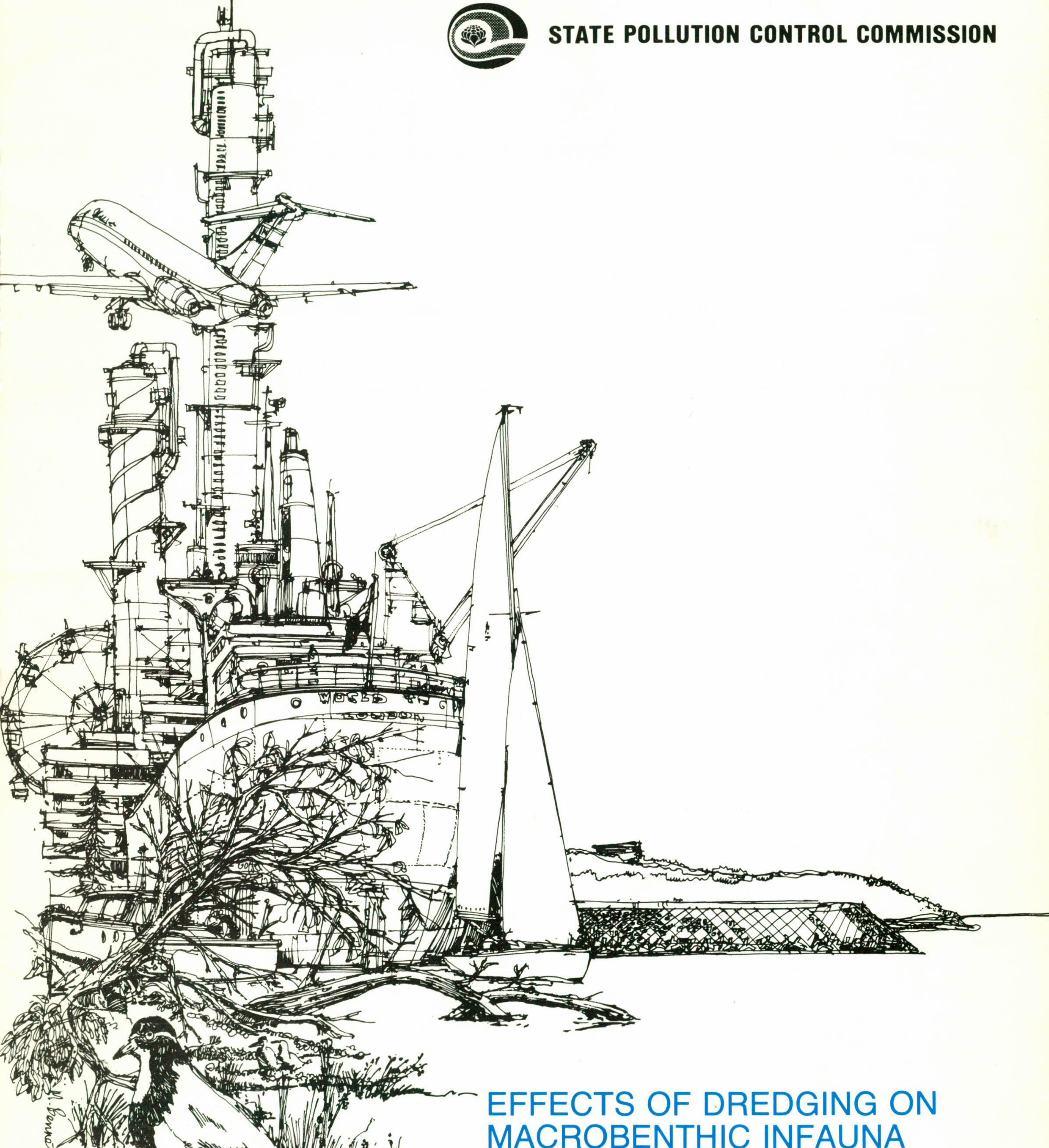
STATE POLLUTION CONTROL COMMISSION



EFFECTS OF DREDGING ON MACROBENTHIC INFAUNA OF BOTANY BAY

Environmental Control Study of Botany Bay

Issued under the authority of
THE HON. PAUL LANDA, LL.B., M.L.C.,
Minister for Planning and Environment

STATE POLLUTION CONTROL COMMISSION

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PREFACE

Arrangements were made in 1975 for the State Pollution Control Commission to carry out an environmental control study of Botany Bay and its tributaries. The study, which began in January 1976, developed from initiatives of the Maritime Services Board of New South Wales and the Board has contributed substantially to it.

The study primarily is of water and water-associated environments, so it covers land-based activities within the catchment only to the extent that these have an impact specifically on the water environment.

The State Pollution Control Commission is responsible for management of the study and for making recommendations developed from it, with advice from its Technical Advisory Committee. Throughout the study period, however, the Commission has been assisted by willing cooperation and communication with many other departments and authorities. Particular elements of the study are being carried out by State Government instrumentalities, universities and consultants. Major elements are supported by technical consultative committees.

Investigations have aimed first to identify and describe the water-associated resources and the activities responsible for environmental change. The effects of activities on important resources can then be assessed and appropriate control measures indicated.

These investigations have led to a series of technical papers on specific aspects, of which this paper is one. Other papers in the series are listed below.

One of the principal objectives of the study is to recommend to the Government a comprehensive water-resource management plan for the bay and its tributaries. These technical reports will contribute to that objective.

This report was prepared by the Commission's Botany Bay study team.

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ABSTRACT

The macrobenthic infauna of dredged and undredged areas in Botany Bay were surveyed in late 1976.

Multivariate analyses revealed a number of distinct communities within the surveyed area. Dredged areas supported species groupings which were different from those of adjacent undisturbed areas but the benthic communities of the two areas were similarly diverse. Faunistic and community structural differences found were related to differences in sediment type and wave exposure, rather than merely to the occurrence of dredging.

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FIGURES

1 INTRODUCTION

Dredging is one of the most common large-scale intrusions by man in estuaries. The recognized high biological, commercial and aesthetic value of estuaries makes an understanding of the environmental effects of dredging essential. However no major studies of the effects of dredging on Australian estuaries have been reported to date.

Large-scale dredging operations in Botany Bay have aroused public controversy over the possible adverse effect of these works on the ecology of the estuary. About 560 ha (representing 12 per cent of the bay area) have been dredged for port and airport developments (Figure 1). Dredging has been at intervals over a period of 25 years, so the time since dredging for different areas of the bay ranges from months to many years.

This study investigates the effects of dredging on the benthos of Botany Bay. Macrobenthic infaunal organisms were chosen for investigation because they are permanent inhabitants of the sediments and have low mobility. They are thus good indicators of prevailing conditions, in contrast to epifauna which are mobile and may not accurately indicate particular environmental conditions. Infauna organisms are also in important element in estuarine food chains and are a major food source for many fish and wading birds.

To date, most studies of dredging effects have dealt with the immediate or short-term consequences. These include :

- Destruction of existing bottom communities
- Increase in depth, often below the euphotic zone
- Increase in water turbidity
- Smothering of organisms by settling silts
- Damage to adjacent areas (often wetlands) by spoil disposal
- Changes in water chemistry as substances are released from dredged sediments
- Changes in water movement patterns

Studies of longer-term effects have indicated that dredging may cause a variety of ecological responses, depending on the area and the nature and extent of dredging. Rosenberg (1977) found that the benthic community structure of dredged areas in the Byfjord estuary, Sweden, was virtually restored to pre-dredging conditions within one and a half years. Such rapid regeneration is not uncommonly reported in literature (May 1973). In contrast, Taylor and Saloman (1968) indicate that the dredging associated with bayfill canal developments in Boca Ciega Bay, Florida, had caused a drastic and apparently permanent reduction in species diversity and abundance. Recolonization of the dredged canals had been negligible in the ten years after dredging. A similar change seems to have occurred locally in the dredged canals of the Sylvania Waters development, Georges River, which remained devoid of benthos about eight years after completion of dredging (O'Gower 1973).

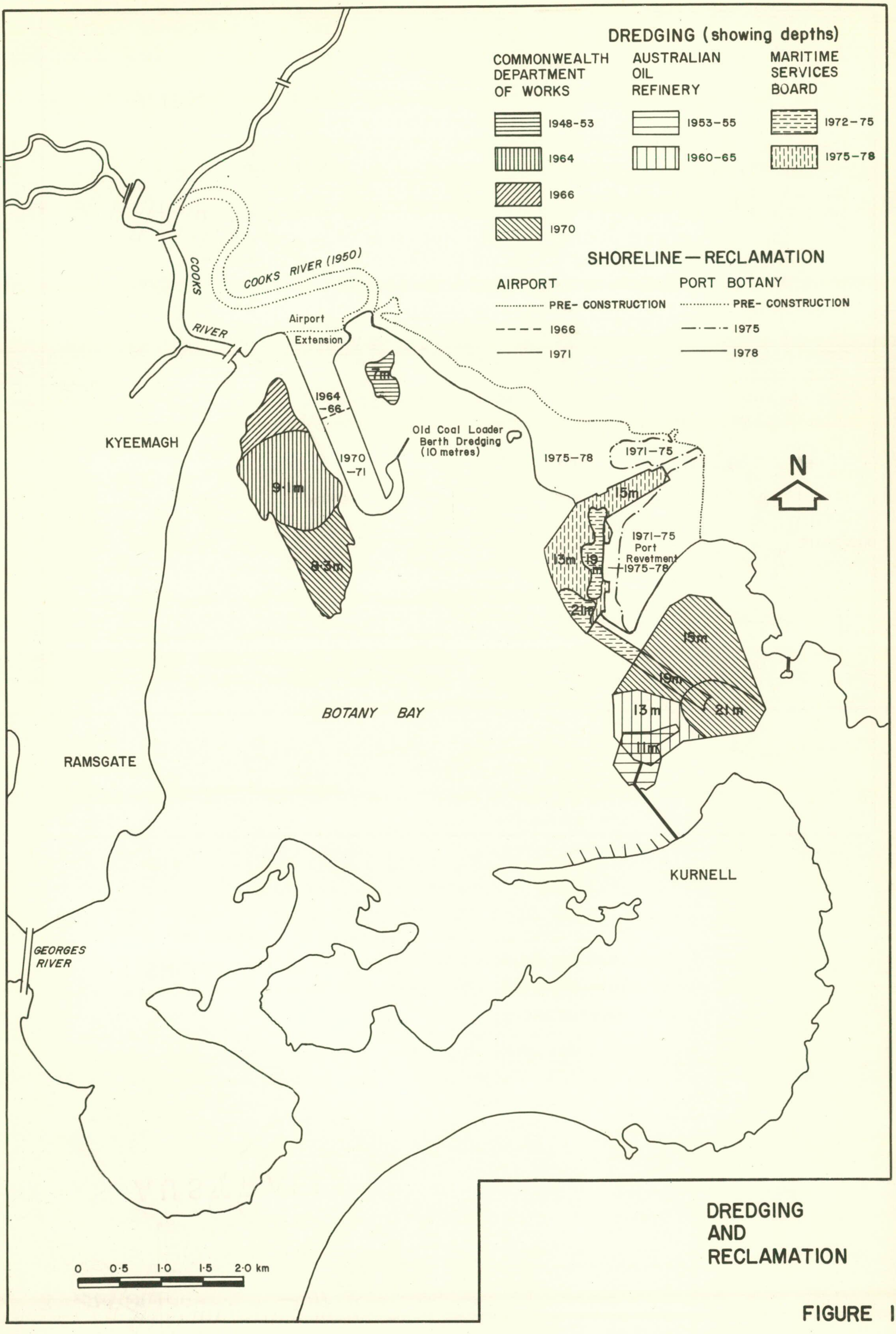
This report presents the results of a survey of macrobenthic infauna of dredged and undredged control areas in Botany Bay. The fauna and community structure of the study areas are discussed in relation to dredging history and the present environment. Studies on the effects of dredging on fish populations, seagrass communities and water turbidity will be reported in other papers of this series.

1.1 Terminology

The data from this study have been subjected to multiple analyses for different purposes. To avoid confusion in presenting results, the following terminology has been adopted.

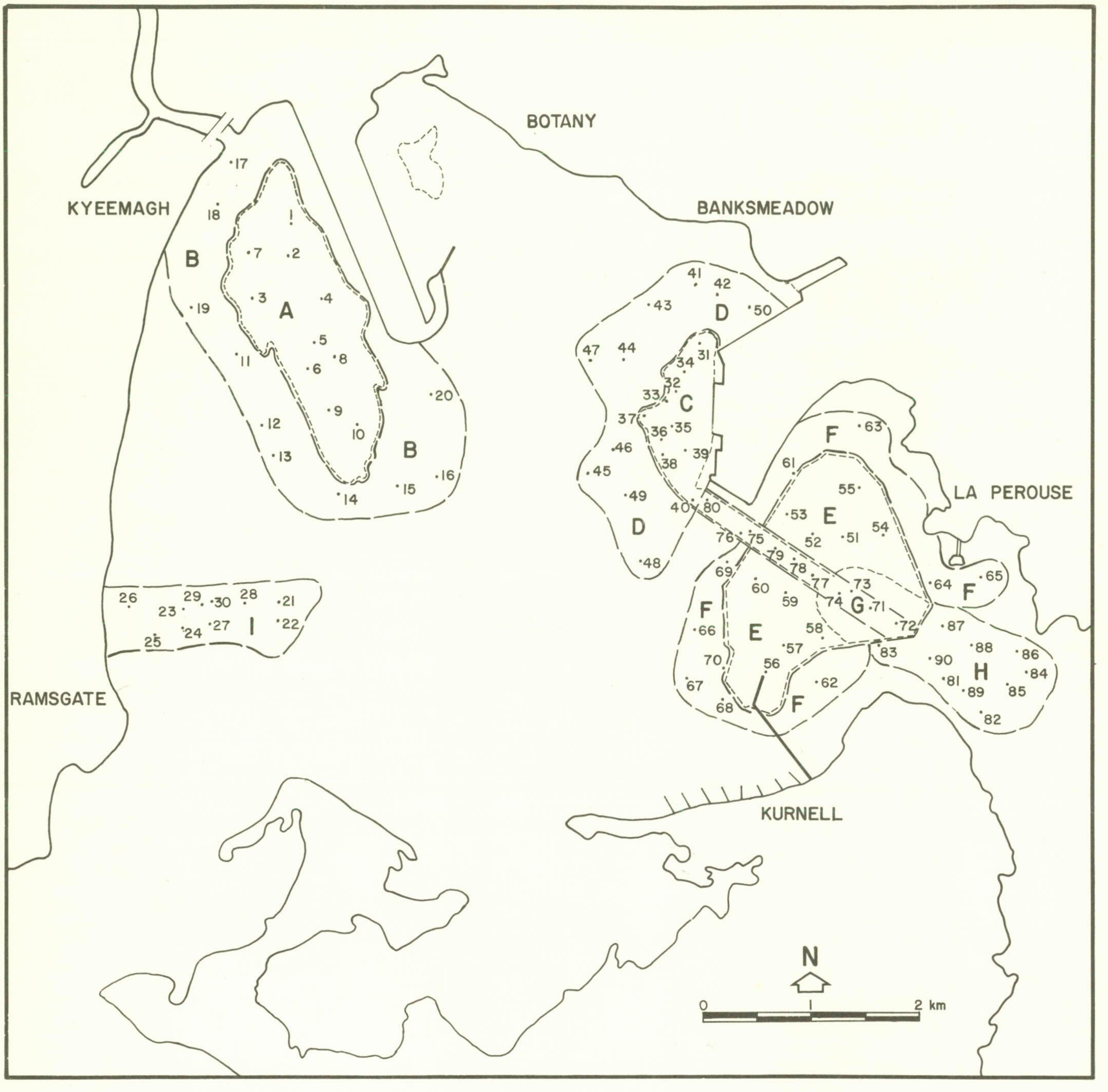
Sampling areas : the dredged and undredged (control) areas delineated at the commencement of the study, within which samples were taken. These areas are shown in Figure 2.

Site groups : clusters of sites (ie samples) produced by analyses of the data, on the basis of similarities in species and their abundances. These groups define geographic areas within the bay which may or may not correspond to the original sampling areas.



DREDGING AND RECLAMATION

FIGURE 1



SAMPLING AREAS
SAMPLE SITES
DREDGED AREAS

SAMPLE LOCATIONS

FIGURE 2

2 METHODS

2.1 Sampling Procedure

Sampling areas were delineated within Botany Bay after consideration of dredging histories and sediment types. Sampling locations in each sampling area were selected using random numbers within a stratified grid system. Squares of the grid which intersected the boundary of a dredged area or shoreline were deleted to minimize edge effects. Field locations were determined by theodolite cross reference and were marked with buoys dropped from a radio-directed boat.

Divers collected the samples using a cylindrical corer (19 cm in diameter and 15 cm deep) which yielded a sample of about 4.25 L of sediment, representing a surface area of 0.028 m^2. The corer was pushed into the bottom, closed with a metal sheet and then inverted so that the contents were emptied into an attached plastic bag. The bag was then sealed and brought to the surface.

Duplicate bottom samples were collected from ten locations within each of nine sampling areas. One sample from each pair was analysed for benthic organisms, the other for sediment particle size and organic content.

All samples were collected in the period November 1976 to January 1977.

2.2 Analysis of Samples

2.2.1 Benthos

Each sample was washed through a 1 mm sieve and the retained material fixed in a 10 per cent (V:V) formalin:seawater solution. In the laboratory, the samples were transferred to 70 per cent ethanol and the organisms sorted from the debris. The rejected material was independently checked to ensure uniformity between sorters.

Polychaetes, crustaceans and molluscs were identified to species level, wherever possible. The numbers of individuals of each species and their alcohol wet weights were recorded for each sample. (Mollusc shells and polychaete tubes were not included in the weights.) The less common phyla (Nemertina, Cnidaria, Phoronida etc) were excluded because of difficulties with their identification.

The Australian Museum acted as reference for taxonomy throughout the study. A representative collection of specimens from the study has been lodged with the Australian Museum.

2.2.2 Sediments

Samples were submitted to an external laboratory for analyses of shell, sand, silt, clay and organic matter. Due to a technical error during analysis, the results of these tests had to be discarded. Re-sampling of the 90 stations was impractical. Sediments at sample locations were therefore defined from field observations and the results of a sediment survey undertaken earlier in 1976 (SPCC 1978).

2.3 Analysis of Data

Two types of statistical approach were used in the analysis of the data from this study, namely :

- Tests of significance - to compare statistically the fauna of dredged and control areas
- Descriptive methods using multivariate techniques - to condense the data and provide an objective overview of the benthic associations of the bay.

2.3.1 Tests of Significance

Analyses of variance (ANOVA) were performed on the average number of species and numbers of individuals for each of the dredged and control areas. To reduce departures from normality, the data were first transformed using ln (n + 1) transformation. The means of the counts were compared using Tukey's w procedure (Steele and Torrie 1960).

ANOVA was also used to compare average Shannon-Weaver diversity indices calculated for each study area. This index (H) is a measure of community structure, and expresses the distribution of importance among species or, more precisely, the uncertainty in the prediction of the identity of a randomly selected individual from a collection (Boesch 1973).

$$H = -\sum_{i=1}^{s} p_i \cdot \ln p_i$$

where $p_i = \frac{ni}{N}$

s = number of species

n_i = number of individuals in species i

N = total number of individuals

H = diversity index.

A Canonical Analysis (Seal 1966) was carried out on the percentages of individuals of the three feeding types in the site groups. The percentages were first transformed using arcsin transformation. The first canonical variate (CV I) is a weighted contrast of per cent deposit and per cent carnivorous against per cent suspension feeders. The second canonical variate (CV II) is a weighted contrast of per cent deposit against per cent carnivorous and per cent suspension feeders.

2.3.2 Descriptive Methods

Descriptive, multivariate methods can identify similarities within unstructured data and may extend the information obtainable from classical, statistical methods. Computer analysis makes these methods practicable, even for large data sets.

2.3.3 Classification

Classification is a technique which clusters entities into related groups. Measures of dissimilarity are calculated between all entities on the basis of one or more attributes. In an agglomerative classification procedure, the entities are successively fused to form a hierarchy which can be represented in a dendrogram.

In classificatory analyses, it is general practice to ignore rare species, as they are usually not important in forming patterns and involve a considerable addition to computing expense. In the present classifications, only those species which had a total abundance of ten or more individuals, or which occurred three or more times in any study area were included for classification. 89 of the 225 species found in the study satisfied these criteria.

- Normal Classification

  Samples (henceforth called 'sites') were classified into groups on the basis of species composition and abundance, using the Bray-Curtis dissimilarity index (Clifford and Stephenson 1972):

$$D_{ij} = \frac{\sum_{k=1}^{s} x_{ik} - x_{jk}}{\sum_{k=1}^{s} x_{ik} + x_{jk}}$$

where D_{ij} = dissimilarity index between the i^{th} and j^{th} sites

s = number of species

x_{ik} = number of individuals of species k in site i.

(Values of D_{ij} range from 0, for identical samples, to 1, for samples with completely different species compositions.) Because the Bray-Curtis index is sensitive to dominance, the data were first transformed by taking the cube root of x_{ik} for all i and k. A hierarchical polythetic clustering algorithm, group average, (CSIRO programme MULCLAS) was used to classify the sites.

Another classification (based on the Canberra - metric dissimilarity measure using group average clustering) produced a very similar pattern of site groups. However, the Gray-Curtis classification was chosen in preference as it was more consistent with ordinations.

. Inverse Classification and Nodal Analysis
Species were classified on the basis of their distribution or abundance ie species became the entities and sites the attributes. The same procedures were used as for normal classification discussed above.

The normal and inverse classifications were combined into a two-way coincidence table (Stephenson et al 1975), to reveal the relationship between species groups and site groups. To facilitate interpretation of the table, indices of constancy and fidelity were calculated for each cell (Boesch and Swartz 1977). Constancy is a measure of the extent to which a given species group occurs in a particular site group. Fidelity indicates the degree to which a species group is restricted to a site group.

2.3.4 Ordination of Sites

Ordination, if profitable, indicates whether the sites form relatively homogeneous groups which are clearly separated from each other, or whether they form a continuum which has been arbitrarily divided by classification (Goodall 1973).

Euclidean distance was used as the dissimilarity measure, after cube root transformation of the data. Euclidean distance is

$$ED_{ij} = \sqrt{\sum_{k=1}^{s} \left(x_{ik} - x_{jk}\right)^2}$$

where ED_{ij} = Euclidean distance between sites i and j.

x_{ik} = number of individuals of species k in site i.

s = number of species.

Ordinations were performed using principal co-ordinate analysis (Gower 1966 - CSIRO Programme GOWER).

2.3.5 Diagnostic Analysis

Diagnostic analysis (Lance et al 1968 - CSIRO Programme GOWECOR) was used to identify those species which had been most influential in ordination of the sites, ie are most closely correlated with principal axes explaining a substantial proportion of the variance.

3 RESULTS

Four dredged and four undredged (control) areas in Botany Bay were sampled (Figure 2). As all the undredged areas were sandy, an additional set of samples was taken from a natural mud area in the bay (area I on Figure 2) to provide a comparison with muddy dredged areas. The nature of the sampled areas is shown in Table 1.

Ten cores from each sampling area (a total of 90 cores) were analysed. These yielded a total of 225 species of benthic macroinvertebrates. Polychaetes were the most diverse group (94 species), followed by crustaceans (75 species) and molluscs (56 species). The species identified during the study are listed in Appendix A and abundance of the 89, most common species is summarized in Table 2.

Cumulative graphs of species recruitment (Figure 3) indicated considerable variability in species richness between sampling areas, with more sandy areas being generally richer than muddy areas.

Taken over the whole study, there was an average of 17 species per sample. The percentage composition by species of the major taxa was fairly uniform over the areas sampled and averaged 55 per cent polychaetes, 27 per cent crustaceans and 18 per cent molluscs. However, percentage composition by numbers of individuals of the major taxa varied considerably between different regions of the bay.

Some species occurred fairly consistently over the whole bay whilst others were restricted to particular areas. The majority of species occurred in relatively low numbers, although several species reached densities of up to $10^5/m^2$. These abundant species were generally not distributed evenly over the bay but occurred in aggregates of very high numbers in preferred areas. Some of this pattern was apparently related to sediment type, as shown below.

The most abundant species were :

Polychaeta : Caulleriella sp 2 (Cirratulidae)
- very high numbers in all muddy areas and the dredged entrance channel

Chone sp (Sabellidae)
- very high numbers in the airport hole and revetment hole

Table 1. Nature of Sampling Areas in Botany Bay

Locality	Sampling Area (Figure 2)		Date Dredged	Bottom Sediments	Depth (m, ISLW)	Wave Exposure	Currents
Airport	A	dredged	1964-70	mud and silty sand	7 - 9	low	low
	B	undredged		sand	2 - 5	low	low
Port Revetment	C	dredged	1972-75	mud and silty sand	18 - 21	low	low to moderate
	D	undredged		sand with some silts	2 - 9	low to moderate	low to moderate
Entrance Wings	E	dredged	1970	sand	13 - 15	moderate to high	moderate to high
	F	undredged		sand	4 - 12	moderate to high	moderate to high
Entrance Channel	G	dredged	1970	silty sand	19 - 21	moderate	moderate to high
	H	undredged		sand	15 - 20	high	moderate to high
Mud 'Finger'	I	undredged		mud	3 - 4	low	low

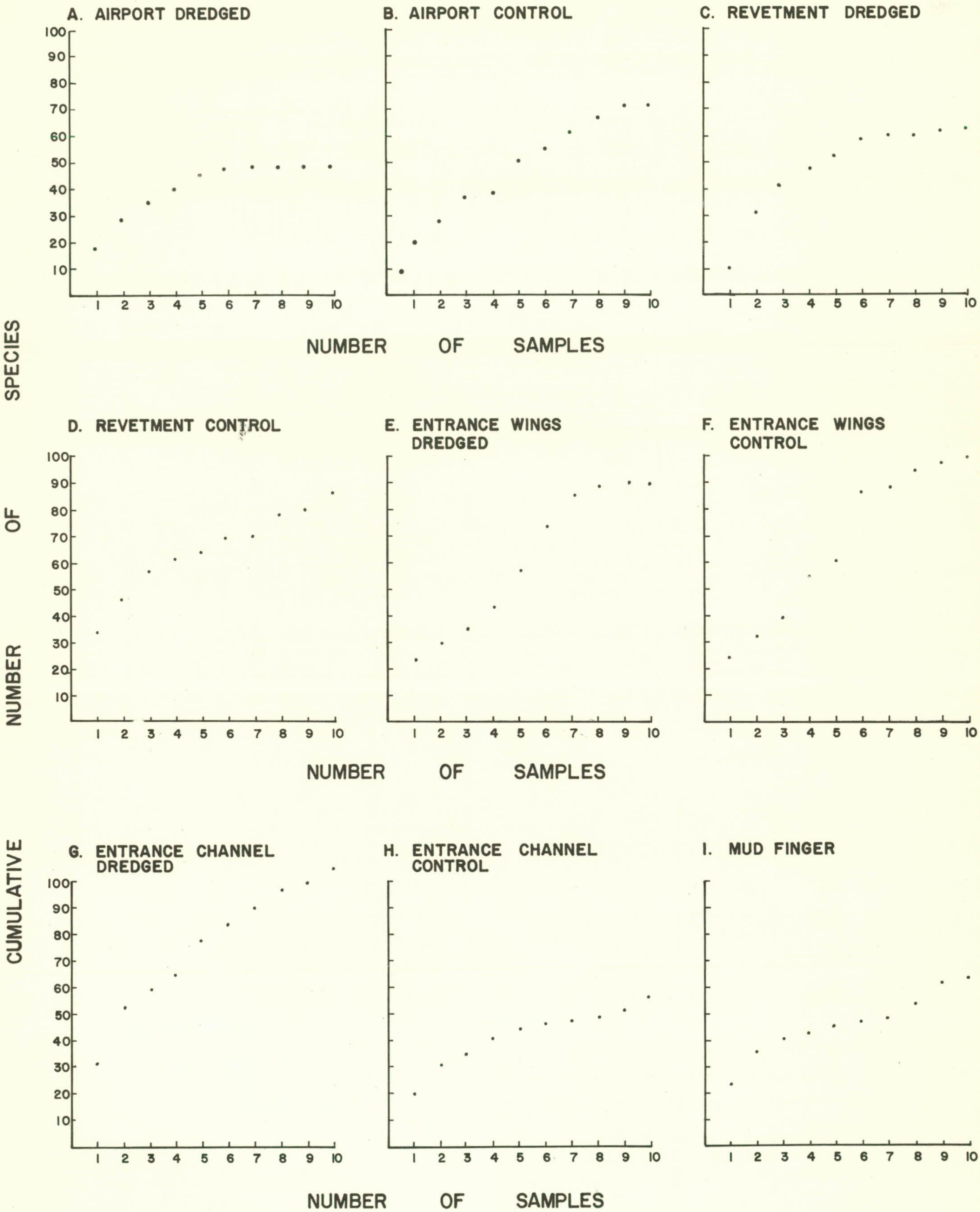
Table 2. Species Occurrence and Abundance in Site Groups

Site Group/Site Number

Species Group	Species	1 (17 21 22 23 24 25 26 27 28 29 30)	2 (1 2 3 4 5 6 7 9 10 31 34 38 44 47 50)	3 (32 33 35 36 37 39)	4 (40 55 56 67 71 73 74 75 76 77 79)	5 (11 12 13 14 15 16 18 19 20 41 42 45 46 48 49)	6 (53 62 63 66 68 70 78 80)	7 (65 69 81 84 85 86 87 88 89 90)	8 (51 52 54 57 58 59 60 61 64 72 82 83)
	Psuedoamphicteis papillosa	1 1	1 1 1 1 1	1 1	1 1 1 1 1 1 1				
	Mediomastus californiensis	2 1 2 1 3 2 2 3 2 2 1	1 1 2 2 2 2 2 1 2 2 1 2 2 2 3	3 4 5 5 5 4	2 2 2 2 2 2 2 3 2 2 3	2 1 1 1 1 1 2 1 2 3 3 2 2 2	1 2 1 1 2 2 3 1	2	1 1 1 1
	Barantolla lepte	2 1 1 1 1 1 1	1 1 3	2 1 1 2 1 1	1	1 1 1 2	1		
	Heteromastus sp	1 1 1 1	1 1 1 1 1 1 1 1 1	1 1 1 1	1 2 1 2 1 1 1 1 1	1 1 1 1 1 1 1 1 1	1 1 1 1 1 1	1	1
	Caulleriella sp 1	1 1 1 1	1 1 1 1	1 2 2 1	1 1 1 2 1 2 1 1	1 1 1 1 1	1 1		1 1
	Caulleriella sp 2	2 4 3 2 3 3 2 2 3 2 2	2 2 2 4 4 4 1 5 4 1 1 1 2 2 2	1 2 2 1 2 2	3 4 1 3 1 4 2 4 3 4 4	1 2 2 1 1	1 1 1 2		
	Glycera sp 2	1 1 1	1 1 1	1 1 1	1 1 1 1	1 1 1			
	Goniada sp 1	1	1 1 1 1 1 1 1 1 1 1	1 1 1 1 1	1 1 1 1 1 1 1 1 1				
	Lumbrineris sp	1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1	1	2		1	1
	Nephtys sp	1	1 1	1	1 1 1 1 1 1 1 1	1 1 1 1 1 1 1	1 1		
	Ancistrosyllis sp	1 1 1 1 1 2 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 2 1 1 1 1	1 1 1 1 1	1	1		
	Chone sp	1	3 2 2 4 3 3 2 4 2 4 3 4 3 3 4	4 6 5 6 6 6	1 1 2 3 1 1 2	1 1 1 1 2 1 1 1 1 1			
	Sthenelais sp	1	1 1 1	1 1 1 1 1 1	1 1 1 1 1 1 1 1		1		
	Polydora sp 1	1 1 1 2 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 2 2 1	1 1 1 2	1 2 1 1 1 1 1		1	
	Polydora sp 2		1 1 1 1 1	1	1 1 1 1 1 1	2			
	Polydora sp 3	1 1				1 1 1	1		
1	Prionospio sp 1	1 1 1 1 2 2 2 1 1	2 2 1 2 1 1 5 1 1 1 1 1 2	4 3 5 5 3 2	1 1 1	1 1 1 1	1		1
	Prionospio sp 2	1 1 1 1 1 1	1 1 1 1 1 2 2 1	1 1 1 1	2 1 1 1 1 1 1 1	1 1 2 1	1 1 1	1 1 1	1 1
	Euphilomedes sp		1	1	1 1 1 2 1 2 1		1		1
	Corophium acherusicum	3 3 1 1 1 1 2	3 1 1 2 2 1 1 1 2 3 4	1 1 1 1 4 2	1	4 4 2 5 3 3 5 4 2 5 5 4 5 2 4	1		
	Photis sp	1 1 1	1 1 1 1 1	1 1 1 1 1	1 1 1 1 1	1 1 1	1	1	
	Ericthonius sp	1 1 1	1 1 2 2	1		1 2 1 1 2 1 1 4 2 2			
	Liljeborgia dubia	1 1 2	1 1	1 1 2 2	1 1 2 1 1 1	1 1 1 1 1 1	1 1		1 1
	Liljeborgia sp 1	1 1	1 1	1	1 1	1 1 1 1 1 1 1 1 1			
	Metaproto haswelliana	1 1	1 1 2 1	2 2 2 2 1 2	1 2 1 1	1 1	2 1 1		1
	Eocuma sp	1 1 1 1	1 1 1 1 1 1 1	1 1	1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1		
	Dimorphostylus sp	1		1 1 1 1 1	1 1 1 1 1 1 1				1 1
	Callianassa arenosa	1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1	1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1			
	Nassarius nigellus	1 1 1 1	1 1 1	1 1	1 1 1 1 1 1 1 1 1	1 1 1	1 1 1		1
	Pupa fumata	1 1 1 1 1	1		1 1	1 1 1 1 1 1 1	1 1		
	Mysella sp	1 4 1 1 1 1 1 1	1 1 1 1 2		1 1 1	1 1 1 1 2 2 2 2 1 1	1 1 2 1	1 1	1 1
	Notospisula trigonella	2 2 5 5 3 2 2 5 5 6	1 1 1 1 2 2 1 2	1	1 1	1 1 1 1 3 1	1 1		1
	Theora sp	1 1 2 1 1	2 2 1 3 1 1 2 1 3 1 1 1	2 1 2 2 1	2 1 2 1 1				
2	Odontosyllis sp		1	1	1 1 1				
	Munna sp		1 1	1 1 1	1			1	
	Mesochaetopterus sp				1		1 2		
	Caulleriella sp 3				1 2 1		1		1 1 1 1 1
	Dorvillea sp				1			1	1 2
	Glycera sp 1	1 1 1 1 1 1	1 1 1 1	1	1 1 1 1 1 1 1	1 1 1 1 1 1	1 1 1 1 1 1 1	1 1	1 1 1 1
	Ophiodromus sp		1			1 1 1 1	1 1		
	Lumbrineris latreilli	1 1 1			1 1 1	1 1 1 1	1 1 1 1 1		1 1 1
	Onuphis sp 1				1 1 1			1	1 1 1 1
3	Phylo felix	1		1	1 1 1	1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 2 1	1 1 1	1 1 1 1 1
	Euchone sp		1		1 1 1 1 1 1	1 1 1 1	1 1 1 1 1 1	1 1	1 1 1 1 1 1 1
	Malacoceros sp	1 1	1 1 1 1		1	1 1 1 2 1 1 1 1 1 1	1 1 1 1 1	1 1 1 1 1	1 1 1
	Syllis (Langerhansia) sp					1 1	1	1	1 1 1 1
	Astacilla vicaria	1 2			1 1		1 1		
	Ampelisciphotis sp				1		1 1 1	1	
	Hippomedon sp				1	1 1 1	1		1 1
	"Phoxocephalid" sp 4	1			1 1	1 1 1	1 1		1 1 1 1
	Tellina subdiluta				1	1	1 1 1 1 1 1 1	1 1 1 1	1 1 1
	Neosolen correctus				1	1	1 1 1 1		1 1
	Chaetopterus varieopedatus		1 1		1 1 1 2 1 1		1		
	Spiophanes sp				1 1 1 1 1				2 1
4	Aora sp				1 1 1 1		1		
	Xenophthalmodes dolichophallus		1	1	1 1 1 1 1	1			
	Polinices conicus		1 1		1 1 1 1		1 1		
	Pupa nivea				1 1		1 1		
	Notomastus sp	1 1 1 1	1 1 1			1 1	1		
	Glycera americana	1 1 1 1	1 1 1 1 1 1 1 1	1	1 1 1				
5	Gyptis sp	1 1	1 1 1 1 1		1	1			
	Diopatra sp 2	1 1 1 1 1			1 1				
	Eriopisa sp	1 1 1							
	Nassarius burchardi	1 1 1 1 1 1 1	1 1			1			
	Anthuridae sp					1	1 1 1		
6	Cirolana woodjonesi					1 1 1	1 1		
	Notocallista sp				1		1 1		
	Veneridae sp						1 1 1		1
	Cirratulus sp	1	1	1 1	1	1	1 1 1		
	Owenia fusiformis	2 1 1 1			1	1 1	1		
	Phyllodoce sp	1 1	1 1 1	1 1 1		1 1	1		
	Prionospio sp 3	1 1				1 1 1	1		
	Pista typha				1	2			1
7	Tanais sp			1		1 2			1
	Apanthura sp		1			1 1 1 1 1			
	Leucothoe assimilis		1	1		1 1	1		
	Phoxocephalidae sp 7		1	1 1	1	1			
	Leipsuropus parasiticus	1			1	1 2 1			
	Caprella scaura	1 1				1 1 1 2 2 1 1			
	Onuphis sp 4				1			1 1	1 1
	Prionospio sp 4							1 1 1 1 1 1	1 1 1
8	Dispio sp							1 1 1 1	
	Siphonoecetes sp				1			1 2 1 1 1	1 2 1 1
	Phoxocephalidae sp 5			1		1		1 1 1 1 1	1
	Pisinna nitida							1 2 1 1 2	
	Marginella sp					1		1 1 1 1 1	
	Cuna atkinsoni					1 1		1 1 1 1 1 1 1	1
	Cyamiomactra sp				1			1 1 1 1	
9	Australonereis ehlersi		1 1						

CODE

Symbol	Number of Organisms
1	1 - 10
2	11 - 40
3	41 - 100
4	101 - 200
5	201 - 400
6	> 400



SPECIES RECRUITMENT
WITHIN SAMPLING AREAS

FIGURE 3

Mediomastus californiensis (Capitellidae)
- widely distributed over bay, with very high numbers in the revetment hole

Prionospio sp 1 (Spionidae)
- high numbers in all muddy areas, particularly the revetment hole (average abundance = 3.2×10^3 individuals/m^2)

Crustacea : Corophium acherusicum (Corophiidae)
- virtually restricted to the western portion of bay; high numbers (average abundance = 5×10^3 individuals/m^2) in sandy sediments

Mollusca : Notospisula trigonella (Mactridae)
- high numbers in the Ramsgate mud 'finger' (average abundance = 6.2×10^3 individuals/m^2).

3.1 Benthic Structure of the Study Area

Normal classification of sites (on the basis of species present and their abundances) produced a dendrogram with eight site groups* at a dissimilarity of 0.5 (Figure 4). These site groups mostly represented geographically coherent sets of sites (Figure 6).

The species composition of the site groups is shown in Table 2. The species groups shown in this table were generated by inverse classification independently of the site groups. (The dendrogram from inverse classification (Figure 5) showed a structural similarity to the normal dendrogram (Figure 4) but no association of a species group with the correspondingly numbered site group is implied. All further presentation of results is based on the normal dendrogram.)

The first major division in the normal dendrogram (Figure 4) separates site groups 7 and 8 from site groups 1 to 6. The main feature distinguishing site groups 7 and 8 is their particularly low numbers of species and individuals (Table 3). The sites comprising these groups are from the entrance region of the bay.

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* One site group, consisting of two particularly depauperate sites (8 and 43) has been omitted from the dendrogram. The occurrence of these faunistically poor sites in the midst of otherwise rich areas probably only reflects a local disorder and does not seem to warrant consideration as a separate site group.

Table 3. Benthos of Site Groups

Group No	No of Sites	Species (mean No)	SD	Individuals (mean No)	SD
1	11	20.5	1.8	313.5	44.2
2	15	19.3	1.6	281.8	31.7
3	6	25.2	1.7	1 043.2	117.5
4	11	30.8	1.4	369.1	51.7
5	15	20.7	1.7	317.2	69.6
6	8	21.1	2.4	295.4	72.5
7	10	9.3	0.5	90.1	65.2
8	12	12.4	1.9	23.0	1.3

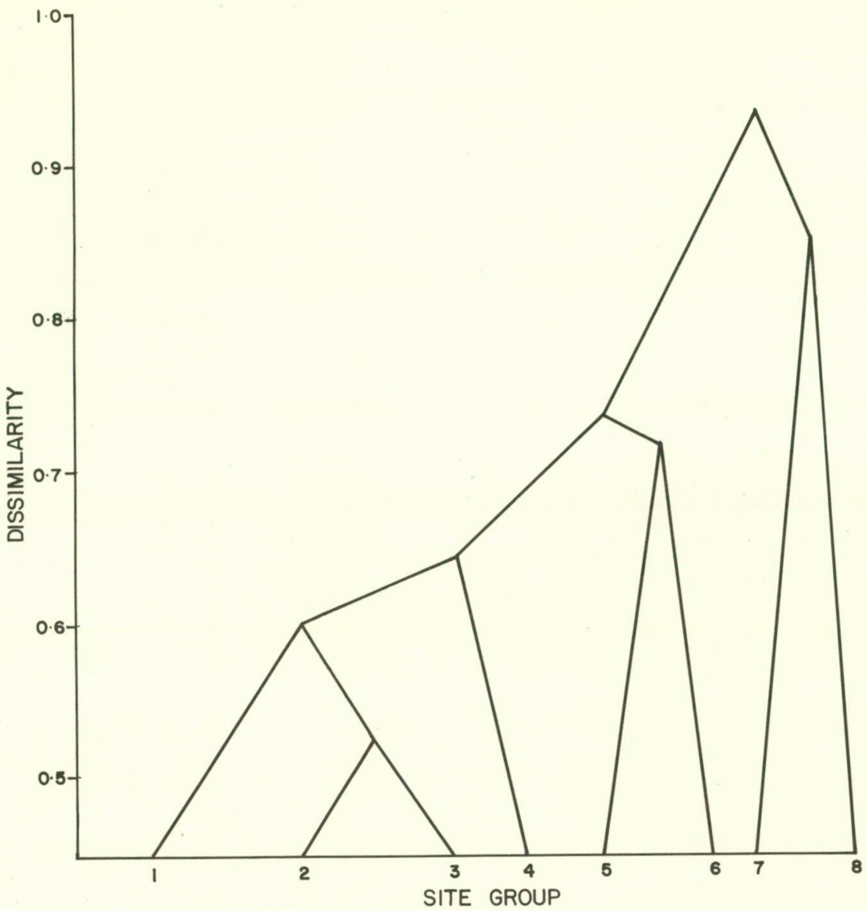


FIGURE 4. **Dendrogram Produced by Normal Classification**

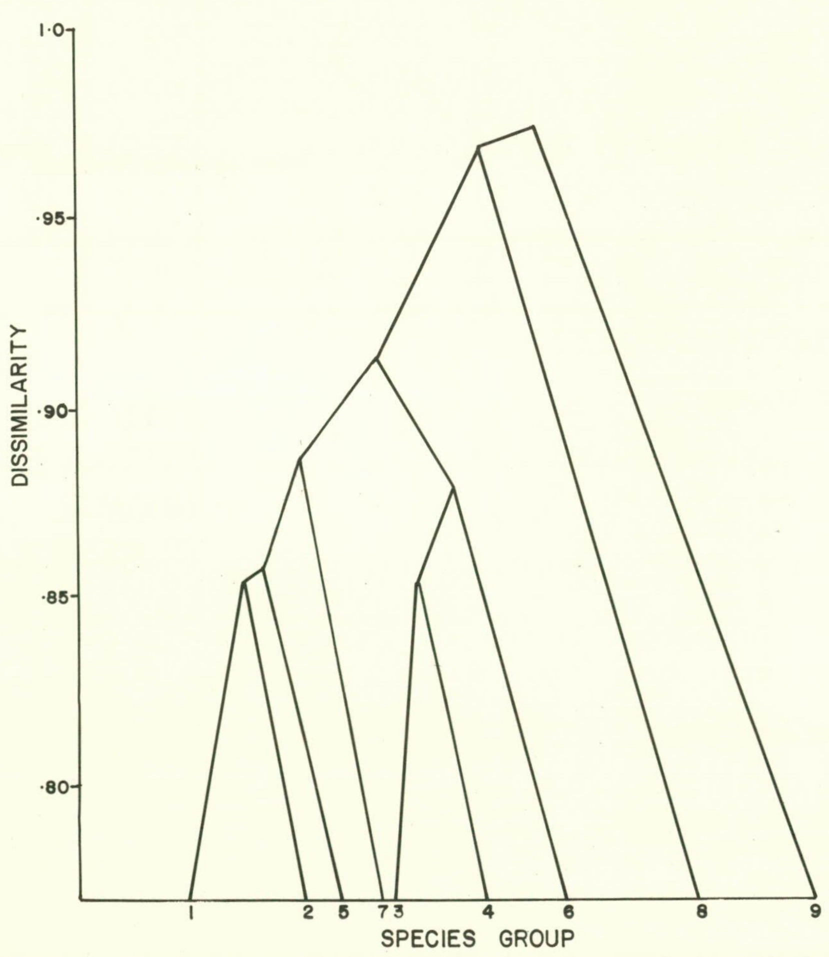
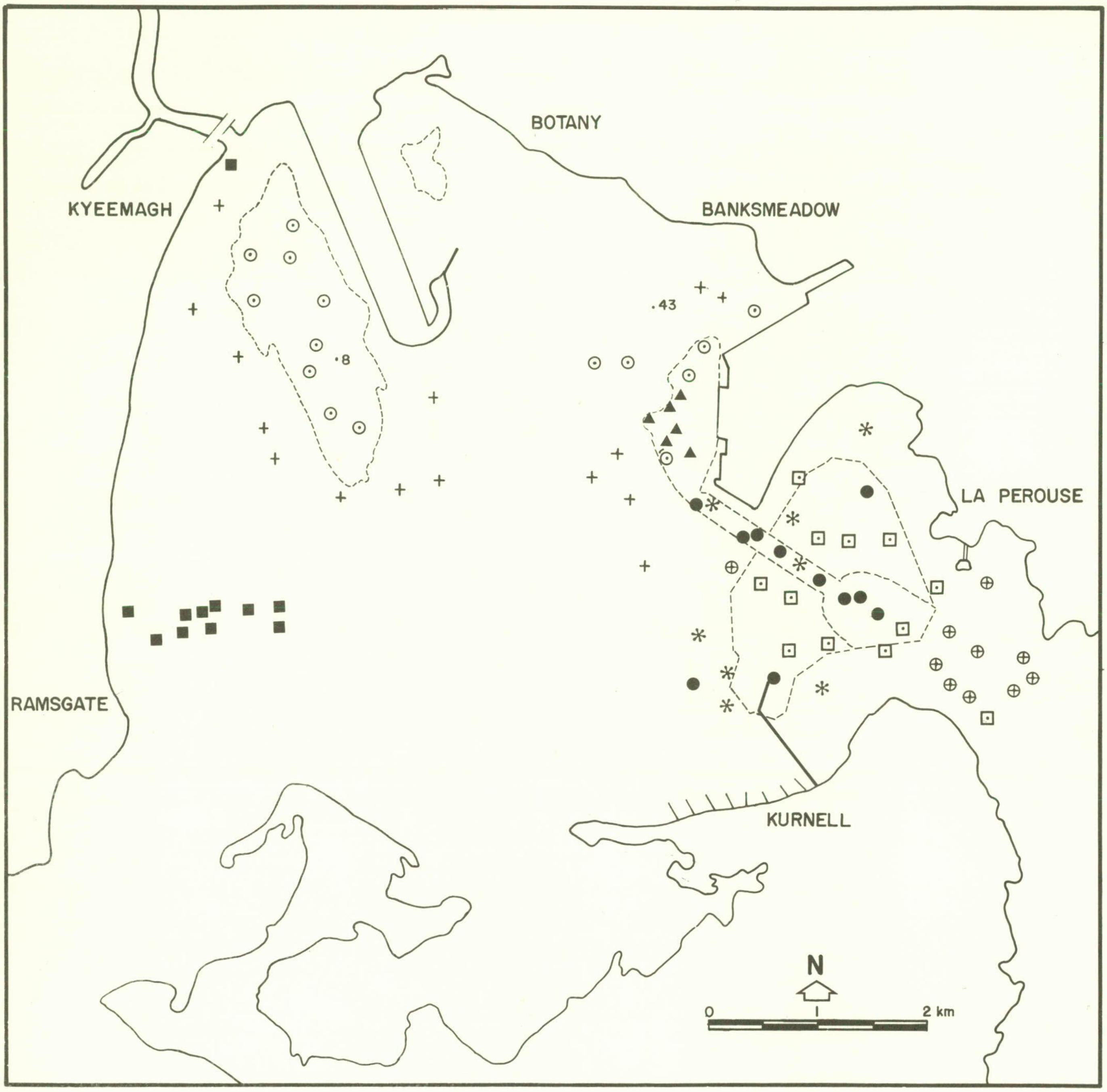


FIGURE 5. **Dendrogram Produced by Inverse Classification**



SITE GROUP NUMBER

■	1
⊙	2
▲	3
●	4
+	5
*	6
⊕	7
⊡	8

------- DREDGED AREAS

NOTE · Sites 8 and 43 omitted from analysis (See page 15)

SITE GROUPS PRODUCED BY NORMAL CLASSIFICATION

FIGURE 6

Table 4. Species Important in Separating Site Groups*

(a) Separation of groups 1, 2 and 3 from groups 4, 5 and 6

Species		Site Groups 1, 2 & 3	Site Groups 4, 5 & 6
Prionospio sp 1	(P)	low-very large numbers	mostly absent
Chone sp	(P)	medium-large numbers (except site group 1)	mostly absent
Ancistrosyllis sp	(P)	low numbers	mostly absent
Polydora sp 3	(P)	mostly absent	large numbers
Phylo felix	(P)	mostly absent	low-medium numbers

(b) Separation of groups 1, 2 and 3

Species		Site Group 1	Site Group 2	Site Group 3
Prionospio sp 1	(P)	low-medium numbers	low-medium numbers	very large numbers
Chone sp	(P)	absent	medium numbers	very large numbers
Notospisula trigonella	(B)	very large numbers	low numbers	absent
Mediomastus californiensis	(P)	low-medium numbers	low-medium numbers	very large numbers
Metaproto haswelliana	(A)	absent	absent	low-medium numbers
Sthenelais sp	(P)	absent	absent	low-medium numbers
Dimorphostylus sp	(C)	absent	absent	low numbers

(c) Separation of groups 4, 5 and 6

Species		Site Group 4	Site Group 5	Site Group 6
Corophium cf acherusicum	(A)	absent	very large numbers	absent
Callianassa arenosa	(D)	absent	low numbers	absent
Caulleriella sp 2	(P)	very large numbers	mostly absent	mostly absent

* Letters in parentheses denote : Amphipod, Bivalve mollusc, Cumacean, Decapod, Polychaete.

Site group 7 is characterized by sites containing a relatively uniform set of species which very rarely occurs outside this site group. Constancy and fidelity indices of species group 8 for site group 7 are both particularly high (Figures 7 and 8). Site group 7 may therefore be regarded as a natural assemblage of sites, faunistically very dissimilar from the rest of the bay. The sites comprising this group are from the undredged sandy region between the heads of the bay.

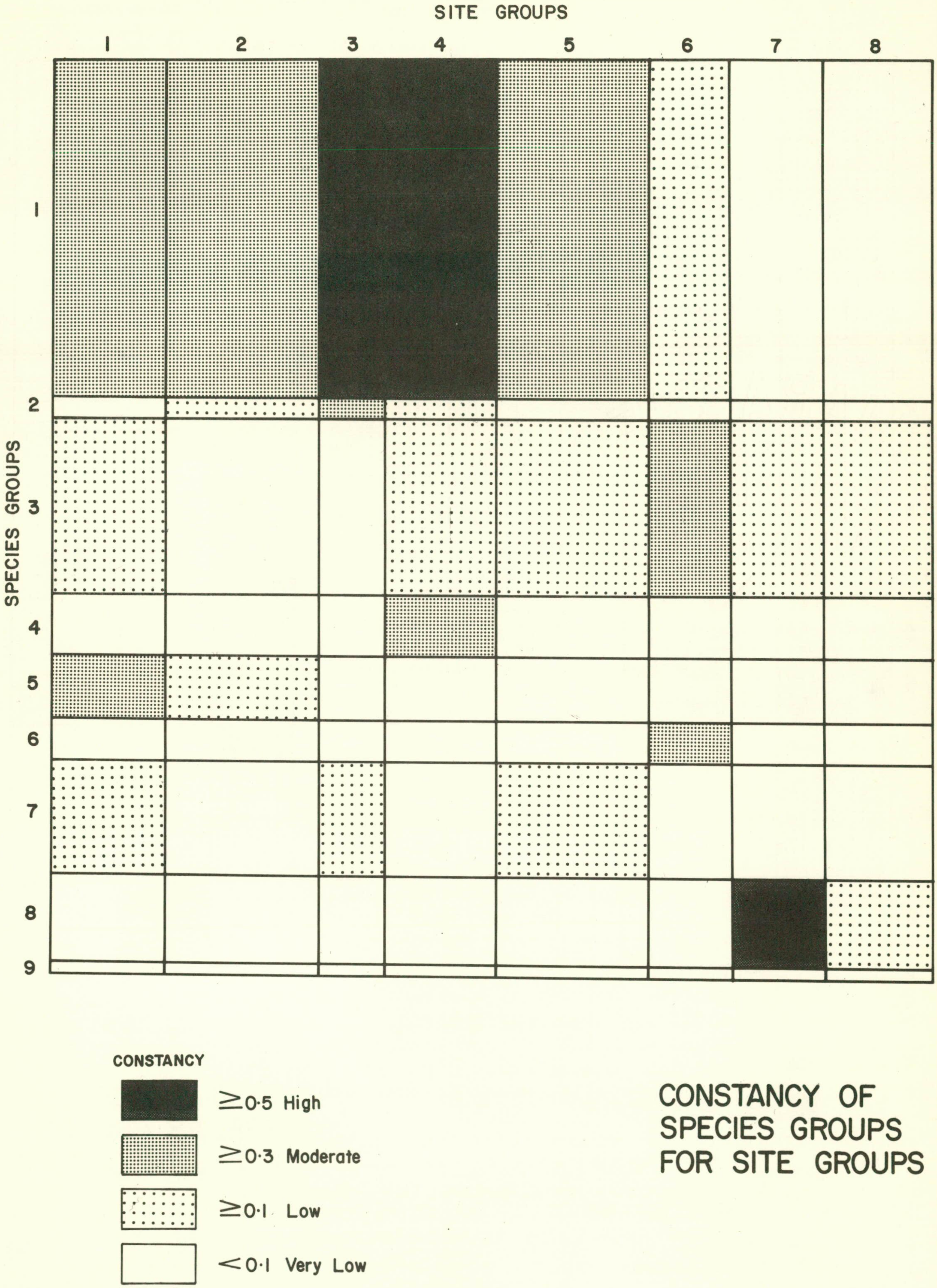
In contrast to site group 7, site group 8 is heterogeneous. Species composition varies considerably between sites, and these sites are consequently highly dissimilar from each other. At the 0.5 level of dissimilarity, site group 8 actually consists of 12 individual site groups, each containing only one or two sites. (These sites have been fused in Figure 4 for convenience.) Site group 8 may therefore be regarded as an artificial site group, characterized only by its paucity of species and individuals. Sites comprising site group 8 are mostly from the entrance dredged wings.

Site groups 1 - 6 are characterized by relatively high numbers of species and individuals. From nodal analyses (Figures 7 and 8) it can be seen that the large species group 1 is moderately to highly constant in site groups 1 to 5. Because of this large degree of species overlap, the separation of site groups 1 to 5 has been based more on the relative abundances of species rather than merely their presence or absence.

Ordination of the sites comprising site groups 1 to 6 (Appendix B) confirmed the normal classification. These sites could be separated into clusters which resembled the site groups, and which largely maintained their integrity within the first 7 principal axes. Site groups 1 to 6 may therefore be regarded as ecologically meaningful groups. The species important in separating these site groups are shown in Table 4.

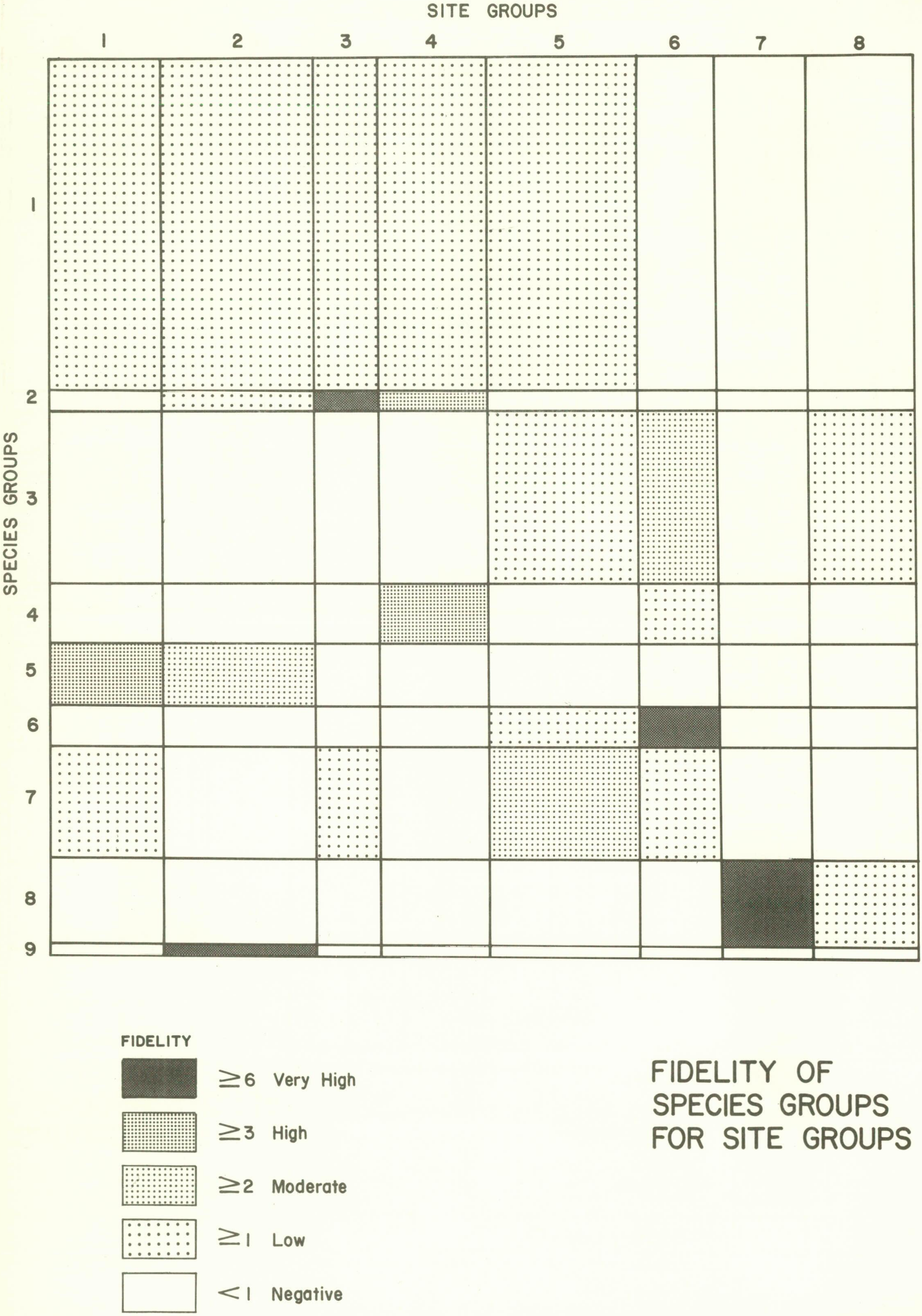
The major division in the classification of site groups 1 to 6, corresponds largely to sediment character (Table 5). Site groups 1, 2 and 3 are all characterized by muddy sediments while site groups 5 and 6, which fuse in Figure 4 implying faunistic similarity, are both characterized by sand. Sediments at sites in group 4 are mostly silty sands (Figure 9).

Faunistically, site group 4 is distinct from nearby groups. It has the highest mean number of species per site (Table 3) and, whilst it includes many species found in other areas of the bay, it is characterized by a small number of species (species group 4) which rarely occur elsewhere (Figures 7 and 8). The sites comprising this group are mostly from the dredged entrance channel.



CONSTANCY OF SPECIES GROUPS FOR SITE GROUPS

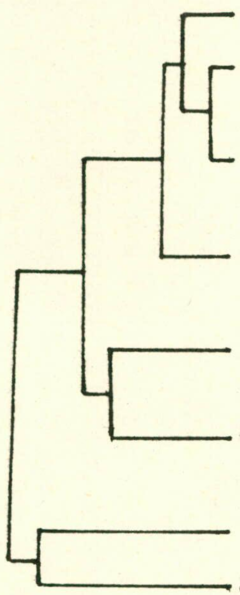
FIGURE 7



FIDELITY OF SPECIES GROUPS FOR SITE GROUPS

FIGURE 8

Table 5. Nature of Site Groups



Site Group	Sediment	Depths	Dredging History (year)	Sampling Areas Included (cf Fig 2)
1	mud	3 - 4	undredged	I (+B)
2	mud and silty sand	7 - 21	part dredged (1964-1975)	A (+C+D)
3	mud and silty sand	18 - 21	dredged (1972-1975)	C
4	silty sand	19 - 21	dredged (1970)	G (+E+F)
5	sand, sand with some silt	2 - 9	undredged	B + D
6	sand	4 - 21	part dredged (1970)	F (+E+G)
7	sand	15 - 20	undredged	H (+F)
8	sand	13 - 20	dredged (1970)	E (+F+H)

Site group 5 is made up of sandy sites from the western and central parts of the bay (in the airport and revetment control areas). Crustaceans are relatively more abundant than in other site groups (56 per cent of all individuals collected, as opposed to a mean of 17 per cent), reflecting high numbers of Corophium acherusicum. Site group 6 is made up of sandy sites mostly from the wings control area near the entrance of the bay. The constancy and fidelity indices of species group 6 for site group six are very high.

Site groups 1, 2 and 3 (the muddy areas) are much more closely related than the sandy site groups (Figure 4).

Site group 1 was composed of ten sites from the 'mud finger' off Ramsgate and one site adjacent to the entrance of Cooks River. Species group 5 showed high constancy and fidelity for this site group. The mollusc, Notospisula trigonella, was abundant in these sites.

Site group 2 is made up of sites from the dredged airport hole plus some of those from the revetment hole and its control area. Inclusion of 3 sites from the revetment control area is not inconsistent with classification on the basis of sediment type, as these particular sites are known to occur in patches of mud within this otherwise sandy area (Figure 9).

Site group 3 consists of the remaining sites from the dredged revetment hole. These sites differ from those in site group 2, in having outstandingly high mean numbers of individuals ($3.7 \times 10^4/m^2$). This is mainly due to the abundance of the polychaetes Mediomastus californiensis, Chone sp and Prionospio sp 1.

3.2 Comparison of Dredged and Control Areas

Classification showed that the dredged areas (largely defined by site groups 2, 3, 4 and 8) were each faunistically different from the surrounding undisturbed areas. It was therefore decided to compare community structure - in terms of species numbers, numbers of individuals, biomass and diversity - in dredged and undredged areas. Faunal variability made pooling of data inappropriate, so each dredged area was independently compared with its control to discern any consistent differences.

The community structural values obtained for sampling areas are summarized in Table 6.* Inspection of the values showed

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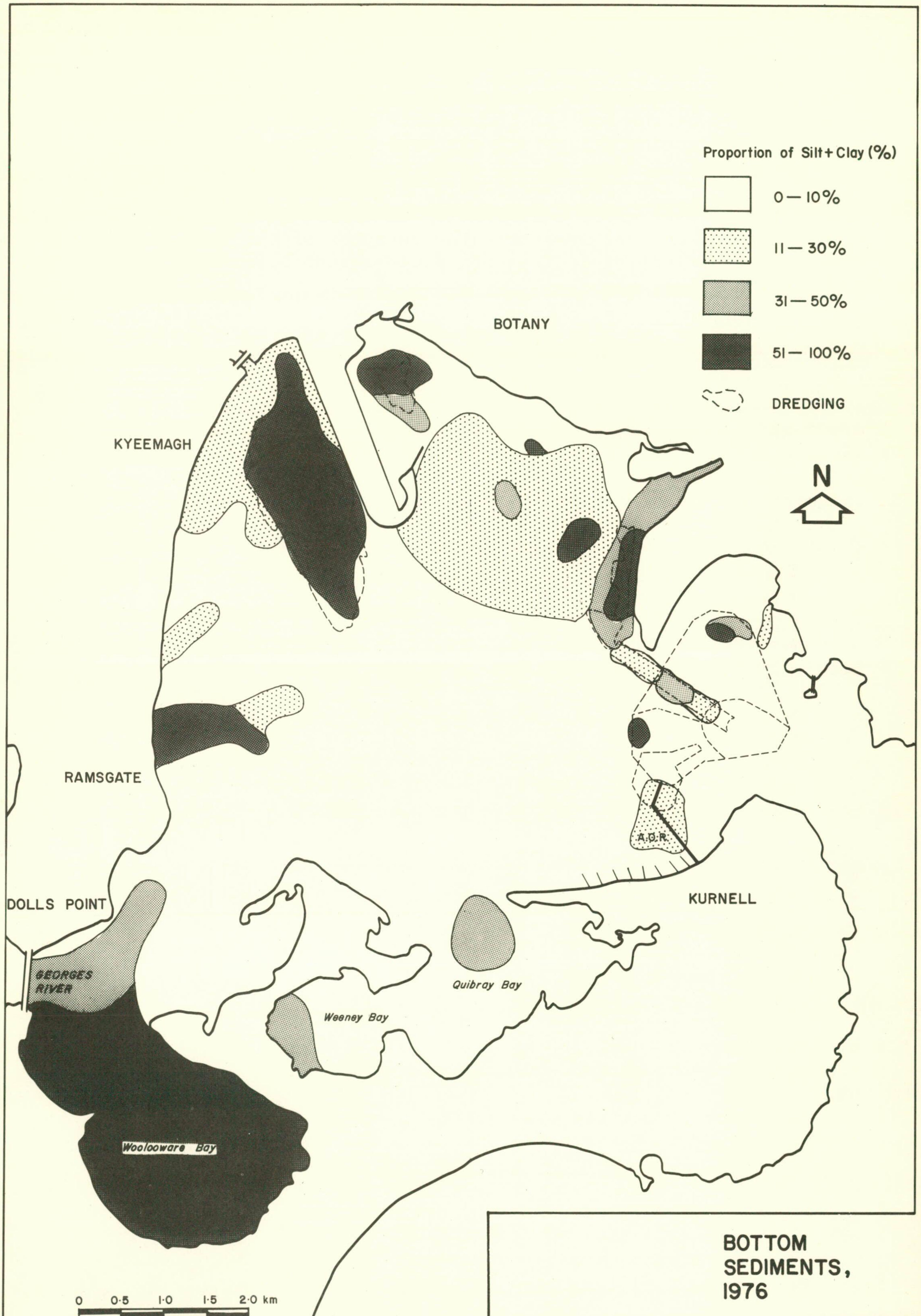
* Raw means are reported in this table for simplicity. However inequalities of variance between sampling areas prevented direct comparison. Significance was evaluated after ln (a + 1) transformation of the data.



BOTTOM SEDIMENTS, 1976

FIGURE 9

Table 6. Community Structure of Dredged and Control Areas

Locality	Sampling Area (Figure 2)		Bottom Sediment	Species		Individuals (mean no. per sample)	Biomass (mean (g) per sample)	Diversity Index (mean)
				(total number)	(mean no. per sample)			
Airport	A	dredged	mud	51	14	171	0.95	1.54
	B	undredged	sand	70	17	174	0.41	0.62
Port Revetment	C	dredged	mud	62	20	527	1.35*	1.55
	D	undredged	sand	86	18	258	0.55	1.64
Entrance Wings	E	dredged	sand	90	12	40	0.28	1.55
	F	undredged	sand	99	14	85	0.40	1.55
Entrance Channel	G	dredged	silty sand	106*	27*	243*	1.37*	2.01
	H	undredged	sand	56	10	23	0.07	1.91
Mud 'finger'	I	undredged	mud	63	18	294	0.59	1.51

* significantly different from undredged (control) area ($p < 0.05$)

considerable variations exist across the whole study area, as might have been expected from the results of classification. However statistical comparisons revealed few significant differences between three of the four dredged areas and their respective controls.

The airport and entrance wings dredged areas were not significantly different from their respective control areas on any of the parameters tested, whilst the port revetment differed only in having a significantly greater mean biomass per sample than its control.

The notable exception was the dredged entrance channel (area G), for which total number of species, mean number of species and individuals, and mean biomass were significantly higher than in the chosen control (area H). Mean diversity, however, was not significantly different.

Classification had shown that area H (essentially corresponding to site group 7) was faunistically dissimilar to any of the other areas studied, and hence may not have been an acceptable control area. The entrance channel was therefore also compared with the nearby areas E and F. The entrance channel again had significantly higher mean number of species, mean number of individuals and mean biomass, but not total number of species or mean diversity.

4 DISCUSSION

A total of 225 species of polychaetes, crustaceans and molluscs were collected during this study, indicating that the unvegetated, sand and mud habitats in the northern part of Botany Bay support a diverse infauna. This diversity would appear to be in the range expected for a marine-dominated estuary (Table 7). However any comparison of Botany Bay with other Australian estuaries is difficult in view of the paucity of information and because of differences between surveys in sampling methods and sampling intensities.

The design of this study, although not ideal, appears to have been appropriate for its purpose. Samples were sufficiently spread to cover all the areas of the bay affected by major dredging works but still produced geographically coherent site groups. Replication of samples within defined sampling areas allowed statistical comparisons of community structural parameters, to supplement the data obtained from classification and other multivariate techniques.

The most significant deficiency was that the intensity of sampling was insufficient to fully represent all the sandy areas studied (Figure 3). This possible deficiency was recognized from the limited benthic data available before the study (New South Wales State Fisheries, unpublished data), but resources precluded processing of any greater number of samples. Comparisons of community parameters were therefore based on mean values per sample, to minimize errors due to varying sampling adequacies.

4.1 Benthic Infauna of the Study Area

Classification and ordination showed the study area to be faunistically complex, with eight coherent site groups. Other studies and subjective knowledge of the bay suggest at least some of the environmental factors which may be operating to produce the observed complexity.

The entrance region of the bay (site group 7) is characterized by low numbers of species and individuals, and by the very high constancy and fidelity of species group 8 which rarely occurs elsewhere in the study area. Environmental conditions in this area are harsh with high exposure to swells and moderate to high tidal currents. Sediments contain large amounts of shell-grit and ripples have been observed on the sandy bottom at depths of 20 m. Hydrologic conditions may exclude species found in quieter areas of the bay.

Table 7. Benthos of New South Wales Central Coast Estuaries - after Hutchings et al (1978)

Locality	No of Species Total	Polychaetes	Crustaceans	Molluscs	
Botany Bay	225	94	75	56	Present study
" "	295*	100*	116	79	Present study and State Fisheries (unpublished data)
Wallis Lake	74	33	8	24	
Smiths Lake	21	7	4	9	
Lake Macquarie	46	8	13	22	
Careel Bay	152	48	43	51	
Port Hacking	200	detritus-feeding polychaetes dominant			CSIRO (1976)

* under-estimate : some genera not classified to species level.

Samples from the entrance wings (site group 8) were also characterized by low numbers of species and individuals, but in contrast to the area between the heads, species composition varied considerably between sites. Species richness was much higher than in area H. This heterogeneity may reflect the existence of a diversity of microhabitats within area E in spite of its apparent uniformity with respect to sediments, depth, wave exposure and tidal currents. If some factor (such as food availability, predation or local disturbance) is operating to restrict population size at particular sites, the patchiness in species composition could result from randomness in recruitment. However there is no evidence to support a hypothesis of preferential restriction in this site group as opposed to other groups in the study area.

Though the entrance channel (site group 4) could be expected to possess a similar community to the rest of the entrance area, it in fact supports a particularly diverse and abundant benthic fauna. Both classification (Figure 4) and species composition indicate that the high diversity in site group 4 may be associated with the presence of varied and substantial contents of silts in the sediments (Figure 9). The resultant diversity of habitats appears to support many species found in other site groups as well as a small number of faithful species rare in other parts of the study area (Figure 8).

The topography and hydrology of the bay suggest that the relatively high abundances noted in site group 4 may be related to tidal flows. The entrance channel is likely to serve as a drainage path for ebb flows from muddy and silty areas west of the revetment. These areas are relatively richer in organic matter, and drainage may provide a food source to channel infauna. Such flows may have been further enriched by liberation of organic detritus from underlying silt and peat horizons exposed by continuing local dredging in the port area (SPCC 1978, Ingle 1952).

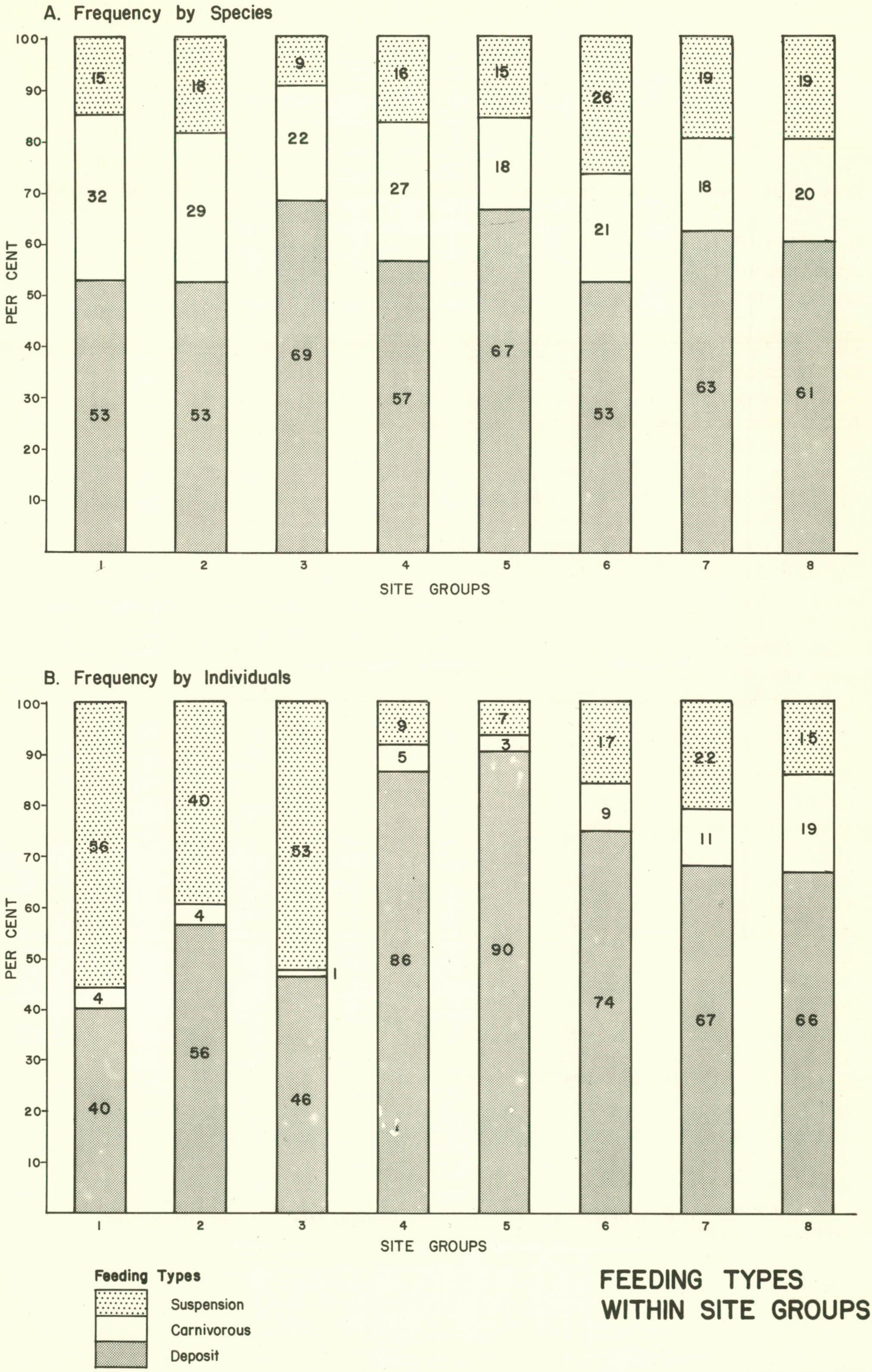
In the remaining, central and western areas the fauna is characterized by higher mean numbers of species and individuals. Depth does not appear to have any significant influence and salinity in all areas is essentially oceanic. Classification and ordination strongly suggest that sediment character is the major factor determining faunal differences. There is however a large overlap of species between the fauna of muddy (dredged or natural) and sandy areas.

A feature of the study was the high abundance reached by individual species in a number of areas. The most outstanding example was in the central area of the dredged hole west of the revetment where polychaetes, notably Chone, Prionspio sp 1 and Mediomastus, reached very high numbers. This could possibly reflect the fact that this area was the most recently dredged. McCall (1977) found that in a disturbed area opportunistic species were often present in densities several orders of magnitudes above those in surrounding areas. However this explanation seems unlikely in view of the time since dredging (about two years). An alternative explanation, for this particular area, is that the high abundance is associated in some way with peat lenses (rich in organic matter) known to have been exposed in the area by dredging. This is supported by the finding of fibrous material in many of these samples. However there is no comparable explanation for other species in other areas.

As the classification defined a number of distinctive communities within Botany Bay, the feeding types of organisms within each site group were analysed. This analysis provides further clues to the factors affecting faunal distribution, although any firm conclusions would be difficult to support in view of the paucity of data on Australian species and the considerable feeding plasticity of many benthic animals (Boesch 1973).

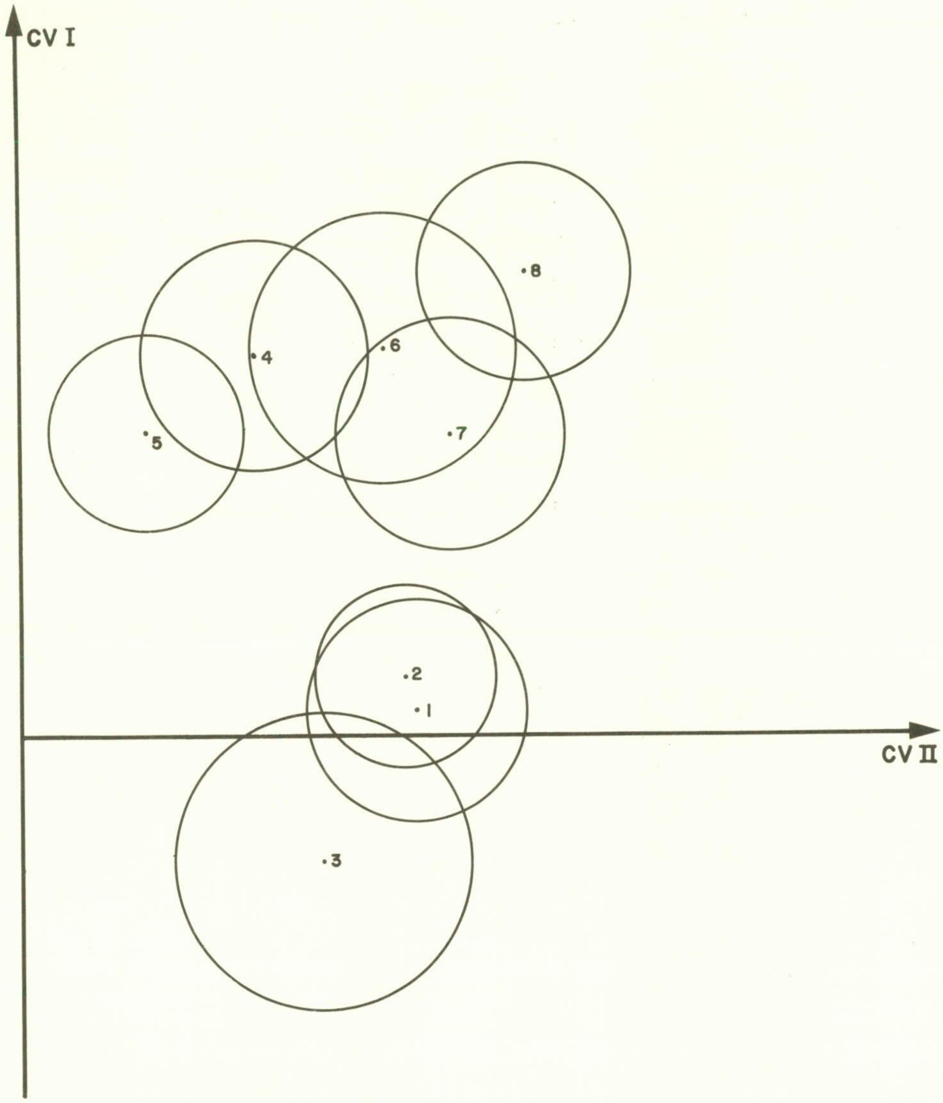
The major species could be assigned a probable feeding type. The composition of species by feeding types (Figure 10a) appeared to be fairly constant over the site groups, with deposit feeders averaging about 60 per cent. Suspension feeders and carnivores (including scavengers) each made up about 20 per cent of the species found. However a second analysis based on numbers of individuals showed much greater variability (Figure 10b). There was a marked dominance of deposit feeders in the sandy site groups whilst the muddy site groups (1, 2 and 3) had a significantly greater portion of suspension feeders (Figure 11). For these muddy areas it is interesting to note that whilst suspension feeders comprised a fairly constant proportion of the individuals, different species dominated this feeding niche in different site groups. Notospisula was outstandingly abundant in site group 1 whilst Chone dominated site group 3.

These findings in relation to feeding types contrast with those of some overseas studies. Sanders (1958) and Rhoads and Young (1970) have reported marked spatial separation of feeding types, with deposit feeders dominating muddy areas and suspension feeders concentrated in sandy areas. The present results are



FEEDING TYPES WITHIN SITE GROUPS

FIGURE 10



NOTE : Circles indicate 95% confidence limits

FIGURE 11. Proportion of individuals, by feeding types, in the site groups

more in accord with Kaplan et al (1974) who recorded a numerical dominance of deposit feeders in sandy areas and of suspension feeders in high silt areas in Goose Creek, a small, disturbed estuary in the eastern United States.

The high proportion of suspension feeders in the muddy areas of Botany Bay can not be explained in terms of the available environmental data. Sanders (1958) hypothesized that the stable environment represented by fine sands and the role of clay in efficiently binding organic matter influenced populations of deposit feeders. However more complex factors probably apply for suspension feeders (Kaplan et al 1974).

Certainly stability does not seem to be a significant factor for the Botany Bay muddy areas. Even if hydrological conditions are quiet in the three muddy site groups, there is considerable variation in the environments of these areas. Site group 1 encompasses a relict ramp margin of a previous course of the Georges River (Roy personal communication) whilst site group 2, in marked contrast, is in an actively accreting area near the mouth of Cooks River (SPCC 1978). Site group 3 is in a recently silted, and probably still accreting, area. Suspension feeders could be expected to be limited by silt loads (Rhoads and Young 1970) at least in site groups 2 and 3. However there is no evidence of such limitation.

4.2 Effects of Dredging

Dredging has permanently altered the environment of the study area. Large areas in the study area which were previously sand are now muds or silty sands (SPCC 1978).

Classification showed that the infaunas of dredged areas were different to those of the corresponding undredged (control) areas. Species compositions have altered and the communities of dredged areas appear to be strongly associated with present sediment types. Species recruitment curves (Figure 3) indicate that species richness has been reduced in the muddy dredged holes near the airport (area A) and the revetment (area C). However richness in the entrance channel (area G) is now significantly higher.

In spite of these changes, community structure in three of the four dredged areas did not differ significantly from that of their control areas on the parameters analysed. On the available evidence, the present communities in the airport and revetment holes and the entrance wings appear to be as diverse as those which would have existed before dredging.

The exception was the dredged entrance channel. Whilst mean diversity was not significantly different from that of the control area, all other parameters indicate that the channel supports a richer and more abundant fauna than before dredging. The observed richness is probably associated with its varied, silty sediments.

Recolonization of dredged areas after removal of the original infauna appears to have been fairly rapid. The community in the airport hole (dredged between 1964 and 1970) is faunistically and structurally similar to that of the most recently dredged area, the revetment hole. These similarities suggest that the infauna of the revetment hole, two to four years after dredging, may represent a stable community rather than an evolving assemblage of colonising organisms.

Maintenance of water quality has probably been an important factor in recolonization. In some overseas estuaries, bottom waters after dredging have low dissolved oxygen levels which may exclude benthic fauna. Such depletion is particularly common in 'key' or canal developments though it can also occur in open waters if they become vertically stratified (May 1973). Fortunately, although dredging altered tidal circulation in the study area in Botany Bay (SPCC 1978), flushing has remained adequate. Dissolved oxygen levels are high throughout the dredged areas of Botany Bay (SPCC in preparation) and have not prevented recolonization by benthos. There is no indication from this study that water quality in the dredged areas may be limiting benthos.

The ultimate ecological changes which may result from the observed alterations of infaunal communities of dredged areas are not predictable at present. However, studies in progress for the Commission by New South Wales State Fisheries, including diet studies, may provide information on the significance of such alterations to selected commercial or recreationally important fish species.

5 SUMMARY

The macrobenthic infauna of four dredged and five undredged areas in Botany Bay was sampled, by coring, during the summer of 1976. 90 samples yielded 225 species of polychaetes, crustaceans and molluscs.

Multivariate analyses (based on the species present and their abundances) identified eight, geographically - coherent site groups in the study area. A number of these site groups corresponded closely to dredged areas. Two groups of sites (7 and 8) near the bay entrance were identified which were highly dissimilar from the rest of the study area and from each other. One of these (group 7) was characterized by a small group of species rarely found in other site groups.

Faunistic variations in the study area were primarily associated with sediment character and hydrologic conditions, but not with depth or salinity (which is essentially marine throughout the study area).

Analyses of feeding types of organisms showed that deposit feeders were dominant throughout the study area, both in terms of species numbers and numbers of organisms. Suspension feeders were, however, proportionately more abundant in muddy areas than in sandy areas.

Comparisons of dredged and undredged areas indicated that species composition and total species richness had altered following dredging. However community structure in three of the four dredged areas was not significantly different ($p < 0.05$) to that of corresponding undisturbed areas, in terms of mean numbers of species, mean numbers of individuals, mean biomass per sample, and mean diversity.

The fourth dredged area, the entrance channel, was significantly different ($p < 0.05$) from its control area and other nearby areas, on all parameters except mean diversity. The infauna of this channel appeared to be more diverse and abundant than before dredging.

The faunal changes which were noted in dredged areas were largely explainable in terms of alterations in sediment character and/or wave distribution following dredging.

Recolonization after dredging may have been relatively rapid. Faunistic and community structural similarities between the most recent and oldest disturbed areas suggest stable (though altered) communities had re-established in the revetment area two to four years after dredging.

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APPENDIX A Invertebrata Species List

MOLLUSCA

GASTROPODA
  OPISTHOBRANCHIA
    Acteonidae
      Pupa fumata
      Pupa nivea
      Pupa tragulata
    Aeolidiidae
      Cerberilla incola
    Aglajidae
      Aglaja taronga
    Gastropteridae
      Gastropteron bicornutum
    Gymnodorididae
      Gymnodoris sp
    Philinidae
      Philine angasi
    Pleurobranchidae
      Pleurobranchaea maculata
    Retusidae
      Retusa sp
    Scaphandridae
      Tornatina avenaria

  PROSOBRANCHIA
    Columbellidae
      Species 1
      Species 2
    Marginellidae
      Marginella sp (juv.)
    Muricidae
      Bedeva hanleyi
    Nassariidae
      Nassarius burchardi
      Nassarius nigellus
    Naticidae
      Polinices conicus
      Polinices didymus
    Neritidae
      Smaragdella pulcherrima
    Pyramidellidae
      Rugadentia doliae
    Rissoidae
      Pisinna nitida
    Trochidae
      Ethminola probabilis
      Leiopyrga lineolaris
    Turridae
      Vexitomina metcalfei

BIVALVIA
  Cardiidae
    Pratulum thetidis
  Condylocardiidae
    Particondyla cuneata
  Corbulidae
    Corbula sp
  Crassatellidae
    Salaputium sp
  Cunidae
    Cuna atkinsoni
  Cyamiidae
    Cyamiomactra sp
  Glycymeridae
    Glycymeris sp (juv.)
  Hiatellidae
    Hiatella australis
  Leptonidae
    Mysella sp
  Mactridae
    Mactra jacksonensis
    Mactra pusilla
    Mactra sp (juv.)
    Meropesta meridiana
    Notospisula trigonella
  Mesodesmatidae
    Ervilia australis
  Myochamidae
    Myodora sp
  Mytilidae
    Modiolus sp (juv.)
    Trichomya hirsutus
  Neoleptonidae
    Neolepton sp
  Pectinidae
    Species (juv.)
  Semelidae
    Theora sp
  Solenidae
    Neosolen correctus
  Tellinidae
    Tellina deltoides
    Tellina subdiluta
    Tellina tenuilirata
    Species 1 (juv.)
    Species 2 (juv.)
  Thraciidae
    Eximiothracia speciosa
  Veneridae
    Chioneryx sp
    Dosinia circinaria
    Eumarcia sp
    Notocallista sp
    Species (juv.)

ANNELIDA

POLYCHAETA

Ampharetidae
- *Isolda pulchella*
- *Mellina* sp
- *Pseudoamphicteis papillosa*
- *Samythella* sp

Amphinomidae
- *Eurythoe* sp

Arabellidae
- *Notocirrus* sp

Capitellidae
- *Barantolla lepte*
- *Capitella* sp
- *Heteromastus* sp
- *Mediomastus californiensis*
- *Notomastus* sp
- Species

Chaetopteridae
- *Chaetopterus varieopedatus*
- *Mesochaetopterus* sp
- *Spiochaetopterus* sp

Cirratulidae
- *Caulleriella* sp 1
- *Caulleriella* sp 2
- *Caulleriella* sp 3
- *Cirratulus* sp

Cossuridae
- *Cossura* sp

Dorvilleidae
- *Dorvillea* sp
- *Protodorvillea* sp

Flabelligeridae
- *Pherusa* sp

Glyceridae
- *Glycera americana*
- *Glycera* sp 1
- *Glycera* sp 2
- *Goniada* sp 1
- *Goniada* sp 2

Hesionidae
- *Gyptis* sp
- *Ophiodromus* sp

Lumbrineridae
- *Lumbrineris latreilli*
- *Lumbrineris* sp

Magelonidae
- *Magelona* sp 1
- *Magelona* sp 2

Maldanidae
- *Lumbriclymene* sp
- Species 1
- Species 2
- Species 3
- Species 4
- Species 5

Nephtyidae
- *Nephtys australiensis*
- *Nephtys longipes*
- *Nephtys* sp

Nereidae
- *Australonereis ehlersi*

Onuphidae
- *Diopatra* sp 1
- *Diopatra* sp 2
- *Onuphis* sp 1
- *Onuphis* sp 2
- *Onuphis* sp 3
- *Onuphis* sp 4

Orbiniidae
- *Leitoscoloplos bifurcatus*
- *Phylo felix*

Oweniidae
- *Owenia fusiformis*

Paraonidae
- *Aricidea* sp 1
- *Aricidea* sp 2

Pectinariidae
- *Pectinaria (Cistenides)* sp

Phyllodocidae
- *Eulalia* sp
- *Phyllodoce novaehollandiae*
- *Phyllodoce* sp

Pilargiidae
- *Ancistrosyllis* sp

Pisionidae
- *Pisione* sp

Polynoidae
- *Antinoe* sp
- *Lepidonotus* sp
- *Parahalosydna* sp
- *Paralepidonotus ampulliferus*

Sabellidae
- *Chone* sp
- *Euchone* sp

Scalibregmidae
- *Hyboscolex* sp
- Species

Sigalionidae
- *Psammolyce* sp
- *Sigalion* sp
- *Sthenelais* sp

Spionidae
- *Dispio* sp
- *Malacoceros* sp
- *Polydora* sp 1
- *Polydora* sp 2
- *Polydora* sp 3
- *Polydora* sp 4
- *Prionospio* sp 1
- *Prionospio* sp 2
- *Prionospio* sp 3
- *Prionospio* sp 4
- *Prionospio* sp 5
- *Scolelepsis* sp
- *Spiophanes* sp

Syllidae
- *Odontosyllis* sp
- *Syllis (Langerhansia)* sp
- *Syllis (Typosyllis)* sp

Terebellidae
- *Amaeana trilobata*
- *Amphitrite* sp
- *Lysilla apheles*
- *Pista typha*

Trichobranchidae
- *Terebellides stroemi*

Trochochaetidae
- *Poecilochaetus serpens*

ARTHROPODA

CRUSTACEA

AMPHIPODA

Aeginellidae

Metaproto haswelliana

Ampeliscidae

Ampelisca sp

Amphilochidae

Gitanopsis sp

Narapheonoides sp

Caprellidae

Caprella scaura

Corophiidae

Ampelisciphotis sp

Aora sp

Corophium cf *acherusicum*

Grandidierella sp

Photis sp

Siphonoecetes sp

Dexaminidae

Atylus sp

Eusiridae

Species

Gammaridae

Eriopisa sp

Ischyroceridae

Cerapus sp

Ericthonius sp

Jassa sp

Leucothoidae

Leucothoe assimilis

Liljeborgiidae

Liljeborgia dubia

Liljeborgia sp 1

Liljeborgia sp 2

Lysianassidae

Hippomedon sp

Oedicerotidae

Oediceroides sp 1

Oediceroides sp 2

Oediceroides sp 3

Philantidae

Palinotus thomsoni

Phoxocephalidae

Species 1

Species 2

Species 3

Species 4

Species 5

Species 6

Species 7

Podoceridae

Leipsuropus parasiticus

CUMACEA

Bodotriidae

Cyclaspis australis

Cyclaspis sp

Eocuma sp

Glyphocuma serventyi

Pomacuma australiae

Diastylidae

Dimorphostylus sp

Gynodiastylus carinirostis

DECAPODA

Callianassidae

Callianassa arenosa

Crangonidae

Pontophilus sp

Goneplacidae

Xenophthalmodes dolichophallus

Hymenosomatidae

Halicarcinus ovatus

Penaeidae

Penaeus plebejus

Processidae

Processa sp

Portunidae

Thalamita sima

Thalamita sp

ISOPODA

Anthuridae

Species

Astacillidae

Astacilla vicaria

Species 1

Species 2

Species 3

Cirolanidae

Cirolana vieta

Cirolana woodjonesi

Munnidae

Munna sp

Pleurogonium sp

Serolidae

Serolis minuta

Sphaeromatidae

Species

MYSIDACAE
  Mysidae
    Afromysis australiensis
    Gastrosaccus dakini
    Gastrosaccus sp
    Mysidella sp

STOMATOPODA
  Squillidae
    Alima laevis

TANAIDACEA
  Apseudidae
    Apseudes sp
  Kalliapseudidae
    Species
  Tanaidae
    Tanais sp

OSTRACODA
  Cylindroleberididae
    Cycloleberis sp 1
    Cycloleberis sp 2
    Cylindroleberis sp
  Philomedidae
    Euphilomedes sp

APPENDIX B Ordinations

Ordination of site groups 1 - 6 is presented in Figure 1. The first three principal axes (PCA) explain 26, 15 and 13 per cent of the total variance respectively. The remaining 4 PCA's explain a further 20 per cent of the total (Table 1). The site groups largely maintain their integrity within the 7 PCA's. Consequently, all six site groups may be regarded as natural, and therefore ecologically meaningful, groups.

PCA 1 clearly separates site groups 1, 2 and 3 (sites with mostly positive values) from site groups 5 and 6 (sites with mostly negative values), while site group 4 takes an intermediate position. The separation of these site groups is largely due to the distribution of the polychaetes *Chone* sp, *Prionospio* sp 1, *Ancistrosyllis* sp and the mollusc *Theora* sp. These species characterize site groups 1, 2 and 3 but are mostly absent from the other groups. Conversely *Polydora* sp 3 occurs consistently in medium to high numbers in site groups 4, 5 and 6, but is mostly absent from the first three site groups. *Phylo felix* displays a similar distribution pattern but is not as abundant or as constant as *Polydora* sp 3 in site groups 4, 5 and 6.

Site group 4 has a somewhat larger dispersion on PCA's 1 and 2 of this ordination than the other site groups. However, it separates clearly from site groups 5 and 6 on PCA 3. This is mainly due to the large numbers of *Caulleriella* sp 2 in all sites of site group 4 compared with the low numbers or absence of this species from site groups 5 and 6. Site group 4 separates from site group 5 on this vector, primarily due to the abundance of *Corophium acherusicum* in site group 5 and its absence from site group 4.

Two further ordinations were carried out; one on site groups 1, 2 and 3, and another on site groups 5 and 6. In the ordination of site groups 1, 2 and 3, (Figure 2), the first 3 PCA's explain 39, 15 and 10 per cent of the total variance respectively while the remaining 4 PCA's explain a further 21 per cent (see Table 2). As in the first ordination, the site groups largely maintain their autonomy over the 7 PCA's. Site groups 1, 2 and 3 are clearly divided on PCA 1. The separation of these site groups is largely due to distribution of the polychaetes *Chone* sp, *Mediomastus californiensis* and *Prionospio* sp 1. *Chone* sp occurs in very high numbers in site group 3, medium numbers in site group 2, but is absent from site group 1. *Mediomastus californiensis* and *Prionospio* sp 1 occur in high numbers in site group 3, but occur in only low-medium numbers in site groups 1 and 2. The crustaceans *Metaproto haswelliana* and *Dimorphostylus* sp and the

Table 1. Ordination of Site Groups 1 to 6

Site Group	Site No	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7
	21	.034	-2.024	.482	-1.157	3.131	.544	-1.623
	22	-1.320	-2.905	1.440	-3.468	.893	1.190	.385
	23	.035	-4.980	-3.851	.239	-1.255	-1.270	1.080
	24	1.209	-4.436	-2.623	-2.821	-1.297	.691	1.567
	25	.497	-3.671	-2.808	-1.509	-.398	.167	-.879
1	26	.240	-3.516	-1.397	-.315	-1.783	1.419	-1.435
	27	.760	-3.369	-1.379	-.474	-1.287	1.188	-.576
	28	1.007	-4.927	-2.076	-4.162	-1.826	.486	1.535
	29	.525	-5.574	-4.148	-.895	-2.763	-1.399	.533
	30	-.174	-6.147	-3.956	-1.494	-2.224	-1.130	1.456
	17	-1.244	-.608	-2.382	-.572	-1.659	-.656	-1.422
	1	2.918	-.811	-1.401	2.971	1.109	-1.016	-1.580
	2	1.851	-.839	-1.147	3.033	1.477	-.714	-1.010
	3	2.343	-1.759	-.570	-.428	1.224	-1.147	-.695
	4	4.907	.539	-1.284	.140	.305	-2.417	-.506
	5	2.375	1.375	-1.696	-.997	1.689	-1.660	-.960
	6	1.831	-.153	-.201	-1.552	1.904	-1.409	.408
	7	3.560	-.719	-1.418	3.884	-.266	-.129	-1.116
2	9	4.077	-.769	-.233	-2.201	2.302	-.798	2.345
	31	3.438	-.096	-.307	3.418	1.508	-1.316	-.180
	34	2.006	-.530	.480	2.253	2.565	-1.668	-.608
	38	3.592	.497	2.212	1.022	1.811	.302	1.229
	50	4.073	.117	-1.915	-.055	-1.936	-2.371	-1.097
	10	2.059	-1.853	-1.383	-2.023	1.030	.227	.464
	44	.292	.760	2.414	-2.725	2.206	-2.374	1.030
	47	-.005	2.746	3.252	-2.094	.788	-1.558	.717
	32	6.805	.754	.757	2.899	-2.170	.271	-.977
	33	8.534	2.974	1.261	1.158	-.873	.941	1.223
3	35	8.344	2.215	.227	2.409	-1.856	1.146	.361
	36	9.838	3.101	1.749	2.158	-3.663	2.050	.616
	37	7.321	2.429	4.392	-1.164	-.903	1.928	1.078
	39	6.619	3.331	1.657	-1.175	-.107	-.435	2.032
	75	1.296	5.676	-3.010	-1.710	1.682	-.512	1.463
	76	-1.673	4.291	-2.700	-1.477	.913	.199	-1.318
	77	1.423	1.050	-2.780	-.779	3.277	2.800	-.285
	40	-.060	2.315	-2.192	-.853	1.142	-.058	-.750
	79	2.028	3.289	-2.711	-1.067	.641	.447	-1.099
4	71	-4.193	2.247	-.576	.908	-.374	1.409	-.688
	73	-3.360	3.573	-3.023	-2.647	1.238	2.844	.346
	74	-3.541	2.781	-2.531	-.852	1.101	2.193	.296
	55	-3.802	3.017	-3.217	-2.269	.495	-.510	-.566
	56	-2.145	.960	-1.327	.686	-.257	-.085	-.382
	67	-2.372	6.242	-2.914	-1.360	.493	-.922	.520

Table 1. (contd)

Site Group	Site No	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7
	13	-2.801	-2.178	1.187	2.090	.262	-1.391	.322
	15	-2.631	-3.056	2.781	2.179	1.600	.581	-.499
	16	-2.531	-3.119	2.668	2.388	1.764	.190	-.546
	11	-2.780	-1.667	3.927	.285	.100	-.433	1.344
	12	-3.266	-1.823	4.438	.318	-.207	-1.435	.561
	14	-4.666	1.098	4.214	-.163	-1.674	-2.781	-.076
	18	-2.260	2.406	4.613	-1.749	-2.987	-1.590	-1.907
	19	-2.475	-3.094	4.338	.809	.832	2.108	.189
5	45	-.649	-2.209	4.290	.573	.944	1.352	.339
	46	-4.132	3.470	6.041	-3.002	-.991	-1.926	1.738
	20	-2.058	-4.418	.967	.208	-.998	1.475	2.175
	41	-.584	-1.059	5.031	-3.112	-.755	2.323	-2.506
	42	1.766	-.916	3.957	-4.383	-1.239	.856	-5.235
	48	-2.187	-2.645	2.624	2.809	2.647	-.762	.440
	49	-2.993	-1.171	.286	2.393	1.559	2.478	2.166
	63	-3.076	-.872	-1.379	2.694	1.147	.086	-.942
	53	-6.196	3.803	-1.061	1.095	-1.012	.774	1.051
	80	-3.138	-.015	-1.944	1.226	1.652	.278	-.915
	78	-5.480	2.712	-.770	1.062	-2.373	1.322	.367
6	66	-5.036	1.710	-1.326	2.725	-.379	-.625	-.172
	68	-3.990	.933	-.469	2.929	-1.186	1.465	.539
	70	-5.017	2.509	-1.283	1.725	-3.354	-.568	-.216
	62	-5.827	3.008	-.297	2.018	-3.381	-.667	.850
Cumulative % of Total Variance		26%	41%	54%	62%	67%	71%	74%

Table 2. Ordination of Site Groups 1, 2 and 3

Site Group	Site No	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7
	1	-.545	-1.414	3.607	-.041	-.107	.251	.515
	2	.042	-.778	3.847	.565	-.641	.108	-.080
	3	.968	.646	.943	.018	-1.045	.138	.133
	4	-1.901	-.615	1.466	-2.107	-.027	-2.474	-.550
	5	-.351	1.618	1.651	-1.995	.761	-1.800	-.069
	6	.495	2.528	.706	-1.000	-.125	-2.276	.481
	7	-1.269	-2.871	3.336	2.150	-.607	-1.281	-1.377
2	9	-.559	1.978	-1.254	-2.181	-2.339	-1.625	1.137
	31	-1.843	-.813	3.688	-.110	-1.443	.543	-.487
	34	-.622	1.329	3.529	-.409	-1.158	2.028	.493
	38	-2.766	1.984	.359	.507	-2.254	2.569	.137
	50	-.961	-1.594	.133	-3.124	3.335	.879	-.786
	10	1.766	1.275	-.938	-.894	-.501	-.871	.959
	44	.361	5.598	-.035	-1.025	.549	1.584	-1.413
	47	-1.106	5.936	.007	.959	2.190	.101	-2.648
	21	2.438	2.964	1.277	2.449	-1.055	-.420	2.113
	22	3.998	3.969	-1.499	2.842	.577	-.738	-1.625
	23	5.369	-2.923	.236	-1.175	-1.124	1.045	-.885
	24	4.509	-1.157	-2.673	.272	-1.266	-1.607	-.236
	25	4.331	-.978	-.247	.090	.319	-.291	1.874
1	26	3.565	-1.245	-.451	2.787	1.593	-.174	.791
	27	3.155	-1.335	-.690	2.359	.790	.428	.801
	28	5.075	-.594	-4.342	.189	-1.650	-.273	-1.412
	29	5.819	-3.656	-1.224	-1.135	.075	1.033	-.375
	30	6.626	-2.707	-1.775	-1.576	-.332	1.591	-.676
	17	3.318	.192	.937	-.415	4.631	.272	2.247
	32	-4.904	-3.145	.376	1.561	.545	.729	-.755
	33	-7.266	-1.139	-1.559	-.721	-.208	.167	.794
	35	-6.569	-2.882	-.677	1.205	-.021	-.977	-1.060
3	36	-8.694	-3.464	-2.565	.952	1.122	-.673	-.322
	37	-6.762	1.723	-3.909	1.390	-.309	1.299	1.842
	39	-5.715	1.570	-2.256	-2.387	-.294	.715	.441
Cumulative % of Total Variance		39%	54%	64%	72%	79%	82%	85%

Table 3. Ordination of Site Groups 5 and 6

Site Group	Site No	PCA 1	PCA 2	PCA 3	PCA 4	PCA 5	PCA 6	PCA 7
	13	.199	-2.161	.985	-1.783	.964	-.509	1.154
	15	2.203	-3.084	.573	-.712	-.605	.825	-.646
	16	2.043	-3.212	.766	-1.114	.003	.434	-.780
	11	2.091	-.307	2.133	.657	-.553	-.938	.951
	12	2.223	.353	2.908	-1.001	.152	-.892	.389
	14	-.043	3.420	3.049	-2.082	.941	-.688	.679
	18	1.343	5.879	.499	-1.522	-1.301	2.913	-.809
5	19	3.346	-1.851	1.089	.884	-1.172	-1.041	-1.781
	45	3.950	-1.321	.245	1.095	-1.143	.342	-1.195
	46	1.120	6.231	3.417	2.936	1.972	-.138	.561
	20	1.801	-2.960	-.086	.428	-3.604	-.322	3.162
	41	5.316	2.777	-2.419	.727	-1.974	.996	-.746
	42	6.550	3.392	-6.324	-.908	2.484	-1.728	.711
	48	1.780	-3.505	1.737	-.064	2.568	.860	-.584
	49	-.953	-3.575	-.756	4.144	2.089	-.581	-.051
	63	-1.891	-2.952	-1.237	-1.368	.642	1.164	.648
	53	-5.512	1.582	-.603	2.263	.495	2.298	.787
	80	-2.259	-2.179	-2.174	-.469	1.089	1.792	-.114
	78	-4.811	1.490	-1.550	2.120	-2.167	-1.150	-.915
6	66	-4.621	-.615	-.370	-1.843	.833	-.179	-1.207
	68	-3.412	-1.234	-.929	-.154	-.617	-.986	-.437
	70	-5.026	1.547	-1.029	-.860	-.352	-.109	1.811
	62	-5.442	2.186	.076	-1.372	-.746	-2.363	-1.588
Cumulative % of Total Variance		30%	51%	62%	69%	75%	79%	82%

Table 4. Component Correlations from GOWECOR

(a) ORDINATION : SITE GROUPS 1 to 6

Species	PCA 1	Species	PCA 2	Species	PCA 3
Chone sp	.76	Polydora sp 3	.62	Corophium acherusicum	.82
Ancistrosyllis sp	.69	Notospisula trigonella	-.57	Liljeborgia sp 1	.43
Mediomastus californiensis	.64			Caullierella sp 2	-.42
Prionospio sp 1	.61				
Polydora sp 3	-.54				
Phylo felix	-.52				
Theora sp	.49				

(b) ORDINATION : SITE GROUPS 1, 2 and 3

Species	PCA 1	Species	PCA 2	Species	PCA 3
Chone sp.	-.85	Corophium acherusicum	.71	Liljeborgia dubia	-.66
Mediomastus californiensis	-.72	Prionospio sp 2	.67	Polydora sp 1	-.47
Metaproto haswelliana	-.72	Ericthonius sp	.66		
Sthenelais sp	-.69	Eocuma sp	.64		
Diamorphostylus sp	-.63				
Prionospio sp 1	-.62				
Notospisula trigonella	.61				

(c) ORDINATION : SITE GROUPS 5 and 6

Species	PCA 1	Species	PCA 2	Species	PCA 3
Tellina subdiluta	-.70	Polydora sp 3	.69	Caullierella sp 2	-.76
Corophium acherusicum	.69	Corophium acherusicum	.68		
Callianassa arenosa	.52	Chone sp	.63		

polychaete Sthenelais occur consistently in site group 3, but are mostly absent from site groups 1 and 2. The mollusc, Notospisula trigonella, on the other hand, occurs in high numbers in all group 1 sites (except site 17), low numbers in some group 2 sites, and is absent from site group 3.

In the ordination of site groups 5 and 6 (Figure 3), the first 3 PCA's explained 30, 21 and 11 per cent of the total variance respectively. With the exception of site 42, the site groups are quite distinct on PCA's 1 and 3. PCA 2 divides both site groups 5 and 6 into smaller groups but this separation does not occur in vectors 4 - 7, which explain an additional 20 per cent of the variance (Table 3).

The clear separation of site groups 5 and 6 on PCA 1 is primarily due to the distributions of the mollusc, Tellina subdiluta, and the crustaceans Corophium acherusicum and Callianassa arenosa. Tellina subdiluta occurs in reasonably constant, although low numbers, in site group 6 but is entirely absent from site group 5. Conversely, Callianassa arenosa occurs in low but constant numbers in site group 5 but is absent from site group 6. Corophium acherusicum, is present in high numbers in virtually all group 5 sites but is absent from site group 6.

The correlations between the major determining species and principal areas are shown in Table 4.

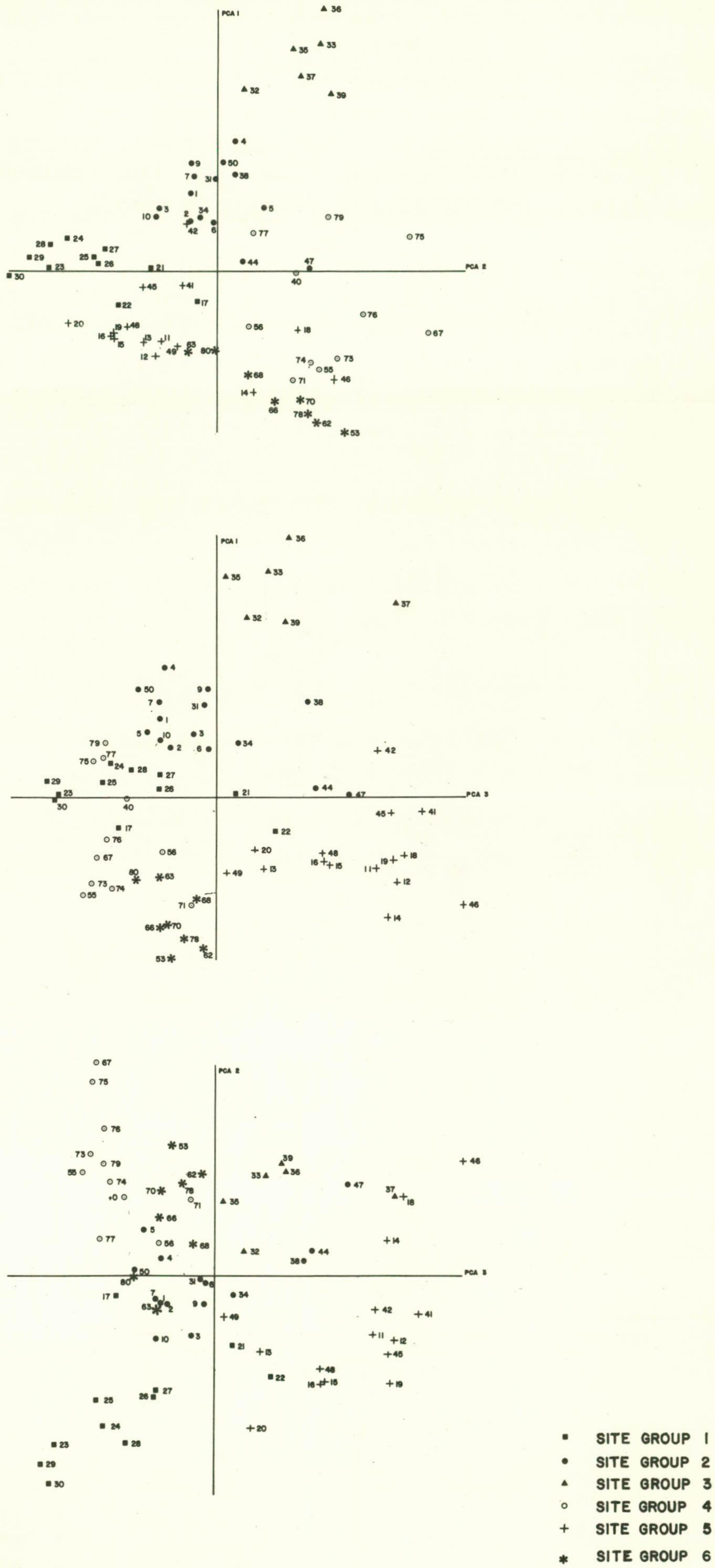

FIGURE A2·1 Ordination of Site Groups 1 to 6

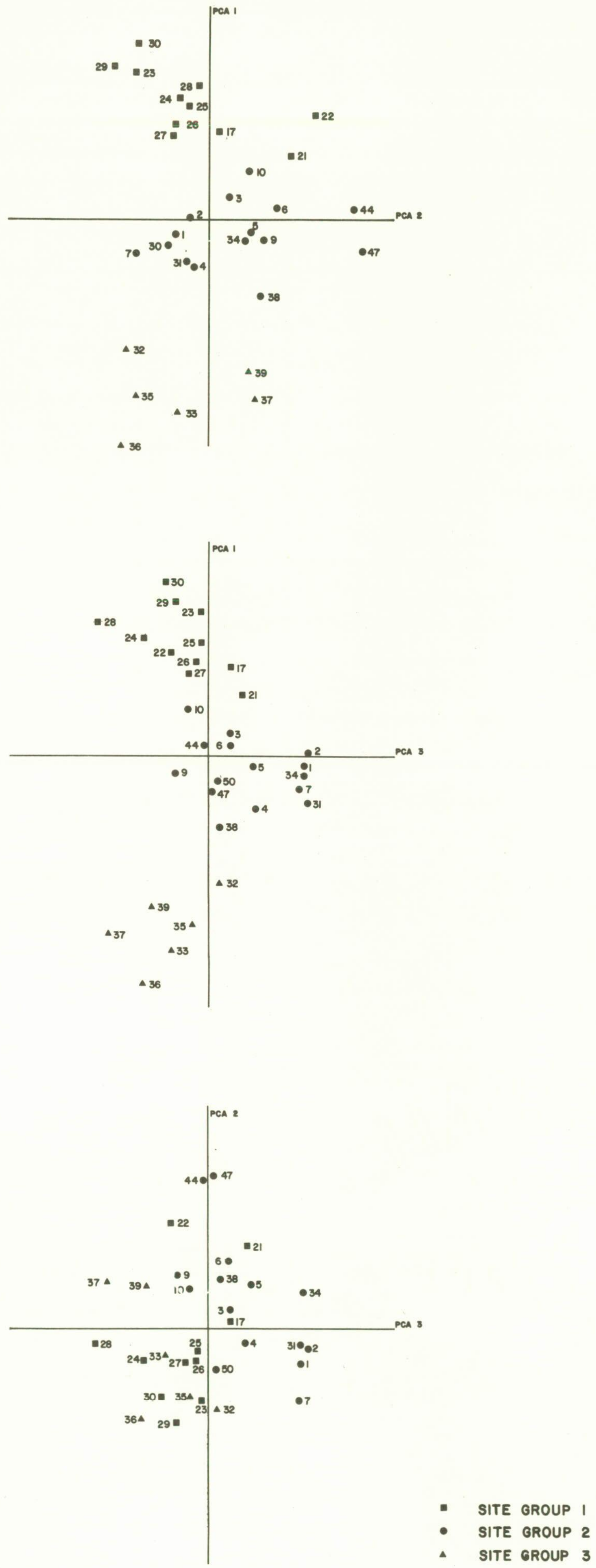

FIGURE A2·2 Ordination of Site Groups 1, 2 and 3

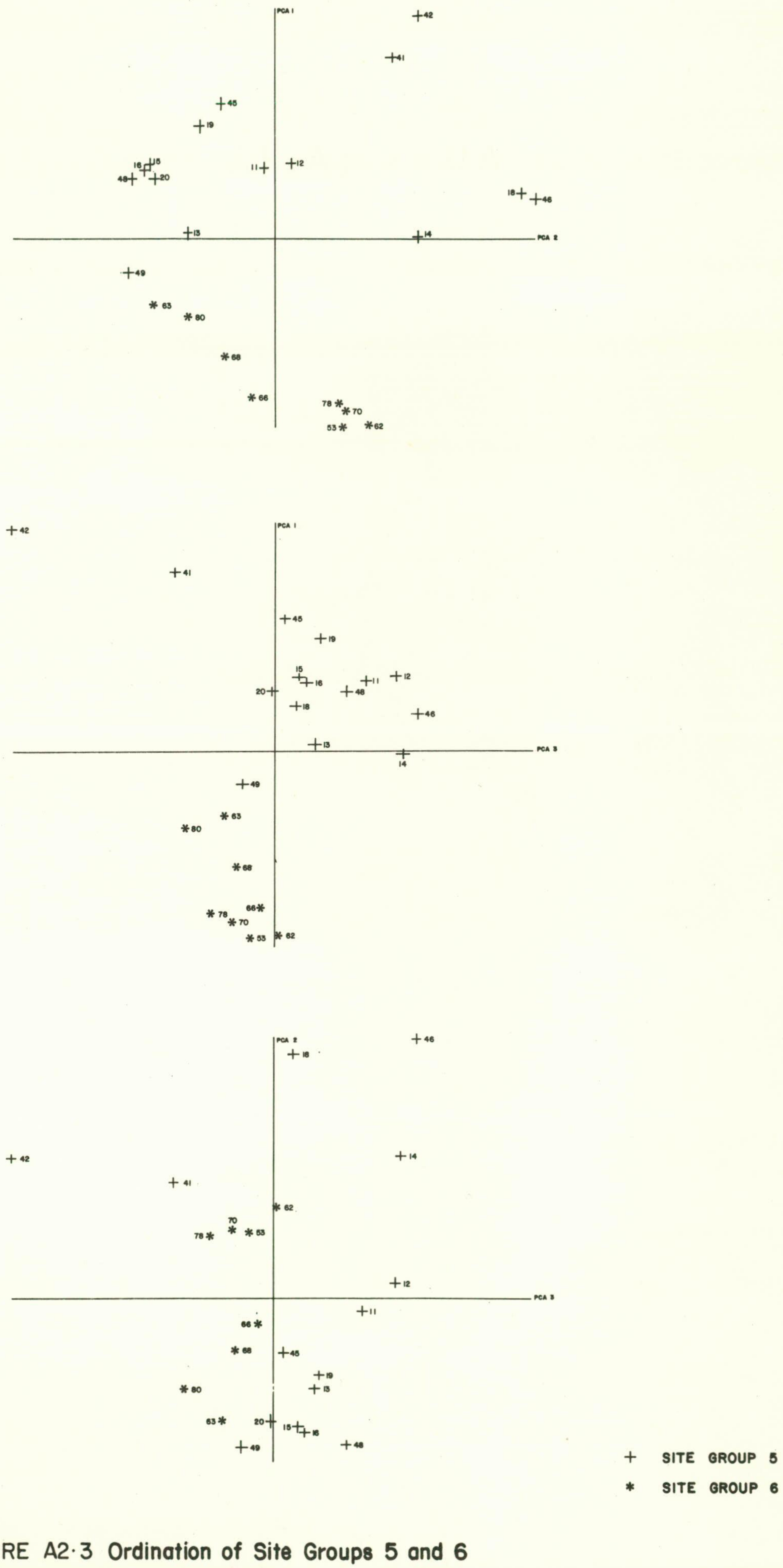

FIGURE A2·3 Ordination of Site Groups 5 and 6