Seabed responses to wood waste in Northumberland Channel.

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ABSTRACT

A study of Northumberland Channel situated between Vancouver and Gabriola Islands in British Columbia, Canada, was undertaken to assess the status of benthic communities present and to relate their condition to chemical-physical sedimentary processes occurring under continuous deposition of wood waste material from a pulp mill underwater outfall.

A mid-channel transect of stations located at distances increasing in a geometrical progression elucidated an organic enrichment gradient, which was marked by decreasing levels of undegraded woody byproducts (mainly fly ash).

The presence of fly ash, in three stations closest to the diffuser, as a densely packed layer buried under 5 to 10 cm of recent sediments indicated average sedimentation rates (1.25-2.25 cm/year) in the channel. Large variability of environmental parameters, greatest in stations closest to the outfall, suggests a non-homogeneous environment.

A benthic community exhibiting a variety of transitional stages and dominated by three small deposit feeding Polychaete families (Capitellidae, Cossuridae, Cirratulidae) was described. An ordination analysis (DCA) on Polychaete data from a 0.5 mm screen separation produced a first axis significantly correlated with percentage of coarse wood (by volume) in grab samples.

A failure of cluster analysis to separate distinct station clusters and high similarity levels indicate a data continuum with high within station variability. It is proposed that such variability is partially based on the patchy deposition of woody compounds whose degradation forms the basis of a sulfuretum in Northumberland Channel.

The presence of a Beggiatoa mat on the sediment-water interface at station T1, in front of the diffuser, was associated with the highest sulfide levels in the sediment pore water and well oxygenated water column, as well as the high levels of cellulose in the surface sediments. A corresponding decrease in abundance and number of taxa of nonmotile macrobenthos in this station is attributed to increased sulfide levels. No accumulation of pulp fiber in the sediments was observed. High rates of cellulose degradation encountered in the first few centimeters of sediment are in accord with the Vance model.

It is therefore concluded that due to well-flushed oceanographic conditions in the channel and the tendency of pulp mill effluent to flocculate in sea water, sediments of Northumberland Channel receive highly variable amounts of mill-derived organic loading. Such loadings lead to the development of variable levels of sulfide accumulation and corresponding anoxia, which is reflected in elimination of highly sensitive species and proliferation of fast breeding opportunists, characteristic of transitional stages of impacted communities.

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INTRODUCTION.

The present study of Northumberland Channel originated in 1982 from questions raised by the federal Environmental Protection Service (EPS) about the environmental and biological significance of a fiber-like mat on the sea bed near the outfall of the kraft pulp mill operated by MacMillan and Bloedel Ltd. at Harmac. As a response to these questions three objectives were set for this study:

1. to determine nature of the mat, its distribution relative to the mill outfall and its environmental consequences
2. to select, describe and compare measurable biological, chemical and physical parameters in the area near the outfall (on and off the mat) and at more distant stations
3. to describe and compare benthic macrofaunal communities in the mat area and along a transect in Northumberland Channel originating at the mill outfall, and to correlate the composition and distribution of these communities with changes in the environmental parameters

After a literature search and a pilot survey three major hypothesis were generated to fulfill these objectives:

1. There is a gradual shift in diversity and abundance of species within the macrobenthic community with increased distance from the outfall, from a depauperate community to a normal (diverse and abundant) community characteristic of the surrounding waters.

2. There are gradual changes in sediment parameters correlated with increased distance from the outfall (and changes in the macrobenthos).
3. There is a positive correlation between depletion of the macrobenthos and the presence of a Beggiatoa mat on the sediment-water interface.

Environmental impact of pulp and paper mills.

In the pulp and paper industry large quantities of wood wastes must be discarded. As the industry has concentrated around waterways mainly rivers, lakes, estuaries and coastal bays, deposition of wastes in these bodies of water at first seemed reasonable. Soon, an environmental response to such deposition became apparent e.g. wood wastes and derivatives covering river, lake and sea beds (and shorelines), and affecting biological resources such as clam beds and fish nursery grounds (Waldichuk, 1962, 1983; Young, 1979).

The pulp and paper industry uses a variety of processes to transform raw wood into usable fibre. The common feature of these processes is that they are designed to separate cellulose from other wood components. The non-cellulose remainder is mainly disposed of as waste and it can constitute up to 50% of the raw material (Pearson, 1980).

In the marine environment the discharged wastes create four hazards (Ladner, 1979; Pearson, 1980; Betts, 1983):

1. Direct and indirect (sublethal) toxic effects on the aquatic biota;
2. Discoloration of the water column;
3. A biological oxygen demand (BOD) due to dissolved organics in the water column and in the sediments;

4. Problems with excessive deposition of suspended solids (SS), mainly of organic origin, from the effluent.

The specific problems associated with different manufacturing processes vary due to different chemical and physical treatments of the wood but they combine in various ways to exert stress on any aquatic ecosystem causing its simplification (Cairns and Dickson, 1971).

The toxicity problem at pulp mills has been studied extensively in relation to some organisms such as oysters (Woelke, 1960; Galstoff et al., 1947) but not at all for some other species. It is commonly accepted that by themselves components of pulp mill effluent (PME), though they may have high short term toxicity (Davis and Hoos, 1975; Poole et al., 1978), pose no serious cumulative threat (Eloranta, 1975; Pearson, 1980). These substances are oxidized rapidly in the marine environment and also usually greatly diluted in the receiving body of water (Bagge, 1969; Pearson, 1980).

Problems with water discoloration are particularly apparent in areas receiving kraft mill effluent. Dyes and lignin derivatives give kraft mill effluent characteristically a dark color. Occasionally reduced water transparency may cause a significant decrease in phytoplankton productivity (Pearson, 1980) and prevent oxygen production (Parker and Sibert, 1973) or even affect settling of marine invertebrate larvae (Harger et al., 1973).

Organics in the effluent, both dissolved and suspended, can pose a significant threat to the marine environment since decomposition of these organics requires large amounts of oxygen generating a Biological Oxygen Demand in the water and in the sediment. Where oxygen is greatly reduced toxic substances such as

hydrogen sulfide (H_2S) and methane (CH_4) can be produced. Most living organisms can not tolerate prolonged low oxygen or anoxia, thus areas exposed to high organic loadings undergo defaunation. This can occur once or periodically depending on the rate and amount of deposition and their fluctuations (Rosenberg, 1980). Oceanographic processes in the particular area have a strong influence on development of such anoxia (Waldichuk, 1968; Anderson and Devol, 1973; Deuser, 1975; Harper et al., 1981; Imabayashi, 1983), thus the amounts of organics responsible vary from site to site.

Benthos impact.

In the last decade a number of investigations revealed effects of organic enrichment on benthic aquatic organisms (Bagge, 1969; Ellis,1970; Pearson, 1971; Pearson, 1972; Shorey, 1973; Anger, 1975; Leppakoski, 1975; Anger, 1977; Ladner, Nilson and Rosenberg, 1977; Pearson and Rosenberg, 1978; Conlan and Ellis, 1979; Pearson, 1980; Mirza and Gray, 1981; Wu, 1982; Read et al., 1983; Kathman, Cross and Waldichuk, 1984). Leppakoski (1975) reviewed much of the literature available at the time. He described communities along organic enrichment gradients and species characterising them. Later Pearson and Rosenberg (1978) demonstrated trends in community development along organic enrichment gradients using species number, abundance and biomass (SAB) diagrams originated by them.

Pearson (1972, 1980) reviewed information specifically concerned with biological disturbances due to pulp and paper industrial wastes. He described many such disturbances and their causative factors, relating them to specifics of the chemical treatment of the wood during its reduction to pulp.

Two sites have been of particular interest: Loch Eil and Loch Linnhe in Scotland, and Gullmar Fjord in Sweden. At these sites there have been long term studies on the effects of the mill pollution. The timespan of the studies and information on the original fauna of the water body allowed scientists to observe not only spatial, but temporal effects of those wastes on the aquatic biota (Pearson and Rosenberg, 1978). The Swedish study was continued after mill closure (Rosenberg, 1972) which allowed observation of the recovery of the area and benthic succession associated with it.

Criteria commonly used to assess community composition and change are:

abundance: total number of individuals per given area,

diversity: total number of taxa per given area,

biomass: the total weight of the organisms present in the given area.

Successional stages of communities along a gradient (spatial or temporal) of organic enrichment have also been defined (Pearson and Rosenberg, 1976; 1978):

grossly polluted: community of the most polluted area, with no macrofauna present;

polluted: depauperate community of a highly polluted area, characterised by low diversity and low abundance of the organisms present;

transitional: communities of a moderately polluted area, characterised by low diversity and high abundance of a few opportunistic species and a corresponding peak in biomass (peak of opportunists), followed by a decline to the ecotone point (community poor in species, abundance and biomass) and followed by community with high diversity, high, but declining, abundance and high biomass,

associated with an increase of deposit feeders due to increase in food supply;

normal: communities either present in the area before organic enrichment occurred or, if this is unknown, communities present in the surrounding waters not affected by enrichment; these communities are characterised by high diversity moderate abundance and biomass, i.e. a relative decrease in numbers from the transitional stage.

These stages of succession are distributed along a gradient of organic enrichment with the depauperate community (which could be preceded by the area void of macrofauna) closest in proximity to the source of enrichment either in space or in time, or both, followed by the transitional community. The normal communities are found in the unpolluted waters in the surrounding area and can reestablish themselves given sufficient time after the input of organic matter has ceased.

In addition to these parameters, indicator species can be used as tools to determine community status for impact assessment purposes (Gray and Pearson, 1982). Indicator organisms are organisms which are known to be characteristic of particular environmental conditions. The use of the indicator species approach however is complex. Many of them are known opportunists and therefore their presence in itself does not signify a polluted environment (Eagle and Rees, 1973; Warren, 1977; Gray and Pearson, 1982; Ramberg and Schram, 1983). Most of them also have a high rate of reproduction (e.g. within 3 weeks for Capitella capitata). They can therefore take advantage of many short-term changes in the environment and their high numbers can be short-lived (Grassle and Grassle, 1974;

Warren, 1976). Thus, unless sampling is done often and sample sizes are large, the short-lived outburst of opportunists can create a complex data set (Pearson, Gray and Johanessen, 1982).

Changes in community characteristics and composition are also dependent on changes in sediment parameters, such as oxidation reduction potential (Eh), acidity (pH), amount of hydrogen sulfide (H_2S), availability of oxygen (O_2), grain size distribution, sediment porosity, quantity of cellulose or wood fibre, etc. (Nichols, 1970; Warren, 1977; Woodin, 1978; Kathman et al., 1984; McGreer et al., 1985). Hence, species associational data, with or without indicator species may not show clear relationships with environmental parameters.

Stanley, Pearson and Brown (1978) derived a causative relationship between fluctuations of the chemical parameters in the sediment and corresponding changes in the amount of total suspended solids (TSS) in the effluent for one month. Oxidation-reduction potential was a good composite indicator of the sediment conditions; highly negative values of this parameter were associated with depletion and elimination of macrofauna (Pearson and Stanley, 1979; Stanley, Pearson and Brown, 1978). The value of Eh at four centimeters below the sediment-water interface changed within three weeks following a change in suspended solids output (Stanley, Pearson and Brown 1978).

In highly reduced sediments, like those found around pulp mills, macrofaunal activity does not control the conditions in the sediment, but chemical conditions in the sediment control, to a large extent, community composition (Stanley,1978).

Changes of Eh recorded in Loch Eil followed changes in carbon input (in the form of SS) within three weeks. Response of the macrofauna to redox changes

was as short as 4-6 weeks for deposit feeding and 12-16 weeks for predatory polychaetes (Pearson, Duncan and Nuttall 1982).

Benthic community processes.

The marine benthic ecosystem in the depositional environment below the euphotic zone is based on organic matter received from river runoff, dead plankton and organics of anthropogenic origin. Around pulp mills the main load of organics is cellulose and other polysaccharides (Fenchel and Blackburn, 1979). Bacteria degrade these compounds to simple sugars, amino acids and inorganic compounds. Decomposition of cellulose in the marine environment is slow, because few marine organisms (only cellulose-degrading bacteria and some fungi) have the necessary enzymes. These organisms are scarce in the water column but can grow abundantly in sediments (Vance, 1977). Degradation rate of woody compounds depends on cellulolytic bacteria concentrations which are influenced by previous inputs of cellulose-containing matter (Hofsten and Edberg, 1972; Pearson, 1980). Where input is high, the system's ability to assimilate and degrade cellulose is greater than in those areas with little or no previous cellulose infusions (Hofsten and Edberg, 1972).

The metabolic byproducts of the cellulolytic bacteria are a medium for growth of sulfate-reducing bacteria, which are the main remineralizers of organic carbon in marine sediments (Jorgensen, 1977). The byproduct of their activity is hydrogen sulfide, which is extremely toxic to living organisms and has a high affinity for oxygen, with which it reacts promptly, making it unavailable to the biota. Hydrogen sulfide is oxidized by chemical action with oxygen and by action of

sulfide-oxidizing bacteria, or it can be precipitated by forming salts of weak acid with iron and other minerals (Fenchel and Riedl, 1970; Fenchel and Jorgensen, 1977).

The presence of dense mats of sulfide-oxidizing bacteria has been reported from areas subjected to natural (Juniper and Brinkhurst, 1986), or man-made (Stanley et al., 1978) organic enrichment and from hot underwater vents (Jannasch and Wirsen, 1981). These bacteria were found to be members of family Beggiatoacea genera Beggiatoa and Thioploca or Beggiatoa-like forms. There is some controversy over the genus Beggiatoa, its systematic position and mode of nutrition (Larkin and Strohl, 1983; Fenchel and Blackburn, 1979). It has a remarkable morphological similarity with Oscillatoria sp. a member of Cyanobacteriaceae.

The recent interest in this group of bacteria has produced studies of their nutritional requirements (Nelson and Jannasch, 1983). Beggiatoa is microaerophilic thus requiring oxygen as well as hydrogen sulfide for metabolism. This requirement limits its distribution to to the narrow zone of sediment-water interface, where these chemical species coexist for very brief periods (Jorgensen, 1977a; Jorgensen, 1977b). Mats of sulfide-oxidizing bacteria Beggiatoa sp. have been found around pulp mills and sewage outfalls and in low oxygen fjords such as Saanich Inlet (Stanley, Pearson and Brown, 1978; Petrie and Holman, 1983; Juniper and Brinkhurst, 1986). The sediment-water interface, where those mats are found, is characterised by much more vigorous chemical and microbiological activity than the water column and even sediment (McCave, 1976). In Loch Eil the area covered by Beggiatoa mats changed following a change in the Eh of the

underlying sediments (Stanley,Pearson and Brown, 1978). The mats were found in areas where sediments are anoxic (highly reduced), but where the water column was well oxygenated. The areas supporting Beggiatoa mats were characterised by Eh lower than -150 mv.

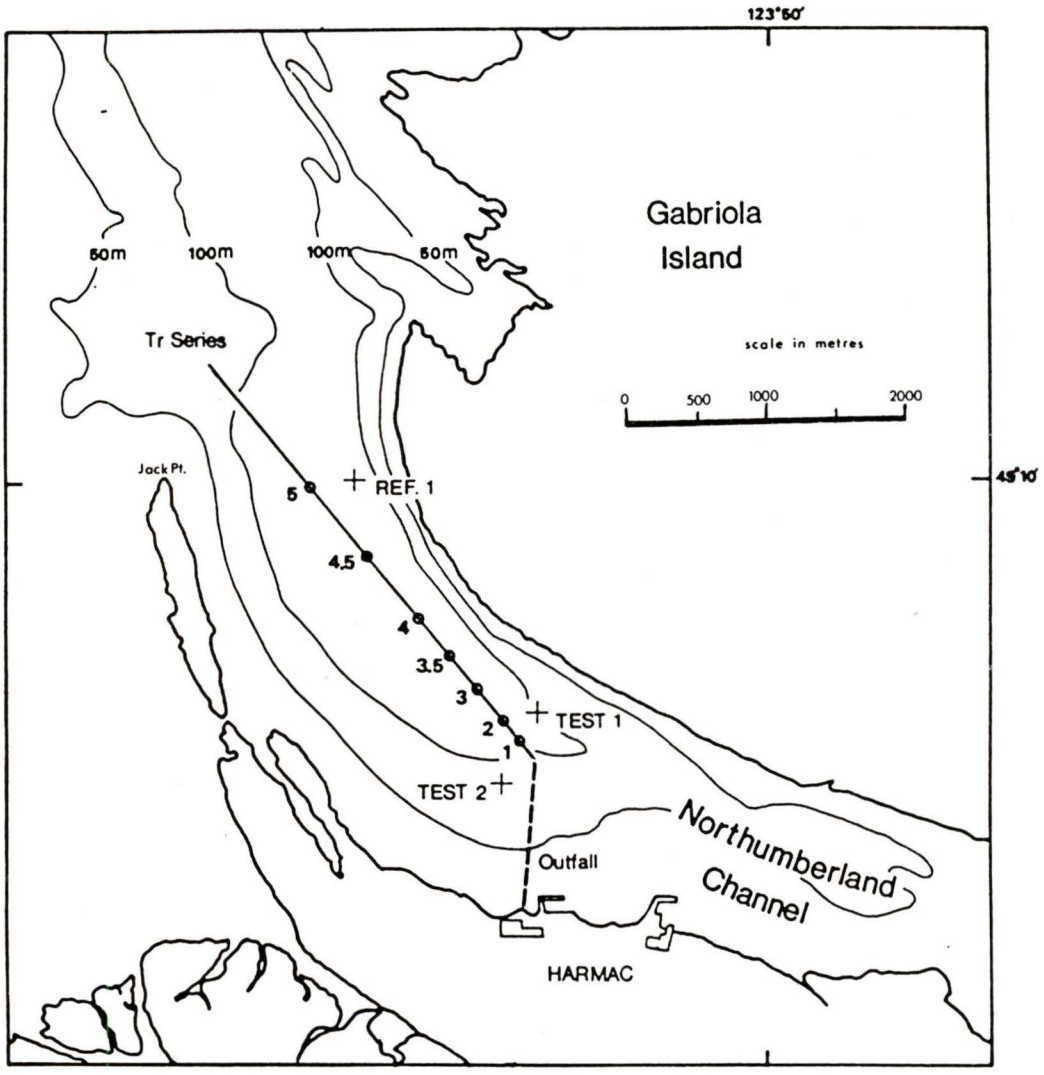
Beggiatoa can be present in oxygenated sediments as well. It utilises micro-gradients of a redox discontinuity layer (RDL) such that small pockets of decaying organic matter can support its continuous presence in the sediments (Jorgensen, 1977a; Jorgensen and Revsbach, 1983). Under such conditions mats are not observed.

History of the study site.

In 1950 the Harmac kraft pulp mill (Figure 1) was opened on the west shore of Northumberland Channel. It used a surface discharge method to dispose of its wastes. The effects of this discharge on the intertidal communities in the Northumberland Channel are documented (Melville, 1973; Ketcham, 1977), but deep water benthos has not been investigated.

In 1958 a sewer carrying domestic sewage from the city of Nanaimo went into operation south of Jack Point (Figure 1) (Packman, 1977). The sewage outfall had a pronounced effect on the benthic fauna in its immediate vicinity (expressed in reduced diversity and increase in the numbers of opportunists) (Packman, 1977). A study of outfalls in the Nanaimo area (Packman, 1977) mentioned the formation of white bacterial deposits on the surface of sediments around the outfall. This outfall was closed in October 1974.

Figure 1: Main survey sampling locations (1983).



In the 1960's the conditions in Northumberland Channel started to deteriorate. Dying oysters, unpleasant odor and foam formation (all due to the pulp mill discharges) aroused the concern of officials. An underwater diffuser for the pulp mill effluent was proposed as the solution to the problem.

The area near the pulp mill was accumulating large wood deposits on the bottom, caused by suspended solids sinking from the surface discharge. It created problems for transport ships. Thus this area was periodically dredged and the dredgate disposed of at unmarked locations near the entrance to the Nanaimo harbour (Young, pers. comm.).

In 1976 a four port underwater diffuser went into operation. It consists of a 300 meter pipe extending to a depth of 105 meters. This outfall discharges 12 tones of suspended solids per day (average). The diffuser plume has a lower density than the surrounding bottom waters of Northumberland Channel and thus it rises and is trapped below the surface (Viegers and Buckingham, 1977; Lawther, 1973). The constituents of the effluent are typical of any kraft pulp mill (Table 1, Appendix E). Lime mud is used to adjust the pH of the effluent close to the levels in the surrounding sea water (Harmac, pers.comm.).

An intertidal monitoring program conducted after the diffuser went into operation documented a marked improvement in species diversity and abundance in previously impacted areas (Ketcham, 1977).

In 1978 EPS conducted a submersible survey of Harmac outfall and discovered a white mat formed on the sediment in front of the diffuser (Packman, 1979) (see Figure 2). Alarmed by the possibility of fiber bed formation, EPS insisted on the investigation of the matter by the mill (EPS memo, Apr. 1981; MacMillan and

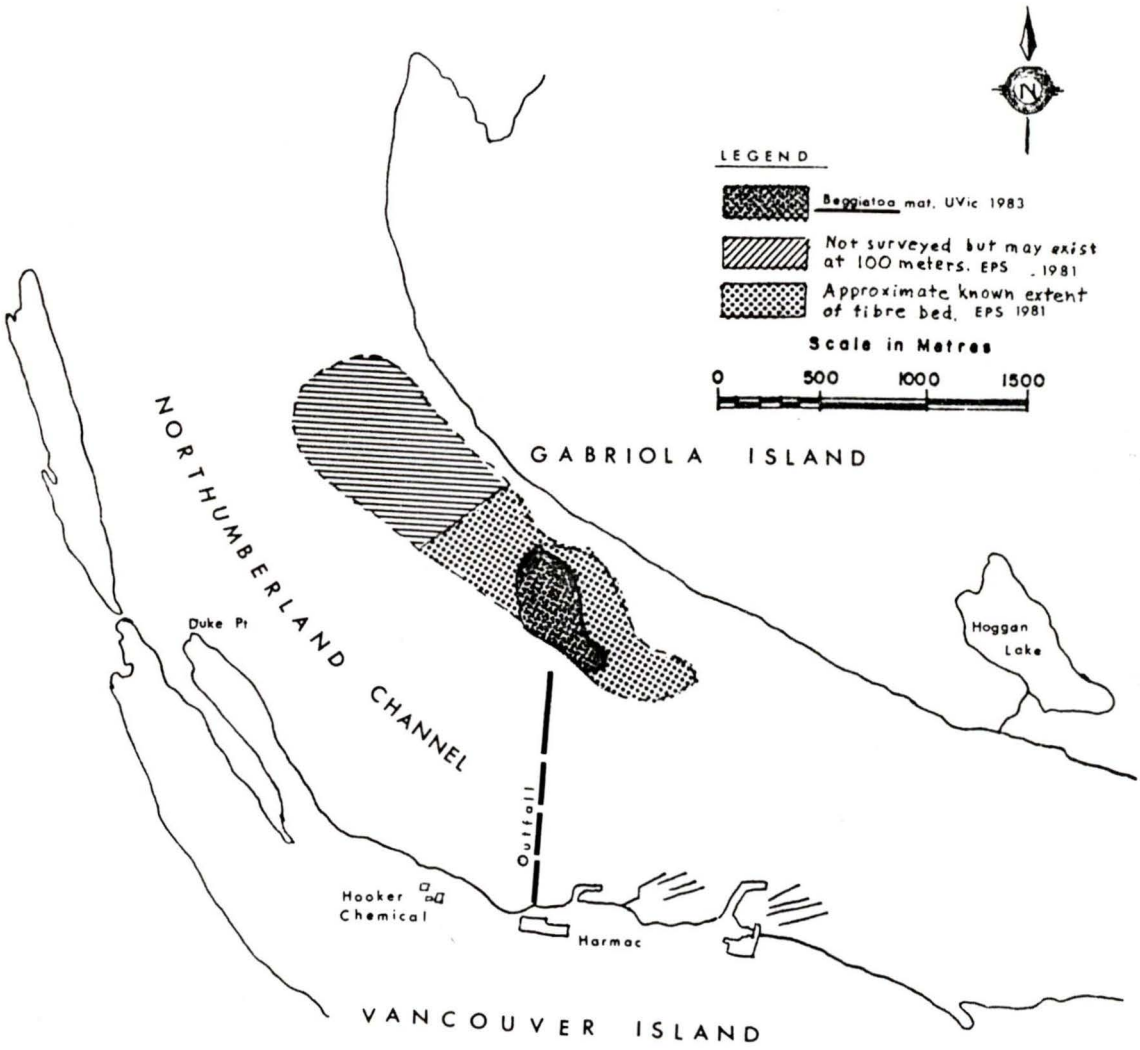
Table 1: Typical composition of kraft pulp mill effluent.

(adapted from Pearson, 1980)

Fibre; bark residue; ash; lime; clay
Lignins and their derivatives; organic acids; alcohols
Resin acids; chlorinated lignins; chlorinated resin acids, phenolics etc; unsaturated fatty acids; diterpene alcohols; juvabiones; lignin degradation products e.g. lignosulphonates; fungicides e.g. chlorinated hydrocarbon mixes, mercuric and zinc compounds etc.

Bloedel memo, May 1981). The mill then contacted the University of Victoria to undertake an appropriate investigation.

Figure 2: The bacterial mat as mapped in 1983 and as indicated in 1981.



Study site description and oceanography of Northumberland Channel.

The Harmac pulp mill (MacMillan Bloedel Ltd) is located 6.0 km southeast of the city of Nanaimo on the Vancouver Island shore of the Northumberland Channel (Fig.1) in British Columbia, Canada. The present study investigated the seabed of Northumberland Channel north of the Harmac pulp mill underwater diffuser.

Northumberland Channel is a tidal passage running approximately northwest-southeast between Gabriola and Vancouver Islands. It is about 6.5 km long and on the average 1.5 km wide (Waldichuk,1965). At its southeast end it flows into two narrow and shallow channels, Dodd and False Narrows. At the northwest end it is connected with the Strait of Georgia via Fairway Channel. The oceanographic features of this channel have been documented by numerous authors (La Croix and Dando,1949; Waldichuk, 1965; Waldichuk et al., 1968; Lawther, 1973; Vigers and Buckingham, 1977) and was summarised in terms of mill effluent dispersal patterns of Harmac pulp mill by Young (1986). The current structure of the channel is complex due to three factors:

1. bathymetry - maximum depth is 146 meters at the entrance to Fairway Channel, and minimum depths are 18.7 and 2 meters at the entrances to Dodd and False Narrows respectively;
2. strong tidal influence;
3. density stratification of waters.

Waldichuk (1965) described a three layered system of currents with the net flow in the southeasterly direction. The surface current flowed to the east, the current at 4.6 m flowed predominantly in the opposite direction and at both 13.7 and 27.4 meters readings show the flow reversed to the east again. The survey of Simons

Ltd. (Lawther, 1973) repeated Waldichuk's observations that the predominant currents in Northumberland Channel occur in depths ranging from the surface to 27 meters (=90 feet), but it stated that the direction of flow varies widely from one location to another within the Channel. The currents are reversed as the direction of the tide changes (see Figure 3 and Figure 4).

During the ebb tide a counterclockwise vortex is created by the two opposing currents. This vortex rotates around a point about 900 meters north of the Harmac west dock, which is in close proximity to the end of the diffuser. This report (Lawther, 1973) predicted levels of plume trapping between 63.6 meters (in the summer) and at the surface (in the winter). This wide fluctuation of the trapping levels was caused by fluctuations in fresh water intrusions. In 1977, a study by Dobrocky Seatech Ltd. (Vigers and Buckingham, 1977) compared the predicted diffuser performance with the actual performance under operating conditions. It found actual trapping depths slightly deeper than predicted. The measured dilutions at the top of the plume were found to be 100:1 to 200:1 which are greater than the predicted dilution of 77:1. Packman (1977) reported the plume trapping depth between 60 and 80 meters, based on observations from the submersible Pisces IV.

The dissolved oxygen data available before the outfall extension and data collected afterwards by Packman (1977) and Ketchman (1977) suggest no reduction in dissolved oxygen from the underwater effluent discharge. Low oxygen concentration in deeper waters of the Channel is thought to be a natural characteristic of inflowing deep water from the Strait of Georgia (Waldichuk, 1965).

Figure 3: Movements of surface water in Northumberland Channel on the ebb tide.

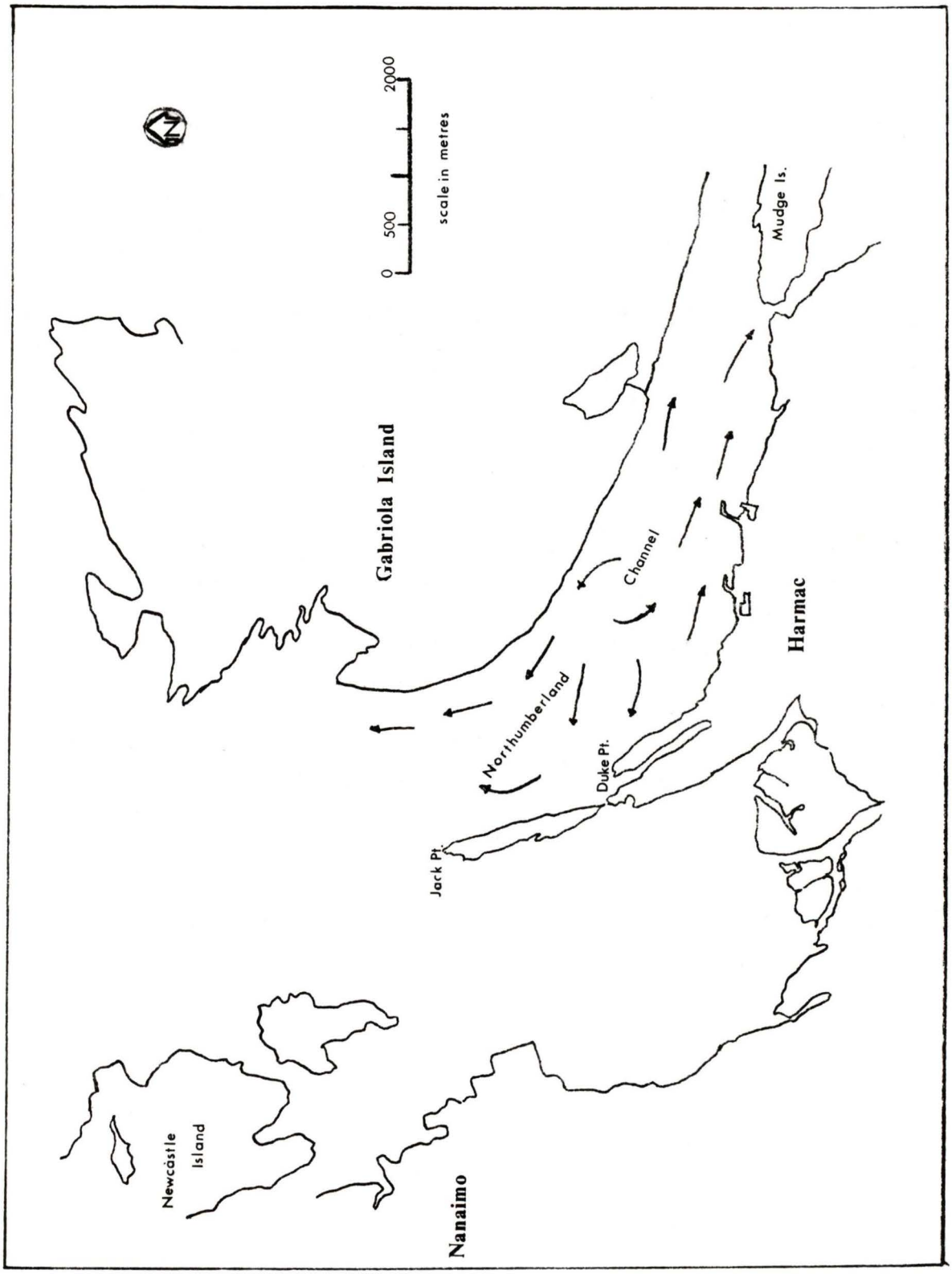
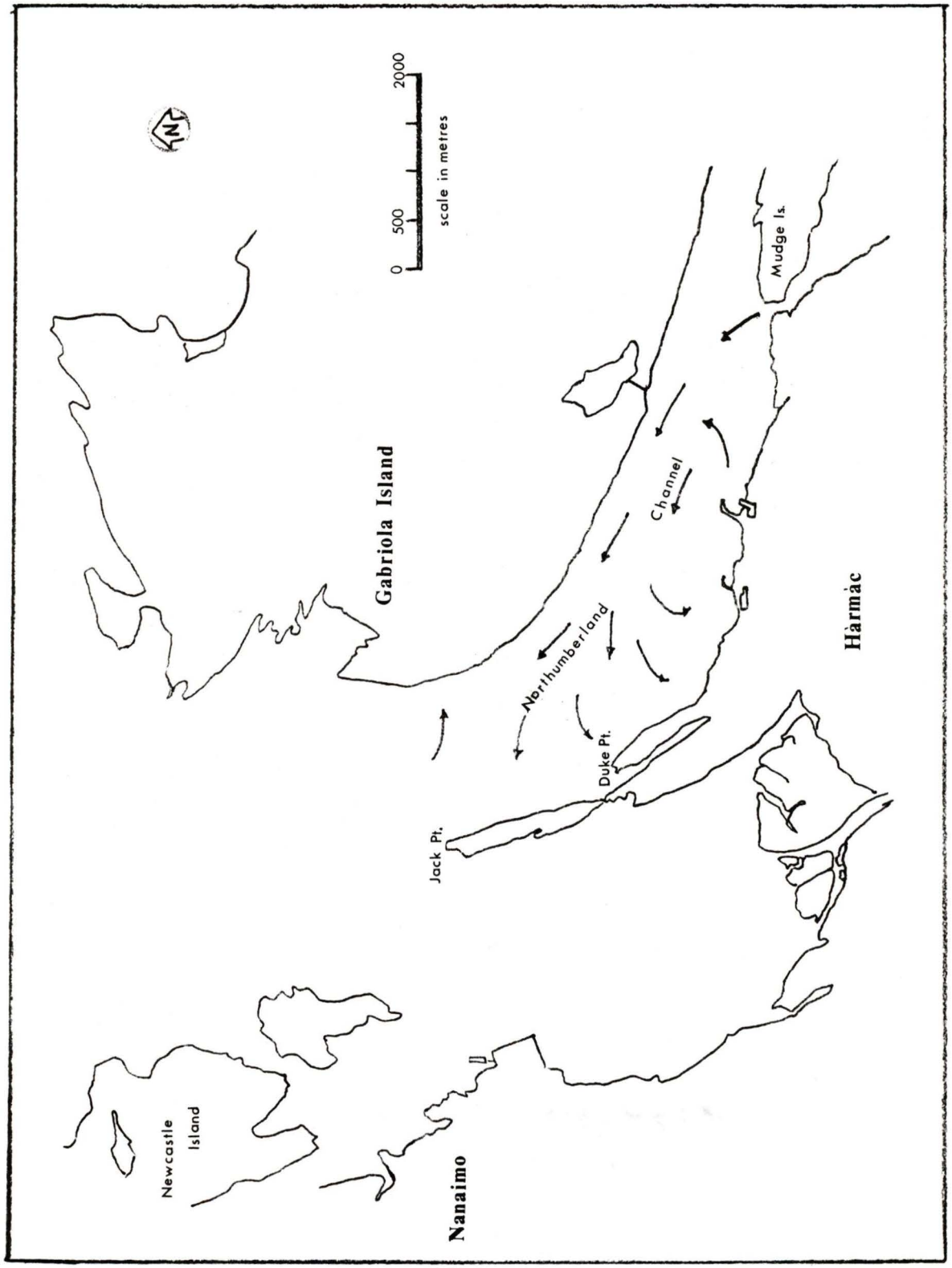


Figure 4: Movements of surface water in Northumberland Channel on the flood tide.



Communities expected in Northumberland Channel.

The absence of information on the existing or original deep-water fauna of the Channel led to a literature search (Ellis and Ostrovsky, 1982) to collate information on the benthic assemblages expected in the channel. The scope of the review was determined by placing special emphasis on near-shore benthos investigations within 60 km of Northumberland Channel (Ellis, 1967; Ellis, 1968; Ellis, 1971). In the south there were collections from Satellite Channel, Crofton pulp mill and Stuart Channel, and to the north collections from just outside Northumberland Channel and Nanoose Bay. Fisheries data were also assembled from the Northumberland Channel area and the Strait of Georgia (Ellis and Ostrovsky, 1982). The conclusion was that benthic communities in Northumberland Channel ought to be diverse and abundant according to collections taken from similar habitats and depths elsewhere on the B.C. coast, although individual species and their abundances could not be predicted.

Additional information was sought from the surveys done around other pulp mills in B.C. as well as Scotland, Sweden and Puget Sound (Anderson and O'Connel, 1977; Ellis, 1970; Pearson and Rosenberg, 1978; US Department of the Interior, 1967). Comparison of highly impacted areas produced a very short list of species (Table 2). Comparison of transitional (or less impacted) areas produced such a wide array of species, that no applicable list of species could be predicted for the transitional areas in the Northumberland Channel with any degree of certainty.

Table 2: **List of species found in highly impacted areas.**

(Ellis and Ostrovsky, 1982)

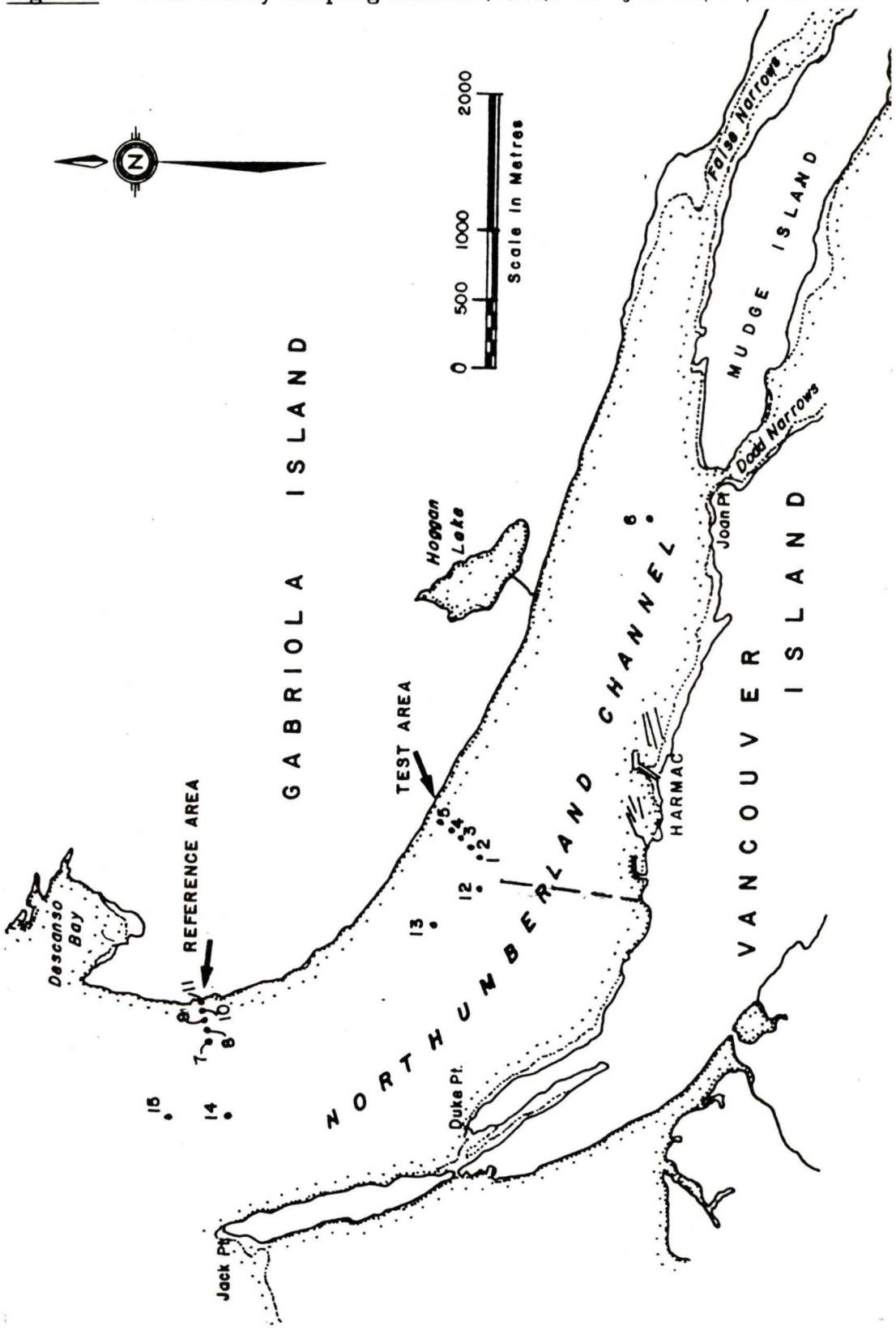
Taxa	Crofton	Scotland	Sweden	Puget Sound
Capitella capitata	x	x	x	x
Epinebalia pugettensis	x			
Dorvillea rudolphi	x			
Protodorvillea kefersteini		x		
Anaitides groenlandica		x		
Scolelepis fuliginosa		x	x	
Nematoda	x			
Bacterium - Beggiatoa		x		
Other species	Occasional	Successional series	Successional series	Occasional

MATERIALS AND METHODS.

Preliminary surveys.

A preliminary survey in August-September 1982 with the submersible Pisces IV provided information on the topography of the sea bed, nature of the sediments, distribution of wood debris and bacterial mat, as well as the nature and amount of epifauna present. A pilot survey of infauna in two areas (designated as Test and Reference) (see Figure 5) was undertaken to facilitate the development of the main survey design (July 1983).

Figure 5: **Pilot survey sampling stations (1982).** One grab sample per station.



Main survey design (July 1983).

To achieve a data set which would meet the main objectives of the study (see Introduction), five sampling stations were located on a mid-channel transect (Figure 1).

The oceanographic conditions along the transect were considered to be uniform and the differences in depths minimized (approximately 100m). To collect maximum information (with available resources) these stations were set up at distances in a geometrical progression: 150m 300m 600m 1200m 2400m from the end of the outfall. There were also two auxilliary stations at 900m and 1800m (material from these stations was to be processed only if the data resulting from the others were insufficient).

Three additional stations were placed to compare the chemical, physical and biological parameters on and off the mat.

#1 - placed in the center of the mat (Test area 1 = T1);

#2 - located at a similar depth and distance from the outfall, but off the mat (Test area 2 = T2);

#3 - placed at a similar depth to the two others but off the mat and at greater distance away from the outfall Pilot survey indicated this could function as an unaffected reference area (Reference area 1 = R1).

Mat identification

Samples of the white mat on the seabed interface were first obtained, by gravity core, during the Aug.-Sep. 1982 pilot survey. They were observed under a light microscope and their morphological similarity to Blue-green Algae (Cyanobacteria) noted, thus they were tentatively identified as Oscillatoria sp.. However a question about their systematic position still remained because the observed organisms lacked the typical coloration of blue-green algae. To clarify this a thorough literature search for possible explanations was undertaken.

The results of the search suggested that the organisms found could belong to the group of sulfur bacteria in the family Beggiatoacea. Observations already made narrowed the uncertanty to a few related genera. A fresh sample obtained on Nov.1 1982 proved this hypothesis to be correct.

Under the light microscope (observations were made at low magnifications - x10, x40 and in oil immersion) intracellular sulfur granuli were observed as well as gliding motility of the strands. Separate filaments were not included in one sheaf as in the genus Thiovulum. Filaments observed were so large that separate filaments could be seen with the naked eye. These described facts together with knowledge of the environment in which the identifiable organisms were found narrowed the identification to the genus Beggiatoa which is known to include large forms (Buchanan and Gibbons, 1974).

Mapping of the mat.

Mapping of the mat was conducted with the help of the submersible Pisces IV and the Navy tug Glendale. A large floating buoy was tied to Pisces by a rope. Its positions were fixed on the surface by radar at frequent intervals. The observer in Pisces coordinated the procedure and kept Pisces on course , zig-zagging along the edge of the mat. The map produced provided an outline for the mat, partly including the patchy area, with an accuracy estimated at ± 25-35 meters.

The enumeration and identification of infauna.

The infauna was sampled during August - September 1982 and during June and July 1983 (see Table 3). All the collections were made from the reseach vessel M.S.S.V. John Strickland using a 0.1 m^2 van Veen grab. Since the use of an anchor was not possible the vessel was repositioned on station, between replicate sample collections, using the Loran-C navigational system.

For each grab sample collected station depth was recorded when the grab struck the bottom. Upon retrieval of the grab, sediment temperature was measured using a glass thermometer (±0.5°C). Approximately 200 g of sediment were bagged and frozen for laboratory sediment analysis. The content of the grab was emptied into a volumeter, sediment volume was recorded and content washed through nested screens with 2.0 and 0.5-mm mesh. (For discussion on the use of different mesh sizes for screening benthic samples see Holme and MacIntyre, 1971.)

Table 3: Summary of sampling.

DATE	PURPOSE
15 Mar.82	Preliminary grab and core survey; Obtaining mat samples
31 Aug. - 3 Sept.82	Grab samples in Test and Reference areas Obtaining mat samples Pisces observational dives
1 Nov.82	Light measurements Mat samples for culturing
15-17 Mar.83	Pisces dives: mapping of the bacterial mat; Macrobenthos enumeration
1-3 Jun.83	Grab samples for cumulative species-area curves
12-15 Jul.83	Grab and core samples of the transect locations for community identification and chemical parameters
27-28 Jul.83	Pisces oxygen, salinity temperature measurements
29 Aug. - 2 Sept.83	Core sampling of transect locations for chemical and physical parameters

Animals were removed from the screenings and preserved immediately in 10% formalin buffered with hexamethylamine. The remainder of the screened material was also preserved in buffered formalin for later laboratory processing.

During the 1982 pilot survey (Figure 5) samples were not replicated. A single sample for each station was screened through a 2.0-mm mesh only. In June 1983 10 replicates were collected at stations Tr1 and Tr5 for species/area analysis. In July of the same year 3 replicate samples were collected at 10 stations (Figure 1). In the laboratory preserved samples were transfered to 70% ethanol for storage (after a minimum of 10 days in formalin). The July 1983 samples were then subdivided (by volume) into two equal portions. The organisms, contained in half of the original sample, were then roughly sorted and identified. Organisms from the 2.0-mm screen were identified to the lowest possible taxonomic level as were the organisms collected in the field. Organisms from the 0.5-mm screen were identified as follows: Mollusca to species, Polychaeta to family and others to the lowest easily identifiable taxon. The following literature was used for identification: Polychaeta - Hartman, 1968, 1969; Banse and Hobson, 1974; Fauchald, 1977; Hobson and Banse, 1981Other taxa (not including Molluscs) - Kozloff, 1974. Molluscs were identified by Dr. R.G.B. Reid, UVic, Victoria. Taxon abundance was recorded and later recalculated per m^2. Biomass was not measured due to two reasons : first - the use of biomass as a community parameter in benthic ecology is controversial (Day, 1984), due to large discrepancies in proportional weight loss in different groups of organisms caused by the preservatives and storing media; second - on the 0.5-mm screen the Polychaeta would have been the main contributers to the biomass figure. The

majority of Polychaeta was represented by very small but numerous species and in such case their biomass would be strictly reflecting their abundance. In the 2.0-mm screenings the number of organisms present was so small that any one large specimen would significantly affect the total figure for the particular station, making it less informative.

Enumeration of motile macrobenthos

Two observers in the submersible identified and counted macrobenthos observed between two projections 2 meters apart pointing forward from the front of the vehicle, hence marking a 2 meter transect width. Three transects were followed in each of the areas indicated as Test, Reference and Mid-channel. The position of the submersible at the beginning and end of each transect was fixed by radar as described previously (see Figure 6 and Figure 7).

Figure 6: Pisces transects in Reference and Mid-channel areas (1983).

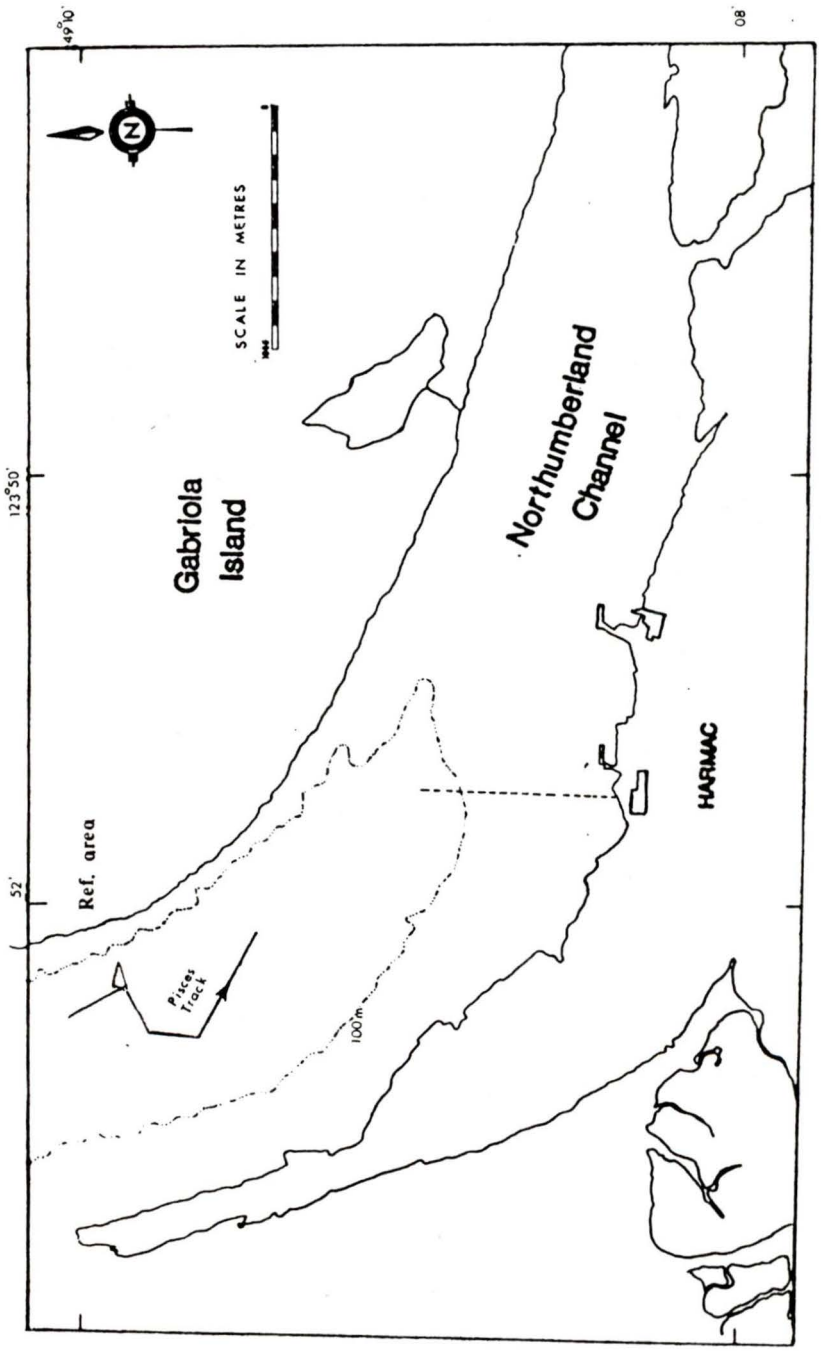
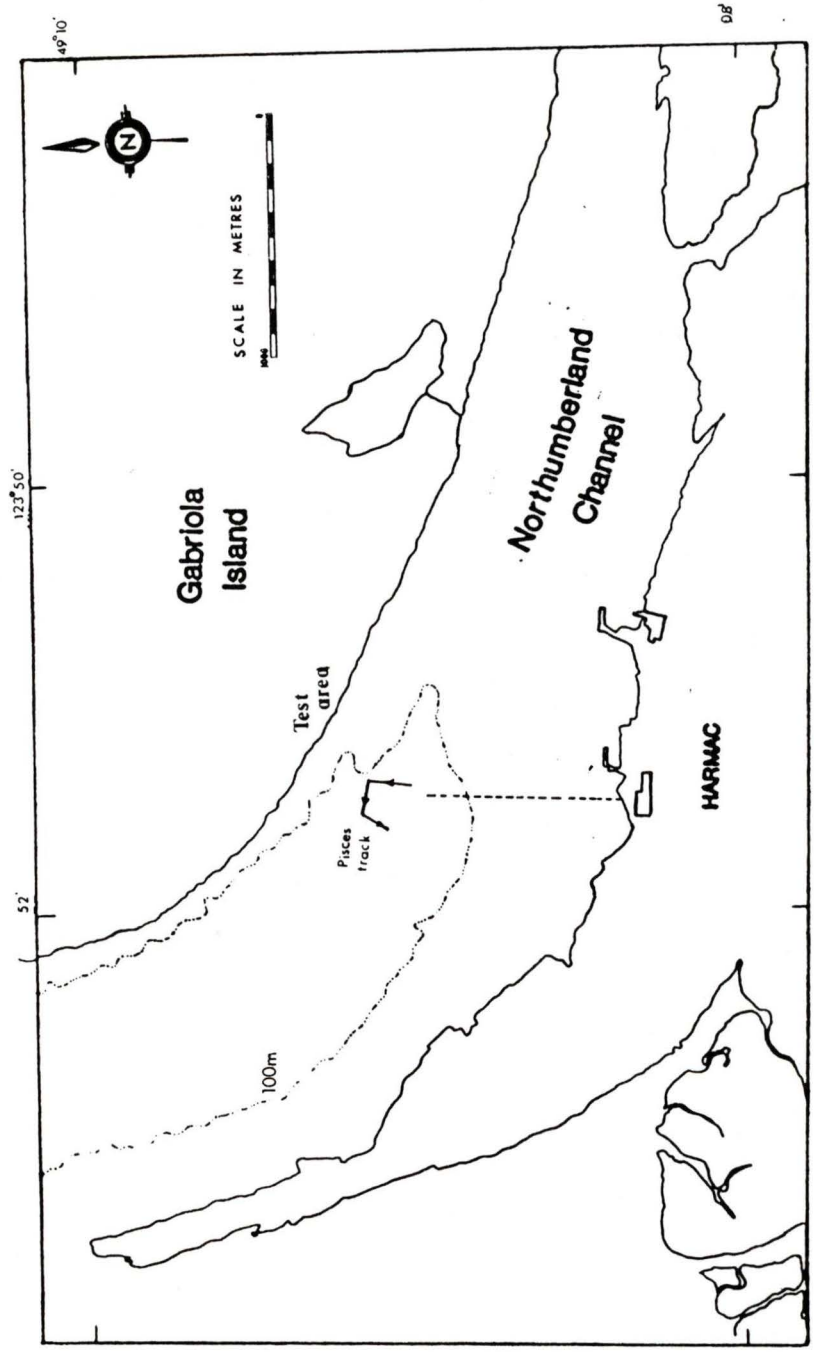


Figure 7: Pisces transects in Test area (1983).



Eh and pH measurements

Oxidation-reduction potential (Eh) and pH were measured on the core samples obtained at stations Tr1, Tr3, Tr5, T1 and T2 during July and August 1983. Cores were obtained by a Pederson corer (from shipboard) using plastic liners, 8 cm in diameter, (which were cut to about 80 cm length) and plastic caps. Cores were processed in a Nitrogen (N_2) glove box, under positive N_2 pressure to protect them from oxidation.

Eh was measured using a platinum wire electrode constructed according to Zobell (1946) and a double junction reference electrode (Orion model 920) and a digital pH-meter (Fisher Accumet model 610; resolution 1mv; accuracy ± 2 mv). pH was measured using a standard pH electrode (accuracy ±0.02 pH) and the same pH-meter as above.

The Eh electrode system was standardized after every three measurements to 230 mv using Zobell buffer solution (Zobell,1946). The pH electrode was standardized using two pH buffers(with pH=6.8 and pH=8).

In July cores were processed on board the MSSV John Strickland, immediately after they were obtained. In August a lab was set up at the Pacific Biological Station in Nanaimo, and the lag time between obtaining the corer and processing it was up to three hours. During most of that time cores, capped from both ends and taped over the cap with airduct tape to minimise oxidation, were kept refrigerated in darkness in a upright position.

Using a jacking-up system connected to a plunger the core content was raised up into the glove box a few centimeters at a time. The Pt electrode was inserted 1 cm into the sediment at the top of each section. For each measurement made

Eh electrodes were given 3 minutes for stabilisation; pH measurements did not need a stabilisation period and were made when readings stopped changing.

Eh and pH were measured at the following intervals down the core (the same sections were later used for sulfide analysis): 0 - 2 cm, 2 - 5 cm, 5 - 10 cm, 10 - 15 cm, 15 - 20 cm, 20 - 25 cm, 25 - 30 cm, 35 - 40 cm. The values of Eh obtained in the field were adjusted for the reference electrode. A Ag/AgCl reference system was used and readings were corrected for the Hydrogen reference by adding 198 mv to the obtained readings (Pearson and Stanley, 1979).

Sulfide analysis.

After the Eh and pH for the particular layer of sediment were obtained the sediment was collected into 250 ml wide-mouth plastic bottle and centrifuged. The supernatant solution was syringed out (in a glove box) filtered through 0.45-um nucleopore filter and fixed with 1 ml of 2m Zn-acetate solution for sulfide analysis. Sulfide precipitated as stable zinc sulfide and samples were stored in the dark under refrigeration. Samples were analysed spectrophotometrically by the method of Cline (1969). A Beckman DU spectrophotometer with 1-cm and 10-cm length cuvettes was used.

Wood fiber observations and measurements.

Coarse wood fiber measurements were taken during the processing of grab samples from July,1983. These observations allow an estimate of the percent of larger wood particles in the sediment; those which do not pass through a 0.5-mm screen.

Material left on the 2.0-mm screen was composed of 99% wood and on the 0.5-mm screen of about 95% wood and 5% detritus. The total volume of grab material was measured immediately after the grab sample was brought on board. The amount of coarse wood in it was measured in the lab. After the samples were sorted and all animals were picked out, the remaining material was air dried and its volume measured. The volume of air dried fine woody material (from the 0.5-mm screen) is approximately 1/4 greater than the volume of the same material water-logged.

Particle size analysis.

Cores for physical analysis were collected in August 1983 and sectioned in the same manner as cores for chemical analysis except for the absence of the 0 - 2 cm section. The core sections were halfed and each half was bagged and frozen separately. One half of each section was used for mechanical analysis, the other for cellulose and organic carbon analysis. The mechanical particle size analysis was performed according to the method described in Buchanan (1971). Sediment samples were thawed and dried to a constant weight at 60°C. They were analyzed for grain size and degree of sorting by dry sieving and hydrometry.

Water column parameters (July 1983).

To collect water samples for oxygen (O_2) analysis and salinity ($^{o}/_{oo}$) the submersible Pisces, operated from the mothership Pandora, was used. Pisces was positioned at the surface, on the station coordinates (by the Pandora navigational system), and allowed to submerge. Water samples were taken through the Pisces

water system, to which a plastic hose (equal in length to the extended arm of the submersible) was added. The hose and oxygen electrode were connected to the end of the arm. The arm held a meter stick which was stuck into the sediment before samples were taken. The arm (with the hose and electrode) was then positioned at the marked points on the meter stick: 2,5,10 and 100 cm above the sediment. The oxygen values and the temperatures were read from the electrode control unit inside the submersible. The water samples were preserved for later oxygen analysis .

To prevent any spillage of chemicals inside Pisces, preservation solutions were put in advance into 1ml disposable syringes. 1 ml of $MgSO_4$ and 1 ml of KI-NaOH reagent were used for each 350 ml bottle (Strickland and Parsons, 1977). Only one sample per water level at each station was taken due to limited space capacity of the submersible.

Salinity samples were taken at 1m from the bottom, mid water 40-60m and surface at each station, 1 sample per level. They were analysed in the lab using a Beckman Inductive salinometer, using standard technique (Strickland and Parsons, 1977).

Organic carbon and nitrogen analysis.

Organic carbon and nitrogen analysis were performed on core and grab samples (from July and August 1983) on a Perkin-Elmer Elemental analyzer model 240 at the Institute of Ocean Sciences, Patricia Bay, B.C., under the supervision of Mr. Frank Whitney. The frozen sediment was thawed and dried at 100°C for 48 hours. Ten gram aliquots of dried mud were removed and ground to a powder with pestle

and morter. Ten milligram aliquots of dried mud were removed and placed on a premuffled (at 550°C) 47-mm glass-fibre filter in the filtering apparatus and 30 ml of 5% HCl was added. If formation of bubbles was observed additional acid was added. The sediment was suspended in acid and left for 20 min, with periodical resuspension by use of a squirt bottle containing 5% HCl. The acid was then drained from the sediment and it was washed thoroughly with deionized water. The filter with the sediment was then placed into a Petri dish and dried at 60°C overnight. The 0.5 to 4.5 mg were then weighed using a Electrobalance (CAHN model 4100), put in Pt incinerating boats and burned in the analyzer at 750°C. For each sample 2 - 10 subsamples were analyzed. The carbon to nitrogen ratios were then calculated.

Analysis of cellulose.

The dried (100°C) and powdered samples (see C/N analysis) were analysed spectrophotometrically by Pearson, Stanley and Stanley's (1982) adapted version of Updegraffe's (Updegraff, 1969) technique. A Beckman DU UV-Visible spectrophotometer was used. The standard curve was prepared with Bacto cellulose and standards were run every day to compensate for the aging of Anthrone reagent.

Statistical methods.

The physico-chemical sediment data were analysed using the SAS statistical package. Simple correlations were run on the whole data set for identification of major trends. Variables exibiting significant correlations at alpha=0.05 level were

then analysed using regression analysis. Parameter measurements for July and Agust 1983 were treated as separate variables in the original correlation matrix. Subsequently those variables were pooled together and correlations and regressions were performed on the pooled data.

To interpret ecological data multivariate techniques such as ordination and cluster analysis were used. Ordination analysis is a form of gradient analysis and is recommended for a data continuum where no sharp changes in community composition are observed (Hill and Gauch, 1980). Ordination plots separate data in such a way that maximum percentage of variance is explained by the first axis of the plot, the lesser percentage of variance is explained by the second axis and so on. This analysis does not relate the variance exibited by the data to any abiotic factor, so identification of the objective gradients within the body of data has to be done subjectively on the basis of the researchers knowlege. A detrended correspondence analysis (DCA) using Cornell University Fortran program DECORANA (Hill and Gauch, 1980) was used to perform ordinations on species abundance data of July 1983. This analysis is based on reciprocal averaging (RA), but is modified to reduce the arch effect, caused by quadratic dependency of the second axis on the first, and the compression of the axis ends (Gauch, 1982). The data set was also analysed by other ordination methods (such as Principal Components Analyses (PCA) - Gauch, 1977), but DCA proved to be superior in providing adequate description of data. Raw data and log-transformed data were used.

Classification analysis (cluster analysis) is considered to be most useful when data are easily separable into discrete units (Noy-Meir and Whittaker, 1977).

Cluster analysis groups pairs of samples sequentially from the most to the least similar. The classification program writen by Hagmeir (1983) utilising the Czekanowski coefficient of similarity on untransformed data was used. The coefficient (which is a complement of Bray-Curtis (1957)) was calculated as 1-C, where

$$C = 2W / (A + B)$$

W - is the sum of the lesser abundances for those species found in both samples, and A and B are summed abundances for samples A and B respectively. To better assess effect of compositional similarities between stations and hauls the Jaccards coefficient (Sokal and Sneath, 1963), utilising presence-absence data, was used as well as the Czekanowski coefficient in the same clustering program. It is calculated as

$$J = c/a + b - c$$

where a - is the number of species in sample A, b - is the number of species in sample B and c - is the number of species in common between A and B.

Multivariate statistical analysis is one way of comparing multidimensional community data, by reducing them to fewer dimensions. A different method of comparison could be employed by reducing data to a single measure, such as a diversity index. The Shannon - Wiener diversity function (H) is one of the oldest and most widely used diversity indices (Pielou,1975). Though diversity indices are dependent on the level of taxa identification (Wu, 1982) and may not be comparable between studies they are useful for within-study comparisons (Washington, 1984). The Shannon - Wiener index takes into account taxa abundance as well as the number of taxa present. It is calculated as

$$H = -\sum_{i=1}^{S} p_i \log p_i$$

where s - total number of taxa, p - the proportion of the total number of individuals represented by the i-th taxa.

Non-parametric statistical tests, such as Wilcoxon matched-pairs signed-ranks test were performed on the data for motile macrobenthos. Due to large and unequal variances these data did not satisfy the assumptions for analysis of variance.

RESULTS.

Bacterial mat.

The bacterial mat observed in front of the diffuser (stn. T1) was identified as Beggiatoa sp. (see section Mat identification in Methods and Materials). The mat was subsequently mapped and the map superimposed on a previously produced EPS map, showing areas suspected of fiber-mat formation in 1982 (see Figure 2).

Environmental parameters.

Detailed results in the form of a sediment data matrix, with statistical processing, is presented in Appendices A, B and C.

Wood particles.

Wood particles are defined as remnants of processed or unprocessed wood of any origin including fly ash. Fly ash is mainly burned residue from the woodroom clarifier. Table 4 displays the distribution of wood in cores from Tr stations. Table 4 indicates that a layer of wood particles, mainly fly ash, was repeatedly found at a depth of 5-10 or 10-15 cm. This layer approximately 5 cm thick varied at its depth in the sediment within the same station. This suggests a heterogeneous environment with variable rates of deposition within a small area.

Percentage dry coarse wood (%cw) from total grab volume is given in Table 5. Percentages of wood particles of two sizes, corresponding to the screen on which

Table 4: Distribution of wood in cores from Tr stations.

- number; core number is given in brackets.

Station # and core	Sections with dense layers of fly ash, wood chips, etc. (cm)	Comments
Tr1(2)	5-10	Layer virtually all wood particles
Tr2(1) Tr2(2)	5-10 10-15	
Tr3(2)	9-14	
Tr4(2)	None	Some dispersed wood particles at 5-10 cm
Tr5(2)	None	Some dispersed wood particles at 20-21.5 cm

they were retained, are also indicated. Percentages of coarse wood present in grabs from stations within and outside the transect are plotted in Figure 8 and Figure 9. There is a decrease in amount of wood particles with increased distance from the outfall. Stations T1 and T2, which are located at the same distance from the outfall as station Tr2, have considerably lower amounts of wood and thus are more similar, from that perspective, to stations Tr4 and Tr5, than other transect stations. This, in conjunction with the fact that station Tr1 has the highest wood loading, suggests that the observed particles came from the diffuser plume, rather then from surface discharges which took place before the diffuser was operable. It also supports the notion that the diffuser plume travels north-westerly depositing suspended solids on the way.

The pure fly ash, from samples sent by MacMillan and Bloedel, was analyzed for carbon and nitrogen by the same technique as sediment samples. It was found to contain 83.67 % carbon and 0.08 % nitrogen.

Table 5: Percentage coarse wood (%cw) from total grab volume.

$\bar{X}$ - mean, SD - standard deviation, fr. gr. vol. - from grab volume

SAMPLE ID	GRAB VOL. (L)	% FROM GR. VOL.	$\bar{X}$% ± SD	%cW >2.0 MM FR. GR. VOL.	0.5< %cW <2.0 FR. GR. VOL.
TR1(1)	11	59.6		22.4	77.6
TR1(2)	14	46.8	42.57±15.91	31.4	68.6
TR1(3)	16	21.3		22.0	78.0
TR2(1)	17	24.8		42.7	57.3
TR2(2)	11	36.7	26.63±7.59	52.5	47.5
TR2(3)	17	18.4		16.7	83.3
TR3(1)	16	22.8		30.8	69.2
TR3(2)	17	23.3	20.30±3.89	33.3	66.7
TR3(3)	17	14.8		26.2	73.8
TR4(1)	17	5.6		33.8	66.2
TR4(2)	19	4.7	4.97±0.45	24.4	75.6
TR4(3)	17	4.6		23.1	76.9
TR5(1)	19	2.4		30.4	69.6
TR5(2)	20	4.8	3.43±1.01	***	37.5
TR5(3)	20	3.1		16.4	83.6
T1(1)	16	10.1		32.3	67.7
T1(2)	16	9.0	8.37±1.73	11.1	88.9
T1(3)	17	6.0		17.6	82.4
T2(1)	18	7.8		40.0	60.0
T2(2)	19	8.2	7.40±0.87	25.6	74.4
T2(3)	19	6.2		41.0	59.0
R1(1)	15	6.1		41.8	58.2
R1(2)	18	5.4	5.60±0.36	30.6	69.4
R1(3)	17	5.3		42.2	57.8

*** Practically no wood present, screenings consist of pebbles.

Figure 8: Percentages of wood of total grab volume in stations Tr1 to Tr5. Means and standard deviation reported.

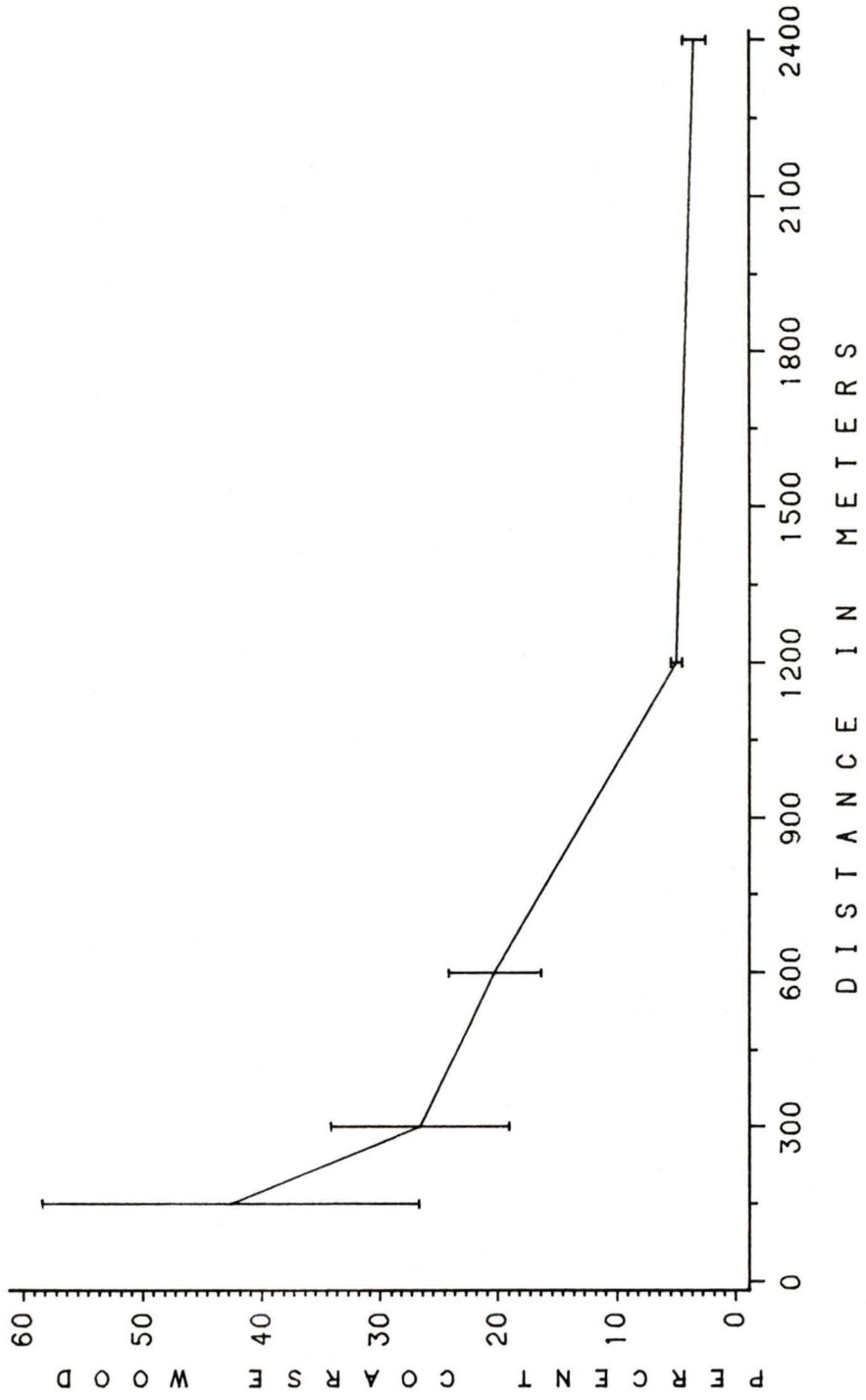
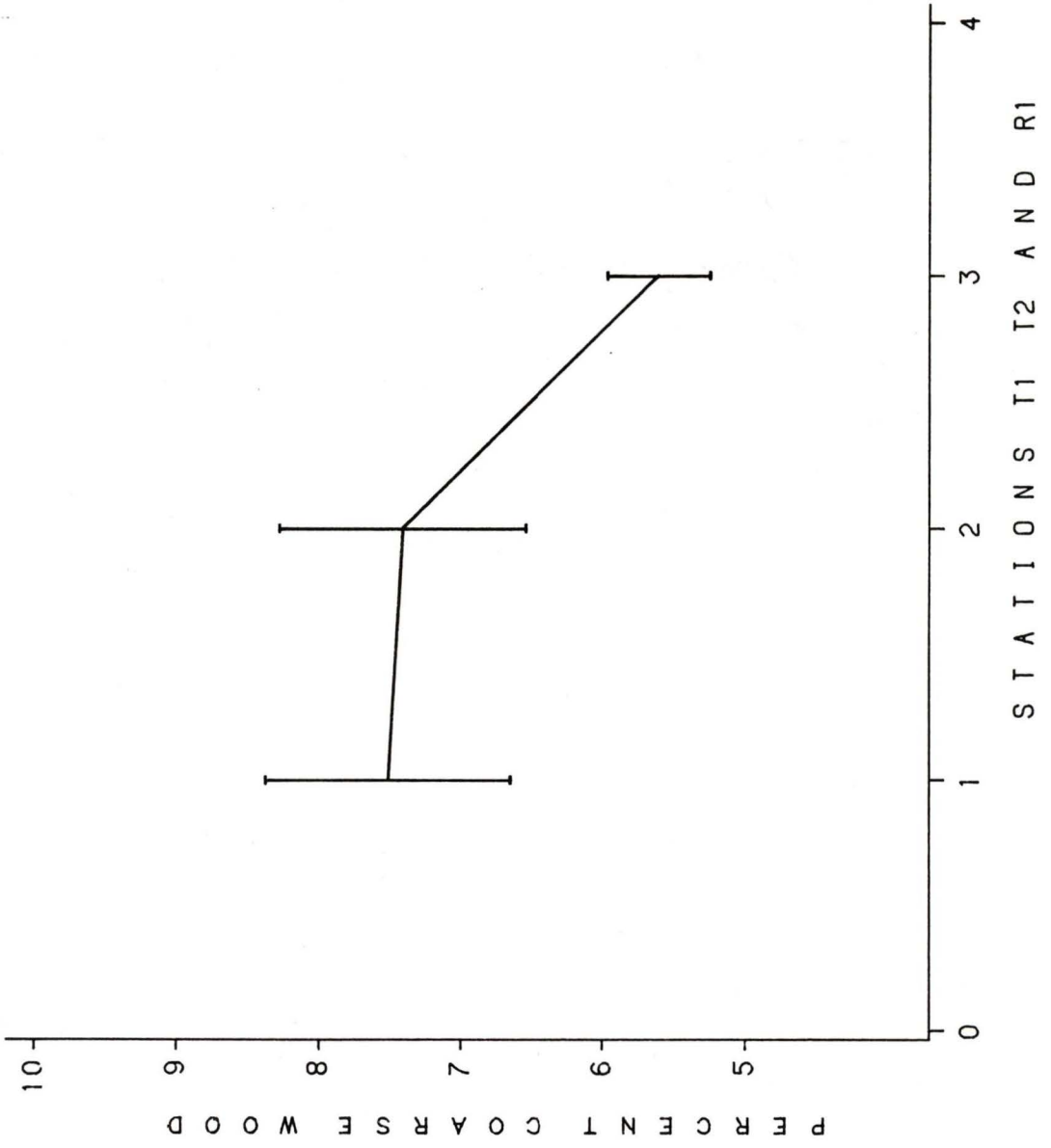


Figure 9: **Percentages of wood from total grab volume in stations T1, T2 to R1.**
Means and standard deviation reported. On the x-axis T1=1, T2=2, R1=3.



Organic carbon and nitrogen.

Organic carbon.

Figure 10 shows changes in the organic carbon percentages, at six different core depths , with increasing distance from the outfall. The relationship between core depth and amount of organic carbon is better seen in Figure 11.

The carbon peak observed at depths 7.5 and 12.5 cm at stations Tr1, Tr2, Tr3 and Tr4 corresponds to the fly ash layer. Core sample from station Tr2 (10-15 cm depth layer) contained 98% (by volume) pieces of fly ash larger then 0.5-mm mesh. Carbon and nitrogen values (as well as the C:N ratio) for this sample were measured separately for the fly ash material and for the remaining sediment-fly ash residue. Values obtained for the sediment-fly ash portion were included into the analysis and are plotted in the following sections. The values obtained for the larger fly ash portion were not included into the analysis, because it was felt that averaging two sets of values would be inappropriate. Values for fly ash portion were: C%=50.60, N%=0.25, C:N=204.86.

The large variability observed within individual stations in measurements of organic carbon at depths of 7.5, 12.5 and 17.5 cm (Figure 11 and Appendix A) is due to the difficulty in obtaining homogeneous samples in layers with high quantities of fly ash. The observed trend of decreasing percentage of organic carbon with respect to depth (excluding the fly ash layer) was expected due to remineralization of organic carbon by bacteria. The examination of Figure 10 prompted the suspicion that the relationship between carbon and distance from the outfall is non linear. Thus linear and quadratic functions were fitted to the pooled July and August 1983 data for Tr-stations. The regressions (by depth)

Figure 10: **Changes in organic carbon percentages, in six core layers, with increased distance from the outfall.** For the purpose of clarity of the plot std.errors are not plotted but are given in Appendix A; Core layers are identified by depth in cm. Stations are located at the following distances: Tr1=150m Tr2=300m Tr3=600m Tr4=1200m Tr5=2400m.

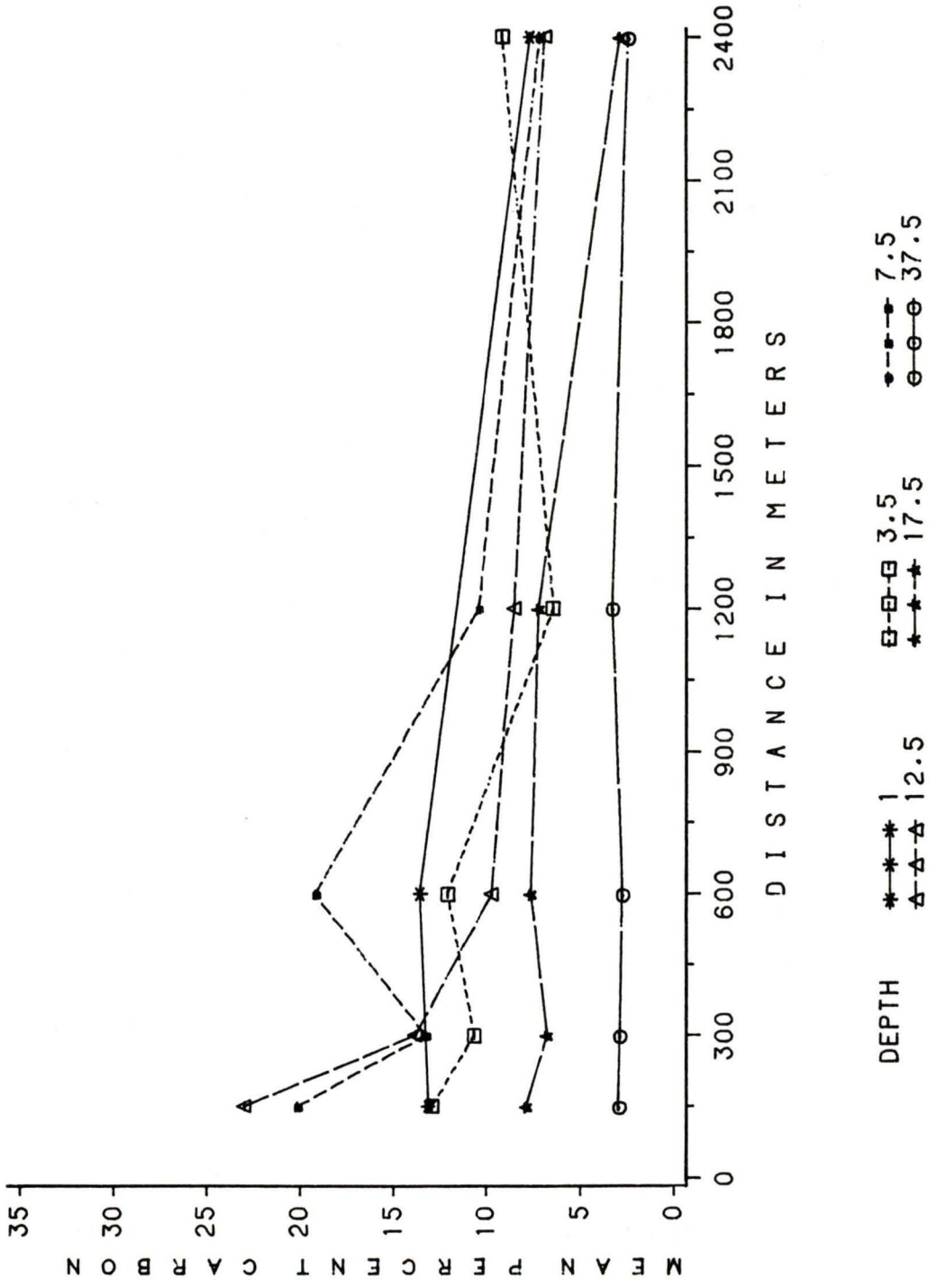
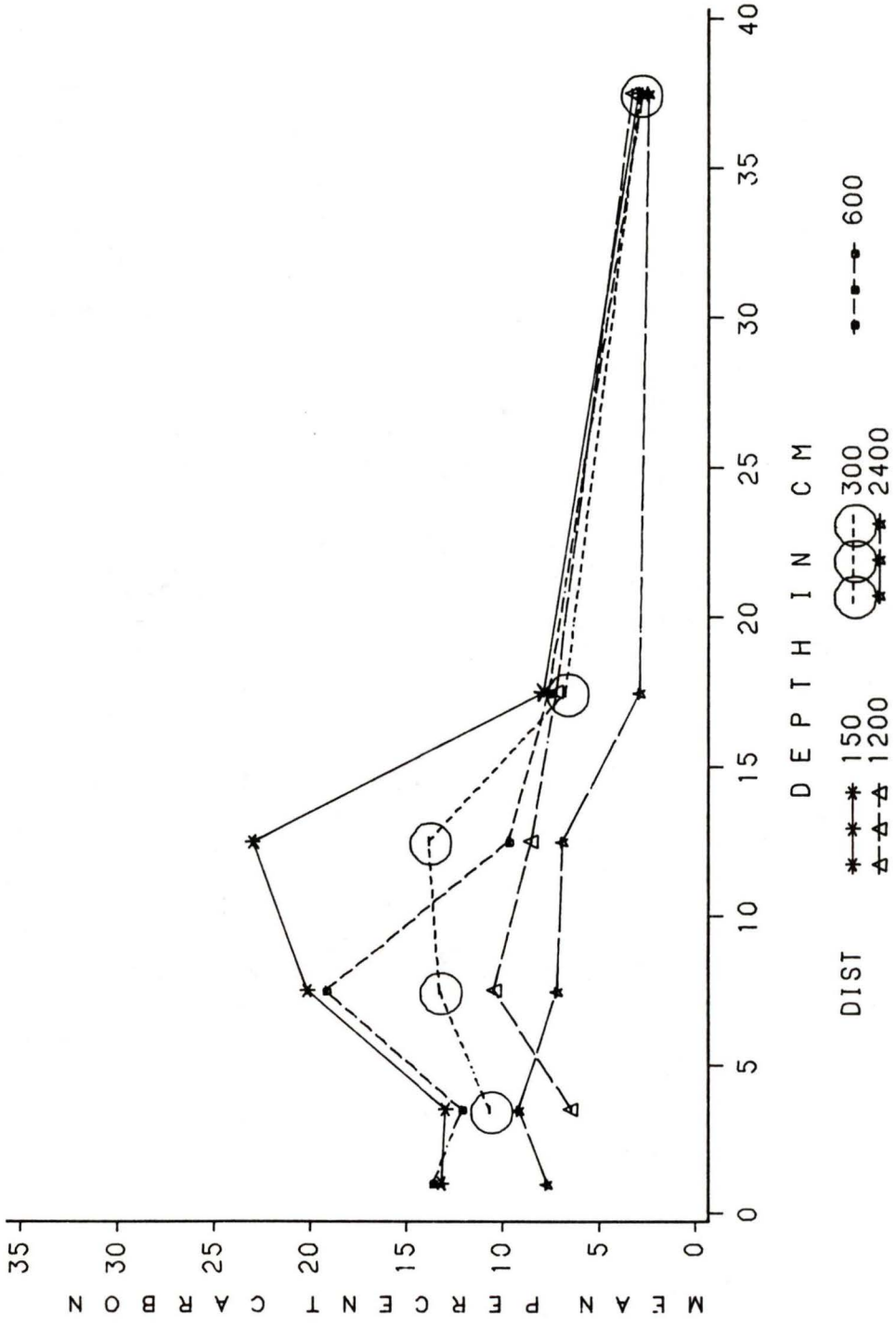


Figure 11: **Change in organic carbon percentages with core depth at Tr-stations.** Means and std.errors are given in Appendix A; Stations are identified by distance (m) from diffuser: Tr1=150m Tr2=300m Tr3=600m Tr4=1200m Tr5=2400m.



showed a significant quadratic relationship between the percentage of carbon and distance from the source at the depths of 3.5, 12.5, 17.5 cm.

depth	df	F	P	R^2
3.5	10	9.585	0.0075	0.6320
12.5	9	9.625	0.0098	0.6571
17.5	5	43.830	0.0060	0.9448

Where $P < 0.05$ indicates significance at alpha=0.05 level, R^2 - percent of variance explained and df - total degrees of freedom. Linear regression for these depths was also significant, but the percentage of variance explained by the quadratic function was higher. At a depth of 7.5 cm no quadratic relationship was found, but a significant linear relationship was observed.

depth	df	F	P	R^2
3.5	10	5.433	0.0447	0.3071
7.5	11	5.595	0.0396	0.2946
12.5	9	9.104	0.0166	0.4738
17.5	5	26.797	0.0066	0.8376

Linear regression performed on the same data set with the addition of stations T1, T2 and R1 produced only two depths with significant carbon-distance relationships - 7.5 cm and 12.5 cm; however the percentage of variance explained by the above analysis decreased compared to the percentage explained by an analysis which excluded stations outside the transect.

depth	df	F	P	R^2
7.5	17	5.245	0.0359	0.1998
12.5	13	5.238	0.0410	0.2459

This is probably due to an increase of variance at the 300 meter distance from the outfall (at which T1, T2 and Tr2 are located). Quadratic regression done by depth on all stations produced significant results only for depths of 3.5 and 12.5 cm and percentage of variance explained decreased from the corresponding analysis on transect stations only.

depth	df	F	P	R^2
3.5	16	3.708	0.0510	0.2529
12.5	13	5.833	0.0188	0.4264

Organic nitrogen.

Figure 12 to Figure 13 show changes in mean percentage of organic nitrogen at stations Tr1, Tr2, Tr3, Tr4 and Tr5, and stations T1, T2 and R1 respectively with increased core depth. The decreasing trend observed in Tr-stations was tested in the ANOVA and produced significant depth effect (P=0.0180) and distance effect (P=0.0182), but no significant interaction.

In data pooled by station the percentage of organic nitrogen was found to correlate significantly with the mean of oxidation reduction potential at station Tr2, and with core depth and pH at station Tr3 (see Appendix B).

Figure 12: **Mean percent organic nitrogen at six core depths in Transect stations.** For the purpose of clarity of the plot std.errors are not plotted but given in Appendix A. Stations are identified by distance (m) from the outfall.

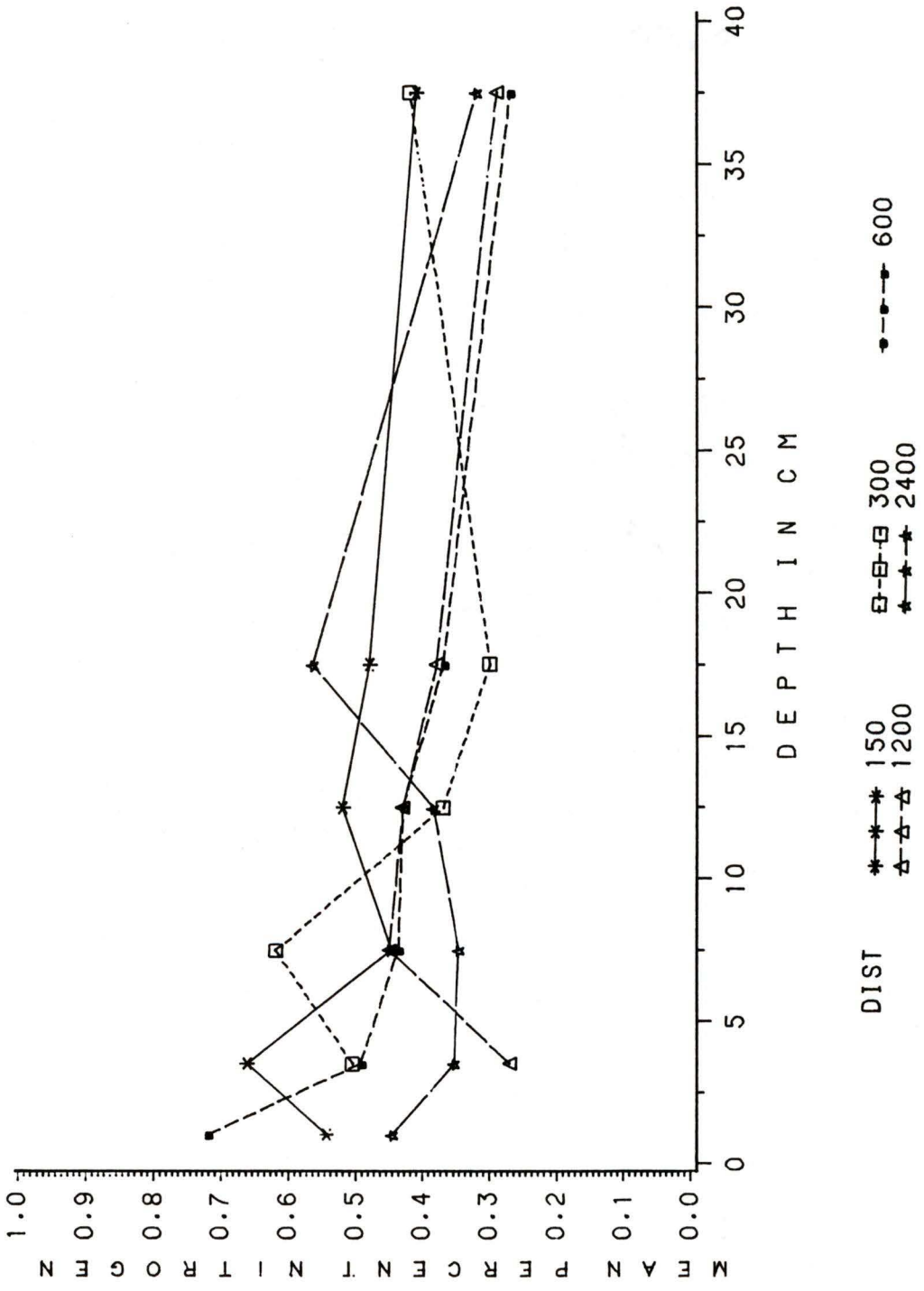
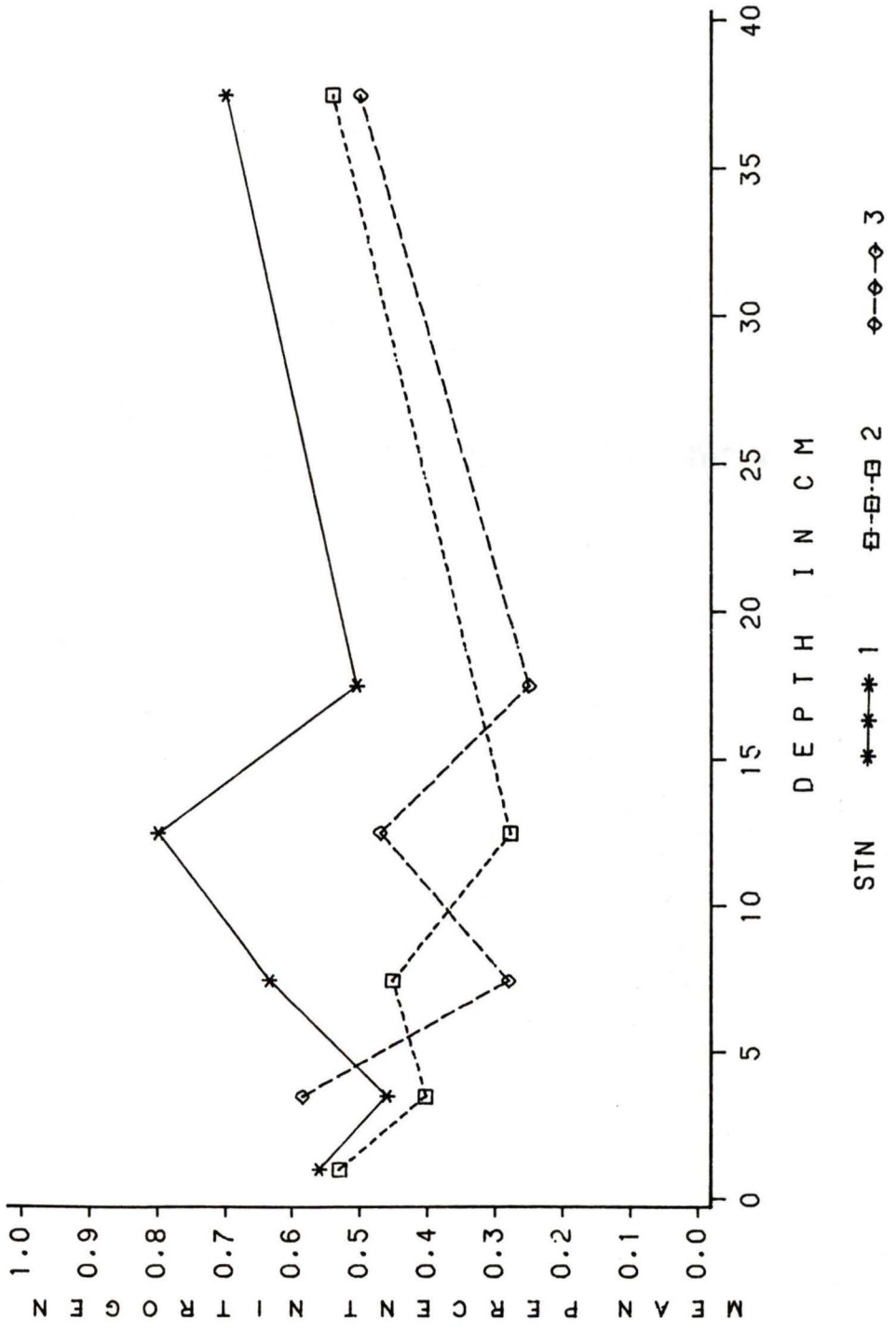


Figure 13: **Change in organic nitrogen percentage with depth (cm) in stations T1, T2, R1.** Std.errors are given in Appendix A; On x-axis stn 1=T1, stn 2=T2 and stn 3=R1.



Carbon to nitrogen ratio.

Though nitrogen and carbon exhibited significant decreases with depth and distance, these trends were found not to be significant for the carbon to nitrogen ratio (see Figure 14). Nevertheless in data pooled by station (Figure 15) the declining trend, with distance, is significant (P=0.0244).

The decrease in mean C:N-ratio, with distance from the outfall, as seen in Figure 15 parallels the trend observed in percent coarse wood. This is expected because the coarse wood measured consisted mainly of fly ash, which is mainly carbon. Since values of nitrogen exhibit significantly less variation than carbon values, the carbon to nitrogen ratio is basically reflecting differences in the amount of carbon present. Large standard deviations and standard errors are due to pooling of data from different depths. The carbon to nitrogen ratio as is seen in Figure 16 and Figure 17 predictably follows the trend of organic carbon. The extraordinarily high ratios observed (C:N > 30) and considerable variability within each station (see Appendix C) are again associated with the fly ash layer.

The large variability around the mean is due to the mentioned previously heterogeneous samples, differences in rates of deposition within each station and possible differences in the rates of decomposition.

Figure 14: **Change in mean carbon to nitrogen ratio with increased distance from the outfall (at different core depths).** Means and std.errors are given in Appendix A.

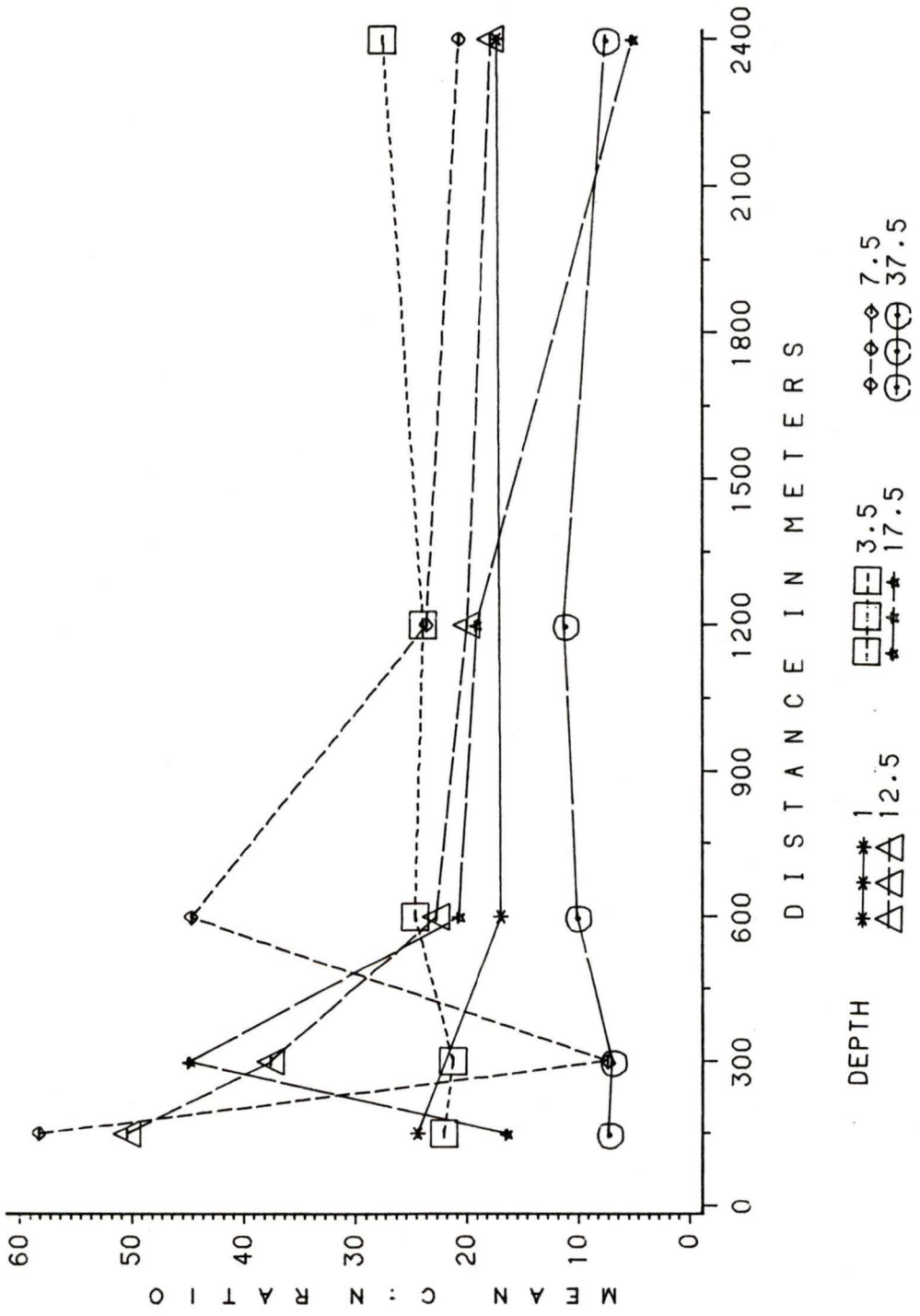


Figure 15: **Change in mean carbon to nitrogen ratio with increased distance from the outfall (data pooled by station).** Means and std.errors are plotted.

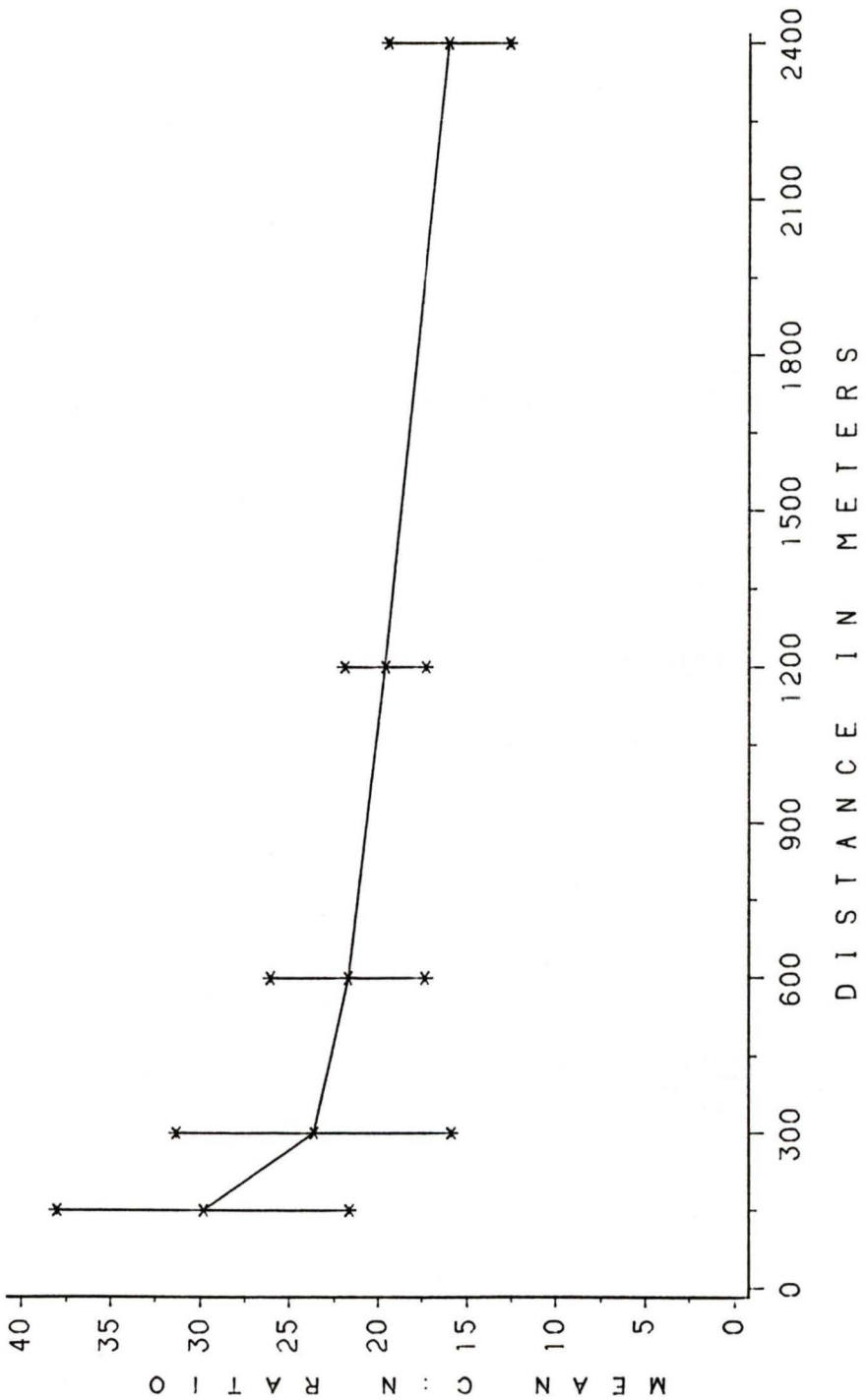


Figure 16: **Change in carbon to nitrogen ratio with increased core depth at five transect stations.** Means and std.errors are given in Appendix A; Stations are identified by distance (m) from the outfall.

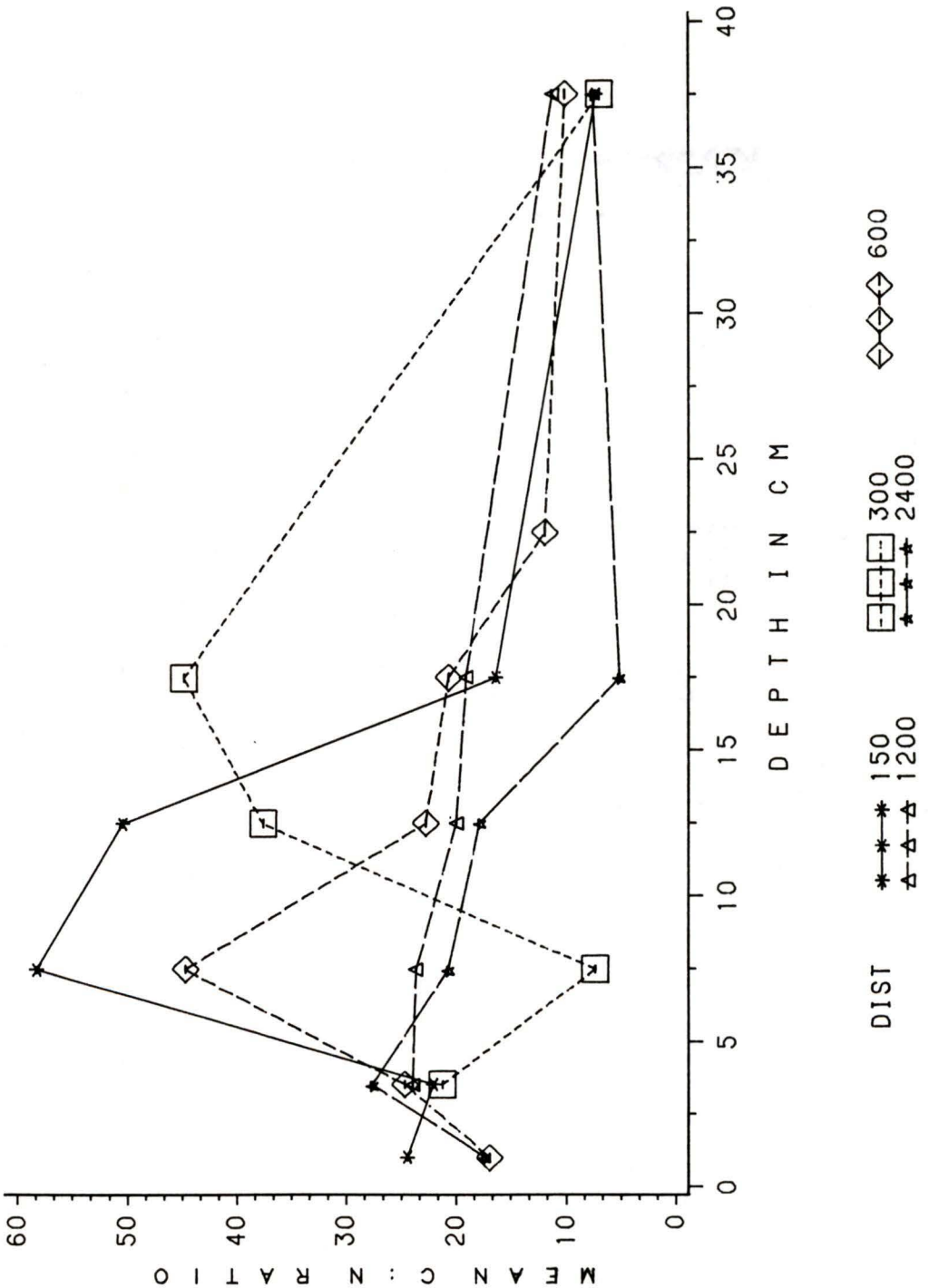
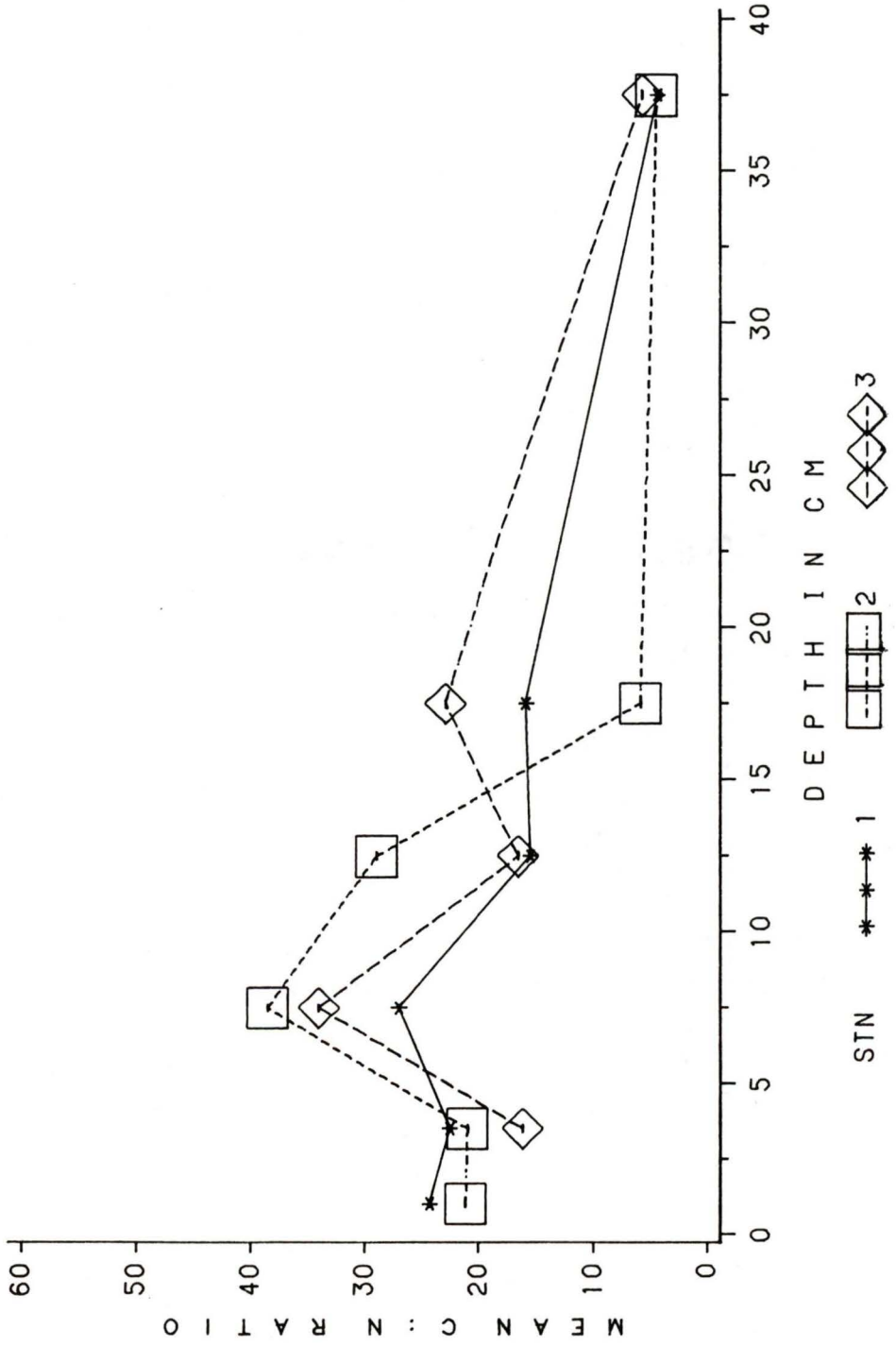


Figure 17: **Change in carbon to nitrogen ratio with increased core depth at stations T1, T2 and R1.** Means and std.errors are given in Appendix A; Stn 1=T1, stn 2=T2 and stn 3=R1.



Sulfide.

The mean data for sulfide is plotted in Figure 18. Comparison of Figure 18 with Figure 11 (organic C) shows a similar trend of decrease with distance.

This relationship was further studied by correlation analysis. No significant correlations were observed between mean organic carbon and mean sulfide values at any station. Station Tr2 was the only station exhibiting significant correlation between sulfide and depth ($r=-0.744$, $P=0.0342$, $n=8$).

Relationships between sulfide concentrations and distance from the outfall were also studied. The plot of quadratic regression fitted to the pooled data from Tr-stations is given in Figure 19. The regression was found to be significant ($P<0.05$). Separate regressions performed on the same data by depth, produced significant quadratic relationships for all but two depths (7.5 and 37.5 cm). Nevertheless these regressions cannot be discussed further due to the fact that the small number of degrees of freedom render their significance levels and R^2 questionable.

Mean sulfide levels, pooled by station, exhibited significant correlations, at alpha=0.05 with depth at station Tr2; with Eh at station T1 and Tr1; and with organic nitrogen at station R1 (see Appendix B).

The sulfide production in the sediments can be roughly monitored from sediment colour, due to natural diagenesis of sediment iron compounds which bind the sulfur. Table 6, Table 7, Table 8, and Table 9 present the field colour and texture observations made on cores in August and July 1983.

Figure 18: **Mean sulfide (µm/l) for six depths in Tr-stations.** Means and std.errors are given in Appendix A.

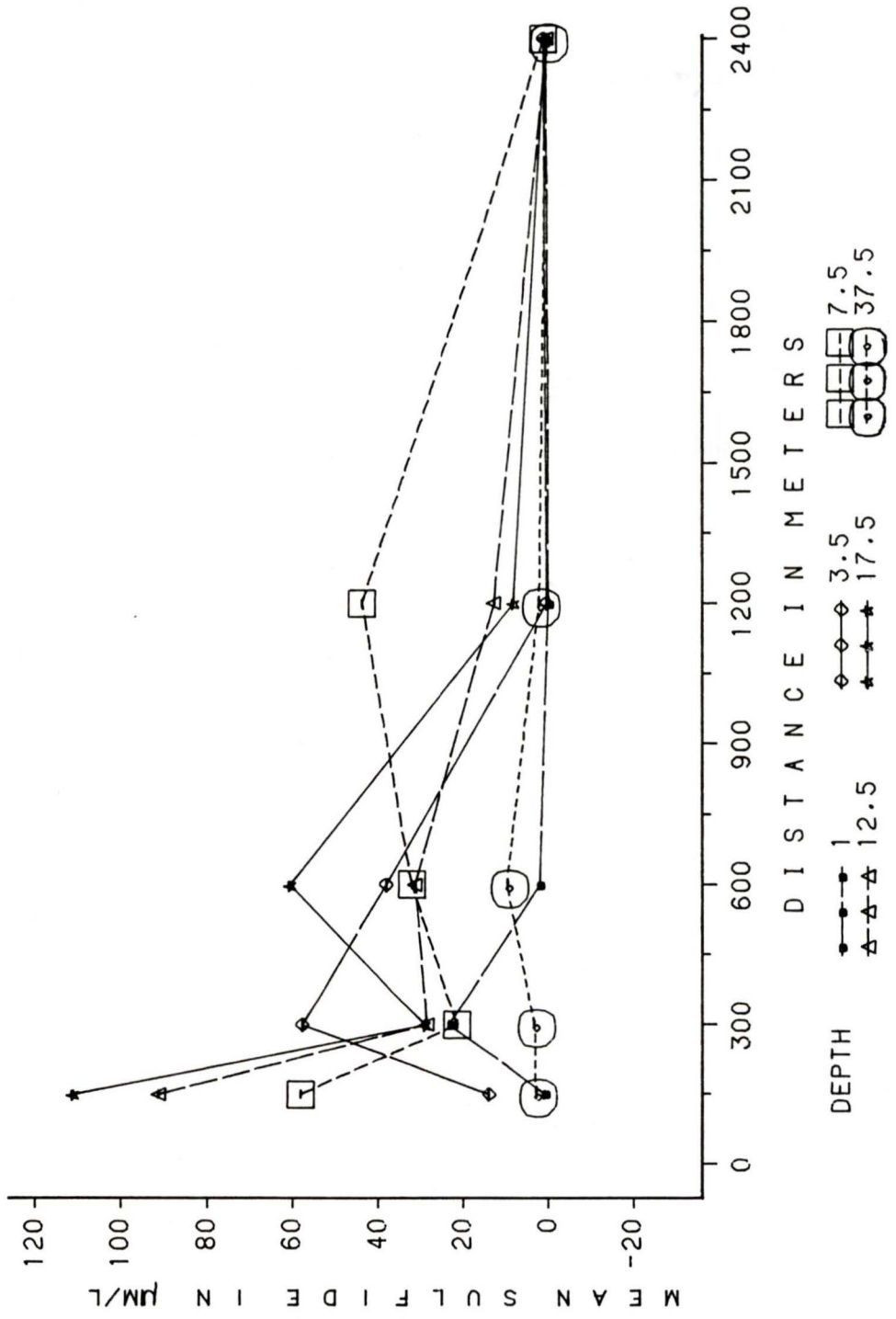


Figure 19: **Plot of quadratic regression curve for sulfide data pooled from stations Tr1-Tr5.** Data points and 95% confidence intervals are plotted df=99, F=18.883, P=0.0001

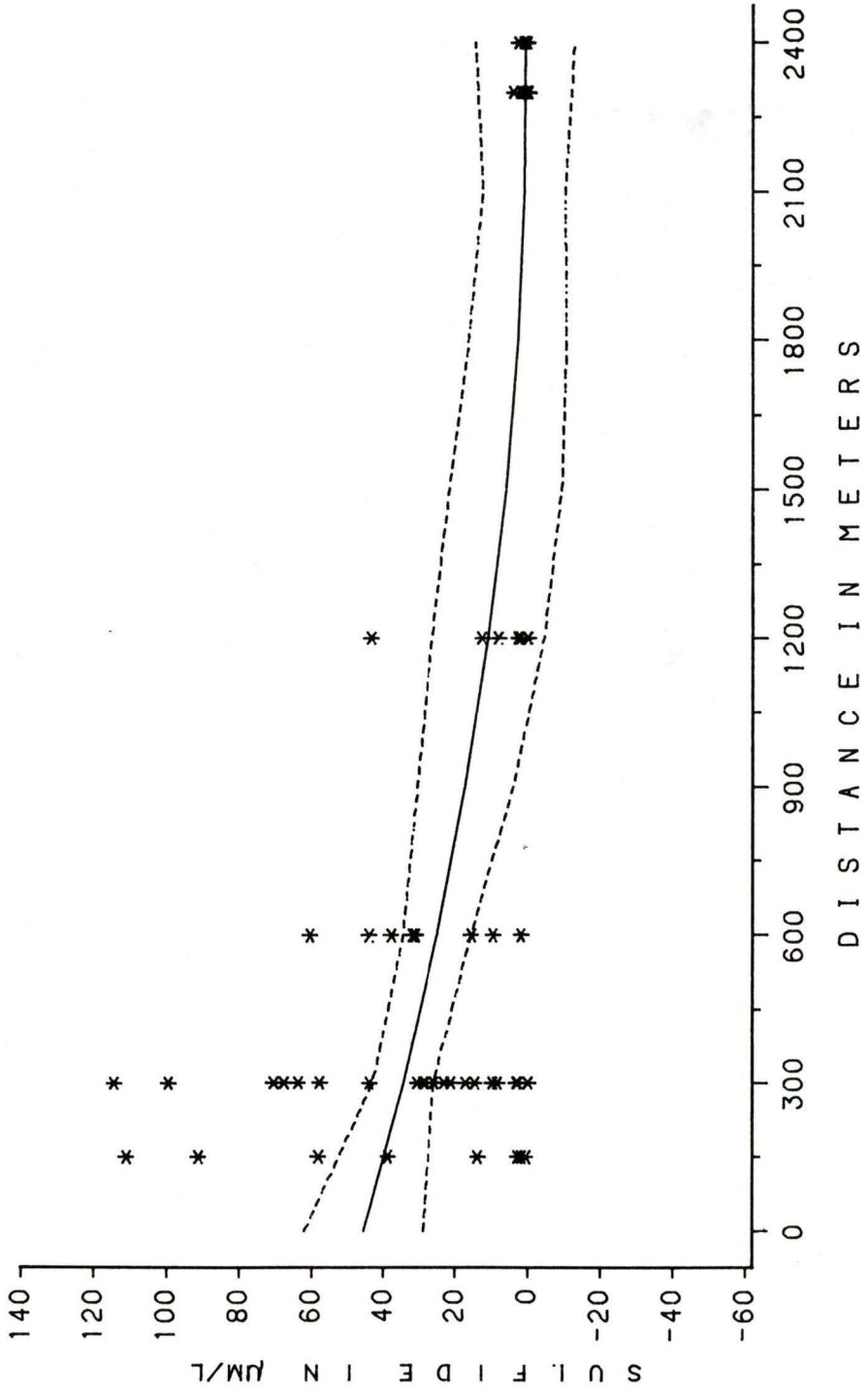


Table 6: Core colour and texture observations (stn. T1 and T2).

pk - pockets, br - brown, bl - black, gr - grey, dr - dark; July-August 1983 survey.

	T1		
depth (cm)	July	August	August
0-2	dr brown *	black	black **
2-5	black		
5-10			
10-15		yellow pk.	
15-20			
20-25		yellow	yellow
25-30	grey		
30-35			
35-40			

	T2		
depth (cm)	July	August	August
0-2	brown	black	black
2-5	black		
5-10			
10-15			
15-20			
20-25		yellow	
25-30	grey		yellow
30-35			
35-40			

* Only interface is brown and flocculent. *Beggiatoa* sp. present.

** Watery; Lots of *Beggiatoa*.

Table 7: Core colour and texture observations (stn. Tr1 and Tr2).

pk - pockets, br - brown, gr - grey, dr - dark; July-August 1983 survey.

	Tr1		
depth (cm)	July	August	August
0-2	black	black	black
2-5			
5-10		fly ash	
10-15			
15-20			
20-25			
25-30	yellow	yellow	yellow
30-35			
35-40			

	Tr2		
depth (cm)	July	August	August
0-2		black *	black
2-5			
5-10		fly ash	
10-15			fly ash
15-20			brownish
20-25		yellow	
25-30			
30-35			
35-40			yellow

* Some Beggiatoa present.
Flocculent interface, very porous first 7 cm.

Table 8: Core colour and texture observations (stn. Tr3 and Tr4).

pk - pockets, br - brown, bl - black, gr - grey, dr - dark; July-August 1983 survey.

	Tr3		
depth (cm)	July	August	August
0-2	black	dr brown *	brownish
2-5		black,br pk	**
5-10		fly ash	
10-15		black,br pk	brown,bl pk
15-20			
20-25			yellowish br
25-30			
30-35	grey	yellow-gr	grey
35-40	grey-yel		yellow

	Tr4		
depth (cm)	July	August	August
0-2	brown	brown-bl*	brown
2-5			black-br***
5-10	brownish-bl	black,br pk	black
10-15			
15-20		black,yel pk	
20-25			
25-30			
30-35			
35-40		grey-yel	grey-br

Tr3

* Leptosinapta sp. on the sediment surface. Burrow holes running though the sediment to the depth of the fly-ash layer.

** Burrow holes.

Tr4

* Some wood particles present on the surface.

** Fibrous particles present.

*** Flocculent material on the interface.

Table 9: Core colour and texture observations (stn. Tr5 and R1).

pk - pockets, br - brown, bl - black, gr - grey, dr - dark ; July-August 1983 survey.

	Tr5		
depth (cm)	July	August	August
0-2	black	brown	brown *
2-5			brown-bl
5-10			
10-15			blacker
15-20		yellowish,	black-br
20-25		bl pk **	
25-30			dr grey
30-35			grey
35-40		yellow	

	R1		
depth (cm)	July	August	August
0-2		brown	dr brown *
2-5			
5-10			brownish bl
10-15		yellow pk	
15-20		yellowish-gr	
20-25			
25-30		yellow	yellow,bl pk
30-35			
35-40			grey

Tr5

* Top 1 cm consists of flocculent matter.

** Fibre present.

R1

* Flocculent matter on the interface, first 15 cm very homogeneous.

Oxidation reduction potentials and acidity.

Oxidation reduction potentials for August and July 1983 are given in Table 10 and Table 11 and in Figure 20, Figure 21, Figure 22, and Figure 23.

pH profiles for July and August are given in Table 12 and Table 13.

There is considerable variability in Eh and pH between surveys, and in July 1983 between stations and depths (see Discussion).

Table 10: Oxidation-reduction potentials (in mv) for August 1983.

Samples transported for analysis in laboratory.

Depth	Station							
(cm)	T1	T2	Tr1	Tr2	Tr3	Tr4	Tr5	R1
0	-238	-231	-233	-249	-214	-252	-161	-139
2	-253	-239	-226	-264	-246	-255	-219	-232
5	-237	-188	-236	-256	-248	-243	-151	-203
10	-244	-193	-250	-210	-222	-183	-168	-196
15	-243	-247	-196	-67	-147	-157	-89	-154
20	-166	-190	-248	-44	-154	-147	-149	-20
25	-191	-31	-176	-93	-179	-160	-71	-161
35	-111	-162	-190	-157	-242	-36	-12	-202

Table 11: **Oxidation-reduction potentials (in mv) for July 1983.**

Samples analysed on board vessel.

Depth	Station				
(cm)	T1	T2	Tr1	Tr3	Tr5
0	15	-250	391	-246	308
2	-67	-252	-261	-244	273
5	-248	-256	-262	-249	-248
10	-253	-304	-269	-223	-215
15	-98	-306	-255	-210	-165
20	24	-174	367	-152	-147
25	-80	-272	407	-173	-
30	-3	-189	-	-174	373
35	77	-148	367	-	-
40	-26	-	371	-185	89
45	-	-	336	-	-

Figure 20: Change in Eh with core depth in July 1983 (stn. Tr1, Tr3, Tr5).

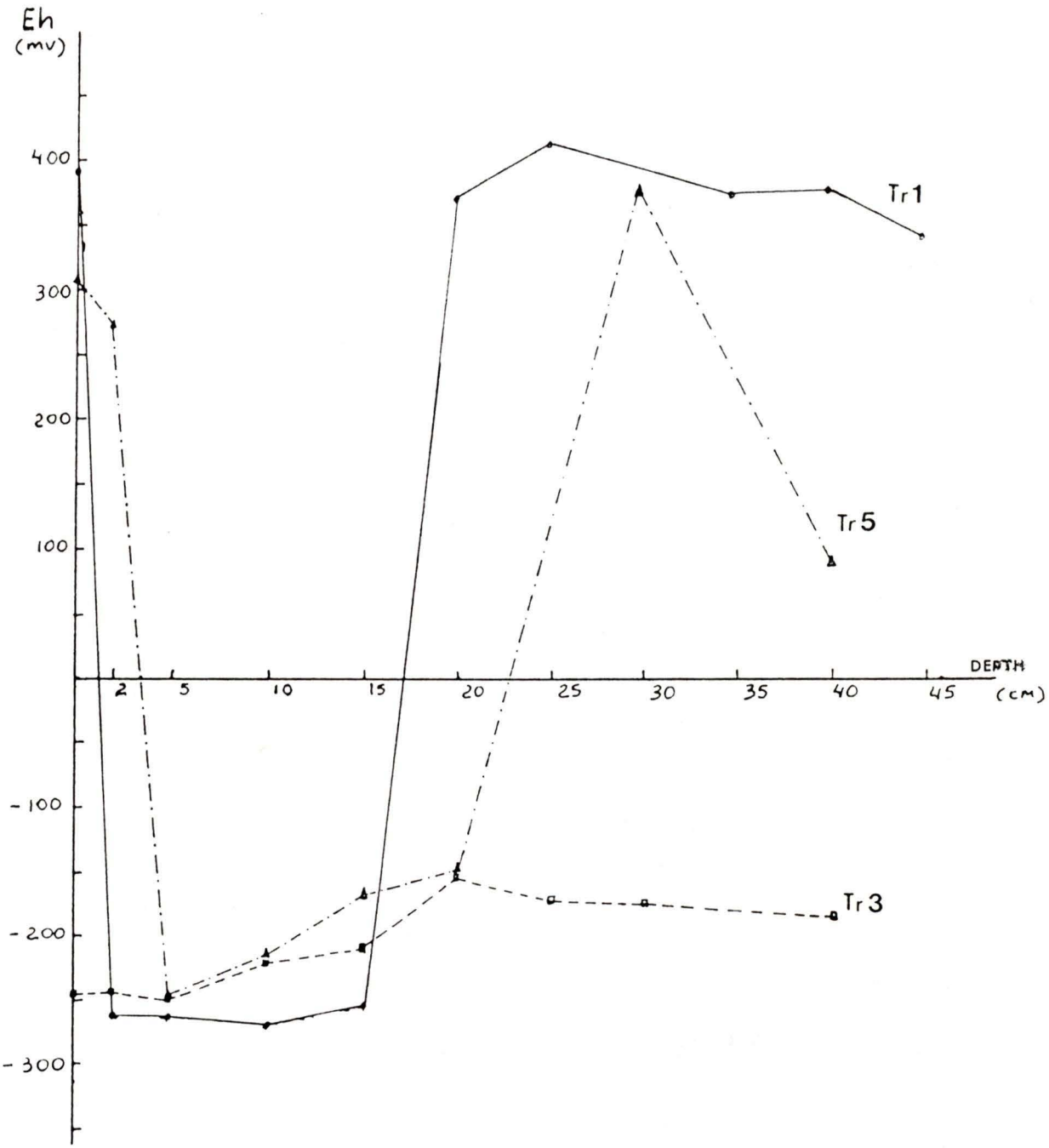


Figure 21: Change in Eh with core depth in July 1983 (stn. T1, T2).

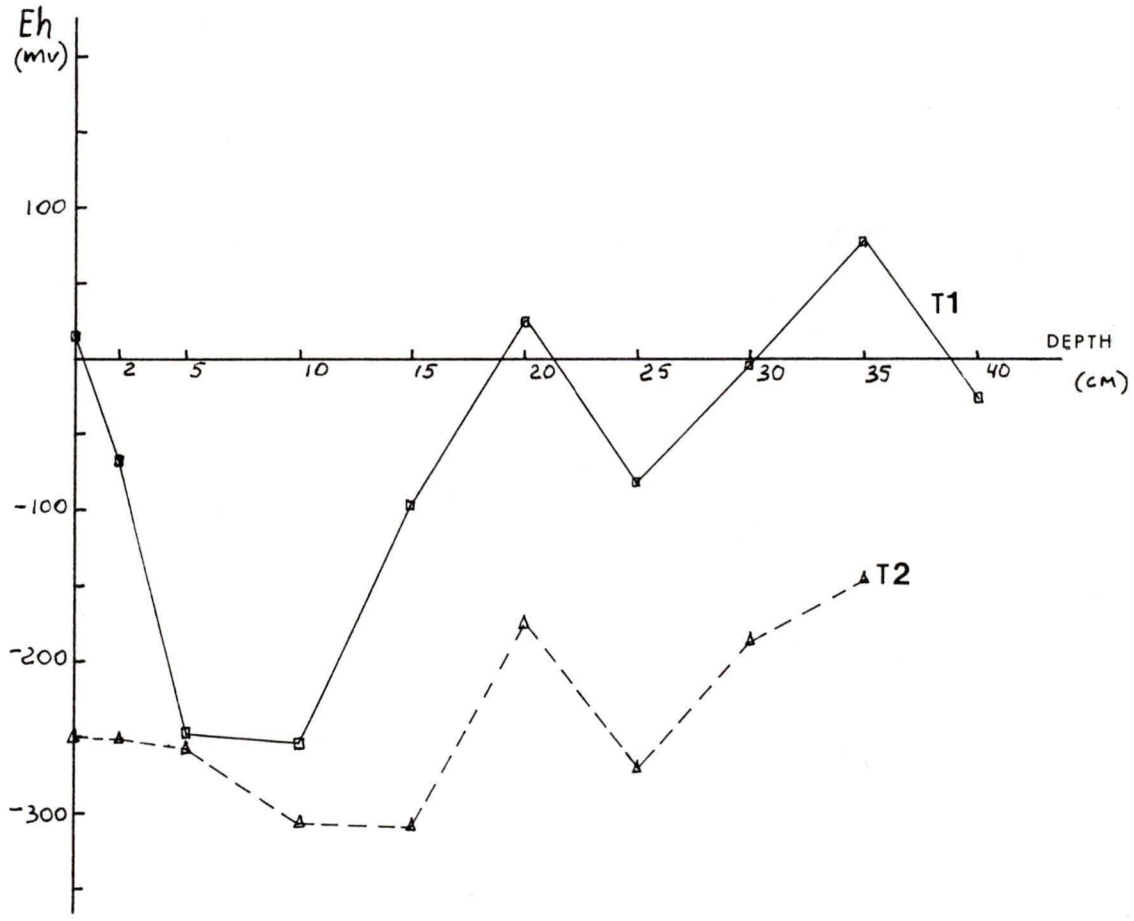


Figure 22: Change in Eh with core depth in August 1983 (stn. Tr1, Tr3, Tr5).

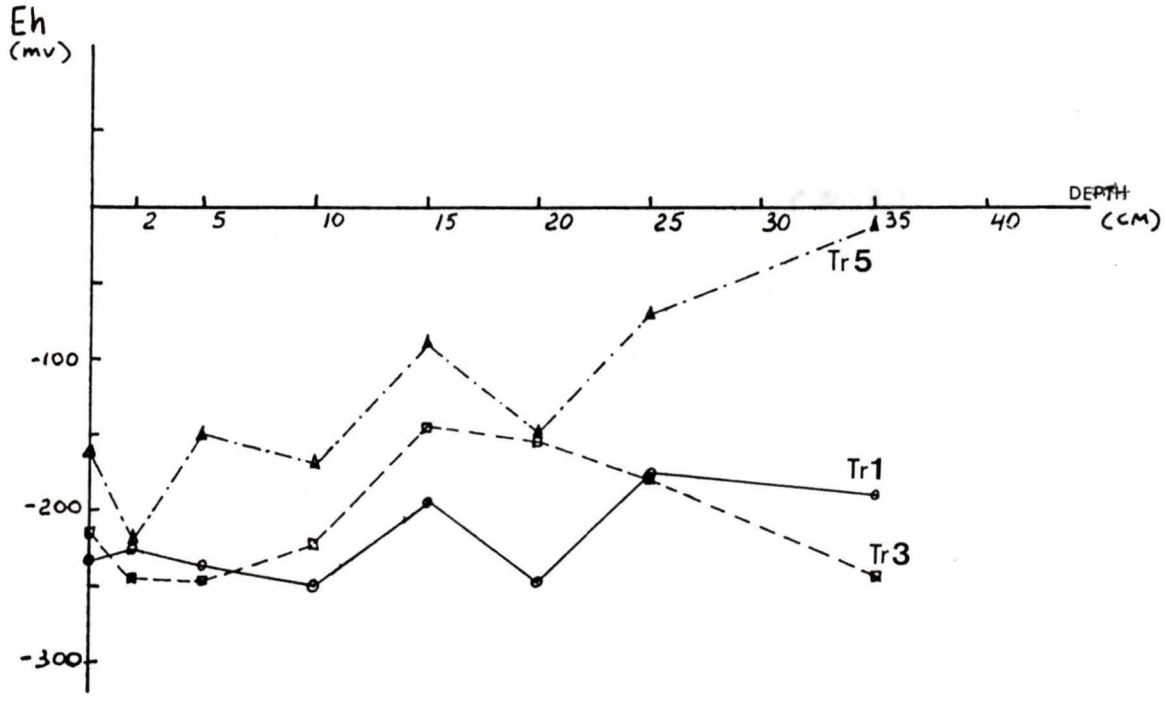


Figure 23: Change in Eh with core depth in August 1983 (stn. T1, T2, R1).

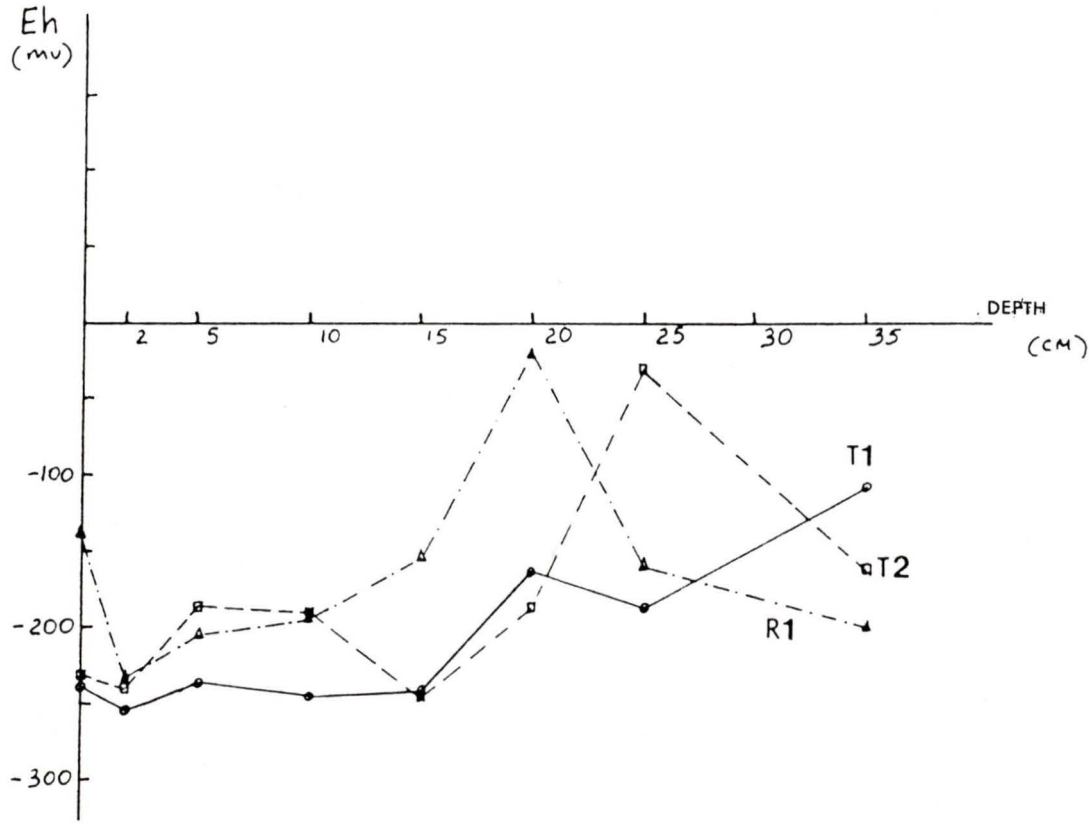


Table 12: pH profiles for the August 1983 survey.

Depth	Station							
(cm)	T1	T2	Tr1	Tr2	Tr3	Tr4	Tr5	R1
0	7.63	7.39	7.15	7.24	7.34	7.41	7.33	7.32
2	7.31	7.02	7.03	7.36	7.30	7.41	7.30	7.28
5	7.36	7.22	7.07	7.69	7.30	7.30	7.24	7.29
10	7.28	7.48	7.06	7.37	7.36	7.32	7.38	7.45
15	7.17	7.38	6.75	7.49	7.40	7.42	7.47	7.40
20	7.15	7.11	7.21	7.34	7.47	7.37	7.20	7.55
25	6.80	7.31	7.19	6.77	7.40	7.45	7.15	7.36
35	7.29	7.18	6.97	7.11	7.44	7.23	7.08	7.36

Table 13: pH profiles for the July 1983 survey.

Depth	Station				
(cm)	T1	T2	Tr1	Tr3	Tr5
0	7.28	6.97	-	7.02	-
2	7.10	7.10	7.24	7.10	6.59*
5	7.14	7.04	7.30	7.11	6.95*
10	7.14	7.08	7.31	7.07	6.89*
15	6.93	7.81	7.49	7.18	6.90*
20	6.75	7.21	7.49	7.09	7.04*
25	6.80	6.91	7.35	7.05	-
30	6.57	6.93	7.38	7.04	6.66
35	6.57	6.96	-	-	-
40	6.61	-	-	7.16	6.75
45	-	-	7.04	-	-

* - Values obtained after centrifugation of sediment
(due to operator error)

Cellulose.

The data for cellulose in Figure 24 demonstrate the changes in amount of cellulose with increase in core depth at stations Tr1, Tr2, Tr5 and T1, T2 and R1 . A test for homogeneity of slopes showed no significant differences between stations (P=0.9936), suggesting similar rates of degradation. The cellulose data were converted to logarithms and then fitted to the linear model. Such treatment produced a better fit than simple regression of non-transformed data. Thus the decrease in the amount of cellulose with depth exhibits a negative exponential tendency. The decrease in the amount of cellulose with depth (expressed as % of amount of cellulose found in the top layer) is given in Table 14.

Regression analysis performed on pooled data from stations T1, T2, R1, Tr1, Tr2 and Tr5 show a significant linear relationship between organic carbon and cellulose (see Figure 25). To understand the relationship between total organic carbon and cellulose, cellulose values were converted to percentages from total organic carbon measured at each particular layer, in the following manner:

$$\frac{\text{Cellulose (µg/mg sediment)}}{\text{Total organic Carbon (µg/mg sediment)}} \times 100\%$$

This data is given in Table 15. There is an initial decrease in values with depth (from about 9% to about 5%), followed by a noticeable increase (to 10 - 18%).

Simple correlations run on data pooled by station showed that: cellulose correlates significantly with depth at station T1, R1 and Tr1; with organic carbon at stations R1, Tr5; with organic nitrogen at station Tr1; with C:N ratio at station Tr5 (see Appendix B). It also shows marginal correlations (at alpha=0.05) with pH

Table 14: Decrease in the amount of cellulose with depth.

The decrease is expressed as % of amount of cellulose found in the top layer; Conversion factor for cellulose 10 µg/ml=1 µg/mg.

stn	depth	mean cellu (µg/ml)	% of cellu	difference in % of cellu
Tr1	0-5	129.98	100.00	
				-28.57
	5-10	92.84	71.43	
				+14.20
	10-15	111.30	85.63	
				-13.85
	15-20	93.30	71.78	
				-29.96
	35-40	54.36	41.82	
Tr2	0-5	93.50	100.00	
				-11.87
	5-10	82.40	88.13	
				- 1.77
	10-15	80.75	86.36	
				-39.30
	15-20	44.00	47.06	
				- 6.74
	35-40	37.70	40.32	
Tr5	0-5	83.00	100.00	
				-41.45
	5-10	48.60	58.55	
				- 0.49
	10-15	49.00	59.04	
				-23.50
	15-20	29.50	35.54	
				- 1.20
	35-40	28.50	34.34	
T1	0-5	112.17	100.00	
				-15.46
	5-10	94.83	84.54	
				- 5.42
	10-15	88.73	79.12	
				- 7.44
	15-20	80.40	71.68	
				-23.09
	35-40	54.50	48.59	

table 14 continued

stn	depth	mean cellu (ug/ml)	% of cellu	difference in % of cellu
T2	0-5	73.50	100.00	
				-36.19
	5-10	46.90	63.81	
				- 9.39
	10-15	40.00	54.42	
				- 7.48
	15-20	34.50	46.94	
				-10.55
	35-40	26.75	36.40	
R1	0-5	74.00	100.00	
				- 6.08
	5-10	69.50	93.92	
				-17.37
	10-15	56.65	76.55	
				-16.55
	15-20	44.40	60.00	
				-19.12
	35-40	30.25	40.88	

Figure 24: Changes in amounts of cellulose with increase in core depth.

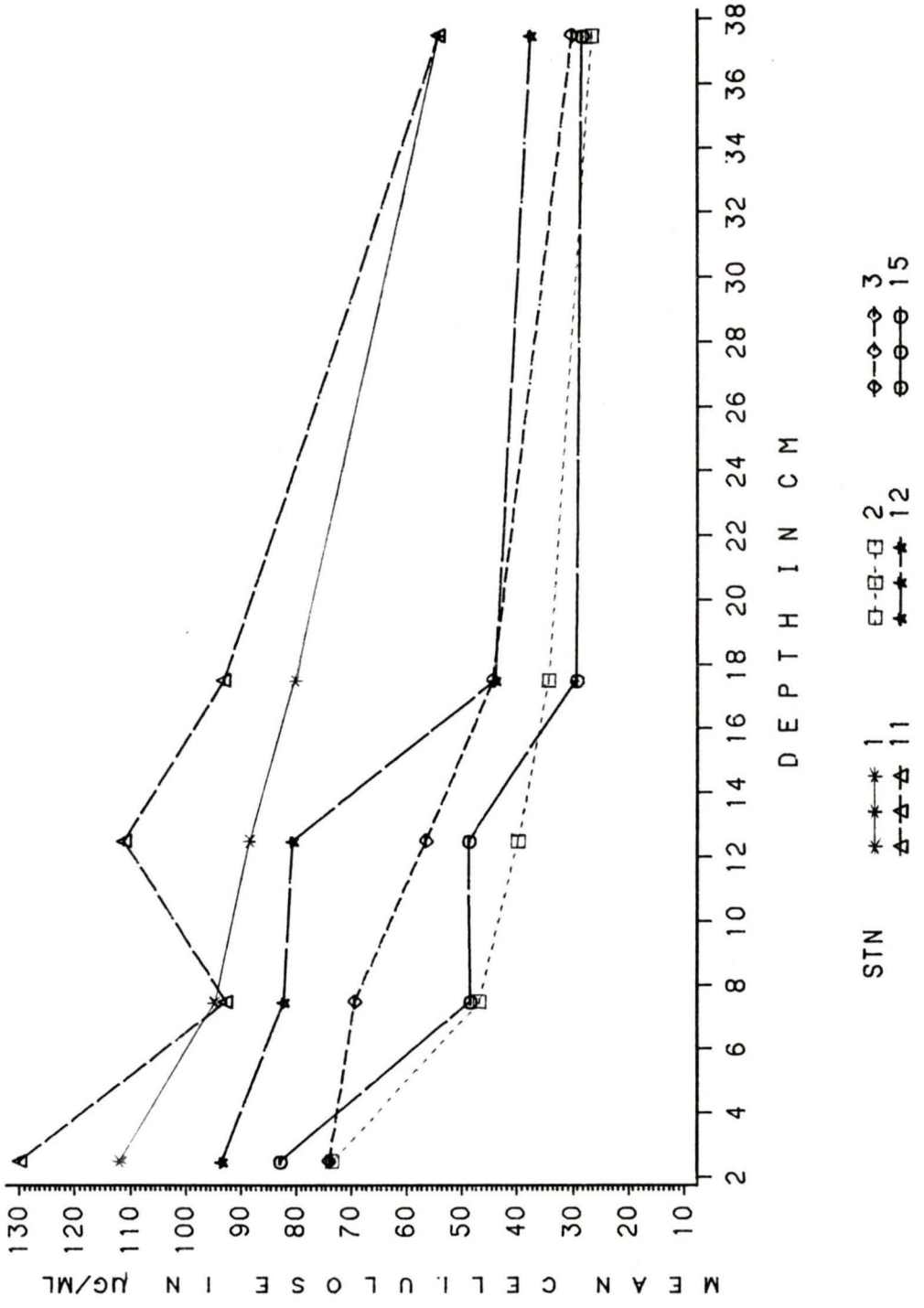
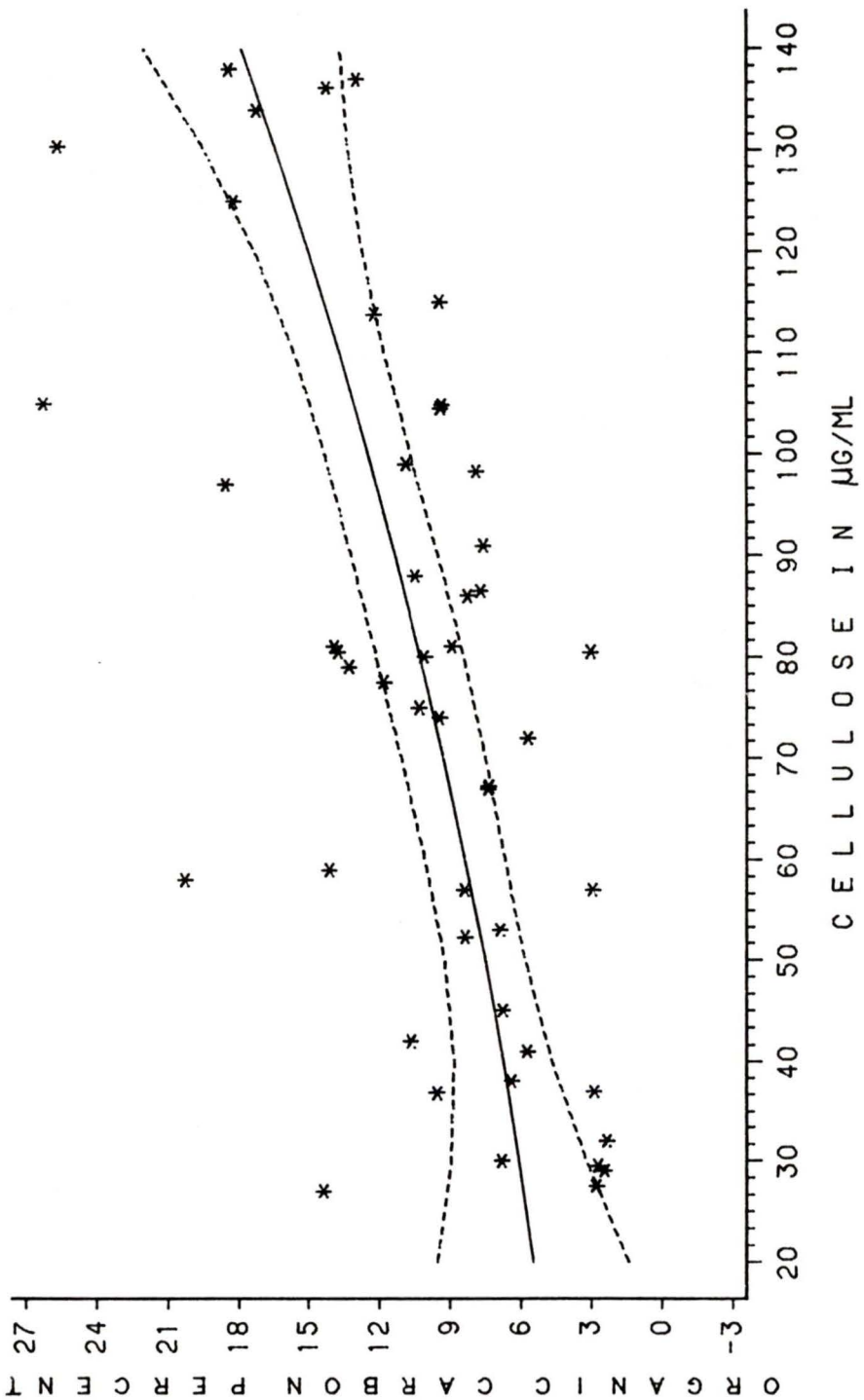


Table 15: Cellulose as percentage of organic carbon.

Stn	depth	% cellu fr Carbon
Tr1	0-5	9.94
	5-10	4.60
	10-15	4.84
	15-20	11.81
	35-40	18.30
Tr2	0-5	8.73
	5-10	6.19
	10-15	5.82
	15-20	6.49
	35-40	12.86
Tr5	0-5	9.83
	5-10	6.76
	10-15	7.09
	15-20	10.17
	35-40	11.59
T1	0-5	9.94
	5-10	6.24
	10-15	5.83
	15-20	10.48
	35-40	17.87
T2	0-5	7.41
	5-10	4.45
	10-15	4.68
	15-20	10.24
	35-40	11.36
R1	0-5	9.06
	5-10	7.35
	10-15	6.76
	15-20	7.75
	35-40	10.77

Figure 25: Linear regression for the carbon - cellulose relationship. 95% confidence intervals plotted df=28, F=33.390, P=0.0001, R^2=0.5363 regression coefficient significantly varies from zero (P=0.0001).



(P=0.0526 r=0.874) and C:N ratio (P=0.0536 r=0.873) at station T1 and with Eh (P=0.0589 r=-0.864) and % organic carbon (P=0.0524 r=0.874) at station Tr2.

Water column parameters.

Oxygen values obtained are presented in Table 16. As is seen from the table water column is oxygenated throughout. Values obtained corresponded well with the values reported for Northumberland Channel and Straits of Georgia by Waldichuk (1965) and Packman (1979).

Salinities measured are given in Table 17. Salinity profiles for Northumberland Channel do not vary from the expected for the particular season (Waldichuk, 1965 and Packman, 1979).

Temperatures are given in Table 18.

Table 16: Oxygen values (mg/l) at 8 stations in Northumberland Channel.

Samples taken during Pisces IV survey, July 1983. Depths measured above the bottom (approximately 100 m depths) are reported as negative values.

DEPTH (m)	T1	T2	R1	TR1	TR2	TR3	TR4	TR5
0	7.60	5.76	6.66	7.5	6.34	6.24	5.8	6.75
40	6.30	-	4.39	6.00	-	-	5.01	4.84
60	-	4.17	-	-	4.68	3.95	-	-
-1	5.80	4.67	5.18	5.87	4.70	5.00	4.75	4.34
-.10	5.30	4.57	5.05	5.45	4.82	4.47	4.57	4.56
-.05	4.80	4.50	4.95	5.30	4.80	4.45	4.15	4.44
-.02	4.35	4.59	4.16	5.00	4.36	4.60	4.13	3.74

Table 17: Salinity values (in ppt) for Northumberland Channel.

Samples taken during Pisces IV survey, July 1983. Depths measured above the bottom (approximately 100m depths) are reported as negative values.

DEPTH (m)	T1	Tr1	Tr2	Tr3	Tr4	Tr5	R1	T2
0	26.8	26.9	27.1	27.2	27.3	27.2	27.1	-
40-60	28.8	29.0	29.3	29.3	28.9	29.0	29.0	-
-1	30.1	30.2	30.0	30.1	30.2	30.2	30.3	30.0

Table 18: Water temperatures (in °C) in Northumberland Channel.

Samples taken during Pisces IV survey, July 1983. Depths measured above the bottom (approximately 100m depths) are reported as negative values.

DEPTH (m)	T1	Tr1	Tr2	Tr3	Tr4	Tr5	R1	T2
0	13.50	13.00	12.75	12.5	12.00	11.60	12.00	12.25
40-60	10.00	9.60	9.25	9.10	9.70	9.90	9.50	9.10
-1	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00

Benthic parameters.

Infauna analysis.

Abundance data 0.5-mm screen.

The abundance data matrix from July 1983 is given in Appendix D. Communities in Northumberland Channel are dominated by Polychaeta. The numeric dominance of Polychaeta is specially obvious in the data collected from the 0.5-mm screen, where Polychaeta represent from 78.1 to 94.5 % of total abundance (see Table 19). Polychaeta abundances per 0.1 m^2 at the transect stations are given in Table 20 and plotted in Figure 26. Abundances of organisms collected from 0.5-mm screens at stations T1, T2 and R1 are given in Table 21.

Table 19: Polychaeta as percentage of total abundance of organisms .

July 1983 survey, 0.5-mm screen; # - number; $\bar{x}$ - mean

gr #	T1	T2	Tr1	Tr2	Tr3	Tr4	Tr5	R1
1	88.5	87.8	88.4	80.9	80.4	91.7	78.1	92.4
2	91.7	87.2	89.5	78.7	91.0	92.6	88.9	89.9
3	94.5	87.8	94.4	86.5	89.2	92.9	92.0	83.3
$\bar{x}$	91.6	87.6	90.8	82.0	86.9	92.4	86.3	88.5

Table 20: Polychaeta abundances per 0.1 m^2 in Tr-stations (July 1983 survey, 0.5-mm screen).

$\bar{x}$ - mean, # - number

Polychaeta	Tr1			Tr2			Tr3			Tr4			Tr5		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cossuridae	92	252	28	52	68	100	104	332	322	200	464	336	16	78	153
Capitellidae	142	304	114	66	72	130	56	128	154	46	134	102	20	96	145
Cirratulidae	82	108	38	26	68	38	32	44	52	24	88	64	24	44	74
Lumbrinereid.	10	36	8	4	6	4		8	4	6	24	18	4	28	34
Paraonidae	10	24		24	2	10	16	42	16	78	30	34	6	28	45
Nephtyidae	12	16	2	4	14	4	4	4	4	10	24	28	9	22	25
Ampharetidae	26	26	10	18	22	12	10	10	18	12	20	24	11	6	9
Spionidae	18	46	2	14	22	30		2			10	36	23		16
Dorvilleidae	10	64	4	2	2	4	2	10	2		2	2	3		7
Syllidae	8	10				6	4					6	1		3
Phyllodocidae	14	8	8	2	4	2		8	2		4				2
Opheleidae	4										2				2
Eunicidae															4
Hesionidae	2					2					4	2			2
Sternaspidae															2
Polynoidae	10	56	6	12	16	8	8	8	4	10	18	10	1	4	9
Glyceroidea	8	2	2		6				2		2	4	1	4	5
Maldanidae	P				P			P	P	P	P	P	P	P	P
Terebellidae	2												1		
Onuphidae													1	2	

table 20 continued

Polychaeta	Tr1			Tr2			Tr3			Tr4			Tr5		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Nereidae		2													
Trochochaet.	6				6			2			2				
Trichobranch.						2	2			2	4			8	
Acrocirridae						4									
Arabellidae						2									
Lysaretidae								2			2				
Pilargidae								4							
Amphictenidae			4			2									
Arenicolidae		2													
Apistobranch.	2														
Abundance per 0.1 m^2	458	956	226	224	308	360	238	604	580	388	834	666	121	320	537
$\bar{x}$ Abund.		546.7			297.3			474			629.3			326	
# of Taxa	19	15	12	11	14	17	10	15	12	10	18	14	15	12	18
$\bar{x}$ # of Taxa		15.3			14			12.3			14			15	

Figure 26: Change in Polychaeta abundance with increasing distance from the outfall. Means of 3 grabs and standard errors plotted.

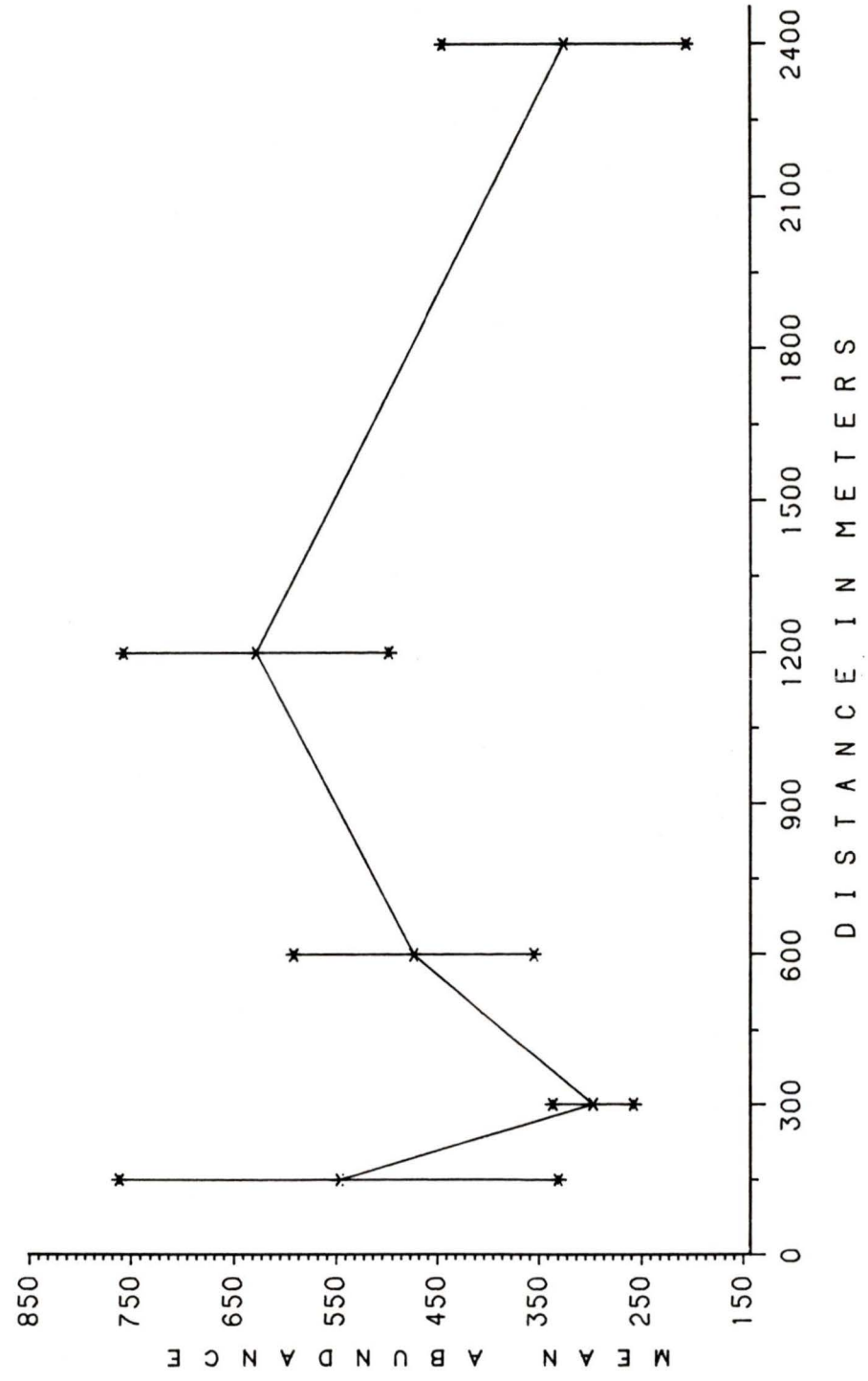


Table 21: Organisms identified from 0.5-mm screen (stn. T1, T2, R1).

July 1983 survey. Abundance is calculated per 0.1 m^2. $\bar{x}$ - mean; # - number.

Station	T1			T2			R1		
taxa/grab #	1	2	3	1	2	3	1	2	3
Cossuridae	2	84	54	42	64	25	54	52	10
Capitellidae	3	12	2	16	46	23	116	128	43
Cirratulidae	2	20	12	16	20	5	48	50	14
Dorvilleidae	8	4	17	2	2	3	2	0	6
Hesionidae	2	2	3	2	0	0	0	2	1
Paraonidae	2	6	2	12	12	12	18	24	4
Ampharetidae	2	4	0	4	4	12	4	14	6
Nephtyidae	2	0	3	16	6	5	16	18	10
Polynoidae	3	12	0	4	4	8	4	8	2
Lumbrinereidae	2	12	3	0	12	0	20	20	13
Glyceroidea	0	2	2	0	2	0	2	6	2
Spionidae	0	6	8	8	10	10	54	72	4
Terebellidae	0	2	0	0	2	0	0	0	0
Phyllodocidae	0	2	0	0	0	3	0	6	0
Maldanidae	0	0	0	0	0	P	P	P	P
Trichobranchidae	0	0	0	0	0	0	4	2	0
Onuphidae	0	0	0	0	0	0	0	2	0
Opheliidae	0	0	0	0	0	0	0	2	0
Amphictenidae	0	0	0	0	0	0	0	2	0
Syllidae	0	0	0	0	0	2	0	0	0
Bivalvia	0	0	0	4	10	7	12	8	5
Crustacea sp.1	0	4	3	4	0	3	2	6	2
Crustacea sp.2	0	0	3	4	2	3	10	8	4
Nemertea	0	P	0	P	P	P	P	P	P
Nematoda	0	0	0	0	0	2	0	0	0
Crustacea sp.3	0	0	0	0	2	0	0	0	0
Leptosynapta	0	0	0	2	0	0	0	6	4
Dentalium sp.	0	0	0	2	0	0	2	4	2
Crustacea sp.4	0	0	0	0	0	0	4	4	0
Pycnogonida	0	0	0	0	0	0	2	2	0
Cylichna sp.	0	0	0	0	0	0	2	0	1
Abund./0.1 m^2	28	172	112	138	198	123	376	446	133
$\bar{x}$ Abund./0.1 m^2		104			153			318.3	
# of taxa	10	15	12	16	16	17	21	25	20
$\bar{x}$ # of taxa		12.3			16.3			22	

Transect analysis: 0.5-mm screen data.

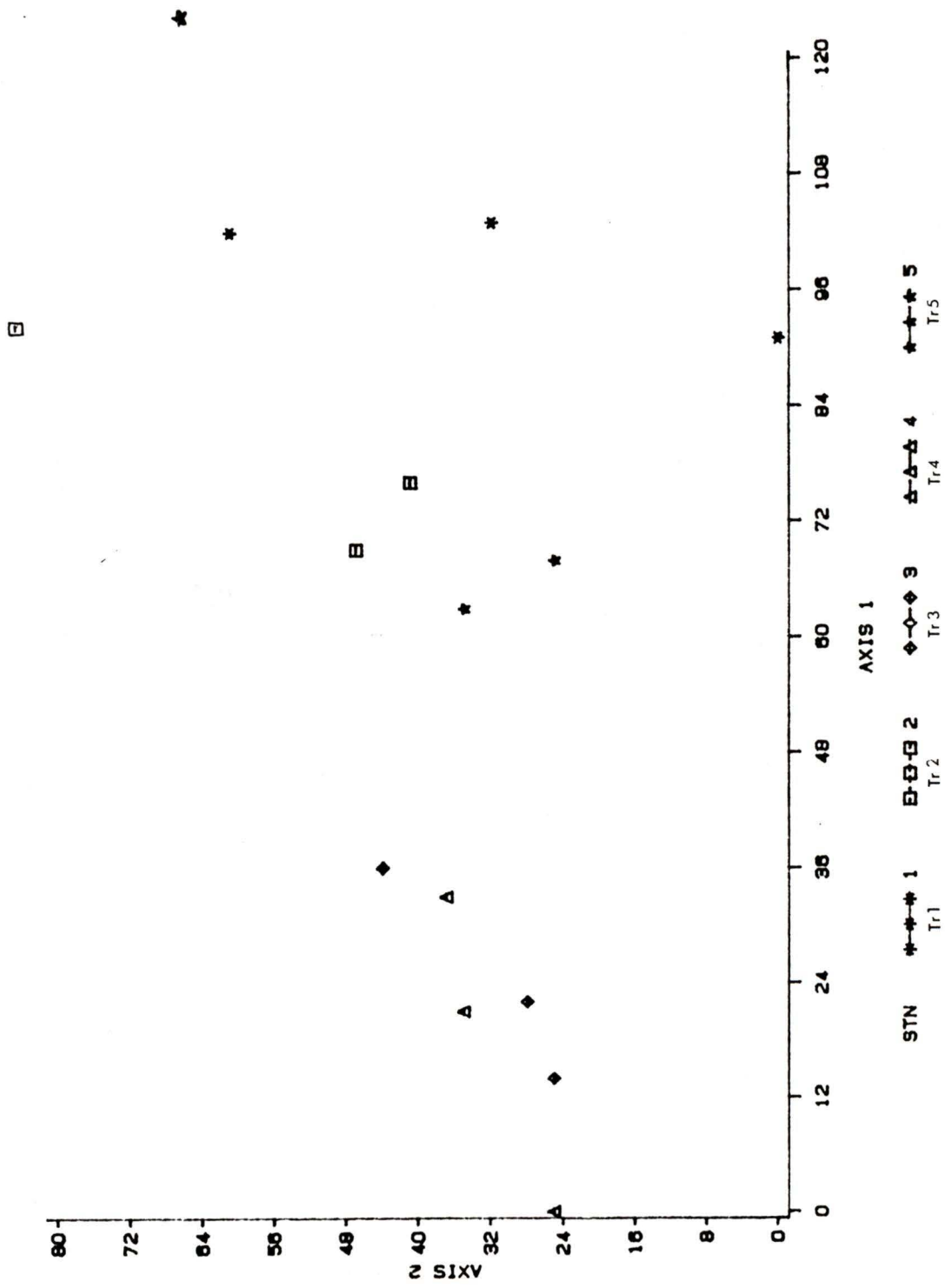
These data were analysed by detrended correspondence analysis and the plot of this ordination is presented in Figure 27. Four eigenvectors were derived from the data by DCA. From these the first axis accounts for 78.66 % of variance explained, the second for 16.01 % and the third for 3.94 %.

A correlation analysis done on the scores from the first three axes, with percent coarse wood (%cw), abundance, number of taxa and Polychaeta diversity (H) (calculated as Shannon-Wiener diversity function) demonstrated that axis 1 is significantly correlated (r=0.74, P=0.0024) with H and with %cw (r=0.64, P=0.0139). However the diversity function and %cw do not produce significant correlations with each other (r=0.49, P=0.0737), though the %cw , as was discussed previously, is significantly correlated with the distance from the outfall. The third axis is negatively correlated with abundance (r=-0.52 , P=0.0563).

A non-centered and centered principal component analysis (PCA) performed on the same data produced similar separation of samples on one of the first three axes, but the variance associated with this axis was smaller than that for DCA. Centered PCA produced clearer separation of stations than non-centered PCA, and DCA clearer results then centered PCA.

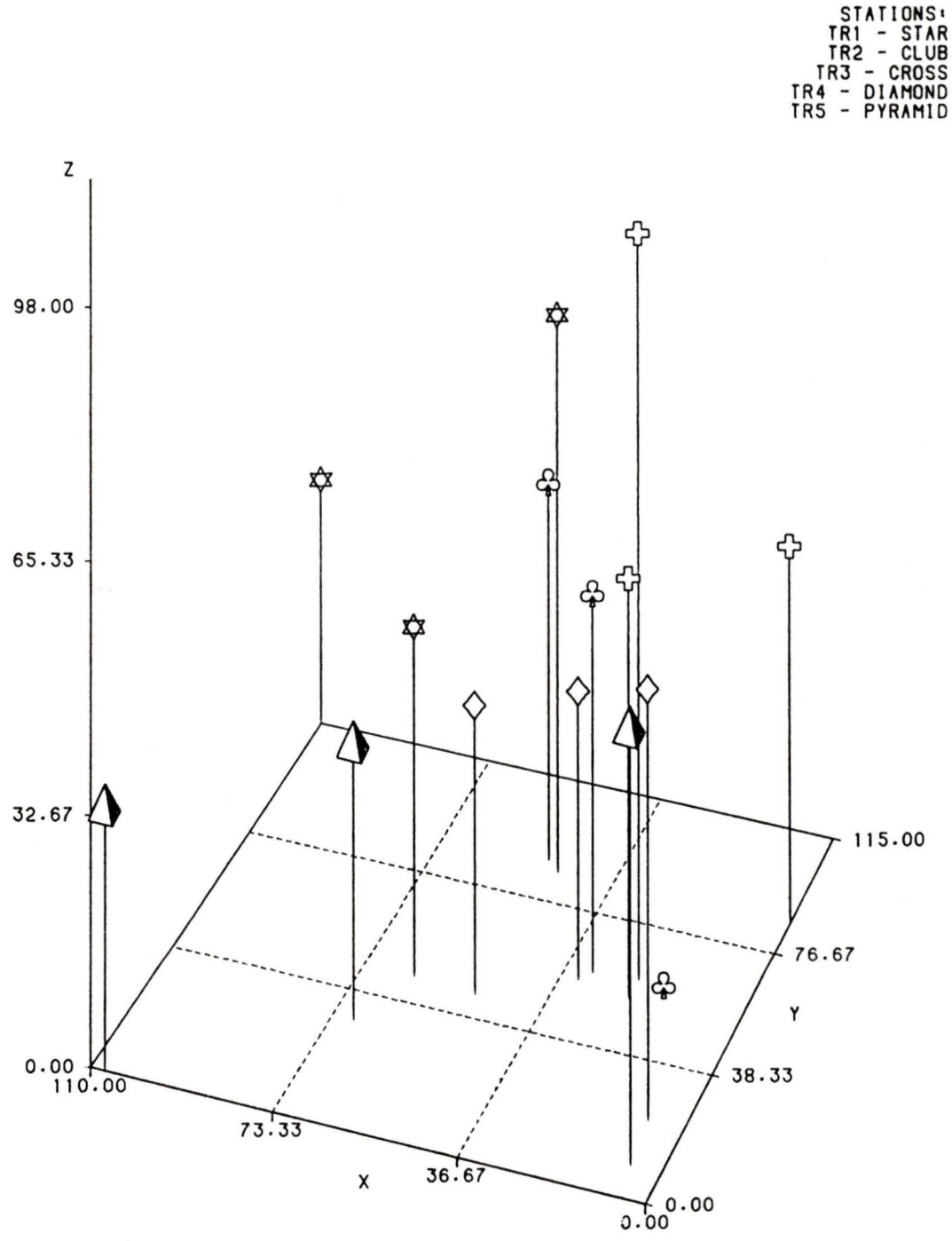
A logarithmic transformation of the 0.5-mm screen data to ln(x+1) form reduced the effect of large abundances of a few numerically dominant Polychaeta families. The results (Figure 28) show that the separation of stations was reduced, but station Tr5 is no longer placed in the centre of the gradient (which was the case with non transformed data), but rather is associated with station Tr4, as would be expected. Stations Tr1, Tr2 and Tr3 do not separate clearly suggesting

Figure 27: Detrended correspondence analysis on Polychaeta data from 0.5-mm screen (Tr-stations, July 1983).



that their separation in ordinations performed on non transformed data is a mere reflection of the increase in abundances of numerically dominant families of Capitellidae, Cirratulidae and Cossuridae, from station Tr1 to station Tr3.

Figure 28: **Result of detrended correspondence analysis on Polychaeta data, from Tr-stations, in logarithmic [ln(x+1)] form.** Data from the July 1983 survey; 0.5-mm screen.



Cluster analysis.

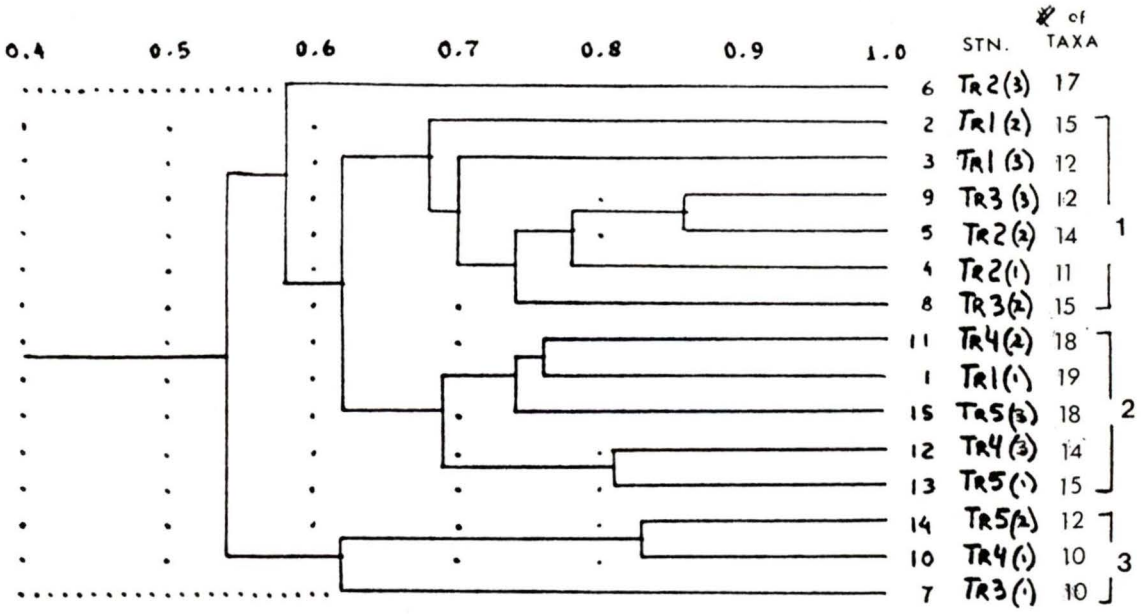
An inverse cluster analysis, using Jaccards coefficient of community and weighted pair-group clustering, produced a dendrogram (see Figure 29) where two samples each from stations Tr1 , Tr2 and Tr3 formed a cluster (1) separated from two other clusters (2 and 3) representing mainly stations Tr4 and Tr5. A high similarity of base clusters (>0.5) and sample scatter suggest that Polychaeta communities are rather similar in their composition throughout the transect. The occasional displacement of individual hauls from clusters associated with their station indicates large within station variability, which was observed in the original data and is assumed to be associated with non-homogeneity of the environment. There is also a trend for hauls with similar number of taxa to cluster together. Thus stations Tr4 and Tr5 sort into two clusters, one with 14-19 taxa present and another with 10-12 taxa present (Figure 29).

The use of the Jaccards coefficient results in loss of information on taxa abundance. Therefore the Czekanowski coefficient, which takes abundance into account, was employed for subsequent clustering. The weighted pair-group clustering showed slightly higher similarity levels for base clusters (Figure 30) than non-weighted clustering. In the dendrogram of weighted pair-group clustering utilizing the Czekanowski coefficient of similarity, two large clusters differing from those with Jaccards coefficient can be distinguished. They separate at the 0.55 similarity level. One of these can be further separated into two smaller clusters, resulting in three distinct categories:

#1 - cluster of samples associated with high Polychaeta abundance (388-956/m^2) ,

#2 - cluster of samples with medium Polychaeta abundance

Figure 29: Dendrogram of Tr-stations hauls (0.5-mm Polychaeta data only). Produced using Jaccards coefficient of community and weighted pair-group clustering.



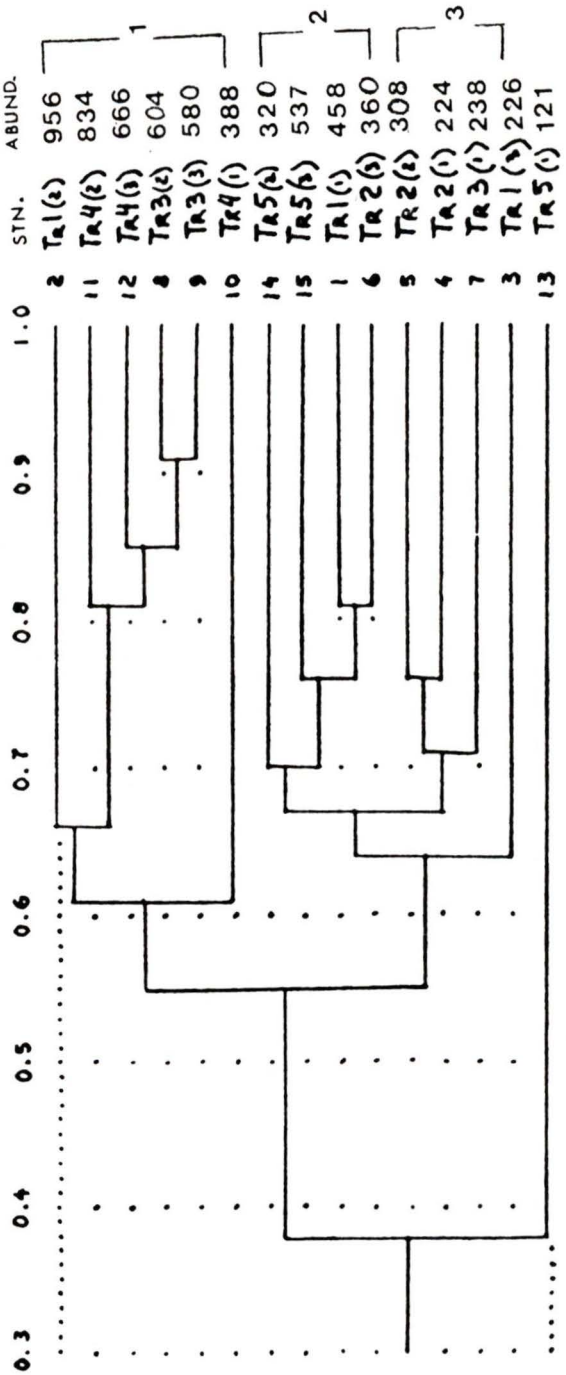
(320-537/m^2),

#3 - cluster of samples with low Polychaeta abundance

(226-308/m^2).

Sample Tr5(1) is an outlier and is clearly separated from the rest of the clusters. The peculiarity of this particular haul is that by its composition it relates well to other hauls at this station, but the abundances of taxa are so low, that any analysis which takes abundance data into consideration sets it aside. Cluster analysis confirms that station Tr1 has the largest within-station variability, as shown previously in Figure 26. The clustering of hauls from station Tr2 together with the hauls from station Tr5 supports the earlier conclusion from the DCA ordination, that their similarity is mainly due to low Polychaeta abundance.

Figure 30: Classification of Polychaeta data from 0.5-mm screen, Tr-stations only. Weighted pair-group clustering utilizing Czekanowski coefficient.



All station analysis: 0.5-mm screen data.

When the data from stations T1, T2 and R1 are added to the analysis of the Polychaeta data from the 0.5-mm screen, the variability is increased and a different picture of station to station relationships is encountered (Figure 31). The first axis of the DCA on these combined data accounts for 66.01 % of the variance and correlates negatively with the diversity function calculated on Polychaeta data ($r=-0.80$, $P=0.0001$). The third axis produces significant correlation with % cw ($r=0.49$, $P=0.0141$) and accounts for 9.08 % of the variance. The first two axes together account for 84.97 % of the variance and clearly separate station T1 from the rest of the stations, substantiating the a priori assumption that this station is indeed different from all the others. The separation of station T1 is also shown in Figure 32.

Axis 2, on which station T1 clearly separates, accounts for 18.96% of the variance, but no direct correlation with any measured parameters was established. Nevertheless the environmental data suggest that this separation most probably due to the amount of hydrogen sulfide in the first 5 cm of sediment (which is much higher at this station than in all others).

Inverse cluster analysis using the Czekanowski coefficient produced a dendrogram (Figure 33) in which two clusters can be distinguished:

1 - hauls with low to medium Polychaeta abundance (46-408/m^2),

2 - hauls with high Polychaeta abundance (580-956)/m^2).

They separate at 0.15 similarity level. The first one can be further subdivided into:

1a - hauls with low abundance (108-122),

1b - hauls with medium abundance (166-388),

1c - hauls with medium-high abundance (226-537).

Figure 31: A three dimensional diagram of results from detrended correspondence analysis on Polychaeta data from 0.5-mm screen (all stations).

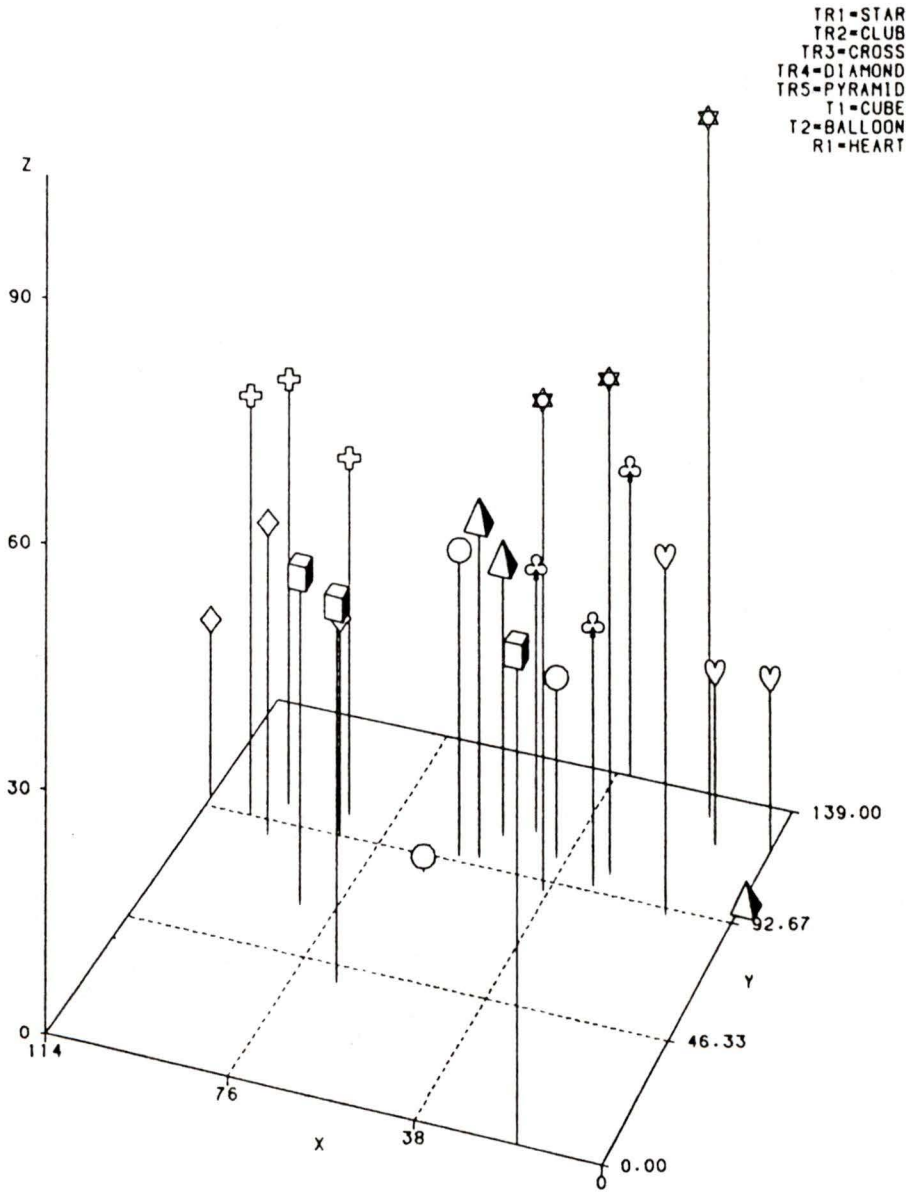


Figure 32: Separation of stations on first two axis derived by detrended correspondence analysis of the Polychaeta data from all stations (July 1983, 0.5-mm screen).

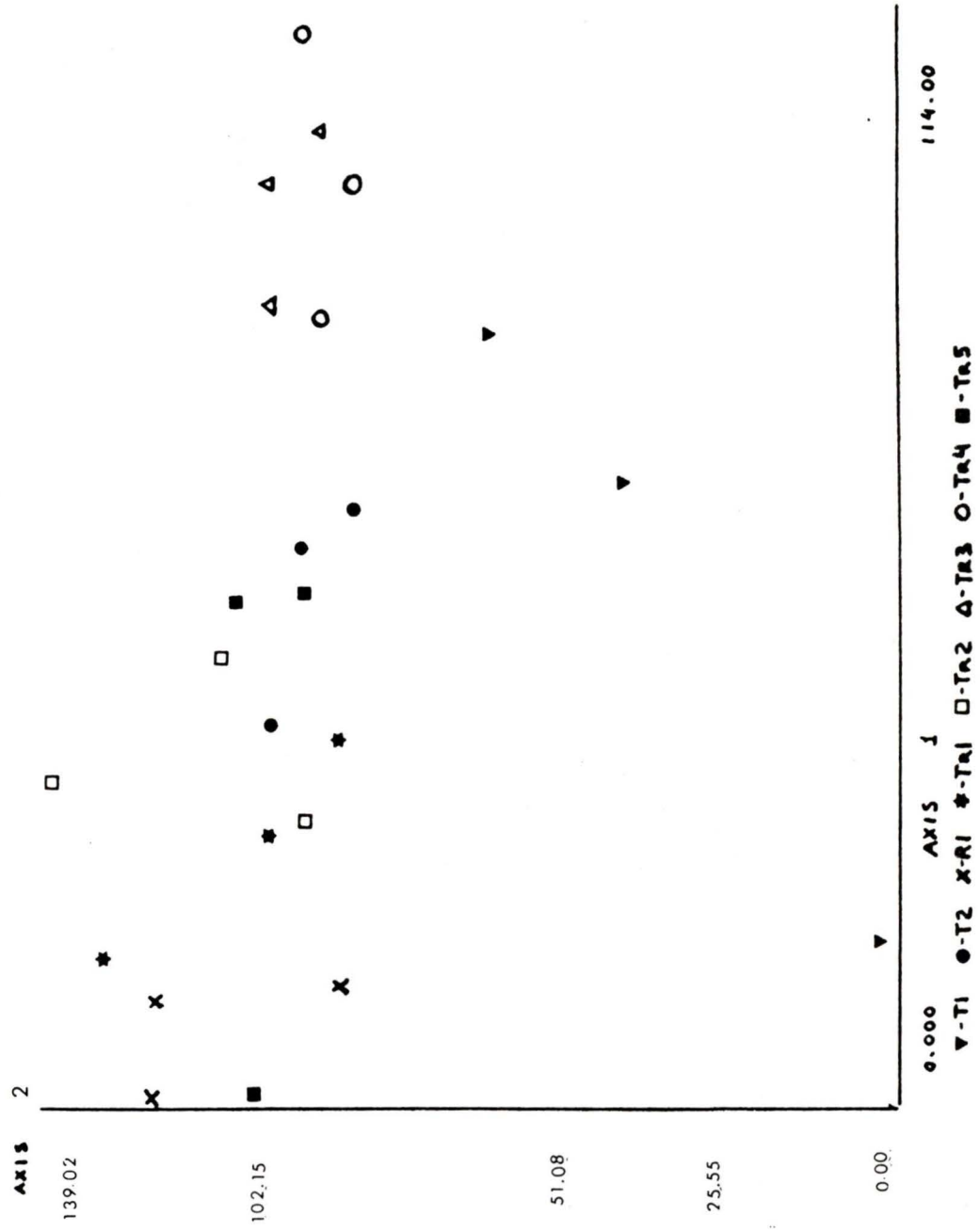
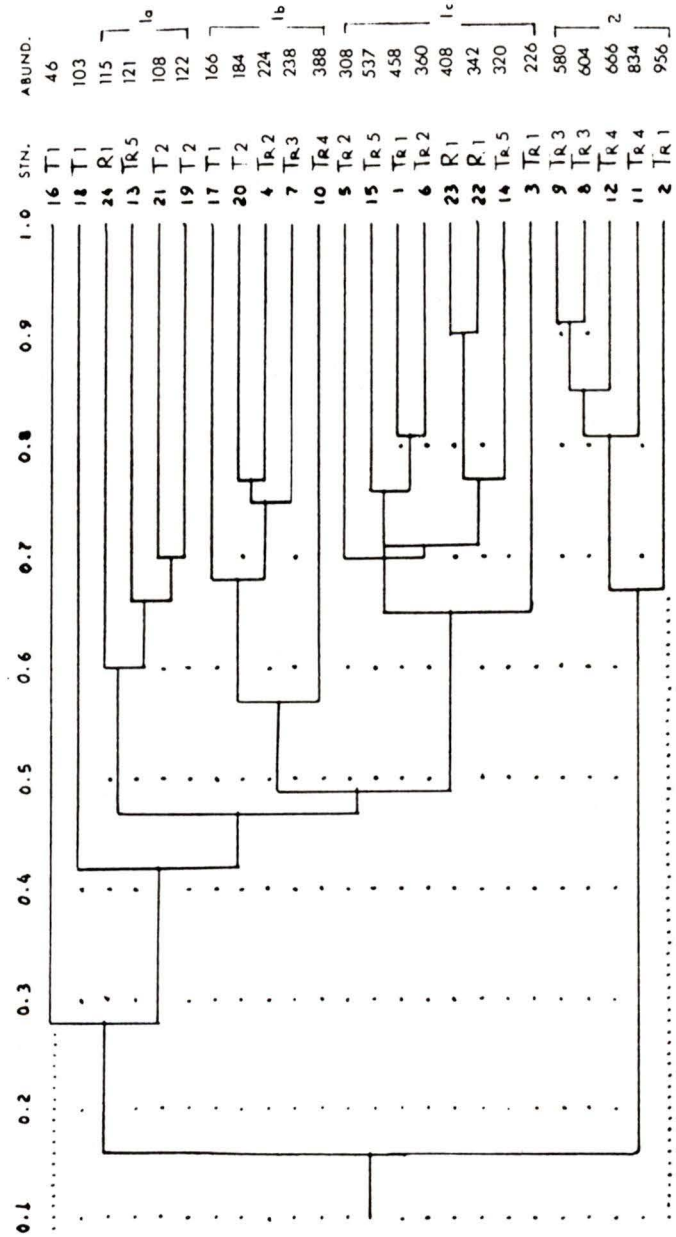


Figure 33: Classification of Polychaeta communities from 0.5-mm screen, all stations. Weighted pair-group clustering utilizing Czekanowski coefficient.



Abundance data: 2.0-mm screen.

Abundance data from the 2.0 mm-screen separations for the transect stations are given in Table 22. Mean abundances and frequencies of occurrence (in three samples) of the two major taxonomic groups found in samples from the 2.0-mm screen, are summarized in Table 23. The mean abundance of taxa is higher in stations closer to the outfall. That tendency may be partially due to the nature of the substrate, since more wood particles retained on the 2.0-mm screen will cause more animals to get caught among the debris.

The mean abundance of Polychaeta and Mollusca in Tr-stations is plotted against distance from the outfall in Figure 34. As seen from Figure 34 the variability in station Tr1 is very high, as was previously observed for the data from the 0.5-mm screen. There is a general trend toward decreasing abundance away from the outfall. When compared with data collected on the 0.5-mm screen, from the same stations, abundance values are ten fold lower and the number of taxa (species richness) is greatly reduced (Table 22).

Data collected from 2.0-mm screen for stations T1, T2 and R1 are presented in Table 24. A general increase in total abundance and species richness in station R1 versus stations T2 and T1 is apparent from Table 24.

Grab sample R1(3) proved to be different from the rest of the samples. No organisms were found in its 2.0-mm screenings. This sample also had the lowest abundance value (for this station) from the 0.5-mm screen data.

Table 22: Abundances (per 0.1 m^2) of Polychaeta and Mollusca identified from Tr-stations (2.0-mm screen).

Organism	Tr1			Tr2			Tr3			Tr4			Tr5		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Capitellidae	32	6		1	4	6		6	3						
Maldanidae	P			P				P	P	P		P		P	P
Ampharetidae	11	2	3	4	2		6	2	2	3	5	3		1	
Harmothoe lunulata	4	3	2	2	1	2		2	2		1				
Sternaspis scutata		2					2	2				3	1		
Laonice cirrata	2					2	2	2	2						
Glycera capitata		2		1	1			1							
Onuphis irridescens			1		1			2							2
Terebellidae			2	1				2							
Eteone californica	2				1		2								
Tharyx multifilis	5							4							
Chaetozone spinosa			2			2									
Dorvillea caeca	9	2			1										
Prionospio cirrifera	2														
Prionospio stenstrupi	2														
Spiophanes kroyeri	2														
Goniada maculata			1												
Cossura sp.	4														
Nephtys punctata				1	1						1	1			1
Nephtys ferruginea									2						
Nephtys caecoides					1										

table 22 continued

Organism	Tr1			Tr2			Tr3			Tr4			Tr5		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Gattyana ciliata					1										
Polynoidae sp.					1										
Trochochaet.					1				2						
Phyllodoce groenlandica				1			2								
Chaetozone setosa					1										
Glycera tenuis					1										
Glycinde armigera				1											
Aricidea lopezi					2										
Nereis neoneanthes					1										
Aricidea ramosa								2							
Pilargis berkelayae							4	2							
Lumbrinereis luti							2			1					
Trichobranchidae										3	2				
Harmothoe sp.													1		
Parvilucina tenuisculpta		3	2	1	1	2	2	6	2	1			1		
Axinopsida serricata		10		1		3	2	2		1		3	2		2
Gari californica		5		1	1		2					1			
Yoldia scissurata					1		2	2						1	1
Solemya reidi				1											
Lucinoma annulata					1										
Macoma calcarea											1				1

table 22 continued

Organism	Tr1			Tr2			Tr3			Tr4			Tr5		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Romboidella sp.							2								
Thyasira flexuosa													1		
Macoma carlottensis													1		
Abundance per 0.1 m^2	77	36	12	15	21	17	28	41	13	9	13	7	7	2	7
number of Taxa	12	10	6	13	20	6	11	17	7	6	6	5	6	3	6
mean	9.3			13			11.7			5.7			5		

Table 23: Mean abundance and frequency of occurrence in three grabs of Polychaeta and Mollusca in Tr-stations (2.0-mm screen).

Organism	Tr1		Tr2		Tr3		Tr4		Tr5	
	freq	abun	freq	abun	freq	abun	freq	abun	freq	abun
Capitellidae	67	126.7	100	36.7	67	30				
Harmothoe lunulata	100	30	100	16.7	67	13.3	33	3.3		
Ampharetidae	100	53.3	67	20	100	33.3	100	36.7	33	3.3
Laonice cirrata	33	6.7	33	6.7	100	20				
Sternaspis scutata	33	6.7			67	13.3	33	10	33	3.3
Glycera capitata	33	6.7	67	6.7	33	3.3				
Tharyx multifilis	33	16.7			33	13.3				
Dorvillea caeca	67	36.7	33	3.3						
Lumbrinereis luti	33	6.7			33	6.7	33	3.3		
Terebellidae	33	6.7	33	3.3	33	6.7				
Onuphis irridesc.	33	3.3	33	3.3	33	6.7			33	6.7
Eteone californica	33	6.7	33	3.3	33	6.7				
Prionospio cirrif.	33	3.3								
Prionospio steens.	33	3.3								
Spiophanes kroyeri	33	3.3								
Cossura sp.	33	13.3								
Goniada maculata	33	3.3								
Nephtys punctata			67	6.7			67	6.7	33	3.3
Chaetozone spin.	33	6.7	33	6.7						
Nephtys caecoides			33	3.3						
Gattyana ciliata				33	3.3					
Polynoidae sp.				33	3.3					
Trochochaetidae			33	3.3	33	6.7				
Phyllodoce groen.			33	3.3	33	6.7				
Chaetozone setosa			33	3.3						
Glycera tenuis			33	3.3						
Glycinde armigera			33	3.3						
Aricidea lopezi			33	6.7						
Nereis neoneanth.			33	3.3						
Maldanidae	33	P	33	P	67	P	67	P	67	P
Nephtys ferrugin.					33	6.7				
Pilargis berkel.					67	20				
Aricidea ramosa					33	6.7				
Trichobranchidae							67	16.7		
Harmothoe sp.									33	3.3
Parvilucina tenui.	67	16.7	100	13.3	100	33.3	33	3.3	33	3.3
Axinopsida serric.	33	33.3	67	13.3	67	13.3	67	13.3	67	13.3
Gari californica	33	16.7	67	6.7	33	6.7	33	3.3		
Yoldia scissurata			33	3.3	67	13.3			67	6.7
Solemya reidi			33	3.3						
Lucinoma annulata			33	3.3						
Macoma calcarea							33	3.3	33	3.3

table 23 continued

Organism	Tr1 freq abun	Tr2 freq abun	Tr3 freq abun	Tr4 freq abun	Tr5 freq abun
Macoma carlotten.					33 3.3
Thyasira flexuosa					33 3.3
Rhomboidella sp.			33 6.7		
Abundance per m^2	406.8	196.3	240	99.9	53.1
number of Taxa	9.3	13	11.7	5.7	5

Figure 34: **Change in abundance (Polychaeta and Mollusca) with distance from the outfall (2.0-mm screen).** Means and std.errors plotted. Stations can be identified by distance from the outfall: Tr1=150m, Tr2=300m, Tr3=600m, Tr4=1200m and Tr5=2400m.

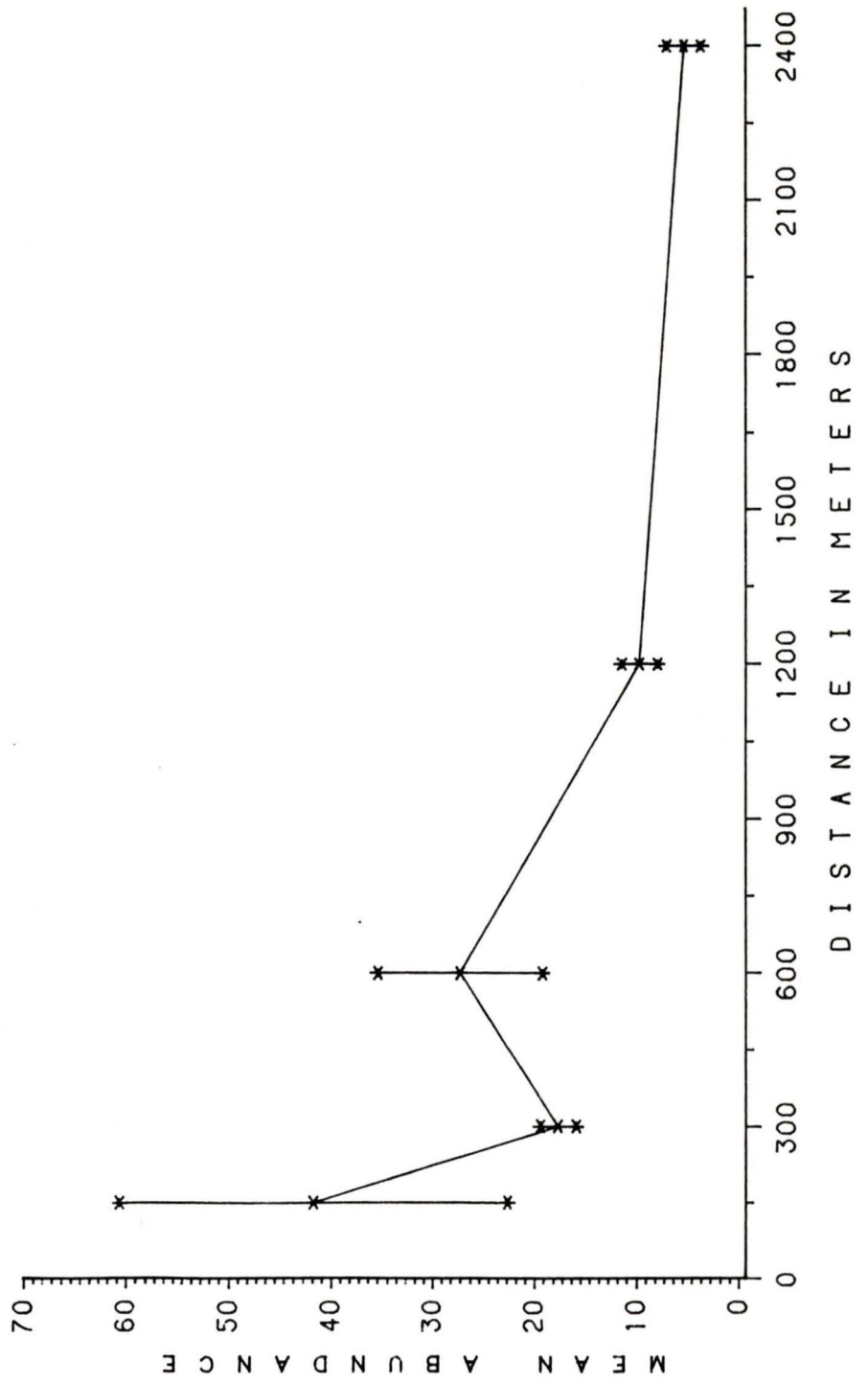


Table 24: Data from 2.0-mm screen for stations T1, T2, R1.

- number

Organism	T1			T2			R1			Comments
	1	2	3	1	2	3	1	2	3	
Capitellidae	2		2			3	3	2		
Spionidae	1		4			P	1			Polydora,Laonice cir.
Leptosynapta		2		4	3	2	16	8		
Glyceroidea	1	1		2	1		3	1		Glycinde armigera
Maldanidae		P	P	P			P	P		
Dorvilleidae		3	1							
Yoldia amigdalea		1								
Axinopsida serric.	1	1		1	9	6	1			
Lucinoma annulata			1							
Macoma calcarea	1				1					
Gari californica						2	1			
Onuphis irridesc.				2	1	1	2			
Pectinaria calif.							2			
Polynoidae							1	1		
Lumbrinereidae							P	2		
Ampharetidae				2	2					
Nemertea					1					
Nephtys ferruginea				2						
Nephtyidae (unid.)							P			
Sternaspis scutata							1			
Thyasira flexuosa							1			
Cirratulidae							1			
Cylichna sp.								2		
Ophiuroidea								1		
Unident. organism							1			
Parvilucina ten.						1	2			
Macoma carlott.							2			
Abundance per 0.1 m^2	6	8	8	13	15	15	37	17	0	
mean		7.3			14.3			18		
# of taxa	5	6	5	7	7	7	18	8	0	
mean		5.3			7			8.6		

Motile macrobenthos.

Results of macrobenthos transects done using submersible Pisces in July 1983 are given in Table 25. In all three areas the motile macrobenthos was fairly abundant and reasonably diverse, contrary to observations made during Aug.- Sep. 1982 dives, where depletion of motile macrobenthos, in the area of the mat, was noted (no counts were made). A Wilcoxon matched-pairs signed-ranks test showed that significant ($P<0.05$) differences exist between the reference and mid-channel area, though no significant differences were found between the test and reference areas or test and mid-channel area . Thus the test was inconclusive and showed that test and reference areas can not be separated on the basis of objective macrobenthos counts. The fact that some of the motile macrobenthos species can burrow and others can migrate into the water column may have affected the results. Time was not devoted in this study to the elimination or reduction of the effects of such occurrences on the macrobenthic counts, but patchiness in distribution of the burrowing holothurian Leptosynapta sp. was noted in the field, as well as its relative abundance during some dives and scarcity during others.

Table 25: Results of Pisces macrobenthos transects.

Species	Test area 16 March 1983 Tr.1 *(272)	Tr.2 (199)	Tr.3 (163)	Reference area 17 March 1983 Tr.1 (344)	Tr.2 (199)	Tr.3 (36)	Reference area Mid-channel 17 March 1983 Tr.4 (290)	Tr.5 (507)	Tr.6 (181)
Shrimp 1	651	385	159	161	81	101	423	333	200
Shrimp 2	2	14	10	-	5	5	18	16	12
Shrimp 3	12	19	8	8	8	6	24	4	1
Sq. lobster	8	-	1	5	7	-	-	1	2
C.magister	2	3	5	-	-	2	3	8	5
Puggettia	4	1	1	1	-	-	4	4	2
Flatfish	4	8	4	-	1	3	-	4	3
Anemone	1	-	1	5	10	2	3	9	6
Polychaeta	1	-	-	4	2	2	2	5	3
Pagurus sp.	1	-	-	1	3	-	1	1	-
Asteroidea	2	-	1	1	-	-	-	-	1
Octopus	1	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	6	-	1	-	-
Ophiuroidea	-	-	-	-	1	-	-	-	-

*length of transect in meters

Notes on probable species within taxa listed

Shrimp 1: Pink shrimp - Pandalus borealis
Smooth pink shrimp - Pandalus jordani

Shrimp 2: Prawn - Pandalus platyceros

Shrimp 3: Coonstripe shrimp - Pandalus danae

Sq.lobster: Munida quadrispina

Anemone: Metridium sp., Stomphia sp.,
Pachycerianthis sp., Cribrinopsis sp.

Asteroidea: Orthasterias, Pycnopodia

Polychaeta: fam.Polynoidae

Gastropoda: fam.Buccinidae

Summary of results obtained.

Summary of environmental trends.

The trends observed in the environmental parameters measured are summarized in Table 26. Such parameters as %cw, organic carbon and nitrogen, C:N ratio and sulfide (both pooled by station), and cellulose exibited significant decreases with distance from the outfall. Organic carbon, organic nitrogen and cellulose also exibited significant decreases with increased in-core depth.

Table 26: Summary of environmental trends.

Parameter	Trend with DISTANCE	Trend with DEPTH (in-core)
Wood-fly ash	Decrease (S)	5-10 cm (NT)
organic C	Decrease (S)	Decrease (S)
organic N	Decrease (S)	Decrease (S)
C:N ratio	Decrease (S)	Decrease (NS)
Sulfide	Decrease (S)	not linear trend
Eh	none	none
Ph	none	Decrease (NS)
Cellulose	Decrease (S)	Decrease (S)

S - significant
NS - not significant
NT - not tested

Summary of biological results.

I. 0.5-mm screen.

Tr stations:

1. Abundance initially increases with increased distance from the outfall. It peaks at stations Tr3 and Tr4 and subsequently decreases at station Tr5. Within station variability is large.
2. Species richness in transect stations does not vary significantly, with minimum value of 14 (Tr3(1)) and maximum 26(Tr5(3)).
3. Detrended correspondence analysis on Polychaeta data separates stations reasonably well, with axis 1 correlated with %cw and Shannon-Wiener diversity function (H) and axis 3 correlated with abundance. The second axis did not correlate directly with any measured parameter.
4. Detrended correspondence analysis on ln(x+1) transformed Polychaeta data separates stn. Tr5 from the cluster of sations Tr1-Tr3, with hauls from station Tr4 occupying an intermediate position.
5. A cluster analysis utilising the Czekanowski coefficient produced clusters based on taxa abundance. Cluster analysis utilising Jacccards coefficient produced clusters based on diversity. Cluster analysis in any form did not show distinct separation between stations.

Stations T1, T2 and R1:

1. Abundance is lowest (mean abundance = 103/0.1 m^2) in station T1 (bacterial mat present) and is highest in station R1 (mean abundance = 318.3/0.1 m^2).
2. Species richness follows the same trend as abundance, with maximum number of taxa present at station R1 (mean=22) and minimum at station T1 (mean=12.3).

All stations:

1. Detrended correspondence analysis on data from all stations separated station T1 from the rest of the stations. The first axis of this ordination was correlated with Shannon-Wiener diversity function (H), the third axis correlated with %cw and the second axis, though not exibiting direct correlation with any parameter, is thought to reflect levels of H_2S at the sediment-water interface.

II. 2.0-mm screen.

1. Tr-stations. - Decrease in abundance with distance (large within station variability).
2. T1, T2 and R1. - Increase in total abundance and species richness in station R1 versus stations T2 and T1. Reduced infauna - station T1.

III. Motile macrobenthos.

No trends observed.

GENERAL DISCUSSION.

In order to discuss the results obtained, the original constraints and the underlying assumptions of the study must be recalled.

The study design was based on the limited (sometimes contradictory) oceanographic data available on Northumberland Channel (Waldichuk, 1965; Lawther, 1973; Viegers and Buckingham, 1977). It was assumed from data available on plume dispersion and current data that during the greater part of the year the plume from the diffuser is trapped under the surface of the channel below a 20m depth. If this assumption is correct then those wastes which sink below 18.7m would have to be flushed through Fairway Channel (north-west) rather than through Dodd Narrows (south-east) (Figure 1) since 18.7m is the maximum mean depth of Dodd Narrows (Waldichuk, 1965). If the wastes are flushed north-westerly, then as the plume moves in this direction the deposition of solids would occur gradually, depending on particle size and density.

The organic loading gradient created by the deposition of suspended solids (woody in origin) from the plume would change physical and chemical parameters of the sediment environment which would elicit a response from benthic communities. The sampling transect (stations Tr1 to Tr5) was designed to document such responses to the gradient (see Introduction and Materials and Methods).

Though no studies have been undertaken at Harmac to assess the proportion of sedimenting matter attributable to diffuser operations versus the total amount of sedimenting matter, it is also clear that this proportion would change, during the year and between years, as the contributions from the other sources, such as river runoff, phytoplankton blooms, log booms and log, wood chip and sawdust transports vary. It was nevertheless assumed that the plume from the underwater diffuser at Harmac Pulp Mill was the major contributor of organic matter to the sediments of Northumberland Channel.

If these two assumptions are true then a more or less unidirectional organic enrichment gradient should be encountered in Northumberland Channel. The data obtained from the transect (stations Tr1 to Tr5) suggest that such a gradient indeed exists.

As was shown in Figure 8 the percentage of coarse wood particles (of total grab volume) larger than 0.5-mm decreases with increased distance from the outfall. It is less apparent but still noticeable that there is a corresponding decrease in the percentage of larger wood particles (>2.0-mm) from the total volume of wood. Also, within station variability was much higher in stations closer to the outfall than in those further away (this holds true for all parameters measured). Such observations support the assumption that the diffuser plume moves northwesterly creating an enrichment gradient. The large variability within the first three stations can be explained by the tendency of fly-ash to form aggregates and other components of the plume to flocculate in the water column, thus creating a patchy distribution in the sediment (Pomeroy, 1982; Peer, 1972). The distribution of plume components in the sediment can be affected by a

possible meandering of the plume, due to changing tides and associated current changes occurring in the channel. Thus it is possible that the plume may pass over certain areas repeatedly, while reaching other areas only occasionally. The core data (Table 4) provide additional information on the dispersion of large wood particles throughout the sediment. The disappearance of the defined fly-ash layer in cores from station Tr4 corresponds to the drastic decrease in the amount of wood found in the grab samples.

The presence of the fly-ash layer in the transect stations located within 600 meters from the outfall (see Table 4), and its absence in station T2 located on the shelf slope on the pulp mill side of the channel, indicates that the layer was formed from the diffuser plume, rather than from surface water discharges carried out prior to the diffuser installment. So if it is assumed that such deposits arose from diffuser operations it is clear from their distribution in the sediment, that they were accumulating during a particular time period in the past, thus forming a defined layer, and that the amount of fly-ash discharge afterwards was dramatically reduced, so that it was no longer accumulating at the same rate and did not constitute a major component of the sediment. It was mentioned (but not confirmed) by Harmac representatives, that large quantities of fly-ash could have been released during initial operations of the diffuser until a special clarifier was put in, and that such discharges diminished approximately three years after the operation commenced.

From the information available the average sedimentation rates in Northumberland Channel could be estimated to be varying between 1.25 and 2.25 cm per year. Such large variability in sedimentation rates, specially when found at

the same station, again suggests a heterogeneity in the environment. The observed high variability within stations is enhanced (or may be even partially created) by errors built into the methodology of remote sampling. Strong surface currents make it difficult to hold the boat on station, depths over a hundred meters do not permit anchoring, thus increasing sampling errors. The actual sampling area for one station was estimated in Loch Eil to be about 90 m^2 (Vance, 1977). That estimate does not seem to be unreasonable for Northumberland Channel, based on vessel drift during sampling.

The patchy deposition of suspended solids creates different physical and chemical conditions in the sediment. The effect of the deposition of fly-ash can be assumed to be mainly physical by smothering, since fly-ash was measured to be 84% carbon. Nevertheless leaching of toxic substances from the fly-ash would not be suprising, due to possible adsorption of ions on the surface of fly-ash. As was stated by Zobell (1946) it is not quantity, but type of organic matter which is of utmost importance, when studying its effects on sediment chemistry. Fly-ash (which is mainly amorphous carbon) can be considered refractile organic matter, basically nondegradable. It will be buried under newly deposited detritus, where as pulp fiber will eventually decompose.

The majority of the average 12,000 tonnes per day of suspended solids coming from the diffuser (see Appendix E) consists of bleached and unbleached wood fiber. This fiber is 40-50 % cellulose (Fenchel and Blackburn, 1979) and is a nutritional medium for cellulolytic bacteria in the sediment, which produce lactate and other low molecular weight components as by-products of their metabolism (Fenchel and Blackburn, 1979). Pulp fiber will degrade better then

bark or wood chips, due to mechanical damage to cell walls during pulping, which makes it more accessible for cellulolytic bacteria (Vance, 1977). Vance (1977,1982) found that the highest rate of degradation of cellulose is found at the sediment-water interface and is due to aerobic cellulolytic bacteria. This agrees with the findings of this study, that degradation of cellulose approaches a negative exponential trend with the rate of degradation decreasing sharply after the first few centimeters in the sediment. Experimental studies of pulp fiber degradation at different core depths show that maximum losses occurred in the upper 10 mm of sediment during the first 2 weeks (34%), but though degradation continued afterwards its rate steadily diminished (Pearson, Stanley and Stanley, 1982).

The linear relationship between the organic carbon and cellulose in the sediments, though still significant (for pooled data), is somewhat obscured at transect stations due to the presence of a fly-ash layer. Cellulose represents approximately 10% of the total measured organic carbon, a value comparable with those found elsewhere (Pearson and Stanley, 1977) in surficial sediments, but its proportion increases with sediment depth to 11-18 %, reflecting the fact that cellulose is one of the slower degrading sources of biologicaly available carbon and the fact that its degradation is severely impeded by its submersion into an anoxic zone.

The metabolic by-products of the cellulolytic bacteria serve as a medium for growth of sulfate reducers, which can only utilise a limited number of carbon compounds (Postgate, 1965). The product of their metabolism is hydrogen sulfide. The maximum amount of sulfate reduction in marine sediments usually occurs within the first 15 centimeters below the sediment water interface (Madden,

Bryder and Poole, 1980). From the values of dissolved sulfide obtained the maximum sulfate reduction in Northumberland Channel occurs within the first 20 cm of sediment (Appendix A).

Another indication of the decrease in sulfide production with depth is the changes observed in the colour of the sediment (see Table 6 to Table 9). The change of colour from black, signifying presence of iron sulfide (FeS), to yellow-grey , characterising pyrite (FeS_2), and a corresponding decrease in levels of dissolved sulfide suggests that the amount of H_2S produced or reaching by diffusion (or both) deep layers of sediment (below 25 cm) is very small.

Thus sulfur present in surficial sediments (0-20 cm) and previously available to the biota is taken out of circulation by a natural process of sediment diagenesis. It is the activity of sulfate reducing bacteria which is responsible for the negative values of the Eh (oxidation-reduction) potentials in the sediments (see Table 10 and Table 11).

The oxidation reduction potential is a very rough measure of chemical sedimentary conditions. There are a number of theoretical and practical problems associated with its measurement (Stumm, 1965; Whitfield, 1969, 1974) and its accuracy is reported to be within 50 mv (Whitfield, 1969). The absence of apparent trends in the values of Eh can also be attributed to the fact that stable Eh's are difficult to obtain (Zobell, 1946). They fluctuate significantly within the first hour of measurement. Due to the fact that Eh is a composite parameter, reflecting the presence of many different ionic pairs in pore water, it can be difficult to compare among studies. Thus the range of Eh, rather than the actual values, can be more significant since it is under conditions of Eh ranging from 0

to -200 mv that hydrogen sulfide replaces oxygen as a primary electron acceptor in the sediments (Fenchel and Riedl, 1970). The precipitation of hydrogen sulfide as metal sulfides may also affect Eh values (Zobell, 1946a). The absence of positive Eh in the surficial sediments during the August survey can be regarded as an artifact of sampling, due to the fact that cores had to be transported to the laboratory facilities and unavoidable shaking disturbed the highly unstable surface sediments.

The products of cellulose degradation and sulfate reduction affect not only Eh but also the pH of the sediments (though these two measures are not independent). In the present study small decreases in pH were observed at stations with higher overall levels of H_2S, but they could not be correlated with increases in the amount of sulfide present in the particular layer. It is possible that pH at some stations was buffered by the presence of carbonates and thus did not exhibit any clear trend. A decrease in pH was reported for sediments undergoing sulfate reduction (Deuser, 1975). The liberation of CO_2 and H_2S and formation of some organic acids (Nedwell and Brown, 1982) are the major reasons for such behavior. Nevertheless other authors have reported opposing trend with pH increasing with depth in anoxic sediments (Gee, 1986). Such discrepancies could be due to the fact that, as with Eh, pH reflects a complicated mixture of processes simultaneously occuring in the sediments, and is dependent on the differences in composition of different sediments as well as differences in technique employed.

Fine, silty, reduced sediments with a dense layer of fly-ash create conditions in which very small shallow-burrowing or tube-building polychaetes dominate the community. This community also includes a few deposit feeding molluscs and crustaceans.

The original hypothesis regarding the effects of organic enrichment on the macrobenthic community stated:

> There is a gradual change in the macrobenthic community with increased distance from the outfall from a depauperate community to a normal (diverse and abundant) community characteristic of the surrounding waters.

It is evident from the data in Tables 20-24 that there are changes in abundance and diversity among stations. However trends are obscured by large natural variability of samples; small sample size and large range overlaps produce unreliable averages.

Pearson (1980) has stated that the decrease in the structural level of organisation of the community as organic input increases involves the elimination of the larger animals which maintain complex burrow structures for filter-feeding purposes, and their replacement by small deposit feeders which maintain only simple, if any, tube structures in the sediments. Such processes are reflected in a low abundance and community diversity found on the 2.0-mm mesh in Northumberland Channel. High abundance in the 0.5-mm mesh samples is largely due to only three Polychaeta families: Capitellidae, Cossuridae, Cirratulidae (Table 20). They constitute a rapidly breeding opportunistic deposit feeders, the majority of which are of very small size. These families have been reported in the literature as numerically dominant in areas of varying degree (from heavy to light) of organic enrichment (Leppakoski, 1975; Pearson and Rosenberg, 1978; Raman and Ganapati, 1983). Thus, the communities found along Northumberland Channel transect can be classified, in terms of organic enrichment, as transitional. The

increase in abundances of these families at stations Tr3-Tr4 may be regarded as the peak of opportunists. The decrease of the total abundance at station Tr5 as well as the decrease in the proportion contributed to this value by opportunists correlates well with decreasing values of dissolved sulfide in the sediments and suggests a transition to a less impacted community. The failure of cluster analysis to separate stations successfully, supports the observation that communities on the transect represent a continuum.

Ordination analysis performed on the data from the 0.5-mm screen separated stations well (except Tr5) , with only one axis being meaningful, that corresponding to the distance from the outfall. This in itself correlates well with the amount of wood present in the samples.

The second hypothesis of the present study stated that:

> There are gradual changes in sediment parameters correlated with increased distance from the outfall (and changes in the macrobenthos).

As was already mentioned sediment parameters exhibit a great deal of within station variability which is reflected in large variability of community parameters, such as abundance. Nevertheless, a trend of decreasing organic carbon and lower sulfide levels in the first 5 cm of sediment with increased distance from the outfall is evident. The corresponding changes in the community are more subtle and expressed more in decreases in the dominance of opportunistic species.

The third hypothesis dealt with the presence of sulfide oxidizing bacteria Beggiatoa on the sediment surface in station T1. It stated:

There is a positive correlation between depletion of the macrobenthos and the presence of a Beggiatoa mat on the sediment-water interface.

The non-parametric statistical tests performed on the macrobenthic transects data showed no significant differences, in the numbers of motile macrobenthos, between the Test area (Beggiatoa mat area) and the Reference area (around station R1), but did show significant differences between the Reference area and the Mid-Channel area (stations Tr3-Tr4). Problems in analysing means similar to those encountered in the analysis of the transect samples arose here due to large within-station variability.

There is a general trend towards an increase in abundance from station T1 to R1, largely due to the increase in numbers of 3 families of sedentary Polychaetes (Capitellidae, Cirratulidae and Spionidae). The other biological parameter, community diversity, seems to follow a similar trend in increasing from T1 to R1.

It is important to note that station T1 seems to have particularly few taxa present other than Polychaetes (Table 21); even the Polychaetes are mainly comprised of a very few families with small numbers of individuals in each. Polychaetes are the group most tolerant to organic enrichment (Leppakoski, 1975; Pearson and Rosenberg, 1976, 1978). Within this group Capitellids and other small sedentary deposit feeders such as Cirratulids are characteristically tenacious in highly impacted communities (Pearson et al., 1978; Rosenberg, 1972, 1980; Raman et al., 1983). The community which is defined as highly impacted - polluted (or depauperate) is characterized either by very low diversity and low abundance or by very low diversity and high abundance ('peak of opportunists'). The community at station T1 fits this definition. The communities at stations T2 and R1, as with

the previously described communities located on the transect (Tr stations), seem to be at different transitional stages, with increasing but still low diversity and low abundances, except for a few species.

From this we can conclude that station T1, characterized by the presence of the Beggiatoa mat, does have a depleted non-motile macrobenthos. It would be reasonable to speculate that the underlying differences between station T1 (with the mat) and T2 (without the mat) are due to oceanographic conditions and patterns of plume dispersion, as well as coarser sediments which contribute to slower development of anoxia and cause preferential settlement of some species.

Unpublished microbiological tests on sediments throughout the channel (M. Pomeroy, pers. comm.) indicates that Beggiatoa is present at all stations although its location and density within the sediment may vary. Thus every station has a capability of developing a Beggiatoa mat if appropriate conditions arise at the interface.

CONCLUSIONS.

1. It became apparent through the course of this research that a more detailed knowledge of oceanographic conditions in Northumberland Channel (specially movements of water below 40 meter depth) is necessary to understand patterns of plume dispersion and associated discrepancies in sedimentation rates.

2. The community parameters measured are characteristic of transitional stages of an impacted community along an organic enrichment gradient. Such progression corresponds well with the observed change in sulfide levels in the sediment.

3. Station T1 located in front of the diffuser is the most heavily impacted. The presence of a Beggiatoa mat at the sediment-water interface is characteristic of the specific conditions encountered at this station (high levels of sulfide in the sediment and oxygenated water column). Nevertheless though indicative of such conditions the extent of the Beggiatoa mat cannot be used as a monitoring tool without corresponding measurements of sulfide (below) and oxygen (above) the sediment surface because mat disappearance (or shrinkage) can mean either improvement or worsening of the interface conditions.

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APPENDIX A

MEANS AND STANDARD ERRORS.

This appendix contains mean values of environmental parameters measured, for each core depth, and corresponding standard errors.

Abbreviations: Stn - station; depth - in-core depth in cm; $\bar{x}$ - mean; c - carbon; n - nitrogen; $\bar{x}$sulf - mean sulfide (μm/l); error - standard error of the mean. Station codes - T1=1, T2=2, R1=3, Tr1=11, Tr2=12, Tr3=13 , Tr4=14, Tr5=15

stn	depth	$\bar{x}$ % c	error
1	1.0	13.1330	1.85430
1	3.5	9.4467	1.09699
1	7.5	15.2125	2.67473
1	12.5	9.3650	0.50500
1	17.5	7.6700	0.06000
1	22.5	.	.
1	27.5	.	.
1	37.5	3.0500	.
2	1.0	11.2233	1.56855
2	3.5	8.0050	1.35792
2	7.5	10.5340	1.58067
2	12.5	8.5350	2.85862
2	17.5	3.3700	0.00000
2	22.5	.	.
2	27.5	.	.
2	37.5	2.3600	.
3	1.0	.	.
3	3.5	8.1700	0.76000
3	7.5	9.4600	.

stn	depth	$\bar{x}$ % c	error
3	12.5	8.3800	.
3	17.5	5.7300	.
3	22.5	.	.
3	27.5	.	.
3	37.5	2.8100	.
11	1.0	13.1767	0.54192
11	3.5	12.9650	0.25510
11	7.5	20.1725	4.61912
11	12.5	23.0200	1.71785
11	17.5	7.9000	.
11	22.5	.	.
11	27.5	.	.
11	37.5	2.9700	.
12	1.0	.	.
12	3.5	10.7050	0.19500
12	7.5	13.3100	.
12	12.5	13.8700	0.08000
12	17.5	6.7800	.
12	22.5	.	.
12	27.5	.	.
12	37.5	2.9000	.
13	1.0	13.6067	6.99100

stn	depth	$\bar{x}$ % c	error
13	3.5	12.1350	0.70201
13	7.5	19.2333	0.79549
13	12.5	9.7450	0.41500
13	17.5	7.6400	.
13	22.5	4.3800	.
13	27.5	.	.
13	37.5	2.7700	.
14	1.0	.	.
14	3.5	6.4600	0.19000
14	7.5	10.4700	1.36000
14	12.5	8.5600	.
14	17.5	7.2500	.
14	22.5	.	.
14	27.5	.	.
14	37.5	3.30000	.
15	1.0	7.69500	0.515000
15	3.5	9.17750	0.817092
15	7.5	7.18667	0.261810
15	12.5	6.90500	0.485000
15	17.5	2.89500	0.175000
15	22.5	.	.
15	27.5	.	.

STN	DIST	DEPTH	$\bar{X}$SULF	ERRSULF
1	300	1.0	44.112	14.8437
1	300	3.5	99.585	57.9383
1	300	7.5	193.045	53.3107
1	300	12.5	250.957	30.1866
1	300	17.5	114.544	41.5382
1	300	22.5	30.780	0.7183
1	300	27.5	14.724	1.0792
1	300	37.5	8.440	0.3900
2	300	1.0	0.000	0.0000
2	300	3.5	9.762	1.0114
2	300	7.5	70.470	4.6023
2	300	12.5	63.800	8.3497
2	300	17.5	67.643	27.8079
2	300	22.5	25.905	7.8350
2	300	27.5	17.360	17.3600
2	300	37.5	9.963	5.5621
3	2300	1.0	0.230	0.2300
3	2300	3.5	0.000	0.0000
3	2300	7.5	2.260	0.5800
3	2300	12.5	1.655	0.2650
3	2300	17.5	4.110	1.2100
3	2300	22.5	0.840	0.0000

STN	DIST	DEPTH	$\bar{X}$SULF	ERRSULF
3	2300	27.5	0.000	.
3	2300	37.5	0.000	0.0000
11	150	1.0	0.670	0.4168
11	150	3.5	13.866	1.3437
11	150	7.5	58.125	22.0415
11	150	12.5	91.250	3.1372
11	150	17.5	111.055	5.8501
11	150	22.5	38.970	21.1062
11	150	27.5	1.950	0.6800
11	150	37.5	2.860	0.1300
12	300	1.0	23.125	1.8450
12	300	3.5	57.760	6.1100
12	300	7.5	21.443	0.5166
12	300	12.5	28.570	0.1756
12	300	17.5	29.000	2.9538
12	300	22.5	2.950	0.7200
12	300	27.5	0.000	.
12	300	37.5	3.140	.
13	600	1.0	1.984	0.8160
13	600	3.5	38.082	0.9865
13	600	7.5	32.067	3.9612
13	600	12.5	31.290	3.0101

STN	DIST	DEPTH	$\bar{X}$SULF	ERRSULF
13	600	17.5	60.564	15.3688
13	600	22.5	44.277	4.3966
13	600	27.5	15.728	3.8363
13	600	37.5	9.690	1.6004
14	1200	1.0	0.000	.
14	1200	3.5	0.410	0.4100
14	1200	7.5	43.800	9.3600
14	1200	12.5	12.795	0.5550
14	1200	17.5	8.210	0.4692
14	1200	22.5	2.540	0.1500
14	1200	27.5	2.840	.
14	1200	37.5	2.1300	.
15	2400	1.0	0.5075	0.31836
15	2400	3.5	1.1900	0.63120
15	2400	7.5	1.1700	0.63492
15	2400	12.5	0.3225	0.32250
15	2400	17.5	0.7775	0.31090
15	2400	22.5	2.6500	1.15000
15	2400	27.5	0.2550	0.25500
15	2400	37.5	0.3675	0.36750

STN	DEPTH	$\bar{X}$ % N	ERROR
11	1.0	0.543333	0.044845
11	3.5	0.662000	0.157652
11	7.5	0.447143	0.037335
11	12.5	0.520000	0.105447
11	17.5	0.480000	.
11	22.5	.	.
11	27.5	.	.
11	37.5	0.410000	.
12	1.0	.	.
12	3.5	0.505000	0.025000
12	7.5	0.620000	.
12	12.5	0.370000	0.030000
12	17.5	0.150000	.
12	22.5	.	.
12	27.5	.	.
12	37.5	0.420000	.
13	1.0	0.720000	0.210079
13	3.5	0.492500	0.010308
13	7.5	0.436667	0.034801
13	12.5	0.430000	0.010000
13	17.5	0.370000	.
13	22.5	0.370000	.

STN	DEPTH	$\bar{X}$ % N	ERROR
13	27.5	.	.
13	37.5	0.270000	.
14	1.0	.	.
14	3.5	0.270000	0.010000
14	7.5	0.450000	0.080000
14	12.5	0.430000	.
14	17.5	0.380000	.
14	22.5	.	.
14	27.5	.	.
14	37.5	0.290000	.
15	1.0	0.445000	0.05500
15	3.5	0.352500	0.03350
15	7.5	0.346667	0.00666
15	12.5	0.385000	0.00500
15	17.5	0.565000	0.00500
15	22.5	.	.
15	27.5	.	.
15	37.5	0.320000	.

STN	DIST	DEPTH	$\bar{X}$	% N	ERROR
1	300	1.0	0.560000		0.050000
1	300	3.5	0.460000		0.030000
1	300	7.5	0.635000		0.145516
1	300	12.5	0.800000		0.380000
1	300	17.5	0.505000		0.115000
1	300	22.5	.		.
1	300	27.5	.		.
1	300	37.5	0.700000		.
2	300	1.0	0.530000		0.005774
2	300	3.5	0.402500		0.095427
2	300	7.5	0.452000		0.149780
2	300	12.5	0.277500		0.042696
2	300	17.5	.		.
2	300	22.5	.		.
2	300	27.5	.		.
2	300	37.5	0.540000		.
3	2300	1.0	.		.
3	2300	3.5	0.585000		0.195000
3	2300	7.5	0.280000		.
3	2300	12.5	0.470000		0.040000
3	2300	17.5	0.250000		.
3	2300	22.5	.		.

STN	DIST	DEPTH	$\bar{X}$	% N	ERROR
3	2300	27.5	.		.
3	2300	37.5	0.500000		.

APPENDIX B

CORRELATION MATRICES.

This appendix contains significant (at $P<0.05$) correlations of environmental parameters from pooled July and August data.

Abbreviations: Dist - distance, C - % organic carbon, N - % organic nitrogen, CN - C:N ratio, Sulf - sulfide , Cellu - cellulose, Grsize - median sediment grain size.

STN=T1

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		–	–	–	–	–	–	–	–	–
DEPTH			–	-0.88223 0.0037 8	-0.85053 0.0318 6	–	-0.93476 0.0062 6	–	-0.97583 0.0045 5	–
EH				–	–	–	–	-0.90634 0.0020 8	–	–
PH					0.84726 0.0332 6	–	0.82346 0.0440 6		–	–
C						–	0.94833 0.0039 6	–	–	–
N							–	–	–	–
CN								–	–	–
SULF									–	–
CELLU										–
GRSIZE										

STN=T2

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		—	—	—	—	—	—	—	—	—
DEPTH			0.75116 0.0317 8	—	-0.92904 0.0224 5	—	—	—	—	—
EH				—	—	—	—	—	—	—
PH					—	—	—	—	—	—
C						—	—	—	—	—
N							—	—	—	—
CN								—	—	—
SULF									—	—
CELLU										—
GRSIZE										

STN=R1

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		–	–	–	–	–	–	–	–	–
DEPTH			–	–	-0.93558 0.0194 5	–	–	–	-0.95591 0.0110 5	–
EH				0.77487 0.0239 8	–	–	–	–	–	–
PH					–	–	–	–	–	–
C						–	–	–	0.92239 0.0257 5	–
N							–	-0.90692 0.0336 5	–	–
CN								–	–	–
SULF									–	–
CELLU										–
GRSIZE										

STN=TR1

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		–	–	–	–	–	–	–	–	–
DEPTH			–	–	–	–	–	–	-0.90773 0.03325	–
EH				–	–	–	–	-0.71668 0.04558	–	–
PH					0.87853 0.02126	–	–	–	–	–
C							0.94264 0.00486		–	–
N							–	–	0.89635 0.03945	–
CN								–	–	–
SULF									–	–
CELLU										–
GRSIZE										

STN=TR 2

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		–	–	–	–	–	–	–	–	–
DEPTH			–	–	–	–	–	-0.74424 0.03428	-0.88181 0.04795	–
EH				–	–	-0.90925 0.03245	–	–	–	–
PH					–	–	–	–	–	–
C						–	–	–	–	–
N							–	–	–	–
CN								–	–	–
SULF									–	–
CELLU										–
GRSIZE										

STN=TR3

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		–	–	–	–	–	–	–		–
DEPTH			–	0.80484 0.0160 8	-0.82610 0.0220 7	-0.83898 0.0183 7	–	–		–
EH				–	–	–	–	–		–
PH					-0.78355 0.0371 7	-0.77316 0.0415 7	–	–		–
C						–	0.87696 0.0095 7	–		–
N							–	–		–
CN								–		–
SULF										–
CELLU										
GRSIZE										

STN=TR 4

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		–	–	–	–	–	–	–		–
DEPTH			0.95318 0.00028	–	–	–	-0.99200 0.00095	–		–
EH				–	–	–	-0.99731 0.00015	–		–
PH					–	–	–	–		–
C						–	–	–		–
N							–	–		–
CN								–		–
SULF										–
CELLU										
GRSIZE										

STN=TR 5

	DIST	DEPTH	EH	PH	C	N	CN	SULF	CELLU	GRSIZE
DIST		–	–	–	–	–	–	–	–	–
DEPTH			–	–	-0.87066 0.0240 6	–	–	–	–	–
EH				0.74445 0.0341 8	–	–	–	–	–	–
PH					–	–	–	–	–	–
C						1	0.95970 0.0024 6	–	0.92664 0.0236 5	–
N							–	–	–	–
CN								–	0.93995 0.0175 5	–
SULF									–	–
CELLU										–
GRSIZE										

APPENDIX C

SEDIMENT DATA.

Raw data matrix.

Abbreviations: Stn - station, Dist - distance, c - carbon; n - nitrogen; CN - C:N ratio, Cellu - cellulose (µg/ml) , sulf - mean sulfide (µm/l); Gr.size - median sediment grain size (mm).

Station codes - T1=1, T2=2, R1=3, Tr1=11, Tr2=12, Tr3=13 , Tr4=14, Tr5=15

			JULY						AUGUST							
STN	DIST	DEP	EH	PH	%C	%N	C:N	SULF	EH	PH	%C	%N	C:N	SULF	CELLU	GR.SIZE
11	150	1.0	391	.	14.18	0.63	22.37	1.72	-233	7.15	.	.	.	0.00	.	.
11	150	1.0	.	.	13.03	0.48	27.43	0.96	.	.	.	.	.	0.00	.	.
11	150	1.0	.	.	12.32	0.52	23.64	.	.	.	.	.	.	.	.	.
11	150	3.5	-261	7.24	.	0.52	.	11.62	-226	7.03	13.01	1.29	10.07	14.98	137.0	0.027
11	150	3.5	.	.	13.20	0.47	27.97	18.61	.	.	13.41	0.55	24.52	11.43	148.0	.
11	150	3.5	.	.	12.24	0.48	25.78	.	.	.	.	.	.	12.69	113.8	.
11	150	3.5	.	.	.	.	.	.	.	.	.	.	.	.	137.0	.
11	150	3.5	.	.	.	.	.	.	.	.	.	.	.	.	114.1	.
11	150	7.5	.	.	12.56	0.40	31.63	50.44	-236	7.07	15.73	0.47	47.67	30.54	59.0	0.044
11	150	7.5	.	.	50.60	0.25	204.86	122.60	.	.	22.17	0.55	14.89	28.92	108.0	.
11	150	7.5	-262	.	20.59	0.47	44.28	.	.	.	8.17	0.47	37.08	.	27.0	.
11	150	7.5	.	7.30	.	.	.	.	.	.	17.28	0.52	27.63	.	134.0	.
11	150	7.5	.	.	.	.	.	.	.	.	14.28	.	.	.	136.2	.
11	150	12.5	-269	7.31	28.95	0.42	69.59	91.19	-250	7.06	22.54	1.15	19.62	98.80	130.5	0.024
11	150	12.5	.	.	23.53	0.46	50.93	91.57	.	.	29.12	0.43	67.87	83.44	105.0	.
11	150	12.5	.	.	20.31	0.38	53.45	.	.	.	.	.	.	.	58.0	.
11	150	12.5	.	.	18.24	0.40	45.38	.	.	.	.	.	.	.	125.0	.
11	150	12.5	.	.	18.45	0.40	46.25	.	.	.	.	.	.	.	138.0	.
11	150	17.5	-255	7.49	.	.	.	112.30	-196	6.75	7.90	0.48	16.39	120.71	98.3	0.023
11	150	17.5	.	.	.	.	.	94.28	.	.	.	.	.	116.93	26.0	.
11	150	17.5	.	.	.	.	.	.	.	.	.	.	.	.	87.0	.
11	150	17.5	.	.	.	.	.	.	.	.	.	.	.	.	125.0	.
11	150	17.5	.	.	.	.	.	.	.	.	.	.	.	.	130.2	.
11	150	22.5	367	7.49	.	.	.	4.86	-248	7.21	.	.	.	91.01	.	0.024
11	150	22.5	.	.	.	.	.	4.38	.	.	.	.	.	55.63	.	.
11	150	27.5	407	7.35	.	.	.	1.27	-176	7.19	.	.	.	2.63	.	.
11	150	37.5	367	.	.	.	.	2.99	-190	6.97	2.97	0.41	7.29	2.73	57.0	0.024
11	150	37.5	.	.	.	.	.	.	.	.	.	.	.	.	89.0	.
11	150	37.5	.	.	.	.	.	.	.	.	.	.	.	.	8.8	.
11	150	37.5	.	.	.	.	.	.	.	.	.	.	.	.	52.0	.
11	150	37.5	.	.	.	.	.	.	.	.	.	.	.	.	65.0	.
12	300	1.0	.	.	.	.	.	.	-249	7.24	.	.	.	21.28	.	.
12	300	1.0	.	.	.	.	.	.	.	.	.	.	.	24.97	.	.
12	300	3.5	.	.	.	.	.	.	-264	7.36	10.51	0.53	20.02	63.87	88.0	0.024
12	300	3.5	.	.	.	.	.	.	.	.	10.90	0.48	22.52	51.65	99.0	.
12	300	7.5	.	.	.	.	.	.	-256	7.69	13.31	0.62	7.36	22.47	79.0	.
12	300	7.5	.	.	.	.	.	.	.	.	.	.	.	20.83	85.8	0.026
12	300	7.5	.	.	.	.	.	.	.	.	.	.	.	21.03	.	.
12	300	12.5	.	.	.	.	.	.	-210	7.37	13.95	0.40	34.69	28.92	81.0	0.082
12	300	12.5	.	.	.	.	.	.	.	.	13.79	0.34	40.56	28.37	80.5	.
12	300	12.5	.	.	.	.	.	.	.	.	.	.	.	28.42	.	.
12	300	17.5	.	.	.	.	.	.	-67	7.49	6.78	0.15	44.88	32.34	45.0	0.021
12	300	17.5	.	.	.	.	.	.	.	.	.	.	.	31.55	43.0	.
12	300	17.5	.	.	.	.	.	.	.	.	.	.	.	23.11	.	.
12	300	22.5	.	.	.	.	.	.	-44	7.34	.	.	.	3.67	.	0.021
12	300	22.5	.	.	.	.	.	.	.	.	.	.	.	2.23	.	.

12	300	27.5	.	.	.	.	.	.	-93	6.77	.	.	.	0.00	.	0.019
12	300	37.5	.	.	.	.	.	.	-157	7.11	2.90	0.42	6.98	3.14	36.9	0.021
12	300	37.5	.	.	.	.	.	.	.	.	.	.	.	.	38.5	.
13	600	1.0	-246	7.02	2.46	0.50	4.91	0.00	-214	7.34	.	.	.	2.96	.	.
13	600	1.0	.	.	11.87	0.52	22.79	0.00	.	.	.	.	.	3.39	.	.
13	600	1.0	.	.	26.49	1.14	23.15	.	.	.	.	.	.	3.57	.	.
13	600	3.5	-244	7.10	12.50	0.48	26.10	38.41	-246	7.30	10.76	0.51	21.05	40.72	.	0.030
13	600	3.5	.	.	13.94	0.47	29.47	36.27	-248	7.30	11.34	0.51	22.24	36.93	.	.
13	600	7.5	-249	7.11	19.45	0.43	45.45	30.27	-248	7.30	17.76	0.50	35.51	29.77	.	.
13	600	7.5	.	.	20.49	0.38	53.36	51.43	.	.	.	.	.	24.56	.	.
13	600	7.5	.	.	.	.	.	.	.	.	.	.	.	27.55	.	.
13	600	7.5	.	.	.	.	.	.	.	.	.	.	.	28.82	.	.
13	600	12.5	-223	7.07	10.16	0.42	24.42	38.57	-222	7.36	9.33	0.44	21.20	26.77	.	0.020
13	600	12.5	.	.	.	.	.	38.57	.	.	.	.	.	24.79	.	.
13	600	12.5	.	.	.	.	.	.	.	.	.	.	.	27.75	.	.
13	600	17.5	-210	7.18	.	.	.	30.22	-147	7.40	7.64	0.37	20.76	93.85	.	0.021
13	600	17.5	.	.	.	.	.	17.36	.	.	.	.	.	77.68	.	.
13	600	17.5	.	.	.	.	.	.	.	.	.	.	.	83.71	.	.
13	600	22.5	-152	7.09	.	.	.	.	-154	7.47	4.38	0.37	11.91	35.67	.	0.021
13	600	22.5	.	.	.	.	.	.	.	.	.	.	.	50.14	.	.
13	600	22.5	.	.	.	.	.	.	.	.	.	.	.	47.02	.	.
13	600	27.5	-173	7.05	.	.	.	28.29	-179	7.40	.	.	.	12.77	.	0.023
13	600	27.5	.	.	.	.	.	20.57	.	.	.	.	.	8.53	.	.
13	600	27.5	.	.	.	.	.	.	.	.	.	.	.	8.48	.	.
13	600	37.5	.	.	.	.	.	11.57	-242	7.44	2.77	0.27	10.09	10.87	.	0.019
13	600	37.5	.	.	.	.	.	.	.	.	.	.	.	11.41	.	.
13	600	37.5	.	.	.	.	.	.	.	.	.	.	.	4.91	.	.
14	1200	1.0	.	.	.	.	.	.	-252	7.41	.	.	.	0.00	.	.
14	1200	3.5	.	.	.	.	.	.	-255	7.41	6.65	0.28	24.18	0.00	.	0.022
14	1200	3.5	.	.	.	.	.	.	.	.	6.27	0.26	23.77	0.82	.	.
14	1200	7.5	.	.	.	.	.	.	-243	7.30	9.11	0.37	24.89	53.16	.	0.024
14	1200	7.5	.	.	.	.	.	.	.	.	11.83	0.53	22.45	34.44	.	.
14	1200	12.5	.	.	.	.	.	.	-183	7.32	8.56	0.43	20.00	12.24	.	0.020
14	1200	12.5	.	.	.	.	.	.	.	.	.	.	.	13.35	.	.
14	1200	17.5	.	.	.	.	.	.	-157	7.42	7.25	0.38	19.13	8.43	.	0.023
14	1200	17.5	.	.	.	.	.	.	.	.	.	.	.	7.31	.	.
14	1200	17.5	.	.	.	.	.	.	.	.	.	.	.	8.89	.	.
14	1200	22.5	.	.	.	.	.	.	-147	7.37	.	.	.	2.39	.	0.017
14	1200	22.5	.	.	.	.	.	.	.	.	.	.	.	2.69	.	.
14	1200	27.5	.	.	.	.	.	.	-160	7.45	.	.	.	2.84	.	.
14	1200	37.5	.	.	.	.	.	.	-36	7.23	3.30	0.29	11.27	2.13	.	0.023
15	2400	1.0	308	.	8.21	0.50	16.32	0.71	-161	7.33	.	.	.	0.00	.	.
15	2400	1.0	.	.	7.18	0.39	18.32	1.32	.	.	.	.	.	0.00	.	.
15	2400	3.5	-273	6.59	8.55	0.36	23.67	2.93	-219	7.30	11.62	0.26	44.17	0.00	80.0	0.024
15	2400	3.5	.	.	8.32	0.37	22.80	1.22	.	.	8.22	0.42	19.75	0.61	86.0	.
15	2400	7.5	-248	6.95	7.06	0.36	19.39	2.58	-151	7.24	7.69	0.34	22.95	0.00	67.2	0.022
15	2400	7.5	.	.	.	.	.	2.84	.	.	6.81	0.34	19.97	0.00	30.0	.
15	2400	7.5	.	.	.	.	.	.	.	.	.	.	.	0.43	.	.
15	2400	12.5	-215	6.89	7.39	0.38	19.24	0.00	-168	7.38	6.42	0.39	16.45	0.00	53.0	0.022
15	2400	12.5	.	.	.	.	.	1.29	.	.	.	.	.	0.00	45.0	.

15	2400	17.5	-165	6.90	.	.	.	1.47	-89	7.47	2.72	0.57	4.76	1.01	29.5	0.030
15	2400	17.5	.	.	.	.	.	0.00	.	.	3.07	0.56	5.52	0.63	.	.
15	2400	22.5	-147	7.04	.	.	.	.	-149	7.20	.	.	.	1.50	.	0.033
15	2400	22.5	.	.	.	.	.	.	.	.	.	.	.	3.80	.	.
15	2400	27.5	.	.	.	.	.	0.00	-71	7.15	.	.	.	.	.	0.029
15	2400	27.5	.	.	.	.	.	0.51	.	.	.	.	.	.	.	.
15	2400	37.5	.	.	.	.	.	1.47	-12	7.08	2.46	0.32	7.59	0.00	29.0	0.026
15	2400	37.5	.	.	.	.	.	0.00	.	.	.	.	.	0.00	28.0	.
3	2300	1.0	.	.	.	.	.	.	-139	7.32	.	.	.	0.46	.	.
3	2300	1.0	.	.	.	.	.	.	.	.	.	.	.	0.00	.	.
3	2300	3.5	.	.	.	.	.	.	-232	7.28	7.41	0.78	9.56	0.00	67.0	0.022
3	2300	3.5	.	.	.	.	.	.	.	.	8.93	0.39	22.72	0.00	81.0	.
3	2300	7.5	.	.	.	.	.	.	-203	7.29	9.46	0.28	34.03	1.68	74.0	0.024
3	2300	7.5	.	.	.	.	.	.	.	.	.	.	.	2.84	65.0	.
3	2300	12.5	.	.	.	.	.	.	-196	7.45	.	0.43	.	1.39	61.0	0.020
3	2300	12.5	.	.	.	.	.	.	.	.	8.38	0.51	16.56	1.92	52.3	.
3	2300	17.5	.	.	.	.	.	.	-154	7.40	5.73	0.25	22.99	2.90	41.0	0.020
3	2300	17.5	.	.	.	.	.	.	.	.	.	.	.	5.32	47.8	.
3	2300	22.5	.	.	.	.	.	.	-20	7.55	.	.	.	0.84	.	0.022
3	2300	22.5	.	.	.	.	.	.	.	.	.	.	.	0.84	.	.
3	2300	27.5	.	.	.	.	.	.	-161	7.36	.	.	.	0.00	.	0.023
3	2300	37.5	.	.	.	.	.	.	-202	7.36	2.81	0.50	5.65	0.00	27.5	0.023
3	2300	37.5	.	.	.	.	.	.	.	.	.	.	.	0.00	33.0	.
1	300	1.0	15	7.28	10.47	0.66	15.93	0.00	-238	7.63	.	.	.	53.78	.	.
1	300	1.0	.	.	12.23	0.51	24.22	0.00	.	.	.	.	.	87.05	.	.
1	300	1.0	.	.	16.70	0.51	32.88	.	.	.	.	.	.	70.49	.	.
1	300	1.0	.	.	.	.	.	.	.	.	.	.	.	53.35	.	.
1	300	3.5	-67	7.10	11.34	0.49	23.32	14.71	-253	7.31	7.54	0.43	21.85	263.15	104.5	0.021
1	300	3.5	.	.	.	.	.	20.06	.	.	9.46	.	.	100.42	115.0	.
1	300	3.5	.	.	.	.	.	.	.	.	.	.	.	.	117.0	.
1	300	7.5	-248	7.14	11.70	0.46	25.27	144.46	-237	7.36	11.96	0.52	22.86	244.94	77.5	0.034
1	300	7.5	.	.	23.07	0.49	46.79	70.88	.	.	14.12	1.07	13.23	311.90	97.0	.
1	300	7.5	.	.	.	.	.	.	.	.	.	.	.	.	110.0	.
1	300	12.5	-253	7.14	9.87	0.42	23.44	238.18	-244	7.28	8.86	1.18	7.50	317.58	104.8	0.022
1	300	12.5	.	.	.	.	.	134.36	.	.	.	.	.	204.51	70.2	.
1	300	12.5	.	.	.	.	.	.	.	.	.	.	.	328.15	91.2	.
1	300	12.5	.	.	.	.	.	.	.	.	.	.	.	282.96	.	.
1	300	17.5	-98	6.93	.	.	.	12.03	-243	7.17	7.73	0.62	12.39	204.53	86.5	0.023
1	300	17.5	.	.	.	.	.	15.96	.	.	7.61	0.39	19.40	172.35	91.0	.
1	300	17.5	.	.	.	.	.	.	.	.	.	.	.	167.85	63.7	.
1	300	22.5	24	6.75	.	.	.	30.46	-166	7.15	.	.	.	32.29	.	0.023
1	300	22.5	.	.	.	.	.	.	.	.	.	.	.	31.43	.	.
1	300	22.5	.	.	.	.	.	.	.	.	.	.	.	28.94	.	.
1	300	27.5	-80	6.8	.	.	.	13.39	-191	6.80	.	.	.	17.11	.	.
1	300	27.5	.	.	.	.	.	13.87	.	.	.	.	.	11.88	.	.
1	300	27.5	.	.	.	.	.	.	.	.	.	.	.	17.37	.	.
1	300	37.5	77	6.57	.	.	.	8.83	-111	7.29	3.05	0.70	4.35	8.05	80.5	0.024
1	300	37.5	.	.	.	.	.	.	.	.	.	.	.	.	38.0	.
1	300	37.5	.	.	.	.	.	.	.	.	.	.	.	.	45.0	.
2	300	1.0	-250	6.97	14.36	0.54	26.74	0.00	-231	7.39	.	.	.	0.00	.	.

2	300	1.0	.	.	9.70	0.52	18.80	0.00	.	.	.	.	.	0.00	.	.
2	300	1.0	.	.	9.61	0.53	18.06	.	.	.	.	.	.	.	.	.
2	300	3.5	-252	7.10	10.00	0.47	21.46	12.33	-239	7.02	10.61	0.64	16.6	9.28	75.0	0.030
2	300	3.5	.	.	6.33	0.28	22.28	10.00	.	.	5.08	0.22	23.63	7.44	72.0	.
2	300	7.5	-256	7.04	8.08	1.02	28.65	78.62	-188	7.22	8.74	0.14	64.77	60.26	57.0	0.039
2	300	7.5	.	.	9.09	0.39	25.39	83.58	.	.	10.03	0.30	32.98	68.11	36.8	.
2	300	7.5	.	.	16.73	0.41	40.80	.	.	.	.	.	.	61.78	.	.
2	300	12.5	-304	7.08	8.38	0.33	25.62	54.65	-193	7.48	4.45	0.2	22.38	51.29	38.0	0.033
2	300	12.5	.	.	16.67	0.37	45.66	88.08	.	.	4.64	0.21	22.32	61.18	42.0	.
2	300	17.5	-306	7.81	.	.	.	102.22	-247	7.38	3.37	0.58	5.86	12.63	36.0	0.035
2	300	17.5	.	.	.	.	.	88.08	.	.	.	.	.	.	33.0	.
2	300	22.5	-174	7.21	.	.	.	47.57	-190	7.11	.	.	.	10.89	.	0.033
2	300	22.5	.	.	.	.	.	25.72	.	.	.	.	.	19.44	.	.
2	300	27.5	-272	6.91	.	.	.	34.72	-31	7.31	.	.	.	0.00	.	.
2	300	37.5	-148	6.96	.	.	.	10.66	-162	7.18	2.36	0.54	4.42	0.00	32.0	0.032
2	300	37.5	.	.	.	.	.	19.23	.	.	.	.	.	.	21.5	.

APPENDIX D

ABUNDANCE DATA 0.5 MM SCREEN.

This appendix contains macrobiota abundance data for stations Tr1 - Tr5 and stations T1, T2 ,R1 (0.5-mm screen; July 1983).

	TR1			TR2			TR3			TR4			TR5			T1			T2			R1		
ORGANISM	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
COSSURIDAE	92	252	28	52	68	100	104	332	322	200	464	336	16	78	153	2	84	51	42	64	25	54	52	10
CAPITELLIDAE	142	304	114	66	72	130	56	128	154	46	134	102	20	96	145	3	12	2	16	46	23	116	128	43
CIRRATULIDAE	82	108	38	26	68	38	32	44	52	24	88	64	24	44	74	2	20	12	16	20	5	48	50	14
LUMBRINEREIDAE	10	36	8	4	6	4	0	8	4	6	24	18	4	28	34	2	12	3	0	12	0	20	20	13
PARAONIDAE	10	24	0	24	2	10	16	42	16	78	30	34	6	28	45	2	6	2	12	12	12	18	24	4
NEPHTYIDAE	12	16	2	4	14	4	4	4	4	10	24	28	9	22	25	2	0	3	16	6	5	16	18	10
AMPHARETIDAE	26	26	10	18	22	12	10	10	18	12	20	24	11	6	9	2	4	0	4	4	12	4	14	6
SPIONIDAE	18	46	2	14	22	30	0	2	0	0	10	36	23	0	16	0	6	8	8	10	10	54	72	4
DORVILLEIDAE	10	64	4	2	2	4	2	10	2	0	2	2	3	0	7	8	4	17	2	2	3	2	0	6
SYLLIDAE	8	10	0	0	0	6	4	0	0	0	0	6	1	0	3	0	0	0	0	0	2	0	0	0
PHYLLODOCIDAE	14	8	8	2	4	2	0	8	2	0	4	0	0	0	2	0	2	0	0	0	3	0	6	0
OPHELEIDAE	4	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	2	0
EUNICIDAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
HESIONIDAE	2	0	0	0	0	2	0	0	0	0	4	2	0	0	2	2	2	3	2	0	0	0	2	1
STERNASPIDAE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
POLYNOIDAE	10	56	6	12	16	8	8	8	4	10	18	10	1	4	9	3	12	0	4	4	8	4	8	2
GLYCEROIDEA	8	2	2	0	6	0	0	0	2	0	2	4	1	4	5	0	2	2	0	2	0	2	6	2
TEREBELLIDAE	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	2	0	0	0	0
ONUPHIDAE	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	2	0
NEREIDAE	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRICHOCHAET.	6	0	0	0	6	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
TRICHOBRANCH.	0	0	0	0	0	2	2	0	0	2	4	0	0	8	0	0	0	0	0	0	0	4	2	0
ACROCIRRIDAE	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ARABELLIDAE	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LYSARETIDAE	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
PILARGIDAE	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMPHICTENIDAE	0	0	4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
ARENICOLIDAE	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
APISTOBRANCH.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMFIPODA	1	1	1	7	4	10	4	3	6	6	11	8	1	0	0	0	4	3	4	0	3	2	6	2
CUMACEA	9	5	2	8	13	13	18	21	10	1	12	5	0	1	3	0	0	3	4	2	3	10	8	4
CRAB	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0
CRUSTACEA 1	0	30	0	1	0	0	0	1	1	1	4	2	0	1	0	0	0	0	0	0	0	4	4	0
COPEPOD	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA 2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SIPUNCULIDAE	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
NOT POLYCH.	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIVALVIA	16	14	2	16	6	4	12	2	10	6	14	10	2	28	16	0	0	0	4	18	6	6	12	5
GASTROPODA	6	4	0	0	0	0	0	0	0	1	2	1	2	2	6	0	0	0	2	2	2	2	2	6
PLECYOPODA	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NEMATODA	2	4	0	0	0	1	1	2	0	3	0	2	1	0	5	0	0	0	2	2	0	0	0	0
NEMERTINA	0	4	0	2	0	2	0	0	0	1	2	5	2	2	2	0	1	0	1	1	1	1	1	1
HERUDINEA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	12	0	0	0	0	0	0	0	0	0
PYCNOGONIDA	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	2	0
OPHIURA	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LEPTOSYNAPTA	0	0	0	0	1	0	0	1	1	0	1	0	1	1	1	0	0	0	2	0	0	0	6	4
ASCIDIA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
SPONGE	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0
ANEMONE	0	0	0	0	0	0	0	0	0	1	0	0	3	1	0	0	0	0	0	0	0	0	0	0

APPENDIX E

HARMAC EFFLUENT DATA.

This appendix contains information on Harmac pulp mill effluent, its origin and its amounts for selected months of 1982-1983.

HARMAC EFFLUENT (Typical)

- = 45,000 US gpm
- = 12,000 Kg/day suspended solids
- = 23,000 Kg/day BOD_5

Process Area	Stream	Flow (US gpm)	Suspended Solids (Kg/day)		B.O.D.$_5$ (Kg/day)	Components*
Cooking, Washing, Screening, Bleaching	Main Alkaline Upstream	12,200	4,900	Screening	5,400	1,2,3,4,7,9
				Digester Cond.	2,700	
Bleaching	Bleach Acid	26,700	2,600	Bleaching	10,800	1,9,5
	Pulp Machine Room	1,200	200	Machines	500	1
	Recausticizing	1,100	1,100			5,6,9
Power Boilers & Screening	Flyash Clarifier (Clarified Effluent)	800	900			2,10
	Recovery	3,000	800	Evap. cond.	2,700	8,9,10
				Spills	900	9
		45,000	10,500		23,000	

*Components:

1. Bleached Pulp Fibre
2. Unbleached Pulp Fibre
3. Chips
4. Knots
5. Lime Slurry (Neutralization)
6. Lime Mud
7. Digester Condensates
8. Evaporator Condensates
9. Process Liquors**
10. Flyash

**White Liquor = Cooking Liquor
Black Liquor = Spent Cooking Liquor
Green Liquor = Uncausticized Cooking Liquor
Caustic = N_aOH
Acid = H_2SO_4, HNO_3, HCP

	suspended solids (tons/day)	
Month	1982	1983
March	8	10
April	12	10
May	9	7
June	11	11
July	21	8
August	8	8
September	17	6

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30 SEPTEMBER, 1987

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