CONFIRMED AND FAECAL COLIFORM BACTERIA IN COCKLES (Chone stutchburyi) IN ESTUARIES NEAR CHRISTCHURCH, NEW ZEALAND

Christchurch Drainage Board

DECEMBER 1988

CONFIRMED AND FAECAL COLIFORM BACTERIA IN COCKLES

(*Chione stutchburyi*) IN ESTUARIES

NEAR CHRISTCHURCH, NEW ZEALAND.

A REPORT PREPARED FOR THE CHRISTCHURCH DRAINAGE BOARD

by

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and

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FOREWORD

Sewage and stormwater disposal from a metropolitan area must be monitored closely if the highest possible standards of public health are to be maintained. The Christchurch Drainage Board is very conscious of this requirement and over the years has initiated many studies into the quality of surface waters within its district. Until recently though, very little attention has been given to the question of shellfish contamination in the local estuaries and this study is possibly the first of its kind to be carried out in the Avon-Heathcote and Saltwater Creek Estuaries and Brooklands Lagoon. It is certainly the most comprehensive one.

Between 1976 and 1978 the Christchurch Drainage Board gave serious consideration to a proposal to construct a new sewage treatment plant north of Christchurch. It was envisaged that if such a plant ever eventuated it would discharge either directly to the open sea via a submerged marine outfall or into the lower reaches of the Waimakariri River. Both options were researched extensively and included hydrological and environmental surveys of the lower Waimakariri system - including Brooklands Lagoon. The effects of pollution from local industry on the surface waters and shellfish beds in Brooklands Lagoon was a matter of particular concern and towards the end of 1977 the Board's consultants of the day (Messrs Steven and Fitzmaurice) contracted Dr M.J. Noonan, a senior lecturer in microbiology at Lincoln College, to undertake a survey of the shellfish beds. This was carried out in liason with the Board's Biologist, Dr J.A. Robb, between November 1977 and February 1978. Two adjacent estuaries - the Saltwater Creek and Avon-Heathcote Estuaries - were also sampled for comparison. Dr Noonan's results were subsequently conveyed to the consultants but never formally released. They comprise the first part of this report.

Towards the end of 1985 Dr Robb and Dr Noonan initiated a joint microbiological study of the shellfish beds in the Avon-Heathcote Estuary in more detail to update their status. The Saltwater Creek Estuary was again used as a comparison but this time Brooklands Lagoon was not included. Mr M. Witty, a graduate student of the Botany Department, University of Canterbury was employed by the Board on a temporary basis to assist with the sampling and laboratory work.

The final report was prepared jointly by Dr Robb and Dr Noonan and our special thanks are due to the latter for the advice and assistance that he has given. Others involved were Miss H.M. Walker (sampling), Messrs K.Sibly and B.E. Sutherland (draughting) and Mrs S.J. Johnson (typing).

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INTRODUCTION AND BACKGROUND

Micro-organisms reaching an estuary in waterborne wastes are readily accumulated by shellfish, especially filter-feeding shellfish such as mussels and cockles. Any pathogenic (i.e. disease-causing) bacteria or viruses derived from human faecal material that may be present, become a threat to public health if they are retained in shellfish that are subsequently taken as food for human consumption. In these circumstances the health risk is dependent upon the level of contamination and the types that are currently circulating within the local community. Often, only a few strains are present at any one time (Goyal *et al*. 1979).

The sanitary status of shellfish exposed to domestic waste discharges has been a matter of concern since the beginning of the 19th century. A causal relationship between shellfish and outbreaks of enteric infections was reported in 1895 when a third of the typhoid fever cases in Brighton, England, were estimated to result from the consumption of oysters or mussels contaminated with sewage (Metcalf, 1975). Since that time outbreaks of bacterial and viral infections resulting from consumption of sewage polluted shellfish have been recognised around the world (Mason & McLean 1962, Mackowiak *et al*. 1976, Metcalf 1975, Ruddy *et al*. 1969, WHO 1977). Johnstone (1980), for example, found that the consumption of raw shellfish accounted for 18 out of the 109 potential sources of infection of type A hepatitis in New Zealand in the year 1978-79.

The ability of shellfish to accumulate bacteria and viruses (Mitchell *et al*. 1966) has led to a restriction being put on either (1) the bacteriological quality of the shellfish growing waters, (in New Zealand under the 1967 Soil and Water Conservation Act and its amendments-the coliform count in waters used for growing shellfish should not exceed 70/100 ml) or (2) the level of faecal coliform bacteria in the shellfish themselves (less than 230 M.P.N. *Escherichia coli* per 100 g shellfish - Housar 1965, New Zealand Health Department).

There is, however, widespread concern about the adequacy of these standards. Slanetz *et al*. (1968), for example, found that the numbers of coliform bacteria present in waters where the oyster *Crassostrea virginica* was being cultivated exceeded 70/100 ml on only two of the seven instances when *Salmonella* spp were detected and on another occasion Metcalf (1975) isolated salmonellae from 23% of samples collected from a station deemed safe for human consumption on the basis of the numbers of coliform bacteria present. Metcalf also demonstrated that it is dangerous to place too much reliance on the levels of faecal coliform bacteria in the shellfish body tissue. Although *E. coli* numbers did not exceed 230/100 g of shellfish in any of the samples collected during his study, every one of them contained enteric viruses and 75% of them also contained salmonellae. He concluded that the coliform index is only useful when faecal pollution is moderate to excessive and that it is particularly unreliable when faecal coliform numbers fall below 70/100 ml in water and/or 230/100 g of shellfish. This conclusion was also reached by Fugate *et al*. (1975) after they had successfully isolated poliovirus 1 and echovirus 4 in separate oyster samples harvested from approved waters (based on faecal bacteria numbers) along the coast of Texas. The sample from which poliovirus 1 was isolated contained 45 *E. coli* /100 g and the one containing the echovirus 4 only 20/100 g. These authors suggest that while the enteroviruses and *E. coli* may have entered the shellfish at the same time, the bacteria were probably eliminated more rapidly than the

viruses when the quality of the water improved. Murphy *et al.* (1979) arrived at a similar conclusion from their study after noting that only 28% of an oyster population associated with an outbreak of gastroenteritis caused by the Norwalk virus carried excessively high numbers of faecal coliforms. Canzonier (1971) has successfully demonstrated that bacteriophages and *E. coli* are eliminated at different rates from hard clams. His experiments suggest that viruses are not eliminated as rapidly when their numbers are low and that they are not eliminated at all during feeding.

Although it has never been demonstrated that viruses can multiply in shellfish (Chang *et al.* 1971) there is good evidence to suggest that some strains can survive in this environment for a considerable period of time. Mackowiak *et al.* (1976) for example concluded that the infectious hepatitis virus probably survived in a shellfish population for 1-2 months prior to an epidemic in Lousiana in 1973.

The extent to which shellfish concentrate micro-organisms is highly variable (Wood 1979) and depends upon a wide range of factors including salinity and temperature. When environmental conditions are less than optimal their filtration rate drops off and the concentrations and types of micro-organisms accumulated internally are no longer a reliable index of water quality. Some species may stop filtering altogether if temperatures fall too far below the optimum range. When they return to this range though it does not take long for the number of micro-organisms accumulated internally to change in line with the bacterial quality of the surrounding water.

Often the source of contamination cannot be clearly defined. Volterra *et al.* (1980), for example, did not record any significant differences in the quality of shellfish at two well-separated sites in a bay along the Italian coastline even though the water at one of the sites was considered to be polluted from nearby sewage outfalls. Local currents may have carried suspended materials and bacteria from one side of the bay to the other but this was not established conclusively from their studies. In other studies, Metcalf and Stiles (1965) identified a bed of *Crassostrea virginica* contaminated with the coxsackie B-4 and echo 9 viruses up to 6.4 km from the nearest raw sewage outfall and Murphy *et al.* (1979) found that although an oysterbed they were studying was contaminated with the Norwalk virus (a source of gastroenteritis) after heavy rainfall, other viruses (such as hepatitis A) which are normally associated with sewage contamination (e.g. Dismukes *et al.* 1969), were absent. This irregularity led them to conclude that this virus may have been released into the overlying water from disturbed sediments that were already contaminated rather than from a concurrent discharge of raw sewage.

Very little information is available on the contamination of gastropod molluscs in relation to the amount of sewage pollution in their growing waters. Patrick and Kendrick (1980) sampled the viscera and meat of the New Zealand paua (*Haliotis iris*) and found that even though the animals were growing in waters which would meet the criteria for shellfish cultivation, the numbers of faecal coliform bacteria present in their guts were relatively high. Perhaps this was a result of grazing on algae to which faecal coliforms had adsorbed. Numbers in the meat were lower than that in the viscera by a factor of 10^2-10^4.
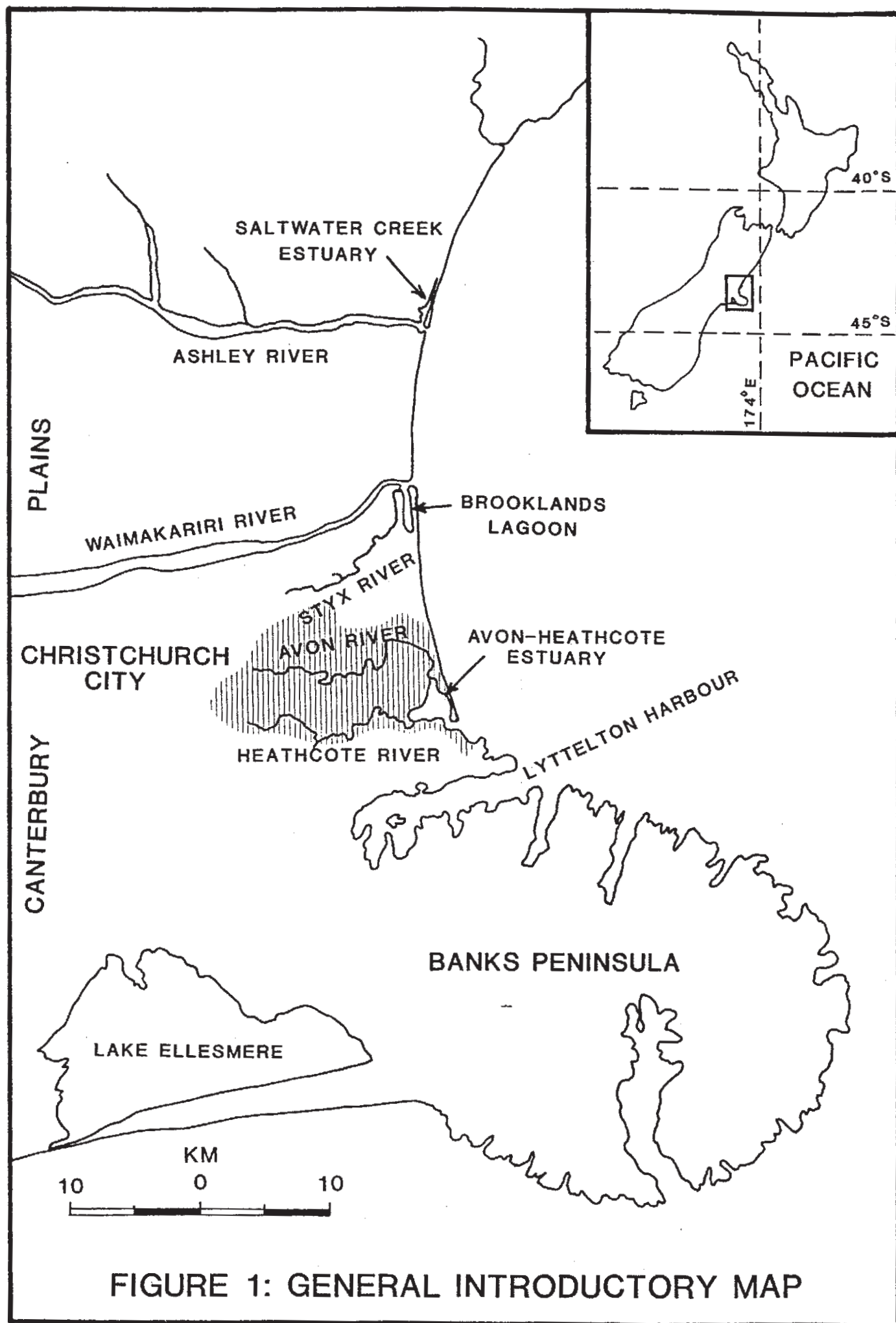
It has frequently been claimed that depuration in clean water eliminates the disease risk from contaminated shellfish. Experiments on shellfish contaminated with *E. coli* and *Salmonella schottmuelerri* and poliovirus have certainly demonstrated this (Arcisz and

Kelly, 1954; Liu *et al*. 1967). On the other hand, Buisson *et al*. (1981) noted that the depuration of *E. coli* from the oyster *Crassostrea gigas* is largely influenced by initial contamination levels and the temperature of depuration. However, Janssen (1974) in experiments with the oyster *Crassostrea virginica* contaminated by *Salmonella typhimurium* and *Francisella tularensis* found that in spite of the large numbers of *S. typhimurium* which must have been passed through the oyster when they were placed in water containing 200,000 organisms/ml only 19,000 to 28,000 organisms per shellfish were retained. Moreover, even after 42 days in clean water, numbers of *S. typhimurium* excreted in the faeces were still high. Similar results were obtained with *F. tularensis* after seven days. Thomas & Jones (1971) found that two out of 59 batches of mussels which had been purified still contained *Salmonella* sp. Conversely, Son and Fleet (1980) concluded that bacterial pathogens including *Salmonella* spp. are in fact removed at comparable rates to *E. coli*.

Depuration of oysters to low levels of faecal coliforms may not mean that all pathogenic viruses have been eliminated (Buisson *et al*. 1981) and in a review Eyles (1980) concluded that at present it can not be stated with certainty whether or not purification processes are totally effective in removing viruses. This viewpoint is shared by Scotti *et al*. (1983). They showed that both the uptake and elimination of insect picornaviruses can vary when bacterial accumulation and depuration are normal. Lewis *et al*. (1986) were also unable to show a reduction in enteroviruses in depurated green lipped mussels (*Perna canaliculus*).

Adequate cooking generally destroys viruses (Mason and McLean 1962) although DiGirolamo *et al*. (1970) have shown that standard cooking procedures did not totally destroy poliovirus in laboratory-contaminated oysters.

SALTWATER CREEK ESTUARY

ASHLEY RIVER

PLAINS

WAIMAKARIRI RIVER

BROOKLANDS LAGOON

STYX RIVER

CHRISTCHURCH CITY

AVON RIVER

AVON-HEATHCOTE ESTUARY

HEATHCOTE RIVER

LYTTELTON HARBOUR

CANTERBURY

BANKS PENINSULA

LAKE ELLESMERE

KM

10   0   10

40°S

45°S

174°E

PACIFIC OCEAN

FIGURE 1: GENERAL INTRODUCTORY MAP

SAMPLING AND ANALYTICAL PROCEDURES

Three estuarine areas close to the City of Christchurch, New Zealand are highly productive and support good populations of shellfish: Brooklands Lagoon, the Avon-Heathcote Estuary and the Saltwater Creek Estuary (Figure 1). All three were visited during the course of this study (i.e. during the summer of 1977-78 and/or 1985-86) in an attempt to evaluate the microbiological qualities of their cockle (*Chione stutchburyi*) beds. Sampling sites are detailed in Appendix 4.

Brooklands Lagoon lies 15 km north-east of Christchurch City at the mouth of the Waimakariri River. It is a long (4.1 km), narrow, blind-ending tidal lagoon with a total area of almost 170 hectares. It is well flushed each tidal cycle and has an estimated tidal compartment of almost $1.6 \times 10^6 m^3$ on a mean high water ordinary spring tide (Christchurch Drainage Board, unpublished data). For much of the year this lagoon is subjected to a measurable level of contamination (Christchurch Drainage Board, unpublished data) from several industries including two freezing works, a fellmongery and a woolscour sited in neighbouring Belfast and Kaiapoi.

The Avon-Heathcote Estuary is a triangular 716 hectare tidal flat with an estimated tidal compartment of $8.5 \times 10^6 m^3$ on a mean tide (Mawson, 1972). Its eastern margin is bounded by a narrow sandspit and the outlet to the open sea lies between the tip of this spit and the volcanic cliffs of Banks Peninsula at the south-eastern corner. The Christchurch Treatment Works administered by the Christchurch Drainage Board discharge directly to the foreshore of this estuary from two points 100 m apart along the western margin for aproximately 3-4 hours directly after each high tide. Although this effluent receives a good level of primary and secondary treatment (including at least ten days retention in an oxidation ponding system) it still contains appreciable numbers of microorganisms (Appendix 2). Many - perhaps most - of these are derived from the prolific bird life that frequents the oxidation ponding area.

The Avon and Heathcote Rivers service predominantly urban catchments (84.3 & 103.4 km^2 respectively) and receive virtually all of the stormwater run-off from the city area. Their estimated low-flows are 2.7 and 0.88 m^3/s respectively. Since 1981 the Christchurch Drainage Board has maintained a regular monitoring programme for faecal coliform bacteria in the surface waters of the estuary and the two rivers (Christchurch Drainage Board, 1981 and unpublished data). A summary of all the relevant data to date from these studies is included as Appendix 3 of this report.

The Saltwater Creek Estuary is situated at the mouth of the Ashley River 26 km north of Christchurch City. It is bounded on the east by a long narrow unstable sandspit and its mouth connects with the Ashley River just before it in turn discharges to the open sea. The tidal flats from this section of estuary have been extensively modified over the last ten years or so due to the erosion of the fore-dunes at the southern end of the spit and an accompanying movement of the Ashley River mouth several hundred metres to the north.

Saltwater Creek is a small stream with an estimated low flow of $1.7 m^3$/S. Like the Ashley its catchment is predominantly rural and is not substantially contaminated with

industrial wastes or urban stormwater run-off. This estuary is therefore a useful reference for evaluating the qualities of the other two.

Shellfish:

Shellfish sampling was carried out during the 1977-78 and 1985-86 summers. Several of the sites were sampled twice within one of the summer periods. Cockles were placed in sterile plastic bags and transported in insulated containers containing ice. Shells were scrubbed under running water of drinking water quality with a wire brush as recommended by APHA (1970). The shellfish were then placed in a sterile beaker and covered with sterile water until they were opened using a flamed sterilised knife. The contents were weighed and transferred to a blender (Waring Model 1005, Waring Products Co., Winsted, USA). Peptone (Oxoid, 0.5%) was added to bring the total volume to either 100 or 200 ml before blending at full speed in two bursts of 30s.

The Most Probable Number (MPN) technique of Anon (1969) was used to enumerate the confirmed and faecal coliforms present. Dilutions were carried out using 0.5% sterile peptone water as required and aliquots were transferred into five replicate tubes of minerals modified glutamate medium (MMG) for incubation at 37°C according to the methods of Anon (1969), within six hours of shellfish collection. Tubes showing a positive reaction were transferred to one tube of brilliant green bile broth (BGBB) held at 37°C for confirmed coliforms and one tube each of BGBB and tryptone water which was incubated at $44.5 \pm 0.1°C$ (Anon, 1969) for faecal coliform bacteria.

Volterra *et al.* (1980) have compared the MPN and poured plate techniques. Generally the plate count method gave lower results. The size of the shellfish sample and the size diluent and dilution used did not affect the results. The authors stressed that it is important to include intervalve water especially if the shellfish are eaten raw because this may be important in the transmission of infectious diseases (WHO 1977). Slanetz *et al.* (1964) compared MPN methods with membrane filter (MF) methods and suggested that the MF technique is more direct and simple and deserves further study. They do concede though that the MF technique cannot be used when numbers of bacteria in the shellfish are low.

For the 1985-86 sampling dry-weight was calculated from shell-length measurements using the relationship $\log_{10}$ weight = 3.987 $\log_{10}$ length - 6.523; (r = 0.97). (Christchurch Drainage Board unpublished data).

Results are recorded in Appendix 1 (pages 17-27) and a graphical representation of the 1985-86 data is presented in Figures 2 and 3.

Waters:

Presumptive and faecal coliform bacteria were enumerated in water according to the Report of recommendations of the Microbiological Society's Committee on Coliform Bacteria (1976) with minerals modified glutamate broth for presumptive coliforms and lauryl sulphate tryptose broth for the faecal coliforms.

RESULTS

3.1 Brooklands Lagoon

3.1.1 1977-78 Summer:

Numbers of faecal coliform bacteria/g wet weight (ww) of cockle ranged between 0.8 and 37.7 in November 1977 (Appendix 1.1 & 1.2) and increased to between 1.6 and 116/g ww by the time of the second visit in February. (Geometric means for the two visits were 6.96 and 13.7 respectively). Furthermore, the range of confirmed coliform bacteria isolated changed from 1.2 - 257 to 2.2 - 343/g ww of shellfish between the two visits and the geometric mean rose from 18.3 to 43.7. It is known that during these intervening weeks the freezing works had lifted their killing rate - and therefore their discharge - quite significantly (CFM, unpublished data).

Virtually the entire cockle bed within the limits sampled (i.e for one kilometre above the point of confluence with the Waimakariri River) was contaminated to some extent with faecal coliforms: only four of the 34 samples analysed satisfied the New Zealand Health Department standard of 2.3/g ww. It cannot be inferred from the data gathered that shellfish living closer to the Waimakariri River are any more contaminated with these microorganisms than those present further up the lagoon.

3.2 Saltwater Creek Estuary

3.2.1 1977-78 Summer:

Confirmed and faecal coliform bacteria numbers present in cockles inhabiting the Saltwater Creek estuary were low on the first sampling occasion (21.11.77) with geometric means of only 0.87 faecal and 1.98 confirmed coliforms/g ww (Appendix 1.3). On the second visit (7.2.78) though they were markedly higher with means of 22.9 faecal and approximately 122 confirmed coliforms/g ww.

3.2.2 1985-86 Summer:

Generally, numbers of faecal coliform bacteria were highest in cockles taken near the mouth of Saltwater Creek and decreased with increasing distance upstream (Appendix 1.4, Figure 2). Cockles living adjacent to the northern drainage channel (i.e. Sites 25 - 44) were of a much better quality than those living near the Saltwater Creek channel. This is closely related to the influence that the Saltwater Creek has had on them. The cockle beds near the mouth are low-lying and exposed to the water-borne contaminants carried in Saltwater Creek for most of the time between mid and low tide when the water is otherwise confined to the main channel. Several of the samples collected further upstream (e.g. Sites 58, 62, 77 & 83) were taken from the mid-tide range which is not exposed to riverwater at this time. Those living adjacent to the northern drainage channel (i.e. between Sites 25 - 44) are not affected at all. Only four of the 29 samples collected complied with the coliform standard laid down by the New Zealand Department of Health. The highest number recorded was 298/g ww which exceeds this standard by more than 100-fold.

FIGURE 2:   FAECAL COLIFORMS/g WET WEIGHT OF COCKLE
SALTWATER CREEK ESTUARY 1985-86
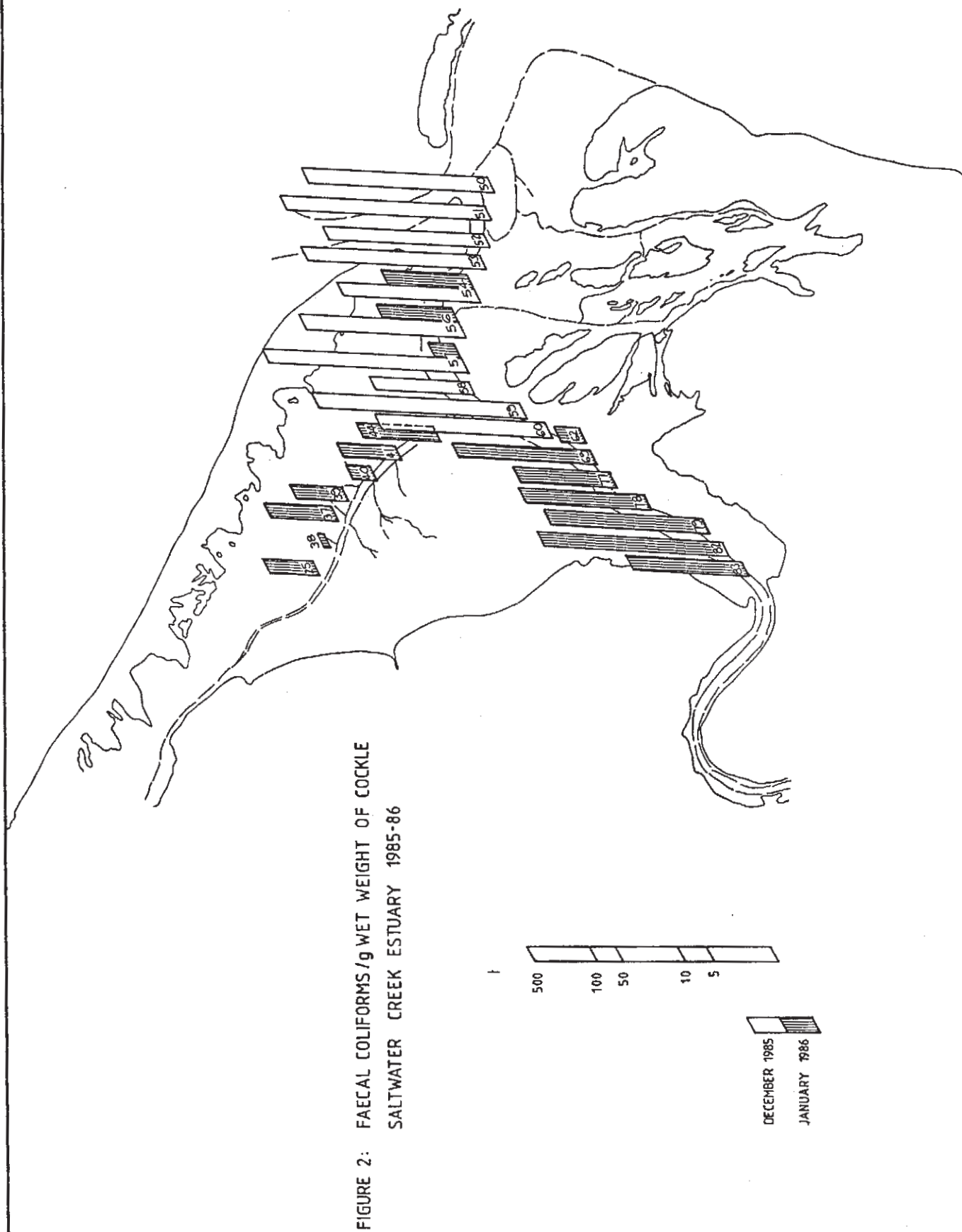
Everyone of the cockles collected in February 1978 contained higher - often much higher - concentrations of faecal coliform bacteria than those collected a few weeks earlier indicating that even within the period of a few weeks bacterial numbers can fluctuate greatly. The data for the 1985-86 period confirms this conclusion. Even though only three sites (54, 56 and 57) were sampled twice it is evident that much higher concentrations of microorganisms were contained in these cockle beds at the time of the earlier visit. When this level of short-term variability is taken into account it can be concluded that there was no significant shift in the quality of these cockle beds between 1977 and 1986. Bacterial numbers found in February 1978 were similar to those found in 1985-86 even though the position of the river mouth had changed and the tidal flats with which these shellfish are associated had been extensively disrupted during the intervening years. Most probably, the quality at any given time is closely related to the frequency and intensity of rainfall and subsequent stormwater runoff from the farmlands that dominate the Saltwater Creek catchment.

3.3 Avon - Heathcote Estuary

3.3.1 1977-78 Summer:

The numbers of faecal coliform bacteria found in cockles inhabiting this estuary were a little lower at the time of the first visit (1.11.77) when a geometric mean of only 0.24/g ww was recorded (Appendix 1.5). This compares with 0.83/g ww four weeks later. Nine (possibly ten) of the thirteen samples collected in total - including the one from Site 5 which lies within the sphere of influence of the oxidation pond outfalls - complied with the New Zealand Health Department standard of 2.3/g ww. Those that did not were located in McCormacks Bay and along the main outlet channel close to the mouth of the estuary. Confirmed coliform numbers were substantially higher though (geometric means >220 and 2.0/g ww respectively).

3.3.2 1985-86 Summer:

Several instances of very high concentrations of faecal and confirmed coliform bacteria were recorded in the Heathcote depository and the sector of tidal flat directly influenced by the discharges from the oxidation ponds - i.e. Sites 64 - 68 (Appendix 1.6). The Avon River is probably not exerting a great deal of influence here as several cockle samples that were more directly influenced by the river water (e.g. those from Sites 16, 18, 21, 23 & 24) were not as contaminated. There can be little doubt that the oxidation pond effluent was primarily responsible for the quality of these shellfish. It has been well established that river water entering the Avon-Heathcote Estuary contains appreciable numbers of faecal coliform bacteria (Appendix 3) and usually the Heathcote River is more contaminated than the Avon. This is reflected in the spatial distribution of coliform bacteria associated with the shellfish beds in this estuary (Figure 3). Cockles living in the Heathcote depository were far more contaminated than those found in the Avon depository in 1985-86. Furthermore, those living in the vicinity of low tide adjacent to the main river channels were appreciably more contaminated than those living further up the tidal flat and/or closer to the mouth where the influence of the incoming seawater becomes increasingly more important. Many of the cockles lining the Avon channel could be occasionally influenced by residual oxidation pond effluent too.
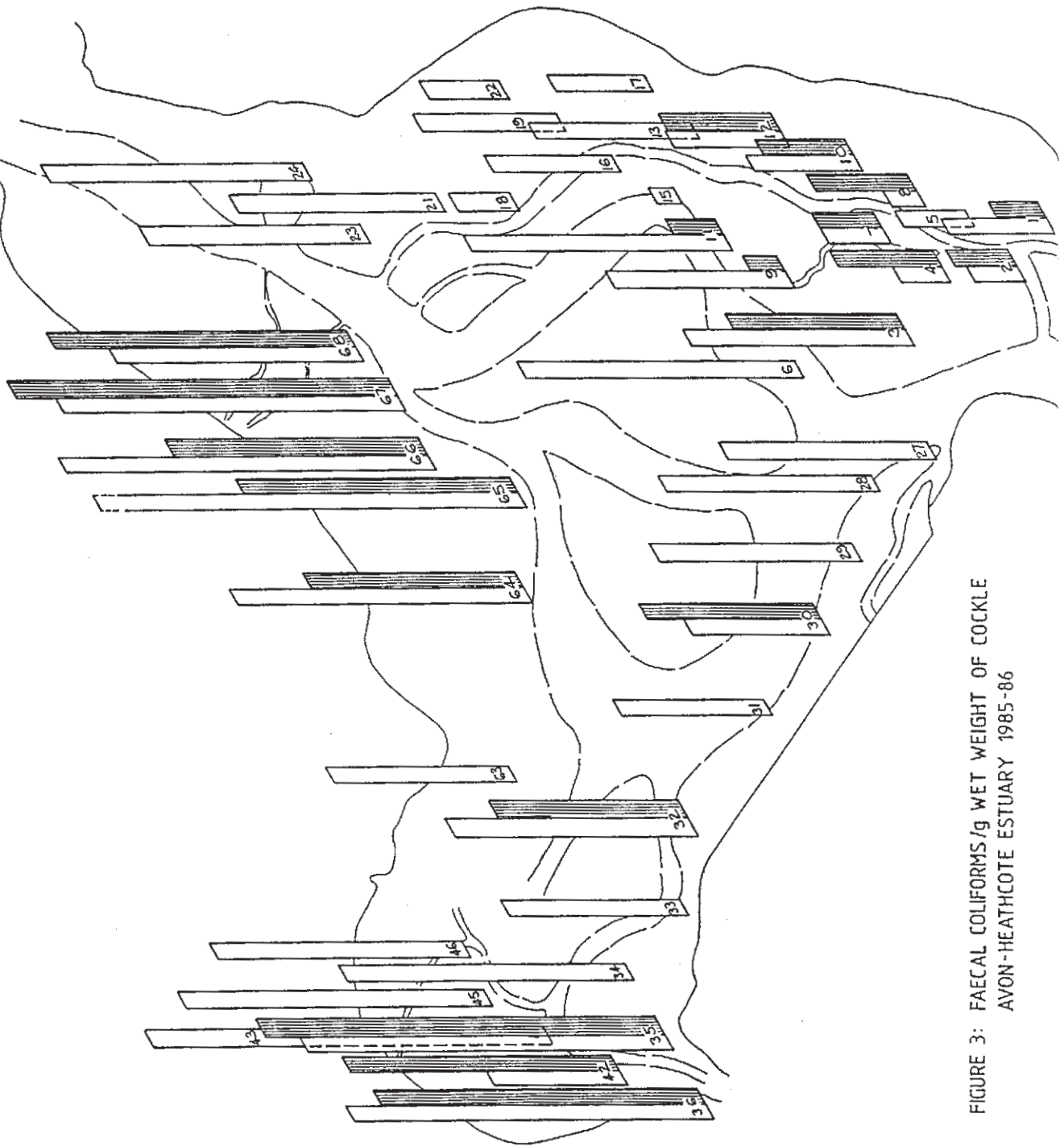
FIGURE 3: FAECAL COLIFORMS/g WET WEIGHT OF COCKLE
AVON-HEATHCOTE ESTUARY 1985-86

NOVEMBER-
DECEMBER
1985

JANUARY-
FEBRUARY
1986

1000
100
10
1

On the basis of size and Health Department standards it is concluded that only cockles living in the mid-tide range of the eastern tidal flats near the mouth were both suitable and safe enough for human exploitation at the time that this survey was carried out.

The results suggest that these cockle beds were substantially more contaminated in 1985-86 than they were in 1977-78. The actual difference is probably not as pronounced as it might appear though as:

(1)   the latter survey was far more extensive and included areas (e.g. the north-western sector) that were not included in the earlier one,

(2)   the analytical technique employed is subject to considerable error and

(3)   in the 1977-78 survey only shells of a size suitable for eating were collected which means that the average wet-weight per sample was significantly higher than in 1985-86 (page 6).

DISCUSSION AND GENERAL CONCLUSIONS

Appreciable levels of coliform contamination were noted in all three localities and most of the values determined in this study fall within the same range as that determined by Stanetz *et al.* (1968) for oyster beds in New Hampshire (i.e. 0.2 - 124 faecal coliform bacteria/g ww).

The condition of the cockle beds in the Avon-Heathcote Estuary and Brooklands Lagoon is not unexpected as both areas are known to be substantially contaminated with water-borne microorganisms. Although some agricultural waste reaches the Waimakariri River - and presumably Brooklands Lagoon - from non-point sources, most of the coliform bacteria present in 1977-78 (and 1985-86) probably originated from the two freezing works. These discharges may also have contained undesirable bacteria such as *Salmonella, Campylobacter* and *Leptospira* spp. but it is highly unlikely that they contributed viruses that would be pathogenic to humans.

Most of the faecal microorganisms contained within the Avon-Heathcote Estuary are derived from urban stormwater run-off and a wildlife reserve which means that most of them originate in the faeces of non-human warm blooded animals over which there can be little control. The area of tidal flat most affected by the oxidation pond discharges is fairly restricted and not easily accessible to the public. Furthermore the cockles living here are small and not really suitable for human consumption. Neither are those living up-estuary in the Heathcote and Avon depositories. The ones most likely to be taken are to be found down-estuary along the eastern tidal flats (Appendix 5). Many of these met the Health Department faecal coliform standard in 1985-86.

The level of coliform contamination in the Saltwater Creek Estuary is most unexpected. For an area that is influenced by run-off from a predominantly rural catchment the results obtained are surprisingly high. In 1985-86, for example, the cockle beds were substantially more contaminated with coliform bacteria than those from the Avon-Heathcote Estuary: geometric means for faecal coliforms were 22.11 and 7.04/g ww respectively. Shellfish contamination is more uniform here too. In sharp contrast to the Avon-Heathcote Estuary, the highest level of faecal contamination occurred close to the mouth (i.e. at Sites 50 - 54) where the largest shellfish are found (Appendix 5). Unfortunately, these are the ones that are most frequently exploited for human consumption. Although there may be more risk of contracting bacteria such as *Salmonella typhimurium* from shellfish in this estuary, the presumed absence of human faecal waste means that viruses such as hepatitis A will be absent. The same cannot be said of the Avon-Heathcote Estuary though, as Lewis *et al.* (1986) found that levels of enteroviruses were only about one order of magnitude less than the numbers of faecal coliform bacteria in shellfish collected near the New Plymouth outfall.

It is concluded that only a small proportion of the cockles from these three localities complied with Health Department requirements for safe human consumption at the time of sampling. With the possible exception of Brooklands Lagoon it is difficult to see how this situation can be significantly improved in the foreseeable future.

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APPENDIX 1:   Confirmed and faecal coliform bacteria in *Chione stutchburyi*. Data for 1977-78 and 1985-86.

         1.1   Brooklands Lagoon (7.11.77)
         1.2   Brooklands Lagoon (7.2.78)
         1.3   Saltwater Creek Estuary (22.11.77 and 7.2.78)
         1.4   Saltwater Creek Estuary (1985/86)
         1.5   Avon-Heathcote Estuary (1.11.77 and 29.11.77)
         1.6   Avon-Heathcote Estuary (1985/86)

1.1: Numbers of confirmed and faecal coliform bacteria in *Chione stutchburyi* collected from Brooklands Lagoon (7.11.77). Bacteria were enumerated using the Most Probable Number method of Anon (1969).

Site	No. of shellfish sampled	Average wet weight (g)	No. of coliform bacteria/g wet weight of shellfish		No. of coliform bacteria/shell fish	
			Confirmed	Faecal	Confirmed	Faecal
1	2	6.50	92.3	37.7	600	245
2	6	8.40	51.6	11.1	433	93
4	1	9.85	49.8	23.4	490	230
5	14	4.03	8.7	8.7	35	35
6	9	6.68	16.3	4.3	109	29
7	11	7.09	12.6	4.4	89	31
8	10	7.17	257	15.1	1840	104
9	10	9.47	1.2	0.8	9	8
10	10	11.47	16.0	3.8	184	44
11	9	11.20	33.7	31.7	378	36
12	10	8.83	38.5	11.1	340	98
13	10	9.91	21.2	6.7	210	66
14	10	7.65	62.7	12.8	>480	98
16	10	7.39	7.6	6.0	56	44
17	10	6.91	1.9	1.6	13	11
18	10	4.65	3.1	1.4	14	6

1.2: Numbers of confirmed and faecal coliform bacteria in *Chione stutchburyi* collected from Brooklands Lagoon (7.2.78). Bacteria were enumerated using the Most Probable Number method of Anon (1969).

Site	No. of shellfish sampled	Average wet weight (g)	No. of coliform bacteria/g wet weight of shellfish		No. of coliform bacteria/shell fish	
			Confirmed	Faecal	Confirmed	Faecal
1	10	7.65	141	12.0	1080	92
2	10	6.60	106	23.9	700	158
3	10	6.55	51.9	4.0	340	26
4	9	6.37	17.1	11.5	109	73
5	10	9.33	343	116	3200	1080
6	10	6.95	155	37.4	1080	260
7	10	7.38	18.9	8.9	140	66
8	10	6.34	111	22.1	700	140
9	10	7.26	3.6	3.6	26	26
10	10	6.62	51.4	14.8	340	98
11	10	6.27	54.2	10.5	340	66
12	10	5.37	89.4	48.4	480	260
13	10	5.54	86.6	10.1	480	56
14	10	4.37	50.3	22.4	220	98
15	10	6.33	41.1	41.1	260	260
16	10	4.98	2.2	1.6	11	8
17	9	5.17	21.1	9.5	109	49
18	10	5.07	31.2	6.7	158	34

1.3: Numbers of confirmed and faecal coliform bacteria in *Chione stutchburyi* collected on two occasions (21.11.77 and 7.2.78) from the Saltwater Creek Estuary. Bacteria were enumerated using the Most Probable Number Method of Anon (1969).

Site	No. of shellfish sampled	Average wet weight (g)	No. of coliform bacteria/g wet weight of shellfish		No. of coliform bacteria/shellfish	
			Confirmed	Faecal	Confirmed	Faecal
(a) 21.11.77						
1	10	6.01	2.6	1.1	18	7
2	10	7.44	4.5	2.1	34	18
3	10	8.17	26.9	8.1	220	66
4	10	6.85	5.0	2.1	34	14
5	9	8.27	0.89	0.46	7	4
6	10	6.96	0.63	0.32	4	2
7	10	6.37	0.44	0.25	3	2
8	10	7.03	0.94	0.66	7	5
9	10	4.18	2.3	0.8	10	3
10	10	6.34	3.5	0.7	22	4
11	10	6.09	0.6	0.5	3	3
12	9	4.22	2.1	0.7	9	3
(b) 7.2.78						
1	10	4.68	>1025	393	>4800	1840
2	10	9.70	>529	77.2	>4800	700
3	10	7.50	93.3	2.93	700	22
4	10	6.30	، 171	76.2	1080	480
5	10	6.27	116	76.5	700	480
6	10	6.79	>707	103	>4800	700
7	10	6.60	23.9	6.97	158	46
8	10	6.49	283	10.1	1840	66
9	10	6.65	6.91	1.47	46	9.8
10	10	6.44	21.7	7.14	140	46

1.4: Numbers of confirmed and faecal coliform bacteria in *Chione stutchburyi* collected on three occasions (1985/86) from the Saltwater Creek Estuary. Bacteria were enumerated using the Most Probable Number method of Anon (1969).

Site	Date of sampling	No. of shellfish sampled	Average wet weight (g)	No. of coliform bacteria /g wet weight of shellfish	
				Confirmed	Faecal
25	13.1.86	36	0.60	7.8	3.6
37	13.1.86	33	0.72	14.0	5.9
38	13.1.86	33	0.91	5.6	1.1
39	13.1.86	24	1.08	12.7	4.2
40	13.1.86	29	0.95	12.0	1.8
41	13.1.86	21	1.78	21.1	4.5
44	13.1.86	23	1.35	15.8	7.4
50	10.12.85	6	4.97	117.4	117.4
51	10.12.85	6	5.13	519.5	298.7
51	10.12.85	7	4.04	123.7	123.7
51	10.12.85	8	3.90	173.1	173.1
52	10.12.85	7	4.73	66.5	66.5
53	10.12.85	7	4.86	158.8	102.9
54	10.12.85	*	*	98.0	32.2
54	20.1.86	8	3.38	13.0	8.9
56	10.12.85	8	3.96	170.3	69.4
56	20.1.86	8	4.00	7.5	7.5
57	10.12.85	7	4.74	277.1	162.7
57	20.1.86	9	2.99	13.0	1.8
58	10.12.85	6	4.50	200.0	12.2
59	10.12.85	7	3.96	194.9	194.9
60	10.12.85	10	2.69	89.2	89.2
62	20.1.86	10	2.60	18.8	1.9
69	20.1.86	12	2.73	165.1	33.6
77	20.1.86	16	1.73	25.3	11.9
78	20.1.86	14	1.99	86.0	28.3
79	20.1.86	32	0.78	84.0	72.0
82	20.1.86	50	0.30	364.9	114.9
83	20.1.86	24	1.03	68.5	19.8

* Number not determined.

1.6: Numbers of confirmed and faecal coliform bacteria in *Chione stutchburyi* collected on five occasions (1985-86) from the Avon-Heathcote Estuary. Bacteria were enumerated using the Most Probable Number method of Anon (1969).

Site	Date of sampling	No. of shellfish	Average wet weight (g)	No. of coliform bacteria /g wet weight of shellfish	
				Confirmed	Faecal
1	19.11.85	24	2.23	6.3	1.0
1	3.2.86	7	3.47	2.0	0.3
2	19.11.85	11	3.61	6.6	0.3
2	3.2.86	8	4.15	2.1	0.4
3	19.11.85	13	7.29	16.7	16.7
3	3.2.86	8	9.00	21.9	4.7
4	19.11.85	13	6.68	3.9	0.3
4	3.2.86	9	7.14	4.0	1.0
5	19.11.85	27	1.49	24.3	0.5
6	19.11.85	9	5.69	50.8	50.8
7	19.11.85	11	4.78	1.3	0.4
7	3.2.86	11	5.43	3.2	0.4
8	19.11.85	28	1.91	0.8	0.2
8	3.2.86	12	2.09	4.4	0.9
9	19.11.85	18	2.53	41.3	5.7
9	3.2.86	14	2.71	1.1	0.2
10	25.11.85	25	0.96	32.8	1.1
10	3.2.86	16	1.81	7.6	0.8
11	25.11.85	11	2.83	70.7	35.4
11	3.2.86	9	2.94	83.0	0.3
12	25.11.85	21	1.10	15.9	1.4
12	3.2.86	20	1.26	13.0	1.3
13	25.11.85	22	0.93	53.7	3.9
15	19.11.85	14	3.49	13.5	<0.1
16	25.11.85	22	2.46	103.5	1.7
17	25.11.85	18	1.11	23.0	0.9
18	25.11.85	*	*	9.5	0.4
19	25.11.85	22	1.00	159.8	2.2
21	25.11.85	12	2.15	9.7	9.7
22	25.11.85	37	0.71	23.6	0.6

1.6 continued:

Site	Date of sampling	No. of shellfish	Average wet weight (g)	No. of coliform bacteria /g wet weight of shellfish	
				Confirmed	Faecal
23	3.12.85	30	0.82	113.4	13.4
24	3.12.85	40	0.48	>1256.5	36.6
27	3.12.85	13	2.52	39.8	10.1
28	3.12.85	25	1.07	63.7	12.4
29	3.12.85	18	1.41	94.9	9.5
30	3.12.85	26	0.85	81.4	2.2
30	27.1.86	30	0.88	18.5	4.9
31	3.12.85	35	0.70	52.9	3.2
32	3.12.85	52	0.56	555.6	27.4
32	27.1.86	44	0.55	28.7	7.0
33	3.12.85	43	0.49	20.4	6.2
34	3.12.85	56	0.43	115.2	57.6
35	3.12.85	32	0.75	384.9	384.9
35	27.1.86	40	0.58	686.7	686.7
36	3.12.85	26	0.67	914.3	308.6
36	27.1.86	30	0.84	632.4	138.3
42	19.12.85	53	0.32	205.6	1.9
42	27.1.86	56	0.27	228.8	45.8
43	19.12.85	22	1.21	>902.3	601.5
45	19.12.85	26	0.95	217.7	96.8
46	19.12.85	41	0.65	131.1	29.6
63	19.12.85	35	0.63	35.6	5.9
64	19.12.85	25	0.98	>983.6	69.7
64	27.1.86	55	0.46	52.0	11.2
65	19.12.85	33	0.85	>854.1	>854.1
65	27.1.86	50	0.52	923.1	50.0
66	19.12.85	25	1.05	>912.6	349.8
66	27.1.86	41	0.62	944.9	31.1
67	19.12.85	25	1.07	>898.9	202.2
67	27.1.86	31	1.10	469.2	469.2
68	19.12.85	21	1.31	579.7	25.4
68	27.1.86	21	1.36	561.4	77.2

1.6 continued:

Site	Date of sampling	No. of coliform bacteria/shellfish		No. of coliform bacteria /g dry weight of shellfish	
		Confirmed	Faecal	Confirmed	Faecal
1	19.11.85	14.2	2.2	53	8
1	3.2.86	7.0	1.1	16	3
2	19.11.85	23.6	0.9	38	1
2	3.2.86	8.8	1.8	15	3
3	19.11.85	121.6	121.5	102	102
3	3.2.86	197.5	42.5	149	32
4	19.11.85	26.2	1.7	26	32
4	3.2.86	28.9	7.3	28	7
5	19.11.85	36.3	0.8	163	4
6	19.11.85	288.9	288.9	503	503
7	19.11.85	6.0	2.0	8	3
7	3.2.86	17.1	2.0	22	3
8	19.11.85	1.5	0.4	8	2
8	3.2.86	9.2	1.9	33	7
9	19.11.85	104.5	14.4	198	27
9	3.2.86	2.9	0.6	8	2
10	25.11.85	31.6	1.1	260	9
10	3.2.86	13.8	1.4	56	6
11	25.11.85	200.0	100.0	59	298
11	3.2.86	244.4	0.9	627	2
12	25.11.85	17.6	1.6	107	10
12	3.2.86	16.5	1.7	99	10
13	25.11.85	50.0	3.6	324	23
15	19.11.85	47.2	<0.3	94	<1
16	25.11.85	254.5	4.2	780	13
17	25.11.85	25.6	0.9	208	8
18	25.11.85	0.0	0.0	73	3
19	25.11.85	159.1	2.2	854	12
21	25.11.85	20.8	20.8	92	92
22	25.11.85	16.8	0.4	163	4

1.6 continued:

Site	Date of sampling	No. of coliform bacteria/shellfish		No. of coliform bacteria /g dry weight of shellfish	
		Confirmed	Faecal	Confirmed	Faecal
23	3.12.85	93.3	11.0	765	90
24	3.12.85	>600.0	17.5	>9847	287
27	3.12.85	100.0	25.4	260	66
28	3.12.85	68.0	13.2	473	92
29	3.12.85	133.3	13.3	748	75
30	3.12.85	69.2	1.9	618	17
30	27.1.86	16.3	4.3	140	37
31	3.12.85	37.1	2.3	345	21
32	3.12.85	307.7	15.2	3914	193
32	27.1.86	15.9	3.9	220	53
33	3.12.85	10.0	3.0	152	46
34	3.12.85	50.0	25.0	834	417
35	3.12.85	287.5	287.5	3078	3078
35	27.1.86	400.0	400.0	5316	5316
36	3.12.85	615.4	207.7	8474	2860
36	27.1.86	533.3	116.7	4818	1054
42	19.12.85	66.0	0.6	1301	12
42	27.1.86	62.5	12.5	1981	396
43	19.12.85	>1090.9	>727.3	>7521	5014
45	19.12.85	207.7	92.3	1426	634
46	19.12.85	85.4	19.3	995	224
63	19.12.85	22.6	3.7	241	40
64	19.12.85	>960.0	68.0	>7796	552
64	27.1.86	23.6	5.1	397	86
65	19.12.85	>727.3	>727.3	>594	>5946
65	27.1.86	480.0	26.0	6998	379
66	19.12.85	>960.0	368.0	>7210	2764
66	27.1.86	585.4	19.3	7193	237
67	19.12.85	>960.0	216.0	>7252	1632
67	27.1.86	516.1	516.1	3413	3413
68	19.12.85	761.9	33.3	3617	158
68	27.1.86	761.9	104.8	4190	576

APPENDIX 2: Coliform bacteria in final effluent from the Christchurch
Treatment Works, 1985-88.

      1.1   Presumptive coliforms

      1.2   Faecal coliforms

CHRISTCHURCH TREATMENT WORKS
FINAL EFFLUENT COLIFORM COUNT

COLIFORM TYPE
—— Presumptive
- - - Faecal

Jan 1985 to Nov 1988
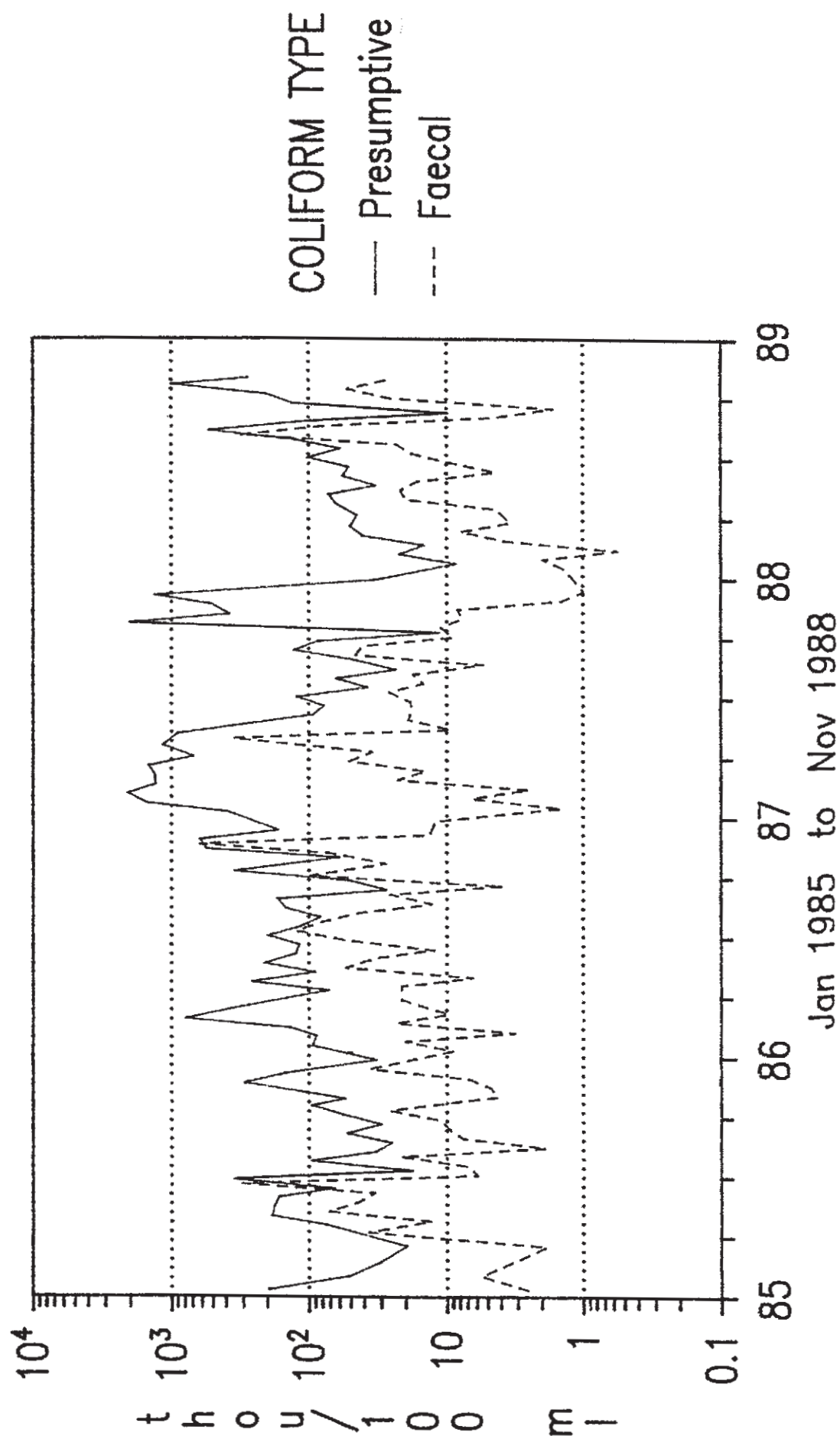
APPENDIX 3: Faecal coliform bacteria in Avon-Heathcote Estuary surface
waters and Avon and Heathcote Rivers 1981-88. Ranges and
mean values*

* For further details of sampling etc. see Christchurch
Drainage Board (1981).

ESTUARY OF AVON & HEATHCOTE RIVERS

SURFACE WATER
SAMPLING SITES

NORTH

SHAG ROCK

PLEASANT POINT
JETTY

BRIDGE ST

PLEASANT POINT
YACHT CLUB

G & I

F

H

C

B

CELIA
STREET

OXIDATION PONDS

BONE TIP

A

Mt PLEASANT
YACHT CLUB

E & J

D

FERRYMEAD
BRIDGE
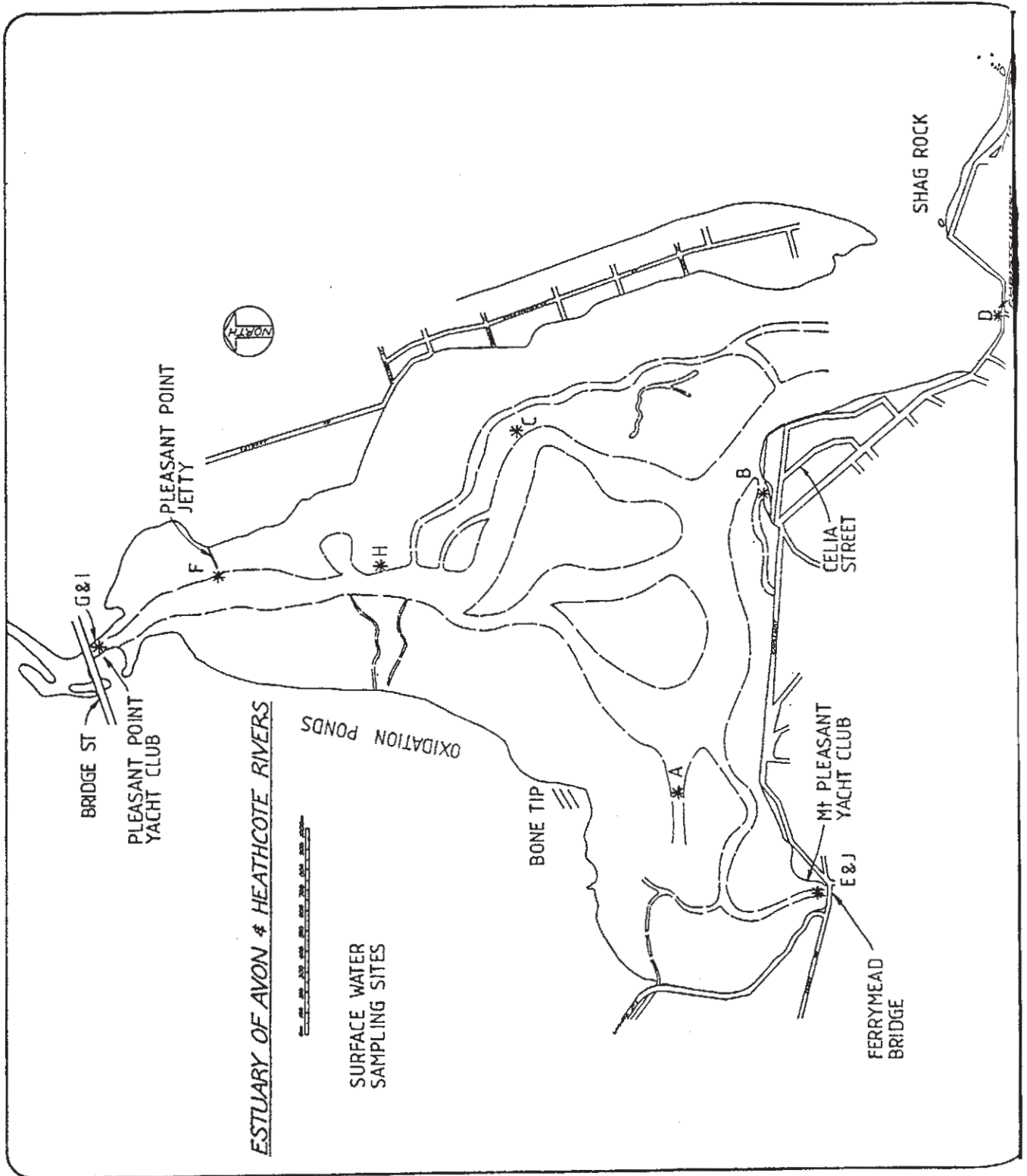
3.1:   OPPOSITE BONE TIP

DATE	N	MIN	MAX	MEAN
27.1.81	7	5.0	15.0	6.46
10.2.81	12	1.0	11.0	2.04
20.2.81	11	1.0	4.0	1.76
25.2.81	2	5.0	22.0	10.49
3.3.81	11	1.0	35.0	6.55
10.6.81	10	1.0	52.0	4.13
24.6.81	8	8.0	454.0	77.29
7.7.81	10	7.0	1840.0	82.33
21.7.81	10	1.0	120.0	8.10
4.8.81	9	1.0	10.0	2.84
10.2.82	11	1.0	20.0	5.54
27.7.82	11	1.0	40.0	7.74
8.2.83	5	1.0	5.0	1.38
9.2.83	7	1.0	160.0	27.73
19.7.83	6	10.0	850.0	47.78
26.7.83	1	10.0	10.0	10.00
24.1.84	5	1.0	10.0	2.19
11.4.84	5	1.0	1.0	1.00
17.10.84	4	1.0	10.0	1.78
13.2.85	4	1.0	50.0	3.76
30.4.85	5	2.0	92.0	13.46
23.10.85	3	1.0	4.0	2.00
20.3.86	2	1.0	160.0	12.65
30.4.86	5	1.0	22.0	7.06

3.2:   BEACHVILLE ROAD JETTY

DATE	N	MIN	MAX	MEAN
27.1.81	11	2.0	10.0	3.30
10.2.81	12	3.0	748.0	36.57
20.2.81	11	2.5	20.0	5.33
25.2.81	11	5.0	367.0	50.87
3.3.81	11	2.5	30.0	7.31
10.6.81	11	1.0	16.0	3.93
24.6.81	11	2.0	18.0	8.67
30.6.81	13	4.0	92.0	26.56
7.7.81	11	2.0	186.0	9.00
14.7.81	13	1.0	96.0	9.56
21.7.81	11	1.0	34.0	4.57
29.7.81	13	1.0	35.0	6.34
4.8.81	11	1.0	9.0	2.10
12.8.81	13	1.0	68.0	7.67
10.2.82	11	1.0	5.0	1.16
27.7.82	11	1.0	10.0	3.89
8.2.83	6	1.0	180.0	6.90
9.2.83	7	1.0	60.0	19.28
19.7.83	7	1.0	1100.0	37.93
26.7.83	5	1.0	6.0	1.89
24.1.84	5	1.0	250.0	4.78
11.4.84	5	1.0	25.0	2.63
17.10.84	5	1.0	5.0	1.38
13.2.85	5	1.0	56.0	6.60
30.4.85	5	1.0	20.0	3.44
23.10.85	5	1.0	1.0	1.00
20.3.86	5	1.0	86.0	8.34
30.4.86	5	1.0	16.0	3.64
11.11.86	4	1.0	2.0	1.41
9.12.87	9	1.0	4.0	1.42
26.1.88	9	1.0	3.0	1.49
20.4.88	9	6.0	50.0	13.60

3.3: OPPOSITE HERON STREET

DATE	N	MIN	MAX	MEAN
27.1.81	10	10.0	10.0	10.00
10.2.81	12	1.0	40.0	6.69
20.2.81	11	2.0	267.0	37.82
25.2.81	9	78.0	524.0	185.48
3.3.81	11	4.0	94.0	9.63
10.6.81	10	1.0	20.0	4.41
24.6.81	8	12.0	1010.0	144.98
7.7.81	10	53.0	272.0	125.55
21.7.81	10	1.0	172.0	17.28
4.8.81	9	1.0	69.0	7.57
10.2.82	11	1.0	1080.0	45.50
27.7.82	11	1.0	15.0	2.61
8.2.83	5	1.0	3.0	2.05
9.2.83	7	1.0	890.0	76.63
19.7.83	6	4.0	490.0	31.74
26.7.83	1	220.0	220.0	220.00
24.1.84	5	1.0	10.0	2.19
11.4.84	5	1.0	1.0	1.00
17.10.84	4	1.0	1.0	1.00
13.2.85	4	1.0	14.0	4.09
30.4.85	5	2.0	46.0	7.67
23.10.85	3	1.0	2.0	1.26
20.3.86	2	10.0	18.0	13.42
30.4.86	5	1.0	26.0	5.95

3.4:   MONCKS BAY

DATE	N	MIN	MAX	MEAN
27.1.81	10	5.0	10.0	5.93
10.2.81	11	9.0	508.0	55.87
20.2.81	10	2.0	13.0	5.02
25.2.81	10	29.0	450.0	91.18
3.3.81	11	2.0	12.0	3.46
10.6.81	11	2.0	48.0	8.36
24.6.81	11	4.0	196.0	35.48
30.6.81	13	9.0	185.0	49.48
7.7.81	11	2.0	23.0	9.18
14.7.81	12	1.0	93.0	12.82
21.7.81	11	2.0	31.0	7.78
29.7.81	13	2.0	51.0	11.45
4.8.81	11	1.0	6.0	1.95
12.8.81	13	1.0	116.0	5.74
10.2.82	11	1.0	35.0	4.95
27.7.82	10	1.0	18.0	2.92
8.2.83	6	2.0	980.0	19.00
9.2.83	8	2.0	330.0	35.52
19.7.83	7	5.0	500.0	28.43
26.7.83	5	12.0	70.0	22.90
24.1.84	5	1.0	520.0	15.08
11.4.84	5	5.0	10.0	7.58
17.10.84	5	1.0	10.0	1.58
13.2.85	5	1.0	32.0	4.80
30.4.85	5	1.0	12.0	3.37
23.10.85	5	2.0	6.0	2.86
20.3.86	5	1.0	16.0	2.30
30.4.86	5	1.0	16.0	6.69
11.11.86	4	1.0	2.0	1.41
9.12.87	9	1.0	12.0	2.46
26.1.88	8	1.0	7.0	1.97
20.4.88	9	5.0	46.0	14.56

3.5:   MT PLEASANT YACHT CLUB

DATE	N	MIN	MAX	MEAN
27.1.81	5	2.5	862.0	41.17
10.2.81	8	7.0	645.0	150.57
20.2.81	8	15.0	85.0	38.88
25.2.81	11	45.0	6300.0	306.75
3.3.81	11	45.0	570.0	132.67
10.6.81	11	5.0	1080.0	80.20
24.6.81	11	165.0	715.0	427.41
7.7.81	11	117.0	1980.0	352.98
21.7.81	11	45.0	210.0	94.11
4.8.81	11	5.0	165.0	25.19
10.2.82	11	15.0	120.0	46.95
27.7.82	11	20.0	1430.0	147.91
8.2.83	6	5.0	200.0	19.79
9.2.83	7	8.0	1060.0	223.16
19.7.83	7	180.0	1530.0	561.46
26.7.83	5	150.0	550.0	338.19
24.1.84	5	10.0	1190.0	57.75
11.4.84	5	10.0	280.0	28.74
17.10.84	5	10.0	60.0	21.41
13.2.85	5	10.0	620.0	91.20
30.4.85	5	34.0	260.0	76.77
23.10.85	5	6.0	868.0	93.15
20.3.86	5	52.0	500.0	133.20
30.4.86	5	20.0	90.0	38.66
11.11.86	4	5.0	140.0	32.53
9.12.87	9	5.0	860.0	52.81
26.1.88	9	5.0	30.0	10.46
20.4.88	8	1.0	170.0	9.97

3.6: PLEASANT POINT JETTY

DATE	N	MIN	MAX	MEAN
27.1.81	11	5.0	130.0	21.82
10.2.81	11	35.0	169.0	69.25
20.2.81	11	17.0	282.0	96.87
25.2.81	9	62.0	242.0	135.94
3.3.81	11	37.0	130.0	65.15
10.6.81	11	12.0	172.0	50.54
24.6.81	11	752.0	4040.0	1637.38
30.6.81	13	62.0	730.0	198.79
7.7.81	11	267.0	1225.0	662.97
14.7.81	13	25.0	192.0	84.74
21.7.81	11	52.0	222.0	127.23
29.7.81	13	10.0	110.0	56.11
4.8.81	11	22.0	112.0	52.49
12.8.81	13	32.0	175.0	74.44
10.2.82	11	20.0	105.0	59.00
27.7.82	11	5.0	135.0	34.97
8.2.83	5	25.0	760.0	114.89
9.2.83	6	150.0	1500.0	437.69
19.7.83	7	218.0	2500.0	605.12
26.7.83	5	1.0	60.0	10.16
24.1.84	5	45.0	280.0	88.42
11.4.84	5	10.0	800.0	69.99
17.10.84	5	10.0	50.0	22.68
13.2.85	5	32.0	1260.0	138.57
30.4.85	5	40.0	300.0	99.83
23.10.85	5	40.0	320.0	94.86
20.3.86	5	260.0	1600.0	919.96
30.4.86	5	40.0	140.0	60.44
11.11.86	4	20.0	1820.0	127.24
9.12.87	9	5.0	230.0	60.98
26.1.88	9	4.0	48.0	21.08
20.4.88	8	45.0	200.0	88.31

3.7:   PLEASANT POINT YACHT CLUB

DATE	N	MIN	MAX	MEAN
27.1.81	10	105.0	995.0	307.23
10.2.81	11	150.0	1420.0	658.62
20.2.81	11	70.0	605.0	229.01
25.2.81	11	745.0	4145.0	1527.67
3.3.81	11	270.0	1270.0	604.55
10.6.81	11	45.0	175.0	83.69
24.6.81	11	800.0	3900.0	1547.14
7.7.81	11	530.0	2200.0	1003.87
21.7.81	11	60.0	240.0	118.48
4.8.81	11	65.0	135.0	88.52
10.2.82	11	60.0	430.0	145.14
27.7.82	11	20.0	120.0	57.07
8.2.83	6	70.0	1100.0	142.72
9.2.83	6	300.0	830.0	537.04
19.7.83	7	120.0	990.0	305.03
26.7.83	5	30.0	80.0	45.22
24.1.84	5	40.0	380.0	118.85
11.4.84	5	180.0	400.0	273.65
30.4.84	5	130.0	500.0	219.58
17.10.84	5	20.0	50.0	26.05
13.2.85	5	128.0	2530.0	326.55
30.4.85	5	130.0	500.0	219.58
23.10.85	5	20.0	50.0	38.98
20.3.86	5	240.0	600.0	356.34
30.4.86	5	80.0	280.0	133.88
11.11.86	4	840.0	3400.0	1579.47
9.12.87	9	10.0	250.0	89.79
26.1.88	9	65.0	550.0	205.97
20.4.88	9	75.0	130.0	97.38

3.8:   OPPOSITE TREATMENT PLANT OUTFALLS

DATE	N	MIN	MAX	MEAN
20.2.81	9	16.0	195.0	88.64
25.2.81	7	47.0	405.0	148.19
3.3.81	11	5.0	167.0	20.21
10.6.81	10	1.0	36.0	14.00
24.6.81	8	166.0	1920.0	543.49
7.7.81	10	126.0	578.0	275.33
21.7.81	10	23.0	246.0	55.95
4.8.81	9	14.0	603.0	114.33
10.2.82	3	160.0	465.0	255.81
27.7.82	11	5.0	240.0	28.70
8.2.83	5	1.0	330.0	3.66
9.2.83	7	3.0	6000.0	229.96
19.7.83	6	80.0	2100.0	389.65
26.7.83	1	36.0	36.0	36.00
24.1.84	5	1.0	110.0	18.91
11.4.84	5	1.0	75.0	18.25
17.10.84	4	1.0	55.0	2.72
13.2.85	4	1.0	130.0	19.71
30.4.85	5	4.0	250.0	43.62
23.10.85	3	4.0	16.0	8.62
10.2.86	8	25.0	160.0	60.68
20.3.86	2	50.0	77.0	62.05
30.4.86	5	4.0	480.0	25.30

3.9: AVON RIVER (BRIDGE STREET): LOW TIDE

DATE	N	MIN	MAX	MEAN
28.1.81	11	395.0	1255.0	708.89
2.2.81	11	360.0	880.0	527.70
12.2.81	11	835.0	1690.0	1208.29
16.2.81	11	380.0	720.0	472.18
23.2.81	11	160.0	690.0	317.68
16.6.81	11	485.0	770.0	565.15
30.6.81	11	160.0	295.0	201.06
14.7.81	11	100.0	485.0	173.03
29.7.81	11	80.0	162.0	120.12
12.8.81	11	86.0	147.0	115.17
24.3.82	11	470.0	1200.0	704.89
20.7.82	5	300.0	390.0	334.33
15.2.84	5	300.0	900.0	503.63
17.4.84	5	200.0	290.0	221.73
10.10.84	5	90.0	150.0	118.30
16.1.85	2	140.0	220.0	175.50
20.2.85	5	2800.0	4400.0	3477.70
12.6.85	5	200.0	400.0	249.15
18.2.86	5	1140.0	1480.0	1270.95
25.3.86	5	500.0	1100.0	790.74
7.5.86	5	140.0	190.0	163.07
23.4.87	5	180.0	360.0	253.79
17.12.87	5	200.0	330.0	256.58
29.3.88	5	60.0	820.0	311.74
13.4.88	5	100.0	220.0	166.18
11.5.88	5	96.0	133.0	117.92
15.6.88	5	60.0	200.0	118.90

3.10: HEATHCOTE RIVER (FERRYMEAD BRIDGE): LOW TIDE

DATE	N	MIN	MAX	MEAN
28.1.81	11	245.0	840.0	407.06
2.2.81	11	560.0	920.0	688.48
12.2.81	11	710.0	1480.0	1153.23
16.2.81	11	540.0	1030.0	731.00
23.2.81	11	200.0	500.0	354.01
16.6.81	11	767.0	1272.0	993.97
30.6.81	11	120.0	320.0	203.13
14.7.81	11	950.0	2270.0	1596.36
29.7.81	11	60.0	345.0	120.68
12.8.81	11	247.0	932.0	566.22
24.3.82	11	233.0	545.0	355.19
20.7.82	5	560.0	800.0	659.23
15.2.84	5	300.0	1600.0	838.59
17.4.84	5	190.0	250.0	218.81
10.10.84	4	180.0	250.0	220.78
16.1.85	2	160.0	370.0	243.31
20.2.85	5	2900.0	4200.0	3510.25
12.6.85	5	200.0	800.0	377.63
18.2.86	5	2000.0	12000.0	6207.32
25.3.86	5	1300.0	2320.0	1960.29
7.5.86	5	160.0	280.0	231.84
23.4.87	5	830.0	1090.0	962.35
17.12.87	5	290.0	480.0	378.67
29.3.88	5	2100.0	3050.0	2540.95
13.4.88	4	580.0	750.0	652.85
11.5.88	2	125.0	125.0	125.00
15.6.88	5	730.0	1030.0	848.18

APPENDIX 4: Sampling Sites

Saltwater Creek Estuary	1977-78
Saltwater Creek Estuary	1985-86
Avon-Heathcote Estuary	1977-78
Avon-Heathcote Estuary	1985-86
Brooklands Lagoon	1977-78
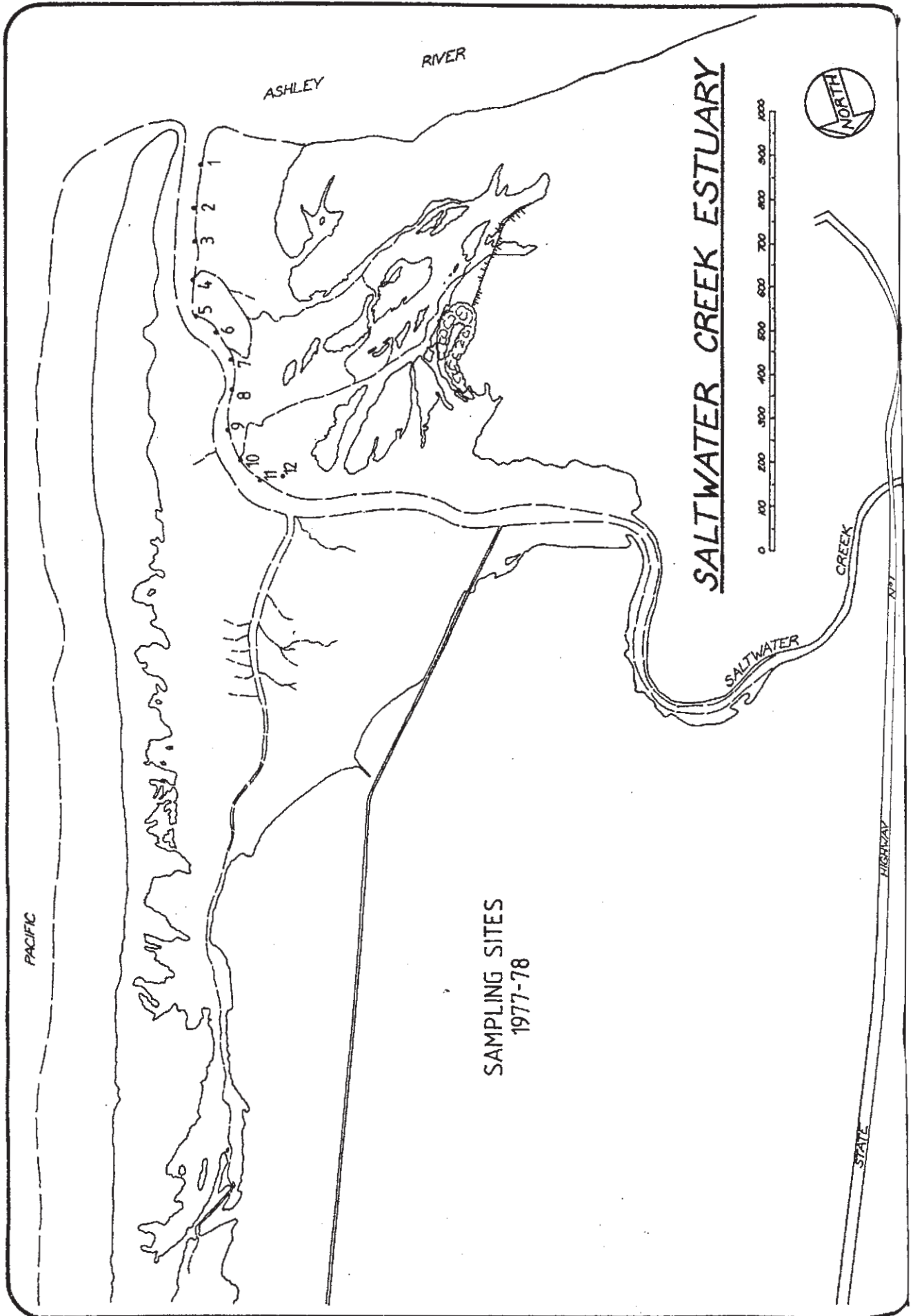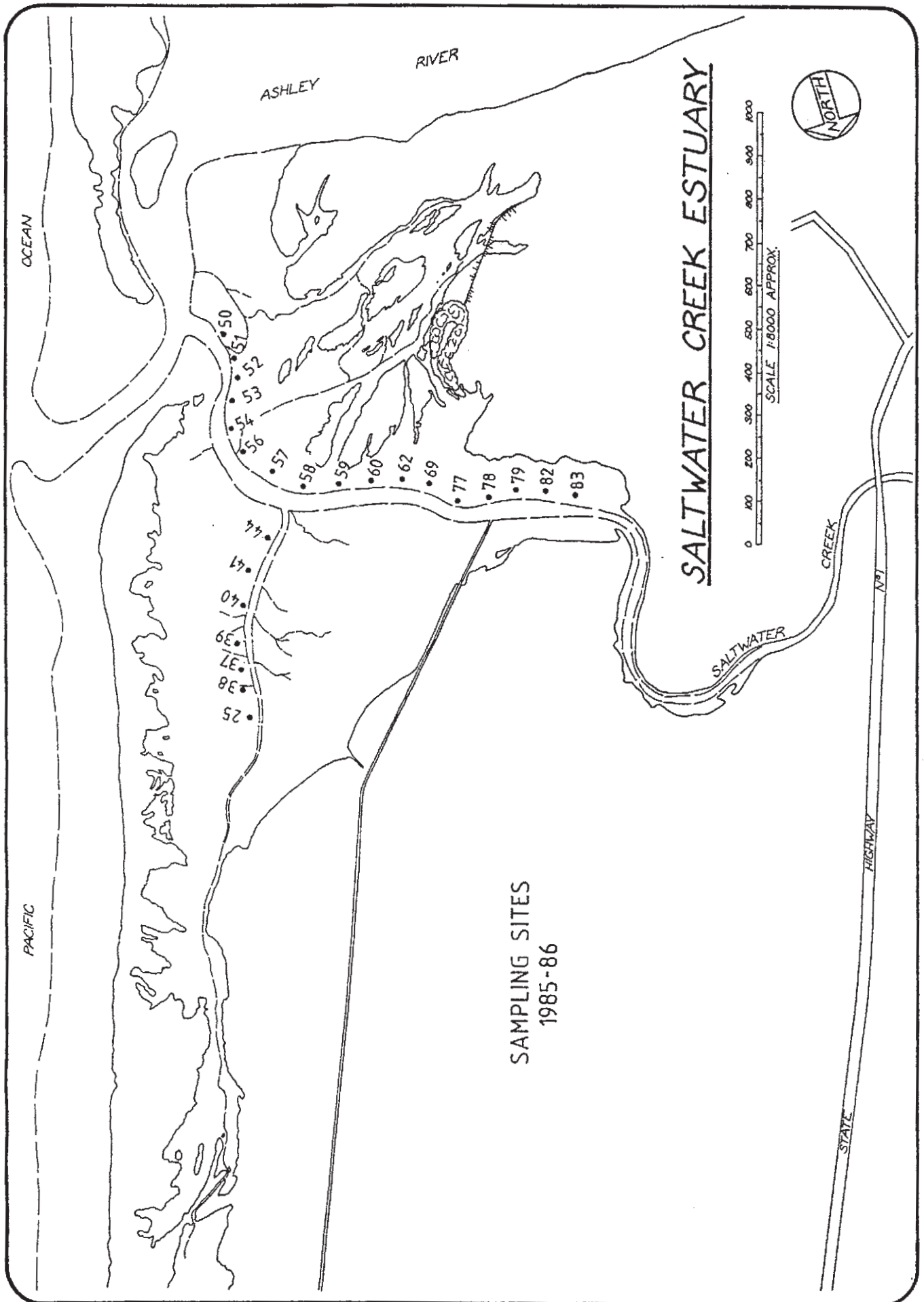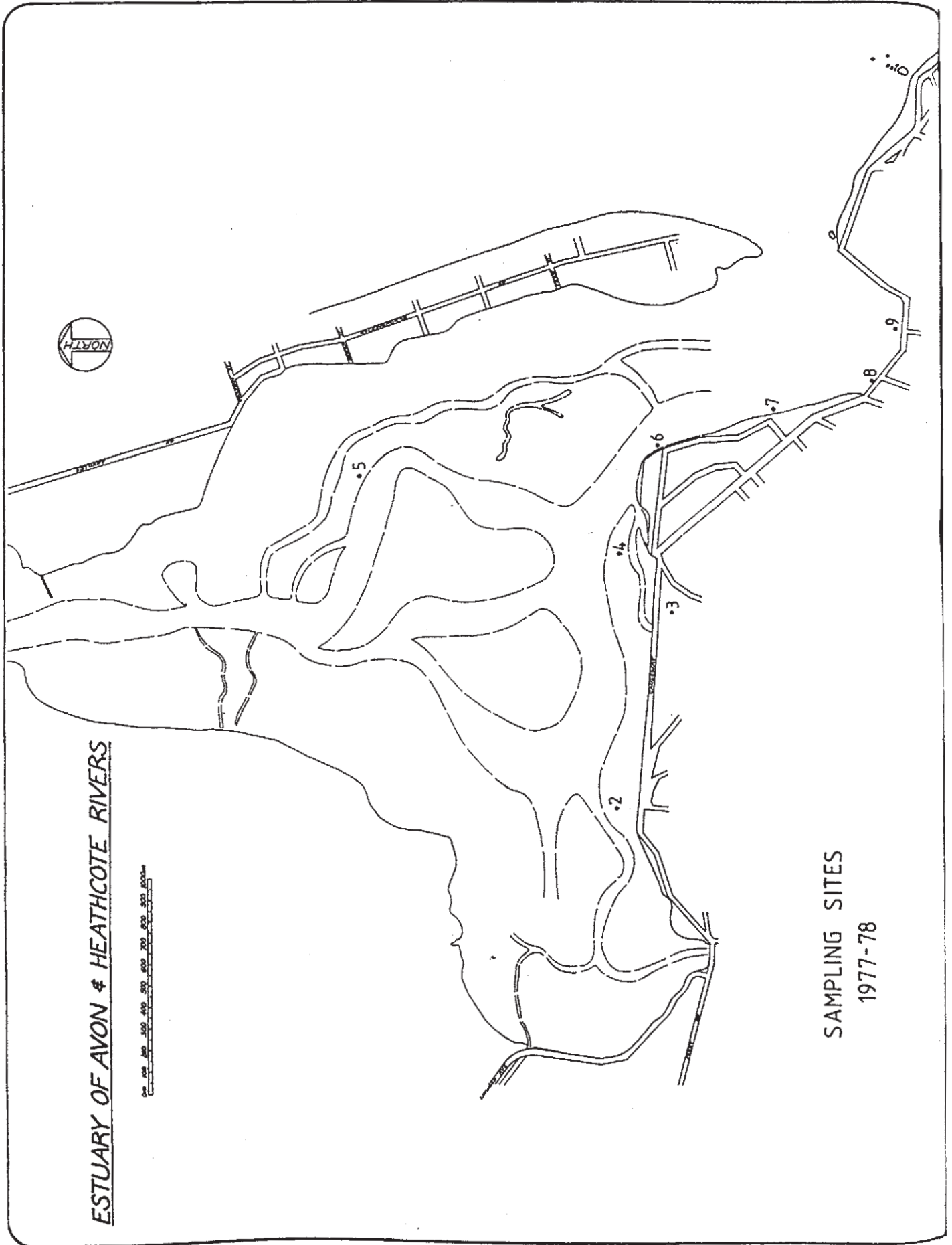
SALTWATER CREEK ESTUARY

SAMPLING SITES
1977-78

SALTWATER CREEK ESTUARY

SAMPLING SITES
1985-86

SCALE 1:8000 APPROX.

ESTUARY OF AVON & HEATHCOTE RIVERS

SAMPLING SITES
1977-78

ESTUARY OF AVON & HEATHCOTE RIVERS

SAMPLING SITES
1985-86

SCALE 1:12500

0m 100 200 300 400 500 600 700 800 900 1000m

NORTH

ESTUARY RD

KAIRAKI

RIVER

FEATHERSTONE AVE

WAIMAKARIRI

STYX

RIVER

BROOKLANDS

ROAD

HARBOUR

LOWER

16 17 18

9 11 13 14

6 7

4 8 10 12 15

5

3

1 2

BROOKLANDS LAGOON
(Lower End)
SAMPLING SITES 1977-78

0m 100 200 300 400 500 600 700 800 900 1000m
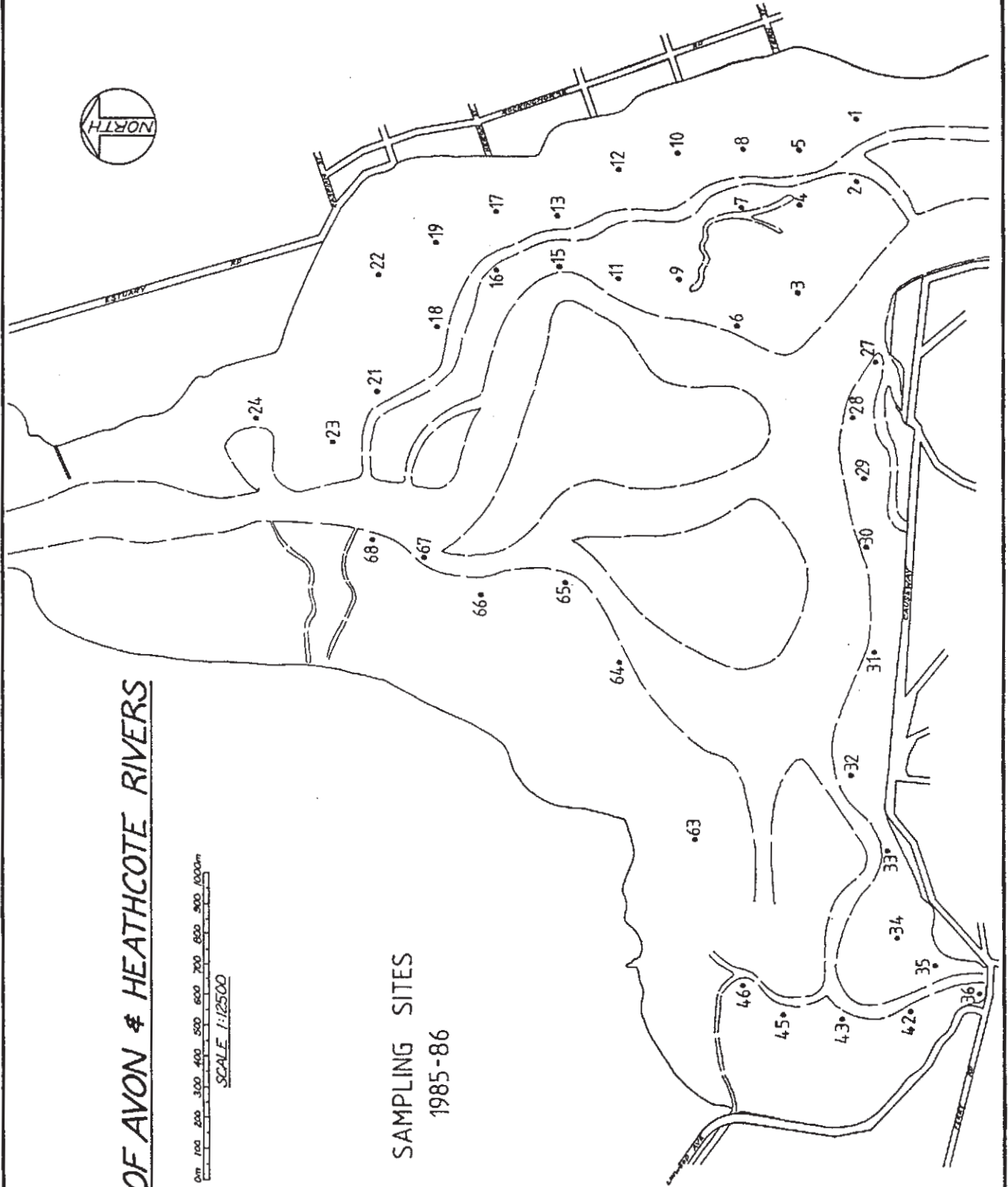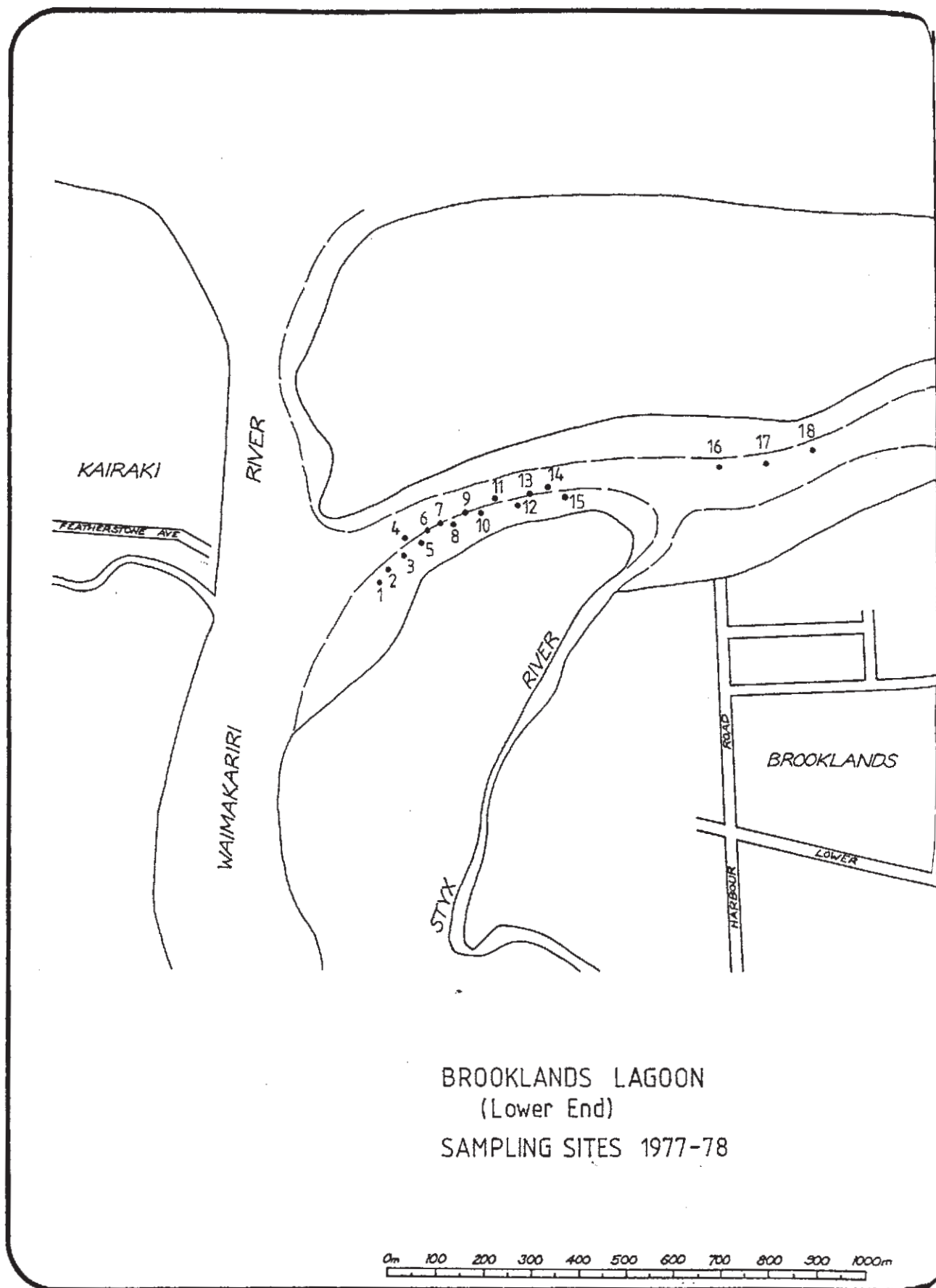
APPENDIX 5:   Cockle sizes, 1985-86.

SALTWATER CREEK ESTUARY

SHELL LENGTH
mm 0 10 20 30 40

ESTUARY OF AVON & HEATHCOTE RIVERS

SHELL LENGTH