EFFECTS OF DISCHARGES OF ACID-IRON EFFLUENT FROM PRODUCTION OF TITANIUM DIOXIDE ON THE ABUNDANCE OF BENTHIC BIOTA OF LESCHENAULT INLET

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure

EFFECTS OF DISCHARGES OF ACID-IRON EFFLUENT FROM PRODUCTION OF TITANIUM DIOXIDE ON THE ABUNDANCE OF BENTHIC BIOTA OF LESCHENAULT INLET

1 INTRODUCTION

1.1 BACKGROUND

Laporte Australia Ltd operates a titanium production plant on the eastern shore of Leschenault Inlet. Acid-iron waste produced in the processing of the mineral is currently disposed of in the dunes on the western side of Leschenault Inlet. The waste crosses the inlet through a pipeline supported by a causeway extending from the eastern shore and then by a trestle above the waters of the inlet (Fig. 1). After reaching the western shore of the inlet, the effluent is piped to selected excavations termed seepage lagoons and is released into these seepage lagoons within the sand dunes comprising the Leschenault Peninsula.

Concern has been expressed that some effluent has periodically entered Leschenault Inlet and may have affected the biota of the inlet. The biota is considered important because Leschenault Inlet is a significant recreational and professional fishery.

The effluent may have entered Leschenault Inlet via two pathways:

(1) Firstly, there have been breakages in the pipeline which crosses the inlet and follows the shoreline along the eastern margin of Leschenault Peninsula for a distance of 3 km, with consequent discharge of the raw effluent directly into the inlet;

(2) Secondly, the effluent disposed into the sand dunes has been observed seeping in a partially neutralised and clarified form, either on the surface or in an aquifer immediately below the surface, into the inlet.

The Leschenault Inlet Management Authority, the body managing Leschenault Inlet, is concerned that, while spillages of the effluent do not have a measurable effect on the fish other than localised mortality, there may be an effect of the effluent on the benthic biota which form the food resource of many species of fish. Thus an altered benthic biota may have an indirect effect on the fish. However, no assessment of the impact of effluent spills on the benthos has been made.

The Waterways Commission therefore commissioned LeProvost, Semeniuk & Chalmer, Environmental Consultants, to investigate the potential effects of acid-iron effluent on the estuarine benthos. This document reports on the results of the investigation. The report describes the benthic biota of Leschenault Inlet, particularly in relation to their role as a food resource for fish and crabs, and assesses the past impact of acid-iron effluent from production of titanium dioxide on the benthic biota.

1.2 OBJECTIVES

The basic objectives of the study were to:

(1) describe the environment and habitats occupied by the benthic biota;

(2) describe the benthic biota and their role as a food resource for fish and crabs;

(3) determine the past effects of leakage of acid-iron effluent on benthic fauna and flora;

(4) assess the likely effects of reduced abundance, due to acid-iron effluent, of benthic biota on fish and crabs via the benthic food chain.

Objectives (1) and (2) were achieved by a collation of existing information, objective (3) was achieved as a result of field surveys, and objective (4) by integrating information resulting from the first three objectives.

1.3 ACKNOWLEDGEMENTS

We wish to thank the Public Works Department for providing the information regarding discharges of effluent into Leschenault Inlet.

2 SUMMARY AND CONCLUSIONS

This report describes the environment, habitats and benthic biota of Leschenault Inlet in relation to accidental discharges into the inlet of acid-iron effluent from the production of titanium dioxide. Field studies of benthic biota in areas where discharges of acid and iron effluent had previously occurred were conducted to determine the effect of the effluent on the abundance of the benthic biota.

Leschenault Inlet is an elongate microtidal lagoon which is subject to both marine influences and, periodically, riverine discharges. The major habitats for benthic biota in the inlet are shallow sand shoals and muddy sand platforms which occur around the margins of the inlet and a deeper mud basin which occurs in the interior of the inlet. While there have been significant modifications to parts of the inlet, particularly the southern end, Leschenault Inlet, from a biological viewpoint, is in a relatively satisfactory condition.

The marginal shoals and platforms of Leschenault Inlet are extensively covered by the seagrasses Halophila and Ruppia, and by algae. The interior mud basin is largely bare of vegetation.

The benthic fauna of Leschenault Inlet is abundant, particularly on the marginal shoals and platforms, although periodically the interior basin is colonised at high density by particular species. The benthic fauna of the inlet, and of other southwestern Australian estuaries, is substantially more abundant than that from similar habitats in coastal embayments and from the coastal seafloor. The benthic fauna serves as a food resource for fish in the inlet, and the high abundance of benthic fauna in the inlet relative to other coastal areas is probably one of the causative factors for the significant commercial fishery in Leschenault Inlet. Most of the commercial species of fish in the inlet feed and depend directly on the benthic fauna.

The benthic biota of the inlet were surveyed in February 1983 at four sites in the inlet where discharges of effluent had previously occurred. These discharges included both direct spillages of effluent in the inlet and indirect discharges which seeped via subterranean pathways into the inlet and had occurred between two months and approximately ten years before the survey. The magnitude of the discharges surveyed was representative of those discharges that had occurred in the last ten years. At these sites, no substantial changes to the abundance of the benthic biota that could be attributed exclusively to being due to the discharges of acid-iron effluent were detected. It is concluded that while the acid-iron discharges may have reduced the benthic biota immediately after the discharge, the effects were probably of a short-term nature and the area was rapidly recolonised by benthic biota. Consequently it is unlikely that a reduced abundance of benthic fauna in the vicinity of an effluent discharge has had, via the food chain, any substantial effect on fish and crabs in the inlet.

3 DESCRIPTION OF ENVIRONMENT

3.1 INTRODUCTION

The objective of this section ultimately is to describe the range of biological habitats which occur within the study area and outline their distribution. However, the major physical elements of the study area which influence the formation and distribution of these habitats are described to provide an understanding of the evolution and long-term stability of the habitats and their associated biotic assemblages.

For purposes of this report, the information on the study area has been collected and synthesised at various scales appropriate to the framework of the natural system and to the processes operating within the system. These scales are as follows:

(1) regional scale (5,000-15,000km^2): the Swan Coastal Plain and adjoining marine and hinterland units;

(2) parochial scale (300-450km^2): the Leschenault Inlet-Geographe Bay system and surrounding terrain which comprises the southern coastal part of the Swan Coastal Plain;

(3) local scale (10-20km^2): Leschenault Inlet-Koombana Bay area which contains a suite of juxtaposed natural units within which the site of detailed studies are made;

(4) immediate vicinity of zones of effluent impact: which is located on the western shoreline of Leschenault Inlet and along the trestle route.

3.2 REGIONAL SCALE SETTING

A brief synopsis is presented here on climate, geomorphology and large-scale processes pertinent to understanding the development and maintenance of Leschenault Inlet habitats.

The regional climate of the Swan Coastal Plain in the vicinity of Bunbury is similar to Perth and has been described as Mediterranean (Gentilli, 1972) or Subtropical humid (Köppen, 1936; Trewartha, 1967; Semeniuk & Meagher, 1981b). The components of the climate which are important to the development and maintenance of habitats (and biota) of Leschenault Inlet include:

temperature, which is mild and typical of subtropical climates;

rainfall/evaporation, which regulate limnological aspects of the inlet; and

wind, which has largely developed the barrier peninsula and has continued to maintain habitats by developing distinct substrate types.

The Bunbury region, with its system of coastal, estuarine and fluvial environments, is situated on the southern part of the Swan Coastal Plain (Gentilli & Fairbridge, 1952; Seddon, 1972; Semeniuk & Meagher, 1981a). The Swan Coastal Plain is the Quaternary (1.5 million years to present) surface of a subsiding coastal lowland which adjoins an uplifted Archaean rock plateau (the Darling Plateau) along a scarp to the east. The lowland is the youngest part of the Perth Basin, a geologic basin that has been subsiding since at least 280 million years ago.

Much of the landform of the Swan Coastal Plain originated by the processes of aeolian deposition, subsequent erosion and weathering, fluviatile deposition/erosion and marine to lacustrine sedimentation. The combination of subtropical, dry summer - wet winter climate and wave-dominated oceanography and limnology of the region has played a large role in the development of the coastal plain environments. The open coast is predominantly wave and wind dominated. Wind waves and oceanic swell combine to build coastal sedimentary deposits. Onshsore winds generated by seabreezes have transported sediment further onshore to build substantial dune fields. Subsequent leaching and induration of these dunes in the vadose zone under subtropical conditions has progressively transformed the calcareous dunes into limestone and has transformed quartz sand dunes into leached degraded forms. Wind waves generated within inlets and lagoons also are a major factor in developing shoreline geomorphology and sedimentary units.

At the parochial scale the geomorphic units present in the study area are (Semeniuk & Meagher, 1981a):

(1) a marine-eroded offshore submarine shelf;

(2) Quindalup dunes which form the shore and shallow marine environments of the open coast;

(3) a barred lagoon, Leschenault Inlet, formed by the barrier dune system;

(4) Spearwood dunes with a cover of yellow sand which form the eastern shore of Leschenault Inlet;

(5) the Preston River and Collie River deltas which have developed on estuarine lowland in the Anglesea Island area, and a digitate delta within Leschenault Inlet, respectively.

The differentiation of these units is biologically important to an understanding of biological systems in that either their materials directly contribute to substrate variability and hence habitat variability, or processes within the geomorphic units aid in the development and maintenance of habitats (e.g. wind waves reworking shallow sand shoals along the eastern shore of Leschenault Inlet).

3.3 LESCHENAULT INLET

Leschenault Inlet is a microtidal lagoon some 14km long, between 1.5km and 2.5km in width and 0.3m to 2m in depth. It lies parallel to the coast and is protected from the Indian Ocean by Leschenault

Peninsula (barrier dunes) (Fig. 1). Wave energy within Leschenault Inlet is due entirely to local wind waves. During summer wind waves generated by the seabreeze are sufficient to suspend muds from the shallow floor of the inlet.

The hydrological characteristics of the water within Leschenault Inlet have changed recently. Prior to 1951 the entrance of Leschenault Inlet to the sea was at the southern end of Koombana Bay. Both the Collie and the Preston Rivers entered Leschenault Inlet and, together with substantial drainage from the north, they exerted a fresh-water influence at the end of winter. As a result, the general characteristic of Leschenault Inlet was brackish during winter and marine during summer (Rochford, 1951; Meagher, 1971). After making an artificial entrance (The Cut, Fig. 1) to the lagoon adjacent to the two rivers, the hydrology changed virtually to that of a marine embayment. Brackish water influences now are much reduced and the inlet remains essentially marine in salinity throughout much of the year other than for the occasional outflow conditions from the Collie and Preston Rivers. The outflow from the Collie River also has been substantially reduced as a result of the catchment upstream.

The limnologic characteristics of the Leschenault Inlet system are distinct from the oceanic system. Characteristics of the inlet system are:

(1) the environment is microtidal and diurnal with a range of <u>ca</u> 0.5m (Hodgkin & DiLollo, 1957);

(2) there are expansive areas of shallow (<2m) water which are protected from oceanic processes;

(3) wind waves are generated on these water bodies by prevailing winds and storms; these agitate surface water, produce mixing and turbidity, develop wave-built structures and transport sediment;

(4) the water bodies communicate with ocean water daily via a flushing channel (The Cut); this provides exchange and also generates tidal currents;

(5) rivers periodically flood and carry into the system substantial quantities of fresh water which seasonally reduce the salinity of the estuary; these floods also distribute sediments and contribute nutrients into the system;

(6) evaporation during the summer causes local development of fields of hypersalinity;

(7) some ocean wind and swell waves pass into the channel entrance (The Cut) and, together with tidal currents, transport and disperse marine-derived sediments in shoals and sand bars.

Leschenault Inlet has been subdivided into three geomorphic sub-units; these are sedimentologically and biologically distinct and can be related readily to depth of water. The sub-units are (Fig. 2): (1) samphire and sedge flats; (2) shoals and platforms, and (3) interior basin.

Samphire and sedge flats: Strandline flats, inundated by high-tide and storm-water level, are covered by vegetation such as samphires *Arthrocnemum bidens* and *Suaeda australis*, and the sedge *Juncus krausii*. Shoreline trees such as *Melaleuca raphiophylla*, *M. cuticularis*, *Casuarina obesa*, and the mangrove *Avicennia marina* occur in scattered and individual copses.

Sediments underlying the surface of this zone are variable; mostly they are root-structured muds, or muds burrowed with sand/mud mixtures and organic detritus. Locally substrates are predominantly shelly gravel, coarse sand and organic detritus. Sediments are grey to black due to organic detritus and iron sulphide.

Shoals and platforms: Shallow sand shoals and muddy sand platforms occur along both sides of the inlet (Fig. 2) between MHHW and 0.2m below MLLW. They become (partially) exposed during a combination of low tide and high barometric pressure.

Shoals are the subaqueous terminal portions of sand dunes that extend into Leschenault Inlet. On the western side they are due to the progradation of the mobile dunes; on the eastern side they are due to the encroachment of the inlet on the old dunes of Pleistocene age. Reworking and mobilisation by currents and waves result in cusps and spits along the shoreline at the tip of shoals. Mud layers that accumulate on the surface during quiescent periods are mixed into the sediment by burrowing organisms. Thus, depending on the intensity of biological activity and rate of mud influx, the shoal and platform areas have varying proportions of shelly sand, muddy sand and burrowed clean sand.

Platforms are narrow units that border the remaining coastline of the inlet; their margins are straight, gently curved or lobate. Platforms originate as wave-built and current-modified features formed from muddy accumulations mixed with sediment eroded off dunes and sandhills adjoining the inlet.

Vegetation on shoals and platforms consists of the seagrasses *Halophila* and *Ruppia*, together with a number of unattached and semi-attached algae. The top layers of sediment are well bioturbated by a range of molluscs, crustaceans, worms and fish. Mollusc fauna of the platforms contribute shells to the sediments.

Interior basin: At the edge of a shoal or a platform there is often a marked slope (Figure 2) which falls from 0.2m to 1.0m below MLLW into the interior basin (generally 2m deep). The basin floor is dark grey to brown mud and some muddy sand. Resident animals contribute shells and burrow the sediment so that bioturbated, shelly muds are developed locally.

Relationships: Leschenault Inlet is quite obviously filling with sediment. Sand derived from margins extends into the inlet interfingering with, and prograding over, muddy sediments. The continuing *in situ* yield of seagrass and algae contributes humic material. The associated mollusc fauna contribute calcium carbonate debris.

Wave action and littoral drift along the inlet result in accumulation of muds on the shallow flats. Mud is commonly deposited on the protected western shore as a veneer on sand. Mud is winnowed off the eastern sand platforms each day when the seabreeze generates small waves and induces long-shore drift. Some of this mud finds its way into the interior basin, but a significant amount of mud also is transported northwards and accumulates in a thick wedge along the northern inlet margin.

3.4 PRESENT CONDITION OF THE ENVIRONMENT

Leschenault Inlet has been substantially modified by various developments, flood control programmes, agriculture and damming of the river in the catchment area, commercial and recreational fishing, dredging, and boating activities.

The first modification, as mentioned above, was carried out in 1951, and involved the construction of a new entrance to the inlet, known as The Cut, located to the west of the Collie River mouth. The original mouth of the inlet at Pt McLeod was sealed. Tidal exchange with the inlet was substantially increased by the new entrance, with the result that the inlet has subsequently developed the characteristics of a marine-dominated embayment. A tidal delta has formed inside Leschenault Inlet adjacent to The Cut.

The construction of Wellington Dam on the Collie River, completed in 1960, reduced the volume of fresh water entering the inlet, particularly the flow associated with peak run-off periods, further contributing to marine dominance of the inlet waters. Reduced flow also had the more localised effect of changing the major process influencing the formation of the delta at the Collie River mouth from river flow to wave action. Further, nutrient levels in the Collie River are relatively high, possibly resulting from agricultural fertilizers, and eutrophication is a potential threat to Leschenault Inlet should exchange of water between the inlet and the sea be greatly reduced.

Development of the inner harbour complex in the early 1970's divided the inlet into two portions separated by the harbour. This work resulted in major destruction of salt-marsh, mangrove and shallow-water habitats. Other alterations to the inlet involved the construction of a rock and concrete-faced channel linking the cut-off southern portion of the inlet to the southern end of Koombana Bay, immediately north of the "plug", and the diversion of the Preston River to its present discharge at the southern end of Vittoria Bay. Disposal of tailings from mineral sands processing has also taken place in the salt marshes adjacent to Anglesea Island where they have been used for land fill.

Additional shoreline modification associated with recreational usage has resulted in further habitat alteration, primarily along the eastern shore of Leschenault Inlet, for jetties, boat-launching ramps, car parks and landscaped foreshores. Restrictions on boat use imposed by the shallow water of Leschenault Inlet have been overcome by the construction of access channels to deeper water from the most utilised launching sites, the most extensive of these being at Australind. A channel has also been dredged across Vittoria Bay to link the mouth of the Preston River with the deeper basin of the inlet. The mouth of the Collie River has also been dredged to maintain the depth of the channels.

Acid-iron effluent has been disposed of into the sand dunes of Leschenault Peninsula. This has involved construction of a granite and limestone causeway, extending 1km from the Australind shoreline into the inlet, and a wooden trestle, traversing the remainder of the inlet, to carry the pipeline. Since completion of the causeway there has been an accumulation of muddy sediments on the northern side of the causeway extending the full length of the causeway out to a distance of approximately 80m from the causeway. Apart from this substrate modification, the presence of the causeway and trestle have apparently had no other gross effects on the benthic habitats. However, in the past, some effluent has leaked via subterranean pathways or pipeline breakages into Leschenault Inlet with resultant mortality of fish and benthos.

Both commercial and recreational fishing for scale fish and crustaceans (blue-manna crabs and prawns) have been practised in Leschenault Inlet since last century, and while there have been changes in the fish fauna of Leschenault Inlet over these years, the effects of fishing pressure are likely to have been of a temporary and reversible nature.

Thus Leschenault Inlet cannot be regarded as being in pristine condition and many of the biological habitats which now occur in the inlet are man made. Despite this, when compared with the Peel-Harvey estuarine system in particular, and with the Swan River estuary, Leschenault Inlet, from a biological viewpoint, is in a relatively satisfactory condition.

3.5 HABITATS OF LESCHENAULT INLET

The term "habitat" is used here to denote those areas which abiotic factors (such as water depth, salinity and substrate) have determined to be suitable as a living space for biota. In Leschenault Inlet there are five main habitats; these are:

(1) (high) tidal mud flats
(2) (low) tidal sand flats
(3) (subtidal) sand shoals and platforms
(4) (subtidal) muddy sand platforms
(5) (subtidal) mud basin.

A description and summary of distribution of these habitats are given in Table 1.

The most widespread habitats are the subtidal sand shoals, muddy sand platforms and subtidal mud basins (Fig. 2). These habitats also constitute the largest feeding grounds for the varied nekton fauna.

3.6 BIOTA OF LESCHENAULT INLET

The biota of Leschenault Inlet is typically estuarine. The specialised assemblages of fauna and flora are adapted for the variability in the physico-chemical environment of the estuarine system as well as for the varied substrate. For the purposes of this report, the biota of the inlet are divided into the following categories:

(1) benthic fauna
(2) benthic flora
(3) nektonic fauna
(4) avifauna

This report is concerned only with the benthic fauna and benthic flora which occur in the subtidal sand shoals, subtidal muddy sand platforms and the subtidal mud basin.

3.6.1 Benthic Flora

The benthic flora has been recorded by Meagher (1971), Schwinghammer (1978), Semeniuk & Meagher (1981b), Chalmer & Scott (in press) and LeProvost, Semeniuk & Chalmer (1983). These records show that the seagrasses *Halophila* and *Ruppia* are extensive (Fig. 3) and abundant (Fig. 4) and, depending on location, the algae *Chaetomorpha, Gracilaria,* phaeophytes and chlorophytes are also common. Table 4 lists the aquatic vegetation of Leschenault Inlet.

The benthic flora occur mainly on the shallow-water marginal shoals and platforms of Leschenault Inlet. Data from LeProvost, Semeniuk & Chalmer (1983) show that the biomass of vegetation is substantial, comprising some 58gm(dry wt)/m^2 of plant material (Table 5). Much of the vegetation is rhizomatous seagrasses *Halophila* and *Ruppia;* the algae are mainly detached floating forms (*Chaetomorpha, Cladophora*), or attached to the substrate (*Gracilaria* and *Lamprothamnion*) or epiphytic (*Ectocarpus, Spyridia, Chondria*).

3.6.2 Benthic Fauna

The fauna of Leschenault Inlet have previously been surveyed briefly in December 1974 by Chalmer & Scott (in press), and more intensively in 1981-83 as part of a wider study of the region by LeProvost, Semeniuk & Chalmer for the State Energy Commission. The following description of the benthic fauna is based on those surveys.

The main elements of the benthic fauna are bivalve and gastropod molluscs, crustaceans and polychaetes. A list of species of benthic fauna recorded from Leschenault Inlet is given in Table 2. The fauna have all been recorded from other estuaries in southwestern Australia (Chalmer *et al.*, 1976; Wallace, 1976a,b, 1977; Wells & Threlfall, 1981; Chalmer & Scott, in press) and none appear rare or restricted to Leschenault Inlet.

The major taxonomic groups and species which comprised the benthic fauna of Leschenault Inlet in December 1974 are shown in Table 3 for both the inlet basin and the marginal platform. These data show that the most abundant fauna in the shallow marginal platform habitat were the polychaetes (35% of all benthic fauna), bivalve molluscs (32%), and amphipod crustaceans (25%). The composition of the inlet basin was similar with bivalve molluscs (52%), and polychaetes (45%), but with a reduced abundance of amphipod crustaceans (3%). The species within the broad taxonomic groups (bivalve molluscs, polychaetes and amphipod crustaceans) were few in number and the same abundant species occurred in both the inlet basin and on the marginal platform. Most of the bivalve molluscs consisted of a single species, *Arthritica semen,* the polychaetes of four taxonomic groups (*Capitella* sp., *Ceratonereis erythraeensis*, *Haploscoloplos kerguelensis*, and *Prionospio* spp), and the amphipod crustaceans of three species, *Corophium* sp., *Melita* sp. and *Paracorophium* sp.

3.6.3 Biotic Assemblages

As a working model for purposes of this report, the low tidal and subtidal benthic biota of Leschenault Inlet are categorised into assemblages, each assemblage virtually restricted to distinct habitats that are related to water depth/tidal level, substrate and salinity. The assemblages (named after the dominant, conspicuous or characteristic species) which comprise the low tidal and subtidal benthic biota are:

(1) *Hydrococcus* assemblage - tidal sand
(2) *Halophila* assemblage - shoals/platforms
(3) *Tellina* assemblage - basin

The composition and distribution of these assemblages according to habitat are shown in Table 6.

3.7 SIGNIFICANCE OF BENTHIC FAUNA

In this description of the benthic fauna of Leschenault Inlet, the abundance of benthic fauna in Leschenault Inlet is first compared with that of other estuaries, embayments and open seafloor areas of southwestern Australia, to provide a regional perspective of the importance of the benthic fauna of Leschenault Inlet.

Data on the abundance of benthic fauna in other areas of southwestern Australia are only available from Hardy Inlet, Swan River Estuary, Sepia Depression and Koombana Bay and the seafloor offshore from Koombana Bay. Table 7 compares the average density of benthic fauna from these areas. It is clear that benthic fauna are least abundant (0.7-5.6 organisms per $0.1m^2$) in the open sea environment (offshore from Koombana Bay, Sepia Depression), at low abundance (36.0-46.4 organisms per $0.1m^2$) in semi-enclosed embayments (Koombana Bay, Cockburn Sound), and most abundant (80-3,625 organisms per $0.1m^2$) in the estuaries (Leschenault Inlet, Hardy Inlet, Peel Inlet/Harvey Estuary, and Swan River Estuary). Note that the abundance of benthic fauna in Peel Inlet/Harvey Estuary may have been elevated to some extent by eutrophication. These data show the importance of the estuaries of southwestern Australia for benthic fauna, and their potential as a food resource for benthic-feeding fish.

3.8 BENTHIC BIOTA AS A FOOD RESOURCE FOR FISH AND BLUE-MANNA CRABS

3.8.1 Commercial Species of Fish and Crustaceans in Leschenault Inlet

Leschenault Inlet is an important area as a fishery for both fish and crustaceans. Records from this fishery for the period 1952-1975 are available from Lenanton (1983) and show which species comprise the commercial catch. The average annual weight of each species of fish and crustaceans caught are shown in Table 8.

An estimated value of each species listed in Table 8 was derived from the weight of fish (or crustaceans) and a price per kilogram based on Australian Bureau of Statistics information. Note that these values apply to the whole of Western Australia rather than just Leschenault Inlet, and that the values shown are approximate only. Further, the value of each species relative to the other species, and their value ranking, changed greatly during the period from which the records were obtained. Thus, for example, while cobblers were on average the most important species for the period 1952-75, they were not consistently the important species in each year, and may not be the most important species at present. However, these data reveal a gross indication of the relative value of each species that comprise the commercial fishery.

Although over 21 species of wet fish form the commercial catch of Leschenault Inlet (Table 8), only 11 fish species (cobbler, yelloweye mullet, sea mullet, western sand whiting, King George whiting, tailor, Perth herring, black bream, skipjack trevally, Australian herring, sea garfish) and one crustacean (blue-manna crabs) comprise approximately 99% of the total value of the catch.

3.8.2 Food of Fish and Crustaceans

In southwestern Australian estuaries, the diet, including benthic fauna, of the fish has been examined in Leschenault Inlet and other estuaries by Thompson (1957), in Hardy Inlet by Wallace, (1976a,b) and in Leschenault Inlet and Peel Inlet/Harvey Estuary by Chalmer & Scott (in press). While there may be minor differences between the diet of fish in the different estuarine systems examined, the feeding patterns of the fish are similar for the estuaries examined, and results from all estuaries are generally applicable to Leschenault Inlet. These studies identified six basic food resources in the estuaries. These were:

(1) benthic fauna
(2) zooplankton
(3) algae
(4) aquatic angiosperms (seagrasses)
(5) organic detritus
(6) diatoms

The fish which utilise each of these food resources are shown in Tables 9 and 10. This report is not concerned with those fish that exclusively feed on organic detritus or diatoms, although it should be noted that there may be links between the benthos of Leschenault Inlet and its plankton and organic detritus resources. The remaining resources (benthic fauna, algae and seagrass) will be dealt with in more detail below. Some components of the zooplankton may have a diurnal activity pattern such that they are planktonic during the night, but form part of the benthic community during the daytime. In Tables 8 and 9, these zooplankton are included with the benthic fauna.

For the commercial fish species for which data are available, benthic fauna form a principal item of diet for 14 of 17 species, and algae for three of 17 species (Table 9). Only two species (sea mullet and Perth herring) of the 17 commercially-important species do not rely on either benthic fauna or algae as a principal item of diet. Of the species of non-commercial fish, 17 of 18 species depend on benthic fauna (including zooplankton), and four of 18 species depend on algae as a principal item of diet (Table 10).

Apart from the four basic food resources listed above, small fish also form a food source for larger predator fish, including tailor, mulloway, flounder and flathead. At this time there is insufficient data on the diet of these higher order predators to determine whether they are reliant on the benthic fauna food chain, or on food chains based on organic detritus, algae and seagrass, or plankton. Further, it is likely that some fish change their diet as they grow, and thus some fish which when large do not utilise the benthic food resource, may do so when they are juvenile.

It is important to note that, at this time, no species of fish appear to rely on the seagrass Halophila, which is the most common seagrass in Leschenault Inlet, as a major food resource.

The food of blue-manna crabs in southwestern Australian estuaries has not been documented. However, this crab is a widespread tropical species and its diet has been recently detailed in Moreton Bay, Queensland. Results from the Moreton Bay study (Williams, 1982) suggested that the crabs were entirely dependent on the benthic fauna as a food source. Examination of the stomach contents of a few (10) crabs from this study has also shown that they were eating benthic fauna. However, in Leschenault Inlet, they may also rely to some extent on algae as suggested by Meagher (1971).

4 ACID IRON EFFLUENT

4.1 NATURE OF THE EFFLUENT

The effluent released from the titanium processing plant, Laporte Australia Ltd at Australind, is highly acidic (sulphuric acid) with a substantial concentration of Fe^{2+} in solution. It also contains mud-sized solids in suspension and variable amounts of other ions, including heavy metals. The major chemical characteristics of the effluent are as follows (Laporte Effluent Disposal Committee, 1982):

ph	0.9-1.0
Fe^{++}	6,000ppm
SO_4^{+}	35,500ppm
Ti	300ppm
Ca	37ppm
Mg	39ppm
Cl	290ppm
Mn	230ppm
Al	80ppm
V	13ppm
Cr	7ppm
Solids	1,000-2,000ppm

The effluent also contains trace amounts of Ba, Cu, Ni, Sr, Ta, Th, and Zn.

4.2 SOURCES OF EFFLUENT POLLUTION

Acid-iron effluent has found its way into Leschenault Inlet by two mechanisms. The first of these is the result of pipeline breakages where substantial amounts of raw, acidic effluent have rapidly entered the inlet over periods of relatively short duration. This type of leakage is likely to have had immediate and short/long-term effects on the biota and is referred to subsequently as acute exposure to effluent. The other leakage of effluent into the inlet has been via subterranean pathways. The effluent here is partially neutralised, clarified and diluted. The leakages are likely to have been over long periods with a lower rate of leakage and perhaps more rapid dilution of the effluent. This type of leakage may not have had immediate effects, although they may have been long-term. It is subsequently referred to as chronic exposure to effluent. As acute exposure and chronic exposure to effluent are likely to produce different effects, they are treated separately in the following sections. The characteristics of these two types of effluent/biota encounters and the potentially harmful component of the effluent are set out in Table 11 and described more fully below.

A summary of the frequency and magnitude of effluent discharges to Leschenault Inlet from the pipeline over the last ten years (January 1974 to June 1983) are shown in Figure 5. Relatively few discharges from the pipeline were the result of subterranean seepage into Leschenault Inlet, and these mostly occurred on the eastern shore before the pipeline entered the inlet. The largest number of discharges that directly entered Leschenault Inlet (i.e. acute exposure) were from breakages or leakages of pipes on the causeway or trestle. However, the largest discharges occurred as a result of pipeline breakages on the Leschenault Peninsula, also with a large amount of effluent discharging directly into the inlet.

4.3 POTENTIAL SOURCES OF IMPACT

Acid-iron effluent contains several components that can be toxic to benthic biota and are potential sources of impact on the benthos of Leschenault Inlet. These are:

- acidity
- iron
- sediment
- heavy metals
- radiation

As these components may act in different ways and respond differently to different situations such as acute and chronic leakage, their actions and effects are reviewed below.

4.3.1 Acidity

Acidity is probably the major toxic component of the effluent. It has been shown to cause mortality of amphipods and benthic seagrass communities (LeProvost & Chalmer, 1983). The acidity of the effluent is neutralised through the buffering capacity of seawater and reaction with calcareous components of the substrate; the effects of the effluent also are ameliorated upon dilution with seawater. Given sufficient dilution and reaction/neutralisation, the acidity can affect only a limited area.

4.3.2 Iron

Ferrous ion oxidising to ferric ion may cause a major depletion of oxygen in water, thereby causing widespread mortality in fauna, especially fish. Ferric (iron) hydroxide floc is formed when Fe^{++} is oxidised and is responsible for colouration or staining of the water. While the effluent is mixing with seawater, ferric hydroxide will adsorb onto or 'coat' any particles that it contacts as it is forming. Coating of the biota with ferric hydroxide also may cause mortality if gills or other essential areas are covered. After formation, the ferric hydroxide floc is chemically stable and should cause few problems although high concentrations of ferric hydroxide floc is believed to affect respiratory processes of fish eggs (Kinné & Rosenthal, 1967), and probably of benthos in general.

4.3.3 Sediment

Fine-grained sediment is a minor but significant component of the effluent. When in contact with biota it appears to have a harmful effect probably because of its fine-grained nature. It is also the component that contains adsorbed or bonded heavy metal ions.

4.3.4 Heavy Metals

Barium, chromium, copper, manganese, strontium, thorium, titanium, vanadium and zinc, are present in the effluent in trace quantities. These elements originally are locked within the lattice of heavy minerals and are released by the titanium-refining process. The effects of these metals on the benthos of Leschenault Inlet are unknown at present.

4.3.5 Radiation

Radiation in the effluent is due to the occurrence of thorium and its decay products. Thorium is the main radioactive element in monzonite, an accessory mineral within the heavy mineral suite. It is released into solution by the titanium refining process.

Radiation has been detected in the shell of the blue-manna crab (Portunus pelagicus) during a preliminary survey of Leschenault Inlet by Cooper et al. (1981). These results prompted a further, more intensive study, the results of which are unavailable at this time. While it has been suggested that the Laporte effluent is the source of the radiation, this has not yet been substantiated. Until definite conclusions have been drawn about the source of the radiation, it is not possible to speculate about the possible effects of radiation which may be contained in the effluent.

5 ASSESSMENT OF EFFECTS OF EXPOSURE TO EFFLUENT ON THE BENTHOS

5.1 INTRODUCTION

The effects of acid-iron effluent on benthic biota have been described for the Humber Estuary by Wilson et al. (1974) and for the seafloor offshore from Koombana Bay by LeProvost & Chalmer (1983). Both of those studies described an area around a discharge point in which all biota were killed and the seafloor was totally barren (abiotic zone). Surrounding the abiotic zone was an area in which some effects of effluent on the biota were evident. At sufficient distance from the discharge point, no effluent-induced effects on the benthos could be detected, and the seafloor beyond that point was considered unaffected.

Acid-iron effluent has been pumped through the pipeline across Leschenault Inlet since 1963. There have been periodic breaks in the pipeline across the inlet during that period and these breakages, with consequent leakage of effluent into the inlet, provide a situation to determine the effects of effluent spills on the benthos. It was expected that if the effluent from those leakages had affected the benthic biota of Leschenault Inlet, then around the leakage site there might be an abiotic zone surrounded by an area in which some benthic biota were present but in reduced abundance. The best method of determining the impact of the acid-iron effluent on the benthic fauna of Leschenault Inlet would be to survey the fauna in an area both before and after a leakage there. However, as the occurrence of effluent leakages is unpredictable, and an experimental leakage was not considered desirable, the Waterways Commission decided the best available means of obtaining an indication of the gross effects of a leakage on the abundance of benthic fauna was to survey areas in which effluent leakages had occurred in the past.

The objectives of this section were to provide quantitative data:

(1) to determine whether the benthic biota in the vicinity of previous effluent leakages showed evidence (e.g. absence or reduced density) of the impact of effluent;

(2) if an impact was detected, to determine the area affected;

(3) to provide an indication, if possible, of the rate of recovery of an area previously subjected to an effluent leak; and

(4) to provide an indication, if possible, of the relative impact of the different types of leakage (pipeline breakage with direct entry of effluent to the inlet and prolonged effluent seepage from the hinterland into the inlet) on the benthos.

It was intended to detect the impact of the effluent on the benthic fauna primarily by establishing a gradient in the density of benthic biota from the lowest density (maximum impact) adjacent to the leakage site, to the highest density (no impact) in an unaffected, control site. Supplementary sampling sites were to be located on each side of the transect to determine whether the effluent, after leakage, travelled along the sampling line and did not diverge to either side of the sampling line. An indication of the scale of area to be sampled was provided by observations of effects on benthic biota of a large discharge which occurred immediately prior (7th February, 1983) to this field survey.

A secondary, and less accurate, method of assessing gross damage to the benthos was to compare the densities of benthos in the affected areas with those obtained from other areas of the inlet in February 1983 (V. Semeniuk, unpublished data), or in earlier surveys in December 1974 (Chalmer & Scott, in press) and May 1982 (LeProvost, Semeniuk & Chalmer, 1983) for the marginal shelves or basin of the inlet. However, because of the wide variability between the densities recorded in those earlier surveys, and the natural spatial variability observed in February 1983 and the earlier surveys, this method of assessment was not particularly accurate and could only detect extremely gross changes.

5.2 METHODS

5.2.1 Site Selection

Four sites in Leschenault Inlet where effluent leakages had occurred in the past were surveyed to determine the impact of the leakages on the benthos. The general location of these sites is shown in Figure 1. A description of the nature, date and volume of effluent leakage at each site is shown in Table 12. The four sites surveyed were selected because:

(1) the time period in which the leakages occurred (July 1979–November 1982) was sufficiently recent: it was expected that effects on the benthos would be evident, and thus the area of effect could be determined;

(2) the span in time over which the leakages occurred might indicate the rate of recovery of the benthos;

(3) these sites had experienced the largest spillages in recent years, and thus the effects on the biota were expected to be most obvious;

(4) the sites covered the range of habitats in Leschenault Inlet (one in the deep basin and three on the shallow marginal shelves);

(5) both effluent spillages from pipeline breakages (two sites) and prolonged effluent seepage through the surrounding hinterland (two sites) were included in these four sites;

(6) the sites selected also are typical of the recurring leakage patterns. Figure 5 shows a summarised history of past effluent discharges from the pipeline into Leschenault Inlet; the occurrence of the leakages in the vicinity of our chosen sampling sites is shown in relation to other leakages over the last ten years.

5.2.2 Timing of Survey

Estuarine benthos in southwestern Australia undergo seasonal changes in distribution and abundance in response to the influx of fresh water in winter and marine water in summer. The benthos are most abundant in summer when they colonise extensive areas of the estuaries. In winter, their range decreases to the more marine parts of the estuaries and their abundance generally decreases. The benthos of Leschenault Inlet were sampled in mid summer when their abundance was greatest and it was believed that any effects of the effluent would be most evident.

5.2.3 Benthic Sampling Techniques

The benthos were sampled over the period 16-23 February, 1983 at four sites (Figure 1). At each site six stations were sampled, the locations of which are shown in Figure 6. Five replicate samples of the benthos were collected at each station. Two different sized areas were used to sample the benthos, depending on the density of each species. The larger species, which usually occurred at a lower density, were sampled using a large quadrat (625cm^2 surface area and depth of 30cm). These species included the seagrass Halophila, all algae, and the large molluscs Tellina, Spisula and Nassarius. Smaller species were sampled using a small core (80cm^2 surface area and depth of 10cm). These species included the amphipods, the small mollusc Arthritica and all polychaetes. All samples were washed through a 1mm sieve and, where possible (large fauna), counted and recorded in the field. The seagrass and algae were preserved in 10% Formalin for later sorting and weighing in the laboratory. The small fauna were preserved in 10% Formalin, stored in 1% Phenoxytol and sorted and counted in the laboratory.

5.3 RESULTS

Site descriptions, timing and amount of effluent leakage, and the results from the benthic surveys are described below for each of the four survey areas. Details of the depths and sediment types at each site are contained in Appendix 1. Raw data on the density of benthic fauna are contained in Appendix 2.

5.3.1 Area 1

5.3.1.1 Site description

The area is located on the marginal shoal/platform on the east shore of Leschenault Inlet. The geomorphology, habitat and biotic characteristics of the area are similar to other shoal/platform environments along this eastern shore.

The location along which the transect sampling took place is a vegetated plane surface composed of fine quartz sand; locally there are small-scale hummocks due to fish feeding and disturbing the substrate, and bioturbation activity of the benthos. The surface vegetation is dense to patchy and forms a nearly continuous carpet. It is composed predominantly of Halophila with lesser amounts of attached and floating algae. The Halophila forms rhizomatous sheets that bind the surface layer of the substrate.

Amphipods and small bivalve molluscs are the most abundant benthic fauna at this site although larger bivalves and gastropods may contribute a greater proportion of the biomass.

5.3.1.2 Discharge of effluent

Over the last ten years there have been six significant leakages of effluent in the vicinity of this site (Fig. 5, Table 12). Two of these discharges (June 1976 and May 1979) were direct spillages of $150m^3$ each.The other discharges which were pipeline breakages on the hinterland involved the effluent running under the road into Leschenault Inlet (April 1978), or subterranean seepage to Leschenault Inlet on three occasions (31 August-9 October 1981) of a total of $450m^3$ of effluent. Thus this site would be expected to have been affected by acute exposure (direct discharge) and, more recently (16 months), by chronic exposure (seepage) to the effluent.

5.3.1.3 Effect of effluent on the benthos

Fauna: The most common species at this site were the bivalve molluscs *Tellina* and *Arthritica*, the gastropod mollusc *Nassarius*, the amphipod custaceans *Corophium* and *Paracorophium*, and the polychaete worm *Ceratonereis*. These are examined in detail below. The numbers of these species, when combined, comprised 98% of the fauna sampled in Area 1.

Tellina (Fig. 7-A): This bivalve mollusc was only present at low numbers in Area 1. There was no relationship between abundance and distance from shore.

Arthritica (Fig. 7-B): This small bivalve mollusc was abundant in Area 1 close to the shore, but at low abundance further offshore.

Nassarius (Fig. 7-C): This gastropod mollusc was common in Area 1, but showed no relationship between abundance and distance from shore.

Paracorophium (Fig. 7-D): This amphipod crustacean was abundant at Area 1. It exhibited a peak in abundance at points mid-distance from the shore, but overall showed no relationship between abundance and distance from the shore.

Corophium (Fig. 7-E): This amphipod crustacean was also abundant in Area 1, and like *Paracorophium*, exhibited a peak in abundance at mid-distance from the shore, but no overall relationship.

Ceratonereis (Fig. 7-F): This polychaete worm was abundant and showed an increase in abundance with distance from the shore.

Number of all benthic fauna (Fig. 7-G): Benthic fauna were abundant at this site, but showed no overall increase in abundance with distance from the shore. The total number of benthic fauna showed similar levels to those recorded in previous surveys (LeProvost, Semeniuk & Chalmer, 1983; Chalmer & Scott, in press), and from other areas in February 1983 (V. Semeniuk, unpublished data) of Leschenault Inlet (Fig. 8).

Number of taxa (Fig. 7-H): The number of taxa at this site varied from four to eight, and showed no relationship with distance from the shore.

Vegetation: The vegetation consisted largely of Halophila (43%) and Ruppia (51%) with only minor amounts of algae (Table 5).

Halophila (Fig. 7-I): This seagrass was not abundant close to the shore, but more abundant further offshore. This variation was probably a reflection of the increase in depth.

Ruppia (Fig. 7-J): This seagrass was present at all sites, but was extremely patchy, and apparently did not show effects of effluent.

Total vegetation (Fig. 7-K): This parameter also increased with depth and distance offshore.

5.3.2 Area 2

5.3.2.1 Site description

This area is similarly located on the shoal/platform along the east shore of Leschenault Inlet. However, it is located on the northern side of the pipeline groyne and as such has been protected from southwesterly seabreezes. Accordingly, in the lee of the groyne, the area has accumulated a proportion of mud which has been mixed into the originally sandy substrate. This accumulation of mud extends for 70-80m north of the groyne along the entire length of the groyne.

The environment along the sampling transect is a vegetated plane surface with local small hummocks due to fish feeding and benthic faunal bioturbation. The substrate is fine-grained sand with variable amounts of interstitial mud.

The vegetation, composed of rhizomatous Halophila and associated algae, forms a dense to patchy cover.

Bivalve and gastropod molluscs, amphipods and crustaceans are the most abundant benthic fauna in this area.

5.3.2.2 Discharge of effluent

Extensive staining of limestone rubble material on the causeway in this area suggests that an effluent discharge of reasonable size has occurred. Records of effluent discharge, which are comprehensive since January 1974, indicate only a minor discharge (February 1980) has occurred in the vicinity of the discharge within that period (Table 12). However, it is possible that a significant discharge prior to 1974, when records were not so comprehensive, was responsible for the staining in this area. This area should show the effects of acute exposure to effluent at a time approximately ten years prior to the survey.

5.3.2.3 Effect of effluent on the benthos

Fauna: The most common species at this area were the bivalve molluscs Tellina and Arthritica, the gastropod mollusc Nassarius, the amphipod crustacean Corophium, and the polychaete worm

Ceratonereis These are examined below. The numbers of these species, when combined, comprised 93% of the fauna sampled in Area 2.

Tellina (Fig. 9-A): This large bivalve mollusc was abundant in Area 2 with low densities close to the causeway and higher densities further offshore.

Arthritica (Fig. 9-B): This small bivalve was common in Area 2 with moderate densities close to the causeway and lower densities further offshore. At one site (Station 11), it was extremely abundant although the density varied greatly between replicate samples.

Nassarius (Fig. 9-C): This gastropod mollusc was also common in Area 2, perhaps with lower densities close to the causeway and higher densities offshore, although the variability between replicates was higher.

Corophium (Fig. 9-D): This amphipod crustacean was abundant close to the causeway with lower densities further offshore, although the variability between replicates was high.

Ceratonereis (Fig. 9-E): This polychaete worm was common at sites close to the causeway, but at lower density or absent from the offshore sites.

Number of benthic fauna (Fig. 9-F): The number of benthic fauna was variable between replicates at each site, but did not greatly change from the sites near the causeway to those further offshore. One site (Site 11) had a particularly high density of benthic fauna, this was largely due to the high, but variable, density of the bivalve Arthritica at that site. The total number of benthic fauna was similar to that recorded in previous surveys by Chalmer & Scott (in press), LeProvost, Semeniuk & Chalmer (1983) and from other areas in February 1983 (V. Semeniuk, unpublished data) of Leschenault Inlet (Fig. 8).

Number of taxa (Fig. 9-G): Like the total number of benthic fauna, the number of taxa at each site showed no change between the sites close to the causeway and those more distant to it.

Vegetation: The vegetation in this area consisted of Halophila (95%) with minor amounts of Ruppia and algae (Table 5). Consequently, only Halophila is considered below.

Halophila (Fig. 9-H): This seagrass was dense in Area 2, but showed no linear trend with distance from the causeway.

5.3.3 Area 3

5.3.3.1 Site description

The area is located on the marginal platform of the western shore of Leschenault Inlet. The geomorphology, habitats and biota of this area are similar to other platform environments along the inlet's western shore.

The location along the sampling transect is a plane surface composed of muddy fine sand. Locally there are small-scale hummocks due to fish feeding and benthic bioturbation. Vegetation cover grades from sparse/nil at landward portions of the transect, to dense at subtidal portions. The vegetation is the rhizomatous Halophila with associated algae.

Amphipods, small bivalve molluscs and polychaetes are the most abundant benthic fauna in this area.

5.3.3.2 Discharge of effluent

This area was subject to subterranean seepage of effluent from a lagoon (No. 17) on the Leschenault Peninsula (Table 12). The discharge was first observed in March 1981 when effluent was observed seeping through the edges of the shoreline. Use of this lagoon was terminated in November 1982. During the period March 1981-November 1982, effluent was sporadically observed seeping into the inlet, particularly during low tides which most frequently occurred in summer. This area would be expected to show the effect of chronic, but intermittent, exposure after a short (2-23 months) time period after the discharge.

5.3.3.3 Effect of effluent on the benthos

Fauna: The most common species in this area were the bivalve molluscs Tellina and Arthritica, the gastropod mollusc Nassarius, the amphipod crustaceans Paracorophium and Corophium, the polychaete worms Ceratonereis and Prionospio. These are examined below. The numbers of these species, when combined, comprised 98% of the fauna sampled in Area 3.

Tellina (Fig. 10-A): This large bivalve was present in moderate numbers in Area 3. It was at lowest density close to the shore and increased to a consistent level with distance from the shore.

Arthritica (Fig. 10-B): This small bivalve was in high abundance in Area 3. Although the variability between replicate samples at each site was extremely high, there appeared to be a trend towards decreased density with distance from the shore.

Nassarius (Fig. 10-C): This gastropod mollusc was present in high numbers in Area 3. It was only present in low numbers close to the shore, but increased with distance from the shore.

Paracorophium (Fig. 10-D): This amphipod crustacean was also present in high numbers in Area 3. Again its density was highly variable between replicates at each site, but there appeared to be a decrease in abundance from the shore to the more offshore sites.

Corophium (Fig. 10-E): This amphipod crustacean was present in moderate numbers. No linear trend with distance from the shore was apparent in the abundance of this species.

Ceratonereis (Fig. 10-F): This polychaete worm was present in high numbers in Area 3 and there was a clear decrease in abundance with distance from the shoreline.

Prionospio (Fig. 10-G): This polychaete worm was present in moderate, but highly variable, numbers in Area 3. It was abundant only at the site closest to the shore.

Number of all benthic fauna (Fig. 10-H): There was substantial variation between replicates at each site for the number of all benthic fauna. However, if a trend existed, then it was towards decreasing abundance with distance from the causeway. Similar total numbers of benthic fauna were recorded in previous surveys of Leschenault Inlet (LeProvost, Semeniuk & Chalmer, 1983; Chalmer & Scott, in press) and from other areas of Leschenault Inlet in February 1983 (V. Semeniuk, unpublished data) (Fig. 8).

Number of taxa (Fig. 10-I): The number of taxa recorded from each replicate in Area 3 varied from four to nine. No trend in number of taxa with distance from the shoreline was observed.

Vegetation: The vegetation at this site consisted predominantly of algae (73%) and Halophila (26%) with only a minor amount of Ruppia (Table 5).

Halophila (Fig. 10-J): This seagrass was absent in the shallow water close to the shore and increased with depth further offshore.

Algae (Fig. 10-K): Algae was most abundant close to the shore and decreased in abundance with distance offshore.

Total vegetation (Fig. 10-L): This parameter showed high values close to the shore (corresponding to high algal values) and high values at the most offshore site (corresponding to high Halophila values).

5.3.4 Area 4

5.3.4.1 Site description

This area is located in the deep-water mud basin of Leschenault Inlet. The surface is plane, non-vegetated and there are numerous burrow entrances. The substrate consists of mud and shelly mud.

Large bivalve molluscs (Tellina and Spisula) and gastropods (Nassarius) are the most abundant benthic fauna in this area.

5.3.4.2 Discharge of effluent

This area was subject to several pipeline breakages over the last ten years (Fig. 5, Table 12). All discharges were of 300m^3 and represent the larger discharges from the causeway and trestle. The last discharge was in August 1979. This area should provide an indication of the effects of acute exposure to effluent 3-5 years after the discharge.

5.3.4.3 Effect of effluent on the benthos

Fauna: The most common species in this area were the bivalve molluscs Tellina and Spisula, and the gastropod mollusc Nassarius. These are examined in detail below. The number of these species, when combined, comprised 91% of the fauna sampled in Area 4.

Tellina (Fig. 11-A): This bivalve mollusc was present in Area 4 in low numbers and showed no trend in abundance with distance from the trestle.

Spisula (Fig. 11-B): This bivalve mollusc was abundant in Area 4. It decreased in abundance with distance away from the trestle on both the north and south sides of the trestle.

Nassarius (Fig. 11-C): This gastropod mollusc was common in Area 4. It showed no change in abundance with distance away from the trestle on the north side, but probably decreased in abundance with distance on the south side of the trestle.

Number of all benthic fauna (Fig. 11-D): This parameter largely reflected the trends for Spisula which comprised 69% of all benthic fauna sampled in Area 4. While substantially higher levels of total benthic fauna were recorded by LeProvost, Semeniuk & Chalmer (1983) and Chalmer & Scott (in press) (Fig. 8), the lower levels recorded in Area 4 probably do not reflect the effects of the effluent because:

(1) the LeProvost, Semeniuk & Chalmer (1983) survey was conducted after an unusual event in which Spisula colonised the central basin of Leschenault Inlet in extremely high numbers. Natural mortality subsequently resulted in a decrease in those numbers such that in February 1983 (Fig. 8) they were more similar to those recorded in Area 4 (V. Semeniuk, pers. comm.);

(2) there was high natural variability both within and between sites sampled In February, 1983 (See Fig. 8, Stations, C, I, J, N); and

(3) the Chalmer & Scott (in press) survey only included a few sites in the central basin of Leschenault Inlet and included some sites where algae was present which resulted in higher numbers compared to Area 4 which had no algae.

Number of taxa (Fig. 11-E): The number of taxa in Area 4 was low and did not exceed six at any one site. This parameter showed no trend in relation to distance from the trestle.

Vegetation: The floor of Leschenault Inlet at this site was naturally bare of vegetation.

5.4 SYNTHESIS OF RESULTS

A major problem that was encountered in interpreting the results of the benthic samples was that along the transects originating from the discharge sites, there were natural, or artificial gradients in physical parameters, other than that induced by possible exposure to effluent, which probably influenced the composition and abundance of the benthos along the transect. For example, in Areas 1, 2 and 3, both depth and substrate changed with distance from the shore or causeway. These two factors are both important in determining the distribution of benthic biota and were probably responsible for many of the changes observed along the transects.

An increase in abundance along a transect emanating from a discharge site was to be regarded as an indication that the effluent had affected (decreased) the benthos close to the discharge site. For the four areas surveyed, seven species (Area 1: Tellina, Ceratonereis, Halophila; Area 2: Tellina; Area 3: Tellina, Nassarius, Halophila) were observed to increase in abundance with distance from the discharge site. However, a similar number (9) (Area 1: Arthritica; Area 2: Corophium, Ceratonereis; Area 3: Arthritica, Paracorophium, Ceratonereis, Prionospio, algae; Area 4: Spisula decreased with distance from the discharge site. In view of these opposing trends, it is difficult to ascribe any of the increases in abundance with distance from the discharge site as being due to the effects of effluent. Instead, they are likely to be the result of natural variations in the environment.

As it is known that acid-iron effluent is toxic (in the short term) to benthos (Grice et al., 1973; Wilson et al., 1974; LeProvost & Chalmer, 1983) and that benthos in the vicinity of the discharge sites must have been killed by the discharge, then it is apparent that these areas have been recolonised since the discharge. The salinity of the estuaries of southwestern Australia is seasonally dynamic, and the estuarine biota cope with these salinity fluxes by either physiologically or behaviourally tolerating the change, or if they are susceptible to the change, by rapidly (within six months) re-invading the estuary (Chalmer et al., 1976); Hodgkin, in Riggert, 1978). It is probably these characteristics (high physiological or behavioural tolerance and rapid invasion mechanisms) that are responsible for the fast recovery of areas affected by acid-iron effluent. It is also apparent that the effluent discharge did not interfere with the subsequent recruitment of benthic fauna to the discharge site.

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TABLE 1

HABITATS OF LESCHENAULT INLET

HABITAT	DESCRIPTION	OCCURRENCE	WAVE ACTION/ TIDAL LEVEL
Tidal mud flats	tidally-inundated, subhorizontal samphire-vegetated muddy platforms less than 10m to approx. 200m wide; frequently separated from other estuarine units by a low (30cm) cliff	marginal to the inlet and most frequently situated in inter-dune corridors	high tidal protected from waves by vegetation
Tidal sand	tidally-inundated, subhorizontal vegetation-free sand flats, less than 10m to approx. 200m wide, grade downslope into subtidal sand flats	marginal to the inlet, mostly on the eastern shore	low tidal, wave agitated
Subtidal sand shoals and platforms	shallow water (less than 1m) gently-inclined sand and muddy sand platforms of mounds (100-500m wide) vegetated by seagrass; grade abruptly into deep-water basin	distributed almost entirely along east shore of inlet and sporadically along west shore	shallow subtidal to 1m, wave agitated by seabreezes
Subtidal muddy sand platform	shallow water (less than 1m) gently-inclined muddy sand and mud platforms (100-500m wide) vegetated by seagrass; grade gently into deep-water basin	distributed mostly along west shore of inlet	shallow subtidal to 1m, wave agitated by land breezes
Subtidal mud basin	linear deep-water (1.5-2m) trough (200-1,000m wide); featureless vegetation-free horizontal muddy surface	distributed along entire length of centre of inlet	deep subtidal 1.5-2m; too deep for wave action

TABLE 2

BENTHIC FAUNA RECORDED FROM LESCHENAULT INLET *

MOLLUSCA	BIVALVIA	Anticorbula amara
		Arthritica semen
		Epicodakia sp.
		Mysella
		Mytilus edulis planulatus
		Sanguinolaria biradiata
		Spisula trigonella
		Tellina deltoidalis
		Tellina sp.
		Theora lubrica
		Venerupis anomala
		Venerupis sp.
		Xenostrobus securis
	GASTROPODA	Acteocina sp.
		Assiminea sp.
		Bedeva paivae
		Bembicium melanostromum
		Hydrococcus graniformis
		Nassarius burchardi
		Nassarius pauperatus
		Nassarius pyrrhus
		Potamopyrgus sp.
		Salinator fragilis
	POLYCHAETA	Capitella spp
		Ceratonereis erythraeensis
		Eunereid sp.
		Haploscoloplos kerguelensis
		Prionospio sp. 1
		Prionospio sp. 2
CRUSTACEA	AMPHIPODA	Corophium sp.
		Melita sp.
		Paracorophium sp.
	DECAPODA	Alpheus eurphrosyne
		Callianassa aequimona
		Cherax plebejus
		Cyclogrpsus audouinii
		Halicarcinus bedfordi
		Halicarcinus ovatus
		Leptograpsodes octodentatus
		Macrobranchium intermedium
		Macrophthalmus (Mopsocarcinus) sp.
		Palaemon serenus
		Palaeomonetes australis
		Portunus pelagicus
		Squilla laevis
INSECTA		HEMIPTERAN sp.
		CHIRONOMID larvae

* Sources: Meagher (1971); Poore & Griffin (1979); LeProvost, Semeniuk & Chalmer (1983); Chalmer & Scott (in press).

TABLE 3

PERCENTAGE COMPOSITION OF BENTHIC FAUNA IN LESCHENAULT INLET IN DECEMBER 1974

INLET BASIN				MARGINAL PLATFORM			
TAXONOMIC GROUP	%	COMMON SPECIES	%	TAXONOMIC GROUP	%	COMMON SPECIES	%
MOLLUSCA - BIVALVES	52	Arthritica semen	43	MOLLUSCA - BIVALVES	32	Arthritica semen	31
MOLLUSCA - GASTROPODS	1	-	-	MOLLUSCA - GASTROPODS	1	-	-
POLYCHAETES	45	Capitella spp Ceratonereis erythraeensis Haploscoloplos kerguelensis Prionospio spp	21 9 8	POLYCHAETES	35	Capitella spp Ceratonereis erythraeensis Haploscoloplos kerguelensis Prionospio spp	4 15 6 7
CRUSTACEA - AMPHIPODS	3	-	-	CRUSTACEA - AMPHIPODS	25	Corophium sp. Melita sp. Paracorophium sp.	6 2 17
				- OTHERS	8		
-	-	-	-	INSECTA	1	-	-
-	-	-	-	TURBELLARIA	1	-	-
-	-	-	-	NEMATODES	1	-	-

TABLE 4

AQUATIC FLORA OF LESCHENAULT INLET

SEAGRASSES

Amphibolis antarctica
Halophila ovalis
Heterozostera sp.
Posidonia australis
Ruppia maritima (= Ruppia megacarpa)
Zostera muelleri

ALGAE

CHLOROPHYTA

Acetabularia peniculus
Chaetomorpha linum
Cladophora sp.
Lamprothamnium palpulosum

PHAEOPHYTA

Ectocarpus spp (epiphyte)
Unid. species

RHODOPHYTA

Chondria sp.
Gracilaria confertoides

Acrochaetium thurettii)
Callithamnion spp)
Ceramium spp) epiphytes
Spyridia spinella)

TABLE 5

BIOMASS OF AQUATIC VEGETATION IN LESCHENAULT INLET

LOCATION	TOTAL BIOMASS (gm dry wt per $625cm^2$)	*Halophila* %	*Ruppia* %	Algae %
Area 1	1.39	43	51	6
Area 2	5.08	95	2	3
Area 3	4.35	26	1	73
Area 4	0	-	-	-

TABLE 6

THE BIOTIC ASSEMBLAGES OF LOW TIDAL AND SUBTIDAL LESCHENAULT INLET

ASSEMBLAGE	MOST ABUNDANT SPECIES	OCCURRENCE
Hydrococcus	*Hydrococcus*, various sand-dwelling polychaetes	tidal sand
Halophila	*Halophila ovalis* *Ruppia maritima* *Gracilaria confertoides* *Chaetomorpha linum* *Tellina deltoidalis* *Nassarius burchardi* *Bedeva paivae* *Arthritica semen* crustaceans polychaetes	subtidal marginal shoals and platforms
Tellina	*Tellina deltoidalis* *Nassarius burchardi* *Spisula trigonella*	mud basin

<u>TABLE 7</u>

COMPARISON OF DENSITIES OF BENTHIC FAUNA FROM VARIOUS LOCATIONS IN SOUTHWESTERN AUSTRALIA

PARAMETERS	ABUNDANCE OF BENTHIC FAUNA PER $0.1m^2$															
	OPEN SEA		EMBAYMENT			ESTUARY										
	Offshore from Koombana Bay	Sepia Depression	Koombana Bay	Cockburn Sound		Leschenault Inlet				Peel Inlet/ Harvey Estuary		Hardy Inlet	Swan River		
DATE	1982	1981	1982	Feb. 1978		Dec. 1974		May 1982		Dec. 1974		July 1974 to May 1975	March 1977		
Source	LeProvost, Semeniuk & Chalmer (1983)	LeProvost, Semeniuk & Chalmer (1981)	LeProvost, Semeniuk & Chalmer (1983)	Wells (1978)		Chalmer & Scott (1983)		LeProvost, Semeniuk & Chalmer (1983)		Chalmer & Scott (1983)		Wallace (1979) (Table 3)	Wallace (1977) (Table 5)		
Sample Area	$0.1m^2$	$0.1m^2$	$0.1m^2$	$0.1m^2$		$0.008-0.040m^2$		$0.008-0.063m^2$		$0.008-0.040m^2$		$0.008-0.04m^2$	$0.0038-0.09m^2$		
Sieve Size	1mm	1mm	1mm	1.7mm		1mm		1mm		1mm		1mm	1mm		
Substrate	sand	sand	sand-mud	sand-mud	mud	sand	mud	sand	mud	sand	mud	sand/mud	sand	mud-sand	mud
Depth	5-15m	15-20m	3-10m	0.10m	10-20m	0.1m	1-2m	0.1m	1.2m	0.1m	1-2m	2m	0.1m	1-3m	>3m
Number	10	110	30	39	51	18	4	35	20	26	4	252	35	30	75
Mean no. of benthic fauna per $0.1m^2$	0.7	5.6	36	14.8	46.4	1,713	538	536	1,131	3,625	438	1,026	1,218	612	80

TABLE 8

WEIGHT AND VALUE OF FISH CAUGHT BY PROFESSIONAL FISHERMEN IN LESCHENAULT INLET FOR THE PERIOD 1952-1974

Average catch weights are derived from Lenanton (in press) and the values are derived from Australian Bureau of Statistics (ABS) figures for 1981/82. Note that the ABS figures are based on the value throughout Western Australia and not just for Leschenault Inlet where local marketing may vary the value of the fish.

Species	Average annual catch weight (1952-1975) kg	Estimated value (1981/82, ABS) $
Wet fish		
Cobbler	24,400	73,932
Yelloweye mullet	33,418	20,056
Sea mullet	16,616	14,622
Western sand whiting	5,329	7,620
King George whiting	4,128	7,595
Tailor	5,093	3,922
Mullet (mixed species)	3,356	2,349
Perth herring	5,057	1,972
Black bream	660	1,293
Skipjack trevally	2,081	1,935
Whiting (mixed species)	538	807
Australian herring	1,649	745
Sea garfish	408	587
Other wet fish	550	550
Skates, rays	150	105
Yellowtail perch	39	98
Tarwhine	93	93
Mulloway	455	91
Dusky flathead	24	36
Trumpeter whiting	8	11
Blue mackeral	3	6
Flounder	11	2
		138,427
Crustaceans		
Blue-manna crabs	7,410	15,783
Prawns	272	666
		16,449
		154,876

TABLE 9

DIET OF COMMERCIAL SPECIES OF FISH IN LESCHENAULT INLET

SPECIES OF FISH		PRINCIPAL ITEMS OF DIET					
COMMON NAME	SCIENTIFIC NAME	BENTHIC FAUNA	ALGAE	AQUATIC ANGIO-SPERMS	FISH	ORGANIC DETRITUS	OTHER
Perth Herring	*Nematalosa vlaminghi*	.	.	.	.	x	.
Cobbler	*Cnidoglanis macrocephalus*	x	x	.	.	.	.
Sea Garfish	*Hyporhamphus melanochir*	.	x	x (*Ruppia*, *Zostera*)	.	.	x (Diatoms)
Flathead	*Platycephalus* sp.	x	.	.	x	.	.
King George Whiting	*Sillaginodes punctatus*	x	.	.	.	.	.
Yellow-finned Whiting	*Sillago schomburgkii*	x x	. .	. .	. .	. .	. .
Tailor	*Pomatomus saltatrix*	x	.	(?*Ruppia*)	x	.	.
Skipjack Trevally	*Pseudocaranx* spp	x	.	.	x	x	.
Australian	*Arripis georgianus*	x	.	.	x	.	.
Australian Salmon	*Arripis trutta*	x	.	(?*Zostera*)	x	.	.
Black Bream	*Acanthopagrus butcheri*	x	.	.	x	x	.
Silver Bream	*Rhabdosargus sarba*	x	.	.	x	x	.
Mulloway	*Argyrosomus hololepidotus*	x	.	.	x	.	.
Yelloweye Mullet	*Aldrichetta forsteri*	x	x	x	.	x	.
Sea Mullet	*Mugil cephalus*	.	.	.	.	x	.
Small-toothed Flounder	*Pseudorhombus jenynsii*	x	.	.	x	.	.
Elongate Flounder	*Ammotretis elongatus*	x	.	.	x	x	.

TABLE 10

DIET OF NON-COMMERCIAL SPECIES OF FISH IN LESCHENAULT INLET

SPECIES OF FISH		PRINCIPAL ITEMS OF DIET				
COMMON NAME	SCIENTIFIC NAME	BENTHIC FAUNA	ALGAE	AQUATIC ANGIO-SPERMS	FISH	ORGANIC DETRITUS
Smooth Stingray	Dasyatis brevicaudata	x	.	.	.	.
Sandy Sprat	Hyperlophus vittatus	x (?Plankton)	.	.	.	.
Blue Sprat	Spratelloides robustus	x (?Plankton)	.	.	.	.
Southern Anchovy	Engraulis australis	x (?Plankton)	.	.	.	.
Hardyhead	Atherinosoma spp	x	.	.	.	x
Red Butterfly Gurnard	Chelidonichthys kumu	x	.	.	x	.
Yellowtail Trumpeter	Amniataba caudavittatus	x	x	.	x	.
Striped Trumpeter	Pelates sexlineatus	.	x	x	.	x
Silverbelly	Gerres subfasciatus	x	.	.	.	.
Pink Snapper	Chrysophrys unicolor	x	.	.	.	.
Old Wife	Enoplosus armatus	x	.	.	.	.
Blue Rock Whiting	Neoodax semifasciata	x	.	.	.	.
Bridled Goby	Amoya bifrenatus	x	x	x	x	x
Long-finned Goby	Favonogobius lateralis	x	.	.	.	x
South-west Goby	Favonogobius suppositus	x	.	.	.	x
Blue-spot Goby	Pseudogobius olorum	x	x	.	.	x
Prickly Pufferfish	Contusus richei	x	.	.	.	x
Common Blowfish	Torquigener pleurogramma	x	.	(?Ruppia)	.	.

TABLE 11

TYPES OF EFFLUENT LEAKAGES INTO LESCHENAULT INLET

TYPE OF LEAKAGE	TYPE OF EFFLUENT	POTENTIALLY HARMFUL COMPONENT
Break in pipe; overflow of pond	raw, undiluted acidic effluent	sediment acidity Fe^{++} content heavy metals radioactive elements
Subterranean seepage	clarified, diluted neutral effluent	? heavy metals ? radioactive elements

TABLE 12

DESCRIPTION OF LEAKAGES OVER THE PERIOD
JANUARY 1974 to JUNE 1983 AT
SITES SAMPLED FOR BENTHIC BIOTA

Sample Area (Fig.1)	Discharge Date	Location of Discharge	Type of discharge to Leschenault Inlet	Volume m^3
1	09.06.1976	Causeway (230m)	Direct spillage	150
	14.04.1978	Australind shore	Flow under road	50
	16.05.1979	Causeway (250m)	Direct spillage	150
	31.08.1981	Australind shore	Seepage	150
	12.09.1981	Australind shore	Seepage	150
	09.10.1981	Australind shore	Seepage	150
2	Prior to 1974	Causeway	Direct spillage	not documented
	05.02.1980	Causeway (expansion joint no. 13)	Direct spillage	0
3	March 1981-November 1982 (sporadic)	Leschenault Peninsula	Seepage	unknown
4	19.03.1976	Causeway (2576m)	Direct spillage	300
	28.06.1977	Causeway (2576m)	Direct spillage	300
	15.08.1977	Causeway (2400m)	Direct spillage	300
	22.02.1978	Causeway (2572m)	Direct spillage	300
	28.07.1978	Causeway (2496m)	Direct spillage	300
	04.05.1979	Causeway (2500m)	Direct spillage	300
	18.06.1979	Causeway (2394m)	Direct spillage	300
	24.07.1979	Causeway (2394m)	Direct spillage	300
	23.08.1979	Causeway (2496m)	Direct spillage	300

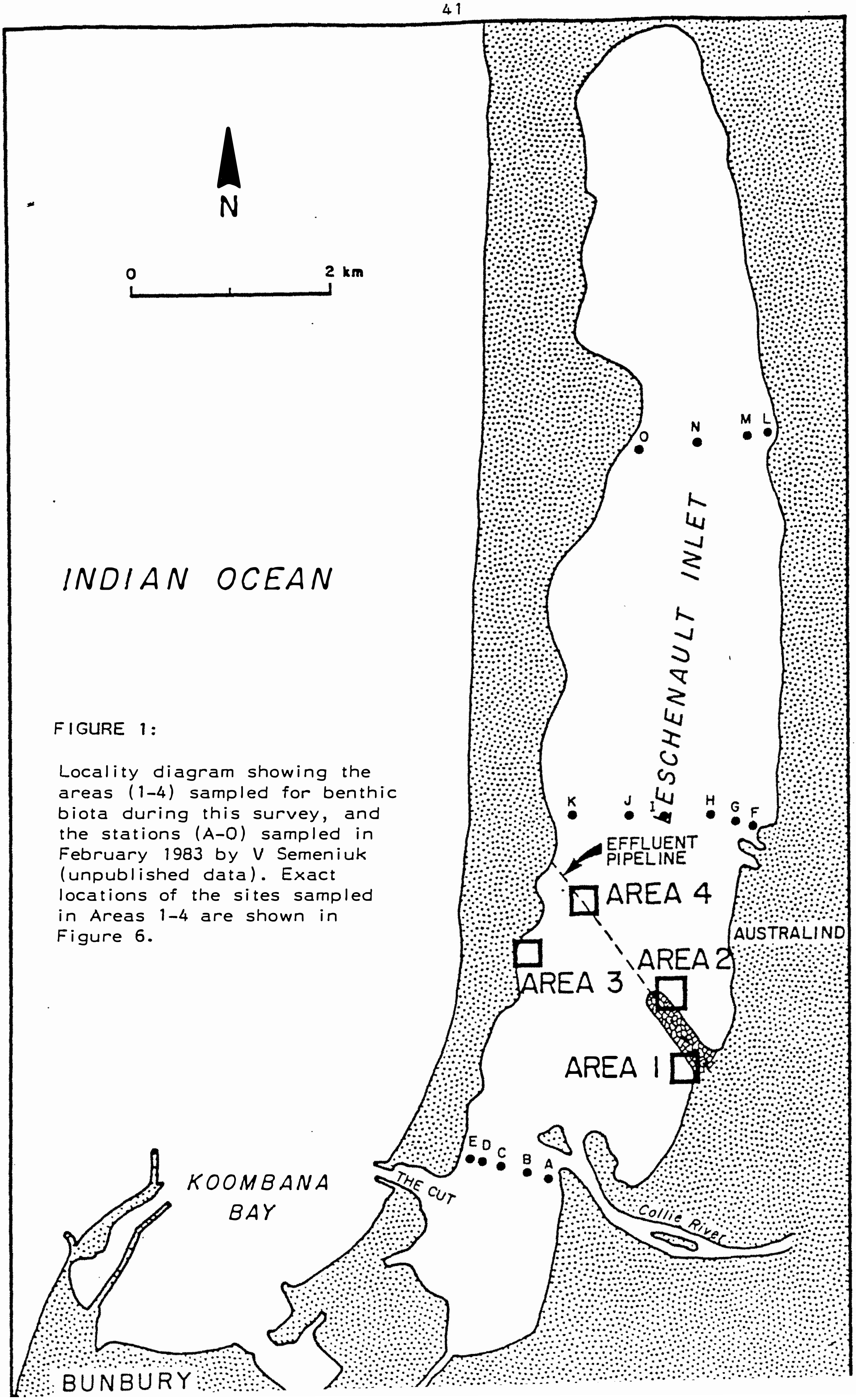


FIGURE 1:

Locality diagram showing the areas (1-4) sampled for benthic biota during this survey, and the stations (A-O) sampled in February 1983 by V Semeniuk (unpublished data). Exact locations of the sites sampled in Areas 1-4 are shown in Figure 6.

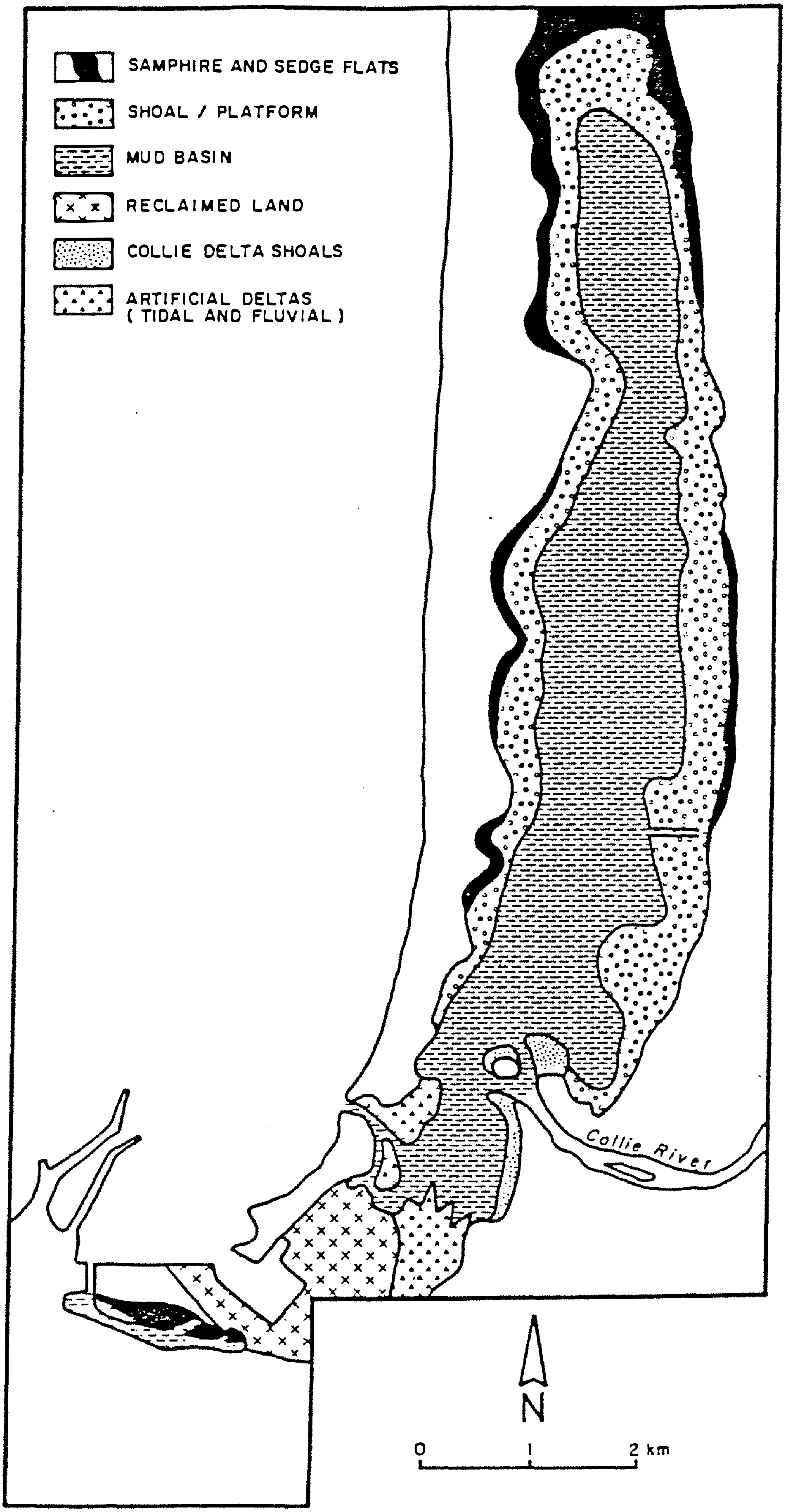


FIGURE 2: Habitats of Leschenault Inlet.

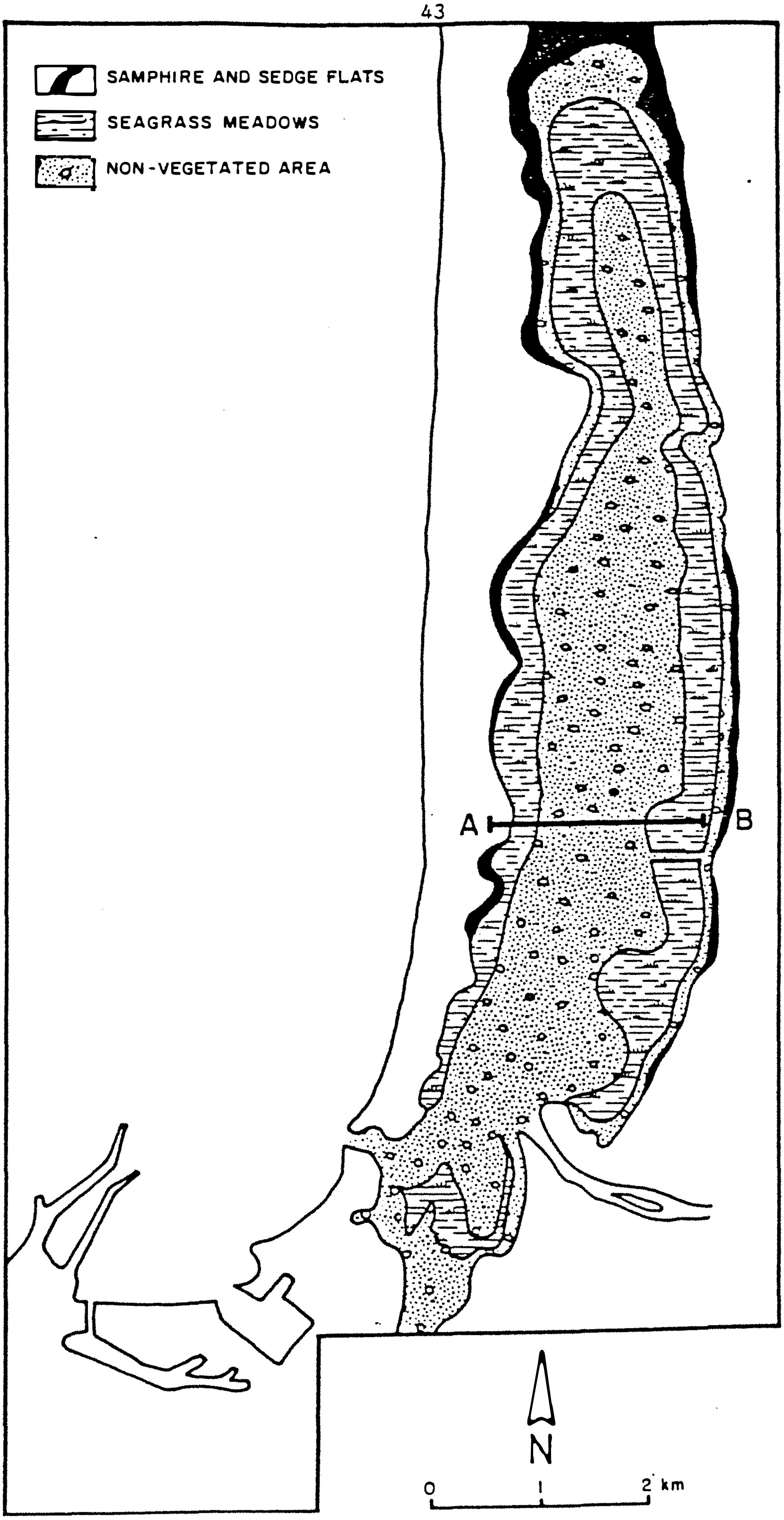


FIGURE 3: Distribution of seagrasses (Halophila and Ruppia) in Leschenault Inlet. The biomass of seagrasses and algae on the transect A-B is shown in Figure 4.

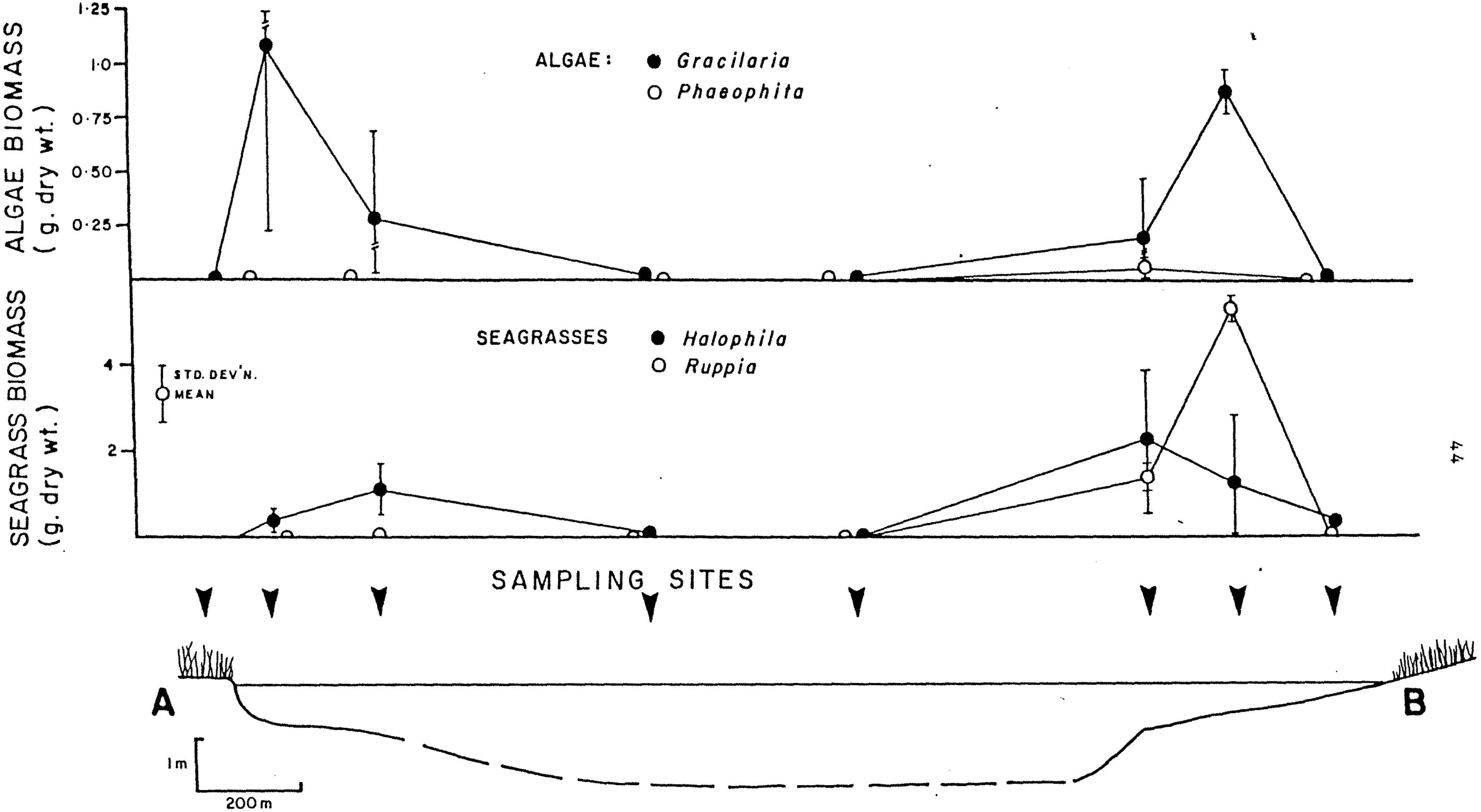
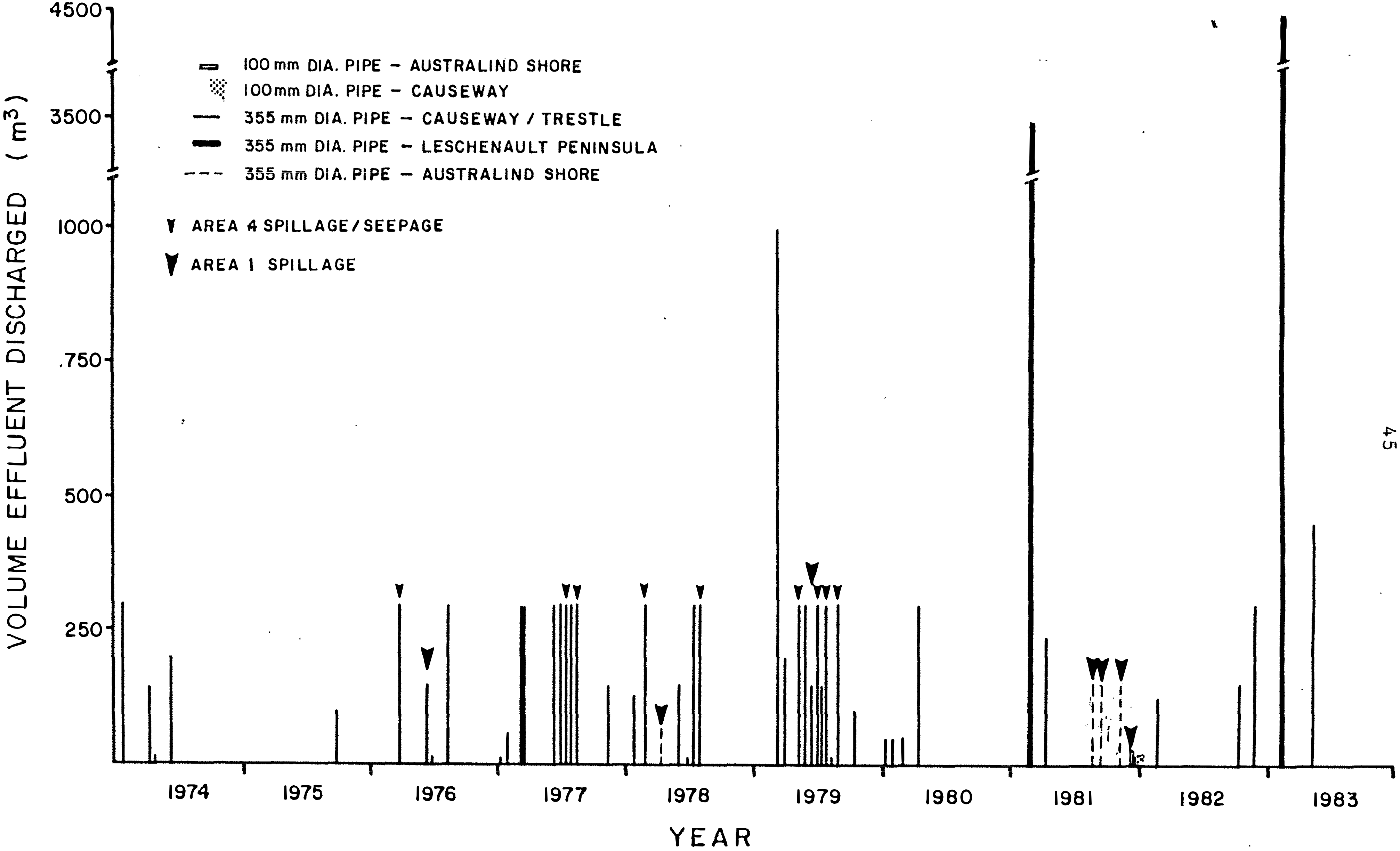


FIGURE 4: Biomass of vegetation in Leschenault Inlet. The location of the transect A-B is shown in Figure 3.



100 mm DIA. PIPE – AUSTRALIND SHORE
100mm DIA. PIPE – CAUSEWAY
355 mm DIA. PIPE – CAUSEWAY / TRESTLE
355 mm DIA. PIPE – LESCHENAULT PENINSULA
355 mm DIA. PIPE – AUSTRALIND SHORE
AREA 4 SPILLAGE/SEEPAGE
AREA 1 SPILLAGE
VOLUME EFFLUENT DISCHARGED (m3)
4500
3500
1000
.750
500
250
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
YEAR

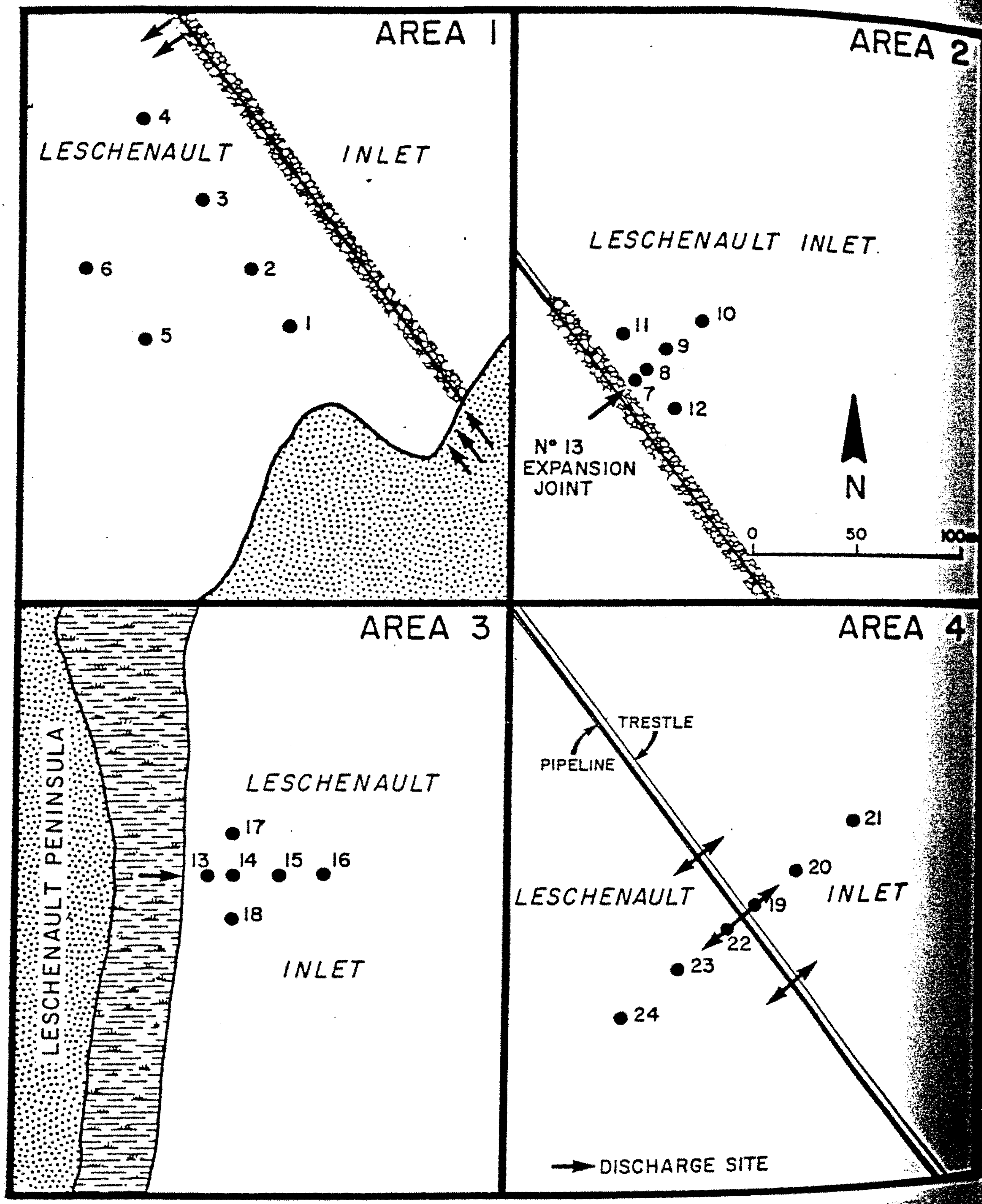


FIGURE 6: Location of the stations sampled for benthic biota. The general location of each area is shown in Figure 1.

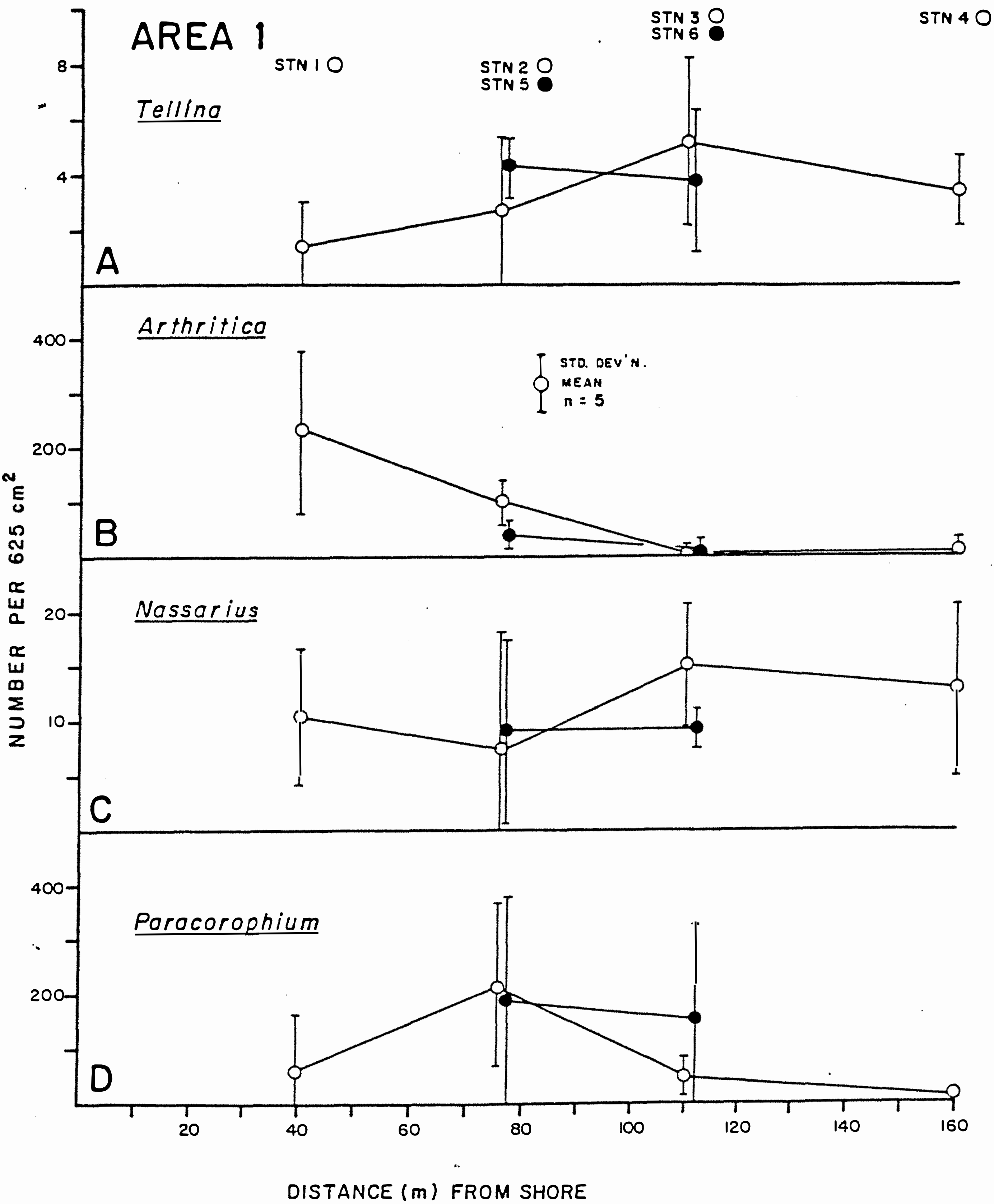


FIGURE 7: Abundance of benthic biota in Area 1.

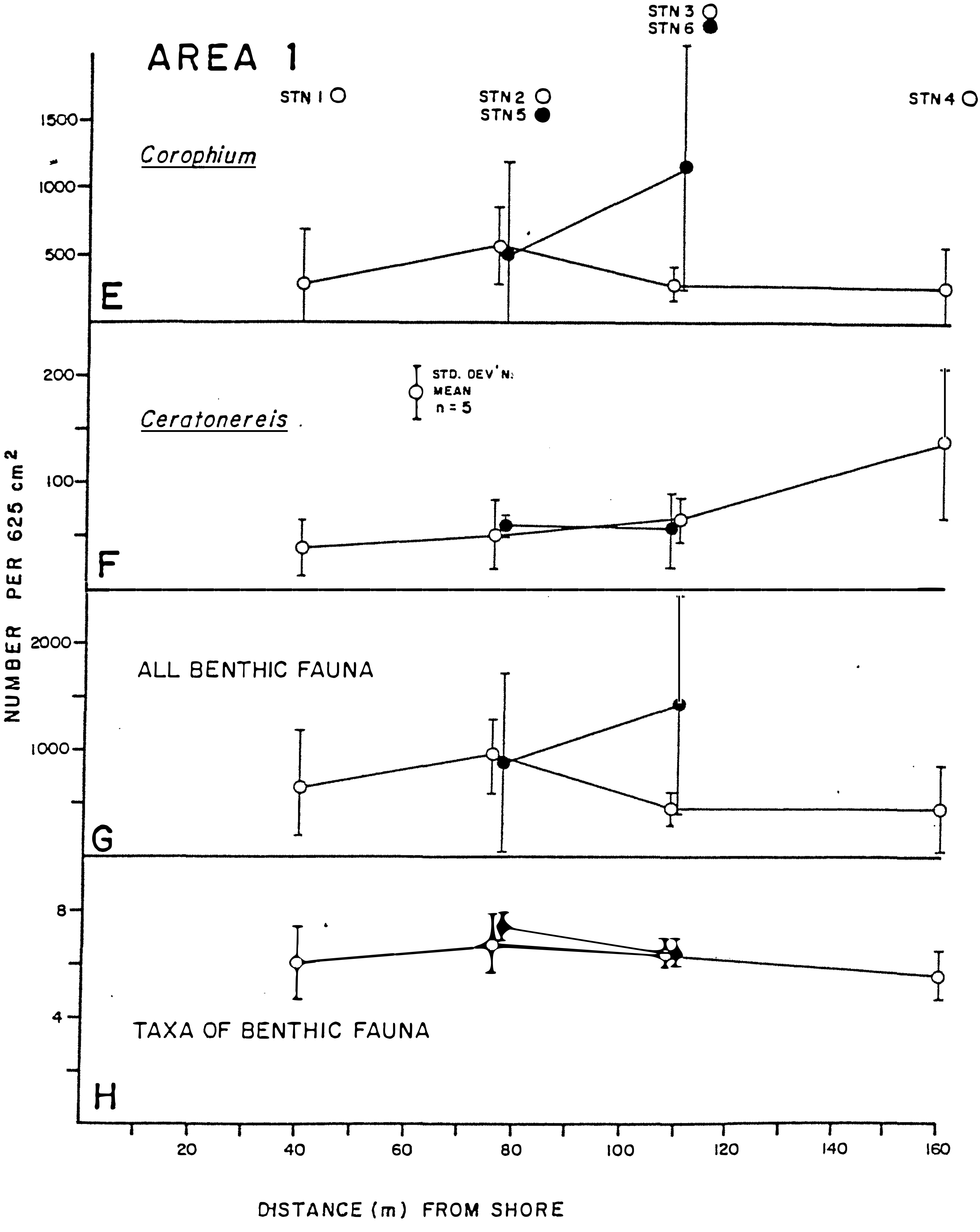


FIGURE 7 (cont'd): Abundance of benthic biota in Area 1.

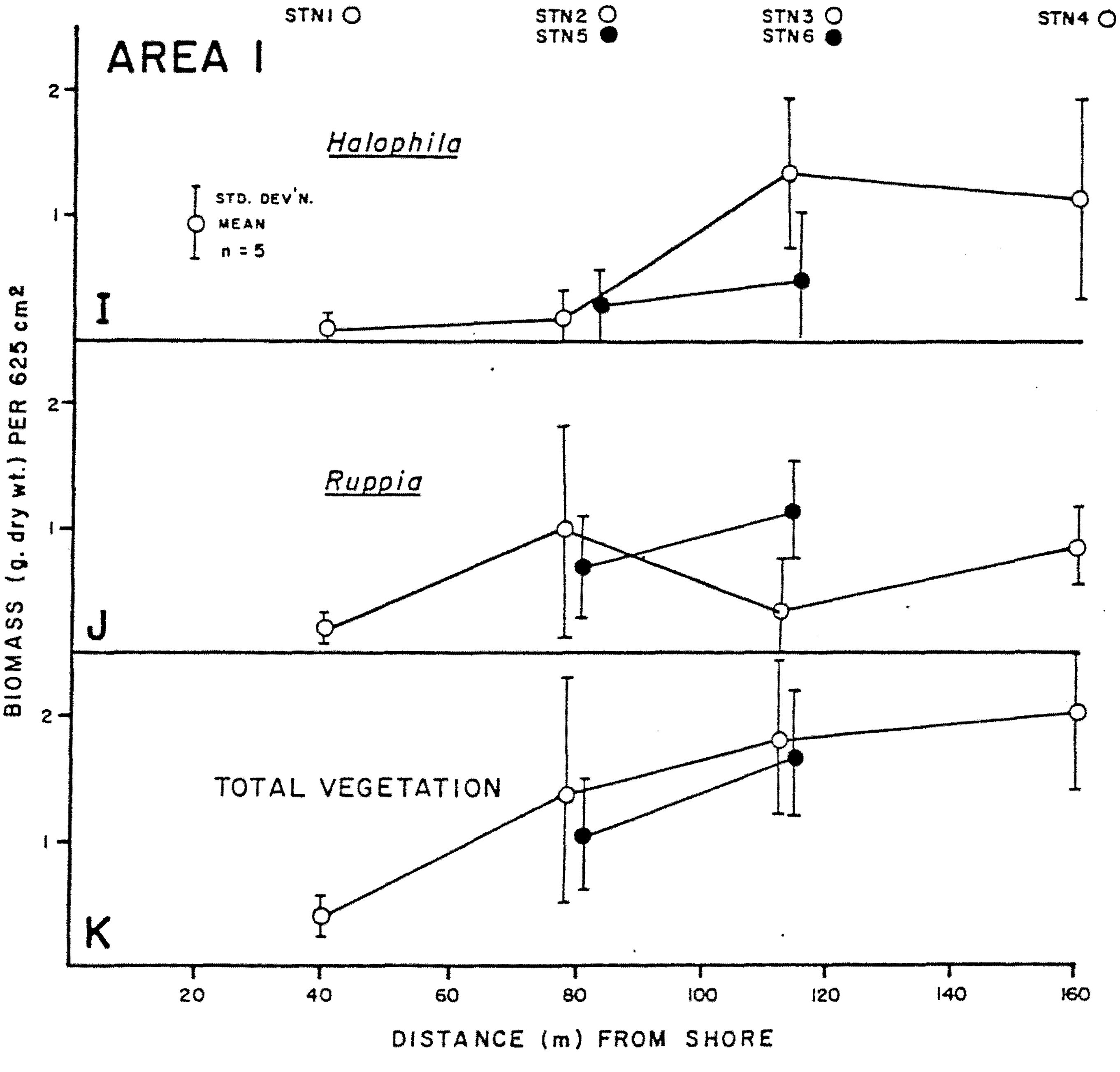


FIGURE 7 (cont'd): Abundance of benthic biota in Area 1.

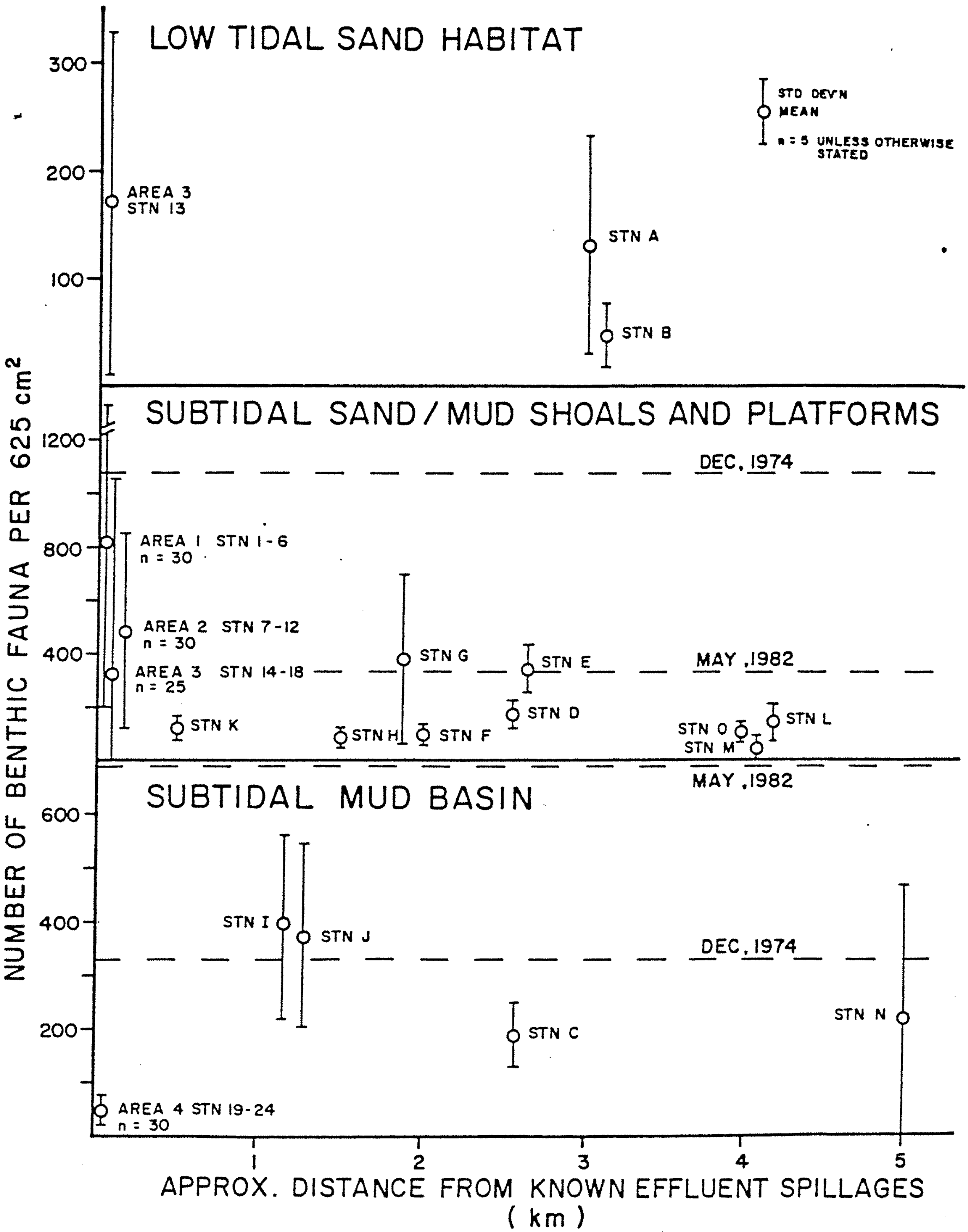


FIGURE 8: Abundance of benthic fauna at effluent leakage locations compared with that recorded during previous surveys in December 1974 (Chalmer & Scott, in press), May 1982 (LeProvost, Semeniuk & Chalmer, 1983), and February 1983 (V. Semeniuk, unpublished data) at sites distant to known effluent leakages. Locations of the sampling stations are shown in Figure 1.

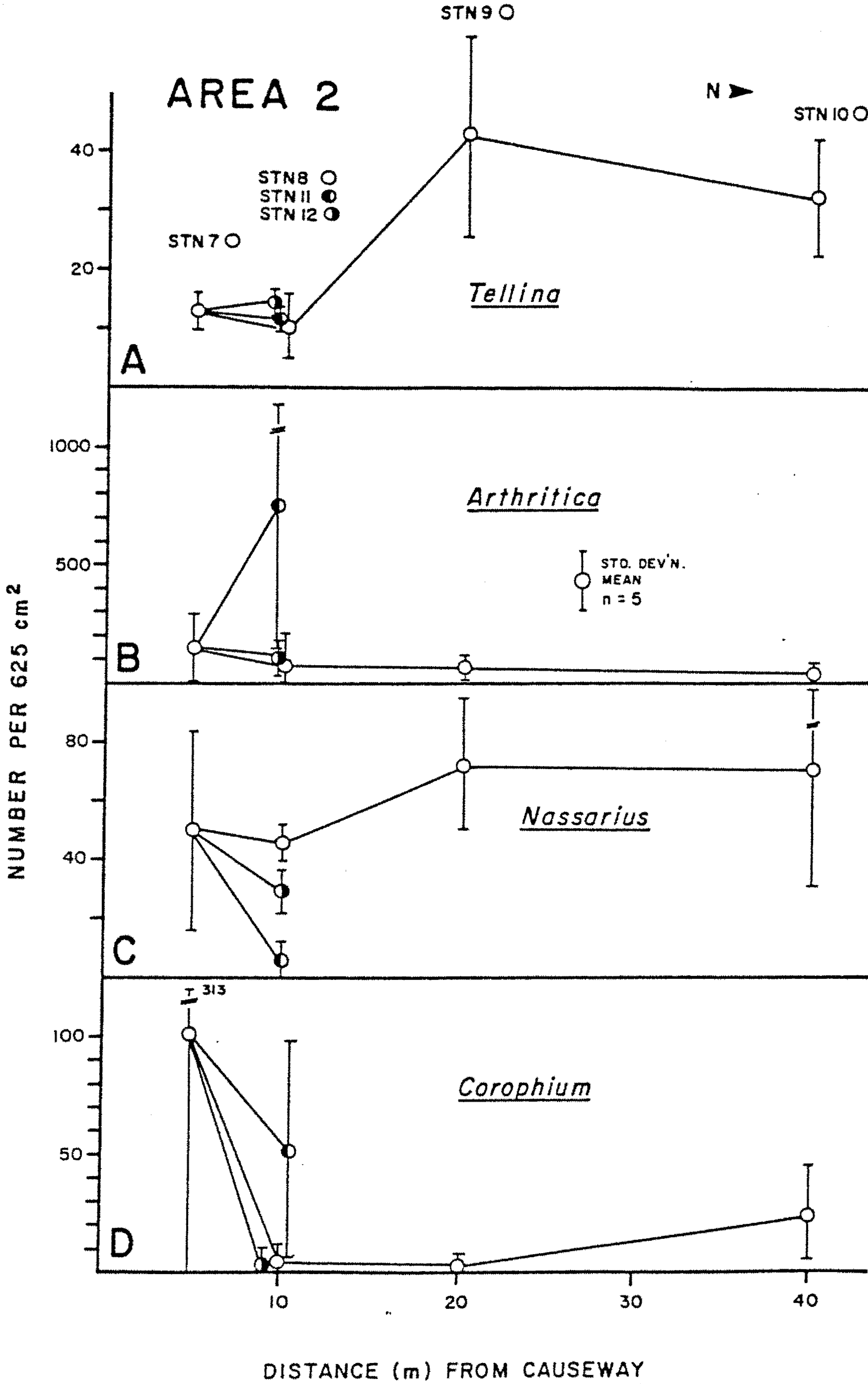


FIGURE 9: Abundance of benthic biota in Area 2.

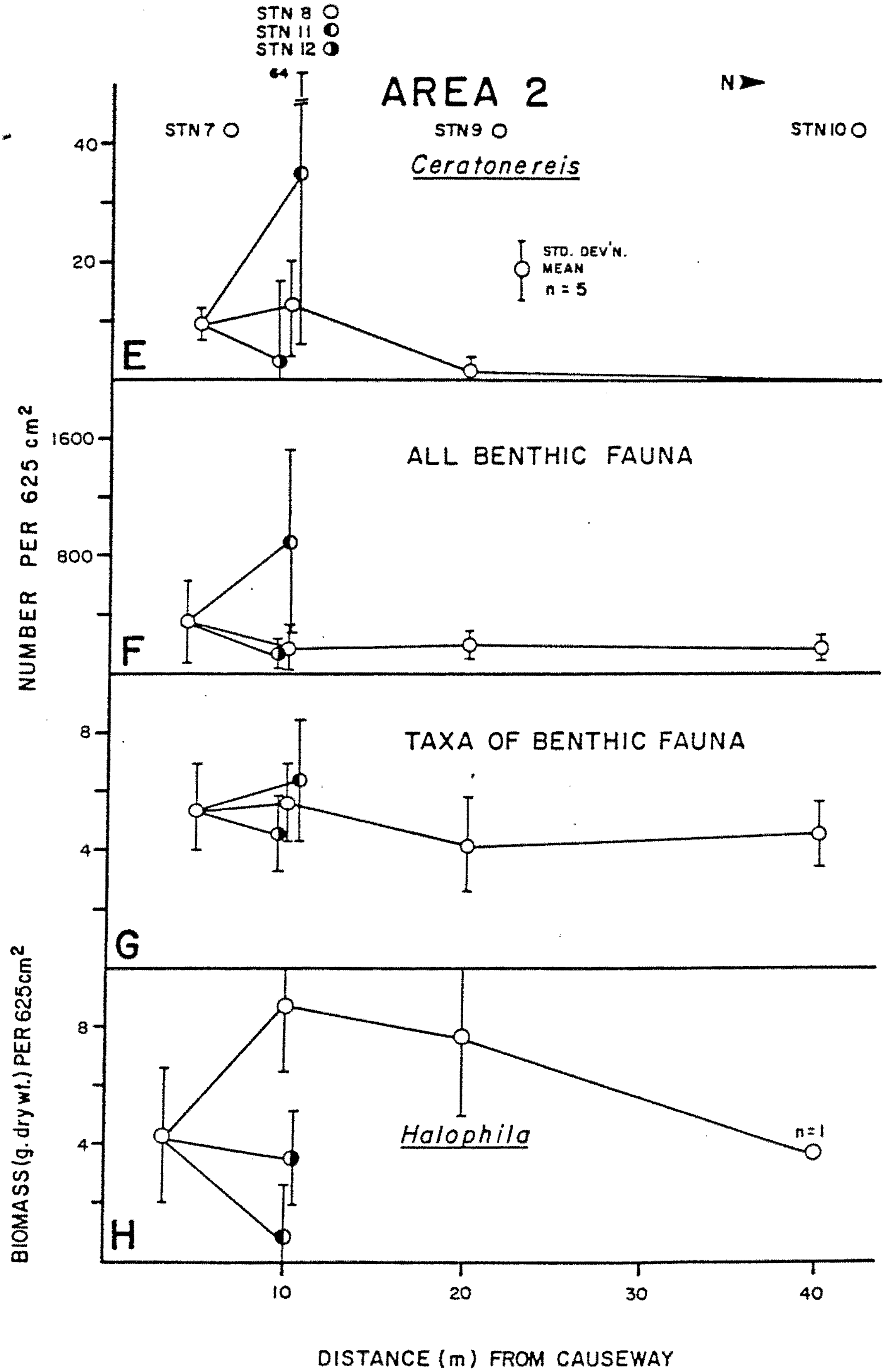


FIGURE 9 (cont'd): Abundance of benthic biota in Area 2.

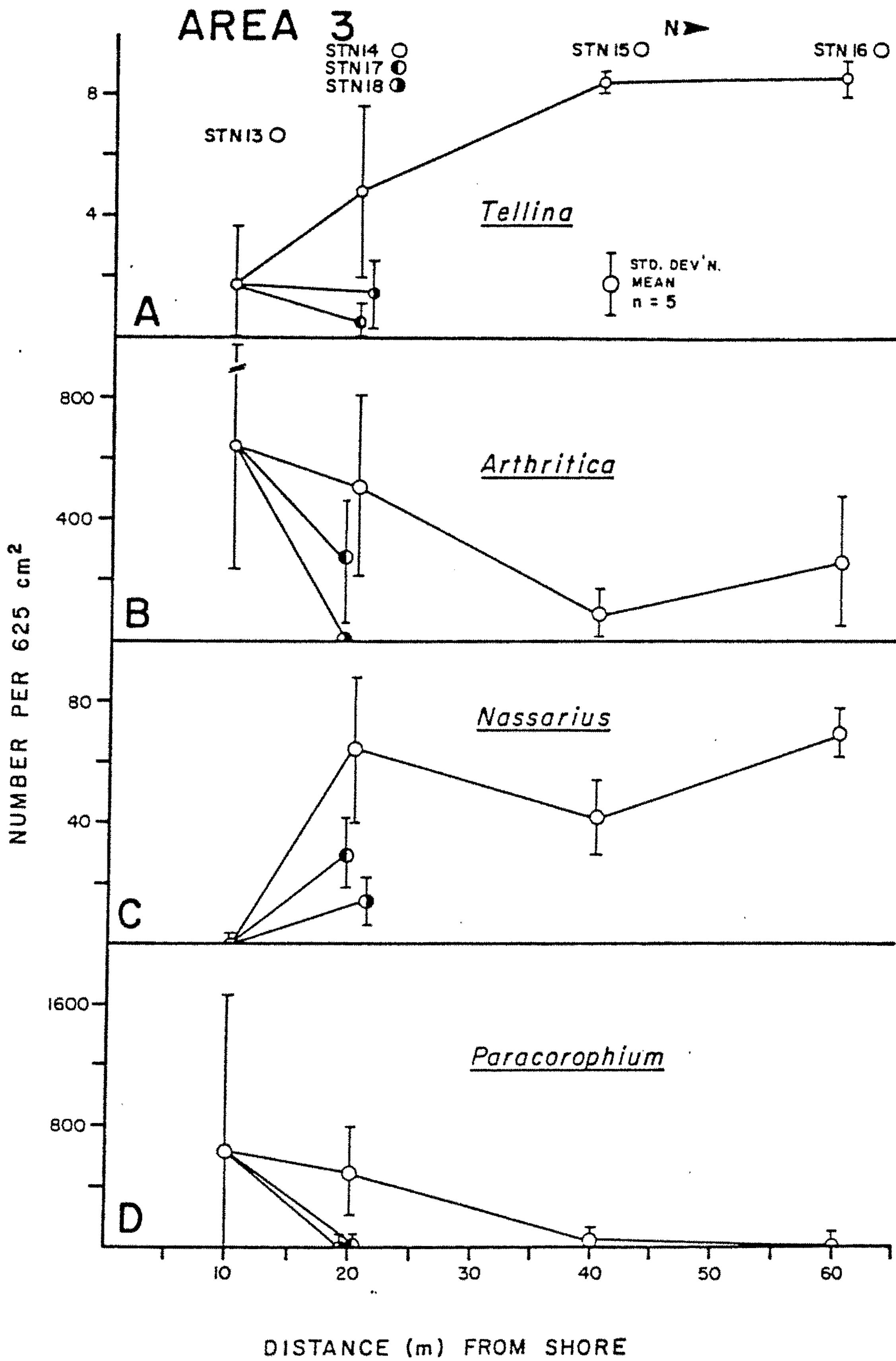


FIGURE 10: Abundance of benthic biota in Area 3.

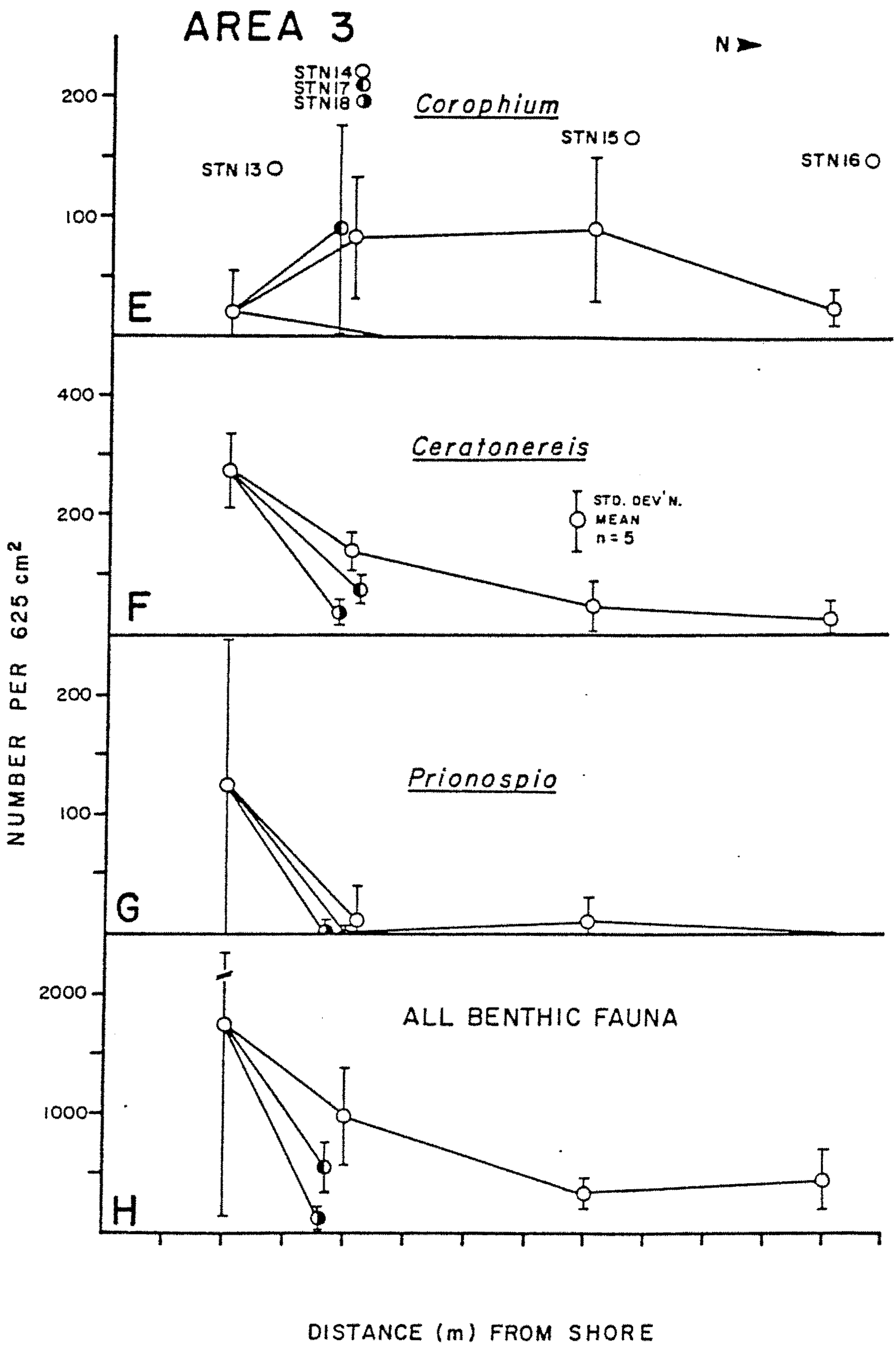


FIGURE 10 (cont'd): Abundance of benthic biota in Area 3.

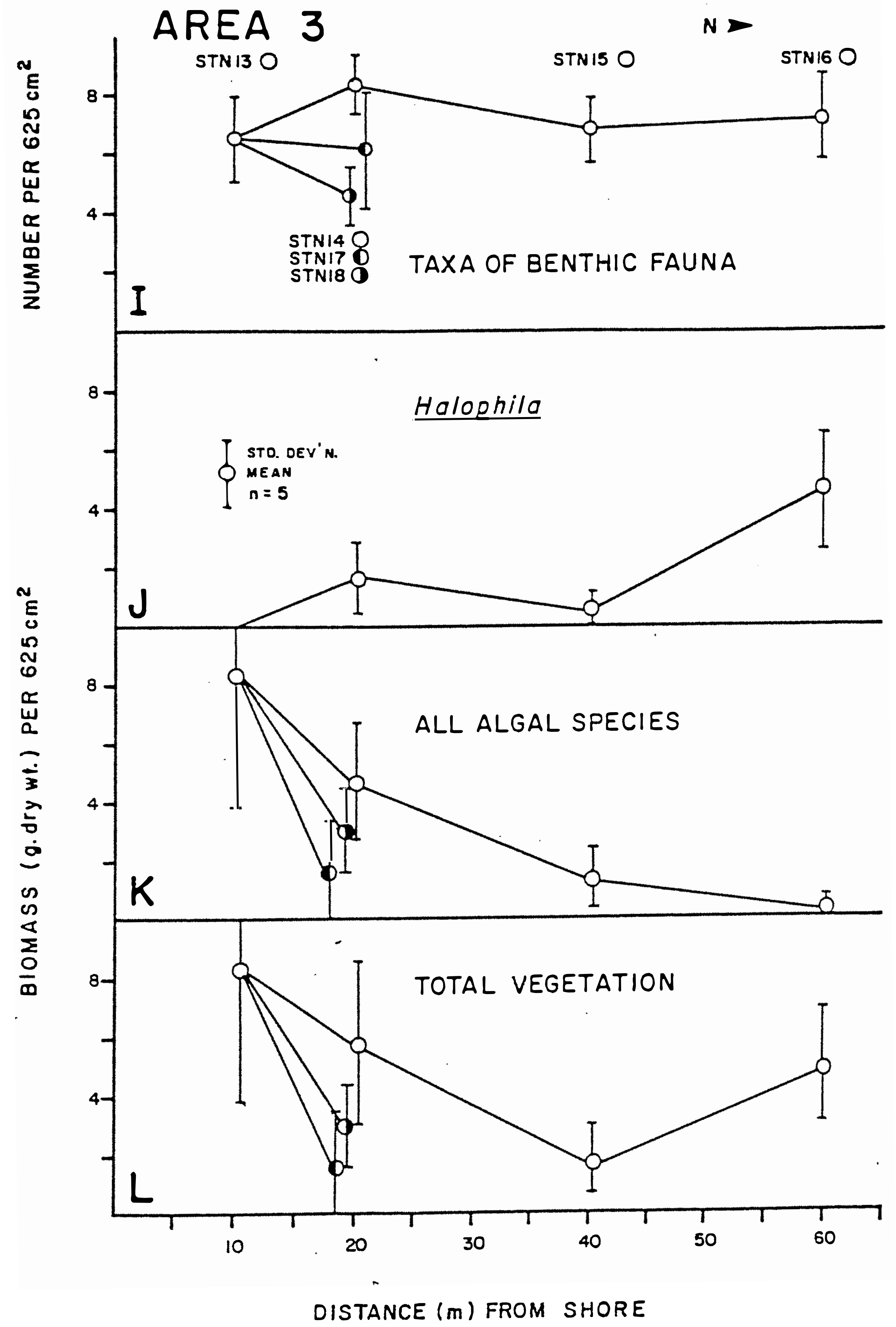


FIGURE 10 (cont'd): Abundance of benthic biota in Area 3.

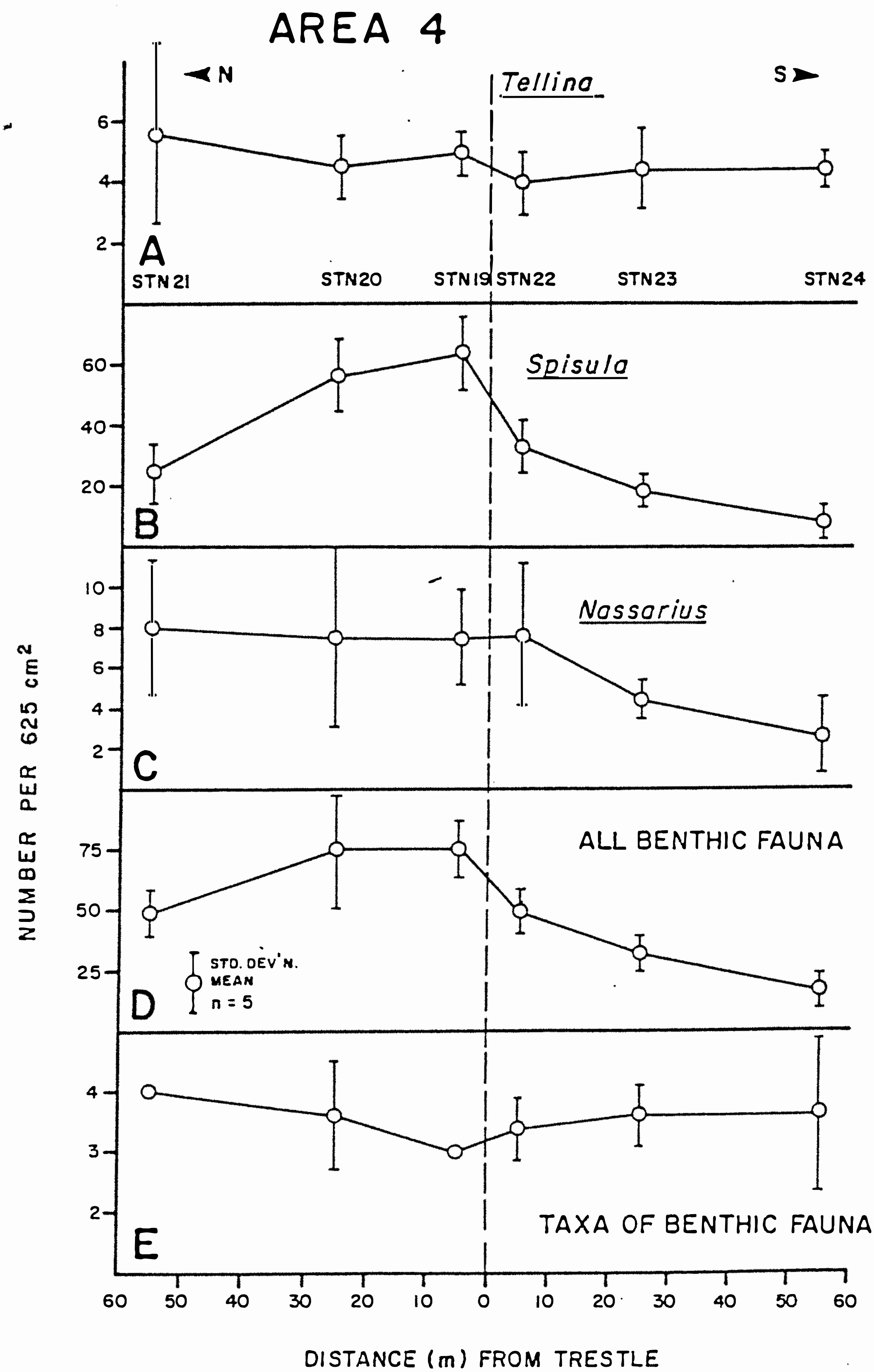
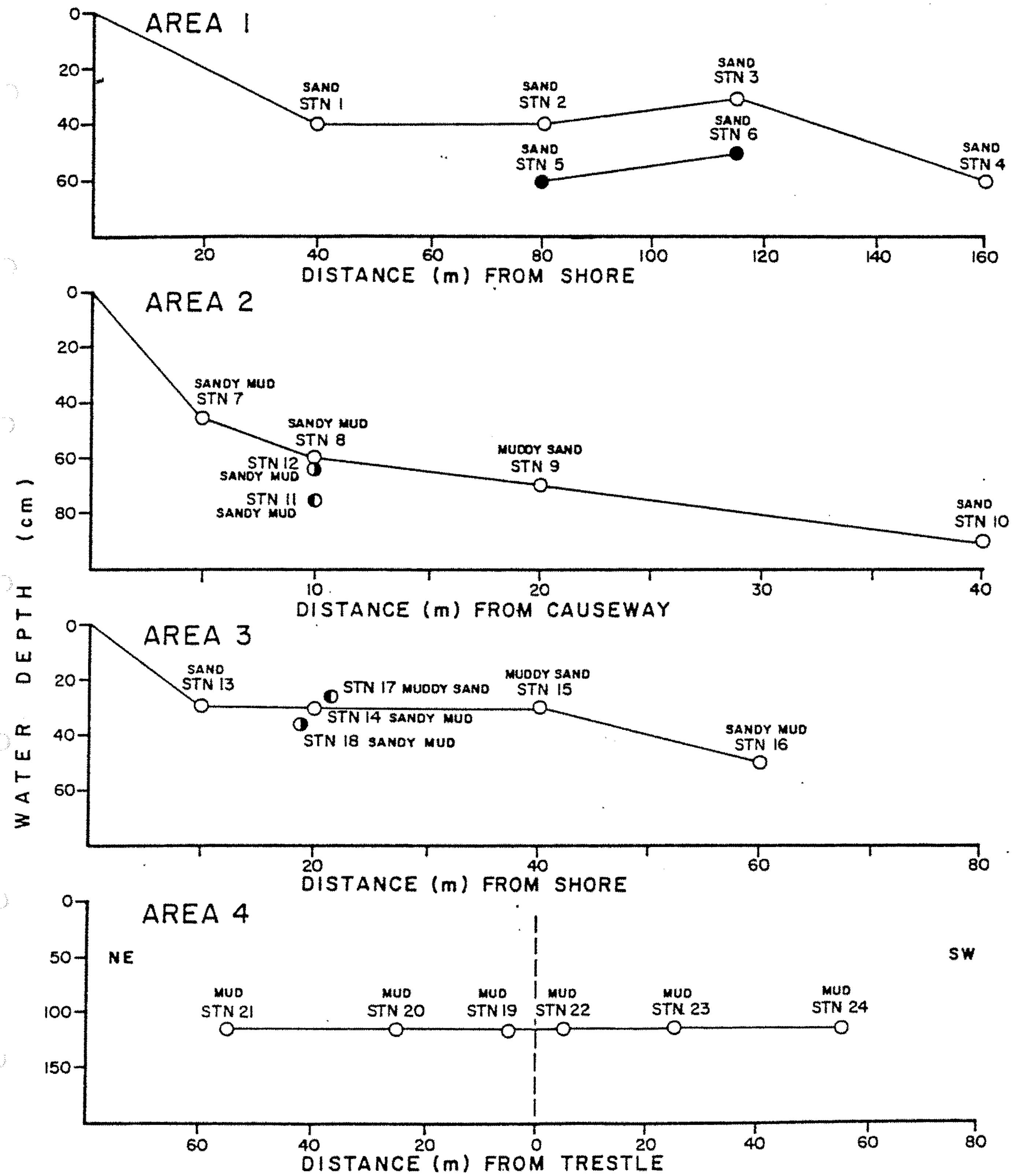


FIGURE 11: Abundance of benthic biota in Area 4.

APPENDIX 1



Depths and substrate types at the sampling locations. Locations of the sampling sites are shown in Figures 1 and 6.

APPENDIX 2

BENTHIC FAUNAL DENSITIES AT THE SAMPLING LOCATIONS
Locations of the sampling stations are shown in Figures 1 and 6

List of Species

BIVALVE MOLLUSCS

Arthritica semen
Sanguinolaria biradiata
Spisula trigonella
Tellina deltoidalis

GASTROPOD MOLLUSCS

Bedeva paivae
Hydrococcus graniformis
Nassarius burchardi

POLYCHAETES

Capitella spp
Ceratonereis erythraeensis
Diopatra sp.
Prionospio spp
Scoloplos kerguelensis
Polychaete spp

AMPHIPOD CRUSTACEANS

Corophium sp.
Melita sp.
Paracorophium sp.

OTHER CRUSTACEANS

Caprellid sp.
Halicarcinus sp.
Isopod sp.
Penaeus latisulcatus

FISH

Favonogobius lateralis

NUMBER OF FAUNA PER SAMPLE

AREA		1														
STATION		1					2					3				
REPLICATE		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Tellina deltoidalis	Sample area = 625cm²	4	1	.	.	.	3	1	1	7	2	9	2	2	6	7
Spisula trigonella		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nassarius burchardi		12	16	17	3	5	.	2	27	4	4	21	8	12	20	17
Bedeva paivae		.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Diopatra sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Penaeus latisulcatus		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Favonogobius lateralis		.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Sanguinolaria biradiata	Sample area = 80cm²	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Arthritica semen		15	34	59	15	25	7	19	13	15	9	3	.	.	2	.
Hydrococcus graniformis		.	.	1	.	.	.	1	1	.	.	.	.	.	1	.
Capitella spp		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ceratonereis erythraeensis		1	3	8	9	4	2	13	7	5	6	4	10	7	10	10
Prionospio spp		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scoloplos kerguelensis		.	.	1	.	.	.	.	.	1	1	.	.	.	.	.
Polychaete spp		.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Paracorophium sp.		.	22	1	16	.	24	21	4	32	50	1	10	5	12	4
Corophium sp.		3	100	13	52	7	84	78	21	122	52	21	22	59	45	39
Melita sp.		.	.	.	1	.	.	.	.	.	.	.	.	1	.	.
Isopod sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Caprellid sp.		.	3	.	.	.	.	.	.	.	.	.	.	.	.	.
Halicarcinus sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

AREA	STATION	REPLICATE	NUMBER OF FAUNA PER SAMPLE																			
			Sample area = $625 cm^2$							Sample area = $80 cm^2$												
			Tellina deltoidalis	Spisula trigonella	Nassarius burchardi	Bedeva paivae	Diopatra sp.	Penaeus latisulcatus	Favonogobius lateralis	Sanguinolaria biradiata	Arthritica semen	Hydrococcus graniformis	Capitella spp	Ceratonereis erythraeensis	Prionospio spp	Scoloplos kerguelensis	Polychaete spp	Paracorophium sp.	Corophium sp.	Melita sp.	Isopod sp.	Caprellid sp.	Halicarcinus sp.
1	4	1	4	.	14	.	.	.	.	.	1	.	.	29	.	.	.	1	82	.	.	.	.
		2	1	.	2	.	.	.	.	.	5	.	.	26	.	.	.	6	72	3	.	.	.
		3	4	.	11	.	.	.	.	.	3	.	.	11	.	.	.	.	4	.	.	.	.
		4	4	.	24	.	.	.	.	.	.	.	.	8	.	.	.	2	2	.	.	.	.
		5	4	.	15	.	.	.	.	.	.	.	.	14	.	.	.	.	13	2	.	.	.
	5	1	6	.	3	.	.	.	.	.	1	3	.	7	.	.	.	22	84	.	.	.	.
		2	4	.	19	.	.	.	.	.	3	1	.	8	.	.	.	2	5	.	.	.	.
		3	4	.	4	1	.	1	.	.	10	4	.	7	.	.	.	61	202	.	.	.	.
		4	4	.	18	1	.	.	.	.	3	.	.	7	.	.	.	3	11	.	.	.	.
		5	3	.	2	.	.	.	.	.	7	.	.	9	.	.	.	33	45	2	.	.	.
	6	1	3	.	10	.	.	1	.	.	.	.	.	2	.	.	.	10	46	.	.	.	.
		2	7	.	7	.	.	.	.	.	1	.	.	6	.	.	.	16	16	1	.	.	.
		3	5	.	10	.	.	.	.	.	3	.	.	8	.	.	.	32	276	2	.	.	.
		4	0	.	11	.	.	.	.	.	5	.	.	12	8	.	.	27	239	.	.	.	.
		5	4	.	11	.	.	.	.	.	.	.	.	10	1	.	.	12	157	.	.	.	.

NUMBER OF FAUNA PER SAMPLE

AREA		2														
STATION		7					8					9				
REPLICATE		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Sample area = 625cm^2	Tellina deltoidalis	12	14	11	15	16	8	10	8	7	20	40	39	55	47	37
	Spisula trigonella	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Nassarius burchardi	64	40	18	22	101	57	46	47	39	45	66	61	109	80	49
	Bedeva paivae	.	.	.	.	.	.	.	.	.	2	.	.	.	2	.
	Diopatra sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Penaeus latisulcatus	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Favonogobius lateralis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sample area = 80cm^2	Sanguinolaria biradiata	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Arthritica semen	3	22	13	8	49	3	10	4	.	38	9	5	17	10	.
	Hydrococcus graniformis	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
	Capitella spp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Ceratonereis erythraeensis	1	2	1	1	1	1	2	.	3	2	.	.	.	1	.
	Prionospio spp	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Scoloplos kerguelensis	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.
	Polychaete spp	.	.	.	1	.	.	.	3	.	.	.	.	.	.	.
	Paracorophium sp.	.	.	2	.	1	.	.	.	.	1	.	4	1	.	.
	Corophium sp.	.	.	60	.	4	.	1	.	.	2	.	1	1	.	.
	Melita sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Isopod sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	Caprellid sp.	.	.	9	.	.	1	2	1	.	.	.	.	1	.	.
	Halicarcinus sp.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

AREA	STATION	REPLICATE	Tellina deltoidalis	Spisula trigonella	Nassarius burchardi	Bedeva paivae	Diopatra sp.	Penaeus latisulcatus	Favonogobius lateralis	Sanguinolaria biradiata	Arthritica semen	Hydrococcus graniformis	Capitella spp	Ceratonereis erythraeensis	Prionospio spp	Scoloplos kerguelensis	Polychaete spp	Paracorophium sp.	Corophium sp.	Melita sp.	Isopod sp.	Caprellid sp.	Halicarcinus sp.
			NUMBER OF FAUNA PER SAMPLE																				
			Sample area = 625cm^2							Sample area = 80cm^2													
2	10	1	37	.	117	.	.	.	.	.	3	.	.	.	.	.	1	1	7	.	.	.	.
		2	40	.	108	.	.	.	.	.	7	.	.	.	.	.	.	.	4	.	.	.	.
		3	44	.	27	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.	.	.	.
		4	25	.	48	.	.	.	.	.	4	.	.	.	.	.	.	2	1	.	.	.	.
		5	22	.	58	.	.	.	.	.	7	.	.	.	.	.	.	1	3	.	.	.	.
	11	1	12	.	11	.	.	.	.	.	23	.	.	.	.	.	.	.	.	.	.	.	.
		2	13	.	5	.	.	.	.	.	205	.	.	4	.	.	1	1	11	.	.	1	.
		3	11	1	.	.	.	.	.	.	58	.	.	4	.	.	1	2	14	.	.	1	.
		4	10	.	1	.	.	.	.	.	131	.	.	10	.	.	.	29	5	.	.	.	.
		5	12	1	16	1	.	.	.	.	52	.	.	4	.	.	.	.	2	.	.	.	.
	12	1	19	.	17	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.
		2	13	.	35	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.
		3	13	.	42	.	.	.	.	.	21	.	.	.	1	.	.	.	.	.	.	.	.
		4	16	.	27	.	.	.	.	.	19	.	.	4	2	.	.	.	2	1	.	2	.
		5	13	.	28	1	.	.	.	.	9	.	.	.	2	.	.	.	.	.	.	.	.

AREA		3														
STATION		13					14					15				
REPLICATE		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Tellina deltoidalis	NUMBER OF FAUNA PER SAMPLE — Sample area = $625cm^2$	.	.	2	3	4	6	1	7	7	3	7	9	9	11	6
Spisula trigonella		.	.	.	.	.	.	.	1	.	1	.	.	.	.	.
Nassarius burchardi		.	.	1	.	.	44	74	43	56	102.	49	46	51	40	22
Bedeva paivae		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diopatra sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Penaeus latisulcatus		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Favonogobius lateralis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sanguinolaria biradiata	NUMBER OF FAUNA PER SAMPLE — Sample area = $80cm^2$	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Arthritica semen		71	73	165	45	47	89	113	31	32	54	6	22	7	3	23
Hydrococcus graniformis		2	4	2	1	1	.	2	1	.	.	.	.	.	.	.
Capitella spp		12	2	42	17	4	2	.	.	.	.	3	.	.	.	6
Ceratonereis erythraeensis		31	23	40	42	37	18	24	14	16	16	15	4	5	8	.
Prionospio spp		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scoloplos kerguelensis		.	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Polychaete spp		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Paracorophium sp.		15	46	299	18	9	50	14	8	19	.	1	4	.	9	1
Corophium sp.		.	3	10	1	.	7	13	7	21	5	19	7	2	20	9
Melita sp.		.	.	2	.	.	6	4	3	2	1	2	.	.	2	.
Isopod sp.		.	.	.	.	.	.	.	.	.	.	.	1	.	.	.
Caprellid sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Halicarcinus sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

AREA	STATION	REPLICATE	NUMBER OF FAUNA PER SAMPLE																				
			Sample area = $625cm^2$							Sample area = $80cm^2$													
			Tellina deltoidalis	Spisula trigonella	Nassarius burchardi	Bedeva paivae	Diopatra sp.	Penaeus latisulcatus	Favonogobius lateralis	Sanguinolaria biradiata	Arthritica semen	Hydrococcus graniformis	Capitella spp	Ceratonereis erythraeensis	Prionospio spp	Scoloplos kerguelensis	Polychaete spp	Paracorophium sp.	Corophium sp.	Melita sp.	Isopod sp.	Caprellid sp.	Halicarcinus sp.
3	16	1	8	2	77	.	.	.	.	.	20	.	.	8	.	.	.	2	3	.	.	1	.
		2	6	.	73	.	.	.	.	.	14	.	.	1	.	.	.	.	.	.	.	.	.
		3	7	4	63	.	.	.	.	.	19	.	.	3	.	.	.	4	3	.	.	.	.
		4	9	.	78	.	.	.	.	.	36	1	.	2	.	.	.	10	5	1	.	.	.
		5	13	2	59	.	.	.	.	.	79	.	.	2	.	.	.	7	5	4	1	2	.
	17	1	.	.	28	.	.	.	.	.	8	1	.	8	.	.	.	9	13	1	.	.	.
		2	1	.	34	.	.	.	.	.	51	1	.	14	.	.	.	13	18	4	.	.	.
		3	1	.	29	.	.	.	.	.	11	1	.	9	.	.	.	20	24	2	.	.	.
		4	.	.	14	.	.	.	.	.	67	.	2	10	.	.	.	.	.	.	.	.	.
		5	1	.	46	.	.	.	.	.	26	.	.	7	.	.	.	.	.	.	.	.	.
	18	1	.	.	20	.	.	.	.	.	2	.	.	5	.	.	.	.	.	.	.	.	.
		2	2	.	15	.	.	.	.	.	6	.	.	9	.	.	.	1	.	.	.	.	.
		3	1	.	17	.	.	.	.	.	3	2	.	4	.	.	.	3	.	.	.	.	.
		4	2	.	12	.	.	.	.	.	3	.	.	3	.	.	.	.	.	.	.	.	.
		5	2	.	10	.	.	.	.	.	.	.	8	4	.	.	.	.	.	.	.	.	.

AREA	STATION	REPLICATE	NUMBER OF FAUNA PER SAMPLE																				
			Sample area = $625cm^2$							Sample area = $80cm^2$													
			Tellina deltoidalis	Spisula trigonella	Nassarius burchardi	Bedeva paivae	Diopatra sp.	Penaeus latisulcatus	Favonogobius lateralis	Sanguinolaria biradiata	Arthritica semen	Hydrococcus graniformis	Capitella spp	Ceratonereis erythraeensis	Prionospio spp	Scoloplos kerguelensis	Polychaete spp	Paracorophium sp.	Corophium sp.	Melita sp.	Isopod sp.	Caprellid sp.	Halicarcinus sp.
4	19	1	5	59	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2	5	85	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		3	5	52	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		4	4	59	11	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		5	6	67	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	20	1	3	55	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2	4	83	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
		3	5	28	12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		4	6	48	12	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		5	5	72	4	.	.	.	.	.	.	.	.	1	.	.	.	.	2	.	.	.	.
	21	1	7	14	12	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
		2	7	20	6	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.
		3	2	23	7	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
		4	3	43	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
		5	9	26	11	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.

NUMBER OF FAUNA PER SAMPLE

AREA 4

Species	Sample area	Stn 22 Rep 1	Stn 22 Rep 2	Stn 22 Rep 3	Stn 22 Rep 4	Stn 22 Rep 5	Stn 23 Rep 1	Stn 23 Rep 2	Stn 23 Rep 3	Stn 23 Rep 4	Stn 23 Rep 5	Stn 24 Rep 1	Stn 24 Rep 2	Stn 24 Rep 3	Stn 24 Rep 4	Stn 24 Rep 5
Tellina deltoidalis	Sample area = 625 cm^2	3	5	3	4	5	3	5	6	5	3	4	5	4	5	4
Spisula trigonella		32	47	24	30	34	15	18	22	14	24	6	18	2	5	4
Nassarius burchardi		6	8	12	9	3	5	5	3	5	4	2	2	6	2	1
Bedeva paivae		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Diopatra sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Penaeus latisulcatus		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Favonogobius lateralis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sanguinolaria biradiata	Sample area = 80 cm^2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Arthritica semen		1	.	1	.	.	.	.	.	.	.	.	.	.	.	.
Hydrococcus graniformis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Capitella spp		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ceratonereis erythraeensis		.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
Prionospio spp		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scoloplos kerguelensis		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Polychaete spp		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Paracorophium sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Corophium sp.		.	.	.	.	.	.	1	.	.	1	.	.	.	.	1
Melita sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Isopod sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Caprellid sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Halicarcinus sp.		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.