a management guideline it is also important to assess the potential threat of pathogenic microorganisms within the estuarine resource. The most probable number (MPN) of faecal coliform bacteria was used an indicator of possible contamination with human pathogens.

The two surveys were carried out on 23 March and 25 July 1991.

3.9.1 Freshwater flow measurements

Freshwater inflows to the Moutere Inlet were assessed during the low flow conditions occurring on 23 March and during a rainfall event (fresh) on the evening of 25 July 1991. Flow rates were measured using either a current meter or a bucket and stopwatch, however very low flows were estimated by eye.

To assess the variability of freshwater inflows, a V-notch weir was installed in the Rowling stream (grid reference NZMS260 N27: 1120 0595) on 6 June 1991. A water level recorder operated at this site until 15 August 1991, and flow gauging during that period allowed a flow hydrograph to be plotted.

3.9.2 Nutrients

Freshwater and estuarine samples for nutrient analyses were collected in acid-rinsed polycarbonate bottles and either frozen upon return to the laboratory (hand collected samples) or preserved in Hg Cl_2 (Manning automatic sampler). Analyses of inorganic and organic N and P were as described in Section 3.4.

3.9.3 Faecal coliform bacteria

Water and shellfish samples for faecal coliform determinations were collected in sterile containers and plastic bags respectively and analysed within two hours of arrival at the laboratory. Shellfish were excised from their shells and the meat and liquor was homogenised and analysed similarly to water samples using the LT/EC standard multiple tube method (APHA 1985). Results were expressed as most probable number (MPN) per 100 g (wet weight) of shellfish or 100 ml of water.

3.9.4 pH, conductivity, salinity

Determinations of pH were carried out in the laboratory according to APHA (1985) method 423. Conductivity and salinities were either determined in the laboratory according to APHA (1985) method 205 and ASTM (1986) method D512, respectively, or in the field using an Orion Model 140 conductivity/salinity meter (27 July 1991 samples only).

3.9.5 Pesticides

Water samples were collected in acid-rinsed glass or polycarbonate bottles and frozen for later analyses according to the methods described in Section 3.8.

3.10 Bathymetry and sedimentation

Deposition and erosion of sediments over time could lead to significant changes in estuarine ecology. To provide a baseline against which future bathymetric changes can be identified, benchmarks were installed and 16 cross sections of Moutere Inlet were surveyed to DOSLI mean sea water datum between 14 May and 29 July 1991. In the area of inlet above the highway bridge and adjacent to Mariri tip, two cross sections (CS4 and CS7) were resurveys of those previously surveyed by the Nelson Catchment Board. Cross section transects were plotted, including a general description of the substrate, using the computer draughting package SDR-MAP.

4.0 RESULTS AND DISCUSSION

4.1 Field survey

Field survey information is summarised in Appendix I and specific aspects will be referred to in later sections of this report. This information, in conjunction with corresponding photographs (see list, p xi)) , will also provide a point of comparison for future investigations should they be required.

4.2 Sediment grain size

Sediment textures of the Moutere Inlet samples ranged from 4 to 80 % silt/clay (Fig. 3a). For discussion purposes, sediments composed of > 40% silt/clay are referred to as muddy whereas those composed of >60% sand are referred to as sandy. It is obvious from Figure 3a that some sites (*i.e.* 1-4, 9 and 13A) are clearly on the sandy side of the scale and others (*i.e.* 5A, 11, 15 and 18) may confidently be defined as mud. Since the remaining sites fall quite close to the cutoff point of 40%, their classifications are somewhat arbitrary. Some discretion must therefore be used when placing the latter borderline sites into the proper sub-groupings for comparison with other Inlets.

4.3 Sediment microbial mineralisation

Rates of microbial mineralisation (mineralisation potential) in Moutere Inlet sediments ranged from 0.1 to 2.7$\mu g.g^{-1}.h^{-1}$ (Fig.3c) and were in the range observed for comparable habitats in unpolluted sites in Delaware Inlet and slightly enriched sites in the Nelson Haven; *i.e.* 0.1 to 6.4 $\mu.g.g^{-1}.h^{-1}$. A comparison of individual site groupings amongst the same inlets, however, suggests some enrichment at sites 5A, 6A and 7. These three sites, located in macroalgal beds along the main tidal channel near the Port Motueka outlet, exhibited mean mineralisation rates of 1.0, 0.6 and 2.2$\mu g.g^{-1}. h^{-1}$, respectively. These rates are markedly higher than the mean of comparable habitats in Delaware Inlet and Nelson Haven (0.28±0.2 $\mu g.g^{-1}.h^{-1}$, n=30). Thus some enrichment of sediment microbes is indicated in the Port Motueka region, however the levels of enrichment were slight in comparison to highly polluted sites in Waimea Inlet where rates were more than one order of magnitude greater than those observed in Moutere Inlet (Gillespie and MacKenzie 1990). For further comparison, the microbial activities observed at sites 5A, 6A and 7 can be compared with the lower rates characteristic of sediments in the vicinity of the Nelson Regional Sewerage Scheme outfall in Waimea Inlet (0.20±0.24, n=20, Appendix V). This comparison suggests that little enrichment of microbial populations occurs near the outfall; probably due to the rapid current velocities there.

The highest rates of mineralisation observed in Moutere Inlet sediments were those from Site 7 where a partial restriction of tidal flow by roading is undoubtedly a major factor contributing to sediment enrichment. Ponding and incomplete tidal flushing results in a build up of algal biomass and an enhanced sediment deposition. Increased nutrient input to this region, from either above or (to a lessor extent) below Wharf Road, could result in a further enhancement of microbial activity and subsequent anoxia compounded by the restricted flushing. Further enrichment here could lead to severe environmental deterioration.

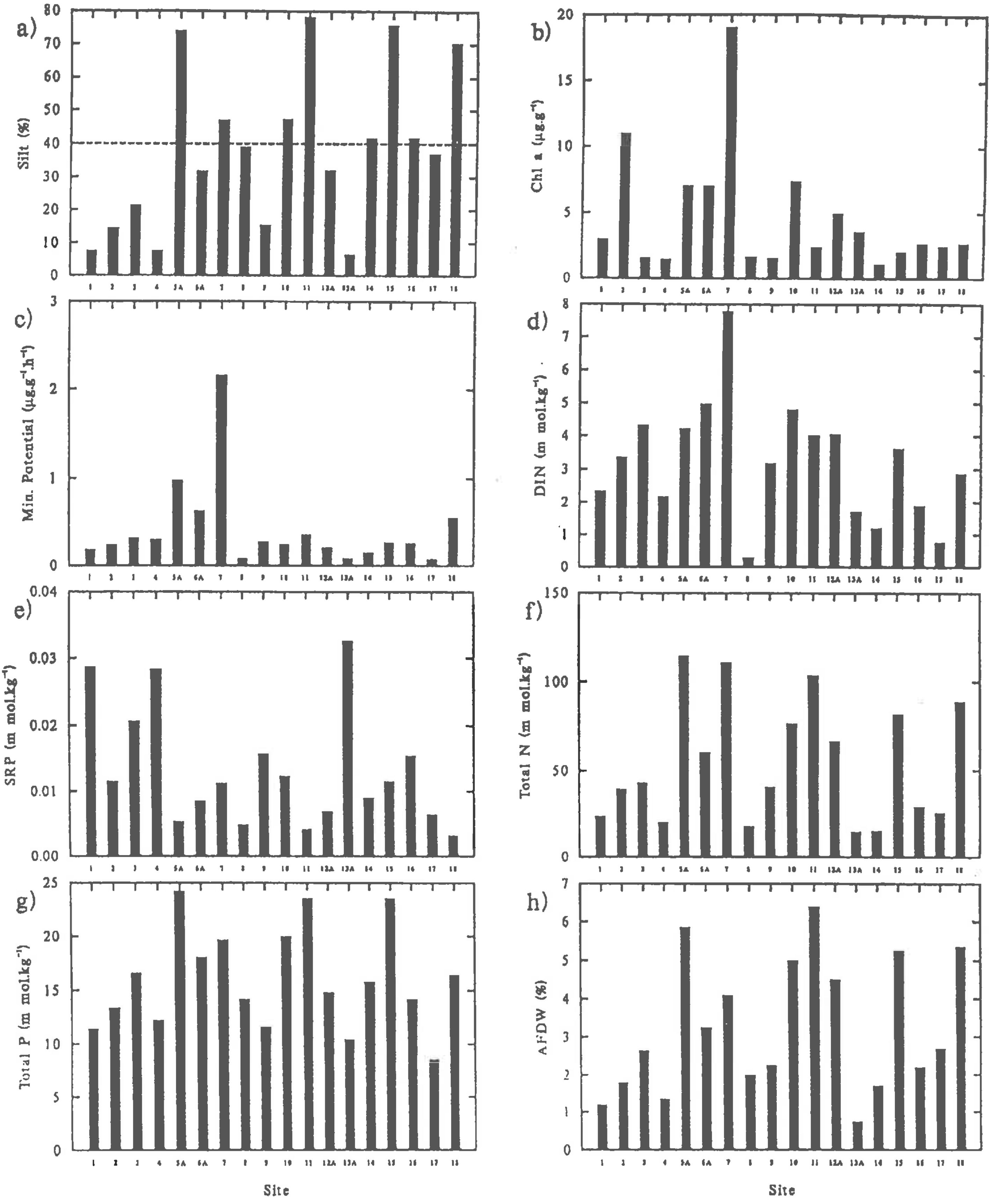


Figure 3 Physico-chemical and microbial characteristics of sediments at 18 sites in Moutere Inlet(March 1991. a) percentage silt composition, b) chlorophyll *a*, c) microbial mineralisation potential, d) dissolved inorganic nitrogen, e) soluble reactive phosphorus f) total nitrogen, g) total phosphorus, h) total organic content. Values presented in table form in Appendix II

4.4 Sediment nutrients and organic content

4.4.1 Inorganic nutrients

Inorganic nitrogen is generally assumed to be the primary limiting nutrient for plant production in estuaries. Potential nutrient forms of inorganic nitrogen include nitrate, ~~nitrate~~ nitrite and ammonia which are rapidly converted from one to the other by microbes. For this reason we have taken the total of these three forms as an indicator of the relative plant enrichment capacity of the sediments at the time of sampling. In all cases the majority of the inorganic nitrogen was in the form of ammonia. This is normal for estuarine sediments as ammonia is released by macrofauna excretion and microbial decomposition. Ammonia, and consequently inorganic nitrogen levels, in all Moutere Inlet sediments (Fig.3d) were high in comparison to unpolluted sites in Delaware Inlet and Nelson Haven, with values as high or higher than those observed in polluted sites being the general case. The reason for the elevated ammonia levels is unclear. It could simply be a result of the length of time the samples were stored prior to being frozen (see section 3.4) and the conversion of organic -N to ammonia via microbial mineralisation. Consequently we will base our interpretation primarily upon variations within Moutere Inlet rather than between Inlets where sample storage times may have varied.

Highest DIN concentrations were observed at site 7 suggesting that considerable plant enrichment potential existed there. This may be due to recycling within the sediments and the relatively low flushing rates rather than an unusually high external source of nitrogen.

As compared to the elevated DIN levels, soluble reactive phosphorous levels were very low in Moutere Inlet sediments (Fig. 3e). Inorganic N / P ratios, which ranged from 53 to 955, suggest that, at the time of sampling, phosphorous may in fact have been limiting in this estuary rather than nitrogen. This can occur at sites which are enriched with a nutrient source having an N / P ratio significantly greater than the optimal ratio of 10 / 1. Total N/P ratios, on the other hand, were much lower and were generally <10, suggesting that the high ammonia levels may have been a short term event. Further sampling would be necessary to determine the significance of these nutrient ratios and the variation between inorganic and total (organic + inorganic) ratios.

4.4.2 Organic nutrients

Comparing total N, total P and AFDW levels of Moutere Inlet sediments (Figs 3 f, g and h) with those of Delaware Inlet, Nelson Haven and Waimea Inlet (Gillespie and MacKenzie 1990, Appendix V) suggests that some Moutere sites are slightly enriched ($P<0.005$), particularly with nitrogen, but not to an extent which would indicate gross pollution. A moderate build up, was observed in the vicinity of both the Port Motueka and Kina tidal inflows; *e. g.* sites 5A, 6A, 7, 10, 11, 12A and 15.

4.5 Benthic microalgae

4.5.1 Sediment chlorophyll *a*

Mean sediment chl *a* concentrations amongst all sites in Moutere Inlet varied approximately 10-fold with the highest values occurring at site 7 (Fig. 3b). In view of the fact that site 7 was covered with a thick layer of *Enteromorpha*, it is unlikely that microalgae contributed significantly to the chl *a* concentrations there. It is more likely that macroalgal detritus (*i.e.*, particles of decomposing plant material) incorporated into the sediments was responsible.

Classical symptoms of excessive enrichment which result in thick microalgal mats were not observed in Moutere Inlet, however less intense and localised "blooms" were observed at sites 5A and 6A. These sites, in the vicinity of the Port Motueka outlet, were characterised by a visible green mat (Plate 8) and the higher chl *a* levels (attributable to microalgae) reflect this.

4.6 Benthic macrophytes

4.6.1 Salt marsh vegetation

Although we have not surveyed the % saltmarsh coverage in Moutere Inlet, a rough estimate based on field observations would be 10 to 12%. This would compare to an estimated 7% for Delaware Inlet (MacKenzie 1983), <1% for Nelson Haven and 5% for Waimea Inlet (Davidson 1990). The overall percentage of saltmarsh occurring naturally in Moutere Inlet has been reduced by an estimated 20-30% by coastal development. In particular, the coastal highway has covered headlands and cut across embayments; some of which have subsequently been filled in or converted to freshwater ponds. Additional infilling has been carried out at the northwestern end of the Inlet. Consequently the nutrient absorptive capacity of the Inlet has been reduced. This may be significant to the enrichment status of some regions but there are still intact stands of sea rush (*Juncus maritimus*) at a number of locations where runoff of nutrients might be expected; *e.g.* the Moutere River arm and a series of smaller embayments.

4.6.2 Macroalgae

The primary species of macroalgae growing in Moutere Inlet are:

- *Ulva lactuca (* sea lettuce) - a sheet-forming, green alga that prefers mid to lower tidal flats, often in association with cockle beds.
- *Enteromorpha* sp. - a seasonal, filamentous, green alga that grows well at upper tidal levels where significant fresh water input occurs.
- *Gracilaria* sp (agar weed) - a filamentous, red alga that is found in similar habitats to sea lettuce.
- *Gelidium caulocanthium* - another filamentous red alga that forms dense spongy turf on rocky shores and cobble.

All of the above algae can be significant (with respect to enrichment) in two ways: 1.) Excessive growth and build-up of plant material can occur in the algal beds themselves; 2.) Tidal transport and deposition of "drift algae" can result in a build-up of plant debris on peripheral mud flats where high decomposition rates result in oxygen depletion leading to sediment anoxia.

Those sites in Moutere Inlet that are characterised by a significant growth of macroalgae or by the deposition of drift algae are listed in Table 3.

Table 3. Estimated macroalgal cover and mean biomass at sites in Moutere Inlet where significant standing crops existed (- refers to not measured).

	Total Macroalgae Cover			
	December 1990		**September 1991**	
Site	**Cover (%)**	**Biomass ($g.m^{-2} \pm$ s.d.)**	**Cover (%)**	**Biomass ($g.m^{-2} \pm$ s.d.)**
M5	50 - 80	-	<5	-
M6	20 - 60	-	<5	-
M6A	20 - 60	-	<5	-
M7	95 - 100	52.8 ± 25.6	70 - 80	35.2 ± 28.8
M9	55 - 65	100 ± 118	50	136 ± 101
M10	5 - 20	18.4 ± 17.9	<10	15.3 ± 23
M11	<10	26.4 ± 19.7	<10	-
M12	<10	9.3 ± 5.5	<5	-
M13	5-10(up to 70 in patches0	-	<5	-

The amount of macroalgal coverage alone is indicative of some degree of enrichment at sites 5, 6, 6A, 7, and 9. Those sites are located at the northern (Port Motueka) end of the Inlet. Although macroalgal beds did occur in the vicinity of the southern (Kina) outlet, the percent coverage and accumulation of plant debris was much lower in that region. Sites 7 and 9 appeared to be the most enriched with respect to macroalgal growth. Although biomass values were lower at the former (site 7), the thick *Enteromorpha* mat at that site provided a complete (100 %) cover and seemed to result in a greater degree of anoxia (oxygen deficit) in surficial sediments.

Warm spring temperatures during September 1991 resulted in a spring bloom of *Ulva* (sea lettuce) in a large area of the Inlet that included Site 9 (Plates 21 and 22) however subsequent observations showed that other parts of the Inlet were not similarly affected. Rapid algal growth during spring is not unusual but we would normally expect the overall biomass to build up gradually to a late summer (March/April) maximum. These observations point out that climatic conditions can play an important role in controlling the expression of the symptoms of enrichment. Species composition of macroalgae also varies seasonally as shown by the data from Site 7 where *Ulva* and *Gracillaria* predominated during spring and *Enteromorpha* contributed the majority of biomass during the summer sampling.

4.6.3 Eelgrass

Although eelgrass (*Zostera muelleri*) beds are not a major feature of Moutere Inlet, they are an ecologically important component of other inlets in the region (Davidson and Moffat 1990, 1991; Franko 1988). Some discussion of their distribution in Moutere Inlet and the possible effects of enrichment is thus warranted.

We have observed established beds of eelgrass along main and small tributary channels in the vicinity of the Kina Peninsula outlet but similar beds do not occur at comparable sites near the northern, Port Motueka outlet. A possible explanation for this is that the more extensive and more productive macroalgal beds in the latter region (see section 4.6.2) overlay the eelgrass thus shading them to restrict their growth. This mechanism of competition for light could represent a long term enrichment effect which results in an ecologically significant change in the relative distribution of the two contrasting plant communities.

4.7 Macroinvertebrates

4.7.1 Surface Counts

Thirty-one different kinds of macroinvertebrates (excluding 'crab holes') were recorded in surface counts from 131 quadrats examined at the 18 sites visited in Moutere Inlet in late December 1990 (Appendix III). Only one of the species recorded in surface quadrats (blue mussel - *Mytilus edulis aoteanus*) was not present amongst the 65 kinds of macroinvertebrate collected in quantitative core samples (see Appendix III; Section 4.7.2 and subsections).

Appendix III presents community composition at 18 sites in Moutere Inlet based upon surface quadrat counts. Between 1 (Sites M8 & M14) and 18 (Site M12) different kinds of surface-dwelling macroinvertebrates were recorded from individual sampling sites. In general, sites at higher tidal elevations had the least variety of animals visible on the surface (e.g. Sites M8 & M14 - M18).

Surface macroinvertebrate densities ranged from more than 9000 animals m^{-2} on medium cobble substrata (Site M12) through to between 90 and 220 animals m^{-2} on bare sand-mud at higher tidal elevations (Sites M14 - M17). The *Juncus* habitat (M18) had very high densities of the small black snail (*Potamopyrgus estuarinus*), but low species richness (only three taxa) and medium-high total densities (nearly 4000 animals m^{-2}).

Eight kinds of benthic animals comprised 1% or greater of the total numbers counted in surface quadrats in Moutere Inlet (Table 4). Most of these animals were common or abundant at several different sites - the exception was *Potamopyrgus estuarinus*, which was found only on the *Juncus* vegetation at Site M18. The spire shell (*Zeacumantus* sp.) was particularly common at Site M9 and present at three others (M6, M7 & M11), but did not contribute greater than 1% by numbers overall (Appendix III).

Table 4 Dominant benthic macroinvertebrates in surface quadrat counts at 18 sites in Moutere Inlet (December 1990). Only taxa comprising greater than 1% of the total number of 16113 animals counted in 131 quadrats are listed.

Rank	Taxon	%	Rank	Taxon	%
1	*Elminius modestus*	56.0	5	*Pomatoceros* sp.	4.1
2	*Potamopyrgus estuarinus*	15.1	6	Crab holes	3.2
3	*Austrovenus stutchburyi*	7.4	7	*Xenostrobus pulex*	1.4
4	*Anthopleura aureoradiata*	5.5	8	*Amphibola crenata*	1.2
				Total of "top 8" taxa	93.9

4.7.2 Cores

Sixty-five different benthic macroinvertebrates were recorded in core samples collected in 96 0.0135m^2 core samples from 18 sites in Moutere Inlet in December 1990 (Appendix IV). Polychaete worms (19 kinds), gastropod snails (12), Crustacea (11) and bivalves (8) dominated the list of animals recorded. Between 5 (Site M17) and 35 (Sites M4, M5 & M13) different kinds of benthic macroinvertebrates were recorded at each site. In general, greatest variety of animals was associated with cobble habitats, with least in mud and sand.

Benthic macroinvertebrate densities ranged from under 15 animals per square metre in mud/sand habitat at high tidal elevations (Site M15), through to more than 42000 animals per square metre in cobble/gravel/sand habitat (Site M12).

Dominant macroinvertebrates in core samples included most of those that were well represented in surface quadrat counts (Table 5 *cf.* Table 4). Smaller or burrowing animals (such as various polychaetes, nematodes and amphipods), were either too small to be seen in the field or were within the substratum and so feature only (or primarily) in the core sample data (Table 4, Appendix IV).

Table 5. Dominant benthic macroinvertebrates in core samples collected from 18 sites in Moutere Inlet (December 1990). Only taxa comprising greater than 1% of the total number of 17350 animals collected in 96 quantitative samples are listed.

Rank	Taxon	%	Rank	Taxon	%
1	*Elminius modestus*	29.3	8	*Heteromastus filiformis*	2.9
2	Spionidae	28.3	9	Nematoda	2.1
3	Amphipoda	8.6	10	*Capitella capitata*	2.0
4	*Austrovenus stutchburyi*	4.2	11	*Anthopleura aureoradiata*	1.7
5	unidentified Polychaeta	3.7	12	Glyceridae	1.2
6	*Xenostrobus pulex*	3.2	13	*Potamopyrgus estuarinus*	1.1
7	*Pomatoceros* sp.	3.0		**Total of "top 13" taxa**	**91.3**

4.7.3 Prevalence of benthic macroinvertebrates

The only benthic macroinvertebrate taxon recorded from all 18 sites sampled in Moutere inlet was Spionidae, a kind of polychaete worm, (Table 6). Nereid worms and unidentified polychates were present at 15 sites and cockles (*Austrovenus stutchburyi*) at 14 sites. The mud crab (*Helice crassa*), the mudflat topshell (*Diloma subrostrata*) and yet another polychaete (*Heteromastus filiformis*) were recorded at 13 sites each.

At the other extreme, fifteen taxa were recorded at single sites, four at two sites each, three at three sites and nine at only four sites (Table 6).

It is not surprising that few macroinvertebrate taxa were recorded everywhere given the wide range of habitats sampled in Moutere Inlet (*i.e.* from cobble through to mud, high-shore sand and vegetation). It is also usual for many taxa to be present at only one or two sites in studies of this kind.

Table 6. Ubiquity of benthic macroinvertebrates in Moutere Inlet as indicated by the number of sampling sites that they were recorded at in December 1990. Data from surface quadrat counts and core samples are combined. A total of 18 sites were sampled.

Site	Benthic macroinvertebrate taxa	No. of Taxa
1	*Actinia tenebrosa*, *Acanthochitona zelandica*, *Melagraphia aethiops*, *Onchidella nigricans*, *Potamopyrgus estuarinus*, *Perna canaliculus*, Maldanidae, Nephytidae, *Owenia fusiformis*, Pectinariidae, Cumacea, Ophiuroidea, *Chironomus* sp A, *Limonia nigrescens*, Muscidae	15
2	*Chiton pelliserpentis*, *Mytilus edulis aoteanus*, *Paphies subtriangulata*, Hexatomini	4
3	Polynoidae, Terebellidae, *Macrophthalmus hirtipes*	3
4	Sipuncula, *Turbo smaragdus*, unident. Gastropoda, *Tellina liliana*, *Amandi maculata*, *Eulalia microphylla*, Sphaeodoridae, Ostracoda, Othocladiinae	9
5	*Zeacumantus* sp., Cirratulidae	2
6	*Amphibola crenata*, Isopoda, *Petrolisthes elongatus*, *Asterina regularis*	4
7	Phyllodocidae, Syllidae	2
8	*Crassostrea gigas*, *Xenostrobus pulex*, *Capitella capitata*	3
9	Nematoda, *Amaurochiton glaucus*, *Paphies australis*, *Halicarcinus whitei*	4
10	Micrelenchus tenebrosus, Pomatoceros sp., Hemigrapsus crenulatus	3
11	*Anthopleura aureoradiata*, *Elminius modestus*	2
12	Nemertea, *Cominella glandiformis*, *Diloma zelandica*, *Notoacmea helmsi*, *Mactra ovata*, Glyceridae, Amphipoda	7
13	*Diloma subrostrata*, *Heteromastus filiformis*, *Helice crassa*	3
14	*Austrovenus stutchburyi*	1
15	Nereidae, unidentified Polychaeta	2
18	Spionidae	1

4.7.4 Indication of environmental state

The macroinvertebrate community structure over 18 sites in Moutere Inlet, is described in terms of species richness and abundance of individuals within major groups (Figure 4). In general, these results suggest that animal populations have not been noticeably disrupted by over enrichment or other forms of estuarine contamination. Given the range of habitat types covered in the 18 sites and their characteristic community structures, it is not possible to identify subtle differences in the state of the estuarine environment. The results provide a baseline, however, against which future deterioration of estuarine health can be assessed. Changes in community structure over time, in conjunction with other physico-chemical and biological descriptors of estuarine health, provide a powerful monitoring tool for this purpose.

4.8 Sediment and/or shellfish trace metals and pesticides

Shellfish and sediment trace metal concentrations were all within ranges observed in other unpolluted intertidal habitats of the region (Tables 7 and 8) but we note that considerably higher total arsenic levels were reported in cockles collected from one upper and one lower Inlet site approximately two years later (Woodward-Clyde, N.Z. Ltd., 1993). Those findings suggest that some contamination has occurred since 1991, however if we assume a 1:10 ratio of inorganic to total arsenic, the reported 1993 values of 11 and $18 \text{mg}\cdot\text{kg}^{-1}$ total arsenic would not exceed NZFR permitted levels. Nevertheless they represent a considerable elevation above background and further study would be warranted to verify and/or identify the significance and source of contamination.

Table 7. Trace metal concentrations of cockles (*Austrovenus stutchburyi*) from selected sites in Moutere Inlet, March 1991. Metals expressed as mg/kg wet weight.

Site	Pb	Cd	Zn	Cr	Cu	Se	As	Hg	Moisture (%)
12	< 0.1	< 0.01	5.4	0.5	0.4	0.2	2.3	< 0.02	91.1
15	0.2	0.02	5.5	0.5	0.6	0.2	2.1	< 0.02	93.0
16	0.1	0.02	5.4	0.5	0.8	0.2	1.2	< 0.02	93.0
17	0.2	0.04	8.6	0.5	1.0	0.1	0.1	0.02	92.2

Table 8. Trace metal concentrations of sediments from selected sites in Moutere Inlet, March 1991. Values expressed as mg/kg dry weight.

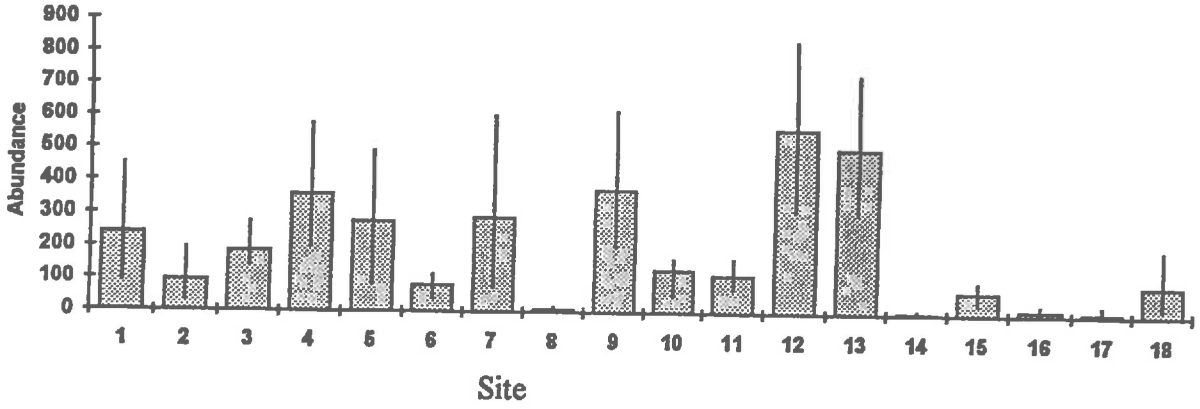
Site	Pb	Cd	Zn	Cr	Cu	Se	As	g
3	10	< 0.5	87	35	24	0.21	4.6	0.03
7	8	< 0.5	83	32	19	0.26	5.1	0.05
12	< 3	< 0.5	31	64	9	0.33	8.5	0.03
15	12	< 0.5	70	24	23	0.29	7.0	0.05
16	9	< 0.5	38	32	9	0.17	7.5	0.03
17	4	< 0.6	34	7	8	0.16	2.5	0.03

Organochlorine and organophosphate concentrations in Moutere sediments were all below detection limits for the methods used (Table 9). The results show that, in general terms, Moutere Inlet is not grossly contaminated with these potential pollutants. It should be noted however that detailed sampling was not carried out for their detection and the detection limits of the analytical procedures used were not sufficient to insure that very low, but potentially "environmentally significant", levels were not present. Woodward-Clyde, N.Z. Ltd. (1993) report low but detectable levels of DDE (a persistent breakdown product of DDT) in surface-grazing mud snails (*Amphibola crenata*) collected during 1993 from one upper and one lower Inlet site. This suggests that sufficient background levels were present to account for some bio-accumulation. For a discussion of lower limits of concentrations that could be significant in a particular coastal environment and the development of guidelines, see MacDonald *et. al.* 1992.

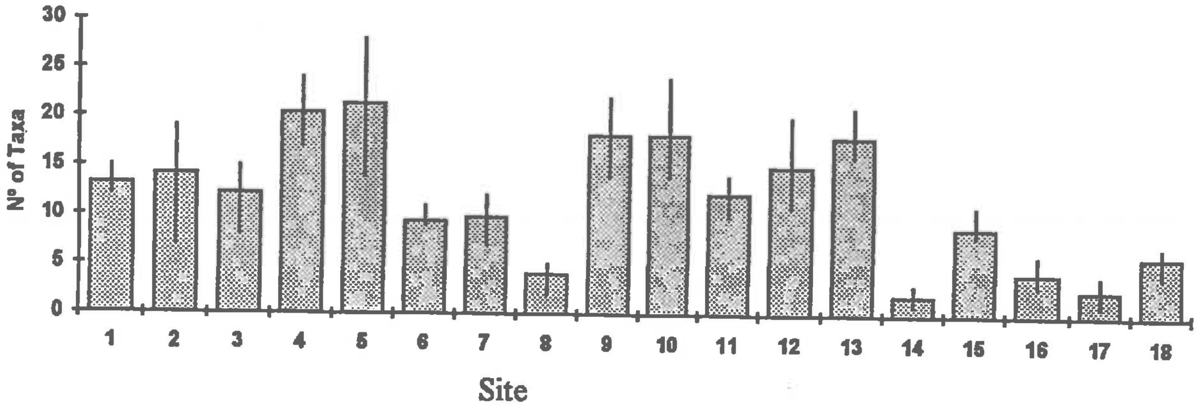
Table 9. Organochlorine and organophosphate concentrations of sediments from selected sites in Moutere Inlet, March 1991. Values expressed as mg/kg.

Site	Aldrin	Heptachlor	Lindane	DDE	Dieldrin	DDT	Screen
3	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
4	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
7	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
9	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
12	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
12B	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
13	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
15	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
16	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3
17	< 0.005	< 0.009	< 0.007	< 0.007	< 0.03	< 0.03	< 0.3

a.) Abundance:



b.) Species Richness:



c.) Total Molluscs:

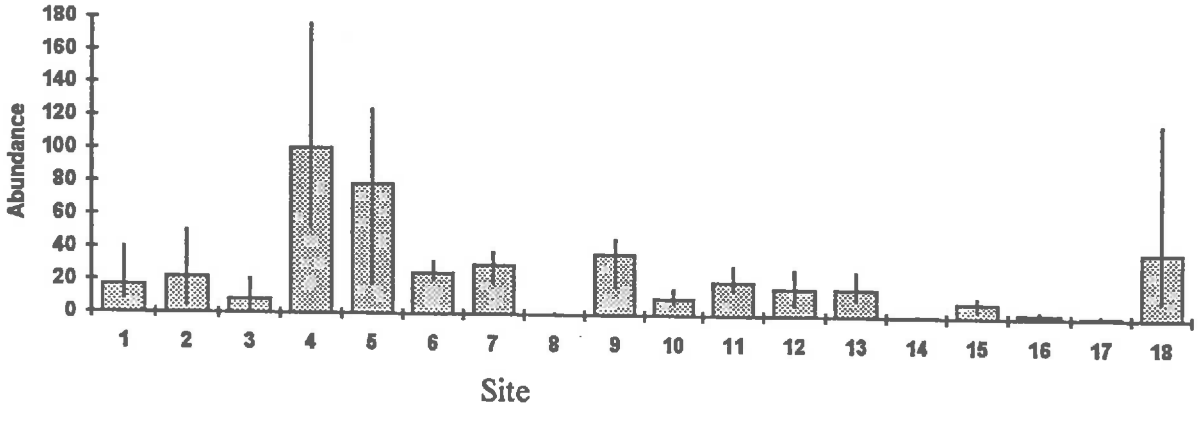
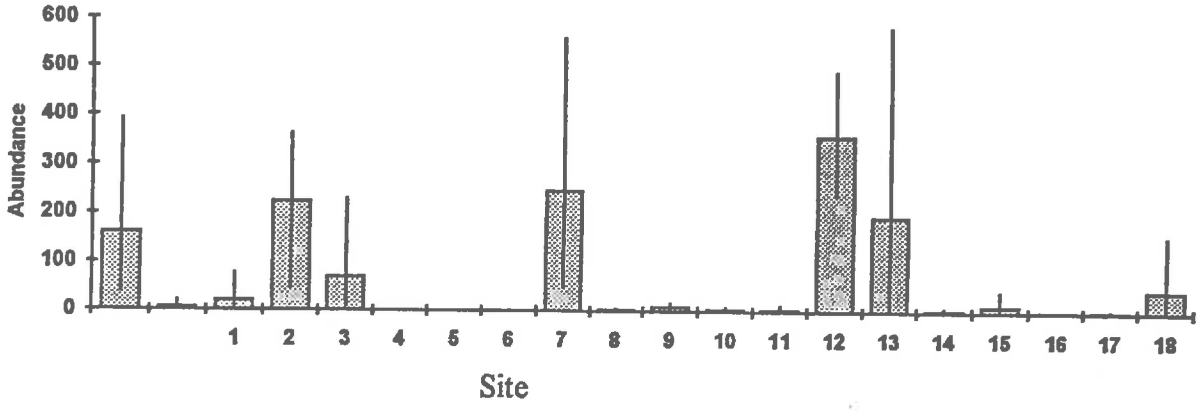
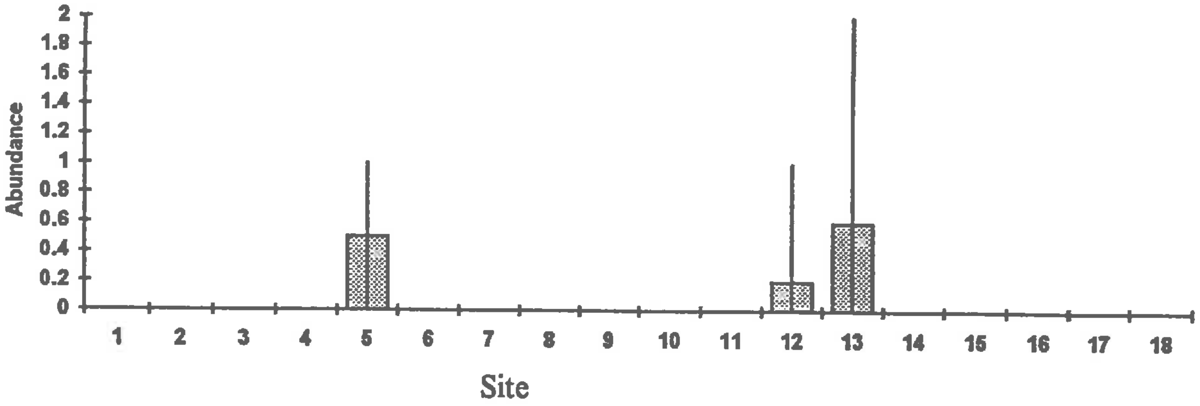


Figure 4. Benthic invertebrate community structure at 18 sites in Moutere Inlet, December 1990. a.) Species richness (no. of taxa); b.) Abundance no. of individuals; c.) Molluscs; d.) Arthropods; e.) Echinoderms; f.) Amphipods; g.) Polychaetes; h.) Capitellidae; i.) Cirratulidae; j.) Spionidae.

d.) Total Arthropods:



e.) Total Echinoderms:



f.) Amphipods:

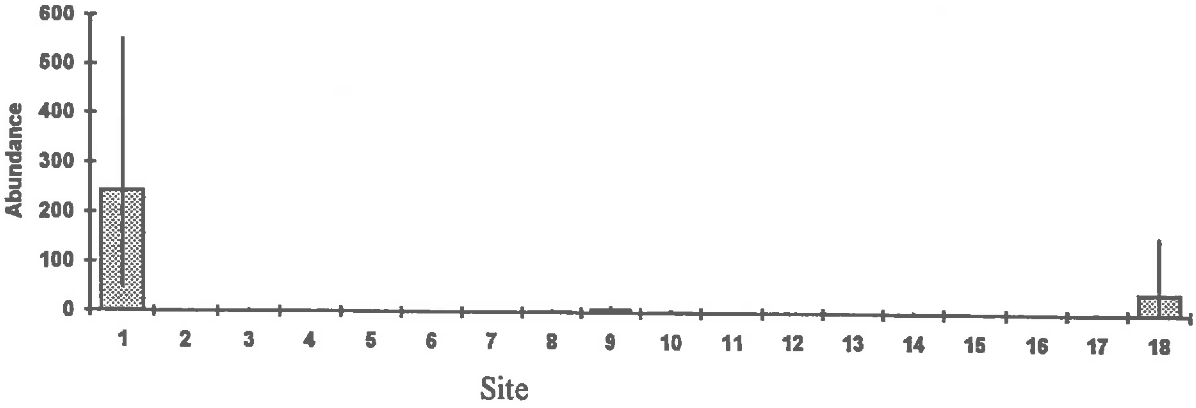
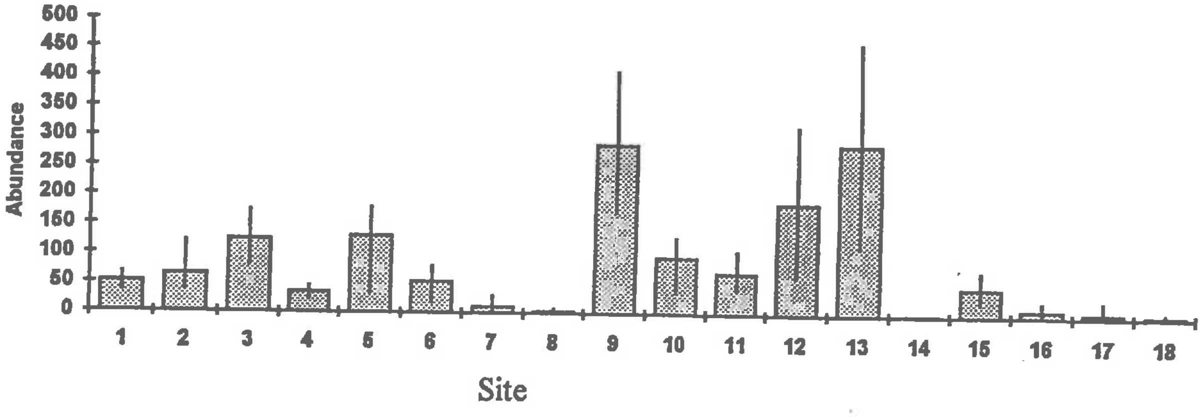
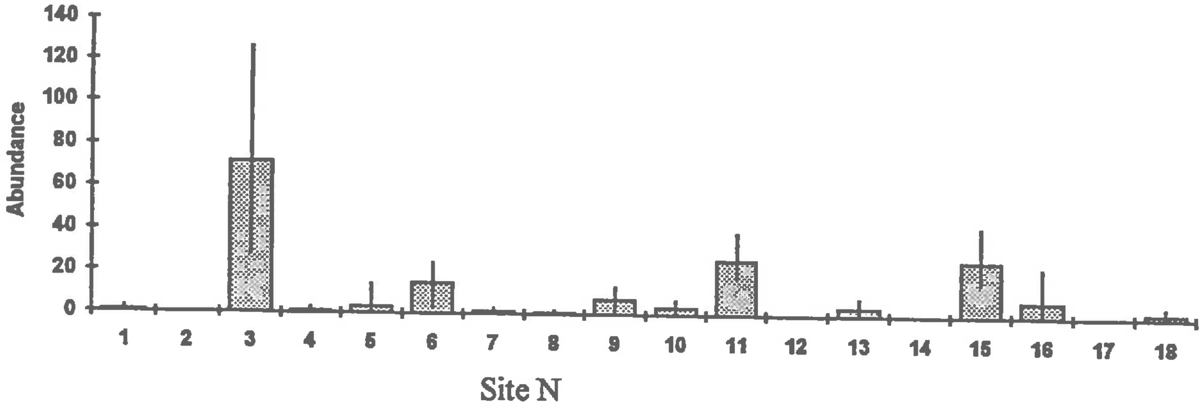


Figure 4. Contd.

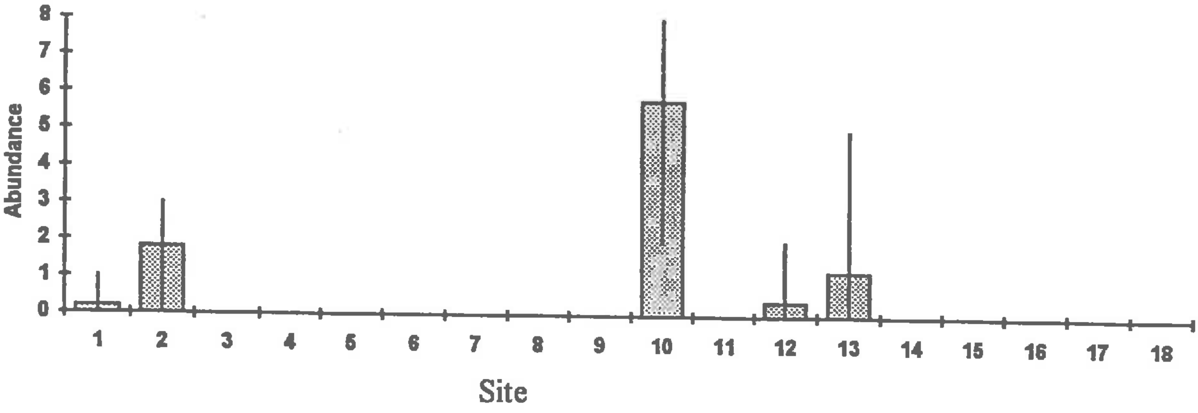
g.) Total Polychaetes:



h.) Capitellidae:



i.) Cirratulidae:



j.) Spionidae:

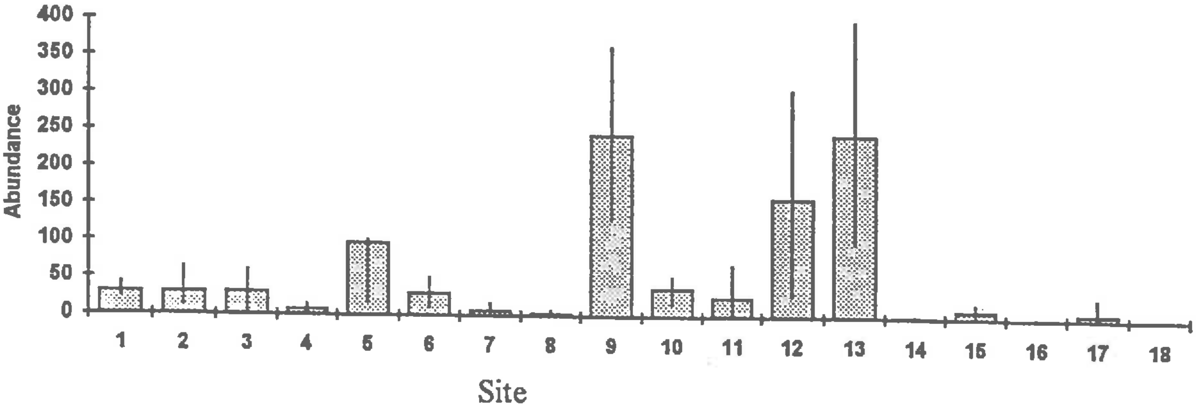


Figure 4. Contd.

4.9 Hydrology and water quality

4.9.1 Fresh water flow measurements

Freshwater flows into the Moutere Inlet totalled 240 litres per second during the summer low flow conditions of 23 March 1991 and 1900 l/sec at the time of sampling (6 - 9pm) during the fresh of 25 July (Table 10). Major flow contributors to the Inlet are the Moutere River, Thorp Drain and Tasman Stream. The remainder are small catchments with minimal base flow, draining Moutere Gravel, many with dams intercepting low flows.

Table 10. Freshwater flows (litres / sec) into Moutere Inlet, 23 March and 25 July 1991. * refers to sites gauged (other sites estimated). For locations, see Figure 2.

CATCHMENT / SOURCE	23 MARCH	25 JULY
FW 1 Thorp Drain * (Plate 43)	130	420
Minor discharges above Wharf Rd (A)	0	?
Irrigation overflow near roundabout (B)	15 / intermittent	?
FW 2 Moutere River * (Plate 44)	72.9	1236
Robinson	1	2
FW 3 Eden * (Plate 45)	1	18
Moana 1	1	3
Moana 2	1	3
FW 4 Rowling * (Plate 46)	3	9.1
Martin	0	1
Weka Stream Embayment	0	0
Weka: Sullivan + Goat Paddock	1	1
Hinkley	1	1
Dicker / Harley	1	50
FW 5 Tasman Bridge * (Plate 47)	10	152
Kina Ditch	1	3
Kina Stream	1	3
TOTAL FRESHWATER INFLOW	240	1903

The V-notch weir and water level recorder installed on Rowling Stream gave a mean flow of 0.96 l/sec from 6 June to 15 August 1991. The Rowling flow record and rainfall at Upper Moutere are plotted in Figure 5. Specific discharge was around 1.5 l/sec/km^2 on an annual basis (M. Doyle, pers. comm.), which is considerably lower than the specific discharge for Tasman Stream (12 l/sec/km^2) or Moutere River at Old House Road (9 l/s/km^2). This is mainly because the larger catchments have greater storage capacity, which sustains base flows.

Using a flow calculated from 27km^2 of catchment in the Tasman area (mean specific discharge 12 l/s/km^2), plus 136 km^2 in the Moutere catchment (9.5 l/s/km^2), plus the recorded mean annual flow of around 170 l/sec from Thorp Drain, the estimated total mean annual freshwater inflow into the Moutere Inlet is 1790 l/sec. Most of this flow occurs during flood events from the Moutere River and is carried rapidly out to sea. Summer base flows into the inlet average around 400 l/sec. Only 28% of this base flow enters from catchments other than the Moutere River and Thorp Drain; *i.e.* most enters the northern third of the inlet.

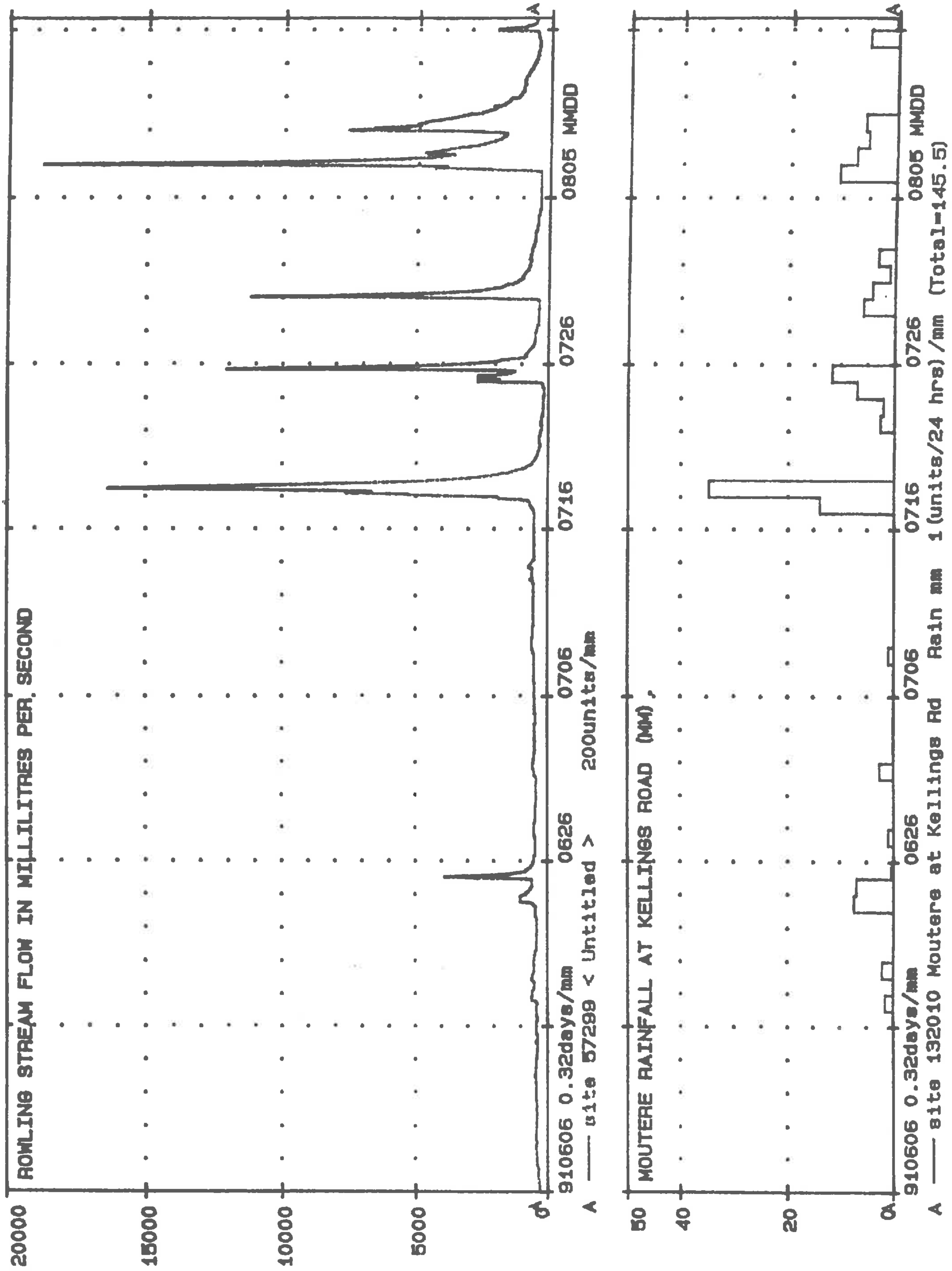


Figure 5. The Rowling Stream flow record and rainfall at Upper Moutere; 6 June -15 August 1991.

4.9.2 pH, conductivity, salinity

During the March sampling, pH values of the fresh water inflow waters ranged from slightly acidic at Thorp Drain to near neutral at the remaining sites while conductivity and salinity values show some salt water mixing at most sites. These analyses were not repeated for the second sampling (Table 11).

Table 11. Water quality characteristics of Moutere Inlet freshwater inflows, 22 March and 27 July 1991 (- refers to not measured).

Site	Date	pH (units)	Conductivity (ms / m)	Salinity (ppt)	Faecal Coliforms (MPN / 100ml)
FW 1 a	22 Mar-91	6.6	210	0.82	790
FW 1 b	"	-	230	0.84	1,700
FW 2 a	"	6.9	26,500	11.9	2,400
FW 2 b	"	-	-	-	330
FW 3 a	"	6.8	560	2.6	170
FW 3 b	"	-	500	2.0	460
FW 4 a	"	7.0	600	4.5	230
FW 4 b	"	-	190	0.61	490
FW 5 a	"	7.2	30	< 0.1	490
FW 5 b	"	-	24	< 0.1	460
FW 1 a	27 Jul-91	-	-	-	2,200
FW 1 b	"	-	-	-	3,500
FW 2 a	"	-	-	-	9,200
FW 2 b	"	-	-	-	5,400
FW 3 a	"	-	-	-	5,400
FW 3 b	"	-	-	-	3,500
FW 4 a	"	-	-	-	3,500
FW 4 b	"	-	-	-	5,400
FW 5 a	"	-	-	-	490
FW 5 b	"	-	-	-	700

Salinity levels of Moutere Inlet waters, measured at high tide during both the March and July samplings, were similar to those of Tasman Bay immediately outside the Inlet (Table 12). Noticeable depressions in salinities occurred only in peripheral embayments where partial flow restrictions result in a slight build up of fresh water. Although a detailed survey of salinity distribution was not carried out, we did note that, concurrent with the rainfall event on the July sampling, a distinct salinity profile occurred at the landward margins of the incoming tide; particularly in embayment areas. This was due to direct land runoff and would undoubtedly have some enrichment effect on plant communities of upper intertidal regions.

Table 12. Water quality characteristics of Moutere Inlet tidal waters, 22 March and 27 July 1991 (missing values refer to not measured).

Site	Date	pH (units)	Conductivity (ms / m)	Salinity (ppt)	Faecal Coliforms (MPN / 100ml)
E 1 a	22 Mar-91	8.0		31.3	2
E 1 b	"	8.1		31.4	8
E 2 a	"	8.1		36.9	70
E 2 b	"	8.1		37.2	8
E 3 a	"	8.1		33.4	2
E 3 b	"	8.1		34.0	2
E 4 a	"	8.1		32.0	< 2
E 4 b	"	8.1		32.2	< 2
E 5 a	"	8.1		31.3	5
E 5 b	"	8.2		31.1	23
E 6 a	"	8.1		31.6	13
E 6 b	"	8.1		32.9	7
E 7 a	"	8.1		33.6	< 2
E 7 b	"	8.1		33.1	< 2
E 8 a	"	8.1		32.5	< 2
E 8 b	"	8.1		32.3	< 2
E 1 a	27 Jul-91		48.2	34.4	20
E 1 b	"				20
E 2 a	"		48.4	34.5	< 20
E 2 b	"				< 20
E 3 a	"		48.5	34.6	< 20
E 3 b	"				< 20
E 4 a	"		48.0	34.2	20
E 4 b	"				< 20
E 5 a	"		46.5	32.9	50
E 5 b	"				50
E 6 a	"		42.6	29.7	230
E 6 b	"				230
E 7 a	"		48.2	34.5	< 20
E 7 b	"				< 20
E 8 a	"		48.5	34.7	< 20
E 8 b	"				< 20

4.9.3 Nutrients

Nutrients were measured in freshwater inflows and estuarine waters of Moutere Inlet on only two occasions. Because seasonal and climatic conditions can have a considerable influence on nutrient concentrations, comparisons with other inlets can only be made in a general sense. Nutrient concentrations of freshwater inflows during a summer (low-flow) period and after a moderate rainfall are shown in Table 13. On both occasions, but particularly during the rainfall event, the inflows were enriched with nitrogen; largely in the form of nitrate. These concentrations were high in comparison to similar measurements of the Wakapuaka River and small inflow streams of Delaware Inlet (Gillespie, unpublished) however Moutere inflow streams did not appear to be enriched in phosphorus. The enrichment effects cannot be assessed without also considering flow rates and tidal dilutions. The mass transport of nitrogen from known sources will be discussed in a later section.

Table 13. Nutrient concentrations of Moutere Inlet freshwater inflows, 22 March and 26 July 1991. Values expressed as g/m^3.

Site	Date	Total-N	Total-P	Nitrate-N	Nitrite-N	Ammonia-N	SRP
FW 1 a	22 Mar-91	2.60	0.02	1.90	0.020	0.034	0.008
FW 1 b	"	1.90	0.02	1.90	0.023	0.050	0.010
FW 2 a	"	0.67	0.03	0.31	0.005	0.073	0.007
F-W 2 b	"	-	-	-	-	-	-
FW 3 a	"	0.34	0.05	0.11	0.004	0.038	0.011
FW 3 b	"	0.38	0.05	0.10	0.005	0.063	0.011
FW 4 a	"	1.10	0.09	0.38	0.008	0.063	0.021
FW 4 b	"	0.68	0.08	0.42	0.005	0.022	0.024
FW 5 a	"	0.37	0.06	0.014	0.002	0.019	0.033
FW 5 b	"	0.30	0.06	0.014	0.002	0.016	0.031
FW 1 b	26 Jul-91	2.1	0.16	1.4	0.004	0.14	0.071
FW 1 a	"	2.4	0.17	1.3	0.005	0.12	0.070
FW 2 a	"	1.6	0.05	0.88	0.004	0.065	0.019
FW 2 b	"	1.8	0.05	0.95	0.004	0.073	0.018
FW 3 a	"	3.0	0.22	2.2	0.008	0.27	0.089
FW 3 b	"	3.6	0.39	2.0	0.008	0.32	0.104
FW 4 a	"	4.8	0.13	4.2	0.022	0.10	0.015
FW 4 b	"	4.6	0.09	3.6	0.022	0.062	0.017
FW 5 a	"	3.7	0.15	2.0	0.009	0.031	0.045
FW 5 b	"	3.7	0.16	1.9	0.009	0.038	0.038

Concentrations of nutrients in Moutere Inlet waters (Table 14) were within ranges observed in Delaware Inlet during high tides occurring under different seasonal and climatic conditions (Gillespie, unpublished). With respect to nitrogen and particularly nitrate, however, Moutere values tended to be on the high side of the ranges.

Table 14. Nutrient concentrations of Moutere Inlet tidal waters, 22 March & 27 July 1991. Values expressed as g/m^3.

Site	Date	Total-N	Total-P	Nitrate-N	Nitrite-N	Ammonia-N	SRP
E 1 a	22 Mar-91	0.16	0.034	< 0.005	0.002	0.015	0.014
E 1 b	"	0.19	0.035	< 0.005	0.001	0.014	0.016
E 2 a	"	0.10	0.023	< 0.005	0.002	< 0.005	0.010
E 2 b	"	0.08	0.019	< 0.005	0.001	< 0.005	0.009
E 3 a	"	0.09	0.018	< 0.005	< 0.001	< 0.005	0.008
E 3 b	"	0.08	0.022	< 0.005	< 0.001	< 0.005	0.008
E 4 a	"	0.11	0.028	< 0.005	0.002	0.015	0.010
E 4 b	"	0.098	0.026	< 0.005	0.002	0.012	0.012
E 5 a	"	0.12	0.023	< 0.005	0.002	0.018	0.012
E 5 b	"	0.15	0.026	< 0.005	0.001	0.026	0.012
E 6 a	"	0.11	0.027	0.009	0.002	0.026	0.012
E 6 b	"	0.12	0.025	0.006	0.002	0.019	0.010
E 7 a	"	0.13	0.018	< 0.005	< 0.001	< 0.005	0.008
E 7 b	"	0.083	0.018	< 0.005	< 0.001	< 0.005	0.007
E 8 a	"	0.081	0.020	< 0.005	< 0.001	< 0.005	0.007
E 8 b	"	0.079	0.020	< 0.005	< 0.001	0.012	0.007
E 1 a	27 Jul-91	0.19	0.030	0.008	< 0.001	0.013	0.017
E 1 b	"	0.22	0.027	0.009	< 0.001	0.014	0.017
E 2 a	"	0.18	0.030	0.007	< 0.001	0.012	0.013
E 2 b	"	0.14	0.027	0.007	< 0.001	0.012	0.012
E 3 a	"	0.15	0.029	0.007	< 0.001	0.013	0.014
E 3 b	"	0.16	0.024	< 0.005	0.001	0.014	0.013
E 4 a	"	0.13	0.030	0.010	< 0.001	0.015	0.014
E 4 b	"	0.14	0.028	0.008	0.001	0.011	0.014
E 5 a	"	0.15	0.026	0.032	0.005	0.016	0.009
E 5 b	"	0.14	0.024	0.023	< 0.001	0.016	0.012
E 6 a	"	0.55	0.046	0.29	0.003	0.044	0.025
E 6 b	"	0.51	0.047	0.020	0.003	0.056	0.024
E 7 a	"	0.18	0.032	< 0.005	< 0.001	0.011	0.012
E 7 b	"	0.20	0.034	0.010	< 0.001	0.015	0.010
E 8 a	"	0.12	0.035	< 0.005	< 0.001	0.017	0.011
E 8 b	"	0.17	0.036	< 0.005	< 0.001	0.022	0.012

4.9.4 Faecal coliform bacteria

MPN^S of faecal coliforms in freshwater inflow streams (Table 11) indicate a slight contamination in all cases with notably higher numbers occurring after a moderate rainfall (July sampling). Resulting counts in receiving Inlet waters (Table 12) were uniformly low with the exception of site E6, in the Moutere River embayment, where MPNs of 230 per 100 ml were observed.

Faecal coliform numbers of most of the shellfish samples also indicate some degree of contamination, with the highest MPNs occurring in the Moutere river arm (>2.4 x 10^4 per 100g, Table 15). Thus the Moutere River would appear to be the main source of bacterial contamination.

Table 15. Bacterial quality of shellfish from Moutere Inlet, March 1991.

Site	Date	Shellfish	Faecal Coliforms (MPN / 100g)
S3	13 Mar-91	Mussel	9,200
S4	13 Mar-91	Mussel	5,400
S4	13 Mar-91	Cockle	230
S7	13 Mar-91	Cockle	490
S12	25 Mar-91	Cockle	700
S13	25 Mar-91	Cockle	20
S15	25 Mar-91	Cockle	790
S16	25 Mar-91	Cockle	80
S17	13 Mar-91	Cockle	> 24,000

4.9.5 Pesticides

Organochlorine and organophosphate levels of Moutere inflow streams were again below detection limits for the methods used (Table 16).

Table 16. Organochlorine and organophosphate concentrations of Moutere Inlet freshwater inflows, March 1991. Values expressed as mg/kg.

Site	Aldrin	Heptachlor	Lindane	DDE	Dieldrin	DDT	Screen
FW2	< 0.001	< 0.005	< 0.004	< 0.004	< 0.02	< 0.02	< 0.3
FW3	< 0.001	< 0.005	< 0.004	< 0.004	< 0.02	< 0.02	< 0.3
FW4	< 0.001	< 0.005	< 0.004	< 0.004	< 0.02	< 0.02	< 0.3
FW5	< 0.001	< 0.005	< 0.004	< 0.004	< 0.02	< 0.02	< 0.3

4.9.6 Potential sources of contamination

Our results suggest that the major input of nutrients and faecal coliform bacteria is in the Northern part of the Inlet. The Moutere River is likely the major "natural" source, overall, however localised impacts affecting specific sites, *e.g.* S5, 6 and 7 (and other sites not included in our sampling programme), probably result from other sources as well. To assist in understanding the potential sources of contamination, a visual inspection of the Inlet margins was carried out in September 1990 by L. Bamford and A. Fenemor (Nelson-Marlborough Regional Council). An account of this inspection is included in Appendix VII.

We can identify three main (external) sources of nutrients that contribute to the state of enrichment of Moutere Inlet sediments. These are: 1.) tidal seawater inflows, 2.) land runoff (direct and via freshwater tributaries) and 3.) effluent discharges as defined in Appendix VII.

The daily contributions of total nitrogen from the three main tributaries (FW1, 2 and 5) and two minor inflows (FW3 and 4) are shown in Figure 6. Under the low flow conditions of 22/3/91, FW1 (Thorp Drain) was proportionally the greatest contributor (21.3kg/d out of a total of 26kg/d). On the 25/7/91 sampling, the Moutere River was the greatest contributor (181.5kg/d) as compared to 83.5kg/d for Thorp Drain and 48.6kg/d for Tasman Stream. These variations in the relative contribution are a reflection of the N concentrations of the individual tributaries and their relative catchment areas. The Moutere River catchment (134,670,000m^2) comprises approximately 65% of the total freshwater input to the Inlet (Nelson Catchment and Regional Water Board, 1980). Thus we would expect it to contribute a much greater proportion of the nutrient inflow during wet periods.

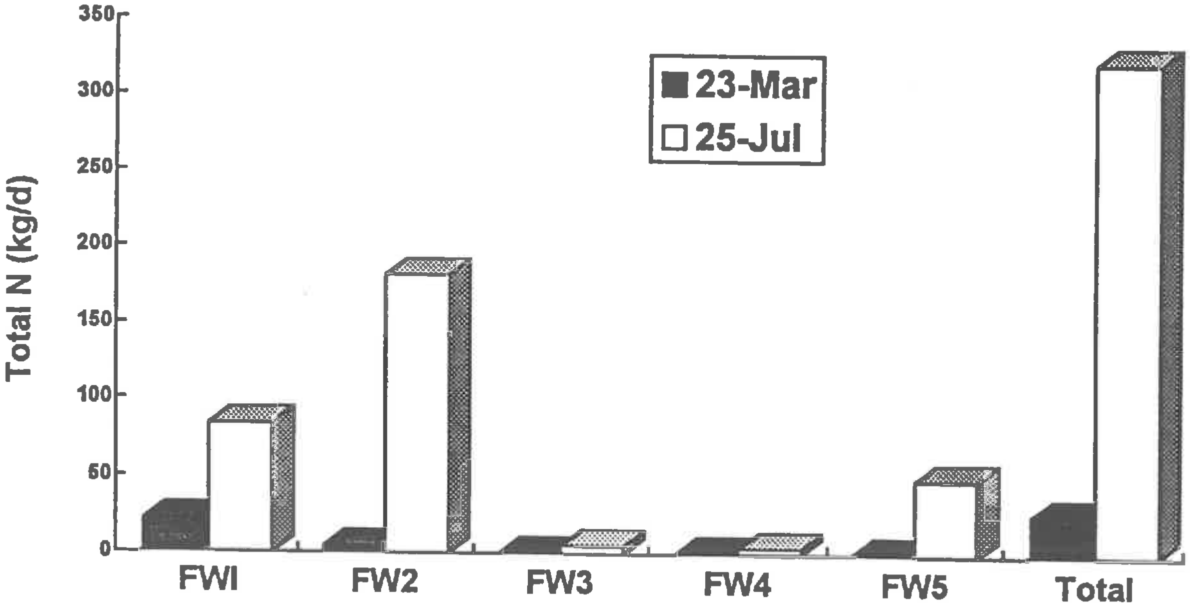


Figure 6. Estimated daily input of nitrogen from the five major freshwater tributaries of Moutere Inlet, 23 March and 25 July 1991 (see Figure 2 for locations of tributaries FW1-5).

Comparing freshwater nitrogen contributions to the Inlet with an estimate of what the marine (tidal) input might be for neap vs spring tides (Table 17), we see that the former would be relatively minor except during rain-affected flows (*e.g.* 13 to 21% during the rain-affected July 1991 sampling).

Table 17. Approximate total N contributions of tidal marine inflows; 22 March and 27 July 1991. Estimates are based on means of measured concentrations at sites E7 and E8 and tidal compartments of $9x10^6$ m^3(neap) and $15x10^6$ m^3(spring) from Crutchley (1988).

DATE	TOTAL N/M³(GRAMS) MEAN CONCENTRATION	TOTAL N/DAY (KG) TIDAL INPUT	
		HW Springs	**HW Neaps**
22 March 1991	0.093±0.02	1395	837
27 July 1991	0.17±0.03	2550	1530

Appendix VII identifies a number of sources of contamination that could contribute to the enrichment status or environmental quality of localised sediment habitats. The present study does not attempt to assess individual impacts but, where nutrient concentrations and flow volumes are available, we can evaluate their contributions relative to "natural" sources. Monitoring reports for Talley's Fisheries Limited (Coastal Permits NN89310-3), providing such information for the fish/vegetable processing (contra-shear plant) effluent, have been made available for this purpose by M.A. Baker (TDC).

Table 18. Estimated discharge of nitrogen from Talley's Fisheries Ltd (Contra- Shear Plant): Based on discharge rates described in effluent monitoring reports.

Date	(m³/day) Discharge	Total-N (kg/m³) Concentration	Total-N (kg/day) Discharge
27-28 Feb 1991	3110	0.0342	134
16-17 May 1991	3405	0.0463	158
3-4 June 1992	2145	0.0428	92
26-27 Jan 1993	2699	0.0442	119
23-24 May 1993	3600	0.0581	209

We see from Table 18 that the discharge from Talley's Contra Shear Plant contributes Total N at a mean rate of 142±12kg/d, n = 5. This equates to more than five times the sum of measured, low flow, freshwater inputs (23 March 1991) and approximately 44% during the fresh of 25 July 1991. Thus it appears that this source of nutrient is significant with respect to the total freshwater input. It would also seem to be important, but to a lesser extent, with respect to the marine (tidal) input; *e.g.* 6-10% during spring tides and 9-18% during neap tides

Additional, smaller nutrient sources, such as Talley's fishmeal plant effluent and others identified in Appendix VII, may also have enrichment potential, particularly if their cumulative effects are considered but no information is currently available describing their contributions.

4.10 Bathymetry and sedimentation

The sixteen cross-sections surveyed to mean sea level datum are presented in Appendix VI. These provide a baseline against which future assessment of morphological changes can be made. Comparison of sections CS4 and CS7 with the same surveys made in 1962 show that the river bed has built up but adjacent areas have been slightly eroded.

5.0 SUMMARY AND CONCLUSIONS

5.1 The state of enrichment of sediment habitats.

The impacts of nutrient enrichment on sediment habitats in Moutere Inlet were investigated at 22 sites representative of the range of habitats found in the Inlet. A series of sediment characteristics known to be affected by nutrient enrichment were assessed and evaluated in relation to enriched and unenriched intertidal sediments from other locations (Delaware Inlet, Nelson Haven, Waimea Inlet). Of the characteristics selected as descriptors of enrichment, the most effective were:

- microbial mineralisation rate,
- organic nutrient concentrations (total organic content, total-N, total-P),
- chlorophyll *a* concentration,
- macrophyte % coverage and
- core profile colouration.

Table 19 demonstrates the levels of enrichment of the study sites as indicated by the individual sediment descriptors. The sites are divided into four categories according to their ranking relative to the comparative inlets. Those assigned an N (non enriched) ranking were within a range observed at unenriched sites of similar textures in Delaware Inlet, Nelson Haven, and Waimea Inlet. Those ranked S (slightly enriched) were above the "normal" range but not to an extent that would indicate a deviation from normal habitat function. Those ranked E (enriched) were sufficiently elevated to indicate an altered habitat function. The ranking of H (highly enriched), was reserved for sites where deviation from normal habitat function resulted in major changes in benthic ecology: *i.e.* within a range observed at highly polluted sites in Waimea Inlet.

The majority of the 22 sites tested remain largely unenriched with respect to the descriptors. The only consistently elevated rankings occurred at sites 5A, 6A and 7 in the vicinity of the northern, Port Motueka, tidal outlet (Figure 2). The levels of enrichment observed there, with the exception of site 7, were insufficient to result in severe ecological alteration. The enrichment status of Site 7 was strongly influenced by a heavy macroalgal cover and this is probably due, largely, to the interruption of tidal flushing by Wharf Road and nutrient input via Thorp Drain.

Sites in the vicinity of the Kina outlet were not similarly enriched. Site 15, near the southern end of the Inlet, however, was characterised by elevated organic nutrients, but other symptoms of enrichment were not expressed; probably because of its higher tidal elevation.

Table 19. Comparative state of enrichment of Moutere Inlet sediments according to individual descriptors (N = No enrichment, S = Slight enrichment, E = Enrichment, H = Highly enriched, - = No data, * = Extreme patchiness, ** = Results invalidated by interference).

Site	SEDIMENT DESCRIPTOR				
	Macrophytes	**Chl *a***	**Min. Pot.**	**Organic nutrients**	**Profile**
1	N	N	N	N	N
2	N	N	N	N	N
3	N	N	N	N	S
4	N	N	N	N	N
5	E	N	-	N	-
5A	N	N	S	S	N
6	S	N	-	N	S
6A	S	N	S	S	S
7	H	N**	S	S	S
8	N	N	N	N	N
9	E	N	N	N	N
10	N	N	N	S	N
11	N	N	N	S	N
12	N	N	N	N	-
12A	N	N	N	S	S*
13	N*	N	N	N	-
13A	N	N	N	N	N
14	N	N	N	N	N
15	N	N	N	E	N
16	N	N	N	N	N
17	N	N	N	N	N
18	N	N	N	N	N

5.2 Sources of nutrients and other contaminants

The pattern of enrichment shown in Table 19 probably reflects, in part, the fact that the major fresh water inflow (Moutere River) is located in the northern arm of the Inlet, but other nutrient sources in this vicinity also contribute. As an example, we have compared total N inputs from inflowing freshwaters, seawater and known discharges. These comparisons suggest that nutrient discharges from Talley's Fisheries Limited are high relative to natural sources and therefore probably dictate the present state of enrichment of sediment habitats in parts of the Inlet. It is important to note, however, that, with the exception of Site 7, symptoms of excessive enrichment have not developed. This is probably due to the near-complete flushing of Inlet waters with each tide. As noted in Section 5.1, flushing is not complete at Site 7 due to flow restriction where Wharf Road bisects the Inlet. Nutrient sources affecting the upper end of the Inlet (e.g. Thorp Drain), in conjunction with less efficient flushing, result in a much increased potential for over-enrichment on the Northern side of Wharf Road.

Faecal coliform levels of fresh water inflows and Moutere shellfish suggest some bacterial contamination; particularly in the upper Inlet. Because the highest MPNs occurred in the Moutere River arm, this tributary would appear to be the main source of bacterial contamination.

Shellfish and sediment trace metal concentrations were all within ranges observed in other unpolluted intertidal habitats of the region, however a later report by Woodward-Clyde, NZ Ltd. (1993) of higher arsenic levels in Moutere cockles (approximately 10 times those observed here) indicate a possible new source of contamination that may warrant further investigation.

Organochlorine and organophosphate concentrations in Moutere sediments were all below detection limits for the methods used, indicating that, in general terms, Moutere Inlet is not grossly contaminated with these potential pollutants. However, we did not investigate the possibility that low, but potentially environmentally significant, levels may be present. A later report of low levels of DDE (an environmentally persistent breakdown product of DDT) in Moutere mudsnails (Woodward-Clyde (NZ) Ltd. 1993), suggests that sufficient background levels of this contaminant were present to account for some bio-accumulation.

5.3 Effects of embayments.

Removal of salt marsh from the periphery of the Inlet has the effect of decreasing its ability to absorb excess nutrients (see Section 3.6.1), however where embayments are converted to freshwater impoundments, interruption of the freshwater nutrient input is probably of overriding importance. Peripheral salt marshes are also significant for ecological reasons. They provide important habitat, including feeding and nursery areas for a variety of fish and invertebrate species. Loss of such habitat diminishes estuarine production with follow-on effects to the coastal food web.

Our sampling design included two embayments where partial flow restrictions occur (the Moutere River and Eden Stream arms). Neither showed signs of over enrichment. This is probably due, in part, to the relatively high tidal elevation of the embayments but it also suggests that flushing is sufficient to prevent accumulation of excess nutrients.

5.4 Present and potential threats to the estuarine environment.

In general, the Inlet seems to be in a relatively healthy condition with respect to plant and animal assemblages and the indicators of sediment enrichment, however some danger signs are evident. Macroalgal blooms (primarily *Ulva lactuca* and/or *Enteromorpha* sp.) were observed covering large areas of the Northern third of the Inlet. In most instances this increased plant productivity has not resulted in a deterioration of macrofauna community structure as defined by species diversity, indicator species, etc. Other characteristics of the sediments in the vicinity of the Port Motueka outlet also suggest some enrichment but again, with one possible exception, these changes are not to a degree that would indicate environmental deterioration. They do, however, provide warning that these locations are sensitive to enrichment and that the potential for over-enrichment does exist.

Shellfish faecal coliform numbers (MPNs) were considerably in excess of N.Z. Department of Health guidelines for the maximum tolerance in foods (*i.e.* 230 per 100g) at six of nine sites tested during low-rainfall conditions. Although these results represent one point in time only, they suggest that shellfish in the Inlet should not be used for human consumption without depuration.

Gross contamination of Inlet sediments or shellfish was not observed with regard to trace metals, organochlorines or organophosphates. As indicated by later reports, however, low but environmentally significant levels of arsenic and DDE may be present at some locations. Further work would be required to determine if these represent a threat to the ecology of biological habitats.

5.5 Future monitoring.

We have assessed the trophic condition of sediment habitats in Moutere Inlet and identified nutrient sources likely to contribute to the observed variation amongst sites. Repeat analyses of the same variables on four occasions at sites 5A and 14 (23 March-13 April 1993) show a slight decline in trophic state as compared to the 1991 sampling (Gillespie, unpublished) but this could be due to normal year to year variation. To date we do not have enough information to know if these habitats have reached a stable state or if the process of enrichment continues. It is likely that the 1991 observations are largely related to the immediate past history of nutrient input (*i.e.* one or two months) but this could also be superimposed on a longer term build-up of sediment organic contents where inputs exceed the microbes ability to decompose and recycle. As pointed out in the previous section, some danger signs are evident. For this reason, monitoring of selected sites would provide useful information for assessment of long term changes. Ideally, repeating the field surveys of all 18 sites with analyses of chl a, mineralisation potential, and organic nutrients at Sites 5A, 6A, 7, 9, 10, 11, 12A and 15 would provide a good indication of change over a monitoring interval *(e.g.* 4-5 years). The sites specified include those showing some degree of enrichment in the vicinity of the northern outlet as well as comparative sites near the southern outlet. If other sites show visual signs of change these could be investigated further as well.

The possibility of low-levels of contamination of Inlet sediments and/or biota with metals (e.g. arsenic) or organochlorines (e.g. DDE) may require further investigation. If levels of environmental concern are consistently observed at particular sites and potential sources are identified, these contaminants could also be incorporated into a monitoring programme.

Removal of salt marsh from the periphery of the Inlet has the effect of decreasing its ability to absorb excess nutrients (see Section 3.6.1) however where embayments are converted to freshwater impoundments, interruption of the freshwater nutrient input is probably of overriding importance.

Our sampling design included two embayments where partial flow restrictions occur (the Moutere River and Eden Stream arms). Neither showed signs of over enrichment. This is probably due, in part, to the relatively high tidal elevation of the embayments but it also suggests that flushing is still sufficient to prevent accumulation of excess nutrients.

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