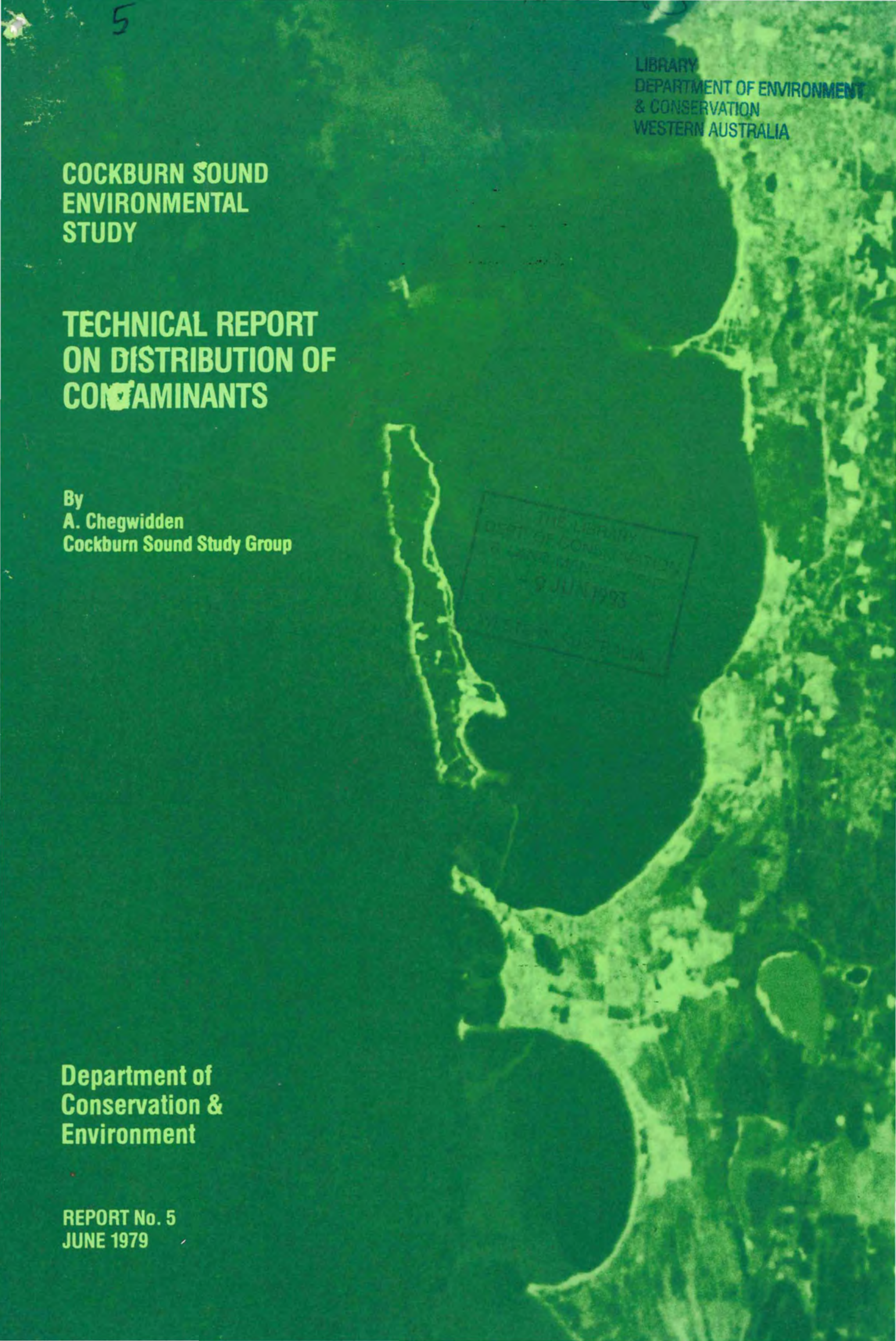

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COCKBURN SOUND ENVIRONMENTAL STUDY

TECHNICAL REPORT ON DISTRIBUTION OF CONTAMINANTS

By
A. Chegwidden
Cockburn Sound Study Group

Department of Conservation & Environment

REPORT No. 5
JUNE 1979

TECHNICAL REPORT ON

DISTRIBUTION OF CONTAMINANTS

by
Adrian Chegwidden

June 1979

A report to the
COCKBURN SOUND STUDY
1976-1979

Department of Conservation and Environment
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FOREWORD

Cockburn Sound began its development as the outer harbour for the Perth-Fremantle area in the 1950's. Since then a major industrial complex has been built up on the eastern shores. Wastewater from several industries and from a major sewage treatment plant is discharged directly into the Sound's waters. A naval facility has been established on Garden Island, which is now linked with the mainland by a causeway, whose construction was completed in 1973.

The industrial area has continued to expand and the Sound's waters are used increasingly for recreation and fishing by both commercial and amateur fishermen.

Concern for deterioration of the marine environment and the building of the causeway led to a series of baseline studies carried out between 1970 and 1975 on the ecology, hydrology and beach morphology of Cockburn Sound. Early in 1975 the Environmental Protection Authority let a contract to a consultant to make a comprehensive review of these studies to identify problems, to propose approaches to solutions and to point out aspects requiring further research. After the review had been considered by the Environmental Protection Authority and the Conservation and Environment Council, the Western Australian Government allocated $500,000 for a three year (1976-1979) environmental study.

As approved by Cabinet, the objective of the environmental study of Cockburn Sound was to obtain the information necessary to manage the Sound for multipurpose use, accommodating recreational and fishing activities as well as use for port and industry.

The Cockburn Sound Study Group, a core group of professional and technical personnel, was established in November, 1976. The major aspects requiring investigation were identified and designated as segments of the overall study. Work on the segments was carried out by members of the Study Group and by consultants, government departments and universities.

This report covers the work of one of these segments. The conclusions and recommendations presented here relate specifically to the work of this segment. They do not necessarily reflect the conclusions or management proposals detailed in the overview Cockburn Sound Study Report, which has drawn from all segment reports.

Colin Porter

COLIN PORTER
CHAIRMAN
COCKBURN SOUND STUDY STEERING COMMITTEE

SUMMARY

A study of levels of heavy metals, hydrocarbons, enteric bacteria and other contaminating agents in the water, sediments and biota from the Cockburn Sound area has shown significant contamination.

Investigations were carried out from September 1977 to December 1978.

The main problem area is the eastern side of Cockburn Sound adjacent to the Kwinana and Owen Anchorage industrial areas. Several industries discharge their waste effluents into the "sink" afforded by Cockburn Sound possibly assuming that dispersion is achieved quickly allowing the marine ecosystem to absorb these inputs without harm. Any assumption that the Sound's waters are regularly flushed, so as to achieve good effluent dispersion has been proved to be incorrect.

Direct effects of stress on the ecosystem are manifested by the decline of the seagrass meadows and the accumulation of contaminants in the waters, sediments, and flora and fauna of Cockburn Sound.

The heavy metals cadmium, lead, zinc and chromium regularly exceeded Western Australian and National Health and Medical Research Council (NH & MRC) recommended levels in certain edible shellfish species from selected sites. On analysis, the level of lead in crab flesh was found to exceed the State and NH & MRC recommended levels on 15 per cent of the sampling occasions. The hepatopancreas from these animals regularly exceeded these recommended levels for copper, zinc, cadmium and lead. Heavy metal levels in fish flesh were not found to exceed State or NH & MRC recommended levels, however, the levels of lead were found to be elevated above background levels from European and Georgia (USA), waters.

The sediments of Cockburn Sound have accumulated the heavy metals cadmium, copper, zinc, lead, chromium, nickel, mercury and arsenic and could act as a source for these contaminants for some time even if all effluent discharge to Cockburn Sound ceased. The sediments of Owen Anchorage have been contaminated with copper, lead and chromium. The main source of heavy metal contamination of Cockburn Sound is in the gypsum waste discharge from the CSBP & Farmers outfall. The sewage outfall in the northern section of the basin of Cockburn Sound is undoubtedly causing an increase in the metal concentrations in the sediments of that area.

Warnbro Sound was used as a baseline to compare with Owen Anchorage and Cockburn Sound. Elevated levels of heavy metals were not found in its sediments.

In August 1977 CSBP & Farmers achieved greater gypsum dispersion by changing the design of their outfall nozzles. The effect of this has become increasingly evident especially with regard to the more than doubling of cadmium (discharged with the gypsum) concentration in the flesh of mussels from the Co-operative Bulk Handling jetty. There has been an increase of more than six times the cadmium concentration in flesh of these animals from the Palm Beach jetty during the period of greater dispersion.

Accumulation of cadmium in biota, resulting from concentrations of cadmium in waters of the southern sector of Cockburn Sound may have health implications for local amateur and professional fishing activities. This is the area of greatest recreational activity in the Sound.

SUMMARY (Cont'd)

Because of Cockburn Sound's very limited water exchange with the open ocean there are many difficulties associated with the siting of discharge points for the maximum dispersion of effluent. Effluents from beach outfalls, such as those from the British Petroleum and Australian Iron and Steel outfalls, have been shown to contaminate nearshore sediments with heavy metals. Although a deep basin submarine outfall such as the Woodman Point sewage outfall causes little metal contamination of nearshore sediments, in the deeper discharge area the accumulation of contaminants is high when compared to other unaffected deep basin areas. In either case dispersion of contaminants out of Cockburn Sound waters is severely restricted.
The BP oil refinery at James Point has the only significant continuous input of hydrocarbons to Cockburn Sound. The alkane fraction of petroleum derived hydrocarbons is at elevated levels in some flora and fauna species. Research elsewhere in the world suggests that petroleum refinery waste, in particular the aromatic materials, can have a deleterious effect on marine life.

The main industries of Owen Anchorage and the sewage treatment plant at Woodman Point have substantial inputs of some metals, but just as significant is their role as sources of enteric bacteria and material with extremely high biological oxygen demand. The mussels and water from these areas are contaminated by enteric bacteria which have the potential to infect man either through seafood harvesting or direct physical contact during recreation. The insecticide dichlorvos has been detected in a meatwork's effluent of Owen Anchorage and the presence of dieldrin has been confirmed in the sediments of this area. These two agents and polychlorinated biphenyls were not found in effluents, sediments or mussels from Cockburn Sound.

From data collected during the course of the Study few contaminants could be positively identified as being at levels in the water liable to cause acute toxicity. Materials such as hydrocarbons and cadmium are discharged in amounts which appear to be environmentally excessive for Cockburn Sound. No facility was available to detect "slug doses" of materials such as sulphuric acid, phosphoric acid, caustic soda wastes and arsenical wastes from industries.

It has been confirmed that contaminants originating from effluents of Cockburn Sound and Owen Anchorage that enter the waters of the area have infiltrated the marine food web and from there have the potential to enter the human diet.

RECOMMENDATIONS

1. Excessive amounts of cadmium, lead and zinc have been found in shellfish from the Cockburn Sound area while those from the Owen Anchorage area contain high levels of chromium and enteric bacteria. It is recommended that the implications of these levels to public health be given the most careful consideration in relation to the exploitation of shellfish by commercial and amateur fishermen.

2. The high chromium content, biological oxygen demand and enteric bacteria counts in some effluents of the Owen Anchorage discharge area necessitate that streams be treated for specific contaminants before discharge or an alternative means of waste disposal be found.

3. If primary treated sewage continues to be discharged in increasing quantities the problems of contaminants accumulating in Cockburn Sound will increase. Removal of most metals and nutrients is not achieved by the normal secondary treatment process (2). The process tends to enhance the availability of metals to contaminate biota and nutrients become accessible for eutrophication. Therefore it is recommended that either tertiary treatment or an alternative discharge site be considered for sewage disposal.

4. Circulation studies have shown conclusively that Cockburn Sound waters have minimal exchange with adjacent oceanic waters. Considering this characteristic of the Sound, a study of the total hydrocarbon input budget would be pertinent to future management plans. In particular the aromatic content of the British Petroleum Oil Refinery hydrocarbon input to Cockburn Sound should be thoroughly investigated for its marine and public health implications.

5. In conjunction with the recommendations of Dybdahl (1), management programmes for Cockburn Sound and Owen Anchorage should be directed towards eradication of contaminants such as heavy metals, petroleum hydrocarbons and enteric bacteria in mussels (*Mytilus edulis*), as well as heavy metals and hydrocarbons in the blue manna crab (*Portunus pelagicus*). There is a considerable commercial and recreational catch potential for these species in the Cockburn Sound and the Owen Anchorage areas.

6. A review should be undertaken to assess the relevance of the Western Australian Public Health Standards with regard to the consumption and toxicological aspects of metals related to fish, shellfish and crustacea. In the present study the above standards, which relate to processed food, have been applied to biota taken straight from the marine environment. Furthermore, people included on the panel for this review should be drawn from departments such as Public Health, Fisheries and Wildlife and Conservation and Environment.

7. A survey of the different forms of certain heavy metals present in effluents, sediments and biota should be performed as these have a direct bearing on toxicity. The survey should include the proportion of total chromium that is present in the Owen Anchorage tannery outfalls in the Cr^{+3} state or the more toxic Cr^{+6}, and speciation of vanadium, copper and cobalt discharged from the relevant Cockburn Sound outfalls.

8. The dredged spoil dumped in Cockburn Sound in 1974 from the CSBP & Farmers gypsum mound should be located, and, noting that changes in metal form can effect its toxicity, analyses be performed to determine the fate of the metals present. These analyses should be related to the possible alkylation of certain metals known to be in the gypsum, namely, mercury, arsenic, lead and chromium which are probably discharged in a sulphate or phosphate form. Such studies could then be used to relate to the metals in the sediments at the CSBP outfall.

9. Either the contaminants from the gypsum effluent be removed before discharge or the waste be diverted away from Cockburn Sound.

10. An accurate assessment be made of the effects on the Cockburn Sound ecosystem of contaminants in groundwater that may be entering the Sound.

11. An accurate assessment be made of the effects that stack emissions from the Kwinana industrial area are having on the Cockburn Sound ecosystem.

12. Regular monitoring of the effluents to Cockburn Sound cited by Murphy (4) as being possible sources for the contaminants, phenol, sulphide, fluoride, cyanide and anionic detergents, should be undertaken. The analysis of these contaminants requires the development and use of accurate 'on site' methods.

13. A survey be taken to quantify the extent of sediment and biota contamination by insecticides and pesticides, particularly in Owen Anchorage.

14. Increased emphasis needs to be placed on the ongoing review of wharf loading and unloading practises to reduce possible contamination input from these sources.

15. Quantities of floating and suspended material described as "honey-comb" slag are being released from the Australian Iron and Steel waste water outfall. Redesign of the collection facility at the discharge point could reduce the load of these solids to Cockburn Sound.

16. An attempt should be made to further quantify the thermal effects resulting from the use of Cockburn Sound as a source of cooling water. This would apply to the effect on biota within the Sound waters and also to those pelagic species that pass through the heat exchange system.

17. Industries chlorinate their cooling water which is drawn from Cockburn Sound. A review of the literature (3) indicates that residual chlorine levels should be no more than 0.01 mg l^{-1}, as levels exceeding this can pose a local threat to marine life. In view of the large quantities of cooling water used daily by the industries of the Sound (4) it is felt that residual chlorine and chloramines should be monitored regularly.

18. Industries using cooling water also use sacrificial zinc anode in their cooling systems to prevent corrosion. A detailed investigation should be made to see if these could be partially or wholly replaced by a less environmentally active element such as aluminium. Impressed current systems might also be used where practical.

19. Although the State Energy Commission Kwinana Power Station has no process water input it apparently discharges heavy metals in its cooling waters. The source of these should be identified and monitored; they are probably due to corrosion or corrosion inhibition agents.

20. Any future studies of the fish population of Cockburn Sound should include a programme of examination of the fish for anatomical lesions.

21. To monitor the effect of changing loads of environmentally deleterious agents a program should be initiated to identify sensitive indicator organisms or communities within the ecosystem of Cockburn Sound. This would enable an assessment of the 'condition' of the water of the Sound to be made on a biological basis in the future.

22. A survey should be undertaken in conjunction with the Public Health Department to determine whether or not there are problems associated with enteric bacteria in the southern section of Cockburn Sound. The specific areas of interest would be the highly recreated area south into Mangles Bay and the area near Cape Peron which is likely to come under the influence of the Cape Peron Sewage Treatment Facility.

23. If, in the future, contaminants are to be analysed in effluents mixed with salt water in cooling water streams or in marine receiving water, a specialised laboratory or group of laboratories need to be developed. The normally low levels of contaminants and the complicated salt water sample matrix necessitate special facilities for these analyses.

ACKNOWLEDGEMENTS

I am grateful to all members of the Cockburn Sound Study Group for their assistance during this project. My particular thanks go to Mr. Trevor Brown who initiated a comprehensive programme upon which to build.

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The following ancillary reports were commissioned for use in compiling this report.:-

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Finally, I should like to thank Miss Debra Totterdell who showed a remarkable degree of patience while typing this report.

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TABLES

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1. INTRODUCTION

1.1 The Study

Comprehensive background information on Cockburn Sound and its environmental setting as well as an overview of the results of the various segments of the Study is contained in the Cockburn Sound Environmental Study Report (4). Figure 1.1 shows the Study area.

The general objectives of this segment of the Cockburn Sound Study were to follow the fate of substances being discharged into the Sound and assess the impact on the ecosystem of those substances likely to curtail multipurpose use of the Sound.

The specific objectives were:-

- To determine present levels of heavy metals in the sediments of Cockburn Sound and contour the results.
- To investigate biota uptake of heavy metals.
- Assess whether hydrocarbons of non-biogenic origin are having a serious impact upon the plant or animal community. Test for toxicity to *Posidonia australis*.
- Assess the impact of other substances entering the Sound which are likely to have significantly harmful effects.

Pollutants may have an effect at two levels, lethal (acute) and sub-lethal (chronic). This study was concerned mainly with levels which may have an impact at the sub-lethal level, there being no facility for detecting the occurrence and path of "slug" doses from industries. In industrial operations these do occur periodically but only very obvious spills such as oil that can be seen floating are reported to the Fremantle Port Authority for action.

The dangers of sub-lethal levels are only now becoming apparent. In the past biologists have emphasised the short-term "lethal effects" of environmental factors on single life stages even though the long-term sub-lethal effects of all life stages have greater ecological implications. For example, the effects of a pollutant can differ according to the life stages of the same species; a concentration of 1.0 $\mu g l^{-1}$ polychlorinated biphenyl killed 50 per cent of juvenile pink shrimp, *Penaeus duorarum*, in 15 days, whereas 3.5 $\mu g l^{-1}$ killed 50 per cent of the adult shrimp in 35 days (6).

Sub-lethal effects of a pollutant have been defined as long-term biological changes of an organism in response to an artificially altered environment. These changes may not necessarily be fatal but may alter certain behavioural and/or physiological responses of the organism to its environment in terms of reduced survival potential of the organism or its progeny (7).

Gilmour and others, in a report to the Joint Technical Working Group on Marine Pollution (8), have emphasised how little knowledge there is in Australia on acute and chronic toxicity effects relating to marine biota. They concluded that:-

1.1 (Cont'd)

> "Specific response data on acute and chronic effects of toxicants to Australian aquatic flora and fauna are largely lacking and thus it is impossible to develop detailed water quality objectives for local ecosystems. The lack of work on sub-lethal effects, in particular, was underlined by a number of the respondents to the present survey. Data on the interacting effects of two or more toxicants operating together are totally lacking".

An understanding of the pathways and rates of contaminant movements through the marine ecosystem, the areas of accumulation and time constants of accumulation, and the ultimate fate of trace metals in the ecosystem is important to an understanding of where, for how long, at what concentration level, and in what form organisms will be exposed to contaminants from various sources (9). The present Study attempts to answer some of these unknowns of the Cockburn Sound ecosystem.

Appendices I, II and III are included to give the reader a quick reference to the main contaminants entering the Cockburn Sound/Owen Anchorage areas. The sources are from outfalls, smoke stack emissions and shipping spillage.

The following industries are referred to in this report:-

COMPANY	INDUSTRY
Australian Iron & Steel Pty. Ltd. (AIS)	Blast Furnace
Broken Hill Pty. Ltd. (BHP)	Steel Rolling Mill
BP Refinery (Kwinana) Pty. Ltd. (BP)	Oil Refinery
Kwinana Nitrogen Company (KNC)	Ammonia, nitric acid, ammonium nitrate production
CSBP & Farmers Ltd. (CSBP)	Fertiliser Manufacture
Alcoa of Australia (W.A.) Ltd.	Alumina Refinery
Western Mining Corporation (WMC)	Nickel Refinery
Co-operative Bulk Handling (CBH)	Grain storage and export
State Energy Commission (SEC)	Power generation (Kwinana and South Fremantle)
Metroplitan Water Supply, Sewerage and Drainage Board - Woodman Point Sewage Treatment PLANT (WPTP)	Sewage Treatment
Anchorage Butchers Pty. Ltd.	Meat Processing
Coogee Fellmongers Pty. Ltd.	Fellmongering
N. Shilkin & Son Pty. Ltd.	Tanners
Eagle West Pty. Ltd.	Tanners
McGilvrays Pty. Ltd.	Tanners
Western Australian Meat Exports (WAME)	Meat Processing

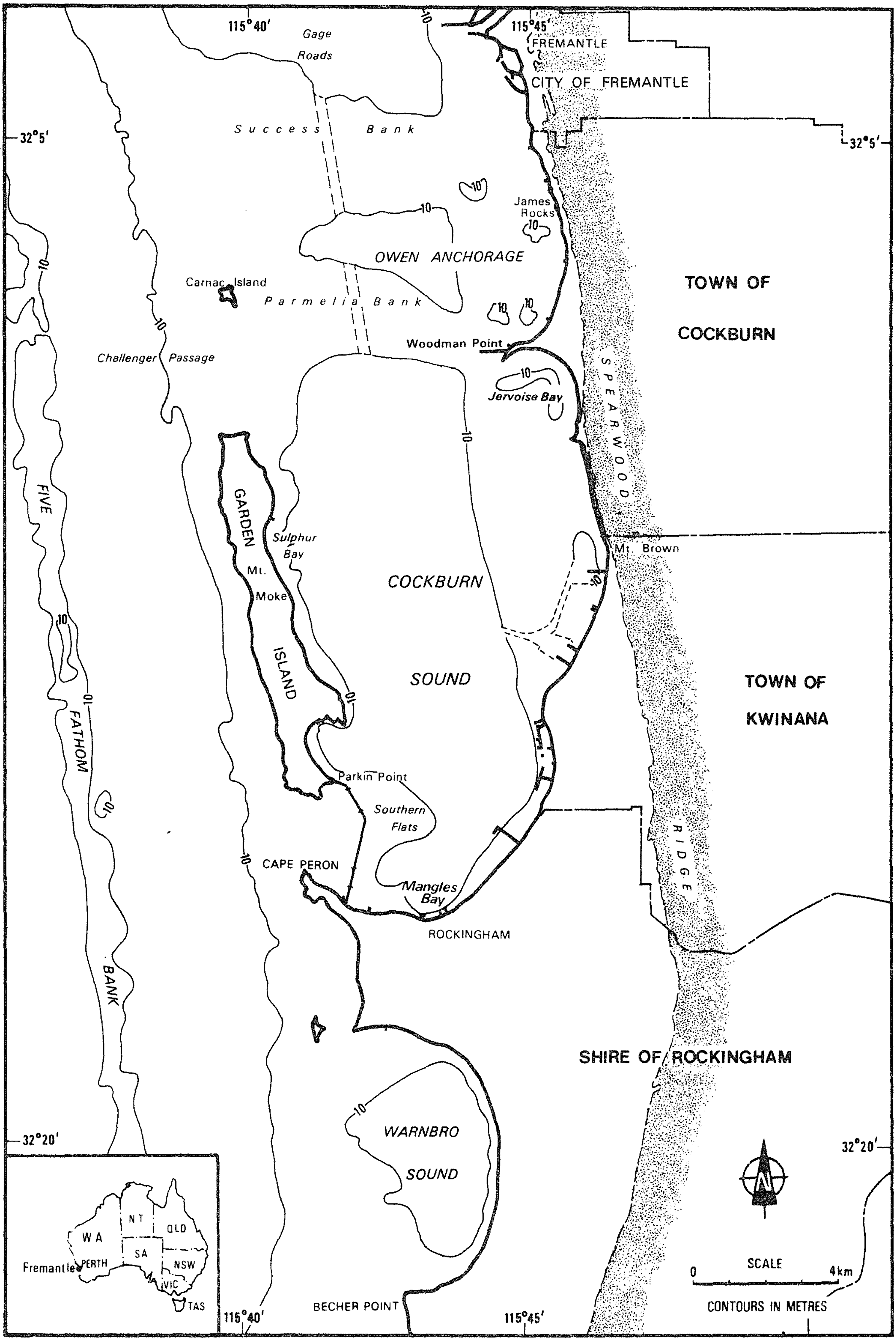

Figure 1·1

Cockburn Sound and Adjacent Areas

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2. WATERS

SUMMARY

A preliminary heavy metal survey of seawater early in 1978 from 24 stations in Cockburn Sound established the need for a more extensive survey.

A further study was initiated late in 1978 in which more than one hundred samples were collected during two separate sampling runs. The samples were analysed for cadmium by two techniques; Mass Spectrometric Isotope Dilution (MSID) and Anodic Stripping Voltammetry (ASV), and for lead and copper by ASV.

The data show that if CSBP gypsum input ceased, within a short time, the levels of cadmium in Cockburn Sound waters would drop rapidly. Following a plant shutdown, there was a significant increase in the level of cadmium in these waters one month after recommencement of gypsum input.

Levels of cadmium, lead and copper were higher in Cockburn Sound than in adjacent coastal waters. This study agreed with recent findings that coastal waters have a cadmium concentration of between 0.005 and 0.020 $\mu g\ l^{-1}$ at background levels.

ASV proved to be a technique well suited to routine analysis of cadmium, lead and copper at the low levels found for these elements in seawater.

In the light of current literature it is believed that the data presented for the MSID cadmium analyses from the study are the most accurate available for any extensive expanse of water.

During a study period from March, 1977 to April, 1978, the Cockburn Sound Study in conjunction with the Public Health Department, collected 313 seawater samples from 31 sites between South Beach and Jervoise Bay and examined them for *Escherichia coli* and salmonella. A total of 85 (27 per cent) of the seawater samples had *E. coli* counts above 500 per 100 ml and 54 (17 per cent) of all the samples collected contained salmonella.

Temperature profiling in the waters adjacent to the SEC Kwinana Power Station, the BP Oil Refinery and the AIS outfalls suggests a strong longshore influence on these discharges with the overall effects fairly localised.

2. WATERS

2.1 Introduction

2.1.1 General

The aim of this survey was to assess whether levels of heavy metals within Cockburn Sound waters were elevated above background. Once analytical techniques had been developed to give consistent results, comparisons could be made between areas both within and outside Cockburn Sound and then related to reported values in the literature, particularly with regard to metal toxicity. Secondly, the cadmium levels were to be used to trace water circulation patterns and these compared with computer simulated patterns of Steedman (5). Cadmium was considered to have great potential as a tracer material especially since the inputs of this material to the Sound were known (3).

2.1.2 Metal surveys

Samples for a preliminary study were collected after examination of available circulation patterns (5) and reference to possible dilution effects. Sampling generally took place within the ten meter contour along the easten side of Cockburn Sound which, coincidentally, covered the area closest to industry and followed the path of the dye during tracking experiments carried out by ERA Pty. Ltd. in 1973 (6). The results of this study showed wide variation and little correlation between sample stations. It was decided to initiate an intensive water survey using the sampling stations of the main 2 km sediment sampling grid (see Chapter 3).

2.1.3 Heavy metals in marine waters

The levels of heavy metals in sea water are controlled by:-

- Precipitation -
  If the concentration of metal is higher than the least soluble compound that can be formed between the metal and anions in the water (such as carbonate, sulphate, hydroxyl, or chloride) then precipitation will occur. Exceptions are the metals iron and manganese, which are readily precipitated leaving very little in solution. Because of the high solubility of some salts, dissolved metal concentrations can occur in seawater which are toxic to marine organisms. The form of the metal is critical in this respect.

- Adsorption or Chelation -
  Metals may be sequestered from seawater by adsorption at the surface of particles such as hydrated ferric oxide, hydrated manganese oxide, clay minerals and phytoplanktonic organisms. Metals most effectively removed by hydrated ferric oxide are arsenic, copper, zinc, cadmium, lead, chromium, tungsten and vanadium. The uptake of elements such as lead and copper by phytoplankton is well documented (1).

  The processes of adsorption and chelation are partially dependant on the route of entry (form) of the trace metal into the marine system. In Cockburn Sound the route covers the whole range of possibilities because both organic and

2.1.3 (Cont'd)

inorganic effluents are discharged. Incorporation into a crystalline particulate structure is the major mechanism for transporting copper and chromium. Manganese can be carried on particle coatings, whereas iron, nickel and cobalt can be distributed equally by coatings and crystalline solids (2). Cadmium (Cd^{++}) forms very stable chloro-complex's and hence may be readily transported in solution in seawater.

- Absorption -
  Removal and deposition of heavy metals from seawater is often promoted by biological processes, such as the vertical transport of metals contained in faecal pellets, crustacean moults and dead biota. Metals in this form may find their way back into the water column or be deposited as detritus and then incorporated into sediments. Decaying phytoplankton that are not incorporated into the sediments can be a substantial source of trace metals to the water column.

Figure 2.1 indicates some of the factors to be taken into account when the toxic effects of heavy metals on marine organisms are being considered.

The bioavailability of the metal ions depends strongly on the nature of the metallic species present; whether it is dissolved or in particulate form, its oxidation state, the extent of chelation or hydrolysis, etc. For example, it has been shown that the toxicity of cadmium to the grass shrimp, *Palaemontes pugio*, is related to the free cadmium ion concentration (or activity) that, in turn, is determined by the total cadmium concentration and the degree of cadmium chelation to ligands (4).

2.1.4 Enteric bacteria in the Cockburn Sound area

In northern Cockburn Sound and in Owen Anchorage seawater and mussels (Chapter 4) were monitored for contamination by enteric bacteria. This survey was carried out during 1977/78 in conjunction with the Enteric Diseases Unit of the Public Health Department.

The Public Health Department has been monitoring seawater on a monthly basis. Samples were taken only at sites off the beach in Owen Anchorage and around Woodman Point and analysed for faecal *Escherichia coli*, an indicator of contamination by enteric bacteria of human or animal origin. As salmonella can be present even when faecal *E.coli* counts are negligible a more comprehensive sampling programme of mussels and seawater was initiated to determine the extent of salmonella, *E. coli* and *Vibrio parahaemolyticis* contamination.

2.2 Experimental Methods

2.2.1 Heavy metals

For the preliminary survey during February to May 1978 seawater samples were collected from 1 m below the surface using an aged, non-metal, ten litre Niskin water sampling bottle at the stations indicated in Table 2.1. A two litre sample from each station was filtered through 0.45 µ cellulose acetate membrane, the filtrate preserved with 5 ml of concentrated HNO_3 (Aristar grade) and stored for analysis in acid washed polyethylene bottles.

2.2.1 (Cont'd)
The filtered water samples were neutralised to pH 4.0, chelated with ammonium pyrrolidine dithiocarbamate and extracted twice into methyl isobutyl ketone prior to measurement of copper, zinc and cadmium by atomic absorption spectrophotometry.

Initial samples were taken from the sites indicated in Table 2.2 on 25 September and 14 November 1978, in preparation for the intensive sampling programme.

For the intensive sampling runs on 29 November (Figure 2.3) and 28 December (Figure 2.4) 1978, Cockburn Sound was divided on the basis of the 2 km sediment sampling station grid with four control stations west of Garden Island as indicated in Figure 2.2. Sampling locations were fixed using the Motorola Mini Ranger III electronic range/range fixing equipment on the Hydrographic Survey Vessel, "Beagle". All samples were taken at a depth of 1 m using the ten litre Niskin bottle.

The November and December sampling dates were chosen to observe concentrations of cadmium in Cockburn Sound waters while CSBP was shut-down (November) and one month after discharge of gypsum had resumed (December); the gypsum being the source of the cadmium.

All samples from the runs were stored chemically unpreserved and unfiltered in high density polyethylene bottles. They were then frozen and taken to the Western Australian Insitute of Technology, Department of Physics, for analysis of cadmium by the MSID technique. Details of the MSID and chemical extraction techniques are given by Rosman and deLaeter (8) and in a technical report by Rosman *et al* (9) filed in the Cockburn Sound Study Data Repository.

The Chemistry Department at WAIT analysed the samples collected on 28 December 1978, for cadmium, lead and copper by ASV. These analyses were performed on chemically unpreserved unfiltered samples.

The MSID technique analysed total cadmium, whereas ASV measured labile cadmium (cadmium that is electroactive under the conditions found naturally in seawater).

The details of the ASV analytical techniques for seawater are similar to those described by Florence (10) and they also appear in the technical report by Bell *et al* (11) which is kept in the Cockburn Sound Study Date Repository.

As well as using the MSID cadmium results as a tracer to compare water circulation patterns with those simulated by Steedman (5) the data was used to see if CSBP effluent made a significant contribution to the cadmium concentration in the Sound waters after about one month of effluent input.

Sound waters were sampled on two occasions to test the t-test null hypothesis (Ho) that: The mean cadmium concentration in Cockburn Sound water did not increase after one month of effluent input from CSBP (a one-tail t-test according to the method of Sokal and Rohlf (13)).

2.2.2 Enteric bacteria
One litre samples were collected from the stations represented in Figure 2.12. Mussel sampling sites are also included and this aspect of the monitoring programme is presented in Chapter 4. Methods are listed by Iveson (12).

2.2.3 Temperature Profiles

All temperature measurements were made using a Martek Mariner Mark II instrument. Investigations were carried out on 27 November and 29 December 1978.

Profiles were measured in the waters adjacent to the SEC Kwinana power station, AIS and BP outfalls. Measurements made at the Cockburn Power Boat Association premises were used as datum. The shoreline portion for this transect was 200 m north of the most northerly groyne and went in a direction due west from this point.

2.3 Results

2.3.1 Heavy Metals - MSID Cadmium Results

A previous study of metals in Cockburn Sound waters was carried out in August 1970, using atomic absorption spectrophotometry. At this time this technique was acknowledged by the investigators as having insufficient sensitivity (15).

Table 2.1 summarises the results of the seawater samples collected from February to May 1978. These results indicated that the elements, cadmium, copper and zinc were at levels higher than would have been predicted from the literature (16), (17). The data also showed that the gypsum (calcium sulphate) discharged from CSBP (the major source of cadmium input to Cockburn Sound (3)) had a marked influence on the cadmium levels in the water from the vicinity of the industrial region, south into Mangles Bay.

By comparing literature values of metals in seawater with those obtained it was clear that if synergism was occurring between cadmium and copper the development of a species of juvenile planktonic crustacea would be inhibited (18). Levels appeared to be high enough to distort enzymatic activity in fish (19). Unanswered questions of seemingly excessive amounts of soluble metals in Cockburn Sound led to further sampling in September, November and December, 1978.

Table 2.2 summarises the results from the initial MSID analyses on seawater collected on 25 September and 14 November, 1978. The results from the CSBP station were 2.28 and 0.13 $\mu g l^{-1}$ on those dates, respectively. The CSBP phosphoric reactor plant officially shut down on 11 November and production was due to start again at 1700 h on 29 November. However, before start-up of the phosphoric acid plant can commence there is always a commissioning period to achieve the correct operating parameters. Some waste materials containing cadmium were discharged up to 48 h prior to start up.

The results for the MSID cadmium surveys conducted on 29 November and 28 December, 1978 are shown in Figures 2.3 and 2.4. Duplicate analyses were carried out on 33 per cent of these samples. From these results a background level for cadmium in coastal oceanic waters would appear to be between 0.020 to 0.005 $\mu g l^{-1}$.

If Figures 2.5 and 2.6 are observed in conjunction with Figure 2.3 and 2.4 several important points arise for the given seabreeze weather pattern.

- There was a very strong longshore movement of cadmium both north and south. This movement of cadmium passed the industrial area and maintained relatively high concentrations in the vicinity of the Naval Base recreation area and along the coast to Jervoise Bay. Mangles Bay water also exhibited elevated concentrations.

2.3.1 (Cont'd)

- Particulate cadmium (40 per cent of the total cadmium in the gypsum (3)), would not be expected to travel very far from the CSBP outfall source. Evidence of particulate fallout can be seen in the sediment results (see Chapter 3).

- A proportion of the soluble cadmium moves northward and crosses the shallow Parmelia Bank just west of Woodman Point (Figures 2.4 and 2.5). Owen Anchorage waters contain elevated cadmium levels, as can be seen at stations 0900 and 0400 (Figure 2.3 and 2.4), possibly as a result of discharges in Cockburn Sound. There are no significant cadmium discharges in Owen Anchorage.

- There appears to be minimal "leakage" of cadmium out of the north west opening between Carnac Island and the north of Garden Island.

- In both surveys there was a definite intrusion of oceanic water from the vicinity of station 5200 into Cockburn Sound under the causeway high bridge past station 4700. The penetration would appear to be a maximum of only 2 km.

- Although the water at station 5000 had the lowest concentration of cadmium for any Mangles Bay station (Figures 2.2 and 2.3) the values obtained are no less than would be expected as a result of increased dilution with distance from CSBP. By comparing results from station 4900 with those of station 5000, we may conclude that at the time of sampling little exchange of water was occurring between the eastern and western sides of the causeway.

- Cadmium is transported south into Mangles Bay, where levels are as much as ten times those of the shallow oceanic waters outside the causeway.

- An average value for the concentration of total cadmium in CSBP effluent is 60 $\mu g l^{-1}$ (3). If, under normal operating conditions a value of about 3.5 $\mu g l^{-1}$ (Figure 2.4) total cadmium is accepted as being indicative of the concentration in water immediately over the CSBP outfall, then the dilution factor for the effluent coming out of the pipe after its initial mixing with seawater is about 20 times. One and a half kilometres north of the CSBP station the dilution is about 400 times whereas 2 km south the dilution is about 500 times. This gives some idea of the north/south movement of cadmium during this particular sampling period. The dilution figures for cadmium are small and indicate that mixing of this effluent with Sound waters is limited.

Table 2.3 compares data for the total cadmium in Cockburn Sound water for the November and December, 1978 surveys.

Statistical analysis indicated that there was a significant increase at the ten per cent level in the mean concentrations of cadmium in Cockburn Sound waters between the two sampling occasions.

This result was achieved even though the initial sampling on 29 November was not taken at a time of minimum cadmium input to Cockburn Sound.

2.3.1 (Cont'd)
Computer simulations of the theoretical cadmium concentration isopleths, streamline patterns and the velocity vector diagrams using the prevailing wind and tide conditions and cadmium input data for ten days before the sampling periods of 29 November and 28 December are given in Figures 2.7, 2.8, 2.9, 2.10 and 2.11 (5).

- Figure 2.7 shows concentration isopleths for cadmium on 29 November with cadmium input from CSBP commencing at 1700 h on that day. Diagrams for 0600 and 1200 h show the contribution of AIS, BP and the Woodman Point outfalls.

  These simulated isopleths did not compare with observed values (see Figure 2.3) and indicate water sampling took place after discharge of some material containing cadmium from CSBP.

- Figure 2.8 shows the cadmium distribution with input from CSBP commencing 24 h earlier than for simulation 1. It suggests that if effluent was in fact released prior to the offical discharge time then the resultant cadmium distribution would be comparable to that seen for the actual chemical analyses.

- Figure 2.9 again shows strong northerly and weak southerly components for cadmium distribution on 28 December. Raised cadmium levels are more widespread; a result which agrees with observed values (see Figure 2.4).

- Typical data from which the simulations above are compiled is given in Figure 2.10 and 2.11. These show cells of water formed in Cockburn Sound, and the Sound being divided into gyres; one of which is a large northern gyre and another the Southern Mangles Bay gyre. The siting of the CSBP outfall is such that cadmium can be incorporated into both systems.

Open ocean cadmium levels are indicated in Figures 2.3 and 2.4.

The MSID analyses indicate that levels of total cadmium in the coastal oceanic environment are at most 0.020 $\mu g l^{-1}$ and are likely to be as low as 0.005 $\mu g l^{-1}$. These results may be compared to other studies as indicated in Table 2.5.

2.3.2 December 1978 Survey: Cadmium, lead and copper analysis by ASV.
Cadmium -
The results for cadmium can be compared to those obtained by the MSID for the same samples (see Table 2.4). There is good overall comparison between the results by the two techniques.

The good technique comparisons and low results obtained are attributed to scrupulous cleanliness during sampling and extremely sensitive analytical techniques.

Lead -
Levels of lead in Cockburn Sound range from 0.07 to 2.72 $\mu g l^{-1}$ (Table 2.4). The results do not show any pattern for lead distribution in the Sound. This could be expected since a significant proportion of lead input may derive from air emissions associated with the burning of fossil fuels (see Appendix 2 for air emission figures).

2.3.2 (Cont'd)

The level of lead in waters sampled west of Garden Island are at the lower end of the range. The values for lead above 1.0 $\mu g l^{-1}$ are significantly higher than the values of 0.02 $\mu g l^{-1}$ quoted by Burnett and Patterson (20) for unpolluted seawater. These workers also express the problems in analysing for lead, their main concern being the ubiquitous nature of lead in our environment causing possible contamination and presenting a serious problem in analysis.

Despite the problems outlined by these workers it is unlikely that sample contamination would be more than twice the lowest value of 0.07 $\mu g l^{-1}$ found in this survey. Therefore, values of lead above 1.0 $\mu g l^{-1}$ would indicate significantly elevated levels of lead in Cockburn Sound. The results however are below the minimum risk threshold of 10 $\mu g l^{-1}$ (21) recommended by the United States Environmental Protection Agency. The levels obtained also compare well with levels obtained for lead in seawater in other parts of the world (see Table 2.5).

Copper -

The results in Table 2.4 for copper show no clear pattern of distribution related to areas where effluents containing copper are known to be discharged. The origin of the copper may be from airborne emissions (Appendix 2).

One feature of the results was the consistently low figure obtained for the three stations outside Cockburn Sound; the average for four analyses was 0.06 $\mu g l^{-1}$. This figure compares favourably with the value of 0.03 $\mu g l^{-1}$ reported by deForest (Table 2.5).

Various amounts of copper in seawater may not be detected by ASV analysis because of chelation with organics. Total copper analysis would have required some acid digestion procedure to liberate all the copper present from the organics. The work carried out by Florence and Batley has shown that in the order of 98-99 per cent cadmium, 78 per cent lead and 65 per cent copper in surface seawater are in the labile form (22).

2.3.3 Enteric bacteria

Facael *E. coli* counts and salmonella isolations for all sampling stations (Figure 2.12) are presented by Iveson (12). During the study period from March, 1977 to April, 1978 a total of 313 samples of seawater from 31 sites between South Beach and Jervoise Bay were examined for *E. coli* and salmonella bacteria. These samples were additional to the on-going Public Health Department monitoring of shoreline waters and effluents.

A short summary of all data collected for seawater and mussel samples is given in Table 2.6, while a comprehensive breakdown for the results of the isolations in seawater, is given in Table 2.7.

A total of 85 (27 per cent) seawaters had *E. coli* counts above 500 per 100 ml and 54 (17 per cent) out of all the samples collected contained salmonella in one litre of water. The vast majority of contaminated samples were derived from waste discharge points and at sites in close proximity to shoreline and offshore outfalls. *E. coli* or salmonella contamination was detected in shoreline waters collected from the South Beach and Coogee Beach recreational sites and at inshore sites at Woodman Point and Jervoise Bay.

2.3.3 (Cont'd)

Salmonella were detected in 50 per cent of samples from the Woodman Point sewerage outfall site located 1600 m offshore and in 31 per cent of samples collected approximately 100 m from the main discharge site.

High levels of contamination averaging 50 per cent were also detected at outfall sites of abattoirs and associated trades. A higher frequency was detected in shoreline waters close to abattoir discharges than at offshore outfall sites.

Salmonella were detected in nine per cent of shoreline samples collected at Coogee Beach and South Beach recreational sites and 22 per cent of these waters averaged *E. coli* levels in excess of 500 per 100 ml.

At other shoreline groynes and jetties salmonella were detected in nine per cent of samples and at offshore pylons and beacons in two per cent of samples.

Altogether in the 313 one litre seawater samples examined, the 85 (27 per cent) positive samples yielded 128 isolations and salmonella were detected on at least one occasion from 17 (55 per cent) of the 31 sites examined. *S. derby* (24), *S. chester* (12), *S. oranienburg* (12), and *S. typhimurium* (10) were the major strains identified in a total of 23 individual serotypes.

No *V. parahaemolyticus* isolations were recorded in seawater throughout the survey.

2.3.4 Temperature Profiles

The data are summarised in Figures 2.13 to 2.16. Details of these data are kept in the Cockburn Sound Study Data Repository. The figures demonstrate some major patterns:

- Decrease in temperature abnormality with depth and distance from shore. Datum was determined by depth averaging until a discontinuity of at least +0.5°C occurred. Control transects (Cockburn Power Boat Association, CPBA) demonstrated discontinuities of +0.3°C at depths to 2 m, 400 and 500 m offshore on 27 November in due west transects (Figure 2.13.)
- The BP and AIS transects indicate a more acute but limited effect. Longshore distributions were not determined. More intermediate transects would be necessary to determine whether residual effects exist along the coast (Figures 2.13 and 2.14).
- The SEC outfall exerts a significant influence to at least 500 m offshore, whereas, the AIS and BP outfalls had little effect after 300 m (Figures 2.13 and 2.14).
- Evidence of longshore distribution for the SEC with a stronger southerly than northerly component despite differing wind regimes. The data indicates that surface temperature increases should be examined over a wider area to complete the distribution (Figures 2.15 and 2.16).
- Heated cooling waters from the SEC Kwinana Power Station had an effect on the receiving waters to a depth of 3 to 4 m at a distance of at least 500 m.

2.4 Discussion

2.4.1 Residence time for metals in oceanic waters

General -

A knowledge of residence time for metals in oceanic waters is extremely important in that it allows planners to know how long certain toxic elements discharged from installations such as sewage treatment works, will remain biologically available in solution in oceanic waters.

Metals such as iron and manganese have relatively short oceanic residence times in the order of 30 to 45 years, respectively. Other metals such as cobalt, copper, zinc or cadmium have times which vary from 1000 to tens of thousands of years, in that order (23).

Metals such as zinc and cadmium are considered to remain predominantly in solution and these are removed only very slowly from the water. Their distributions in the surface layer are probably controlled by mixing and to a lesser extent metal incorporation into the biological components of the mixed layer. The deep water dissolved metals are maintained by the degradation and dissolution of biogenic detritus or resolution from sediments. Thus, surface sampling should reflect the status of cadmium through the water column in Cockburn Sound with minor variations of concentration with depth.

Lead and copper in Cockburn Sound -

There is very little data available on the oceanic residence time of lead. However, at concentrations which are less than 1 ppm in seawater, lead tends to be precipitated as hydroxide carbonate and phosphate (1). This means there will be no relatively high values in seawater but there could be consistently elevated levels above background values over large areas of water. This seems to be the case for Cockburn Sound.

Copper has a large oceanic residence time in the order of 4 000 - 5 000 years (23). Cockburn Sound waters do not exhibit high values when this longevity is taken into account.

Cadmium -

The soluble form of this element is among the more conservative of the heavy metals in seawater. Marine biota such as phytoplankton, which are renowned for lead removal, have little effect on cadmium concentrations in seawater. In one experiment conducted over four weeks, 14 different phytoplankton species were involved and at the end of the experiment less than one per cent of the cadmium in the test seawater had been removed. The maintenance of cadmium levels in the seawater was partially attributed to release of soluble cadmium after die-off of the phytoplankton (24).

In the survey on 28 December the conservation of "cadmium mass" is particularly noticeable in Cockburn Sound. After initial dilution of about 500 times within 2 km of the CSBP outfall the figure rarely falls below a dilution of about 700 times for most areas in the Sound. Many studies have reached the conclusion that cadmium is uniformly distributed in the water column (14).

Assuming that there is uniform mixing of cadmium through the Sound's water column and taking the total cadmium input to Cockburn Sound from all sources to about 6.0 kg per day (not all of which is soluble) (3), the amount of cadmium discharged in the 29 days from

2.4.1 (Cont'd)

29 November to 28 December would have been about 174 kg. The volume of the Sound has been calculated for Indian Spring low water to be $1.49 \times 10^9 m^3$ or 1.49×10^{12} 1. Assuming an average increase in the Sound of about 0.05 $\mu g l^{-1}$ cadmium (Table 2.3), a total amount of about 75 kg of cadmium was conserved out of one month's input, i.e. in the order of 50 per cent of the cadmium remained in the water column in a soluble (transportable) form over a period of one month. Depth profiles are needed to give credence to these calculations but they lend support to the theory of the extremely low flushing rate of Cockburn Sound as well as supporting the results of analyses of effluents and waters.

Further studies which include depth profile analysis of the water column were planned for May 1979. A summary of the results of this programme are included in Appendix IV.

2.4.2 Thermal waste -

One of the last studies of thermal pollution by outfalls in Cockburn Sound was by E.R.A. in 1972 (35). The main conclusion of this study was that although marine communities are extremely sensitive to temperature fluctuations, the thermal effects in this water body were not severe enough, by themselves, to be biologically significant. Cambridge (36), supports this idea with respect to the death of the seagrass within Cockburn Sound.

Although it is likely that waste heat dissipates within a short distance of each outfall, long periods of calm in Cockburn Sound are when the most problems with waste heat are liable to arise. The use of seawater in Cockburn Sound is likely to increase from the 1978 rate of $1\ 600 \times 10^6$ litres per day to about $2\ 100 \times 10^6$ litres per day by the end of 1979. A moderate increase in temperature having no deleterious effect by itself, might lower the threshold of a species to some other pollutant. It has been shown by Reynold et al (32) that raising the temperature from 20°C to 24°C considerably increases the toxicity of phenol.

The volume of the Sound has been estimated at 1.5×10^{12} litres (33). If, on average, industries are using 2.0×10^9 litres of water for cooling purposes per day, then in one month 0.13 per cent of the volume of the Sound passes through cooling water systems. Obviously all the waters of Cockburn Sound are not used in cooling water systems and only the eastern side should be affected making the water usage for that side higher than the 0.13 per cent calculated. An implication of this simple calculation is that the cooling systems could possibly be having an effect on the planktonic species, fish larvae and fry in Cockburn Sound. The temperature elevations would possibly be enough to kill most of these biota notwithstanding the chlorination processes that these cooling waters undergo (34).

2.4.3 Enteric bacteria

During the course of investigations for enteric bacteria it became evident that the Woodman Point sewage outfall and the special industries based in Owen Anchorage are sources of *E. coli* and salmonella.

2.4.3 (Cont'd)

Iveson (12) states that:

> "At present, in Western Australia, no statutory standards exist for *E. coli* levels in recreational waters and shellfish harvested for human consumption. However, the Public Health Authority considers that waters which regularly exceed 500 *E. coli* per 100 ml are significantly contaminated with faecal organisms derived from human or animal excreta. When these levels also include the isolation of salmonella bacteria or other pathogens, then a significant public health hazard is present. More stringent standards are applied to waters considered acceptable for the harvesting of shellfish for human consumption without further cleansing procedures. These, in general, follow recommendations and standards applied internationally which recognise that shellfish harvested from waters which exceed ten *E. coli* per 100 ml, are unsuitable for human consumption without further treatment. No pathogenic organisms must be present in 50 gram of representative samples.
>
> In the publication, "A Compilation of Australian Water Quality Criteria", (Hart 1974) it was noted that the link between bacteriological levels and health risks was tenuous pending further epidemiological studies. It was also reported in this publication that if the level of 200 faecal coliforms/100 ml is approached or exceeded regularly during the recreational season, that action be taken by the appropriate authority to assess the possible health risk. *E. coli* levels in the range 1000 to 2000/100 ml were classified as representing distinct pollution and the water suspect as a health risk. It was stressed that these criteria were a guide based on the possibility of health hazards rather than a probability of actual danger to the swimmer. Also health risks were usually based on correlation with salmonella levels and little was known about the relationships between faecal coliform levels and other pathogenic bacteria including viruses and other parasites, for example, *G. lamblia*.
>
> The foregoing criteria have been considered (in this report) as a general guide to the interpretation of *E. coli* levels and salmonella isolations at the various sites."

The Public Health Department has been investigating abattoir process floors and effluents since 1973 for salmonella infection.

Details of salmonella isolations and serotypes identified from abattoir process floors and final effluents prior to ocean discharge are detailed by Iveson (12). Serotypes of epidemiological significance commonly found in adjacent coastal waters were identified from cattle, sheep and pig processing effluents.

Quantitative estimations of salmonella numbers in abattoir floor run-off prior to effluent discharge were also undertaken and in a total of 85 samples, 83 (98 per cent) were contaminated with salmonella. The majority of salmonella counts were in excess of 1000 per 100 ml and some in excess of 110 000 per 100 ml.

Additional monitoring was also undertaken at one abattoir open pond/lagoon system frequented by silver gulls and water fowl, and since 1974, salmonella were detected in 90 per cent of effluent samples collected from this site.

2.5 Conclusions

Computer simulation of the concentration isopleths for the cadmium discharges into Cockburn Sound are comparable with the MSID field data isopleths and they are supported by ASV data. For a summer seabreeze pattern there is a strong northerly flow of cadmium from the industrial area as well as a steady flow south into the Mangles Bay area. Some leakage is predicted around Woodman Point into Owen Anchorage with very little, if any, loss from the north west of Cockburn Sound. Both sets of November and December data highlight the Sound's very limited exchange capacity with the open ocean.

As suspected, cadmium has proved to be an excellent tracer element. The southward movement may cause concern because of the proximity of the Rockingham population centre and the unique family recreation base afforded by the shoreline (26); it is the largest section of the Perth region suitable for intensive family beach recreation.

It has been claimed that trace metal concentrations of about ten times the natural environmental level are biologically deleterious (27). The difficulties of establishing natural levels, to within one order of magnitude, for common elements such as cadmium, copper, lead or zinc are considerable; cadmium and copper certainly fall into this category in Cockburn Sound. The analyses of this study have supported the findings in the latest publications that the cadmium concentration in open ocean is in the order of 0.20 μgl^{-1} and is more likely to be as low as 0.005 μgl^{-1}.

This study has shown that an effluent input of one month from CSBP and Farmers Ltd., raises the level of cadmium in Cockburn Sound waters very significantly. During a time of minimum cadmium input from CSBP, remembering that the Sound has at least three other possible minor inputs (3), the level of cadmium dropped to about 0.04 μgl^{-1} or eight times the concentration of the oceanic water.

Cadmium or copper at about 5 to 6 μgl^{-1} has been observed to interfere with growth and photosynthesis in phytoplankton (28). The levels of cadmium determined by MSID, may be elevated sufficiently to cause chronic toxicity to sensitive marine organisms in the Sound. Cadmium, lead and copper on their own or acting as synergists are at levels high enough to warrant concern with respect to chronic low level toxicity, given the enclosed nature of Cockburn Sound.

One point, however, that cannot be emphasised too strongly is that the ingestion of excessive quantities of cadmium represents a grave health risk to man (29), (30), (31). If the gypsum discharge ceased the elevated levels of cadmium in Cockburn Sound waters would eventually fall thus reducing the potential health risk.

Faecal *E. coli* and salmonella contamination is plainly evident in the Owen Anchorage and northern waters of Cockburn Sound. The effluents from the Woodman Point sewage outfall and the Owen Anchorage special industries represent a significant source of bacterial contamination to the relevant marine waters. The consequent hazard with respect to seafood are discussed in Chapter 4.

TABLE 2.1

RESULTS OF SEAWATER SAMPLES
Collected February - May, 1978 from Cockburn Sound
($\mu g\ l^{-1}$)

Sediment Sampling Grid Station Number	Element	Mean	Range	Number of Samples
2100 (Northern Cockburn Sound)	Cu	5	3-8	3
	Zn	8	7-8	3
	Cd	<1	-	3
3226 (BHP jetty)	Cu	4	2-8	8
	Zn	8	6-9	8
	Cd	<1	-	8
4105 (North of B.P. Refinery intake)	Cu	5	2-7	3
	Zn	7	3-12	3
	Cd	3	<1-10	3
4128 (CSBP)	Cu	4	2-5	8
	Zn	7	4-12	8
	Cd	4	<1-18	8
4504 (South of CSBP jetty)	Cu	5	3-8	3
	Zn	5	3-7	3
	Cd	<1	-	3
4510 (Off Kwinana Wreck)	Cu	4	2-8	8
	Zn	7	4-13	8
	Cd	2	<1-10	8
4524 (North of CBH jetty)	Cu	5	5-6	3
	Zn	8	4-13	3
	Cd	3	<1-8	3
5016 (Southern Cockburn Sound)	Cu	5	2-7	3
	Zn	6	5-7	3
	Cd	2	<1-6	3

TABLE 2.2

INITIAL SEA WATER SAMPLING FOR DETERMINATION OF Cd.
By Mass Spectrometric Isotope Dilution ($\mu g\ l^{-1}$)

Station	25/9/78	14/11/78
CSBP	2.28	0.13
4510	0.153	0.054
3226	0.127	0.061

TABLE 2.3

COMPARISON OF TOTAL CADMIUM DATA FOR NOVEMBER AND DECEMBER SURVEYS, 1978

Station Grouping (No Stations outside Cockburn Sound)	Mean ($\mu g\ l^{-1}$)		Standard Deviation		Range ($\mu g\ l^{-1}$)		No. of Stations		Test of Hypothesis (a)
	29/11/78	28/12/78	29/11/78	28/12/78	29/11/78	28/12/78	29/11/78	28/12/78	
Main 2 km Grid Stations (Stns. 2 km apart excluding Stn. CSBP)	0.064	0.096	0.043	0.045	0.021 to 0.216	0.009 to 0.186	33	33	** (b)
Cockburn Sound Stations (excluding Stn. CSBP)	0.065	0.109	0.043	0.065	0.021 to 0.216	0.009 to 0.404	35	41	** (c)

(a) Ho: the mean cadmium concentration in Cockburn Sound water did not increase after one month of effluent input from CSBP.

(b) F = 1.0952. T = 2.9534. **, $P<0.01$ (Sokal and Rohlf, Formula 9.3)

(c) F = 2.2850. T = 3.5242. **, $P<0.01$ (Sokal and Rohlf, Formula 13.13)

TABLE 2.4

ANODIC STRIPPING VOLTAMMETRY ANALYSIS OF Pb, Cu and Cd IN SEAWATER SAMPLES FROM 28TH DECEMBER, 1978 WITH COMPARISON OF Cd BY MASS SPECTROMETRY ON THE SAME SAMPLES

Grid Reference	Concentration μg l^{-1}			
	Pb(ASV)	Cu(ASV)	Cd(ASV)	Cd(MSID)
0400	2.72	0.37	0.05	0.088
0900	0.88	0.24	0.05	0.073
1200	1.02	0.32	0.06	0.057
1300	0.40	0.07	0.09	0.130
1400	0.43	0.21	0.18	0.147
1700	0.62	0.14	0.036	0.013
1800	0.97	0.26	0.05	0.097
1900	0.24, 0.22*	0.24, 0.22*	0.09, 0.09*	0.094
2000	1.09	0.16	0.09	0.120
2100	0.20	0.28	0.16	0.148
2200	0.90	0.26	0.012	0.027
2300	0.44, 0.45*	0.16, 0.14*	0.07, 0.07*	0.051
2400	1.15 ± .05	1.17	0.13	0.109
2500	0.64	0.21	0.05	0.092
2600	0.23	0.16	0.10	0.186
2700	0.12	0.22	0.44	0.178
2900	0.35	0.22	0.06	0.081
3000	0.64	0.13	0.06	0.102
3100	0.65	0.19	0.04	0.083
3200	0.49	0.12	0.05	0.072
3206	1.70, 1.30*	0.34, 0.35*	0.11, 0.09*	0.183
3300	1.87	0.63	0.06	0.074
3400	0.14	0.04	0.05	0.094
3500	2.10	0.54	0.13	0.113
3600	0.31	0.13	0.06	0.081
3622	0.70	0.17	0.07	0.139
3700	0.34	0.40	0.09	0.217
3802	0.42	0.27	0.08	0.071
3900	1.25	0.29	0.14	0.086
4000	0.23	0.39	0.09	0.079
4100	0.14	0.05	0.06	0.076
4104	1.42	0.30	0.14	0.154
4300	0.36	0.15	0.06	0.060
4400	0.36	0.05	0.042	0.073
4430	0.42	0.16	0.07	0.122
4500	1.39	0.19	0.05	0.094
4510	1.02	1.76	0.57	0.404
4700	0.07, 0.06*	0.18, 0.19*	0.03, 0.03*	0.009
4800	0.93	0.09	0.08	0.080
4812	0.75	0.21	0.11	0.146
5000	0.38	0.12	0.05	0.092
5018	0.19	0.28	0.08	0.106
5100	0.51	0.13	0.11	0.137
5200	0.11	0.08	<0.005	0.003
6001	0.37	0.06	0.006	0.017
6003	0.31, 0.30*	0.07, 0.05*	<0.005, <0.005*	0.002
CSBP	0.48, 0.51*	0.18, 0.16*	2.82, 2.83*	3.47

* Duplicate analyses

TABLE 2.5

TRACE METALS IN OCEANIC WATER
(After De Forest et al, 1978 {14})

Reference	Cd ($\mu g\ l^{-1}$)	Cu ($\mu g\ l^{-1}$)	Pb ($\mu g\ l^{-1}$)
This Study (1979)*			
MSID (Total) 28/12/78	0.002 - 0.017	--	--
ASV (Labile) 28/12/78	<0.005 - 0.006	0.05 - 0.08	0.11 - 0.37
De Forest et al (1978)	0.02 - 0.54	0.03 - 4.5	0.10 - 2.7
Chester and Stoner (1974)	0.02 - 0.30	0.10 - 3.9	--
Brewer and Spencer (1969)	--	0.3 - 2.8	--
Alberts et al (1976)	0.13 - 1.2	0.67 - 1.78	--
Sagi et al (1974)	0.0 - 0.65	--	--
Florence (soluble) (1972)	0.27 - 1.06	0.93 - 9.8	0.42 - 1.91
Rojahn (1972)	0.09 - 0.18	--	0.17 - 1.3

* Oceanic Seawater Stations are considered to be those Stations West of the Garden Island Causeway and Garden Island.

TABLE 2.6 SUMMARY OF *E. COLI* AND *SALMONELLA* IN SEAWATER AND MUSSELS SOUTH BEACH, FREMANTLE TO JERVOISE BAY, COCKBURN SOUND MARCH - APRIL, 1978

(*Salmonella* +ve samples in brackets)

SAMPLING SITES	SEAWATER					MUSSELS				
	E. COLI/100 ml				TOTALS	*E. COLI*/gm				TOTALS
	0-10	11-100	101-500	>500		0-10	11-100	101-500	>500	
1. Jervoise S.L.C.B.	9	1	1	1	12	10	1	1(1)	0	12(1)
2. Woodman groyne	3	0	0	0	3	2(1)	0	0	0	2(1)
3. Woodman O/F	2	0	1(1)	9(5)	12(6)					0
4. " 100 yds W	4	0	1(1)	7(3)	12(4)					0
5. " 100 yds E	4	1	2	5(3)	12(3)					0
6. " 100 yds N	3	0	0	9(3)	12(3)					0
7. " 100 yds S	2	1	0	9(5)	12(5)					0
8. " N.L.C.B.	13	0	1(1)	0	14(1)	9(3)	4(3)	0	0	13(6)
9. Quarantine groyne	1	0	0	0	1					0
10. Explosives Jetty	9	3	0	2(1)	14(1)	11(3)	2(2)	1(1)	0	14(6)
11. Coogee Jetty	8	3	1	4(2)	16(2)	10(4)	4(3)	0	1(1)	15(8)
12. Anchorage abatt. O/F	1	2(1)	4(1)	9(5)	16(7)	4(1)	5(5)	2(2)	4(4)	15(12)
13. " O/F (offshore)	4	2(1)	0	2	8(1)					0
14. Cockburn Cement jetty	8(1)	3	1(1)	0	12(2)	8	2(2)	0	0	10(2)
15. Power Stn. jetty	11	2	1	1(1)	15(1)	7(3)	4(1)	2(1)	1(1)	14(6)
16. W.A.M.E. O/F	1(1)	0	0	14(12)	15(13)	0	0	0	13(13)	13(13)
17. Success spit	10	3	1	1	15	8(4)	6(2)	1	0	15(6)
18. Nook spit	12	1	1	1	15	10(3)	2(1)	2(1)	0	14(5)
19. N.W. midground	13	1	9	1	15	12	3(1)	0	0	15(1)
20. Elbow pylon	14	0	1(1)	0	15(1)	13(1)	1(1)	0	0	14(2)
21. Midline Carnac/Arch.	9	1	3	0	13					0
22. " G.I./Anchorage	3	1	0	0	4					0
23. Channel bcn No. 1	8	2	1	1(1)	12(1)	8	2(1)	1	1(1)	12(2)
24. Jervoise C.B.	7	0	1	1	9	4	1	0	0	5
25. Woodman offshore	1	0	0	0	1					0
26. South beach	3	1	2	1	7	3	0	1	1(1)	5(1)
27. Windmill N lead	10	1	0	0	11	10(1)	1	0	0	11(1)
28. Calista lead	1	0	0	0	1	1(1)	0	0	0	1(1)
29. Watsons O/F	2	0	0	3(2)	5(2)					0
30. Shilkins O/F	0	0	0	2	2					0
31. Coogee fellmongers	0	0	0	2(1)	2(1)					0
TOTALS	176	29	23	85	313	130	38	11	21	200
SALMONELLA +VE	2	2	6	44	54	25	23	6	20	74
% *SALMONELLA* +VE	1.1%	6.9%	26.1%	51.8%	17.2%	19.2%	57.9%	54.5%	92.2%	37%

TABLE 2.7 SEA WATER SURVEY MARCH 1977 - APRIL 1978

E. coli M.P.N./100 ml and *Salmonella* Positive Samples (+) (sites sampled five times or more)

Site No. (refer Table 2.6)	SEAWATER SAMPLING DATES *E. COLI*/100 ML AND *SALMONELLA* +VE SAMPLES																Samples & *Salm* +ve	*E. coli*/100 ml	
	9/3/77	21/3	13/4	27/4	1/6	27/6	25/7	23/8	26/9	25/10	16/11	20/12	23/1/78	25/2	21/3	19/4		>10	>500
1.	N	N	N	N	4	0	75	150	0	0	0	0	0	0	0	>	12	3	1
3.	N	N	N	N	> (+)	> (+)	430 (+)	> (+)	> (+)	> (+)	0	0	>	>	>	>	12 (6)	10	9
4.	N	N	N	N	9	210 (+)	750 (+)	> (+)	> (+)	4	0	0	>	>	>	>	12 (4)	8	7
5.	N	N	N	N	3	11	> (+)	> (+)	> (+)	4	0	0	>	>	460	460	12 (3)	8	5
6.	N	N	N	N	4	> (+)	> (+)	>	> (+)	0	460	0	>	>	>	>	12 (3)	9	8
7.	N	N	N	N	> (+)	> (+)	40	> (+)	> (+)	> (+)	0	0	>	>	>	>	12 (5)	10	9
8	N	N	0	9	0	0	0	240(+)	9	9	0	0	0	0	9	4	14 (1)	1	0
10.	N	0	N	43	43	0	0	> (+)	9	0	0	0	0	0	93	>	14 (1)	5	2
11.	43	0	0	9	> (+)	0	4	> (+)	43	>	0	0	0	>	43	460	16 (2)	8	4
12	> (+)	460	> (+)	290	>	> (+)	43 (+)	230 (+)	460	43	> (+)	3	23,	>	>	> (+)	16 (7)	15	8
13.	N	0	0	N	43	9	N	75(+)	N	N	N	>	>	N	0	N	8 (1)	4	2
14.	N	N	0	15	4	4	0	240(+)	0	0	0	0	4	N	23	15	13 (2)	4	0
15.	N	9	0	9	0	0	0	460	0	0	0	0	0	43	23	> (+)	15 (1)	4	1
16.	N	> (+)	> (+)	> (+)	>	> (+)	> (+)	> (+)	> (+)	> (+)	> (+)	4	>	> (+)	> (+)	> (+)	15 (13)	14	14
17.	N	0	9	23	0	0	0	43	0	>	460	0	0	0	20	4	15	5	1
18.	N	0	0	0	0	0	0	460	4	>	0	0	0	0	23	4	15	3	1
19.	N	0	0	0	0	0	0	93	0	>	0	0	0	4	4	0	15	2	1
20.	N	0	0	0	0	3	0	240(+)	0	7	0	0	0	0	0	9	15 (1)	1	0
21.	N	0	N	0	0	240	0	N	240	0	4	28	460	0	0	0	13	4	0
23.	N	N	N	N	44	43	0	> (+)	0	0	0	0	0	0	0	150	12 (1)	4	1
24.	N	N	N	N	240	N	N	7	0	0	N	0	0	0	0	>	9	2	1
26.	430	N	N	4	N	N	N	N	N	N	0	>	N	9	43	240	7	4	1
27.	N	N	N	N	N	0	0	21	0	4	0	0	0	0	4	0	11	1	0
29.	N	N	N	N	N	N	N	N	> (+)	9	0	N	N	>	> (+)	N	5 (2)	3	3
SAMPLES	3	11	11	13	21	21	20	21	22	22	22	23	22	22	24	22	300	132	79
E. coli *	3	2	2	5	9	9	8	20	10	8	4	3	9	10	15	15	132		
E. coli **	1	1	2	1	5	5	4	9	7	7	2	2	7	9	7	10	79		
Salmonella +ve	1	1	2	1	3	6	6	13	7	3	3	1	0	1	2	3	53		

N = No test samples, and, > = most probable number of *E. coli* > 1 000

* Waters unsuitable for direct harvesting of mussels (*E. coli* >10/100 ml)

** Waters suspect for bathing and swimming (*E. coli* >500/100 ml)

1. Form of metal in solution
   - (Inorganic
   - (Organic
     - (Soluble
       - (ionic
       - (complexed ion
       - (chelated ion
       - (molecular
     - (Particulate
       - (colloidal
       - (precipitated
       - (adsorbed

2. Presence of metals-joint action
   - (synergistic (more than additive)
   - (additive (no interaction)
   - (antagonistic (less than additive)

3. Physiochemical factors influencing physiology of organisms and possibly the form of the metal in water
   - (temperature
   - (pH
   - (dissolved oxygen
   - (light
   - (salinity

4. Condition of the organism and behavioural response
   - (life history
   - (life cycle
   - (growth rate
   - (sex determination
   - (feeding habits
   - (behavioural changes
   - (metal tolerance

FIGURE 2.1

FACTORS INFLUENCING TOXICITY OF HEAVY
METALS TO ORGANISMS IN SEAWATER.

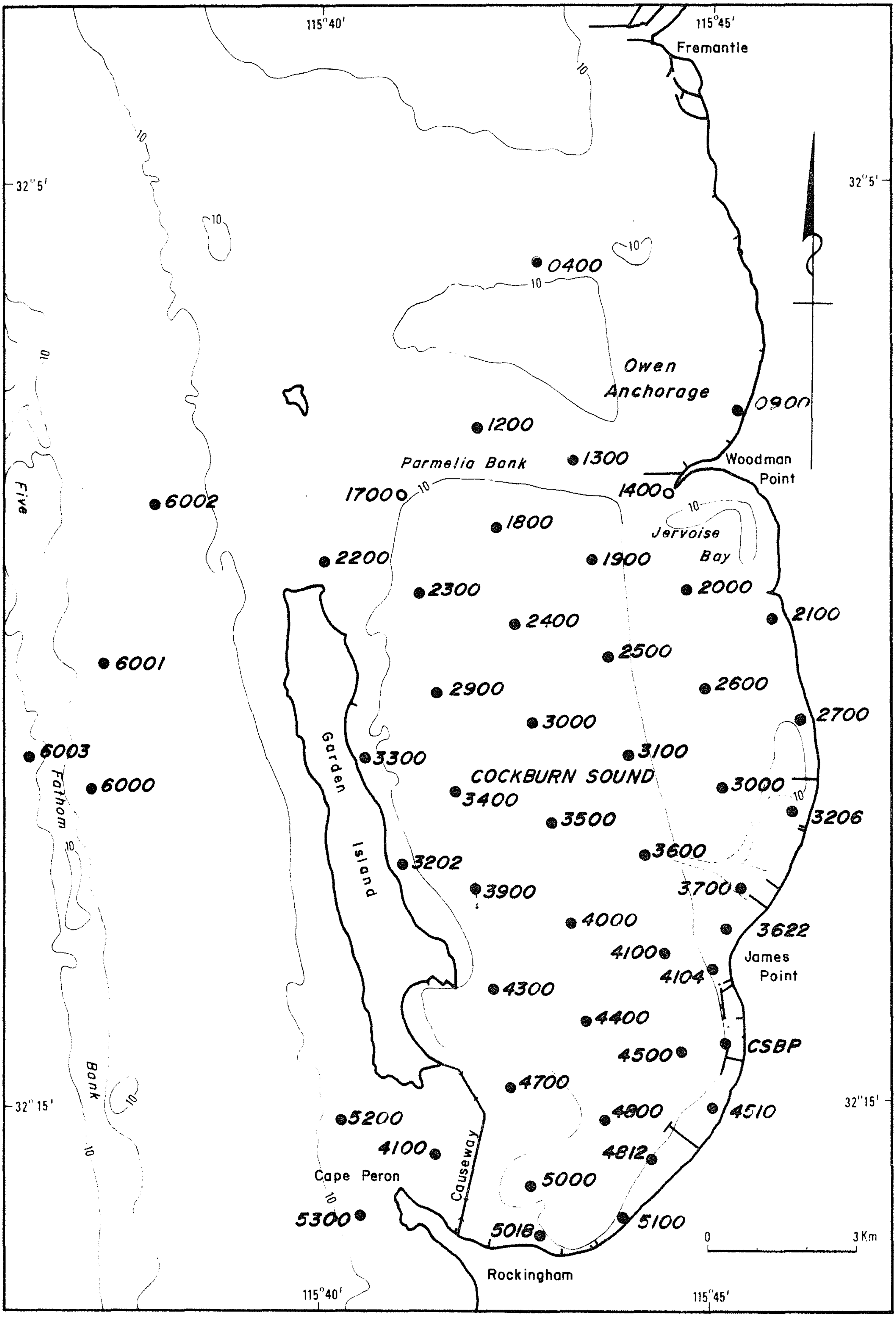


Figure 2·2

SAMPLING STATION LOCATIONS FOR THE INTENSIVE MONITORING OF WATERS IN THE COCKBURN SOUND AREA

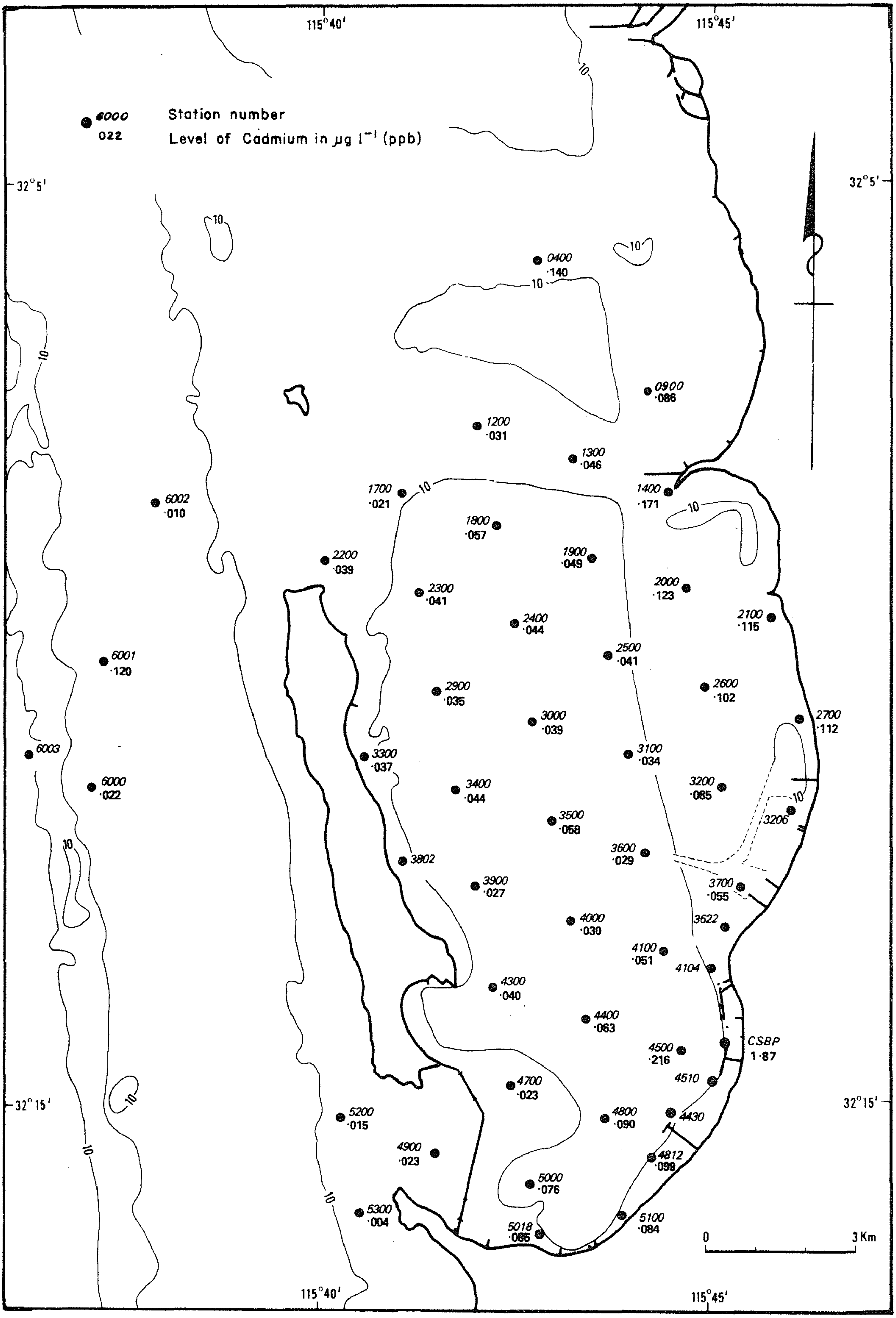


Figure 2·3

SURVEY (29 NOVEMBER 1978) OF THE SURFACE WATERS OF COCKBURN SOUND FOR CADMIUM. (M.S.I.D. analysis technique.)

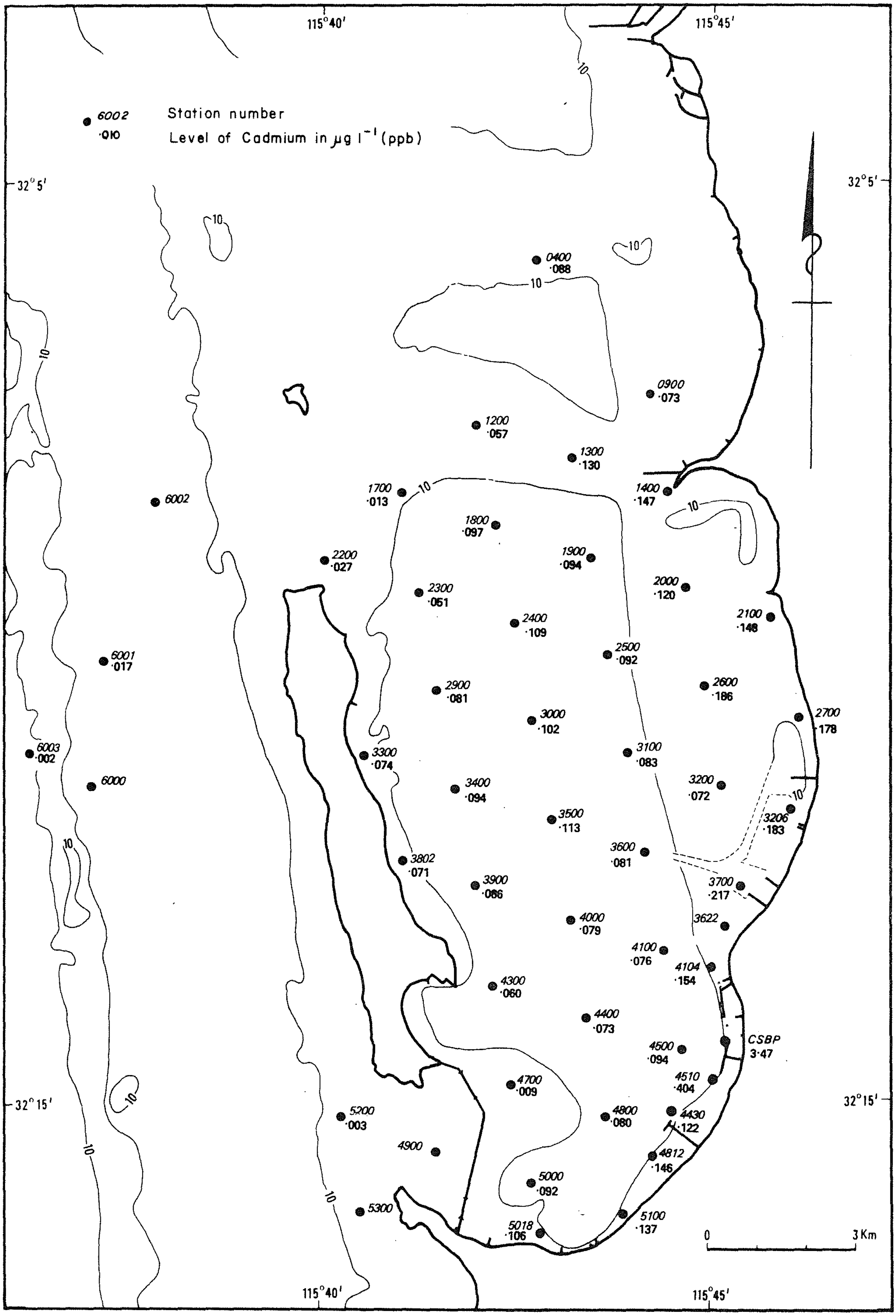


Figure 2·4

SURVEY (28 DECEMBER 1978) OF THE SURFACE WATERS OF COCKBURN SOUND FOR CADMIUM. (M.S.I.D. analysis technique)

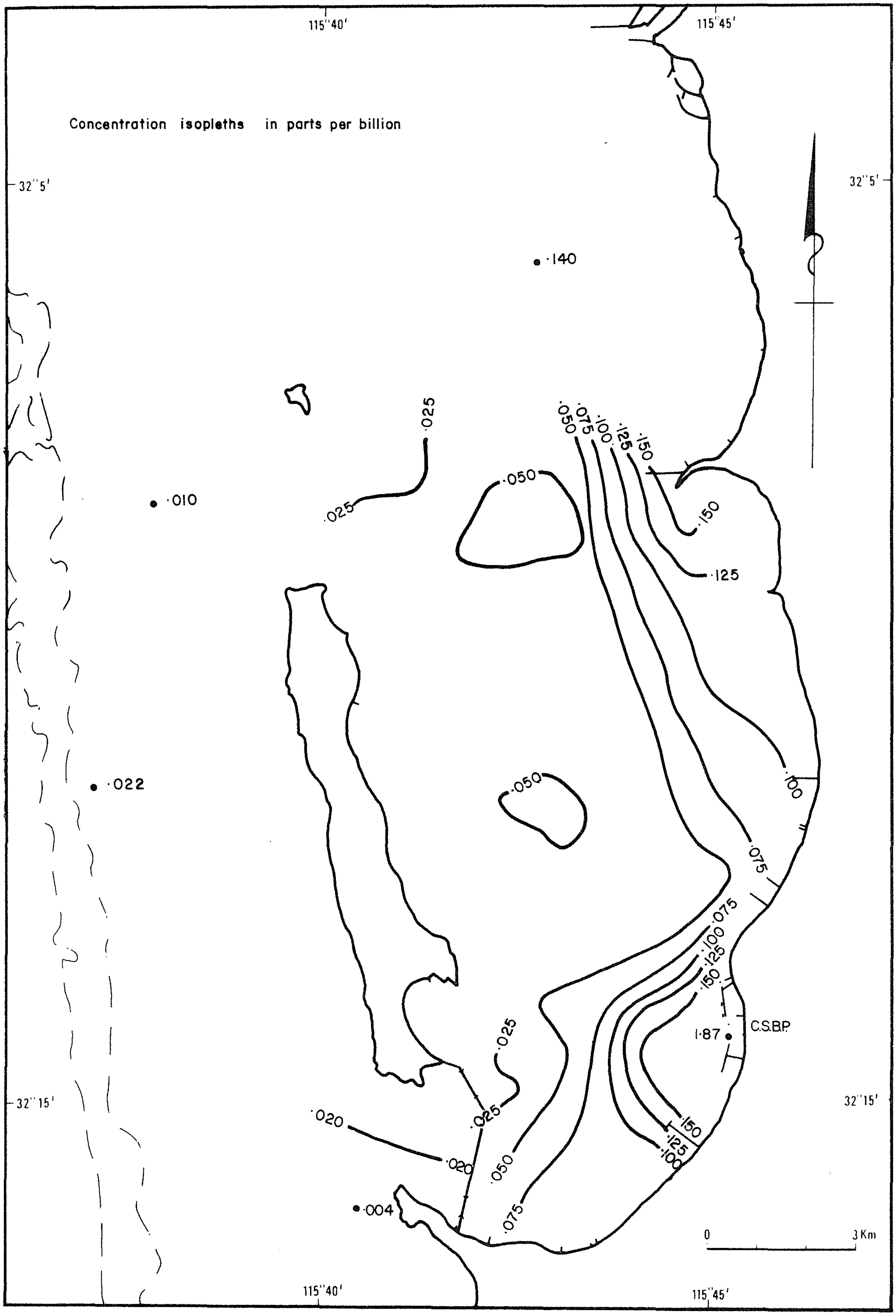


Figure 2.5

CONCENTRATION ISOPLETHS FOR CADMIUM IN COCKBURN SOUND SURFACE WATERS FOR 29 NOVEMBER 1978

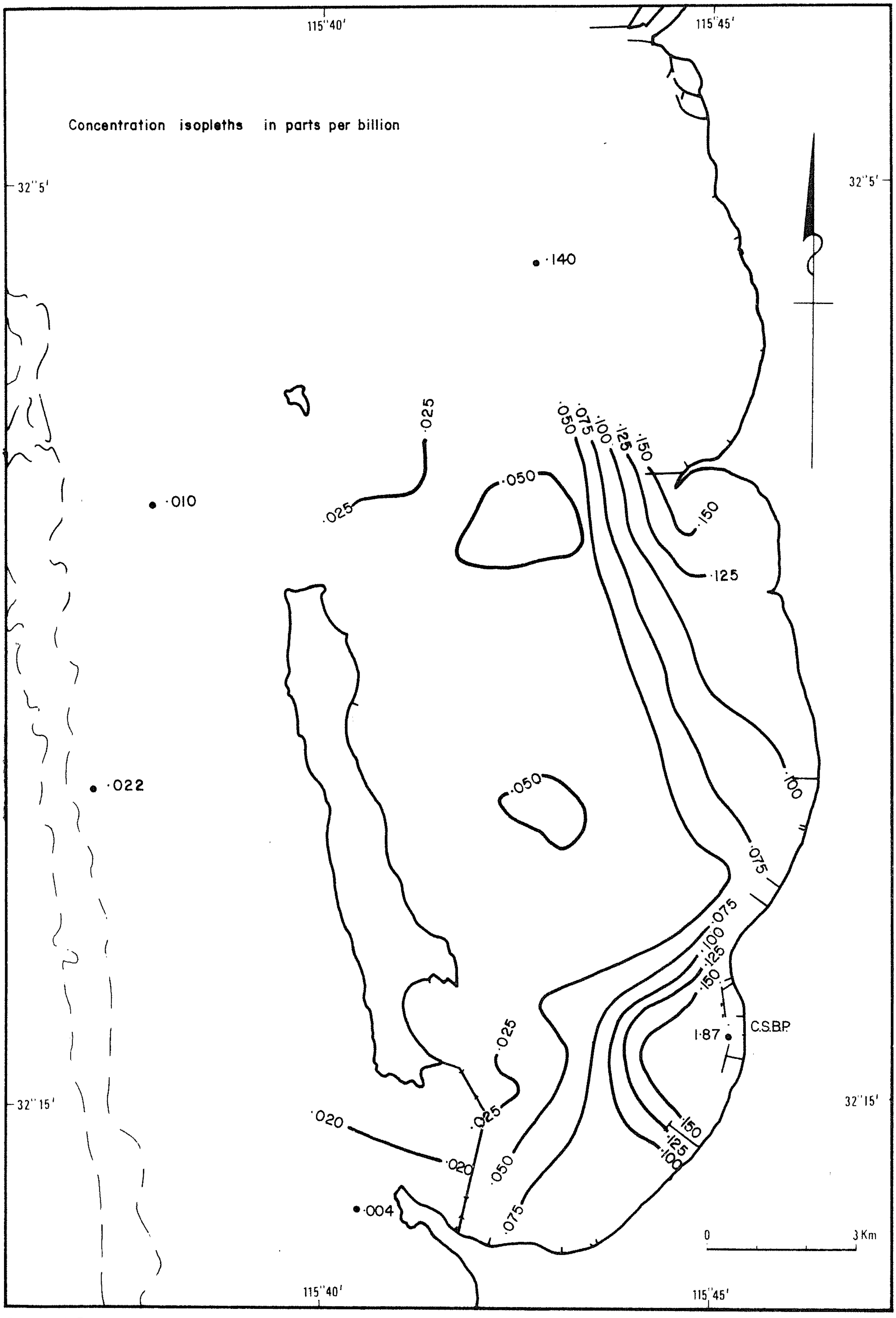


Figure 2.5

CONCENTRATION ISOPLETHS FOR CADMIUM IN COCKBURN SOUND SURFACE WATERS FOR 29 NOVEMBER 1978

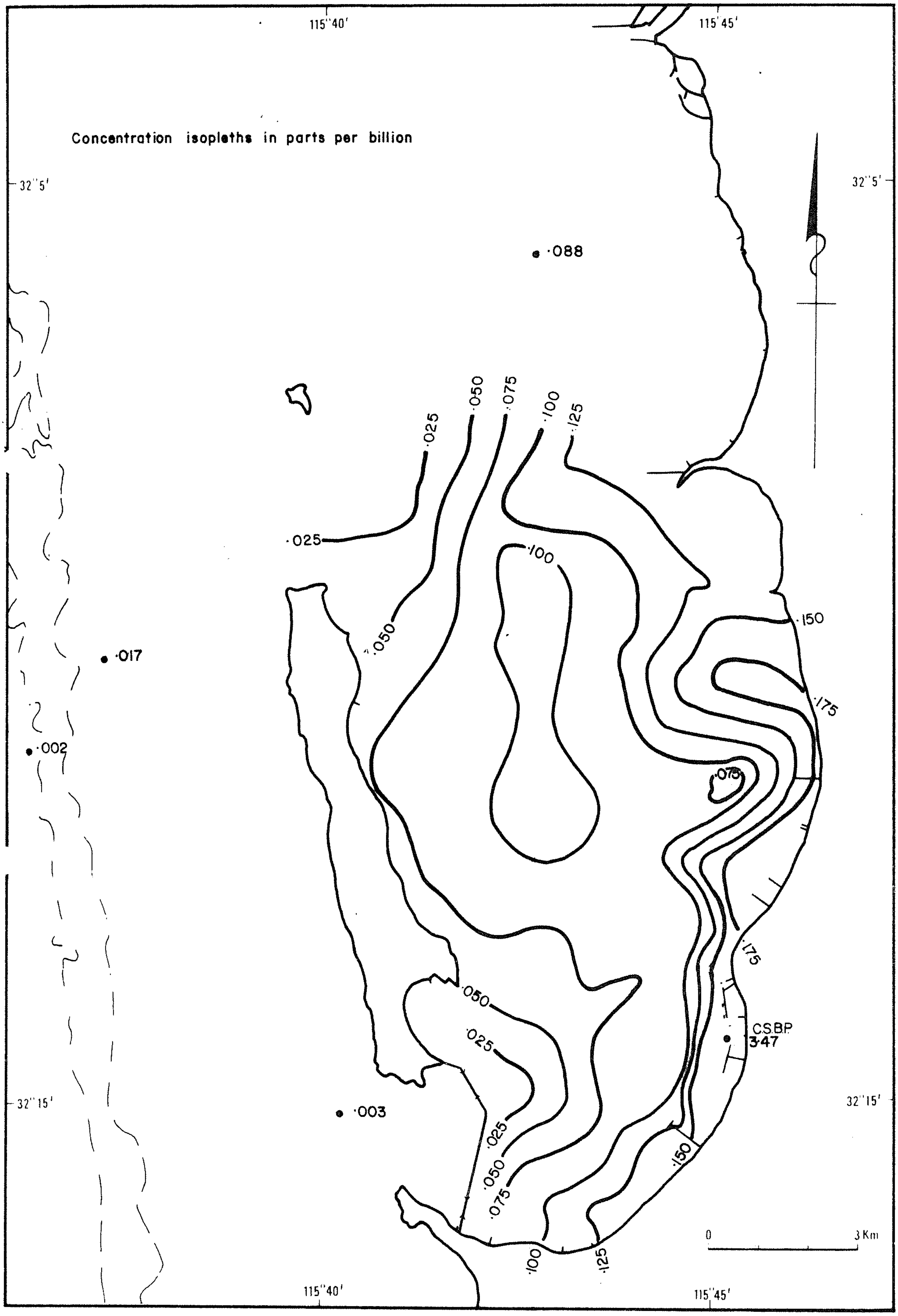
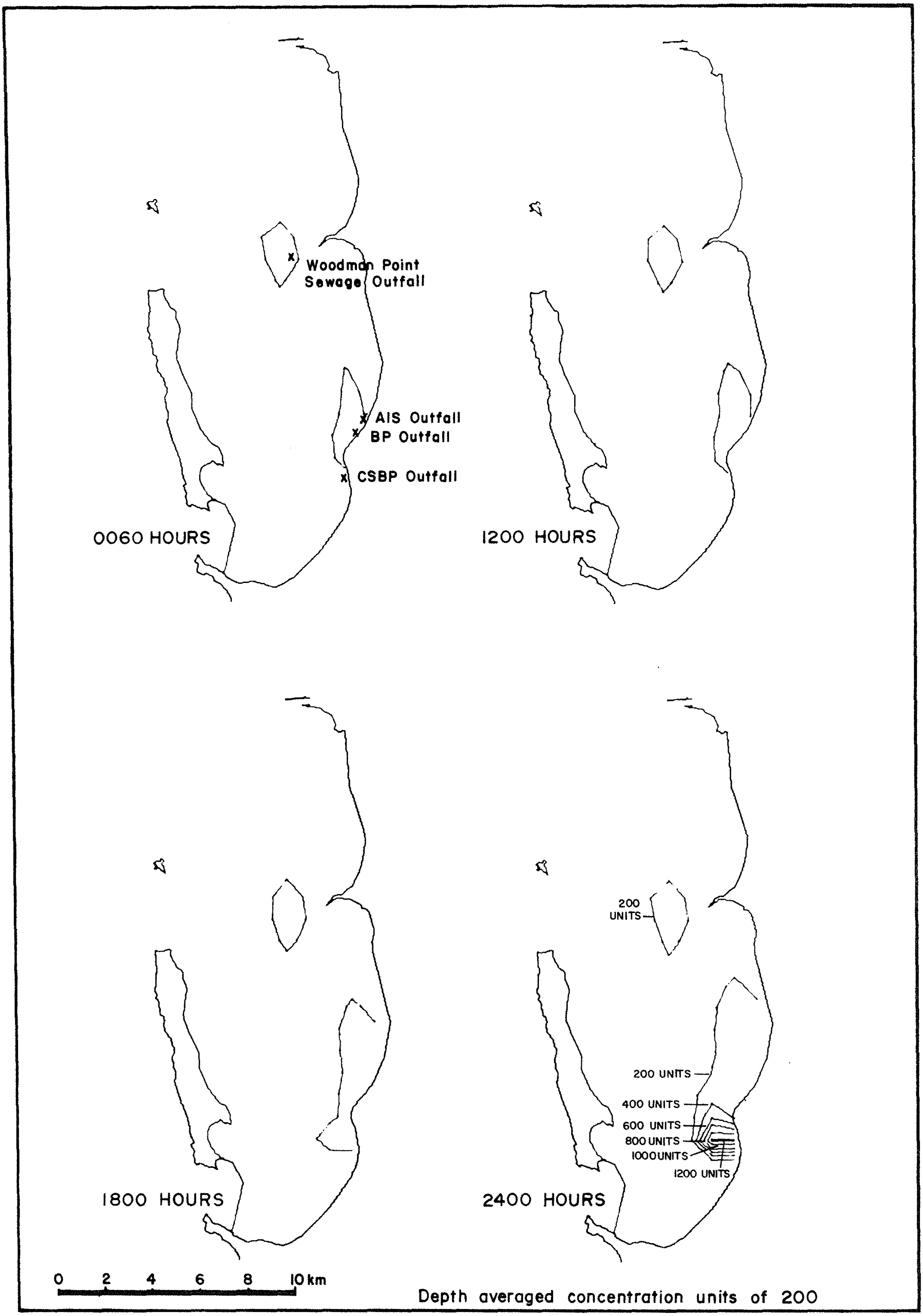


Figure 2·6

CONCENTRATION ISOPLETHS FOR CADMIUM IN COCKBURN SOUND SURFACE WATERS FOR 28 DECEMBER 1978



Depth averaged concentration units of 200

Figure 2·7 COMPUTER SIMULATIONS

CADMIUM CONCENTRATION ISOPLETHS FOR 29 NOVEMBER, 1978

Assuming material containing Cd was released from the CSBP outfall from 1700 hrs. 29 November 1978.

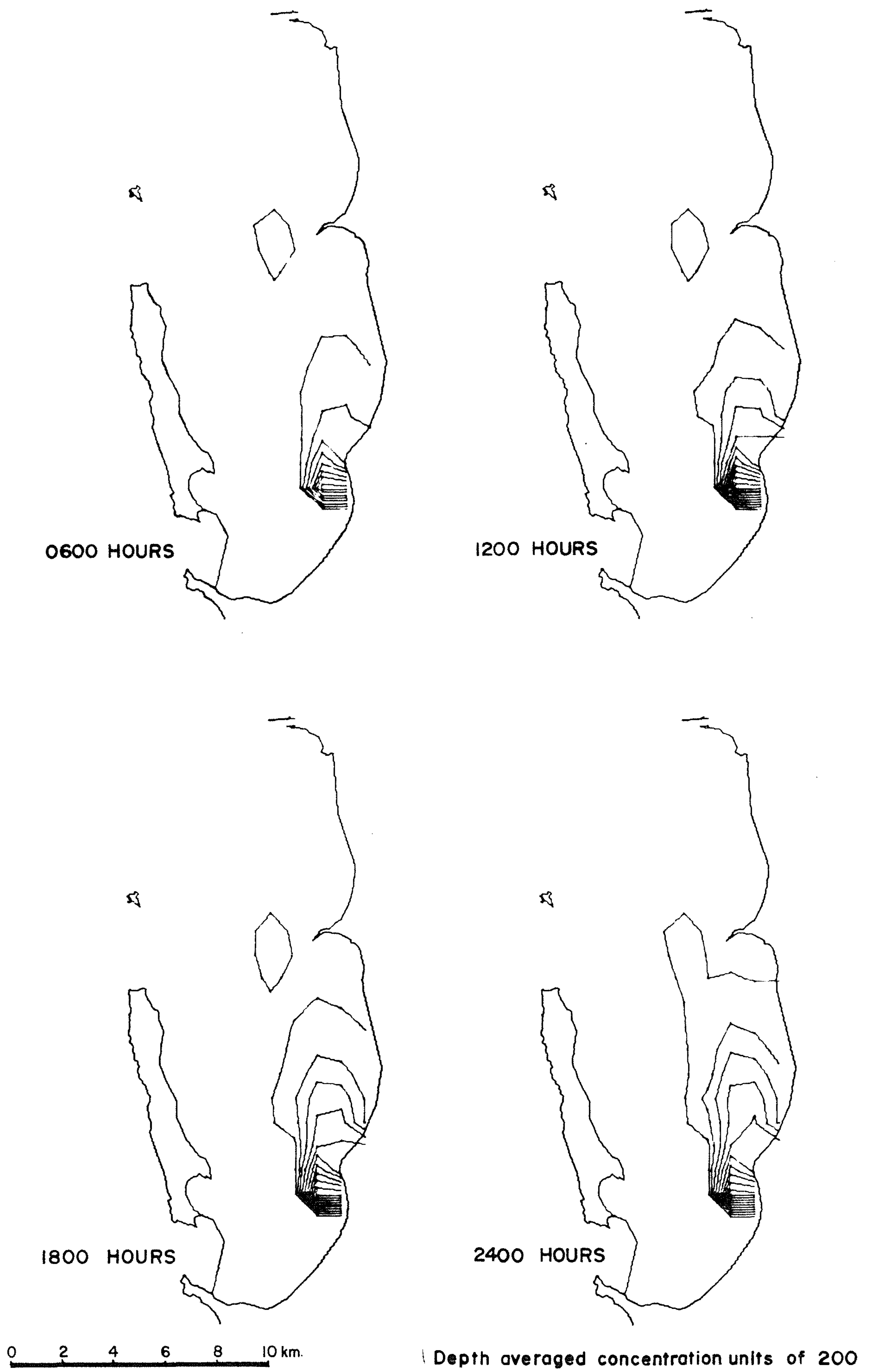


Figure 2·8 COMPUTER SIMULATIONS
CADMIUM CONCENTRATION ISOPLETHS FOR 29 NOVEMBER, 1978
Assuming material containing Cd was released from the CSBP outfall from 1700 hrs. 28 November 1978

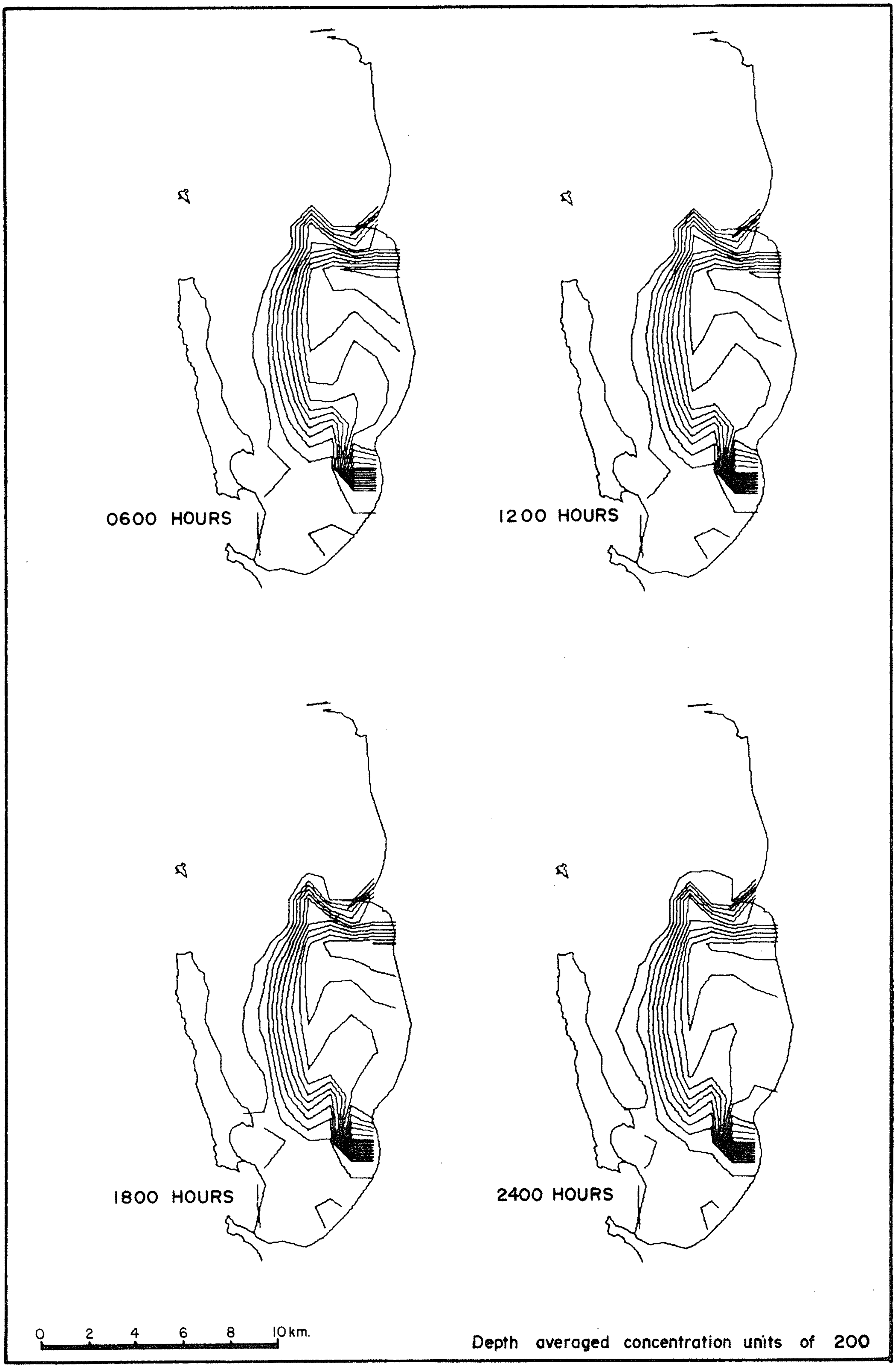


Figure 2·9 COMPUTER SIMULATIONS
CADMIUM CONCENTRATION ISOPLETHS FOR COCKBURN SOUND - 28 DEC. 1978

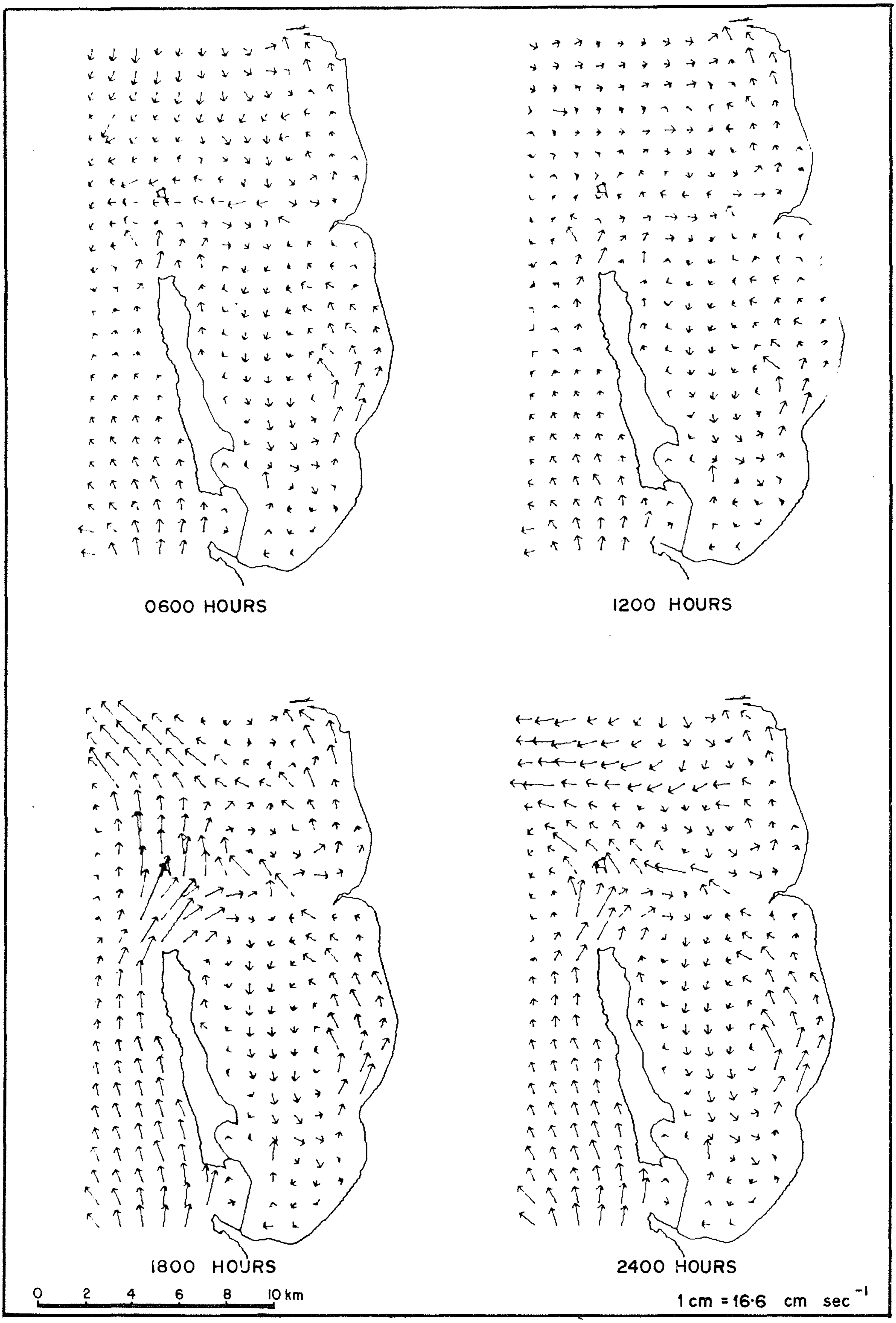


Figure 2·10

VELOCITY VECTOR DIAGRAM FOR THE WIND AND TIDAL CONDITIONS PREVAILING IN COCKBURN SOUND ON 29 NOVEMBER, 1978

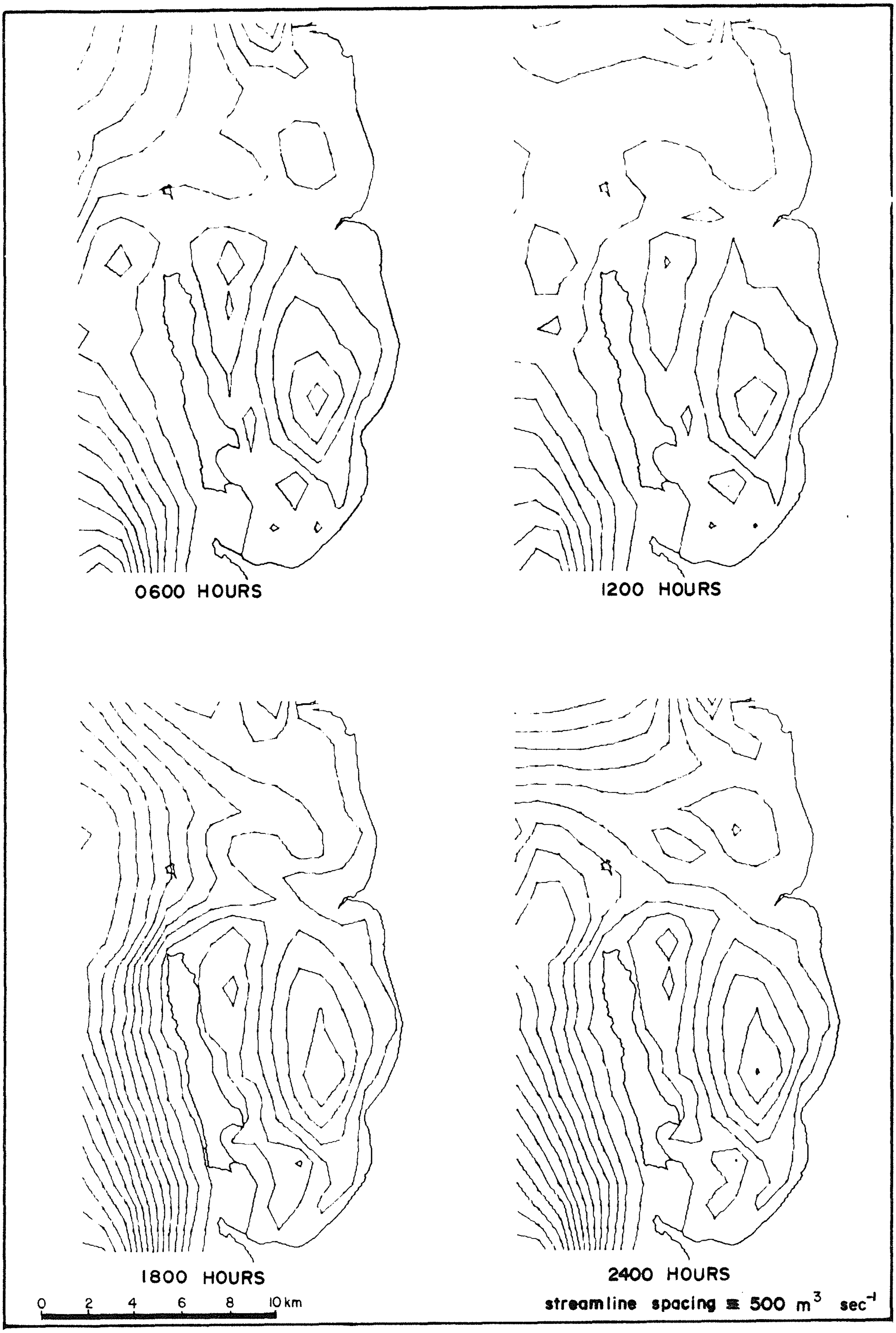


Figure 2·11

STREAMLINE PATTERNS FOR THE WIND AND TIDAL CONDITIONS PREVAILING IN COCKBURN SOUND ON 29 NOVEMBER, 1978

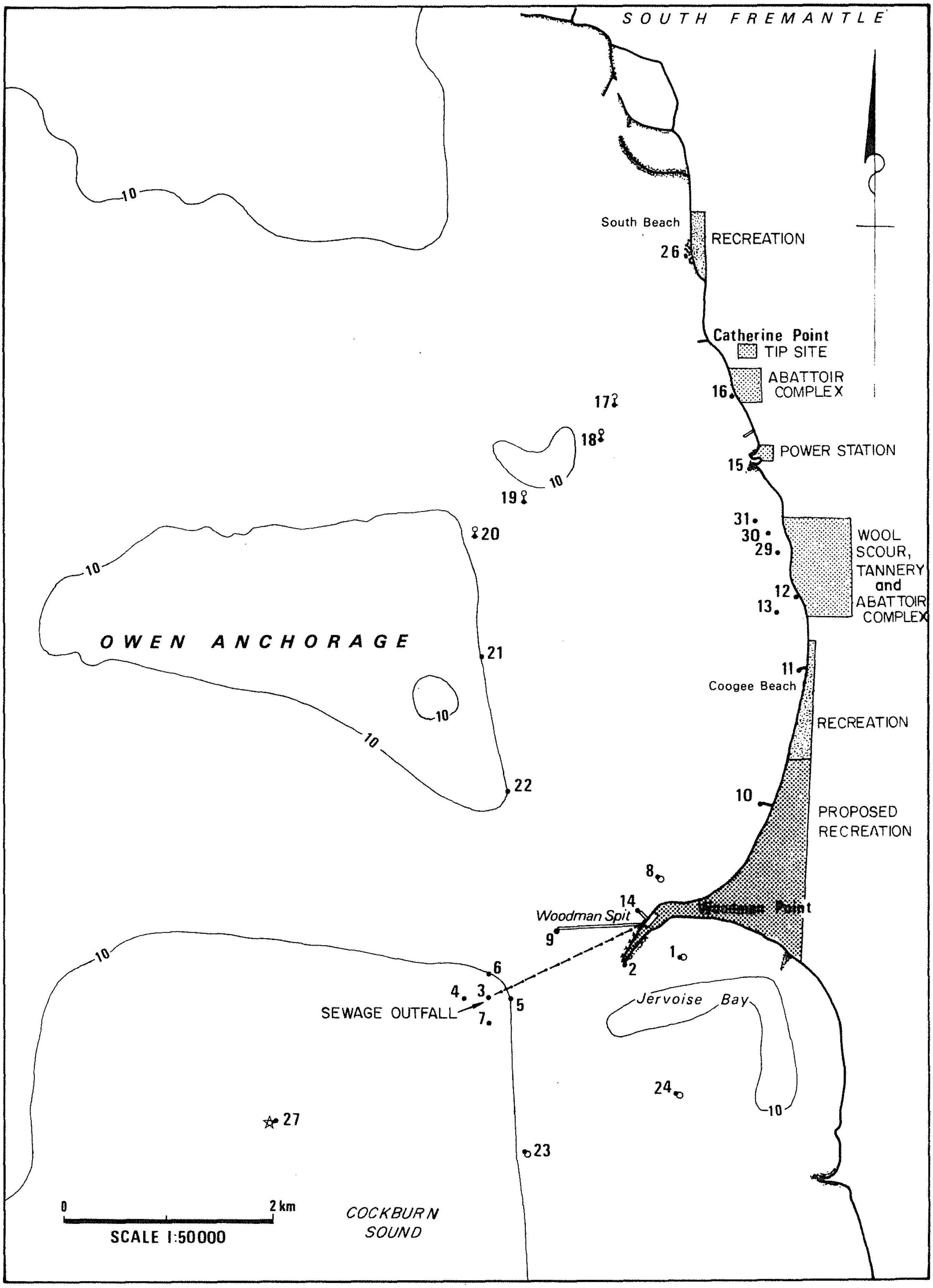


FIGURE 2·12

ENTERIC BACTERIA SAMPLING STATIONS

Station 25 is 1 km west of the map border opposite Woodman Point.
Station 28 is the Calista Channel lead beacon; 7 km south of Woodman Spit.

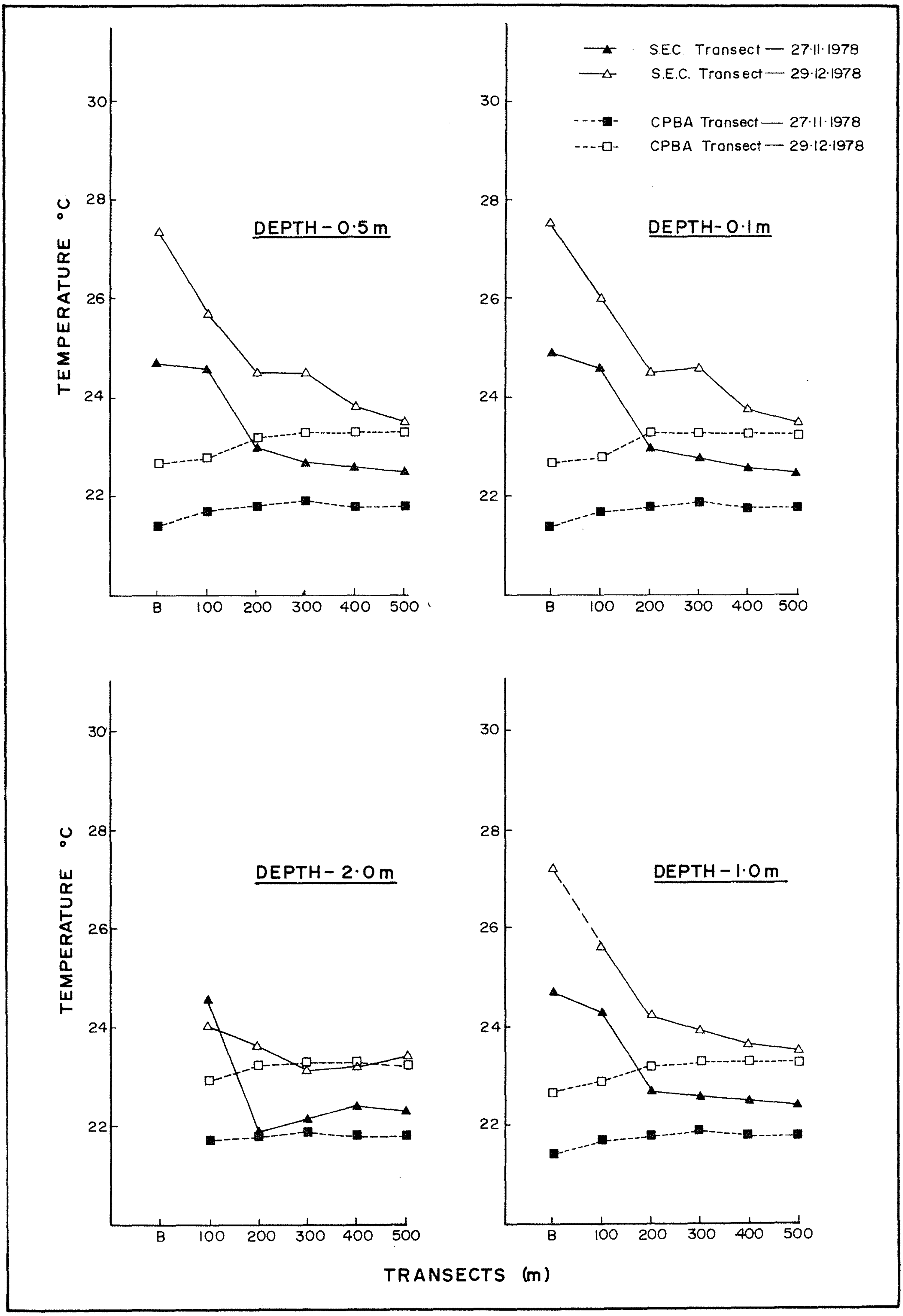


Figure 2·13

RECEIVING WATER TEMPERATURE TRANSECTS

CPBA & SEC - DUE WEST TRANSECTS – SURFACE READINGS 27·11·78, 29·12·78

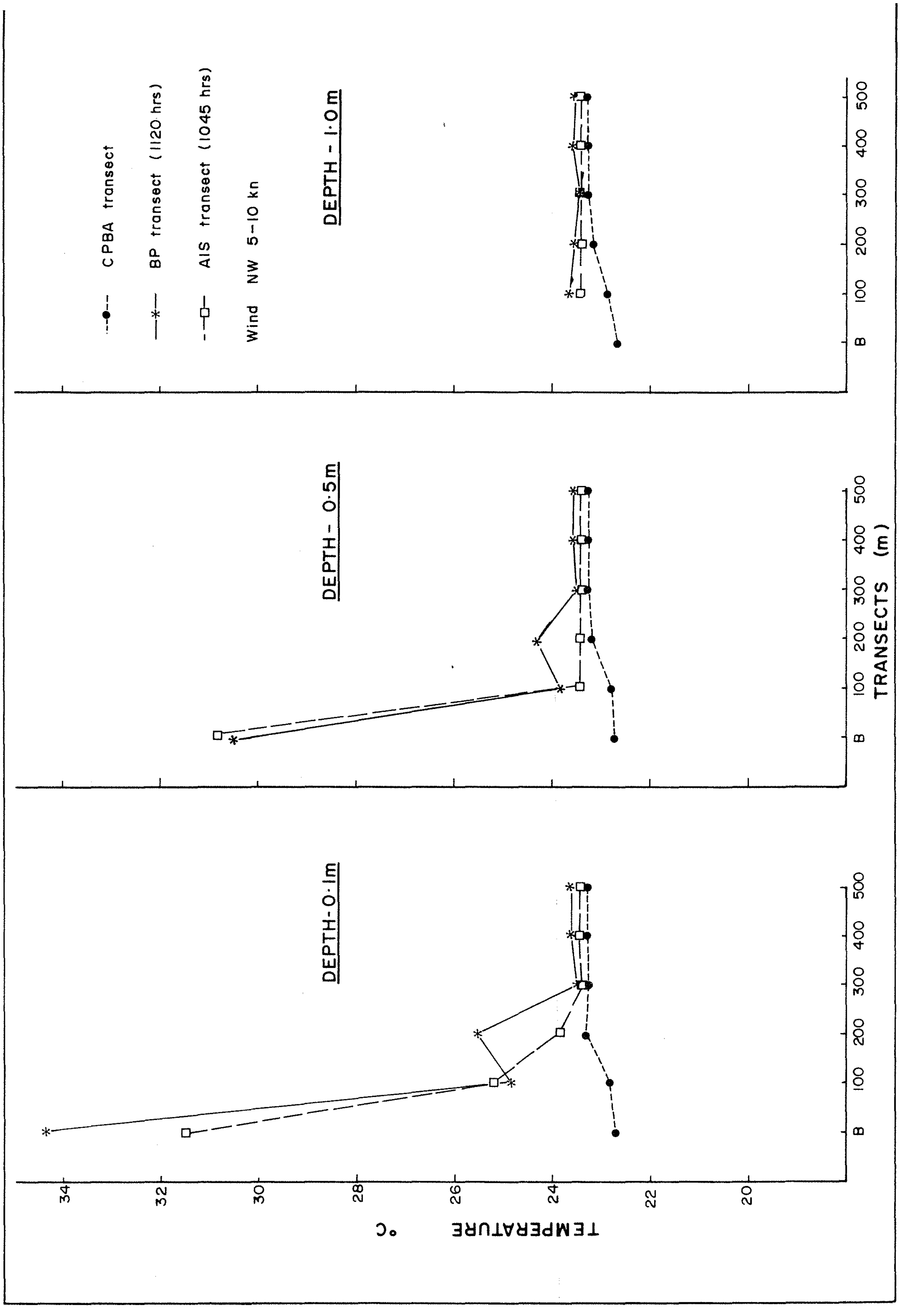


Figure 2·14

RECEIVING WATER TEMPERATURE TRANSECTS
29·12·1978 – DUE WEST TRANSECTS – SURFACE READINGS

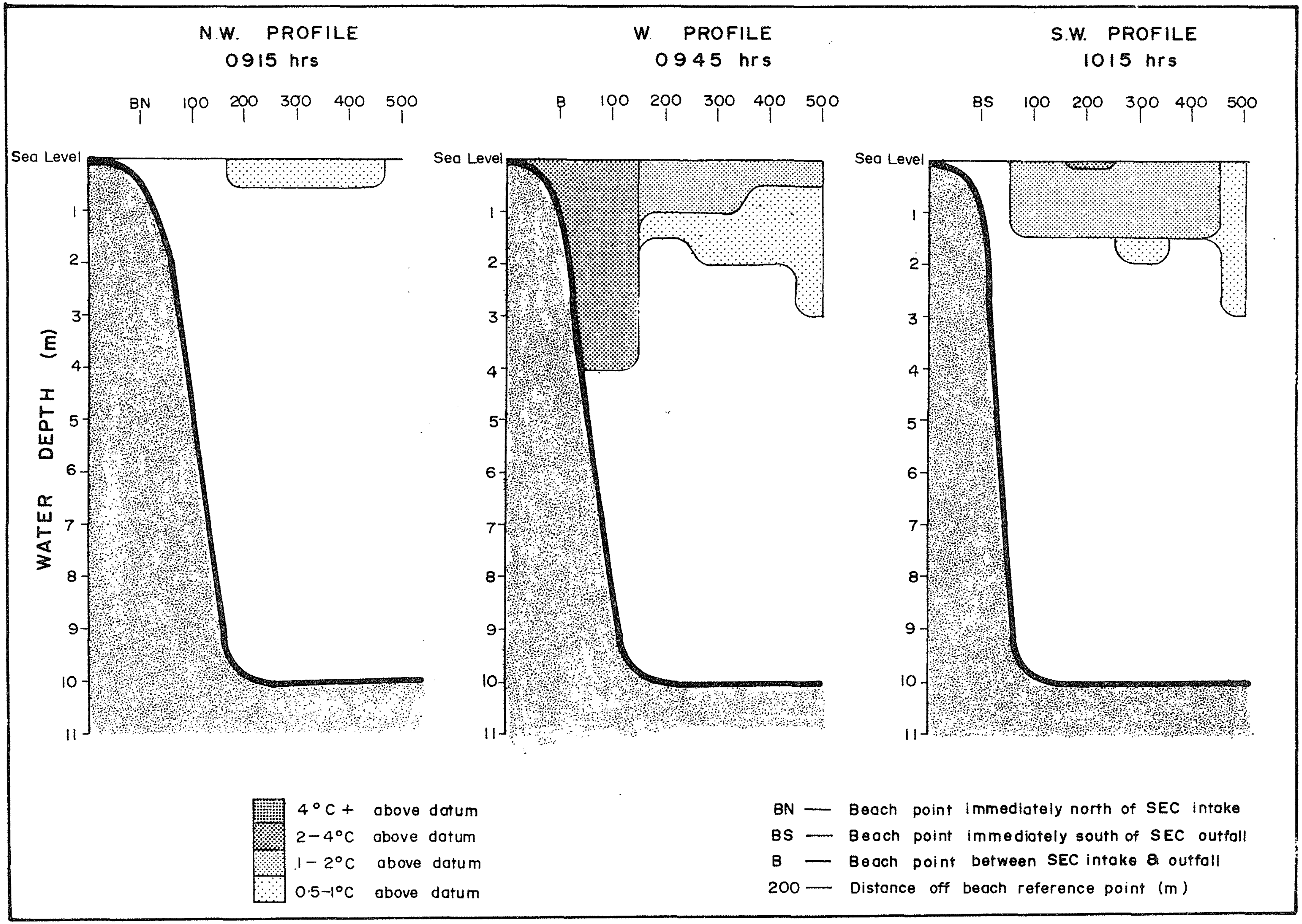


Figure 2·15

RECEIVING WATER TEMPERATURE PROFILES

SEC PROFILES 27·11·78, WIND SSW (15–20 kn)

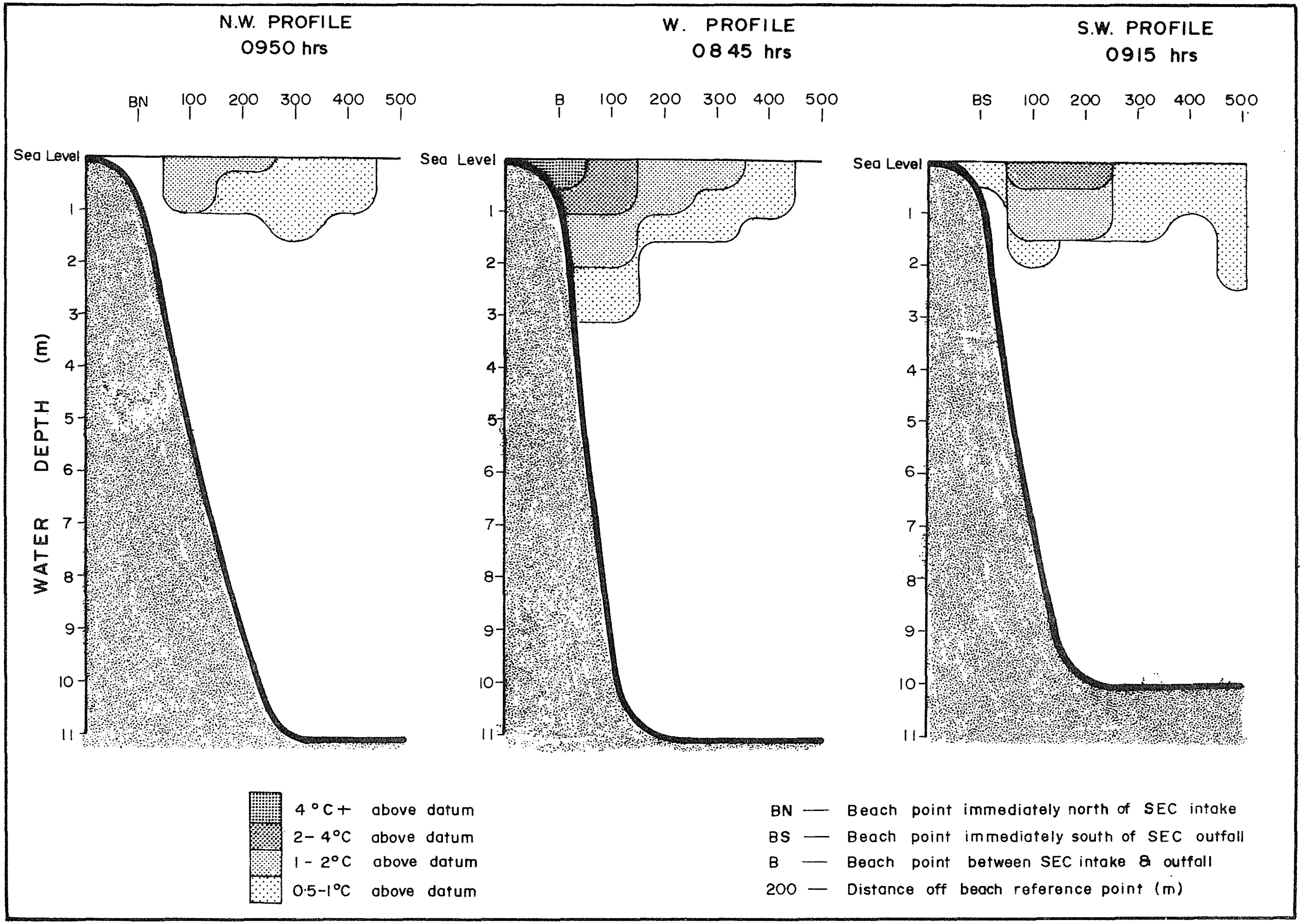


Figure 2·16

RECEIVING WATER TEMPERATURE PROFILES
SEC PROFILES 29·12·78, WIND E (5–10kn)

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3. SEDIMENTS

SUMMARY

Sediment samples were collected from a total of 87 stations. There were 75 from Cockburn Sound and six each from Owen Anchorage and Warnbro Sound. This sampling program was implemented from September to November of 1977 in an attempt to highlight the different sediment characteristics of the three sites with reference to heavy metal content, particle size, organic matter content, Eh and pH, hydrocarbon and pesticide levels.

Core samples of 32 mm diameter were collected and analysed using atomic absorption spectrophotometry (AAS), gas chromatography (GC) and anodic stripping voltammetry (ASV).

The advanced analytical techniques and different sampling philosophies of the present study have made comparison of results with those of past studies in Cockburn Sound difficult. Comparisons have been made wherever practicable. Levels of the various contaminants have also been compared with Australian and overseas data.

Sediment contamination was found to be related to point sources of effluent input. Levels of accumulation of heavy metals were localised around the James Point and Woodman Point areas and on the eastern shores of Owen Anchorage. The two major sedimentary systems within Cockburn Sound, the fringing banks and the deep basin, were clearly differentiated by particle size distribution and organic matter content. All surface sediments sampled exhibited similar Eh and pH values except for the area around the gypsum outfall where conditions were anaerobic. Hydrocarbons showed little accumulation in the sediments except for the area adjacent to the petroleum refinery at James Point. The hydrocarbon work concentrated on alkanes as an indicator of petroleum-derived hydrocarbons. Literature suggests that the aromatic fractions of petroleum are more highly toxic, more likely to accumulate and are of more concern because of their sub-lethal effects. Time did not permit aromatics in the marine environment to be investigated. Chlorinated pesticides and polychlorinated biphenyl (PCB) analysis showed no positive results in Cockburn Sound sediments, however, dieldrin was detected in Owen Anchorage sediment.

3. SEDIMENTS

3.1 Introduction

3.1.1 General

The upper 2-3 cm of coastal marine sediments are usually well oxygenated (1), and this has a direct bearing on the partitioning of mobile material between the sediments and the overlying waters (2). As a result of high oxygen availability, decomposition of organic material in these surface layers occurs through both biological and chemical oxidation. The deeper strata, however, usually exhibit oxygen depletion and organic matter is reduced largely by anaerobic bacteria. The change from oxidising to reducing conditions is often sharply defined by a decrease in redox potential (Eh), pH and oxygen concentrations, and the production of hydrogen sulphide (3), (4). Measurements of Eh and pH in sediments have shown that the pH in oxidised surface sediments may vary between 7.5 and 8.3 and in reduced sediments between 6.9 and 7.5 (1). These conditions will have a very distinct bearing on chemical transformations of the metals within the sediments (5), (6), (7), (8).

3.1.2 Processes affecting metal exchange between sediments and interfacial water

Chemical -

The levels of different metals in interstitial water vary according to the parameters mentioned above. Zinc and copper, for example, will be relatively more soluble in oxidised surface sediments. Hydrated ferric and manganese oxides are readily reduced in deeper sediments to the more soluble ferrous and manganous forms. As a result, both iron and manganese are commonly found as higher concentrations in deeper interstitial waters.

If low levels of oxygen exist in the waters overlying sediments reducing conditions can also be found in surface sediments. As a result other metals adsorbed or co-precipitated with iron and manganese will go into solution with them. The mechanism of the formation of complex compounds may depress release of metals such as zinc and copper from normal well-oxygenated surface sediments. It is worth noting that once in solution most metals can be stabilised by complexing with inorganic and organic bases.

The concentrations of metals in the interstitial water are usually higher than in interfacial water. Migration of metal ions from sediments was considered the cause of relatively high levels of zinc and manganese in interfacial waters found by Presley et al. (9). Lu and Chen (10) studied the migration of trace metals between the interface of polluted surficial sediments and seawaters in different underlying sediments and seawater redox conditions. They concluded that redox potential was the principal agent regulating metal migration. Their findings for a range of metals are summarised in Table 3.1.

Physical -

Surface sediments and interfacial waters may be enriched by diffusion of interstitial water along temperature and/or pressure gradients from the deeper layers. Seasonal changes in the temperature of overlying waters may precede that of sediment by up to a month (11). This may introduce buoyancy effects overriding small temperature gradients within sediments. Elderfield and Hepworth (12) maintain that in the long-term surface sediments may be enriched during diagenesis.

3.1.2 (Cont'd)

Interstitial water may also be released through sediment resuspension by hydro-dynamic effects such as wind-induced currents, shipping activity and dredging operations.

Biological -

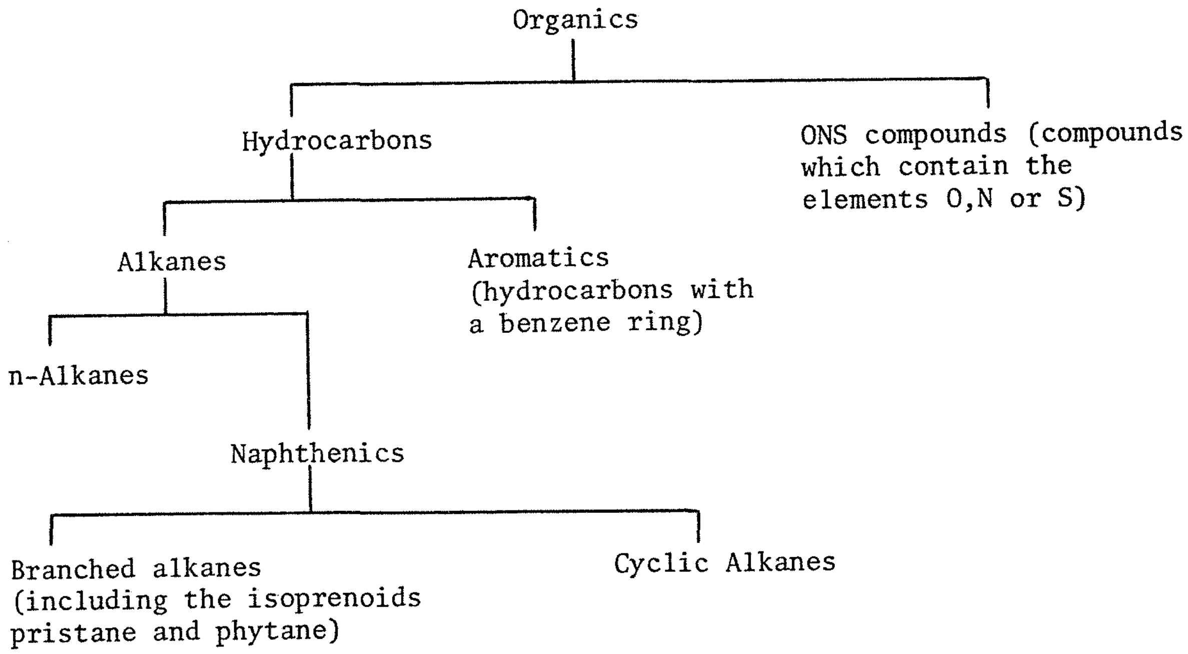
Benthic biota contribute to the cycling of metals in a variety of ways. Burrowing fauna such as crabs disturb surface sediment layers while polychaetes such as the deposit feeder *Chymenella torquata* and the filter feeder, *Chaetopterus variopedatus*, which is found in Cockburn Sound, may affect sediments to a significant depth. *C. torquata* exerts an influence to a depth of 30 cm (13). This would serve to mix sediments physically and oxygenate sub-surface layers.

Micro organisms involved in both aerobic and anaerobic processes, produce gases which may aid transport of interstitial water to the surficial sediments during upward diffusion. They also play an important role in both mobilising and binding metals during metabolism and altering their availability by processes such as methylation (14).

3.1.3 Hydrocarbons in sediments

Nomenclature -

A variety of nomenclature systems are used by analytical chemists, petroleum technologists and geochemists to describe the different types of compounds found in petroleum. The following system was used by Alexander *et al* (15) who did the hydrocarbon analysis for this report.



The origin of hydrocarbons - biogenic or non-biogenic -

Hydrocarbons of recent biological origin occur in many organisms and in most recent sediments. One of the most frequently used criteria for identification of this type of hydrocarbon is the predominance of n-alkanes with an odd number of carbon atoms over those with an even number of carbon atoms (16). In petroleum the predominance of this type of n-alkanes is less significant due to diagenetic processes which lead to randomisation of the chain length. As a consequence, except for very immature oils, most petroleum samples show no odd-carbon preference (17).

3.1.3 (Cont'd)

Processes altering crude oil in aquatic environments -

Weathering is the term most frequently used which collectively describes the many individual and mutually competitive processes by which crude oil is degraded. Some of the processes which contribute to weathering of crude oil are:-

- Evaporation
- Solubility
- Chemical degradation
- Photochemical degradation
- Microbiological degradation

In one particular study (18) six months after an oil spill little oil degradation was apparent. Ten months after, however, the effects of microbiological degradation were becoming evident in the depletion of n-alkanes. After two years, n-alkanes had disappeared, but some isoprenoids were still evident, and the aromatic and saturated ring structures were relatively unchanged.

Scope of the work undertaken -

The principle objective of this study's hydrocarbon work was to establish the extent of contamination of Cockburn Sound by petroleum - derived organics. A major difficulty with such an investigation is that organic extracts from sediments and from biota contain very complex mixtures of a wide variety of compound types which are intractable to analysis. Therefore, attention was focused on the medium to high molecular weight alkane fraction of the extracts. This greatly simplified the analytical problems, and as the alkanes from petroleum and from sediments and biota are characteristic and hence are readily distinguishable, and broad levels of petroleum derived material in the Sound were determined. On the other hand, it is widely recognised that other chemical types, for example, low molecular weight alkanes, aromatic hydrocarbons and phenols, are very toxic to biota. The use of alkanes as representatives of total petroleum - derived organics, therefore, had its limitations.

3.1.4 Literature review of past studies in Cockburn Sound

General -

After reviewing earlier work on Cockburn Sound it was felt that due to a lack of precise information on sampling locations and an absence of any details of analysis most of the information available was inadequate as a base for detailed investigations. Consequently very little of the information on the Sound gathered until 1977 has been used. A comparison of successive sets of data from different projects are given in Tables 3.2. and 3.3. The sediment samples in these tables are probably the only samples taken from comparable areas over about seven years of investigations. This illustrates the need for coordination by a single body in marine studies such as these.

Accumulation of heavy metals -

Since 1970 a series of six surveys attempted to trace heavy metal distribution in Cockburn Sound deep basin sediments. Five studies were carried out to 1973 by a consultant for the Fremantle Port Authority (FPA) (19), (20), (21), (22), (23), and the most recent was

3.1.4 (Cont'd)

conducted by the Estuarine and Marine Advisory Committee (EMAC) for the Environmental Protection Authority in November 1974 (60). Trends in heavy metal distribution that were identified during these studies initiated more intensive investigations of sediments adjacent to the Kwinana industrial areas. The results of these and previous studies have been reviewed by EMAC (24) and W.D. Scott (25). Both these reviews and the earlier reports found difficulty in relating results from one survey to another. In cases where apparently similar sampling locations, techniques and analytical methods invited comparison, irregular variations in heavy metal concentrations were apparent. These variations are illustrated in Tables 3.2 and 3.3.

Whereas in some cases results may be well within the same order of magnitude, clearly attempts to relate them in an historic sense are dangerous. It is worth looking at the reasons for these variations as it should be possible to greatly improve the comparability of separate studies.

- Advances in the sensitivity of atomic absorption spectrophotometry have produced a marked lowering of detection limits over the last five to six years. This has been the major technique used throughout the previous surveys. Analytical methods generally have not been outlined in detail although techniques have apparently reached the extreme of geochemical digestion. No comparison with national or international standards has been presented.

- Species diversity and abundance of benthic biota vary throughout Cockburn Sound as does the ability of these organisms to disturb surface layers which may well introduce local variation in heavy metal concentrations. Against these, perspective errors involved in sampling techniques and station position fixing are very large. In the 1973 studies of Environmental Resources of Australia Pty. Ltd. (ERA) the sample depth was based on a straightforward calculation of the amount of sediment deposited since the Kwinana industrial development commenced. A depth of 2 cm was interpreted as representing 30 to 50 years of sedimentation (19). In 1974 the EMAC utilised a benthic grab sampler which took sediment to a depth of 5 to 8 cm. Data from two comparable cores was not sufficient to define the effects of bioturbation on metal distribution.

Distribution of heavy metals -

The earlier surveys of surface sediments conducted for the Fremantle Port Authority showed consistent increases in cadmium, chromium, zinc, manganese, iron and to a lesser extent, copper over localised areas of Cockburn Sound. Any finer assessment of these early results was limited by the relatively small number of sampling stations as well as lack of confidence in chemical analysis.

The 1974 study of surface sediments was carried out by EMAC (60). Thirty six stations were sampled in the deep basin of Cockburn Sound. Statistical analysis showed significantly higher concentrations of cadmium, copper, lead, nickel, zinc and vanadium in the southern half and eastern margin of the basin. Arsenic, iron and chromium were higher in the southern half of Cockburn Sound. More stations were sampled in the southern section of Cockburn Sound.

3.1.4 (Cont'd)

Specific studies of nearshore sediments have been largely centred around the gypsum outfall south of James Point. Results of these studies will be discussed in the next section of this review. The only other study was carried out in the James Point area in May 1973 (22). Surface sediment data was considered to indicate differential distribution of such metals as copper, zinc, chromium, manganese and iron according to the source of contaminant and hydrological factors.

Gypsum outfall surveys -

The sediments in the area of the gypsum outfall have attracted attention since it became evident that the rock phosphate used in the production of phosphoric acid by CSBP and Farmers Pty. Ltd. contained high concentrations of metals such as cadmium and mercury.

Heavy metal analysis of the plant's rock phosphate has continued to show similar levels to those reviewed by W.D. Scott (60). In particular the concentration of mercury (about 0.4 $\mu g\ g^{-1}$) and cadmium (50 to 60 $\mu g\ g^{-1}$) in the rock phosphate drew attention to the potential hazard of discharged effluent.

In 1972 detailed mercury analyses of the gypsum mound, which had formed around the outfall, were carried out. Surface (0-1 cm) mercury values ranged from 0.16 to 4.8 $\mu g\ g^{-1}$ dry weight and the average cadmium from one station was 104 $\mu g\ g^{-1}$ (20).

Later studies for the Environmental Protection Authority in July and August, 1974 showed a reduction of around 50 per cent in their ranges of mercury and cadmium values (60). Ranges are quoted in an attempt to compensate for difficulty in definition of sampling sites. It should be noted that "surface" sampling in these 1974 studies represents on average the top 50 cm of deeper core samples. Three sediment samples from the July study showing mercury concentrations of 1.6 to 2.3 $\mu g\ g^{-1}$ were also analysed for the methyl form but none was found to a reported detection limit of 0.1 $\mu g\ g^{-1}$ on a dry basis. Arsenic levels were recorded at between <1 to 9 $\mu g\ g^{-1}$ in both July and August but results were not consistent.

Tests were carried out to determine resolution of metals from sediments after shaking in seawater for 24 h (26). Arsenic results were again inconsistent and lead analysis was not sufficiently sensitive. Both the cadmium and mercury results were interpreted as indicating the metals were in a seawater insoluble form. The gypsum mound was dredged in December 1974 and again in 1977 before August when the company constructed a larger disposal pipe with twin nozzles in an attempt to achieve greater gypsum dissolution and dispersion.

Particle size studies -

In the ERA sediment particle size studies of September 1971 (19), all the sampling stations were situated in the deep basin of Cockburn Sound. Stations I and H of this Study would correspond closely to Stations 2400 and 3000 of the present study.

A sediment grab sampler was used for the benthic fauna survey of ERA and a sample for analysis of particle size was taken from this - it represents a grab to a depth of around 8 to 10 cm.

The results were consistent with those of the present Study although they were not strictly comparable due to mesh size difference.

3.2 Experimental Methods

3.2.1 Sediment sampling grid design

The sampling grid was based on a 2 km pattern which provided a coverage of Cockburn Sound and Owen Anchorage, and the basis for further subdivision to 500 m intervals in areas around effluent discharge points.

The 2 km sampling grid design was such that there was a similar number of stations in shallow (17 in < 10 m) and in deep water (19 in > 10 m). In Owen Anchorage and Warnbro Sound the twelve stations were evenly divided into deep and shallow areas.

The latitude and longitude readings for each station are listed in the Cockburn Sound Study Data Repository.

The stations of the sediment grid are demonstrated in Figure 3.2. Figures 3.4 and 3.5 include the subdivided 2 km grid stations around the discharge points.

3.2.2 Choice of sampling and analytical procedures

A consistent and reliable method was needed for sediment sampling and to this end three techniques were tried, namely a Rigosha grab, hand and core sampling.

The three methods were used simultaneously at two sites in Cockburn Sound with the site selection being based on the different sediment characteristics of the two areas. The areas chosen were in the vicinity of stations 1400 and 1800. Physical and chemical parameters were measured.

The top 2 cm of sediment was chosen as the stratum for comparison and samples were taken as close as possible to the 2 cm depth. Hand samples were collected with a scoop designed to take only the top 2 cm of sediment and the core samples were separated into the top 0-2 cm and subsequent 5 cm layers.

Each sample was dried at 100-105°C for 16-20 h and sieved through a 1 500 μ nylon mesh to remove the larger shell fragments. The sample was then sieved through a 1 000 μ, 475 μ, and a 150 μ mesh sieve and the results recorded in Table 3.4. The results show a consistently lower percentage of finer material in the grab samples which is compatible with the observation that a cloud of fine material was lost through the base of the grab during retrieval.

The hydrochloric/nitric acid digestion procedure of Anderson (1974) (27), and adaptation of the method of Bloom and Ayling (28) was the most practical approach for digestion of Cockburn Sound sediments. The 0-2 cm sediments were analysed in duplicate by the Study Group, and a commercial laboratory. The results in Table 3.5 indicate that there were no practical differences in metal concentrations between the samples from grab, hand and core techniques. Representative results for zinc and manganese are given in this table.

An analysis of various sieve fractions was performed to check for any difference in heavy metal concentration associated with particle size (29), (30). The results of these analyses for copper, manganese and zinc, are given in Table 3.6. There was little difference between the fractions below 475 μ.

3.2.2 (Cont'd)

The results for total zinc and manganese in these tests differ significantly from those of the sampling carried out a month later in September (see stations 1400 and 1800 in Table 3.7). This difference has been attributed to a more precise sample station location and possibly some seasonal variation in the sediments.

Since it was likely that the two samples involved in the tests were indicative of coarse and fine sediment types in Cockburn Sound and the fraction of sediments greater than 475 µ would be less than 20 per cent, then it was decided to treat the sediments below 1 500 µ in size as total samples. The size fraction above 475 µ appeared to contribute a small amount of dilution to the overall results.

The procedure chosen was core sampling, exclusion of material greater in size than 1 500 µ followed by hydrochloric/nitric acid digestion.

The results of subsequent analyses (Table 3.12) indicate that the appropriate choice was made for the sampling and analytical methods. However, the results of metals for true bank stations may be low because of dilution due to a higher proportion of fractions greater than 475 µ in these areas.

3.2.3 Sediment analysis

Core samples were collected by divers from the stations located on Figure 3.1. Station sites were located using line coordinates, sextant angles and if necessary compass bearings.

The core samples were taken in clear polycarbonate tubing 500 mm long with 32 mm internal diameter and 38 mm external diameter. The tubing was worked into the sediment, capped and removed. Sediment strata could be seen in each core.

Triplicate cores were taken at each station and the individual sediments were removed and sectioned into strata at 0-2, 2-7, 7-12, 12-17 cm depths. The triplicate samples were treated individually and the results expressed as a mean value. Depth strata were analysed for heavy metals, particle size, Ca as $CaCO_3$, organic matter, Eh, pH, hydrocarbon and pesticide levels to assess accumulation in the upper strata compared to the lower strata.

A diver's description of the appearance of the seabed area where the cores were taken, and the visual assessment of colour, apparent particle size, and presence of shell, seagrass debris and biota are detailed for each station in the Cockburn Sound Study Data Repository.

The sediment core samples were then subjected to the procedure set out in Figure 3.1.

For the analysis of heavy metals (except mercury and arsenic) the samples from all depth strata were dried at 100-105°C for 16 h and digested according to the method of Anderson (27) which is a HCl/HNO_3 digestion procedure. The results of the triplicate samples are reported as a mean value, for each sediment station. Where a wide discrepancy existed between triplicates repeat cores were collected and analysed to determine the mean.

Analysis of each sample for metals was carried out using a Perkin-Elmer 503 Atomic Absorption Spectrophotometer and air-acetylene flame, with deuterium lamp background corrections applied in the case of cadmium, lead, cobalt and nickel.

3.2.3 (Cont'd)
The depth strata results were used to assess concentrations versus depth profiles to gauge the degree of accumulation of trace metals in the sediments.

Particle size was determined to provide a guide to the percentage differences of the sieved fractions between different sample stations. The dried samples were sieved through nylon screens of 1 500, 1 000, 475 and 150 μ mesh size. The samples were not ground prior to sieving, but the finer deep basin sediments, which tended to dry into a lump were gently broken up. The lack of grinding has tended to underestimate the fine particles (i.e. less than 150 μ) in these samples but the percentage of this fraction compared to the other areas of the Sound was still significantly higher.

Organic carbon was determined by the dichromate oxidation method of Walkley (31), and the organic matter calculated according to Metson (32). The loss on ignition was determined after drying and ashing in a muffle furnace.

The Eh and pH (redox potential) parameters were measured on the samples as soon as they were collected. Both measurements were made with a portable Schott meter equipped with a polycarbonate combination glass/calomel pH electrode, and a platinum/glass combination redox probe (Pt 62). Zo Bell's solution was used as a reference solution in Eh measurements.

For mercury analysis sediment samples were collected and frozen immediately. The mercury was determined on selected sediments using flameless atomic absorption and AOAC method 25.103-25.105 modification 25.VOI-25.COZ.

For the analysis of hydrocarbons, chlorinated pesticides, and polychlorinated biphenyls (PCB's), samples were collected and frozen or extracted immediately for subsequent gas chromatograph separation (Figure 3.6). Hydrocarbons were assessed by an adaption of the method of Burns and Smith (1977) (33). Chlorinated pesticides were determined by A.P.H.A. method 509 (Standard Methods for Water and Wastewater) (34). Samples were screened for PCB's using the method specified by Environmental Sanitation Division of the Ministry of Health and Welfare of Japan (35).

Arsenic was determined on selected core samples. Samples from the vicinity of the gypsum outfall were examined from the 0-2 cm and the 2-7 cm layers. The analytical technique used was an adaptation of the arsine evolution method originally proposed by Vasak and Sedivec (36), (37).

Figures 3.2 to 3.10 indicate the numbers and positions of sampling stations that were involved in the sediment analysis section.

Sediments were also checked for their ability to release heavy metals under conditions simulating periods of storm, dredging or shipping activity.

Details of the measurement of the parameters mentioned are kept in the Cockburn Sound Study Data Repositiory; "Details of Analytical Procedures".

The Cockburn Sound Study Group instituted a sampling programme for radionuclides in surface layer sediments (and mussels) from HMAS Stirling on Garden Island. See Chapter 4 for details.

3.3 Results

3.3.1 Heavy metals in sediments

Surface sediments (0-2 cm) in Cockburn Sound -

Concentrations of heavy metals in the surface sediments (0-2 cm) for all stations in Cockburn Sound and adjacent areas are given in Table 3.7.

Stations on the 2 km grid (i.e. all sampling stations numbered between 0100 and 5300 and ending in 00, Figure 3.2) were assessed for significant heavy metal accumulation. If the value for an element at a station exceeded the figure for the mean value (all stations on 2 km grid) plus twice the standard deviation then that element was regarded as elevated. This assumes that observations from 36 stations taken uniformly across the Sound are from a Normal Distribution. The probability that an observation in this type of distribution exceeds the mean plus twice the standard deviation is approximately 2.5 per cent (a one tail t-test with 35 degrees of freedom) (pers. comm. Norman Hall, Western Australian Marine Research Laboratories). Means plus two standard deviations for these stations are given in Table 3.8.

Using these criteria, metal accumulation in surface sediments was found to be localised around the AIS/BP/CSBP and Woodman Point outfall areas and in Owen Anchorage, as summarised in Table 3.9.

Knowing where metals have accumulated allowed the finer sampling grids in Figures 3.3, 3.4 and 3.5 to be constructed. Using the main sampling grid mean plus two standard deviation criteria,allowed areas from the finer grids and outside of Cockburn Sound to be appraised. Table 3.10 lists all stations other than those on the main 2 km grid with significantly greater amounts of metals compared with the area of the main 2 km grid. At significantly raised levels, copper and lead were the most widespread on a geographical basis.

Concentration isopleths for nine heavy metals in the surface sediments of the Cockburn Sound area are given in Appendix V. They indicate the main metal loads are in the sediments close to the CSBP outfall, the James Point area and the Woodman Point sewage treatment facility outfall.

Stations showing "significantly greater levels" for four or more elements are in Cockburn Sound, and these are 1900, 3220, 3700, 4120, 4126, 4500, 4502, C, D, E and F (Table 3.9 and 3.10). With the exception of 1900, they are all within 1 km of the outfall, some being much closer. A comparison of the accumulated metals with those in effluents (42) shows that the metals being discharged are accumulating in sediments near the respective outfalls. Some examples are, cadmium and zinc near the CSBP outfall, iron and lead near the AIS/BP outfalls and chromium and copper in the vicinity of the Woodman Point sewage outfall. Station 3220 is in a marine depression lying between the SEC and AIS/BP outfalls. Copper, lead and zinc have been accumulated at this station and are also discharged in quantity from the AIS/BP outfall. The SEC effluent contributes a significant zinc load to the area (see Appendix I).

Station 1400 is 1.25 km south of the sewage outfall and high up on the fringing bank. Taking these facts into account, the levels of metals in the surface sediments at this station are higher than would be expected. The water circulation model (48) has indicated that a gyre

3.3.1 (Cont'd)

circulates water in Jervoise Bay which traps settleable particles in this area. The high metal values in this area are probably due in part to the influence from the sewage effluent but also, to the importation and settling of material from other areas. A similar arguement may be applied to the area around station 5000 in Mangles Bay.

Figure 3.9 has been designed as a quick reference showing areas of significantly greater levels of heavy metal concentrations in Cockburn Sound surface sediments. From this figure it can be seen that discharge of industrial effluents and sewage have had a significant bearing on the amount of heavy metals in sediments in their vicinity.

Statistical analysis (38) was used to test the null hypothesis (Ho) that: The mean metal concentration in surface sediments from one area does not differ from the mean metal concentration in sediments from another area. The hypothesis was accepted if the result was not significantly different (Table 3.11 lists the findings).

The results of these comparisons for surface sediments from grid locations (Table 3.7) for the means of six heavy metals given in Table 3.11 show, that in broad terms, Cockburn Sound sediments were found to be more contaminated than Owen Anchorage sediments which in turn were more contaminated than Warnbro Sound sediments. Of the three areas, Warnbro Sound appears to be the only one which has sediments containing baseline anthropogenic heavy metal levels (Table 3.8). Specifically, copper, cadmium, lead and chromium were found to be elevated in the sediments of Cockburn Sound when compared to Warnbro Sound, as was manganese in Cockburn Sound when compared to Owen Anchorage. Lead and cadmium in the sediments of Owen Anchorage were significantly higher than in the sediments of Warnbro Sound as was lead in Owen Anchorage when compared to Cockburn Sound.

In the initial programme sediment was collected from three stations between AIS and Alcoa jetty; 2630, 3220 and 3228. As the metal results from 2630 and 3220 were higher than those of adjacent stations, a second collection was made to confirm these values. The increased values were confirmed, and a series of stations - 3212, 3212.1 and 3212.2 were selected for further investigation. These, along with the initial three stations, were resampled and a pattern of accumulation within the shallow depressions of the bottom became evident.

The results from the resampling are given in Table 3.12. The stations all show relatively high values for metals with 50 per cent of the values for all metals being significantly greater than the other stations on the main 2 km grid in Cockburn Sound. All the stations except 3228 are situated in depressions which are recorded on marine charts.

The increased values could be explained by the trapping of particulate matter with associated metals in these depressions. The seasons prior to summer 1977-78 did not have periods of high storm activity which would have disturbed and redistributed the fine sediment found in these shallow depressions, so these results may represent an accumulation and build up for more than one season. Repeat sampling of these stations following a period of heavy storm activity may show a lowering of the values in the depressions compared with the surrounding area due to disturbance and redistribution of the fine sediment. The resampling of the stations 2630, 3220 and 3228 demonstrated that if the stations are not disturbed, and are located accurately and if representative samples are analysed carefully, reproducible results for sediments can be obtained.

3.3.1 (Cont'd)
Table 3.13 indicates the types of tests performed on the sediment core samples. This particular station (3300) is in Cockburn Sound but it is as far as possible from outfall areas. A complete set of data sheets are stored in the Cockburn Sound Study Data Repository.

Surface sediments (0-2 cm) in Owen Anchorage -
Copper, lead and chromium were shown to be at levels significantly greater than would normally be expected for sediments in Owen Anchorage (Table 3.9). Chromium was higher in the northerly section because of a 10 kg per day tannery input (42).

Lead contamination of all the shoreline station sediments is more difficult to account for. Instead of high levels of this element being restricted to areas such as around sulphide ore bodies, with generally lower natural levels elsewhere, man's activities have been responsible for the ubiquitous nature of this element. In Owen Anchorage, contributions may well come from power house and vehicle emissions, run-off from roads on shore, and from boating activities.

3.3.2 Heavy metal depth profiles
Three sets of data are included to illustrate change in metal concentrations with depth. These are the Tables 3.8, 3.13 and 3.14 illustrating data from selected stations. These show the range of tests performed at each sediment station.

In Table 3.8 the mean concentrations of metals at the 36 main 2 km grid stations are given. Cadmium in sediments is a particularly good tracer of man's activities (49), (50), in relation to input of effluents containing metals to the marine environment. Overall the results indicate that the metal effects extend to a depth of about 7 cm. This is not clearly evident for the elements copper and zinc and is probably due to different mobilisation rates of these metals in sediments.

A more realistic approach is to investigate individual stations and relate them to particular areas of Cockburn Sound. In Table 3.13 and Table 3.14 the use of cadmium as a tracer to metal input to sediments can be fully realised. All stations except 1900, 3700 and CSBP 'C', which are in close proximity to discharge points, show a definite influence to a depth of 7 cm possibly extending to 12 cm because of factors such as bioturbation and diagenesis. These influences would appear to cease at about 12 cm.

The stations influenced by industrial input show very distinct sedimentation features. Deep basin stations 1900 and CSBP 'C' are unique in that they have high levels of industrial metal to depths greater than 27 cm. The shallow bank station 3700, which has been under the influence of industrial input as long as any area in the Sound, has a very definitive cut-off at 12 cm.

In general, whereas most stations show industrial metal influence to a depth of 7 cm some stations exhibit this trend to 12 cm and a few other deep basin stations are affected to 27 cm because of their proximity to certain outfalls.

3.3.3 Mercury in Cockburn Sound surface sediments (0-2 cm)

Table 3.7 summarises the results for the limited survey carried out in Cockburn Sound to gauge the extent of mercury contamination of the sediments. These show that the main mercury accumulations are in the immediate vicinity of the CSBP and AIS/BP outfalls. CSBP sediment levels were the highest found with a range of <0.02 - 2.60 µg g^{-1} dry weight.

Levels of mercury over the main basin of Cockburn Sound are 0.02 µg g^{-1} of dry sediment. Levels on the northern and western side of the Woodman Point sewage outfall point show a range of acid-soluble mercury from 0.02 - 0.09 µg g^{-1}.

The stations 3700 and 3702 near the AIS southern jetty showed a fine sediment build up and mercury levels of 0.24 and 0.11 µg g^{-1}.

3.3.4 Arsenic in sediments in the Cockburn Sound area

Table 3.7 summarises the results of the limited survey carried out to gauge the extent of arsenic contamination of the sediments. In Cockburn Sound the main arsenic accumulation is in the immediate vicinity of the CSBP outfall.

Arsenic values in Cockburn Sound ranged from 0.75 to 10.0 µg g^{-1} with no particular trends except for higher values at CSBP. With no further investigation to consider, these values may be queried. However, two samples were taken from Warnbro Sound for comparison; one from deep basin station contained 11.0 µg g^{-1} arsenic and a shallow station sample contained 7.5 µg g^{-1}.

These results are difficult to explain until they are considered in relation to the similar trends exhibited by manganese. In analytical schemes hydrated manganese oxide is one of the most efficient scavengers of arsenic. Higher levels of arsenic in Cockburn Sound may be due to industrial or sewage input, both of which contribute to the arsenic load to Cockburn Sound (42).

At CSBP the grid system samples and depth profiles data indicate that the arsenic content around the outfall is extensive covering an area of six to seven hectares to a depth of at least 7 cm.

Effluent analysis (42) has shown that BP is the biggest contributor of arsenic to Cockburn Sound. Samples from sediments in the vicinity of its outfall has levels ranging from 0.75 to 5.5 µg g^{-1}. These are not particularly high when compared to those in Warnbro Sound.

3.3.5 Gypsum discharge from the CSBP outfall

Heavy metals -

Table 3.16 can be used to gauge the extent of the metal reservoir that has been created in the sediments by input of CSBP gypsum effluent. A conservative estimate of the area affected by the heavy metals in the gypsum outfall would be 20-25 ha based on a diver's observation and Eh measurements. About half of this area is severely influenced to depths greater than 22 cm while the rest shows significant levels to a depth of 17 cm.

Conditions in this area are such that sulphate reducing bacteria have been able to thrive on the gypsum (calcium sulphate) input and produce hydrogen sulphide in the sediments. In most systems such as these a carbon source is usually the limiting factor while the sulphate is the bacterial enrichment factor.

3.3.5 (Cont'd)

To highlight the effect that hydrogen sulphide has on most transition metals the resolution properties of a representative metal, cadmium, were tested. In this test, conditions akin to vigorous dredging or storm activities were simulated by shaking sediments in seawater in a system excluding air. The results shown in Table 3.15 indicated that although sediments from station CSBP 'D' have cadmium levels which are orders of magnitude greater than the other samples, there was no leaching of cadmium from the sediment. The results from 23 January would seem to indicate that cadmium was extracted from the seawater. The metal sulphide formed is very insoluble.

3.3.6 Physical and chemical parameters of Cockburn Sound sediments

Organic matter -

Organic matter was determined from the organic carbon content in sediments. Table 3.18 indicates that levels of organic matter in surface sediments show increased values near the Woodman Point sewage outfall and the CSBP gypsum discharge point. For the rest of the Sound, taking a very general view, the deep basin has a higher organic matter content on a dry weight basis than the banks as indicated by the following figures from the main 2 km grid stations:-

	Number of Stations	Mean Result (%)	Range (%)	Standard Deviation
Deep Basin	20	4.1	0.6-7.7	2.1
Margins	16	2.4	0.6-7.2	2.2

Loss on ignition and calcium as calcium carbonate -

The percentage of calcareous material is high throughout the Sound. On the simple basis of deep stations versus shallow stations the results show increased calcium carbonate levels for deeper areas. This is illustrated by the following figures (Table 3.18) from the main 2 km grid station -

	Number of Stations	Mean Results (%)	Standard Deviation
Deep Basin	20	81.4	9.4
Margins	16	60.0	24.0

The results of a recent study by France (45) record the composition of the Western/Barrier Banks and the Deep Basin sediments of Cockburn Sound as follows:-

		% Carbonate Material	% Quartz
Barrier Banks -	Sand Sheet Unit	36	20
	Bank Unit	17	10
Western Fringing Bank -	Sand Sheet Unit	37	13
	Bank Unit	30	12
Deep Basin		64	2

3.3.6 (Cont'd)

A comparison of the above results with those from this Study shows agreement; the deep basin is much higher in carbonate content than the fringing banks. The differences in the actual results can be accounted for by the fact that in this study, prior to sieve analysis, all material greater than 1 500 μ was discharged, whereas the above results by France are on the total sample.

Particle size -

The coarse particles greater than 1 500 μ were sieved out of each sample before analysis. This removed the large shell fragments, seagrass debris, and coarse silicate sand particles. The percentages of each fraction and descriptions of the coarse material are included in the data recorded for each station. (This information is kept in the Cockburn Sound Study Data Repository; Distribution of Contaminants).

Sizing results for samples were examined for their percentage of particles either side of 150 μ and this was used to divide the area of Cockburn Sound into segments. The results obtained showed the main basin and the edge of the Sound to be easily separated on the basis of sediment particle size.

On this basis almost all main 2 km grid stations in the deep basin have more than fifty per cent of size fractions less than 150 μ while the reverse applies for the stations on the fringing banks. Notable exceptions are station 1800, 1900 and 1316 (Figure 3.3) where the mean of the size fractions less than 150 μ is 19.0 per cent. The larger particles at the northern end of the deep basin are due to the influence of the Parmelia shipping channel. Coarser banks sands are funnelled down the channel either by shipping movements or tidal effects. It is interesting to note that fish productivity from this northern section of the Sound is relatively high (56), indicating a possible detrital food input.

The coarse particles found around the edge of the Sound consist mainly of calcium carbonate which although relatively large in size (range between 150-475 μ) are not smooth in texture, and the 'pitted' surface increases the surface area of the individual particles.

Electrode Potential (Eh) -

The surface sediments (i.e. 0-2 cm strata) generally showed a positive Eh ranging from +20 to +30 mV (Table 3.18) when Eh values and the observation of colour variations in the cores were taken into account. The only negative readings observed in the surface sediments were at stations 2500, 4510, 4812 and sites in the vicinity of the CSBP gypsum outfall.

Sandy sediments around the periphery of the Sound showed positive Eh readings to approximately 7 cm depth, while the deep basin sediments and areas of high organic matter content (e.g. areas near the sewage outfall) showed negative Eh readings below 2 cm depth.

Owing to the technical problems of taking Eh readings of deep sampling sites, measurements of Eh were performed on the sediment in the core tubes, rather than *in situ*. The Eh values, therefore, reflect the overall pattern of conditions rather than exact measurements of the oxidation and reduction status of the various strata.

To interpret the reason for Eh values showing a negative bias compared with adjacent sites they may be considered in relation to the organic matter estimates. The sediments of the Sound below 2 cm all

3.3.6 (Cont'd)
show moderately reduced conditions to a depth of 20 cm. In appearance the areas, south of, and around the CSBP gypsum outfall were exceptions. The black, anaerobic layer extended to depths greater than 45 cm in some cases.

Stations 4510 and 4812 are on the shallow eastern edge of the Sound and were part of a seagrass meadow area before its recession. The high organic matter content probably accounts for the negative Eh reading. The CSBP outfall is one kilometre from 4510 and may have some effect over sediment Eh in this area.

pH surface sediment -
The pH surface sediments at all stations sampled excluding the area directly influenced by CSBP had values ranging from 7.5 to 8.1 with a mean of 7.9 (Table 3.18). Of these only one station, 1316, 0.5 km from the sewage outfall, had a pH of 7.5.

The results for CSBP outfall stations C, D, E and F in November 1977 were as follows:-

	0-2 cm	2-7 cm	7-12 cm
C	7.1	6.2	5.8
D	7.3	6.9	6.2
E	7.4	5.9	5.7
F	7.2	6.2	5.7

With these pH values reducing conditions evidentally exist in all depths and stations. For a highly buffered marine environment these sediments are relatively acid.

3.3.7 Polychlorinated biphenyl (PCB) and chlorinated pesticides (PC)
Effluents, sediments and mussels were screened for the presence of PC and PCB's. See Figure 3.6 for sampling details.

Gas chromatographic (GC) separations did not reveal any significant levels of chlorinated pesticides in the sediments or mussels of Cockburn Sound, or the Woodman Point effluent. Standards were prepared for 14 chlorinated pesticides. Levels of total chlorinated pesticides were less than 1 $\mu g\ g^{-1}$. Sediments from station 0600 and effluent from Anchorage Butchers revealed the presence of two chlorinated compounds; the sediment contained 4 $\mu g\ kg^{-1}$ dieldrin while the effluent contained 15 $\mu g\ kg^{-1}$ dichlorvos.

Samples were analysed for six of the more common poly-chlorinated biphenyls. No pattern of compounds which compared to standard Arochlor solutions were found in the sediments, mussels or effluents examined.

3.3.8 Hydrocarbons (alkanes) in sediments
Using the Five Fathom Bank level as a baseline (Table 3.19) the levels of alkanes in Cockburn Sound sediments are elevated. This effect is most apparent along the eastern shore of the Sound. The trace for Five Fathom Bank sediment shows (Figure 3.11) the regular pattern for a mixture of mainly n-alkanes. Odd numbered homologues characteristic of biogenic alkanes dominate the trace. This pattern is totally masked in the other three traces by a broad unresolved envelope of naphthenic alkanes characteristic of petroleum hydrocarbons. These traces also show that the north Garden Island sediments contain a

3.3.8 (Cont'd)
smaller proportion of lower molecular weight hydrocarbons than sediments from the eastern shoreline of the Sound. In addition there is a gradation of petroleum derived hydrocarbons in the sediments of Cockburn Sound decreasing in concentration from the eastern industrial site to the western side and out to the Five Fathom Bank. Sample locations are given Figure 3.7 and 3.8.

3.4 Discussion

3.4.1 Siting of outfalls in Cockburn Sound

When considering suitable positions for outfall sites the Sound's very limited water exchange rate with open ocean should be borne in mind (Chapter 2 of this report and R.K. Steedman & Associates (48)).

In Chapter 2, relating to the heavy metals in the Sound's waters, the point was made that the siting of the CSBP outfall allowed soluble cadmium to be transported both north and south by incorporation into the appropriate gyre formed during a seabreeze system. The boundary between the gyres can occur in line with the CSBP outfall and runs west allowing the outfall to contribute soluble metals and nutrients to both systems.

This movement is reflected by the surface sediment results where the cadmium level 500 m north of the CSBP submarine outfall was 1.7 $\mu g\ g^{-1}$ (station 4120) while 750 m south it is 0.9 $\mu g\ g^{-1}$ (station 4510) and 750 m west south-south-west it is 3.9 $\mu g\ g^{-1}$ (Station 4500). The distribution of lead, chromium and nickel in sediments in the basin can also be accounted for in terms of these circulation characteristics.

The outfalls of BP and AIS are about 300 m apart. Sediment at station 3700 are contaminated by copper, zinc, lead, chromium and nickel compared with stations 3620 and 3622 which are also close to, but west or south-west of, the two outfalls. The implication here is that the prevailing direction of the effluent plume is northwards. Shipping spillage may also have some influence over metals in the sediments in this region (see Appendix III).

Sediment analysis suggests that dispersion of most of the metals from the Woodman Point submarine sewage outfall is restricted to the northern deep basin area of Cockburn Sound. The Woodman Point sewage discharge point is bounded north and east by fringing banks that rise about twelve metres above the basin floor. These and the resulting water circulation patterns cause the heavy metals to be confined to the north eastern sector of the deep basin rather than being dispersed. Some of the metals discharged are deposited on the fringing banks toward Owen Anchorage and Jervoise Bay. Some are deposited near the outfall or west of it and south towards station 1900, one of the most polluted stations in the Sound.

A comparison of metal concentration in sediments at different depths for the shallow station 1320 (0.6 km from the sewage outfall) and the deep basin 1900 (1.2 kg from the outfall) (Figure 3.3) indicates how much accumulation has taken place in the deep basin relative to that on the fringing banks (see Table 3.14). By using cadmium as a tracer the depth of sediment accumulation at 1900 is at least 22 cm with some effect at 32 cm. At station 1320 the cadmium contamination reaches a depth of 7 cm at the most. This is general for deep and shallow stations around the sewage discharge and illustrates the heavy metal build up in deep sediments due to the barrier effect of the fringing banks.

3.4.1 (Cont'd)

Assuming that the first very small but significant cadmium input to Cockburn Sound began with the industrial development in 1955, then cadmium concentrations have been building up in sediments for 23 years to 1978. Initially it was hoped to use cadmium as a tracer to predict sedimentation rates. Other reports (25), (45), suggest that the natural rate would be of the order of 0.025 to 0.05 cm per year and 0.04 to 0.09 cm per year from geological studies. The cadmium results from various areas in Cockburn Sound were too inconsistent to to be used for an overall figure.

3.4.2 Oxygenation of sediments and metal release

Literature suggests that surface sediments with an adequate supply of oxygen will exhibit an Eh value in the vicinity of +100 to +200 mV. Surface sediments with Eh values between +350 to +550 mV are considered well oxygenated (1). On a gross basis sediments from all the areas examined, while not being classified as anoxic, appear to have a limited amount of oxygen. The manganese and arsenic results earlier in this chapter suggested that Cockburn Sound, in particular, has had a history of limited oxygen content in its sediments. Algal blooms, the introduction of waste stream with high chemical oxygen demand and limited water circulation (or combinations of these events) could have led to this condition.

By comparison of the Cockburn Sound results with results from stations W1 to W6 in Warnbro Sound it can be seen that only manganese at station W1 approaches a level that could be considered as a "significantly greater level" (Table 3.9).

A comparison of the levels of manganese in surface sediments of Cockburn Sound and Warnbro Sound areas is interesting. Generally, low manganese levels result from anoxic conditions and indicate areas where conditions of long standing oxygen deficiency might have occurred. If the eight stations for Mangles Bay in Cockburn Sound are compared to the six Warnbro Sound stations for manganese then the respective means are 1.7 $\mu g\ g^{-1}$ and 20.3 $\mu g\ g^{-1}$ on a dry weight basis. This could indicate that the southern end of Cockburn Sound is oxygen deficient compared to Warnbro Sound. The seagrass meadows of Warnbro Sound are healthy while in the southern section of Cockburn Sound the meadows are in decline (43). Decaying rhizobia may be contributing to lower oxygen levels in the sediments.

An understanding of the effects of effluent outfalls on metal levels in sediments is important as they will effect metal levels throughout the Cockburn Sound ecosystem. The comparisons of specific areas in Cockburn Sound with Cockburn Sound as a whole and with Warnbro Sound, indicate that the sediments harbour quantities of metals from effluent outfalls. Based on the six elements examined statistically by t-test comparison of means, the Woodman Point sewage outfall area had the most heavily contaminated sediments.

If the low manganese levels for Mangles Bay and in Owen Anchorage indicate low oxygen levels in the sediments at those locations, then Table 3.1 indicates that these conditions will tend to hold the elements cadmium, copper, nickel, lead and zinc in the sediments. However, should the sediments become more oxygenated through activities such as shipping, dredging or increased wave energy in the Sound through degradation of the Parmelia or Success Banks (44), (45), then the sediments could become a source of heavy metals and nutrients as indicated from other studies (46), (47).

3.4.2 (Cont'd)

A recent study (61) of heavy metals in Sydney Harbour sediments found that by simulating bioturbation of molluscs or worms or dredging they could achieve the release of 12-60 per cent copper, 2-5 per cent lead, 10-95 per cent zinc and 10-35 per cent chromium from the sediments to water. Until this report was released it was thought that the metals were effectively "locked up" in the sediments in chemically stable, non-toxic forms.

3.4.3 Metals in the gypsum discharge

Under the 1964 Industrial Lands Agreement No 93, CSBP may discharge up to 350 tons of gypsum (calcium sulphate) into Cockburn Sound per day. It was thought that this material would dissolve and disperse and as such would pose no threat to the marine ecosystem. However, analysis has shown (42) that the gypsum contains significant levels of heavy metals, some of which are, cadmium, cobalt, chromium, zinc and mercury. In addition this effluent stream also contains large amount of nitrogen and phosphorus which create eutrophication problems for the Sound (51).

The problems related to heavy metals in this region are linked to the calcium sulphate input. One aspect not immediately obvious is that this substance is a standard enrichment medium for sediments when culturing and isolating marine bacteria, especially sulphur bacteria (52). In a Winogradsky column, enriched with calcium sulphate, stratification of bacterial species occurred, with sulphur or sulphide bacteria at the surface and sulphate reducing bacteria below the surface. In this case the sediments were typically anaerobic with different species of bacteria being separated within the column as levels of hydrogen sulphide increased.

In the case of the CSBP outfall it is likely that the presence of sulphide under reducing conditions will precipitate most transition metals with resultant very low solubility. It has been suggested that the oxidation of sulphide or sulphate under oxidising conditions (assisted by bacteria) will release these elements back into the overlying water (53). At present factors such as free hydrogen sulphide (observed by divers and in samples) coupled with high organic matter content are controlling the solubility of the trace metals in the area.

If the gypsum discharge were to cease the effects of stopping the supply of sulphate to the sediments would have to be monitored closely. In the 1974 study by the Western Australian Government Chemical Laboratories (26) no methyl mercury was found around the outfall. In view of the hydrogen sulphide generation the mercury is probably "bound up". Should the situation arise where there is no further hydrogen sulphide generation but some organic matter and bacterial content remained it is possible that methylation of metals such as mercury, arsenic, lead or cadmium could occur. In addition if the gypsum flow were to cease it may not immediately herald the end to elevated metal levels in biota in the vicinity of the CSBP outfall.

The gypsum mound has been dredged in the past and the spoil dumped into the deeper waters of the Cockburn Sound basin. If methylation is occurring this would possibly be the best chance to detect it; especially at the periphery of the spoil dump where oxidation is more probable.

Government Chemical Laboratories Report 1974 also showed increased mercury levels in the area of the CSBP gypsum mound with a range of 0.2-3.0 $\mu g\ g^{-1}$.

3.4.3 (Cont'd)

During August 1977 the gypsum outfall was modified by fitting twin nozzles to achieve greater dispersion. This modification coupled with higher discharge rates has achieved this aim. The area of anaerobic sediments rich in sulphur bacteria increased west from a distance of 125 m from the nozzles in August 1977 to 250 m in January 1978 and to at least 500 m by September 1978. This width of influence north/south is a minimum of 500 m so that the area directly affected now is at least 25 ha.

3.4.4 Insecticide in sediments

The Survey for PCB compounds was not comprehensive. Although no trace could be found of the six more common PCB's, many more than this number are used in Western Australia. The range extends from polychlorinated naphthalenes (PCN), polychlorinated terphenyls (PCT) to a whole series in which the chlorine atoms are replaced by bromine atoms.

The lack of accumulation was expected as these agents are not used or manufactured by industries bordering Cockburn Sound and Owen Anchorage. However, the sewage discharge being the most likely source, if any, may require further investigation.

Other workers have reported the following figures for dieldrin (which has been isolated from Owen Anchorage sediments) in sediments (57); Irish Sea, 0.2-140 $\mu g\ gk^{-1}$, Hawaii, 2-39.5 $\mu g\ kg^{-1}$, Los Angeles Harbour, 0.6-4.5 $\mu g\ kg^{-1}$, and San Antonio Bay, 0-20 $\mu g\ kg^{-1}$. A level of 4 ppb for Owen Anchorage sediment may be low by comparison, however, no conclusion on the extent of contamination may be drawn from the one contaminated sample. This showing is obviously the result of some accidental spillage.

As Young *et al* have demonstrated that sediments can act as a source of pesticides to biota for a very long time after the input to the system has ceased (58), these substances warrant more intensive investigation.

3.4.5 Honeycomb slag from AIS outfall

The design of the AIS outfall is allowing a solid material described as "honeycomb slag" to enter Cockburn Sound. There is a boom across the outlet designed to skim this floating material, but the volume of the wastewater is pushing it past. The material is a soft grey solid with the characteristic porosity of honeycomb - the trapped air can allow it to float. It can be crumbled between the fingers and upon doing so a strong smell of hydrogen sulphide is evident. Divers have observed some of this material which has sunk to the sediments around the AIS outfall. During the course of this study people have sent in samples of this material requesting identification, and in fact, it is evident at the water mark in most areas of the Sound. It is in evidence at the high water mark in Sulphur Bay, Jervoise Bay and Mangles Bay.

3.4.6 Physical parameters

Cockburn Sound sediments generally have a medium to high range organic matter levels compared to other places (54), (55), (59). Localised effects are evident regardless of water depth. The increased values in the area of the CSBP outfall are not easily explained because the effluent contains little, if any, organic matter. The sediment around the discharge pipe supports an active bacterial population which may provide most of the organic matter present. Another possible source is the prolific phytoplankton blooms which occur in the Sound. The

3.4.6 (Cont'd)
undissolved gypsum forms a floculant when it is mixed with seawater and would tend to settle out any algal cells in the water column in that area.

High organic matter content in the sediments around the Woodman Point sewage outfall is a direct result of this matter being discharged. There is probably a large bacterial population associated with the nutrients flux to sediments from this source. Figure 3.10 characterises areas of high organic matter.

At outfalls in the Sound where the sediments are anaerobic the organic matter levels are generally high (7 to 10 per cent) and this is consistent with high bacterial flora. In such a habitat most unspecialised marine life does not survive.

Particle size can be related to the metal content of sediments (30); there is a correlation between a sediment's particle surface area and its metal adsorbing capacity. The Cockburn Sound particle size data is, therefore, of importance in comparing results from other areas with varying particle size sediments. A strong correlation between organic matter and particle size was also found. The sediments with a high percentage of fine materials contained considerably more organic matter than coarse samples.

The loss on ignition results (Table 3.18) are in close agreement with the values reported by ERA in 1972 (20). These results are closely linked to the calcium carbonate results. They are low in the area surrounding the CSBP outfall which consists of calcium sulphate and various silicate compounds which are discharged as by-products or residues of the rock phosphate treatment process.

3.4.7 Comparison with other study areas

Table 3.20 compares ranges of data from various studies. These studies investigated metal values in surface sediments and used comparable analytical leaching techniques, in that, they only tried to look at metal inputs from man as opposed to geochemically derived metals.

Cockburn Sound sediments appear to be less polluted than Port Phillip Bay sediments overall and those of Long Island Sound. They are, however, comparable to Corio Bay sediments and considerably more contaminated than those of Westernport Bat.

3.5 Conclusions

A range of heavy metals have accumulated in the sediments near industrial and sewage discharge points. There is an unequivocal relationship between the accumulated metals and those reported to be in the effluents. Cadmium in the sediments around the gypsum discharge at CSBP, chromium at the Woodman Point sewage discharge and in Owen Anchorage, copper at the Woodman Point sewage discharge, lead at the BP discharge and zinc at the SEC, AIS, BP and CSBP discharges.

In Cockburn Sound heavy metals that have accumulated and may ultimately pose a threat to the ecosystem or to public health include cadmium, chromium, lead, and mercury. In Owen Anchorage the list covers chromium and lead.

On a statistical basis for surface sediments there are significantly elevated levels of copper, cadmium, lead and chromium in Cockburn Sound and cadmium and lead in Owen Anchorage, when compared to Warnbro Sound. No statistical comparison is made for subsurface sediments, but from the data obtained, a similar relationship is evident.

3.5 (Cont'd)

Because of the Sound's limited water exchange with the open ocean there are many difficulties associated with the siting of discharge points for the maximum dispersion of effluent. With outfalls at beach level the effects of effluents in sediments are liable to remain close to shore and their metal contaminants will pollute sediments close to the shoreline. The sediment analyses from the area of the BP and AIS outfalls indicates this. However, if a deep basin, submarine outfall such as the Woodman Point sewage outfall is chosen there is little metal pollution of near-shore sediments but there is a tendency for accumulation in the sediments of the deep basin.

Evidence of heavy metal accumulation in sediments, the present understanding of water circulation and the high residence time of cadmium in Cockburn Sound, all suggest that the present siting of the sewage outfall achieves minimum dispersal and flushing of the effluent.

The siting of the CSBP outfall results in contamination of the shoreline sediments as well as those of the deep basin close to the discharge point.

The sediment area around the CSBP outfall has special problems. Both the surface and deeper sediments contain the heavy metals cadmium, lead, chromium, nickel, mercury and arsenic. Sulphate reducing bacteria, using the discharged calcium sulphate produce hydrogen sulphide leaching to extremely anaerobic conditions. This environment stabilises most of the heavy metals present by converting them to the insoluble metal sulphide form. A potential hazard exists if the sulphate supply is stopped even though carbon is normally the limiting element in these situations. Hydrogen sulphide may no longer be produced in quantity, the surficial sediments could become anoxic and then start to oxidise. This would convert some of the accumulated metals to a more soluble form making them available for dissolution into the water column.

Methylation is another possibility. The metals mercury, lead and cadmium in the sulphide form are "unavailable" for this process but with a fall in hydrogen sulphide production, limited oxygen and the relatively high organic matter content (about 2 to 10 per cent), methylation is a real possibility. Dredging or storm activity could initiate methylation given the present conditions. The dredged gypsum spoil which was dumped in the deep basin should be located and investigated for methylated metals.

The area around the Woodman Point sewage and the BP outfalls should also be investigated for the possibility of the methylation of metals because of the large quantity of organics and metals discharged.

The 1977 changes to the CSBP pipe and discharge rates have achieved wider dispersion of the effluent and reduced the hazard presented by the gypsum mound to shipping. This survey has found that the anaerobic area around the outfall increased from about 2 ha in August 1977 to at least 25 ha in September 1978.

Levels of petroleum derived hydrocarbons in Cockburn Sound sediments are elevated, this effect being most apparent along the eastern shore of the Sound. BP is the only industry on the shores of Cockburn Sound releasing substantial quantities of this type of material (approximately 2 000 kg per day - see Appendix I). It is reasonable to conclude that they make a significant contribution of petroleum derived hydrocarbons to the sediments.

3.5 (Cont'd)

Overall the organic matter level of sediments in Cockburn Sound are medium to high when compared to other estuarine or embayment areas. The areas of high organic matter content in the sediments can be directly attributed to the organic matter and nutrients discharges by the Woodman Point sewage treatment plant and the nutrients discharged by CSBP.

Surface sediment has a uniform size of less than 150 μ in the deep basin except for the northern end. This area is being influenced by coarse grain sand being funnelled into the Sound via the Parmelia Channel.

The results of the redox potential measurements in the sediments of Cockburn Sound indicate that the area was not well oxygenated during the period September to January, 1977-78.

Polychlorinated pesticides are probably discharged by accidental spillage into Owen Anchorage. Dieldrin has been found in sediments and dichlorvos in one of the meatworks effluents. These agents are known to be detrimental to the marine environment even at extremely low levels (62).

TABLE 3.1

METAL MIGRATION AT SEDIMENT/SEA WATER INTERFACE

Metal	Sediment Redox Condition	Migration from Sediment To Interfacial Water
Fe, Mn	reducing	increased
Cd, Cu, Ni, Pb, Zn	Oxidising	increased
Cr, Hg	reducing or oxidising	no specific change

TABLE 3.2

HEAVY METAL CONCENTRATIONS IN SEDIMENTS FROM MANGLES BAY/LOCATION 10 (ERA) AND STATION 5000 (CSSG)

Date Sampled	Station[a]	Depth Sampled	Metal concentration (μg g^{-1} dry wt.)							
			Cu	Pb	Zn	Ni	Cd	Cr	Mn	Fe
August 1970	10	0-15 cm	4	30	11	9	1.5	14	13	98
September 1977 (CSSG)	5000	0-17 cm	13.3	18.2	25.2	2.7	0.5	10.5	1.8	6230
January 1973	10	0-1 cm	11	30	36	39	0.2	29	29	7000
May 1973	10	0-2 cm	18	30	50	29.5	-	41	28	5963
October 1973	10	0-2 cm	6	30	13	29	-	26	29	2020
September 1977 (CSSG)	5000	0-2 cm	13.5	21.4	27.2	5.7	0.7	12.1	1.8	7250

(a) Station 5000 of the Cockburn Sound Study (CSSG, 1977) was at the same location as station 10 for the Environmental Resources of Australia studies (ERA, 1970-73).

TABLE 3.3

HEAVY METAL CONCENTRATIONS IN SEDIMENTS FROM LOCATIONS 4 AND 11 (EMAC OCTOBER 1975) AND STATIONS 2300 AND 3900 (CSSG) (comparable station locations)

Date Samples	Station	Depth Samples	Metal concentration (μg g^{-1} dry wt.)							
			Cu	Pb	Zn	Ni	Cd	Cr	Mn	Fe
November 1974	4	0-7 cm average	6.0	13	20	6.0	0.2	22(a)	30	8000
September 1977 (CSSG)	2300	0-7 cm	11.7	12.9	20.7	0.8	0.2	13.5	1.8	9000
November 1974	11	0-7 cm average	3.5	10	20	7.5	<0.2	31(a)	25	8000
September 1977 (CSSG)	3900	0-7 cm	11.6	19.1	19.7	2.9	0.3	21.5	1.9	6650

(a) Analysed by X-Ray fluorescence

TABLE 3.4

% PARTICLE SIZE COMPOSITION OF SEDIMENTS SAMPLED BY THE THREE COLLECTION TECHNIQUES - AUGUST, 1977

Particle Size	Station 1400			Station 1800		
	Hand	Core	Grab	Hand	Core	Grab
> 1500μ	7.4	7.9	6.8	2.3	1.8	6.2
1000μ - 1500μ	1.8	2.2	4.8	1.0	0.7	2.1
475μ - 1000μ	6.0	6.2	13.2	5.9	7.9	6.0
150μ - 475μ	42.6	44.1	50.6	86.2	84.6	81.9
< 150μ	42.2	39.6	24.6	4.6	5.0	3.8

TABLE 3.5

REPLICATE HAND, GRAB AND CORE SAMPLE ANALYSIS FOR DEMONSTRATION OF CHEMICAL VARIABILITY BETWEEN SAMPLING TECHNIQUES - AUGUST, 1977 ($\mu g g^{-1}$. dry wt.)

STATION NO./ TECHNIQUE	COMMERCIAL LABORATORIES Zn	Mn	COCKBURN SOUND STUDY GROUP Zn	Mn
1400				
Grab A	25.5	10.0	24.8	9.5
B	26.0	9.5	23.8	10.3
Hand A	21.5	10.0	22.0	12.8
B	25.0	10.5	25.1	11.0
C	19.5	9.5	23.1	11.2
D	19.0	9.0	23.9	10.4
Core A	24.0	11.5	20.6	10.6
B	22.5	11.0	22.4	11.0
C	21.0	12.0	21.3	9.9
D	24.0	9.0	22.1	9.7
1800				
Grab A	4.2	11.5	3.9	12.4
B	5.1	10.5	4.5	11.8
Hand A	4.7	12.0	6.2	10.1
B	6.2	11.5	6.9	11.3
C	5.3	13.0	6.1	11.4
D	5.4	10.5	5.4	10.9
Core A	4.4	11.5	5.2	10.0
B	4.2	11.5	5.6	10.8
C	3.6	12.0	4.8	10.8
D	3.8	10.0	5.1	10.6

TABLE 3.6

METAL ANALYSIS OF SIEVED FRACTIONS TO MEASURE VARIATION WITH PARTICLE SIZE - AUGUST, 1977 ($\mu g g^{-1}$. dry wt.)

STATION NO./ SIZE FRACTION	Cu	Zn	Mn
1400			
1000μ - 475μ	6.4	10.2	8.1
475μ - 150μ	12.6	28.1	9.9
<150μ	11.6	23.9	11.4
Total <1500μ	10.6	21.6	9.8
1800			
1000μ - 475μ	7.8	4.2	8.2
475μ - 150μ	12.9	5.6	10.6
<150μ	9.6	6.2	10.4
Total <1500μ	10.6	5.9	10.5

TABLE 3.7

CHEMICAL ANALYSIS OF SEDIMENTS 0-2 cm

Station No.	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Hg	As[a]
Cockburn Sound Main 2 km Grid											
1300	8.6	8.2	0.3	1800	32.0	32.2	23.9	0.9	3.0		
1400	13.6	34.7	0.3	2450	35.0	41.3	44.0	1.7	2.1		
1500	14.9	8.2	0.3	1750	4.7	24.2	18.1	0.9	0.6		
1700	8.8	5.1	0.4	2700	14.6	11.6	13.8	1.2	1.2		
1800	10.6	8.9	0.4	3700	28.0	34.0	27.2	0.9	3.9		
1900	15.1	28.7	0.4	11000	35.0	41.3	54.6	1.6	4.9		
2000	12.4	12.9	0.3	3800	18.0	34.6	26.8	1.4	1.8		
2100	10.1	3.0	0.1	500	2.4	10.8	6.2	0.1	0.7		
2200	8.4	4.8	0.3	2400	4.2	18.4	14.2	0.2	0.6		2.0[b]
2300	11.9	23.5	0.2	9600	1.9	13.1	14.2	0.3	0.9		
2400	10.6	24.6	0.4	7750	2.5	13.4	16.2	0.3	1.3		
2500	9.7	16.7	0.4	6300	1.9	14.2	13.1	0.3	1.6		
2600	9.1	14.9	0.3	2600	1.6	13.8	17.2	0.3	2.1		
2700	9.9	9.7	0.3	2450	4.6	15.2	18.4	0.4	1.2		
2900	10.5	24.5	0.4	5400	2.7	13.6	14.2	0.3	1.2		
3000	9.2	24.0	0.4	4850	2.7	12.8	12.6	0.2	1.3		5.0
3100	10.0	17.6	0.3	6050	2.1	12.9	14.6	0.4	1.9		
3200	12.0	22.9	0.6	3900	2.2	12.8	14.3	0.3	1.6		
3300	10.0	7.6	0.3	2650	8.8	8.9	14.2	0.3	2.4		
3400	11.8	25.1	0.4	7350	1.9	11.0	14.1	0.3	2.0		
3500	9.3	21.1	0.3	6400	2.4	11.6	15.2	0.3	2.1		
3600	11.0	20.3	0.3	6200	9.7	28.6	31.4	1.3	3.6		
3700	17.1	56.2	0.4	7350	47.0	40.0	49.8	1.8	7.3		
3900	11.3	20.9	0.3	6900	2.0	19.7	22.6	0.9	2.8		
4000	10.5	21.7	0.2	7800	2.6	20.6	27.1	1.1	3.7		
4100	12.8	25.0	0.3	4450	2.5	26.8	24.1	1.4	5.4		
4300	9.0	23.8	0.3	7150	2.3	21.2	29.6	1.0	3.1		
4400	11.2	24.1	0.8	5950	2.9	31.4	36.4	1.9	4.7		6.0

a) All samples for As analysis were collected on 17 November, 1978 and sampled from the 0-2 cm section of the core.

b) Station 2200 resample gave a result of 2.5 $\mu g\ g^{-1}$ as dry weight basis.

(Results are the Mean of three samples in $\mu g\ g^{-1}$ dry weight)

Sampling Period: September to November, 1977.

Table 3.7 (Cont'd)

Station No.	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Hg	As[a]
4500	12.0	41.3	3.6	7450	19.0	28.5	24.2	1.9	6.2		
4700	8.7	9.3	0.4	7350	1.9	23.4	19.6	0.8	2.1		
4800	7.2	6.5	0.2	4300	1.0	11.4	12.8	0.2	1.3		
4900	9.4	11.3	0.2	3450	1.9	10.6	11.4	0.1	1.2		
5000	13.5	27.2	0.7	7250	1.8	21.4	12.1	0.6	5.7		
5100	8.6	13.4	0.5	3100	2.3	11.6	12.1	0.1	0.6		
5200	8.8	10.1	0.2	4350	2.2	10.7	10.9	0.2	0.9		
5300	7.8	9.4	0.1	3950	2.0	9.6	11.2	0.2	1.1		
Owen Anchorage											
0300	8.6	13.0	0.4	2500	2.8	42.6	68.3	0.4	0.9		
0500	6.6	8.4	0.2	1500	2.2	19.4	12.2	0.2	1.0		
0600	16.7	22.5	0.3	2100	2.4	31.6	56.1	0.6	0.9		
0800	16.3	10.5	0.1	1900	2.6	21.6	12.8	0.2	0.3		
0900	6.5	4.4	0.2	2100	8.1	28.2	15.2	0.2	0.6		
1000	19.7	28.2	0.3	2300	4.8	38.6	14.8	0.7	1.0		
Warnbro Sound											
W1	6.2	11.0	0.1	3850	32.0	19.0	14.2	0.9	1.7		11.0
W2	7.1	11.7	0.2	3200	26.0	16.0	12.1	0.7	1.1		
W3	8.0	9.7	0.1	3400	24.0	15.0	12.1	0.8	1.1		
W4	9.7	16.4	0.1	2900	14.0	13.5	8.4	0.6	1.2		
W5	9.6	19.2	0.2	3100	16.0	12.8	9.7	0.7	1.5		7.5
W6	8.2	14.6	0.1	2900	9.5	12.1	8.4	0.6	1.0		
Woodman Point											
1300	8.6	8.2	0.3	1800	32.0	32.2	23.9	0.9	3.0	<0.02	
1304	7.0	6.3	0.4	9250	29.0	33.9	26.8	0.9	8.2	0.09	
1316	22.0	41.2	0.4	9850	30.0	35.1	39.0	1.9	4.3	0.07	
1320	11.4	19.8	0.3	2750	32.0	38.0	33.6	1.8	2.5	0.06	
1400	13.6	34.7	0.3	2450	35.0	41.3	44.0	1.7	2.1	0.07	
1416	8.5	9.4	0.2	2450	25.0	36.9	23.6	1.5	2.0	0.02	
1800	10.6	8.9	0.4	2700	28.0	34.0	27.2	0.9	3.9		
1900	15.1	28.7	0.4	11000	35.0	41.3	54.6	1.6	4.9	0.02	
1904	11.1	19.6	0.3	3800	29.0	39.0	29.4	2.0	4.1	<0.02	
2000	12.4	12.9	0.3	3800	18.0	34.6	26.8	1.4	1.8	<0.02	

Table 3.7 (Cont'd)

Station No.	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Hg	As[a]
Mangles Bay											
4510	7.4	12.0	0.9	3000	1.2	31.4	18.7	0.4	4.8	0.13	
4524	8.5	10.9	0.4	2200	1.6	34.6	19.4	0.5	2.8	0.04	
4800	7.2	6.5	0.2	4300	1.0	11.4	12.8	0.2	1.3		
4812	8.4	14.1	0.4	2650	1.7	29.4	20.1	0.7	4.1	<0.02	
4928	11.4	16.3	0.6	3350	1.8	52.8	19.6	0.8	4.1		
5000	13.5	27.2	0.7	7250	1.8	21.4	12.1	0.6	5.7		
5016	10.1	10.6	0.5	3200	1.8	29.4	19.2	0.6	4.9		
5100	8.6	13.4	0.5	3100	2.3	11.6	12.1	0.1	0.6		
AIS/BP											
2630	20.0	39.2	0.5	9750	5.3	29.6	30.0	1.4	2.2		
3220	26.8	62.0	0.4	16050	7.4	37.5	38.2	1.8	4.8		
3228	18.5	26.8	0.5	9800	12.1	37.4	36.4	2.1	2.7		
3600	11.0	20.3	0.3	6200	9.7	28.6	31.4	1.3	3.6		
3604	5.4	17.2	0.2	3950	32.0	10.4	16.8	1.6	2.4		
3612	8.0	16.5	0.4	3450	25.0	32.7	26.6	2.1	3.1		
3614	7.8	15.2	0.3	6350	25.0	32.8	20.4	2.2	2.0		0.
3620	11.1	21.9	0.4	4100	28.0	30.3	33.4	2.1	7.0	<0.02	5.
3622	5.0	12.7	0.2	2950	24.0	23.9	11.6	1.7	6.2		0.
3628	5.0	7.8	0.3	950	21.0	30.0	14.4	1.3	0.9		
3629	5.9	4.9	0.2	11250	19.0	26.8	15.6	1.6	8.4		
3700	17.1	56.2	0.4	7350	47.0	40.0	49.8	1.8	7.3	0.24	
3702	11.5	31.0	0.1	5400	51.0	32.2	23.4	1.2	5.8	0.11	0.
3708	16.6	36.8	0.1	2100	27.0	26.2	17.6	1.2	2.7		2.
4100	12.8	25.0	0.3	4450	2.5	26.8	24.1	1.4	5.4		
4104	13.7	34.3	0.2	4050	36.0	34.5	35.6	1.7	2.4		
4105	8.4	19.3	0.2	1550	45.0	27.5	22.2	1.3	2.6		
CSBP											
4120	21.1	45.0	1.7	16950	15.2	37.4	22.6	1.2	7.8		
4126	25.2	48.7	2.6	7500	13.5	21.6	23.0	1.4	8.9		
4414	11.0	27.2	0.5	9100	9.6	37.2	20.4	0.8	5.3		
4500	12.0	41.3	3.6	7450	19.0	28.5	24.2	1.9	6.2	0.42	
4502	18.0	69.7	8.4	8050	40.0	42.4	26.2	2.0	8.1	0.76	
4504	2.2	6.4	0.1	850	12.0	24.6	20.2	0.9	9.8		

Table 3.7 (Cont'd)

Station No.	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Hg	As[a]
A	11.4	10.2	3.5	1850	25.0	24.5	26.8	1.7	8.4	<0.02	2.
B	11.7	14.1	3.4	1800	23.0	21.8	38.2	1.3	10.6	0.02	
C	12.7	12.3	10.7	400	58.0	44.8	21.8	0.9	17.4	2.48	
D	33.4	63.6	16.1	8200	67.0	26.0	24.2	1.6	15.0	2.60	10.
E	38.3	93.5	25.2	9850	46.0	37.1	26.2	1.7	17.2	0.97	
F	44.5	133.2	19.2	10000	48.0	41.4	22.4	1.8	18.4	1.97	
G	13.9	11.4	2.9	1000	20.0	34.1	24.3	1.2	10.4	0.04	1.
H	8.5	12.9	0.6	2100	27.0	40.1	10.0	0.4	9.8	<0.02	
K											6.
L											6
A 2-7 cm											2
D 2-7 cm											10
G 2-7 cm											1
K 2-7 cm											10
L 2-7 cm											8

TABLE 3.8

HEAVY METALS IN SEDIMENT PROFILES. Stations 1300 - 5300 (Main 2 Km Grid)

Element and number of stations (n)	Core segment depth (cm)	Range (ug g^{-1}) dry	Mean Value (ug g^{-1}) dry	Mean + 2x Standard deviation
Copper: n = 36	0 - 2	7.2 - 17.1	10.7	15.1
n = 35	2 - 7	4.7 - 15.5	10.5	14.7
n = 35	7 - 12	6.0 - 16.0	10.0	14.1
n = 32	12 - 17	1.2 - 13.9	9.1	13.5
Zinc: n = 36	0 - 2	3.0 - 56.2	18.5	40.7
n = 34	2 - 7	2.4 - 43.0	17.8	36.8
n = 35	7 - 12	3.9 - 40.9	15.4	32.5
n = 32	12 - 17	2.7 - 23.4	10.8	21.7
Cadmium: n = 36	0 - 2	0.1 - 3.6	0.43	1.5
n = 35	2 - 7	<0.1 - 2.8	0.34	1.2
n = 35	7 - 12	<0.1 - 1.2	0.23	0.6
n = 32	17 - 17	<0.1 - 0.3	0.12	0.3
Iron: n = 36	0 - 2	500 - 11000	5050	9900
n = 35	2 - 7	950 - 10900	4950	9650
n = 35	7 - 12	700 - 10800	4750	9050
n = 32	12 - 17	650 - 10400	4200	8400
Manganese: n = 36	0 - 2	1.0 - 47.0	8.6	32.6
n = 35	2 - 7	1.2 - 43.0	8.0	30.6
n = 35	7 - 12	0.9 - 40.0	6.6	25.8
n = 32	12 - 17	0.7 - 26.0	4.6	18.5
Lead: n = 36	0 - 2	8.9 - 41.3	19.9	39.8
n = 35	2 - 7	9.6 - 40.6	19.4	38.3
n = 35	7 - 12	9.9 - 43.4	16.8	28.6
n = 32	12 - 17	9.4 - 39.6	14.4	26.2
Chromium: n = 36	0 - 2	16.2 - 54.6	20.6	42.9
n = 35	2 - 7	10.6 - 60.6	19.7	42.1
n = 35	7 - 12	9.6 - 49.4	17.6	35.0
n = 32	12 - 17	9.4 38.6	15.7	29.3
Nickel: n = 36	0 - 2	0.6 - 7.3	2.4	5.8
n = 35	2 - 7	0.4 - 7.4	2.1	5.1
n = 35	7 - 12	0.3 - 7.1	1.6	4.5
n = 32	12 - 17	0.3 - 4.1	1.2	3.0
Cobalt: n = 36	0 - 2	0.1 - 1.9	0.7	1.9

TABLE 3.9

MAIN GRID 2 KM STATIONS WITH METALS GREATER THAN THE MEAN + 2 STANDARD DEVIATIONS FOR ALL THE STATIONS (0 - 2CM)

Element	Grid Area	Stations with significantly greater metal levels
Copper:	Owen Anchorage	0600, 0800, 1000
	Woodman Point	1500, 1900
	A.I.S. / B.P.	3700
Zinc:	A.I.S. / B.P.	3700
	C.S.B.P.	4500
Cadmium:	C.S.B.P.	4500
Iron:	Woodman Point	1900
	A.I.S. / B.P.	3700
Manganese:	Woodman Point	1300, 1400, 1900
	A.I.S. / B.P.	3700
	Warnbro Sound	W1
Lead:	Owen Anchorage	0300, 1000
	Woodman Point	1400, 1900
	A.I.S. / B.P.	3700
Chromium	Owen Anchorage	0300, 0600
	Woodman Point	1400, 1900
	A.I.S. / B.P.	3700
Nickel:	A.I.S. / B.P.	3700, 4100
	C.S.B.P.	4500
	Mangles Bay	5000
Cobalt:	A.I.S.	3700
	C.S.B.P.	4400, 4500

TABLE 3.10

FINE GRID 2 KM STATIONS WITH METAL CONCENTRATIONS GREATER THAN THE MEAN + 2 STANDARD DEVIATIONS FOR ALL THE MAIN 2 KM GRID STATIONS

Element	Grid Area	Stations with significantly greater metal levels
Copper:	Woodman Point	1316
	A.I.S. / B.P.	2630, 3212, 3212.1, 3212.2, 3220, 3228, 3708
	C.S.B.P.	4120, 4126, 4502, D E F
Zinc:	Woodman Point	1316
	A.I.S. / B.P.	2630, 3212.1, 3220
	C.S.B.P.	4120, 4126, 4502, D E F
Cadmium:	C.S.B.P.	4120, 4126, 4502, A, B, C, D, E, F, G
Iron:	A.I.S. / B.P.	2630, 3212.1, 3212.12 3220 3629
	C.S.B.P.	4120, F
Manganese:	Woodman Point	1320
	A.I.S. / B.P.	3604, 3702, 4104, 4105
	C.S.B.P.	4502, C, D, E, F
Lead:	Woodman Point	1320, 1904
	A.I.S. / B.P.	3220
	C.S.B.P.	4502, C, F, H
	Mangles Bay	4928
Cobalt:	Woodman Point	1316, 1904
	A.I.S. / B.P.	3228, 3612, 3614, 3620
	C.S.B.P.	4502
Nickel:	Woodman Point	1304
	A.I.S. / B.P.	3620, 3622, 3629, 3702
	C.S.B.P.	4120, 4126, 4502, 4504, A, B, C, D, E, F, G, H

TABLE 3.11

STATISTICAL COMPARISON(a) BY GRID LOCATION OF MEAN SURFACE SEDIMENT CONCENTRATIONS FOR SIX HEAVY METALS.

(means for t-test comparisons are in $\mu g\ g^{-1}$)

Grid Location (X)		WARNBRO SOUND (W)					COCKBURN SOUND (C)				
		$\bar{X}$	$\bar{W}$	t	df	p(c)	$\bar{X}$	$\bar{C}$	t	df	p(c)
Cockburn Sound	Cu	10.70 :	8.13	2.77	40	**					
	Zn	18.53 :	13.76	(b) 2.01	40	NS					
	Cd	0.43 :	0.13	(b) 3.14	40	*					
	Mn	8.62 :	20.25	2.27	40	*					
	Pb	19.90 :	14.73	(b) 2.54	40	*					
	Cr	20.60 :	10.82	(b) 4.67	40	*					
Owen Anchorage	Cu	12.40 :	8.13	(b) 1.75	10	NS	12.40 :	10.70	(b) 0.71	40	NS
	Zn	14.50 :	13.76	0.19	10	NS	14.50 :	18.53	0.93	40	NS
	Cd	0.25 :	0.13	2.63	10	*	0.25 :	0.43	(b) 1.77	40	NS
	Mn	3.82 :	20.25	(b) 4.59	10	*	3.82 :	8.62	(b) 2.17	40	*
	Pb	30.33 :	14.73	(b) 4.02	10	*	30.33 :	19.90	2.53	40	*
	Cr	29.92 :	10.82	(b) 1.84	10	NS	29.92 :	20.60	(b) 0.89	40	NS

(a) Ho: That the mean metal concentrations in area X does not differ from the mean in either area W or area C (For area description see Table 3.7).

(b) Where variances of the two test samples differed significantly (by F test) an approximate t-test was used to test for significance at the 5 per cent level ( ).

(c) NS p >0.05
* P <0.05
** p <0.01
*** p <0.001

TABLE 3.11 (Cont'd)

Grid Location (X)		WARNBRO SOUND (W)					COCKBURN SOUND (C)				
		$\bar{X}$	$\bar{W}$	t	df	(c) p	$\bar{X}$	$\bar{C}$	t	df	(c) p
Woodman Point	Cu	12.00 :	8.13	(b) 2.54	14	*	12.00 :	10.70	(b) 7.25	44	*
	Zn	18.90 :	13.76	(b) 1.44	14	NS	18.90 :	18.53	0.36	44	NS
	Cd	0.33 :	0.13	6.09	14	*	0.33 :	0.43	(b) 1.04	44	NS
	Mn	29.30 :	20.25	2.71	14	*	29.30 :	8.62	(b) 8.09	44	*
	Pb	36.63 :	14.73	14.10	14	***	36.63 :	19.90	(b) 8.92	44	*
	Cr	32.90 :	10.82	(b) 6.62	14	*	32.90 :	20.60	3.14	44	**
AIS/BP	Cu	12.04 :	8.13	(b) 2.46	21	*	12.04 :	10.70	(b) 0.87	51	NS
	Zn	26.30 :	13.76	(b) 3.08	21	*	26.30 :	18.53	2.08	51	*
	Cd	0.40 :	0.13	(b) 2.54	21	*	0.40 :	0.43	0.19	51	NS
	Mn	24.53 :	20.25	0.67	21	NS	24.53 :	8.62	4.20	51	***
	Pb	29.84 :	14.73	(b) 7.85	21	*	29.84 :	19.90	3.93	51	***
	Cr	26.32 :	10.82	(b) 5.83	21	*	26.32 :	20.60	1.79	51	NS
CSBP	Cu	14.92 :	8.13	(b) 1.99	10	NS	14.92 :	10.70	(b) 1.25	40	NS
	Zn	39.72 :	13.76	(b) 2.94	10	*	39.72 :	18.53	(b) 2.38	40	NS
	Cd	2.82 :	0.13	(b) 2.17	10	NS	2.82 :	0.43	(b) 1.93	40	NS
	Mn	18.22 :	20.25	0.36	10	NS	18.22 :	8.62	1.83	40	NS
	Pb	31.95 :	14.73	(b) 4.89	10	*	31.95 :	19.90	2.94	40	*
	Cr	22.77 :	10.82	8.92	10	***	22.77 :	20.60	(b) 1.04	40	NS
Mangles Bay	Cu	9.39 :	8.13	1.25	12	NS	9.39 :	10.70	1.53	42	NS
	Zn	13.88 :	13.76	0.04	12	NS	13.88 :	18.53	1.14	42	NS
	Cd	0.53 :	0.13	(b) 5.19	12	*	0.53 :	0.43	(b) 0.84	42	NS
	Mn	1.65 :	20.25	(b) 5.38	12	*	1.65 :	8.62	(b) 3.48	42	*
	Pb	27.75 :	14.73	(b) 2.68	12	*	27.75 :	19.90	2.01	42	NS
	Cr	16.75 :	10.82	3.44	12	**	16.75 :	20.60	(b) 1.70	42	NS

TABLE 3.12

RESULTS OF SURFACE SEDIMENT RESAMPLE NORTH OF AIS JETTY

($\mu g\ g^{-1}$ dry weight)

Station No.(a)	Cu	Zn	Cd	Fe
Original 2630 Resample	20.0 20.0	39.2 39.0	0.5 0.5	9750 9450
Original 3220 Resample	26.8 25.4	62.0 65.8	0.4 0.4	16050 18500
Original 3228 Resample	18.5 18.1	26.8 22.2	0.5 0.6	9800 9700
Resample 3212	16.8	23.2	0.2	8700
Resample 3212.1	27.2	51.4	0.2	14800
Resample 3212.2	19.6	27.1	0.2	11700

(a) Original sampling and repeat sampling took place at least one month apart.

TABLE 3.13

CHEMICAL and PHYSICAL DATA in SEDIMENTS

Station No: 3300

Date : Sept.'7

ug/g		Core depth in cm.						
Element	0-2	2-7	7-12	12-17	17-22	22-27	27-32	32-37
Cu	10.0	12.2	10.2	10.4	11.1	10.3		
Zn	7.6	8.6	6.4	4.2	3.3	3.0		
Cd	0.3	0.2	0.1	0.1	0.1	0.1		
Fe	2650	2750	2400	1800	1550	1500		
Mn	8.8	8.1	2.8	2.1	2.2	2.4		
Pb	8.9	9.6	10.4	9.8	9.8	9.9		
Cr	14.2	12.8	13.0	13.2	13.0	12.9		
Co	0.3							
Ni	2.4	2.0	1.0	0.6	0.6	0.7		
Hg								
	(The Metal Results are Mean Values for Three Separate Corings)							
O.M. %	1.6							
LOI %	11.8							
pH	7.9							
Eh	+40	+20	+10	-10	-40	-50		
$CaCO_3$%	23.1							
%Sieve analysis :								
>1500	2.9	8.4	9.5	13.6	21.0	16.4		
>1000	8.5	4.8	6.1	15.2	4.0	4.2		
> 475	20.7	18.0	17.4	4.9	7.6	9.8		
> 150	56.9	59.5	60.2	58.5	59.0	61.6		
< 150	11.0	9.3	6.8	7.8	8.4	8.0		

TABLE 3.14

SEDIMENT DEPTH VERSUS METAL CONCENTRATION FOR SELECTED STATIONS.

Station /	Depth	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Ni	Co
	(cm)						(µg g^{-1} dry weight)			
0600	0- 2	16.7	22.5	0.3	2100	2.4	31.6	56.1	0.9	0.6
	2- 7	9.6	18.5	0.2	2000	1.9	19.6	48.3	0.7	
	7-12	8.8	15.7	0.1	1800	1.7	12.4	34.6	0.6	
	12-17	7.4	10.8	<0.1	1600	1.4	13.6	22.5	0.7	
1320	0- 2	11.4	19.8	0.3	2750	32.0	38.0	33.6	2.5	1.8
	2- 7	9.6	16.2	0.1	2600	29.0	32.1	30.1	2.1	
	7-12	8.2	12.8	<0.1	1900	21.0	21.3	22.1	1.3	
	12-17	5.1	7.8	<0.1	1600	14.0	13.1	14.6	0.7	
	17-22	4.9	6.2	<0.1	1550	10.8	12.6	12.1	0.6	
1900	0- 2	15.1	28.7	0.4	11000	35.0	41.3	54.6	4.9	1.6
	2- 7	15.5	28.9	0.3	10900	30.0	40.6	60.6	4.6	
	7-12	16.0	29.8	0.2	10800	26.0	43.4	49.4	4.9	
	12-17	13.9	23.4	0.3	10450	20.0	39.6	38.6	3.7	
	17-22	11.9	9.8	0.3	9150	11.6	36.9	35.2	2.0	
	22-27	11.1	4.8	0.1	10500	5.8	32.6	26.4	2.1	
	27-32	11.0	3.7	0.1	7100	5.2	21.4	29.4	1.0	
3400	0- 2	11.8	25.1	0.1	7350	1.9	11.0	14.1	2.0	0.3
	2- 7	12.1	23.1	0.3	7300	1.7	10.9	13.7	1.9	
	7-12	11.0	16.4	0.2	7300	1.6	10.1	13.8	1.6	
	12-17	10.7	13.7	<0.1	5400	1.7	9.8	12.6	1.1	
3700	0- 2	17.1	56.2	0.4	7350	47.0	40.0	49.8	7.3	
	2- 7	15.4	43.0	0.2	8400	43.0	43.2	48.0	7.4	
	7-12	14.5	40.9	0.1	6600	40.0	30.2	37.8	7.1	
	12-17	1.2	2.8	<0.1	1800	9.0	16.1	14.4	1.2	
	17-22	1.3	2.6	<0.1	1700	6.4	12.8	14.2	0.7	
4700	0- 2	8.7	9.3	0.4	7350	1.9	23.4	19.6	2.1	
	2- 7	8.7	10.9	0.3	5100	1.8	20.8	17.4	1.9	
	7-12	8.7	11.1	0.2	4300	1.7	17.4	16.3	1.7	
	12-17	8.5	10.0	<0.1	4000	1.7	16.2	13.1	1.1	
CSBP 'C'	0- 2	12.7	12.3	10.7	400	58.0	44.8	21.8	17.4	0.9
	2- 7	12.4	10.8	10.3	400	56.0	41.4	19.4	17.8	
	7-12	12.7	11.6	9.8	700	74.0	45.6	20.6	16.8	
	12-17	15.9	33.2	8.2	1000	82.0	40.4	18.2	18.2	
	17-22	19.2	52.5	9.6	800	66.0	38.6	16.4	21.6	
	22-27	17.9	16.1	8.0	800	64.0	37.4	18.0	17.8	
W1	0- 2	6.2	11.0	0.1	3850	32.0	19.0	14.2	1.7	0.9
	2- 7	5.9	11.1	0.1	3100	30.0	17.0	12.6	1.2	
	7-12	5.7	9.9	<0.1	3900	27.0	14.0	10.8	0.9	
	12-17	5.8	8.7	<0.1	2700	21.0	14.0	11.4	0.9	

TABLE 3.15

RESOLUTION OF CADMIUM FROM SURFACE SEDIMENTS

Analysis of seawater leach by anodic stripping voltammetry for labile cadmium ($\mu g\ l^{-1}$)

6th December 1978	Cd
Seawater - leach solution	0.05
4800	0.06
2200	0.28
CSBP 'D'	0.05
3614	0.52
1316	0.33
23rd January 1979	**Cd**
Seawater - leach solution	0.05
4800	0.05
2200	0.25
CSBP 'D'	0.02
3614	3.78
1316	1.25
1400	0.52
2700	0.61

TABLE 3.16

MEAN CONCENTRATION VERSUS DEPTH PROFILES FOR C.S.B.P. OUTFALL AREA:

Stations in more than 10 m of water versus bank stations

($ug\ g^{-1}$ dry basis)

	Bank Stations A, B, G, H				Stations in water deeper than 10 m C, D, E, F				
Depth (cm)	0 - 2	2 - 7	7 - 12	12 - 17	0 - 2	2 - 7	7 - 12	12 - 17	17 -22
Cu	11.4	10.4	10.0	9.9	32.2	28.4	26.4	22.5	21.2
Zn	12.2	7.8	3.3	2.2	75.7	65.3	56.9	41.6	40.3
Cd	2.6	1.7	0.9	0.4	17.8	17.0	13.0	9.4	9.8
Fe	1690	1250	880	1080	7110	6510	6250	4800	4380
Mn	31.0	15.7	13.3	13.0	54.8	55.0	57.0	54.8	46.0
Pb	30.1	23.0	15.6	13.6	38.1	35.8	34.4	28.3	28.2
Cr	24.8	20.5	16.2	14.3	23.7	21.3	21.3	18.2	20.3
Ni	9.8	5.5	2.7	1.4	17.0	16.5	14.4	11.5	13.7

TABLE 3.17

EH MEASUREMENTS AT SEDIMENT STATIONS NEAR THE C.S.B.P. OUTFALL.

September 1977

Station Depth (cm)

	0 - 2	2 - 7	7 - 12	12 - 17
'A'	+40	+10	+10	-
'C'	-320	-340	-460	-590
'E'	-10	-260	-280	-340
'G'	+20	+10	-30	-40

10 January, 1978

Station Depth (cm)

	0 - 2	2 - 7	7 - 12	12 - 17	17 - 22
'C'	-370	-340	-460	-590	-360
'D'	-420	-380	-550	-410	-
'E'	-110	-360	-380	-240	-
'I'	-10	-120	-180	-	-
'J'	-10	-220	-210	-190	-200

26 September 1978

Station Depth (cm)

	0 - 2	2 - 7	7 - 12	12 - 17
'A'	+10	-80*	-100*	-180*
'C'	-420	-400	-450	-400
'E'	-200	-190	-200	-300
'G'	+20	+10	-80	-80
'I'	-200	-240	-170	-260
'J'	-180	-250	-340	-290
'K'	-200	-280	-270	-280
'L'	-210	-300	-280	-290

* Rotting rhizome material in sample

TABLE 3.18

PHYSICAL AND CHEMICAL PARAMETERS 0-2 CM SEDIMENTS

(Results in $\mu g\ g^{-1}$ on a dry basis from mean of three samples)

Station No.	Station Depth(m)	% Organic Matter	% Loss on Ignition	% Ca as $CaCO_3$	pH	Eh(mV) (instrument value)
Cockburn Sound						
2 km Grid						
1300	2.5	1.1	38.9	85.9	7.9	+ 40
1400	10.0	6.2	41.8	80.9	7.6	+ 10
1500	10.0	1.5	30.4	65.6	8.0	+ 40
1700	8.0	0.5	12.0	26.1	8.1	+ 40
1800	19.0	0.8	42.2	94.1	7.9	+ 60
1900	18.0	6.1	40.7	78.6	8.0	+ 20
2000	9.0	2.6	35.6	74.9	8.0	+ 40
2100	4.0	0.7	10.7	22.7	8.0	+ 60
2200	6.0	1.2	34.7	76.1	8.1	+ 60
2300	20.0	3.7	40.7	84.1	7.8	+ 20
2400	20.0	4.1	41.8	85.6	7.9	+ 10
2500	18.0	2.8	41.4	87.7	7.9	- 30
2600	9.0	2.0	35.9	77.0	7.8	+ 10
2700	5.2	1.9	23.4	48.8	7.9	+ 40
2900	20.0	6.5	42.3	81.3	8.0	+ 30
3000	19.0	5.4	40.3	79.3	8.0	+ 10
3100	16.0	3.3	39.8	82.9	7.9	+ 10
3200	9.0	2.7	37.4	78.8	7.8	+ 20
3300	3.0	1.6	11.8	23.1	7.9	+ 40
3400	20.0	4.4	41.0	83.1	8.0	+ 120
3500	19.0	3.9	38.8	79.3	7.9	+ 60
3600	16.0	4.4	41.9	85.2	7.9	+ 40
3700	10.0	6.3	24.8	42.0	7.7	+ 60
3900	20.0	4.6	41.5	83.8	8.0	+ 40
4000	19.0	5.0	41.6	83.1	7.9	+ 40
4100	15.0	0.6	40.0	89.5	7.9	+ 20
4300	19.0	1.2	42.4	93.6	8.0	+ 20
4400	20.0	7.7	40.6	74.7	8.0	+ 20

Table 3.18 (Cont'd)

Station No.	Station Depth(m)	% Organic Matter	% Loss on Ignition	% Ca as $CaCO_3$	pH	Eh(mV)
Cockburn Sound						
2 km Grid						
4500	18.0	6.7	41.9	79.9	7.7	+ 60
4700	2.0	7.2	40.0	74.5	7.9	+ 210
4800	20.0	4.3	41.2	83.8	7.8	+ 120
4900	2.0	1.2	31.0	67.7	8.0	+ 30
5000	18.5	6.3	28.9	50.6	7.8	+ 30
5100	5.0	0.8	39.2	87.2	7.9	+ 20
5200	12.0	0.6	31.5	67.9	8.1	+ 40
5300	5.5	0.6	13.1	28.4	8.1	+ 60
Owen Anchorage						
2 km Grid						
0300	6.0	3.5	39.5	81.8	8.0	+ 30
0500	18.0	0.8	28.3	62.4	8.0	+ 30
0600	10.5	4.1	34.6	69.3	7.9	+ 30
0800	13.0	2.4	42.2	90.4	7.9	+ 20
0900	7.0	0.8	30.2	66.8	8.0	+ 40
1000	8.0	3.6	20.8	39.0	7.9	+ 30
Warnbro Sound						
Grid						
W1	18.0				8.1	+ 30
W2	15.0				8.0	+ 30
W3	15.0				8.1	+ 20
W4	6.0				8.1	+ 10
W5	8.0				8.1	+ 30
W6	3.0				8.0	+ 30
Woodman Point						
Grid						
1300	2.5	1.1	38.9	85.9	7.9	+ 40
1304	3.0	0.8	15.1	32.5	8.1	
1316	18.0	9.4	24.6	34.5	7.5	+ 10
1320	14.0	9.8	41.2	71.3	7.6	

Table 3.18 (Cont'd)

Station No.	Station Depth(m)	% Organic Matter	% Loss on Ignition	% Ca as $CaCO_3$	pH	Eh(mV)
Woodman Point						
Grid						
1400	10.0	6.2	30.2	63.8	7.6	+ 10
1416	10.0	2.1	30.2	63.8	7.8	
1800	19.0	0.8	42.2	94.1	7.9	+ 60
1900	18.0	6.1	40.7	78.6	8.0	+ 20
1904	9.0	8.4	22.1	31.1	7.8	
2000	9.0	2.6	35.6	74.9	8.0	+ 40
Mangles Bay						
Grid						
4510	7.0	1.3	23.0	49.3	8.0	- 10
4524	7.0	1.0	22.4	48.6	8.0	+ 10
4800	20.0	4.3	41.2	83.8	7.8	+ 120
4812	7.0	1.9	33.4	71.6	7.8	- 20
4928	1.0	2.9	18.1	3.4	8.0	+ 40
5000	18.5	6.3	28.9	50.6	7.8	+ 30
5016	2.0	1.6	32.0	69.1		
5100	5.0	0.8	39.2	87.2	7.9	+ 20
AIS/BP Grid						
2630	10.0	3.2	26.3	52.5	7.7	
3220	10.0	7.3	37.8	69.3	7.8	+ 10
3228	10.0	1.5	8.6	16.1	7.9	+ 20
3600	16.0	4.4	41.9	85.2	7.9	+ 40
3604	7.0	5.1	36.8		8.0	
3612	8.5	2.9	31.2	64.3	7.9	
3614	8.0	2.0	33.1	70.6	8.0	
3620	14.0	4.5	38.2	76.5	7.9	
3622	4.5	1.6	15.7	32.0	8.0	
3628	12.0	1.4	23.5	50.2	8.0	
3629	8.0	1.0	21.4	46.3	8.0	
3700	10.0	6.3	24.8	42.0	7.7	+ 60

Table 3.18 (Cont'd)

Station No.	Station Depth(m)	% Organic Matter	% Loss on Ignition	% Ca as $CaCO_3$	pH	Eh(mV)
AIS/BP Grid						
3702	4.5	1.9	23.2	48.4	8.0	
3708	6.0	4.8	17.8	29.5	7.9	
4100	15.0	0.6	40.0	89.5	7.9	+ 20
4104	16.0	5.2	26.5	48.4	7.9	
4105	12.0	1.6	26.8	57.2	8.0	+ 40
CSBP Grid						
4120	14.0	6.4	38.3	72.5	7.8	
4126	14.0	5.8	18.6	46.5	7.9	
4414	17.0	5.8	39.0	75.4	7.9	+ 40
4500	18.0	6.7	41.9	79.9	7.7	+ 60
4502	15.5	5.9	38.7	74.5	7.7	+ 20
4504	5.0	1.0	16.0	34.1	8.0	
A	2.5	1.6	9.9	18.8	8.0	+ 40
B	4.5	0.3	8.8	19.3	8.0	+ 60
C	12.0	1.9	19.2	39.3	7.1	- 320
D	14.5	3.9	21.1	41.3	7.3	- 420
E	18.0	9.8	26.1	37.0	7.4	- 10
F	18.0	8.6	29.4	47.2	7.2	- 20
G	11.0	1.5	6.8	12.0	7.8	+ 20
H	2.0	1.3	28.1	60.9	7.8	+ 20

TABLE 3.19

STATIONS LISTED IN ORDER OF DECREASING ALKANE CONTENT WITHIN SEDIMENTS

Date	Station	Location	Total Alkanes ($\mu g\ g^{-1}$ wet weight)
16.10.78	10	S.E.C.	28
"	11	James Point	17
"	12	Sth BP Dolphin Centre	13
"	13	James Point	10
"	14	James Point	9
"	15	BP Outfall	8
"	1	Nth Garden Island	3
"	16	Five Fathom Bank	<1

TABLE 3.20

COMPARISON OF METALS IN THE 0-2 CM SEDIMENT OF COCKBURN SOUND WARNBRO SOUND AND OWEN ANCHORAGE WITH DATA FROM OTHER STUDIES

($\mu g\ g^{-1}$ dry weight)

	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Hg
Cockburn Sound	2.2-44.5	3.0-133.2	0.1-25.2	400-18200	1.0-67.0	8.9-52.8	6.2-54.6	0.1-2.2	0.6-18.4	<0.02- 2.6
Warnbro Sound	6.2- 9.7	9.7- 19.2	0.1- 0.2	2900- 3850	9.5-32.0	12.1-19.0	8.4-14.2	0.6-0.9	1.0- 1.7	--
Owen Anchorage	6.5-19.7	4.4- 28.2	0.1- 0.4	1500- 2500	2.2- 8.1	19.4-42.6	12.2-68.4	0.2-0.7	0.3- 1.0	--
Pt Phillip Bay (39)	1.0-856	5.4-1398	0.2-60	--	--	--	--	--	--	0.07-20.7
Corio Bay (14)	2-50	4-398	0.1-12.6	430-30800	8-187	2-210	--	--	--	--
Western Port Bay (40)	--	<0.7-34.9	0.1-0.67	202- 9238	116-364	<0.5-13.3	1.3- 8.0	0.5-7.5	<0.5-6.1	0.002-0.042
Derwent Estuary (28)	<5-10100	<50-104000	<0.5-862	570-161000	0.8-8900	<5-15000	0.5-258	0.4-137	0.3-42	<1-1200
Long Is. Sound (41) New York	<2-269	3-354	1-4.2	--	15-1218	6-210	3.3-207	0.5-14.8	<2-41.6	<0.1-2.2

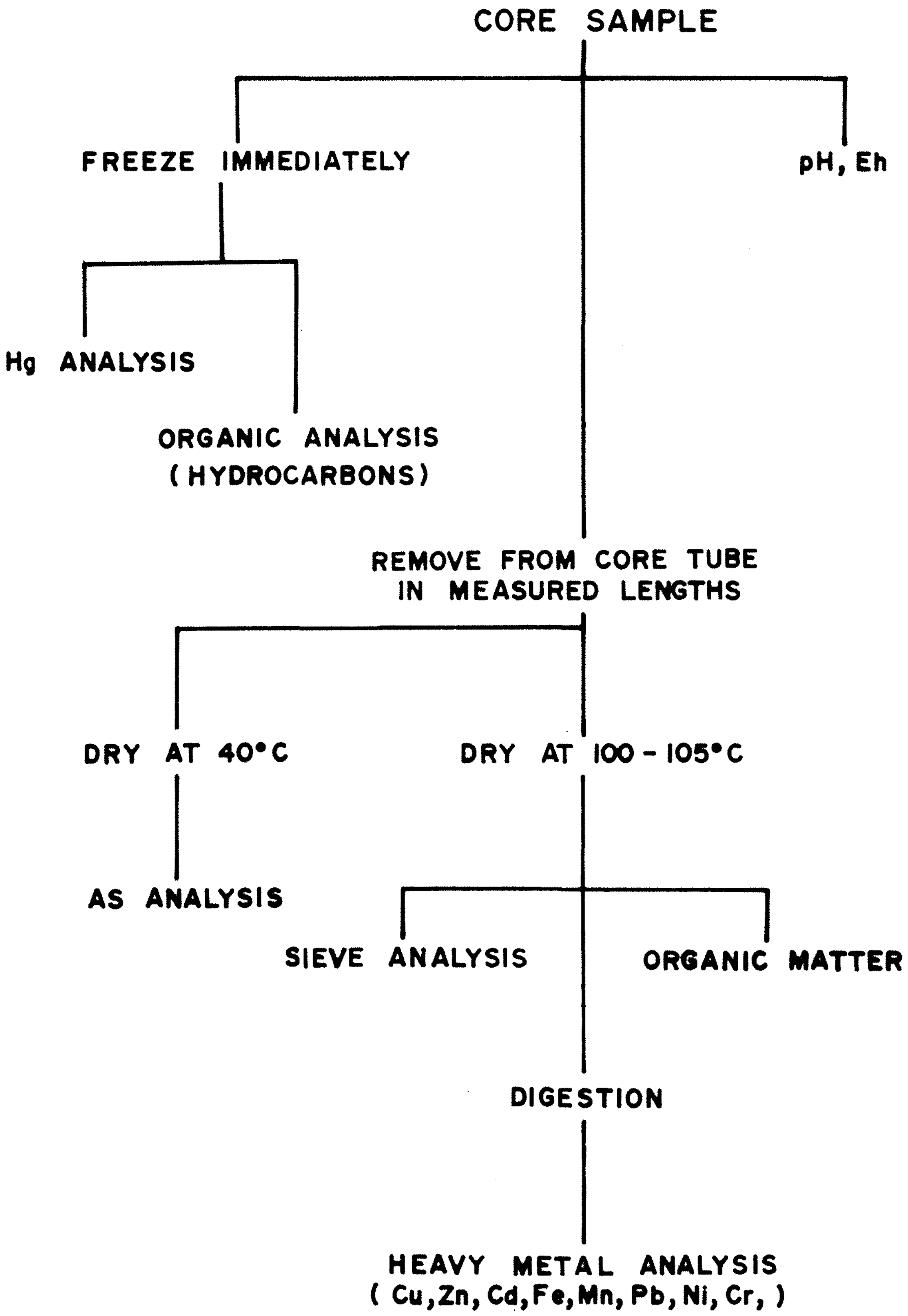


FIGURE 3·1
PROCEDURES ADOPTED FOR PROCESSING SEDIMENT CORES

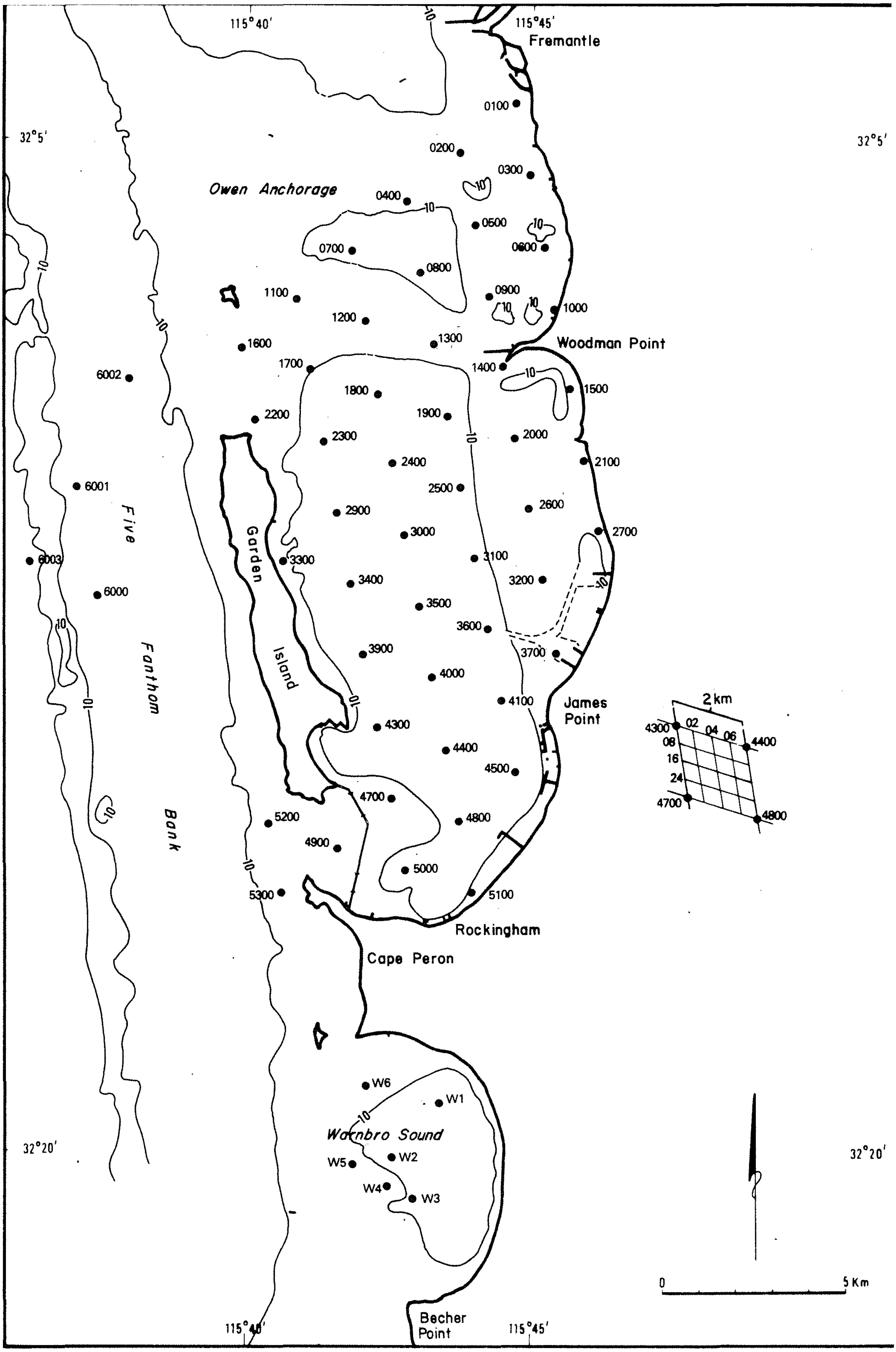


Figure 3·2

MAIN SEDIMENT SAMPLING SITES IN THE COCKBURN SOUND AREA

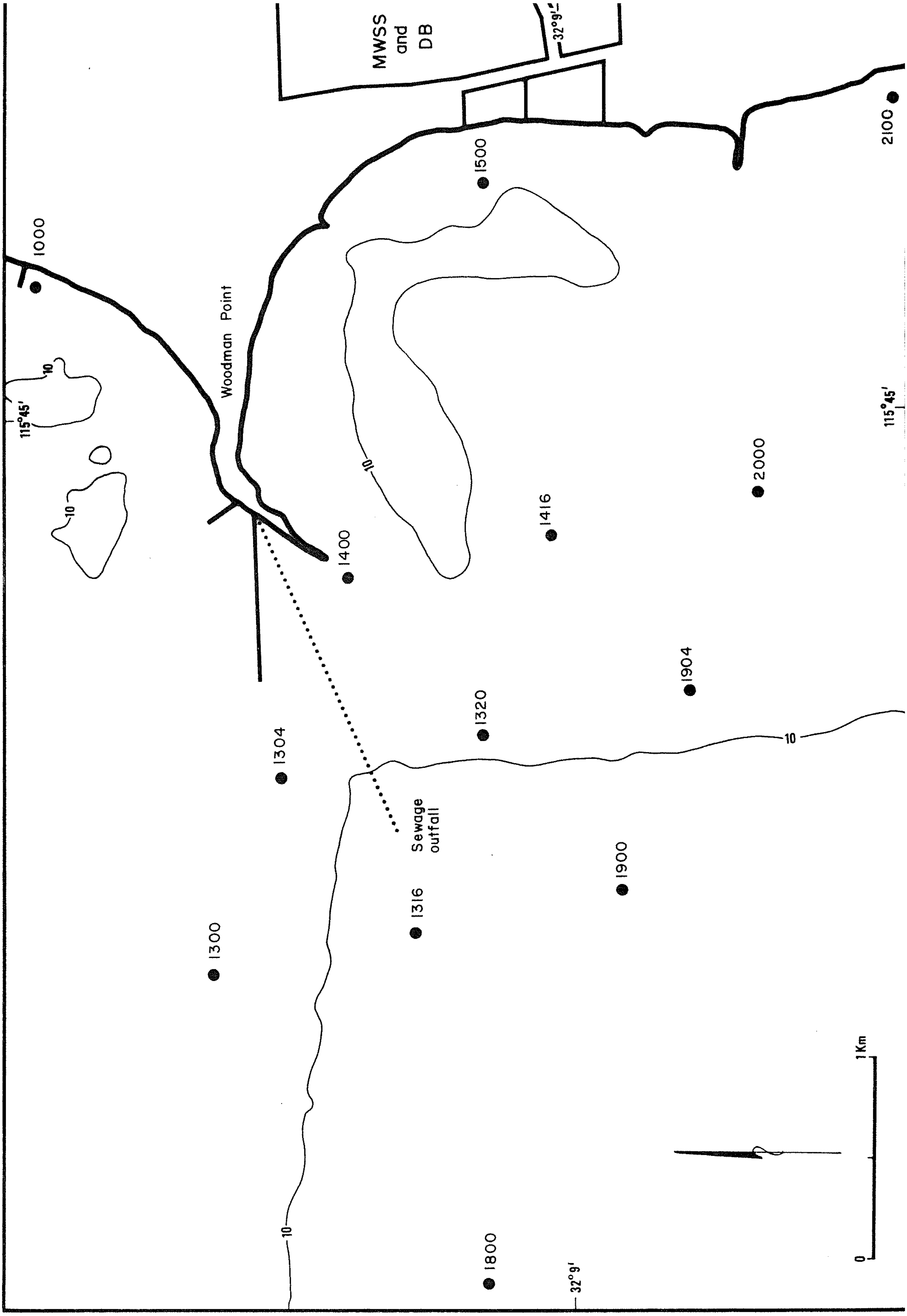


Figure 3·3

FINE SAMPLING GRID IN THE WOODMAN POINT SEWAGE OUTFALL AREA

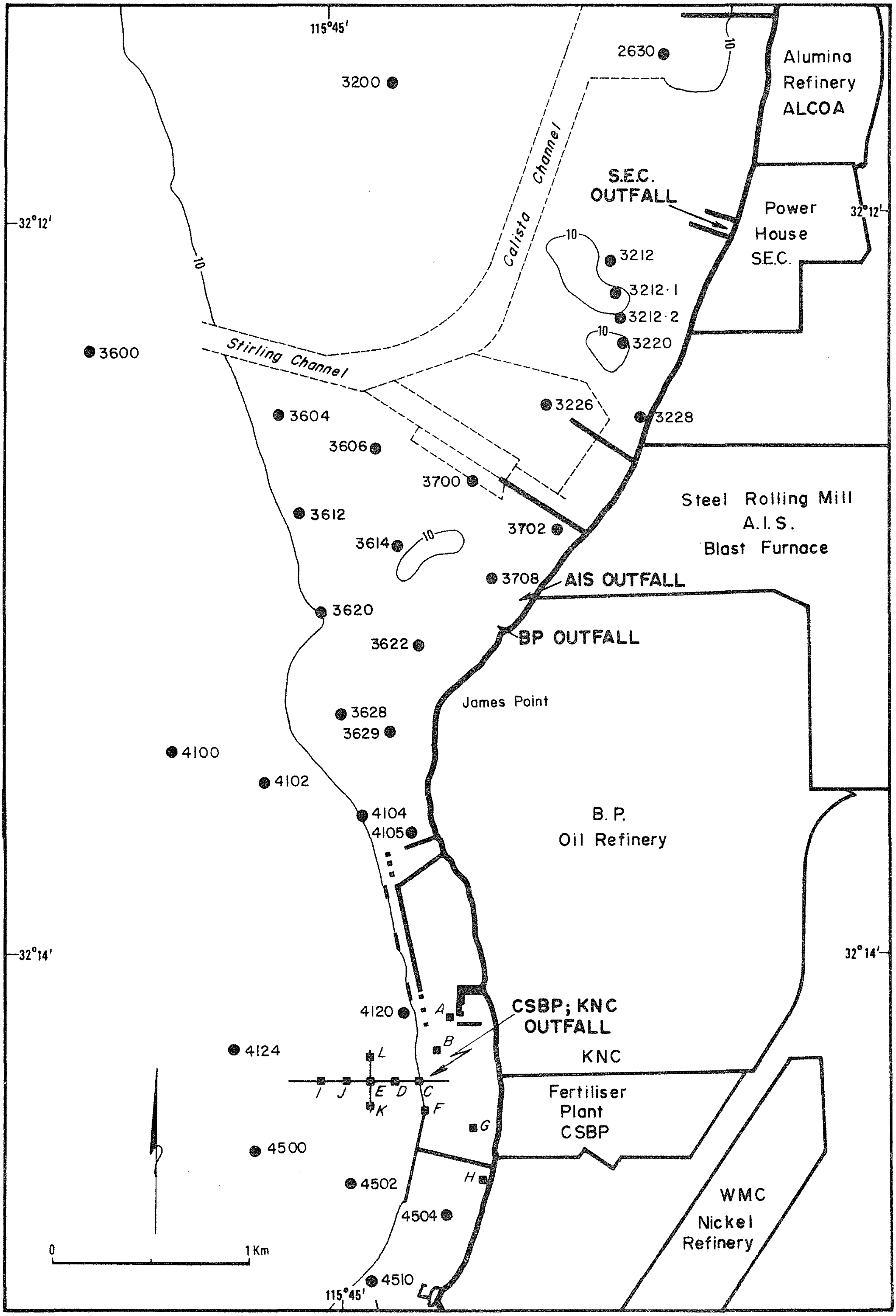
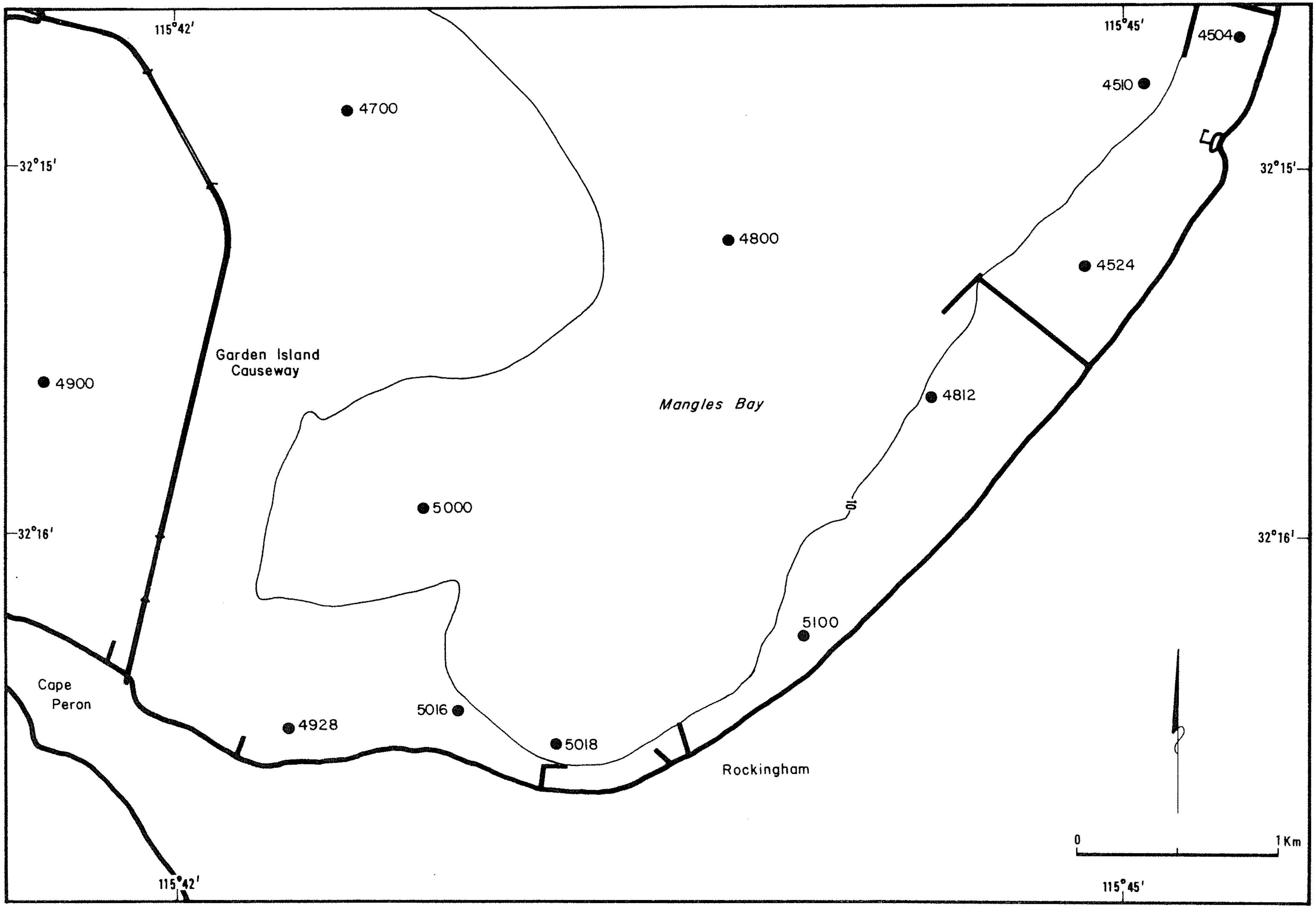


Figure 3·4

FINE SAMPLING GRID IN THE AIS/BP/CSBP OUTFALL AREAS

Figure 3.5

FINE SAMPLING GRID IN THE MANGLES BAY AREA



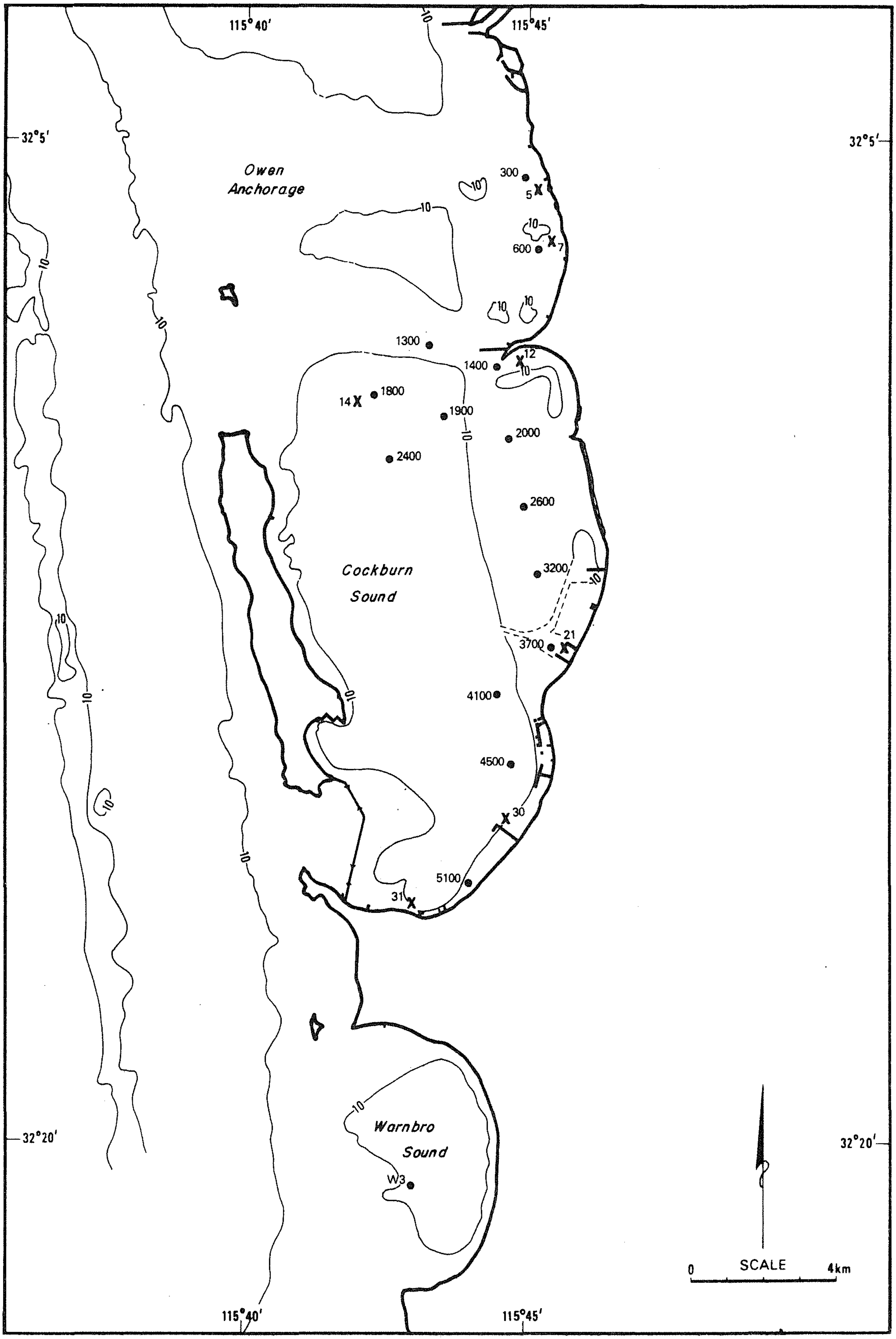


Figure 3·6
SAMPLING STATIONS FOR MYTILUS (crosses) AND SEDIMENTS (dots) FOR DETERMINATIONS OF CHLORINATED PESTICIDES AND POLYCHLORINATED BIPHENYLS

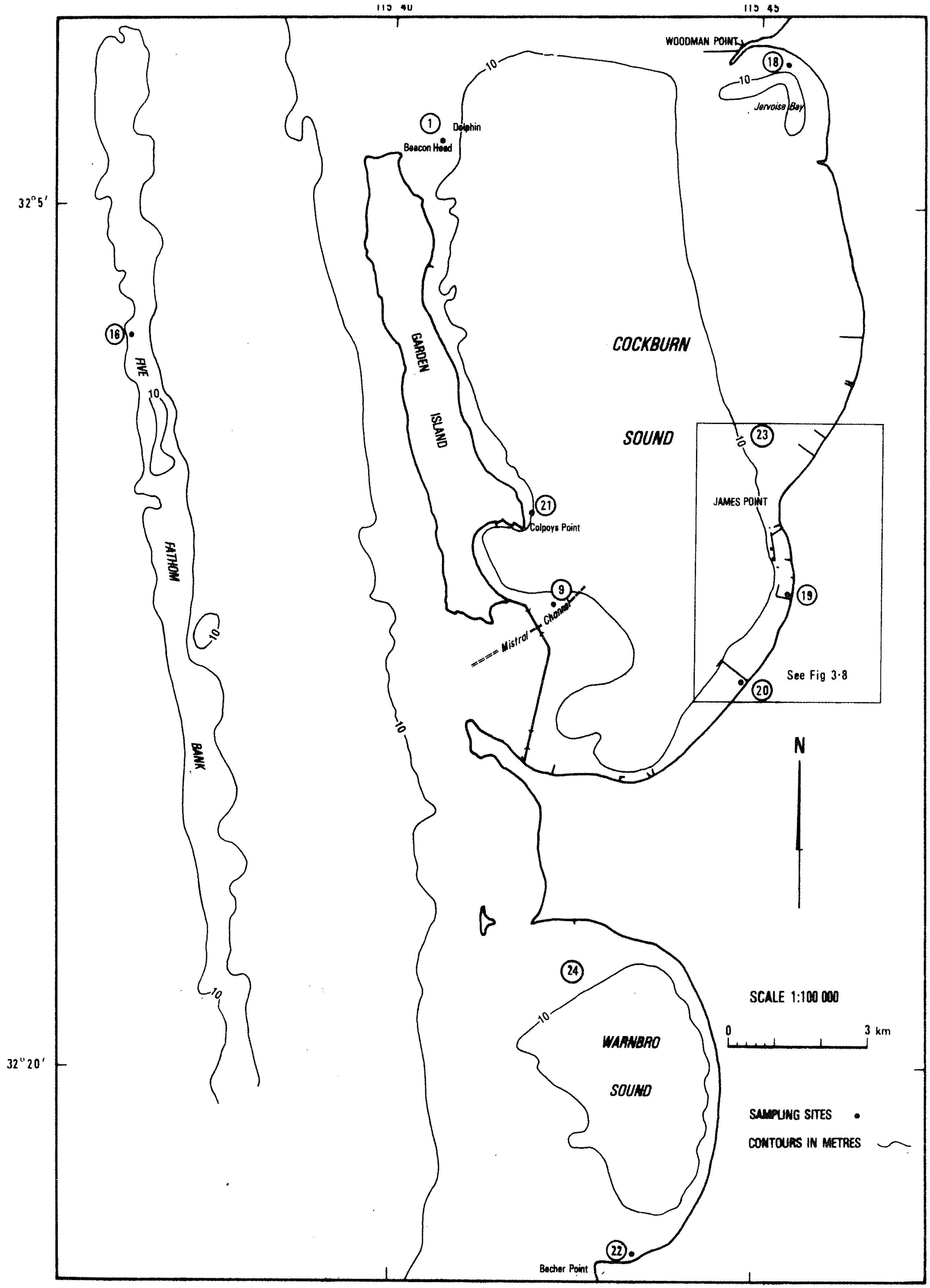


FIGURE 3·7

SEDIMENT AND BIOTA SAMPLING SITES IN COCKBURN AND WARNBRO SOUNDS FOR HYDROCARBON ANALYSIS

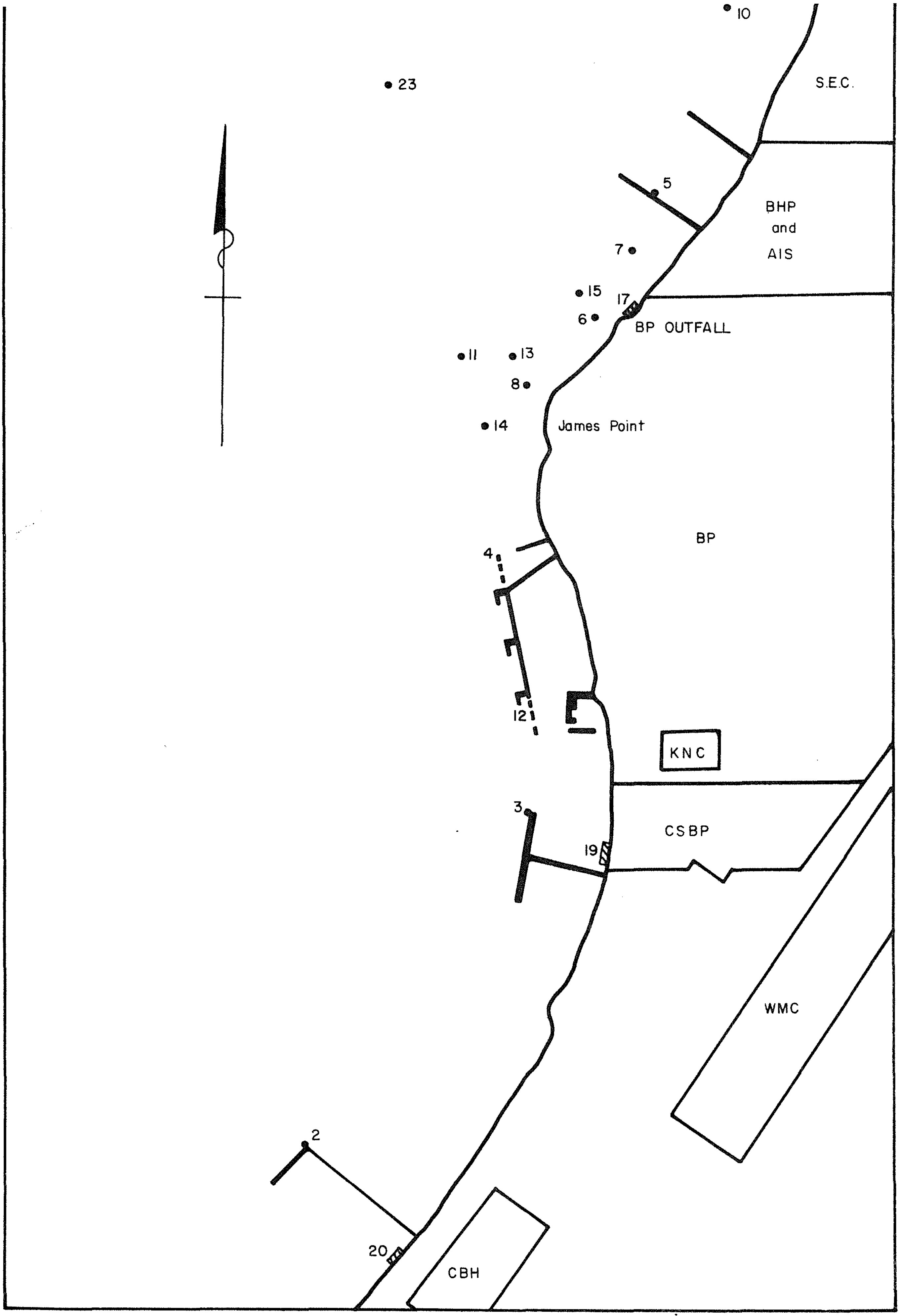


FIGURE 3·8

SEDIMENT AND BIOTA SAMPLING SITES IN THE JAMES PT AREA FOR HYDROCARBON ANALYSIS

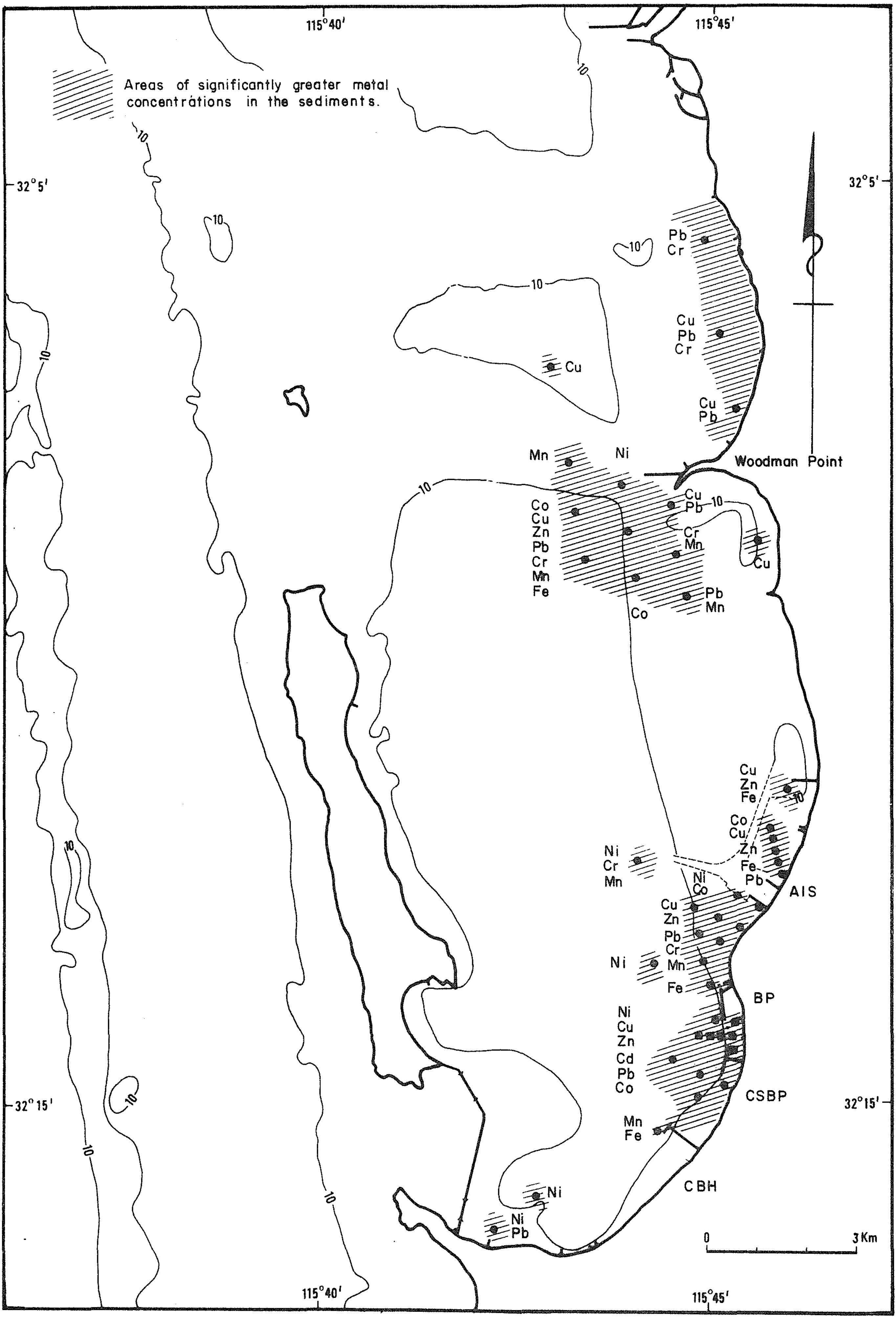


FIGURE 3·9

SEDIMENT (0-2 cm) STATION AREAS SHOWING SIGNIFICANTLY GREATER LEVELS OF HEAVY METALS

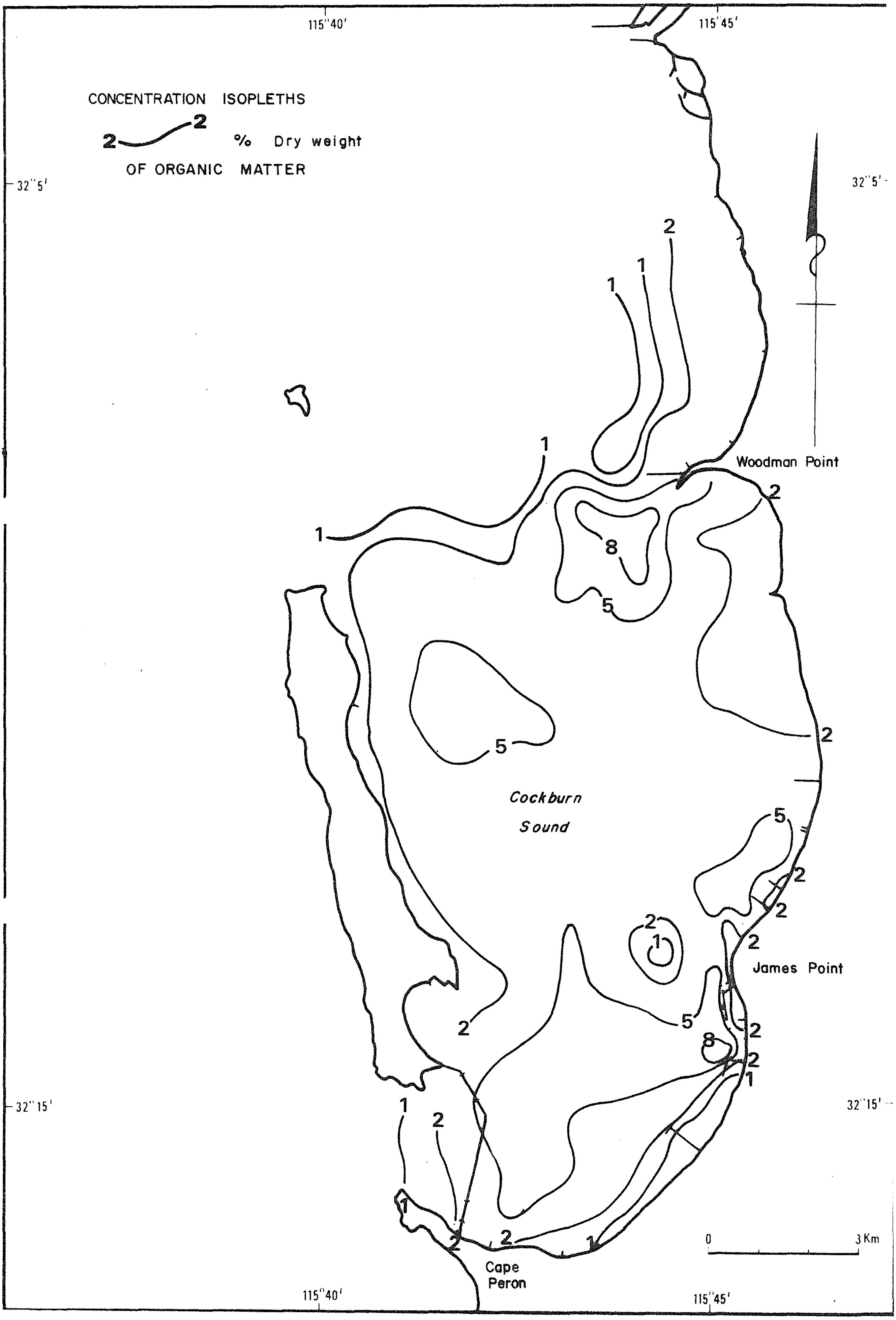


FIGURE 3·10

CONCENTRATION ISOPLETHS FOR ORGANIC MATTER IN SEDIMENTS

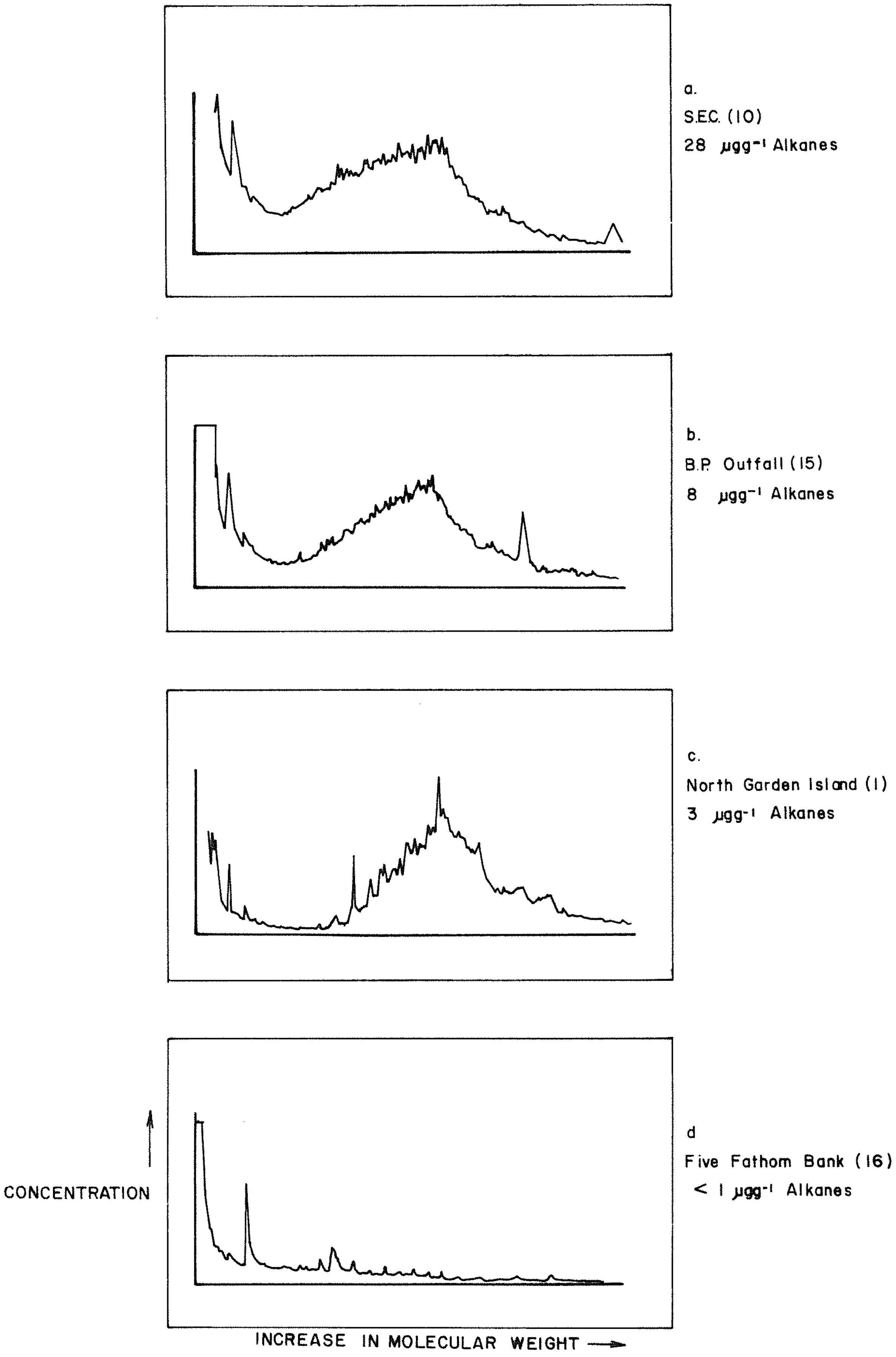


FIGURE 3·11

GAS CHROMATOGRAMS OF ALKANES ISOLATED FROM SEDIMENTS COLLECTED IN COCKBURN SOUND AND AT FIVE FATHOM BANK

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4. BIOTA

SUMMARY

Marine fauna and flora from Cockburn Sound and surrounding areas were collected and analysed for various heavy metals including copper, zinc, cadmium, lead and chromium. Some of the species were examined for enteric bacteria and petroleum derived hydrocarbons.

The fauna sampling programme included the common mussel, *Mytilus edulis*, blue manna crabs, *Portunus pelagicus*, mud oysters, *Ostrea angasi*, and the polychaete worm, *Chaetopterus variopedatus*. Mussels were examined periodically from November 1977 to February 1979, for heavy metal accumulation and to a lesser degree for hydrocarbon uptake and enteric bacteria contamination. Crabs were sampled during 1978/1979 and their flesh and hepatopancreas were analysed for heavy metals and hydrocarbons. Polychaete worms were surveyed once for heavy metal content. The results from these programmes suggest that in some of these species heavy metals, hydrocarbons and enteric bacteria are elevated to various degrees in the Study area.

Mytilus were analysed for chlorinated hydrocarbon content but none was detected.

The species of flora sampled and analysed were the sea lettuce, *Ulva lactuca*, the seagrasses, *Posidonia australis and Posidonia sinuosa*, and their epiphytes. The results show some accumulation of heavy metals in the flora but there was little evidence of a build-up of the alkane fraction of petroleum derived hydrocarbons in the samples.

From a total of 200 mussel samplings, 92 (46 per cent) were unsatisfactory for human consumption because of bacteria. The criteria used as an indicator of bacterial contamination were *Escherichia coli* greater than ten per gram of mussel flesh or the presence of salmonella.

The results of a fish sampling programme and subsequent analysis for heavy metals and hydrocarbons are given in Chapter 5.

4. BIOTA

4.1 Introduction

4.1.1 General

The selection of biota species for the measurement of accumulation of contaminants depended on the following:

(a) the distribution of species in Cockburn Sound,

(b) the ability of species to accumulate foreign substances,

(c) the position of the species in food chains, and

(d) public health considerations.

The F.A.O. Bulletin 150 (1976) (1) suggested numerous species as indicators of contamination by accumulation. These suggestions were taken into consideration when the selection was made.

4.1.2 Marine fauna

The common mussel, *Mytilus edulis* -
Research reported in the literature increasingly suggests that some bivalve molluscs may have a valuable role as indicators of pollutants in coastal marine waters (2), (3). Several species accumulate metals, chlorinated hydrocarbons, petroleum hydrocarbons and pathogenic bacteria by their filter feeding habits. A single *Mytilus* 50 to 60 cm long may filter about 37 litres of seawater per day (4). If an organism is to act as a reliable indicator of trace metals a simple correlation should exist between the metal concentration in the organism and that in the surrounding water. Another consideration when comparing concentrations of metals in an organism from several areas is that local environmental conditions can cause atypical net uptake of metals. In bivalves the concentrations of some metals vary with the size of the individual, season, position of the animal in the water column and salinity (5). Knowledge of the population age is also important as an aid to interpretation of data. If these factors are known, *Mytilus* can be used very effectively as a pollution indicator. In the present study these variables were accounted for and sampling sites were selected for an initial screening of *Mytilus* encompassing Owen Anchorage, Cockburn Sound and Shoalwater Bay (see Figure 4.1).

To complement the seawater monitoring survey discussed in Chapter 2, mussels were sampled from the same areas for enteric bacteria examination (see Figure 2.12, Chapter 2). Shellfish elsewhere in the world have been widely implicated in transmission of complaints such as *Salmonella*, gastro-enteritis, typhoid and paratyphoid fevers, and *Vibro parahaemolyticus* infection. *Mytilus*, as sedentary filter feeders, are particularly susceptible to contamination by micro-organisms.

The mud oyster, *Ostrea angasi* -
Ostrea is a bivalve mollusc with accumulation abilities similar to *Mytilus*. Concentration factors attributed to an oyster species are compared to those of scallop species and mussel species in Table 4.1 (6).

4.1.2 (Cont'd)

The blue manna crab, *Portunus pelagicus* -
The aim of the sampling programme for *Portunus* was to gauge heavy metal accumulation in relation to Western Australian public health standards and to relate the feeding habits to these levels. Specifically, metal concentrations in the flesh were to be related to the catch area, and levels in the hepatopancreas to those in the food species of the immediate environment (see Figure 4.2).

The polychaete worm, *Chaetopterus variopedatus* -
These animals are filter feeders and possibly exhibit similar trends for heavy metal concentration as do *Mytilus* from the same area. Polychaetes live in the finer deep basin sediments in large numbers, but few were available from the coarse sand on the shallower banks (see Figure 4.3).

4.1.3 Marine flora

Seagrass of the *Posidonia* species -
These flora were analysed to gauge variations in the metal and hydrocarbon content from various places within Cockburn Sound and Warnbro Sound.

The epiphytic growth on the seagrass leaves varied in species composition and quantity with different locations. The epiphytes, thought to be good indicators of pollution (7) were scraped from the seagrass and analysed for heavy metal accumulation.

The sea lettuce, *Ulva lactuca* -
Ulva has been cited as a species which not only assimilates heavy metals but also thrives in polluted waters (8). It was examined principally to gauge its potential as a pollution indicator.

4.1.4 Role of the species examined

Mussels, oysters and polychaete worms were examined because of their contaminant accumulation tendencies as well as their positions in the food chain. The aim was to link the distribution of contaminant concentrations in these faunal species and the flora examined with contaminants known to be discharged in effluent streams (24) and with those found in the sediments and water.

Dybdahl (26) has found that large quantities of crabs and mussels from Cockburn Sound are sold for consumption.

Western Australian and recommended NH & MRC standards are listed in Table 4.2. Appendix VI gives a "Draft of the Revised Standard (NH & MRC) for Metals in Foods", June 1979.

4.1.5 Review of previous studies on heavy metals in the common mussel, *Mytilus edulis*, in Cockburn Sound

Mussels were analysed for a range of heavy metals in two studies in 1970 for the Fremantle Port Authority (7). No particular distribution of contamination was evident and no pattern of accumulation or otherwise could be established from the two sets of data. This was considered by the authors to be due to an ability by mussels to avoid accumulation of trace metals.

Population and growth characteristics of mussel colonies around the Sound were also investigated in these studies. They showed a wide variation in growth rates with area and, therefore, little correlation between length and age.

4.1.5 (Cont'd)
Overall it was concluded by the authors that mussels were unsuitable as indicators of water quality.

Data from the Government Chemical Laboratories study in July, 1974 (9), however, showed raised cadmium, chromium and mercury levels in the vicinity of CSBP. While that trend was established within the data, actual levels, particularly those which might be termed background, were generally an order of magnitude lower than those of this study and those reported by Goldberg *et al* (1978) (2).

4.2 Experimental Methods

4.2.1 *Mytilus edulis*

This work was undertaken in three distinct phases:

(a) the initial screening of mussels in areas mentioned in 4.1.2 to evaluate possible areas of metal contamination,

(b) long-term monitoring of selected areas within Cockburn Sound, and

(c) assessment of the uptake and depuration rates for cadmium in mussels.

On the 16 November 1977 divers collected bulk samples of approximately 50 to 100 *Mytilus* from each of 32 sites between Owen Anchorage and Shoalwater Bay (Figure 4.1). The samples were taken from fixed man-made structures at depths of 1 m below the water surface and 1 m above the bottom (water depth permitting) to test for contamination and differences in metal concentration due to depth. Five representative mussels with lengths between 55 and 75 mm were chosen from each bulk sample. The shells were scrubbed in running water and then the animals were left to depurate in clean seawater for 48 hours. Details of locations are given in Table 4.3.

As Cockburn Sound results of the initial screening for cadmium, lead and zinc exceeded Western Australian or NH & MRC health standards (see Results) for some stations, these were sampled from that time until February 1979 as indicated in Table 4.5.

To test for uptake rates for cadmium mussels were collected from the Buchanan Bay Buoy (Station 20) and selected to a standard shell length of 50 to 54 mm. Fifteen to 20 individuals were placed in each of 20 nylon mesh bags and five bags hung at each of the CBH, CSBP and AIS jetties with bags remaining at Buchanan Bay to act as controls (Figure 4.6).

Excretion rates were checked using a similar transplant method. Mussels from CSBP and CBH jetties were taken to Buchanan Bay Buoy and also placed in clean seawater aquaria (Figure 4.6). The mussels were analysed monthly over a period of five months.

Forty four mussels were taken from stations 11 to 20 during November 1977 and dried at 105°C to determine the moisture content to aid comparison with other studies.

For analysis, the cleaned, depurated mussels were shucked and drained and a constant weight of sample digested in Aristar nitric acid. The digestion procedure adopted in this study proved to be very effective during extensive work by Bloom and Ayling (10). Analyses were carrried out using a Perkin Elmer 503 Atomic Absorption Spectrophotometer with

4.2.1 (Cont'd)

an air-acetylene flame. Deuterium lamp background corrections were applied in the case of cadmium, lead, cobalt and nickel. The experimental method was checked by standards addition and by frequent analysis of the following standards; two working standards prepared at Murdoch University (fish and mussel), a Victorian EPA mussel standard used in inter-laboratory calibrations, NBS orchard leaf and bovine liver standards (see Table 4.7). A proportion of samples from previous batches were also examined during each of the analyses (see Table 4.8). All molluscs examined had their whole soft parts analysed.

Details of analytical procedures and quality control checks are held in the Cockburn Sound Study Data Repository; "Details of Analytical Procedures".

Hydrocarbon analysis -

The Cockburn Sound Study initiated a study on hydrocarbons and a report entitled "A Preliminary Survey of Petroleum Contamination in Cockburn Sound" has been prepared by Alexander *et al* (11). In this investigation mussels were analysed for hydrocarbons and full details of the analytical procedures are given in this report which is kept in the Cockburn Sound Study Data Repository.

Mussels from Station 1 (Beacon Head at north Garden Island) were collected for comparison with mussels from other parts of Cockburn Sound. This area was thought to be relatively free from contamination, so batches from this site were transplanted to other sampling stations within the Sound to assess the rate of hydrocarbon uptake. At subsequent collections of transplants, mussels which were indigenous to that station, and also more mussels from Beach Head, were collected simultaneously for comparative purposes. A sample from Busselton jetty was also obtained and analysed to serve as a location for comparative purposes (see Figure 3.7 and 3.8). Sampling frequency and location is detailed in Table 4.11.

Each sample was made up from at least 25 individuals from water depths greater than one metre. The samples were shucked, drained, wet weighed and frozen until they were analysed. The procedures adopted were similar to those of Burns and Smith (1977) (12).

Enteric bacteria survey -

Mussels were sampled from the 18 locations shown in Figure 2.12, Chapter 2. Individual mussels were shucked under sterile conditions and pooled to give a 50 g sample. *E. coli* enumeration and *Salmonella* isolation techniques are given by Iveson (13).

Radionuclides -

The Cockburn Sound Study Group instituted a sampling programme for mussels (and surface layer sediments) from HMAS Stirling on Garden Island. Sampling commenced during February 1978. Analysis took place at the Australian Radiation Laboratory for cobalt - 60 and any other artificial gamma-ray emitting radionuclides known to characterise the radioactive waste likely to be held in a nuclear powered warship. The Study Group relinquished responsibility for sampling to the Navy in December 1978.

4.2.2 *Ostrea angasi*

Heavy metal analysis -

The numbers of individuals obtained were limited by availability in Cockburn Sound. Six collections of samples were made, two in each of March and April 1978 and four in each of September and October 1978

4.2.2 (Cont'd)
(see Table 4.13). Samples were obtained from close to the south west end of the CBH jetty and from the Destroyer Escort berth in Careening Bay, Garden Island. Those collected on the first two sampling dates were large and mature whereas those from the latter dates were only half the size. Individuals were shucked, drained, digested and the whole animal analysed in the manner described for *Mytilus*.

4.2.3 *Portunus pelagicus*
Heavy metal analysis -
Mature male and female crabs were collected by divers, trawl net and beach seine (see Figure 4.2). The initial sampling took place in May 1978, followed by more sampling during October, November and December 1978 (for sampling numbers and frequency refer to Table 4.13). Individual animals were dissected and the flesh (body muscle) and hepatopancreas digested in nitric acid prior to measurement for heavy metals by atomic absorption spectrophotometry using the instrument conditions described for the analysis of *Mytilus*.

Hydrocarbon analysis -
As with *Mytilus*, the report on "A Preliminary Survey of Petroleum Contamination in Cockburn Sound" by Alexander *et al* (11) dealt with the analytical method for this section. Crab samples comprised of at least ten individuals were divided into flesh and hepatopancreas for separate analysis. Each tissue sample was then weighed wet and frozen until analysis. Table 4.16 details the collection frequency and numbers of crabs involved in the programme.

4.2.4 *Chaetopterus variopedatus*
Heavy metal analysis -
Intact polychaete worms were collected by divers from stations shown in Figure 4.3. For analysis the whole polychaete was removed from its tube by carefully dissecting the wall, flushing out the worm with deionised water and then removing any extraneous sediment by further washing. The whole animal was digested in nitric acid and analysed by the atomic absorption spectrophotometric procedure used for *Mytilus*. Table 4.17 details the collection frequency and numbers of worms involved in the programme.

4.2.5 *Posidonia* species and their epiphytes
Heavy metal analysis -
After collecting a representative sample of seagrass from sites represented in Figure 4.4, the epiphytes were scraped from the leaves and both samples were then washed lightly and dried at 105°C and finally ground to provide homogeneous samples. A nitric acid digestion was then employed followed by atomic absorption spectrophotometric analysis. Table 4.18 details the collection frequency of this programme.

Hydrocarbon analysis -
Alexander *et al* (11) cover the experimental method for hydrocarbons in their report, "A Preliminary Survey of Petroleum Contamination in Cockburn Sound". A sample of seagrass was wet weighed and stored frozen until required for analysis. Figure 3.8 and 3.9 in Chapter 3 illustrate sampling location while Table 4.20 gives collection frequency.

4.2.6 *Ulva lactuca*

Heavy metal analysis -

Representative samples of *Ulva* were collected from four areas (see Figure 4.4); north Garden Island (Entrance Rocks), Cockburn Power Boat Club (rocks), Jervoise Bay (channel beacon) and James Point (pickets 150 m from the BP outfall), to test whether they were contaminated by heavy metals. Sample numbers are given in Table 4.19.

Samples were analysed by the same method as described above for *Posidonia*. Details of analytical procedures and quality control checks are kept in the Cockburn Sound Study Data Repository; "Details of Analytical Procedures".

Hydrocarbon analysis -

The report by Alexander *et al* (11) details the analytical procedures adopted for *Ulva*. Sample numbers are given in Table 4.20.

4.3 Results

4.3.1 *Mytilus edulis*

Heavy metals -

Table 4.4 summarises the results of the analyses of *Mytilus* from the November 1977 initial screening period. Stations are listed in Table 4.3.

Metals that were shown in this survey to exceed health standards in Cockburn Sound were cadmium, zinc and lead, with chromium and nickel of particular concern, as was lead to a lesser degree.

The analytical results for mussels sampled from selected sites in Cockburn Sound between November 1977 and February 1979 are summarised in Table 4.5.

A notable feature of this 16 month survey in Cockburn Sound is the spread of cadmium contamination southward into Mangles Bay. Each series of results in this table exhibit interesting points. For example, the results for the mussels from the Buchanan Bay Buoy are quite different to those from the Colpoys Point Buoy although they come from adjacent areas. In this case the difference would appear to be due to the age of the mussels. The mussels from the Buchanan Bay Buoy on 16 November 1977 had an average length of 68 mm with a flesh weight of 6.8 g; their age being from one and a half to two years. Whereas the mussels from the Colpoys Point was laid in May 1977. Their average length was 53 mm with a corresponding 2.5 g flesh weight. Other studies have also highlighted differences in metal concentration with the age of *Mytilus*.

At AIS the metal levels have three distinct features; there are consistently high zinc levels and relatively low copper and cadmium levels. The low uptake of cadmium may represent preferential uptake of a metal other than cadmium. These mussels are under the direct influence of the effluent streams from the AIS and BP outfalls which together contribute a third of the total zinc load to the Sound (24).

Important features relating to the CSBP results were the comparatively high values for cadmium and zinc. CBH and Palm Beach results reflect the increasing levels of cadmium in the Mangles Bay area.

Figure 4.5 shows the sampling sites around the James Point area and presents some results for November 1977 and December 1978. It illustrates the major problem areas of mussel contamination by heavy metals.

4.3.1 (Cont'd)

The results of the accumulation and depuration trials are summarised in Figure 4.7 (a), (b) and (c) while Figure 4.6 illustrates the procedures adopted in these trials.

Depuration trials illustrated in Figure 4.7 (a) indicate that cadmium levels remain high even after five months in clear seawater. The apparent small loss of cadmium concentration can be accounted for by the increase in flesh weight as the animals grew.

Cadmium uptake rate (Figure 4.7 (b) and (c)), on the other hand, had an initial rapid period with levels of cadmium in the test mussels increasing from about 0.3 $\mu g\ g^{-1}$ to more than 2 $\mu g\ g^{-1}$ in less than a month. At CBH the initial jump took the test animals to the levels seen in the local population, but as illustrated in Figure 4.7 (b) this level was about half the value for the local population at CSBP. Over the next five months the cadmium concentration of transplant animals at CSBP came within 25 per cent of the local population.

Table 4.6 indicates the type of information available from the mussel analyses. Other data sheets such as this are kept in the Cockburn Sound Study Data Repository.

Table 4.7 indicates the results obtained while checking the consistency of analyses data.

Moisture determinations carried out using 44 individual mussels resulted in a mean dry weight to wet weight conversion factor of 0.166 with a range of 0.162 to 0.171. This agrees well with the general literature range of 0.162 to 0.168 for mussel tissue.

A comparison of Cockburn Sound mussel results for heavy metals with the results from the seven studies in Table 4.8 reveals that the cadmium levels in mussels from CSBP are as high as those cited in other parts of the world. Similarly, with the exception of the Derwent Estuary study, the lead and zinc results for Sound mussels show abnormal levels when compared to the other investigations.

At Colpoys Point Buoy mercury concentrations in mussels were high, as were the cadmium results. Once again, this fact is probably due to the mussels' age when compared to the other mussels collected.

According to Murphy (24) mercury input to Cockburn Sound is from the Woodman Point sewage outfall, the AIS outfall and the CSBP outfall. Sediment contamination (see Chapter 3) correlate with the location of inputs as do the sites of mussel contamination.

Hydrocarbon (alkanes) -

The results from the analyses of mussels are shown in Table 4.10. The G.L.C. traces shown in Figure 4.8 were from the flesh of the mussel samples. Figure 4.9 and 4.10 include G.L.C. traces showing the distribution of hydrocarbons in effluent from the BP outfall to compare with traces of mussels from the Sound.

Two things are apparent from these results. The first is that mussels in Cockburn Sound are clearly contaminated with petroleum. The second is that the levels of contamination vary considerably with time and place. This is probably due to the mussels ability to depurate hydrocarbons over a relatively short period of time (27).

4.3.1 (Cont'd)
A selection of G. C. traces of alkane extracts from mussels is presented in Figure 4.8. Taking the trace for Busselton mussels as a point of reference, it is apparent that mussels from all stations in Cockburn Sound are contaminated with petroleum hydrocarbons. Although there is a wide variation in the molecular weight distribution and the types of alkanes present in different samples, in all cases the broad envelope due to napthenics and the similar amounts of odd numbered and even numbered n-alkanes which are characteristic of petroleum contamination are evident.

In an attempt to assess the contribution of BP outfall to petroleum contamination of the Sound, mussels were collected at north Garden Island (Beacon Head) and transplanted to BP outfall (Station 6). The G. C. traces obtained from alkanes isolated from these mussels were compared with a G. C. trace of BP effluent alkanes in Figure 4.9.

As would be expected, the composition of BP effluent alkanes varies from time to time, however, the trace shown in Figure 4.9 (a) is representative of those obtained in the present study. The isolation procedure used for the effluent depleted the lower molecular weight alkanes. In this way it differed from the technique for mussels. In order to assess the extent of this depletion, a separate trial was carried out (11).

Comparison of the traces shown in Figure 4.10 shows that when the BP effluent was extracted in a manner similar to that used for mussels (Figure 4.10 (a)), the organics obtained,contained a substantial amount of low molecular weight material which was lost when the extracts were subjected to the procedures used for isolation of alkanes from BP effluent (Figure 4.10 (b)). The traces shown in Figure 4.8 and 4.9 and other traces of mussel alkanes obtained in this work show that mussels collected along the eastern shore of the Sound usually contained low molecular weight alkanes, however, it was not possible to determine conclusively whether these were derived from BP effluent water.

Enteric bacteria -
Refer to Figure 2.12 and Iveson (13) for details of sampling sites of comprehensive breakdown for the results of the isolations in mussels is given in Table 4.11. Salmonella were detected in 74 (37 per cent) of 200 mussel samples examined from 17 sites and 20 serotypes were identified.

S. derby (39), *S. anatum* (20), *S. adelaide* (18), *S. havana* (18), *S. livingstone* (13), and *S. typhimurium* (12) were the major strains detected.

At abattoir outfall sites and associated trades 90 per cent of mussels were infected, shoreline recreational sites 45 per cent, other shoreline groynes and jetties 38 per cent and offshore pylons and beacons 22 per cent.

E. coli levels greater than 10 per g with or without the presence of salmonella were recorded in 90 per cent mussels from abattoir shoreline sites,public recreation areas 30 per cent, shoreline pylons and groynes 30 per cent and offshore pylons and beacons 24 per cent. Overall on the basis of greater than ten per g *E. coli* or salmonella positive criteria in a total of 200 mussel samples 92 (46 per cent) were unsatisfactory for human consumption without further treatment and presented a significant health hazard to the individuals harvesting mussels at contaminated sites. No *V. parahaemolyticus* isolations were recorded throughout the survey in mussels.

Radionuclides -
Tests for these contaminants from February to December, 1978, proved negative in mussels (and surface sediments.)

4.3.2 *Ostrea angasi*

Heavy metals -

Samples of mud oysters were collected and a summary of results for the analyses are given in Table 4.12.

Ostrea display a very large range of high metal concentrations. Concentrations of lead, copper and cadmium are comparable to the *Mytilus* high range figures.

Levels of chromium and zinc for these animals are extremely high in the Sound, although concentrations up to 6 400 $\mu g\ g^{-1}$ zinc have been reported for *Ostrea* in the Derwent Estuary. This can be compared to maximum values of 1 190 $\mu g\ g^{-1}$ in Cockburn Sound and 770 $\mu g\ g^{-1}$ reported in Westernport Bay.

The only consistent difference in metal levels between animals from the east side of the Sound versus the west side was for cadmium. *Ostrea* from the east coast near CBH had approximately one third more cadmium in them than those from the Destroyer Escort berth on Garden Island, for comparable samplings.

The five elements analysed had levels that exceeded Western Australian and NH & MRC recommended health standard on at least two samplings.

4.3.3 *Portunus pelagicus*

Heavy metals -

Samples of crab flesh and hepatopancreas from crabs collected in two summer sampling periods were analysed. The results are summarised in Table 4.13 and 4.14. The sex of the individual animals was noted. However, there appeared to be no detectable sex based difference in analyses, so the results were pooled.

Lead was the only metal to exceed health regulation levels in flesh and this occurrred in 15 per cent of the samples. Heavy metals were found to accumulate in the hepatopancreas. Levels of zinc, cadmium and lead were consistently higher than the State health standards in this organ.

The only metal to show no difference between levels in flesh and hepatopancreas was chromium. The metals copper, zinc, cadmium and lead had concentration factors in the hepatopancreas of about 3.5, 4.5 and 2.5, respectively, when compared to flesh values. Those people who eat both crab hepatopancreas and flesh, therefore, ingest a higher metal load than those who might eat flesh alone (Tables 4.14 and 4.15).

Hydrocarbons (alkanes) -

The results from the analyses of crab flesh and hepatopancreas sampled in Cockburn Sound are shown in Table 4.15. The G.L.C. traces illustrating the alkane distribution in selected samples are shown in Figure 4.11.

The outstanding feature of these results are the variability of the levels found (greater than one order of magnitude) and some show very high levels of contamination. The sample G.L.C. traces shown in Figure 4.11 show the unresolved envelope between C_{14} and C_{26} characteristic of naphthenics from petroleum (11). Low molecular weight alkanes were not found in any samples, and the proportion of n-alkanes is also very low. The distribution of alkanes in flesh was similar in all cases to that in the corresponding hepatopancreas sample.

4.3.4 *Chaetopterus variopedatus*

Heavy metals -

Table 4.16 presents the data for the analysis of whole polychaete worms.

These animals proved to be very good heavy metal indicators when compared to the sediments from which they were taken. Although they are filter feeding polychaetes rather than sediment feeders, by living in the sediments they ingest some of the fine silt that surrounds them. Thus the heavy metals in the gut probably contribute a high proportion of the total heavy metal figure for the whole animal.

If the metal levels in the polychaetes from Shoalwater Bay are taken as a baseline then the only animals from Cockburn Sound that approach their low values are those from sample I (sediment station 1800) and sample X (sediment station 5000). These two stations are at the extreme ends of the Sound (Figure 4.3) The nearest effluent input to sample I area is the Woodman Point sewage discharge but the area is also influenced by an influx of clean water and larger sediment fractions carried down the Parmelia Bank Shipping Channel. Sample X was collected in Mangles Bay and is south of the Kwinana industry. The generally elevated levels at all sampling stations indicate the widespread contamination by metals in Cockburn Sound compared to Warnbro Sound, particularly for copper and cadmium.

The presence of the copper, zinc and cadmium discharges are reflected in the elevated levels of these metals in the polychaetes from the CSBP area. The animals from the BP and sewage discharge areas indicate high copper and zinc values. The elevated levels of zinc and cadmium extends south past the CBH jetty, with cadmium presumably originating from the CSBP discharge.

4.3.5 *Posidonia* seagrass species and their epiphytes

Heavy metals -

Table 4.17 presents the data for the analyses of *Posidonia* seagrass species (*P. sinuosa* or *P. australis*) and their epiphytes.

The results in Table 4.18 indicate that, for the metal examined, the levels in the *Posidonia* species and the epiphytes from Cockburn Sound are different although, for cadmium, a degree of similarity exists. The elevated levels observed for iron when compared to other metals in both the seagrass and epiphytes could be, in part, due to iron being an essential element in these organisms.

Excluding cadmium, the results for seagrass and epiphytes at Station T were generally higher than all the others. This station is close to the Alcoa jetty and reflects generally raised metal levels in the water column on the eastern side of Cockburn Sound. Two stations (U and W) from Warnbro Sound show some of the lowest metal values of all the samples gathered. However, the copper results for the third sample from this area (station V) do not show this trend. Copper, zinc amd cadmium were slightly higher in *Posidonia* from Cockburn Sound than in this species from Warnbro Sound.

4.3.6 *Ulva lactuca*

Heavy metals -

The levels for metals in *Ulva* reported in Table 4.18 show some striking differences between collection areas. Zinc, cadmium, iron, manganese and lead show increased levels around the BP - James Point area using the Garden Island results as a baseline. The Garden Island station, while having relatively low values for the five elements just mentioned,

4.3.6 (Cont'd)

also has the lowest values for cadmium and lead. The results indicate that all the sea lettuce collected from within Cockburn Sound was contaminated by cadmium and lead. Levels of zinc, iron and manganese were elevated only in the samples from James Point. Copper has not accumulated suggesting that the plant may have a mechanism for its protection.

Hydrocarbons (alkanes) in the alga *Ulva lactuca* and the seagrass *P. sinuosa* -

The results for samples collected from the Cockburn Sound and Warnbro Sound areas are shown in Table 4.19.

As is evident from the G.L.C. traces shown in Figure 5.6, alkanes isolated from these samples showed no prominent unresolved envelope due to naphthenics. The concentration of alkanes was 3 ppm or less in all samples. The GC traces which gives a measurement for the total pentane-soluble organics (see Figure 6 (c)) shows that aromatics, in particular cresols, were present in this sample, but detailed work was not carried out on this extract.

4.4 Discussion

An assessment of the mussel results for metals from Cockburn Sound areas distant from industry, and other areas of the world (Figures 4.4, 4.5 and 4.9), suggest that the levels which indicate metal contamination are in excess of 0.5 μg g^{-1} cadmium, 1.5 μg g^{-1} copper, 1.0 μg g^{-1} lead, 30 μg g^{-1} zinc, 0.5 μg g^{-1} chromium, 40 μg g^{-1} iron, 2.0 μg g^{-1} manganese, 1.0 μg g^{-1} cobalt and 1.0 μg g^{-1} nickel (wet weight).

Beacon Head (north Garden Island) was chosen for sampling because it was felt that mussels from this area would show only background levels of contaminants. This assumption proved to be wrong as cadmium levels were relatively high and on one occasion the Western Australian health standard for zinc was exceeded (see Table 4.5). The results reflect the generally high elevated levels of these two metals in the Cockburn Sound environment and possibly an influence from the Woodman Point sewage outfall.

Values for the Western Australian and recommended NH & MRC health standards were used to compare with the results obtained for metal analysis of biota. For some metals one or the other of the standards may not be applicable. For example the Western Australian standard for cadmium would appear to be too high when compared to Food and Agriculture Organisation/World Health Organisation (F.A.O/W.H.O) and NH & MRC recommendations. Alternatively the Western Australian zinc standard is probably too low. These types of anomalies have been recognised by the NH & MRC in the June 1979 draft paper recommending standards for metals in foods (28) (see Appendix VII).

Cadmium is a highly toxic metal to man with no known biological function. Recent studies have linked cadmium with serious renal damage, hypertension, respiratory effects, carcinogenesis, tetratogenesis and embryotoxicity. Some minor effects have been noted on livers, moderate anaemic and testicular damage (18).

The W.H.O. provisional tolerable weekly intake for cadmium in food is 0.4-0.5 mg per person per week (28). The NH & MRC has computed the average Australian dietary intake of cadmium from non seafood sources as

4.4 (Cont'd)

0.2-0.3 mg per person per week (19). Taking a mean for these two sets of figures and subtracting one from the other leaves an allowable intake of 0.2 mg of cadmium per person per week from seafood sources.

The results for cadmium in mussels taken from CSBP (station 27, Figure 4.1) on the 19 December 1978 were an average 8.9 μg g^{-1} (wet weight) for a 7.9 g mussel. Therefore, the average load of total cadmium for a mussel from this sampling was 0.070 mg.

Since the allowable cadmium intake from seafood sources has been calculated at 0.2 gp per person for week, a person eating more than three mussels per week from the CSBP bulk cargo jetty would ingest the W.H.O. provisional tolerable weekly intake for cadmium.

Using the same criteria, the provisional tolerable weekly intake for cadmium would be reached if a person were to eat more than four mussels from CBH jetty, eight mussels from Palm Beach jetty or 14 mussels from the Beacon Head dolphin.

By comparison, the Palm Beach mussel results from the 16 November 1977 indicate that an average 7.6 g mussel contained 0.4 μg g^{-1} cadmium (wet weight). In this case, a weekly intake of about 65 mussels per person was required before the provisional tolerable weekly intake for cadmium was reached.

A discussion of the philosophy for using provisional tolerable weekly intake levels for the consumption of food containing cadmium, in preference to using acceptable daily intake figures, is given in Appendix VII.

In the latest draft submission on standards for metals in foods (28) the NH & MRC recommended that a person's provisional tolerable weekly intake of cadmium from all sources should be 0.0067-0.0083 mg per kg body weight. Using a mean cadmium figure of 0.0075 mg per kg and applying it to a 70 kg person the numbers of mussels that could be eaten before reaching the NH & MRC provisional tolerable weekly intake are four from CSBP bulk cargo jetty, five from CBH jetty, 11 from Palm Beach jetty and 18 from the Beacon Head dolphin (19 December, 1978, sample).

From this study, it has been possible to demonstrate the approximate levels of which mussels (*M. edulis*) concentrate metals from seawater. For example, by using the areas around Beach Head dolphin (mussel sampling station 13) and Palm Beach jetty (mussel sampling station 31) the December 1978 water (Chapter 2) and mussel analysis figures the following concentration factors were observed.

Station	Cockburn Sound Study Factors	Brooks and Rumsby Factors (6)
	Cadmium	Cadmium
Beacon Head dolphin	66 700	100 000
Palm Beach	27 300	
	Lead	Lead
Beacon Head dolphin	2 500	4 000
Palm Beach	3 700	
	Copper	Copper
Beacon Head dolphin	14 300	3 000
Palm Beach	5 000	

4.4 (Cont'd)

The concentration factors demonstrate some variation within each metal group but generally there is a difference for each between metal groups which can be compared to the factors found by Brooks and Rumsby (6).

Although metal concentration factors are quite high mussels have been shown to have a limited role as a monitor of copper pollution (20). Survival and behaviour of mussels exposed to discontinuous copper concentrations were investigated under both fluctuating and constant salinity conditions. The animals were able to detect copper and avoid detrimental effects in discontinuous (six h on - six h off) exposures by closing their shell valves (20). This behaviour may have influenced the marked break in the copper levels at CSBP in July 1977.

The results of analyses for mercury in Cockburn Sound mussels are given in Table 4.10. Total mercury levels in mussels from Cockburn Sound can be compared to the levels in mussels from the other studies in Table 4.10. These results indicate that the mean value for Sound mussels, while not exceeding health standards, is as high as the highest values recorded from European countries.

The local results indicate consistent mercury accumulation throughout Cockburn Sound. While the upper range of results cannot compare to a very polluted estuary, the Derwent, no value for mercury could be found which was significantly lower than the lowest mercury levels in mussels for that estuary. Data from overseas would appear to indicate that Cockburn Sound does not have an imminent inorganic mercury problem by present standards.

The concentration factors given in Table 4.1 of the oyster compared to the mussel are, Copper - 4.6 : 1, Zinc - 12.1 : 1, Cadmium - 3.2 : 1, Lead - 0.8 : 1, and Chromium - 0.2 : 1. Results for Cockburn Sound are available for oyster and mussels from CBH for 25 September and 23 October, 1978. The ratios from these results are, Copper - 6.6 : 1, Zinc - 16.5 : 1, Cadmium - 1.2 : 1. These results can only be regarded as indicative but they are similar to those in Table 4.1 for these elements. No lead or chromium results were available for these dates but the oyster to mussel concentration ratio for lead from previous analyses was about one whereas the chromium is 4.2 : 1. The chromium figure was the only serious departure from the figures given by Brooks and Rumsby in Table 4.1 (note that *Ostrea* from both studies were not the same species).

Studies of *O. angasi* from elsewhere have shown extreme variability in concentrations of lead, copper and cadmium. For example mud oysters from unpolluted Westernport Bay (17) have been found to have maximum levels of about 0.3 μg g^{-1} cadmium while the upper limit for these animals in the Derwent Estuary is about 29 μg g^{-1} cadmium (10), on a wet weight basis. These figures indicate the relative amounts of cadmium concentration between the two areas. The highest value of cadmium obtained for a mud oyster from Cockburn Sound was 8.7 μg g^{-1}, wet weight.

Consumption figures for cadmium may be calculated for crabs (*P. pelagicus*) by applying similar F.A.O./W.H.O. calculations as those used for mussels. The data showed that a 50 g flesh weight crab taken from the areas around CSBP and south into Mangles Bay contained about 0.025 mg of cadmium in its flesh. If, as suggested, the average Australian dietary intake for cadmium from non seafood sources is about 0.2-0.3 mg per week and the recommended limit is 0.4-0.5 mg per week (19) (leaving 0.2 μg to be ingested from seafood sources), only eight crabs may be

4.4 (Cont'd)

eaten per week from these areas without reaching the provisional tolerable weekly intake figure. By contrast at least 40 crabs per week may be eaten from Becher Point in Warnbro Sound without exceeding the intake figure for cadmium (based on results from Table 4.14).

As indicated by the results for metal analysis of crab flesh and hepatopancreas there is normally a significant concentration factor for metals between these two tissues (particularly for cadmium). The function of the hepatopancreas in a crab may be likened to the role played by the kidneys or possibly the liver, in mammals. It is five per cent to 15 per cent of the total *P. pelagicus* flesh weight on a wet weight basis. From discussions it became evident that a proportion of the population eat this crab (and rock lobster) organ. In fact, it is a "highly prized" portion in cooking where it is used to make a sauce for the crab meat (30).

When questioned, it was evident that few people eat the mud oyster because of its unpalatability and the difficulty in obtaining the animal. Their role may be more that of a pollution indicator.

Prolific growth of *U. lactuca* has been associated with increases in sewage contamination. It reportedly assimilates metals and this has been used as an indicator of lead and mercury contamination from sewage (23). From the limited study of this green alga in Cockburn Sound it seems that it may have a potential as a monitor of cadmium, lead, iron and manganese in marine waters.

4.5 Conclusions

Evidence presented in this Report demonstrates that the biota of the Cockburn Sound area are contaminated by hydrocarbons, heavy metals and enteric bacteria. All three of these types of material have been found in elevated concentrations in Cockburn Sound while the latter two are elevated in Owen Anchorage.

On the basis of the figures for the metal analyses it is suggested that cadmium, copper, lead, zinc, chromium, iron, manganese, cobalt and nickel are accumulating in the mussels from the James Point area, cadmium and chromium are accumulating in mussels in the Mangles Bay area and chromium is accumulating in the mussels in Owen Anchorage.

The most serious metal contaminant in the Sound is cadmium. The danger of this element to human health cannot be stated. The contaminantion of mussels by cadmium can be linked directly to gypsum effluent. Although there is no evidence of metal toxicity to the animals themselves there can be no doubt that Western Australian, W.H.O. and NH & MRC recommendations have been exceeded, especially around the industrial area and south into Mangles Bay.

If the W.H.O. recommendations for cadmium were applied only three mussels from the CSBP bulk cargo jetty could be eaten per week before the total cadmium from all dietary sources has exceeded the provisional tolerable weekly intake.

While mercury levels in mussels do not exceed State health standards, they indicate the presence of this metal in the Cockburn Sound waters.

Concentrations of lead in Cockburn Sound crab flesh exceeded State health standard levels on 15 per cent of the sampling occasions. Levels in the hepatopancreas were about 2.5 times higher, on average, than in the flesh.

4.5 (Cont'd)

Crabs collected from CSBP and south into Mangles Bay did not exceed recommended NH & MRC or State health standards for cadmium. However, calculations using the data obtained have shown that if more than eight crabs per week were eaten from this area it is possible that the person would ingest the W.H.O. provisional tolerable weekly intake for cadmium. This is an important observation considering the number of people taking large quantities of crabs from this area (26).

The main significance of the data showing heavy metals in the marine flora are that heavy metals assimilated into living seagrass or epiphytes can be passed into the marine food chain of Cockburn Sound via grazing or the detrital cycle. Overall, elevated levels of heavy metals in polychaete worms, sea lettuce and seagrasses are evidence of these contaminants in the detritus cycle and food webs of the Cockburn Sound ecosystem.

Mussels harvested directly from Owen Anchorage and Woodman Point areas frequently did not conform to widely recognised international standards for shellfish hygiene and present a significant health hazard to the individuals harvesting at contaminated sites (21.)

The results of this Study show that the primary problem area for the contamination of mussels by salmonella and *Escherichia coli* is in the waters out from, and between, South Beach and Woodman Point exposives jetty (see Figure 2.12). This is due to the influence of the effluent from the meat and hide processing industries of Owen Anchorage on this area. The secondary area of mussel contamination by enteric bacteria was Woodman Point.

Forty six per cent of the mussel samples tested for bacteria were found to be unsuitable for human consumption due to faecal *E. coli* counts greater than 10 per gram or salmonella contamination. None of the 18 locations investigated were uncontaminated. Examimation of serotypes isolated in mussels and seawater (see Chapter 2) demonstrates a direct spacial relationship between abattoir and sewage treatment plant effluents, seawater and hence, mussel contamination.

Levels of bacterial contamination in the Owen Anchorage/Woodman Point areas exceed widely recognised international standards for shellfish hygiene (13) and serious consideration should be given to public health implications.

Alkanes were shown to have accumulated in the flesh of mussels from Cockburn Sound. Although no direct relationship could be established between petroleum alkanes in mussels and the BP effluent, it is highly probable that the hydrocarbons from that outfall are major components of the accumulations. Since approximately 2 000 kg of hydrocarbons discharged daily from the BP outfall consist of 1 000 kg of alkanes, 500 kg of phenols, 400 kg of cresols and other aromatics, and 100 kg of highly polar material containing oxygen, nitrogen or sulphur atoms (see Appendix I) it is reasonable to conclude that at least some of the aromatics are accumulated by mussels. Evidence in the literature suggest that there would be a possible health risk to persons consuming mussels so affected (see Chapter 5, Discussion).

The analyses of mussels and crabs for alkanes illustrates two important features of hydrocarbon distribution in Cockburn Sound:

4.5 (Cont'd)

- Firstly, most samples showed characteristic evidence of petroleum-derived alkanes; the broad unresolved envelope from C_{16} to C_{26} due to naphthenics and the equal occurrence of odd and even numbered n-alkanes. These accumulations were derived from sources of industrial effluents and oil discharges from shipping.

- Secondly, the concentration of n-alkanes in mussels from Cockburn Sound were in all cases substantially greater than a reference bulk sample from Busselton jetty. Concentrations of n-alkanes were in the same order in crab flesh as the hepatopancreas.

Although n-alkane concentrations in *Ulva* and seagrass were low, one sample of *Ulva* from the James Point area clearly showed contamination by aromatic hydrocarbons, in particular cresols, characteristic of effluents discharged from BP Refinery (11). Mussels from this area showed clear contamination by the alkane fraction of petroleum derived hydrocarbons.

TABLE 4.1

POSSIBLE CONCENTRATION FACTORS FOR TRACE ELEMENTS IN SHELLFISH COMPARED WITH THE MARINE ENVIRONMENT

(Brooks and Rumsby, 1965) (6)

Metal	CONCENTRATION FACTORS		
	Scallop *(Pecten novaezelandiae)*	Oyster *(Ostrea sinuata)*	Mussel *(Mytilus edulis)*
Cu	3,000	13,700	3,000
Zn	28,000	110,300	9,100
Cd	2,260,000	318,000	100,000
Fe	291,500	68,200	196,000
Mn	55,500	4,000	13,500
Pb	5,300	3,300	4,000
Cr	200,000	60,000	320,000
Ni	12,000	4,000	14,000

TABLE 4.2

WESTERN AUSTRALIAN AND RECOMMENDED N.H. & M.R.C. (1973) STANDARDS FOR METALS IN SEAFOOD ($\mu g\ g^{-1}$ WET WEIGHT)

Element	W.A. Standard	Proposed NH&MRC Standards
Cd	5.5*	2.0
Zn	40.0	1000.0
Cu	30.0	30.0
Pb	2.0	2.0
Ni	5.5*	N.A
Cr	5.5*	N.A
Co	5.5*	N.A
Hg	0.5	0.5
As (as As_2O_3)	1.5	1.5

* These are accepted standards for fresh seafoods in Western Australia - they actually apply only to processed seafoods in containers.

(N.A. - not available)

TABLE 4.3

MUSSEL SAMPLING STATIONS
(Refer Figure 4.1)

Station No.	Location	Water Depth in metres	1 m below surface	1 m abov bottom
01	Elbow	7.0	*	*
02	N.W. Middle Ground	7.6	*	
03	Nook	4.6	*	
04	Success Spit	7.9	*	
05	Robb Jetty wreck	3.0	*	
06	Power Station inlet	3.9	*	*
07	Anchorage (Meatworks) Butchers	2.9	N.S.	
08	Coogee Jetty	2.0	*	
09	Explosives Jetty	5.0	*	
10	Jervoise Bay north lead beacon	1.9	*	*
11	Cockburn Sound Cement Co. Jetty	1.3	*	
12	Jervoise Channel south lead beacon	4.5	*	*
13	Beacon Head dolphin	7.2	*	
14	No. 2 Windmill	19.2	*	*
15	Woodman Channel beacons	6.4	*	*
16	Jervoise Bank beacon	9.2	*	*
17	Jervoise-Medina Channel beacons	10.2	*	*
18	Alcoa Jetty	12.0	*	*
19	SEC Intake beacons	8.2	*	*
20	Buchanan buoy	20.1	*	*
21	AIS Jetty	12.2	*	*
22	Kwinana Wreck Jetty	3.1	*	*
23	James Point	1.2	N.S.	
24	James Point bank spit post	3.3	*	*
25	Mistrel Channel north beacons	3.8	*	*
26	B.P. Jetty north dolphin	8.2	*	*
27	CSBP Jetty, north end	3.5	*	*
28	CSBP Jetty, east end	3.0	*	*
29	Southern Flats beacon	4.0	*	*
30	Coop. Bulk Handling Jetty	7.5	*	*
31	Palm Beach Jetty	3.6	*	*
32	Shoalwater Bay	4.0	*	*
33	Colpoys Buoy (southern naval)	18.0	*	

N.S. - Not sampled

TABLE 4.4

SUMMARY OF HEAVY METAL RESULTS FOR MUSSEL SAMPLING NOVEMBER, 1977

The results are the mean of the analyses for five separate individuals and are given in µg g^{-1}, wet weight. Samples collected on November 16, 1977 - see Figure 4.1 for locations).

Station No.	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Mean Shell Length (mm)	Mean Wet Weight (g)
1. Top	1.1	27	0.8	33	0.9	1.1	2.8	<1.0	<1.0	71	8.6
Bottom	1.0	21	0.4	42	1.2	0.7	3.6	<1.0	<1.0	75	9.2
2. Top	0.9	18	0.3	37	1.0	1.1	1.5	<1.0	<1.0	70	7.3
3. Top	1.1	21	0.3	37	1.0	0.9	2.4	<1.0	<1.0	70	7.1
4. Top	1.2	36	0.3	67	1.2	1.1	1.5	<1.0	<1.0	70	6.8
5. Top	1.1	26	0.5	61	1.0	0.9	5.1	<1.0	<1.0	47	2.9
6. Top	1.1	37	0.5	64	0.9	0.9	6.0*	<1.0	<1.0	61	5.5
7. N.S.											
8. Top	1.1	31	0.5	31	1.6	1.4	7.2*	<1.0	<1.0	71	7.2
9. Top	0.7	24	0.8	31	1.9	1.9	2.5	<1.0	<1.0	80	8.2
10. Top	1.3	29	0.4	25	0.9	0.8	2.4	<1.0	<1.0	69	9.3
Bottom	1.2	20	0.6	25	0.9	1.0	2.0	<1.0	<1.0	71	9.6
11. Top	6.3	44*	0.2	29	0.9	1.0	0.7	<1.0	<1.0	74	7.3
12. Top	2.5	25	0.3	43	2.0	1.0	1.9	<1.0	<1.0	72	7.2
Bottom	2.4	43*	0.3	47	2.4	1.0	1.6	<1.0	<1.0	78	10.0
13. Top	0.9	28	0.5	26	0.9	0.7	0.2	<1.0	<1.0	80	9.1
14. Top	1.1	19	0.7	37	1.8	1.3	0.7	<1.0	<1.0	74	8.9
Bottom	1.0	35	0.6	58	1.6	1.2	0.8	<1.0	<1.0	70	7.6
15. Top	0.8	23	0.6	64	2.5	1.5	0.7	<1.0	<1.0	80	10.6
Bottom	0.7	22	0.6	90	7.0	1.1	0.5	<1.0	<1.0	77	10.6
16. Top	1.1	25	0.6	61	4.4	1.2	0.7	<1.0	<1.0	68	8.0
Bottom	0.9	26	0.3	81	3.7	1.3	0.8	<1.0	<1.0	68	8.7
17. Top	2.4	29	0.3	27	1.2	1.5	0.6	<1.0	<1.0	68	8.0
Bottom	2.7	35	0.4	27	1.1	1.0	0.9	<1.0	<1.0	79	10.0
18. Top	3.6	47*	0.7	40	2.5	1.1	1.9	<1.0	<1.0	71	6.3
Bottom	3.3	49*	0.3	38	1.8	1.0	1.9	<1.0	1.3	69	7.6
19. Top	1.9	31	0.6	33	0.9	1.1	1.2	<1.0	<1.0	69	6.9
Bottom	1.5	24	0.4	23	1.5	1.1	1.1	<1.0	<1.0	78	9.5
20. Top	2.1	18	0.1	39	1.0	1.3	0.4	<1.0	<1.0	68	6.8
Bottom	1.7	22	0.2	39	1.0	1.1	0.4	<1.0	<1.0	55	3.6
21. Top	5.5	85*	1.2	160	0.5	4.1*	0.6	<1.0	<1.0	67	4.4
Bottom	5.0	79*	2.1*	186	1.2	4.8*	2.1	<1.0	<1.0	69	4.7
22. Top	3.7	65*	1.8	75	3.0	1.9	1.4	1.6	2.3	74	8.5
Bottom	3.6	77*	2.0*	168	3.8	2.3*	2.4	1.2	1.2	73	7.4

* Exceed either W.A. or recommended N.H. & M.R.C. Standards.

TABLE 4.4 (Cont'd)

Station No.	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Mean Shell Length (mm)	Mean Wet Weight (g)
23. N.S.											
24. Top	5.7	56*	1.1	105	2.7	3.1*	2.1	1.1	2.8	68	6.9
Bottom	7.7	65*	1.3	113	4.2	2.7*	2.8	1.3	3.5	67	5.8
25. Top	1.8	30	0.3	39	1.6	1.3	0.6	<1.0	<1.0	83	11.6
Bottom	1.1	26	0.8	38	2.7	1.0	1.7	<1.0	<1.0	75	9.6
26. Top	2.1	52*	1.7	40	4.2	2.2*	1.7	1.2	3.4	68	7.6
Bottom	2.0	52*	2.4*	39	5.0	4.7*	1.3	1.2	5.0	66	4.0
27. Top	13.7	135*	5.8*	240	6.9	2.2*	2.5	<1.0	<1.0	71	7.8
Bottom	13.8	149*	5.5*	361	5.6	2.8*	3.2	<1.0	<1.0	72	7.6
28. Top	12.9	127*	2.3*	152	6.6	0.8	3.6	<1.0	<1.0	71	8.6
Bottom	14.3	132*	3.6*	152	3.8	1.8	3.1	<1.0	<1.0	79	8.9
29. Top	2.4	27	0.3	32	1.8	1.9	0.6	<1.0	<1.0	60	4.2
Bottom	2.0	31	0.4	27	1.6	1.2	0.8	<1.0	<1.0	74	8.5
30. Top	1.9	25	2.0*	39	0.8	1.8	3.3	<1.0	<1.0	69	6.9
Bottom	2.0	17	1.8	37	0.6	0.8	3.2	<1.0	<1.0	68	8.3
31 Top	1.7	34	0.3	27	1.6	1.7	1.3	<1.0	<1.0	71	9.3
Bottom	1.8	31	0.6	48	1.6	1.1	1.3	<1.0	<1.0	68	5.9
32. Top	1.5	33	0.5	-	-	-	-	-	-	68	5.7
Bottom	1.5	32	0.6	-	-	-	-	-	-	65	6.1

* Exceeds either W.A. or recommended N.H. & M.R.C. Standards.

TABLE 4.5

MEAN METAL CONCENTRATION OF FIVE INDIVIDUAL MUSSELS FROM SELECTED SAMPLING LOCATIONS OVER A PERIOD OF 16 MONTHS
(all samples were taken at least 1 m below spring low water and results are in μg g^{-1} wet weight)
(see Figure 4.1 for locations)

Location	Location No.	Metal	Date																
			16.11.77	13.12.77	9.1.78	13.2.78	22.3.78	19.4.78	5.5.78	23.5.78	27.7.78	28.8.78	6.9.78	28.9.78	23.10.78	22.11.78	19.12.78	23.1.79	14.2.79
Buchanan Bay Buoy	20	Cu	2.1	1.8	2.4	1.4	1.4	1.5					Colpoys Point Buoy (∿2.5 km South of Station 20)				1.1	1.2	1.3
		Zn	18.0	27.9	29.1	23.2	25.2	22.5									20.0	43.7*	31.0*
		Pb	1.2														0.4	0.3	0.3
		Cd	0.1	0.5	0.4	0.2	0.2	0.2									1.4	2.2*	2.1*
Beacon Head	13	Cu	0.8									1.3	1.8	1.2	2.0	1.9	1.0		1.0
		Zn	28.0									31.1	37.6	26.7	35.9	44.1*	29.2		32.0
		Pb	0.6													1.3	1.0		1.0
		Cd	0.7									1.6	1.3	0.8	2.0	1.6	1.7		1.1
AIS	21	Cu	5.5	3.5	3.6	2.9	3.6	3.5			2.0	1.2	2.4	1.8	1.7	1.9	1.0		1.1
		Zn	85.3*	29.9	45.7*	44.3*	49.7*	51.1*			32.5	51.0*	43.9*	43.7*	55.9*	47.4*	30.9		42.1*
		Pb	4.1*													1.5	1.2		1.2
		Cd	1.6	1.9	1.9	1.7	1.8	1.9			1.7	1.7	1.3	1.2	1.8	1.3	1.5		1.7
CSBP	27	Cu	13.7	11.4	11.7	12.0	14.2	12.8	12.6	13.1	2.2	1.5	1.6	1.3	1.3	3.1	1.2	1.5	1.0
		Zn	134.8*	104.0*	74.8*	60.6*	55.9*	51.1*	45.2*	40.8*	30.6	41.1*	31.2	32.7	36.3	49.1*	41.4*	46.1*	39.5
		Pb	2.2*													1.0	1.5	1.8	1.3
		Cd	5.6*	5.6*	5.0	4.9*	5.6*	5.9*	6.0*	6.1*	6.1*	6.5*	5.4*	5.5*	6.5*	7.9*	8.9*	9.1*	8.6*
CBH	30	Cu	1.9		2.3	2.0	2.1	2.3			2.9	1.6		1.5	1.7	1.5	1.0		1.5
		Zn	25.1		17.1	21.9	16.7	19.7			33.5	31.8		25.7	37.1	47.0*	28.4		30.1
		Pb	1.8													1.5	0.7		0.8
		Cd	1.9		1.9	1.8	1.6	1.9			3.0*	2.7*		2.7*	2.9*	4.2*	3.4*		4.1*
Palm Beach	31	Cu	1.8													1.1	1.4		1.5
		Zn	33.0													31.2	25.1		30.2
		Pb	1.4													0.9	0.7		0.7
		Cd	0.5													3.0*	2.9*		3.2*
Jervoise Bay	12	Cu	2.4																0.9
		Zn	34.0																24.0
		Pb	1.0																0.8
		Cd	0.3																1.2

* Exceeds either W.A. or recommended N.H. & M.R.C. Standards.

TABLE 4.6

DATA SHEET 1

MUSSEL DATA - HEAVY METALS.

Date	Station No.	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Co	Ni	Hg	Shell length-mm	Wet wt. in g.
16 11 77	30 Top												
	1	1.6	26.7	2.0	52	0.7	1.5	2.5	<1.0	<1.0		80	9.32
	2	2.3	21.4	2.4	37	0.8	3.3	3.4	<1.0	<1.0		68	5.10
	3	1.8	35.2	2.1	27	0.7	1.4	3.2	<1.0	<1.0		67	6.47
	4	2.0	20.4	1.5	35	0.9	1.5	3.4	<1.0	<1.0		64	6.36
	5	1.8	22.1	1.9	44	1.1	1.4	4.1	<1.0	<1.0		69	7.46
	Mean	1.9	25.1	2.0	39	0.8	1.8	3.3	<1.0	<1.0		69	6.94
	S. Dev.	0.3	6.1	0.3	9	0.2	0.8	0.6				6	1.57
16 11 77	30 Bottom												
	1	1.4	24.5	1.9	41	0.7	0.9	2.4	<1.0	<1.0		72	9.28
	2	2.3	11.9	1.1	37	0.6	0.8	3.8	<1.0	<1.0		71	6.20
	3	2.2	15.7	2.4	51	0.5	0.8	2.9	<1.0	<1.0		74	8.70
	4	1.8	20.2	2.2	29	0.7	0.5	2.9	<1.0	<1.0		71	10.79
	5	2.6	11.8	1.6	28	0.7	1.0	4.1	<1.0	<1.0		54	6.70
	Mean	2.0	16.8	1.8	37	0.6	0.8	3.2	<1.0	<1.0		68	8.33
	S. Dev.	0.5	5.5	0.5	9	0.1	0.2	0.7				8	1.89

All results in ug/g wet weight.

TABLE 4.7.

STANDARD SAMPLES FOR CONTROL OF METHODOLOGY
(Reference material with typical results obtained by the Cockburn Sound Study)
All results in µg g $^{-1}$

	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Ni
Orchard Leaves NBS 1571								
Certified Values	12±1	25±3	0.11±0.01	300±20	91±4	45±3	2.6±0.3	1.3±0.2
Analysed Values	12.8	28.1	0.1	265	85	44	2.5	1.4
	11.8	26.4	0.1	310	88	44	2.5	1.4
	12.1	24.9	0.2	295	89	45	2.2	1.3
	12.4	25.1	0.1	280	92	42	2.1	1.2
Bovine Liver NBS 1577								
Certified Values	193±10	130±10	0.27±0.04	270±20	10.3±1.0	0.34±0.08	-	-
Analysed Values	189	122	0.3	275	9.9	0.3	-	-
	182	125	0.3	255	9.6	0.3	-	-
	188	130	0.3	250	9.8	0.4	-	-
	182	121	0.2	252	9.9	0.3	-	-
Mussell EPA of Vic.								
Certified Values	12±2	248±9	4.7±0.8	489±28	7±1	22±3	-	-
Analysed Values	15	275	4.7	493	8.7	23.2	-	-
	13	242	4.5	498	7.4	24.9	-	-
	12	252	4.3	480	7.6	23.0	-	-
	12	240	4.0	511	8.2	24.2	-	-
Fish 2^{o} Standard								
Murdoch Values	3.2±0.3	25.4±1.0	0.2±0.05	31.5±1.5	2.5±0.2	2.1±0.2	1.0	1.0
Analysed Values	3.2	27.0	0.1	32	2.3	1.8	1.2	1.2
	2.9	31.4	0.1	30	2.2	1.9	1.2	0.9
(Murdoch University,	2.8	30.0	0.1	29	2.2	1.4	1.0	0.9
E.L.S.)	2.7	31.0	0.1	30	2.3	1.5	1.2	0.9
Mussel 2^{o} Standard								
Murdoch Values	5.2	189	7.6	86	4.7	3.5	0.8	1.9
Analysed Values	5.4	181	7.8	-	-	3.4	-	-
	5.3	194	7.8	-	-	3.2	-	-
(Murdoch University,	5.3	189	7.8	-	-	3.3	-	-
E.S.L.)	5.2	183	7.6	-	-	3.4	-	-

TABLE 4.7.

TABLE 4.8

MUSSEL ANALYSIS CHECK FOR CONSISTENCY IN METAL RESULTS
Carried out January 23, 1979. Results in μg g^{-1} wet weight.

Location Date	Sample No	Cadmium		Zinc		Copper		Lead	
		Orig.	Check	Orig.	Check	Orig.	Check	Orig.	Check
CSBP 6.9.78	1.	9.2	9.2	40.1	39.4	1.7	1.6		
	4.	3.2	3.4	43.8	43.1	1.9	2.0		
	5.	5.3	5.4	18.0	17.1	0.9	0.9		
CSBP 28.9.78	2.	6.1	6.4	42.2	40.1	1.5	1.5		
	3.	6.3	6.4	36.6	37.9	1.1	0.9		
CSBP 23.10.78	2.	10.4	10.1	81.9	80.0	1.6	1.2		
	5.	6.1	5.8	24.3	24.3	1.4	1.4		
CSBP 22.11.78	3.	11.5	10.8	46.6	48.1	2.3	2.4	1.1	1.3
	4.	8.3	8.3	35.4	37.4	3.5	3.7	1.2	1.2
	5.	8.3	8.0	94.3	95.8	2.1	2.1	0.8	0.8
CSBP 19.12.78	1.	7.6	7.9	46.0	48.6	1.1	1.2	0.9	0.8
	2.	7.8	7.9	30.9	32.4	1.1	1.2	1.6	1.4
	3.	12.3	12.3	40.0	41.3	1.4	1.3	2.3	2.0
	4.	8.6	8.3	32.4	33.2	1.6	1.3	1.3	1.0
	5.	8.3	8.2	57.9	61.5	0.9	0.7	1.4	1.4
CBH 23.10.78	1.	3.7	3.5	50.9	49.1	1.8	1.5		
	2.	3.1	3.0	29.1	29.1	1.6	1.4		
CBH 22.11.78	2.	4.6	4.5	24.2	25.3	1.1	1.0	1.6	1.2
	3.	6.8	6.5	126.	121.	1.9	2.0	1.7	1.4
CBH 19.12.78	3.	3.3	3.3	21.2	20.6	0.8	0.7	0.5	0.5
	5.	4.3	4.2	22.3	21.7	0.8	0.7	0.8	0.5

TABLE 4. 9

MEAN CONCENTRATION OF HEAVY METALS IN WHOLE SOFT PARTS OF *MYTILUS EDULIS* FROM OTHER STUDIES

The results are given in μg g^{-1} wet weight. The factor used for the conversion of dry weight results to wet weight results is 0.166.

Area		Cd	Cu	Pb	Zn	
North and South Island	Mean	0.6	8.3	0.7	12.6	
of New Zealand (1975) (14)	Range	0.3-1.6	1.7-18.0	0.2-2.0	3.8-26.0	
Derwent River Estuary,	Mean	3.1		33.1	85.6	
Tasmania (1976) (10)	Range	0.7-6.3		0.5-88.3	28.4-224	
Corio Bay	Mean	3.8	1.2	0.6	27.3	
Victoria (1976) (16)	Range	1.6-8.8	0.8-3.5	0.2-1.6	17.4-68.1	
						Cr
Western Port Bay	Mean	0.4	0.8	0.5	33.2	0.2
Victoria (1974-1976) (17)	Range	<0.1-4.0	<0.5-2.7	<0.1-1.9	16.9-54.9	<0.1-0.2
The United States						
(1976) (2)*						Ni
West Coast	Mean	0.8	1.1	0.6	24.7	0.3
	Range	0.4-1.7	0.6-1.4	0.3-1.5	14.9-43.2	0.2-0.4
East Coast	Mean	0.3	1.1	0.5	17.6	0.2
	Range	0.1-1.0	0.7-1.8	<0.1-1.6	11.1-31.3	0.1-0.6
						Cr
European Countries	Mean	0.22-	2.8	0.78	23	0.44
(1975) (15)	Range	0.09-0.44	0.8-9.4	0.30-2.1	13-44	0.28-0.60
European Countries	Mean	0.31	2.4	0.99	20	
(1977) (15)	Range	0.02-1.1	0.6-6.6	0.2-2.0	10-64	

* In this study areas of very high contamination were not included.

TABLE 4.10

TOTAL MERCURY CONTENT OF THE WHOLE SOFT PARTS OF *MYTILUS EDULIS*

The mean results of five individual mussels are given in μg g^{-1} wet weight. The factor used for the conversion of dry weight results to wet weight results is 0.166.

Area	No. of Samples	Mean	Standard deviation	Range
The Cockburn Sound Study 19.12.78				
Station No.				
12 (Woodman Point Beacon)		0.202	0.039	0.140-0.239
21 (A.I.S. Jetty)		0.201	0.034	0.153-0.244
26 (North B.P. Dolphin)		0.242	0.101	0.147-0.407
27 (C.S.B.P. Jetty)		0.212	0.081	0.127-0.336
30 (C.B.H. Jetty)		0.105	0.028	0.081-0.152
31 (Palm Beach Jetty)		0.101	0.023	0.063-0.124
33 (Colpoys Buoy)		0.239	0.058	0.143-0.300
13 (North Garden Island Dolphin)		0.113	0.032	0.079-0.150
Cockburn Sound	40	0.18	0.05	0.06-0.41
Derwent River Estuary, Tasmania (1976) (10)	22 sites	0.69	0.61	0.07-2.16
North and South Island, New Zealand (1975) (14)	70 samples	0.23	0.20	0.02-0.48
European Countries (1975) (15)	22 stations	0.05		0.02-0.13
European Countries (1977) (15)	21 stations	0.05		0.01-0.19

TABLE 4.11

ALKANE CONTENT OF MUSSELS, *MYTILUS EDULIS*

All samples designated as transplanted orginated from Beacon Head

COLLECTED	STATION	LOCATION	ALKANE CONTENT ($\mu g\ g^{-1}$ wet weight)
	4	Nth. B.P. Dolphin	102
	5	AIS Jetty	17
28.09.78	6	BP Outfall (transplanted 5.9)	35
	3	CSBP	18
	9	Minstrel Channel	13
9.10.78	6	BP Outfall (transplanted 5.9)	19
22.11.78	6	BP Outfall (transplanted 5.9)	4
	1	Nth. Garden Island (Beacon Head)	7
	6	BP Outfall (transplanted 22.11)	10
	4	Nth. BP Dolphin (transplanted 22.11)	9
6.12.78	1	Nth. Garden Island (Beacon Head)	8
	5	AIS Jetty (transplanted 22.11)	5
	7	Between AIS and BP Outfall (transplanted 22.11)	5
	8	Station 3629 (transplanted 22.11)	<1
9.11.78		Busselton Jetty	<1

TABLE 4.12 MUSSELS *E. COLI* M.P.N./g, AND SALMONELLA POSITIVE SAMPLES
March, 1977 - April, 1978

SITE NO.	LOCATION	MUSSEL SAMPLING DATES *E. COLI* M.P.N./g, AND SALMONELLA +VE SAMPLES																MUSSELS	
		9.3.77	21.3	13.4	27.4	1.6	27.6	25.7	23.8	26.9	25.10	16.11	20.12	23.1.78	25.2	21.3	19.4	Satis-factory	Not Satis factory-
1.	Jervoise S.L.C.B.	N.T.	N.T.	N.T.	N.T.	4	4	9	23	0	4	0	4	0	4	0	230 (+)	10	2
8.	Woodman M.L.C.B.	N.T.	N.T.	0	15 (+)	90	0	0	9 (+)	0 (+)	93 (+)	4	23 (+)	0	4	0	N.T.	6	7
10.	Explosives Jetty	N.T.	0	N.T.	43 (+)	4	4	3 (+)	230 (+)	4	0	0 (+)	0	0	0	0 (+)	40 (+)	8	6
11.	Coogee Jetty	23 (+)	0	0	40 (+)	40 (+)	4	9	>1 000 (+)	40	4 (+)	0 (+)	0	0	4 (+)	4 (+)	N.T.	6	9
12.	Anch. Abatt (in)	>1 000 (+)	930 (+)	>1 000 (+)	210 (+)	23 (+)	9 (+)	93 (+)	900 (+)	43 (+)	40 (+)	0	0	9	400 (+)	40 (+)	N.T.	3	12
14.	Cockburn cement Jty	N.T.	N.T.	0	23 (+)	4	9	9	40 (+)	0	0	0	0	N.T.	N.T.	N.T.	N.T.	8	2
15.	Power Stn Jetty	N.T.	40	4	230	43	9	93 (+)	920 (+)	230 (+)	4 (+)	40	0	9 (+)	4 (+)	4	N.T.	4	10
16.	W.A.M.E. abatt O/F	N.T.	>1 000 (+)	>1 000 (+)	>1 000 (+)	1 000 (+)	>1 000 (+)	>1 000 (+)	N.T.	>1 000 (+)	>1 000 (+)	>1 000 (+)	>1 000 (+)	>1 000 (+)	>1 000 (+)	>1 000 (+)	N.T.	0	13
17.	Success Spit	N.T.	0	0	230	23	4 (+)	7 (+)	90	23	40 (+)	90	9	0	7 (+)	11 (+)	4 (+)	4	11
18.	Nook Spit	N.T.	0	0	9	0	0	9 (+)	230	9 (+)	430 (+)	40	0	9	4 (+)	40 (+)	N.T.	7	7
19.	N.W. Mid ground	N.T.	0	0	0	0	40	0	23	0	23 (+)	0	9	0	0	0	3	13	3
20.	Elbow Pylon	N.T.	0	0	0	0	4	0	90 (+)	4	0	0	4	0	0	0 (+)	N.T.	12	2
23.	Channel bcn No. 1	N.T.	N.T.	N.T.	N.T.	930 (+)	9	9	40 (+)	0	0	0	0	0	40	0	230	8	4
26.	South Beach	430	N.T.	N.T.	9	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	0	930 (+)	N.T.	0	N.T.	N.T.	3	2
27.	Windmill N. lead	N.T.	N.T.	N.T.	N.T.	N.T.	4	4	23	0	4	0	0	0	4 (+)	4	0	9	2
MUSSELS SATISFACTORY		0	6	8	4	6	10	8	0	7	6	9	12	11	6	5	2	100	-
MUSSELS UNSATISFACTORY		3	3	2	8	7	4	6	13	7	8	6	3	2	8	8	4	-	92
SAMPLES AND SALMONELLA +VE		3(2)	9(2)	10(2)	12(6)	13(4)	14(3)	14(6)	13(8)	14(5)	14(8)	15(3)	15(3)	13(2)	14(7)	13(8)	6(3)	192(72)	

N.T. = site not sampled.

Mussels Satisfactory = E.Coli < 10/g and Salmonella nagative
Mussels Unsatisfactory = E.coli > 10/g or Salmonella positive

* Totals based on sites sampled a minimum of 5 times
Salmonella results are in brackets.

TABLE 4.12

TABLE 4.13

HEAVY METALS IN THE MUD OYSTER, *OSTREA ANGASI*
Results are for the mean of six individual animals expressed in µg g^{-1}, wet weight. The range for each sampling occasion is also given.

South of C.B.H. jetty						Mean wet weight of oyster (g)
Date	Cu	Zn	Cd	Pb	Cr	
1. 3.78	25.1 24.8-37.6*	191* 174*-214*	5.6* 2.9*-8.7*	1.2 0.8-2.1*	15.0* 8.6*-24.2*	43.4 39.6-48.4
19. 4.78	29.9 21.2-40.1*	166* 126*-215*	5.6* 3.8*-7.8*	2.1* 1.4-3.2*	11.9* 8.6*-15.6*	42.4 36.1-47.1
25. 9.78	4.3 3.6-5.9	613* 300*-1190*	3.6* 2.8*-4.5*	-	-	21.7 17.3-26.9
23.10.78	13.0 6.9-26.0	422* 285*-710*	3.2* 1.5*-4.4*	-	-	19.2 15.1-23.6

Destroyer escort berth - Naval facility						Mean wet weight of oyster (g)
Date	Cu	Zn	Cd	Pb	Cr	
25. 9.78	11.9 8.5-17.8	590* 350*-760*	1.9 1.8-2.5*	-	-	23.8 21.0-31.4
23.10.78	6.6 2.6-10.1	605* 350*-1025*	2.3* 1.9-2.7*	-	-	19.8 11.0-28.0

* Exceeds either W.A. or recommended N.H. & M.R.C. Standards

TABLE 4.14

MEAN RESULTS FOR HEAVY METAL ANALYSES OF CRAB FLESH
µg g^{-1}, wet weight

Location	Date	Cu	Zn	Cd	Pb	Cr	Mean Carapace width (mm)
Palm Beach	May 1978	11.9	-	0.8	1.4	1.0	142
	28.11.78	2.4	17.9	0.7	1.2	-	133
	Range:	1.3-3.4	14.8-22.9	0.5-1.4	0.6-1.4		126-140
	9.12.78	4.0	20.5	0.6	0.7	-	129
	Range:	1.8-6.1	14.0-24.2	0.3-1.5	0.4-1.0		117-140
C.B.H.	May 1978	9.6	-	0.5	0.5	1.0	137
	Range:	7.5-14.6		0.2-0.6	0.4-0.6	0.9-1.1	127-162
	18.10.78	7.0	23.4	0.4	1.3	-	134
	Range:	6.1-7.8	24.5-22.3	0.3-0.4	1.0-1.5		125-142
	28.11.78	2.0	16.6	0.4	0.2	-	105
	12.12.78	7.4	20.4	0.3	1.8	-	99
	Range:	4.6-9.5	15.0-30.7	0.2-0.5	1.5-2.1		95-108
C.S.B.P.	May 1978	8.4	-	0.9	0.9	1.0	150
	Range:	6.9-10.9		0.7-1.1	0.6-1.1	0.8-1.2	136-164
	18.10.78	8.2	12.6	0.3	1.2	-	115
	Range:	6.3-10.1	8.6-16.6	-	0.9-1.4		112-117
	28.11.78	4.0	21.8	0.5	1.3	-	134
	Range:	3.5-4.5	20.8-22.8	0.4-0.6	0.6-2.0*		125-142
	12.12.78	5.2	20.4	0.3	0.9	-	114
	Range:	4.4-5.8	15.0-30.7	0.1-0.4	0.9-1.4		108-118
James Point	18.10.78	6.8	18.2	0.5	2.0*	-	101
	Range:	5.3-7.3	16.9-19.5	-	0.9-3.0*		92-110
	28.11.78	3.5	17.8	0.3	0.3	-	113
	Range:	3.2-3.7	16.9-18.7	-	0.2-0.3		105-121
	12.12.78	5.8	18.0	0.2	1.0	-	130
	Range:	3.2-8.9	15.9-22.6	0.1-0.3	0.8-1.2		122-138
Jervoise Bay	18.10.78	5.1	23.8	0.4	1.0	-	142
	Range:	4.9-5.3	15.3-32.2	0.3-0.4	0.7-1.3		115-170
	28.11.78	1.5	17.0	0.3	0.7		121

* Exceeds either W.A. or recommended N.H. & M.R.C. Standards.

TABLE 4.14 cont'd

Location	Date	Cu	Zn	Cd	Pb	Cr	Mean Carapace width (mm)
Parmelia Channel No.2 Lead Beacon	May 1978	4.0	-	0.2	0.4	0.7	143
	Range:	3.9-4.1		0.1-0.2	0.3-0.4	-	134-152
Cliff Point	May 1978	4.2	-	0.2	0.5	0.9	151
	Range:	2.9-5.8		0.1-0.3	0.3-0.6	0.8-1.1	146-152
Colpoys Point	18.11.78	5.1	21.5	0.1	2.5*	-	112
	Range:	3.5-6.6	15.6-27.4	-	2.2*-2.8*		111-112
	28.11.78	1.8	17.2	0.2	0.2	-	110
	12.12.78	4.9	20.8	0.2	1.6	-	126
	Range:	1.8-7.4	16.1-31.4	0.1-0.2	1.1-2.4		118-138
Becher Point (Warnbro Sound)	19.12.78	5.7	20.5	0.1	1.1	-	123
	Range:	4.2-7.2	17.1-22.7	-	1.0-1.2		116-133
	5. 4.79	3.8	22.6	0.1	0.9	-	121
	Range:	2.0-5.9	18.1-26.8	-	0.5-1.5		110-130

*Exceeds either W.A. or recommended N.H. & M.R.C. Standards.

TABLE 4.15

MEAN RESULTS FOR HEAVY METAL ANALYSES OF CRAB HEPATOPANCREAS
μg g^{-1}, wet weight

Location	Date	Cu	Zn	Cd	Pb	Cr	Mean Carapace Width (mm)
Palm Beach	May 1978	26.1	-	5.4	1.3	0.8	142
	28.11.78	6.6	92*	13.2*	3.3*	-	133
	Range:	4.1-12.4	56*-151*	6.7*-19.2*	1.6-5.7*		126-140
	9.12.78	12.8	68*	17.3*	5.0*	-	129
	Range:	4.7-33.0*	32-88*	4.1*-37.9*	2.3*-10.0*		117-140
C.B.H.	May 1978	18.0	-	3.7*	0.7	1.2	137
	Range:	12.4-31.8*		2.6*-5.6*	0.4-1.2	0.8-1.9	127-162
	18.10.78	30.5*	163*	41.3*	2.9*	-	134
	Range:	20.9-40.1*	68*-256*	31.4*-52.2*	1.6-3.9*		125-142
	28.11.78	7.3	112*	11.9*	0.5	-	105
	12.12.78	21.3	71*	8.5*	6.3*	-	99
	Range:	13.6-32.9*	42-92*	3.0*-16.6*	5.5*-6.8*		95-108
C.S.B.P.	May 1978	11.4	-	10.7*	1.0	0.9	150
	Range:	7.8-15.1		6.9*-14.1*	0.6-1.5	0.7-1.1	136-164
	18.10.78	27.2	81*	18.5*	3.0*	-	115
	Range:	20.7-33.7*	46*-115*	18.1*-18.9*	2.0*-3.9*		112-117
	28.11.78	13.5	150*	48.2*	5.7*	-	134
	Range:	9.9-17.0	60*-239*	28.2*-68.2*	-		125-142
	12.12.78	10.1	87*	19.4*	2.5*		114
	Range:	7.3-16.1	29-147*	10.8*-27.0*	2.2*-2.8*		108-118
James Point	18.10.78	32.8*	64*	9.3*	5.6*	-	101
	Range:	31.3-34.2*	51*-77*	2.6*-15.9*	4.8*-6.4*		92-110
	28.11.78	9.1	75*	16.9*	2.3*		113
	Range:	8.4-9.8	22-127*	13.7*-20.1*	1.3-3.2*		105-121
	12.12.78	10.1	77*	18.2*	3.1*		130
	Range:	6.9-12.3	40*-93*	9.5*-33.2*	2.0*-4.6*		122-138
Jervoise Bay	18.10.78	27.3	44*	10.1*	1.5	-	142
	Range:	11.9-42.7*	31-56*	6.3*-13.8*	0.8-2.1*		115-170
	28.11.78	5.2	65*	3.8*	1.5		121

* Exceeds either W.A. or recommended N.H. & M.R.C. Standards

TABLE 4.15 Cont'd

Location	Date	Cu	Zn	Cd	Pb	Cr	Mean Carapace Width (mm)
Parmelia Channel No. 1 Lead Beacon	May 1978	6.7	-	1.5	0.5	0.7	143
	Range:	6.4-6.9		1.4-1.6	0.4-0.6	0.6-0.7	134-152
Cliff Point	May 1978	8.8	-	1.6	0.5	0.9	151
	Range:	7.2-10.3		1.3-2.0*	0.4-0.6	0.6-1.2	146-152
Colpoys Point	18.11.78	15.2	88*	19.7*	1.2	-	112
	Range:	13.3-16.5	74*-102*	7.1*-32.3*	1.1-1.2		111-112
	28.11.78	13.3	67*	5.3*	0.3	-	110
	12.12.78	44.1*	70*	10.9*	3.3*	-	126
	Range:	6.3-113.5*	67*-75*	5.6*-18.3*	2.1*-3.9*		118-138
Becher Point (Warnbro Sound)	19.12.78	31.0*	52*	1.2	5.3*		123
	Range:	15.6-62.5*	34-65*	0.4 - 2.0*	3.6*-7.1*		116-133
	5.4.79	34.0	39	1.8	3.2*	-	121
	Range:	24.8-43.0*	36*-4.2*	0.4 - 2.7*	1.7 -4.8*		110-130

* Exceeds either W.A. or recommended N.H. & M.R.C. Standards

TABLE 4.16

ALKANE LEVELS IN THE HEPATOPANCREAS AND FLESH OF CRAB, *PORTUNUS PELAGICUS*

Listed in order of decreasing alkane content.

DATE	STATION	LOCATION	ALKANE CONC. ($\mu g\ g^{-1}$ wet weight)
		Hepatopancreas	
18.10.78	20	CBH	78
18.10.78	17	James Point	65
28.11.78	17	James Point	60
28.11.78	19	CSBP	30
18.10.78	18	Jervoise Bay	27
18.10.78	19	CSBP	14
28.11.78	18	Jervoise Bay	11
18.10.78	21	Colpoys Point	6
		Flesh	
8.11.78	18	Jervoise Bay	25
28.11.78	19	CSBP	12
28.11.78	17	James Point	<1

TABLE 4.17

ANALYSIS OF INDIVIDUAL POLYCHAETES, *CHAETOPTERUS VARIOPEDATUS* FOR COPPER, ZINC AND CADMIUM.
Results in μg g^{-1} wet weight.
Samples collected on the 14th February 1978.

	Station and Location	Cu	Zn	Cd
I.	Sediment sampling station 1800 (No. 2 Windmill) Depth 20 m	0.6 0.9 0.8 1.1	5.9 14.5 6.7 16.9	0.8 1.0 0.3 1.2
II.	Sediment sampling station 1900 (South of sewage outfall) Depth 18 m	15.1 12.2 8.7	30.7 34.2 22.8	0.3 0.5 0.1
III.	Sediment sampling station 1400 (Woodman Point) Depth 10 m	1.7 2.8	22.1 18.6	0.5 0.2
IV.	James Point Depth 14 m	12.1 8.2 6.3	13.4 14.0 9.7	1.2 1.3 0.9
VII.	C.S.B.P. Sediment station 'E' Depth 17 m	27.5 34.9 26.7	49.1 25.1 30.3	4.7 4.5 5.2
VIII.	Sediment sampling station 4510 (Kwinana Wreck) Depth 17 m	1.5 2.8 3.4	18.5 21.6 31.6	2.4 2.2 2.6
IX.	C.B.H. jetty Depth 18 m	2.1 2.0 1.7	20.7 16.2 14.1	1.8 1.3 1.5
X.	Sediment sampling station 5000 (Mangles Bay) Depth 17 m	1.2 1.3 0.8	7.9 9.2 6.1	0.6 0.3 0.8
XI	Shoalwater Bay Depth 4 m	0.6 0.3 0.1 0.5	6.8 7.3 5.6 5.1	0.1 0.2 0.3 0.2

TABLE 4.18

RESULTS FOR THE ANALYSES OF METALS IN *POSIDONIA* SEAGRASS SPECIES AND THEIR EPIPHYTES.

Results in μg g^{-1} dry weight.
Samples collected in December 1977.

(Refer to Figure 4.4.)

	Posidonia seagrass samples				Epiphytes from seagrass samples			
Station[(a)]	Cu	Zn	Cd	Fe	Cu	Zn	Cd	Fe
C	-	-	-	-	5.2	58.2	0.5	252
E	3.1	57.6	0.6	80	4.9	32.8	0.3	216
F	3.4	60.0	0.5	90	6.4	30.0	0.4	298
G	2.3	47.8	0.6	78	7.0	21.2	0.4	222
H	3.4	68.6	0.7	152	5.7	21.0	0.2	344
I	3.8	69.6	0.6	78	7.2	28.0	0.4	354
J	2.9	54.0	0.4	80	6.5	40.4	0.5	264
K	3.1	70.6	0.6	90	7.2	33.8	0.5	296
L	2.2	62.6	0.6	70	5.0	41.2	0.5	204
M	3.3	52.0	0.4	104	6.7	33.8	0.4	484
N	1.6	43.2	0.5	150	6.2	27.2	0.3	388
O	1.5	47.4	0.3	60	6.6	40.8	0.6	272
R	1.8	56.2	0.3	96	7.6	36.4	0.4	338
S	3.5	67.2	0.4	80	6.3	38.0	0.5	394
U	0.6	36.4	0.2	54	8.8	57.6	0.5	328
V	2.6	38.8	0.3	118	6.7	24.2	0.4	294
W	0.9	33.4	0.2	24	5.2	17.0	0.4	326
T	7.9	169.4	0.4	118	10.7	67.6	0.5	628

(a) No results were available to stations A, B, D, Q or P.

TABLE 4.19

RESULTS FOR THE ANALYSES OF METALS IN THE SEA LETTUCE, *ULVA LACTUCA*

Results are in μg g^{-1}, dry weight.
Samples collected in May 1978

Station	Cu	Zn	Cd	Fe	Mn	Pb	Cr	Ni	Hg
Garden Is., Entrance Rocks	9.3	28.3	0.2	192	1.7	0.2	<1	<1	<0.0
Cockburn Power Boat Club	6.6	24.7	0.6	156	2.1	0.9	<1	<1	<0.0
Jervoise Bay	4.6	30.4	0.3	134	1.9	0.4	<1	<1	<0.0
B.P. - James Point	6.5	44.4	1.6	415	10.6	1.7	<1	<1	<0.0

TABLE 4.20

ALKANE CONCENTRATIONS IN SEAGRASS AND ALGAE.
Results in μg g^{-1} wet weight.

Date	Station No.	Location	Sample	Alkane Concen. μg g^{-1} wet weight
28. 9.78	1	Garden Island	*Ulva lactuca*	2
28. 9.78	6	James Point	*Ulva lactuca*	1
28. 9.78	17	James Point	*Ulva lactuca*	1
28. 9.78	23	James Point	*Posidonia sinuosa*	3
30.10.78 to 2.11.78	24	Safety Bay	*Posidonia sinuosa*	3
30.10.78 to 2.11.78	6	James Point	*Posidonia sinuosa*	3

Figure 4.12 illustrates G.L.C. chromatograms of *Ulva* and *Posidonia*.

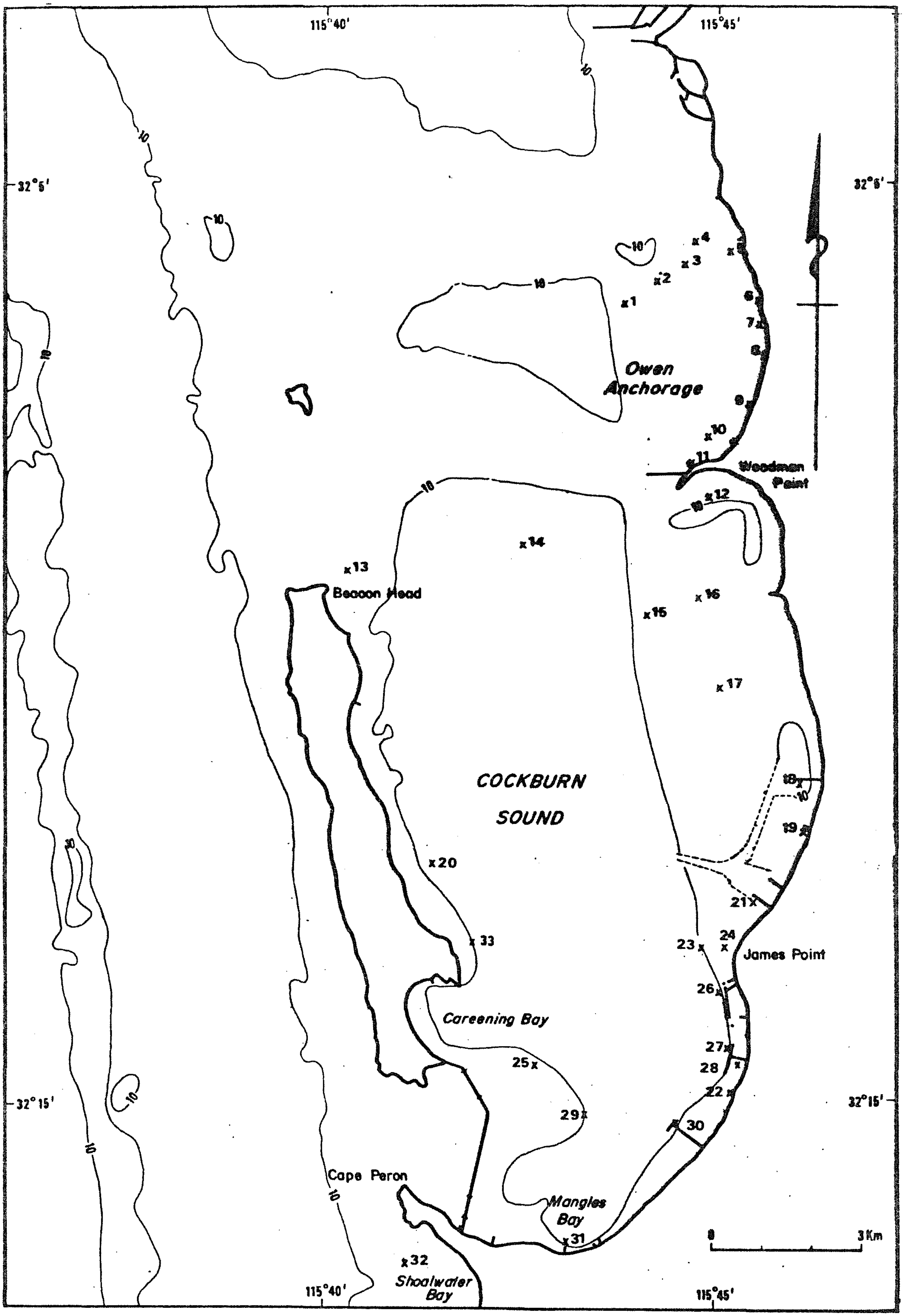


Figure 4·1

SAMPLING SITES FOR THE MUSSEL, *MYTILUS EDULIS*

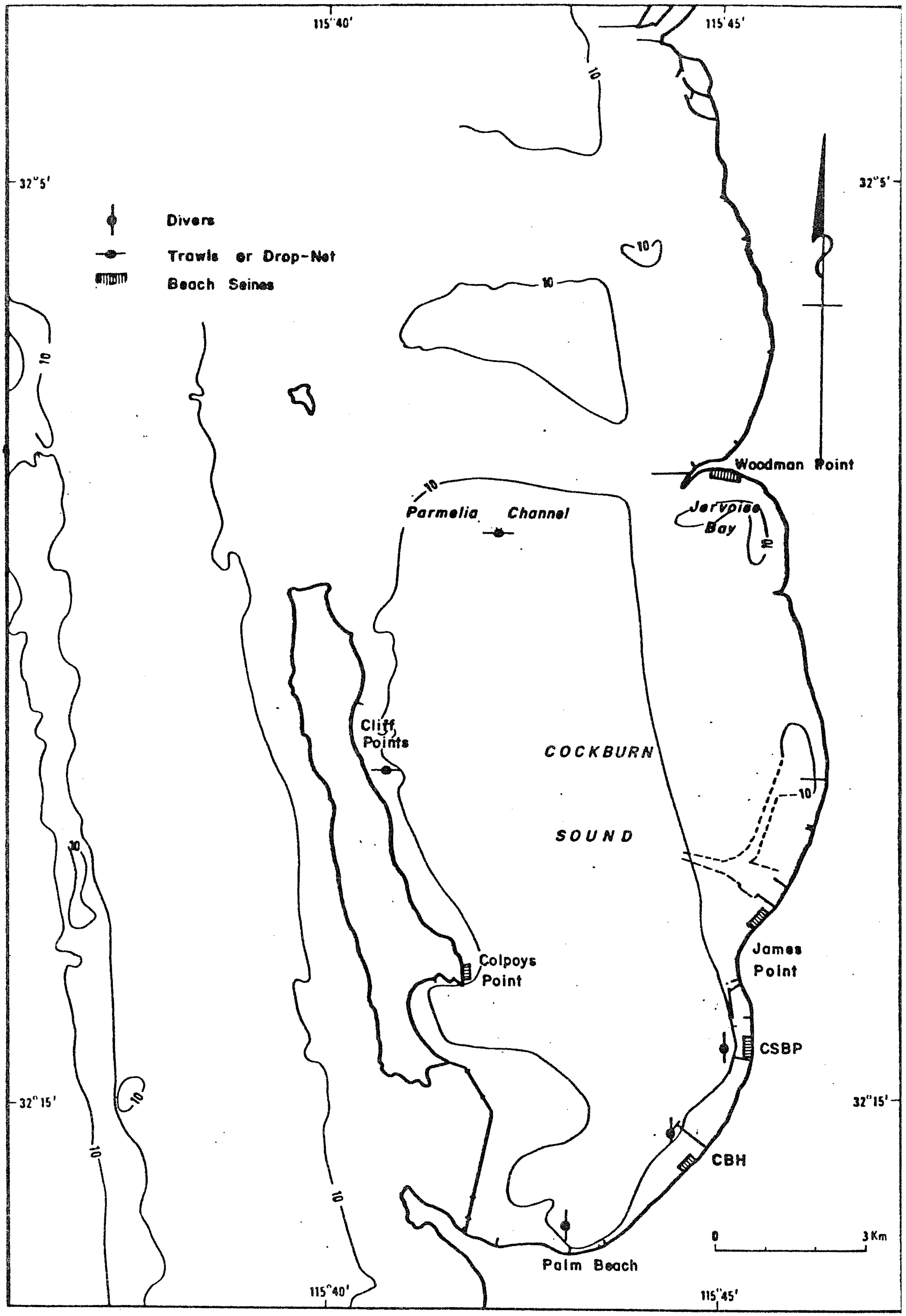


Figure 4.2

CRAB, *Portunus pelagicus*, SAMPLING STATIONS IN THE COCKBURN SOUND AREA

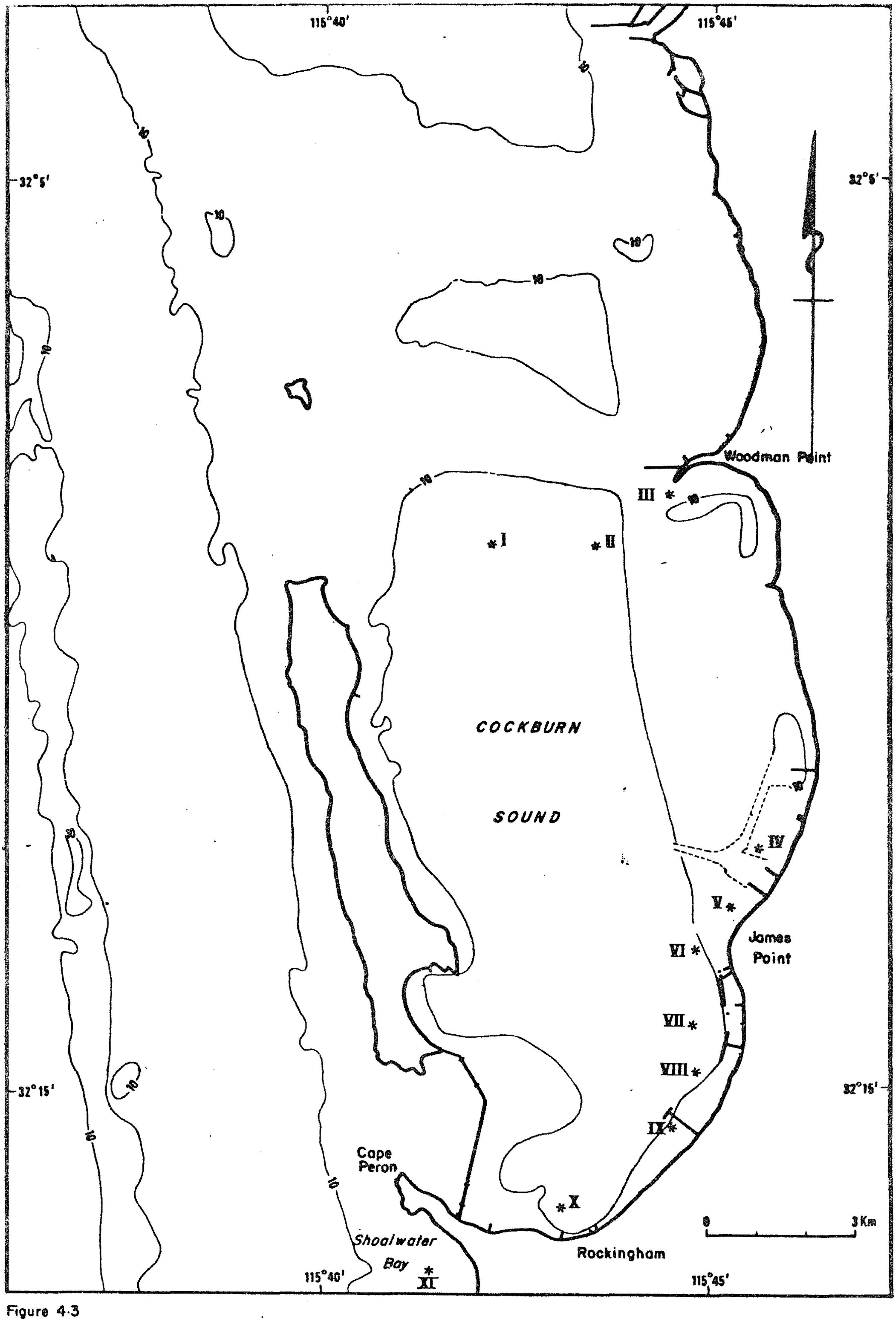


Figure 4.3

POLYCHAETE WORM, *Chaetopterus variopedatus*, SAMPLING STATION IN THE COCKBURN SOUND AREA

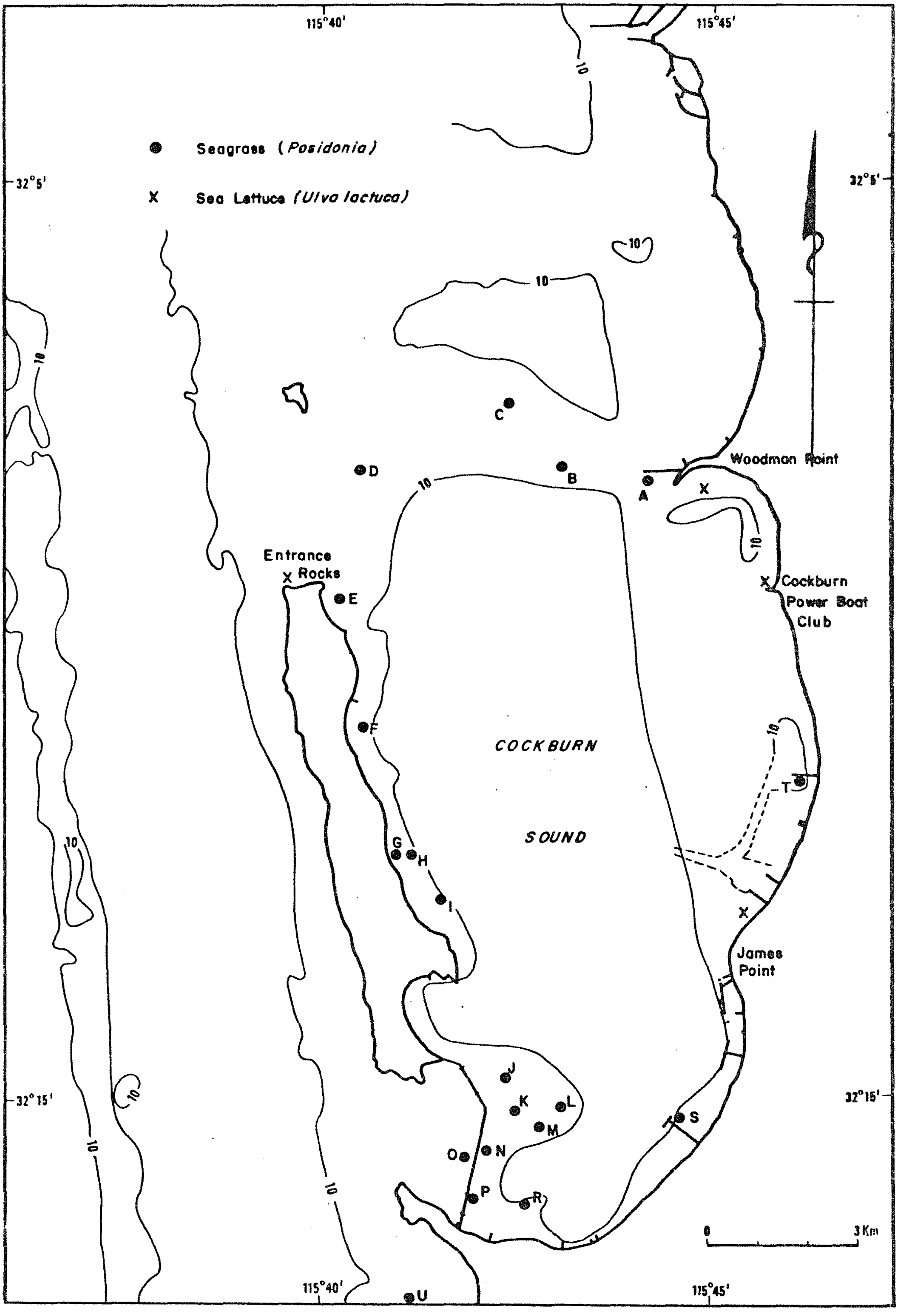


Figure 4·4

SEAGRASS (dots), *Posidonia* SPECIES AND SEA LETTUCE, *Ulva lactuca* (crosses), SAMPLING STATIONS IN THE COCKBURN SOUND AREA. Stations V & W are in Warnbro Sound.

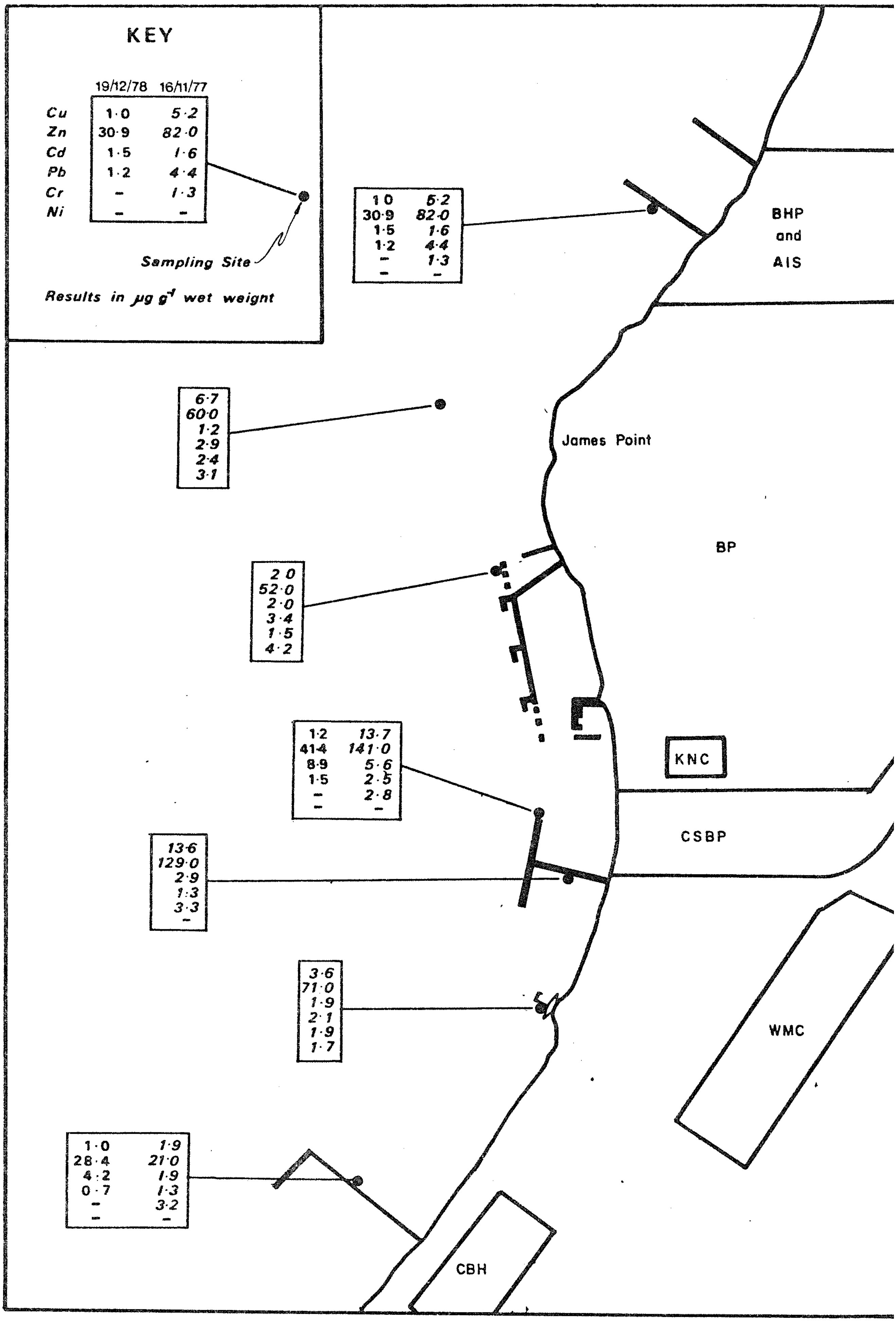


Figure 4·5

HEAVY METAL CONCENTRATIONS IN MUSSELS SAMPLED IN THE JAMES POINT AREA

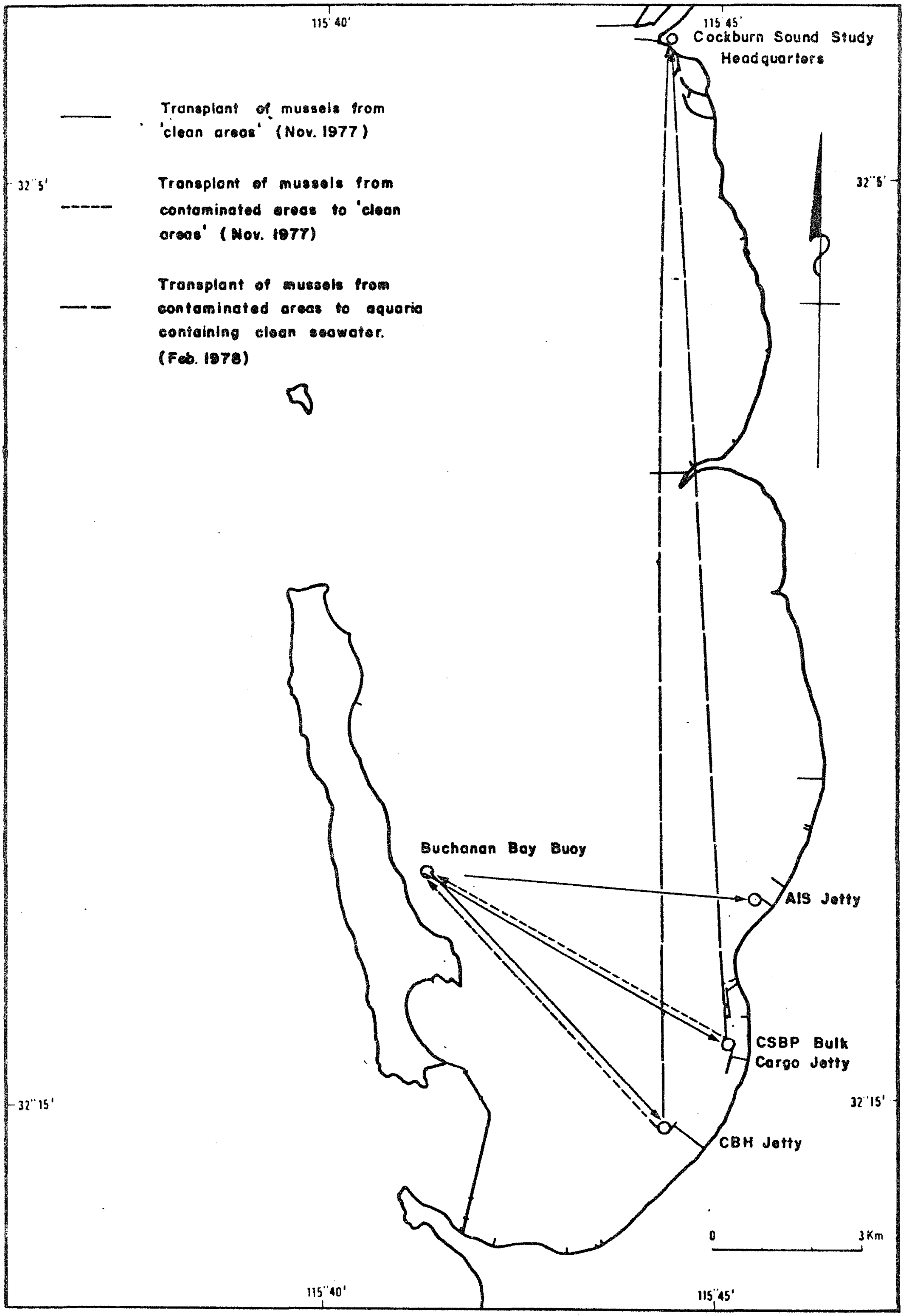


Figure 4·6

MUSSEL TRANSPLANT TRIAL LOCATIONS

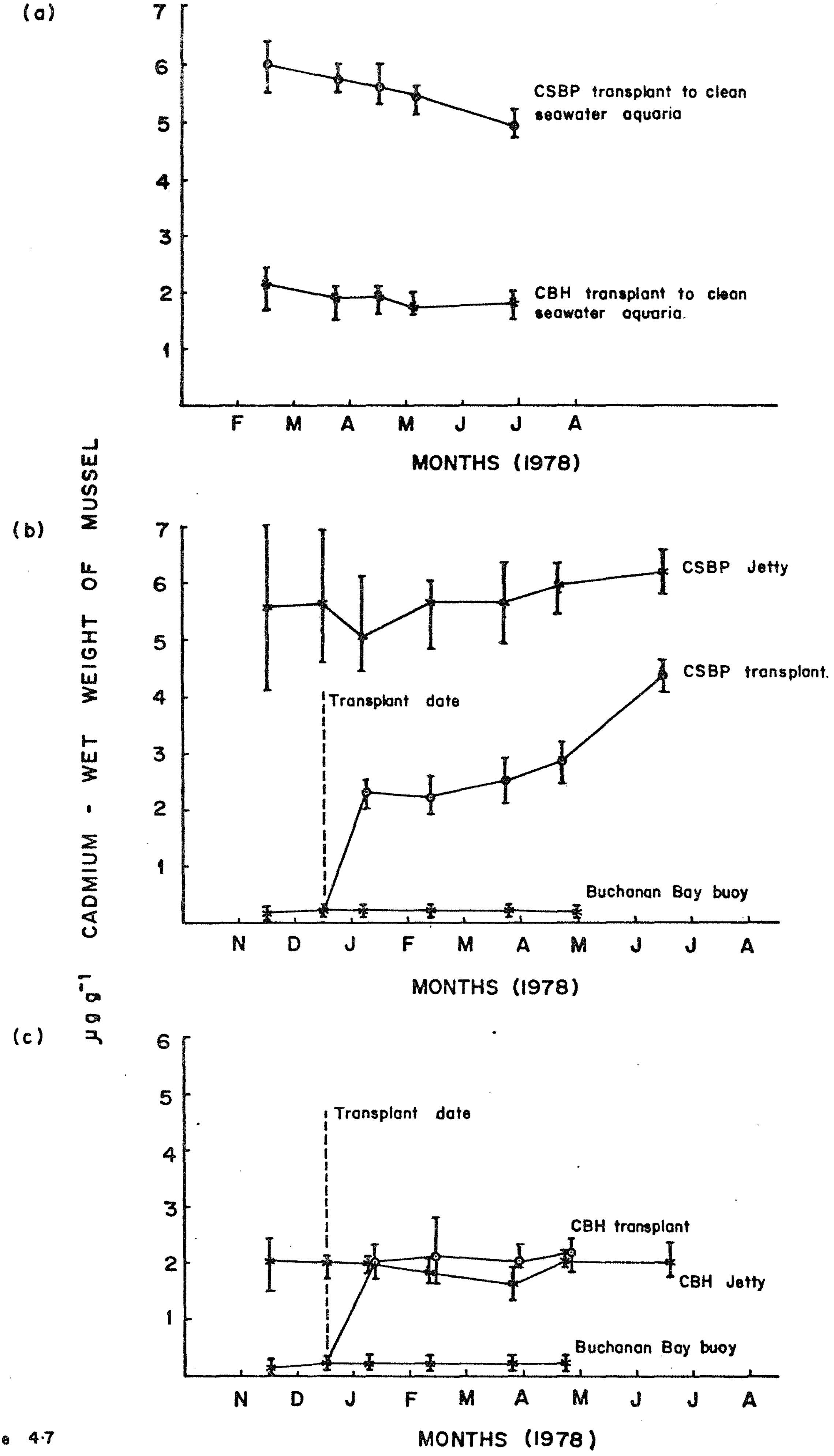


Figure 4·7

(a) *MYTILUS* TRANSPLANT FROM CBH & CSBP TO ASSESS EXCRETION OF CADMIUM

(b) *MYTILUS* TRANSPLANT FROM BUCHANAN BUOY TO ASSESS UPTAKE OF CADMIUM

(c) *MYTILUS* TRANSPLANT FROM BUCHANAN BUOY TO ASSESS UPTAKE RATE OF CADMIUM

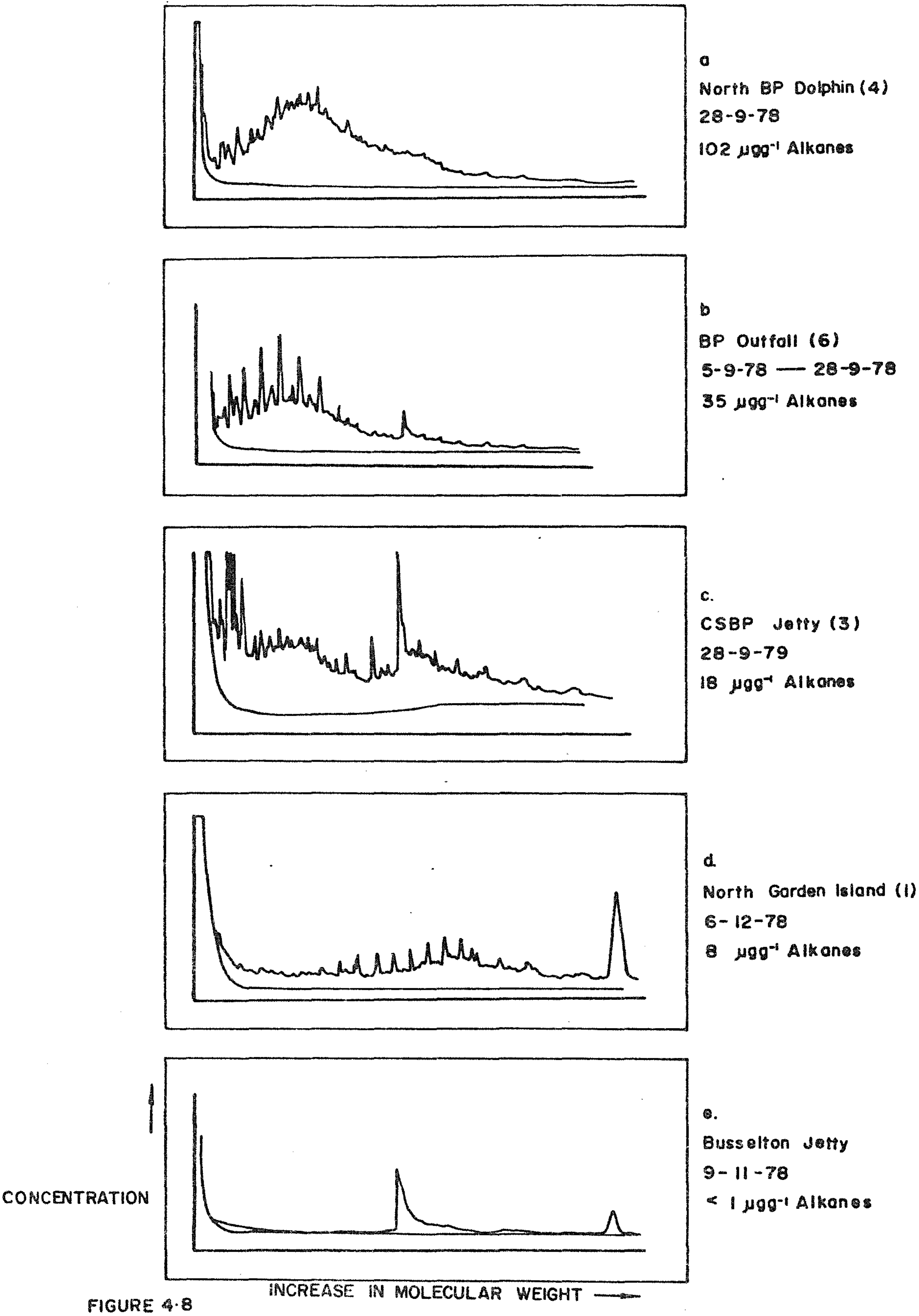
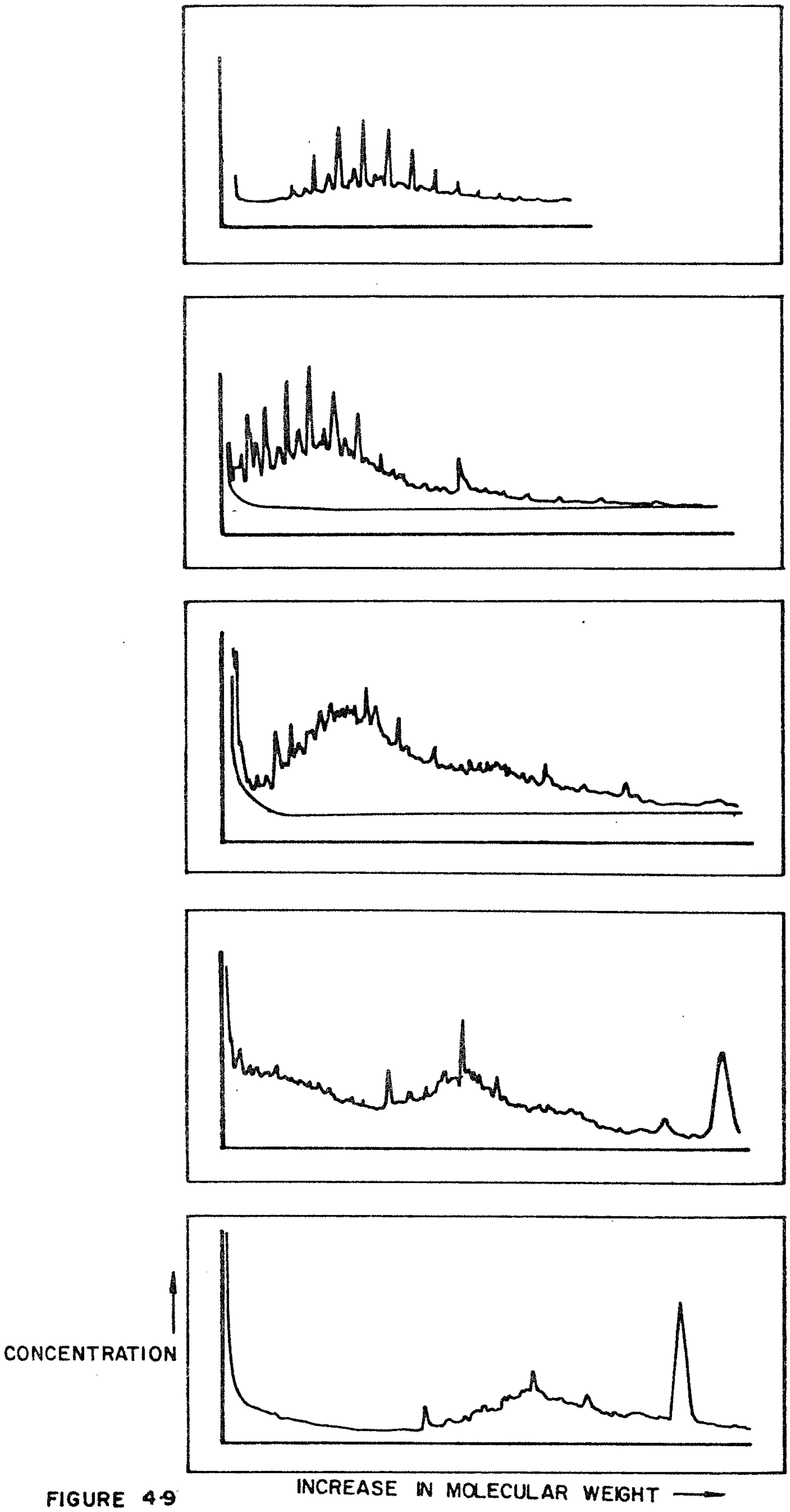


FIGURE 4·8

GAS CHROMATOGRAMS OF ALKANES EXTRACTED FROM MUSSELS COLLECTED IN COCKBURN SOUND AND AT BUSSELTON JETTY.



a.
B.P effluent alkanes depleted in low molecular weight material due to the isolation procedure used.

b.
28-9-78
35 μgg^{-1} Alkanes

c.
9-11-78
19 μgg^{-1} Alkanes

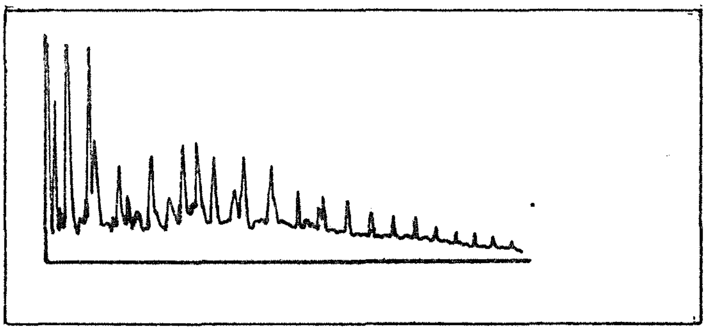
d.
6-12-78
10 μgg^{-1} Alkanes

e.
22-11-78
4 μgg^{-1} Alkanes

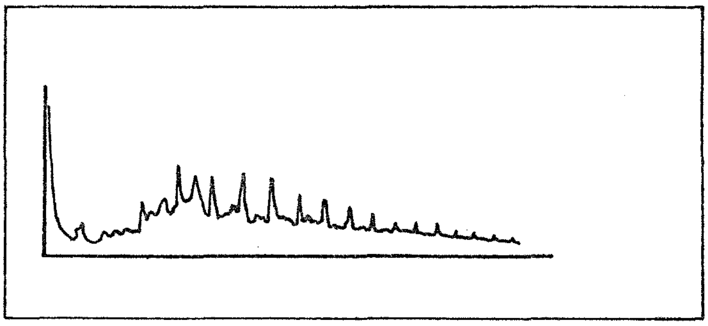
FIGURE 4.9

GAS CHROMATOGRAMS OF ALKANES ISOLATED FROM MUSSELS TRANSPLANTED FROM NORTH GARDEN ISLAND TO BP OUTFALL AND SAMPLED PERIODICALLY.

A trace of alkanes isolated from BP effluent water using a different isolation technique which depletes the extract of low molecular weight hydrocarbons is shown in Figure a for comparison.



a. Gas chromatogram of pentane - soluble organics isolated from BP effluent water by absorption on XAD - 2, elution with methanol and extraction into pentane.



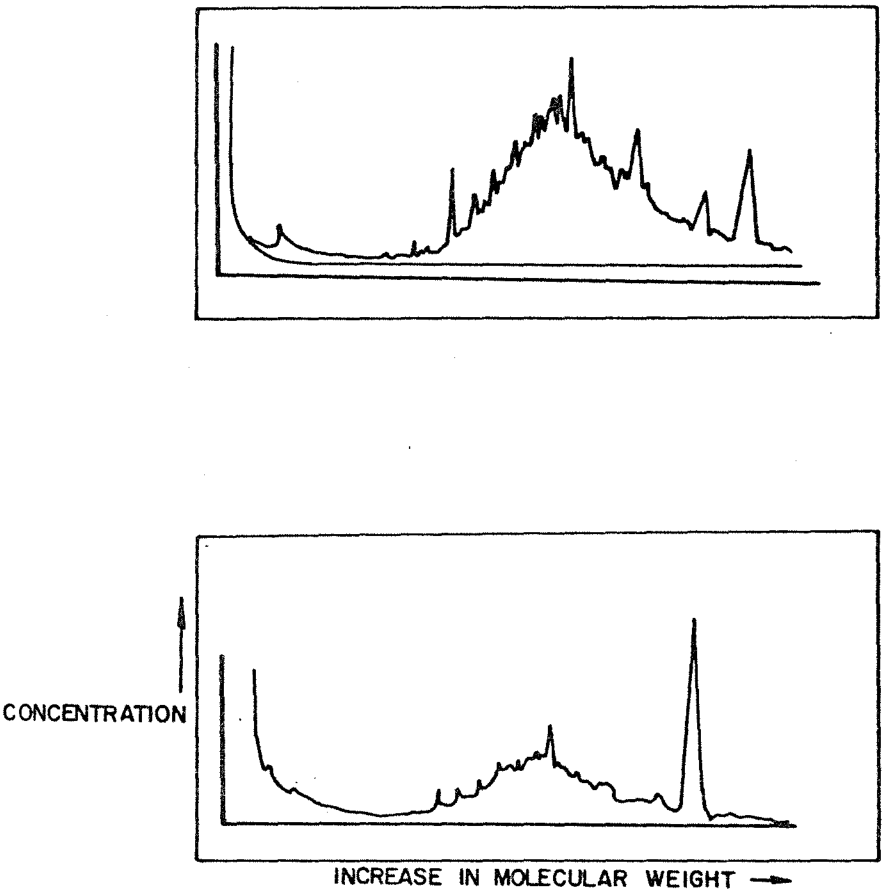
b. Gas chromatogram of sample obtained as above further treated by being dissolved in acetone - water, evaporation of acetone, extraction into dichloromethane and evaporation of dichloromethane.

FIGURE 4·10

COMPARISON OF GLC TRACES OF TOTAL PENTANE - SOLUBLE ORGANICS ISOLATED FROM B.P. EFFLUENT WATER BY:

a A procedure similar to that used to isolate alkanes from mussels which retain low molecular weight material, and

b. A procedure similar to that used to isolate organics from B.P. effluent water (Part II of Reference II) in which low molecular weight material is lost.



a.
Crab hepatopancreas
CBH (20)
18-10-78
78 µgg⁻¹ Alkanes

b.
Crab flesh
Jervoise Bay (18)
28-11-78
25 µgg⁻¹ Alkanes

FIGURE 4·11

GAS CHROMATOGRAMS OF ALKANES EXTRACTED FROM FLESH AND HEPATOPANCREAS OF CRABS *(Portunus Pelagicus)*

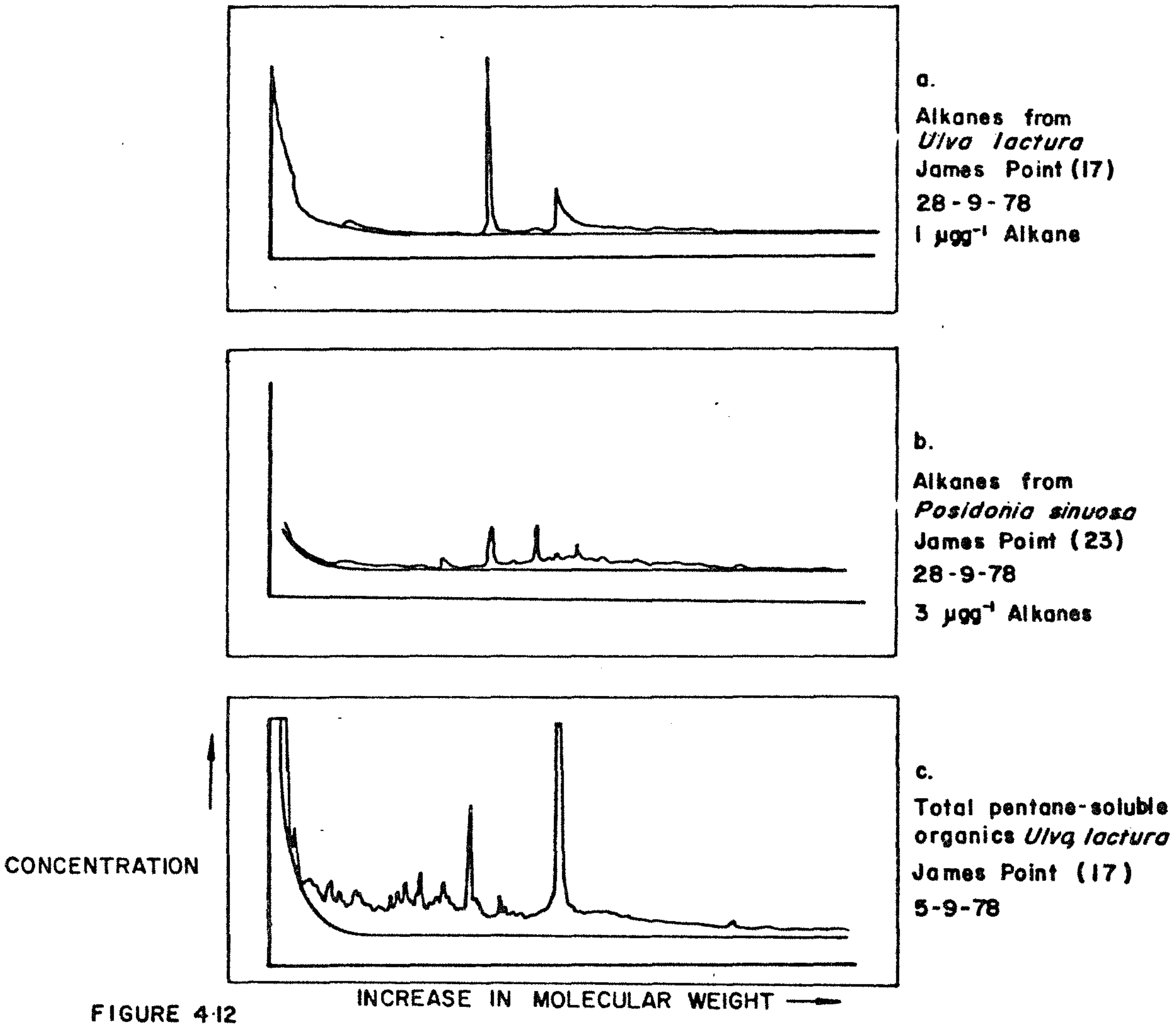


FIGURE 4·12

GAS CHROMATOGRAMS OF EXTRACTS FROM *Ulva lactuca* AND *Posidonia sinuosa*.

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5. FISH

SUMMARY

The wet and dry weight concentrations of cadmium, zinc, copper, lead, iron, manganese, nickel, chromium and cobalt were measured in muscle taken from samples of 12 species of teleost fish caught in Cockburn Sound.

The maximum concentrations of the nine metals were well below the Western Australian and proposed National Health and Medical Research Council (NH & MRC) standards for these elements in seafood (Table 4.2). Furthermore, the metal concentrations in fish flesh were many times lower than in invertebrates such as the common mussel, *Mytilus edulis* from the same area. The low levels in fish flesh probably reflect the relatively low rate at which heavy metals are accumulated by teleost muscle and also the movement patterns of fish within the polluted and relatively unpolluted regions of the Sound and between the Sound and the Indian Ocean.

The effect of metals on the fish population in Cockburn Sound may be more subtle than simply accumulating metals in muscle tissue. The possibility of sublethal effects are discussed.

Petroleum derived hydrocarbons are present in fish from this region and the problems associated with these substances are considered.

5. FISH

5.1 Introduction

5.1.1 Metals

Initial work carried out by the Cockburn Sound Study Group in Cockburn Sound had shown that the amounts of heavy metals in the sediments and water, and in selected invertebrates were much higher than would be expected for an unpolluted marine embayment (see Chapters 2, 3 and 4) (1). Industrial effluents and fallout from smoke stake emissions are the main sources of metal input to Cockburn Sound. The Sound provides a nursery ground for many species of teleosts and is widely used by both amateur and professional fishermen (2). For this reason the present study was initiated to ascertain whether teleosts, particularly those of commercial importance, had accumulated the nine heavy metals that are known to be discharged in appreciable amounts into the Sound.

The 12 species of commercial teleost used in this study were of sea mullet (*Mugil cephalus*), yellow-eye (*Aldrichetta forsteri*), Australian herring (*Arripis georgianus*), King George whiting (*Sillago punctata*), yellow-finned whiting (*Sillago schomburgkii*), cobbler (*Cnidoglanis macrocephalus*), sea garfish (*Hyporhamphus melanochir*), tailor (*Pomatomus saltator*), rock flathead (*Platycephalus laevigatus*), small-toothed flounder (*Pseudorhombus jenynsii*), skipjack trevally (*Caranx georgianus*) and six-lined trumpeter (*Pelates sexlineatus*).

Toxicological studies were not performed on any marine fauna during the Cockburn Sound Study. However, an extensive survey of the waters for cadmium, copper and lead was carried out and indications are that the levels of these metals are not high enough to cause acute toxicity within the fish population.

This study's results for metals in flesh are of the same order of magnitude as those of two limited studies of some teleost species in Cockburn Sound in June 1974 (3) and March 1975 (4). Both studies demonstrated consistently low mercury concentrations of between 0.01 and 0.16 $\mu g\ g^{-1}$ wet weight. Mercury was not analysed in this study.

5.1.2 Hydrocarbons

Fish were caught from selected areas around Cockburn Sound to assess whether hydrocarbon accumulation in muscle tissue varies from one area to another. The alkane fraction of hydrocarbons was used in this assessment.

The petroleum hydrocarbon input comes primarily from industry (mainly an oil refinery) and a secondary source is from shipping activities.

5.2 Experimental Methods

The fish were caught either in beach seines, trawls or set nets operated at seven different sampling areas (Figure 5.1.). Four of these were in areas where appreciable amounts of heavy metals were known to be discharged, namely off Woodman Point, and adjacent to AIS, BP and CSBP. Three were located in relatively unpolluted areas, namely off Rockingham, Colpoys Point and Dance Head. Some fish were taken from Becher Point at the southern end of Warnbro Sound (Figure 1.1).

5.2 (Cont'd)

Representatives of the 12 teleost species studied were measured and weighed to the nearest 1 mm and 100 mg (Table 5.1). Fillets were then wet weighed and freeze dried to constant weight.

The analytical method used was a modification of the nitric/perchloric acid digestion of Anderson (5). Analysis of each sample was carried out in duplicate using a Perkin Elmer 503 Atomic Absorption Spectrophotometer and air-acetylene flame, with deuterium lamp background corrections applied in the case of cadmium, lead, cobalt and nickel.

Complete details of the analytical method are given by the analysts, Plaskett and Potter (6). Validation of heavy metal analysis of fish is given in the Report by these authors which is held in the Cockburn Sound Study Data Repository.

For analysis of the alkane fraction of hydrocarbons, the fish were identified, filleted, and the wet weight of each flesh sample recorded. Each sample consisted of pooled fillets from at least two individuals. The experimental details are given in the report entitled "A Preliminary Study of Petroleum Contamination in Cockburn Sound", by Alexander, *et al* the analysts, kept in the Cockburn Sound Study Data Repository.

5.3 Results

5.3.1 Heavy metals in Cockburn Sound fish

The concentrations of the metals in muscle of the teleosts examined in this study are given as mean μg g^{-1} wet weight (Table 5.2). The concentrations of the metals in muscle tissue reported for dry weights are given by Plaskett and Potter (6).

The amount of information on the heavy metals in various species that could be used for comparisons between different times of the year and between areas under direct and intermittent effluent discharge was limited. However, in the case of the sea mullet and the yellow-finned whiting, data was available for five samples taken from both of these types of areas on each of three separate occasions (April, October and December, 1978). In neither of these species was there any indication of the presence of high heavy metal levels in fish from polluted areas or at any one particular sampling time. Since there was no clear trend with site or season in the above two species, and no consistently high values were found in the other species at a particular location or time, metal values are presented as a mean for each species (Table 5.2). Results were collated for 221 individual species.

Cadmium -

The concentration of cadmium, expressed in terms of wet body weight, found in all 12 species was small, with the lowest mean (0.04 μg g^{-1} occurring in the six-lined trumpeter and the highest (0.08 μg g^{-1}) in the yellow-eye mullet (Table 5.2).

Cadmium concentrations in teleost muscle tissue from Cockburn Sound are low when compared to the health standards. The highest value obtained for any individual fish, namely the 0.18 μg g^{-1} in a 320 g yellow-eye mullet, is much lower than the 2 μg g^{-1} recommended NH & MRC standard for this metal.

5.3.1 (Cont'd)

In the Cockburn Sound area, the levels of cadmium in fish flesh are much lower than those found in mussels. For example, mean cadmium concentrations in mussels frequently exceeded 1.5 μg g^{-1} (wet weight) and values greater than 6.0 μg g^{-1} were recorded in contaminated areas on several occasions (see Chapter 4). The latter value represents approximately a 100 times greater concentration in the mussel than was normally found in the flesh of teleosts from the same environment.

Zinc -

The levels of zinc are low in fish in Cockburn Sound and fall well below the Western Australian standard of 40 μg g^{-1} and the recommended NH & MRC standard of 1 000 μg g^{-1}, wet weight (Table 4.2). The lowest (4.0 μg g^{-1}) and the highest (15.1 μg g^{-1}) mean wet weight concentrations were found in the tailor and six lined trumpeter respectively, with the highest individual value (21.6 μg g^{-1}) occurring in a 167 g trumpeter fish.

Zinc levels in mussels from Cockburn Sound ranged from 16.7 μg g^{-1} to 134.8 μgl^{-1} (see Chapter 4), representing concentrations from two to 12 times greater than are generally found in flesh from fish in the same environment.

Copper -

The mean wet weight concentration of copper in teleosts in Cockburn Sound ranged from 0.17 μg g^{-1} in the flounder to 0.60 μg g^{-1} in the tailor, with the highest individual value of 1.38 μg g^{-1} occurring in the 34 g representative of the sea mullet (Table 5.2). This last value is well below the 30 μg g^{-1} recommended NH & MRC standard for copper.

In contrast to fish muscle, the greatest mean wet weight concentration in mussels from the Sound was 14.2 μg g^{-1} (see Chapter 4). This represents approximately a concentration 24 times greater than is found in the tailor which had the highest mean copper levels of all the fish examined.

Lead -

The maximum concentration of 1.24 μg g^{-1} found in any fish (320 g yellow-eye mullet) in the Cockburn Sound area was below the recommended NH & MRC standard of 2 μg g^{-1} for lead (Table 4.2). The maximum mean concentration in all fish was 0.57 μg g^{-1} in the same species, while the minimum was the 0.35 μg g^{-1} recorded for the cobbler.

Iron -

The concentration of iron in fish from Cockburn Sound does not reflect the high discharge rates of this metal into Cockburn Sound The highest individual concentration of 14.0 μg g^{-1} wet weight was found in a 40 g sea mullet and the mean values ranged from 1.6 μg g^{-1} in the garfish to 6.8 μg g^{-1} in the tailor.

Manganese, Chromium, Cobalt and Nickel -

For manganese, chromium, cobalt or nickel there are no recommended NH & MRC standards. In Western Australia the accepted standard for chromium, cobalt and nickel is 5.5 μg g^{-1}. This level was not reached in any fish examined (Table 5.2).

5.3.2 Alkanes in Cockburn Sound fish

The results from the analyses of alkanes in a variety of fish are

5.3.2 (Cont'd)

presented in Table 5.3. Some of the gas chromatograms of alkanes extracted from fish in Cockburn Sound are given in Figure 5.2.

In interpreting these results, several facts must be borne in mind. Samples usually comprised fillets from two or more individuals, and as fish tend to be fairly mobile, there is a strong possibility that the contamination levels of a fish sample may not be a reliable indicator of the contamination at the particular sampling station at which it was collected. Notwithstanding this reservation, all fish samples collected showed appreciable levels of alkanes, and where comparison is possible with samples from Warnbro Sound (Australian herring, Trumpeter whiting, Yellow-tail and Trumpeter) the figures for Cockburn Sound tend to be higher, in some cases by as much as one order of mangitude. Any doubts that more than a small proportion of the alkanes in the fish are of biogenic origin are dispelled by the sample of G.L.C. traces shown in Figure 5.2. These all show the characteristic signs of petroleum-derived alkanes: the broad unresolved envelope from C_{16} to C_{26} due to naphthenics and the relatively similar amounts of odd-numberd and even-numbered n-alkanes.

5.4 Discussion

5.4.1 Metal levels in fish muscle tissue

It has been shown that Cockburn Sound is a nursery area for more than 100 species of teleost fish (2).

Cadmium -

The 0.05 $\mu g\ g^{-1}$ obtained for cadmium in both the tailor and sea mullet in Cockburn Sound is virtually identical to the values of 0.04 $\mu g\ g^{-1}$ recorded for both these species taken from off the New South Wales coast (8). In a study carried out in the Derwent Estuary, Tasmania, the cadmium levels of the sea mullet are given as less than 0.05 $\mu g\ g^{-1}$(9). Whereas all nine species in the New South Wales study produced values of 0.04 $\mu g\ g^{-1}$ there was far greater variability in the Derwent, where values for different species ranged from 0.05 $\mu g\ g^{-1}$ to 0.3 $\mu g\ g^{-1}$. The highest mean cadmium value for any species was less than the mean of 0.09 $\mu g\ g^{-1}$ given for the black marlin, *Makaira indica*, from the north eastern Australian waters (10).

Moreover, the mean cadmium values in this study lie within the lower end of a range of mean values given for fishes taken in the Northern Hemisphere, where values were well in excess of 0.1 $\mu g\ g^{-1}$ wet weight for many species in a variety of environments (10), (11), (12).

Zinc -

Mean values of 4.0 $\mu g\ g^{-1}$ wet weight for the sea mullet may be compared with the 9.6 and 4.2 $\mu g\ g^{-1}$ wet weight recorded respectively for the same species in New South Wales (8). Both the above values for sea mullet are below the 13.3 $\mu g\ g^{-1}$ wet weight recorded for this species in the Derwent Estuary (9).

The values are similar to those recorded for teleosts in several Northern Hemisphere localities (12), (13), (14), (15). However, some of the species studied (12) exhibited much higher levels, particularly in the sprat, *Clupea sprattus*, whose muscle had a mean zinc concentration of 119 $\mu g\ g^{-1}$

5.4.1 (Cont'd)

Copper -

In the case of the sea mullet, the mean copper concentration of 0.41 μg g^{-1} wet weight is lower than the 0.80 and 0.86 μg g^{-1} wet weight found in the Derwent Estuary and the New South Wales studies (5), (6), and also the 1.9 μg g^{-1} dry weight recorded for a similar species from the North Atlantic (16). For tailor, however, the copper concentrations of 0.60 μg g^{-1} were only slightly lower than the 0.69 μg g^{-1} found in the same species in New South Wales (8). The mean copper concentration of 0.4 μg g^{-1} in black marlin, from Australian waters (10) was within the range of the means for the Sound's 12 species. The data shows that the level of copper is low in the flesh of fish from Cockburn Sound. For example, dry weight copper concentrations for fish muscle of between 8 and 23 μg g^{-1} have been recorded for seven North Atlantic teleosts (16), whereas the means for fish in Cockburn Sound ranged from 0.80 to 2.44 μg g^{-1} dry weight with the miximum value in any individual being 5.77 μg g^{-1}.

The latter Cockburn Sound value is virtually identical to the 7.0 μg g^{-1} recorded for tailor caught in the Atlantic Ocean (18). The recorded range compares with that found in nine species of teleost caught off the New Zealand coast, where the minimum and maximum values were 2.2 and 9.2 μg g^{-1} (17). In terms of dry weight, this represents from 6.4 to 27.8 μg g^{-1} similar to the 7.7 to 35.8 μg g^{-1} found in eight species caught on the South Texas outer continental shelf (19).

Manganese, Chromium, Cobalt and Nickel-

The mean concentrations for manganese in fish muscle for the Cockburn Sound area (0.18-0.44 μg g^{-1} wet weight) are similar to the values recorded for marine teleosts in the Northern Hemisphere (15), (18), (20), (21). The mean concentrations for chromium in Cockburn Sound fish (0.05-0.18 μg g^{-1} wet weight) was generally near the range given in a New Zealand investigation and in several Northern Hemisphere studies on the muscle tissue of teleosts, but the upper mean values given in all these investigations are greater than our highest mean concentration (17), (18), (19), (22), (23). Although the nickel concentrations in Cockburn Sound teleosts (0.11-0.39 μg g^{-1} wet weight) are considerably higher than those found in New Zealand marine fishes (17), they are similar to the lower values given in several Northern Hemisphere studies (15), (19), (23). However, they are well below that found in some species of fish caught off the Northumberland coast of the United Kingdom, where values as 7.2 μg g^{-1} wet weight were recorded (12). The concentrations of cobalt (0.24-0.36 μg g^{-1} wet weight) showed similar patterns to those of nickel.

Lead -

Means for the concentration of lead of 0.45 μg g^{-1} for sea mullet and 0.43 μg g^{-1} tailor are lower than values for the species caught in New South Wales (8). Values are very similar to those found in several other marine species in Australia (8) and New Zealand (17).

The data for the nine heavy metals in fish muscle tissue are low compared to similar marine locations elsewhere and they do not exceed Western Australian or NH & MRC recommended standards. However, analysis of results for the element lead reveals that all the fish caught may in fact have elevated levels of that metal in their flesh. For comparison, wet weight analysis results of more than 400 fish from European marine waters on each of two occasions gave a range of 0.037 to 0.50 μg g^{-1} and 0.01 to 0.40 μg g^{-1}, for lead (24), and a total of 133 fish from Georgia estuaries had a range of lead

5.4.1 (Cont'd)

concentrations from about 0.002 to 0.40 μg g^{-1} (25). Burnett and Patterson (26) claim that uncontaminated tuna muscle (*Thunnus alalunga*) contains about 0.0003 μg g^{-1} lead. Not all the fish in these samples were teleosts. Comparison of the above figures with the range of 0.15 to 1.24 μg g^{-1} lead found in the 221 teleosts analysed from Cockburn Sound indicates that even the lower range of lead results were elevated.

Horowitz and Presley (19) have drawn attention to the markedly lower concentrations of heavy metals in teleosts from a continental shelf region compared with those in neuston, shrimp and squid. However, many studies have shown that heavy metal concentrations in fish muscle are usually lower than in other tissues and may have less significance from a toxicological point of view (12). In a review of current work, Phillips points out that "the use of teleosts, or their tissues, as an indicator of pollution by trace metals does not at this time seem justifiable.".

Although, from a public health point of view, none of the teleost flesh had metal levels that exceeded Western Australian or NH & MRC recommended standards, levels of heavy metals may be high enough in the Sound waters (see Chapter 2) to be causing stress to fish at sub-lethal levels (11). (see Appendix VI for a "Draft of the Revised Standard (NH & MRC) for Metals in Foods", June 1979).

5.4.2 Review of heavy metal effects on marine fish

In 1972 the United States Environmental Protection Authority proposed marine water quality standards for cadmium, copper, lead, zinc, mercury, nickel, iron and manganese. The standard concentrations were achieved by applying a factor of 0.01 to 0.02 to 96 h L.C. 50 data for a range of marine fauna. Synergistic effects between such metals as Cadmium, Copper and Zinc warranted a factor of 0.001. Thus the basic approach which water quality authorities have taken is to extrapolate from available data by application of what may seem a reasonable safety factor with respect to known background concentrations of metals in oceans (27).

Recent work on toxicology of marine biota has centred on sub-lethal physiological impairment resulting from the chronic low level exposure more characteristic of the environment. Although work on these aspects is still at an early stage, indications from overseas research are that the above approach to safe water quality may still encompass metal concentrations which can produce metabolic stress, particularly in the important development stages. One problem being encountered is the lack of reliable water sampling and analytical expertise.

The biochemistry of marine animals is not as well known as that of terrestrial organisms. It is well known that enzyme metabolism of heavy metals alters in relation to different concentrations in the body, especially in mammal pathology. Thus, the few studies undertaken of sub-lethal effects in marine fish have pursued the possibility of the same relationship. In the Winter flounder, *Pseudopleuronectes americanus*, exposed to cadmium chloride at between 5 and 10 $\mu g l^{-1}$ for 60 days, zinc based enzymes have shown significant increases in activity. This was interpreted as a compensatory mechanism to overcome inhibition, a process naturally requiring a continuous increase in energy supply (28). Other features of this study were desensitisation of magnesium modulated enzymes and a decrease in gill tissue respiration in 10 $\mu g l^{-1}$ cadmium chloride. This same effect on respiration was noted for the flounder species at 5 $\mu g l^{-1}$ by Calabrese *et al* (29), although tests were conducted at a lower salinity level than that of ocean water. Mercuric chloride at a concentration of 10 $\mu g l^{-1}$ had an opposite effect; an

5.4.2 (Cont'd)

increase in oxygen consumption of around 15 per cent. In general, metal toxicity thresholds seem to increase with salinity (30), (31).

5.4.3 Review of hydrocarbon effects on marine fish

Elevated levels of petroleum derived alkanes occur in fish, sediments and mussels in Cockburn Sound (see Chapters 3 and 4). Apart from oil spillages from shipping, the main petroleum derived hydrocarbon input is a direct contribution of about 2 000 kg a day (see Appendix I) from oil refinery effluents mixed with approximately 330 million litres of water (32). This hydrocarbon input may be compared to the San Fransisco Bay (33) situation where the "chronic hydrocarbon insult amounts to about 0.4 tons per day". Côté (34) has noted that, "chronic low level oil pollution is potentially more damaging to ecosystems than isolated catastrophic spills".

Within the sphere of sub-lethal effects of hydrocarbons on fish there are numerous structural changes which range from gross anomalies to subtle subcellular defects (35). At the organismal level, fish may exhibit severe anatomical alterations, such as curvature of the spine, which has been noted in the larvae of Pacific herring (*Clupea pallasi*) when exposed to benzene (36). At the tissue level, lesions may develop on the skin or gills when toxic fractions of hydrocarbons are present in water (37) or in the intestine when the contaminant is introduced via the food (35). However, the overall function of a fish may be affected through cellular alteration even though no lesions are observed. There were no examinations for these types of abnormalities in this study.
Aromatic compounds are accumulated by marine animals to a greater extent and are retained longer than alkanes (38). The daily input of aromatics to the Sound is about 900 kg, made up of phenols, cresols and other aromatics (32). Many polycyclic aromatics are carcinogenic. Benz(α)pyrene, which is found in oil refinery products and effluents (39), (40), (41) is one of the most potent (42), (43), (44).

A problem already encountered in the vicinity of the refinery is a tainting of fish (generally said to have a "kerosene" flavour. Following complaints by members of the public to members of the study group, qualitative taste tests were performed on cooked fish taken from the James Point area. Tainting was clearly evident. Not all species of fish in the area are affected; mullet and tailor are more strongly tainted than skipjack, and whiting do not appear to be affected (45). Oiled bottom sediments could impart a kerosene taint. Mullet, being a detritus feeder with relatively high proportion of body fat, is likely to take up petroleum hydrocarbons more readily than other species of fish living in the same environment (46). Within a school (or single net haul) not all specimens were affected. In a taste trial one fish in five was contaminated. One Cockburn Sound fishermen has reported a catch of 1 500 kg of tainted fish (45). Elsewhere taste and odour problems in aquatic biota have been caused by hydrocarbons at μgl^{-1} (ppb) levels, e.g. 10 μgl^{-1} of oil caused tainting of oysters in Canada (34). Taste thresholds of specific hydrocarbons range from 1.0 mg 1^{-1} for phenol to 0.005 mg 1^{-1} for 2, 4 dichlorophenol (34).

5.5 Conclusions

The data indicated that heavy metal levels in fish muscle tissue from Cockburn Sound were lower than the Western Australian and NH & MRC recommended health standards. Generally, comparable levels of metals

5.5 (Cont'd)

in flesh were found in fish caught off the New South Wales coast and in relatively unpolluted areas in New Zealand and the Northern Hemisphere. However, the fish of the Cockburn Sound area have been shown to contain elevated levels of lead when compared to areas where the flesh of fish show true background concentrations for this element.

Within Cockburn Sound all nine metals investigated are known to be discharged into the environment where they settle in certain regions. However, a comparison between sampling sites showed little variation in the muscle concentrations of each species. Concentrations did not vary greatly between species and no particular species showed a consistently greater or lower concentration for all metals than the other eleven species.

Comparisons with concentrations of metals in the mussel, *Mytilus edulis*, showed that heavy metal levels are always many times greater than in fish muscle tissue. This illustrates how much more effectively mussels accumulate heavy metals than fish, a feature which is attributable to the mussel's sedentary and filter feeding habit (23), (47). By contrast, teleosts are mobile and can avoid areas of elevated contaminants or "slug" doses of pollutants. Low metal levels in fishes compared with other fauna in both polluted and unpolluted areas have been found in a number of studies elsewhere in the world.

As analytical techniques improve and background sea water levels of certain important metals such as cadmium and copper are lowered, levels around the lower $\mu g l^{-1}$ (ppb) range will be more widely considered for sublethal toxic effects. While tissue abnormalities may not be present at chronic low level metal inputs, fish can nevertheless be subject to physiological stress. Any further environmental studies where fish are taken should include some investigation of anatomical lesions in the fish.

Analyses have shown that fish from Cockburn Sound contain concentrations of alkanes substantially greater than reference samples. The presence of petroleum derived alkanes suggests accumulation from shipping discharges and industrial effluent sources in the Cockburn Sound area.

Hydrocarbons are likely to be having a deleterious effect on the fish at the sub-lethal toxicity level in Cockburn Sound, manifested at present by tainting. There is adequate evidence of a significant aromatic hydrocarbon input to Cockburn Sound and this should be investigated, not only by toxicological research, but also for its public health implications.

Areas of chronic low level cadmium, copper and lead contamination have been defined in Cockburn Sound waters (Chapter 2). From the observed distribution of fish contaminated by hydrocarbons a similar area has been affected. The limited exchange of Cockburn Sound waters with oceanic water (48) are likely to contribute significantly to the maintenance of contaminated levels if present inputs continue.

TABLE 5.1

THE LENGTHS AND WEIGHTS OF THE SAMPLES OF TWELVE SPECIES OF TELEOST values given are numbers of individual fish (n), the mean ±95% confidence limits and the range (in parentheses)

Species	n	Length (mm)	Weight (g)
Sea mullet *Mugil cephalus*	57	235±13 (130-330)	145.0±23.7 (13.0-301.2)
Yellow-eye mullet *Aldrichetta forsteri*	13	204±47 (100-320)	110.6±56.7 (20.6-235.8)
Australian herring *Arripis georgianus*	27	223±15 (95-265)	130.8±16.3 (13.4-199.5)
King George whiting *Sillago punctata*	26	214±17 (100-260)	68.6±11.3 (18.7-109.1)
Yellow-finned whiting *Sillago schomburgkii*	29	232±17 (135-310)	118.8±24.1 (20.6-235.8)
Cobbler *Cnidoglanis macrocephalus*	16	285±56 (170-480)	178.9±113.6 (28.0-731.2)
Sea garfish *Hyporhamphus melanochir*	18	309±45 (220-390)	94.8±23.7 (21.8-173.0)
Tailor *Pomatomus saltatrix*	5	196±13 (185-210)	76.8±7.7 (70.4-86.5)
Rock flathead *Platycephalus laevigatus*	8	226±71 (160-400)	104.4±114.0 (21.8-434.0)
Small-toothed flounder *Pseudorhombus jenynsii*	3	263±133 (180-310)	207.7±226.7 (65.5-287.65)
Skipjack trevally *Caranx georgianus*	9	191±15 (155-210)	106.4±19.8 (54.4-142.3)
Six-lined trumpeter *Pelates sexlineatus*	10	188±28 (145-240)	100.7±42.1 (35.7-179.5)

TABLE 5.2

MEAN WET WEIGHT CONCENTRATION

±95% confidence limits and the concentration range in parentheses $\mu g\ g^{-1}$

Species	Cd	Zn	Cu	Pb	Fe	Mn	Cr	Ni	Co
Sea mullet	0.05±0.006 (0.03-0.14)	5.3±0.572 (2.6-11.3)	0.41±0.054 (0.16-1.38)	0.45±0.029 (0.26-0.78)	4.0±0.55 (2.0-14.0)	0.21±0.017 (0.10-0.41)	0.16±0.020 (0.05-0.29)	0.20±0.033 (0.04-0.68)	0.26±0.028 (0.09-0.50)
Yellow-eye mullet	0.08±0.021 (0.04-0.18)	8.8±1.37 (3.5-18.5)	0.39±0.078 (0.14-0.60)	0.57±0.174 (0.20-1.24)	4.2±0.45 (2.7-7.8)	0.44±0.159 (0.14-0.94)	0.16±0.019 (0.06-0.29)	0.39±0.078 (0.09-0.89)	0.34±0.033 (0.21-0.52)
Australian herring	0.07±0.007 (0.04-0.12)	7.3±1.33 (3.5-15.9)	0.45±0.041 (0.25-0.71)	0.40±0.053 (0.16-0.65)	4.5±0.27 (3.2-6.4)	0.29±0.077 (0.12-0.76)	0.17±0.028 (0.08-0.36)	0.22±0.067 (0.04-0.68)	0.24±0.023 (0.10-0.31)
King George whiting	0.05±0.009 (0.02-0.10)	6.4±0.40 (4.8-8.6)	0.21±0.095 (0.04-0.41)	0.47±0.032 (0.29-0.63)	2.1±0.17 (1.6-3.3)	0.30±0.024 (0.19-0.39)	0.11±0.015 (0.04-0.17)	0.20±0.025 (0.09-0.32)	0.27±0.033 (0.18-0.44)
Yellow-finned whiting	0.06±0.009 (0.04-0.11)	8.1±0.74 (4.9-11.8)	0.26±0.033 (0.08-0.48)	0.51±0.041 (0.30-0.70)	2.5±0.41 (1.4-6.9)	0.24±0.022 (0.14-0.36)	0.12±0.012 (0.06-0.18)	0.17±0.027 (0.07-0.28)	0.24±0.017 (0.15-0.32)
Cobbler	0.05±0.010 (0.03-0.09)	4.3±0.55 (2.7-6.5)	0.22±0.044 (0.05-0.38)	0.35±0.069 (0.15-0.52)	2.7±0.31 (1.7-3.8)	0.24±0.041 (0.17-0.46)	0.14±0.034 (0.07-0.29)	0.23±0.062 (0.07-0.48)	0.31±0.051 (0.15-0.52)
Sea garfish	0.06±0.012 ((0.03-0.12)	6.4±0.83 (4.0-9.5)	0.20±0.017 (0.16-0.31)	0.55±0.032 (0.42-0.67)	1.6±0.11 (1.0-2.0)	0.31±0.087 (0.16-0.99)	0.08±0.025 (0.01-0.18)	0.19±0.059 (0.08-0.56)	0.31±0.040 (0.16-0.48)
Tailor	0.05±0.014 (0.03-0.06)	4.0±0.52 (3.3-4.6)	0.60±0.175 (0.42-0.80)	0.43±0.040 (0.37-0.46)	6.8±1.01 (4.3-10.2)	0.18±0.023 (0.15-0.21)	0.05±0.006 (0.05-0.06)	0.19±0.164 (0.22-0.43)	0.36±0.054 (0.27-0.41)
Rock Flathead	0.07±0.008 (0.03-0.10)	4.5±0.39 (3.2-7.0)	0.32±0.138 (0.16-0.75)	0.46±0.106 (0.19-0.69)	2.4±0.56 (1.8-3.8)	0.19±0.047 (0.08-0.28)	0.18±0.021 (0.7-0.25)	0.24±0.109 (0.10-0.44)	0.32±0.096 (0.15-0.47)
Small-toothed flounder	0.07±0.061 (0.02-0.09)	4.9±2.55 (3.3-6.7)	0.17±0.104 (0.09-0.21)	0.41±0.083 (0.35-0.46)	2.8±0.73 (2.5-3.4)	0.25±0.079 (0.19-0.29)	0.09±0.031 (0.07-0.11)	0.21±0.110 (0.15-0.29)	0.26±0.031 (0.24-0.28)
Skipjack trevally	0.06±0.012 (0.03-0.07)	9.7±4.47 (3.8-21.0)	0.44±0.068 (0.31-0.55)	0.49±0.031 (0.39-0.54)	3.4±0.71 (2.3-5.0)	0.22±0.057 (0.17-0.43)	0.11±0.025 (0.05-0.17)	0.17±0.073 (0.04-0.30)	0.33±0.072 (0.18-0.44)
Six-lined trumpeter	0.04±0.10 (0.02-0.06)	15.1±3.02 (9.4-21.6)	0.43±0.051 (0.31-0.58)	0.48±0.026 (0.43-0.53)	4.2±0.48 (3.1-5.1)	0.33±0.043 (0.24-0.41)	0.09±0.026 (0.01-0.14)	0.11±0.030 (0.03-0.17)	0.26±0.048 (0.08-0.29)

TABLE 5.3

ALKANE LEVELS IN FISH COLLECTED IN COCKBURN SOUND AND IN WARNBRO SOUND

Locations indicated in Figure 3.7 and Figure 3.8

DATE	STATION	LOCATION	ALKANE CONCEN. (µg g^{-1}) WET WEIGHT
		YELLOW EYE MULLET *Aldrichetta forsteri*	
28.11.78	18	Jervoise Bay	4
		AUSTRALIAN HERRING *Arripis georgianus*	
28.11.78	17	James Point	8
9.12.78		Warnbro Sound (Becher Point)	7
		PERTH HERRING *Nemathalosa vlaminghi*	
9.12.78	22	Warnbro Sound (Becher Point)	3
		TRUMPETER WHITING *Sillago maculata*	
28.11.78	17	James Point	22
9.12.78	22	Warnbro Sound (Becher Point)	8
12.12.78	21	Colpoys Point	8
		YELLOW TAIL *Trachurus mccullochi*	
28.11.78	17	James Point	25
28.11.78	18	Jervoise Bay	12
9.12.78	22	Warnbro Sound (Becher Point)	4
		TRUMPETER *Pelates sexlineatus*	
18.10.78	21	Colpoys Point	28
18.10.78	22	Warnbro Sound (Becher Point)	2

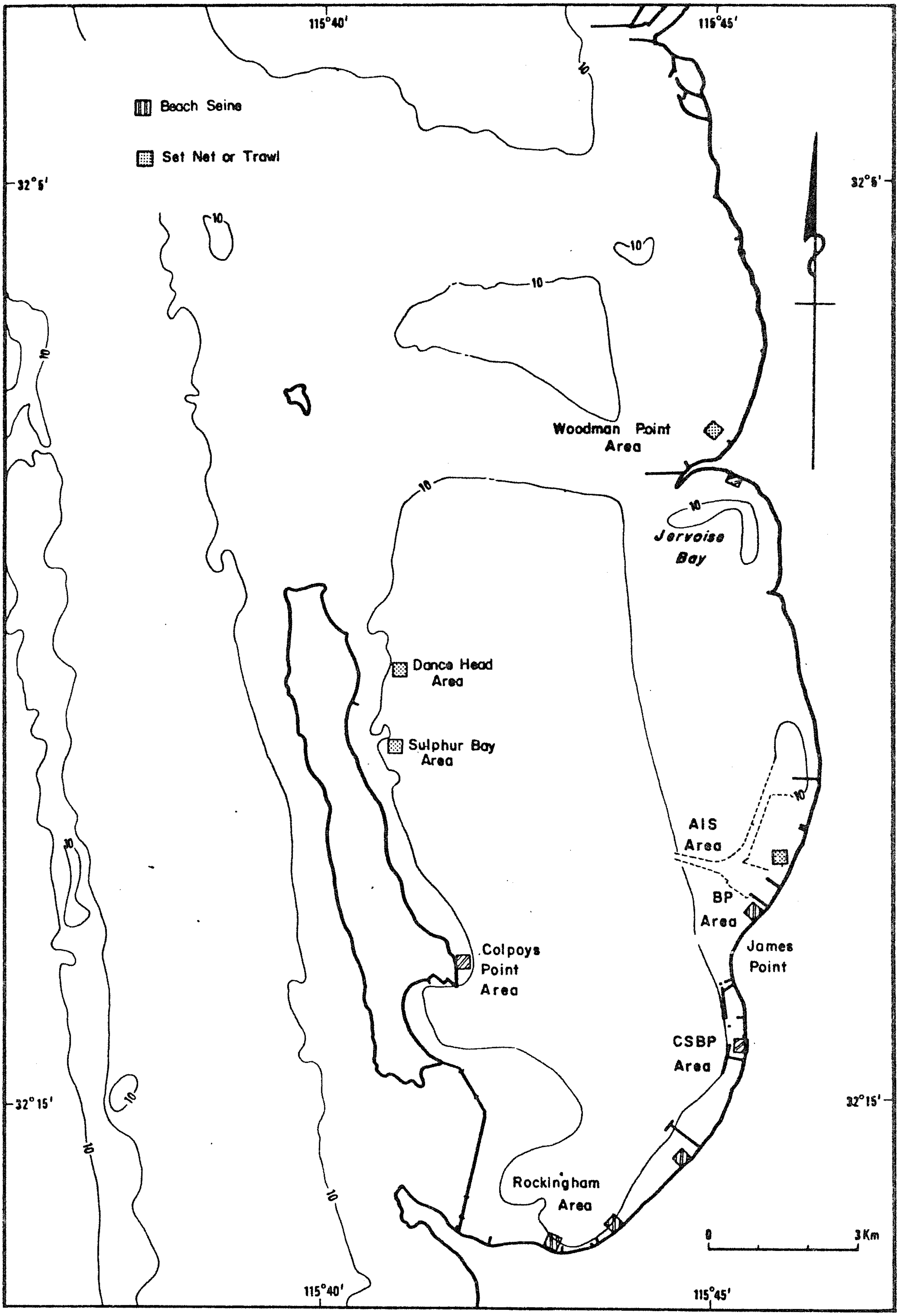

Figure 5.1

AREAS WHERE FISH WERE CAUGHT BY BEACH SEINE & SET NET OR TRAWL

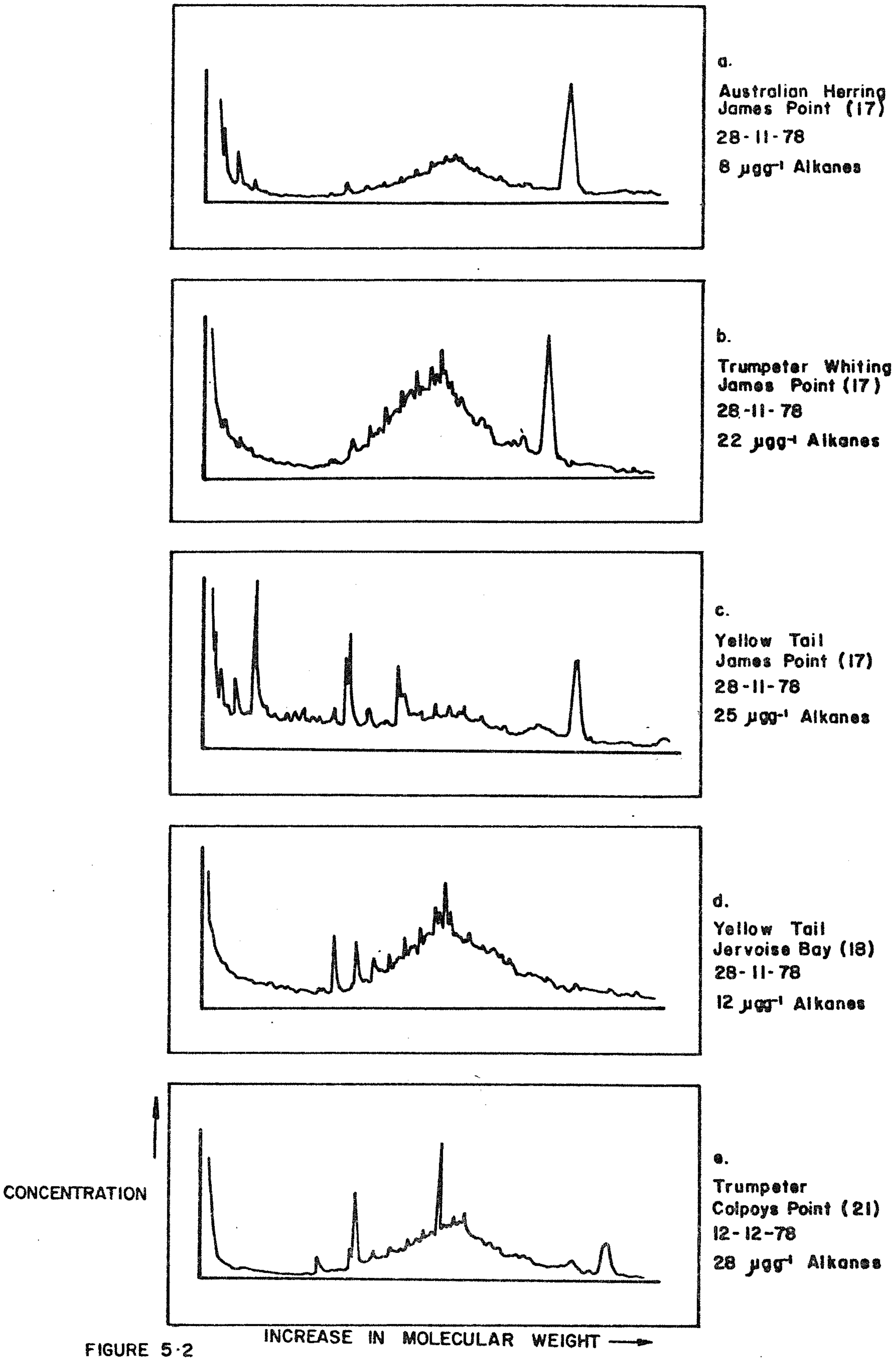

FIGURE 5·2

GAS CHROMATOGRAMS OF ALKANES EXTRACTED FROM FISH COLLECTED IN COCKBURN SOUND.

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APPENDIX I.

SUMMARY OF EFFLUENT CONTAMINANTS ENTERING COCKBURN SOUND WATERS

Murphy (1) lists in detail the contaminants entering Cockburn Sound waters. A summary of loads is given in the following table. Chlorinated pesticides, pathogenic bacteria and oxalates were not quantified. The eutrophic properties and loads of phosphorus and nitrogen are discussed by Chiffings (2).

TABLE I(a)

CONTAMINATING AGENTS ENTERING WATERS IN THE COCKBURN SOUND AREA

AGENTS	SOURCE OR OUTFALL	INPUT TO MARINE WATERS
Chlorinated pesticides	Anchorage Meatworks and other noxious industries in the Owen Anchorage area	No estimate
Enteric bacteria	Noxious industries of Owen Anchorage and the Woodman Point Sewage Treatment Plant (WPTP)	No estimate
*Hydrocarbons (Petroleum Derived)	BP Oil Refinery	Approximately 2 000 kg per day* maximum, made up of:- . alkanes, 1 000 kg per day . phenol, 500 kg per day . cresols and other aromatics, 400 kg per day . ONS containing organics, 100 kg per day
Anionic detergents	WPTP BP Oil Refinery	250 kg per day BPS stream, 2.7 kg per day - Total BP stream 3.3 kg per day
Sulphide	1. BP Oil Refinery 2. WPTP	1. BPC stream, 157 kg per day BPS stream, 435 kg per day 2. 240 - 480 kg per day
Fluoride (soluble)	1. CSBP/KNC 2. WPTP	1. 6 050 kg per day 2. 24 kg per day

*Refinery sources have calculated a discharge figure of 980 kg per day oil content in their combined effluents using an infra-red analytical technique. The maximum petroleum derived hydrocarbon discharge from the Refinery has been estimated using data combined from infra-red, gas chromatography and gravimetric analytical techniques. Phenols are listed separately by the Refinery.

TABLE I(a) (Cont'd)

AGENTS	SOURCE OR OUTFALL	INPUT TO MARINE WATERS
Nitrate and nitrite in association with ammonia	1. BP Oil Refinery 2. WPTP 3. CSBP/KNC	BP total, 4.2 kg per day as N <10 kg per day as N 665 kg per day as N
Ammonia	1. AIS 2. BP Oil Refinery 3. CSBP/KNC 4. WPTP	51 kg per day as N 271 kg per day as N 2 350 kg per day as N 1 114 kg per day as N
Total inorganic nitrogen	1. AIS 2. BP Oil Refinery 3. CSBP/KNC 4. WPTP	49 kg per day 310 kg per day 2 410 kg per day 1 422 kg per day
Total Nitrogen (Kjeldahl)	1. AIS 2. BP Oil Refinery 3. CSBP/KNC 4. WPTP 5. SEC	49 kg per day 322 kg per day 3 075 kg per day 1 422 kg per day 110 kg per day
Total phosphorus	1. CSBP/KNC 2. WPTP 3. SEC	3 275 kg per day 261 kg per day 220 kg per day
Thermal wastes	All industries in Cockburn Sound that use a saltwater cooling system	A mean of about 1 600 x 10^6 litres of water per day is returned to the Sound about 8 to 10°C above the intake temperature At times of peak load on power generation, the heat input may be doubled.
Chemical oxygen demand (COD)	1. Owen Anchorage noxious industries 2. BP south outfall (ex API No. 1)	13 700 kg per day 2 800 kg per day
Biological oxygen demand (BOD_5)	1. WPTP 2. Owen Anchorage	8 900 kg per day 8 950 kg per day
Grease and Fats	1. WPTP 2. Owen Anchorage	1 230 kg per day 2 110 kg per day
Suspended solids	1. AIS 2. BP Oil Refinery 3. WPTP 4. Owen Anchorage	1 225 kg per day 261 kg per day 4 000 kg per day 6 210 kg per day

TABLE I(a) (Cont'd)

AGENTS	SOURCE OR OUTFALL	INPUT TO MARINE WATERS
Combined residual chlorine (Chloramines)	1. SEC	20 kg per day
	2. AIS	3.5 kg per day
	3. BP Oil Refinery	3.3 kg per day
	4. CSBP/KNC	2.4 kg per day
METALS:		
Cu	BP Oil Refinery	3.1 kg per day
	WPTP	2.6 kg per day
	SEC	2.0 kg per day
	CSBP/KNC	1.5 kg per day
Zn	CSBP/KNC	7.8 kg per day
	BP Oil Refinery	4.9 kg per day
	WPTP	3.5 kg per day
	SEC	3.0 kg per day
	AIS	2.0 kg per day
Cd	CSBP/KNC	4.3 kg per day
Fe	AIS	200 kg per day
	CSBP/KNC	140 kg per day
	BP Oil Refinery	85 kg per day
	SEC	80 kg per day
	WPTP	10.4 kg per day
Pb	WPTP	1.6 kg per day
	BP Oil Refinery	1.3 kg per day
	AIS	0.5 kg per day
	CSBP/KNC	0.4 kg per day
Cr	1. CSBP/KNC	2.5 kg per day
	WPTP	2.6 kg per day
	BP Oil Refinery	0.6 kg per day
	AIS	0.2 kg per day
	2. Owen Anchorage Hide Processors	11.8 kg per day*
Co	CSBP/KNC	0.4 kg per day
	WPTP	0.2 kg per day
Ni	SEC	3.0 kg per day
	BP Oil Refinery	0.7 kg per day
	CSBP/KNC	0.6 kg per day
	WPTP	0.4 kg per day
Hg	CSBP/KNC	0.1 kg per day
	AIS	0.1 kg per day
	WPTP	0.1 kg per day

*These industries dispose of an extra 9.9 kg per day chromium, by ground soakage.

TABLE I(a) (Cont'd)

AGENTS	SOURCE OR OUTFALL	INPUT TO MARINE WATERS
METALS (Cont'd)		
As	BP Oil Refinery AIS WPTP CSBP/KNC	1.2 kg per day 0.4 kg per day 0.3 kg per day 0.1 kg per day
Mo	BP Oil Refinery	0.3 kg per day
V	BP Oil Refinery	1.8 kg per day

N.B.

1. Results in the above table are derived mainly from analyses performed by Cockburn Sound Study analysts. Some results are from figures supplied by industry.

2. For the purposes of this report, the metals listed above were referred to as heavy metals.

3. BPS denotes the southern-most of the three beach drains of the BP Refinery and PBC the central drain.

4. Industries referred to by abbreviation are:-

   Australian Iron and Steel - AIS
   CSBP & Farmers (Fertiliser) - CSBP
   Kwinana Nitrogen Company - KNC
   State Energy Commission - SEC
   Woodman Point Wastewater Treatment Plant - WPTP

5. The contaminant loads calculated in Table I(a) are based on available data as at June 30, 1979. Data supplied in September, 1979 by B.P. Oil Refinery suggests that because of internal plant modifications the phenol and sulphide loads to Cockburn Sound have been reduced (see Reference (1)).

The various metal loads from industry have been estimated using the wastewater flows from Table I(b)

TABLE I(b)

AVERAGE FLOW RATES FOR WASTEWATER RETURNED TO COCKBURN SOUND WATERS BY THE VARIOUS INDUSTRIES

OUTFALL	FLOW (Litres per day)
AIS	175×10^6
BHP	0.5×10^6
BHP North	87×10^6
BP Centre	157×10^6
BP South	88×10^6
BP Total	332×10^6
CSBP Pipe	80.8×10^6
WPTP	23.8×10^6
SEC Kwinana	$1\,000 \times 10^6$

REFERENCES:

(1) Murphy, P.J. 1979. Cockburn Sound Study Technical Report on Industrial Effluents. Department of Conservation and Environment, Western Australia, Report No. 6.

(2) Chiffings, A.W. 1979. Cockburn Sound Study Technical Report on Nutrient Enrichment and Phytoplankton. Department of Conservation and Environment, Western Australia, Report No. 3.

APPENDIX II

SMOKE STACK EMISSIONS

Various elements emitted from industrial smoke stacks in the Cockburn Sound area include copper, lead, cobalt, manganese, zinc and nickel as well as the compounds, sulphur dioxide and oxides of nitrogen.

Estimates by the State Energy Commission have been used to compile Table II(a) for coal fired boilers 5 and 6 at the Kwinana Power Station. The figures are calculated for the electrostatic precipitators working at 99 per cent efficiency (1).

TABLE II(a)

ESTIMATES OF AIR EMISSIONS FROM NUMBER 5 AND 6
COAL FIRED BOILERS AT THE KWINANA POWER STATION.

EMISSION*	RATE (kg.day^{-1})
Copper	17.4
Lead	5.8
Cobalt	2.9
Manganese	2.9
Zinc	1.45
Nickel	1.45
Sulphur (as SO_2)	16 400
Oxides of Nitrogen (as NO_2)	8 300
Ash (before electrostatic precipitators - not emitted	82 900
Particulates not removed by electrostatic precipitators	2 900

* Flue gas volume of 167.9 m^3 sec^{-1}

Wind direction data for the 14 years from 1949 to 1962 (2) indicates that about 55 per cent of the year the wind blows from an easterly direction between, and including, north-north-east and south-south-west. This wind direction takes emissions from the industrial area over Cockburn Sound.

The quantities of copper, lead and cobalt emissions indicated in Table II(a) are greater than the daily input for these metals from all the direct effluent discharges to Cockburn Sound.

Plates II(a) and II(b) illustrate stack emissions during easterly wind conditions. As can be seen from Plate II(a) other industries along the shores of Cockburn Sound have smoke stake emissions. The SEC example above illustrates some of the more common emission contaminants.

APPENDIX II (Cont'd)

Plate II(a)

Early morning smoke stack emission over Cockburn Sound during summer (courtesy of Ian Watson)

Plate II(b)

Smoke Stack emission from the SEC and alumina loading problems in Cockburn Sound (courtesy of G. & N. McMahon)

REFERENCES:

(1) State Energy Commission of Western Australia. 1976. Kwinana Power Station Conversion of Units 5 and 6 to Coal Firing. Report RP 44.

(2) Commonwealth of Australia Bureau of Meteorology. 1969. The Climate of Perth, Western Australia. Hughes, T.J., Government Printer, Tasmania.

APPENDIX III

WHARF HANDLING OPERATIONS IN COCKBURN SOUND

Table III(a) lists the imports and exports that passed over the Cockburn Sound wharves during 1977/1978. These are the agents which may possibly end up in Cockburn Sound by accidental spillage.

TABLE III(a)

TOTAL CARGOES OF 467 SHIPS ENTERING COCKBURN SOUND DURING 1977/1978

IMPORTS	(TONNES)
Petroleum	5 669 300
Caustic Soda	573 500
Coke	445 100
Fertiliser - Phosphate rock	400 100
Iron and Steel	209 800
Limestone, Sands	104 100
Manganese Ore	17 300
TOTAL	7 420 100
EXPORTS	**(TONNES)**
Alumina	2 224 300
Grain	1 890 600
Petroleum	1 475 100
Iron and Steel	535 000
Iron Ore	235 800
Bunker Fuel	170 500
Bauxite	19 300
TOTAL	6 550 600

Plates II(b), III(a) and III(b) illustrate problems involved with handling cargoes of a finely divided or dusty nature. Alcoa and CSBP wharf facilities have been used to highlight the difficulties associated with the handling of some of the materials in Table III(a).

APPENDIX III (Cont'd)

In a personal communication, CSBP & Farmers supplied the following information:

TABLE III(b)

ORIGINS OF THE ROCK PHOSPHATE USED IN THE PHOSPHORIC ACID PLANT OF THE CSBP & FARMERS FERTILISER WORKS KWINANA.

(For the year 1 July 1978 to 30 June 1979)

PERIOD	SOURCE		
	Nauru	Christmas Island	Senegal
July 1978-January 1979	70%	30%	-
February 1979		'A mixture'	
March 1979-June 1979	-	20 %	80%

TABLE III(c)

CADMIUM CONCENTRATION OF ROCK PHOSPHATE FROM VARIOUS AREAS

PHOSPHATE ROCK	CADMIUM (μg g^{-1})
Christmas Island	50
Nauru Island	64
Ocean Island	120
Queensland	8
Florida	12
Senegal	94
Morocco	103
Togo	69
Spanish Sahara Bucra 75% BPL	42
Spanish Sahara Bucra 80% BPL	47
Israel	2

There are some doubts as to whether cadmium introduced into the marine environment via the spillage of the relatively insoluble rock phosphate would be immediately available to that environment. However, there can be no doubt that slow dissolution by processes such as microbial attack and bioturbation by animals, will release cadmium, (and most other metals associated with the rock phosphate) from the phosphate, over the long term.

Plate III(a)

Alumina loading problems in Cockburn Sound

Plate III(b)

Rock phosphate spilt from the CSBP (FPA) bulk cargo jetty into Cockburn Sound

Plates II(a) and III(b) are scenes of the Alcoa alumina ship loading jetty. In a personal communication from that company, they estimate that over a period of one month about ten tonnes of alumina is lost from their wharf loading operations and a further 13 tonnes is lost from their land based handling facilities.

Plate III(b) is an aerial photograph of the phosphate rock which has fallen into Cockburn Sound from the CSBP (FPA) bulk cargo handling jetty.

APPENDIX IV

SURVEY OF CADMIUM IN COCKBURN SOUND WATERS (1)
(Results for 5 May, 1979)

Figure IV(a) shows concentration isopleths for cadmium in the surface waters of Cockburn Sound for 5 May, 1979. The pattern is completely different to that indicated when Cockburn Sound was sampled on 28 December, 1978 (see Figure 2.6 of the main text).

The reason for the difference is simply the change in circulation (as has been suggested by other investigators of water circulation in Cockburn Sound). The variations of wind speed and direction are evident from the wind rose diagrams in Figure IV(c) and Figure IV(d).

During the week prior to 28 December, 1978, the wind came predominantly south-west and south-east, whereas for the week prior to 5 May, 1979, the direction was from north-east and south-west. Wind velocities during the December period were also much higher.

The most important data from this sampling, as far as Chapter 2 of this text is concerned, is in the Figure IV(b); the plots of cadmium concentration versus depth for selected stations, the low wind speeds, and hence, lower water circulation velocities during the May sampling would suggest relatively little mixing in the water at that time.

From the depth data, the largest variation in cadmium concentration through the water column was 0.035 $\mu g l^{-1}$ (0.035 ppb) at station 5000. Given this variation, even if the lowest profile value of 0.10 $\mu g l^{-1}$ were used to represent cadmium in the water column at this station, it would still fit into the category of a station of higher cadmium concentration. In fact, the isopleths around this station in Figure IV(a) would not change substantially and the same arguement applies to the other stations in Cockburn Sound that were profiled.

What these results suggest is that there is some structure in the water column of Cockburn Sound, but that it was not unrealistic to use samples of water taken from one metre below the surface to indicate cadmium distribution in Cockburn Sound

REFERENCE:

(1) Rosman, K.J.R, deLaeter, J.R., Chegwidden, A. and Biddiscombe, R.E. 1979. Cadmium Levels in Cockburn Sound (Surface Levels and Depth Profiles). Department of Physics, Western Australian Institute of Technology.

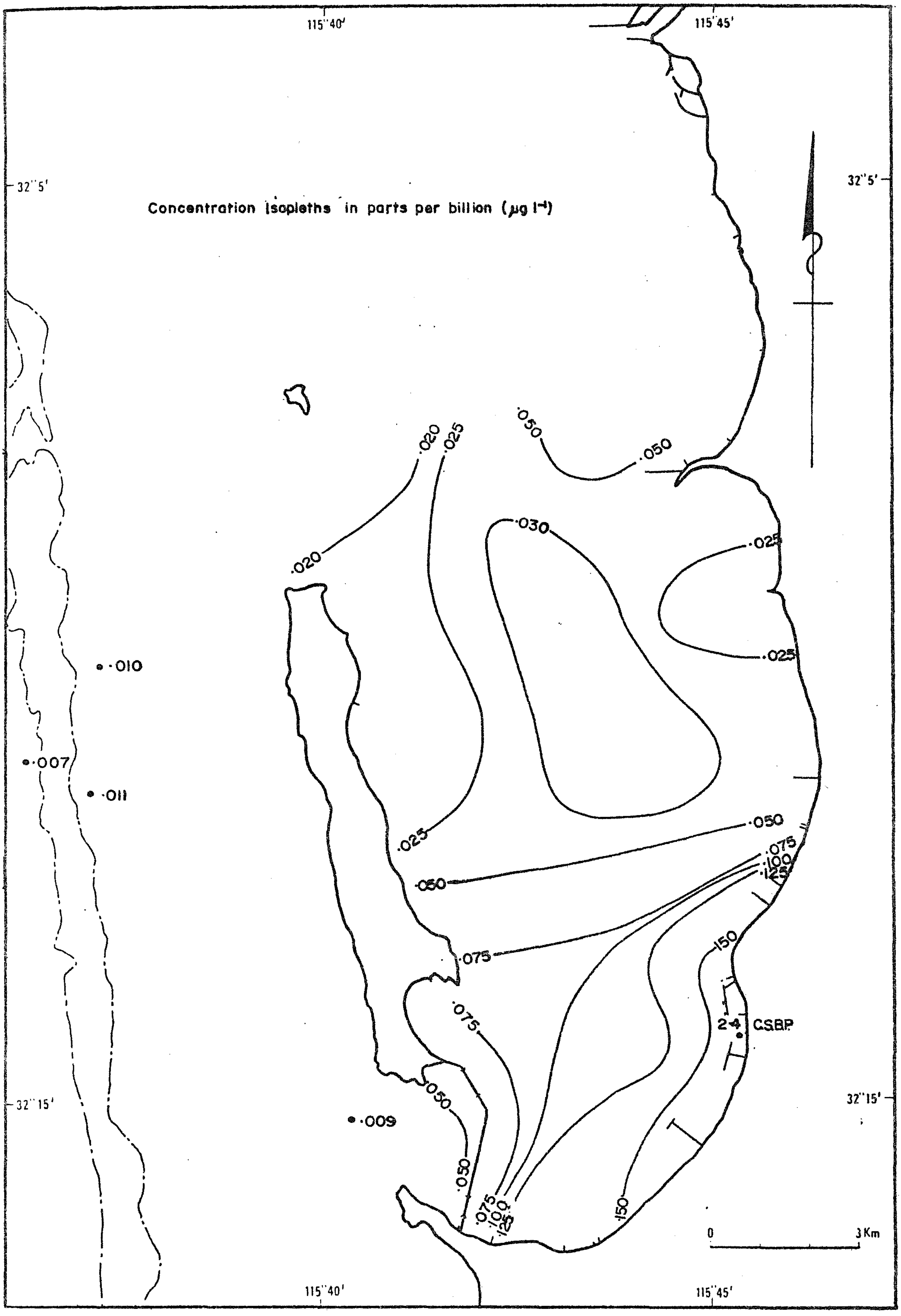
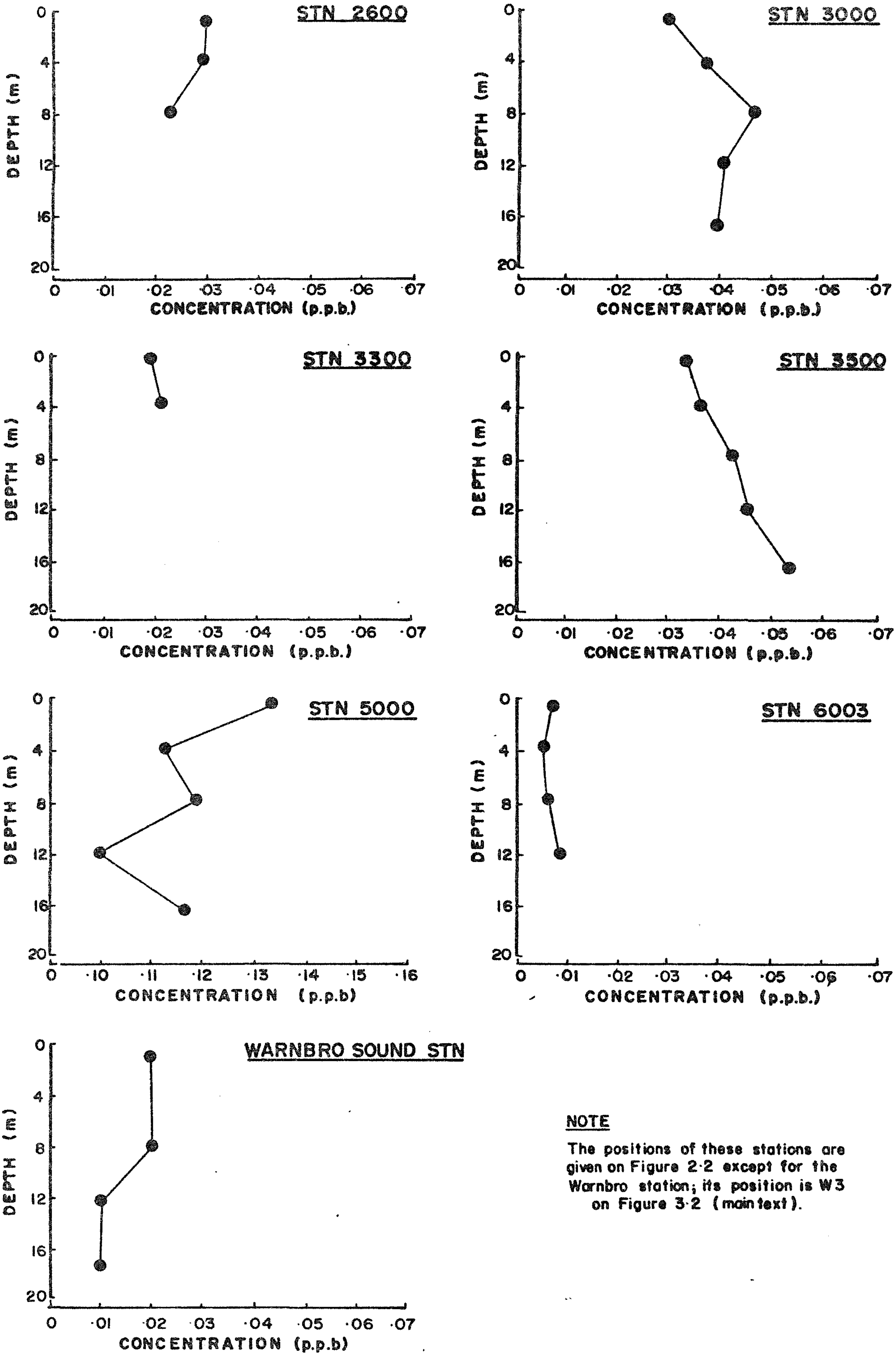


Figure IV (a)

SURVEY (5 MAY 1979) OF THE SURFACE WATERS OF COCKBURN SOUND FOR CADMIUM (M.S.I.D. analysis technique)

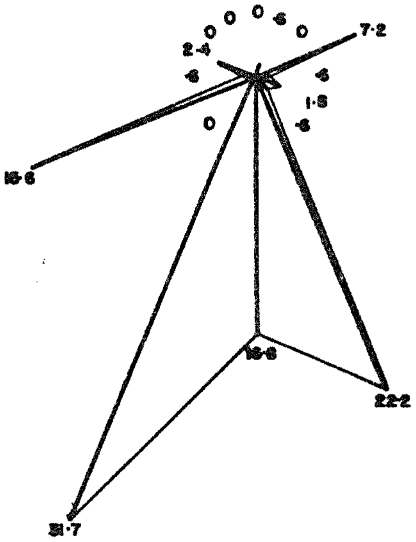


NOTE

The positions of these stations are given on Figure 2·2 except for the Warnbro station; its position is W3 on Figure 3·2 (main text).

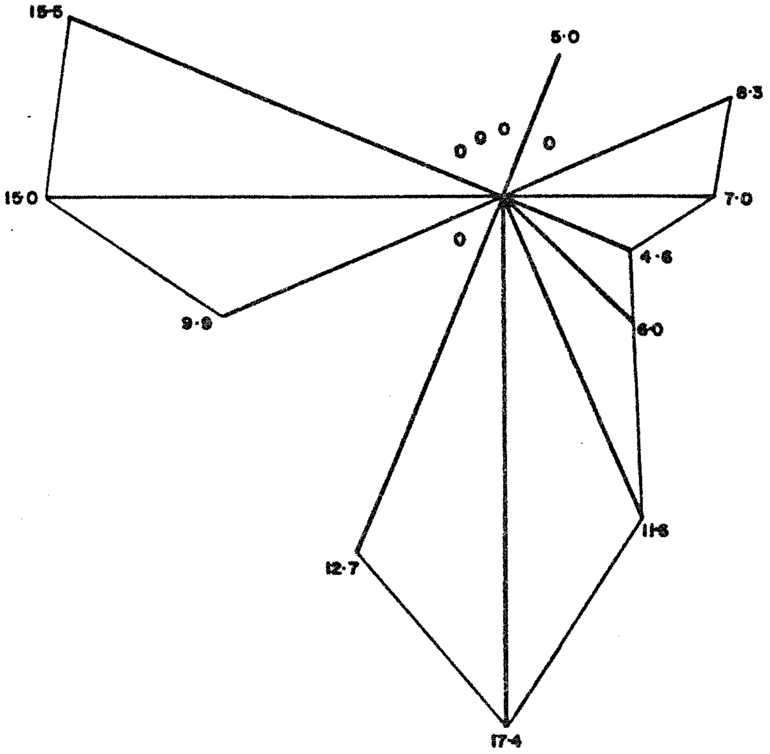
Figure IV (b)

PLOT OF CADMIUM CONCENTRATIONS WITH DEPTH AT SELECTED SITES. 5 MAY, 1979 (μg. l⁻¹)



WIND DIRECTION FREQUENCIES

SCALE: 1 cm = 5 %

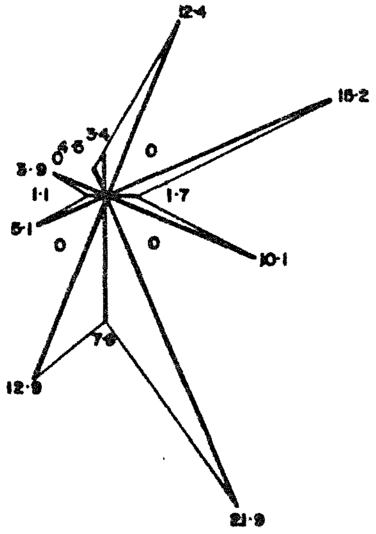


WIND VELOCITY

SCALE: 1 cm = 2·5 knots

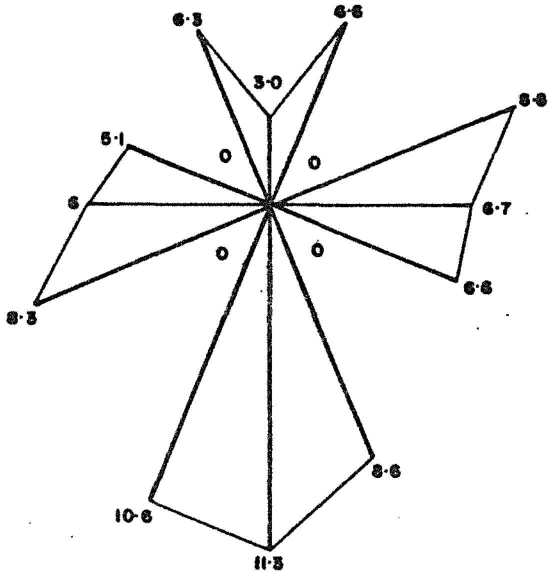
Figure IV (c)

AVERAGE HOURLY WIND ROSES FOR THE WEEK PRIOR TO, & INCLUDING
28 DECEMBER, 1978



WIND DIRECTION FREQUENCIES

SCALE: 1 cm = 5 %



WIND VELOCITY

SCALE: 1cm = 2·5 knots

Figure IV (d)

AVERAGE HOURLY WIND ROSES FOR THE WEEK PRIOR TO, & INCLUDING 5 MAY, 1979

APPENDIX V

DISTRIBUTION OF HEAVY METALS IN THE SURFACE SEDIMENTS (0-2 cm) OF THE COCKBURN SOUND AREA

Concentration isopleths have been drawn for the analytical results for nine heavy metals in the surface sediments of the Cockburn Sound area. The results are given on a dry weight basis in $\mu g\ g^{-1}$ (ppm).

Refer to Figures 3.2 to 3.5 for sampling locations.

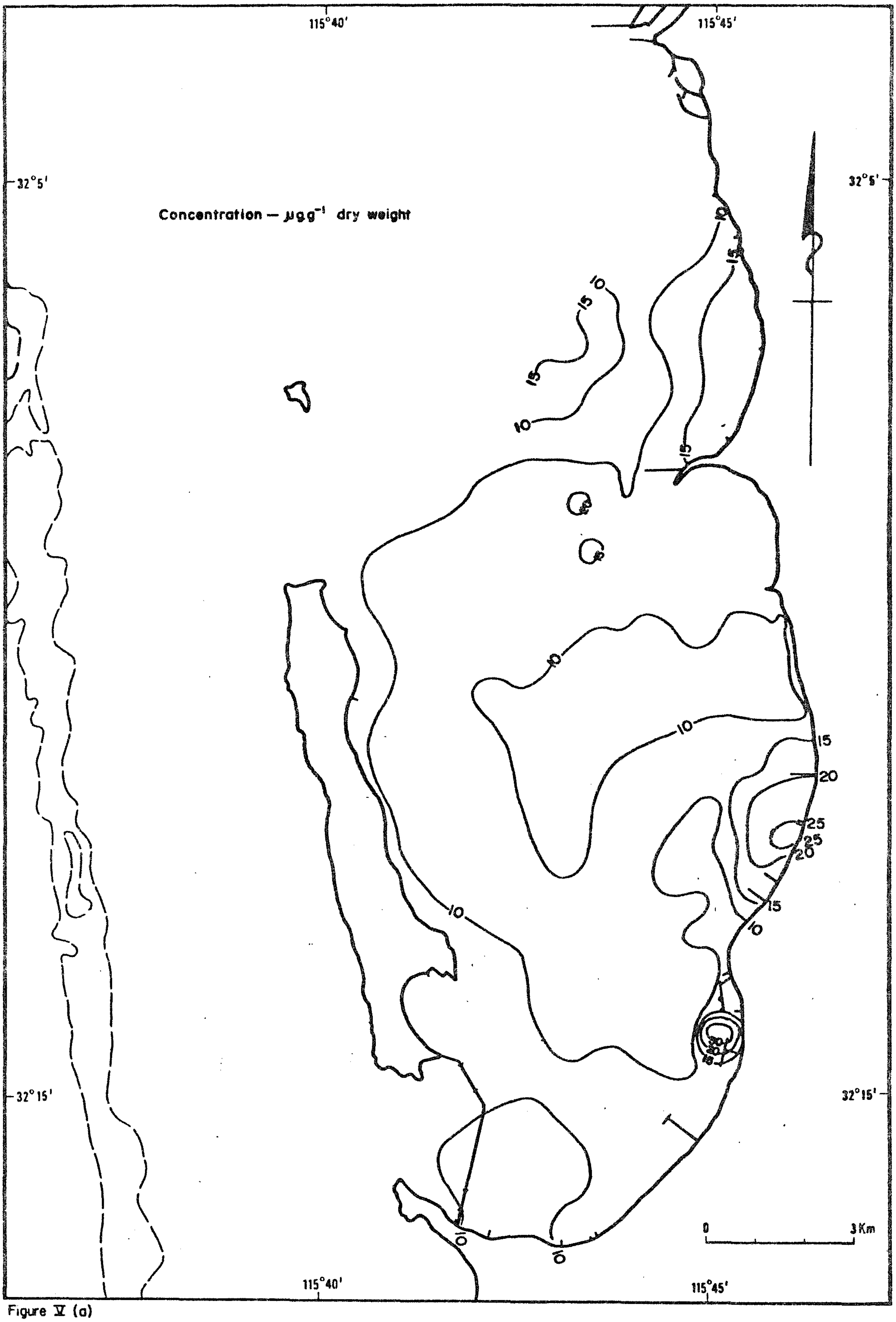


Figure V (a)

DISTRIBUTION OF COPPER IN THE SURFACE SEDIMENTS OF COCKBURN SOUND
SEPTEMBER TO NOVEMBER 1977

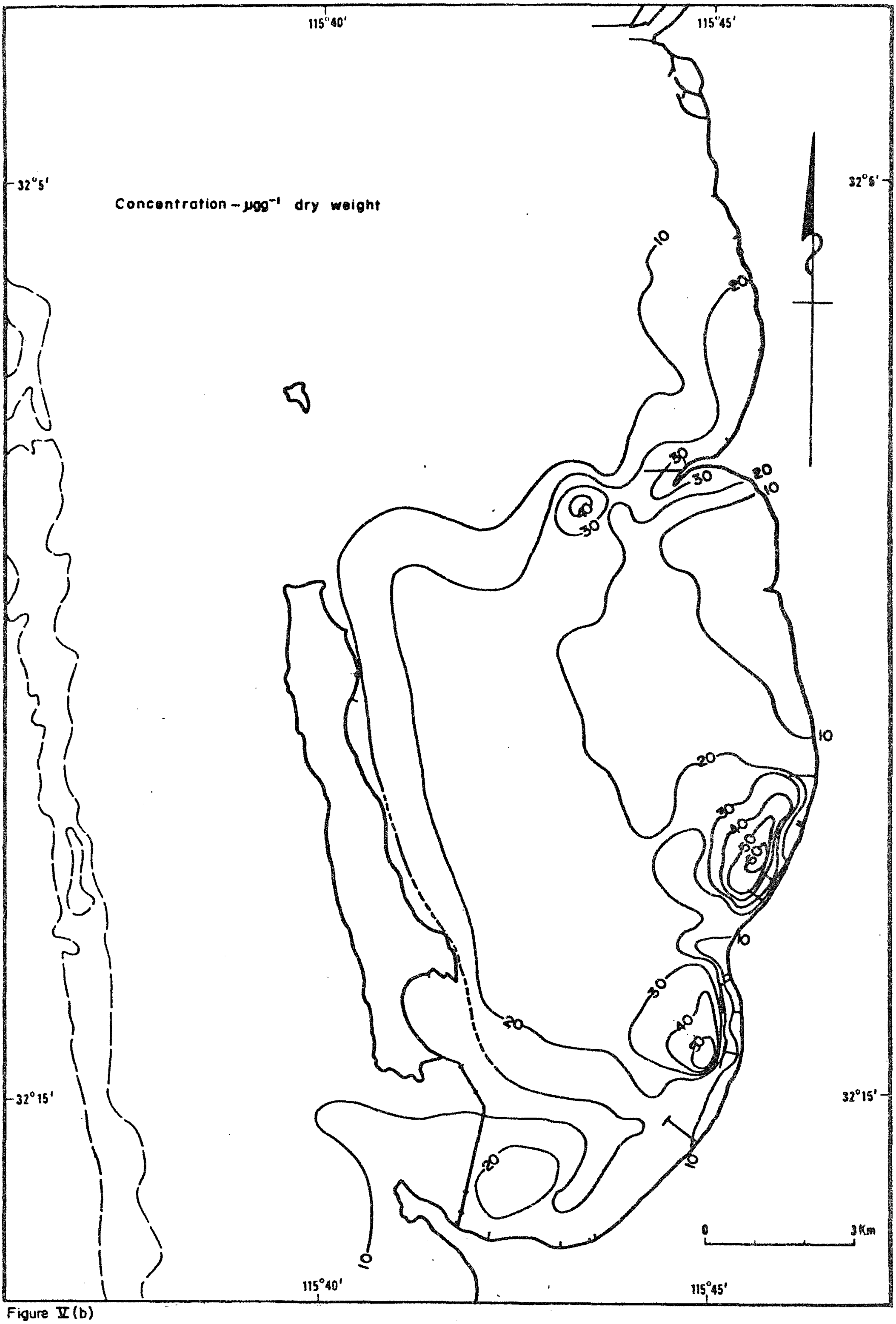


Figure V (b)

DISTRIBUTION OF ZINC IN THE SURFACE SEDIMENTS OF COCKBURN SOUND
SEPTEMBER TO NOVEMBER 1977

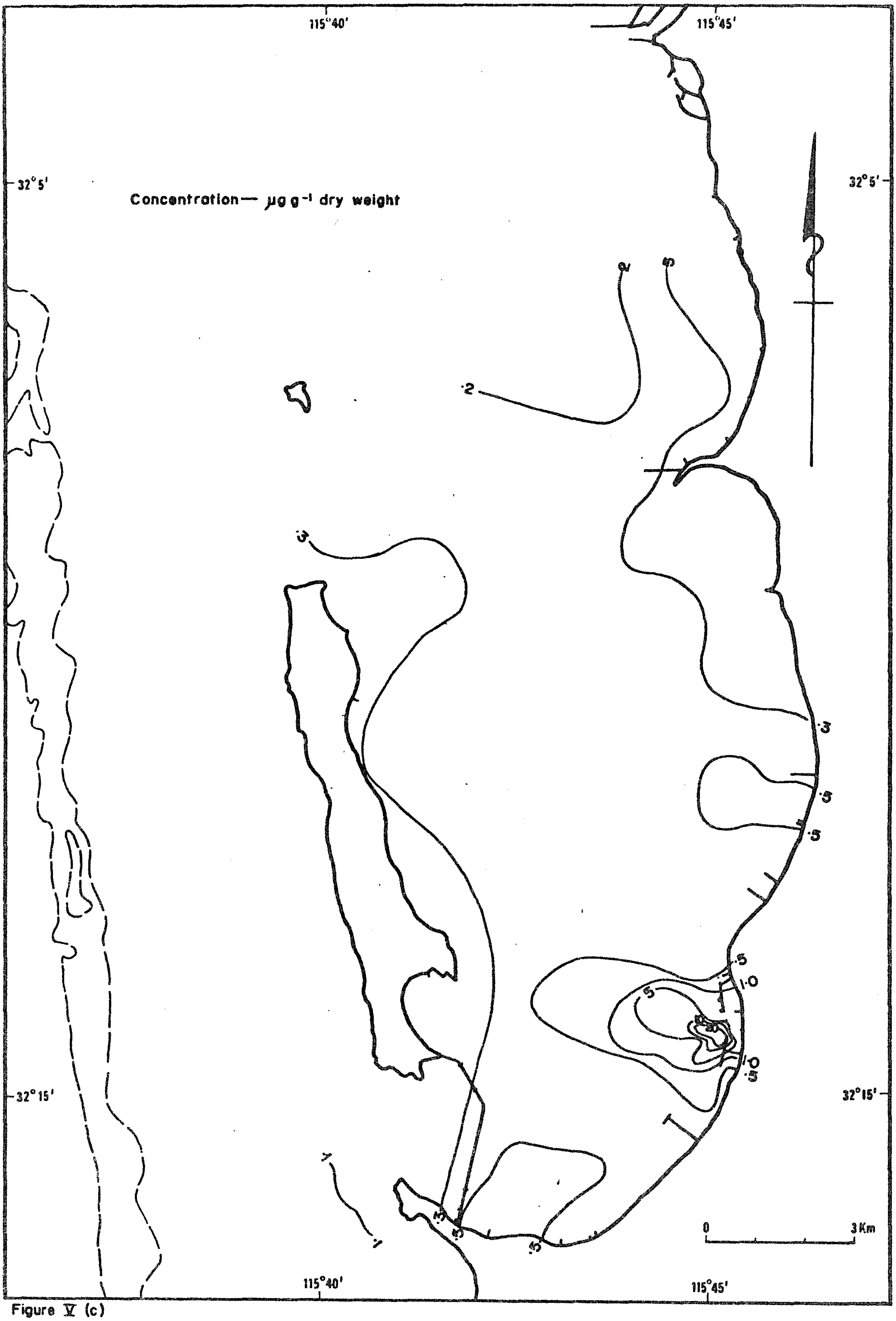


Figure V (c)

DISTRIBUTION OF CADMIUM IN THE SURFACE SEDIMENTS OF COCKBURN SOUND SEPTEMBER TO NOVEMBER 1977

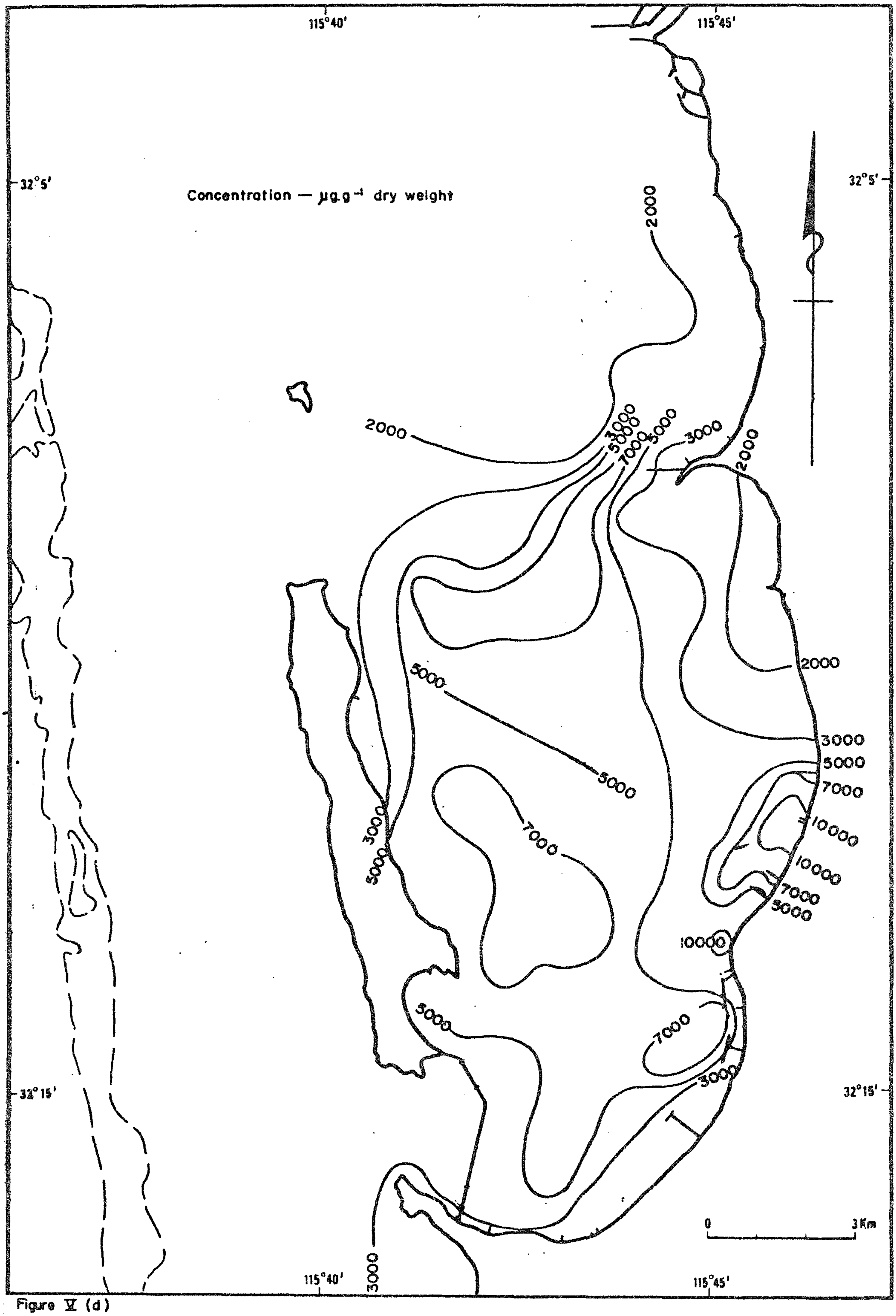


Figure V (d)

DISTRIBUTION OF IRON IN THE SURFACE SEDIMENTS OF COCKBURN SOUND
SEPTEMBER TO NOVEMBER 1977

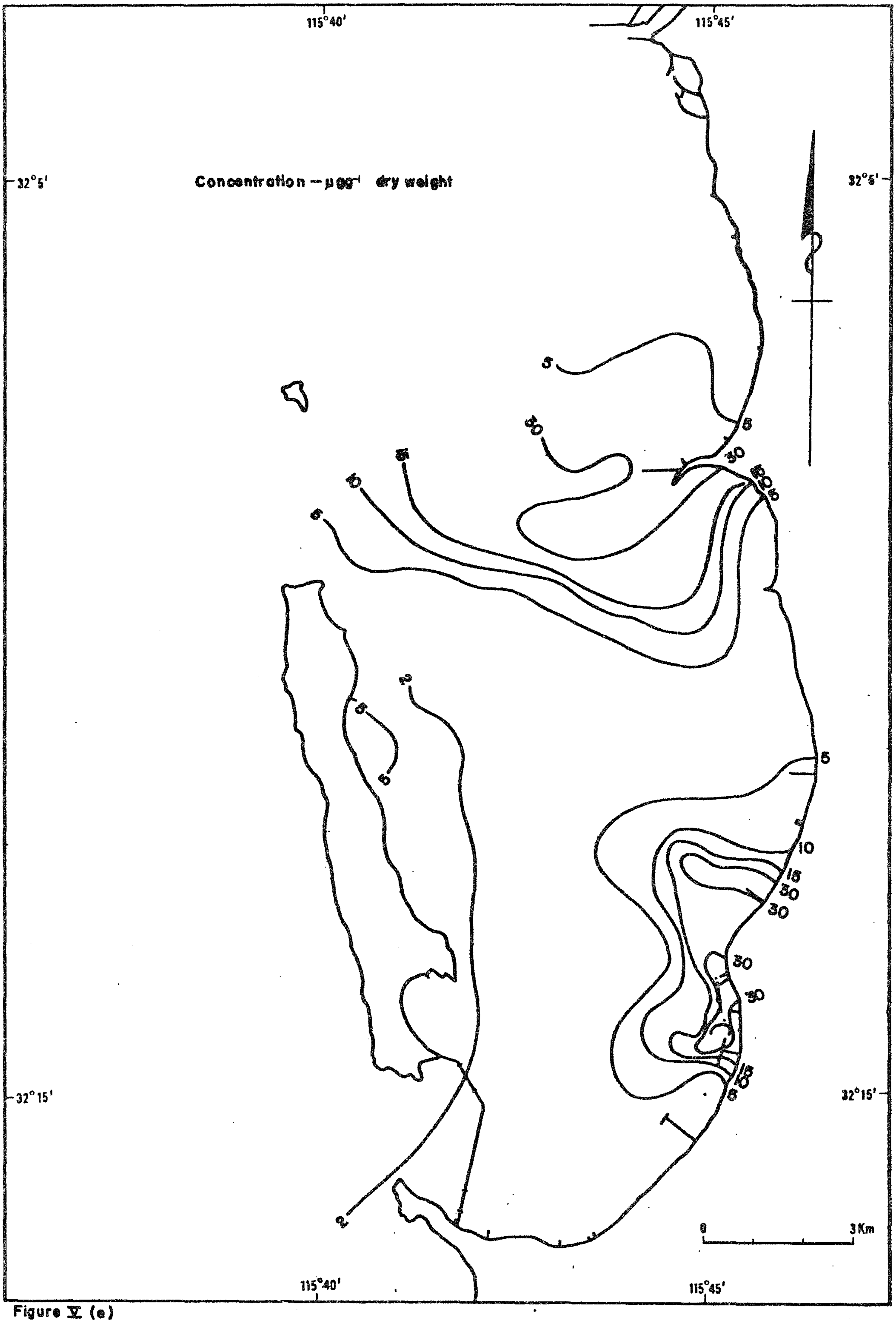


Figure V (e)

DISTRIBUTION OF MANGANESE IN THE SURFACE SEDIMENTS OF COCKBURN SOUND SEPTEMBER TO NOVEMBER 1977.

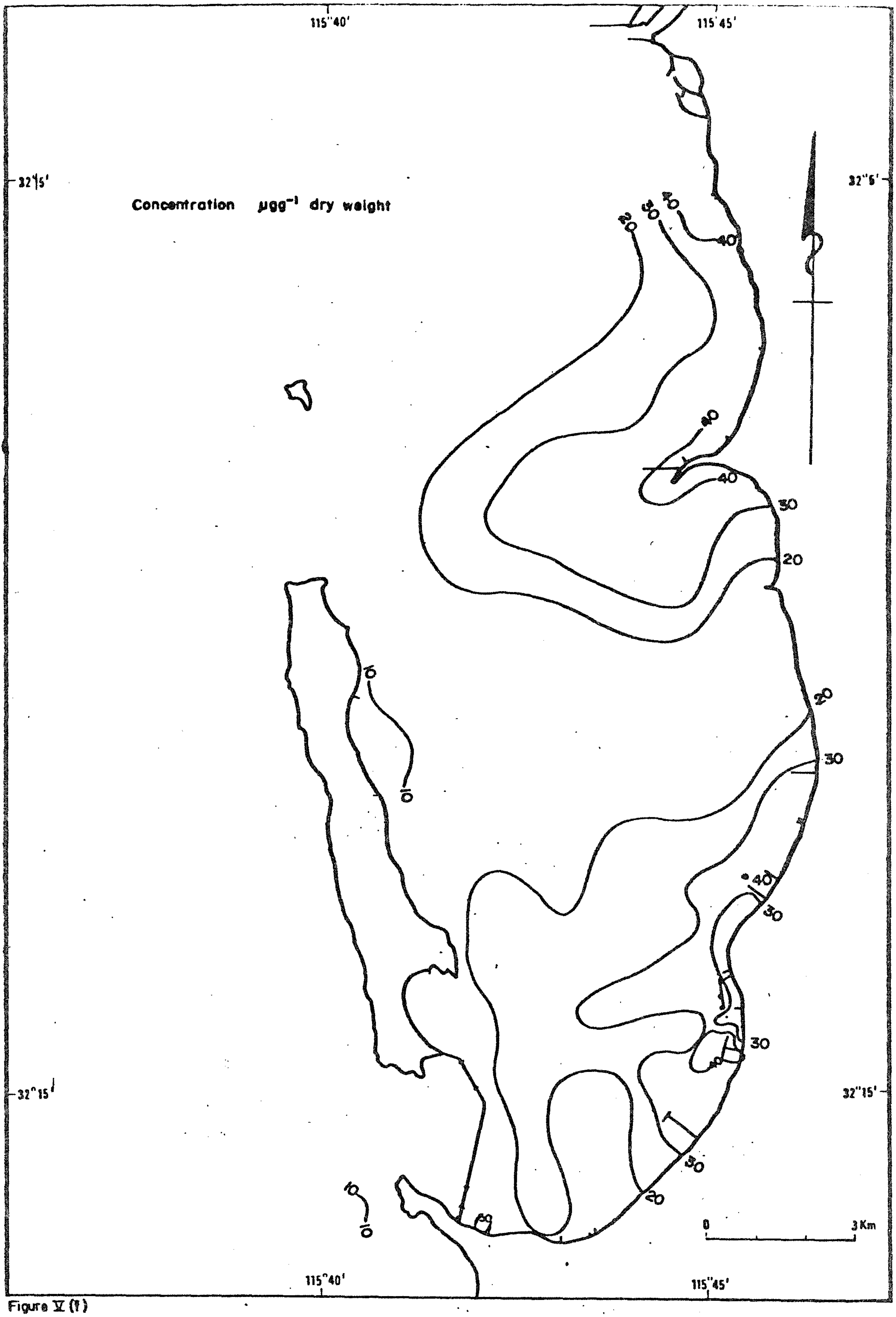


Figure V (7)

DISTRIBUTION OF LEAD IN THE SURFACE SEDIMENTS OF COCKBURN SOUND
SEPTEMBER TO NOVEMBER 1977

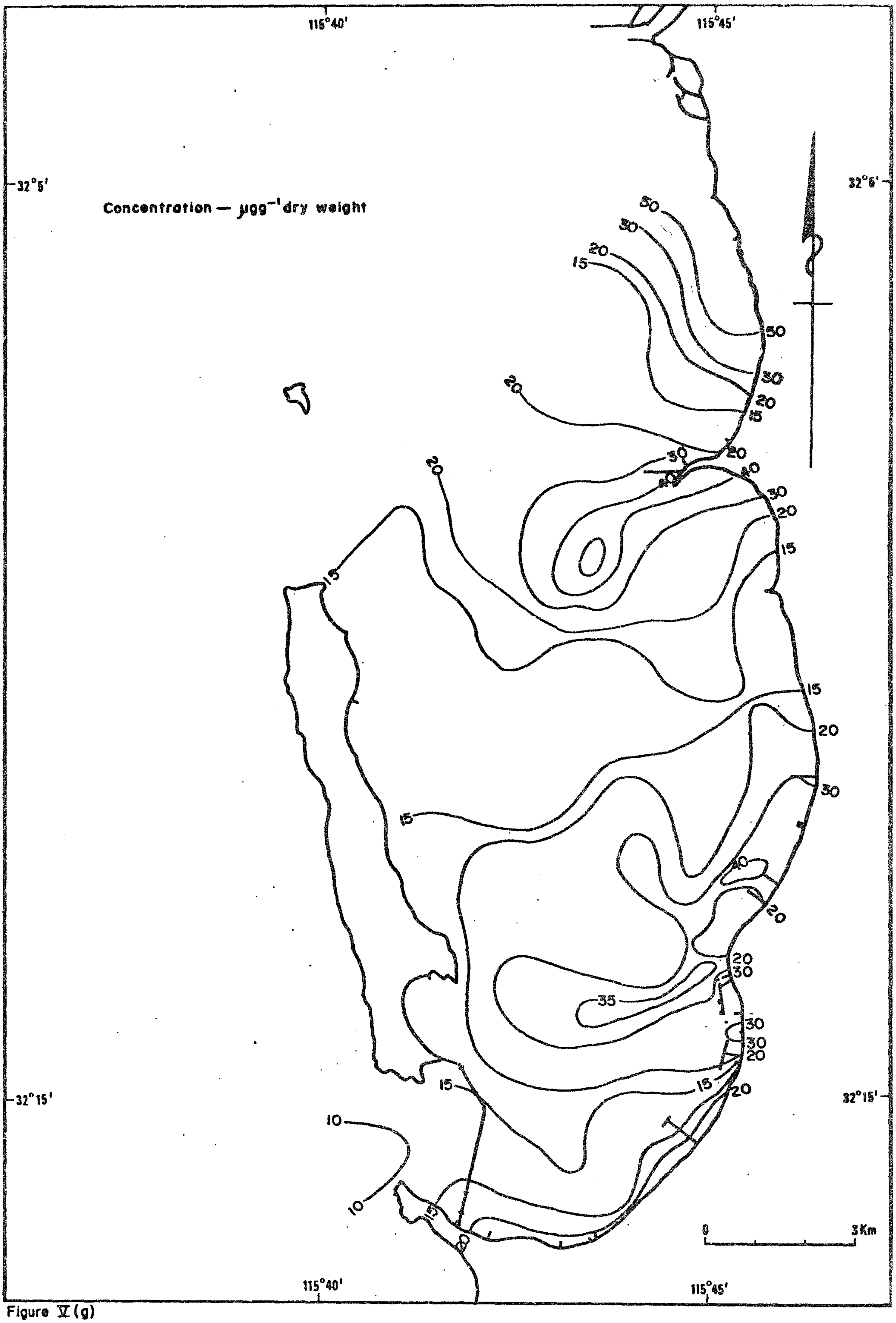


Figure V (g)

DISTRIBUTION OF CHROMIUM IN THE SURFACE SEDIMENT OF COCKBURN SOUND SEPTEMBER TO NOVEMBER 1977

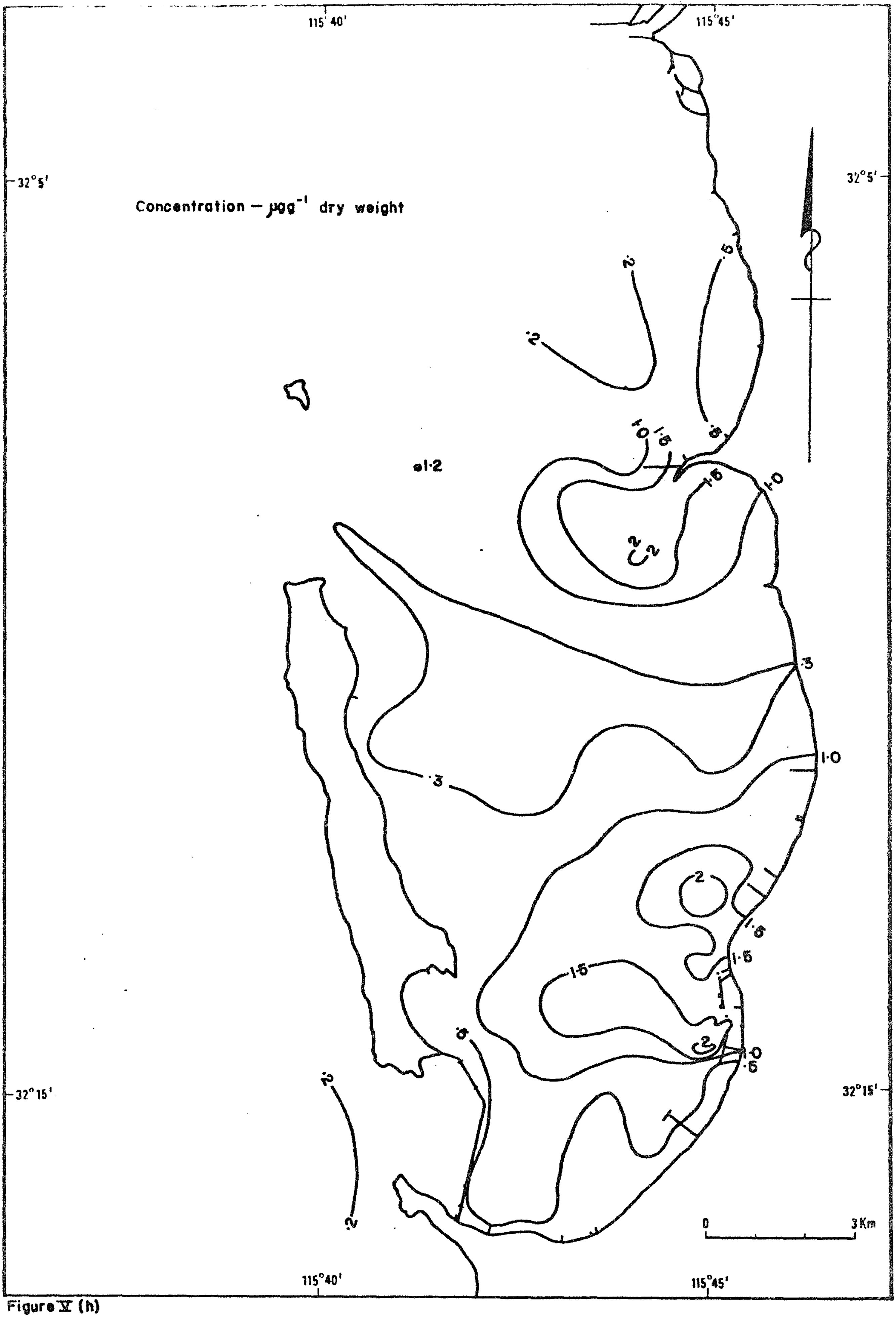


Figure V (h)

DISTRIBUTION OF COBALT IN THE SURFACE SEDIMENTS OF COCKBURN SOUND
SEPTEMBER TO NOVEMBER 1977

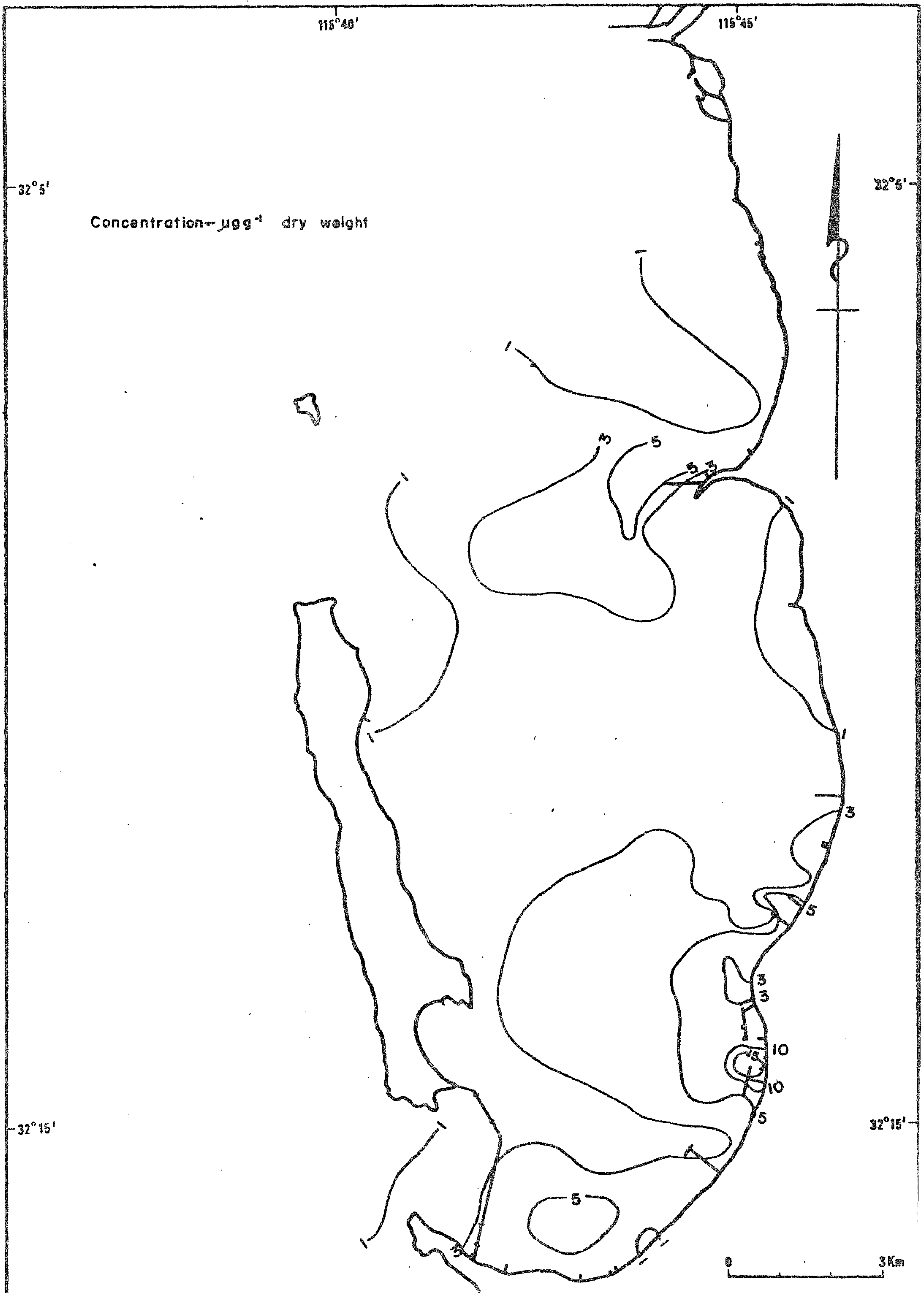


Figure V (i)

DISTRIBUTION OF NICKEL IN SURFACE SEDIMENTS OF COCKBURN SOUND
SEPTEMBER TO NOVEMBER 1977

DRAFT

APPENDIX III

NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL

FOOD SCIENCE AND TECHNOLOGY SUBCOMMITTEE

JUNE 1979

REVISED STANDARD FOR METALS IN FOOD

1. No food specified in Column II of the Schedule to this Standard shall contain any metal or compounds of any metal, as specified in Column I, in excess of the limits specified in Column III.

2. No food shall be in contact with any metals or alloy containing that metal if this is likely to cause the limit for that metal in the food to be exceeded.

3. The levels of metals in food additives shall not exceed those levels prescribed in the Standard for the Specifications of Identity and Purity of Food Additives.

4. The levels of metals specified in this Standard refer to the level in that portion of the food which is normally consumed.

5. For the purposes of this Standard, antimony, arsenic and selenium are deemed to be metals.

6. Solid foods as listed in this Standard include thick gels and semi-solid foods but exclude beverages and liquid foods.

7. Unless otherwise specified beverages and liquid foods as listed in this Standard include fruit juices, fruit drinks, milk and alcoholic beverages.

8. Limits on metals specified in this Standard apply to foods as consumed. Concentrated foods should be diluted or made up to the strength at which they are used or consumed in order to apply this Standard.

9. Except where specifically prescribed by these Standards the metals aluminium, calcium, iron, magnesium, manganese, potassium and sodium are exempt from maximum limits.

10. Any metal, other than:

    (a) those listed in Clause 9, or

(b) those for which a maximum level has been prescribed in the Schedule of this Standard;

shall not exceed the following levels:

(i) in any solid foods:- not more than 1.0 mg/kg calculated as the metal;

(ii) in any beverages:- not more than 0.1 mg/kg calculated as the metal.

SCHEDULE

Column I Metal	Column II Food	Column III Limit in Food (mg/kg calculated as the metal)
Arsenic	Beverages and liquid foods	0.1
	All other foods	1.0

Provided that levels for inorganic arsenic in fish crustacea and shellfish shall not exceed 1.0 mg/kg. No limit is required for organically bound arsenic in these foods.

Column I Metal	Column II Food	Column III Limit in Food (mg/kg calculated as the metal)
Barium	Beer	0.2
	Beverages and liquid foods (except beer)	0.1
	All other foods	1.0
Cadmium	Beverages and liquid foods	0.05
	Fish and fish content of fish products	0.2
	Edible offal	2.5
	Shellfish (including molluscs) and the shellfish content of shellfish products	1.0
	All other foods	0.05
Copper	Beverages and liquid foods	5.0
	Chocolate	15.0
	Cocoa beans, Mass nib	30.0
	Edible offal	100.0
	Press cake, cocoa powder	50.0
	Shellfish including molluscs	70.0
	All other foods	10.0
Lead	Beverages and liquid foods	0.2
	Infant foods in containers other than tinplate	0.3
	Infant foods in tinplate containers (except milk and milk products)	0.8
	Fish	1.5
	Fish in tinplate containers	2.5
	Fruit juices and fruit juice drink	0.5
	Glucose (solid and liquid forms)	2.0
	Meat in tinplate containers	2.5

	Milk and milk products in tinplate containers	0.3
	Shellfish (including molluscs)	2.5
	Tomato products in tinplate containers	2.5
	Vegetables	2.0
	All other foods	1.5
Manganese	Beverages and liquid foods	0.1
	Edible offal	5.0
	All other foods	1.0
Mercury	Fish, crustacea, shellfish including molluscs, the fish content of fish products and the fish content of canned fish	0.5
	All other foods	0.03
Nickel	Beverages and liquid foods	0.1
	Edible offal	2.0
	All other foods	1.0
Selenium	Beverages and liquid foods	0.2
	Edible offal	2.0
	All other foods	1.0
Strontium	Beer	0.75
	Beverages and liquid foods (except beer)	0.1
	All other foods	1.0
Tin	Canned - Asparagus	250
	- Fruits	250
	- Fruit juices	250
	- Green beans	250
	- Tomato products	250
	Any other food packed in tinfoil or tinplate containers	250
	Foods not packed in tinfoil or tinplate containers	50
Zinc	Beverages and liquid foods	5.0
	Edible offal	120.0
	Fish and crustacea	150.0
	Meat	100.0
	Oysters	1000.0
	Shellfish other than oysters	100.0
	All other foods	50.0

APPENDIX VII

PROVISIONAL TOLERABLE WEEKLY INTAKE FOR MERCURY, LEAD AND CADMIUM

In its sixteenth report the joint F.A.O./W.H.O. Expert Committee on Food Activities indicate that the acceptable daily intake (ADI) rationale used for most metals was inappropriate for mercury, lead and cadmium. The reasons why this is so were cited as:

(1) The metals and some of their organic derivatives are cumulative and may attain equilibrium within the body only after prolonged exposure; selective localisation of such materials in susceptible organs and tissues of the body may cause injury when high levels are attained. There is also the problem of distinguishing accurately the relative proportions of different forms of the contaminant, such as inorganic mercury and methylmercury compounds, in view of their distinctive toxicological implications.

(2) A narrow margin exists between the exposure of "normal" populations in many countries and the exposure known to cause overt symptoms and signs of intoxication. The allocation of an ADI on the basis of animal experiments, using a reasonable safety factor, might result in figures that would not permit a normal intake of food.

(3) There is uncertainty concerning many of the essential factors about the response to current levels of population exposure:

    (a) the degree to which individual adults vary in their susceptibility, and the influence of the usual variables within and between populations, are still unknown;

    (b) the special susceptibility of the fetus, neonate, and child cannot at present be accurately expressed;

    (c) subclinical indices of effect, as distinct from measurements indicating exposure, have not been adequately delineated;

    (d) the possibility of genetic effects exists, but the levels of exposure needed to bring them about (if, in fact, genetic damage is elicited in man) are unknown;

    (e) the potential biological interactions of heavy metals with each other and with neurotoxic, nephrotoxic, and lipophilic chemicals present in food or derived from the environment have not been evaluated.

(4) ADIs are intended to be used in allocating the acceptable amounts of an additive to specific intended uses where it will serve necessary technological purposes and will be employed in accordance with good manufacturing practice. Such concepts are inapplicable to trace contaminants.

A provisional tolerable weekly intake for each of the above metal contaminants has been allocated. This basis for this approach was as follows:

(1) The contaminants are able to accumulate within the body at a rate and to an extent determined by the level of intake and by the chemical form of the heavy metal present in food. Consequently, the basis on which intake is expressed should be more than the amount corresponding to a single day. Moreover, individual foods may contain above-average levels of a heavy metal contaminant, so that consumption of such foods on any paricular day enhances that day's intake. Accordingly the provisional tolerable intake is

(1) (Cont'd)
expressed on a weekly basis.

(2) The term "tolerable", signifying permissibility rather than acceptability, is used in those cases where intake of a contaminant is unavoidably associated with the consumption or otherwise wholesome and nutritious foods, or with inhalation in air.

(3) The use of the term "provisional" expresses the tentative nature of the evaluation, in view of the paucity or reliable data on the consequences of human exposure at levels approaching those with which the Committee is concerned.

This Expert Committee proposed that for cadmium, the provisional tolerable weekly intake should be 0.4 to 0.5 mg per individual.